Navigation Leads for Exploratory Search and Navigation in Digital Libraries

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Abstract

In our dissertation, we focused on the exploratory search, which is characterized by ill-defined information needs of the users, is often open-ended and requires use of various search strategies. We addressed two main goals: (1) utilisation of the data characteristic for the digital libraries domain with the purpose of improving the quality of the keywords extracted in the process of exploratory search and navigation, and (2) support of iterative query formulation in the process of (exploratory) search considering previous information needs of the users and their feedback with the aim of improving domain sense-making and increasing important concepts coverage and understanding.

We proposed an approach of exploratory search and navigation using navigation leads, with which we augment the search results, and which serve as navigation starting points allowing users to follow a specific path by filtering only documents pertinent to the selected lead. Our main contributions lies in using citation and co-citation analysis for keywords extraction for the identification of navigation lead candidates and in examining different aspects of selecting the suitable navigation leads based on their informational and navigational value.

Categories and Subject Descriptors

H.3.3 [**Information Storage and Retrieval**]: Information Search and Retrieval—*information filtering, selection process, query formulation*; H.3.7 [**Information Storage and Retrieval**]: Digital Libraries—*user issues*; H.5.4 [**Information Interfaces and Presentation**]: Hypertext/Hypermedia—*navigation*

Keywords

exploratory search, navigation, digital libraries, navigation leads, navigational value, query refinement, Annota

*Recommended by thesis supervisor: Prof. Mária Bieliková

1. Introduction

When humans look for information, they manifest their *information-seeking behaviour*, which is, however, only a part of a much broader *information behaviour* [18]. This term encompasses all information activities, i.e., receiving of information (intentional or incidental) when interacting with the environment or other humans, looking for information, information processing, and communication of information to others.

Although we limit the scope of our work to the information-seeking behaviour and more precisely only to the specific type of information-seeking that humans manifest when they look for information on the Web or in the digital libraries, there are still two views to consider:

- The traditional computer science view—denoted as information retrieval—that understands search as a retrieval of documents from a system that are the best match for the user query.
- The more general information and library science view that understands search as a human information-seeking activity. Therefore, it puts more stress on the human (user) perspective in the process of search.

These views complement each other [18]: information search (or retrieval) is nested in the more general information seeking, which is in turn nested in the information behaviour. At the most specific level in this hierarchy, query refinement serves the purpose of better conveying the intended meaning of a user for the system to be able to guess it more accurately, while the user's information need stays fixed.

However, in reality, the users' information need can change during the process, especially if it is not clear at the beginning; this is recognized by many information-seeking models and theories, such as Kuhlthau's Information Search Process [9], information foraging theory [14], berrypicking [1], or by the theories of sense-making [7, 19]. It is also in the focus of the exploratory search; this term is usually used to denote search tasks that have exploration, investigation, and learning as their goals [11, 17].

An example of such a task is *researching a new domain* – a task the researcher novices, such as the master's or the doctoral students are usually faced with. In order to research a new domain, they have to search the digital libraries such as ACM DL[1], Springer Link[2] or IEEE Xplore[3] to find articles relevant for a given field and get to know the main concepts and relationships among them. This was the main scenario of our dissertation as well as of the multi-disciplinary research project TraDiCe[4] (Cognitive Travelling in Digital Space of the Web and Digital Libraries) [12], to which also the results of our dissertation contributed.

1.1 Thesis Goals and Research Questions

If we look closer on the domain of digital libraries and compare it with the "wild" Web, we can find out that there are similarities, but also specifics that need to (or should) be taken into consideration when designing an exploratory search and navigation approach. Examples of these are the additional metadata that are associated with the documents in the domain, or the connections between the documents based on the co-authorship or cocitation. This led us to formulate our first goal:

Goal 1. Explore the similarities and the differences between the domain of digital libraries and the "wild" Web and utilise the data characteristic for the former in order to improve the quality of the extracted keywords, which are used in the process of exploratory search and navigation.

