Visualization for Geographical Information Retrieval

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(Invited contribution)

[Abstract] Majority of the available digital information are associated with some location or regions on the Earth. Traditional visual interfaces to digital libraries were not designed to deal with the unique geospatial characteristics of data, nor did they take full advantage of the georeferencing as a mechanism for browsing and retrieving information. This paper highlights the trends of visual interfaces to geospatial information, and suggests major challenges towards effective visualization of multimedia geospatial document space. Citing recent research efforts, we review the attempts to integrate document visualization (developed in information science) with geovisualization techniques (developed in geographical information science) to support science, information access and decision making. We conclude by a set of spatial cognitive principles that influence future development of such visual interfaces to geographic information.

1. Introduction

Geographical information refers to any documents that reference some part of the Earth’s surface. Finding relevant geographic information over the network is critical to many digital library users ranging from scientists involving global change studies to families preparing for relocation. Future information services should allow anyone to locate and integrate information quickly and easily about any place on the Earth surface. This new frontier of ubiquitous geographical information access is exemplified by the report “distributed geolibraries” (National Research Council. 1999). The problem presents a broader challenge than those that have been dealt with by individual disciplines such as library information scientists and geographical information scientists, and the solution might require integration of multiple disciplines and perspectives. For example, in the library tradition, textual geographical information tend to be indexed using library catalog methods and retrieved by keyword searching, while cartographic maps and other visually-encoded geographical information are treated as special collections of books. However, a user is likely to be interested in all types of geographical information within certain spatial and thematic scopes (irrespective of media types). To this criterion, current information retrieval systems are ineffective for retrieving multimedia geographical information in the sense that they do not support user’s interactions with the document collection through user-perceived spatial and thematic relevance criteria.

From another camp, geographical information scientists have developed specialized systems, geographical information systems (GIS), for handling maps, images and other visual geographical data with clearly defined boundaries or extents. GIS index data and documents in geographical coordinate systems using geometric shapes. The dominant form of information retrieval queries in GIS is by spatial selection. However, there are considerable amount of geographical information existing in textual forms that are not easily integrated into GIS for mapping and spatial analysis, due to the difficulties of natural language understanding for geo-referencing text. This forces us to manage geographical information in two separate types of systems: using GIS for maps and images, and using traditional catalog methods and keyword indexing for textual documents. However, a user is likely to be interested in all types of geographical information within certain spatial and thematic scopes (irrespective of media types), and it would be far more valuable to the users if visual and textual forms of geographical information can be integratedly retrieved from one system environment. To this end, neither a GIS nor a textual IR system is adequate.

From the user interface point of view, current information retrieval interfaces are also less effective in the sense that they do not support user’s interaction with the document collection through user-perceived geographical and conceptual relevance criteria. For example, most on-line searching interfaces to libraries and to the web are based on matching keywords between the query and the index of a document. In
contrast, geographical information systems (GIS) provide special utilities for matching the geographical locations of a query to the geographical index of documents, but the layered organization of themes in GIS, although working well with maps and images, is too restrictive for handling free-text documents. Recent efforts have been made to unify the retrieval models and user interfaces to either geographical, coordinate-based retrieval systems (Larson 1996) or keyword-based systems (Buttenfield and Kumler 1996), but have met with limited success.

With the exploding volume of available geographical information and the increasing complexity of the information space, searching relevant information is getting harder due to the difficulties of knowing what information are there and how to ask questions. Artificial intelligence techniques are often embedded into information retrieval algorithms that attempt to deal with the complexity on user’s behalf. However, model-driven approaches worked only to a limited degree. Recent progress on visualization in general (Chen 2002) and in digital library in particular (Ahlberg and Shneiderman 1994, Zhang 1999, Ancona and Smith 2002) represent a philosophical shift towards information support for human thinking and knowledge discovery through visualization tools and techniques. Jin Zhang (1999) presented a number of advantages of visualization, including (1) making visible the relationships between query and documents, (2) making visible the information retrieval process, (3) making the results more interpretable by providing visual context, and (4) facilitating explore and recognition in discovering relevant information. This is consistent with the observation that information retrieval is increasing being treated as a process of sense making, knowledge acquisition, and problem solving (Marchionini 1995) through interacting with the information space presented by a system. The cognition of geographic information space is inherently more complex, and involves actively reconstructing knowledge about the document collection by multidimensional (spatial and semantic) navigation, pattern reading, and reasoning. Such domain will benefit significantly from visual information seeking methods.

