Search transition as a measure of effort in information retrieval interaction

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ABSTRACT
In this article we introduce the concept of search transitions as a unit for measuring the effort invested by searchers in information retrieval interaction. The concept is discussed and compared to traditional measures of effort, such as time. To investigate the usability of the search transition measure we have performed an analysis of 149 logs in an IR system indexing a collection of 650.000 Wikipedia articles. Our findings show that search transitions correlate with other, more mechanistic, effort measures. Additional experiments are necessary to investigate if it is a better measure of effort than e.g. number of documents examined.

Keywords
Interactive information retrieval, effort, search transitions

INTRODUCTION
Search systems traditionally aim to provide searchers with documents relevant to a query, as effectively and effortlessly as possible. The effort invested in finding and identifying a relevant document may be expressed as a combination of a number of factors describing searchers' investment in a search: time spent, search statements expressed or reformulated, potentially relevant documents examined etc. We suggest to identify effort in searching through the concept of *search transition*, which is intended to take into account operationalized aspects of the search task complexity. This concept can, e.g. be used to analyze IR processes, as well as applied as a measure to evaluate IR systems' efficiency, by investigating the number and types of search

transitions used for retrieving relevant units of information. In this paper we limit our analysis to this latter application of search transitions.

The term *transition*, or parallel expressions such as shifts, state changes etc. is widely used in both the general literature on information seeking and more specifically in studies of information search behavior. It is generally defined in terms of a move from one state to another (or a sequence of such moves). Stages or patterns of stages appear in more and more fine-grained form in models of information seeking behavior from Ellis' and others' early models (Belkin, Cool, Stein, & Thiel, 1995; Ellis, 1989), and are becoming more and more fine-grained, as in Xie (2000), where the interest is in shifting patterns between search stages. Such stages may be identified for instance in information seeking mediation, as in (Olah, 2005) where stages are identified as sets of cognitive and operational elements and transitions between stages are identified through vocabulary changes in dialogue. Transitions have been of particular interest to studies of search system interactions, where it has been thought that being able to detect transitions or distinct shifts in interaction would enable the automatic detection of patterns that might engender some kind of machine assistance or inform interface design (Dennis, Bruza, & McArthur, 2002). Variants of Markov modeling have often been suggested for such modeling, in (Kantor & Nordlie, 1999) weaknesses of this approach is discussed, and an alternative modeling approach with Petri nets are suggested. Both in this paper and many others the transitions themselves are vaguely defined, and this is a persistent problem in the literature.

This paper is built up in the following way: in Section 2 and 3 we discuss the concepts of *effort* and *search transition* respectively. In Section 4 we present an experiment designed to test the validity of search transitions as a measure of search effort. Section 5 contains our conclusions and discussion.

MEASUREMENT OF EFFORT
Although the term "effort", defined by Fenichel (1981) as "a set of search variables [including] e.g. number of commands and descriptors [and] connect time", or similar expressions are applied quite often in studies of search systems and searcher behavior in the information science literature, we find little systematic exploration of these expressions in the literature

Effort is quite often considered in the more general literature on information seeking behavior, where Zippf's "principle of least effort" is often invoked to explain users' choice of information channel, see for instance (Bronstein & Baruchson-Arbib, 2008), which refers to a number of studies who take this perspective. When effort is considered in the more restricted environment of information search behavior, however, it is often relatively vaguely defined. Typically, it is treated as in (Yuan, 1997), where, in an investigation of the influence of user experience on

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search outcomes, effort is considered as one of several "search language use patterns" and defined to consist of "mean number of cycles per topic, mean command frequency per topic, and mean number of documents visited per cycle" without any motivation for this choice of parameters.

A number of authors invoke "cognitive effort" as distinct from observable, logged actions in their characterization of search (Thatcher, 2008). Cognitive effort is a concept well known from fields such as psychology and decision theory, but as a parameter of search effort it is often treated with a similar lack of specific definition as the concept of effort in general. Where it is defined the measurement definitions range widely, from "pupil dilation" (Lorigo et al., 2006) or number of eye fixations and time spent on fixation (Balatsoukas & Ruthven, 2012) in eye-tracking studies of search and evaluation behavior to "number of iterations, i.e. queries in a search" (Belkin et al., 2003).

Studies which are directly aimed at investigating the effect of effort on search success or search outcome often use very complex combinations of variables to measure effort, (Bailey & Kelly, 2011) list "number of documents opened, number of documents placed into piles, number of piles used, number of search iterations, number of search terms, number of unique search terms, and search time. (Rieh, Kim, & Markey, 2012) similarly use eleven variants of time spent on different activities, number of clicks and number of actions to measure mental effort.

