How to Search the Internet Archive Without Indexing It

Nattiya Kanhabua¹, Philipp Kemkes², Wolfgang Nejdl²
Tu Ngoc Nguyen², Felipe Reis², Nam Khanh Tran²

¹ Department of Computer Science, Aalborg University, Denmark
² L3S Research Center / Leibniz Universität Hannover, Germany

Abstract. Significant parts of cultural heritage are produced on the web during the last decades. While easy accessibility to the current web is a good baseline, optimal access to the past web faces several challenges. This includes dealing with large-scale web archive collections and lacking of usage logs that contain implicit human feedback most relevant for today’s web search. In this paper, we propose an entity-oriented search system to support retrieval and analytics on the Internet Archive. We use Bing to retrieve a ranked list of results from the current web. In addition, we link retrieved results to the WayBack Machine; thus allowing keyword search on the Internet Archive without processing and indexing its raw archived content. Our search system complements existing web archive search tools through a user-friendly interface, which comes close to the functionalities of modern web search engines (e.g., keyword search, query auto-completion and related query suggestion), and provides a great benefit of taking user feedback on the current web into account also for web archive search. Through extensive experiments, we conduct quantitative and qualitative analyses in order to provide insights that enable further research on and practical applications of web archives.

1 Introduction

Traditional institutions, e.g., national libraries, keep our cultural heritage and need to be complemented with facilities for preservation and public access to online cultural assets. This is critical given that even for the presumably interesting resources shared through social media like Twitter were estimated that 27% of those are lost and not archived after 2½ years [8]. National and international initiatives have recognized this need and started to collect and preserve parts of the web. The Internet Archive has by far the largest web archive collection among the institutions active in web preservation, where it has collected more than 2.5 Petabyte of web content since 1996. Another important European initiative is the Internet Memory Foundation, active in several EU-funded research projects on web archiving, with a set of smaller crawls for specific topics, domains and projects. Two important national libraries engaged in web preservation are the British Library and the German National Library, with the aim to preserve their national web content.

Easy access to historical web information becomes more and more important as the means for accessing and exploring these archives, but the current facilities are severely underdeveloped [1][3]. None of the archive initiatives is able to provide their collections through an interface, which comes close to the functionalities we see on today’s web search engines. The Wayback Machine[3] provides the ability to retrieve and access web
pages stored in the Internet Archive. However, it requires users to represent their information needs by specifying the URLs of web pages to be retrieved; thus demanding a lot of manual effort compared to the current web search engines, such as, Google, Yahoo! and Bing. Clearly, a simple, yet effective search interface is needed to retrieve information, which is stored in the Internet Archive and other web archive collections.

![Fig. 1: URLs in blue areas are long-term relevant; URLs in the red area are short-term relevant.](image)

One major problem with web archive search is an absence of query logs. Without search logs in web archives, it is difficult to understand users’ information needs and thus not able to provide a good ranking of search results without bias. Consider the top search results of the entity Angela Merkel in Fig. 1 which was retrieved from Bing on August 20, 2015. Top search results for a popular entity like the German politician consist of both long-term relevant pages, e.g., the Wikipedia page or bibliography pages in news websites, and short-term relevant pages, i.e., news articles about the entity. It can be seen that no news articles aged over one day appear in the top results, the rest of the search results are long-term relevant web pages associated with static URLs (those that are unchanged over a long time period).

To compensate this shortcoming, we built a prototype archive search system on top of Bing, which already provides a good mix of long-term and short-term relevant results. Our assumption is that, on the current web search, there are certain types of query intents that are similar to information needs on web archive search. In particular, we are interested in supporting web archive searches for named entity queries, which represent a significant fraction of current web search queries [5,11].

The goal of this work is to provide a scalable and responsive search system that supports entity-oriented search on web archives. We propose a novel web archive search system that leverages a current web search engine and the Internet Archive. Relying on commercial web search engine technologies for accessing web archives help us to achieve good quality ranking results (with high precision) based on search sessions and implicit human feedback. While providing entity-based indexing of web archives is crucial, we do not address the indexing issue in this work, but instead extend the WayBack Machine API in order to retrieve archived content.

