Scholarly Engagement of Web Archives and Historical Search

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Abstract

In this thesis, we tackle the issue of scholarly access to web archives. Through a combination of surveys and user studies we identified problems faced by scholars when utilizing web archives for their research. A major concern is the performance of keyword search algorithms which do not take into account a scholar's information intent which we identify as historical in nature, i.e, the user is interested in the development of a topic over time. Keyword queries with an inherent historical intent over longitudinal text corpora are interesting for a variety of special user groups like historians, social scientists and journalists. While searching articles published over time, a key preference is to retrieve documents which are from the important aspects from important points in time. To this extent, we introduce the notion of a *Historical Query Intent* and define an aspect-time diversification problem over news archives. We also propose a new metric Tia-Sbr to evaluate the effectiveness of methods intending to solve it.

We present a novel algorithm, HistDiv, that explicitly models the aspects and important time windows to which the results of the query belong. We test our methods by constructing a test collection based on *The New York Times Collection* with a workload of 30 queries assessed manually. Our experiments show that we outperform all the competitors in most of the measures, and remain competitive in a select few.

Contents

1 Introduction

The web today encompasses almost all walks of life. It is the medium of choice to share and access information rapidly. Every major organisation and government has an online presence. Individuals also possess strong online auras thanks to blogs and social networks. Newspapers in print are slowly losing out to their online counterparts. All major newspapers now have an online portal where they publish their stories. Major events are being covered with live blogs and social netowrks as well. The web also promotes discourse and debate through social media. Organizations and companies use their web presence to promote and deliver news to their customers. Even our shopping has moved online.

All of the information on the web serves as valuable documentation for human society so it is natural for us to want to preserve it. Just like the digitization of old books and newspapers to preserve them for longer, society and scholars in particular are interested in preserving the web [47]. Newspapers have a long history of being maintained in archives for future reference. *The New York Times* like many other leading publications maintain their archives on the web as well.

Since the mid 1990s the Internet Archive begun to preserve the web. Today, to deal with the explosion in growth of the web, the Internet Archive is joined by several national libraries and institutions. With the growing importance of the web to society, researchers from sociology, politics and history have started to delve into web archives to study human society and the web itself. Web archives present many opportunities for various kinds of historical analyses [53], cultural analyses [55], and analytics for computational journalism [21]. Researchers can retrospectively analyze the web and study the development of trends [37] or the web at a certain time. Many studies of social phenomena on the web to date have been based on observations conducted at a single point in time (the present), or during a more extended period but without explicit consideration of the possibility of changes during that period. Web archives expand the scope of potential research by enabling developmental analyses of web and certain real world phenomenon as it changes over time by tracking changes in web objects between cycles of capture in the archiving process.

For scholars of any field to study web archives they need to construct corpora specific to their study [42] and to do that they need to be able to access data in the archive effectively. The Internet Archive provides a look up service called the wayback machine[9] which allows the user to enter a URL and see the various versions of the URL over time. He can also surf the web at that time using the hyperlinks. This however is an inferior access method when compared to keyword search which overtook surfing as the dominant way of accessing the web a decade ago. However based on user studies conducted with the Portugese Web Archive [5], it was found that the state of the art search techniques applied on the web are not satisfactory for web archive search [22].

Through a series of discussions with scholars using web archive search systems we found that in particular the ranking of documents is not helpful. Scholars are interested in studying phenomena as they develop across time; more specifically, they are interested in the history of a topic. History implies that scholars would like to study documents cover different aspects of the topic from important time periods. For any longitudinal collection, like archives in general, with standard retrieval models users are not guaranteed to get documents from across time and also covering different aspects within a reasonable top k documents. And for scholars who pay very close attention to every document in the result set they may have to go through the entire search result set which, after filtering, can be over a few thousand at least to find what they are looking for. Instead, if users are presented with documents that cover important historical aspects at the top of the result list, they can quickly get a grasp of the important time intervals and aspects of their topic. From here they can choose a number of ways to reformulate their query if need be to unearth details about a particular time window or aspect.

In our work we attempt to answer the historical search intent of scholars over a longitudinal collection. We conduct our experiments on news archives because newspaper articles encode history as it happens by capturing events and their immediate impact on society, politics, business and other important spheres. These are of immense value to historians, sociologists, and journalists who rely on a fairly reliable, accurate and time-aligned information sources. Consequently, numerous news archives like [3, 2, 6] have gained prominence consisting not only of digitally born content but digitized content from the distant past and can be considered as a subset of the overarching web archive. Query models and indexing methods based on keyword search and time filtering [13, 11] have been proposed which are a natural access methods to discover and explore content in such archives. However the support for advanced retrieval models which encode historical intents is limited.

The classical diversification approaches like [16, 49, 10, 17, 25] which are optimized for the more traditional query intent do not take time into account. As a result, documents retrieved might still cover a good number of aspects but might be from the same time period disregarding the temporal salience of the aspect. Also, time-aware approaches which take into account latent topics or aspects like [41] are optimized to present results which are valid at querying time or in other words reward recency. On the other hand Berberich et. al. in [12] diversify based on time without explicitly considering document aspects. Although this ensures that results are temporally distant from each other, as a consequence of the inherent aspect-agnostic nature they still might belong to similar aspects. We on the contrary, explicitly model document aspects and jointly diversify both in the aspect and time dimensions.

In this thesis, we make the following contributions:

- Based on a user study, we identify the problems faced by humanities scholars like historians, sociologists, and journalists when engaging with web archives for their research. In particular, we found that retrieval models currently available are not satisfactory for a scholar's search intent of finding documents to study the past of a topic.
- we introduce the notion of *Historical Query Intents* and model this as a search result diversification task on both the aspect and time dimensions.
- we develop a novel retrieval algorithm called HistDiv which jointly diversifies both dimensions by appropriately discounting the contribution of aspect mass and time. we also propose a evaluation measure called Tia-SBR.
- and finally we establish the effectiveness of our methods by building a test collection based on the 20 years of the *New York Times Collection* as a dataset and a workload of 30 manually judged queries.

The rest of this these is organized as follows: In Chapter 2 we try to understand the research practices of humanities scholars when working with web archives. We also seek to find problems faced by the scholars when accessing web archives using keyword search. Based on our findings we introduce Historical Query Intents(HQIs) in Chapter 3. In the same chapter we also motivate and develop a novel retrieval model suited for HQIs. The experiments to test the performance of this model against its competitors is covered in the same chapter. The penultimate Chapter 4 details the architecture of the system that was built to demonstrate the efficacy of the retrieval models to users. Finally, in Chapter 5 we add some concluding remarks and describe future work.

2 Researcher engagement with Web Archives

2.1 Introduction

A web archive is created using web crawlers. A web crawler is a program that tries to capture a page at a given address at the time of access. A crawler traverses the web by following the links on the pages that it has captured and stops when there are either no more links to be followed based on some condition set by the creators of the crawler. The live web is continuously changing over time so crawlers are made to revisit URLs periodically. Thus the archive consists of multiple snapshots of the web that do not change over time. If the web is envisioned as a large corpus of documents, then a web archive is a corpus of the same documents with multiple versions, each corresponding to the time that they were chosen for archiving. We must realize that there is a limit on how much we can crawl and how often based on the resources available. Given the sheer scale of the web, with today's technology we cannot capture every URL at every time point. Strategies have been set in place for archiving what is most important at a reasonable rate over time [32].

The archived web though has properties quite different from the live web that must be kept in mind when using it. These characteristics according to Brügger in [15] are:

- 'The Archived Web is a Reborn, Unique and Deficient Version and Not Simply a Copy of What was Once Online' - we cannot expect to have an exact replica of what is on the web.
- 'The Broad Web Archive is Multitemporal and Multispatial' - Since a web archive spans a across time, multiple versions of the same URL can be found whereas on the web there is only one version of a URL. Also it is no guarantee that all pages of a website are archived equally over time.
- 'The Web Archive Tends to be Reactive' - Web archives are always a step behind the web due to the rapid adoption of new technological trends on the web. Every time a new type of technology is applied on the web, the archiving process needs time to adjust to it. This means archives will always be out of sync for certain time periods.

Brügger also outlines the potential problems that researchers face when working with web archives like:

- Temporal and spatial inconsistency of material found in the web archive.
- Temporal and spatial inconsistency of hyper links found in the web archive.
- There is no clear archive creation strategy to help researchers describe their corpus.
- To construct a corpus from a web archive you first need to construct a set of URLs
- The lack of meta data and quality checking.

While computer scientists deal with large scale data where these deficiencies have a significantly lesser impact, other scholars working with smaller samples and more complex questions struggle. According to the report on E-research in web archives by Dougherty et. al. [29] the major disadvantage of using web archives for scholarly research is 'lack the depth and precision in data capture that are usually imperative for scholarly datasets'. Also scholars who work with archives are used to having well curated archives to work with. These problems are due to the very nature of the web archive itself and the preservation process which is being studied more closely now to help improve the situation facing scholars.

In spite of such pitfalls, web archive research is a growing field. In the same report by Dougherty, examples are given of significant scholarly works using web archives:

> 'The investigation of the U.S. election processes by studying and archiving Web sites of candidates is a good example of substantive implica tions of Web archiving for social science research (Graubard, 2004). In this study, novel questions about the role of new media in political campaigns could be answered, as well as their implications for the character of political campaigns in the era of the Web. A related study is the Web archive of Dutch political parties maintained at the University of Groningen (Voerman, 2002). In the humanities, the Digital Archive for Chinese Studies (DACHS) focuses on Chinese Web sites in the framework of sinology at the universities of Heidelberg and Leiden (Dougherty, 2007)'

From this point on we take a closer look at how scholars engage with archives when conducting their research. The following sections will cover research methodology on web archives, select studies done on web archives, how researchers engage with web archive systems, case studies of research questions being posed today to web archives and the challenges faced by researchers when trying to answer these questions with current state of the art web archive systems.

2.2 Web Archive research and methodology

There are several research communities interested in web archives and they all share a similar path when conducting their research. A framework for research using web archives was suggested by Niels Brügger during his speech at the IIPC meet in 2014. This framework consists of 4 basic steps:

- Corpus creation: search, select and isolate.
- Analysis: tools and visualisation.
- Dissemination: sharing of shcolarly work.
- Storage: storing evidence corpora of scholarly work.

This framework is quite general and builds on sensemaking models suggested for research on document collections. In 1993, Russel et al. [48] applied the term sensemaking specifically to the process of making sense of a collection of documents. Their model consisted of the following phases: âĂŸcollect dataâĂŹ, âĂŸsearch for representationsâĂŹ and âĂŸinstantiate representationsâĂŹ. Pirolli and Card were one of many researchers to refine this model with more specific steps for the task of 'intelligence analysis'[45]. Scholars first forage the collection to get a sense of the data available and start building a hypothesis. Then they look for instances that represent evidence of their hypothesis and finally present those instances as justifications of the research carried out. In Brügger's model as well the order of steps the user takes is the same, however each step in itself is impacted significantly due to the charactersitics of a web archive as mentioned earlier. In the next section let us look at some relevant studies that have been conducted using web archives. We will look at these studies very specifically from the corpus creation and analysis point of view.

2.3 Characterizing web archive research

When discussing web archive research a distinction must be made between studying the web archive itself and using the web archive to study phenomena. Schneider and Foot in [51] advocate the archive itself as an object of study that can help gain new insights. Brügger in [14] proposes the study of history based on the evolution of the linking structure of the web archive. He also proposes a study of a nation's web sphere, a large linked set of URLs, over time in order to understand the development of the nation and it's web space. Studies like this treat the archive itself as the cause for the study. On the other hand, researchers are also interested in studying how certain phenomenon evolve or have been discussed on the web. In this case the archive is used to find relevant material for the study rather than being the object of the study.

