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Cognitive Information Retrieval

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INTRODUCTION

This chapter reviews and discusses critically the development during the last decade of the cognitive approach to information retrieval (IR) research and theory. The focus is analytic and empirical research on the complex nature of information need formation and situation, their inherent association with the concept of relevance, and the development of cognitive and related IR theory and evaluation methods. The time span is largely 1992-2000 (references to earlier works are provided as needed). Thus, the review complements and extends the previous *ARIST* chapters on cognitive research (ALLEN, 1991) and the user-oriented perspectives of IR research and analysis methods (SUGAR).

Since its start in 1977, the cognitive approach to information science has developed in two periods. The first covers 1977-1991 and can briefly be characterized as user- and intermediary-oriented. The second period is 1992-2000 (the major concentration of this chapter), when the approach turns into a holistic view of all the interactive communication processes that occur during information transfer.

Following the introduction, the review falls into five major sections. The first section highlights the scientific developments, characteristics, and substantial results of the cognitive approach in the first period. This section also includes drawbacks and criticisms of the approach, that is, the lack of realism, theory integration, and holistic perspective. This is followed by a section covering the development in the second period about the focus shift into a holistic cognitive view, with a subsection on views of information processing. The third section covers information structures, with a subsection on information need. The fourth section looks into the dimensions of cognitive IR theory in a holistic perspective. Subsections concern polyrepresentation of information objects, the cognitive space and IR interactions, and relevance and evaluation issues. This section includes work task conceptions and issues concerned with feedback and query modification. The fifth section approaches the integration of cognitive models of information seeking, IR, and scientific communication, including a discussion of critical issues. A concluding section ends the review.

THE INDIVIDUAL COGNITIVE VIEW

The cognitive approach in information science and IR research started at the end of the 1970s. It was influenced by discussions of cognitive science in the early 1970s, the establishment of the journal *Cognitive Science*, and De Mey's epistemological contributions on the cognitive viewpoint in general (DE MEY, 1977, 1982) and its relation to information science (DE MEY, 1980). While initially the cognitive viewpoint influenced theory building in information science as such (see, for instance, BROOKES's equation), it soon became useful to the growing user-centered IR research community. The viewpoint was here clearly seen as an alternative to the mainstream system- and document-driven IR research tradition. Reviews and discussions of the cognitive approach to IR during the 1980s can be found in BELKIN's (1990) overview, ELLIS's (1989; 1992) critical essays, and INGWERSEN's (1992) book. Belkin outlines the major contributions of an analytic and empirical nature that have been rather explicitly based on the cognitive approach. Ellis (1992) contrasts the system-driven mainstream tradition in IR, which he calls physicalistic, with the user-oriented and the cognitive school, both merged under

the label of a cognitive paradigm. One may argue that the concept of paradigm in a Kuhnian sense is an exaggeration with respect to the cognitive approach. However, in relation to the system-driven tradition in IR, there is no doubt that it possesses paradigmatic properties. Ingwersen (1992) discusses in detail the cognitive viewpoint and its implications for the concept of information in information science, the understanding of information need development leading to user modeling—the Mediator Model—and, in particular, its theoretical potential for IR research.

One may divide the development of the cognitive approach to IR into two distinct periods. During the first period, 1977-1991, cognitive IR research built on DE MEY's (1977; 1980) original theses, mainly his central point: "that any processing of information, whether perceptual or symbolic, is mediated by a system of categories or concepts which, for the information processing device, are a model of his (its) world" (1977, p. xvi-xvii). To this Ingwersen adds that the world model consists of cognitive structures that are determined by the "individual and social/collective experiences, education, training etc." (INGWERSEN, 1982, p. 168).

During the second period, 1992-2000, De Mey's core evolutionary view, consisting of four stages through which thinking on information processing has developed (DE MEY, 1980, p. 49), gained importance, for example, in relation to the conceptualization of information and the understanding of the limitations of information processing by computers (INGWERSEN, 1992, 1995, 1996).

Clearly, the current cognitive state of the individual is affected by the past and the social context. This understanding of the central assumption of the cognitive view was influenced by the Russian cognitive psychologist LURIA and his empirical work in the 1920s on humans' classification of objects. Luria demonstrates how educational background as well as work routines and situations trigger the way humans classify objects and separate their relationships into situational and into categorical (generic and part-whole) categories. Naturally, such classificatory behavior impacts the perception by individuals (users) of, for instance, knowledge organization in libraries.

The cognitive view assumes a variety of individual differences in cognitive structures. According to INGWERSEN (1982), the task of IR is to bring into accord the cognitive structures of authors, systems designers, and indexers with those of the intermediary (human or computer) and the user, in order to cope with the actual information need. Ingwersen emphasizes that collective cognitive structures, the result of social interaction and subject domains, as well as scientific and social paradigms, also influence the structure of indexing systems and the relations of topics and concepts treated in the body of literature and in information needs. This notion of bringing into accord cognitively different structures immediately ought to have ensured the establishment of a dominant and workable holistic approach to IR. With the exception of BROOKES, this was unfortunately not the case during the first period. Instead, the main bulk of researchers focused on the individual nature of the cognitive structures in a range of empirical studies of the behavior and cognitive structures of users, human intermediaries, their interactions (including interactions with operational Boolean IR systems), and individual information need formation. The goal was to obtain an improved understanding of such interactive phenomena and factors affecting the actors in order to improve IR performance from a stand different from that of the prevailing system-driven research. One must bear in mind that researchers taking the system view did not involve real users in their experiments, which at that time were carried out on small-scale test collections as a means to find and tune the best retrieval algorithm.

Major Research Results

The results of several studies highlight applications of the individual cognitive view. BELKIN ET AL. (1982a) originated the Anomalous States of Knowledge (ASK) hypothesis, which concerns the development of individual information needs founded in the notion of a problem situation. As a quite novel approach in user-centered research, BELKIN ET AL. (1982b) applied a best-match (non-Boolean) system in their empirical investigation matching structures of users' need descriptions with document abstract structures. The idea was that the user narrative should provide context to the ASK in the form of a problem description. Although the results of these comprehensive experiments were unsatisfactory, they led the IR community to new knowledge concerning the role of the intermediary mechanism and systems design. In similar studies, FENICHEL

investigated on a pragmatic psychological basis the influence of different types of experience on end-user online searching and BATES (1981) produced her well-known search tactics for online retrieval. Quite comprehensive empirical investigations of user or of intermediary communications with online systems (BORGMAN; FIDEL, 1991a, 1991c; SARACEVIC ET AL., 1990, 1991) led to a detailed understanding of interactive processes and use of feedback by end users. INGWERSEN (1984) demonstrated how frequency analyses of indexing terms and other representative structures may aid users in their understanding of the information contents of IR systems. Cognitive subject representation and feedback mechanisms are further explored by INGWERSEN & WORMELL and by MCALPINE & INGWERSEN in relation to supportive interface designs. To a great extent WORMELL (1981; 1984) builds her implementation of the inherent natural-language features of monographic material on the cognitive approach in combination with semiotics in the Subject Access Project and database system. The application of controlled vocabulary versus natural language during online searching was further investigated empirically by FIDEL (1991b). At the same time, T. D. WILSON (1980) started his empirical studies of nonscientific information seeking processes with the INISS project, which pursued quite a different track in investigating the task-driven information seeking behavior of social workers in community environments. T. D. Wilson's (1981) analyses were to a great extent inspired by the cognitive approach. One may find that, in particular, the ASK work as well as the INISS project point to the present state of research in which the integration of broader information seeking processes and IR interaction based on domain work tasks and problem situations is an emerging research issue (VAKKARI, 1999, 2000).

Based on empirical evidence and international cooperation during the mid-1980s, BELKIN ET AL. (1983) and BROOKS (1986) investigated the possibility of creating a user-oriented and cognitively based framework for intelligent interface design based on discourse analyses of user-intermediary-system interactions: the Monstrat Model. Similar protocol analyses led Ingwersen to the discovery of the Label-Effect and the influence of context concerned with information requests (INGWERSEN, 1982) and to a typology of information needs (INGWERSEN, 1986). The Label-Effect means that users, even those with well-defined knowledge of their information gap, tend to label their initial requests for information verbally by means of very few terms or single concepts. This implies two obstacles to successful IR. First, intermediary mechanisms have difficulty in reaching out into the proper directions in information space where data are located relevant to a particular user. Due to the lack of context in the request, a multitude of directions are indeed possible. This was observed in the scientific online age 10 to 20 years ago, and the same phenomenon is dominant today in web searching. Second, intermediary mechanisms may not be capable of distinguishing between users with detailed, some, or no knowledge about their information requirements, that is, whether the user's ASK is intrinsically well- or ill-defined. Independently of Belkin et al. (1982a; 1982b), Ingwersen's observations (1982) of the situational influence of context on information need descriptions and perceptions, for instance in the form of reasons for having a knowledge gap, confirmed the problem situation conception in the ASK hypothesis by Belkin et al. (1982a). Also, the investigations point to contextual perceptions of users leading to problem situations, e.g., perceived goals or interests, and a certain randomness and nonrationalism in the cognitive behavior of searchers. The information need typology consists of three categories, depending on the nature and strength of the conceptual cognitive structures of the user: verificative, conscious topical, and intrinsically muddled or ill-defined. The importance of distinguishing between levels of retrieval knowledge (from novices to experts) and status of conceptual or subject-domain knowledge was originally analyzed in BATES's doctoral dissertation (1972) on catalog search success. The effect of the two distinctive types of knowledge was confirmed—also as a result of BORGMAN's and MARCHIONINI's detailed studies of user-system interaction. Borgman investigates online searchers with different knowledge levels while Marchionini focuses on novice users of full-text encyclopedias (1989), later generalized in 1995. Mainly due to the ASK hypothesis, the development of the Monstrat Model, and the user-need typology, a great deal of interest was invested in the area of cognitive user modeling. DANIELS, as part of the Belkin team, produced an extensive overview of research on cognitive models, including her own, and OFORI-DWUMFUO stressed the importance of dialogue modeling, an issue already investigated by ODDY (1977a; 1977b).

These research efforts led to two novel lines of research within the IR community. First was the intelligent retrieval attempts, as reviewed by BROOKS (1987). These were carried out by researchers such as CROFT &

THOMPSON and FOX in projects where artificial intelligence (AI) tools were used to create knowledge-based IR systems and experiments. Although belonging to the cognitivistic Strong-AI tradition, not the information science cognitive view, these designs demonstrated an interesting similarity to the otherwise user-driven and empirical Monstrat Model. The second line of research was the supportive IR systems approach, in which interface and systems design aid the user by means of a detailed empirical analysis of user, domain, and retrieval characteristics. This approach was shown, for instance, by PEJTERSEN (1980; 1989) in her Bookhouse project on fiction. Pejtersen's and similar lines of research into systems design (e.g., BATES, 1989) completely contrast with the approach taken by RICH (1979) in the Grundy project, which was also on fiction retrieval, but founded in the cognitivistic AI tradition of user stereotype applications. While the supportive systems approach has developed into a comprehensive model for general systems design based on ideas from cognitive engineering in the area of human-computer interaction in the 1990s (FOX ET AL.; RASMUSSEN ET AL.), the former intelligent IR perspective ran out of steam in the 1980s along with other complex expert system-based design attempts. The main reasons are that automatic knowledge acquisition in complex IR scenarios thus far is unsolvable and presumes the same user and domain analyses carried out as for supportive systems. The supportive systems are easier to design and implement than expert systems and, according to SPARCK JONES (1987; 1990), traditional retrieval systems yield better IR results than the knowledge gained by the expert system from question-answering. In a cognitive sense, this outcome is not surprising given that the user is the only truly intelligent and dynamically knowledge-based actor in interactive IR.

Critical Issues

From the results of this first period of cognitive research, it is apparent that the individual cognitive approach falls short in three ways: realism, theory integration, and holistic perspective.

Lack of realism. Too much emphasis was put on the analysis of user and human intermediary behavior during interaction without also including the cognitive structures embedded into the system side and the contextual environment. Further, the systems under investigation were mainly Boolean, large-scale online systems, not experimental best-match retrieval engines. The most interesting and promising exception was the THOMAS retrieval system, or rather program as ODDY put it (1977a; 1977b). THOMAS represented an approach quite different from traditional online or experimental IR to the nature of interaction between user and database. IR was meant to be facilitated not by issuing orders to the system, but rather by forms of dialogue that should resemble personal communication. Thus, comprehensive IR theory-building was not really attempted, and the predictive power of the cognitive viewpoint in collaboration with best-match techniques leading to novel workable research questions and investigations was in general not put to use. For instance, during this first period it would have been appropriate to ask which (combination of) retrieval engines and relevance feedback methods best suit different types of information needs, and *why*. Only the BELKIN & KWASNIK work comes to mind as an explicit example of addressing such issues. Although CROFT & THOMPSON's famous I^3R system actually made use of both clustering and probabilistic models, this was done to improve precision and recall but not founded in any particular cognitive theory of, say, user relevance. Also, the prevailing methods of IR systems evaluation and testing (the Cranfield methodology) suffered from lack of user involvement—that is, lack of realism—which was not improved by cognitive researchers. One critical reason was perhaps that only a few of the researchers, even the pragmatic user-centered investigators, knew enough about best-match retrieval principles, probabilistic and vector space models, or logic. This changed substantially during the second period in connection with the upscaled TREC experiments, initiated in 1991-1992. Generally, too much ignorance prevailed in most sectors of the IR research community, particularly about results obtained in other sectors. An exception from this gloomy picture was the result of a workshop held at Rutgers University (BELKIN ET AL., 1987). A number of leading IR researchers from various approaches came together to exchange views on the current state of affairs in IR research and to attempt to bring together the variety of views, from intelligent IR over traditional experimental research to cognitive and user-oriented pragmatic views.

Lack of theory integration. During the first period other scientifically based approaches to information transfer were proposed. In 1986 DERVIN & NILAN presented their sense-making theory in a substantial *ARIST* chapter

based on communication theory and regarded as an alternative to pragmatic and cognitive approaches. Also in 1986 WINOGRAD & FLORES published their more general socio-hermeneutic approach to systems design. Where Dervin & Nilan's work became highly influential in information need and seeking studies (although hardly in IR research), Winograd & Flores' ideas did not penetrate heavily, except into certain metatheoretical approaches to information science (BRIER) and into the reopening of the relevance discussion by SCHAMBER ET AL. in 1990. Perhaps due to its broader scope, Dervin & Nilan's sense-making theory was not sufficiently compared to nor integrated into the cognitive approach, although both theories deal profoundly with information need formation by individuals and its underlying rationale. Now it is possible to observe mutual agreements between the sense-making and the cognitive approaches, because both fundamentally concern communication phenomena and acts of interpretation in a social context (DERVIN).

Lack of holistic perspective. With researchers conducting empirical studies on the individual cognitive properties of end users, intermediaries, and their interactions, the cognitive approach became open to various kinds of criticism. Because IR consists of a human side *and* a system side it is evident that any (new) theory for IR *must* circumscribe both sides. Retrieval systems require search engines and research into such engines, including their underlying assumptions as well as strengths and weaknesses.