For the best of our knowledge, we are the first to provide entity-oriented search on the Internet Archive, as the basis for a new kind of access to web archives, with the following contributions: (1) We propose a novel web archive search system that supports entity-based queries and multilingual search. (2) We make our search system publicly accessible for enabling further research on and practical applications for web archives. (3) Through extensive experiments, we conduct qualitative and quantitative studies and provide detailed analysis on the results returned through our web archive search system. (4) Finally, we outline the next steps towards more advanced retrieval and exploration of web archive content.
The organization of the rest of the paper is as follows. In Section 2, we provide a discussion of related work. In Section 3, we present our problem statement. In Section 4, we describe our proposed web archive search and the underlying methodology. In Section 5, we present the evaluation of our proposed approaches and discuss the experimental results. Finally, we conclude our work in Section 6.

2 Related Work

The Internet Archive is a non-profit organization with the goal of preserving digital document collections as cultural heritage and making them freely accessible online. Another important European initiative is the Internet Memory Foundation, active in several EU funded research projects on web archiving. Two important national libraries engaged in web preservation are the British Library and the German National Library, with the aim to preserve national web content. Despite an enormous amount of information is stored in web archives, there are a few search prototypes to provide access to these archives, but all come with a number of limitations [2]. In 2009, the Internet Archive ran a pilot in providing full-text searchability for parts of their archive, making the first five years of their web archive (1996-2000) available for searching. However, the search ranking mechanisms available at that time were not adequate, and the search results were full of spam; thus limiting users from advanced search and exploration of archived content.

The Wayback Machine, a web archive access tool developed by the Internet Archive, provides the ability to retrieve and access web pages stored in a web archive, but it requires a user to access data by specifying the URL of a web page to be retrieved. For example, given the query URL [http://www.usa.gov](http://www.usa.gov), search results are displayed in a calendar view showing the number of times the URL was crawled (not how many times it was actually updated). To date, it is not possible to search by keywords. Similarly, the Memento project [4] provides access to previous versions of a web page existed at some dates in the past, by entering the web page’s URL, and by specifying the desired date in a browser plug-in. In this manner, Memento makes archived content discoverable via the original URL that the searcher already knew about, and redirecting the user to the archive, which hosts the page at the time indicated by the user. Archive-IT [5] is a web archiving service for collecting and accessing cultural heritage sites on the web, built by the Internet Archive. The service supports organizations to harvest, build, and preserve collections of digital content, as well as full-text search on the archived collections. Nevertheless, this search functionality is only limited to a set of smaller crawls for specific topics, domains and projects.

In the context of searching web archives, Nguyen et al. [7] proposed an approach to discovering important documents along the time-span of the web archives by combining relevance, temporal authority, diversity and time in a unified ranking framework. Singh et al. [9] proposed a novel algorithm, HistDiv, that explicitly models the aspects and important time windows for supporting historical search intent. For an application of web archives, Tran et al. [10] studied a timeline summarization of an entity served as important memory cues in a retrospective event exploration.

---

[2] http://timetravel.mementoweb.org
[4] http://timetravel.mementoweb.org
[5] https://archive-it.org
3 Problem Statement

**Information needs.** Entity queries, e.g., person, organization and location, comprise a significant fraction in web search logs [5,11]. Due to a lack of web archive search logs, we assume similar search behavior, i.e., information needs are either (1) exploring entity-related information, or (2) seeking a specific event in which entities involve. We allow users to search archives using entity queries that exist in Wikipedia for both English and German. To enhance query formulation, we provide two techniques, namely, auto-completion and related-entity suggestion. Finally, we also determine the categories for a given entity, by using a heuristic approach [4] for a further analysis.

**Search results.** In our context, we define two main types of relevant results for entity queries: (1) general or static pages about the entity that do not change much over time (which are relevant over a long period of time), so-called *long-term relevant* and (2) dynamic pages such as news articles or blogs (which are only relevant for a short-time period), denoted *short-term relevant*.

**Ranking method.** In this work, we aim at providing high precision search results, rather than optimizing recall. In order to achieve our goal, we build on the ranking of search results provided by Bing, given that the current web search engines already try to provide a suitable mix of long-term and short-term relevant pages, while taking a lot of user feedback into account. Although we assume Bing returns relevant results, we still need to investigate search results for different kinds of entities in a principled way.

