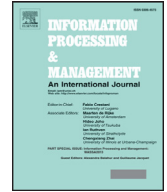


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Evaluating user search trails in exploratory search tasks

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ABSTRACT

Exploratory search is characterized by a user's uncertainty towards a complex information seeking task. A user conducting such a search in an information retrieval (IR) system may need help and recommendations that are beyond mere query suggestions. In this paper we propose a new method for recommending search trails to struggling users. We first use a search process prediction model from the literature to predict whether a user is likely to under-perform in an exploratory search task, and given that case, recommend a search trail based on other users' search behaviors in a similar context. We then present a method to evaluate the effectiveness of these recommendations that involves two different evaluation criteria. First, we use Open Directory Project (ODP)-based categorization of user-traversed Web pages to evaluate each user's information coverage. Next, we evaluate the order of users' search trails while simultaneously incorporating a novel set of metrics that use adjacency of queries issued and Web pages traversed. To evaluate search trails, we incorporated proposed metrics with transactional log data from multiple user studies in which more than 300 users conducted exploratory search tasks on different topics.

We demonstrate the effectiveness of the proposed evaluation criteria by measuring how the recommended search trails lead to improvements in both information space coverage and search performance metrics for users across multiple user search datasets. Based on the analysis results, we demonstrate that the order of the recommended search trails plays a significant role and it outperforms the random order of search trails thus being beneficial for the struggling users in improving their overall search effectiveness. We also show that by providing search trail recommendations, users are able to discover more information across multiple facets (in breadth) as well as investigate certain facets in more detail (in depth). These findings provide substantial evidence across multiple datasets to confirm that recommended search trails improve users' information seeking coverage and overall knowledge acquisition throughout their search processes.

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1. Introduction

Exploratory searching behavior is characterized by significant uncertainty towards the goals of a search or a dearth of knowledge about a search topic's domain (White and Roth, 2009, pp.10; Kuhlthau, 2004). As a consequence, searchers who are exploring need support to help them sift through the unknown. One possible solution is to help exploratory searchers

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by automatically providing them with *trails*, or previously traveled search paths that have proven useful to other searchers with similar exploratory search behaviors. Pirolli and Card (1999) developed a sophisticated model of user behavior called *information foraging* derived from animals' behavior when foraging for food in the wild. They use a foraging metaphor to discuss how information seekers could use cues left by previous visitors to find and consume patches of information in a collection to satisfy their own needs. We utilize both the information foraging theory and a recent prediction and recommendation approach that incorporates implicit features proposed by Hendahewa and Shah (2015) to recommend search trails to users to improve their overall information coverage and search performance.

When analyzing user search behavior, developing a user profile is a challenging task because it may change throughout the search process. For example, over time a user can develop from an ineffective searcher to an effective searcher or vice-versa. Evaluating a user's profile in a dynamic manner in order to provide real time recommendations to improve their search performance can be considered an improvement upon traditional recommender systems. Current IR systems often use query auto-completion and related services to provide recommendations. Considering that some exploratory searchers may not even have a reasonable query to begin with, these methods can be limiting. Rather than adhere to a traditional recommender system's paradigm, the work presented in this paper will attempt to evaluate recommendations based on dynamic user behavior analysis throughout the search process in a specific order of search paths and visitations.

1.1. Research objective

In this article, we focus on addressing two main research objectives related to recommendation and evaluation of search trails.

- **RQ1:** Can we assist struggling users by recommending them better search paths in order to improve their search performance and reach the task goal?
- **RQ2:** Provide a set of metrics for performance assessment based on the recommended search trails.

It should be noted that for the purpose of this article, we use the definition of *search trail* as being defined by White and Huang (2010) as a search path that begins with a search engine query and comprises a set of pages visited until the trail terminates with a new query or an inactivity or timeout.

For users who are deemed to be under-performing according to the evaluations proposed in the algorithm by Hendahewa and Shah (2015) as shown in the pseudo-code below, we provide similar interventions in order to improve their search process (Algorithm 1).

Data: Search trails of each user

Result: Simulated search path recommendations for under-performing users;

```

while Remaining under-performing performers(l) do
  Find matching high performers with similar first search path;
  for (h = 1; h ≤ num(high performers); h++) do
    if QueryEditDist(Firstsearchpathl - Firstsearchpathh) ≤ Threshold
      then
        | Switch remaining searchpathl with remaining searchpathh;
      else
        | No simulation;
      end
    end
  end
end

```

Algorithm 1: Search Process Recommendation Simulation Algorithm.

Many possible methods of search intervention have been considered, including query suggestions (Karisani, Rahgozar, & Oroumchian, 2016; Marchionini & Shneiderman, 1988; Niu & Kelly, 2014; Vidinli & Ozcan, 2016), query auto-completion (Cai & de Rijke, 2016; Smith, Gwizdka, & Feild, 2016), trail suggestions (Singla, White, & Huang, 2010; Wexelblat & Maes, 1999; White, Bilenko, & Cucerzan, 2007) and entity suggestions (Balog, Bron, & De Rijke, 2011; Brando, Santos, Ziviani, de Moura, & da Silva, 2014). In exploratory search, where the emphasis is placed on complex extended search processes, we argue that the recommendation of search trails is useful and appropriate. Recommendation of search trails goes beyond both related query suggestions and relevant document suggestions, as search trails allow a user to explore diverse and undiscovered areas of relevant information. In assessing **RQ1**, by providing search trail based recommendations (that were deemed to be successful by other searchers) to the struggling users we evaluate whether they would benefit from such recommendations.

Further, we propose a set of metrics that utilizes information coverage using Open Directory Project (ODP)-based categorization of Web pages and also proposed measures to evaluate goodness of a search trail that address **RQ2**. Using search trails as the unit of analysis and search trail recommendation as the mode of intervention in real time, the work reported in this paper will demonstrate that we can improve search performance metrics and achieve higher information space coverage.

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