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Supporting geographically-aware web document foraging and sensemaking

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ABSTRACT

This paper reports on the development and application of strategies and tools for geographic information seeking and knowledge building that leverages unstructured text resources found on the web. Geographic knowledge building from unstructured web sources starts with web document foraging during which the quantity, scope and diversity of web-based information create incredible cognitive burdens on an analyst's or researcher's ability to judge information relevancy. Determining information relevancy is ultimately a process of sensemaking. In this paper, we present our research on visually supporting web document foraging and sensemaking. In particular, we present the Sense-of-Place (*SensePlace*) analytic environment. The scientific goal of *SensePlace* is to visually and computationally support analyst sensemaking with text artifacts that have potential place, time, and thematic relevance to an analytical problem through identification and visual highlighting of named entities (people, places, times, and organizations) in documents, automated inference to determine document relevance using stored knowledge, and a visual interface with coupled geographic map, timeline, and concept graph displays that are used to contextualize the contexts of potentially relevant documents. We present the results of a case study analysis using *SensePlace* to uncover potential population migration, geopolitical, and other infectious disease dynamics drivers for measles and other epidemics in Niger. Our analysis allowed us to demonstrate how our approach can support analysis of complex situations along (a) multi-scale geographic dimensions (i.e., vaccine coverage areas), (b) temporal dimensions (i.e., seasonal population movement and migrations), and (c) diverse thematic dimensions (effects of political upheaval, food security, transient movement, etc.).

1. Introduction

The web provides tremendous and exponentially expanding information resources that can be used to support diverse research and analytical tasks. Examples include: exploring public and local government responses to flu outbreaks (based on news reports and health department bulletins), understanding geographic variation in perspectives on environment-development trade-offs (based on analysis of organization web sites and reports), monitoring and anticipating changing geopolitical situations (through integrated analysis of government documents and news stories), and analyzing the context of humanitarian crises for relief funding decision making through situation report analysis.

Assembling and making sense of relevant web resources to support these and other similar tasks is continually problematic due to the escalating volume of information contained in semi-structured and unstructured documents available through open source information channels (news reports, organization web sites, government information bulletins, blogs, etc.). The volumes of potentially relevant data are much greater than can be processed by hand. We propose a visual analytics approach to cope with this data volume. Broadly, visual analytics has been defined as the "science of analytical reasoning facilitated by interactive visual interfaces" (Thomas & Cook, 2005). Here, we focus on integration of visual and computational methods to augment human information foraging and sensemaking abilities; thus to augment abilities to find relevant information and construct knowledge from that information.

Document foraging and sensemaking with large numbers of diverse documents creates three essential challenges. The first is a scientific challenge to make foraging effective by identifying and contextualizing the most relevant documents and to support sensemaking that is based upon context-dependent relationships among topics, themes, events, and locations identified in those documents. The second is a technical challenge of quickly harvesting and processing documents (i.e., extracting relevant text from web pages, geocoding locations, extracting key words) to support

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the iterative foraging-sensemaking process. The third is a visual interface challenge of leveraging human expertise and supporting analytical reasoning with fragmentary information of uncertain quality and relevance extracted by the computational processes (e.g., information providing input about where, when, and why events are happening).

In this paper, we present the Sense-of-Place (*SensePlace*) analytic environment that is designed to address these challenges. *SensePlace* is a proof-of-concept system for rapid web document acquisition and contextualization. In particular, the concept behind *SensePlace* is a visual analytics approach and associated software application that (a) integrates visual interfaces with computational methods that reason and/or support reasoning with or about place-based information and that (b) can be used successfully to forage through web documents relevant to both concepts of interest and places of interest and enable a sensemaking process with the foraged heterogeneous, semi-structured, place-based information. We provide a proof-of-concept of the first component through our implementation of a working system, a demonstration that the system can in fact be used, and open source software that others can build upon. We provide evidence of the potential application to foraging and sensemaking in complex problem domains by (a) describing an analytical scenario that was used to formulate the requirements for *SensePlace* and (b) presenting detailed results of an analysis based on the case study that used *SensePlace* to build an integrated understanding of human population movements in a place (the country of Niger and its neighbors) to support infectious disease analysis.

We begin by outlining the theoretical framework that underlies the design, motivation, and implementation of *SensePlace* to address the research challenges detailed above. After this, we provide a technical overview of the *SensePlace* environment. Then, we present results of a case study analysis using *SensePlace*. Next, based on insights from the case study, we provide ideas for future work and enhancements to our system. The paper ends with conclusions we draw from our work.

2. Theoretical framework

2.1. What is sensemaking?

According to Klein, Moon, and Hoffman (2006:71) "Sensemaking is a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively". In most real-world problem domains, sensemaking is a complex, iterative, non-linear process that involves multiple overlapping tasks; these tasks are often focused on finding structure in ill-structured information. While much of the early research on sensemaking emphasized organizational management (Weick, 1988), and that focus remains, more recent attention has been directed to the sensemaking process of individual intelligence, crime, bibliographic, and other analysts (Bex et al., 2007; Pirolli & Card, 2005; Stasko, Gorg, Liu, & Singhal, 2007; Zhang, Qu, Giles, & Song, 2008). There is a strong commonality between current sensemaking research foci and past work in geographic visualization on support for scientific thinking and knowledge construction using integrated visual and computational methods (for examples, see: Gahegan, 2005; MacEachren, Gahegan, & Pike, 2004). Drawing upon these separate but related developments in sub-sections below, we discuss the close connection between information foraging and sensemaking that motivates our work together with the role of visual analytics in supporting sensemaking and then discuss the place, time, and concept inputs that are critical to place-based sensemaking about evolving situations.

2.2. Information foraging and sensemaking & visual analytics

According to Pirolli and Card (1995:52), "... information foraging refers to activities associated with assessing, seeking, and handling information sources"; for details, see Pirolli (2007) and Pirolli and Card (1999). Information foraging is integrally connected to the processes of sensemaking. Mental or tangible representations of information being retrieved through foraging activities will be compared to, integrated with, and sometimes replace existing knowledge so that (a) task-specific questions can be answered and (b) determination of level of effort to identify additional relevant information can be made (Pirolli & Card, 1995; Russell, Stefik, Pirolli, & Card, 1993). Pirolli and Card (2005) model the interaction between knowledge and mental or tangible representations of retrieved information by conceptually coupling information foraging and sensemaking into two "loops." The first is the foraging loop where data is first collected and organized. The second is the sensemaking loop where hypotheses are generated, tested, and presented. Both loops can incorporate analytical reasoning (by human analysts, supported by representations and interfaces) to support decision making about documents to forage for as well as reasoning about the foraged information to draw conclusions and to augment existing or build new knowledge.

Those engaging in sensemaking rely on both mental and tangible (typically visual) representations to structure or frame the information organization process (Peuquet, 1994). When the focus of attention is sensemaking about geographic-scale phenomenon and processes (e.g., disease diffusion, drought, population migration, etc.), mental and tangible representations individually or collectively must provide a basis for reasoning about the place, time, and concept components of information (Tomaszewski, 2008). Visual interfaces provide a key support mechanism for creating these representations (Bier, Card, & Bodnar, 2008; Proulx et al., 2006; Stasko, Görg, & Liu, 2008). In the present work, we emphasize visual interfaces to geographic and temporal representations that can be used to organize unstructured web content by spatio-temporal location and scale.

2.3. Place, time, and concept inputs to sensemaking

From various philosophical, geographical, psychological, and scientific perspectives place, time, and concept (sometimes characterized as object or attribute) together provide a partial basis for general understanding of the world (Peuquet, 2002). Furthermore, space and time can shape the themes, concepts, and perspectives used to understand geographic events and processes, Thus, it is logical, particularly for domains in which geography is relevant, to conceptualize sensemaking as having place, time, and concept inputs. A practical aspect of using place, time, and concept as inputs to sensemaking is to help simplify reasoning about complex geographic events and processes (Tomaszewski, 2008; Wang, Miller, Smarick, Ribarsky, & Chang, 2008). Using the intuitive categories of space, time, and concept can help to simplify reasoning by providing a common-sense structure of information (i.e., comparable to the classic "what, when, where, who and why" structure of news reporting) (Peuquet, 1994).

In the following section, we present our proof-of-concept system based on the principals discussed in Section 2.