**Result coverage.** Coverage of results returned by Bing is concerned about how many of these results are archived on the Internet Archive. We hypothesize that many of these general pages about the entity are archived already, while news or recent pages are not be indexed yet. In fact, important news sites or domains themselves should all be archived. Another aspect to be addressed is the *temporal dynamics* of search results. We assume that the top-ranked results returned by Bing at different time points and rate of their changes vary by entity categories. Finally, we will analyze result variations over time in order to gain more insight.

4 Our Approach

The huge size of web archives has not only created great challenges for indexing them, but also increased the difficulty for users to express their information needs. More precisely, it is not easy for users to compose a succinct and precise query because of the temporal dimension. Our archive search system provides keyword-based search functionalities, similar to existing web search engines. Users can issue an entity-based query for any entity described in Wikipedia in English and German. The system returns a ranked list of search results, which provides links to both the current page on the web, as well as the archived versions in the Internet Archive, using blue and green links. Blue link refers to the current page on the web. Green link refers to the archived versions in the Internet Archive. Our system is publicly accessible [6] Fig. 2 shows the overview of our system framework and a search user interface. In the following, we will describe the proposed approach underlying different components, which comprise query auto-completion, Bing search API, archive linking, caching, and related entity suggestion.

[6] http://alexandria-project.eu/archivesearch/
4.1 Query Auto-Completion

We support the query formulation process using query auto-completion. When a user types a query, we suggest a short list of relevant entities in order to help the user complete his/her information needs. We use a Wikipedia entity index comprised of all Wikipedia entities and store it in a trie data structure to allow fast prefix lookup. Additionally, we split all entities at white and special characters. All strings starting at each token are added to the trie as an additional reference to the original entity. Furthermore, we also take into account simplified versions of all tokens which contained letters with accents in our index. This allows our application to suggest entities even if the user does not know the exact name or cannot type the name in a foreign alphabet. As an example, for the query “schroder” we would suggest the former German chancellor “Gerhard Schröder”. We further rank the suggested query completions by their popularity using the cumulative page views (see the detailed description below). To penalize the time-sensitive popularity of the entities, the daily page views are accumulated over a long period. Finally, the entity selected by the user is sent as input to the search API.

Wikipedia page views are statistics consisting of the number of times a particular Wikipedia page has been requested over time. In Wikipedia, the view counts for pages that redirect to a given page are not combined with page views of the page being redirected to. In this work, we aggregate all these related views to present the popularity (reflected by the page views) of an entity query for all its query variants. We computed the aggregated statistics of page views approximately a period of 4 years (2011 to 2015).

4.2 Bing Search API, Archive Linking and Result Caching

Bing is Microsoft’s search engine providing access to their current web index through a RESTful API available at the Azure Marketplace. Bing returns results in XML or JSON data formats and offers two different API endpoints: (1) the full featured Bing Search API, and (2) the restricted and less expensive Bing Search API - web Results Only. The later lacks of few meta data like the overall result count. Nevertheless, it provides
all basic search result information, such as URL, title and a text snippet. By specifying parameters, we can request optimized results for different languages/countries. We therefore use the endpoint with web results only. Yahoo! and Google provide similar search APIs but at higher costs with more restriction.

After obtaining search results from the Bing search API, we link the ranked list of results to the WayBack Machine to support browsing through the archived versions of web pages. The WayBack Machine is a tool provided by the Internet Archive that allows access to its web archives by specifying a URL. The URL-based access can be programmatically used through an API provided by the Internet Archive. For a given URL it returns a list of all dates when the URL has been archived. When a URL has been archived many times in the past, retrieval can take very long time. Therefore, we use two requests to retrieve only the first and last capture dates to display the time span at which the web pages has been archived. When the temporal intent of the user is provided, we narrow down to return only the revisions around the interested time point.

