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Geographic Information Retrieval: Progress and Challenges in Spatial Search of Text

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Geographic Information Retrieval: Progress and Challenges in Spatial Search of Text

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ABSTRACT

Significant amounts of information available today contain references to places on earth. Traditionally such information has been held as structured data and was the concern of Geographic Information Systems (GIS). However, increasing amounts of data in the form of unstructured text are available for indexing and retrieval that also contain spatial references. This monograph describes the field of Geographic Information Retrieval (GIR) that seeks to develop spatially-aware search systems and support user's geographical information needs. Important concepts with respect to storing, querying and analysing geographical information in computers are introduced, before user needs and interaction in the context of GIR are explored. The task of associating documents with coordinates, prior to their indexing and

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ranking forms the core of any GIR system, and different approaches and their implications are discussed. Evaluating the resulting systems and their components, and different paradigms for doing so continue to be an important area of research in GIR and are illustrated through a number of examples. The article concludes by setting out a range of future challenges for research in this field.

1

Introduction

1.1 Setting the scene

The importance of location in search seems obvious. A large proportion of search queries include explicitly geographic search terms, for example in the form of place names (Gan *et al.*, 2008; Aloteibi and Sanderson, 2014). Local search, that is the provision of access through search engine interfaces to structured information, such as opening hours, business locations or local product availability, is estimated to be accessed by 80% of search engine users, and these users actively wish advertising to be locally relevant to their needs[1]. Location-based services, where a user's current or predicted location is used as real time contextual information in the delivery of services, are propagating at a furious pace, with a focus on providing information relevant to mobile users' needs (Reichenbacher *et al.*, 2016).

Although search engines have invested heavily in local search in recent years, results retrieved by some search engines are mostly limited to information found in commercial directory listings. The situation is certainly improving with the increasing availability via local search

[1] https://searchenginewatch.com/sew/study/2343577/google-local-searches-lead-50-of-mobile-users-to-visit-stores-study

of other non-commercial structured or semi-structured georeferenced sources and their associated web sites. There is however a large body of unstructured web content that refers to geographical information but which at present will only be retrieved if there is a direct match between the query terms and terms in the document. Effective access to unstructured documents, in which geographical relevance can be inferred, requires methods that can recognise the presence of geographic references in documents and resolve these unambiguously to locations on the earth's surface. This includes automated interpretation both of place names and of qualifying spatial relationships in queries and in documents. The development of such methods in combination with techniques for indexing, ranking and retrieval of the associated content is the focus of this article.

Understanding geographical information in natural language or free text presents many challenges. Consider the query "beaches near Calgary". It consists of three important parts, a theme (*beaches*), a spatial relationship (*near*) and a location (*Calgary*). As is typical of most queries in information retrieval, it is under-specified and ambiguous. The geographical nature of the query delivers a number of additional challenges, many of which are difficult to address through standard information retrieval techniques. For example, it is unclear which Calgary is referred to (the landlocked but populous capital of Alberta in Canada, or the beautiful Calgary Bay, found on the Scottish island of Mull). Furthermore, what does "near" mean in such a context? Is it simply a set of beaches ranked by distance from some point location (the centre of downtown Calgary for instance), or all of the beaches found in some constrained space (e.g. all of the beaches on Mull), or beaches within some context-specific travel time or distance from Calgary?[2] Finally, beaches themselves can range in length from a few tens of meters to many kilometers, raising the question of appropriate ways of representing, ranking and comparing documents describing different beaches in the user interface.

[2]Note that however "near" is defined for beaches, it will have a different definition when the reference and user location change. "beaches near Calgary" implies a different definition of *near* than "coffee near the Hilton" or "airports near Laramie".

Dealing with these, and numerous other challenges, lies at the core of what has been termed geographic[al] information retrieval[3]. The field was initially defined by Larson (1996) as "an applied research area that combines aspects of DBMS research, User Interface Research, GIS research, and Information Retrieval research, ... concerned with indexing, searching, retrieving and browsing of geo-referenced information sources, and the design of systems to accomplish these tasks effectively and efficiently" (p. 81). Jones and Purves (2008) refined this definition by emphasising, analogous to definitions of information retrieval, the importance of unstructured text: "GIR is therefore concerned with improving the quality of geographically specific information retrieval with a focus on access to unstructured documents such as those found on the Web" (p. 219). In the context of the example query given above, this definition has the important implication that GIR must be able to detect and resolve references to locations, typically but not exclusively in the form of place names, or more formally *toponyms*, from unstructured text documents.