ELLIS (1989) raises some critical questions associated with the individual cognitive approach as a theory for IR. He questions the ability of the viewpoint on its own to support cognitive empirical investigations that are different from the traditional pragmatic user-system studies carried out in operational IR environments. Ellis (1992; 1996) merges cognitive and pragmatic user-oriented research into one line of cognitive research and development in IR, but essentially his arguments are the same.

It is important to understand that from a methodological point of view, the user-centered studies and the cognitive studies have data collection methods in common, including direct observations, recordings of thinking/talking aloud, post-search interviews, and transaction logs. Due to Belkin and colleagues (BELKIN, 1984; BELKIN ET AL., 1982a, 1982b, 1983; BROOKS, 1986), INGWERSEN (1982), and T. D. WILSON (1981), among others, the methodological issues concerned with the widespread use of these inherently obtrusive methods, mainly in combination, became evident to the user-centered research community. The major problem lies in the treatment of the collected data during data analysis. Micro as well as macro protocol analyses and discourse analyses were used both at qualitative and quantitative levels by cognitive researchers to produce both descriptive results and causal cognitive explanations of, for instance, user-librarian interactions (BELKIN & VICKERY; PEJTERSEN, 1989). It is essential to uncover the kind of cognitive factors or structures that trigger users' information needs and problem statements, for instance, the reasons for users' (mis)conceptions of classification structures or icons in systems. The cognitive nature of representative structures of information objects or knowledge sources are thus of direct interest. Common semantics, that is, social or collective cognitive structures influencing the IR outcome, can then easily be detected. Causality analyses require models in order to function. However, several so-called pragmatic studies are actually based on phenomenological approaches or general social science investigative models. Hence, their outcomes may be quite similar to, but often more descriptive than, those of more "pure" cognitive studies. Evidently, the results of pragmatic investigations are of high value when their hypotheses and assumptions are clearly stated. INGWERSEN & PEJTERSEN discuss the utility of a variety of qualitative and quantitative methods, and INGWERSEN (1993) provides a list of cognitively inspired empirical research in response to ELLIS's (1992) questions. SANDSTROM & SANDSTROM present a detailed discussion and exemplification of anthropological methods, including their misuse and proper use in information science. YUAN & MEADOW investigate the use of the variety of variables pertaining to IR user studies, and PORS argues for the introduction of more rigorous social science-based experimental models in interactive IR research, including the application of the classical setting of control groups, also known from medical drug testing.

THE HOLISTIC COGNITIVE VIEW

The reasons for initiating the second period of cognitive research at the beginning of the 1990s are several. (1) The SCHAMBER ET AL. article on situational relevance in 1990 inspires an increasing amount of hitherto

unanswered or ignored questions about relevance phenomena in fora outside the algorithmic IR domain. For instance, HARTER proposes in 1992 the conception of psychological relevance and its relationship to information need formation. With respect to the concept of information need, he challenges the ASK hypothesis proposed a decade earlier by BELKIN ET AL. (1982a). However, he misinterprets the central point of the hypothesis, that is, that the system design in the paper by Belkin et al. is based on the idea of a constantly changing ASK, exactly by virtue of the interaction process over IR session time. Essentially, Harter (p. 610) restates the Belkin et al. view and adds nothing new to the information need and ASK discussion. What is important is the quite comprehensive understanding of the relevance issue seen as a dynamic and complex phenomenon. (2) This discussion of relevance complexity is in direct contrast to the view on relevance and interaction taken in the large-scale mainstream TREC experiments that start in 1991-1992 (HARMAN). In TREC, continuing the empirical Cranfield tradition, relevance is regarded as a binary, topical, and stable, manifestation. TREC forces IR research to reconsider the nature of IR and IR theory. IR theory is not simply algorithmic solutions to technical problems in settings without realism, nor just socio-psychological theories of user behavior in more realistic settings. Both mainstream, cognitive and user-centered theorists recognize the fragmented often black-box like state of affairs at this point in time, and some serious attempts are made during the ensuing years to clarify and understand the situation. (3) ROBERTSON & HANCOCK-BEAULIEU point to three recent revolutions in IR that, in their opinion, are crucial to understand in order to proceed toward a more holistic theory of IR: the cognitive, the relevance, and the interactive revolutions. The cognitive and relevance revolutions in empirical IR require realism with reference to the processes of information need development and human relevance assessments. This means that an information need ought to be treated as a potentially dynamic concept, and that the multidimensional and similarly dynamic nature of relevance should be taken into account. Relevance ought to be judged against the information need situation, not the query or request, by the person who owns the information need or problem situation. The interactive revolution points to the fact that (even experimental) IR systems have become increasingly interactive, due to actual applications of dynamic relevance-feedback and query- modification techniques by users over IR session time. Thus, experimental or evaluative IR settings, as well as theory, have to incorporate this realism that would incorporate the context or situation surrounding the IR activity, i.e., seeking processes. At the same time, experiments must maintain a degree of control. The question is, what do IR researchers wish to observe, analyze, measure, or make theories about? The revolutions can thus be seen as the real challenge to the IR community. (4) DE MEY's (1980; 1982) original view of cognition in contextual social interaction as well as his stages of information processing, their effect on the concepts of information and information need formation, and their association with IR research are not fully explored. An attempt is thus made by INGWERSEN in 1992 and 1996 to discuss in detail the state of IR theory and research from an interactive perspective, hereby following up on the work by BELKIN & VICKERY.

By contrasting the usual relevance notion of topicality with the concept of situational relevance, SCHAMBER ET AL. also stress the importance of context in IR. Situational relevance derives from P. WILSON's original concept in 1973. Context may come from the information objects or knowledge sources in systems, but may also be influenced by the actual information seeking situation adhering to a domain. Situational also implies a series of dynamic cognitive states in the mind of the user during an IR session. Essentially, this means that if relevance evaluation is dynamic, the corresponding information need is dynamic as well. During an IR session, an information object may thus be topically relevant in the sense of the TREC experiments (HARMAN), but may not be useful to the situation the end user is facing at that time. Obviously, only the user can assess this type of relevance.

There is some similarity between situational relevance and LURIA's situational classification of objects. For example, one can easily detect situational assessments in the empirical studies of user-intermediary-system interactions. The user's current perception of the situation, rather than the user per se, becomes the focal point for IR interaction. The intentionality of the user (in the sense presented by SEARLE, i.e., the user's goal or purpose) and background knowledge at a given time can be seen as the crucial components in IR interaction. IR implies a continuous process of interpretation and cognition. In a holistic sense such processes take place both on the user side and on the system side during human-machine interactions. However, DE MEY's (1980; 1982) stages of understanding information processing in a broad sense define the limitations and characteristics

involved on both sides in a cognitively asymmetrical way. The shift into a holistic cognitive view implies that the belief that the variety of cognitive structures in IR (e.g., indexing structures, information object structures by authors, or users' cognitive interpretations) can be commonly understood shifts to the acceptance that such structures are inherently different. The goal is to explore and employ the cognitive differences of structures in such a way that IR can be facilitated and improved. At its current level of cognition, i.e., recognition and algorithmic processing following implemented rules, the machine cannot become aware of and understand what the user is looking for, in particular when the user's ASK initially is ill-defined. The machine may, however, be designed to support the user during the interactive process of IR in order to make the user interpret and learn so he/she feeds data back to the machine, which eases its way of further supporting the user. Ultimately, information retrieval in its real sense takes place only in the mind of the information seeker, that is, information is seen as process or as knowledge and cognition, as discussed by BUCKLAND (1991a; 1991b). The road is constantly uphill from the machine point of view.

Information Processing

Generally, the shift into a situational context assumes consideration of intentionality and processes of interpretation. We are thus seeking an understanding of phenomena that pertain to both machine functions and human cognition. To this end, INGWERSEN (1992, p. 33) proposes a model of the cognitive communication system for information retrieval originally put forward by BELKIN (1977), and, later made more detailed in INGWERSEN (1996, p. 6). The latter model is depicted in Figure 1. It shifts the focus of the cognitive viewpoint into the four generalized evolutionary stages proposed by DE MEY (1980): monadic, structural, contextual, and cognitive. These are seen as stages of information processing consistent with the similar common evolutionary levels of language understanding (SMEATON): morpho-lexical, syntactic, semantic, and pragmatic.

In human information processing, the world model constitutes the cognitive space, consisting of highly dynamic autopoietic and changeable cognitive structures, that controls the perception and further processing of external input, for instance during communication and IR interaction. Originating from BOULDING, the individual cognitive space and, in particular, the individual's current cognitive/emotional structures and states, are determined by the experiences gained over time in a social and cultural context through social interaction. In computerized information processing, the computer's world model is not self-contained. It consists of the human cognitive structures embedded in the system prior to processing. Its cognitive structures (e.g., algorithms or textual symbolic strings) may interact with one another and with structures generated by humans external to the system, according to the capabilities of the system's algorithms. However, the processing constantly takes place at a linguistic sign level of communication, never at a cognitive level (see Figure 1). The linguistic sign levels consist of the morpho-lexical, the syntactic, and the semantic levels of language understanding. For human recipients of communicated signs, perception may also take place at a cognitive-emotional level. In this case, the signs provide information that may transform the current cognitive states into new states of knowledge. During any act of human or computerized communication, all communicated messages are regarded as signs transferred at a morpho-lexical linguistic level. Only perception and interpretation by humans in their current cognitive states can transform signs into information at a cognitive level. This implies that any intentionality and meaning underlying the communicated messages are immediately lost (SMEATON) in what is known as a cognitive free fall (Figure 1). The message must be rebuilt, or interpreted, by individuals (or the computer) based on the presuppositions, in context, that they bring to the communication act. Cognitive free fall means that essentially all cognitive manifestations in messages are lost when uttered or transmitted, whether from machine or any other entity. The messages consist of signals, data, or signs at a monadic stage. This is the reason we may not, or only partly, perceive and understand people's, nature's, or machines' messages, which inherently are ambiguous. However, we may give meaning to or interpret (also erroneously) perceived messages or objects according to our current presuppositions in a situational context. Naturally, machines constantly suffer from similar problems of correct recognition and interpretation at the linguistic sign-processing levels. Figure 1 shows one instance of communication between a sender or generator and a recipient. In true interaction the recipient role becomes the sender role at the following instance (summarized from INGWERSEN,

1992, 1996).

Computers (or books for that matter) hold fixed human presuppositions, while those of humans are unpredictable, formed by episodic, semantic, and tacit knowledge, or emotional experiences in context. The semantic level is identified as the stage of language understanding in which a domain or culture shapes the common interpretation of a sign at a given point in time by means of social interaction in a common context (context A overlapping context B).

Four fundamental characteristics are of crucial importance to IR:

- All interactive communication activities during IR can be regarded as processes of cognition, which may occur in all the information processing components involved, but at different levels of cognition.
- The presuppositions and intentionality underlying messages are vital for the perception and understanding of such messages, but are lost by any transmitting system between sender and recipient, whether human or machine.
- Uncertainties and unpredictabilities are inherent in IR interaction and associated with all acts of interpretation carried out by senders and recipients, whether human or machine.
- Direct and real information retrieval, as opposed to text retrieval performed at a linguistic level, Figure 1, is possible only by the individual user in context.

Because of these characteristics, IR systems may be most successful only when they support IR by humans. Further, because of the dynamic nature of cognition, time becomes an important issue in interactive IR.

DE MEY's (1980) four information processing stages stated above limit the level of cognition for machines to a linguistic sign level, up to and including the contextual (or semantic) stage. Communicative discrepancies may occur between humans and between humans and machines because machines cannot reach the same level of understanding as humans unless the meaning of a sign is common to both. To be understood by human or machine, a text or image must be interpreted at a certain linguistic stage. The lower the stage, the larger the semantic openness of the object or sign. This means that an object or sign does not necessarily yield the same information to the recipient as intended by the sender or, for that matter, does not yield the same information to different recipients at the same time.

INFORMATION STRUCTURES

In the comprehensive cognitive view, the concept of information, building on WERSIG, BROOKES, BELKIN (1978), and SEARLE, must satisfy two conditions simultaneously (INGWERSEN, 1992, p. 33): "on the one hand information being the result of a transformation of a generator's knowledge structures (by intentionality, model of recipients' states of knowledge, and in the form of signs); and on the other hand being something which, when perceived, affects and transforms the recipient's state of knowledge." The satisfaction of these two conditions means that information goes beyond meaning. A sentence or an image may have several meanings or semantic values, and each meaning may provide many different interpretations and transformations of the state of knowledge. In machine translation, the attempt is to establish the one correct linguistic meaning (semantics) by means of textual context. In IR, the goal is to give recipients access to plausible meanings or values for interpretation at a pragmatic level in their specific situational context. The information is associated with the situation in context, not just with its general semantic value.

The implication for the interactive communication process taking place between human and machine is that messages sent by machines or humans to a human recipient can become information in the real sense; however, signs communicated by machines or humans to a machine can *never* become information, although they are perceived and affect the embedded cognitive structures. Such signs stay signs, or remain as potential information (BELKIN, 1978; INGWERSEN, 1984, 1992) at a linguistic surface level. Figure 1 demonstrates the two conditions that must be met. The first condition is found at the sign level and corresponds to the information concept applied by SALTON and others who conduct system-driven research. Texts and text

features *are* information; hence the possibility of retrieving information in text retrieval by means of term weighting and similarity measures in the algorithmic approach. The second condition corresponds to information concepts centered on reduction of uncertainty and similar transformations of cognitive structures. In a very generic sense LOSEE ends his information understanding discussion by viewing information "as the result of a process." The process may be any process, such as chemical, biological, mental, etc. In our cognitive framework each condition is a process involving intentionality—and both conditions must be met. Hence, our information concept, like BROOKES's and BUCKLAND's (see below), is a limited case in terms of Losee's almost universal concept. Further discussions of the cognitive information understanding are provided by Ingwersen (1992; 1996) and, in connection to Popper and Shannon, by COLE in a recent analysis.

BROOKES's and BUCKLAND's (1991a; 1991b) information concepts have properties in common. Brookes regards information as an increment of knowledge where information interacts with the existing cognitive structures of an individual. The result is a modified set of structures: $K(S) + \delta I = K(S + \delta S)$. This, BROOKES's equation, is in pseudo-mathematical form and acts like a model. It states in a very general way that the knowledge structures K(S) are changed into a new modified state of knowledge $K(S + \delta S)$ by the information δI, the δS indicating the effect of the modification. In other versions the equation symbol is replaced by an arrow pointing to the right, whereby its irreversible aspects are stressed. The equation can be illustrated by the dynamic interaction at the cognitive levels of information between generator and recipient (Figure 1). By introducing Popper's Three World Ontology into information science, Brookes suggests a dual model of knowledge: Objective knowledge (World 3), that is, man-made data structures, such as books or computer files; and Subjective knowledge (World 2), that is, the cognitive spaces of individuals. The interaction between the two constitutes the information processes and the focus for information science. Brookes places the focus on World 3. (World 1, i.e., artifacts, is not discussed.) The problem with his model is the omission of the forces driving the information processes, for example, intentionality and interpretation, the reasons for information transfer.