There is interest from a variety of fields including computer science, digital humanities and the more traditional humanities like history, literature and sociology

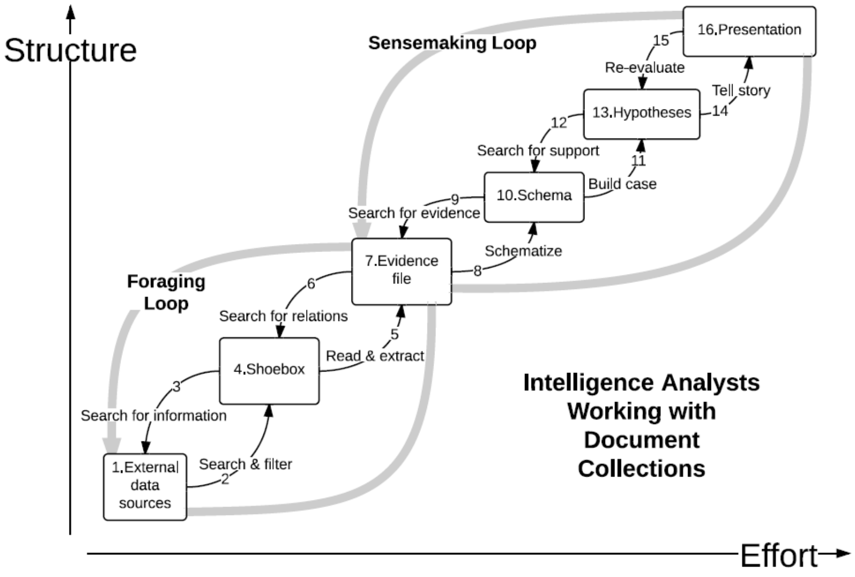


Figure 2.1: Pirolli and Card's sensemaking process for intelligence analysis

to study phenomena from our recent past using web archives. The main difference between digital humanities and the humanities though is the former's use of computational methods to study digitized documents. However the web and the archive are not digitized content; they are born digital and reborn digital respectively. Richard Rogers in [46] advocates the use of digital methods to study the web. Digital methods are a set of practices designed specifically to analyse the web and in turn these can also be applied to web archives. In [34], Huurdeman et. al. show how digital methods can be applied to the Dutch news archive for analysis. As a result of their work they developed a suite of tools that has been incorporate in the WebArtist system at the University of Amsterdam.

A key point to note is that Rogers also advocates the use of digital methods so that scholars can work at a larger scale which allows them overcome some of the flaws of the web archive as alluded to earlier.

Humanities scholars like historians and sociologists however do not tend to use such computational methods.They spend a lot of their effort in carefully constructing a body of evidence for their hypothesis and then manually analyze this corpus for interesting insights. All humanities and social science scholars share a set of activities when conducting research which are: searching for information, gathering and organizing it, skimming and re-reading it in order to gain new knowledge and assess its importance, note-taking, translating, gathering materials for writing, and constructing a final product [42]. This implies that scholars partake in the process of sensemaking and can be accommodated in Brügger's framework for web archive research.

There are also two distinct types of research being carried out with web archive. The first is large scale link analysis. Studies from this domain try to gather insights from the archive by studying how links between pages/ websites/ domains change over time. Links are not readily extractable from web archives though so they need some amount of technical expertise to gather the data. Hence link based studies have generally been carried out by researchers from a more technical background. Internet research institutes and web mining groups in particular are interested in large scale web data and have been responsible from the majority of studies using link analysis. For instance [33] is one of the latest studies based on web archive link analysis from the Oxford Internet Research Institute. In that paper, they draw conclusions from the UK web space by studying the link relationships between domains over a 14 year time period from 1996 to 2010. The outcomes of this study include the growth of domains in terms of URLs over time and also the relationship between domains based on the link density between them. They do not however go into the content of each URL. Many studies involving web archives have focused on the link structure. Foot et. al. [30] studied the linking practices between electoral candidates during the 2002 elections. In [43] the link structure between university pages is studied to draw correlations between research productivity and in-links. Toyoda et. al. [55] go as far as using links between URLs in the Japanese web archive to analyze the evolution of communities on the web.

The second type of research being carried using web archives is the analysis of the content on a given page or set of pages. Here the emphasis is on the page at each URL and not the just the links between pages. Researchers observe a set of web pages to find evidence for their hypothesis rather than writing computer programs to extract evidence.

A closer look Sophie Gebiel, a historian from the Centre d'information et d'études sur les migrations internationales, studied the history of North African immigration memory in France by using a corpus of web pages collected from the French web archive [31]. One of the crucial aspects of her work was the definition of a corpus of study. In large scale studies, the criteria for selecting a corpus are usually rudimentary; like all web pages in a domainsubdomain or all web pages in English. Sophie decided to approach her analysis from both a quantitative and qualitative perspective. Due to the nature of her study, the constraints for selecting a corpus were much stricter. Sophie's work though did not focus on an entire domain but instead on a representative sample, which was selected based on her definition of a relevant corpus, of the whole web archive. Her corpus of study was 70 websites whereas in [33] the corpus was over a few million. The objective of her qualitative study was to understand how memories of North African immigration are portrayed on these websites whereas the quantitative study provided more of a supporting role by providing evidence in the form of network graphs. Qualitative studies such as Sophie's cannot be easily carried out on large corpora which makes the process of selecting a sample very important for her qualitative research.

Another interesting study performed on the content of web archives rather than the link structure was the analysis of google's home page evolution. Rogers in [46] shows that just by studying the home page of google over a 10 year span we can see the decline of the web directory and the rise of web search. They use a time lapse video to show the change in position of the link to the directory from its most prominent position in the early 2000s to its complete disappearance in 2008.

In the rest of this chapter we pay more attention to the second type of research which is content based research. The next section delves into how researchers, who do not have the expertise to write programs to work with web archives, access web archives to construct corpora and analyze these corpora.

2.4 Accessing and analyzing web archives

The most popular way for non-technical users to access web archives at the moment is through the wayback machine interface [9]. A user can enter the URL she is interested in to get a list of versions for that URL over time. Selecting one of the versions leads to the HTML file of the version, which is rendered by the browser for the user. The user can also click on the links of the page to be taken to archived versions of anchor URLs if available. The wayback machine allows the user to surf the past web. In the past, with the advent of search engines, surfing became less commonplace and users searched for particular pages instead.

To search the web archive we need an index. Indexing that amount of data has many challenges to overcome. To avoid the complexity of indexing the world's web archive the IIPC (International Internet Preservation Consortium) indexes small event centric subsets of the web archive instead, like the Socchi Winter Olympics archive [7]. Governments across the world have tasked the national libraries with preserving their nation's web and these institutions are working on creating an index for their nation's web archive. For instance, the British Library is responsible for archiving web pages from the `.co.uk` domain space and for making this archive available to the public. With the help of donations from the Internet Archive, some nations now possess web archives spanning from the early 90s to 2013. There have been successful attempts at indexing web archives like the Portugese web archive [5] and the Dutch web archive [**?**]. They also provide users with keyword search interfaces to access the data. The British Library also provides a search interface to its web archive. Even though this is a big improvement over the wayback machine in terms of access, more fundamental issues exist when accessing and analysing web archives.

2.5 Understanding researcher access requirements

In general, research with web archives consists of 4 steps as mentioned before. However these steps are still quite general and the requirements of the researcher can vary greatly depending on the type of study. In the subsequent sections we focus predominantly on humanities scholars and their needs when using web archives. The objective of studying researcher methodology is twofold; first is to understand the overall requirements of a web archive system geared towards humanities research and in turn, secondly to identify open research problems for the computer science community. To better understand humanities web archive methodology, we conducted a series of discussions and interviews with humanities researchers, who have varying degrees of experience of working with web archives.

2.5.1 Setup

The study was conducted with 20 researchers in total. The researchers can be divided into 3 groups based on their experience. The first is the group of scholars that gathered at Aarhus University, Denamrk for a summer school in June 2014. This group represents a set of scholars who have worked quite extensively with web archives. The second group of scholars are the bursary holders from the British Library's web archiving project, BUDDAH (Big UK Domain Data for the Arts and Humanities) [1]. These are a group of researchers who are only recently starting to work more closely with web archives. The third group of researchers is the budding Digital Humanities group at the University of GÃűttingen, Germany. Here the experience with web archive based research is for all intents and purposes, negligable.

The format of the discussions was varied in each case due to the setting and venue. Most were open ended discussions that centered on the methodolgy used for research and in particular the problems faced when doing so. One of the methods considered for the interview process was the ACTA technique [40]. This method is a streamlined version of the Cognitive Task Analysis methods for identifying cognitive skills, or mental demands, needed to perform a task proficiently. However for this technique to be applied, all participants in the interview process should share a similar level of experience. The experience of the interviewed researchers with web archives though varies from over 10 years for Niels Brügger to no experience for Gerhard Lauer. But each individual brings a certain perspective to research in web archives which should be considered when trying to understand their needs. This approach of bringing humanities scholars in contact with developers and computer scientists to improve web archive systems has been advocated strongly in technical reports like [29].

In the subsequent sections we discuss the insights gained based on data gathered during discussions regarding the participants methodology and problems faced.

2.5.2 Insights on research methodology

Over the course of the summer school in Aarhus University, I indulged in several interviews and group discussions with the researchers. We also participated in the presentations made regarding their wrok. There were presentations regarding both qualitative and quantitative research on web archives.

Researchers more used to a qualitative approach doubted the consistency and quality of the data used in large scale quantitative analysis whereas some researchers doubted the validity of results produced on small albeit high quality samples of the archive. What was immediately clear to us and everyone present though was the potential of web archives to combine both types of research if certain points could be addressed. This was alluded to by Schneider and Foot as well in [52]. An excerpt from their report that sheds more light on this is shown below:

> ’Web archiving does seem to promise novel ways to combine quantitative and qualitative research in one design. First of all, the fact that the datasets can be huge will enable qualitative researchers to check whether a particular phenomenon or pattern they have found in one particular case also seems to be relevant if one looks at a large number of case studies. This could technologically be supported by âĂIJpattern matchingâĂİ software tools (either in the form of Perl or Python scripts, or in NVivo or Atlas.ti type of tools). Second, qualitative data pertaining to a particular case study can be represented as a node in a network, thereby possibly contributing to a bet ter feel for the âĂŸplaceâĂŹ of oneâĂŹs case. Third, Web archiving methods enable researchers to collect a variety of quantitative data as harvested metadata. This minimizes the effort on the side of the researcher while still enabling her to couple her own data (whether quantitative or qualitative) to these meta-data. And lastly, quantitative research designs may be enhanced by exploration of concrete instances (e.g., Web pages) of phenomena about which one has quantitative data.’

Apart from the suggestions made by Schneider and Foot, we believe for humanities scholars more used to working qualitatively with text documents they need to better understand the limitations of a web archive. For humanities scholars beginning to work with web archives there are 2 main concerns: the absence of all versions of web pages and the timestamp for each is only the crawl date and not the actual publication date. Since their collections are often small samples, the consistency and quality of these samples must be very high. These inconsistencies can be glossed over however when taking a large enough sample. This is probably why we have seen more large scale link based analysis as the predominant mode of study for web archives. In order to encourage more humanities researchers to use existing web archive data it is imperative for them to understand the limitations of the crawlers and also define a set of error boundaries when defining their small corpus. By gaining a better insight into some of the technical challenges behind creating an archive, in my opinion, humanities scholars can define select a reasonable corpus and motivate its usage despite its shortcomings.

What we found most surprising though was the corpus creation procedure for many of the studies. The large scale studies were based on broad domain based selection whereas the small scale qualitative studies were based on human curated list of URLs. This is mostly due to the nature of the primary access point for web archives, the wayback machine. The wayback machine acts as a look up service which given a URL as input will show the list of versions available and render the content of each version when requested. This sort of access doesn’t allow for any kind of search or exploration. To build a corpus of relevant web pages, scholars should not have to manually build catalogs of URLs. A search feature is paramount to helping them find more relevant pages and sites for their corpus. To enable search though, the archive needs to be indexed. This is not a trivial task given the sheer size of just 10-15 years worth of web archive data. To date there have been only a handful of large scale web archive indexes like the Portugese Web Archive and British Web Archive. The IIPC chooses not to index the whole web archive but instead create indexes for pages related to particular topics or events. The participants in the summer school had not been exposed to a full text web archive search system during their work and hence relied on the wayback machine.

Another interesting discussion that came up was centered around the first of Schneider and Foot's suggestions to combine both forms of research. The question raised by Leigh Graham was: how can I check if my hypothesis is valid on all discussions about my subject not just the small sample I have worked with? Pattern checking is one possibility while the other is the actual scaling up of the theory behind the hypothesis. This is closely related to Mathew Webber's work on 'big theory'.

There is a need to translate these theories to a web scale, where the primitives need to be redefined as simple formulas that can be applied to large aggregates of the whole dataset. In essence if we can define theory from the social sciences and humanities as precise mathematical formulas then we can approximate the variables used accordingly and try to evaluate the theory on a much larger scale.

