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Geovisual analytics to support crisis management: Information foraging for geo-historical context

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Abstract

Information foraging and sense-making with heterogeneous information are context-dependent activities. Thus visual analytics tools to support these activities must incorporate context. But, context is a difficult concept to define, model, and represent. Creating and representing context in support of visually-enabled reasoning about complex problems with complex information is a complementary but different challenge than that addressed in context-aware computing. In the latter, the goal is automated system adaptation to meet user application needs such as location-based services where information about the location, the user, and user goals filters what gets presented on a small mobile device. In contrast, for visual analytics-enabled information foraging and sense-making, the user generally takes an active role in foraging for the contextual information needed to support sense-making in relation to some multifaceted problem. In this paper, we address the challenges of constructing and representing context within visual interfaces that support analytic reasoning in crisis management and humanitarian relief. The challenges stem from the diverse forms of information that can provide context and difficulty in defining and operationalizing context itself. Here, we focus on document foraging to support construction of geographic and historical context for facilitating monitoring and sense-making. Specifically, we present the concept of geo-historical context and outline an empirical assessment of both the concept and its implementation in the Context Discovery Application (CDA), a web-based tool that supports document foraging and sense-making. We also discuss the CDA's transition into applied use for the United Nations to demonstrate the generality of underlying CDA concepts.

Keywords

Context, foraging, sense-making, mapping, text analysis, user studies

Introduction

Context is an important concept for understanding the world. A common question is "what is the context?" For crisis management, context includes where the crisis is occurring, what events have transpired, and who is involved. Although a ubiquitous concept, context is a difficult term to define and operationalize. Typically, it is thought of as a type of setting that gives meaning and describes the situation and circumstances of an entity.[1] Geography and history offer unique perspectives on context through study of the interconnectedness of phenomena, events, and places across multiple spatial and temporal scales through which situations are understood. The research we report here has two goals. Our first goal was to introduce a conceptual

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framework for the fusion of geographical and historical epistemological perspectives into a form of context we define as geo-historical context (GHC). From a visual analytics perspective, our emphasis is not on context as input to automated filtering (as in context-aware computing) but as a framework for sense-making, with context actively assembled through analyst–system interaction. Our second goal was to develop, implement, and demonstrate application of methods for addressing the challenge of foraging for relevant information and using it to construct and represent GHC. Major contributions of the work presented here, as per our two research goals, are that we have (a) developed a conceptual and computational model that is instantiated to represent GHC to support sense-making, (b) implemented a visual analytic system to assemble context information, and (c) evaluated the system with crisis management domain experts.

Often, knowledge and awareness of past associations, concepts, and places are critical to how situations are understood.[2] Thus, foraging for and integrating information that can contextualize situations from geographical and historical perspectives depends upon recognizing links across information fragments derived over extended time spans, geographic scales, and conceptual meaning. GHC creates a basis for creating these linkages. It supports understanding the interconnectedness of phenomena, events, and place across multiple spatial and temporal scales and it enables situations to be reasoned about, often through visual representations such as maps. The complex nature of GHC requires formalization to impose structure on the seemingly limitless parameters that must be related in order to make practical use of GHC for crisis management and similarly complex domains.

Here, we outline the conceptual framework for a GHC model, describe its implementation in the Context Discovery Application (CDA), and present the results of usability and utility evaluation. United Nations (UN) staff participated in the utility evaluation, providing input on the potential of the GHC framework and its instantiation in the CDA to support work in humanitarian crisis management. More specifically, the GHC model and its implementation in the CDA were assessed for their potential to help analysts: (a) forage for, structure, and operate on heterogeneous information artifacts (documents, maps) that are (b) assembled, processed, interrelated, and interpreted in order to produce and represent GHC, which, in turn, (c) allows situations to be understood and reasoned about within sense- and decision-making activities.

The paper is organized as follows. First, we present the theoretical foundations for our approach to context. Next, we outline a model of GHC developed and implemented on this foundation. This is followed by a brief overview of the CDA prototype, focusing on how its functionality reflects the GHC model. We then report on a usability study to refine the CDA. Finally, we report on a utility study, which offers insight into the GHC framework from the perspective of international crisis management practitioners, and of the CDA as an implementation of the model. We end the paper with a discussion of how the CDA has been transitioned into applied use by the United Nations. We also offer some final conclusions on the overall research; these comments emphasize use of geovisual analytics tools for assembling context to support information foraging and sense-making tasks.

Theoretical foundations for GHC

Conceptualizing context

Context as an object of research is conceptualized in diverse ways across different domains; Bradley and Dunlop[3] provide a useful review and synthesis of perspectives from linguistics, computer science, and psychology. Starting with a standard dictionary definition of context as "the interrelated conditions in which something exists or occurs,"[4] we adopt Brezillon's[5] view that these conditions act as a filter or framework to support a human agent's reasoning in order to provide the correct meaning and interpretation for available information that is potentially relevant to a sense- or decision-making task at hand.

Following from this, we make a distinction between (a) contextual information, or information that creates, represents and provides context and thus implicitly provides a framework for problem solving, most often in the form of constraints and (b) contextualized information, or information that is the focus of attention and that has been given meaning through the framework provided by contextual information. For example, contextual information providing a framework for crisis management in a situation like the Haiti earthquake of 2010 might include a topographic map depicting terrain and infrastructure before the earthquake combined with information from news reports about building and infrastructure damage. This information framework helps to contextualize official information in situation reports about rescue team activities and distribution of relief supplies. At a later point in relief efforts, when an aftershock hits and situations change, the recently contextualized information about distribution of relief supplies becomes part of the overall framework of contextual information through which new situation reports are contextualized.

Context: static or dynamic (or both)?

Given the shift and duality that can occur between information being contextual and contextualized, it is important to distinguish between (a) context as a static set of information categories that can be used like a cookie-cutter for constraining situational factors and (b) context as ephemeral and evolving, with parameters and properties that change dynamically.

Static, pre-described categories or classes of information that can be used to represent context are often used in artificial intelligence (AI)-based efforts to model context. For example, the Context-Web Ontology Language (C-OWL), an extension to descriptive capabilities of the Web Ontology Language (OWL), is designed to formally capture static concept contexts within a single ontology in order to support machine-based matching of concepts with other ontologies.[6] Gahegan and Pike,[7] in work focusing on capturing, modeling, and representing how concepts are socially constructed in scientific processes, emphasize the static component of context, as a fixed set of concept properties that essentially serve as basic concept metadata (i.e., who created a concept and when, and how the concept was created). Information categories that create a static context have also been used for schema matching and query matching in heterogeneous geospatial database integration[8] and in semantic similarity matching procedures.[9] The CYC project's knowledge base and common-sense reasoning engine incorporates the notion of static context using predescribed categories. CYC includes 12 "mostly-independent dimensions along which contexts vary (Absolute Time, Type of Time, Absolute Place, Type of Place, Culture, Sophistication/Security, Granularity, Epistemology, Argument-Preference, Topic, Justification, and Anthropacity)"[10] (p. 4).

A dynamic, shifting view of context is more prevalent in ubiquitous computing and distributed/situated cognition research where the focus is on human/machine/artifact interactions. In these domains, context and content are not separable entities; instead, context arises and is produced by activity.[11] More specifically, context can be interpreted as emerging from both activity and combinations of tools, settings, goals, and artifacts imbued with history.[2] A dynamic perspective of context creates challenges to modeling context or formally representing context information (whether visually, in a database, or an ontology) in that it is difficult, if not impossible, to imagine all possible contextual states, information needed to convey those states, and appropriate action within a given state.[12]

Whether a conceptualization of context is based on a static set of pre-determined descriptive categories used for processing and integrating information, or as a dynamic state formulated from a complex series of interactions of artifacts, social interactions, environmental conditions, or their combination, contexts provide a mechanism for reasoning (both human and computer) with situational factors. Human reasoning, in particular, is critical to crisis management sense- and decision-making activities. A particular emphasis in research reported here is on understanding how the notion of context functions as a human reasoning framework and mechanism for such activities.

Theories of contextual reasoning

Formalization of context into logical theories for use as reasoning mechanisms has been an active area of inquiry in AI and knowledge representation/reasoning since the 1980s. A motivation behind formalizing context has been as input to models of human, context-based reasoning for understanding situational factors within automated, machine-based reasoning systems.

A concept addressed in these efforts is generality, related to the range of contexts across which assertions are true.[13] Stated simply, situations are unique, but unique systems are impractical and any knowledge representation or reasoning system that applies to all situations will be too general to be useful. The generality problem makes it difficult (if not impossible or desirable) to conceive of a universal knowledge representation and reasoning language based on a homogeneous world.[14] An approach to deal with the generality problem is the use of contexts to localize knowledge and then to find "compatibility" between localized contexts. Compatibility here is treated as the relations that can be defined between contexts that enable reasoning across contexts. Localized and compatible perspectives on context as a reasoning mechanism are the core ideas underlying local model semantics and multi-context systems, which are discussed in the following section and used as a theoretical principle underlying the GHC model presented in this work.

Local model semantics and multi-context systems

A multi-context system begins with the premise that context, as a formal structure for reasoning, is based on "local" facts derived from a global knowledge base and used for reasoning about a given goal.[15] Giunchiglia and Bouquet[15] argue that a local context of reasoning is based on a cognitive context, or an individual's cognitive representation of the world, as opposed to a pragmatic context, or the external structure of the world. For example, in a conversation between two people, the pragmatic context might be composed of the speakers themselves, the time the conversation is taking place, and the location of the conversation. Reasoning with information that depends on the pragmatic context is utilized only as much as that information is represented or relevant within a given state of the cognitive context.[15]

The utility of situating reasoning in a cognitive context is that it accounts for different and/or conflicting perspectives within an agent's cognitive view of the world.[15] Perspectives taken by different agents often differ in level of detail and interpretation will depend on what is implicitly assumed.[16] As a very simple example, the statement "The report is due on April 25th" could also be true if expressed as "The report is due today" with an implicit assumption that today is April 25th.