A similar flaw occurs in BUCKLAND's (1991a; 1991b) tripartite notion of information. Without reference to Brookes' 1980 contribution, Buckland divides the world into similar concepts. (1) Information-as- Thing, that is, the words, texts, images, man-made data structures, exhibitions of natural artifacts, etc. equals Objective knowledge. (2) Information-as-Knowledge is analogous to Brookes's Subjective knowledge. (3) Information-as-Process is like Brookes's interactions, or the informing acts during which data structures transform into cognition and knowledge. Also, Buckland introduces an additional notion of information processing, which signifies the tangible manipulation of data at a linguistic sign level (Figure 1) and may take place in computers. In contrast to Brookes, Buckland discusses whether a natural artifact such as an animal or a DNA molecule is Information-as-Thing. In my opinion, this question is about how sensory data can become information, that is, can inform and become cognition and knowledge. With the two-conditional concepts in mind, one would suggest that this is possible if an intentional hypothesis exists concerning an object. For example, a person observing an object, such as a star, with a hypothesis in mind, acts both as sender of a message (a test) and as recipient of data (the test result). Depending on the person's perceptions and presuppositions (a theory), influenced by a domain, this process affects and transforms the state of knowledge. The test data becomes information on the object.

According to his holistic cognitive model (INGWERSEN, 1992, p. 16), later enhanced (1996, p. 9) to attempt a cognitive IR theory, IR interaction consists of interactive communication processes involving five major cognitive actors: (1) information objects or knowledge sources, including their representations, originating from author and indexer knowledge structures; (2) system structures, such as retrieval algorithms, generated by designers, system owners, etc.; (3) interface functionalities, made by system designers or consisting of human intermediary cognitive structures; (4) the user's cognitive space, consisting of work task and situational perceptions, current state of knowledge, problem and uncertainty states, etc.; and (5) the socio-organizational environment, including the situational context, domain structures, work tasks, strategies, and preferences. The model emphasizes that the last two components interact and influence human behavior and the generation of new information objects over time.

This cognitive model illustrates BUCKLAND's (1991a; 1991b) tripartite notions. Foremost, the information objects as well as the system setting encompass his concept of Information-as-Thing. His Information-as-Knowledge equals the cognitive space, and the interactions occurring during information transfer between the components illustrate Information-as-Process. Information processing, his other notion, coincides with the interaction of information objects and the setting. Only the socio-organizational environment is not dealt with explicitly by Buckland.

Information Need

According to the cognitive approach, an individual information need is a function of the current knowledge state of the individual (BELKIN ET AL., 1982a; BELKIN & VICKERY; WERSIG; WILSON, 1981).

Information needs may be stable and well-defined, as is often the case in patent searching and selective dissemination of information (SDI) or information filtering. However, frequently information needs are variable, especially in initial exploratory search sessions where they may be vaguely stated or ill-defined (BORLUND & INGWERSEN; SCHAMBER ET AL.; SU).

According to INGWERSEN (1996, p. 15) four types of information need initiation cases may occur, each of which affects subsequent interaction and information need development. If the cognitive structures behind the information need are strong, the probability that the need can be well-defined is high; the information need may then be either (1) stable or (2) variable. If it is variable, the user is not sure whether the initial information need is adequate but is willing to learn. However, if the structures are weak, that is, the user scarcely knows how to define the lack of information, two cases occur: (3) the need is intrinsically ill-defined or muddled and the user feels the need as stable, or (4) the user is motivated for change, that is, willing to learn. Ill-defined stable information needs (case 3) can be observed in cases of librarians carrying out retrieval on behalf of users, as shown by INGWERSEN (1982). All four cases represent different problems to the computer interface/human intermediary and the retrieval system.

Under the individual cognitive view, the suggestion would have been to provide feedback to the user about the information space, such as characteristics of the knowledge resources stored in or retrieved by the system; see for example, proposals by INGWERSEN (1984) and evaluations by EFTHIMIADIS (1995). Under the holistic view, this might work for the two cases in which the user's information need is well-defined. In the two cases in which the user's cognitive structures are weak, the information need may be too ill-defined to be useful for interactive system activities such as providing relevance feedback or assisting in query modification, expansion, or enhancement. In such cases of cognitive confusion, additional means for information transfer and cognition are required. According to the cognitive view, one way is to provide exploratory means for learning and cognition in IR systems, e.g., by browsing and navigation, as proposed by BATES (1989), and supported by plausible inference networking (TURTLE & CROFT). It is important to be aware of the distinctions between (1) the real work tasks, problem situations, or simply interests that lead people to engage in information seeking behavior; (2) the intrinsic perception or understanding of such situations or tasks presumably of more stable nature than a need for information triggered by such perceptions; and (3) the statements concerned with the perception of the information need. WILSON (1981) makes similar distinctions between the intrinsic information need and the perceived reasons underlying it in his cognitively based analyses of information need characteristics.

Current interactive TREC experiments involve feedback from systems; relevance feedback to systems; and query modification, expansion, or enhancement. Because noninteractive TREC experiments typically evaluate IR systems based on stable and well-defined topics, one may argue that the results basically pertain only to stable and well-defined information need statements. The most recent interactive experiments, however, allow for variations in information need and its perception over IR session time. Generally, the interactive TREC experiments as well as the OKAPI evaluation studies (ROBERTSON) provide useful results that demonstrate (1) the actual limitations of TREC, in particular concerning its noninteractive tracks; and (2) how searcher inconsistency, feedback, and query modification can support a holistic cognitive IR theory.

Preliminary interactive TREC experiments on the retrieval performance of combined query versions

generated by several searchers, but deriving from the same well- and pre-defined information need statement (i.e., a TREC topic), demonstrate a performance result similar to that of the best-performing single query. This single-query result is, of course, always unknown beforehand and hence unpredictable (BELKIN ET AL., 1993). IIVONEN also looks into searcher and search-term inconsistencies in applying interactive TREC topics. This interesting research on intersearcher consistency, similar to the interindexer consistency and hypertext interlinker consistency experiments made outside TREC (ELLIS ET AL.), strongly indicates that the individual cognitive nature of the request formulation is rooted in intrinsic situational causality. Following the cognitive view, the intrinsic causality concerns the perception and interpretation in context of the incoming messages, say a TREC topic and the ensuing interactive feedback from the system. With scarce or no situational context provided around the test topic—the why of the search—the user must provide for it him/herself. This may be the reason for the variations and inconsistency observed in the experiments. More realistically, the most recent interactive TREC experiments ask the test persons to retrieve aspects of topics over session time (HARMAN). This makes room for more dynamics in the IR processes. In a cognitive sense the next step toward more realism during experimentation would be to introduce problem situations or work tasks to be solved by the test persons. In this way the test persons would have cause for their retrieval behavior, and one might make use of the persons' work-task perceptions in the form of statements or search activities, in addition to often vague descriptions of the information gaps. From empirical research outside TREC we obtain strong indications that feedback from systems is used differently during IR sessions (SPINK & LOSEE; SPINK & SARACEVIC, 1998). During the session users increasingly tend to focus on the perceived underlying situation, problem, or task leading to information seeking in the first place, or other aspects of the interaction (ROBINS)—and less on the topic. This conception of utilizing the "problematic situation"—but less explicitly the perceived work task—essentially refers to WERSIG's (1979) original ideas, the ASK hypothesis (BELKIN ET AL., 1982a), and the Monstrat Model (BELKIN ET AL., 1983).

DIMENSIONS OF THE HOLISTIC VIEW

During this second period the understanding of information as a situational phenomenon is quite clear. A direct consequence of the situational approach and the enhanced cognitive model is a shift away from the idea of simply bringing cognitive structures into accord. Instead, the new cognitive IR theory focuses on the explicit application of the cognitive structures of different origin involved in IR interaction. The objective is to point to the potential value of matching the multidimensional variety of representations inherent in or extracted/interpreted from information objects and from the cognitive space of a user in a social and situational context. The work task and its perception by a user is regarded as just as valuable as the information need in the form of requests (INGWERSEN, 1996).

Polyrepresentation of Information Objects

Cognitive IR theory favors all kinds of variations in information structures, and particularly favors retrieval overlaps between such variations. The assumption is that the more disparate the structures in cognitive origin, logic, functionality, and time, the smaller the overlap and the better and probably more relevant the retrieval outcome (INGWERSEN, 1996). The concepts of cognitive retrieval overlaps, data fusion (BELKIN ET AL., 1995b), and request fusion are essential elements of a theory framed by the cognitive perspective. For example, SARACEVIC & KANTOR point to retrieval overlaps and their potential for improved retrieval outcome in a combined information seeking and retrieval user study.

The overlaps are based on a principle of multiple evidence or polyrepresentation. The principle originates from the arguments proposed by TURTLE & CROFT in 1990 with regard to their generic inference network proposal. The network implies different ways of referring to the same concept and of linking different concepts in the form of a conceptual net thrown over the underlying information objects. Following INGWERSEN (1992, p. 201), the principle implies analog representations in a variety of different forms of one information object, or of an information requirement. Fundamentally the representations are forms of the different cognitive

structures noted above.

Representations of different cognitive origin and type are generated via a variety of well-known retrieval and (automatic) indexing methods applied to IR systems. Different indexing methods, for example, natural language versus controlled vocabulary, applied to the same text collection retrieve different sets of text or passages for the same query. A passage can equal a paragraph, a section, or a figure in a full-text object. In online bibliographic databases, human indexing with a small number of controlled terms per document results in a representation based on human interpretation and domain expertise of the entire full-text object. As such, this leads to a heavy reduction in access possibilities, although new facets of potential informative value may have been added by the indexer. The automatic natural-language processing (NLP) approach provides many more access points, but generated by the author. The author's terms in section headings or titles are assumed to have greater weight than similar words in the text body. Hence, the writing style in scientific communication influences the NLP result differently due to its domain dependence. The NLP result can be automatically filtered through a domain-specific thesaurus of controlled terms. Thesauri are actually interpretations of a domain by experts different from the indexers (INGWERSEN, 1996).

Several empirical investigations carried out in the operational Boolean environment demonstrate clearly that the combination or the overlap of controlled index terms and natural-language representations yields better retrieval results than the two separately (KATZER ET AL.; LANCASTER; TENOPIR). The more variety in cognitive origin of representation, the more different the results and narrower the overlaps. Because of individual variance in interpretation, human indexing results in retrieved sets rather different from those based on automatic indexing. INGWERSEN (1996) exemplifies how the mixing of author-generated title and abstract terms with indexer-generated terms can be applied following a Boolean quorum logic combined with the cognitive principle of polyrepresentation or multiple evidence in traditional online bibliographic databases. AHLGREN (1998; 1999) proposes how to improve and logically simplify this cognitive online approach.

One of very few investigations of the overlap in retrieval of journal articles using term indexing and citation indexing was carried out by MCCAIN. As expected, for the same queries in Medline and the citation databases, the two very different cognitive structures of indexers and citing authors yielded an overlap of only 11% on average. PAO's (1993; 1994) similar investigations of the overlap between indexing and citation analysis went further by clearly demonstrating that up to 90% of retrieved documents in the narrow overlap set were judged relevant by experts. HARTER ET AL. investigated two confirmatory representative structures associated with scientific communication—those of citing and cited authors—and observed their semantic relationships or overlaps. SWANSON's 1986 methodology for examination of scientific communication patterns to discover hitherto unknown connections between two medically remote research communities belongs to the same kind of multiple evidence approach. There is a small but increasing interest in these approaches to retrieval based on different types of citation indexing. When invented three decades ago, citation indexing was seen as an alternative to text retrieval (GARFIELD). Now in light of current cognitive theory and information technology, they appear to offer far more in combination than anticipated.

With respect to overlaps between sets of texts retrieved via different best-match (and Boolean) techniques or search engines for the same user statement, the picture is identical. From a cognitive perspective, this evidence of variety is obvious. This is the idea behind data fusion as discussed by KANTOR and first put into practice in the I^3R system developed by CROFT & THOMPSON.

An interesting line of research is proposed by VAN RIJSBERGEN & LALMAS and LALMAS & RUTHVEN. Van Rijsbergen & Lalmas suggest the application of uncertainty logics, including abduction, because uncertainty and unpredictability are fundamental obstacles to effective access to information in IR. They go on to propose the application of the Dempster-Schafer theory of evidence as a logical tool in IR. The proposal is carried on by Lalmas & Ruthven. In many ways their approach seems associated with or complementary to cognitive theory, primarily with regard to the use of uncertainty and multiple evidence or polyrepresentation of information objects. A comprehensive cognitive IR theory should not only attempt to bridge or associate with prevailing theories in mainstream research, but it ought also to be able to explain some fundamental problems that occur in such theories. One example is the well-known but unrealistic assumptions of term and relevance-assessment independence concerning probabilistic and vector-space techniques (ELLIS, 1996). The term-independence

assumption implies that each term or feature in an information object is independent of other features. Terms are the entities on which probabilistic or vector calculations are made, and they seem to yield a better performance result on average than the use of concepts or composite terms or phrases. Similarly, each relevance assessment of a ranked list of objects is assumed to be independent, or not to influence other assessments. The first assumption is in fact realistic in a cognitive sense if we assume that authors actually write meaningful texts and the query is rich. In such cases (INGWERSEN, 1996), when a text passage is retrieved containing a vast number of independent query terms, the probability that we reach a meaningful text entity is high and correct topicality is assured. Clearly, we have not necessarily retrieved information in a cognitive sense, but conceivably a meaning quite identical to the query. DRETSKE's semantic information theory comes to mind, in which information (seen as the text itself, as opposed to the cognitive information conception) leads to meaning, that is, to making sense. In addition, although phrases are more concise and precise features, they are more semantically closed than single terms. In a cognitive sense, the bigger the context, the more disambiguation at the semantic linguistic level (Figure 1), and the fewer the paths into information space of possibly useful nature to the user. Hence, phrases limit recall. The relevance-independence assumption should be seen in the light of the Cranfield-like experiments in which titles or short abstracts were presented to users. In that case the assumption does not necessarily hold because each assessment will be as fast and possible to remember as the ensuing one. This depends, of course, on the presentation mode of objects. However, if full-text objects are assessed, the independence assumption may very well hold due to cognitive overload during assessments.

Cognitive Space and IR Interactions

Two particularly important structures in the cognitive space of the user are the perceptions of the work task and the information need that drive the user's seeking behavior. Various researchers are finding ways to observe and understand the relationship of work task to information need with the goal of designing more responsive IR systems that employ mechanisms such as feedback and query expansion.

Work task. As part of the situational context surrounding the world model of the user (Figure 1) are the work tasks imposed by the social-organizational environment and perceived by the user by means of his or her current cognitive state as an interest, problem, or task to be pursued (INGWERSEN, 1996). This act of perception can be seen as a dominant component of the problematic situation conceived in the ASK hypothesis (BELKIN ET AL., 1982a), or the component regarded as the cause for information need development. In a cognitive sense the user's perception of a work task is likely to be more stable over IR session time than the corresponding dynamic information need. The perception of work task is thus appropriate to utilize, as it may provide the context necessary for the system to retrieve relevant information, i.e., information useful to that user in carrying out the work task. This conception of context and information use is associated with WILSON (1981). In this respect we may see how decade-old conceptions, proposals and observations often are resurfacing and tuned into new shapes due to the ongoing process of research in the field.