To avoid recurring requests to the Bing and WayBack Machine APIs, we store the search results locally in our cache, using a simple relational database. In order to take into account the fact that search results change over time, we update search results monthly to keep our cache up-to-date and to track changes at both sources. Besides the queries entered by our users, we use also the 10,000 most viewed English Wikipedia entities as queries. As a side effect, this procedure results in building a corpus of past search results, which will support promising, longitudinal studies of web archive search, investigating how results change over time, triggered by events or changing user behavior. In Section 5 we will analyze the cache in order to reveal several important aspects, e.g., how long a web page stays relevant and when it fades away from top-ranked results. This insight will help improving the next version of our web archive search prototype.

4.3 Related Entity Suggestion

A traditional web search engine supports exploration by suggesting related queries, which is based on analyzing search sessions and identifying the co-occurrences of the issued query. For web archive search, we do not have query logs for obtaining search sessions, thus we leverage a dump of Wikipedia articles and build an entity graph in order to find related queries for our entity-oriented search. We follow the approach to determining the link-based entity relatedness originally proposed in [6]. Relatedness between two entities \(e_1\) and \(e_2\) is measured based on the overlap between the set of Wikipedia articles that link to \(e_1\) and the set of articles that link to \(e_2\).

\[
\text{relatedness}(e_1, e_2) = \frac{\log(\max(|S_1|, |S_2|)) - \log(|S_1 \cap S_2|)}{\log(|W|) - \log(\min(|S_1|, |S_2|))}
\]

where \(S_i\) is the set of articles that links to entity \(e_i\), and \(W\) is the set of all articles in Wikipedia. Our entity graph is constructed from a recent Wikipedia dump (downloaded from September 2015 for both English and German Wikipedia), with the assumption that the link-based relationships between a pair of two entities can be accumulated; thus relaxing time sensitivity (in this case, the relatedness does not bias to any time point). An interesting extension will be to take time dependent relationships into account, which is planned for the next version of our system.
4.4 Multilingualisms
The described components are designed to support different languages. Dependent on the language selected by the user, we use the corresponding Wikipedia version to generate the query auto-completion and the related entities suggestions. More importantly, we request search results from Bing, which are optimized for the selected language and region. Furthermore, we leverage Wikipedia inter-language links when a user changes the front-end language. For example: When an English user searched the term “climate change” and switches to German, he will be redirected to “Klimawandel”. Currently, we support English and German, but will add additional languages in the future.

5 Experiments
We conducted extensive experiments in order to gain insight into our assumptions presented in Section 4. We seek to answer two main research questions as follows.

RQ1. What is the coverage of archived content retrieved by the current search engine?
RQ2. To what extent the search results change over time, and why they change?

In the following, we will divide our experimental results into two main parts, where we describe our quantitative and qualitative analyses for each of the aforementioned research questions.

Part I: Analysis Results for RQ1. Our system relies on the assumption that many pages returned as search results for entity queries are archived by the Internet Archive. To check this assumption, we took all English Wikipedia entities sorted by their view count and selected buckets of 1,000 entities at different positions in this list to represent entities from different popularity categories. We started with the 1,000 most viewed entities and continued with the entities from position 50,001 to 51,000 and so on. For each entity in an individual bucket, a search query was conducted and we checked how many results on the first five pages (10 results per page) were archived by the Internet Archive. Table 1 and Fig. 3 show the average results per page and bucket.

The results of popular entities (rank: 1 - 1000) show a very high coverage with the Internet Archive. On page one, 94% of the results are archived. On pages two to five, still 87% to 89% are available at the Internet Archive. Overall the coverage declines for less popular entities. Interestingly, it drops faster for the first pages of the search results than for the posterior ones. Upon inspection, this seems to be caused by the fact that Bing ranks recent results higher (for example on the first page of its search results), while the Internet Archive needs much more time to archive less popular pages.