Despite potentially differing local reasoning contexts to describe a given domain, compatibility and overlap can and do exist. From the local model semantics perspective, compatibility between local reasoning contexts refers to mutually influential relationships between local reasoning contexts where similar perspectives can describe the same piece of the world, but with different details.[16] For example, two people looking at a globe may both see the Atlantic Ocean, but one person can see only North America (from his/her viewpoint), and the other can see only Europe. Thus, compatibility emerges from the fact that their reasoning is related (they are both seeing the ocean), but distinct as they are looking at different land masses.

Ghidini and Giunchiglia [17] (p. 229) encapsulate these ideas in two basic principles for local model semantics:

- Principle 1 (of Locality). Reasoning uses only part of what is potentially available (e.g., what is known, the available inference procedures). The part being used while reasoning is called the context (of reasoning);
- Principle 2 (of Compatibility). There is compatibility among the kinds of reasoning performed in different contexts.

These local model semantics concepts have clear application to geographic problems such as a disaster relief, where context might differ on the basis of place, time, or concept/theme. Two local contexts could share a place but differ by theme (e.g., using a hydrological versus a transportation perspective) or time frame (based on the long history of a resident versus a short duration from an external emergency response manager brought in to help). Alternatively, local contexts might represent adjacent places that share only a border and common regional perspective. "Local" also can be defined at different geographic scales, such as the perspective of the county emergency manager whose local context is a single county and that of the state emergency manager whose local context is the entire state. Furthermore, the compatibility relations among the different kinds of local contexts will be different. To summarize, local reasoning contexts that are derived from subsets of global knowledge and then paired into compatibility relationships with other local reasoning contexts are the essence of local model semantics and multi-context systems.

Context modeling challenges

Information foraging and sense-making must integrate two perspectives on context. The first is static, descriptive context categories used for integrating and relating heterogeneous information. The second is the distributed/situated cognition perspective, where context emerges from a complex mixture of tools, artifacts, beliefs, and intentions imbued with history and existing within a social context of use where context is dynamic (subsumes static categories of context). Both static and dynamic contexts provide a mechanism for reasoning with situational factors. A context of reasoning to support information foraging and sense-making is a localized, cognitive view of the world based on a subset of facts that retains unique characteristics of a perspective. Compatibility needs to exist and be formalized for cross perspectives of local reasoning.

From this theoretical framework, two core challenges for developing a conceptual model and visual representation of GHC information can be defined. The first is that the sheer limitlessness of geography, the past, and other situational factors makes complete computational representation of geo-historical (or any other form of context[1]) unachievable. To address this challenge, it is necessary, for particular situations, to establish information categories that define a static context to underpin a model of geo-historical context that can implicitly intervene in a task, provide constraints, and explicitly contextualize information when needed. The second challenge is that although geographical or historical information can be used to formulate a static context (as discussed in the first challenge), these and other information elements are not context unto themselves, but rather become parts of a broader dynamic geographic–social context that the information categories defining a static context must adjust to as situations evolve. Conceptual models and visual representation of and interfaces to GHC information, therefore, must find a balance in meeting these two challenges.

The following is a brief humanitarian crisis example used to illustrate these challenges. Information categories that define a static context such as areas that

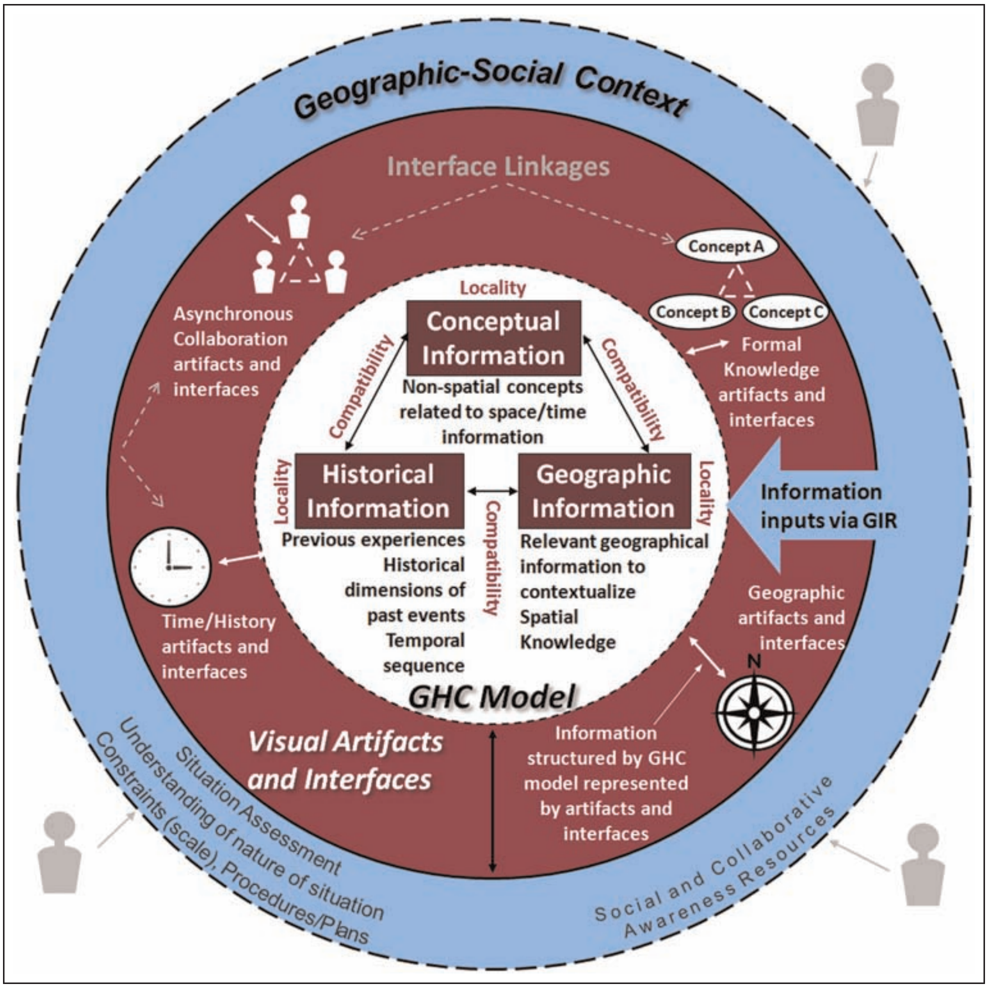

Figure 1. The overall process by which GHC is produced.

have been affected by famine over time and ethnic and tribal information about groups affected by the famine must be able to operate and adjust within dynamic social contexts such as the activities of an international aid organization. The organization will use static geo-historical contexts based on relevant information categories to derive geo-historical meaning to support their tasks and goals. An example goal might be to prioritize aid delivery based on locations of famine victims. As an analyst's work toward such a goal progresses, information categories that define a static context will need to adjust or expand as their relevancy to the situation evolves. For example, after addressing the initial needs of the famine victims by providing food relief within the static context of areas and people affected by the famine, the organization will then need to focus on myriad tasks that must be contextualized based on information categories such as social and political aspects of the affected area to ensure that relief efforts are lasting and sustainable.

The GHC model

Figure 1 is a high-level model representing the process of GHC production within a geographic–social context.

The GHC model serves two purposes. First, it provides a formal structure for the theoretical and conceptual components of GHC discussed in the "Theoretical foundations for GHC" section; these include (a) events, places, and concepts that represent a static form of context (as per the discussion in the "Context: static or dynamic (or both)?") as well as (b) relationships and constraints among these components such as scale, and spatial and temporal topological relationships—a set of relationships deemed robust and appropriate enough for the initial development of the GHC and its evaluation. The GHC model is specifically structured using three sub-models—geographical, historical, and conceptual—which represent windows into locality of context, along with compatibility relations among the components, as per the ideas discussed in the "Context: static or dynamic (or both)?" section. In addition to being based on the ideas of local model semantics, this structure is also theoretically motivated by other data models that organize spatiotemporal phenomena into space/time/concept (or object) sub-models based on the intuition that these categories correspond with the way people think (cf. refs 18 and 19). Special characteristics of the GHC model when compared with other spatiotemporal models include the emphasis that the GHC model makes on (a) modeling context in particular, (b) modeling-derived knowledge and information rather than raw observational data, and (c) modeling reasoning contexts using local model semantics. For further discussion of the GHC model's geographical, historical, and concept sub-models, see ref 20.

Second, the model can be used as a conceptual template for structuring and representing specific information instances retrieved, compiled, developed, and ultimately used as part of foraging and sense-making processes. Context information can then be applied to fulfill a task or achieve a goal requiring geographical, historical, and thematic interpretations of situational factors. The GHC model is represented formally through an OWL-DL computational ontological structure (one of several sublanguages of the OWL), which is effective at representing, capturing, and describing aspects of real-world contextual information in computer readable formats.[21]

The GHC model has a simple structure. The three main sub-models (geographical, historical, and conceptual) begin as sub-classes of the supreme OWL Thing class. The specific structures of each respective sub-model were defined using existing, established ontological definitions wherever possible. In particular, the GHC ontology uses two existing ontologies as a starting point for dealing with space and time. The Geonames Ontology (GO) is used for representing discrete, coordinate-based geographic entities as per the conceptual structure of the geographic sub-model of the overall GHC model (http://www.geonames.org/ontology/). The OWL Time Ontology (TO)[22] is used for representing discrete instances of historical events in linear time as per the conceptual structure of the historical GHC sub-model.

Context Discovery Application (CDA)

The GHC conceptual framework has been instantiated in the CDA, a prototype geovisual analytics environment focused on document foraging and sense-making. In this section, we provide an overview of CDA functionality and outline a focused usability assessment designed to "proof" a version of CDA prior to conducting the utility study presented in the next section.