These and other papers represent attempts to measure effort by indirect observation of activity. Alternatively, effort may be based on self-reporting. From psychology, the construct AIME (Amount of invested mental effort), introduced by Salomon (1981) is defined as "the number of non-automatic mental elaborations applied to a unit of material". This can be affected, for instance, by "Perceived self-efficacy", introduced by Bandura (1982) as "people's sense of personal efficacy to produce and to regulate events in their lives". High level of self-efficacy is seen as conductive to persistence and investment of effort in a task. Smith and Kantor (2008) seem to demonstrate this experimentally when they present searchers with systematically confused search result sets and observe searchers adapt their scanning behavior to poor system performance, achieving equal search success with the faulty system by apparently investing more effort.

If we assume that invested effort has an effect on search outcome, we would wish systems to be able to automatically identify effort investment, and ideally adapt to this identification. This precludes identification of effort through self-reporting or direct measurement. We will attempt to identify effort through a set of search transitions which go beyond simple activity counts and at the same time are automatically identifiable.

SEARCH TRANSITIONS

In our understanding a search transition is defined as a series of activities with the intent to obtain an information unit (cf Pharo, 2002). When a searcher switches the focus from one information unit to another a search transition ends and a new one starts. Search processes will typically consist of interplays of such events. During a transition the searcher will be mentally targeted at acquiring an information unit. As a transition ends the searcher's mental focus will switch towards the pursuit of a new information unit. Not all transitions will produce a searcher-information unit interaction; in some cases no documents (information units) are found, in other cases there are no documents that are assessed as relevant by the searcher. What is important, however, is that the transition covers the process initiated by the searcher's intent to obtain a piece of information that could help him/her in solving a search task. A possible extension of this concept is to differentiate between interaction with document surrogates (metadata) and "real" documents, but for the sake of simplicity we choose to use search transition as a concept that covers interaction with both types of information units. A search session can contain a series of transitions, but it can also end after a single transition.

Depending on system features different types of transitions can occur. Transitions bear some resemblance with information seeking-strategies (ISSs) as defined by Belkin, Marchetti and Cool (1993), but they are on a higher macro level, in that one transition may contain several ISSs. Transitions also differ from ISSs in the sense that we think that taxonomies of transitions types should be developed for individual system rather than being general. However, as we shall see later, there are some generic transitions.

Factors that represent mental effort invested during IR interaction include query formulation and reformulation, the learning about and use of specific system features (e.g. suggested terms or search history), the selection of source and document types, the number of documents and/or other units of information viewed etc. The rationale behind using search transition as a measure of effort is to take into account the cognitive load required by searchers to deal with a variety of such challenges during interaction.

Search transitions vary in complexity depending on the IR system in use. A system that offers many facilities for user interaction and manipulation may generate many different types of transitions. The citation indexes from Institute for Scientific Information (ISI) exemplifies a quite complex IR system with its many filtering and refinement options. In contrast search engines like Google default offer very simple options for interaction. Another important feature of the IR system is whether it contains documents in full text or only metadata, i.e. document surrogates. Most library systems, e.g., only provide bibliographic records to users, who need to order the books or fetch them on the shelf. On the other hand full text IR systems integrate both the metadata and the entire documents in the system. In between there are systems (such as Google) that contain links to external documents, i.e. the documents are available at other sites. Due to the extra mental effort required by the searcher to relate to a new system when (s)he moves from a metadata system to a full text document we have considered this to be a switch from one transition to the next.

We propose the following generic set of search transitions:

a) Query – result – inspection
b) Query – result
c) Result – inspection
z) End interaction

Transition a) describes the searcher performing a query in the IR system, and from the result list selects a unit of information (independent of it being (part of) a document or metadata). In transition b) the searcher performs a query, but no information

unit is selected for further inspection. In transition type c) the searcher returns to the results from having inspected a unit of information and then selects a new unit, without a new query being performed. Transition z) is used to indicate that system interaction stops, this could be provoked by the searcher logging out of or exiting the system in other ways or by system failure.

To illustrate the use of transition we can use the following example: a searcher who wishes to borrow a book on the Java programming language enters a query in her local library's Opac ("Java") and selects for inspection the first record in the result list (transition type a). This is not exactly what she is looking for, so she returns to the result list and select record no 3 (transition c). She realises that her query should be more specific so she enters a new query ("Java programming language") and selects the first record, once more (transition type a). Having found what she needs she ends her session (transition type z). Rather than conceptualising the effort purely mechanistic (entering query term, clicking on a link etc) our use of transitions signifies the involvement of three distinct processes during the session.