3. The Sense-of-Place analytical environment

The scientific goal of the Sense-of-Place (*SensePlace*) analytical environment is to visually and computationally support geographically-centric sensemaking with text artifacts having potential place, time, and concept relevance to an analytical

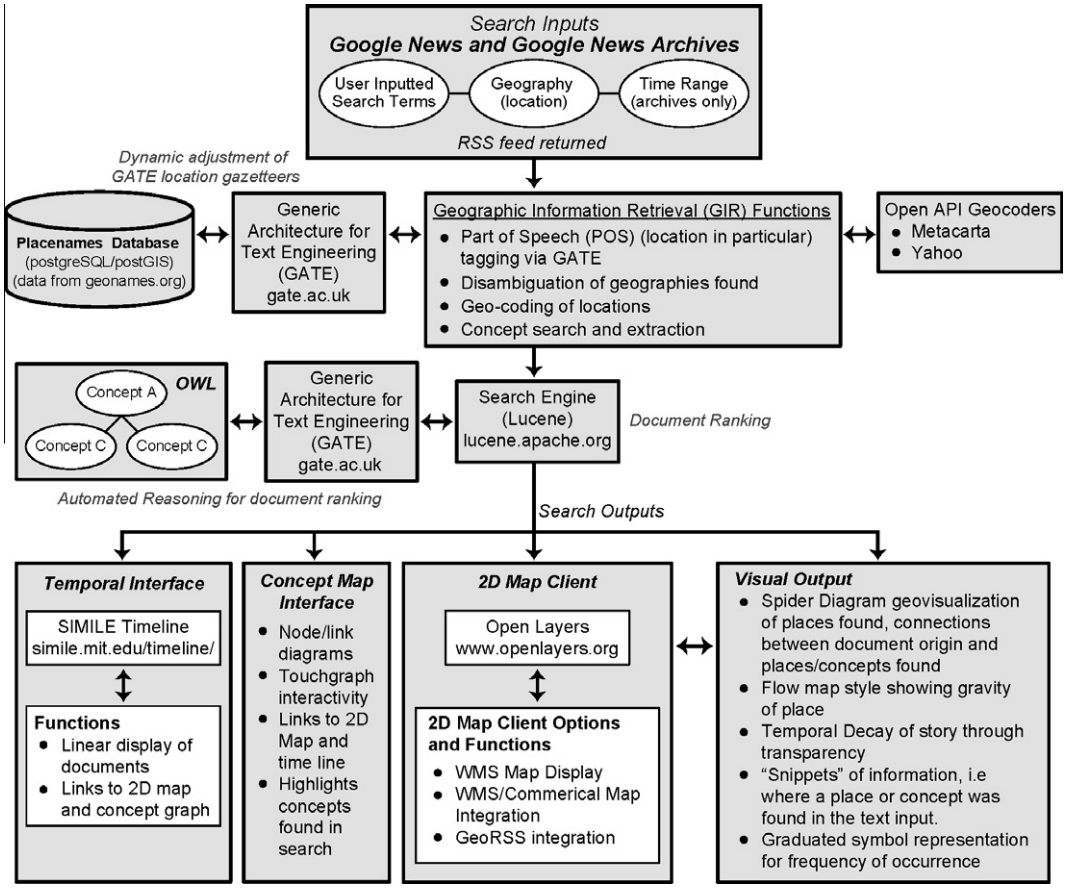

Fig. 1. *SensePlace* architecture overview.

problem. *SensePlace* is a free open source web environment built using Adobe Flex, Java, and Open Geospatial Standards technologies.[2] The label "*SensePlace*" used for the environment is meant to convey a duality with "sensemaking," as per the ideas discussed in Section 2, and "Sense-of-Place," as a perspective in Geography that examines the characteristics and attachments that make locations (or places) unique (Tuan, 1990). An important aspect of *SensePlace* from a visual analytics research perspective is the emphasis we put on combining machine-based sensemaking and reasoning with visual interfaces that support human sensemaking and reasoning. Fig. 1 provides a high-level overview of the *SensePlace* system architecture.

In the following sections, we discuss the major computational and visual interface components of *SensePlace*.

3.1. Computational sensemaking

Computational sensemaking in *SensePlace* is facilitated using ontologies. Ontologies are a common representation device used to formally model knowledge domains (Masolo et al., 2002). Knowledge modeled in an ontology can be utilized as a precursor to and support mechanism for human sensemaking; this support can be provided using automated reasoning services, or what we call computational sensemaking methods.

In its current implementation, *SensePlace* supports use of an existing, user-defined (rather than formally defined or automatically constructed) ontology for automated reasoning. *SensePlace* uses automated reasoning (AR) techniques to determine relevance rankings of documents retrieved from RSS (Really Simple Syndication) feeds in relation to queries sent to the document repositories by using, in part, query terms derived from the user-defined ontology. AR supplies reasoning that is not realistic for a human analyst to do, such as making inferences about 1000 s of documents in a time span of a few seconds to find the few that are most likely to be relevant. In essence, AR is used to "make sense" (in a rough, first approximation) of what is retrieved in terms of the classic information retrieval paradigm of attempting to match the documents retrieved to the user's information needs (Pirolli, 2009). The visual interface then supports an iterative human sensemaking process to refine (or refute) this approximation.

The specific way in which AR is used to "make sense" of document relevance is through query expansion (Vallet, Fernández, & Castells, 2005). Query expansion is the notion of taking a base query string and reformulating or adding additional terms to the base query to increase retrieval performance (Efthimiadis, 1996). For example, a search using the term "refugee camp" could be expanded to include the terms "displaced persons camp", "tent city", or "transitional shelter." More specifically, *SensePlace* incorporates the basic idea of query expansion by using AR to select additional query terms from an ontology that are related to user-supplied search terms through class subsumption and realization relationships. Succinctly, class subsumption is the determination of sub/super concept relationships, and is in essence, used to compute class hierarchies (Turhan, Springer, & Berger, 2006). Using a geographic example, US states are subconcepts of political entities and all instances of states (i.e., New York, Pennsylvania) are also political entities. When all subsumption relationships have been

[2] http://code.google.com/p/geovista/ (Last retrieved 27 April 2010).

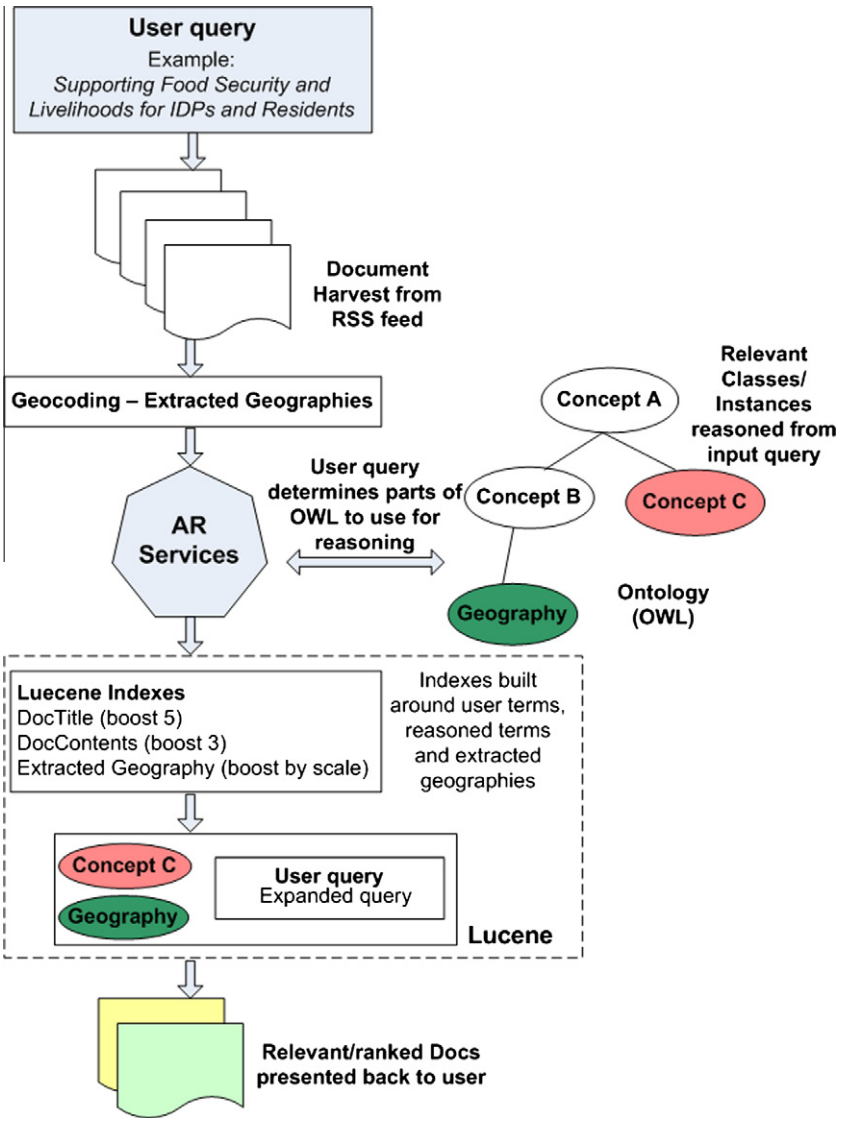

Fig. 2. Query expansion and document ranking process.

computed, the ontology is said to be classified, a step needed to support other reasoning services, such as instance realization. Instance realization determines which concept an instance is most closely related to (Baader, Calvanese, McGuinness, Nardi, & Patel-Schneider, 2003). For further technical details of the AR methods and their software implementation incorporated in *SensePlace*, see Tomaszewski (2009).

Fig. 2 provides a high-level overview of the *SensePlace* query expansion and document ranking processes. The ontology used in the Niger case study presented below (derived from our prior work on humanitarian crisis contextualization Tomaszewski & MacEachren, 2010), included information on disease, food security, political events, livelihood, infrastructure, migration and mining.