To gain more insight, we conducted a coverage study by entity categories. More precisely, we analyzed top-100 search results for 300 popular entities from 14 different categories, for example, actor, journalist, painter, and politician, where there are approximately 20 entities per category. In this study, we only considered search results with .DE domains (German web pages), and checked the coverage with our local German web archive, instead of web archives of the Internet Archive. As shown in Fig. 4, the coverage statistics on the German web archive shows significantly lower results than the one based on comparison with the Internet Archive due to search result bias towards English web pages, in general, even for the German version of Bing. It can be observed
Table 1: Coverage (percentage) of archived content at different top-k results over entities ranked by their popularity.

| Entity rank          | Top 10 | Top 20 | Top 30 | Top 40 | Top 50 |
|----------------------|--------|--------|--------|--------|--------|
| 1-1000               | 94%    | 91%    | 91%    | 90%    | 89%    |
| 50001 - 51000        | 85%    | 81%    | 79%    | 78%    | 77%    |
| 100001 - 101000      | 81%    | 76%    | 74%    | 72%    | 71%    |
| 150001 - 151000      | 79%    | 73%    | 71%    | 69%    | 68%    |
| 200001 - 201000      | 77%    | 70%    | 67%    | 65%    | 64%    |
| 250001 - 251000      | 74%    | 68%    | 66%    | 64%    | 63%    |
| 300001 - 301000      | 74%    | 68%    | 65%    | 63%    | 61%    |
| 350001 - 351000      | 73%    | 67%    | 64%    | 62%    | 60%    |
| 400001 - 401000      | 73%    | 65%    | 62%    | 60%    | 59%    |
| 450001 - 451000      | 71%    | 65%    | 62%    | 60%    | 59%    |
| 500001 - 501000      | 70%    | 63%    | 60%    | 58%    | 57%    |
| 600001 - 601000      | 67%    | 61%    | 58%    | 56%    | 55%    |
| 700001 - 701000      | 66%    | 58%    | 56%    | 54%    | 53%    |
| 800001 - 801000      | 63%    | 57%    | 54%    | 53%    | 52%    |
| 900001 - 901000      | 63%    | 56%    | 53%    | 51%    | 51%    |
| 100001 - 1001000     | 59%    | 53%    | 51%    | 50%    | 49%    |
| 150001 - 1501000     | 54%    | 48%    | 46%    | 46%    | 45%    |
| 200001 - 2001000     | 48%    | 44%    | 43%    | 43%    | 42%    |
| 250001 - 2501000     | 43%    | 41%    | 40%    | 40%    | 41%    |
| 300001 - 3001000     | 36%    | 36%    | 36%    | 37%    | 38%    |
| 350001 - 3501000     | 32%    | 33%    | 34%    | 35%    | 36%    |
| 400001 - 4001000     | 29%    | 30%    | 31%    | 31%    | 31%    |

Fig. 3: Coverage (percentage) of archived content at different top-k results over entities ranked by their popularity.

that categories with lower coverage tend to associate with recent and dynamic web content, whereas the results of the categories with higher coverage are rather static and less changed. Note that, result URLs are not always archived (e.g., for newspaper articles), but nearly all domains (i.e., news sites) are archived, regardless of entity categories.

We also performed search result annotation of 9 entities that were manually selected. We employed 5 human annotators to label top-100 search .DE results (by filtering out non .DE domains). For each (query, URL) pair, we asked at least 4 assessors to give a label based on relevance assessment criteria consisting of three scales: long-term relevant, short-term relevant and unknown. The results are shown in Table 2 where we can notice that non-active entities, such as, Pablo Picasso and Ernest Hemingway, have more long-term relevant results than active entities like Elon Musk and Leonard Nimoy (to be expected).
Table 2: Percentage of long-term relevant and short-term relevant pages in top-100 results (filtered out non .DE domains).

| Entity                   | Category | Long-term | Short-term |
|--------------------------|----------|-----------|------------|
| Leonard Nimoy            | Actor    | 52.00%    | 48.00%     |
| Elon Musk                | Business people | 37.50%    | 62.50%     |
| Costa Concordia灾难     | Incidents | 52.40%    | 47.60%     |
| Ernest Hemingway         | Journalist | 81.48%    | 18.52%     |
| Giuliana Rancic          | Journalist | 40.00%    | 60.00%     |
| Pablo Picasso            | Painter   | 97.60%    | 2.40%      |
| Banksy                   | Painter   | 48.10%    | 51.20%     |
| Vietnam                  | Politics  | 100.00%   | 0%         |
| Ku Klux Klan             | Politics  | 12.50%    | 87.50%     |

Fig. 4: Coverage (percentage) of archived URLs and domains at top-100 results for different entity categories.