CDA functionality

The following is a brief discussion of what a user might expect when working with a version of the CDA seeded with information relevant to humanitarian decision-making to ground specific functionality in a usage context (and present the version used in subsequently reported user studies). Thus, the version described has constraints over the "full", unconstrained CDA.[23] When started via loading the CDA web-client, the CDA will (a) visually render a small domain ontology in a graph display, (b) load a list of predetermined humanitarian project names into a dropdown list for selection by the user, (c) load a predetermined list of relevant specific date or time span event references into a timeline interface, (d) load a list of country names into a dropdown list for selection by the user to use with open text queries and, (e) display a base map of the world. Each of these items was compiled and incorporated into the CDA by the developer of the CDA using standard information technology tools such as ontology authoring, XML, and database systems for over a period of 1 month of part-time effort utilizing relevant information sources such as ReliefWeb (http://reliefweb.int/). To make the CDA a production tool, methods to enable end-user creation of this base information would be needed. But, the goal of the system reported was to act as a proof of concept for the GHC model introduced and to assess potential of the model to act as a framework for tools to enable real-world work, not to create a production tool. Thus, providing test users with initial base information loaded into the system seemed reasonable. All other functions are driven by actions taken by the user. A user will formulate a query by either entering an open keyword search much like a Google search or utilizing a query string automatically generated from the pre-determined list of humanitarian project titles. Using either approach, the user will then submit the query as the basis for processing by other CDA functionalities. In particular, the CDA supports ontology-enhanced queries to information sources such as Google News. Small domain ontologies (e.g., based on entities and relations extracted from an existing reference document) are used to support query expansion that makes it possible for an analyst to retrieve multiple, relevant documents without precise keyword matches in documents, an approach similar to that used in ref 24. The CDA uses the Named Entity Extraction methods of the open-source General Architecture for Text Engineering (GATE)

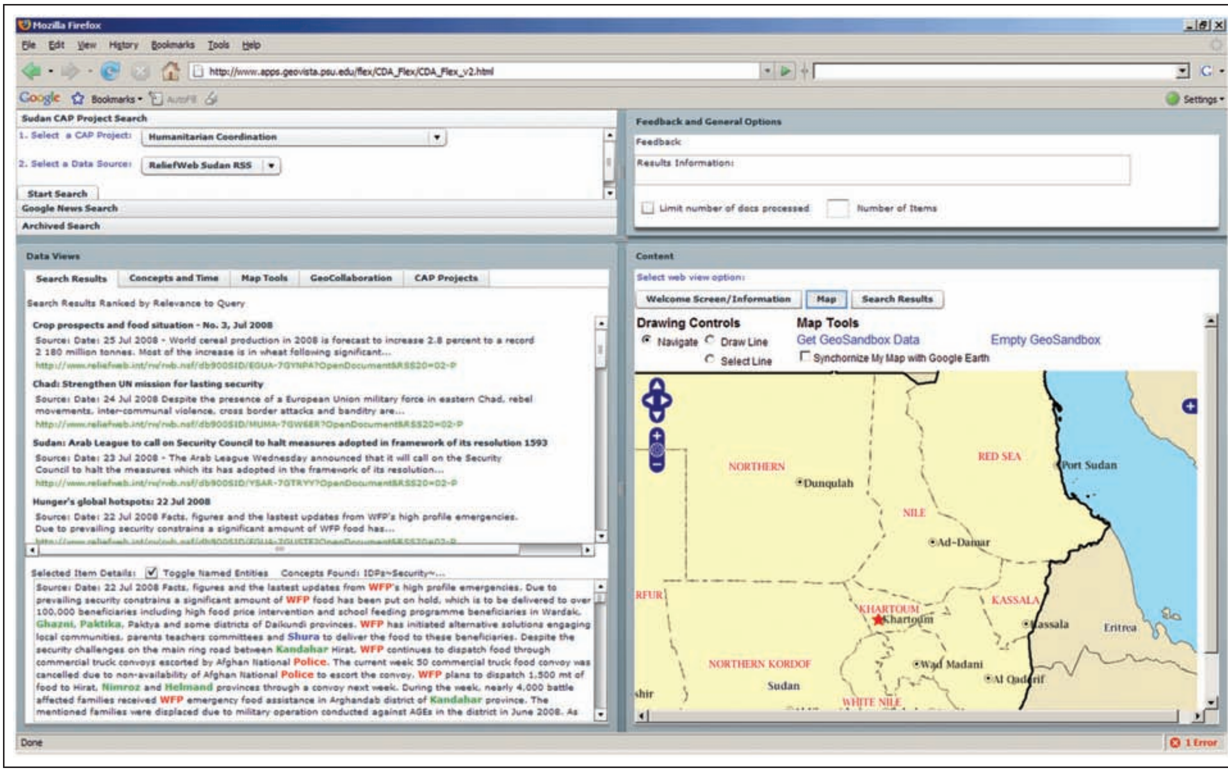

Figure 2. Representative example of the CDA.

environment to extract entities such as people, places, organizations, and things from the documents.[25] The CDA uses algorithms developed by the authors to disambiguate and geocode places extracted. Technical details of the CDA were described previously in ref. 23; here we sketch core features of the version adapted for usability and utility assessments to provide background for discussion of these assessments.

The CDA visually represents and allows users to explore implicit geographical information extracted from RSS feed-based sources. The information is represented in a set of linked views that included a two-dimensional (2D) map, Google Earth™ view, concept graph, timeline, named-entity extraction window, and web browser that enables the analyst to organize information, identify links, and use understanding derived to iteratively pose additional queries as understanding of situations and relationships is developed. The concept graph, timeline, and 2D map views are linked using geographic coordinates and temporal references. For example, a concept represented in the concept graph will have a latitude and longitude coordinate associated with the concept when the concept was created prior to analysis sessions. When the concept is clicked on, the 2D map will pan to the latitude and longitude coordinate so the user can see the geography associated with the coordinate. The 2D map and Google Earth™ views are linked using a map synchronization algorithm discussed in ref. 23.

Figure 2 shows one view in which the user has selected a news story about humanitarian action in southern Sudan and how the user can browse through people, places, and organizations related to the story in the entity view (lower left). In this scenario, an analyst is cognitively gaining a contextual understanding of locations related to humanitarian events in the Sudan after doing a search. Locations involved in a complex crisis situation may have multiple conceptual and/or temporal dimensions that may be relevant for producing GHC. By "dimension", we mean some aspect of the GHC that can potentially be analyzed. For example, a conceptual dimension such as food insecurity and a temporal dimension such as the history of food security in a region. Conceptual and/or temporal dimensions can thus provide cognitive filtering capabilities that determine which locations are relevant based on relationships among concepts, events, and locations.

As a next step, the user has picked the timeline and concept map panel (Figure 3). A concept map depicting humanitarian relief activities is shown. Concepts that are extracted from a Sudan RSS feed and also found within the pre-determined small domain ontology discussed previously in this section are highlighted

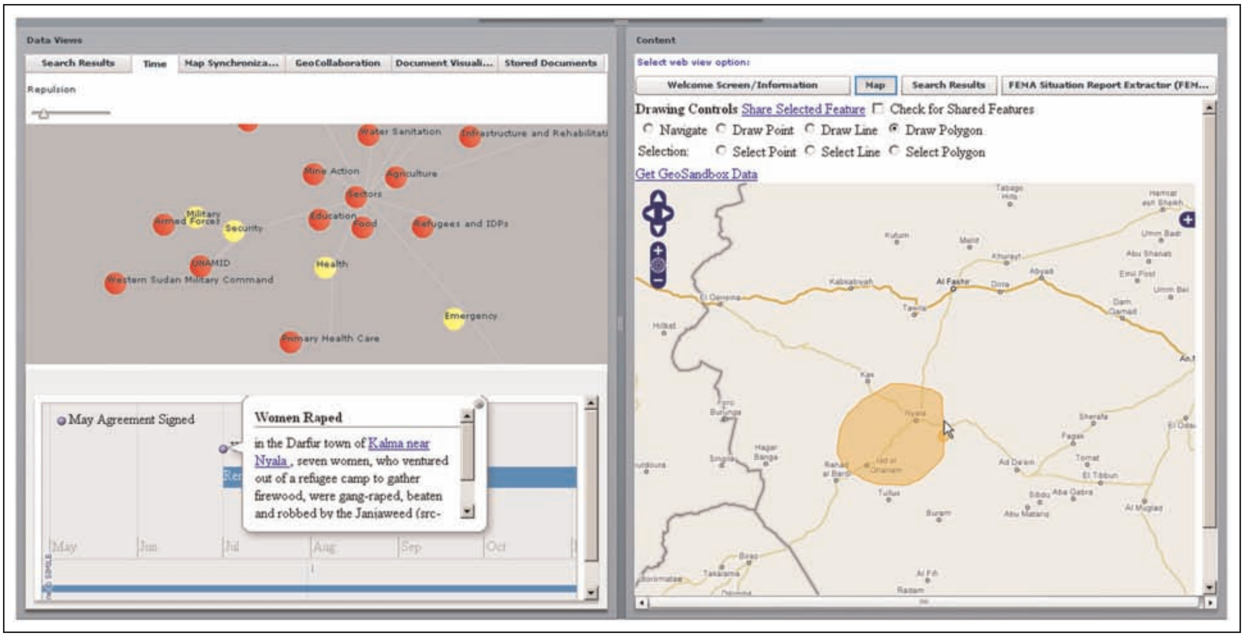

Figure 3. Concept map (top-left), timeline (bottom-left).

in yellow to provide a high-level overview of the conceptual content of the document. The concept map may prompt the user to recognize unanticipated concepts as contextually relevant.[26]

The scenario depicted illustrates: (a) selection of a concept, UNAMID, by clicking (Figure 3, upper left); (b) identification of a UNAMID security event from 2005 to which the concept is linked, resulting in auto-scrolling of the timeline to highlight this event, or specific time reference, about atrocities (Figure 3, lower left); (c) mapping the event by clicking on a link to automatically re-center the map to the event (Figure 3, right), and (d) drawing an annotation on the map; see ref. 23 for a detailed account of this scenario and see ref. 27 for a video that illustrates how the dynamic changes help users to make sense of the interconnections among information fragments interactions. These interactions generate a set of explicit, linked artifacts such as map views, timeline references, highlighted concepts within the concept graph and external annotations that enable the analyst to construct GHC both in the analyst's mind as the linked artifacts enable analyst reasoning and through the linked artifacts themselves for interpreting events. The overall process is iterative, and the user can conduct further searches to find out more about topics learned during the initial search.