This paper will review the tools, models, and the trends of visualization for geographical information repositories. After a brief discussion on the properties of the document space for geographical information in section 2, we shall describe the visualizations in geographical subspace and thematic subspace (section 3). Then, we introduce integrated multi-view approaches that allow users to navigate and judge relevance of documents in a visual and interactive manner. Based on known facts of human information searching behavior, we provide a set of design principles for digital libraries to better support searching of geographical information. As an example, we cite a prototype visualization system, named GeoVIBE, that demonstrates our design concepts, with an emphasis on an integrated geographic and keyword searching environment, combined with effective visualization techniques. The system suggests a joint research agenda for relevant fields including geographical information science, information retrieval, and information visualization.

2. Document Space of Geographical Information

In the following discussion, we formalize the interpretations of some important concepts. The content and structure of a document collection is best viewed as a high dimensional space, called document space, where each dimension represents an attribute that is a potential discriminator of the documents. For the purpose of this study, our concern is on geographical information – documents that refer to some part of the Earth surface. Such documents exist in visual forms (such as maps, remote sensing images, and aerial photographs) or in textual forms (such as field survey descriptions, technical papers, and reports). Common to all these documents is that each has some form of geographic “footprint”. Cartographic maps and geo-referenced images have geographic footprints defined by bounding coordinates of their edges. Textual documents also have footprints, but they are defined by geographical terms such as place names. The two types of footprints can be made compatible by converting one type to the other with the help of a gazetteer (a form of index that relates place names to coordinates of locations and extents). Each document may also be associated with a number of thematic subjects (non-spatial attributes) assigned by human catalogers or derived from automated document analysis. Users may search geolibraries by geographical location, by geographical place name, and by thematic subjects.

For geographical information, the document space can be divided into two kinds of subspaces: a geographical space and a thematic space. These two document subspaces are inherently different:

Geographical space: This is a two dimensional space, commonly represented by a geographical coordinate system, such as latitude and longitude. A document may be concerned with a small part of earth surface, which can be geometrically represented as points, lines, or areas, which can be used as the footprint of the document in the geographical space. Documents may
be considered similar or different based on the spatial relationships of their footprints in geographical space.

**Thematic space:** This is a multidimensional space, where documents are placed according to their thematic concerns. The number of dimensions in theme space may vary depending on how specific the concepts in the document are categorized into themes.

3. Representing Geographical Documents

To facilitate automated retrieval of relevant documents from a collection of documents, a digital library commonly maintains one or more representations of these documents that serve as surrogates. Creating informational surrogates and using them properly has been a long-standing goal that motivates many research efforts in digital libraries, and some of the useful guidelines have been developed by Greene and colleagues (Greene et al. 2000). These guidelines can inform the choice of visual interfaces for geographical information, particularly where the use of multiple surrogates and visual interfaces for navigating within and linking across surrogates are concerned.

Surrogates for geographical information documents should be designed to serve three functions in an information retrieval system. First, they are abstractions and homomorphic reductions of the original documents that require less time to process and analyze but at the same time provide enough semantic cues for users to judge relevance. For example, most textual IR systems use a set of term vectors as surrogates of the original documents, and all analysis and visualizations are performed in the term vector space.

The second function of document surrogates is to mediate the differences (or bridge the gaps) between the literal space in which the documents were originally encoded and the semantic space with which users perceive relevance. By literal space, I mean a representation space that comprises attributes that are directly extractable from the documents, such as content-bearing terms, visual attributes (color, texture, composition of images), and legends (from maps). Semantic space is comprised of those attribute dimensions that are most salient to the users’ judgment of relevancy. For geographical information, semantic space can be divided into two kinds of subspaces: a geographical space and a thematic space. These two document subspaces are inherently different.

**Geographical space** is a two-dimensional space corresponding to the surface of the Earth and is most commonly represented by a geographical coordinate system, such as latitude and longitude. A document may be concerned with a small area on the earth surface, which can be geometrically represented as points, lines, or areas in a geographical coordinate system, and can be used as the footprint of the document in the geographical space. **Thematic space** is a multidimensional space, where documents are placed according to their thematic concerns. The number of dimensions in thematic space may vary depending on how specific the concepts in the document are categorized into themes. With the definition of literal space and semantic space, document surrogates can be constructed from selected dimensions in literal space, or selected dimensions from semantic space, or some mix of dimensions taken from both spaces.