Search transitions may be studied individually, in sequence or accumulated over search sessions[1]. In the study presented below, we have been interested in the effects of the cumulated effort expended by searchers over the course of a session, since the experimental conditions in our case makes search sessions easily comparable. For a fuller understanding of the relationship between effort and search result it is necessary to break these sessions up into sequences of individual transitions (as in the simple example above). This will be investigated in a forthcoming study.

MEASURING EFFORT IN AN EMPIRICAL STUDY

Based on the discussion above we propose the hypothesis:

H1: *search transition is a reflection of effort and can thus be used as a measure off effort*.

From the literature (Smith & Kantor, 2008) we further make the assumption that when searchers invest more effort they are able to find more relevant documents. To test the hypothesis we thus need to design a study where we can measure the effect of effort investment on relevant documents found.

Searchers will select strategies that depend on the search task's domain and complexity (Vakkari, 1999). Task complexity (Byström & Järvelin, 1995) is connected with the predictability of task outcome, which in turn depends on the task structure. More complex tasks typically require searchers to use heuristic-based processing of information. We thus hypothesize that this is one of a set of factors that may lead searchers to invest more effort in a search task. In our study we therefore also will test the effect of the following four factors on effort investment:

- search experience
- search task structure
- search task complexity
- perceived difficulty of search tasks

To test the validity of search transitions as a measure of search effort we have performed an empirical study of searchers performing search tasks in an IR system indexing a collection of 650.000 Wikipedia articles.

Data and Method

The search system applied in the study is a java-based retrieval system built within the Daffodil framework, which resides on a server at and is maintained by the University of Duisburg. The search system interface is developed for the INEX (Initiative for the Evaluation of XML retrieval) interactive track (Malik, Tombros, & Larsen, 2007). The system returns elements of varying granularity based on the hierarchical document structure. Each Wikipedia article is indexed and is retrievable on three levels of granularity; article level, section level and sub-section level. Searchers have performed simulated work tasks (Borlund, 2000) in both systems.

A total of 149 search logs from 40 different searchers have been analyzed. The large majority of searchers were students in their twenties, a smaller group being older faculty members. The article elements are grouped by document in the result list (Figure 1) and up to three high ranking elements are shown per document. When a searcher chooses to examine a document (Figure 2), the system shows the entire full text of the document with background highlighting for high ranking elements. In addition to this it shows a Table of Contents built on the basis of the XML formatting. To help searchers select query terms a box appears showing terms related to the current query. Searchers may browse the full document, select document elements to browse from the TOC by clicking on the relevant element title, select embedded links to other documents or select new documents to view from the result list. They are asked to indicate the degree of relevance of any document or element they chose to examine. The relevance scale used was designed to take into account both topical relevance (relevant, partly relevant and not relevant) and specificity (relevant but too broad, and relevant, but too narrow) and searchers were asked to assess the relevance of all articles and sections inspected, but the system did not force searchers to do the assessments.

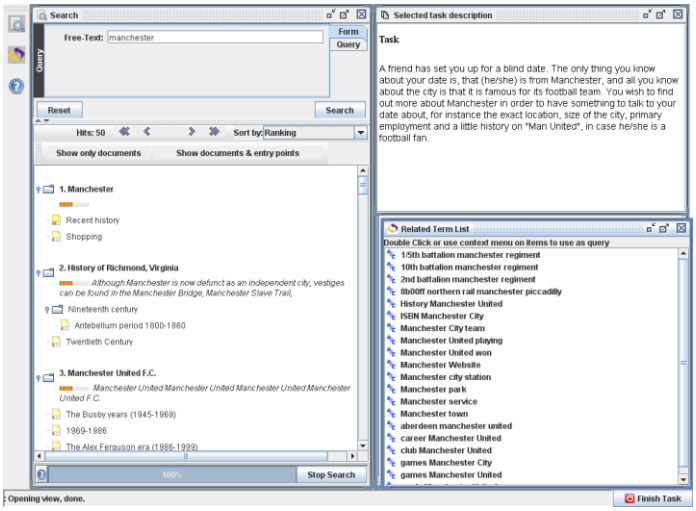

Figure 1 Search interface of Daffodil

[1] For a more thorough understanding of the search process as a phenomenon we would prescribe the analysis of individual transitions and transition patterns.

