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Modeling interaction in information retrieval (IR): a review and proposal

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Abstract

The purpose is to critically examine traditional and interactive models that have emerged over the years in IR, particularly in relation to evaluation, and to propose an interactive IR model based on different levels in the interactive processes. The proposal is presented as work-in-progress. The traditional IR model was explicitly or implicitly adapted in majority of algorithmic works on IR, and it is the major model used in Text Retrieval Conference (TREC). Strengths and weaknesses of the traditional model are examined. The major weakness of that model is that it does not account for or incorporate IR interaction, which is the dominant feature of contemporary IR in practice. Several interactive IR models have been developed over the years; the cognitive model by Ingwersen and the episodes model by Belkin are examined. However, no leading and commonly accepted interactive IR model has emerged, particularly not in evaluation. A stratified interactive IR model is proposed here with suggestion that it has a potential to account for a variety of aspects in the processes involved in IR interaction. It is suggested that IR interaction may be decomposed into several levels that subtly affect each other. The paper concludes with general remarks on the state of IR interaction research.

1. Introduction

Information retrieval (IR) systems emerged in the 50's and 60's as static, batch processing systems. Starting in the '70s, with the revolutionary symbiosis between computer and communication technologies, the access to IR systems became dynamic, interactive. In practice, interaction became THE most important feature of information retrieval. Means, ways, models, and types of IR interactions are still evolving, changing, and at times improving. However, we still do not fully understand the many complex aspects of interactive processes, despite a long historical interest in IR interaction (Bennet, 1972), and a number of theoretical and experimental studies, and scholarly treatises (Ingwersen, 1992, 1996). Furthermore, most of the IR research and development (R&D) efforts concentrating on improvement of effectiveness in automatic representation and searching, treated IR systems and processes as static and *not* as dynamic or interactive (Saracevic, 1995). Such research, carried now for over thirty years, has reached a certain maturity, as evidenced by Text Retrieval Conference (TREC) experiments (Harman, 1995). In contrast, research on interactive aspects of IR has not reached a maturity; it may be even said that it is barely emerging out of infancy. There is a clear need for three things:

1. to concentrate more of research in IR, on interactions, to more resemble what is actually going on in practice;
2. in particular, to involve interaction in a major way in test and evaluation of IR systems, a move that started with TREC 4; and
3. to apply whatever was found in interactive research to the design and development of improvements in IR interfaces and processes. Since we know relatively little about the complexity of various interactive processes in IR, and particularly about the effects of variables involved, design of IR interfaces "is not straightforward" (Belkin & Croft, 1992).

The purpose of this paper is to provide a progress report on a study whose aim is to critically evaluate various models of interactions in IR, and to develop a general model of IR systems, incorporating the interactive aspects.

True, a number of interactive IR models have been proposed (some are reviewed below), and the literature on IR interaction is growing. But, as yet we do not have an IR interaction model or models that can be generally applied. This particularly includes application in evaluation the way the traditional IR model has been applied so successfully from Cranfield and SMART evaluations to TREC. As reviewed below, the traditional IR model implies interaction, but it does not address the interactive processes directly. Consequently, the traditional model while successful in one sense, has not been successful in recognizing the major variables involved in interaction, and even less in evaluation of interactive aspects of IR, which became glaringly evident in TREC (Beaulieu, Robertson, & Rasmunsen, 1996).

What general characteristics should an interactive IR model have? Ideally, it should:

- provide an enumeration of and distinction between different kinds of interactive processes going on during IR (and there is enough evidence to show that indeed a number of different kinds of interactions do occur);
- enumerate the major classes of variables involved in all interactions, and in specific kinds of interactions, and incorporate the relations to major elements in the 'computer' side of IR systems, for instance to those as suggested by the traditional IR model;
- relate to models and/or definitions used in human-computer interaction (HCI) research (I consider IR interactions to be closely related to if not even a subset of HCI);
- be applicable in evaluation of interactive IR;
- be testable in a scientific sense.

I am NOT claiming that the model proposed here has attained all these characteristics. Not by a long shot. But I am considering these characteristics as goals toward which this and all other modeling work related to IR interactions should proceed.

2. Traditional model

The traditional model represents IR as a two prong set (system and user) of elements and processes converging on comparison or matching, as shown in Figure 1.