Figure 1.1 illustrates schematically a basic model of a GIR system (from a more system-oriented perspective), which allows us to introduce the core concepts which will make up this article. The first component in such a system is a user interface, which mediates between the user and the system and supports user interaction, for example, helping users formulate queries, evaluate results and reformulate their search. With regard to query formulation it is important to consider cognitive representations of space and how these might influence natural language used to specify an information need that includes a spatial component. After a query has been formulated, it must be processed by the system to resolve under-specified information, or present the query and/or initial results to the user for reformulation. Typically, the query is then passed to one or more indexes and documents are retrieved, along with some information as to their (system defined) relevance. Based on these values, documents are ranked, and the results presented to the user in the interface. The representation of results may be optimised to

[3]Further details about Information Retrieval systems can be found in IR textbooks, such as (Baeza-Yates and Ribeiro-Neto, 2011; Manning *et al.*, 2008; Hearst, 2009; White, 2016)

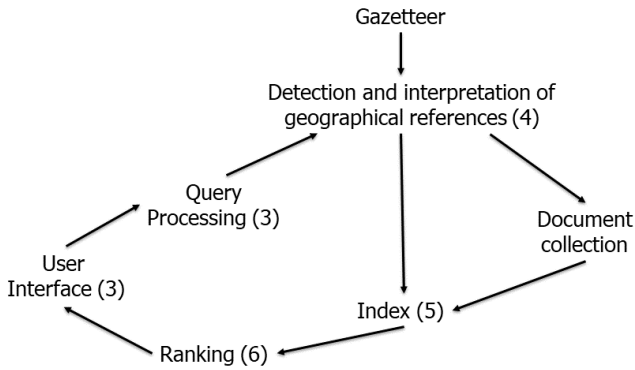

Figure 1.1: Schematic conceptual diagram of a GIR system and its related components - numbers indicate chapters where these topics are handled

allow browsing of large volumes of data or, in a more typical search paradigm, provide a ranked list of potentially relevant results. The user may then choose to refine the query, or click through to further information based on the results initially presented. Having designed a system capable of responding to queries with geographic content, an important research task is to demonstrate that a given system offers advantages over previously published work, through a thorough and reproducible evaluation.

Underlying such a system are a number of other key elements, always including a document collection itself, and typically a gazetteer (which records place names and associated information such as coordinates) or other structured geographical information. Document collections may simply be some part of the web, or more specific documents, for example relating to news stories, travel reports or mountaineering literature. The nature of these collections, for example in terms of their spatial distribution and biases or in terms of the target readership of a set of articles, have important implications for the design and evaluation of any

resulting GIR system, and should be carefully considered. Gazetteers, which typically take the form of lists of place name related information, including geographic coordinates, form one of the key bridges between the disciplines of Information Retrieval (Baeza-Yates and Ribeiro-Neto, 2011) and Geographic Information Science (GIScience) (Goodchild, 2010). These disciplines, underpinned by research in computer science and geography, form two important areas from which much work in the field of GIR has emerged.

1.2 Exemplar GIR systems

As set out in the previous section, the focus of this article is on unstructured text, and methods which allow geographic references in such text to be identified and indexed, together with associated thematic information. By indexing such information it is then possible to both perform targeted searches using some form of query interface, and to explore content with respect to location and theme. In practice, as we will show in the following sections, much research on GIR has focussed on individual aspects of the process (e.g., on georeferencing, ranking, indexing or evaluation). However, in the last decade or so numerous authors have developed more or less complete process chains aimed at performing Geographic Information Retrieval. These process chains vary widely: firstly, with respect to their purpose; secondly, in terms of the text corpora analysed; thirdly, with regard to the external resources used in, for example, structuring space and retrieving toponyms; and fourthly, through the different methods applied to carry out georeferencing, indexing, as well as querying and ranking. Here we introduce a number of exemplar systems and summarise key points with respect to the first three issues. The reader should note that the selection of systems chosen here is not exhaustive; rather these have been identified to illustrate different aspects of GIR in the remainder of this article. In selecting systems our focus was on published literature related to the systems, which have mostly been implemented in a research context and, as is typical in research, many of these systems are no longer maintained. Further examples and a comparison of systems can be found in Palacio

et al. (2010). In subsequent sections we will refer to the approaches taken by these systems where appropriate.

One of the earliest examples of a GIR system was GIPSY (Larson, 1996) which aimed to allow search within a so-called Digital Library. GIPSY focussed on analysing documents rich in geographic content, and used a gazetteer derived from the US Geological Survey's Geographic Names Information System (GNIS) for California. The Web-a-Where project was one of a number of early initiatives which linked locations from gazetteers to web pages (Amitay *et al.*, 2004). Web-a-Where used a number of corpora including a small (200 page) collection of .gov pages, mostly stemming from the US, and a second small collection from the Open Directory Project (ODP) with worldwide coverage. Gazetteer data were again derived from GNIS for the US, and from a number of other sources for non-US locations.