3.2. Geographic information retrieval

The ontology-based computational sensemaking tools described above are used to support the Geographical Information Retrieval (GIR) components of *SensePlace*." We discuss *SensePlace* GIR capabilities in this section. It is important to note that GIR is an enabler within *SensePlace*, not the focus of research advances. Thus methods implemented and described here leverage a suite of existing GIR web services and open source tools in support of the research advances at the heart of *SensePlace*; the latter as outlined above are advances in visual interfaces to support foraging and sensemaking enabled by computational methods to process volumes of data larger than practical for individual analysts.

The foundation of GIR methods used in *SensePlace* is geographic term identification and resolution to latitude and longitude coordinates using the Metacarta (Rauch, Bukatin, & Baker, 2003) and Yahoo geocoding services.[3] As developing new methods for disambiguating place references in documents is not a focus of this research, the disambiguation capabilities of these commercial-grade geocoding services were deemed useful for our research. Furthermore, we are also able to impose a geographic focus to documents by using the advanced search options of Google News, which can restrict documents searches to certain locations.[4]

[3] Between initial submission of this paper and revision, Metacarta's free service was removed from the web but other services have become available (e.g., Yahoo, OpenCalais) – our system is designed to allow flexibility about which geocoding service is used.

[4] http://news.google.com/news/advanced_news_search?pz = 1&cf = all&ned = us&hl = en (Last retrieved 27 April 2010).

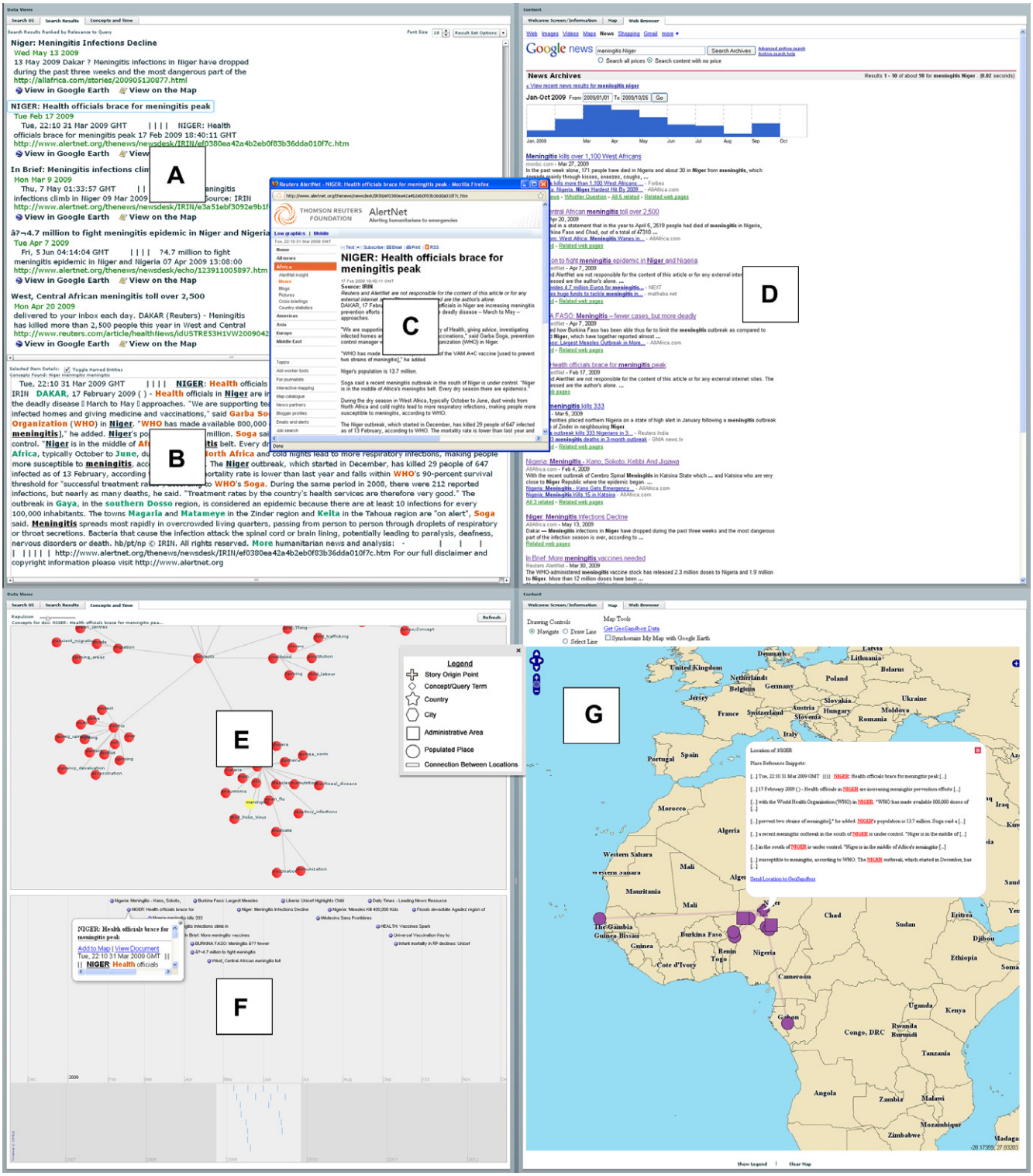

Fig. 3. Overview of the tool's visual interface components. Label **A** is the search results interface, **B** is the selected item details view, **C** is a document that has been retrieved, **D** is the Google search results interface, **E** is the ontology graph view, **F** is the timeline view and **G** is the geographic. In this figure, news stories related to meningitis in Niger are being examined. Label **A** presents a list of articles found. The analyst is able to view a summary of this article in Label **B**. The key search terms are easily recognized in bold, black, underline. In addition the analyst can check the concepts found by viewing the ontology graph view (Label **E**) where the concept will be highlighted in yellow. If the article is relevant the analyst can read the article (Label **C**) by clicking on the link in Label **A** and map the geographic content of the article (Label **G**). Colors indicate different documents; point shapes indicate different scales of locations found; line thickness represents the frequency in which a place has been referenced in a document. The user can further examine the context in which a place has been referenced in a document by clicking on the symbol on the map, as evidenced by the map bubble showing a place reference "snippet". Lastly, the user can determine the timing of events by seeing when documents were published on the timeline graph (Label **F**).

Leveraging these geographic term identification and resolution services, *SensePlace* GIR methods focus on using geographic terms indentified from documents along with ontology-based terms (discussed in the previous section) for document ranking. The basic idea behind document ranking is to assess how closely related a given document is to a query posed against a set of documents.

The more closely related a document is to the query, the more *relevant* the document is considered to be for the information needs of the person or computational process conducting the search. One of the most common and popular mechanisms to support document ranking is the vector-space model (VSM), discussion of which is beyond the scope of this paper, see (Manning, Raghavan, & Schütze, 2008; Salton, Wong, & Yang, 1975).

SensePlace utilizes a version of the VSM that is supplied as part of the Lucene[5] open source search engine. Lucene was selected as it is a stable, easy to use, well documented search engine. In terms of its interaction with other *SensePlace* components, Lucene was used to make the final rankings of the documents retrieved by a query. The Lucene rankings utilize a custom procedure to set the indexes, document fields and boost factors for documents when applying its version of VSM.

In Lucence terminology, an "index" refers to a collection of documents that are stored in an indexed database repository and are analyzed as one unit. Documents within the index have *n* number of fields assigned to them. Fields are used to create reference points within documents for querying. For example, a document from an RSS feed actually consists of four components – the document's title, description, date published, and the document's body. The contents of each of these components can be added as separate fields when creating a document in Lucene that is added to a given index. Then, when queries are run against the index, selected fields can be included in the query if needed. By restricting fields included to the most relevant ones, query processing time can be reduced.

Boost factors refer to additional numerical weights that can be added to terms when calculating their rank scores. Boost factors are a feature that Lucene adds to the classic VSM approach it uses for calculating document/query similarities.[6] *SensePlace* takes advantage of this powerful feature of Lucene by setting boost values for terms based on factors such as the scale of geographic terms found in documents, reasoned query terms versus user defined explicit query terms, and reasoned geographic terms and geographic terms derived through the geocoding procedures. Boost values for geographic terms were based on weights used in Overell, Magalhaes, and Ruger (2007).

The combined results of computational sensemaking and GIR methods are presented to analysts through a place-time-concept enabled interface. We discuss the visual interface provided by *SensePlace* in the next section.

3.3. Visual interface

SensePlace provides a visual interface with a series of views onto the artifact processing methods and their results that individually and collectively are designed to support sensemaking by an analyst. The interface and its views are implemented in Adobe Flex and are organized as interchangeable tabs within the overall interface. Fig. 3 shows the specific views that were created. These views include a search results interface (Fig. 3A–D), a timeline (Fig. 3F), a geographic map (Fig. 3G), and a concept graph (Fig. 3E).

Users have simultaneous access to pairs of views; thus they can explore highlighted text and adjacent maps, text and a timeline + concept map, map and timeline + concept map, etc. By dragging tabs from one side of the interface to the other, they can rearrange views to suit their analytical needs and preferred work process. Original documents pop up in a separate browser window. A particular emphasis is made in each component to provide the analyst with visual summaries of foraged information so decisions about which artifacts to investigate further can be made quickly. The combination allows analysts to investigate the where, when, and what components of artifacts independently and together. The integrated analysis helps to address questions about why particular events have happened or situations have developed at particular times and in particular places. In the following sub-sections, each of these interface views is described.