In the traditional model the *system* prong involves information objects ('texts', images, data ...), that were represented in a given way, then organized in a file, and in this way got ready for matching. The *user* prong starts with a user's information problem/need, that is represented (verbalized) by a question, which is transformed into a query acceptable to the system; then matching between the two representations (texts and query) occurs. A feedback function is included that allows for modification of representations, but usually involves only the modification in the user prong. The strength of the model is that it allows for straight forward isolation of variables and for uniform analysis. This strength was evidenced in TREC, where it allowed for widely diverse IR methods and algorithms to be compared as having common objectives and using common evaluation methods.

But with strengths, the model has serious weaknesses (Belkin, 1993). As mentioned, they became glaringly evident in TREC, when attempts got underway to evaluate interactive aspects of IR. Considerable difficulties were encountered. To start with, interaction is not directly depicted in the traditional model at all. In a way, it is assumed and subsumed under feedback. In turn, feedback was treated mostly as an instrument for query modification. Yet, even a most casual observance of IR interaction can see that there is much more involved. Among others, even in feedback there is more involved than relevance judgment-based query modification (Saracevic, Mokros, & Su, 1990; Spink, 1993).

No one has yet successfully modified the traditional model to include interactive aspects. But, the issue is not to reject and abandon the tradition model to the heap of history. The issue is to somehow incorporate the appropriate portions of the traditional model into an interactive model. Namely, at least the system side will for the foreseeable future incorporate the elements associated with Acquisition, Representation, and File Organization as the computer side base for interaction, together with a set of variables, procedures, and algorithms involved - thus they have to be accounted for.

3. Some basic concepts from HCI

As mentioned, IR interaction can be treated as being related or even belonging to a larger class of human-computer interactions. Researchers from a number of fields addressed a variety of aspects involved in HCI, bringing perspectives from computer science, cognitive science including AI, communication, psychology, philosophy, and information science. This is a 'hot' topic because there are considerable research funds available, and there is a lot of practical interest. While progress was made, still a lot of unknowns remain. After all, the topic does not deal with computers alone, which are complex in their own right, but also with humans, which are infinitely more complex. Modeling and understanding the interaction between these two complexities is not an easy and readily achievable goal.

Storrs (1994), along with a number of others, attempted to get at definition and classification of the basic concepts and entities involved in HCI. In IR we can borrow from these to establish a common ground for further discourse. Following Storrs (ibid. p. 181), we can consider HCI as "the exchange of information between participants where each has the purpose of using the exchange to change the state of itself or of one or more of the others." The definition applies to IR interactions.

Key elements are: *participants* - people and 'computer' (which stands for a number of things involved - hardware, software, information resources ...); *exchange* - a discourse accomplished through an *interface* (it does involve 'computer', but in given situation can include human intermediaries as well); *purpose* - intentions associated with each participant; and *change* - relation to some results. As such, IR interaction is a complex process that is very much situation or context dependent: it starts from and relates to users, their tasks or problems, competencies, knowledge states and intents on the one hand, but it also involves characteristics and capabilities of the system, the information resources (documents, or broadly "texts", their representations, ...), and the interface, on the other hand. While clearly, we can distinguish between two main classes of participants: humans and computers, this is just a start. There is a wide variety in both, and we have to distinguish between a variety of purposes and roles played by each.

Humans as one of the participants involve a number of cognitive aspects, as well as other attributes, and purpose or purposes. Moreover, 'computer' as the other participant involves much more than the computer itself. It is a metaphor for a lot of things, hardware and software, information resources and their processing, capacities, connections, and a host of possible other artifectual elements and cognitive aspects.

Interaction can be direct or mediated, co-operative or individual, expending less or more resources. Each of these represent different classes of interaction, and there be more, involving distinct attributes for identification and study.

Interaction is composed of *utterances,* and these can be characterized in some way. A *dialog* is a pattern of exchanges of utterances between participants. "The nature of these patterns - how they are constrained, how they are generated, how they are tracked, and so on - is a central area of empirical study and theoretical development for HCI. ... An interaction, we can now say, is a dialogue for the purpose of modifying the state of one or more participants." (ibid. p 182).

These concepts are directly applicable to characterizing IR interactions in a general way. They also provide a research agenda for investigation of IR interaction, such as: describing the elements, variables, and roles of participants; distinguishing their attributes in different kinds of interactions; identifying variety of purposes; characterizing utterances, and differentiating them according to purposes; describing patterns in dialogues; optimizing patterns for given purposes; and so on.

