

Modeling interactive behavior with state diagrams and Markov models

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ABSTRACT

We are interested in methodologies for exploring the users' information seeking behavior, and especially the influence of factors ranging from familiarity with the topic to search success, on the search strategies employed and on behavioral patterns. To that end, we have developed a novel methodology that integrates the conceptual design of the user interaction for Information Retrieval systems with the analysis of the interaction logs. It is based on (i) formalizing, via UML state diagrams, of the functionality that is supported by a system and of the interactions that can take place; (ii) on deriving XML schemas for capturing the interactions in activity logs; and (iii) on deriving log parsers that reveal the system states and the state transitions that took place during the interaction. The next step, discussed here, is building models of user behavior based the analysis of the log data.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces – *evaluation/methodology*; H.3.3 [Information Storage and Retrieval]: Information search and retrieval – *search process*.

1. INTRODUCTION AND MOTIVATION

While much of the research work in **Information Retrieval** (IR) has focused on the systemic approach of developing and evaluating models and algorithms for identifying documents relevant to a well-defined information need, there is increasing consensus that such work should be placed in an **Information Seeking** framework, in which a searcher's context, task, and personal characteristics and preferences should be taken into account (Ingwersen and Jarvelin, 2005).

Since Robertson and Hancock-Beaulieu (1992) described the cognitive, relevance and interactive "revolutions" expected to take place in IR evaluation, the focus in interactive IR experimentation has shifted to exploring the dynamic information need that evolves during the search process, the situational context that influences the relevance judgments and

the strategies and tactics adopted by information seekers in satisfying their information need. This paradigm shift to a cognitive approach to exploring search interactions and to studying **Human Information Behavior** has generated a large number of theories that attempt to model the search interaction and to predict the user's behavior in different contexts and at different stages of the interaction (Fisher et al, 2005).

Of particular interest to this author are models of the search interaction process and empirical work to validate such models by observing consistent patterns of user behavior (Ellis, 1989; Kuhlthau, 1991; Belkin et al, 1995; Saracevic, 1996; Xie, 2000; Vakkari, 1999, 2001). The interest is not simply in validating theoretical models, but also in predicting user behavior in certain situations, and in designing systems that better respond to user needs, that can adapt to support various search strategies, and that offer different functionality in different stages of the information seeking process.

Olah (2005) provides an excellent overview of work in HIB, describing the research problems and the theoretical framework underlying such work. She goes a step forward and describes the methodology and the results of her own analysis of information seeking sessions in which library patrons interact with search intermediaries in the complex process that comprises describing the search intentions, selecting a database, iteratively formulating queries and evaluating results, etc. The focus of Olah's study is the transitions between the different search stages displayed by searchers. She looks for patterns of behavior described by these transitions, and builds Markov models aimed at predicting user behavior.

Our own investigation is related to Olah's with a number of differences. While her methodology is based on discourse analysis of transcribed audio records, and on identifying and defining and coding search stages, we rely on an integrated approach to interaction modeling and analysis (Muresan, 2006). The interaction model is built in parallel with the user interface design, so the possible states of the system, the valid actions in each state and the possible state transitions are known in advance. Moreover, the semantic events that happen during the search interaction and the state transitions are explicitly captured in the interaction logs, so the log analysis can be conducted automatically, without the need for the human researcher to interpret the various actions and to identify the states.

2. CASE STUDY: MEDIATED INFORMATION RETRIEVAL

We have applied our approach on **MIR** (Mediated Information Retrieval), a current project that we are running, which we describe briefly.

We proposed the use of **mediated information retrieval** to address the problem of exploratory searches, when the searcher may be unfamiliar with a problem domain, uncertain of what information may be useful for solving a particular task, or what query terms would be helpful in retrieving relevant information (Muresan and Harper; 2001, 2004). Our intention was to emulate the function of the librarian or intermediary searcher, who interacts with the information seeker, elicits more information and helps the searcher refine, clarify and formulate her information need. Our implementation of mediation is based on so-called **source collections**, specialized collections of abstracts or documents that cover the searcher's problem domain. These collections, which emulate the librarian's knowledge of a certain domain, are either manually structured (based on some ontology that describes that domain) or are automatically clustered in order to reveal the concepts and structure of the domain, in order to inform and "educate" the searcher.

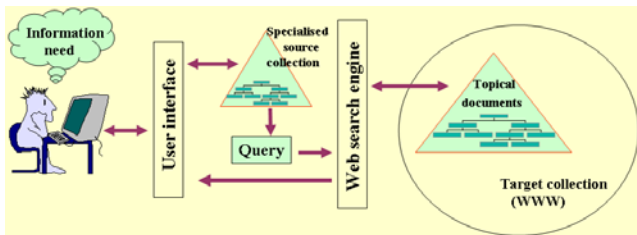


Figure 1. The interaction model in mediated information retrieval

The interaction model is captured in Figure 1. In the first stage the searcher interacts with the *source collection* so that (i) she becomes more familiar with the terminology, concepts and structure of the problem domain, and better able to convey her information need; and (ii) the system monitors the user's interaction and her selection of documents, and "learns" the type of documents that she is interested in. Following the mediation stage, the search target moves to the Web or any other *target collection* where the user hopes to find new information to satisfy her need and complete some task. At this point the system is able to support the searcher by suggesting query terms; also, the user is expected to be more familiar with the problem domain, and able to formulate better queries than before the mediation.