The initial phase of query formulation is crucial for a successful search, especially if the users start with ill-defined information needs. Instead of forcing them to verbalise their needs at the beginning of the search, the search system should allow iterative querying and provide leads (cues) on how to reformulate the initial query. Therefore, the initial search results can be understood as mere starting points for further exploration [13]. At the same time, it is important to provide the users means of making sense of the domain and of exploration, learning, and understanding the important concepts in the domain. This constituted our second goal:

Goal 2. Support iterative query formulation in the process of (exploratory) search considering previous information needs of the users and their feedback and the subsequent navigation in the information space of a digital library of research articles through a series of navigational steps with the goal of improving domain sense-making and increasing important concepts coverage and understanding.

We addressed these goals in our work by examining the following three research questions:

1. Does the use of domain-specific metadata in the process of keyword extraction help to improve the overall quality of the extracted keyword set?
2. Does considering the navigation history help to identify relevant terms that are useful for exploratory search and navigation?
3. Does considering the navigational value of terms help to identify relevant terms that are useful for exploratory search and navigation?

[1]https://dl.acm.org
[2]http://link.springer.com
[3]http://ieeexplore.ieee.org
[4]http://tradice.fiit.stuba.sk

2. Approaches to Exploratory Search and Navigation

We identified and analysed several exploratory search approaches; the most prominent were the following:

- *Faceted search and navigation* – this is historically the oldest approach, since it followed upon the idea of web directories. It has firmly established itself and is widely used in commercial systems, digital library systems, etc. The current research problems are with extending the faceted search into the open Web [8].
- *Results clustering and diversification* – it started in part as an alternative to faceted search when a predefined taxonomy was missing as was the case with the open Web. There is still research into novel ways of results clustering [3], but in recent years the main focus has shifted more into *results diversification*, which has the same basic idea [10].
- *Tag navigation* – it started as a means of resources organisation and their future retrieval. The current trends in this regard include personalisation of the tag cloud content or improving its navigability [4].

All these approaches provide a global overview of the domain. Similarly, they support view creation, since filtering is the basic feature of all the search systems. However, they differ in the means of view creation. The faceted search relies on the predefined taxonomy, while the tag navigation relies on the users to create their own *folksonomy.* The results clustering is based on the similarity measures comparing the document contents (or their surrogates).

There are similarities in the query formulation and refinement; users always select some values, whether they are facets, tags, or queries. They also support navigation to some extent (e.g., the users can preview the number of documents with a certain facet value, importance of a tag, or the size of the document clusters). On the other hand, all the approaches have their limits concerning the scalability. The faceted search becomes impractical, if there are too many facets or facet values. It there are too many documents, it becomes very computationally demanding to create the document clusters at a reasonable level of hierarchy (abstraction). Also, if we use tags, there are problems with tag clouds as analysed in [6].

All of the approaches can be personalised with the exception of results clustering, because it tries to maximise the diversity, which is in opposition to the goal of personalisation. It is also worth noting that although personalisation is possible with other approaches, it is still rare. As to the transparency, the faceted search and tag navigation have a high level, because the users are always aware, how the documents were filtered and have also some kind of indication of the size of the information sub-space, should they take the next step. The clustering has a moderate level of transparency, because the users are presented with the identified clusters and thus have a control of what should be filtered in the next step, but the selection itself is hidden from them.

2.1 Evaluation of Exploratory Search Systems

We analysed evaluation methodologies used in 83 research articles in the domain of exploratory search and information seeking that were published in various journals and conference and workshop proceedings ranging from 2003 to 2016. We found out that a typical evaluation of an exploratory search system consists of a controlled laboratory user study, the results of which are quantitatively assessed. We observed that there is in general a lack of longitudinal studies that would examine the natural behaviour of the users as they use the system over longer periods of time. Also, the number of qualitative studies was smaller than we had expected; sometimes a quantitative study with a small user sample or a quantitative user-centred study was incorrectly categorised as a qualitative study by its authors.