Several extensive studies of the influence of work task on IR have been made. BYSTRÖM & JÄRVELIN, in a study based partly on the cognitive view and partly on sense-making theory, investigated the complexity of work tasks and how it affects not only IR but also information seeking and use in decision making. Their results show that, in the case of complex and ad hoc work tasks, both the information need and corresponding problem perception are extremely weak or nonexistent. The user can describe only the perceived work task itself. Evidently, any IR design and/or evaluation ought to take that factor into consideration. Researchers should investigate the socio-organizational environment and domains with respect to characteristics of work tasks and preferences as well as their associated problem and need manifestations. This type of domain analysis can be carried out by means of common social science data collection and analysis methods, such as process analysis. A detailed model for work-task analyses is provided by RASMUSSEN ET AL. (p. 206) in their empirically based cognitive ecological framework, which covers both design and evaluation issues of information systems and is both analytical and empirical.

In evaluation of IR systems, BORLUND & INGWERSEN (1997) created simulated work-task situations, or cover stories, that were employed by test users to generate their own information needs. Although the study

was small in scale, the results indicate that IR systems can be tested applying simulated task frames. Currently, the technique of applying real information needs generated by test users in response to simulated work tasks is being studied in large-scale IR system evaluation experiments involving full-text and best-match algorithms including query modification (BORLUND; BORLUND & INGWERSEN, 1999). ALLEN (1996a, 1996b) and HERSH ET AL. use the work-task approach in a more pragmatic and user-centered study, while JOSE ET AL. rely on the Borlund technique of simulated tasks and information situations in an evaluation study of image retrieval. REID supports Borlund's technique in promoting a task-oriented approach to IR evaluation in general. It should be noted that a task can be understood in two ways in IR: (1) as a work task that originates external to the user from an information and domain situation and (2) as one or several different retrieval or search tasks of specific conceptual or retrieval nature to be performed in connection with searching for information. Hersh et al. study the task phenomenon in its latter capacity as does MARCHIONINI, who regards information seeking as a process in which the search task consists of a series of actions in pursuit of an aim. The aim is identical to the work task or interest. Search tasks are also (re)investigated in relation to online searching, i.e., searching virtual environments, such as digital libraries or the World Wide Web. Various approaches to investigating cognitive style are recently discussed. FORD introduces the use of neural networks to handle fuzzy navigational behavior, while PALMQUIST & KIM observe search performance in terms of time spent and number of nodes traversed, and S. PARK looks into the role of integrated interaction and user control of the distributed environment including database selection.

The work task and its effect on the user's perception constitutes a valuable dimension of the cognitive space of the user, in line with problem and information need perceptions. Conceivably, this multidimensionality can be further exploited in building request models to extract descriptions of various user perceptions.

Feedback and query expansion. SPINK ET AL. (1998a) conducted a large-scale empirical investigation of elicitations of information from users by search intermediaries in standard online IR situations. By means of 40 mediated IR interactions and more than 1500 elicitations, the authors establish a categorization of purpose and strategies for mediated questions from users with real needs and monitor the transition sequences from one type of question to another. Their conclusions are compared to previous interaction studies and models (BELKIN ET AL., 1987; INGWERSEN, 1982, 1996; SARACEVIC, 1996a; SARACEVIC ET AL., 1990) and stress in a very detailed manner the importance of extracting information from the user on search terms, domain knowledge level, previous information seeking experience, and search knowledge. SPINK & SARACEVIC (1997) found that search terms evaluated from systems feedback and later applied to query expansion were found to be highly productive, as was the interactive IR session in teams of users.

Feedback from IR systems is thus a fundamental element both in standard online retrieval and in relation to best-match IR, for instance, in TREC. Based on the cognitive approach and cybernetics theory, SPINK analyzes three different feedback frameworks applied in information science research. She suggests enhancing the feedback concept within the cognitive understanding of information, thus illuminating the information seeking and retrieval context. In an *ARIST* chapter, SPINK & LOSEE present a comprehensive overview of feedback issues in IR. SPINK & SARACEVIC (1998) provide a smaller but highly structured review related to human-computer interaction in IR.

Manual query modification during experimentation, for example, in the OKAPI experiments (HANCOCK-BEAULIEU ET AL.), combined with relevance feedback, demonstrates highly interesting results from a cognitive view. It provides the basis for improved cognition and expression by the user of the underlying problem or work task and, possibly, of the actual need for information, by forcing the user to interpret the search outcome (SPINK ET AL., 1998a). This outcome does not have to be monolithic, that is, one simple ranked list, but may also contain pointers to several conceivable routes into information space, for example, hypertext links, class names, condensed or structured lists of concepts, and analogous means of conceptual feedback. The structures of monolithic term lists have been empirically evaluated by EFTHIMIADIS (1995) from a cognitive and user-centered view. Simple frequency-ranked term lists seem less valuable than lists ranked with the "best" search terms first.

The results of some investigations disagree on the effect of query modification on retrieval outcome. BELKIN ET AL. (1996a) maintain that interactive query modification adds to the performance of the total IR system,

measured as recall and precision in interactive TREC experiments. In contrast, HANCOCK-BEAULIEU ET AL. claim that manual query expansion in various forms does not increase overall performance but rather decreases it. The latter result has been confirmed by MAGENNIS & VAN RIJSBERGEN. However, the investigations on this matter are very few and, due to the experimental settings, difficult to compare. We have indications that successful use of ranked retrieval systems depends heavily on the users' mental models of how such systems operate, including functionality like relevance feedback and query modification (BELKIN ET AL., 1996b).

It should be noted that equal treatment, accumulation, or fusion of request versions (or relevance feedback) over IR session time, as done in noninteractive best-match algorithms, is incompatible with a cognitive theory for information transfer. Because cognitive theory assumes that dynamic interpretations, learning and cognition take place during information interaction, the latest versions of requests should be given higher priority or weighting than previous versions in interactive best-match algorithms. This does not make objects redundant that previously have been judged relevant and still are seen as useful by the user. The systems design should obviously allow for a return path or save functions, consistent with the observations of relevance behavior by FLORANCE & MARCHIONINI. CAMPBELL and CAMPBELL & VAN RIJSBERGEN propose an application of a probabilistic model, called the Ostensive Model, that reduces the weights given to previous relevance feedback results, thus conforming to the realistic concept of information need and situational variation during IR. The implemented system is intended to work without query reformulations by the user, a conception similar to that of the THOMAS system (ODDY, 1977b); instead it displays image representations of the information objects in the form of clusters of candidate objects generated by the highest-ranked objects based on the previous relevance feedback actions with falling probabilistic weights. In the effort to reduce clutter, the candidates are only shown around the current object chosen by the user. The path of previously assessed clusters is the sequence of objects from the starting point to the current object. The user is thus free to select any object at any time as the new current object (CAMPBELL).

Relevance and Evaluation

The TREC and other interactive investigations and experiments demonstrate the problematic issues concerned with the concept of relevance and the evaluation methods generally applied in IR. Until recently a basic drawback of the cognitive approach has been a lack of discussion directed toward these issues. Yet, the number of journal articles on relevance alone has increased tremendously since the SCHAMBER ET AL. article in 1990: in that year 9 articles were published and in 1996-1997 the trend peaked with more than 50 articles per year. Schamber reviews the issue of relevance in *ARIST* (SCHAMBER, 1994) and has herself contributed to the empirical study of relevance assessment criteria from a cognitive approach (SCHAMBER, 1991), along with others, including BARRY, BARRY & SCHAMBER, BRUCE, and T. K. PARK. A thorough discussion of evaluation of IR systems can be found in the *ARIST* 32 chapter by HARTER & HERT.

The relevance experiments and investigations, including those associated with TREC, led SARACEVIC (1996b) to produce the most comprehensive model of relevance types and IR interaction. The model is seen as an alternative to but strongly associated with the cognitive models proposed by INGWERSEN (1992; 1996) and BELKIN ET AL. (1995a). Saracevic's model is at least two-dimensional. One dimension is occupied by three communication levels. The (1) processing level corresponds roughly to SMEATON's morpho-lexical and syntactic linguistic levels, and the (2) interactive and (3) cognitive levels to Smeaton's semantic and pragmatic levels. The other dimension consists of five increasingly subjective types of relevance: from (1) algorithmic, which is similar to ranked machine output, e.g., in TREC; through (2) topicality; (3) pertinence to information needs; and (4) situational relevance. Situational relevance corresponds to the work-task situation. Saracevic also introduces (5) an emotional/intentional type of relevance that can be seen as a socio-cognitive assessment category referring to the domain and its collective preferences (COSIJN & INGWERSEN). Later SPINK ET AL. (1998b) add two new dimensions to the model: time and relevance scaling. BORLUND & INGWERSEN (1998) propose the application of scaling during IR experimentation and two new performance measures built on the Saracevic model: relative relevance, which compares different types of relevance assigned by users to the same ranked output; and ranked half-life measures, which measure the capacity of the system to rank the most

relevant object as high on the list as possible. From a more logical and structured stand, MIZZARO (1996; 1997) analyzes the variety of conceptualizations of relevance, including cognitive contributions in IR.

INTEGRATION OF MODELS

The holistic cognitive approach to IR attempts to cover both the information object and system facets of the retrieval processes as well as the user and socio-organizational environment. Information is seen as situational and contextual. Only recently we begin to observe a trend of integrating information retrieval with its natural context: information seeking processes and behavior. The question of integration has always been there, for instance already modeled implicitly by WILSON (1981). Another integrative approach can be seen in connection to the field of scientific communication and informetrics, for which IR has been an essential means to data collection. However, prior to looking into those integrative efforts we will deal with the critical issues of the cognitive view, mainly arising from a meta-theoretical stand.

Critical Issues

VICKERY outlines the individual cognitive approach, mainly belonging to the first period, 1970s to 1990s, and compares it to other epistemological views on information science. His main criticism of the approach is that it is said to lack predictability and practical investigations along its theoretical lines. Since the cognitive view does not adhere to a natural science research tradition, no formal ways exist to model IR and IR interaction from that standpoint. Nevertheless, at a theoretical conceptual level—as a middle-range theory—the holistic cognitive view predicts that deliberate simultaneous use of several different formal IR techniques or algorithms will produce retrieval overlaps that are more relevant (useful) to a user, the more cognitively different the techniques. The condition is that the user's cognitive space is also represented in IR by different but causal cognitive structures in terms of polyrepresentation or multi-evidence. We have seen some empirical indications that this prediction may be correct (MCCAIN; PAO) when applying citation and term representations simultaneously. Another prediction is that simulated work-task situations or cover stories may function just as well as real needs, and more realistically than simple queries, during controlled investigations of interactive IR activities (BORLUND & INGWERSEN, 1997), mainly due to their situational and contextual nature. So far this assumption seems not to have been falsified (BORLUND). The building and use of cognitive user and request models that successfully guide researchers through large-scale studies of interaction with IR systems seem successful in the sense that we know of their functional limitations (BELKIN ET AL., 1983; BROOKS, 1987; INGWERSEN, 1992). Hence, more elaborated models, based on empirically investigated successes, errors, or limitations of the former models have been proposed, discussed, and empirically tested (BELKIN ET AL., 1995a; BORLUND & INGWERSEN, 1997; HARTER & HERT; INGWERSEN, 1996; MIZZARO, 1996, 1997; RASMUSSEN ET AL.; SARACEVIC, 1996a; SPINK ET AL., 1998b; WILSON, 1999). This is perhaps the major contrast to the prevailing black-box system-driven research tradition in IR. The crude Cranfield model (CLEVERDON ET AL.) has hardly changed for decades, although the same tradition increasingly produces evidence that suggests including variables of more interactive nature than simplistic relevance feedback. The complexity on the user side, framed by social interaction in dynamic situational contexts, forces the cognitive researcher to finely grain the investigative models in order to observe and analyze the dependent variables between system elements, properties of information objects, and actors in context. One should note that the context surrounding the actor actually includes both the socio-environmental (domain) influence and the information objects embedded in system settings produced by that environment. Some research concepts are common to both types of context, but with quite different connotations. For instance, uncertainty is a dominant concept in formal probabilistic retrieval models. However, uncertainty is regarded as a state of mind during social interaction, information seeking, and IR activity. This uncertainty during interpretation of knowledge sources was predicted earlier (BELKIN ET AL., 1982a; INGWERSEN, 1992; WERSIG) and is found empirically to increase during the initial stages of interaction, dependent on the knowledge state of the user (KUHLTHAU, 1991, 1999). Comprehensive cognitive models should operate with both kinds of uncertainty.

One may agree with VICKERY and ELLIS (1992) that both cognitive (and user-oriented) research as well as system-driven R&D (named physicalistic by Ellis (1992)) suffered from a kind of theory weakness or, at least, theory fragmentation. With respect to the individual cognitive approach Ellis's objections concern mainly two aspects of the theory. First, he disapproves of the attempt to view cognitive structures in systems and information objects, seen as artifacts, and human cognition under the same model (1992, p. 59). In a cognitive theory for IR this unified conception is, however, regarded as a strength, exactly in order to understand the differences between and limitations of such structures that prohibit the interaction. In contrast to traditional IR research, the cognitive view does not per se regard user behavior as highly rational, well-defined, and purposeful. Rather, random action and vagueness are seen as typical elements of retrieval behavior, due to uncertainties and ambiguities as, for instance, demonstrated by the label effect. Second, Ellis indicates that the cognitive view lacks empirical research results (1992, p. 53). This observation is surprising exactly because cognitive modeling is empirically based, for instance by studying the activities and language use during interaction as manifestations of cognitive processes. The modern holistic cognitive view continues to build a unified theory that circumscribes interactive IR processes in which one of the cornerstones is the understanding of the complexity of relevance, relevance assessments, and information use over time. With the recognition of the three revolutions by ROBERTSON & HANCOCK-BEAULIEU, i.e., the cognitive, the interactive, and the relevance revolutions, and the proposed research perspectives by VAKKARI (1998; 1999), VAKKARI & HAKALA, and WILSON (1999) on information behavior, the possibility of creating a unified theory of ISR (information seeking and retrieval)—or at least a comprehensive research framework or program—has increased. The strength of the cognitive approach is its encouragement to engage in empirical investigations at both general and quite detailed levels of study due to its models, assumptions, hypotheses, and hitherto obtained results. Typical to cognitively inspired research is the diversity of data-collection methods, including case-based, observation, and interviewing, and qualitative and quantitative analyses at various levels, including talking-aloud protocol, log, contents, and discourse analyses. However, as in other complementary information research perspectives or approaches, such as the sense-making framework (DERVIN & NILAN), one must be aware of the pitfalls of investigation. For instance, when studying variables in interactive IR or information behavior and seeking processes it is important not only to focus on the correlation of some selected variables, but also to ask whether such variables in fact happen to be marginal, or possibly related to other known variables recognized in earlier work. Similarly, it is important not to invent new names for old concepts, and to relate really novel conceptions to already existing ones.