We have recently completed a user experiment based on mediation, and are now conducting an analysis of the data. As the focus here is on the methodology, and also due to space limitations, the details of the experiment are omitted. It is sufficient to say that we are investigating the effectiveness of mediation as well as the user behavior when faced with a mediation system that encourages a novel interaction model.

3. STATE-BASED DESIGN OF INTERACTION AND LOGGING

Our semi-formal approach to interaction design and analysis is based on statecharts (Harel, 1988) or, in the more modern UML (Unified Modeling Language)¹ speak, on state diagrams. These are extensions of finite state diagrams², in which the use of memory and of conditional transitions makes it practical to describe system behavior in reasonably compact diagrams. Such a model of a system describes; (i) a finite number of existence conditions, called **states**; (ii) the **events** accepted by the system in each state; (iii) the **transitions** from one state to another, triggered by an event; (iv) the **actions** associated with and event and/or state transition (Horrocks, 1999; Douglass, 1999; Fowler, 2004).

Figure 2 shows the state diagram that depicts the user states during the MIR interaction. In the Idle state between search sessions, the user may perform related activities such as filling in questionnaires. When the session starts, triggered by an *evStartTask* event, the system displays the current search task, so the user enters the Think state, in which she reads the task description and thinks of appropriate queries (or alternative actions) to be used. If the user starts typing a query (marked by an *evQueryEdit* event), there is a transition into the *EditQuery* state. On the other hand, in the case of using the mediation system, the user has the choice of starting to browse the source collection first (marked by expanding the cluster hierarchy or selecting a cluster, i.e. an event different from query editing). While editing the query (i.e. typing or using copy-and-paste), the user stays in the *EditQuery* state; when the query is submitted and the search results are displayed in the *Search Results* panel, the user enters the *ViewResult* state. This is a "superstate", which has a number of "substates": the user may choose to explore the source collection, corresponding to the *ExploreSource* state, or the target collection (the Web), corresponding to the *ExploreTarget* state.

The granularity of the states depends on the required precision of modeling the interaction, as dictated by the research hypotheses. For the MIR project, we considered an additional level of substates. When exploring the source collection, the user may be browsing the cluster hierarchy (*ViewSourceHierarchy*) or scanning the list of search results (*ViewSourceHitList*), or selecting and viewing one of the documents (*ViewSourceDoc*). When exploring the target collection, the user may be scanning the list of hits (*ViewTargetHitList*), or may be viewing a selected hit (*ViewTargetDoc*) or may be in the process of saving a search result judged relevant, and typing in the aspects covered by that document (*SavingDoc*), or may have second thoughts and may look again at a saved document trying to decide whether to unsave it (*ViewSavedDoc*). The searcher can shift focus of the exploration between the source and target collections (the *evSelectPane* captures this shift). This choice is captured by the history pseudo-state (H), which dictates if future transactions from *EditQuery* should go to *ExploreSource* or *ExploreTarget* following a query submission to the search engine.