3.3.1. Search results view

SensePlace currently supports queries to the Google News[7] and Google News Archives[8] search engines. Google News is used for obtaining current documents about a subject of interest. Google News documents are obtained via an RSS feed in which the contents of each document referenced in the RSS feed is obtained from the documents' source web page and geographic and thematic references within the document are extracted – a procedure outlined in Tomaszewski (2008). Google News Archives contains stories generated by news agencies as well as documents such as press releases from non-governmental organizations (NGOs). Google News Archive information is obtained by (a) transforming the Google News Archive HTML page that is returned from a query into an XML document which allows (b) the Google News archive page to be computationally processed using the tag structure that the XML imposes on the HTML page. The XML document is then traversed to find the source URL of a given Google News Archive document. Once the source URL is found, the document is then processed using the same procedure for processing documents derived from Google News RSS feeds.

Queries done to both Google News and Google archives are presented in the search result view. The primary purpose of the search result view (the top left half of the Fig. 3) is to provide quick overviews of the contents of documents foraged by web queries.

On the top of the view (Fig. 3A), documents are shown ranked by their relevance to a given query. The relevance of each article is based on the automated reasoning procedures discussed in Section 3.1 Articles ranked by *SensePlace* differ from the default Google relevance rank due to the query expansion capabilities of *SensePlace*. Formal comparison between the *SensePlace* relevance ranking and the Google relevance ranking was outside the scope of the present work; the *SensePlace* relevance rankings proved to be useful in the case study analysis conducted (see Section 4 below for details).

Overviews of individual documents are designed to look similar to Google search results (Fig. 3A). Thus, an individual document is visually represented using three components – the title of the document in bold, a two to three line summary of the beginning of the document, and the link to the original document in green. This design was selected to follow general interface design strategies that favor having each visual component of an interface match existing, familiar interface conventions (Cunningham, 2002). This approach was intended to make *SensePlace* easy to learn how to use. In usability studies of a *SensePlace* precursor system, 1 h of training was found to be sufficient to enable United Nations (UN) humanitarian relief staff to understand how to use the tools and interface (Tomaszewski, 2009). Furthermore, we have received quite positive reactions in a range of demonstrations, including to other researchers, to funding agency program officers, and even to a law enforcement officer tasked with surveying the current situation in foreign countries before study-abroad students travel to those places. These reactions, while anecdotal, suggest that the *SensePlace* environment is intuitive.

Users can obtain detail about any document of interest in two ways, by accessing the linked original web page (which appears in the adjacent tab, Fig. 3C) or accessing a *selected item details* view (Fig. 3B). The *selected item details* view applies a standard

[5] http://lucene.apache.org/ (Last retrieved 17 September 2008).

[6] For detailed information on the similarity measure used by Lucene, see http://lucene.apache.org/java/2_3_2/api/org/apache/lucene/search/Similarity.html (Last retrieved 17 September 2008).

[7] http://news.google.com/ Last retrieved 3 September 2009.

[8] http://news.google.com/archivesearch Last retrieved 3 September 2009.

overview + detail approach (Schneiderman, 1997). Detail is provided in the form of extracted 'raw text' comprising the main content from the retrieved document. This relevant raw content is extracting using HTML processing tools developed for this purpose in previous work, see: Tomaszewski (2008). The overview contains the named entities, specifically people, places, and organizations, that were identified in the raw text; entity identification is accomplished using the natural language processing functions of the General Architecture for Text Engineering (GATE) program (Cunningham, 2002). Named entities in each category are highlighted in distinct colors: people in purple, organizations in orange, and places in green. In addition, the view also highlights the concepts found in the document (in bold underscore). Concepts, in this context, are query terms entered by the human analyst and terms from the search support ontology (as discussed in Section 3.1).

3.3.2. Timeline

The timeline view (shown in Fig. 3F) allows analysts to quickly search for documents by time and to recognize temporal proximity of particular documents, clusters of documents in time, and sequences of related documents. This view supports the representation of single events (i.e., an event with a specific date/time). It also supports the representation of time spans with specific starting and end dates.

The time view is implemented using the SIMILE timeline interface (SIMILE project, n.d). As seen in Fig. 3F, the timeline supports the addition of descriptive balloons for adding additional information to events. Users can temporally review documents returned from a search in the time view by panning the time view at either the year scale (bottom part of the time view shown in Fig. 3F) or month scale (top part of the time view shown in Fig. 3F). Users can then click on a single event or duration icon, which opens an information window. This information window includes text from the original document as well as a link to add the places geocoded from the document to the geographic map.

3.3.3. Geographic map views

As each document is being processed by *SensePlace*, place names and spatial relationships are extracted, geocoded, and mapped. The integrated map view enables users to explore this derived spatial context through display on the map.

The geographic information extracted from each document includes the origin of the document (when possible to derive), any locations referenced by the document and the connections between origins and locations. Locations are represented by point symbols that vary based on the geographic scale (e.g. country, city, etc.). Lines represent the relationship between locations and the origin of the document and the thickness of the line indicates how many times the location was referenced in the document. A legend that can be moved around the interface is also provided to help the analyst understand the map (Fig. 3G).

The geographic map is interactively coordinated with the timeline. This enables the analyst to quickly recognize spatio-temporal context of the documents. Additionally, the spatial focus and extent for the geographic map can be adjusted based on interactive functions of the time and graph views of *SensePlace*. For example, selecting an event on the timeline that has a geographic connection will automatically pan the map to the location associated with the event.

The geographic information derived from each document is also provided as a Keyhole Markup Language (KML) file that can be downloaded. This file can be saved for future use as well as viewed immediately using Google Earth, allowing the analyst to take advantage of contextual information that may already be available in KML format through both publicly available and internal sources.

3.3.4. Concept graph view

The concept graph view is used to support ontology integration in order to help an analyst find and explore potentially relevant non-spatial dimensions within retrieved information. As discussed previously, the ontology is user supplied (but the current implementation requires a system administrator to insert it) and results of queries are matched against the ontology so that the user is able to see relevance of the stories to components of the ontology. Visual representation of ontologies in graph-based formats can help to conceptually structure information found in searches (which is usually loosely structured) and by making concepts of a given domain accessible to a non-expert user by highlighting those concepts when they are found in the search and thus indicating which terms may be of relevance to the user (Tergan, 2005). Concepts are visually represented in *SensePlace* using a node-link graph interface (Fig. 3E).

The following section outlines the case study we use for grounding our theoretical framework and demonstrating the practical application of the *SensePlace* analytical environment. While we present the case study here after presenting the details of the system, development of SensePlace was motivated by the underlying scenario characterized by the case study – of searching for information to understand regional situations in developing countries (to support research on infectious disease dynamics as in the case study below as well as to support activities such as sustainable development, humanitarian relief and others).

4. Case study – infectious disease dynamics in Niger

Vaccine-preventable infectious diseases such as measles continue to threaten the lives of people around the world, with the highest rates of fatality occurring among children under the age of five. In 2007, there were 279,006 measles cases reported globally. Of these, there were an estimated 197,000 deaths (World Health Organization (WHO), 2006). In regions where data are good (where, for example, records exist for cases of a disease outbreak, vaccinations, and movement of people), there are well established methods to identify the source of infection, how it moves through a population, and the rate at which it will move (see Bharti, Xia, Bjornstad, and Grenfell (2008)) However, in regions where resources are not available for collecting and maintaining such records, trying to understand disease dynamics within a population is more difficult.

In the case study reported here we are interested in understanding the dynamics of measles in sub-Saharan Africa. In particular, we focus on Niger. Ranked nearly last on the United Nations Development Fund index of human development, Niger is one of the poorest countries in the world and is continually hampered by drought cycles and desertification. Measles is a major problem, among other diseases in Niger. Since 1980, measles epidemics have occurred regularly with as many as 90,000 people infected in a single year. Vaccine coverage has helped reduce measles outbreaks, with the latest campaign in 2005. Although vaccination campaigns are in effect, populations continue to be at risk to measles and other diseases such as meningitis and polio, particularly since Niger has a very high birth rate – 51.6 births per year per 1000 population (Central Intelligence Agency (CIA), 2009).

Thus, in an effort to minimize measles epidemics (and optimize future vaccination campaigns) we are trying to understand the space–time dynamics of measles in Niger. Key components to identifying measles dynamics include:

1. Where disease reservoirs may exist. For example, areas where vaccine coverage is non-existent or limited both within Niger and within surrounding countries.

2. Understanding the movement of people. For example, restrictions on movement due to political upheaval, seasonal movement within Niger due to workforce requirements, movement outside of Niger due to food security issues, and transient movement through Niger.

Niger has good data on measles incidence over more than a decade but little or no formal data on population movement. It is, therefore, possible to develop reasonable models of past measles dynamics (as our colleagues have done, (Ferrari et al., 2008), but not to explain the patterns as they relate to geographic scale behavior of the population. *SensePlace* offers an approach and tools to fill in part of the information gap. In the following section, we report on a *SensePlace* case study application focused on the challenge of understanding past population movements in Niger (over the time period for which measles data are available). The case study, in addition to generating information to support research on disease dynamics, demonstrates how *SensePlace* can support web document foraging and related sensemaking, which can lead to further foraging as well as insights derived from information as it is contextualized using the place, time, and concept tools in *SensePlace*.