The *central questions* for HCI are the same for IR interactions:

- What variables are involved in different kinds of interaction?
- How do they affect the process, and performance or outcomes?
- How to control them?
- To what extent do certain interventions (e.g. patterns of dialogue) improve or degrade the process and outcomes?

- Can interfaces be designed so that they give choices that will improve performances in a variety of kinds of interactions?

Answers to these questions will have to be sought in large part, in HCI in general and in IR in particular, through study and observation of the human side of the participants, and of the human interventions and purposes in interaction, given, of course, the assumption that the interaction is for the benefit of humans rather than computers. Observing design and capabilities of a number of computer interfaces provided for interaction up to now, this assumption is not always warranted.

3. Ingwersen's cognitive model of IR interaction

Peter Ingwersen is a pioneer in development and promotion of the cognitive model if IR, which is in stark contrast to the traditional IR model. He presented the discussion of this model in a number of writings, the most representative are his book (Ingwersen, 1992, 1996). The basic model is represented in Figure 2. (from Ingwersen, 1992, p. 16).

The model concentrates on identifying processes of cognition which may occur in all the information processing elements involved. A number of complex interactions are revealed and modeled in some detail. The main points are these:

- IR interaction is a set of processes of cognition, potentially occurring in all the information processing elements in IR. The participants engage in a variety of cognitive modeling.
- Users interact not only with IR systems, but with information objects - 'texts' - which are cognitive structures, considered as an information space.
- User's cognitive space is a set of structured causality elements; user cognitive and situational contexts are predominant. (Figure 2. provides a list).
- Interactions occur at different levels and subsequently are of different types.
- The process is highly dynamic. A polyrepresentation is applied simultaneously to both, the user's cognitive space and the information space of information systems.

Admittedly, these are gross oversimplifications of the complex cognitive model as proposed by Ingwersen. However, even in this general interpretation the model provides us with a differing picture of what is involved in interaction. This is the strength of the model. The weakness is in that it does not provide for testability (at least up to now it was not tested), and even less for application to evaluation of IR systems. In other words, the model does not satisfy the last two criteria as postulated above.

4. Belkin's episode model

Nick Belkin is another pioneer in advancing the interactive viewpoint in information retrieval. Over the years he has been engaged in identification of a variety of components and processes in information seeking by users of IR systems and other information and library services, and in classification of the interactive variables. A number of publications resulted, among them are Belkin & Vickery, (1985), Belkin (1993), Belkin, Cool, Stein & Thiel (1995), and others listed in the bibliography of these papers.

Belkin and colleagues have undertaken development of a radically different IR interaction model. They consider that the real problem in IR is not how to represent texts but how to represent the users' Anomalous State of Knowledge (ASK), the cognitive and situational aspects that were the reason for seeking information and approaching an IR system. While the Belkin model is connected to cognitive processes, it concentrates and it is based on the more specific processes of users' information seeking behavior. The model considers user interaction with an IR systems as a sequence of differing interactions in an episode of information seeking, as depicted in Figure 3.

The central process is user's interaction with information. Each of the traditional IR processes (enumerated in the model as REPRESENTATION, COMPARISON, SUMMARIZATION, NAVIGATION, VISUALIZATION) can be instantiated in a variety of ways. However, a user engages over time in a number of different kinds of interactions, each dependent on a number of factors, such as user's current task, goals, intentions, the history of the episode, the kind of information objects being interacted with, and

possibly other factors, that need to be uncovered through observation. The different kinds of interactions support variety of processes such as judgment, interpretation, modification, browsing and so on. Belkin enunciates that the problem of IR interfaces is to devise methods and ways to optimally support different kinds of interactions and different kinds of information seeking strategies.

The strength of this model is in that it directly addresses interaction, and goes on to specify that there a number of types of interactions. The goal of this research is to depict in greater detail the information seeking strategies and related interactions, and suggest on basis of these what kind of approaches are needed (including design of interfaces) to optimize them. It is to early to discuss the weaknesses of the model, because of its early stage of development. But one of the weaknesses may be the evident connection with the notion of scripts, championed in some of the expert system research. The scripts require a great deal of specificity for every process and situation involved, and as such had limited practical application, while at the same time enjoying a great deal of intellectual appeal unconcerned with reality of application. Moreover, it is not clear at all that humans actually act according to scripts. However, the Belkin model could be testable and probably could be used in evaluation of IR systems and interactions.