VICKERY and ELLIS (1992) are critical of the cognitive view in IR because they do not observe a drastic improvement in the theoretical basis of the field. They both wish to see theory proceeding into a better understanding of phenomena, applications, and information practice. A quite different critical view of the individual cognitive view derives from metatheoretical and philosophical approaches to information science. Observations start with FROHMANN (1990), who argues that the individual cognitive view shows heavy signs of mentalism, signifying that reality and the social context are a mental construct. Frohmann (1992) takes his critique further by implying that the view as applied in IR (and in the sense-making framework of DERVIN & NILAN) signifies the "erasure of the social" (FROHMANN, 1992, p. 376), mechanistic instrumentality and, indeed, cognitivism (p. 380), also known as Strong AI. Frohmann's critical views are based on discourse analysis of a variety of articles produced in the 1980s, foremost by Belkin and his teams. HJØRLAND (1992) sees the approach as subjective idealism—close to the mentalistic position—as opposed to his own (1997) methodological collectivist point of view. In our view, such metatheoretical criticism is unavoidable in a research field which, in reality, is heavily technology-dependent but progressing from a natural science-like IT-focused framework into the domains of social science with all its variety of philosophical attributes and schools.

The essential research problem in information science, IR and information seeking, and like fields is to understand the reality and functionality of complex formal technologies, such as best-match retrieval systems, in interaction with a multitude of interlinked and unstructured knowledge resources, some even constantly changing like the World Wide Web, and individuals in a situated social context. In such information fields and sciences, the system/knowledge source/actor/domain/social context of interactivity is most often seen as a phenomenon in which the totality of activities becomes fragmented into separate elements. This is unfortunate

because it reduces the potential for understanding the complexity of information phenomena.

HJØRLAND & ALBRECHTSEN propose domain analysis as a "new horizon in information science" as opposed to the individual cognitive view. Domain analysis in their sense assumes that the domain and social-cultural structures are the determining factors for information transfer and communication. From a cognitive stand, however, such structures only influence the symbolic and perceptual cognitive structures of individuals in their current situations. The actors in context, i.e., all the derived human knowledge structures involved in IR interaction and seeking of information, are the determining factors that change the domain. For instance, the World Wide Web changes over time due to individual contributions in social interaction. Human social domains can only be dynamic and changeable if individual cognitive structures change, and when they involve and change other structures collectively. The critique is recently summarized by JACOB & SHAW in connection to document representation in an *ARIST* review, in particular with respect to the linguistic issues of representation.

The major differences between the (holistic) cognitive approach in information science and the critical approaches of social realism, including critical hermeneutics, semiotics, and social constructivism (TALJA), are that the latter theoretical constructs thus far have not generated workable empirical research methodologies.

Converging Models

During the 1990s several models of an integrative nature have emerged. The production of convergent models takes place in two dimensions: vertically, by placing interactive IR as an integrative part of information seeking processes, framed by information behavior (VAKKARI 1998, 1999; WILSON, 1999); and horizontally, by modeling interactive IR as seeking strategies or episodes (BELKIN ET AL., 1995a), or by viewing interactive IR in a stratified way (SARACEVIC, 1996a), including the modeling of relevance (1996b).

WILSON (1999) outlines earlier models of information seeking and other aspects of information behavior, initiated by his model (1981). He demonstrates the relationship between communication and information behavior in general with information seeking and retrieval in IR systems in the form of a nested model, arguing that the earlier models address issues at various levels of information behavior. By investigating and discussing the sense-making framework (DERVIN & NILAN), ELLIS's (1989) feature model, KUHLTHAU's (1991) phenomenological stage process model, BELKIN ET AL.'s (1995a) episodic model, INGWERSEN's (1996) cognitive communication model for interactive IR, SARACEVIC's (1996a) stratified IR processing model, and SPINK's feedback framework, Wilson succeeds in bringing together and generalizing the variety of central aspects involved in information behavior in context (1999, pp. 257, 264). In this comprehensive study Wilson further views uncertainty stages in the transition process of (pragmatic) problem solving as an alternative way of approaching information behavior and thus IR. On this issue Wilson relies on the comparison or merge of Ellis's feature and Kuhlthau's stage process models. In relation to uncertainty and problematic situations and solutions Wilson might, for example, have pointed to the ASK hypothesis (BELKIN ET AL., 1982a). Wilson suggests that the discussed models are complementary rather than conflicting, and that his problem-solving model (p. 266) provides a basis for relating the models in appropriate research strategies. In a pioneering effort, VAKKARI (1998) provides a detailed analysis of theory growth in information seeking, in particular the growth of a theoretical research program on the relation between work-task complexity and information seeking. Vakkari follows up on this effort by explicitly addressing and emphasizing the processes and theoretical aspects that link information retrieval theory to information seeking research frameworks (1999).

BELKIN ET AL.'s (1995a) episodic model of information seeking strategies (ISS) or behavior considers the types of search a system must support. It might br considered a model of IR interaction behavior rather than an information seeking model, depending on the level of generalization at which one regards it. The idea behind the model is that people commonly engage in multiple searching behaviors both during IR sessions and across sessions. The goal of the model is to support retrieval (or seeking) by making design and implementation of IR systems adapt to the changing requirements of the systems. Implementation was done in the so-called MERIT system. The model consists of 16 types of behaviors or episodes within a four-dimensional classification of IR modes. Each mode contains a binary number of values and each type of behavior is defined by the four-dimensional values. The four modes are method of searching (scanning or browsing); mode of retrieval

(recognition or specification of relevant objects); the goal of retrieval (learning about the system and information space or finding relevant information); and the resource considered (information objects or meta-information). The model has been applied to Web searching and navigation studies, for instance by PHARO. Pharo's test seems to show that the model is not exhaustive and that there is a potential for interdependency between the method of searching and mode of retrieval (p. 211).

SARACEVIC's model of stratified interaction displays a three-level structure consisting of surface, cognitive, and situational strata (1996a). The surface stratum deals primarily with the computational data processing based on a query. The cognitive stratum embraces the process of perceiving information during human-machine interaction in relation to the perceived need for information, and the situational stratum refers to the information use with respect to a perceived work task in context of the environment. The model is clearly associated with that of INGWERSEN (1996, p. 9) and is seen as an alternative model for interactive IR. It is made more comprehensive by incorporating a typology of relevance (1996b), consisting of five different types of relevance: algorithmic, in relation to the system output; topical, in relation to aboutness of information objects and query; pertinence or cognitive relevance, associated with the perceived information need of the user; situational, seen as the usefulness of the objects to the current interest of the user; affective/motivational, associated with the goal of the user.

This model has recently inspired several empirical studies and further modeling of relevance phenomena. For instance, BORLUND & INGWERSEN (1997) explored the possibility of applying situational relevance and topicality assessments in interactive IR experiments using nonbinary relevance assessments and by modeling SARACEVIC's typology (1996b) in relation to real as well as simulated work tasks. That model was later (1998) modified to emphasize the relation between a perceived work task, the dynamic information need developing over time, and relevance categories for test persons as well as assessors in IR experiments. The Borlund & Ingwersen approach also suggests performance measures that incorporate types of relevance (1998). SPINK ET AL. (1998b) empirically investigate what they call regions of relevance, including the application of nonbinary assessments in large-scale interactive studies. Very recently, COSIJN & INGWERSEN re-analyze Saracevic's typology and propose to replace the affective/motivational relevance type with a socio-cognitive category, directly associated with the contextual environment and domain, and originating from ØROM.

With the re-incorporation of situational relevance and situated context into IR and information seeking models, the issue of information use becomes paramount as a research topic. This issue extends the time line commonly observed during IR investigations and makes it increasingly necessary to view information seeking and retrieval as a whole (VAKKARI, 1998). Longitudinal studies of information behavior and search processes should hence play a more central role as an empirical foundation for information seeking and retrieval (ISR) models. KUHLTHAU's (1999) investigations of problem solutions and information behavior over time come to mind, as do the more retrieval-oriented longitudinal studies by WANG and WANG & WHITE. Kuhlthau's study included observations of uncertainty developments in relation to the knowledge state of the user. Wang investigates the alterations of the perceived information needs over research project time, represented by the distribution of articulated unique and novel versus overlapping search terms. Also in an empirical research environment, VAKKARI (2000) and VAKKARI & HAKALA follow the development of relevance, relevance criteria, and contributing information types of searched documents in task performance over an academic term period. Similarly, Wang & White investigate and provide a cognitive model of the actual application of documents at the reading stage, in particular in relation to decisions of citing the works used.

As a special case, one may regard author co-citation maps as adequate indicators of actual interpretations of information and its use. NOYONS ET AL. demonstrate the technique in a bibliometric sense but also with reference to citation mapping that can be applied as a visual IR gateway to the underlying information. WHITE & MCCAIN and DING ET AL. visualize the clustering of the most co-cited authors in information science and IR respectively. The maps visualize the cognitive authority over a given time period in a scientific community and inform about how the community makes use of scholarly works as well as how it perceives closeness of relationships among works through co-citations on reference lists. In principle, maps of words or other representative means, like journals, produced by identical multidimensional scaling methods and factor analysis from document data, have similar meanings, i.e., how terms or journals are used in connection with one another

in information objects that all are results of interpretation and information use.

CONCLUSIONS

The cognitive research approach, based on the epistemological cognitive view, has made significant contributions to a more comprehensive understanding of retrieval processes. As stated by JACOB & SHAW (p. 131), this approach has been instrumental in shifting the focus from the system per se to the interaction between user and the system. However, we cannot claim that the view has completely penetrated the frameworks applied to mainstream research on IR. This fact can easily be observed in the co-citation maps published recently (WHITE & MCCAIN; DING ET AL.) that show the amount and concentration of purely system-driven researchers. Only recently can we detect a more comprehensive view of information retrieval in the context of information seeking, that is, in the context of the social and cultural environment (BYSTRÖM & JÄRVELIN; VAKKARI, 1998, 1999; WILSON, 1999).

Generally speaking, the cognitive approach has from its start in the 1970s been associated with the user and intermediary mechanism configuration in the universe of IR research. Later, in the 1990s, the cognitive view broadens its scope by also seeking to encompass and understand the formal and experimental dimensions of IR by concentrating on all the processes of interaction that take place between the complex variety of actors in interactive IR. Thus, there appear elements of a holistic theory for IR that attempts to view such interactions between representative structures of information objects, symbolic structures in systems, and the user's cognitive space in context of the work or interest domain in a situated manner.

In a more detailed manner we may regard the years 1977-1982 as a time when the cognitive view is established as a theoretical perspective that moves into a research program with initial research models and empirical investigations carried out in accordance with those models. During the period 1982-1986 we find the next wave of empirical research and theoretical analyses, which achieve the ASK hypothesis (BELKIN ET AL., 1982a), the Monstrat Model for knowledge-based intermediary and systems design (BELKIN ET AL., 1983), and the observation of the Label-Effect and information need typologies (INGWERSEN, 1982, 1984, 1986). The central issue is the user-system interaction via an intermediary mechanism (BELKIN & VICKERY). From 1987 to 1991 we observe the drawbacks of the so-called intelligent (knowledge-based) IR approach (BROOKS, 1987) and attempts to integrate the variety of investigative models in IR (BELKIN ET AL., 1987). We can observe a shift in user-driven research toward exploratory information behavior (BATES, 1989) and situated context (SCHAMBER ET AL.). The period 1992-2000 can be characterized by the increasing interest in phenomena of relevance and uncertainty (SARACEVIC, 1996a, 1996b; SCHAMBER, 1994; WILSON, 1999), the TREC experiments that reinforce the discussion of measures of relevance, realism, and control in experimental settings (HANCOCK-BEAULIEU ET AL.; INGWERSEN, 1996; ROBERTSON & HANCOCK-BEAULIEU), and in particular the focus on a comprehensive perspective on IR interaction in work-task and domain context (BORLUND; BYSTRÖM & JÄRVELIN; VAKKARI, 1999). During this period we further observe remodeling of interactive IR as well as information seeking, based on solid empirical studies of a broad nature in both fields. The critique of the individual cognitive view also appears during this period (HJØRLAND & ALBRECHTSEN; TALJA).

The history of the cognitive view in IR and information studies thus covers nearly 25 years of impressive activity of both theoretical, analytic and, foremost, empirical nature. Although still weak on aspects of information seeking and behavior, the viewpoint increasingly demonstrates the potential of contributing interesting and valid research questions, directions, and solutions to the integrated study of information seeking and retrieval (ISR) in situated context. “We shall not cease from exploration and the end of all our exploring will be to arrive where we started and know the place for the first time.”

T. S. Eliot “Little Gidding V” in *Four Quartets*

BIBLIOGRAPHY

AHLGREN, PER. 1998. A Note on Search Formulation Redundancy. Journal of Documentation. 1998 June; 54(3): 352-354. ISSN: 0022-0418; CODEN: JDOCAS.

AHLGREN, PER. 1999. On Cognitive Search Strategy. In: Aparac, Tatjana; Saracevic, Tefko; Ingwersen, Peter; Vakkari, Pertti, eds. CoLIS 3: Proceedings from the 3rd International Conference on Conceptions of Library and Information Science: Digital Libraries: Interdisciplinary Concepts, Challenges and Opportunities; 1999 May 23-26; Dubrovnik, Croatia. Lokve, Croatia: Naklada Benja; 1999. 245-254. ISBN: 953-6003-37-6.

ALLEN, BRYCE L. 1991. Cognitive Research in Information Science: Implications for Design. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 26. Medford, NJ: Learned Information, Inc. for the American Society for Information Science; 1991. 3-37. ISSN: 0066-4200; ISBN: 0-938734-55-5; CODEN: ARISBC.

ALLEN, BRYCE L. 1996a. From Research to Design: A User-Centered Approach. In: Ingwersen, Peter; Pors, Niels Ole, eds. CoLIS 2: Proceedings of the 2nd International Conference on Conceptions of Library and Information Science; 1996 October 13-16; Copenhagen, Denmark. Copenhagen, Denmark: Royal School of Librarianship; 1996. 45-59. ISBN: 87-7415-260-2.

ALLEN, BRYCE L. 1996b. Information Tasks: Toward a User-Centered Approach to Information Systems. San Diego, CA: Academic Press; 1996. 308p. ISBN: 0-12-051040-5.

BARRY, CAROL L. 1994. User-Defined Relevance Criteria: An Exploratory Study. Journal of the American Society for Information Science. 1994; 45(3): 149-159. ISSN: 0002-8231; CODEN: AISJB6.

BARRY, CAROL L.; SCHAMBER, LINDA. 1998. Users' Criteria for Relevance Evaluation: A Cross-Situational Comparison. Information Processing & Management. 1998; 31(2/3): 219-236. ISSN: 0306-4573; CODEN: IPMADK.

BATES, MARCIA J. 1972. Factors Affecting Subject Catalog Search Success. Berkeley, CA: University of California, 1972. 287p; (Ph.D. dissertation). Available from: UMI, Ann Arbor, MI (UMI order no. 74-15639).

BATES, MARCIA J. 1981. Search Tactics. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 16. White Plains, NY: Knowledge Industry Publications, Inc. for the American Society for Information Science; 1981. 139-169. ISSN: 0066-4200; ISBN: 0-914236-90-3; CODEN: ARISBC.

BATES, MARCIA J. 1989. The Design of Browsing and Berrypicking Techniques for the Online Search Interface. Online Review. 1989; 13(5): 407-424. ISSN: 0309-314X.

BELKIN, NICHOLAS J. 1977. Internal knowledge and external information. In: de Mey, Marc; Pinxten, Rik; Poriau, M.; Vandamme, Fernand, eds. CC77: International Workshop on the Cognitive Viewpoint; 1977 March 24-26; Ghent, Belgium, University of Ghent. Ghent, Belgium: University of Ghent; 1977. 187-194. OCLC: 6906871.