5. Using *SensePlace* – results of an analysis

SensePlace, as outlined above, is a web-based tool that provides the analyst with a quick way to sift through text-based information and to consider place, time, and concept components of that information. More specifically, it supports this process by (1) enabling the analyst to perform specific searches by geographic location, (2) highlighting key information quickly within an article (e.g. search term, geographic names and organizations), (3) providing the ability to view geographic locations mentioned in a particular article or in sets of articles on a map, and (4) supporting investigation of the timing of single/multiple events (see Figs. 1 and 2 for components and technical information). Here, "the analyst" was one of this paper's co-authors who is also a member of the Vaccine Modeling Initiative research team that is doing research to understand disease dynamics in developing countries.

While *SensePlace* includes basic tools for saving, reloading, and sharing information during foraging and sensemaking activities, we found it useful to also rely on two external tools to supplement these capabilities, the Mozilla add-in, Zotero™,[9] and Microsoft Excel. Specifically, Zotero was used to capture copies of documents found and Excel was used to record information about when and where different events occurred, e.g., droughts, disease outbreaks, vaccination campaigns, conflicts, political events (such as elections, and civil wars). The information recorded included: **Date** (i.e., Year–Month), which was either the date of the news source (if the article was talking about a current event) or the date described in the text (when the article was talking about a historical event); **Geographic location(s)**, which could be either region, country, state, district, department, or city; **Description**, or a brief description of the event; **Source**, the data source, e.g. BBC, New York Times, etc.); and a **Hyperlink** to the source.

The overall analysis process supported by *SensePlace* is illustrated in Fig. 4 with the components included within *SensePlace* illustrated in the red boxes and those in tools used together with *SensePlace* indicated in gray.

The *SensePlace* visual interface (see Fig. 3) allows the analyst to identify key time spans and to assess relevancy of articles retrieved by searches in seconds. For time, a broad overview of relevant time periods to analyze can be assessed using the histogram (Fig. 3D)

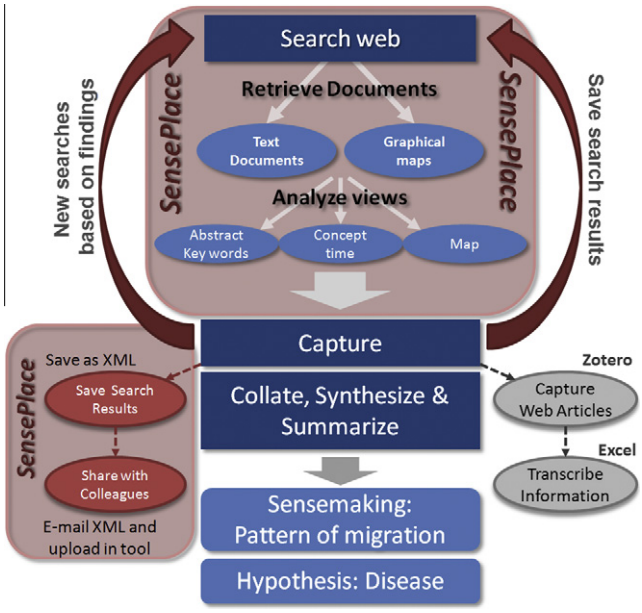

Fig. 4. The process used for foraging and sense making. The tool searches the web for text documents about a particular geographic location using the search terms entered by the user. Retrieved documents are displayed in the Results tab and analyzed by the user through the visual interface components (see Fig. 3). The user views the articles by (i) viewing the **abstract** and highlighted **keywords** to determine relevancy, (ii) view where the article is about through the **map**, and (iii) view the concepts affected and the sequence of events through the **timeline**. Articles can be captured using an add-in, Zotero, and information from relevant documents can be transcribed to a spreadsheet for later use. In addition, links to the articles and search terms can be saved using the Save Results Option to an XML and TXT file, respectively, which can be shared with colleagues or uploaded again if required in the future. Information from the articles/documents will highlight new information and prompt new searches using new keywords. The process is repeated again until the user is satisfied that they have gathered sufficient information about the topic of interest. Information gathered through this tool can then be collated, synthesised and summarized by the user. Features/Components contained within *SensePlace* are illustrated within the red box. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

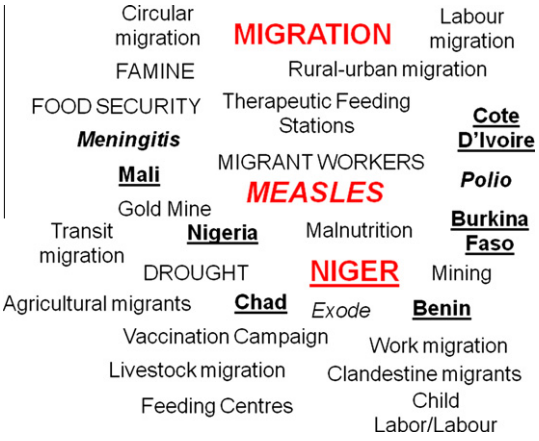

Fig. 5. An example of some of the search terms utilized to find web documents using *SensePlace* about disease and migration patterns in Niger and the surrounding countries. The search started with Migration and Measles, Niger (highlighted in red). As articles were retrieved and read new search terms were used. Some of these are illustrated here. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

with a more detailed sequence of events and possible patterns examined using the timeline (Fig. 3F). For relevancy, the combination of the *selected item details* view, with highlighted keywords, organizations and place names and the ability to depict the geographic foci of articles on a map both help analysts quickly narrow

[9] http://www.zotero.org/ Last retrieved 4 November 2009.

in on potentially relevant documents. For example, while searching for information about migration patterns, a single search provided a key article that showed the geographic range of migration (Niger to Cote D'Ivoire (approximately 700 miles South of Niger) (e.g. New York Times (1996a)). Also, geographic weighting helped the analyst find information about meningitis pathways that may be indicative of pathways for other diseases, including measles. Specifically, in Niger during the last outbreak in 2009, the sequence of reports uncovered by the analyst highlighted that meningitis was first reported in Kano, Sokoto (Nigeria) with subsequent reports in Niger and Burkina Faso.

An important feature of *SensePlace* is its focus on supporting an extended process of foraging and sensemaking rather than one-off queries. As information is being gathered the analyst can perform new searches using new terms found from articles and therefore build on existing query results. This process can continue until an analyst has obtained sufficient information about the topic of interest. For this case study, approximately 22 search terms were used for seven countries (see Fig. 5) to identify potential disease reservoirs and transmission corridors. The information was cataloged in a spreadsheet and is presented next.

5.1. Results of SensePlace Niger case study

In this section, we present the findings of the Niger case study analysis using *SensePlace*. These findings are supported with citations to the large number of sources used. All sources were either identified directly through use of *SensePlace* (i.e., they were among the results returned for search queries) or indirectly through links/pointers within the documents found directly. These results provide a proof-of-concept demonstration of *SensePlace* as an application and of the overall visually-enabled sensemaking approach it implements.