One of the trends in the exploratory search evaluation is to *simulate* user navigation and search behaviour. It is suitable in situations when there is no objective notion of relevance, but a subjective one, which prevents using a standardised dataset. Also, it allows to test new means of interactions and compare different parameter settings, which would not be feasible in a classical user study. A *hierarchical decentralised search algorithm* is often used for this purpose [5], other possibilities include *Markov chain model* [15] or *Click chain model* [16]. Although there are limitations to this approach, since it is only an approximation of true user behaviour, we examined it in our work and employed this methodology to evaluate our proposed approach of exploratory search and navigation.

3. Exploratory Search and Navigation Using Navigation Leads

In order to support exploratory search and navigation, we proposed an approach of exploratory navigation using *navigation leads*—important words automatically extracted from the documents present in information space—that serve as navigation starting points allowing the users to follow a specific path by filtering only documents pertinent to the selected lead. We distinguish two types of navigation leads:

1. *View navigation leads*, which provide a global overview of the domain—what the most important concepts or the most promising leads (paths) to follow are—before the initial query and an overview of the generated view of the domain consisting of the documents of the filtered information subspace at the later stages of search. They are usually presented to a user in a cloud and play a crucial role in formulating an initial query.

2. *Document navigation leads*, which highlight terms (keywords) relevant in the context of a single document (search result) as well as the terms with the highest navigational value. They are placed directly in a summary (or an abstract) of a document (see Fig. 1) or below it in order for the users to perceive them in their context. They play crucial role in query refinement and add an aspect of serendipity by allowing the users to follow also unexpected new paths.

The selection of a navigation lead (both view-related and document-related) by a user results in a query refinement and subsequently in a construction of a new partial view of the information space (when a new set of results is retrieved).

The proposed approach consists of two main steps that we elaborate on in the following sections: (1) identification of the navigation lead candidates (see sec. 3.1) and (2) selection of the navigation leads (see sec. 3.2). There is a third step—navigation leads placement—for which we examined the already mentioned cloud placement (in case of the view navigation leads) and in-text or below-text placement (in case of the document leads). We proposed methods for the first two steps, which we evaluated in a web-based bookmarking system *Annota*[5] (see Fig. 2) and on its associated dataset. This system was developed as a part of the research project TraDiCe.

3.1 Identification of Navigation Lead Candidates

We explored the role of domain-specific metadata and relationships in the process of identification of navigation lead candidates. More specifically, we focused on citations, or more precisely, *citation sentences* as well as co-citations, thus addressing the first research question.

We proposed a method of keyword extraction using citation and co-citation analysis that combines keywords extracted from the document content with those extracted from citation sentences and from the co-cited articles. It weights the extracted keywords (navigation lead candidates) using a set of defined rules based on the *co-citation weight* and *proximity.*

We quantitatively evaluated our method in the domain of digital libraries using experts' judgement on the relevance of the extracted keywords. Although a single relevance judgement of an expert can be considered qualitative, since we evaluated the performance of the method based on the set of all judgements by computing a metric (*precision* in our case), the evaluation is quantitative. We collected 844 assessed keywords from eight domain experts. We found out that using citations and co-citations outperforms the TF-IDF method. The differences were significant with $P@2$ metric (based on the *test of equal proportions* that uses χ^2 test statistic).

Besides examining the quality of the extracted keyword set, we also analysed, whether the use of citations and co-citations is capable of finding new words or promoting the important words by boosting their relevance in comparison with the content-based (TF-IDF) and solely citations-based baselines. Almost 15% of the assessed words were identified only when considering also co-citations with more than half of them relevant or somewhat relevant (as assessed by the experts).