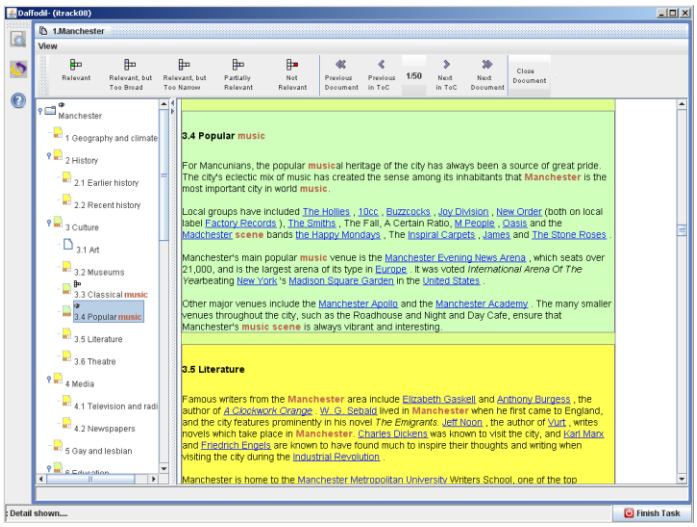

Figure 2 Document interface of Daffodil

Since the system offers interaction *within* information units we found that it was possible to add system specific transitions to the generic set presented above. These transitions reflect that the system offers both direct access to the full document, parts of the document and the possibility of inter- and intra-document interaction. In addition we have added transition types that take into account the use of the system's suggested term-feature. As with the generic transitions all following transition types can be automatically collected from the transaction logs:

d) inspection – link to other page – inspection

e) back button – link to other page – inspection

f) use system suggested terms – results – inspection

g) use system suggested terms – results

In transition d) the searcher from within an article selects a link to another article. In transition type e) the searcher uses the system's back button to the previous page and then selects a link to another article (note that transition type e) is always preceded by transition type d)). The difference between transition types f) and g) is that in the latter the searcher does not select any of the entries in the result list for further inspection. Note that interaction within an article, using the TOC is treated as part of the same transition.

12 tasks were developed for the experiments. The tasks were constructed to represent two structural types (Hierarchical and Parallel) and three different task types ("Decision making", "Fact finding" and "Information gathering"). Before the experiment searchers were asked to assess their own search experience and after each task they assessed the difficulty of performing the task.

The experiments were designed to let each searcher perform four tasks, evenly distributed with respect to task structure and task type, with a time limit of 15 minutes for each task. Sessions were logged in detail, and for this study we extracted and accumulated from the logs data on time spent during each transition, rank in result list of documents examined by the searcher, number of sub-elements (sections and subsections) which were browsed and examined, number of elements assessed, and the level of relevance for each assessed document/sub-element.

As stated above we assume that effort investment increases the chance of finding more relevant information units. In this experiment these units are Wikipedia articles (documents) and article sections and subsections (document elements). Since time is the effort measure most commonly in use we have analyzed what we believe is the effect of effort, using both number of search transitions and time. If both measures show the same effect it strengthens hypothesis H1.

Results

To test our hypothesis we first used SPSS to perform correlation analysis identifying the effect of search transition and time on the number of relevant information units retrieved. We have looked at the influence on the retrieval of both "to some degree relevant" (i.e. all assessments except for not relevant) and "fully relevant" documents. We also looked at the distribution of relevance judgments and found that neither individual user characteristics nor individual task characteristics, which might both conceivably have influenced results, proved in any way to vary systematically with relevance judgments

Our data set for analysis consists of 148 sessions, varying in time from 96 to 2231 seconds with an average of 669 seconds. The number of to some degree relevant (fully relevant in parentheses) documents or document elements identified in each session varied from 0 to 24 (12), with an average of 5.5 (2.7) and a median of 5 (2). The number of search transitions per session varied between 1 and 45 (an extreme outlier), with an average of 8.95. In total our data set contains 1324 search transitions.

Pearsons R correlation was measured for both measures and is shown in Table 1. A preliminary analysis showed that both measures also positively correlated with somewhat relevant information units found. If we look at the relationship between effort and *fully* relevant information units, then time showed no significant correlation. From Table 1 (where fully relevant and somewhat relevant unit assessments are combined) we see that number of transitions seems to be a better predictor than time. A possible explanation could be document load time of the IR system.

Effort expression	Correlation (Pearson's R)
Number of search transitions	0.408**
Time	0.267**

Table 1. Correlation between two expressions of effort and number of relevant information items found

**Correlation is significant at the 0.01 level

The analysis indicates that number of transitions is a valid expression of effort, as the number of transitions increase so does the number of relevant documents found. We have performed a scatter plot to control for the effect of extreme outliers (Figure 3), it shows that there are some outliers, i.e. some sessions consisting of few transitions returns quite many relevant information units and one session consisting of 45 transitions which returns only 5 somewhat relevant units.