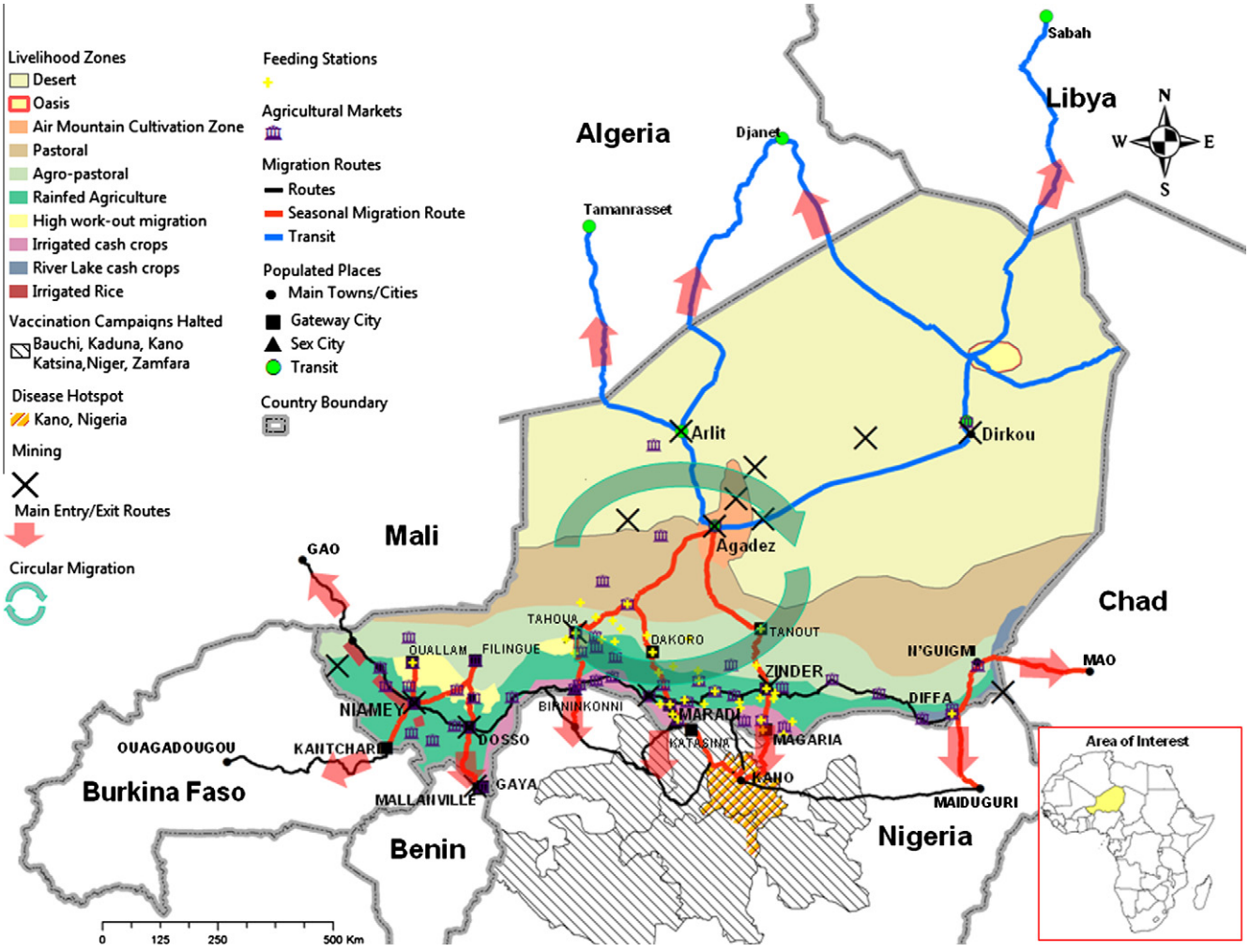

Fig. 6. A map illustrating the main travel routes throughout Niger and the surrounding countries. Migrants will enter/depart Niger through a variety of routes along the border of the country (black lines). Once they have reached Agadez, Arlit or Dirkou they will take the main Transit Routes (blue lines) to Europe via Algeria/Morocco or Libya. Seasonal migration is circular and exists throughout the region with mainly a North–South movement (illustrated through the red lines). Migrants will move through the different livelihood zones either to agricultural or pastoral areas. High out-migration occurs in three main areas Loga, Ouallam and Tahoua (FEWSNET, 2005). During the dry season movement can be to feeding centers (purple crosses), mining areas, larger towns/cities in Niger (e.g. Niamey, Maradi, Zinder, Agadez) and Northern Nigeria (e.g. Kano, Sokoto, Maiduguri) as far as Abidjan (Cote D'Ivoire). The map was constructed manually in ArcInfo, but is based on a combination of information found in sources identified directly by SensePlace plus information in sources pointed to by the SensePlace identified documents: Feeding Stations (Médecins Sans Frontières (MSF), 2005), Mining (compiled from (Alfa, 1999; Herald Tribune, 2008; IRIN Africa, 2007a; United State Geological Survey (USGS), n.d)), Livelihood Zones (FEWSNET, 2009),Gateway City (Rain, 1999) Transit City (compiled from (IRIN Africa, 2007a; IRIN Africa, 2008a; Johnson, 2005; New York Times, 2001b; OECD, 2008; OECD, 2009; Reuters, 2002)), Sex City (compiled from (New York Times, 2001b; Reuters, 2002; The Independent, 2001)), Transit migration route (compiled from IRIN Africa (2007a), Johnson (2005), New York Times (2001b), OECD (2008, 2009)), Seasonal migration routes (Daily Trust, 2008; New York Times, 1996a; OECD, 2009; Rain, 1999). Roads (Environmental Systems Research Institute, 1993a), Boundaries (Environmental Systems Research Institute, 1993b), Cities (Environmental Systems Research Institute, 1993b). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

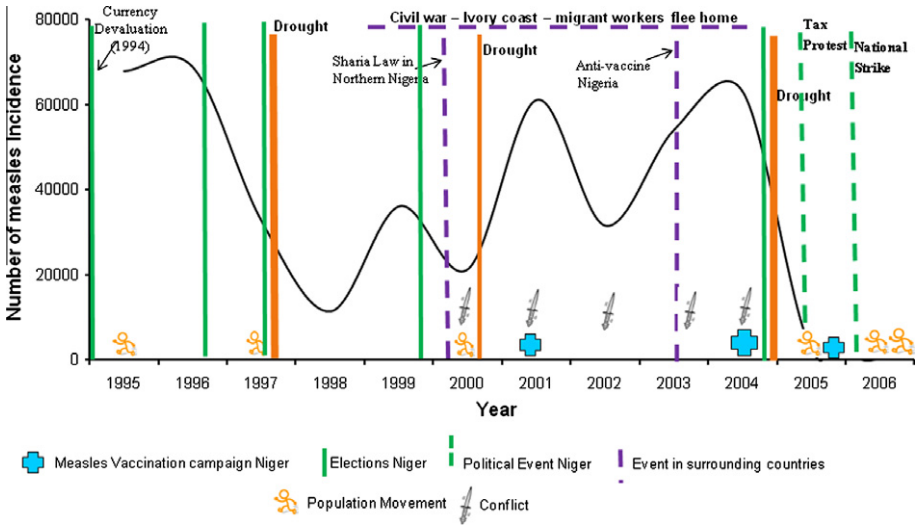

Fig. 7. The timeline of events occurring between 1995 and 2006 in Niger and the surrounding countries in relation to measles occurrence in Niger (solid black line). Detailed description of each event along with the source of the data is summarized in Table 1. Droughts are highlighted in orange with worse years being depicted with thicker lines. Vaccination campaigns for Niger are shown with a blue cross with national countrywide coverage illustrated with a larger blue cross. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Human migration patterns in Sub-Saharan Africa are strongly linked to the geography of the region. Migration patterns in Niger mainly follow historic trading routes (see Rain, 1999 where detailed fieldwork was conducted in the city of Maradi, Niger to understand migration patterns) such as the former trans-Saharan salt trade routes, which are mainly used by clandestine/transit migrants today (ECOWAS-SWAC/OECD, 2006; IRIN Africa, 2008b; New York Times, 2002). Due to the harsh Sahelian climate, the nomadic existence of the majority of the population has been used as a survival strategy against the annual hunger season; from June (post planting) to September/October (harvest) and has subsequently led to the development of seasonal migration patterns where millions of people will travel to find work to help their families survive, returning home when the rains begin to help plant and harvest (IRIN Africa, 2007b).

Three main forms of migration occur within Niger and the surrounding countries (summarized in Fig. 6) and include:

A. *Transit* or temporary migration *en route* to a destination beyond the Nigerian border. Niger and Mali are the gateway countries to Europe for many Africans and house a large number of transient migrants (New York Times, 2001b; OECD, 2008). This has lead to an increase in transit migrants in particular towns such as Agadez, Dirkou and Arlit as they wait for passage (New York Times, 2001a; OECD, 2009; IRIN Africa, 2008b; New York Times, 2002). The consensus is that number of migrants passing through Niger remains difficult to estimate (IRIN Africa, 2008a; New York Times, 2001a; OECD, 2009).

B. *Exode* or semi-permanent work migration beyond the country border. This category includes temporary work migration of Niger residents leaving their villages to seek work outside of Niger particularly in Nigeria, Libya and Cote d'Ivoire (Bliss, 2008). Migrations can last 3 months to several years. *Exode* migration is vital to many families with remittances totaling close to $60 million in 2005 (IRIN Africa, 2007a) from Libya and almost $200 million (Oxford Analytica, 2005) during 2003 from Cote D'Ivoire to Niger, Mali and Burkina Faso.

C. *Dan Cin Rani* or temporary, circular migrations (Rain, 1999); this is the most important type of migration for the people of Niger and are likely to exhibit the strongest signal in disease dynamics data. Temporary seasonal circular work movement of migrants can last approximately 3–6 months. During non-drought years, these movements are mainly rural–urban (from subsistence farms to larger towns/cities (New York Times, 1996b)) but can also be rural-rural (from subsistence farm to large commercial farm (Daily Trust, 2008) and to commercial or small-scale artisanal mines (e.g. uranium, coal, gold, trona, salt, cement) (Alfa, 1999; Herald Tribune, 2008; IRIN Africa, 2007a). The distances migrants travel varies and is not necessarily based on economics but instead is influenced by family connections and the need to remain within close proximity to family so that they can return home to work the land easily (Daily Trust, 2008; Rain, 1999). Destinations selected by migrants may also vary from year to year (Daily Trust, 2008). Not only does this type of migration occur in Niger but also Mali, Chad, Burkina Faso and Nigeria (Daily Trust, 2008; IRIN Africa, 2007b). The majority of migrants are males, many leaving their families behind, but can include the movement of families, the migration of young children (Rain, 1999) and more recently women, as is the case in Mali (Haan, Brock, & Coulibaly, 2002).

Seasonal, climate-driven migration is an important component of disease-relevant population movements, but it is not the only factor, and is not sufficiently well documented on an annual basis over the years for which detailed measles data are available. Thus, information foraging with *SensePlace* was used to build a more complete picture of the role different events may have influenced the movement of people and transmission of disease between 1995 and 2006. These are summarized in Fig. 7 with details of each event and its source documented in Table 1.