Literal space surrogates are easiest to construct because they can be extracted directly from the original document, and can potentially be automated. However, constructing document surrogates in semantic space means that we have to take a user-centered perspective to identify informational objects that convey meaning, and is generally more difficult to do because it often involves significant content transformations and abstractions from literal space representations, and may require human knowledge and intervention. The challenge for designing surrogates for geographical information documents stems from the dual nature of their literal space (visual and textual) and the dual nature of their semantic space (spatial and thematic). As a general guideline, document surrogates should be defined separately in geographical subspace (using geographical “footprints”) and thematic subspace (using term vectors). The process of deriving these surrogates is defined as the mapping from the literal spaces to the two semantic subspaces.

The third function of document surrogates is to serve as interface objects to assist users’ navigation and relevance judgments in a visual and controllable environment. The works by Greene, Marchionini, Plaisant, and Shneiderman (2000) on preview and overview surrogates fall into this category. Overview surrogates as interface objects aid the retrieval of relevant documents by presenting to the user a comprehensible “picture” of the document space for maximum comprehension and minimal disorientation. Meanwhile, preview surrogates help users decide whether the original document should be accessed. Interface level surrogates should also give users control of what attributes and objects to focus on in the display.
Choosing document surrogates for geographical information is likely to be based on multiple IR models, two of which are reviewed below.

3.1 Vector Space Model

Vector space model (Salton et al. 1975, Salton and McGill 1983) assumes that each document can be approximately described by a vector of (content-baring) keywords which are generally considered pair-wise orthogonal. Under this model, an information retrieval system stores a representation of a document collection using a document-by-term matrix, where the element at \((i, j)\) position corresponds to the frequency of occurrence of term \(j\) in the \(i\)th document. By representing all the objects (terms, documents, queries, concepts, etc) as vectors in a vector space, the model can compute a similarity coefficient that measures the similarity between a document and a query or another document. Those documents whose contents are most similar to the query are considered the most relevant.

3.2 Geographical model

Although geographical information can be accessed by linguistic queries, geographic access is sometime the most important mode. Here, geographic access is given a special meaning to refer to a coordinate based access in which by referencing a place or a region on a map, we can retrieve all information dealing with the identified point or zone.

Following the database model of a geographical information systems (GIS), a geographical model of document space is best conceptualized as a data cube, where cartographic primitives of points, lines, and polygons are used as indexing shapes to documents. Index shapes of different themes, such as roads, rivers or vegetation types, are organized into multiple map layers that are separately stored and that can be linked together by geography. A prerequisite for coordinate indexing is that all the documents are geo-referenced. Spatial indexing of maps and remote sensing images is straightforward, since their spatial extents are usually well-defined. Spatial indexing of textual document is more challenging, and requires translating linguistic geographical references to geometric shapes defined in geographical coordinate systems (Woodruff and Plaunt 1994).

Information queries to a geographical digital library can be arbitrarily complex, but the most common spatial queries are believed to be of four types: point, region query, and buffer zone (Laurini and Thompson 1992). A point query essentially asks any
is often a phrase of geographical description that should be interpreted as a whole, rather than being treated as independent terms. Due to these reasons, geographical terms are a bad representation of the geographical scope of a document. The use of geographical terms as indexes has a number of well-known problems, such as, non-unique place names, place name might change over time, and spelling variations (Holmes 1990, Abdelmoty and El-Geresy 2000) (Griffiths 1989).

In comparison, coordinate based indexing and access has many advantages in dealing with geographical information. Spatial indexing based on coordinates generates persistent indexes for documents, since it is well defined and is immune from any changes in place names, political boundaries, and linguistic variations. Indexing texts and other geo-referenced objects (such as photographs, videos, remote sensing data sets, etc.) by coordinates also permits the use of the hypermap concept (Laurini and Milleret-Raffort 1990), as will be discussed later.