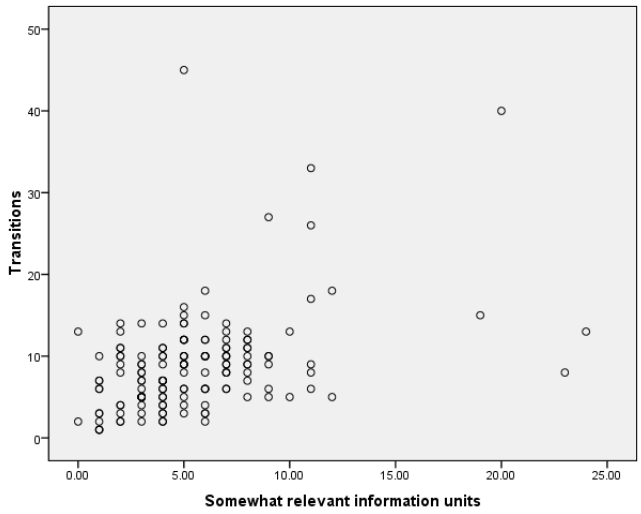

Figure 3 Scatter plot of the relationship between the number of search transitions and somewhat relevant information units

The findings give us reason to believe that effort can be measured using number of transitions. To test its validity further we therefore analyze the effect of search task structure, search task complexity, search experience and task difficulty on effort, using both time and number of search transitions.

Difference in search task structure may influence the effort needed to perform them. Some topics are difficult to express as search queries, some topics are only covered in very few documents and thus generates more effort etc. In order to control for this we looked at searchers performance on search tasks of different structure (six parallel and six hierarchical tasks) in order to see if they reflected the same pattern of effort.

The search task sessions were quite evenly distributed between the two task types (80 hierarchical sessions and 68 parallel). We have analyzed the investment of effort used for solving the task types, expecting that hierarchical tasks, which represent a task type designed for searchers to go more in depth (Malik et al., 2007), requires more effort. Table 2 show distribution of the different effort measures per task types.

Effort measure	Hierarchical	Parallel
No of transitions	9.39	8.51
Time (secs)	655.09	646.35

Table 2 Investment of effort for hierarchical and parallel search tasks

Our analysis show no significant difference in effort (measured in time or as number of transitions) invested in the two task types. It does show, however, that the number of transitions is a measure that follows the same pattern of investment as time, hence our hypothesis is not falsified.

The tasks also differed with respect to type; categorized as belonging to the three different groups "Decision making", "Fact finding" and "Information gathering". Of these we considered Fact finding-tasks to be simpler (Low complexity in Table 3) than the other two (coined High complexity). This is because both decision making and information gathering tasks typically will require more interpretation of results (Bell & Ruthven, 2004) than fact finding tasks and as such would require more analysis of the documents found in order to be assessed as relevant or not.

Table 3 shows effort invested for the two different task groups, and even if both effort measures follow the same pattern the T-test showed no significant difference in the effort spent by searchers preforming the two different types of tasks.

Effort measure	High complexity	Low complexity
No of transitions	8.87	9.05
Time	664.36	676.60

Table 3 Investment of effort for high complexity and low complexity search tasks

We expected that search experience would be a factor that influences the searchers' effort investments. Our analysis did show that searchers with high search experience use less time and execute fewer transitions than those with less experience (Table 4). The difference is only significant, however, for the time spent.

Effort measure	High	Low
No of transitions	8,21	10,20
Time	599,79	769,34

Table 4 Investment of effort from users with different levels of search experience

The users were also asked to state their perceived easyness of the task (Table 5). The analysis shows that there is a significant difference between effort investments (both measured as time and no. of transitions) between the users, those who found the tasks easy invest, not surprisingly, less effort than those finding the tasks difficult.

Effort measure	Easy	Difficult
No of transitions	7,50	10,29
Time	600,83	768,26

Table 5 Investment of effort for difficult and easy tasks

DISCUSSION

In applying the concept of search transitions, we have attempted to find a measure of search effort, termed search transitions, that captures a rich set of aspects, but which still can be established on the basis of recorded search logs rather than through direct interactions with the searchers. Judging from our results, our measure is able to capture the same tendencies as the most obvious alternative, time, given that both time and number of search transitions correlate well with our chosen measure of search success, the number of relevant documents found.

In contrast to time, which is relatively sensitive to external factors such as system weaknesses and searcher distraction, search

transitions only measure the searcher activities which may involve effort.

Our results also show that search transition follows the same pattern as time when affected by several independent factors thought to influence effort. This strengthens our hypothesis that search transition can be used as measure for effort.

To test our hypothesis further it is possible to perform experiments where expressions of user satisfaction are used instead of the relevant documents found.

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