During years of drought (as illustrated in Fig. 7), the movement of people increases. For example, during 2003/2004 Niger suffered food shortages brought about by a drought and major locust outbreak (Asia Africa Intelligence Wire, 2004; BBC News, 1997; BBC News, 2004). Not only did this result in mass losses in agriculture, but also forced many residents of Niger to leave home and seek food in urban centers, neighboring countries such as Nigeria and Togo (The Independent, 2005b) and therapeutic feeding centers (established by Doctors without Borders/Médecins Sans Frontières – MSF). During this time, due to a lack in basic health care and feeding facilities in Nigeria, many Nigerians came to Niger (IRIN Africa, 2007b).

Forced migration, either through bonded labor, such as slavery and people trafficking, particularly of children (Global March Against Child Labour (GMACL), 2006, Khaleej Times Online, 2005), or political events is also likely. Although slavery was outlawed in 1991 it is still prevalent today in Niger (The Guardian,

Table 1
Source of data used to illustrate the timeline of events captured in Fig. 7. Events are summarized by Drought (orange), Movement (yellow), Vaccination (blue), Conflict (red), Political events in Niger (green) and other (purple).

Year	Geography	Description of Event	Source	Link
1994	Niger	Drought	NY Times	http://www.nytimes.com/1993/02/14/world/niger-s-1st-democratic-vote-beset-by-revolt-and-famine.html
1994	West Africa	Political – Devaluation of the French Franc by 50%	NY Times	http://www.nytimes.com/1994/02/23/world/french-devaluation-of-african-currency-brings-wide-unrest.html
1995	Niger, Mali	Movement – Peace agreement with Tuareg tribes leads to return of thousands of refugees.	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1054274.stm http://news.bbc.co.uk/2/hi/africa/country_profiles/1022844.stm
1996	Niger	Political – Coup: Ousmane ousted by Colonel Ibrahim Mainassara	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1054274.stm
1997	Niger	Political – Election: Mainassara wins presidential elections	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1054274.stm
1997	Niger	Drought & Famine	BBC	http://news.bbc.co.uk/2/hi/africa/133956.stm http://news.bbc.co.uk/2/hi/africa/21866.stm
1997	Niger	Movement – Famine more than 2000 villages at risk and fleeing, Large numbers of villagers are reported to have left for the towns or neighboring countries in search of food, leaving children and the elderly behind.	BBC	http://news.bbc.co.uk/2/hi/africa/21866.stm http://news.bbc.co.uk/2/hi/africa/133956.stm
1998–2004	Cote D'Ivoire	Conflict – Civil War in Cote D'Ivoire (6 years)	Qantara, Oxford Analytica	http://www.qantara.de/webcom/show_article.php/_c-476/_nr-454/i.html http://www.forbes.com/2005/08/31/ivory-coast-civil-war-cx_0831oxan-ivorycoast.html
1998	Cote D'Ivoire	Movement: Civil War in Cote D'Ivoire led to many west Africans driven back to poorer homelands	Qantara, Oxford Analytica	http://www.qantara.de/webcom/show_article.php/_c-476/_nr-454/i.html http://www.forbes.com/2005/08/31/ivory-coast-civil-war-cx_0831oxan-ivorycoast.html
1999	Niger	Political – Election: Mamadou Tandja elected	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1054274.stm
2000	Northern Nigeria	Sharia Law	NY Times, BBC	http://www.nytimes.com/2001/02/02/world/firgi-journal-winds-of-militant-islam-disrupt-fragile-frontiers.html http://news.bbc.co.uk/2/hi/africa/country_profiles/1067695.stm
2000	Niger	Drought	AllAfrica.com, Aker, J. 2008	http://allafrica.com/stories/200010020020.html; Aker, Jenny C., Droughts, Grain Markets and Food Crisis in Niger (May 3, 2008). Available at SSRN: http://ssrn.com/abstract=1004426
2000	Nigeria, Niger	Movement – Firgi – Hundreds of prostitutes, gamblers and bar owners have settled here in the last year, having fled the rise of militant Islam in northern Nigeria.	NY Times	http://www.nytimes.com/2001/02/02/world/firgi-journal-winds-of-militant-islam-disrupt-fragile-frontiers.html
2000	Northern Nigeria	Conflict – Hundreds of deaths in clashes between Christians and Muslims.	NY Times, BBC	http://www.nytimes.com/2001/02/02/world/firgi-journal-winds-of-militant-islam-disrupt-fragile-frontiers.html http://news.bbc.co.uk/2/hi/africa/country_profiles/1067695.stm
2001	Niger	Conflict – Muslim & Christian Conflict Maradi	NY Times	http://www.nytimes.com/2001/02/02/world/firgi-journal-winds-of-militant-islam-disrupt-fragile-frontiers.html
2001	Niger, Nigeria	Vaccination – Meningitis & Measles	MSF	http://www.msf.org/msfinternational/invoke.cfm?objectid=2DB9FD23-76DB-4A4A-91CAF1E306AD0BB8&component=toolkit.report&method=full_html
2002	Nigeria	Conflict: Tribal war in Benue state, in eastern-central Nigeria, displaces thousands of people; rioting in Kaduna due to Miss World (more than 400 die)	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1067695.stm
2001–2002	Nigeria	Movement: 1000's flee (Ethinic violence) clashes between Hausas from mainly-Islamic north and ethnic Yorubas from predominantly-Christian southwest.	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1067695.stm

Table 1 (*continued*)

Year	Geography	Description of Event	Source	Link
2003	Nigeria	Anti-vaccination	VOANews, Lancet, CNN	http://www.voanews.com/english/archive/2008-03/2008-03-29-voa30.cfm?CFID=215051994&CFTOKEN=24197438&jsessionid=8830869b63ec2ab0718a602d2e13462d752d Kapp C. (2003) Surge in polio spreads alarm in northern Nigeria. Lancet. 362:1631–2 http://www.cnn.com/2003/WORLD/africa/10/27/nigeria.polio.reut/index.html
2003	Niger, Benin	Movement: River islands along the disputed Benin-Niger border awarded to Niger	BBC	http://news.bbc.co.uk/nolpda/ifs_news/hi/newsid_3638000/3638535.stm
2004	Niger	Political – Election: First local elections & President Mamadou Tandja wins a second term	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1054274.stm
2003	Nigeria	Conflict – Nationwide general strike in 9 days after govt agrees to lower fuel prices	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1067695.stm
2004	Nigeria	Conflict – State of Emergency in central Plateau State after more than 200 Muslims killed in Yelwa in attacks by Christian militia ; Kano, Revenge attacks by Muslim youth	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1067695.stm
2004	Niger	Vaccination – First Measles Initiative-supported campaign backed by UN	UN	http://www.scoop.co.nz/stories/WO0801/S00103.htm
2004–2005	Niger, Burkina Faso, Mali	Drought & locust infestation & late rains with estimated cut in cereal harvest by 40–45%	BBC, NY Times, Agenzia Fides, BBC	http://news.bbc.co.uk/2/hi/africa/4699643.stm http://www.nytimes.com/2004/09/05/international/africa/05locust.html?_r=1 http://www.fides.org/eng/news/2004/0411/20_3534.html http://news.bbc.co.uk/2/hi/africa/country_profiles/1022844.stm
2005	Niger	Movement – fleeing hunger in Niger and crossing the border into Nigeria (Kano)	BBC, AFP	http://news.bbc.co.uk/2/hi/africa/4699643.stm http://www.fides.org/eng/news/2004/0411/20_3534.html http://findarticles.com/p/articles/mi_kmafp/is_200507/ai_n14759272/ http://findarticles.com/p/articles/mi_kmafp/is_200507/ai_n14759272/
2005	Niger	Political – Protests: Widespread tax protests	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1054274.stm
2005	Niger	Vaccination – Measles in Agadez & Diffa	WHO	http://www.humanitarianinfo.org/niger/uploads/bulletins/health/WHO_Niger_Health%20Action%20Newsletter_22%20Aug%2005_eng.pdf
2006	Niger	Political – Protests: National strike to protest against the high cost of living	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1054274.stm
2006	Niger	Movement – Government expels Mahamid Arabs to Chad	BBC	http://news.bbc.co.uk/2/hi/africa/6087048.stm
2006	Chad	Movement – Thousands of Darfur refugees flee eastern areas penetrate deeper into Chad	BBC	http://news.bbc.co.uk/2/hi/africa/country_profiles/1068745.stm

2005; The Independent, 2005a). Many of these include children who are sent to work in agriculture, mining,[10] as domestic labor, or illegally traded and sent into prostitution (Global March Against Child Labour (GMACL), 2006); (Asia Africa Intelligence Wire, 2002; Herald Tribune, 2008).

Many parts of Africa are highly volatile causing people to move from areas of conflict or instability. Since Niger's first democratic vote in 1993 there have been three elections, two coups and the assassination of President Mainassara in 1999 (BBC News, 2009). In addition there have been numerous protests and regional conflicts (e.g. National strike against the high cost of living and protests against taxes; Taureg uprising in the North; Muslim/Christian clashes in Maradi). However, three main events seem to have had the most significant impact on the region since 1996. These include the devaluation of the Central African French Franc (CFA) by fifty percent in 1994 (New York Times, 1994), the civil war in Cote D'Ivoire (Johnson, 2005; Oxford Analytica, 2005), and the introduction of *Sharia Law* in Northern Nigeria (New York Times, 2001a; The Independent, 2001), all of which are summarized in Fig. 7.