As an analyst works, he or she can simultaneously view geographic components of information extracted from text documents on the 2D map view built into the CDA and on an independent 3D Google Earth™ view depicting origins of news stories as points plus lines that connect to places mentioned (Figure 4).

The maps are dynamically linked and the 2D map includes a GeoSandbox feature enabling the analyst to save information to a central database; information that can be saved includes "snippet text" or text that surrounds a place reference, the URL of the source document, and latitude and longitude coordinates extracted from GE as deemed contextually relevant. Here, the user saves information from a news story mentioning Omdurman (see snippet in GE view, left) to the GeoSandbox within the CDA (markers indicate other saved information). The GeoSandbox is related to the idea by Wright et al.[28] of an analysts' Sandbox; their Sandbox offers a more general purpose concept-focused rather than geographic-focused organizational "space" for evidence fragments to support intelligence analysis. The information saved to the GeoSandbox repository can later be recalled using a database query with the results rendered in the CDA's map interface.

In addition to the above features, the CDA contains support for remote collaboration. One objective is to help analysts share analytic insights related to production of GHC and subsequent sense-making activities as per the ideas of situated cognition and dynamic context discussed in the "Context: static or dynamic (or both)?" section. This objective is addressed through the idea of a *geomessage* (Figure 5).

A geomessage uses a standard email message as a metaphor to support a spatiotemporally-enabled message for asynchronous geocollaboration. Conceptually,

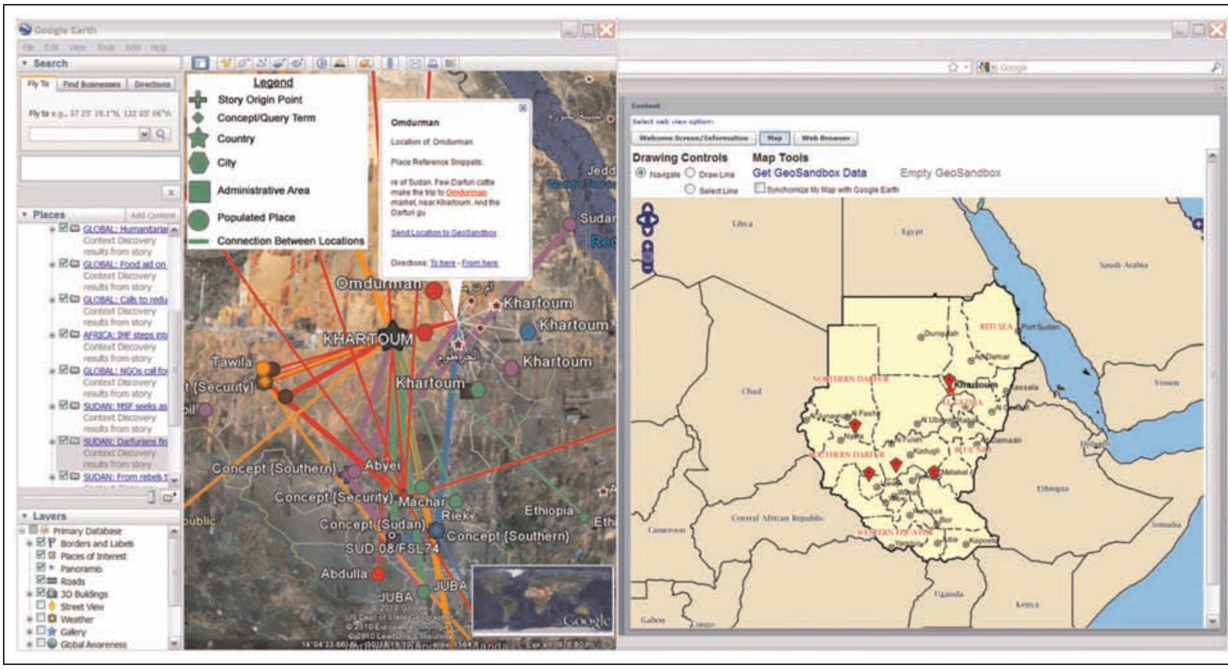

Figure 4. The GeoSandbox view linked to Google Earth™.

the body of a geomessage is a map extent linked to a text note like an email message.

Geomessages include an attachment mechanism designed explicitly to support geospatial artifacts that can be added to the user's map. In its current form, the geomessage supports attachments of map annotations and shared web map service (WMS) layers. WMS layers allow users to collaboratively create maps by sharing any individual and external geospatial resources from Open Geospatial Consortium (OGC)-compliant servers. Map layers from a given server can be loaded into the CDA by parsing the XML-based results from a GetCapabilities request made to the server (Figure 5).

Users can then select available layers and attach them to the geomessage. The benefits of this approach are that it (a) allows users to maintain a private view of their own data but share components as needed, (b) provides users with the flexibility to use multiple spatial data providers, (c) overcomes technical challenges to data sharing, such as when a novice user with geospatial technologies needs a layer for decision-making from a geospatial expert, and (d) supports user dialog through annotation tools that link formal geographic data to user knowledge, enabling holistic geographic awareness about a situation.[29]

CDA usability assessment and refinement

A targeted usability assessment of the CDA has been carried out. The primary goal was to develop a limited but robust version of the CDA through which to assess utility of the GHC conceptual framework (see "Evaluating the utility of the GHC framework"), and not to do a comprehensive user study. We summarize the methods and outcomes here, briefly.

Participants included two postdoctoral and three graduate students from the Penn State GeoVISTA Center; all were experienced with geographic information systems (GISs) and geovisual analytic technologies, enabling them to provide expert review from a tool design perspective. Five additional participants were from UN groups within the Office for the Coordination of Humanitarian Affairs (OCHA); all but one of the latter had some experience with GIS (and the one who did not was familiar with using Google Earth™); all were experts in humanitarian relief activities. The usability assessment had three components: a task analysis, a survey, and a focus group with the first two done individually by each participant and the last as a group.

Tasks. Each participant carried out tasks with representative features of the CDA such as extracting text from news articles and viewing the results in a map. Before the session, participants received instructions on how to use basic CDA features and on concepts such as the Consolidated Appeals Process (CAP). During the session, participants were asked to "talk aloud" while they worked and the work was observed and recorded. "Talk aloud" is slightly different than

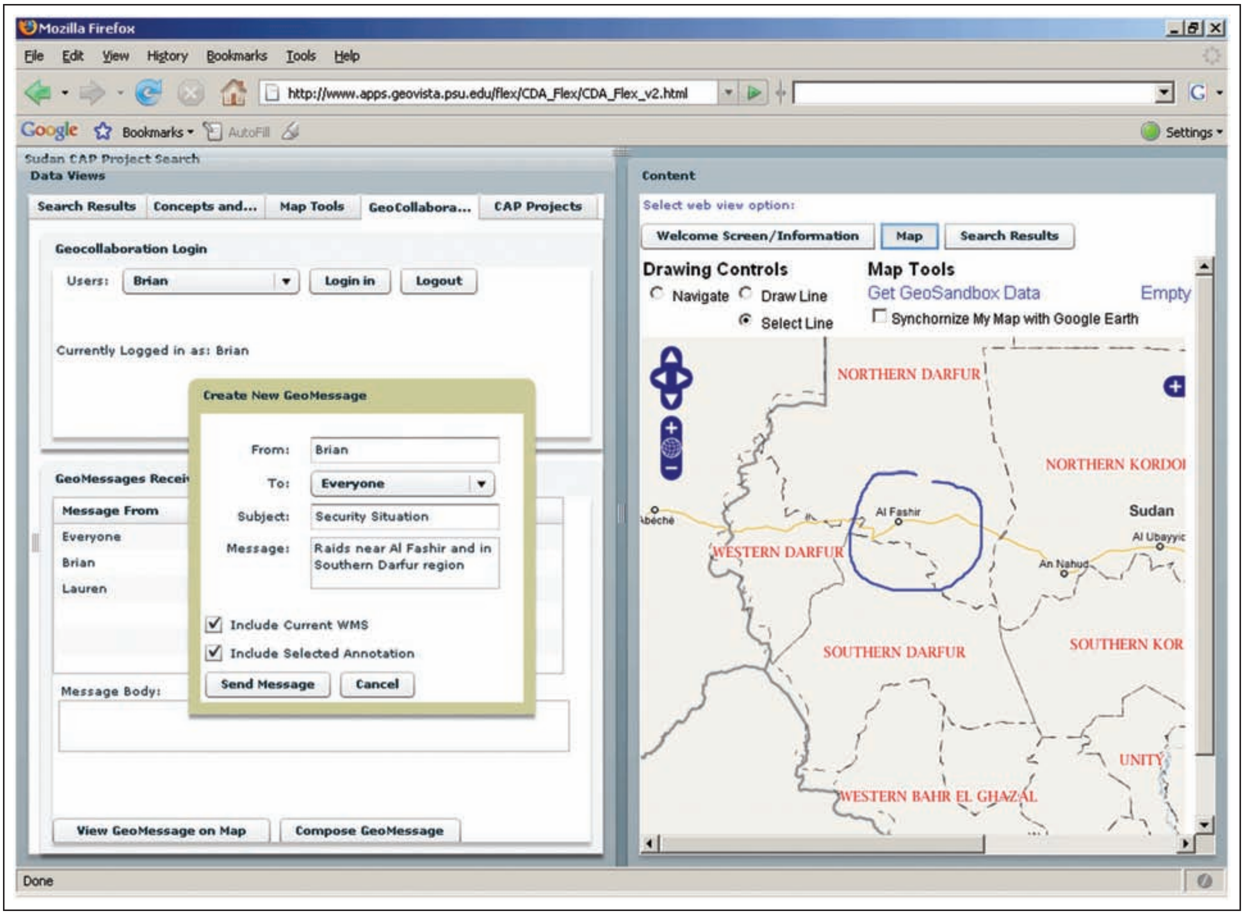

Figure 5. Example geomessage with map and annotation.