For scholars like Frederico Nanni, a historian at the University of Bologna, there is a great deal of interest in studying web archives using a combined qualitative and quantitative approach. He wanted to use LDA (Latent Dirichlet Allocation) to generate topic models in order to study the evolution of topics in Italian university websites. However without programming knowledge, both extracting the data and building a topic model is very difficult today. This hurdle of technical expertise discourages a lot of humanities scholars from utilizing the full scale of web corpora. There is a need to build systems that incorporate algorithms like LDA based topic modeling in a user friendly manner.

For scholars who are not aware of the strengths and weaknesses of the algorithms it can seem like using these methods creates an inherent bias. But if researchers can gain more transparency to the working of mining algorithms then they can use it more effectively and also describe it more accurately. A simple way of adding transparency is to allow users to tweak the parameters for algorithms and see how the output can is affected.For example, in any form of clustering we need to set the number of clusters k. Why not let the researchers vary these values and observe the effects. Easy to use tools with transparent algorithms is key to helping humanities scholars.

2.5.3 Insights on corpus creation and web archive search

After getting an overview of some of the more general problems faced by researchers when working with web archives, we decided to focus on the following subset of researchers: humanities researchers using the web archive as a source for a predominantly qualitative study. The BUDDAH project at the British Library, London, is an effort to encourage humanities scholars to use web archives. To encourage scholars to work with archives an adequate system needs to be in place first. Another major goal of the BUDDAH project is the development of a system suitable for scholarly access to web archives by working in tandem with scholars. The British Library possess over 15 years of the UK web (.co.uk) gathered by their own crawls and donations from the Internet Archive. As part of the BUDDAH project, a bursary scheme was announced at the beginning of the project to select candidates to work with web archives. Candidates were asked to send in applications describing the topic they want to study using web archives and also the methodology they would employ if selected. A total of 11 applicants were chosen and given access to the British Library's web archive search system. At the time of interviews only a random 12% sample of the entire dataset was indexed and made available to the users. The index for the whole dataset was close to completion at the time and the intention was to swap the indices and retain the same interface.

The very first step for any scholarly work is the formation of a corpus. As seen from the sensemaking model by Pirolli and Card, the first stage of corpus creation is exploration of the data. To help scholars explore this large UK web archive dataset they indexed it so as to make it accessible to keyword search. Keyword search is a better choice to explore the archive if you are unaware of the URLs you actually want to use. The search functionality provided to all scholars is keyword based faceted search. The facets are based on the domains and subdomains of the resulting documents as well as the crawl date. There is a form that users can use to specify advanced search functionality as well like: phrase search, proximity search, etc. A negative keyword filter was also made available to remove spam results.

At the time of our meeting with the bursary holders and members of the BUDDAH project, scholars had just begun working with the search system and trying various keywords to find some relevant documents. We had a group discussion with both the developers of the system and the bursary holders to try and understand the challenges they were facing. We also had the chance to study the applications of the scholars. These applications proved to be an invaluable source for understanding the intent of the scholar when they use the search system to explore the archive.

Overall the scholars were happy with the search features provided. They did find it difficult to find the right set of keywords to express their intent though. Upon closer analysis of the applications though we found that users wanted all documents related to a certain topic. The topics can have multiple facets which are not evident to the user straight away from the search results. For example when one of the users was searching he found a large number of results from amazon which were irrelevant to his study. To overcome this he had to add the word 'amazon' to the negative keyword list and repeat his search only to find more 'spam'.

We found that almost all users were using advanced queries to narrow down their results to a number small enough that they could go through manually. One major feature that was requested by the scholars was an ability to create corpora from within the system. Some users resorted to using a spreadsheet to keep track of the web pages selected along with thew keywords used. As with any form of scholarship the documentation of corpora formation is key to replicating the study. The engineers at the British Library at the time had decided to add a simple corpus creation feature where users could add relevant results from the search page to a user defined bucket. Based on this feature, the scholars also requested a possibility to export the results in a suitable format for their analysis of this dataset. If the system in itself is only for search and not for analysis then exporting of corpora becomes the link that joins stage 1 and 2 of Brügger's framework.

A web archive search system for scholars should support at the very least the following tasks:

- Exploration: search using keywords with advanced querying like phrase match and proximity at the very least. There exists a rich body of work on content analysis and data mining that can help users explore corpora more intelligently.
- Selection and documentation: The system should also document in detail the actions of the user when selecting search results for his corpus similar to the search history. Citing is a key concern for scholars. To cite web objects they need, not only keywords used to locate them but also the crawl meta data from where the object came from.
- Export: exporting a corpus with its documentation in popular formats like CSV and JSON so that further analysis can be done with tools that researchers are already comfortable with.

A consequence of detailed user tracking should be the use of relevance feedback techniques to improve the search process. To the best of our knowledge relevance feedback in web archive search has yet to be studied.

An example of web archive search system developed for scholars is the WebArtist initiative [34]which combines search with better data visualization and rudimentary aggregates. It also allows users to export their results in CSV.

The rest of the issues discussed that day were centered around the search interface and results. Overall the users were satisfied with the result presentation in the 10 blue links paradigm. The search results themselves are hard to comprehend with large number of versions for each page. The ranking of search results in their system is time ordered so as to not get clusters of versions of the same URL in the result list. This method is rudimentary at best and really points to the need for better search result ranking and visualization paradigms. Costa et al [22] have already shown that standard IR ranking models do not produce satisfactory results for users of web archives. There is a need for models that are time and version aware. An interesting point to note is also the scholars need to avoid bias. Time ordering is easy to understand and explain when describing the corpus creation process using search. However with ranking algorithms, the scholars feel the system is introducing a certain amount of bias. Scholars need to better understand the objective of each ranking algorithm so that they can use it when the need arises and explain it in their work. This is once again a case of algorithms being made transparent and known to the user when they are being employed.

Bursary applications We shift our focus to the bursary applications of the scholars selected to work with the archive. Each bursary application consists of the following fields: General subject area, Title of the study, Description of the study (500 words), Proposed methodology (200 words) and the benefits of the research. To maintain the privacy of the bursary holders I will not be delving into their areas of research in detail. Instead I will focus on their methodology for corpus creation and analysis. Since the dataset is the UK web archive from 1996 to 2013 the scholars chose topics which are relevant to the UK. The scholars come from a variety of disciplines ranging from the medical domain to history. First I classify the studies based on the scale of study suggested in the proposal. Out of 11 participants all chose small scale studies where they would construct the corpus of study manually using a combination of keywords and filters for search. 2 scholars also consider large scale studies to determine trends. 2 out of 11 scholars also restrict themselves to only a particular subdomain within the entire UK domain space. 1 participant wants to compare her results against results from the live web. 5 of the scholars explicitly propose to use popular or leading URLs from their field of study as starting points for corpus creation. This approach can be flawed due to the fact that web pages do change addresses over time. All participants however used the keyword search feature to start exploring the dataset. 2 scholars want to build their corpus purely based on keywords and no restrictions in terms of types of websites. Some scholars are more interested in the social aspect of the web like blogs, forums and discussions; while others in the more formal authoritative websites like an organization's main website. 1 scholar expressed his interest in studying an image archive from the UK web archive, which we believe can be an interesting problem to solve. *It is interesting to note that in most cases the web page is considered the first class citizen in search but users could be interested in rather specific elements on each page. A closer look could be taken at the indexing granularity to cater to these needs.*

In terms of analysis, most users were happy to visualize the link structure in the corpus they were going to create. 2 participants made the link structure of their corpus their main focus. 7 of the 11 scholars explicitly state an interest in studying their subject over time using terms like evolution and understanding the past in the description of the study. While most participants were interested in the content of the web pages in the archive, 2 scholars were particularly interested in the HTML structure of the pages they collect. The type of analysis they will conduct on the final curated corpus varied from scholar to scholar. Only 3 scholars wanted to conduct quantitative studies.

During discussions with the scholars, we found that generating keywords to find relevant documents for their topic was a tedious task. The web pages they were looking for were not annotated with any kind of topical taxonomy. The more metadata there is regarding the type of the web page and the topics covered, the easier it will be for researchers to search for relevant material faster. Another major concern for researchers was how to get an overview of the result sets when even after filtering the result set was over a few thousand documents. The current time ordered ranking is neither helpful in terms of finding the most relevant documents nor getting an overview of the result set.

In the next section, we make a case for better methods to help search and exploration in web archives and use this as motivation to develop a novel retrieval model for archive search.

2.6 Intelligent access to web archives

Recap To form a corpus of study from a web archive scholars need effective ways to access the data in the archive. Until recently the most commonly used form of access was the wayback machine service. This kind of lookup service is useful when you only want to study a limited set of URLs. To allow researchers to search the corpus with keywords rather than URLs, national libraries and the IIPC have taken to indexing either their whole collection or parts of it. Search is already a major improvement compared to the wayback machine for access.

For an access method to be considered intelligent it should have features that make it easier for the user to quickly access the data they are interested in. Search in itself is a generic access method but it can be considered to be an intelligent method of access for web archives with the addition of domain and time based filtering. However even with these features researchers we have observed scholars having to do a lot of manual filtering to find relevant documents.

Search should not only find all documents containing the keywords but also rank more relevant documents closer to the top. By ranking the most relevant documents towards the top we save the user time and effort.Web archives though pose their own set of challenges for search result ranking due to the temporal version-ed nature of the documents in the collection. Costa et al. have already shown that traditional IR retrieval models are not very good when used for web archives. We also observe that with the British Library's decision to rank results in descending order of timestamp instead of using the baseline retrieval models provided by Solr. Traditional retrieval models are time averse so it is extremely likely that the top k search results for a query could be different versions of the same document across time.

Let us look more closely at a select set of the bursary applications to understand the information seeking nature of certain scholars. Once again, we will refrain from going into the actual research topic but instead try to abstract the scholars intention alone.

Case 1: The scholar wants to study the evolution of the reception by the online community towards a certain topic, say X. This topic can be expressed by keywords. In the application, the scholar mentions entities relevant to the topic as well that could be used as keywords. The information intent of the author can be interpreted as: I want to get documents from different time periods about X. These documents should provide an opinion of a person or a group about topic X.

Case 2: The scholar wants to study the blogs from a community C chronologically. The scholar more specifically states that she wants blogs that mention a particular aspect A. Once she has the blogs she would like to find patterns in them. The intent can be expressed using keywords that describe the community. Filters can be used to narrow down results to the blogosphere as well. The complete user intent however can be interpreted as: I want to get all relevant blogs from C that mention A from different time intervals that possess documents about community C.

Case 3: The scholar wants to study the history of politician P. The scholar wants to know the interesting facts about the life of P from various aspects. The intent is represent as keywords which in this case is the name of politician P. The user intent when studied more closely can be interpreted as: I want to get all documents that cover diverse aspects of P's life.

From the cases mentioned above, we can see that inherently scholars want results which are diverse. Scholarly search in web archives can be considered as a high recall high precision task. Scholars want not only relevant documents but documents which are from important and diverse time intervals and cover a broad range of aspects. By diversify we also provide the user with a brief overview of the result set. We believe that one of the ways to make the current search methods for web archives more intelligent is to to add diversity; diversity not just over time but also over aspects.

In the next chapter we motivate and develop a retrieval model for scholars whose search intent is to study the evolution or history of a topic.

3 Historical search

3.1 Introduction

From our study of scholarly access of web archives, we found that keyword search is the primary access method. Our findings also show that ranking search results is a problem faced by scholars at the British Library. Users are interested in a getting an overview of search results not only across aspects of the query but also across time. Keyword queries with an inherent historical intent over longitudinal text corpora like web archives are interesting for the scholars like historians, social scientists and journalists. While searching documents published over time, a key preference as we have seen is to retrieve documents which are from the important aspects from important points in time. To this extent, we introduce the notion of a *Historical Query Intent* and define an aspect-time diversification problem over archives.

In particular, we chose news archive since we have reliable publication dates and a wider time span when compared to some of the standard web crawls available for experimentation. Also since we do not address the problem of multiple versions of the same page, news archives are the ideal sample to test our work.

Consider **Case 3** from the previous section. Lets say the scholar interested in the history of Rudolph Giuliani, the ex-mayor of New York City in the time interval between 1987 to 2007. She is not only interested in the important facets like `mayoral campaigns, his mayorality, race for senate` and `his efforts during 9/11`, but she is interested in articles which cover these aspects when they were important. News articles of historical interest can be classified into breaking news, opinion pages, or summary and reflective pieces. Although reflective or summary articles might mention important aspects, events and news they might always belong to the time of interest of the aspect in question. Thus, presenting a news article about Giuliani's efforts for 9/11 during 2001-2002 is deemed more interesting than articles from other time periods. Similarly, articles talking about the mayoral campaigns in 1989, 1993 and 1997 (the years when the mayoral elections were held) are more effective than documents covering this aspect in 2007. We introduce the notion of such historical query intents or *HQI* which aims to diversify search results by explicitly taking into account the aspects to which the news articles belong alongwith the time of importance of the aspect.