Additionally, we scrutinised the limitations of using the citation and co-citation analysis with respect to the number of citations of an individual article. With the increasing

[5] http://annota.fiit.stuba.sk

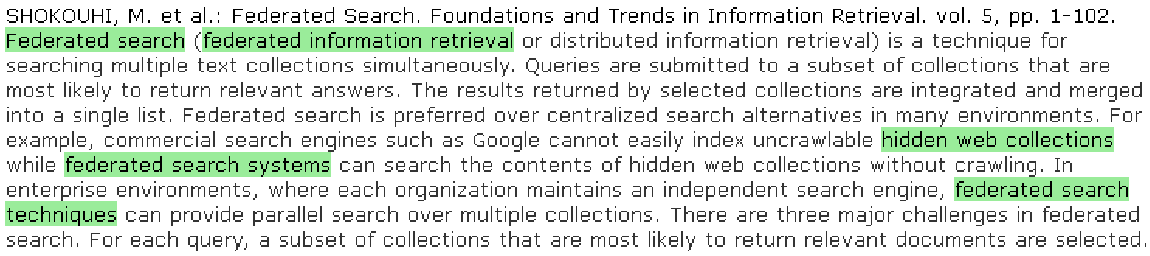
SHOKOUHI, M. et al.: Federated Search. Foundations and Trends in Information Retrieval. vol. 5, pp. 1-102.
Federated search (federated information retrieval or distributed information retrieval) is a technique for searching multiple text collections simultaneously. Queries are submitted to a subset of collections that are most likely to return relevant answers. The results returned by selected collections are integrated and merged into a single list. Federated search is preferred over centralized search alternatives in many environments. For example, commercial search engines such as Google cannot easily index uncrawlable hidden web collections while federated search systems can search the contents of hidden web collections without crawling. In enterprise environments, where each organization maintains an independent search engine, federated search techniques can provide parallel search over multiple collections. There are three major challenges in federated search. For each query, a subset of collections that are most likely to return relevant documents are selected.

Figure 1: Navigation leads (highlighted in green) placed directly in the text. The users can click on them in order to refine their query.