"think aloud" as in the talk aloud protocol, subjects describe but do not explain their actions.[30] The following six tasks were completed: (1) select (from a list) a CAP project to run a query against the Relief Web Sudan RSS feed, (2) review documents found in the search results interface (Figure 2, left), (3) use the space/time/concept interface (Figure 3) to review concepts, locations, and events that were potentially contextually relevant, (4) review search results in Google Earth, (5) use the GeoSandbox to save and select contextually relevant places, and (6) send a Geomessage. Tasks were conducted in 30-minute sessions.

Focus group. Given time constraints of UN personnel, only a focus group with Penn State participants was conducted. The goal was to leverage expertise of these individuals in design of geographic information technologies and visual interfaces focused on geographic analysis.

Surveys. Ten confidential survey forms were returned. The survey included Likert scale rankings (assessing understandability of the interface and of the displays, consistency of design, acceptability of response time, and overall usability) and three questions allowing written response (focused on best features, worst features, and suggestions for improvement).The Likert ratings were summarized using descriptive statistics (mean, mediam, mode). Table 1 presents survey form response data from both the Penn State and UN usability studies. Figure 6 presents the information graphically using box plots, which provide information on the distribution of responses.

As can be seen in Table 1 and Figure 6, the range of responses to each question varied greatly. Most response questions averaged slightly above four points on the seven-point scale, indicating general, overall positive reactions to the usability of the CDA. Participants were most positive about system response time; in addition, the assessment of the consistency of interface component appearance was largely positive. However, results were not all positive; for the first question the central tendency was below the "average rating" and for the fourth and fifth central tendency was an "average rating." Responses to the first

Table 1. Usability study confidential evaluation form response data. The scale of measurement is 1 to 7.

ID	Question	Mean	Median	Mode
Q1	The software interface was easy to understand	3.6	3.5	2
Q2	The software responded to actions in expected ways	4.2	4.5	6
Q3	The visual appearance of interface components is consistent	4.4	5	5
Q4	The interface controls work in a consistent way	4.1	4.5	5
Q5	Visual displays of information were easy to understand	4	4	4
Q6	System response times were acceptable	5	5.5	6
Q7	Please rate the overall usability of the software	4.2	4.5	3

Color key
Negative response
Neutral response
Positive response

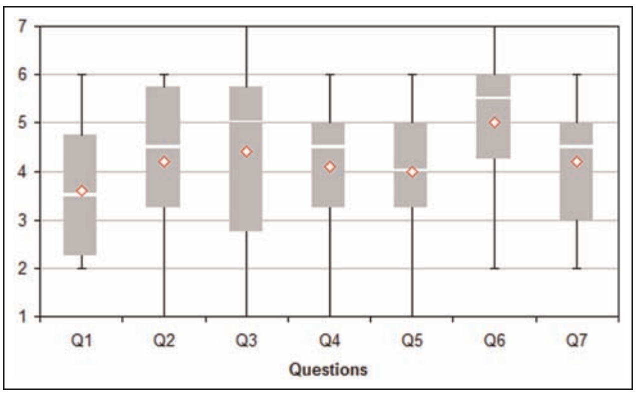

Figure 6. Usability study confidential evaluation form response question data box plots. Red diamond shapes in the center of each box are the average rating for the box.

question ("The software interface was easy to understand") indicate that a majority of users found the interface less easy to understand than average, and thus changes to the interface and/or improved training were deemed necessary. Responses to the fourth question add to this, with a rating for consistency of interface controls of average. Making the software interface and the visual displays easier to understand and controls more consistent were primary tasks undertaken between the usability and utility studies, as discussed in "Evaluating the utility of the GHC framework".

Data from talk aloud and observations during task completion, the focus group results, and the written responses to surveys were coded based on Nielsen's usability heuristics categories.[31] Table 2 presents illustrative quotes from the usability study pertaining to each usability heuristic. The full set of qualitative data from the task analysis, survey form written responses, and focus group discussions of the usability study, as classified into the 10 usability heuristics is provided in ref. 20.

As can be seen in Table 2, the usability study identified system issues related to all 10 usability heuristics. Of the usability issues that were identified, the one category that had the most comments was error prevention. In particular, geocoding errors were deemed by study participants to be the main issue that needed to be remedied. The geocoding errors made some participants feel that the software could not be trusted in terms of the analysis it was providing. Several participants also commented that the software was difficult to understand in terms of control layout, flow between using tools for the various tasks, and presentation of the search results. Many comments were also made about the need to add a legend to the CDA's Google Earth™ output. Other minor specific design and functionality recommendations were made, such as adding better navigation for the concept view and redesign of the geocollaboration interface.

The combined analysis resulted in four primary changes to the CDA. The first change was to improve the geocoding algorithm's ability to identify geographic terms such as cities and countries and resolving identified terms to correct geographic coordinates. The second change was simplification of the overall user interface; from an interface with five main frames that each included many sub-controls to an interface with only two main frames and fewer controls. The third change was a modification of the search results interface, shifting from a tree view of retrieved documents with text fragments visible for the selected document to a view modeled on a Google Search results display at the top matched with a tagged document view below (as shown in Figure 2). The fourth change involved addition of a legend to the Google Earth display.

Evaluating the utility of the GHC framework

Utility of the GHC theoretical framework was evaluated through a study conducted at the New York offices of the UN. The emphasis was on evaluating the

Table 2. Usability issues from usability study.

Nielsen (2005) usability heuristic	Issue identified from usability	Illustrative quotes
Visibility of system status	Users asked for better system feedback	"That's why it is even more important to have those visual cues I think as to give people a sense of what is happening, so it has to be that when you do that search it comes back with something right away"
Match between system and the real world	Information not appearing in natural order	"Flow and visual organization of features is needed to better guide the users"
User control and freedom	User felt out of control when using the CDA	"I don't feel confident using the tools, that I know what's going to happen and what's linked to what … I don't feel in control much"
Consistency and standards	Search results deemed difficult to interpret Software was considered "inconsistent" (google earth CAP discussion)	"Too many clicks to review documents, needs to be more concise like Google" "Consistency is important, sometimes I click and a get a project note, sometimes I click on something that looks the same, like the outlines is thicker, and I get an explosion"
Error prevention	Users requested fixing geocoding errors. Search bug should be a top priority to fix because it will help to get a better idea of what will be shown	"A lot of room for error in analysis"
Recognition rather than recall	Users asked for a legend in the Google earth representation	"It would be ideal to add a legend graphic to Google Earth"
Flexibility and efficiency of use	Participants found concept map hard to navigate	"I would like to be able change the scale of this (the concept map), I have too many blinders, hard to navigate to get an overview, suppress the instances to get an overview"
Esthetic and minimalist design	Participants commented that the interface needed to be "more user friendly, more simple and attractive"	
Help users recognize, diagnose, and recover from errors	No explicit comments were made on this category, but when bugs/errors did occur, no feedback was provided to the user. Users only knew there was a problem from the developer (the author) being present and pointing out the problem. This issue was most prevalent in the geocollaboration tools	
Help and documentation	Participants found it hard to understand software—without explanation, it [the software] is difficult to understand	"I felt a bit lost … there were a whole bunch of tools that each one of which is individually interesting, but it was not clear how they connect and what I'm supposed to do"

GHC conceptual framework and the general strategy for instantiating it in the CDA, not to do a comprehensive evaluation of the CDA as production software. Thus, a limited version of the CDA was used that contained features relevant to humanitarian relief. The particular focus for the evaluation was on the problem of making humanitarian funding decisions. The scenario required contextualizing humanitarian crisis situations via analysis of implicit geographic information derived from open-source documents. More specifically, while using CDA, study participants conducted tasks focused on contextualizing and reasoning with open-source information about humanitarian disaster relief projects in the Sudan.

Four UN staff members participated in the study, each from groups within the UN's OCHA, including the Field Information Services bureau and ReliefWeb. Having access to UN staff provided a key opportunity for examining a use of the GHC conceptual framework for application to real problems and not hypothetical scenarios. However, since UN OCHA personnel are constantly dealing with ever present world-wide disasters, the evaluation was necessarily much less controlled with fewer participants than the typical laboratory study with student or similar participants.

The first part of the utility evaluation (task analysis) consisted of 1-hour sessions at the ReliefWeb office. The second and final part of the utility evaluation was a focus group evaluation. During the task analysis sessions, participants were observed conducting tasks and assistance was provided to the participants when requested.

To provide a comparable experience during task completion so that a follow-up focus group would be productive, the CDA was loaded with pre-complied datasets for the task analysis sessions. Specifically, datasets from the ReliefWeb Sudan RSS feed and IRIN Sudan RSS feed were used. Each contained (a) documents that were processed by the CDA automated reasoning document classification and (b) a KML - Keyhole Markup Language representation of the RSS feed derived using the CDA.

Specific tasks were developed to assess the GHC model; these tasks incorporated geographic, thematic/conceptual, and historical components and the interrelations among them. Tasks were motivated by the following prototypical scenario that was also presented to participants at the beginning of each individual session.

Scenario: OCHA financial decision makers want an executive summary report on the evolving context of a select CAP project in the Sudan. They want to know how food security at local, regional, and international scales is playing out in the Sudan and how this may or may not relate to the efforts of the CAP project.