In this chapter, we present a novel algorithm, HistDiv, that explicitly models the aspects and important time windows to which the results of the query belong. We also propose a new metric Tia-Sbr to evaluate the effectiveness of methods intending to solve it. We test our methods by constructing a test collection based on *The New York Times Collection* with a workload of 30 queries assessed manually. Our experiments show that we outperform all the competitors in most of the measures, and remain competitive in a select few.

3.2 Historical Query Intent

Historical Query Intent is the moniker we choose to describe a user's intent to cover as many historically relevant subtopics and time windows for a given topic. I operate on a document collection $\mathcal{D}$, where each document d_t is associated with a timestamp t corresponding to its publication date. The entire span of the document collection is sub-divided into a set of non-overlapping time windows $\mathcal{T} = \{t_1, t_2, t_3 ... t_n\}$. I require that each document d_t has exactly one publication date t implying that it belongs to exactly one time window denoted by $w(d_t) \in \mathcal{T}$, i.e., $begin(w(d_t)) \leq t \leq end(w(d_t))$ where $begin(w(d_t))$ and $end(w(d_t))$ denote the begin and end time boundaries of $w(d_t)$. Additionally, each $d_t \in \mathcal{D}$ is labeled with a set of aspects which are used to describe the content of d_t. I let $\mathcal{A}$ be a universal set of all aspects such that $A(d) \subseteq \mathcal{A}$ is the set of aspects for the document d_t.

In order to satisfy the aforementioned historical query intents which requires documents from relevant aspects and relevant points in time, I propose a search result diversification problem called *Historical Search Result Diversification* task. In this task, given a set of retrieved results $R_q \subseteq \mathcal{D}$ for a query q, we intend to diversify aspects from $\mathcal{A}$ and time windows from $\mathcal{T}$ such that I get a set $S \subseteq R_q$ of k documents that cover the most important aspects and time windows for a given topic expressed by q. As with prior work on *explicit search result diversification* [10], we assume each topic q has a set of subtopics $c \in C(q)$, with a probability distribution $P(c|q)$ which S looks to satisfy. Generalizing the traditional search result diversification tasks to include time I seek to maximize an objective function $P(S|q)$ to find the best S over a set of subtopics $C(q)$.

Definition 3.1 *The Historical Search Result Diversification task intends to find a set* S *which maximizes* $P(S|q)$ *over a set of subtopics* $C(q)$ *as well as a set of time windows* $T(q) = \bigcup_{d_t \in R_q} w(d_t)$.

$$P(S|q) = \sum_{t \in T(q)} P(t|q) \sum_{c} P(c|q)(1 - \prod_{d \in S}(1 - V(d|q, c, t)) \tag{3.1}$$

$P(S|q)$ represents the probability that the user finds at least one relevant document from an important time window. $V(d|q, c, t)$ is the utility of a document d given subtopic c, query q and in the time window t. This utility decreases for other documents if we add a document to S which has a high probability of satisfying a user interested in time t and subtopic c. By doing so we also expose ourselves to quirks of their interpretation of diversification, i.e, if there is a dominant time window or subtopic then more documents are added to S until they are sufficiently satisfied. The problem we have defined is akin to a 2-dimensional diversification problem. Being a generalization to earlier formulations, which were based on the classical Maximum k-Coverage Problem, the historical search diversification task is also $\mathcal{NP}-$hard.

3.3 Time-Aware Effectiveness Measures

Since we follow a diversification based approach to historical search we adapt the existing diversity measures to take time into account. We first extend existing diversification metrics by making them two dimensional, and then we proceed to propose a new metric which takes into account the importance of the aspects along with time.

3.3.1 Time-augmented Diversification Metrics

Similar to aggregating metrics like Precision, NDCG, ERR and Subtopic Retrieval across intents in [50], we aggregate the contribution of each of these metrics to every time window. Let C is the set of subtopics for a topic q in the workload Q and $rel(j|c)$ is the relevance of a document at j to a subtopic c belonging to the time window t. In this subsection we show how th traditional intent aware measures can be augmented to include time.

Time aware alpha-IA-NDCG NDCG (Normalized Discounted Cumulative Gain) is a measure that rewards result lists of length k that rank relevant documents closer to the top of the list. The core of the measure is cumulative gain which is then discounted based on the position of the documents in the ranked result list. Intent awareness is added to the measure by computing a weighted sum of NDCG for each subtopic c such that $\sum_c P(c|q) = 1$. We introduce time awareness in a similar fashion. The importance of a time period or window is represented by conditional probability of a time window over the query. We compute intent aware NDCG over each time window within the time range of the collection and compute the weighted sum over all time windows where $\sum_t P(t|q) = 1$. Time aware Intent aware α-NDCG rewards result lists of length k that rank, for each intent, relevant documents from important time windows closer to the top of the list.

$$P(t|q) = \frac{|d_{t,q}|}{|d_q|} \tag{3.2}$$

where $d_{t,q}$ is a document with time stamp t and relevant to the query q.

$$DCG = \sum_{j=1}^{k} \frac{2^{rel(j)} - 1}{\log(1+j)} \tag{3.3}$$

where j is the rank of the document and $rel(j)$ is the binary relevance judgement of the document at j. For intent awareness, DCG is modified by changing $rel(j)$ to $rel(j|c)$. NDCG is computed as $\frac{DCG_k}{IdealDCG_k}$.

$$\text{ia-Ndcg}(Q)_k = \sum_c P(c|q)NDCG(Q, k|c) \tag{3.4}$$

$$\text{Tia-Ndcg}(Q)_k = \sum_t P(t|q) \sum_c P(c|q)NDCG(Q, k|c) \tag{3.5}$$

Time aware IA-ERR Intent aware estimated reciprocal rank (IA-ERR) has been used by TREC as its primary measure for measuring diversity performance. It is a cascade user model based metric and it is shown to be more accurate than position based metrics like NDCG. Temporal ERR-IA is computed by introducing time as an extra dimension of intent in the original computation of ERR-IA.

$$\text{ia-Err}_k = \sum_r^n \frac{1}{r} \sum_c P(c|q)rel(r|c) \prod_{i=1}^{r-1}(1 - rel(i|c)) \tag{3.6}$$

$$\text{Tia-Err}_k = \sum_r^n \frac{1}{r} \sum_t P(t|q) \sum_c P(c|q, t)rel(r|c) \prod_{i=1}^{r-1}(1 - rel(i|c)) \tag{3.7}$$

Time aware IA precision Time-aware intent-aware precision at k, Tia-Precision@k can be defined as

$$\text{ia-Precision}_k = \frac{1}{|C|} \sum_{c=1}^{|C|} \frac{1}{k} \sum_{j=1}^{k} rel(j|c) \tag{3.8}$$

where C is the topic represented as a set of subtopics c. $rel(j|c)$ is the relevance of a document at j to a subtopic c. This measure determines how precise a ranked list is over a set of intents. For historical search we need to measure precision not only over subtopics but also over time. We want a ranked list to consist of documents from diverse subtopics and diverse time windows. To measure the precision of covering time as well as subtopics we introduce time in IA-Precision in the following way:

$$\text{Tia-Precision}_k = \sum_{t \in T(q)} P(t|q) \underbrace{\frac{1}{|C|} \sum_{c=1}^{|C|} \frac{1}{k} \sum_{j=1}^{k} rel(j|c, t)}_{\text{Precision } \textit{in time wind. } t} \tag{3.9}$$

Time aware average IA-precision & MAP-IA Average IA-Precision is used to measure how precise a retrieval model is for $1 \leq k \geq n$. To compute Mean average precision, Average IA-Precision is computed for all queries in Q and then we compute

Measure	Formula
Tia-NDCG$_k$	$\sum_t P(t\vert q) \sum_c P(c\vert q) NDCG(q, k\vert c, t)$
Tia-ERR$_k$	$\sum_r^k \frac{1}{r} \sum_t P(t\vert q) \sum_c P(c\vert q) rel(r\vert c, t) \prod_{i=1}^{r-1} (1 - rel(i\vert c, t))$
Tia-AvgPrecision$_k$	$\sum_{k=1}^{n} (\text{Tia-Precision}_k * rel(k))/\vert R\vert$
Tia-MAP$_k$	$\sum_Q \text{Tia-AvgPrecision}_k/\vert Q\vert$
T-Sbr$_k$	$\frac{\vert subtopics(S)\vert + \vert timeWindows(S)\vert}{\vert subtopics(q)\vert + \vert timeWindows(q)\vert}$

Table 3.1: Time-Aware Effectiveness Measures

the mean. We use Time Aware IA-Precision instead of the standard IA-Precision to introduce time awareness.

$$IA - AvgP(q)_k = \frac{\sum_{k=1}^{n} (2d - IA - Precision(k) * rel(k))}{\#relevant\ documents} \tag{3.10}$$

$$\text{Tia-MAP}_k = \frac{\sum_Q IA - AvgP(q)}{|Q|} \tag{3.11}$$

Subtopic recall Subtopic recall is the measure of intent coverage for a given result list at depth k.

$$\text{Sbr}_k = \frac{|subtopics(S)|}{|subtopics(q)|} \tag{3.12}$$

$$\text{T-Sbr}_k = \frac{|subtopics(S)|\ +\ |timeWindows(S)|}{|subtopics(q)|\ +\ |timeWindows(q)|} \tag{3.13}$$

T-Sbr$_k$, our adaptation of subtopic recall, considers both time windows and subtopics to be members of a single set of intents. $subtopics(S)$ and $timeWindows(S)$ denote set of subtopics and time windows covered by the diversified result set S respectively. Similarly, $subtopics(q)$ and $timeWindows(q)$ denote the set of all subtopics and time windows for a given query q.

3.3.2 Time-Aware Subtopic Recall

To accurately measure the historical value of a result set we need a metric that models the coverage of important time windows and subtopics. It is fair to consider the equal importance of each subtopic although doing the same for time would not provide an accurate way to discriminate. For example, it is safe to assume that a user searching for the history of the 9/11 attacks would prefer to get relevant documents from the year 2001 rather than 2007. Hence it desirable to reward result lists that rank relevant documents from important time periods. We introduce a variant of subtopic recall called time aware subtopic recall. This measure's discriminatory power comes from direct modeling of time windows as bursts rather than

Algorithm 1: Temporal IA select

```
Input: $k, q, A(q) \in l_R, R(q), A(d) \in l_R, P(a|q), V(d|q,c), S =$
Output: $S$
$\forall a, U(a|q,S) = P(c|q)$
while $|S| \leq k$ do
    for $d \in R$ do
        $g(d|q,a,S) \leftarrow \left(\sum_{c \text{ in } A(d)} U(a|q,S)V(d|q,a)\right)$
    $d^* \leftarrow \operatorname{argmax} g(d|q,a,S)$
    $S \leftarrow S \cup \{d^*\}$
    $\forall a \in A(d^*)$ , $U(a|q,S) = (1 - V(d^*|q,a))U(a|q,S/d^*)))$
return $S$
```

new subtopics like in our adaptation of subtopic recall. Each time window t is given a burst weight $P(t|q)$ just like each subtopic.

Definition 3.2 *The time-aware subtopic recall at k,* Tia-SBR$_k$*, is defined as*

$$\text{Tia-SBR}_k = \alpha \underbrace{\sum_{c}^{C \in S} P(c|q)}_{\text{Sbr}_k} + (1 - \alpha) \underbrace{\sum_{t}^{t \in S} P(t/q)}_{\text{burst recall at } k} \tag{3.14}$$

where Sbr$_k$ is a weighted interpretation of subtopic recall. Considering equal importance for all subtopics leads to $P(c|q) = \frac{1}{|C|}$ which is the standard subtopic recall used for diversity evaluation. Intent aware measures will just favor algorithms that can cover more subtopics. Adding time awareness to these measures will have favorable results for algorithms that select important time periods and subtopics. Hence by combining time awareness and intent awareness in the standard measures we are able to determine just how well an algorithm performs for a historical query intent. We also choose Tia-Sbr as the measure of choice for the historical diversification task.