¹ <http://www.uml.org/>

² http://en.wikipedia.org/wiki/Finite_state_machine

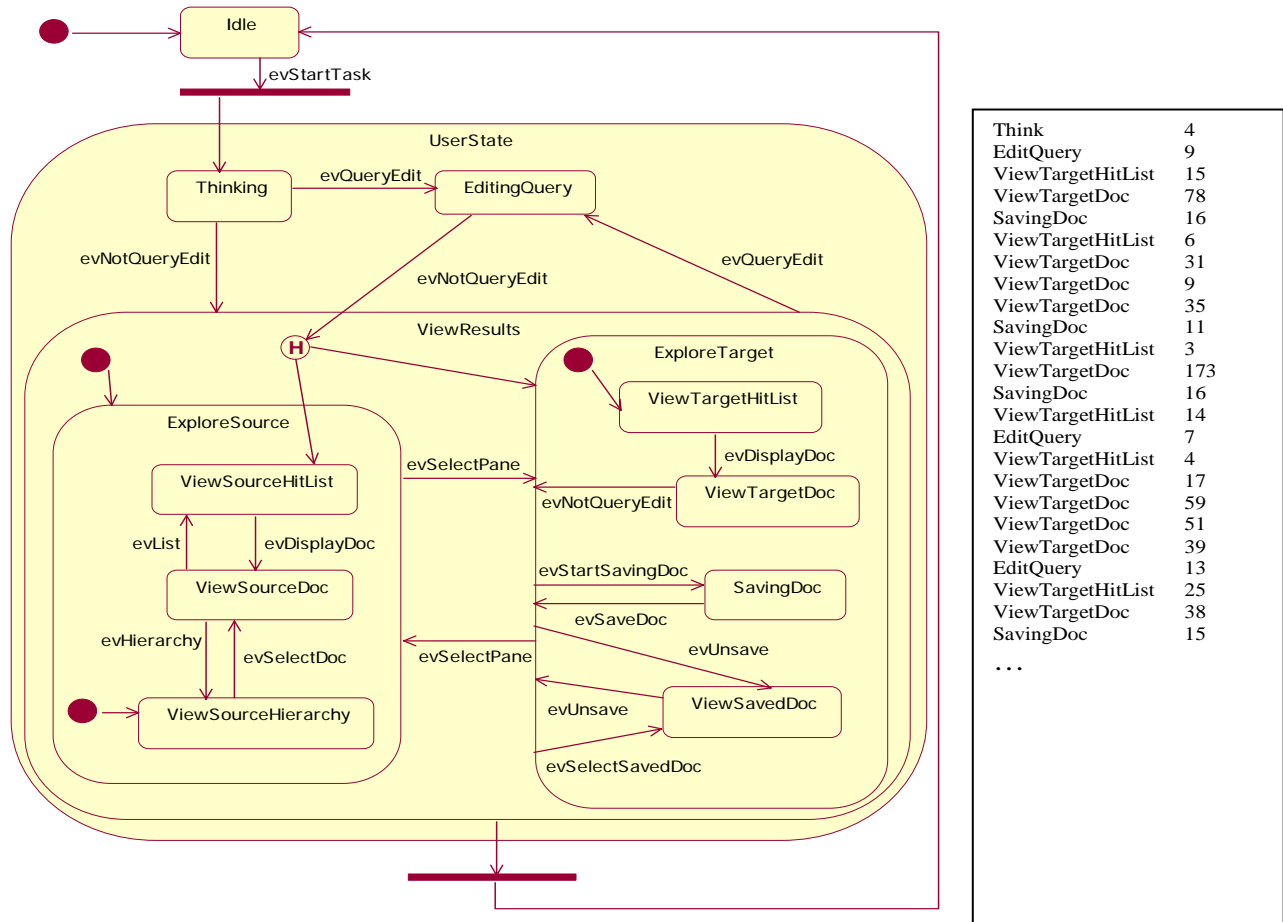


Figure 2. State diagram for the MIR project, and a state sequence sample extracted from logs

4. LOG ANALYSIS – A DISCUSSION

Each of our 16 subjects conducted two searches on each of the two experimental conditions that we set up (details not essential). By comparing these logs we hope to find both common behavior and individual behavior, and to find the effects of different factors on the latter.

We will analyze the states and state transitions from all the log files in order to (i) observe patterns of behavior and be able to predict the next state at a given point; or to (ii) find what are the most common states and most common transitions, in order to optimize the use of the interface for those situations; or to (iii) detect and correct usability problems (e.g. detecting transitions that never happen, because some functions are not sufficiently visible in the user interface).

The analysis of the logs is not trivial. Below we describe the issues and decisions that we are facing.

In order to analyze the state transitions and the patterns of behavior, two alternative representations are available:

a. State sequence

The text-box in Figure 2 shows a sample report obtained by listing the class names for each leaf state from a search session log file, together with the duration of that state (in

seconds). By studying each of these sequences and comparing them with each other, we hope to identify behavioral patterns.

b. Transition matrix

An alternative approach is to count transitions and compute transition probabilities for each pair of state, in effect building a Hidden Markov Model (Jurafsky, 2000). The graph representation shows each state as a node and each state transition as a directed edge, labeled by its probability.

Both approaches should be implemented in order to provide more information, and also in order to inform each other. For example, the length of cycles or repeated sub-sequences in the state sequence can suggest the order of the HMM to be built. Actually, a pure Markov Model may prove inappropriate. It may be the case that state transitions are not determined just by the current state and certain events, but also by some parameters of the state, such as the amount of time spent, or the number of documents examined.

Another decision regards the computation of the transition probabilities. The two potential approaches are based on:

a. Macro statistics

The transitions are counted and the probabilities are computed for each individual user, then the probabilities are averaged over the users.

b. Micro statistics

The transitions are counted and the probabilities computed over all the user logs.

The former approach is expected to highlight the differences between individual subjects, and the latter to show common behavior. Both approaches should probably be used so that together they paint a better picture of what is happening. Moreover, where the difference between individual and common behavior is significant, correlations with individual factors (such as familiarity with the topic) should be sought.

Considering the hierarchic structure of states, it is obvious that another issue to consider is state granularity. Taking into account just the top levels may give too coarse a view of the interaction and may not provide sufficient details to answer research questions. On the other hand, the leaf states may provide too much detail and may hide patterns in higher levels; moreover, due to the limited amount of data generated in a lab user experiment, some of the leaf states may appear rather seldom, so drawing conclusions from such sparse data may be dangerous. It is probably better to repeat the analysis for different levels of granularity.

5. CONCLUSIONS

We briefly describe our integrated approach to modeling interactive IR systems, designing user interfaces, and analyzing search logs. We also describe work in progress aimed at build models of search behavior based on states and state transitions captured in log files.

The expected outcome of this work is two-fold. On the one hand, the results will confirm or not our research hypotheses related to mediated information retrieval. On the other hand, we hope to validate our methodology for investigating interactive information retrieval, which should be generalizable to the investigation of interactive systems.

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