5. Stratified interaction model

This model is an evolution from previous work involving: interactive aspects of IR (Saracevic et al., 1988; Saracevic, Mokros, & Su, 1990); cooperative investigations with the colleagues in communication research at our School (Mokros, Mullins, & Saracevic, 1995), and several doctoral dissertations in our doctoral program (Wu, 1992; Spink, 1993). The model borrows from the concepts elucidated in HCI as above, and from notions incorporated in the stratificational theory in linguistics and communication.

It starts with several assumptions, among them that users interact with IR systems in order to use information, and that the use of information is connected with cognition and then situational application. The assumption sounds trivial, but it provides a focus and orientation for the model. A model of use of information (developed in connection with our efforts to study value of library and information services, Saracevic & Kantor, In press) is applicable. We call it an *Acquisition-Cognition-Application,* or A-C-A model of information use. The *Acquisition* component involves getting information, but such information may be of various kinds; the *Cognition* component involves absorbing and otherwise cognitively processing information; and *Application* relates to using absorbed information for a task or problem-at-hand, within a given situation and environment. Each of these components involves different elements with different roles, purposes (intentions), processes, adaptations, and the like. The IR interaction is then a dialogue between the participants - user and 'computer' - through an interface with the main purpose to affect the cognitive state of the user for effective use in connection with an application at hand. The dialogue can exhibit a number of patterns. The goal of research is similar as Belkin's: to discover and typify critical kinds of dialogues and patterns, relate them to effectiveness, and try to incorporate in the designs, particularly of interfaces, mechanisms that will provide for increase in effectiveness and efficiency of dialogs and ultimately of results. The stratified model is depicted in Figure 4.

The elements are users (with a host of variables of their own) related to a situation (task, problem-at-hand) within and environment, each having a number of characteristics and dynamics. 'Computer' is depicted as having computational resources and capacities, but also separately informational resources - 'texts' as cognitive structures, representations, metainformation about texts, and informational and computational resources, and possibly other information for adaptation to different kinds of interactions and user intents. The interface instantiates a variety of interactions, but it is not the focus of interactions, despite that it can in its own right effectively support or frustrate other interactions.

We can think of interaction as a process (i.e. a sequence of events in time with some result) occurring in several connected levels or strata. Each strata/level involves different elements and/or specific processes. On the human side processes may be physiological, psychological, and cognitive. On the computer side they may be physical and symbolic. Figure 4 does not depict these levels specifically, but lists the elements involved in the levels during interaction To model the levels or strata in IR interaction here we will simplify it to three levels *surface, cognitive,* and *situational*, recognizing that a more refined classification of levels may be possible.

On the *surface* level interaction is a sequence of events in which:

1. Users carry out a dialogue by making utterances (e.g. commands) and receiving responses ('computer' utterances) through an interface with a system to do not only the searching and matching (as depicted in the traditional IR model), but also engage in a number of other processes or 'things', above and beyond searching and matching, such as: understanding and elicitations about the attributes of a given system, or information resource; browsing; navigating within and among information resources; determining the state of a given process; visualizing of displays and results; obtaining and providing various feedbacks; passing judgments; and so on, and
2. Systems interact with users with given processes and 'understandings' of their own, and provide given responses in this dialogue, or may provide elicitations or request for responses from the user in turn

Investigations of the surface level could concentrate on observation of what 'things' users did in order to achieve something, what 'things' systems did in that episode, with what results, and how they worked or did not work together.

On the *cognitive* level users interact with the 'texts' (including images, data … and their representations) in the information resources considering them as cognitive structures. After all, texts do have certain content that is generated in and put there and represented (in some more or less effective way) by a cognitive structure and interpreted cognitively, thus interaction is between cognitive structures, above and beyond the system. Users interpret and judge cognitively the texts obtained, and may assimilate them cognitively. Investigations at the cognitive level may concentrate on cognitive processes and results, such as relevance judgments, effects of or changes in the state of knowledge, and a number of others

On the *situational* level users interact with the given situation or problem-at-hand which produced the information need and resulting question. The results of the search may be applied to the resolution or partial resolution of problem. Users judge the texts obtained according to their utility. On this level investigations may concentrate on effects on tasks or problems at hand, changes in the problem, categorization of problems for interactive decisions, and the like.