Two categories of cross-cutting tasks were developed to address this scenario. These tasks are targeted at establishing a preliminary context of a CAP project, thus to constrain/shape/contextualize a CAP project from geographic, historical, and thematic dimensions. One task sub-category includes tasks to assemble context information needed to answer a question (e.g., selecting the map in order to review basic CAP project information). The second sub-category includes tasks targeted at determining the contextual relevancy of a given piece of information (e.g., viewing a document's geographical footprint in Google Earth™).

Within these broad categories, distinct tasks were developed to utilize information from each of the GHC sub-models (geographic, historical, and conceptual/thematic) in different forms as per the ideas of locality (different view on the same world), and compatibility (interconnections existing with varying degrees of detail). The following are examples of GHC sub-model components related to sub-tasks that were developed to assess the GHC model in terms of locality:

- Geographic sub-model: View the document's geographical dimension in Google Earth (as seen in Figure 4).
- Concept sub-model: Review thematic information of potential relevance to a selected document that seems potentially useful (as partly seen in Figure 2 and also using the concept and timeline view of the CDA as in Figure 3).
- Historical sub-model: Review historical information of potential relevance to a selected document using the CDA concept and timeline view (see Figure 3).

The following are examples of tasks developed to assess the GHC model in terms of compatibility:

- Compile/synthesize your findings (a finding is something you think is potentially relevant that you would record/add to your report).
- Repeat (previous steps) as needed to support your analysis. For example, review several documents from different sources.

The intent of these tasks, in relation to evaluating compatibility in the GHC model, was to see how GHC sub-model information could be combined in order to represent the context of a humanitarian project. Each participant worked for approximately 1 hour and was asked to talk aloud during task completion. Participants used industry standard information technology tools such as Microsoft Word and Microsoft Powerpoint to compile and synthesize their findings. These tools were used as development of a specialized analysis synthesis tool was outside the scope of the CDA and the participants were comfortable with using these tools.

In addition to the specific detailed tasks outlined above, the participants were asked to create an executive summary report that outlined geographical, historical, and thematic dimensions of the CAP project's context. Figure 7 shows a map and the related excerpt from a report generated by one participant.

The report fragment and map shows multiple geographic dimensions of humanitarian projects in the Sudan in order to contextualize the project. On the map, colors represent individual news stories and lines represent locations computationally extracted from RSS feed to reveal potential geographic relationships between news stories. The ideas of locality and compatibility are reflected in this graphic in terms of how the study participant reports countries (locality) that

Figure 7. Example report section from one participant.

share similar but not identical food security problems (compatibility).

Following completion of the tasks, a focus group was used to prompt discussion targeted at key aspects of the GHC framework, its implementation in CDA, its applicability to the kind of task presented, and the general utility of the tools and the overall framework for supporting humanitarian relief activities.

Data from the utility assessment included notes taken while observing participants, transcription of the talk-aloud during portions of the task analysis sessions that focused on carrying out the task, and full transcriptions of the focus group session. Comments made in the transcriptions were analyzed using an approach outlined in Krueger[32] which has been utilized by cartographic/geography researchers such as Kessler.[33] In this approach, comments made during discussions are analyzed in terms of (a) frequency (or the number of times an individual or the group raises a specific comment), (b) extensiveness (which can be indicative of objection or support to a given topic), (c) intensity (potentially revealing feelings/emotions connected to a topic), and (d) what was not said (indicating that participants did not mention anything about a given issue). Using an approach outlined by Kessler,[33] comments derived from the transcriptions were then matched to the specific research questions outlined above. Space permits only highlight from results.

In addition to assessing the viability of the tools developed (see ref. 34 for a discussion of evaluating the virtual globe aspects of the CDA), a sub-goal of the overall study was to examine whether the participants felt it was useful to consider context as a concept with geographic, historical, and conceptual components. The following are excerpts from the focus group transcriptions where the participants answered questions about utility of the GHC theoretical framework to support answering strategic-level questions.

As a prelude to examining GHC specifically, participants were first asked what the term “context” meant. P1 and P2 responded that context was a series of relationships between information components. This view matches closely with the theoretical perspective grounded in local model semantics outlined above. P1 even noted an idea discussed above that context acts like a framework: “it’s also a very complex relationship let’s say, because you’re looking at some info and how it connects or relates to a ton of other information may be around that subject, so that's, what I, I would consider a context of something." P4 made a comment that context was "the environment and situation", demonstrating how the terms context and situation can often be intermixed. As a follow-up to the basic question about a general definition of context, a question was then posed to the group about the notion of "analyzing a context" as per the language of the humanitarian case study the participants were conducting. P1 and P2 said that analyzing the context was in essence looking at the background to a specific situation. P4, however, restated that analyzing the context was in fact analyzing the situation.

Finally, probes directed discussion to whether it is useful to consider context to have geographical, historical, and conceptual components. All participants agreed that it is useful to consider context (and context for humanitarian projects in particular) to have geographical, historical, and thematic components. In agreeing with this, P4 related the notions of geographical, historical, and thematic components to humanitarian profile maps developed by ReliefWeb, as illustrated in the following quote: "yes because otherwise we couldn't, if we don't know the situation of one country … provide funding so that's why we also decided to put together a profile map. We can provide the situation of country, therefore they will learn of the situation and then they can provide some funding, so the situation, … the awareness of the situation is very important. It's key." Beyond the geographic dimensions mentioned explicitly, historical and thematic dimensions of context are implied in P4's quote implicitly. Humanitarian profile maps contain numerous references to thematic and historical information that is essential for understanding the situation. Also of note in the previous quote from P4 is the sentiment that the GHC helps provide a context in which decisions about funding can be made (although P4 didn't use the term context specifically). P1 and P2 also echoed this sentiment, and P3 agreed.

Participants were also asked to discuss how successful the CDA was at visually representing the geographic–social context of asynchronous group work that is characteristic of humanitarian relief efforts. During the questioning and subsequent discussion, P4 had stated that the collaborative aspects of the CDA were very useful – "the collaborative aspect and if it working since as it didn't work, that we would be able to collaborate, so you have the map, and you can draw top on it, and for example, and say 'oh look at that, I received the latest refugee information', and you can send and people can see it in a collaborative manner, and this I found it very well." As can be seen in P4's comment, a software bug with the geocollaboration system that was encountered did not greatly impact P4's opinion about the potential of geocollaboration tools.

Further discussion about geocollaboration was prompted by asking "were you able to learn anything from your collaborators?" P4 indicated that since there was a bug, nothing could be learned from others, but that the geocollaboration tools would be useful as this is the era of Facebook. P2 reinforced this point by stating that CDA's geocollaboration tools are like a Myspace page.

Reports produced by participants were also reviewed. With the exception of Report 3, each of the four reports provided some indication of geographical, historical, and/or conceptual dimensions of the CAP projects contexts. The level of detail and means to represent and describe the GHC dimensions varied based on the form of information used by the report author. For example, participants 1 and 2 relied on Google Earth images with minimal accompanying text to describe contextual information. The author of Report 3 used numerous screen captures of web pages and the named entity view to describe geographical, historical, and thematic/conceptual dimensions, but did not include any map, concept, or timeline views. With the exception of Report 3, all participants used the geomessage tool to share findings. What was interesting to note was that two participants used the geomessage tool to develop messages with expressive annotations.

Three observations can be made from the focus group results. First, in spite of earlier usability assessments with UN personnel (who also participated in the utility study) and subsequent CDA revision, several usability issues were identified that were sufficiently serious to impede use for the tasks posed; in addition, one of the four participants needed to spend a substantial proportion of the hour-long session relearning CDA functionality before starting on the tasks. This suggests that simpler interfaces and perhaps training in tool use will be necessary to put tools like these into practice. More positively, although participants could not agree on an exact definition of what context was, they all generally agreed that it was useful for context to be composed of geographic, historical, and thematic components for humanitarian information work. Finally, all participants, in different ways, saw the future value of specific components of the CDA (with an improved interface) for use in humanitarian information management.

Follow-up: the UN-OOSA RIVAF project

Since the CDA evaluation study, the CDA has been repurposed for use in disease dynamics analysis[35] and was also re-purposed by the United Nations Office for

Outer Space Affairs (UN-OOSA) for use in assessing the effects of the 2007–2009 global economic crisis (GEC) on the vulnerability of impoverished people around the world. The CDA is well suited to support such an analysis given the complex, heterogeneous, abstract nature of large volumes of data related to poverty indicators such as multi-scale economic markets, social network support, health and well-being and livelihoods. Specially, CDA visual analytic concepts and software tools were expanded upon and used, in part, on a research project titled "A Visual Analytics Approach to Understanding Poverty Assessment through Disaster Impacts in Africa", led by UN-OOSA and funded by the Rapid Impact and Vulnerability Analysis Fund of the UN Global Pulse initiative.[36,37] The objectives of the UN-OOSA RIVAF project are:

1. Understand GEC effects on relationships between livelihood, poverty, and vulnerability to natural disasters.
2. Understand how natural disaster impacts are potential indicators of GEC impacts on the poor and vulnerable.

To meet these objectives, a next generation of the CDA was developed via an online visual analytic environment called the "Visual Analytic Globe." This names change reflects the emphasis the new tool will make on incorporating space-based information as the per the mission of UN-OOSA Space-based Information for Disaster Management and Emergency Response Programme (UN-SPIDER)[38] into the overall visual analytic process via virtual globes.

Modifications to the CDA for development of the Visual Analytic Globe were motivated by (a) the results of the CDA usability and utility studies presented in this paper and (b) development of more robust geovisual analytic tools to support the tasks of the UN-OOSA RIVAF project. Specifically, the modifications include:

- Integrated, web-based virtual globe representations (vs. using an external standalone virtual globe) (Figure 8). Furthermore, each visual interface element (such as the space/time/concepts view discussed in the "CDA functionality" section but not shown in Figure 9) is now contained on a tab that can be easily repositioned, thus giving the analysts flexibility to configure the environment to support analytic tasks.
- Integrated quantitative data representations (Figure 9).