In the following, we provide analyses for two selected entities in order to better understand the coverage aspect of search results and web archives.

**Lady Gaga (view count rank: 108; views: 9,453,966; querying date: 19.01.2016)** Lady Gaga is a famous American artist. Her Bing top-50 results have almost complete coverage on the Internet Archive. More specifically, 98% of the results are archived. Among the results, only one URL is not archived. This URL points to a gossip news article inside the entertainment section of the New York Daily News web site that only mentions the entity in question. As the entity is not the core mention, the article has relatively low relevance. We checked again on January 25, 2016, and the URL was still not archived. The URL was published online on January 18, 2016. Thus, we interpret that low relevance news are unlikely to be archived.

**Battle of Rathmines (view count rank: 1,000,798; views: 8,723; querying date: 18.01.2016)** The Battle of Rathmines was fought in the area what is now the Dublin suburb of Rathmines in August 1649, during the Irish Confederate Wars, the Irish theatre of the Wars of the Three Kingdoms. The number of page views for this entity is 8,723, which is not very popular.

8 [http://www.nydailynews.com/entertainment/gossip/linda-perry-slams-lady-gaga-article-1.2500319]
Nevertheless, about 56% of the top-50 Bing results are archived. Among the other 44% of results, which are not archived, is the (4th ranked) page from a website that shows information from Wikipedia, and the (48th ranked) page that is a blog post. This entity is related to a real event in Ireland history that took place in almost 500 years ago, but is very local and rather unimportant outside of Ireland.

Part II: Analysis Results for RQ2. In this section, we present the analysis of Bing results for entity-based queries executed in three time periods: June 2015, August 2015 and January 2016. For a given entity, we computed the overlap between the top-ranked results at different time periods. Through this, we gain insight into our question RQ2, on how Bing query results change over time. We conducted a study on 300 popular queries of 14 different categories as explained in RQ1. We discuss a few samples ranging from low to high overlapping rates.

Fig. 5 illustrates the change of search results (as measured by the overlap statistics) over time for different entity categories over the period of 2, 5 and 7 months, respectively. In general, result change after 2 months results in approximately 47% of the top-100 URLs not returned any more. After 7 months, result change increases to 60%. Across different categories, there is not much difference in temporal dynamics for the search results. The Actor category varies most, whereas the result variation is least for Philosopher. The main explanation here is that the entities in our Actor category are more active than entities in the Philosopher category, thus having more short-term relevant web pages in the top-100 result list, which change over time. We observe in Fig. 6 that the overlap in the top-50 results is slightly higher than in the top-100 results. This indicates there is less result change in the first 50 results than in the next 50 results. However, the difference is not significant.

9 http://www.thefullwiki.org/Battle_of_Rathmines
10 http://irelandinhistory.blogspot.de/2014/08/blog-post_11.html
Entity: Barack Obama  For the President of the United States 47.5% of the results from August overlap with the results retrieved in June. These shared results are URLs pointing to biography or permanent pages, and most of them appear in high ranks. The remaining 52.5% are URLs mostly to news or categories inside news web portals, which change over time. The overlapping of search results in this context decreases proportional to the number of recent events related to the entity: the higher the proportion of news results, the lower the overall overlapping with future result sets.

Entity: Donald Trump  For Donald Trump, more than 80% of the URLs are news (National Journal, newsobserver.com, NBC). Most of these news articles published in June and do not overlap in August and January. Our data analysis in this experiment shows that the URLs from the news category, which is listed in results from June will probably not be shown in August or January. Total overlap average is 24%, which is very low. Even for the shorter periods, June to August, and August to January, a result overlap is low with 30%. Search results for Trump are a very clear sample for fast changing results, caused by frequent news articles.

6 Discussion and Conclusion

Although the system described in this paper already provides interesting functionalities, it is obviously still work in progress. As one important extension of functionality, we are working on more complex types of entity-based queries in order to support exploratory search, e.g., giving a main entity Donald Trump and related search intents. The search intent can consist of an entity, such as, Hillary Clinton aiming to find all events, which involve these two entities, and a specific time period such as 2015-2016 narrowing down search results to a specific time period, or any contextual query, such as a concept presidential campaign.