3.4 The HistDiv Approach

In devising a retrieval model for our historical search let us look at how we can add time to the existing diversification models which explicitly model aspects. A naïve approach is to enrich the aspect space by adding time as aspects. Since we deal with two dimensions we can project or *linearize* the temporal dimension onto the aspect dimension. Say the result set R has a document d with m aspects $\{a_1, \ldots, a_m\}$ and belongs to the time window t_i, it contributes m linearized aspects denoted as $l_d = \{a_{1,i}, \ldots, a_{m,i}\}$. Thus the overall linearized aspect-time space l_R or a result set R can be represented as $\cup_{d \in R} l_d$. Methods like Ia-Select [10] and Pm2 [25] can then operate on this enriched aspect-time space.

We consider these time-enriched diversification models as baselines in our experiments denoted as Tia-Select and Tpm2. The algorithms are detailed in Algorithm 1

Algorithm 2: Temporal PM2

```
Input: $k, q, A(q) \in l_R, R(q), A(d) \in l_R, P(a|q), P(d|q,a), S = null$
Output: $S$
for $a_i \in A(S)$ do
    $quotient[i] = \frac{v_i}{2a_i+1}$
$i^* \leftarrow argmax\ quotient[i]$
$d^* \leftarrow argmax_{d_j \in R}\ \lambda * quotient[i] * P(d_j|q, a_{i^*}) + (1-\lambda) \sum_{i \neq i^*} quotient[i] * P(d_j|q, a_{i^*})$
$S \leftarrow S \cup \{d^*\}$
$R \leftarrow R/\{d^*\}$
for $a_i \in A(d^*)$ do
    $a_i = a_i + \frac{P(d^*|q,a_i)}{\sum_{a_j} P(d^*|q,a_j)}$
return $S$
```

and Algorithm 2 respectively. Both retrieval models offer different takes on diversity. Ia-Select is based on the assumption that if a user has seen a high quality document d with aspect a_i then there is no need to immediately serve the user with another document from a_i. Ia-Select uses a greedy approach to finding the set S which offers an approximation guarantee. Documents are sequentially added to the result set S based on the utility score g of the documents at that step. The utility of a document depends on the document utility V (given by the relevance score) and the aspect utility U (given by the probability of an aspect in the set R R). The aspect utility score depends on the aspects covered already by the set S at that point. If a document d with a high relevance score covers an aspect a which is already in S then the aspect utility of d is very low and causes the overall utility of the document g to be low.

Pm2 approaches the problem of diversity by proportionality. It assumes that the user's intent is to get a result set S that has the same proportion of aspects as R. It models diversity as a parliament seat allocation problem where aspects are parties which need to be assigned to a limited number of seats. Here each aspect is given votes based on the number of documents it covers in R. Based on these votes, aspects are assigned a portion of the seats in parliament which is the set S and the seats are placeholders for documents. They use the St. Lauge algorithm to solve the problem of proportionally assigning seats to aspects. Instead of computing utility scores for documents like Ia-Select, Pm2 computes the quotient of an aspect at every step and then selects a document from the aspect with the highest quotient score. This quotient depends on the proportion of aspects already covered by S at the given step as compared to the number of votes it has garnered. When a document d is added to S then the proportion of aspects covered in S is updated instead of discounting utility like Ia-Select.

A potential drawback with the linearized models is that newly formed aspects do not always ensure maximum coverage of the temporal and aspect space. An alternative would be to keep the dimensions separate akin to the multi-dimensional approach proposed in [28]. In this general framework for the diversification of n arbitrary dimensions, the utility score $g(d|q, c, S)$ computation reflects how the dimensions are combined. The marginal utility of aspects given a document d is computed

Algorithm 3: The HistDiv Algorithm

```
Input: $k, q, A(q), R(q), T(q), V(d|q, c), S = \emptyset$
Output: Set S of diversified documents
$\forall c \in A(q)$ , $\forall t \in T(q)$, $U_aspect(c|q, S, t) = P(c|q, t)$
$\forall t \in T(q)$, $U_time(t|q, S) = P(t|q)$
while $|S| \leq k$ do
    while $d \in R$ do
        $g(d|q, S) \leftarrow \alpha.V(d|q) \ + \ (1-\alpha).(\beta.\sum_{c}^{A(d)} U_{aspect} \ + \ (1-\beta).U_{time})$
    $d^* \leftarrow argmax_d \ g(d|q, c, S)$
    $S \leftarrow S \ \cup \ \{d^*\}$
return S
```

based on rank of d for the given aspect. This approach is a general framework for the diversification of n arbitrary dimensions. The way the dimensions are combined is reflected in the computation of the utility score g(d|q, c, S).

$$g(d|q, c, S) \leftarrow \alpha P(d|q) + (1-\alpha) \sum_{C}^{\mathbb{C}} \mu(C) V(d|S, C) \tag{3.15}$$

where $\mathbb{C}$ is the set of dimensions and $\mu(C)$ is the weight of a dimension C such that $\sum \mu(C) = 1$. $V(d|S, C)$ is the aspect utility of the given document for the current state of S and the dimension C. The interesting feature of this algorithm though is the computation of the utility of aspects which depends on the rank of the document given an aspect.

$$V(d|S, m) = \sum_{c}^{C} w_c \phi(c, S) r(d, c) \tag{3.16}$$

where w_c is the weight of an aspect, $\phi(c, S)$ is utility of the aspect which is calculated as follows:

$$w_c \phi(c, S) = \begin{cases} 1\&\text{if } S = \varnothing \\ \prod_{d_i}^{S} (1 - r(c, d_i))\&S \neq \varnothing \end{cases} \tag{3.17}$$

$$r(d, c) = \frac{1}{\sqrt{rank(d, c)}} \tag{3.18}$$

and $rank(d, c)$ is the rank of document d in $R|c$. This method works well for the TREC diversification task but it is shackled by its generality when it comes to a specific task like historical search. We can naturally add time as a second dimension and use it for diversification. However, they discount each aspect in the same way which might not work well with all aspects. For example, an exponential discounting function is typically associated with time much different from 0/1 or document relevance based discounting for other *non-topical* aspects. We also use this approach as a competitor referred to as MDIV.

Our approach HistDiv(c.f. Algorithm 3) builds on Mdiv [28]; however, we differ significantly in the way we model each dimension's utility.

HistDiv is a greedy algorithm, similar to Ia-Select and Mdiv, and retains the $(1 - 1/e)$ approximation guarantee due to the fact that we treat time windows also as sets. In HistDiv aspects are topical labels assigned to a document with equal probability. Time, on the other hand is modeled as time windows and each time window has its own probability $P(t|q) = \frac{|d_t|}{|d|}$, $d \in R$. Each document, as described earlier, can belong to a single window designated by its publication timestamp whereas it can have one or more aspects. Similar to [56] we consider that aspects are more relevant at certain periods when compared to others (especially for historical intents). Each aspect also has a span ranging from its first occurrence to its last in R.

The importance of an aspect is measured by a utility function $U_{aspect}(c|q, S, t)$, where $c \in \mathcal{A}$, with the exception that we treat the aspect in various time windows differently. The probability of an aspect c in time window t is $P(c|q,t) = \frac{|d_{c,t}|}{|d_t|}$, $d \in R$. This preferential treatment of aspects is due to the usage of the decay function in the time based discounting factor Δ_t while computing utility.

$$U_{aspect}(c|q, S, t) = P(c|q,t) \underbrace{\prod_{d \in S} \left(1 - \frac{1}{1 + e^{-w + |t - t_d|}}\right)}_{\Delta_t} \tag{3.19}$$

We use the decay function suggested in OnlyTime [12] to discount all aspects at any time t, where t^* is the timestamp of the winner document at a given step. In the time dimension, we need to be wary of discrediting a time window too heavily. Consider OnlyTime which produces a result set with high temporal diversity. More formally this is considered as an optimization problem of finding a set Sthat maximizes the following sum:

$$\sum_{t}^{T} \left(P(t|q).(1 - \prod_{d_i}^{R}(1 - P(R|t, t_i).P(R|q, d_i))) \right) \tag{3.20}$$

where $P(t|q)$ is the relative importance of the time point t for the query q. $P(R|t, t_i)$ indicates the probability that a user interested in time point t is satisfied with a document published at time t_i. Similarly, $P(R|q, d_i)$ is the probability that a user issuing the query q is satisfied with the document d_i. OnlyTime is a greedy approach to find S very similar to ia-Select except for the discounting of utility which is based on the decay function Δ_t.

OnlyTime selects relevant documents from important bursts but discounts that burst heavily with the aforementioned decay function so as to get better temporal coverage. This approach to discounting bursts doesn't consider the fact that a single burst could consist of many diverse aspects. For example, in 2000-2001 Giuliani was divorced, diagnosed with cancer and was involved in helping New York recover from 9/11. Hence we discount the burst of the winning document d^* in the time dimension by the weighted proportion of aspects covered by it denoted by Δ_a and where D_t is the set of all documents in R in time window t.

$$U_{time}(t|q, S) = P(t|q) \underbrace{\prod_{d_t \in S} \left(1 - \frac{| \cup_{c \in A(d_t)} \; d_{c,t} |}{|D_t|}\right)}_{\Delta_a} \tag{3.21}$$

3.5 Test Collection and Setup

Competitors

Traditional diversity algorithms such as Ia-Select, OnlyTime, Pm2 and MDIV were considered as the main competitors to our method HistDiv. We also strengthen Ia-Select and Pm2 by incorporating time in the algorithm by linearinzing the aspects with the publication year of the document. The improved versions of these algorithms, called TIa-Select and T-Pm2, are also added to the list of competitors. We do not consider xQuad [49] and other diversity techniques that explicitly model subtopics as query expansions due to the absence of a reasonable query log for this time period. MDIV is a general framework for an n dimensional diversity problem. The 2 dimensions we consider for our experiments are document aspects and the publication year. Overall we compare our method HistDiv against the following competitors: TIa-Select, Ia-Select, TPm2, Pm2, MDIV, OnlyTime and a language model LM with Dirichlet smoothing as the baseline. The smoothing parameter is set to 1000.

3.5.1 Test collection

Since there are no established test collections which we can measure the effectiveness of our retrieval model we build our own test collection. As a dataset we use the *Annotated New York Times* collection [8] which qualifies as a news archive since it spans for 20 years, i.e., 1987 - 2007. Also, the timestamps associated with the articles are accurate and do not have to be estimated as in other web collections.

To build the test collection we followed Soboroff's tutorial [54] and suggestions made by Costa in [23]. Soboroff defines 5 basic steps to building a test collection which are as follows:

- Determine the task. - Task abstraction, define relevance, define measures (covered in section 3.2 and 3.3)
- Identify a document collection - *Annotated New York Times* collection.
- Build topics.
- Make relevance judgments.
- Conduct experiments to measure stability of the collection.

A group of experts were tasked with the creation of topics and subtopics for historical query intents given the NYT dataset. They explored the corpus with a simple keyword search interface. To form the topics the experts first described the intents verbosely and then proceeded to identify keywords that represent the user's intent. The user intents chosen are from a set of historically relevant issues related specifically to the USA and some of a more global nature due to characteristics of our news corpus. A key point to note is that topic and subtopic creation was not guided by a query log due to the unavailability of a suitable set of logs spanning this time period. To define the subtopics of each topic the experts used their prior knowledge, documents from the corpus and the history sections from relevant *Wikipedia* articles. Each intent has a description, input keywords (query) and a set of subtopics. We have a total query workload of 30 topics. On average there are 6 subtopics per topic. The topics can be broadly classified into 3 types: *profile queries* for entities like `Rudolph Giuliani` and `the World Trade Organisation`; history of an event like the `reunification of germany` and `team usa soccer world cup`; and controversial subjects like `gay marriage` and `sarin gas`. A key assumption made when creating subtopics is the omission of historical facts that lie outside of the 20 year time period of the NYT corpus.

The evaluations for the test collection are gathered using pooling. In general, competitiors submit runs after which a union is made of these documents to form the pool of documents to be evaluated. The key to pooling is to set a reasonable pool depth. We choose a pool depth of 100 for each topic. Evaluators were instructed to assign binary relevance judgements to topic,subtopic,document triples. For example, an assessor was asked to judge if the document d^* with the headline 'Giuliani Fighting Prostate Cancer; Unsure on Senate' published on 28.4.2000 was relevant to one or more of the manually created subtopics for the topic *Rudolph Giuliani*. When judging the relevance of a document, the assessor is given the headline of the article, the body and the publication date. An article can also be relevant to more than one subtopic.