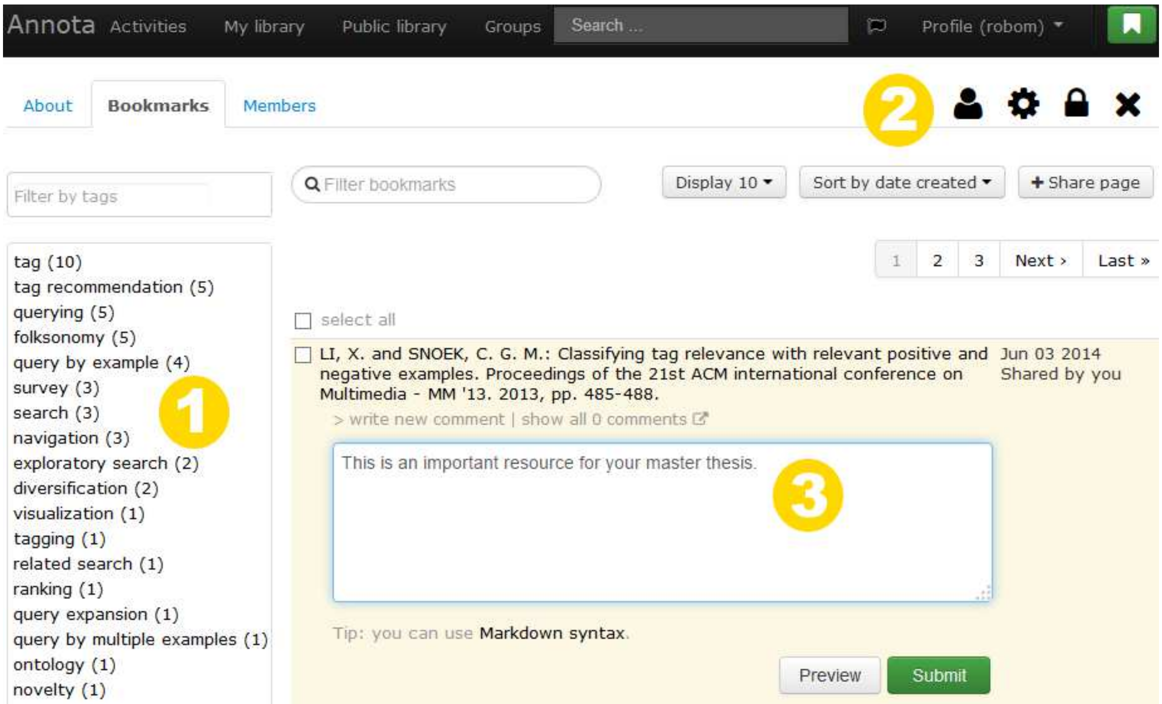

Figure 2: *Annota* web interface – users can organise and retrieve their resources using tags (1). They can create and manage groups (2), in which they can share and discuss their bookmarks with their colleagues (3).

number of citations of an article, the performance of our method increases; the difference proved to be statistically significant using χ^2 test statistic.

3.2 Selection of Navigation Leads

The step of navigation leads selection can be viewed as assessment of the navigational value of the navigation lead candidates identified in the previous step that is combined with their document relevance in order to select terms the most suitable for navigation. In our work, we examined multiple aspects for assessment of the navigational value of the candidate terms:

- *User context* – there are many types of user context that are relevant for search, such as temporal context, context of activity, or social context. We focused mainly on the context of activity in the form of previous user queries, i.e., their search history, which can partially model short or long term interests of users.
- *Corpus relevance* – the existing approaches, such as tag navigation, use term frequency and co-occurrence as a function of their navigational value. We utilise the structure of the information space (underlying topics and clusters of documents) and assess, how the navigation lead candidates reflect the information subspace that is covered by them.

3.2.1 Employing History of User Navigation

We proposed to employ—besides the document relevance of the terms—users' *query history* in a specific period of time in the process of selection of view navigation leads from navigation lead candidates. The terms added from navigation history reflect the various paths foot-worn by the users seeking for information and can, therefore, help researcher novices to find new topics to explore. This is especially useful for the exploratory search scenario, because it helps users to discover and explore what other users had been looking for. The history records from a specific period of time are used for adapting the content of a cloud according to the user query.

We conducted a live experiment in *Annota* with 17 participants that lasted for one week, thus addressing our second research question. In total, the participants con-

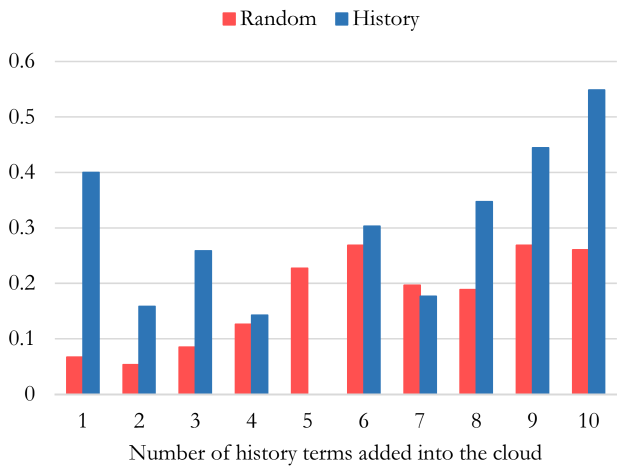

Figure 3: Selection of terms added from history into the cloud (denoted *History*) and probability of their selection (denoted *Random*) w.r.t. the number of history terms in the cloud.

Table 1: An example of two identified topics (top 5 terms for each topic) for *Annota* dataset used in our evaluation. We used 10 as a total number of topics in our experiment (based on the 10-fold cross-validation).

Topic #1	Topic #2
ontology	social
annotation	site
metadata	navigation
service	recommendation
RDF	collaboration

structed 45 queries consisting overall of 858 navigation steps and 124 terms (65 unique) during the experiment. For the purpose of evaluation, we filtered out those navigation steps that occurred with a cloud with no terms from history present, leaving us with 764 navigation steps.