The devaluation of the CFA has had some impact on population movements throughout west Africa and may have increased the number of transit migrants as they try to improve their lost wealth (OECD, 2009). Cote D'Ivoire is a popular destination among migrants with its big city (Abidjan) and cocao plantations and during the civil war many foreign migrants were forced to return home leading to a reductions in remittances (Oxford Analytica, 2005). While the establishment of the *Sharia Law* in Northern Nigeria is reported to have played a key role in fueling a thriving sex industry along the Niger-Nigerian border, particularly in Maradi, Konni, Sashi, Maimoujia and small towns such as Firgi (New York Times, 2001a; The Independent, 2001). Not only has this increased the traffic and migration to these areas (Kirwin, 2004), but these regions have also seen an increase in the number of Muslim/Christian clashes and been a driver in anti-vaccination campaigns in many Northern States of Nigeria (FOX News, 2005) resulting in the suspension of vaccination campaigns (e.g. in States of Kano, Zamfara Kaduna, Bauchi, Katsina and Niger) (Associated Press, 2004; CNN, 2003; New York Times, 2006). As a result of this, vaccination-deficit areas have lead to the development of disease reservoirs, particularly in Kano, known as the polio epicenter (Boston Globe, 2004), a main source for meningitis (IOL, 2006) and a hotspot for measles (Médecins Sans Frontières (MSF), 2003) (see Fig. 6).

Diseases, such as polio are not only crossing the border from Nigeria into Niger but have also affected between 8 and 21 countries at any one time (e.g. wild polio Reuters, 2009; Xinhua, 2006). Many of these diseases are being imported through people as they move from place to place, such as polio along bus routes through Niger (Boston Globe, 2004), polio from migrants returning home from working abroad (e.g. AIDS from Cote D'Ivoire New York Times, 1996a), meningitis from Darfur Refugees in Chad (The Medical News, 2004), or meningitis from migrants passing through Niger (AllAfrica, 2009).

For much of this region, where the majority of the population is nomadic, borders act as an artificial boundary and are by no means a barrier to disease movement, particularly for clandestine migrants. Thus, knowing where people are travelling from (allows the source of infection to be identified) and determining how they are getting into and passing through countries (by foot, bus, donkey on main roads or clandestine routes) can help combat future epidemics through the implementation of effective surveillance and control strategies. These may include surveillance and vaccination campaigns located at border crossings, in towns within close proximity along country borders or towns that are major crossroads for travelers (e.g. sex cities, gateway cities or transit towns illustrated in Fig. 6). Precautions against particular diseases are already being implemented in some of these areas. For example, recent articles highlighted border vaccination strategies against meningitis along Niger-Nigeria border (IOL, 2006) and polio along Burkina Faso-Niger (World Health Organization (WHO), 2002), as well as anti-AIDS campaigns in Firgi and Agadez (Reuters, 2002).

As outlined at the start of this section, the characterization of population movements and disease reservoirs detailed above was compiled by one analyst (who was knowledgeable in disease dynamics but not in Niger). *SensePlace* was used iteratively to forage for place-relevant documents, attempt to make sense of and synthesize information derived, use insights to refine or extend foraging activities, and ultimately build a comprehensive picture of events, disease, and population movements over time within and around Niger. In the following section, we outline ideas for future work.

6. Future work

As indicated, *SensePlace* is in an initial proof-of-concept, prototype of the information foraging and sensemaking process introduced above. Although it is a prototype, *SensePlace* proved to be functional and useful enough to help us build a detailed understanding of population movements in Niger and related contextual factors that have a potential impact on disease dynamics in that country. The *SensePlace* visual interface currently provides linked place, time, concept, and document views that enable an analyst to find relevant documents on the basis of location, time, and theme and use documents found as part of a broader sensemaking process. While the approach and tools allowed an analyst to build a comprehensive understanding of the geographic situation in Niger and identify changes in that situation over time using web-retrieved, unstructured text documents, the case study also identified multiple parts of the analytical process where the current prototype implementation could be improved.

Based upon the results of this research and the case study application of *SensePlace* to analysis of population movements and public health in Niger, six specific next steps are planned.

First the analytical reasoning methods for determining document relevance will be enhanced. Formal quantitative measurement of document ranking improvements using F-measures will be added, this is a common means of measuring the effectiveness of information retrieval systems.

Second, although the *SensePlace* concept map is useful in highlighting concepts occurring within an article, the concept map is currently tied to a single predetermined ontology inserted by a system administrator. To be more useful, concept map functionality should be extended to: (1) enable users to fine-tune their search criteria by providing specific user defined concept maps and (2) provide self-learning concept maps that are dynamically created with each new search.

Third, refinements to the visual interface will be made to better support human reasoning. For example, incorporating new search engines. Currently, *SensePlace* uses Google News and Google Archives search engines to retrieve information. Although not presented here, we have started to investigate the ability to incorporate new search engines and formats and visual interfaces to those search engines and their formats so as to provide the user with the ability to customize their searches.

Fourth, methods outlined in Section 4 that emphasize document foraging and sensemaking about relevant documents will be integrated with exploratory spatial data analysis methods

[10] See Alfa (1999) for a breakdown of tasks.

applied to numerical data that analysts may be trying to contextualize with the *SensePlace* tools (e.g., in our case study, data about measles incidence and related socioeconomic and demographic statistics).

Fifth, to better support an extended analytical process, methods will be added to enable artifact collection and organization, analysis history, and insight provenance. Several ideas related to this step include:

(a) Ability to edit saved search results. In the system presented in this paper, search results can be saved to an XML file format and shared with colleagues or reloaded at a later date. Being able to edit the result list would be useful in sharing key articles with colleagues and provide the ability to avoid duplication of information from multiple sources.
(b) Ability to save full query terms. Currently, *SensePlace* can save key search terms and the geography specified. Being able include the search dates and type would be beneficial in logging the searches performed.
(c) Capturing web documents. Although the add-in Zotero was utilized during this study to capture a plethora of web documents, it requires the users to manually edit data fields. Providing a feature to automatically capture web documents systematically (e.g. by key search term) will help catalog the articles in an easily retrieval manner.
(d) Saving data to a spreadsheet or database. The case study demonstrated a need to transcribe data from the web articles to a spreadsheet (see Section 5.1) in support of the overall analytical processes. Automating the task of saving key data to a spreadsheet is critical as it would speed up the data capture process, and thus the ability to produce analytical outputs. Key data to capture and store in a spreadsheet include: date, place, detailed description, brief description, source, hyperlink to source, and date information was accessed.

A sixth planned step is to formally evaluate tool usability and utility, and investigate the sensemaking process as supported by these tools, using methods and approaches similar to (Robinson, Chen, Lengerich, Meyer, & MacEachren, 2005; Tomaszewski, 2011).

6.1. Other application domains for SensePlace

Although the application domain used in this research was disease dynamics, *SensePlace* is designed to support information foraging and sensemaking activities in any application domain where place-relevant information is likely to be found in large document repositories. In particular, our team is investigating application of the *SensePlace* approach to vulnerability assessment of impoverished people (Tomaszewski, in press). *SensePlace* is particularly well suited for vulnerability assessment due to the complex and often abstract nature of indicators that can be used to assess vulnerability; these include but are not limited to items such as livelihoods, access to health care and clean water, social relationships and financial capitals (Frankenberger, Luther, Becht, & McCaston, 2002). Data and information related to these and other vulnerability indicators are often derived from diverse sources like those discussed in the *SensePlace* case study.

7. Summary and conclusions

In this paper, we introduce a visual-analytics based approach to foraging for and sensemaking with the currently underutilized place-relevant information contained in rapidly growing document repositories. The approach is implemented in *SensePlace*, a web-based application. *SensePlace* uses coordinated visual interfaces that include timelines, geographic maps, and concept graphs and computational procedures such as ontology-based document relevance processing, entity extraction, and geocoding to assist the human sensemaking processes.

Using a detailed case study, we demonstrate that the approach and its implementation is effective in enabling an analyst to quickly build a comprehensive understanding of a complex and dynamic situation, human migration over a decade in a developing country for which formal data are lacking. The analyst was able to use *SensePlace* to improve her understanding of the main migration patterns occurring in Niger, identify key disease hotspot areas surrounding Niger and determine major entry points for diseases. All of these insights are relevant for developing more robust models of disease dynamics and the implications of events that impact human migration patterns. Case study results also highlight key infection zones (e.g. border trade towns, e.g. sex cities, transit towns, and gateway cities) and identify problem areas where vaccination coverage has been halted, resulting in those areas becoming disease reservoirs (e.g. Northern Nigerian States), and thus enhance program guidelines for vaccinations in Niger and other developing counties.

From a geographic information science perspective, taking a place-time-concept approach to visually-enabled information foraging and sensmaking has been demonstrated to be viable as an approach for collecting and making sense of large volumes of unstructured documents, at least in the case study presented. This research provides input to a broader visual analytics goal of developing integrated visual-computational methods that support human reasoning in the context of complex problems with heterogeneous information. Ultimately, tools like *SensePlace* and the theoretical approaches that motivate their development can lead to improved scientific research, situation assessment, and evidence-based decision making.

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