As can be seen in Figures 8 and 9, parts of the technology implementation have shifted from open-source to commercial tools to fit UN work practices. This provides some additional evidence that the core framework is fairly robust and extensible. While the information graphics tools included are relatively standard ones (in this case implemented using Esri[39] and Google[40] mapping tools), including them in the integrated environment meets clear needs of UN personnel to understand the effects of the global economic crisis on vulnerability using reliable, industry-standard tools vs. research prototypes.

Furthermore, core analytic capabilities of the CDA were expanded in the Visual Globe based on a user requirement that published documents be incorporated into the analytic processes of CDA use. This user requirement led to the a design choice to include new information retrieval tools that allow for the integration of archival documents such as government reports and studies by non-governmental organizations (NGOs). For example, numerous reports and studies on the effects of the global economic crisis such as socio-economic impacts were published in 2008–09. Often, these reports and studies contain valuable situational and contextual information of how people across varying geographic scales are coping with the effects of the GEC. Although valuable assets to support sense-making tasks, from an information retrieval and analytic perspective, the underlying knowledge in these assets are difficult to integrate with other data assets such as those that the CDA incorporates (as discussed in "CDA functionality") as these assets are often very large (25 + pages) documents that are time-consuming to analyze and make sense of. To overcome the challenges associated with incorporating archival documents into the CDA, a workflow was designed that allows the contents of archival documents to be structured to take advantage of the CDA's existing ontology-based querying tools and visual interfaces (see ref. 35 for discussion of these tools). In particular, the contents of each document were extracted from their source (often a PDF) and added to an XML template for storing the extracted contents in order to load them into a searchable document index.

Figure 10 graphically summarizes the workflow that was established to structure the contents of archival documents so the documents could take advantage of existing CDA tools and how documents processed in the workflow are incorporated into CDA visual interfaces.

Development of these new information retrieval tools to support annotation of archival documents to support subsequent access to the documents also provides evidence of how the core analytic framework of the CDA was capable of incorporating new types of data inputs to enable sense-making tasks. Ultimately,

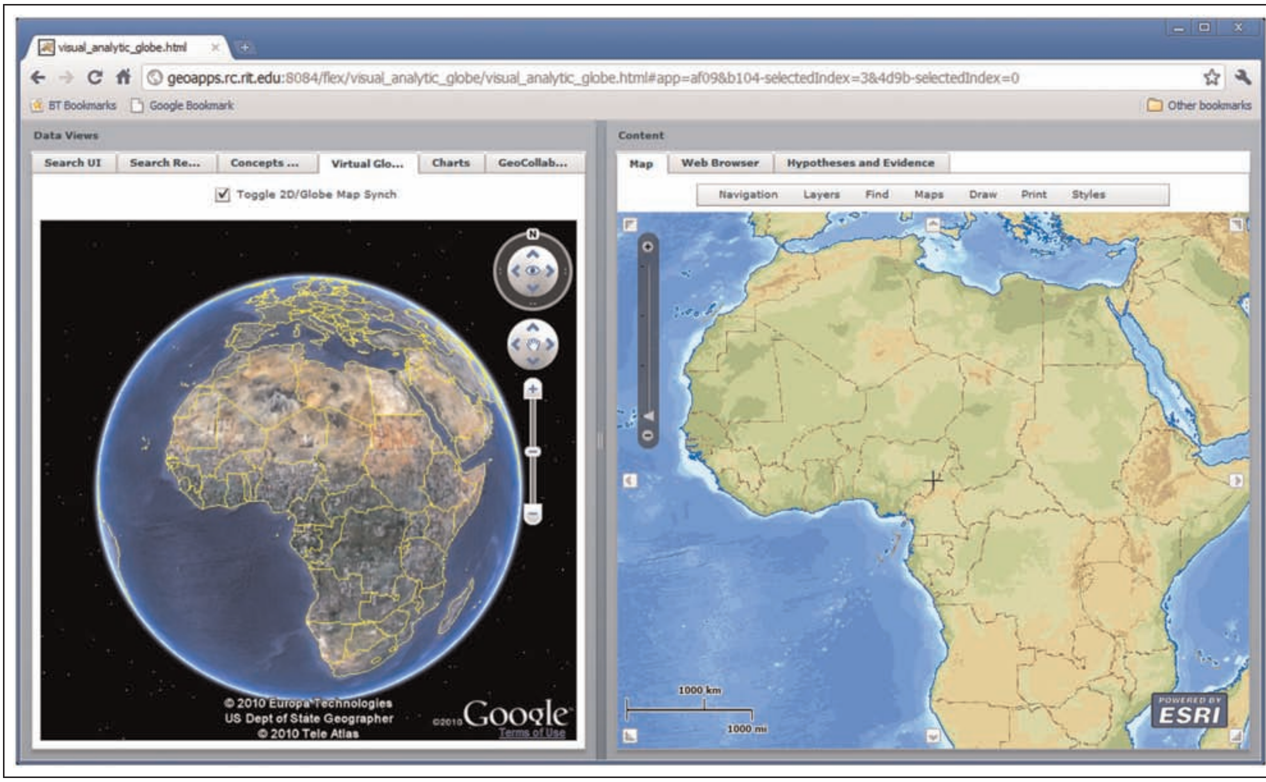

Figure 8. Integrated Virtual Globe and 2D map views. These views can be synchronized with one another. For example, panning and zooming the Virtual Globe shown on the left will make the 2D map show the right pan and zoom to the same display extent as the Virtual Globe. In this example, an analyst is beginning to conduct an analysis of Africa and is synchronizing the Virtual Globe and 2D map views so as to begin looking at specific areas within Africa, such as the cotton-growing area of Burkina Faso.

the CDA analytic framework can be expanded to include other types of data inputs, such as social media, in order to provide analysts with any relevant data artifacts that can be reasoned with and provide situational context using the CDA's visual interfaces.

Preliminary analysis

The following section briefly outlines select results from an analysis of Burkina Faso that was conducted for the RIVAF project based, in part, on use of the CDA analytic framework (as implemented in the Visual Globe tool). The example provided is meant to highlight the sense-making support and contextualization capabilities of the CDA and not to provide a full discussion of RIVAF project results, as such a discussion is beyond the scope of this paper. Subsections below summarize the analytic results then detail how the CDA analytic framework supported generation of these results.

Analytic results. Identifying the specific effects of the GEC on vulnerable communities in Burkina Faso was a challenging, if not impossible, task. In the case of Burkina Faso, the challenge stemmed mainly from the complex web of vulnerabilities created via systemic poverty, economic disadvantages from being a landlocked country, limited government expenditures to fund activities such as public investment due to low state revenue and high reliance on external aid, and economic vulnerabilities created via trade fluctuation and a limited range of export commodities such as gold, livestock, and cotton.[41] According to the International Monetary Fund (IMF), although cotton contributes only 5–8% of gross domestic product (GDP), it accounts for 50–60% of Burkina's export revenues and foreign exchange.[42] Understanding the context surrounding cotton issues was thus of particular interest to the analysis.

For example, according to the Boards of the African Development Bank (ADB) and the African Development Fund (ADF), between 2005 and 2009, the average annual real GDP growth rate in Burkina was 5%.[43] The cotton sector drove the growth despite the challenging international context of the food, fuel, and economic crisis and a significant drop in world

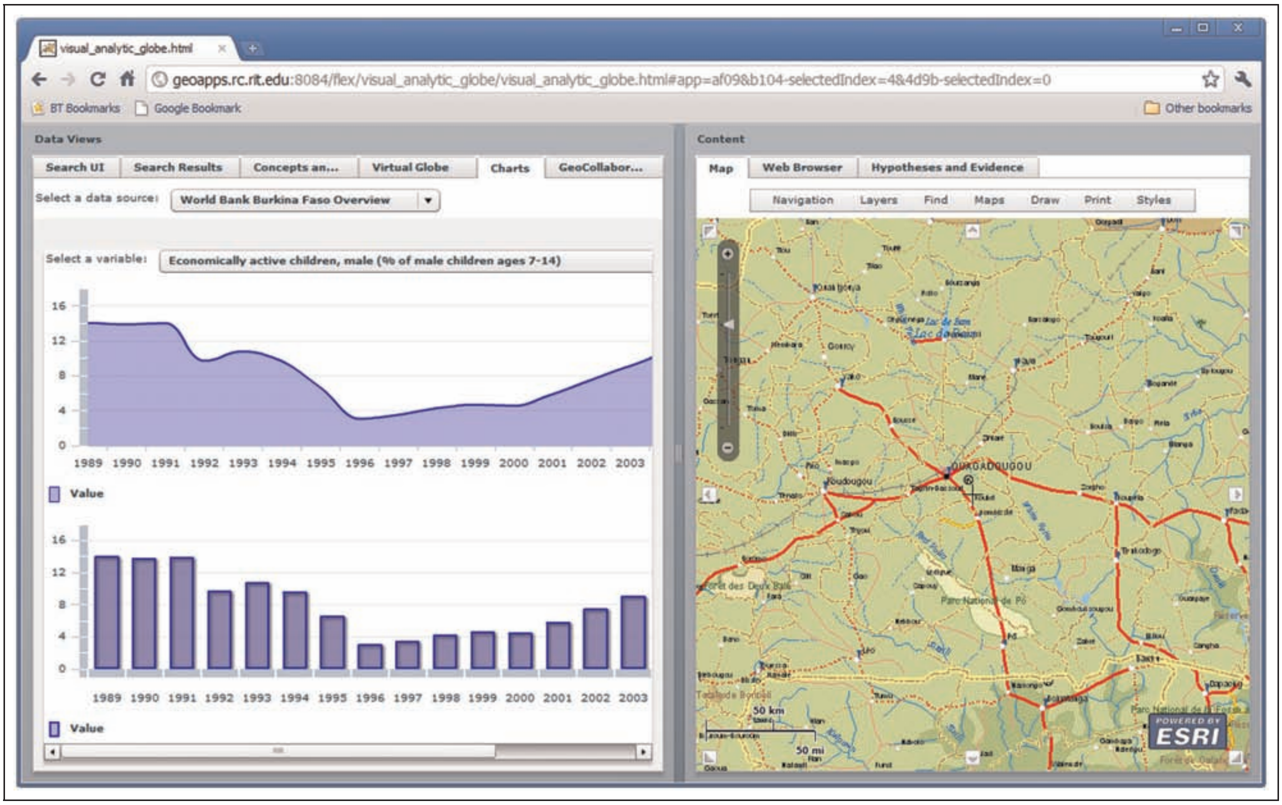

Figure 9. Integrated quantitative data representations. In this example, World Bank data related to economically active children in Burkina Faso are shown. Reviewing data such as these can help an analyst make sense of longer term social and economic trends in a country.