BELKIN, NICHOLAS J. 1984. Cognitive Models and Information Transfer. Social Science Information Studies. 1984 April/July; 4(2/3): 111-129. ISSN: 0143-6236; CODEN: SOSSD3.

BELKIN, NICHOLAS J. 1990. The Cognitive Viewpoint in Information Science. Journal of Information Science. 1990; 16(1): 11-15. ISSN: 0165-5515.

BELKIN, NICHOLAS J.; BORGMAN, CHRISTINE L.; BROOKS, HELEN M.; BYLANDER, TOM; CROFT, W. BRUCE; DANIELS, PENNY J.; DEERWESTER, SCOTT; FOX, EDWARD A.; INGWERSEN, PETER; RADA, ROY; SPARCK JONES, KAREN; THOMPSON, ROGER; WALKER, DONALD. 1987. Distributed Expert-Based Information Systems: An Interdisciplinary Approach. Information Processing & Management. 1987; 23(5): 395-409. ISSN: 0306-5817; CODEN: IPMADK.

BELKIN, NICHOLAS J.; BROOKS, HELEN M.; DANIELS, PENNY J. 1987. Knowledge Elicitation Using Discourse Analysis. International Journal of Man-Machine Studies. 1987; 27: 127-144. ISSN: 0020-7373.

BELKIN, NICHOLAS J.; COOL, COLLEEN; CROFT, W. BRUCE; CALLAN, JAMES P. 1993. The Effect of Multiple Query Representations on Information Retrieval Performance. In: Korfhage, Robert; Rasmussen, Edie; Willett, Peter, eds. SIGIR '93: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM/SIGIR) 16th Annual International Conference on Research and Development in Information Retrieval; 1993 June 27-July 1; Pittsburgh, PA. New York, NY: ACM Press; 1993. 339-346. ISBN: 0-89791-605-0.

BELKIN, NICHOLAS J.; COOL, COLLEEN; KOENEMANN, JÜRGEN; NG, KWONG BOR; PARK, SOYEON. 1996a. Using Relevance Feedback and Ranking in Interactive Searching. In: Harman, Donna K., ed. Proceedings of the 4th Text REtrieval Conference (TREC-4); 1995 November 1-3; Gaithersburg, MD. Gaithersburg, MD: National Institute of Standards and Technology; 1996. 181-188. (NIST Special Publication 500-236). OCLC: 36640879.

BELKIN, NICHOLAS J.; COOL, COLLEEN; KOENEMANN, JÜRGEN; PARK, SOYEON; NG, KWONG BOR. 1996b. Information Seeking Behavior in New Searching Environment. In: Ingwersen, Peter; Pors, Niels O. eds., CoLIS 2: Proceedings of the 2nd International Conference on Conceptions of Library and Information Science: Integration in Perspective; 1996 October 13-16; Copenhagen, Denmark, Royal School of Library and Information Science. Copenhagen, Denmark: Royal School of Library and Information Science; 1996. 403-416. ISBN: 87-7415-260-2.

BELKIN, NICHOLAS J.; COOL, COLLEEN; STEIN, ADELHEIT; THIEL, ULRICH. 1995a. Cases, Scripts, and Information Seeking Strategies: On the Design of Interactive Information Retrieval Systems. Expert Systems with Applications. 1995; 9(3): 379-395. ISSN: 0957-4174.

BELKIN, NICHOLAS J.; KANTOR, PAUL; FOX, EDWARD A.; SHAW, J. A. 1995b. Combining the Evidence of Multiple Query Representations for Information Retrieval. Information Processing & Management. 1995; 31: 431-448. ISSN: 0306-4573; CODEN: IPMADK.

BELKIN, NICHOLAS J.; KWASNIK, BARBARA. 1986. Using Structural Representations of Anomalous States of Knowledge for Choosing Document Retrieval Strategies. In: Rabitti, F. ed. Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM-SIGIR) 9th Annual Conference on Research and Development in Information Retrieval; 1986 September 8-10; Pisa, Italy. New York, NY: ACM Press; 1986. 11-22. ISBN: 0-89791-187-3.

BELKIN, NICHOLAS J.; ODDY, ROBERT N.; BROOKS, HELEN M. 1982a. ASK for Information Retrieval: Part I. Background and Theory. Journal of Documentation. 1982 June; 38(2): 61-71. ISSN: 0022-0418; CODEN: JDOCAS.

BELKIN, NICHOLAS J.; ODDY, ROBERT N.; BROOKS, HELEN M. 1982b. ASK for Information Retrieval: Part II. Results of a Design Study. Journal of Documentation. 1982 September; 38(3): 145-164. ISSN: 0022-0418; CODEN: JDOCAS.

BELKIN, NICHOLAS J.; SEEGER, THOMAS; WERSIG, GERNOT. 1983. Distributed Expert Problem Treatment as a Model for Information Systems Analysis and Design. Journal of Information Science. 1983; 5: 153-167. ISSN: 0165-5515.

BELKIN, NICHOLAS J.; VICKERY, ALINA. 1985. Interaction in Information Systems. London, UK: British Library; 1985. 250p. ISBN: 0-7123-3050-X.

BORGMAN, CHRISTINE L. 1989. All Users of Information Retrieval Systems Are Not Created Equal: An Exploration into Individual Differences. Information Processing & Management. 1989; 25(3): 237-252. ISSN: 0306-4573; CODEN: IPMADK.

BORLUND, PIA. 2000. Experimental Components for the Evaluation of Interactive Information Retrieval Systems. Journal of Documentation. 2000 January; 56(1): 71-90. ISSN: 0022-0418; CODEN: JDOCAS.

BORLUND, PIA; INGWERSEN, PETER. 1997. The Development of a Method for the Evaluation of Interactive Information Retrieval Systems. Journal of Documentation. 1997 June; 53(3): 225-250. ISSN: 0022-0418; CODEN: JDOCAS.

BORLUND, PIA; INGWERSEN, PETER. 1998. Measures of Relative Relevance and Ranked Half-Life: Performance Indicators for Interactive IR. In: Croft, W. Bruce; Moffat, Alistair; Van Rijsbergen, C.J.; Wilkinson, Ross; Zobel, Justin, eds. SIGIR '98: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM/SIGIR) 21st Annual International Conference on Research and Development in Information Retrieval; 1998 August 24-28; Melbourne, Australia. New York, NY: ACM Press; 1998. 324-331. ISBN: 1-58113-015-5.

BORLUND, PIA; INGWERSEN, PETER. 1999. The Application of Work Tasks in Connection with the Evaluation of Interactive Information Retrieval Systems: Empirical Results. In: Dunlop, Mark, ed. Mira '99: Final Mira Conference on Information Retrieval Evaluation; 1999 April 14-16; Glasgow, UK. Glasgow, UK: Department of Computing Sciences; 1999. 29-46. Avail. WWW: http://www.dcs.gla.ac.uk/mira/workshops/conference.

BOULDING, KENNETH E. 1956. The Image. Ann Arbor, MI: University of Michigan Press; 1956. 175p. OCLC: 376662.

BRIER, SØREN. 1996. Cybersemiotics: A New Interdisciplinary Development Applied to the Problems of Knowledge Organization and Document Retrieval in Information Science. Journal of Documentation. 1996; 52(3): 296-344. ISSN: 0022-0418; CODEN: JDOCAS.

BROOKES, B. C. 1980. The Foundation of Information Science: Part 1: Philosophical Aspects. Journal of Information Science. 1980; 2: 125-133. ISSN: 0165-5515.

BROOKS, HELEN M. 1986. Developing and Representing Problem Descriptions. In: Intelligent Information Systems for the Information Society. Amsterdam, The Netherlands: North-Holland; 1986. 141-161. ISBN: 0-444-70050-1.

BROOKS, HELEN M. 1987. Expert Systems and Intelligent Information Retrieval. Information Processing & Management. 1987; 23(4): 367-382. ISSN: 0306-4573; CODEN: IPMADK.

BRUCE, HARRY W. 1994. A Cognitive View of the Situational Dynamism of User-Centered Relevance Estimation. Journal of the American Society for Information Science. 1994; 45: 142-148. ISSN: 0002-8231; CODEN: AISJB6.

BUCKLAND, MICHAEL K. 1991a. Information as Thing. Journal of the American Society for Information Science. 1991; 42(5): 351-360. ISSN: 0002-8231; CODEN: AISJB6.

BUCKLAND, MICHAEL K. 1991b. Information and Information Systems. New York, NY: Praeger; 1991. 225p. ISBN: 0-275-93851-4.

BYSTRÖM, KATRIINA; JÄRVELIN, KALERVO. 1995. Task Complexity Affects Information Seeking and Use. Information Processing & Management. 1995; 31(2): 191-214. ISSN: 0306-4573; CODEN: IPMADK.

CAMPBELL, IAIN. 2000. Interactive Evaluation of the Ostensive Model Using a New Test Collection of Images with Multiple Relevance Assessments. Information Retrieval. 2000; 2(1): 87-114. ISSN: 1386-4564.

CAMPBELL, IAIN; VAN RIJSBERGEN, C. J. 1996. The Ostensive Model of Developing Information Needs. In: Ingwersen, Peter; Pors, Niels Ole, eds. CoLIS 2: Proceedings of the 2nd International Conference on Conceptions of Library and Information Science: Integration in Perspective; 1996 October 13-16; Copenhagen, Denmark. Copenhagen, Denmark: Royal School of Librarianship; 1996. 251-268. ISBN: 87-7415-260-2.

CLEVERDON, CYRIL W. 1967. The Cranfield Test on Index Language Devices. Aslib Proceedings. 1967 June; 19(6): 173-194. ISSN: 0001-253X.

COLE, CHARLES. 1999. Activity of Understanding a Problem during Interaction with an "Enabling" Information Retrieval System: Modeling Information Flow. Journal of the American Society for Information Science. 1999; 50(6): 544-552. ISSN: 0002-8231; CODEN: AISJB6.

COSIJN, ERICA; INGWERSEN, PETER. 2000. Dimensions of Relevance. Information Processing & Management. 2000; 36: 533-550. ISSN: 0306-4573; CODEN: IPMADK.

CROFT, W. BRUCE; THOMPSON, ROGER H. 1987. I^{3}R: A New Approach to the Design of Document Retrieval Systems. Journal of the American Society for Information Science. 1987; 38(6): 389-404. ISSN: 0002-8231; CODEN: AISJB6.

DANIELS, PENNY J. 1986. Cognitive Models in Information Retrieval. An Evaluative Review. London, UK: City University; 1986. 67p. OCLC: 17620605.

DE MEY, MARC. 1977. The Cognitive Viewpoint: Its Development and Its Scope. In: de Mey, Marc; Pinxten, Rik; Poriau, M.; Vandamme, Fernand, eds. CC77: International Workshop on the Cognitive Viewpoint; 1977 March 24-26; Ghent, Belgium, University of Ghent. Ghent, Belgium: University of Ghent; 1977. xvi-xxxi. OCLC: 6906871.

DE MEY, MARC. 1980. The Relevance of the Cognitive Paradigm for Information Science. In: Harbo, Ole; Kajberg, Leif, eds. Theory and Application of Information Research: Proceedings of the 2nd International Research Forum on Information Science; 1977 August 3-6; Copenhagen, Denmark, Royal School of Librarianship. London, UK: Mansell; 1980. 48-61. ISBN: 0-7201-1513-2.

DE MEY, MARC. 1982. The Cognitive Paradigm: An Integrated Understanding of Scientific Development. Dordrecht, The Netherlands: D. Reidel Publishing Co.; 1982. 314p. ISBN: 90-277-1382-0.

DERVIN, BRENDA. 1997. Given a Context by Any Other Name: Methodological Tools for Taming the Unruly Beast. In: Vakkari, Pertti; Savolainen, Reijo; Dervin, Brenda, eds. Information Seeking in Context: Proceedings of an International Conference on Research in Information Needs, Seeking and Use in Different Contexts; 1996 August 14-16; Tampere, Finland, Department of Information Studies. London, UK: Taylor Graham; 1997. 13-38. ISBN: 0-947568-71-9.

DERVIN, BRENDA; NILAN, MICHAEL. 1986. Information Needs and Uses. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 21. White Plains, NY: Knowledge Industry Publications, Inc. for the American Society for Information Science; 1986. 3-33. ISSN: 0066-4200; ISBN: 0-86729-209-1; CODEN: ARISBC.

DING, YING; CHOWDHURY, GOBINDA; FOO, CHUBERT. 1999. Mapping the Intellectual Structure of Information Retrieval Studies: An Author Co-citation Analysis, 1987-1997. Journal of Information Science. 1999; 25(1): 67-78. ISSN: 0165-5515.

DRETSKE, FRED I. 1981. Knowledge and the Flow of Information. Oxford, UK: Basil Blackwell; 1981.

EFTHIMIADIS, EFTHIMIS N. 1995. User Choices: A New Yardstick for the Evaluation of Ranking Algorithms for Interactive Query Expansion. Information Processing & Management. 1995; 31(4): 605-620. ISSN: 0306-5817; CODEN: IPMADK.

EFTHIMIADIS, EFTHIMIS N. 1996. Query Expansion. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 31. Medford, NJ: Information Today, Inc. for the American Society for Information Science; 1996. 121-187. ISSN: 0066-4200; ISBN: 1-57387-033-1; CODEN: ARISBC.

ELLIS, DAVID. 1989. A Behavioural Approach to Information Retrieval System Design. Journal of Documentation. 1989; 45(3): 171-212. ISSN: 0022-0418; CODEN: JDOCAS.

ELLIS, DAVID. 1992. The Physical and Cognitive Paradigms in Information Retrieval Research. Journal of Documentation. 1992 March; 48(1): 45-64. ISSN: 0022-0418; CODEN: JDOCAS.

ELLIS, DAVID. 1996. Progress and Problems in Information Retrieval. London, UK: Library Association Publishing; 1996. 220p. ISBN: 1-85604-123-9.

ELLIS, DAVID; FURNER-HINES, JONATHAN; WILLETT, PETER. 1994. On the Creation of Hypertext Links in Full-Text Documents: Measurement of Inter-Linker Consistency. Journal of Documentation. 1994 June; 50(2): 67-98. ISSN: 0022-0418; CODEN: JDOCAS.

FENICHEL, CAROL HANSEN. 1981. Online Searching: Measures That Discriminate among Users with Different Types of Experience. Journal of the American Society for Information Science. 1981; 32(1): 23-32. ISSN: 0002-8231; CODEN: AISJB6.

FIDEL, RAYA. 1991a. Searchers' Selection of Search Keys: I. The Selection Routine. Journal of the American Society for Information Science. 1991; 42(7): 490-500. ISSN: 0002-8231; CODEN: AISJB6.

FIDEL, RAYA. 1991b. Searchers' Selection of Search Keys: II. Controlled Vocabulary or Free-Text Searching. Journal of the American Society for Information Science. 1991; 42(7): 501-514. ISSN: 0002-8231; CODEN: AISJB6.

FIDEL, RAYA. 1991c. Searchers' Selection of Search Keys: III. Searching Styles. Journal of the American Society for Information Science. 1991; 42(7): 515-527. ISSN: 0002-8231; CODEN: AISJB6.