Once the pools were evaluated, a standard robustness test was carried out with Tia-SBR$_k$ as the primary measure. We selected 25% of the query workload at random and split them into two equal sets. We selected 50% of the runs at random for retrieval depth 10 and calculated ranked the system runs for both sets of queries. We found that the rankings were consistent for $p<=0.05$.

3.5.2 Setup

We chose to mine the aspects of each document using a wikipedia based annotator. By doing so, the aspects we used were possible wikiedia articles that could be linked to from the document. In our implementation aspects are mined using wikiminer[4] on the first 1000 words of each article. We only use mined aspects which have a confidence rating of 0.8 or higher from wikiminer for our computations. For example, some of the aspects mined for document d^* are: New York City, Hillary Rodham Clinton, Prostate cancer and Mayor of New York City. For temporal diversity we use a fixed window size of 1 year akin to OnlyTime, which implies

	T-Sbr	TIA-Ndcg	TIA-Prec.	TIA-Map	TIA-Err	TIA-SBR
LM	0.302	0.209	0.01	0.01	0.023	0.453
TIA-Select	0.325	0.213	0.01	0.012	0.028	0.456
T-PM2	0.182	0.107	**0.011**	0.012	0.022	0.322
IA-Select	0.258	0.161	0.008	0.009	0.02	0.376
PM2	0.295	0.192	0.011	0.011	0.025	0.444
MDIV	0.309	0.209	0.009	0.011	0.025	0.454
OnlyTime	0.344	0.22	0.007	0.01	0.024	0.482
HistDiv	**0.351**	**0.275**	0.01	**0.012**	**0.031**	**0.519**

Table 3.2: Retrieval Effectiveness (k = 10)

	Sbr	TIA-Ndcg	TIA-Prec.	TIA-Map	TIA-Err	TIA-SBR
LM	0.211	0.293	0.01	0.011	0.02	0.321
T-IA-Select	0.203	0.316	0.01	0.012	0.023	0.315
T-PM2	0.131	0.175	0.011	0.012	0.018	0.233
IA-Select	0.164	0.239	0.008	0.009	0.016	0.253
PM2	0.195	0.3	0.01	0.011	0.022	0.299
MDIV	0.228	0.368	0.01	0.011	0.022	0.36
OnlyTime	0.228	0.352	0.008	0.011	0.021	0.358
HistDiv	0.237	0.425	0.011	0.014	0.027	0.377

Table 3.3: Retrieval Effectiveness (k = 5)

	Sbr	TIA-Ndcg	TIA-Prec.	TIA-Map	TIA-Err	TIA-SBR
LM	0.361	0.152	0.01	0.01	0.026	0.513
T-IA-Select	0.387	0.162	0.009	0.011	0.029	0.52
T-PM2	0.222	0.077	0.01	0.012	0.022	0.372
IA-Select	0.329	0.133	0.008	0.009	0.021	0.465
PM2	0.349	0.143	0.01	0.011	0.027	0.497
MDIV	0.376	0.156	0.01	0.01	0.028	0.53
OnlyTime	0.443	0.184	0.007	0.009	0.026	0.573
HistDiv	0.421	0.195	0.01	0.012	0.034	0.579

Table 3.4: Retrieval Effectiveness (k = 15)

$d_t^* \in w(d_t^*)$ where $w(d_t^*) = 2000$. The baseline retrieval model used was a language model with a smoothing factor of 1000. Our competitors are state of the art techniques in search result diversification that we have strengthened for historical query intents. In the first phase of experiments, we tune each competitor on a random set of 10 evaluated topics. These tuned competitors are then evaluated over the entire query workload in the final phase of experiments. We evaluated all competitors for metrics mentioned in 3.3.1 at retrieval depth k=10. For Tia-NDCG and Tia-SBR we set α to 0.5 and β to 0.5. In all metrics we assumed equal distribution of subtopics such that $P(c|q) = \frac{1}{|C|}$. The distribution of time window weights was modeled from the collection as document bursts. For a time window t, $P(t|q) = \frac{|D_{t,q}|}{|D_q|}$ such that $\sum_t P(t|q) = 1$, where $D_{t,q}$ is the set of all documents relevant to q from time window t and D_q is the set of all documents relevant to q.

	Sbr	TIA-Ndcg	TIA-Prec.	TIA-Map	TIA-Err	TIA-SBR
LM	0.391	0.109	0.009	0.01	0.026	0.544
T-IA-Select	0.447	0.131	0.009	0.011	0.031	0.58
T-PM2	0.25	0.061	0.01	0.012	0.023	0.408
IA-Select	0.382	0.11	0.009	0.009	0.023	0.526
PM2	0.381	0.107	0.01	0.011	0.028	0.526
MDIV	0.401	0.115	0.01	0.01	0.027	0.563
OnlyTime	0.481	0.134	0.006	0.009	0.026	0.603
HistDiv	0.48	0.151	0.009	0.011	0.034	0.637

Table 3.5: Retrieval Effectiveness ($k = 20$)

3.6 Results & Discussion

In this section we analyze and discuss the outcomes of our experiments. In Table 3.2 we present the effectiveness of the considered approaches with respect to the temporal measures introduced in Table 3.1 for $k = 10$. We see a similar trend for high values of k. Firstly, we note that HistDiv outperforms other competitors in all measures expect Tia-Precision. Also, approaches which take time into account fare better than the non-temporal methods with the exception being Tpm2. This is particularly evident in the *user-centric* measures like Tia-Ndcg and Tia-Err.

The time awareness added to the user centric measures indicates the extent to which a user has to scroll down the list in order to find a relevant result to his intent from the corresponding important time period. Tia-Err helps guage the extent to which the average user has to scroll through this list in order to find a relevant result whereas Tia-Ndcg is used to measure the cummulative information gain of a list. The gain for each document in the list is discounted depending on its rank due to the assumption that the user is less likely to keep scrolling down the list. Thus documents from lower ranks contribute little to the cummulative gain of a ranked list. HistDiv outperforms its competitors in both user centric measures due to its unique calculation of time and aspect utility. The first document in a ranked list generated by HistDiv is from the most important time window with the most important aspects or vice versa depending on the tuning parameters. The aspects of the document are then discounted only within a certain time interval defined by the decay function. This allows HistDiv to reselect the same aspect but from a different time window thereby increasing its temporal awareness. Similarly if the document only covers a small portion of important aspects in a time window, HistDiv can revisit the time window to find a relevant document with diverse aspects which could increase the probability of covering a different subtopic.

Since HistDiv tends to select important aspects from important time points and hence tends to satisify historical intents better than other methods which optimize for (a) one of the dimensions like OnlyTime or Ia-Select (b) rewards aspects (topical or temporal) which have a high mass contribution like Tpm2 or Pm2. Secondly, HistDiv outperforms other approaches when it comes to T-Sbr. To analyze this a bit further, we consider the temporal and aspect-based contributions to subtopic recall. In our experiments we see that OnlyTime performs best when in the temporal dimension, hence the contribution of the temporal dimension towards T-Sbr

1	Giuliani, Shouting for Quiet, Fights to Concede Graciously - 1989
2	Helen Giuliani, 92, Mother Of Former New York Mayor passed away - 1992
3	Giuliani Pulls a Negative TV Ad As Dinkins Broadcasts First One - 1989
4	Why Giuliani Only Came Close - 1989
5	New York Label May Not Fit All In Giuliani Run - 2007

Table 3.6: Results for `Rudolph Giuliani` - *LM*

1	GIULIANI AND LAUDER: 2 PATHS TO SAME GOAL -1989
2	Giuliani Swamps Lauder In G.O.P. Mayoral Primary - 1989
3	In Debate, Dinkins Ties Innis to Giuliani -1993
4	BADILLO DROPS OUT OF RACE FOR MAYOR WITH SPARSE FUNDS - 1993
5	Who Has to Do What As New York Prepares To Pick a New Mayor - 1989

Table 3.7: Results for `Rudolph Giuliani` - *T-PM2*

1	GIULIANI AND LAUDER: 2 PATHS TO SAME GOAL - 1989
2	Pensively, Giuliani Still Debates His Future - 2000
3	Ready for a Race, Mayor Goes to Saratoga - 1999
4	In Debate, Dinkins Ties Innis to Giuliani - 1993
5	Political Memo; Cuomo and Giuliani, Looking For Allies, Find Each Other - 1994

Table 3.8: Results for `Rudolph Giuliani` - *T-IA-Select*

1	Bush Offers Giuliani Help On the Right - 1999
2	Reporter's Notebook; Giuliani Is by the Sea; Could It Be a Vacation? - 1998
3	Giuliani Wisely Bides Time on Endorsement in Governor's Race - 1994
4	Giuliani Fighting Prostate Cancer; Unsure on Senate - 2000
5	In Homestretch of Campaign, Mayor Endorses Bloomberg - 2001

Table 3.9: Results for `Rudolph Giuliani` - *HistDiv*

is high. However, it still does not outperform HistDiv suggesting that although it selects results from different time periods it tends to choose similar topics. The linearized methods understandably optimize the coverage in the projected aspect-time space but that does not lead to maximizing overall coverage. Interestingly, in proportionality-based approaches Tpm2 fares worser than Pm2 which is unlike the intent-aware approaches. A closer examination suggests that this is due the inability of the proportionality-based approaches to penalize the over representation of an aspect. Proportionality-based approaches attach high preferences to results where certain time windows are dominant with a given aspect and hence suffer in the overall coverage.

Although T-Sbr measures the coverage in both the time and aspect dimension, at times it is deterimental to just introduce a spread over time if the time windows covered are not important. This is where Tia-Sbr (introduced in Section 3.3.2) is a more accurate measure which takes into account the relative importance of time windows and aspects while computing coverage. Table 3.10 presents the effectiveness of various measures at different values of k alongwith the win-loss values in braces. First, HistDiv's modeling of aspect importance decaying over time helps it choose the most relevant aspects for a given time period. These aspects can be covered again thanks to the temporal utility function which discounts aspect utility only within a certain time frame. Second, HistDiv also reconciles multiple important aspects in a single time window, unlike OnlyTime, thus capturing multiple important events from the same time window rather than trading-off with less relevant events from a different interval. Mdiv is the only other algorithm that also accounts for two dimensions like HistDiv explicitly. However, a generic discounting scheme based on ranks suffers in this scenario because (a) it does encode the degree of relevance per aspect because of using ranks and (b) it treats time similar to the other (more topical) aspect whose semantics are clearly different. These reasons contribute consequently to HistDiv outperforming other competitors both in terms of the actual value and in terms of win-loss ratio for Tia-Sbr.

Finally, we note that although HistDiv performs better in most of the scenarios there are cases where it falters specifically in Tia-Precision. This can be atrributed to the nature of some topics which are bound very closely to a small time window with very little aspect diversity, like `reunification of germany`. HistDiv covers enough important aspects in the important time windows and subsequently diversifies to find aspects in other less relevant windows. In such a scenario proportionality-based approaches do well in precision since they reward documents in the important aspect due to the dominant mass of the time window.

Rudolph Giuliani Table 3.11 shows the performance of algorithms specifically for `Rudolph Giuliani`. We find that HistDiv performs better than its competitors in all metrics including precision based metrics at retrieval depth 10. We observe a similar trend at varying depths. Figure **??** shows the temporal distribution of the result set $\mathcal{R}$ as well as the diversified set $\mathcal{S}$ for various competitors. We observed that OnlyTime being a purely temporal diversification algorithm produces a temporal distribution similar to the global trend. T-PM2 T-IASel also try tend to follow the temporal distribution of $\mathcal{R}$ because of the linearization of the aspect-time space. This shows that the mined aspects have an inherent temporal nature, i.e. some aspects only exist at certain points in time. However the selective treatment of time and aspects causes HistDiv to not adhere to the global temporal distribution trend as strictly as its competitors. HistDiv is also aware of the aspect dimension explicitly which helps it produce a document set that is more suitable for a historical intent as shown by the numbers in 3.11. The top 5 results for HistDiv, shown in Table 3.9 shows better diversity in both time and aspects when compared to its competitors which seem to be dominated by his election campaigns.