However, things are not that simple. The situation that was the reason for interaction to start with, produced a problem that sometimes may be well sometimes ill defined, and the related question, if not on paper then in user's mind, may also be defined in various well-ill degrees. A user also brings a given knowledge state, belief, intent and motivation related to the situation. Trying to capture all these is called "user modeling," a diagnostic process that has not been mastered well in automated IR, or for that matter in any automated procedure, such as in various AI applications. All this is used on the surface level to specify and modify queries, select files, search terms, search tactics, and other attributes to use in searching and decision-making, and on the deeper, cognitive level to interpret and otherwise cognitively process the texts, and make relevance judgments and other decisions.

During IR interaction, as the dialog progresses through episodes, these deeper level cognitive and situational aspects in interaction can and often do change - problem or question is redefined, refocused, and the like. Thus, as the interaction progresses things on the surface level change as well: e.g. new search terms are selected, old abandoned, tactics are adapted and changed, and so on. Interaction also involves a subtle, direct interplay between deeper and surface level of interaction. For instance, search term selection for the query from different sources and at different stages of the process, reflects such an interplay. Understanding of interaction requires understanding of these interplays.

If the interaction is mediated involving an intermediary, still another complex stratum, is added, very interesting in itself. Among others, it brings in communicative aspects of human discourse which can be analyzed in their own right (Mokros, Mullins, & Saracevic, 1995). The roles that intermediaries play can also be decomposed into levels. On the surface level, intermediaries use their mastery (knowledge and competence) about IR systems - contents, representations, metainformation, techniques, peccadilloes - not mastered by users. This is used to provide effective interaction with the system on the surface level.

But on the deeper or cognitive level, intermediaries also provide clarifying and diagnostic aspects. They provide help in defining the problem, focusing the question, incorporating the context, and other aspects that enter into user modeling. As the interaction and search progresses they also may suggest changes in problem or question definition. All this plays a critical role in selection of search aspects on the surface level: files, terms, tactics, attributes etc. Through their professional training and experience professional intermediaries become highly skillful in user modeling (which is on a deeper level of interaction), and on translating that into the surface level of interaction with a system. (Similarly, doctors and other professionals become through experience skillful in diagnosis, which then they use in treatment.) As in other situations where user modeling or diagnosis are involved we do not understand the process very well. For this reason I believe that it is important that we study in great detail IR interactions involving intermediaries. In other words, if we wish to enhance user modeling by computer-based interfaces, and incorporate it with any degree of success in IR systems, then we must study and understand first what is going on in interactions involving humans, intermediaries included in particular.

What goes on in the 'computer' side of interaction can also be considered in levels or strata. The interface (capabilities, display for visualization, and many other variables) can be considered to operate on the *surface* level, and analyzed as such. Algorithms that process the texts or representations and match them with the query can be considered as being on the *processing* level. The contents of and organization of files or information resources can be treated as on the *input* level. The hardware and software capabilities and performance can be treated on the *engineering* level. Clearly, there is an interplay between those levels. But also as clearly, there are very different considerations present in different levels, such as related to design, programming, effectiveness, efficiency, and many other aspects.

The strength of the stratified model lies in decomposition of different types of interactions as related to different elements involved. Intuitively, as we interact with an IR system we understand that we are doing different things for different purposes. And people who deal with design and other aspects of 'computer' side concentrate at different times on very different computer levels. In that sense the model is related to the idea of different kinds of interactions on the human side, as suggested by Belkin, and different types of "things" and processes involved on the computer side, as suggested in the traditional IR model. As in Belkin's model, this one has the superstructure, but not yet enough details to be testable and applicable in evaluation.

The general weakness of the stratified model is the same as found in the stratificational models in linguistics and communication. Decomposition is not that easy, and depiction of interplays between levels, a critical aspect, is hard to specify. A specific weakness is that it yet has to be tested in a larger interaction study. Clearly, much more has to be done to bring the model to practical applications.