The SPIRIT search engine again focussed on web documents (Purves *et al.*, 2007), but used an initial corpus of some 94 million web pages to georeference 900,000 documents referring to locations in the UK, France, Germany and Switzerland. Gazetteer data were sourced from two datasets - firstly SABE (Seamless Administrative Boundaries of Europe) and, secondly, only relevant to the UK, the Ordnance Survey 1:50000 Scale Gazetteer. The STEWARD search engine (Lieberman *et al.*, 2007) was also initially developed to search general web documents, but also introduced the notion of searching on more specialised corpora, and in particular news articles.

News stories have proved very rich sources of corpora for GIR. Perhaps the most prominent example of an individual system is NewsStand (Teitler *et al.*, 2008), which focussed on collecting and effectively visually summarising news stories in real time, and required the use of gazetteers adapted to the geographic coverage of the sources used. NewsStand thus differed from the systems described previously in that the system was designed to deal with streamed, rather than static, content. Content sourced from newspapers and news wires formed the basis for many of the evaluation tasks in the cross-lingual geographic evaluation efforts known as GeoCLEF (Gey *et al.*, 2005; Mandl *et al.*, 2008a). Sources included, among others, the Los Angeles Times and the Glasgow Herald in English, Der Spiegel in German and Público in Portuguese. The vary-

ing coverage of these collections, and their underlying languages, meant that systems had to adapt in terms of the supporting data used, with challenges emerging due to the local nature of coverage and resulting gaps in gazetteer based knowledge (Stokes *et al.*, 2008).

Methods from GIR have obvious applications in allowing corpora to be analysed and explored. One commonly cited class of corpora relates to cultural heritage. Thus, for example, the Virtual Itineraries in the Pyrenees (PIV) project focussed on extracting spatial and temporal information from a regional media library containing articles pertaining to the Pyrenees (Gaio *et al.*, 2008). As with NewsStand, this in turn implies that a locally adapted gazetteer is made available, so that more fine-grained toponyms can be identified. A similar approach, focussing on natural features, was taken by Derungs and Purves (2014) to characterise spatial regions according to text used to describe them. This work analysed articles from the Swiss Alpine Club dating back to 1865, and used an administrative gazetteer provided by the Swiss national mapping agency to identify fine grained toponyms.

Both of the examples described above deal with corpora with primarily national or regional coverage. Other researchers have used GIR methods to summarise large textual corpora at coarser scales and for much larger geographic regions (ranging from the US to the entire world). The requirement for detailed information in gazetteers is correspondingly lower, and systems of this nature have also sought to use machine learning methods to georeference content without recourse to gazetteers. Key here is the availability of training data with coordinates, of which perhaps the most prominent example is GeoWiki - the set of Wikipedia pages associated with latitudes and longitudes. Two examples of such systems are FrankenPlace, which allows visualisation of thematic terms extracted from travel blogs and Wikipedia (Adams *et al.*, 2015) and an exploration of two much more specialised corpora, both of which nonetheless have global coverage, using the TextGrounder system (Brown *et al.*, 2012). A final example is recent work from Wang and Stewart (Wang and Stewart, 2015) who seek to link semantic information about hazards to both location and time.

1.3 Structure of the article

In this article we aim to bring together research on all elements of Geographic Information Retrieval, with a focus on methods which are applied directly to unstructured text[4], where geographically relevant information is present, but must be detected and annotated through the use of appropriate methods. Our aim in writing the article is to provide an overview of the research field, and in so doing identify key remaining research challenges in GIR.

In the following chapters, we start by exploring some basic geographic concepts, and reviewing ways in which space is represented and analysed in Geographic Information Science. Chapter 3 then considers the issue of user needs in GIR and how these can be met by different forms of user interface, many of which are designed to assist the user in visualising the geographic context of the retrieved information. The next chapter, on georeferencing, addresses the fundamental problem, highlighted in this introductory chapter, of identifying references to geographic location in unstructured text, typically in the form of place names, and resolving these references to specific locations on the Earth's surface. The following chapter on indexing reviews various approaches of spatio-textual, or spatial keyword, indexing, that integrate techniques of text indexing and spatial indexing to provide efficient access to large document collections in ways that support user queries that refer both to thematic concepts and to geographical location. The challenge of how to rank the resulting retrieved documents to take account of both the thematic and geographic context is the subject of Chapter 6 on relevance and ranking. Key to improving the quality of retrieval systems in ways that help to make the results useful and accessible to the user is the effective development and implementation of schemes for evaluation, which form the subject of Chapter 7. Each of Chapters 3 to 7 refers to some of the exemplar systems that were introduced in the current chapter. This is either in a separate section of the chapter or, in the case of Chapter 3, they are referred to directly within parts of the chapter. We conclude by presenting a number of research challenges that we

[4] Our focus in this article is on written text, rather than social media.

believe need to be overcome in order be successful in advancing the field of geographic information retrieval.

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