We compared the frequency of selection of terms from history by users with the probability of history terms selection. We found out that the users selected the terms from history twice as often as they would if they selected terms in the cloud randomly. We also examined the frequency of selection of cloud terms added from the navigation history with respect to the overall number of terms added from history present in the cloud (see Fig. 3). Using a *Wilcoxon signed-rank test*, we found that the users selected terms from history more frequently; thus, they seem valuable for the users when navigating in the information space using view navigation leads.

3.2.2 Employing Navigational Value of Terms

We proposed to utilise a structure of the underlying information space in order to assess the corpus relevance, i.e., the *navigational value* of the terms, thus addressing the third research question. For this purpose, we cluster the information space using LDA (Latent Dirichlet Allocation) [2]. An example of the identified topics and relevant terms from the documents in the *Annota* dataset are shown in Tab 1.

Each identified topic represents a cluster of documents and is in turn represented as a probability distribution of terms. Each document is represented as a probability distribution of topics (meaning that it can belong to multiple clusters). After selecting a navigation lead, only documents from the associated cluster are filtered. However, since a document can belong to multiple clusters, it is possible to explore the surrounding relevant topics as well.

We carried out a synthetic quantitative experiment on the *Annota* dataset, the design of which was inspired by the existing works that examined the similarity of human navigation behaviour and a decentralised search in the information networks [5]. In order to simulate the navigation behaviour, we used various search strategies on a *navigational network*, which we constructed from the documents in the dataset based on the selected navigation leads. When comparing the document relevance and the navigational value, the results of our experiment showed that employing navigational value helps cover more (relevant) documents when conducting the exploratory search and that the computed measure of relevance outperforms the prevalent measure of popularity (corpus frequency).

4. Contributions and Conclusions

Addressing the goals presented in sec 1.1, the main outcomes and contributions of our dissertation are:

- A proposal of a *general model of exploratory search and navigation*, which we extended with our proposed approach of *navigation leads* that serve as navigation starting points and means of query refinement.
- *Method of keywords extraction using citation and co-citation analysis* used in the process of identification of navigation lead candidates. We made a contribution to keywords extraction in demonstrating that using the set of selected citations and co-citations (based on the proposed selection rules) improves the precision of the extracted keywords when compared with the TF-IDF method and is capable of finding new keywords that would not have been otherwise extracted.
- *Method of navigation leads selection* focusing on the problem of assessment of their navigational value that would convey their information scent. We made a contribution in navigational value assessment for exploratory search and navigation by considering *navigation history* of the users and the *corpus relevance* of the candidate terms employing the topic clustering. We showed in a quantitative user study that view navigation leads selected from the navigation history were valuable for the users, since they were selected more frequently than other terms. In a quantitative synthetic experiment aimed at evaluating the corpus relevance, we showed that taking corpus relevance into account during the document navigation leads selection improves the coverage of the (relevant) documents in the domain, which can lead to its better understanding by the users.

A significant amount of work on the dissertation was devoted to development and maintenance of *Annota*. We designed its A/B testing functionality turning *Annota* into an evaluation platform capable of testing various scenarios and methods on different groups of *Annota* users based on their activity within the system. We also extended its core functionality; all this allowed us to collect data from more users and in a better quality. Thus, *Annota* as an evaluation platform and its related dataset that was collected over four years of its use, can be considered a partial outcome of this work and have potential to be used for evaluation also in the future works.

Acknowledgements. This work was partially supported by the Slovak Research and Development Agency under the contracts No. APVV-0208-10 and APVV-15-0508, by the Scientific Grant Agency of The Slovak Republic, grants No. VG 1/0675/11 and VG 1/0971/11, and by the Cultural and Educational Grant Agency of the Slovak Republic, grant No. KEGA 009STU-4/2014.

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