Another important aspect for our future development is to advance our ranking. As our current method is relying on the Bing search API, we sacrifice recall. Learning from Bing over time as well as from our user logs, we will be able to provide more sophisticated ranking taking different features into account. Bing results can act as ‘soft’ ground truth for learning the model. Our ranking model will then be able to return relevant documents, which are not longer available on the current Web.

Finally, we also work on improving our suggestion components, i.e., related entity suggestion to deal with queries having time as another aspect (e.g., Obama 2008). In the current system, we exploited a state-of-the-art method to suggest related entities to the query entity, with the assumption that their relationship strengths are accumulated over time. This relationship measure is reasonable to serve for queries with arbitrary relevant time. However, in reality relationships between entities do change over time, typically triggered by events. We can therefore return different related entities for different time periods to the input entity. For instance, the entities mostly related to Hillary Clinton in 2008 should differ from those in 2012, because of her different political positions. Moreover, with an exploratory query for example Donald Trump and search intent Hillary Clinton, it is more helpful to recommend the entities which are related to both Donald Trump and Hillary Clinton.
To summarize, we discussed a web archive search prototype that for the first time supports entity-oriented queries on the Internet Archive. Our system leverages Bing and the WayBack Machine to allow users to search the past Web. We provided search functionalities including keyword search, query auto-completion, query suggestion, and a ranked list of results, which are close to the current search engine systems. We conducted extensive analyses that shed light on web archive search, and included a discussion of future work as well as ideas/challenges for the next steps.

Acknowledgments
This work was partially funded by the European Commission for the ERC Advanced Grant ALEXANDRIA under the grant number 339233.

References
1. M. Costa, D. Gomes, F. Couto, and M. Silva. A survey of web archive search architectures. In Proceedings of the 22nd International Conference on World Wide Web (Companion), WWW ’13, pages 1045–1050, 2013.
2. M. Dougherty and C. van den Heuvel. Historical infrastructures for web archiving: Annotation of ephemeral collections for researchers and cultural heritage institutions. In Proceedings of Media in Transition MIT6 Conference 2009, 2009.
3. D. Gomes, J. a. Miranda, and M. Costa. A survey on web archiving initiatives. In Proceedings of the 15th International Conference on Theory and Practice of Digital Libraries: Research and Advanced Technology for Digital Libraries, TPDL’11, pages 408–420, 2011.
4. N. Kanhabua and K. Norvåg. Exploiting time-based synonyms in searching document archives. In Proceedings of the 10th Annual Joint Conference on Digital Libraries, JCDL ’10, pages 79–88, 2010.
5. I. Miliaraki, R. Blanco, and M. Lalmas. From ”selena gomez” to ”marlon brando”: Understanding explorative entity search. In Proceedings of the 24th International Conference on World Wide Web, WWW ’15, pages 765–775, 2015.
6. D. Milne and I. H. Witten. Learning to link with Wikipedia. In Proceedings of the 17th ACM conference on Information and knowledge management, pages 509–518, 2008.
7. T. N. Nguyen, N. Kanhabua, C. Niederée, and X. Zhu. A time-aware random walk model for finding important documents in web archives. In Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR ’15, pages 915–918, 2015.
8. H. M. SalahEldeen and M. L. Nelson. Losing my revolution: how many resources shared on social media have been lost? In Proceedings of the 2nd International Conference on Theory and Practice of Digital Libraries, pages 125–137, 2012.
9. J. Singh, W. Nejdl, and A. Anand. History by diversity: Helping historians search news archives. In Proceedings of the 2016 ACM on Conference on Human Information Interaction and Retrieval, CHIIR ’16, pages 183–192, 2016.
10. T. A. Tran, C. Niederée, N. Kanhabua, U. Gadiraju, and A. Anand. Balancing novelty and salience: Adaptive learning to rank entities for timeline summarization of high-impact events. In Proceedings of the 24th ACM International on Conference on Information and Knowledge Management, CIKM ’15, pages 1201–1210, 2015.
11. X. Yin and S. Shah. Building taxonomy of web search intents for name entity queries. In Proceedings of the 19th International Conference on World Wide Web, WWW ’10, pages 1001–1010, 2010.