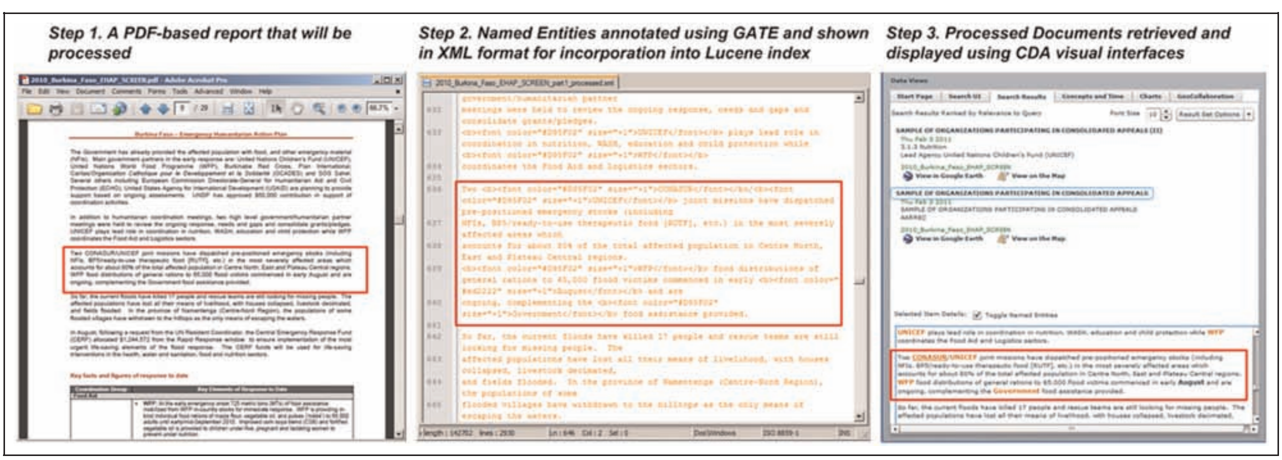

Figure 10. In this figure, a selection of text (outlined with a red box) from the 2010 Burkina Faso Emergency Humanitarian Action Plan published by UN OCHA is shown in various stages as it is processed for use as an archival document. This particular document was chosen as it provides valuable context information for Burkina Faso—a country that has been greatly impacted by the global economic crisis of 2008. The first step in the process is to run the PDF document (step 1) through the GATE program (not shown) to annotate named entities of interest in the text. Once the entities are annotated, the annotated text is stored in an XML-based template (step 2) that allows the document to be added to a customized Lucene-based search index, which can queried by an analyst, and return data artifacts such as named-entity annotated text that can be rendered in the CDA's existing visual interfaces (step 3) that are also used by the CDA's open-source information retrieval tools.

cotton prices between 2008 and 2009. In addition to pressures created by decreases in global cotton prices and demand, Burkina's cotton sector has also faced pressure because of subsidies given to US and other countries' cotton farmers that undercut cotton production.[44] In 2006, Burkina and other cotton-producing countries proposed that US cotton subsidies should be cut by 82.2% over a 2-year period as part of the World Trade Organization (WTO) Doha talks of reforming international trading systems by lowering barriers,[45] but the USA has yet to make a response.[46]

CDA support for understanding the Burkina Faso context. The CDA analytic framework helped develop this context in the following four ways. First, the news archive querying tools allowed analysts to quickly find relevant documents and activities between 2007 and 2009 (the approximate time period when the GEC was at its peak) (Figure 11).

Second, the named entity extraction and visual representation tools help to quickly discern organizations of interest such as the World Trade Organization, the Board of Governors of the African Development Bank (as seen in Figure 11), the World Food Programme (WFD), and locations of interest. For example, although Burkina Faso was the primary country of interest, understanding how Burkina Faso economically interacts with and is affected by other countries such as the USA is key to a contextual understanding of the cotton industry in Burkina Faso. Third, the integrated quantitative data representations (see Figure 9) helped to contextualize socio-economic trends in Burkina Faso. Finally, the integration of archival documents from UN-OCHA helped to make sense of how people were coping and adapting to economic fluctuations in the country such as diverting financial resources to purchase food at the expense of education and health, and switching to lower quality food.[47]

To summarize, the ability of the CDA analytic framework to contextualize complex situations, as demonstrated in the studies presented in this paper, helped in part to provide a key sense-making support role for the UN-OOSA RIVAF project. Specifically, the CDA assisted with understanding of the chain of effects that the GEC has had on poverty, livelihoods, and subsequent vulnerability to natural disasters and other stressors such as food insecurity.

Conclusions

Context is a difficult term to define and has many usages and meanings in different research and application domains. This research has defined a particular

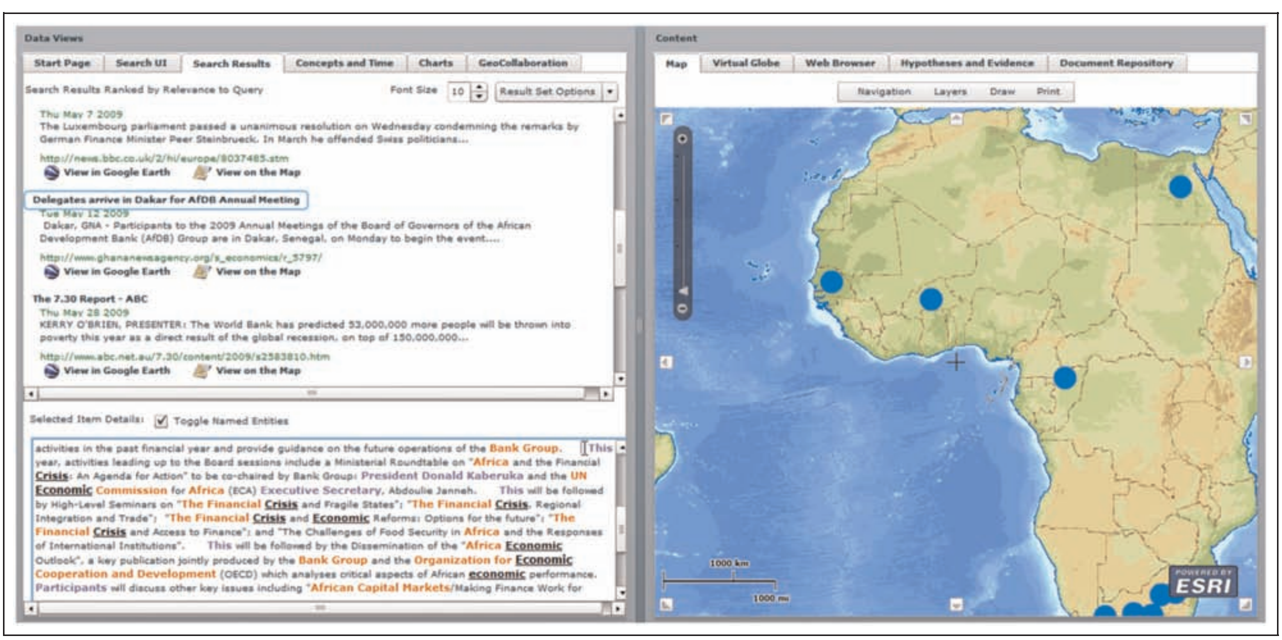

Figure 11. This figure shows how the CDA assisted with finding news stories from 2009 related to a regional organization within Africa (the Board of Governors of the African Development Bank) that was conducting round-table meetings and seminars and publishing reports related to African economic issues. In particular, the CDA's named entity recognition functions highlighted organizational names (as seen in orange on the bottom left of Figure 11). Items in bold, black, and underline are analyst query terms that were used to retrieve the news stories from Google News Archives.

type of context, called GHC, through the development of a GHC model that is based on relevant theoretical perspectives and computational representation strategies. The GHC model was the basis for developing a geovisual analytics environment designed to produce GHC from unstructured information sources within a challenging application domain, namely context analysis activities that underlie information foraging and sense-making in humanitarian crisis management.

While the evaluation of GHC as a conceptual framework presented here is a limited one, the limits are countered by the ecological validity of obtaining focused input from experts in international humanitarian relief. Evidence presented suggests that GHC is a viable framework for structuring situational reasoning tasks related to the assembling of GHC information. In particular, outcomes of the evaluation revealed that study participants thinking about the general notion of context matched closely with the local model semantics theoretical perspective as reflected in evaluation task outcomes and focus group discussions. Furthermore, participants were able to use the computational text processing and visual interface tools of the CDA to find relevant information and focus more of their attention on developing CAP reports. Most importantly, insights from implementation and the user studies have led to an adaptation of the methods and tools for real-world use by the UN.

Future research can incorporate the notion and evaluations of GHC promoted in this research to develop more robust geovisual analytics tools that are well suited to the information foraging and sense-making tasks of finding and interpreting information, identifying relationships, monitoring changes, and making decisions. Ideally, such efforts will lead to the development of visual analytics and other information systems that can effectively contextualize crisis situations from geographic, historical or any other dimension of interest.[48] Properly contextualizing crisis situations can lead to improved crisis mitigation, response, and coordination, and ultimately improve or save lives.

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Declaration of conflicting interests

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