6. Conclusions

The main theme of the paper revolves around the question: *How well do various models of IR systems and processes reflect the interactive aspects?* The traditional model does not reflect interaction at all. And since the traditional model was over the past three or more decades a guide for the overwhelming majority of efforts related to improvements in IR techniques and in IR evaluation, interaction was ignored. Nevertheless, there were real improvements in techniques of IR representation and query modification, and in the understanding what works better and what does not. However, it seems that these improvements have reached a plateau, and further algorithmic work using traditional model is dangerously close to sterility. While there was a tacit admission of its existence, interaction was not and still is not in the main stream of IR research. This is despite the fact that quite a few research efforts (as reviewed here plus a number of others) addressed interaction as a research problem. Only now interaction research is "getting out of the closet."

The interaction models proposed so far address IR interaction in differing ways, but in my judgment they do not as yet satisfy the criteria set forth in the Introduction. It is a no-brainer to observe that there are different kinds of interaction involved when users use IR systems. Yet we do no have a classification, a commonly agreed upon list of such interactions, on basis of which to proceed. The basic interaction concepts, elements, and processes are not yet elaborated and agreed upon by the interaction research community. As a result, for instance, IR evaluation involving interaction has great difficulty in settling on

the basic questions: *What to evaluate? What criteria and measures to use?* Thus, so far each such evaluation effort is proceeding along its own tangent, in splendid isolation of others. As yet, there is no choice but to do so. History of science teaches us that this kind of chaos is not unusual at the outset of exploration of a specific complex problem. Thus, there is hope for progress. But such progress has little chance unless the issues and questions raised here are clarified.

Actually, IR interaction confronts us with a marvelous paradox. On the one hand, IR practice, the use of IR systems in a myriad of incarnations and databases, is all interaction. Millions upon millions of interactive searches are performed by end-users and intermediaries worldwide, every year, if not even every month. The information professionals involved with interaction understand professionally the process, and have professionally mastered IR interaction very well. On the other hand, the IR research community and those funding IR research, have not by and large concentrated on IR interactions. Our scientific understanding of IR interaction is low, and we have not mastered the scientific investigation of the process very well, be it oriented toward theory, applications, or evaluation. Interaction practice is flourishing, interaction research is not. A balance is needed.

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Figure 1.

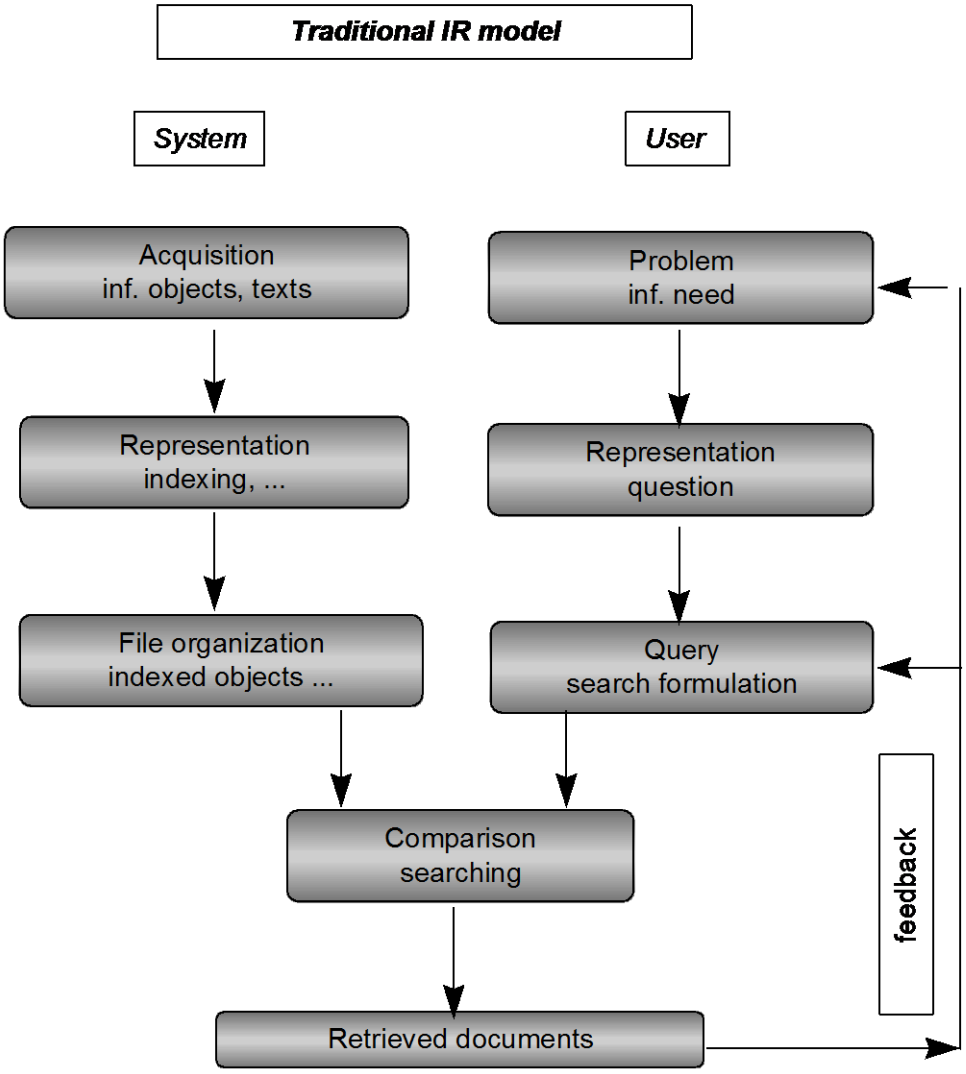
Traditional IR model
System
User
Acquisition
inf. objects, texts
Representation
indexing, ...
File organization
indexed objects ...
Problem
inf. need
Representation
question
Query
search formulation
Comparison
searching
Retrieved documents
feedback