FLORANCE, VALERIE; MARCHIONINI, GARY. 1995. Information Processing in the Context of Medical Care. In: Fox, Edward A.; Ingwersen, Peter; Fidel, Raya eds., SIGIR '95: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM-SIGIR) 18th Annual Conference on Research and Development of Information Retrieval; 1995 July 9-13; Seattle, WA. New York, NY: ACM Press; 1995. 158-163. ISBN: 0-89791-714-6.

FORD, NIGEL. 2000. Cognitive Styles and Virtual Environments. Journal of the American Society for Information Science. 2000; 51(6): 543-557. ISSN: 0002-8231; CODEN: AISJB6.

FOX, EDWARD A. 1987. The Development of the CODER System: A Testbed for Artificial Intelligence Methods in Information Retrieval. Information Processing & Management. 1987; 23(4): 341-366. ISSN: 0306-4573; CODEN: IPMADK.

FOX, EDWARD A.; HIX, DEBORAH; NOWELL, LUCY T.; BRUENI, DENNIS J.; WAKE, WILLIAM C.; HEATH, LENWOOD S.; RAO, DURGESH. 1993. Users, User Interfaces, and Objects: Envision, A Digital Library. Journal of the American Society for Information Science. 1993; 44: 480-491. ISSN: 0002-8231; CODEN: AISJB6.

FROHMANN. BERND. 1990. Rules of Indexing: A Critique of Mentalism in Information Retrieval Theory. Journal of Documentation. 1990 June; 46(2): 81-101. ISSN: 0022-0418; CODEN: JDOCAS.

FROHMANN, BERND. 1992. The Power of Images: A Discourse Analysis of the Cognitive Viewpoint. Journal of Documentation. 1992 December; 48(4): 365-386. ISSN: 0022-0418; CODEN: JDOCAS.

GARFIELD, EUGENE. 1998. From Citation Indexes to Informetrics: Is the Tail Wagging the Dog?. Libri. 1998; 48: 67-80. ISSN: 0024-2667.

HANCOCK-BEAULIEU, MICHELINE; FIELDHOUSE, MARGARET; DO, THIEN. 1995. An Evaluation of Interactive Query Expansion in an Online Library Catalogue with a Graphical User Interface. Journal of Documentation. 1995 September; 51(3): 225-243. ISSN: 0022-0418; CODEN: JDOCAS.

HARMAN, DONNA K., ed. 1999. TREC Publications. Gaithersburg, MD: National Institute of Standards and Technology; 1999. Available WWW: http://trec.nist.gov/pubs.html.

HARTER, STEPHEN P. 1992. Psychological Relevance and Information Science. Journal of the American Society for Information Science. 1992; 43: 602-615. ISSN: 0002-8231; CODEN: AISJB6.

HARTER, STEPHEN P.; HERT, CAROL A. 1997. Evaluation of Information Retrieval Systems: Approaches, Issues and Methods. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 32. Medford, NJ: Information Today, Inc. for the American Society for Information Science; 1997. 3-94. ISSN: 0066-4200; ISBN: 1-57387-047-1; CODEN: ARISBC; LC: 66-25096.

HARTER, STEPHEN P.; NISONGER, THOMAS E.; WENG, AIWEI. 1993. Semantic Relationships between Cited and Citing Articles in Library and Information Science Journals. Journal of the American Society for Information Science. 1993; 44(9): 543-552. ISSN: 0002-8231; CODEN: AISJB6.

HERSH, WILLIAM; PENTECOST, JEFFREY; HICKAM, DAVID. 1996. A Task-Oriented Approach to Information Retrieval Evaluation. Journal of the American Society for Information Science. 1996; 47(1): 50-56. ISSN: 0002-8231; CODEN: AISJB6.

HJØRLAND, BIRGER. 1992. The Concept of "Subject" in Information Science. Journal of Documentation. 1992 June; 48(2): 172-200. ISSN: 0022-0418; CODEN: JDOCAS.

HJØRLAND, BIRGER. 1997. Information Seeking and Subject Representation: An Activity-Theoretical Approach to Information Science. Westport, CT: Greenwood Press; 1997. 213p. ISBN: 0-313-29893-9.

HJØRLAND, BIRGER; ALBRECHTSEN, HANNE. 1995. Toward a New Horizon in Information Science: Domain Analysis. Journal of the American Society for Information Science. 1995; 46(6): 400-425. ISSN: 0002-8231; CODEN: AISJB6.

IIVONEN, MIRJA. 1995. Consistency in the Selection of Search Concepts and Search Terms. Information Processing & Management. 1995; 31(2): 173-190. ISSN: 0306-4573; CODEN: IPMADK.

INGWERSEN, PETER. 1982. Search Procedures in the Library Analysed from the Cognitive Point of View. Journal of Documentation. 1982 September; 38(3): 165-191. ISSN: 0022-0418; CODEN: JDOCAS.

INGWERSEN, PETER. 1984. A Cognitive View of Three Selected Online Search Facilities. Online Review. 1984; 8(5): 465-492. ISSN: 0309-314X.

INGWERSEN, PETER. 1986. Cognitive Analysis and the Role of the Intermediary in Information Retrieval. In: Davies, R., ed. Intelligent Information Systems. Chichester, West Sussex, UK: Ellis Horwood; 1986. 206-237. ISBN: 0-85312-896-0.

INGWERSEN, PETER. 1992. Information Retrieval Interaction. London, UK: Taylor Graham; 1992. 246p. ISBN: 0-947568-54-9.

INGWERSEN, PETER. 1993. The Cognitive Viewpoint in IR. Journal of Documentation. 1993 March; 49(1): 60-64. ISSN: 0022-0418; CODEN: JDOCAS.

INGWERSEN, PETER. 1995. Information and Information Science. In: Kent, Allen, ed. Encyclopedia of Library and Information Science: Volume 56, Supplement 19. New York, NY: Marcel Dekker; 1995. 137-174. ISBN: 0-8247-2056-3.

INGWERSEN, PETER. 1996. Cognitive Perspectives of Information Retrieval Interaction: Elements of a Cognitive IR Theory. Journal of Documentation. 1996 March; 52(1): 3-50. ISSN: 0022-0418; CODEN: JDOCAS.

INGWERSEN, PETER; PEJTERSEN, ANNELISE MARK. 1986. User Requirements: Empirical Research and Information Systems Design. In: Ingwersen, Peter; Kajberg, Leif; Pejtersen, Annelise Mark, eds. Information Technology and Information Use. London, UK: Taylor Graham; 1986. 111-124. ISBN: 0-947568-06-9.

INGWERSEN, PETER; WORMELL, IRENE. 1988. Means to Improved Subject Access and Representation in Modern Information Retrieval. Libri. 1988; 38(2): 94-119. ISSN: 0024-2667.

JACOB, ELIN K.; SHAW, DEBORA. 1998. Sociocognitive Perspectives on Representation. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 33. Medford, NJ: Learned Information, Inc. for the American Society for Information Science; 1999. 131-186. ISSN: 0066-4200; ISBN: 1-57387-065-X; CODEN: ARISBC.

JOSE, JOEMON M.; FURNER, JONATHAN; HARPER, DAVID J. 1998. Spatial Querying for Image Retrieval: A User-Oriented Evaluation. In: Croft, W. Bruce; Moffat, Alistair; van Rijsbergen, C. J.; Wilkinson, Ross; Zobel, Justin, eds. SIGIR '98: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM/SIGIR) 21st Annual International Conference on Research and Development in Information Retrieval; 1998 August 24-28; Melbourne, Australia. New York, NY: ACM Press; 1998. 232-240. ISBN: 1-58113-015-5.

KANTOR, PAUL B. 1994. Information Retrieval Techniques. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 29. Medford, NJ: Learned Information, Inc. for the American Society for Information Science; 1994. 53-90. ISSN: 0066-4200; ISBN: 0-938734-91-1; CODEN: ARISBC.

KATZER, JEFFREY; MCGILL, MICHAEL J.; TESSIER, JUDITH A.; FRAKES, WILLIAM; DASGUPTA, PADMINI. 1982. A Study of the Overlap among Document Representations. Information Technology: Research and Development. 1982; 1: 261-274. ISSN: 0144-817X.

KUHLTHAU, CAROL COLLIER. 1991. Inside the Search Process: Information Seeking from the User's Perspective. Journal of the American Society for Information Science. 1991; 42: 361-371. ISSN: 0002-8231; CODEN: AISJB6.

KUHLTHAU, CAROL COLLIER. 1999. The Role of Experience in the Information Search Process of an Early Career Information Worker: Perceptions of Uncertainty, Complexity, Construction, and Sources. Journal of the American Society for Information Science. 1999; 50(5): 399-412. ISSN: 0002-8231; CODEN: AISJB6.

LALMAS, MOUNIA; RUTHVEN, IAN. 1998. Representing and Retrieving Structured Documents Using the Dempster-Shafer Theory of Evidence: Modelling and Evaluation. Journal of Documentation. 1998 December; 55(5): 529-565. ISSN: 0022-0418; CODEN: JDOCAS.

LANCASTER, F. W. 1991. Indexing and Abstracting in Theory and Practice. London, UK: Library Association Publishing; 1991. 328p. ISBN: 1-85604-004-6.

LOSEE, ROBERT M. 1997. A Discipline Independent Definition of Information. Journal of the American Society for Information Science. 1997; 48: 254-269. ISSN: 0002-8231; CODEN: AISJB6.

LURIA, A. R. 1976. Cognitive Development: Its Cultural and Social Foundations. Cambridge, MA: Harvard University Press; 1976. 175p. ISBN: 0-674-13731-0.

MAGENNIS, MARK; VAN RIJSBERGEN, C. J. 1997. The Potential and Actual Effectiveness of Interactive Query Expansion. In: Belkin, Nicholas J.; Narasimhalu, A. Desai; Willett, Peter, eds. SIGIR '97: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM/SIGIR) 20th Annual International Conference on Research and Development in Information Retrieval; 1997 July 27-31; Philadelphia, PA. New York, NY: ACM Press; 1997. 324-332. ISBN: 0-89791-836-3.

MARCHIONINI, GARY. 1989. Information-Seeking Strategies of Novices Using a Full-Text Electronic Encyclopedia. Journal of the American Society for Information Science. 1989; 40(1): 54-66. ISSN: 0002-8231; CODEN: AISJB6.

MARCHIONINI, GARY. 1995. Information Seeking in Electronic Environments. Cambridge, MA: Cambridge University Press; 1995. 224p. ISBN: 0-521-44372-5.

MCALPINE, GORDON; INGWERSEN, PETER. 1989. Integrated Information Retrieval in a Knowledge Worker Support System. In: Belkin, N. J.; van Rijsbergen, C. J., eds. SIGIR '89: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM/SIGIR) 12th Annual International Conference on Research and Development in Information Retrieval; 1989 June 25-28; Cambridge, MA. New York, NY: ACM Press; 1989. 48-57. ISBN: 0-89791-321-3.

MCCAIN, KATHERINE W. 1989. Descriptor and Citation Retrieval in the Medical Behavioral Sciences Literature: Retrieval Overlaps and Novelty Distribution. Journal of the American Society for Information Science. 1989; 40: 110-114. ISSN: 0002-8231; CODEN: AISJB6.

MIZZARO, STEFANO. 1996. A Cognitive Analysis of Information Retrieval. In: Ingwersen, Peter; Pors, Niels Ole, ed. CoLIS2: Proceedings of the 2nd International Conference on Conceptions of Library and Information Science: Integration in Perspective; 1996 October 13-16; Copenhagen, Denmark. Copenhagen, Denmark: Royal School of

Librarianship; 1996. 233-250. ISBN: 87-7415-260-2.
MIZZARO, STEFANO. 1997. Relevance: The Whole History. Journal of the American Society for Information Science. 1997; 48(9): 810-832. ISSN: 0002-8231; CODEN: AISJB6.
NOYONS, E. C. M.; MOED, HENK F. LEWEL, M. 1999. Combining Mapping and Citation Analysis for Evaluative Bibliometric Purposes: A Bibliometric Study. Journal of the American Society for Information Science. 1999 February; 50(2): 115-131. ISSN: 0002-8231; CODEN: AISJB6.
ODDY, ROBERT N. 1977a. Information Retrieval through Man-Machine Dialogue. Journal of Documentation. 1977; 33: 1-14. ISSN: 0022-0418; CODEN: JDOCAS.
ODDY, ROBERT N. 1977b. Retrieving References by Dialogue Rather Than by Query Formulation. Journal of Information Science. 1977; 1: 37-53. ISSN: 0165-5515.
OFORI-DWUMFUO, G. 1984. Using a Cognitive Model of Dialogue for Reference Retrieval. Journal of Information Science. 1984; 9: 19-28. ISSN: 0165-5515.
ØROM, ANDERS. 2000. Information Science, Historical Changes and Social Aspects: A Nordic Look. Journal of Documentation. 2000; 56(1): 12-26. ISSN: 0022-0418; CODEN: JDOCAS.
PALMQUIST, RUTH A.; KIM, KYUNG-SUN. 2000. Cognitive Style and On-line Database Search Experience as Predictors of Web Search Performance. Journal of the American Society for Information Science. 2000; 51(6): 558-566. ISSN: 0002-8231; CODEN: AISJB6.
PAO, MIRANDA L. 1993. Term and Citation Searching: A Field Study. Information Processing & Management. 1993; 29(1): 95-112. ISSN: 0306-4573; CODEN: IPMADK.
PAO, MIRANDA L. 1994. Relevance Odds of Retrieval Overlaps from Seven Search Fields. Information Processing & Management. 1994; 30(3): 305-314. ISSN: 0306-4573; CODEN; IPMADK.
PARK, SOYEON. 2000. Usability, User Preferences, Effectiveness, and User Behaviors When Searching Individual and Integrated Full-Text Databases: Implications for Digital Libraries. Journal of the American Society for Information Science. 2000; 51(5): 456-468. ISSN: 0002-8231; CODEN: AISJB6.
PARK, TAEMIN KIM. 1993. The Nature of Relevance in Information Retrieval: An Empirical Study. Library Quarterly. 1993; 63(3): 318-351. ISSN: 0024-2519.
PEJTERSEN, ANNELISE MARK. 1980. Design of a Classification Scheme for Fiction. In: Harbo, Ole; Kajberg, Leif, eds. Theory and Application of Information Research: Proceedings of the 2nd International Research Forum on Information Science; 1977 August 3-6; Copenhagen, Denmark, Royal School of Librarianship. London, UK: Mansell; 1980. 146-159. ISBN: 0-7201-1513-2.
PEJTERSEN, ANNELISE MARK. 1989. A Library System for Information Retrieval Based on a Cognitive Task Analysis and Supported by an Icon-Based Interface. In: Belkin, N. J.; van Rijsbergen, C. J., eds. SIGIR '89: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM/SIGIR) 12th Annual International Conference on Research and Development in Information Retrieval; 1989 June 25-28; Cambridge, MA. New York, NY: ACM Press; 1989. 40-47. ISBN: 0-89791-321-3.
PHARO, NILS. 1999. Web Information Search Strategies: A Model for Classifying Web Interaction. In: Aparac, Tatjana; Saracevic, Tefko; Ingwersen, Peter; Vakkari, Pertti eds. CoLIS 3: Proceedings of the 3rd International Conference on Conceptions of Library and Information Science: Digital Libraries: Interdisciplinary Concepts, Challenges and Opportunities; 1999 May 23-26; Dubrovnik, Croatia. Lokve, Croatia: Naklada Benja; 1999. 207-218. ISBN: 953-6003-37-6.
PORS, NIELS O. 2000. Information Retrieval, Experimental Models and Statistical Analysis. Journal of Documentation. 2000; 56(1): 55-70. ISSN: 0022-0418; CODEN: JDOCAS.
RASMUSSEN, JENS; PEJTERSEN, ANNELISE MARK; GOODSTEIN, L. P. 1994. Cognitive Systems Engineering. New York, NY: Wiley; 1994. 378p. ISBN: 0-471-01198-3.
REID, JANE. 1999. A New, Task-Oriented Paradigm for Information Retrieval: Implications for Evaluation of Information Retrieval Systems. In: Aparac, Tatjana; Saracevic, Tefko; Ingwersen, Peter; Vakkari, Pertti, eds. CoLIS 3: Proceedings of the 3rd International Conference on Conceptions of Library and Information Science: Digital Libraries: Interdisciplinary Concepts, Challenges and Opportunities; 1999 May 23-26; Dubrovnik, Croatia. Lokve, Croatia: Naklada Benja; 1999. 97-108. ISBN: 953-6003-37-6.
RICH, ELAINE A. 1979. User Modelling via Stereotypes. Cognitive Science. 1979; 3: 329-354. ISSN: 0364-0213.
RICH, ELAINE A. 1983. Users Are Individuals: Individualizing User Models. International Journal of Man-Machine Studies. 1983; 18: 199-214. ISSN: 0020-7373.
ROBERTSON, STEPHEN E., ed. 1997. Overview of the Okapi Projects. Journal of Documentation. 1997 January; 53(1): 3-8. ISSN: 0022-0418; CODEN: JDOCAS.
ROBERTSON, STEPHEN E.; HANCOCK-BEAULIEU, MICHELINE. 1992. On the Evaluation of IR Systems. Information