Consider the topic Summer Olympics Doping Scandals. The user's intent is to know the history of all doping scandals at the summer olympics between 1987 and 2007. The subtopics of this topic as per our test collection are:

1. 1988 Seoul - doping mostly in wrestling and judo

	k =5	k =10	k =15	k =20
LM	0.318	0.453	0.502	0.540
T-IA-Select	0.325(15/15)	0.456(16/14)	0.525(17/13)	0.574(18/12)
T-PM2	0.243(8/22)	0.322(6/24)	0.376(7/23)	0.409(7/23)
MDIV	0.350(13/17)	0.454(12/18)	0.520(12/18)	0.555(10/20)
OnlyTime	0.362(12/18)	0.482(14/16)	0.569(18/12)	0.605(19/11)
HistDiv	**0.376**(17/13)	**0.519**(22/8)	**0.577**(25/5)	**0.641**(24/6)

Table 3.10: Tia-SBR(win/loss) at k=5,10,15 & 20

	Sbr	TIA-Ndcg	TIA-Prec.	TIA-Map	TIA-Err	TIA-SBR
LM	0.185	0.04	0.003	0.004	0.007	0.203
T-IA-Select	0.333	0.223	0.008	0.009	0.023	0.457
T-PM2	0.148	0.052	0.006	0.006	0.011	0.18
IA-Select	0.259	0.21	0.005	0.004	0.006	0.32
PM2	0.074	0.017	0.004	0.004	0.004	0.087
MDIV	0.222	0.16	0.004	0.004	0.007	0.298
OnlyTime	0.333	0.314	0.008	0.011	0.029	0.457
HistDiv	0.407	0.461	0.01	0.013	0.033	0.628

Table 3.11: Retrieval Effectiveness (k = 10) for the topic `Rudolph Giuliani`

	Sbr	TIA-Ndcg	TIA-Prec.	TIA-Map	TIA-Err	TIA-SBR
T-PM2	0.008	0.044	0.005	0.077	0.111	0.007
HistDiv	0.004	0.217	0.013	0.192	0.246	0.005

Table 3.12: Results for *summer olympics doping scandals*

2. 1992 Barcelona - mostly athletics related cases

3. 1996 Atlanta - very few cases. only 2 in athletics.

4. 2000 Sydney - quite a few in athletics and weight lifting. Marion Jones was the most popular one.

5. 2004 Athens- Massive increase in doping compared to previous years

6. Measures taken by the IOC to combat doping

From the subtopics there is no clear important time window for this topic and it seems like a straightforward temporal diversity case. However since the underlying corpus is the New York Times, the majority of doping stories emanate from the Marion Jones case from 2000. Reports in the following years then continue to follow Jones and talk about her until the 2004 olympics. The 2004 olympics saw a sudden spike in doping cases as well leading to a large number of articles publised about doping in 2004. Thus the time awareness of metrics here hurts methods which actually try to introduce wide temporal spread to cover the other subtopics. Temporal PM2 due to its nature to proptionally represent aspects restricts the majority of top documents to the dominant time window. ASPTD on the other hand does not favour proptionality so it tends to start traveling outside the important time windows to look for diverse events once it has covered the important time periods and the most important aspects. Time awareness in the metrics here penalizes ASPTD unfairly. For topics with disproptionately heavy time windows, temporal PM2 does well.

Another case where HistDiv is not the best is for historical intents whose subtopics are broad disjoint categories like *elections in the middle east*. Here the subtopics are divided based on region and no temporal aspect is present. As expected in such cases, Ia-Select is the best performing algorithm. Since there are no major time windows the lack of a temporal dimension does not hurt the performance of the algorithm. From these observations we can conclude that HistDiv, without specific parameter tuning, is not particularly competitive to diversification problems of a purely temporal or non-temporal nature.

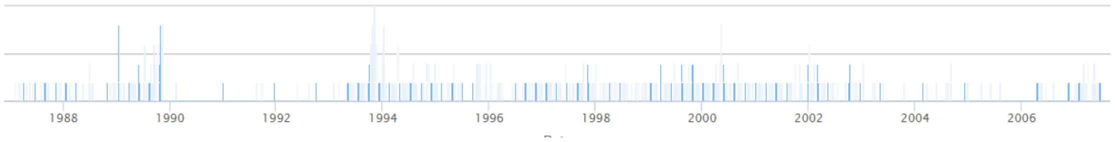


Figure 3.1: Temporal distribution of top 1000 documents for `Rudolph Giuliani`

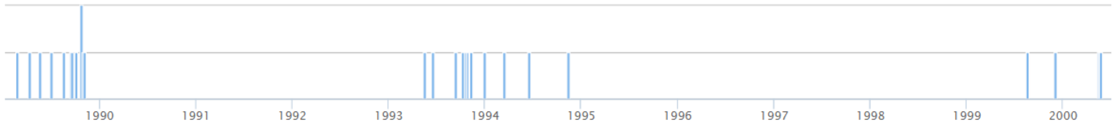


Figure 3.2: Temporal distribution of top 1000 documents for `Rudolph Giuliani` after diversification using **T-PM2**

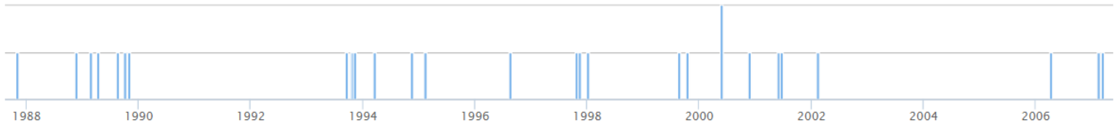


Figure 3.3: Temporal distribution of top 1000 documents for `Rudolph Giuliani` after diversification using **T-IASEL**

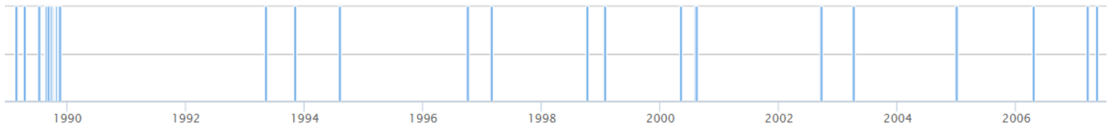


Figure 3.4: Temporal distribution of top 1000 documents for `Rudolph Giuliani` after diversification using **T-MDIV**

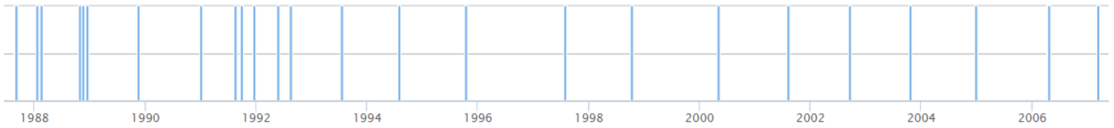


Figure 3.5: Temporal distribution of top 1000 documents for `Rudolph Giuliani`after diversification using **Only Time**

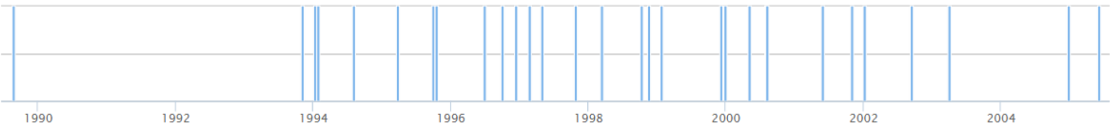


Figure 3.6: Temporal distribution of top 1000 documents for `Rudolph Giuliani`after diversification using **HistDiv**

3.7 Related Work

One of the first attempts to incorporate time in search result ranking was suggested by Li et al. [38] who used temporal language model approach where time and term importance are handled implicitly. Various approaches have been suggested that consider time more explicitly. Identifying the time period most useful for query expansion [36, 18] has been shown to improve result ranking. Ranking for recency on the other hand considers the freshness of a document when ranking [27].

For queries which are temporally ambiguous, temporal diversification is applied. Burst detection is first used to find the possible periods of interest for the query, also known as the query's temporal profile[26, 44], followed by selecting documents from these bursts. Berberich et al. in [12] proposed a diversification model which considers time windows as a set of intents for a query while modeling the importance of each intent as the weight of its burst. In traditional aspect-based diversification tasks like [20, 19], intent importance is considered static over time. However, intent importance was shown to vary across time; thus affecting the diversity evaluation of queries issued at different time points [56]. Keeping this in mind, Kanhabua et al.[41] consider the time at which the query is issued to diversify intents based on their temporal significance at that time. Their approach also explicitly models time and aspects, although latent, but rewards recency. HistDiv, on the other hand, is query-time agnostic, since it is intended for historical search, and seeks to diversify documents based on both time and aspects.

Diversity in search (both explicit and implicit) has seen a rich body of literature lately in [24, 16, 10, 49, 17, 57, 39, 25]. However, none of them take time into account or model the historical information intent.

Work on temporal test collections for information retrieval has seen limited attention. The work which comes closest to our test collection is *Temporalia*[35] however, our query intents are different and moreover their dataset does not have the temporal spread required for our historical queries.

4 The Historical Search System

To show researchers the qualitative results of the HistDiv algorithm, a search system was developed. The system is also a showcase for the baselines so that results from various algorithms can be compared qualitatively. A seperate system was also developed for evaluators to judge documents from the pools. In this chapter, the architecture and user interface of the historical search system are described in detail.

4.1 Architecture

4.1.1 Server side

The backend of the Historical Search system comprises of 2 major components: the **retrieval module** and the **aspect miner**. The development of both components was carried out in Java. The documents from the NYT corpus were first indexed using the standard Lucene 4.0 API. All fields for all documents were indexed using the standard analyzer.

The aspect miner is responsible for mining topics from the documents. Wikiminer is a REST API that is freely available. A java client was developed for the annotation service so that it can be easily used in the aspect miner. The mined topics with their confidence scores are stored in a Redis database and not in the Lucene index. This is because we only need to lookup the topics for each document when computing diversity. Redis is a high performance key value store that maximizes throughput. The data is stored in JSON which Redis supports natively. The aspect miner component is heavily parallelized and can be used during index creation as well as on demand.

The main component of the system though is the ranking component housed inside the retrieval module. A REST API using the JAX-RS specification is the interface between frontend and backend. The API has a set of endpoints that cater to different funtionalities of the system. The data exchange format used by the API is JSON. The major endpoint is the `reRank` endpoint which accepts a HTTP GET request with the following parameters:

- q: the query specified by the user

- dmin: start date filter
- dmax: end date filter
- method: the type of retrieval model to use.
- k: the number of results