Figure 2. Ingwersen's cognitive model of IR interaction

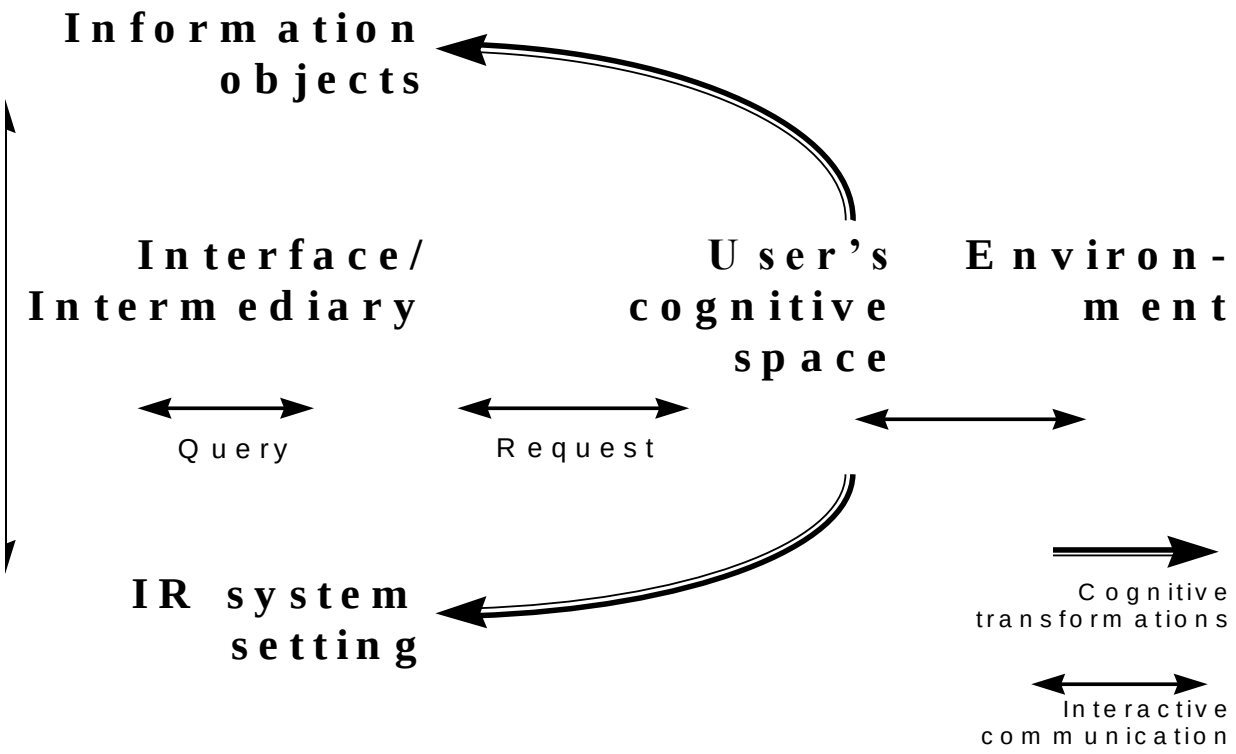

Figure 3.