Processing & Management. 1992; 28(4): 219-236. ISSN: 0306-5817; CODEN: IPMADK

ROBINS, DAVID. 2000. Shifts of Focus on Various Aspects of User Information Problems during Interactive Information Retrieval. Journal of the American Society for Information Science. 2000; 51(10): 913-928. ISSN: 0002-8231; CODEN: AISJB6.

SALTON, GERARD. 1989. Automatic Text Processing: The Transformation, Analysis and Retrieval of Information by Computer. Reading, MA: Addison-Wesley; 1989. 530p. ISBN: 0-201-12227-8.

SANDSTROM, ALAN R.; SANDSTROM, PAMELA EFFREIN. 1995. The Use and Misuse of Anthropological Methods in Library and Information Science Research. Library Quarterly. 1995; 65(2): 161-199. ISSN: 0024-2519.

SARACEVIC, TEFKO. 1996a. Modeling Interaction in Information Retrieval (IR): A Review and Proposal. In: Hardin, Steve, ed. ASIS '96: Proceedings of the American Society for Information Science (ASIS) 59th Annual Meeting: Volume 33; 1996 October 21-24; Baltimore, MD. Medford, NJ: Information Today, Inc. for ASIS; 1996. 3-9. ISSN: 0044-7870; ISBN: 1-57387-037-4; CODEN: PAISDQ.

SARACEVIC, TEFKO. 1996b. Relevance Reconsidered '96. In: Ingwersen, Peter; Pors, Niels Ole, eds. CoLIS 2: Proceedings of the 2nd International Conference on Conceptions of Library and Information Science: Integration in Perspective; 1996 October 13-16; Copenhagen, Denmark. Copenhagen, Denmark: Royal School of Librarianship; 1996. 201-218. ISBN: 87-7415-260-2.

SARACEVIC, TEFKO; KANTOR, PAUL. 1988. A Study of Information Seeking and Retrieving, III: Searchers, Searches, and Overlaps. Journal of the American Society for Information Science. 1988; 39(3): 197-216. ISSN: 0002-8231; CODEN: AISJB6.

SARACEVIC, TEFKO; MOKROS, HARTMUT; SU, LOUISE. 1990. Nature of Interaction between Users and Intermediaries in Online Searching: A Qualitative Analysis. In: Henderson, D., ed. ASIS '90: Proceedings of the American Society for Information Science (ASIS) 53rd Annual Meeting: Volume 27; 1990 November 4-8; Toronto, Ontario, Canada. Medford, NJ: Learned Information, Inc. for ASIS; 1990. 47-54. ISSN: 0044-7870; ISBN: 0-938734-48-2; CODEN: PAISDQ; LC: 64-8303.

SARACEVIC, TEFKO; MOKROS, HARTMUT; SU, LOUISE; SPINK, AMANDA. 1991. Nature of Interaction between Users and Intermediaries in Online Searching. In: Williams, Martha E., ed. Proceedings of the 12th National Online Meeting; 1991 May 7-9; New York, NY. Medford, NJ: Learned Information, Inc.; 1991. 329-341. ISBN: 0-938734-51-2.

SCHAMBER, LINDA. 1991. Users' Criteria for Evaluation in a Multimedia Environment. In: Griffiths, José-Marie, ed. ASIS '91: Proceedings of the American Society for Information Science (ASIS) 54th Annual Meeting: Volume 28; 1991 October 27-31; Washington, DC. Medford, NJ: Learned Information, Inc. for ASIS; 1991. 126-133. ISSN: 0044-7870; ISBN: 0-938734-56-3.

SCHAMBER, LINDA. 1994. Relevance and Information Behavior. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 29. Medford, NJ: Learned Information, Inc. for the American Society for Information Science; 1994. 3-48. ISSN: 0066-4200; ISBN: 0-938734-91-1; CODEN: ARISBC.

SCHAMBER, LINDA; EISENBERG, MICHAEL B.; NILAN, MICHAEL. 1990. A Re-Examination of Relevance: Toward a Dynamic, Situational Definition. Information Processing & Management. 1990; 26(6): 755-776. ISSN: 0306-5817; CODEN: IPMADK.

SEARLE, JOHN R. 1984. Intentionality and Its Place in Nature. Synthese. 1984; 61: 3-16. ISSN: 0039-7857.

SMEATON, ALAN. 1992. Progress in the Application of Natural Language Processing to Information Retrieval Tasks. Computer Journal. 1992; 35: 268-278. ISSN: 0010-4620.

SMEATON, ALAN; HARMAN, DONNA. 1997. The TREC Experiments and Their Impact on Europe. Journal of Information Science. 1997; 23(2): 169-174. ISSN: 0165-5515.

SPARCK JONES, KAREN. 1987. Architecture Problems in the Construction of Expert Systems for Document Retrieval. In: Wormell, Irene, ed. Knowledge Engineering: Expert Systems and Information Retrieval. London, UK: Taylor Graham; 1987. 34-52. ISBN: 0-947568-30-1.

SPARCK JONES, KAREN. 1990. Retrieving Information or Answering Questions: The 8th British Library Annual Research Lecture. London, UK: The British Library; 1990. 12p. ISBN: 0-7123-3215-4.

SPINK, AMANDA. 1997. Information Science: A Third Feedback Framework. Journal of the American Society for Information Science. 1997; 48(8): 728-740. ISSN: 0002-8231; CODEN: AISJB6.

SPINK, AMANDA; GOODRUM, ABBY; ROBINS, DAVID. 1998a. Elicitation Behavior during Mediated Information Retrieval. Information Processing & Management. 1998; 34(2/3): 257-273. ISSN: 0306-4573; CODEN: IPMADK.

SPINK, AMANDA; GREISDORF, HOWARD; BATEMAN, JUDY. 1998b. From Highly Relevant to Not Relevant: Examining Different Regions of Relevance. Information Processing & Management. 1998; 34(5): 599-621. ISSN: 0306-4573; CODEN: IPMADK.

SPINK, AMANDA; LOSEE, ROBERT M. 1996. Feedback in Information Retrieval. In: Williams, Martha E., ed. Annual

Review of Information Science and Technology: Volume 31. Medford, NJ: Information Today, Inc. for the American Society for Information Science; 1996. 33-78. ISSN: 0066-4200; ISBN: 1-57387-033-1; CODEN: ARISBC.

SPINK, AMANDA; SARACEVIC, TEFKO. 1997. Interaction in Information Retrieval: Selection and Effectiveness of Search Terms. Journal of the American Society for Information Science. 1997; 48(8): 741-761. ISSN: 0002-8231; CODEN: AISJB6.

SPINK, AMANDA; SARACEVIC, TEFKO. 1998. Human-Computer Interaction in Information Retrieval: Nature and Manifestations of Feedback. Interacting with Computers. 1998; 10: 249-267. ISSN: 0953-5438.

SU, LOUISE. 1994. The Relevance of Recall and Precision in User Evaluation. Journal of the American Society for Information Science. 1994; 45: 207-217. ISSN: 0002-8231; CODEN; AISJB6.

SUGAR, WILLIAM. 1995. User-Centered Perspective of Information Retrieval Research and Analysis Methods. In: Williams, Martha E., ed. Annual Review of Information Science and Technology: Volume 30. Medford, NJ: Information Today, Inc. for the American Society for Information Science; 1995. 77-109. ISSN: 0066-4200; ISBN: 1-57387-019-6; CODEN: ARISBC.

SWANSON, DONALD R. 1986. Undiscovered Public Knowledge. Library Quarterly. 1986; 56(2): 103-118. ISSN: 0024-2519.

TALJA, SANNA. 1997. Constituting "Information" and "User" as Research Objects. In: Vakkari, Pertti; Savolainen, Reijo; Dervin, Brenda, eds. Information seeking in Context. Proceedings of an International Conference on Research in Information Needs, Seeking and Use in Different Contexts; 1996 August 14-16; Tampere, Finland. London, UK: Taylor Graham; 1997. 67-80. ISBN: 0-947568-71-9.

TENOPIR, CAROL. 1989. Issues in Online Database Searching. Englewood, CO: Libraries Unlimited; 1989. 188p. ISBN: 0-87287-709-4.

TURTLE, HOWARD; CROFT, W. BRUCE. 1990. Inference Methods for Document Retrieval. ACM-SIGIR Forum. 1990 June; 1-24. ISSN: 0163-5840.

VAKKARI, PERTTI. 1994. Library and Information Science: Its Contents and Scope. Advances in Librarianship. 1994; 18: 1-55. ISSN: 0065-2830; ISBN: 0-12-024618-X.

VAKKARI, PERTTI. 1998. Growth of Theories on Information Seeking: An Analysis of Growth of a Theoretical Research Program on the Relation between Task Complexity and Information Seeking. Information Processing & Management. 1998; 34(3): 361-382. ISSN: 0306-5817; CODEN: IPMADK.

VAKKARI, PERTTI. 1999. Task Complexity, Problem Structure and Information Actions: Integrating Studies on Information Seeking and Retrieval. Information Processing & Management. 1999; 35(6): 819-837. ISSN: 0306-5817; CODEN: IPMADK.

VAKKARI, PERTTI. 2000. Relevance and Contributing Information Types of Searched Documents in Task Performance. In: Belkin, Nicholas J.; Ingwersen, Peter; Leong, Mun-Kew, eds., SIGIR '2000: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval (ACM-SIGIR) 23rd Annual Conference on Research and Development in Information Retrieval; 2000 July 24-28; Athens, Greece. New York, NY: ACM Press; 2000. 2-9. ISBN: 1-58113-226-3.

VAKKARI, PERTTI; HAKALA, NANNA. 2000. Changes in Relevance Criteria and Problem Stages in Task Performance. Journal of Documentation. 2000 September; 56(5): 540-562. ISSN: 0022-0418; CODEN: JDOCAS.

VAN RIJSBERGEN, C. J.; LALMAS, MOUNIA. 1996. Information Calculus for Information Retrieval. Journal of the American Society for Information Science. 1996; 47(5): 385-398. ISSN: 0002-8231; CODEN: AISJB6.

VICKERY, BRIAN C. 1997. Metatheory and Information Science. Journal of Documentation. 1997 December; 53(5): 457-476. ISSN: 0022-0418; CODEN: JDOCAS.

WANG, PEILING. 1997. Users' Information Needs at Different Stages of a Research Project: A Cognitive View. In: Vakkari, Pertti; Savolainen, Reijo; Dervin, Brenda, eds. Information Seeking in Context: Proceedings of an International Conference on Research in Information Needs, Seeking and Use in Different Contexts. 1996 August 14-16. Tampere, Finland. London, UK: Taylor Graham; 1997. 307-318. ISBN: 0-947568-71-9.

WANG, PEILING; WHITE, MARILYN DOMAS. 1999. A Cognitive Model of Document Use during a Research Project. Study II. Decisions at the Reading and Citing Stages. Journal of the American Society for Information Science. 1999; 50(2): 98-114. ISSN: 0002-8231; CODEN: AISJB6.

WERSIG, GERNOT. 1973. Informationssoziologie. Pullach bei München: Verlag Dokumentation; 1973.

WHITE, HOWARD D.; MCCAIN, KATHERINE W. 1998. Visualizing a Discipline: An Author Co-Citation Analysis of Information Science, 1972-1995. Journal of the American Society for Information Science. 1998; 49(4): 327-355. ISSN: 0002-8231; CODEN: AISJB6.

WILSON, PATRICK. 1973. Situational Relevance. Information Storage & Retrieval. 1973; 9(8): 457-471. ISSN: 0020-0271.

WILSON, THOMAS D. 1980. Information Systems Design Implications of Research into the Information Behaviour of Social Workers and Social Administrators. In: Harbo, Ole; Kajberg, Leif, eds. Theory and Application of Information Research: Proceedings of the 2nd International Research Forum on Information Science; 1977 August 3-6; Copenhagen,

Denmark, Royal School of Librarianship. London, UK: Mansell; 1980. 198-213. ISBN: 0-7201-1513-2.
WILSON, THOMAS D. 1981. On User Studies and Information Needs. Journal of Documentation. 1981; 37(1): 3-15. ISSN: 0022-0418; CODEN: JDOCAS.
WILSON, THOMAS D. 1999. Models in Information Behaviour Research. Journal of Documentation. 1999 June; 55(3): 249-270. ISSN: 0022-0418; CODEN: JDOCAS.
WINOGRAD, TERRY; FLORES, FERNANDO. 1986. Understanding Computers and Cognition: A New Foundation for Design. Norwood, NJ: Ablex; 1986. 207p. ISBN: 0-89391-050-3.
WORMELL, IRENE. 1981. SAP—A New Way to Produce Subject Descriptions of Books. Journal of Information Science. 1981; 3: 39-43. ISSN: 0165-5515.
WORMELL, IRENE. 1984. Cognitive Aspects in Natural Language and Free-Text Searching. Social Science Information Studies. 1984 April/July; 4(2/3): 131-141. ISSN: 0143-6236; CODEN: SOSSD3.
YUAN, WEIJING; MEADOW, CHARLES T. 1999. A Study of the Use of Variables in Information Retrieval User Studies. Journal of the American Society for Information Science. 1999; 50(2): 140-150. ISSN: 0002-8231; CODEN: AISJB6.