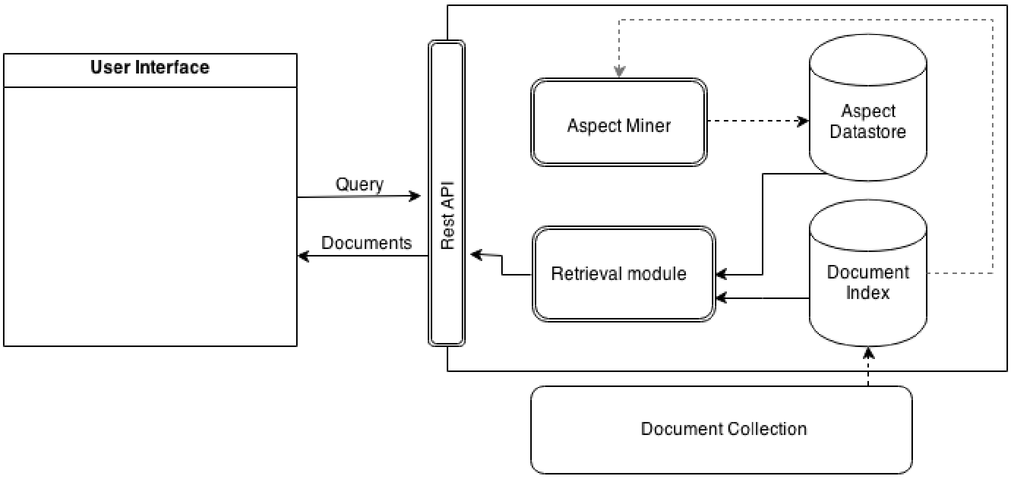


Figure 4.1: System Architecture

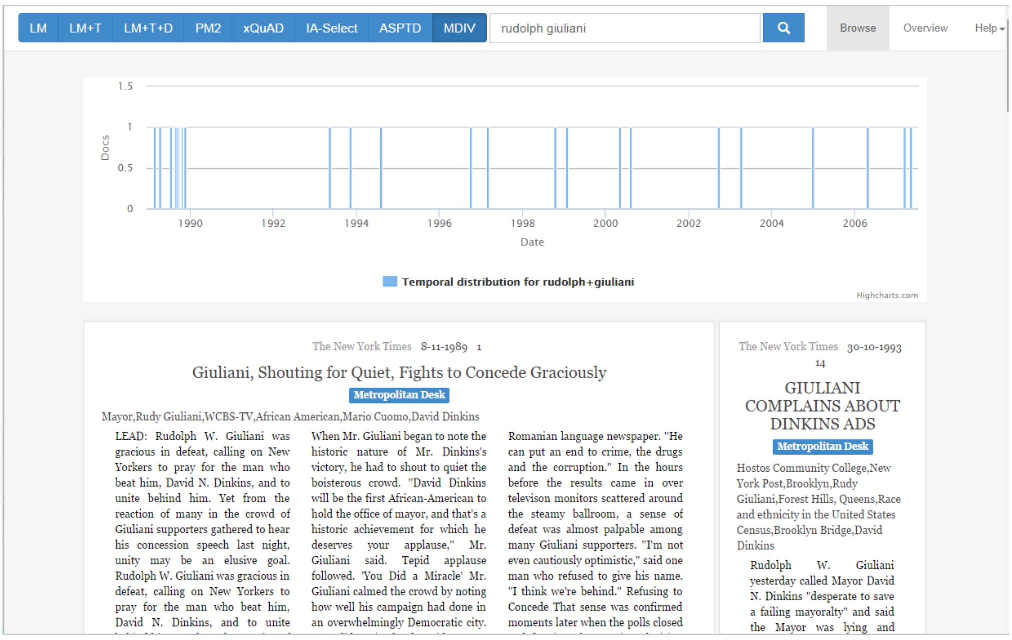
The architecture of the system is shown in Figure 4.1 where the dashed lines represent processes that have completed before the system went online. Every competitor mentioned in the experiments section is available to the user. The user can also specify a date range to limit his search results. When the reRank endpoint receives a request, it first retrieves the top 1000 documents using the query q and specified date range. If the range is `null` then the whole 20 year span of the corpus is considered. The results returned from the index are then given as input to the algorithm mention in the method parameter. The algorithm then returns the top k results from the 1000 given as input. The results are returned to the user as a JSON array with all the fields of each document populated. CORS headers are also sent with the result to allow clients running on different servers to use the API as well.

4.1.2 Client side

The frontend of the Historical Search system is a single page client side application developed using Backbone.js. Backbone.js is a javascript framework for building interactive client side applications that work with data through REST APIs. The UI framework used was Bootstrap 3.0, a responsive framework based purely on CSS and Javascript. The UI itself consists of 3 components: the search bar, the timeline and the search result display.

The search bar consists of an input text box for the user to enter his query and a selector for the type of diversification algorithm to use. There is also a search button for the user to initiate his search. When the user initiates a search, an AJAX request is made to the reRank endpoint of the rank API with the user's query and method. The date filters are initially set to null. Once the results are returned, the timeline component creates the input JSON data it needs from the returned results. Once the timeline component has initialized, the timeline and search results are rendered on the screen. Highcharts API is used to generate the timeline. The timeline is a bar chart of the number of documents at a given date. Highcharts also has a feature for zooming into tinmelines by highlighting the required area on the timeline. This zooming in triggers another search request to be fired albeit with the date range filter now representing the boundaries of the newly selected portion of the timeline. By clicking on the back arrow of the browser the user can zoom out and return to his previous state. Each bar in the timeline when clicked displays a preview of the article from that date.

The search results are displayed in a newspaper style format as shown in Figure 4.2. Each document is represented by its headline, publication date and body. News articles which are more relevant to the query according to the ranking method chosen are given more area to display the contents of the body. To neatly present these results of uneven area freewall.js was used. It uses a packing algorithm to reduces the amount of white space between articles, thus giving it the look of a newspaper.



The New York Times 8-11-1989 1

Giuliani, Shouting for Quiet, Fights to Concede Graciously

Metropolitan Desk

Mayor,Rudy Giuliani,WCBS-TV,African American,Mario Cuomo,David Dinkins

LEAD: Rudolph W. Giuliani was gracious in defeat, calling on New Yorkers to pray for the man who beat him, David N. Dinkins, and to unite behind him. Yet from the reaction of many in the crowd of Giuliani supporters gathered to hear his concession speech last night, unity may be an elusive goal. Rudolph W. Giuliani was gracious in defeat, calling on New Yorkers to pray for the man who beat him, David N. Dinkins, and to unite When Mr. Giuliani began to note the historic nature of Mr. Dinkins's victory, he had to shout to quiet the boisterous crowd. "David Dinkins will be the first African-American to hold the office of mayor, and that's a historic achievement for which he deserves your applause," Mr. Giuliani said. Tepid applause followed. 'You Did a Miracle' Mr. Giuliani calmed the crowd by noting how well his campaign had done in an overwhelmingly Democratic city. Romanian language newspaper. "He can put an end to crime, the drugs and the corruption." In the hours before the results came in over televison monitors scattered around the steamy ballroom, a sense of defeat was almost palpable among many Giuliani supporters. "I'm not even cautiously optimistic," said one man who refused to give his name. "I think we're behind." Refusing to Concede That sense was confirmed moments later when the polls closed

The New York Times 30-10-1993 14

GIULIANI COMPLAINS ABOUT DINKINS ADS

Metropolitan Desk

Hostos Community College,New York Post,Brooklyn,Rudy Giuliani,Forest Hills, Queens,Race and ethnicity in the United States Census,Brooklyn Bridge,David Dinkins

Rudolph W. Giuliani yesterday called Mayor David N. Dinkins "desperate to save a failing mayoralty" and said the Mayor was lying and

Figure 4.2: Newspaper interface with timeline.

The system was deployed on a live server. The same system also consists of the test collection evaluation setup; both the pooling logic and the interface.

- URL: `http://pharos.l3s.uni-hannover.de:7080/ArchiveSearch/starterkit/`
- Evaluation: `http://pharos.l3s.uni-hannover.de:7080/ArchiveSearch/starterkit/rele`

5 Outlook

5.1 Conclusion

With more nations working actively to preserve the web due to the importance it plays in our lives, scholars from various fields have started looking to web archives as a data source waiting to be analyzed. We find that scholarly research with web archives carried out until today can be broadly classified as link based and content based studies. The link structure of web archives has been studied on a quantitative scale by Internet research institutes and computer scientists. They either study the link structure over time to analyze the evolution of the web or try to correlate the linking structure to real world phenomena. In this thesis we first looked at the usage of web archives by scholars. According to Brügger there are 4 major steps when conducting any type of research on web archives: corpus creation, analysis, dissemination and storage. An ideal system for web archive research should support all 4 steps however we find that adequate steps are only now being made to help researchers with the first step: corpus creation. Humanities scholars are usually interested in doing small scale qualitative and quantitative studies for which they need to explore web archives for relevant material. But the access to web archives with current web archive access systems like the wayback machine and rudimentary keyword search is not satisfactory. There are many other factors as well that have led to the lack of humanities studies on web archives. We attempted to illicit these through literature surveys and group discussions with humanities scholars conducting web archive research. Some of the interesting outcomes of this study were:

- The absence of abilities to explore the web archive discourage scholars from pursuing their ideas. Search engines are the predominant way of exploring the web today whereas archives seem to be left behind.
- The wayback machine is not an effective tool for building a corpus unless you know the exact set of URLs you are interested in. Full text search should be provided for researchers who want to explore the archive.
- More details of the crawl should be exposed so that scholars can motivate their

corpus of study better. The details of the crawl strategy should be added to the meta data of all documents.

- Scholars are used to working with well curated archives. Web archives pose greater burden for scholars in corpus creation since they need to curate the materials themselves.
- Due to the inconsistent nature of web archives, an error margin should be defined and an approximation of confidence as well even for small scale qualitative studies.
- Algorithms and features used to help scholars find new documents should be made transparent to users so that they can effectively document the corpus creation process.
- A web archive search system should allow for the corpus and its history of creation to be exported in standard formats researchers are used to working with.
- Scholars are interested in leveraging digital methods to analyze their data but find it hard to find tools flexible enough for their needs.

Scholars also saw potential in the usage of web archives as a playground for combining qualitative and quantitative studies. Based on our discussions with the scholars who attended the summer school in Aarhus University, we found that many would be interested in the ability to scale results up. They also bemoaned the lack of analysis tools currently available to work with web archives. The lack of technical expertise was clearly affecting a scholar's ability to conduct his research even though they knew what kind of analysis they wanted to do. We proposed that computer scientist should bridge this gap by either providing tools to support scholars or work with them on scaling up their hypothesis using pattern recognition and data mining techniques.

Initiatives are being made kick-start humanities research in web archives but to do the necessary infrastructure to first access web archives has to be in place. These initiatives are currently being carried out by national libraries and institutions like the Internet Archive and the IIPC. The BUDDAH project, a joint effort between the British Library and leading Universities in the UK, is working towards building a web archive search system by working in tandem with humanities scholars working with the UK web archive. We held discussions with members of the BUDDAH project and scholars to identify the pitfalls with the current web archive search system they were working with. The British Library web archive search prototype already provides its users with keyword search and filtering based on domain and crawl date. As noted by Costa et. al. current IR techniques like keyword search do not fare well in web archive search. We observed this first hand with the British Library's choice to rank search results by crawl date. This makes it very difficult for users to easily comprehend a large result set. We decided to better understand a scholar's search intent by analyzing written descriptions of proposed studies on web archives by humanities scholars involved in the BUDDAH project. We found that scholars are interested in studying results over time and covering a variety of aspect for their topic.

To this end we introduced the notion of a historical query intent over longitudinal collections like web archives. Historical query intent was modeled as a 2 dimension diversification problem where one dimension is time and the other aspects. In this thesis we limit ourselves to a subset of web archives: the news archive. We proposed a new evaluation metric Tia-SBR to evaluate the performance of retrieval models for this task. We also adapted existing diversity metrics to take time into account. To evaluate the retrieval models we built a new temporal test collection based on 20 years of the *New York Times* collection. We strengthened existing 1 dimensional diversity methods by linearizing the aspect-time space into a single set. We also consider temporal diversity retrieval models in our experiment. We introduced HistDiv which shows improvements over temporal and non-temporal methods for most of the time-aware diversification methods. We also outperform all competitors in Tia-SBR showing the suitability of our approach for historical query intents. We observe that HistDiv works well for topics which have aspects that span across multiple time intervals and have fluctuating importance at different times. It trades-off nicely between important aspects and important times which we perceive as important in historical search. HistDiv does not perform quite as well for queries which only one dominant aspect at a certain time window. We also described the architecture of the History Search system which consists of: a REST API to access the retrieval models used in our experiments, a user interface designed specifically to show results as newspaper articles and a time line to provide an overview and ability to filter.

5.2 Future Work

The performance of the HistDiv algorithm encourages us to look beyond the traditional approaches and devise methods more suited to archives. HistDiv currently considers time as a set of disjointed windows. It will be interesting to see if bursts rather than time windows are more effective for historical query intents. In our current implementation, subtopics are mined using wikiminer which is a relatively naive approach. In the future, we want to experiment with different types of aspect mining like LDA for instance. We also want to add more dimensions to the model like geographic locations. Just like aspect utility decays based on time, we can also decay it based on location. The absolute distance between lat long coordinates can be used or a taxonomy based approach.

The results also indicate where HistDiv performs badly and other algorithms perform well. We believe that if the user is presented with a choice of algorithms, she can effectively select the algorithm best suited to her need. A step beyond this would be to train a classifier that selects the appropriate retrieval model based on features from the query's aspect and temporal profile.

The test collection we built is still relatively small when compared to collections by TREC. We must strive to add to this test collection, by increasing the workload, or explore different avenues for evaluating retrieval models meant for archive search.

For our test collection it will also be interesting to get actual historians to provide topics. More research is also needed to construct test collections for other query intents for archives.

Having performed admirably in a news archive test collection, it will be interesting to test HistDiv and the other methods on a web archive or at least a subset which is not just news. Existing web crawl datasets only span a small period of time but it might be interesting nonetheless to experiment with smaller time window sizes for these collections. Another important temporal feature that we want to consider is the temporal references within an article. It is reasonable to assume that major bursts are usually covered by summary articles after the end of the burst. These articles are valuable but may get neglected because they do not occur within the burst based on our current algorithm. HistDiv's ability to find documents from important time windows and aspects can also be applied in Temporlia's query classification task to interesting effect.

There is also much to be done to help scholars better engage with web archives. In this thesis we have only scratched the surface of the issues surrounding intelligent access to web archives. We must work together with scholars in order to develop effective algorithms and user friendly systems so that the researchers of tomorrow can conduct their studies with far greater ease than today.

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Appendix

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