Belkin's episode model of IR interaction

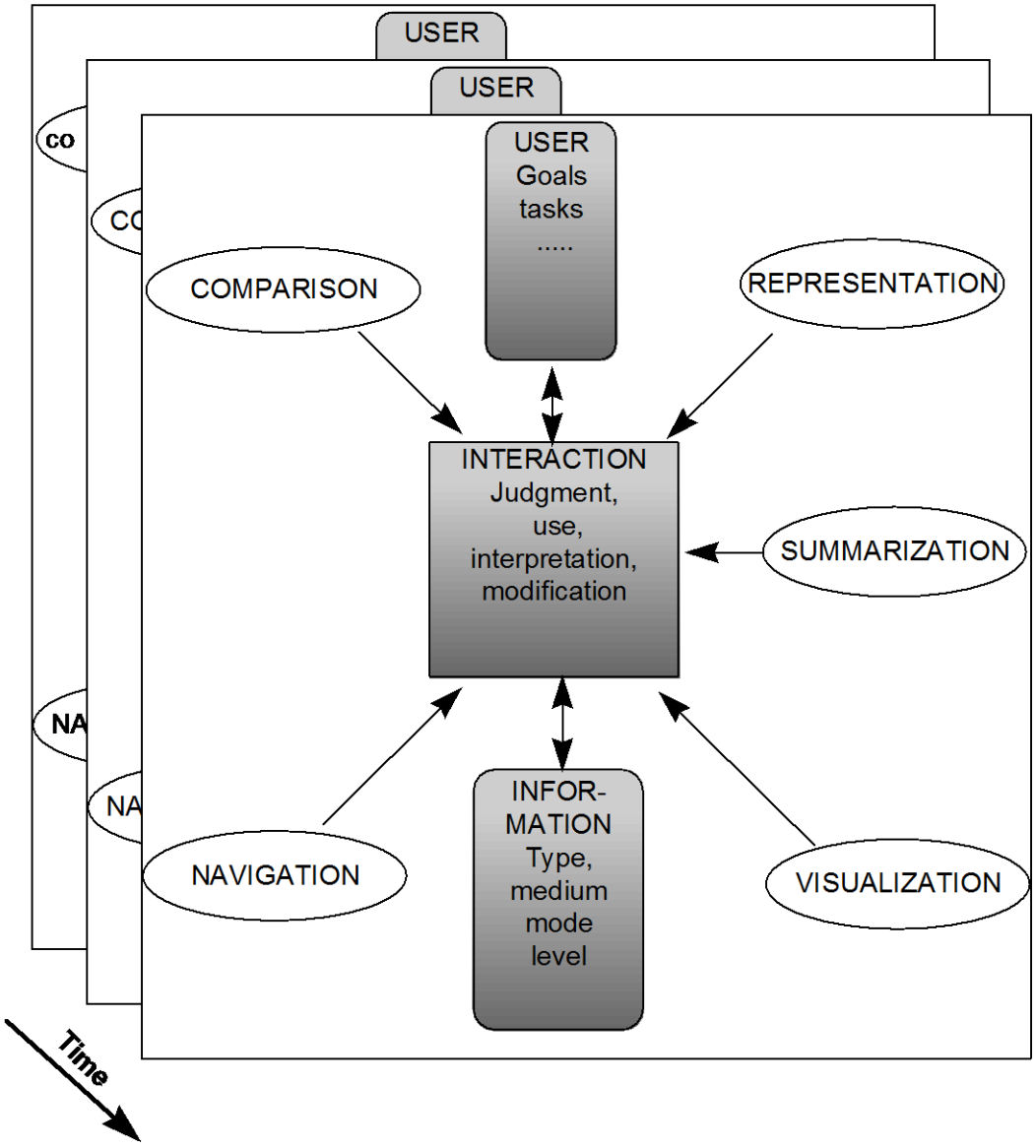

Figure 4.

Elements in the stratified model of IR interaction