4. VISUALIZING DOCUMENT SPACE IN GEOGRAPHICAL DOMAIN

When dealing with the geographical information in digital libraries, the selection of appropriate interface metaphors and the definition of visual query languages becomes an especially challenging task. This is due to the double nature of a geographic data, which has a geometric component (needed to define the spatial relations) and a thematic component (referring to a real-world entity or concept) (Sebillo et al. 2000). Though different, the two components turn out to be complementary for the description of geographic data. On the user side, people seem to have two separate and inter-related cognitive facilities in dealing with spatial information: spatial and conceptual (Jones and Dumais 1986, Jackendoff 1992). People also maintain two separate representations of the same object (e.g., a room). Previous study has revealed that human subjects tend to draw a geographic object by providing its geometric representation, while referring to its meaning in the real world, namely to the theme that the object describes (Mark et al. 1995). This means that the two parts of representations of geographic data are intrinsically related in human minds.

Based on the above principles, we may conclude that geographical information libraries should ideally be equipped with two separate sets of interface metaphors and query languages (spatial and thematic), which are internally linked by an integrated indexing and retrieval mechanism. Digital libraries have explored both spatial and conceptual approach for visualizing geographical information, but have not achieved the right balance in utilizing both in an integrated fashion. Next, we shall review existing interface metaphors and query languages for visualizing document space in spatial and thematic dimensions, with the intention of formulating new ways to integrate them.

4.1 Geography as Information Space

The view of geography as an information space emphasizes the use of the abstract sense of the world (places, and locations) in judging relevance and browsing large number of documents. When documents are put into the context of the geographical world, the potential spatial interactions between places (diffusion, movement of information through space) and/or the spatial patterns of document distribution provide rich clues for judging relevance of a document in its associated geographical context. Information browsing by geography is best facilitated by a map-based graphical user interface. This allows visual inspection of document space with contextual interpretation of relevance implicit in spatial relationships. A map-based graphical interface tends to be intuitive and comprehensible to anyone who is familiar with maps (Larson 1996). Morris (Morris 1988) suggests that when users are given a choice between menu (text-based) and map-based graphical interfaces to a geographic database, they prefer the maps.

There are a number of variations of map-based interfaces in existing library systems. Alexandria digital library (ADL) (Smith 1996) uses the idea of geographic footprint to represent the location on the earth surface associated with maps and image objects or with user queries. Users can specify arbitrary query area and retrieve all information items whose footprints overlap with the query area. ADL map interface is currently not integrated with term-based search methods such as gazetteer and catalog search, but this is an expected improvement [Hill, 2000 #499].

Other systems use ‘tiles’ metaphor as visual surrogates of documents, where a tile is the smallest regular division of the space that has indexing capability. For example, Microsoft TerraServer (Barclay et al. 2000) is a multimedia geographical data warehouse that serves aerial, satellite, and topographic imagery. It indexes source images and photos by scenes and tiles. It also use multi-layered index maps which categorize imagery
into “themes” by data source, projection system, and image “style”. A user may query images in three styles: coverage map, place query, and coordinate query.

A related line of research is the use of Hypermaps as access interface to hypermedia or multimedia spatial information (Laurini and Milleret-Raffort 1990, Laurini and Thompson 1992, Voisard 1998). In a hypermap, the links to documents are represented by an icon or footprint (a polygon that outlines the area described by the object linked to the footprint), and selection brings up the document referenced by the link. A hypermap interface is dynamic because the view is made up of a collection of map layers, each of which may be turned on/off independently of other layers. This allows users to control what is shown on the display at any situation.

4.2 Desktop as Information Space

In visualizing document space based on simple Boolean and vector space models, a real challenge is to support users in visually exploring the structure of the high dimensional document space and visually formulating queries with ease and efficiency. In particular, complex queries usually involve multiple user-defined concepts (also called “reference points”) against which all the documents are judged for their relevancy. There have been visual interfaces that facilitate the visualization of complex relationships among documents and support specifying arbitrarily complex queries graphically. For a review of these interfaces, see (Korfhage 1997, Zhang 1999). Two of them are of most interest to this study and are reviewed here.

InfoCrystal (Spoerri 1993) provides a spatially compact interface for complex Boolean or vector space queries. An InfoCrystal interface has two sets of icons: criteria icons represent user-defined criteria and are placed at the surrounding edges with even space; interior icons representing unique types of queries are placed according to proximity and ranking principles. Queries can be specified by selecting individual or a group of interior icons in a graphical manner. InfoCrystal is most commonly used with Boolean retrieval model, but it also has been extended to handle vector space model.

VIBE system, originally proposed by Olsen et al (Olson et al. 1993), has the similar goal as InfoCrystal. A user can select arbitrary number of reference points which are placed on the screen at user-specified locations. Then the positions of visualized documents are determined according to the ‘desktop-pile’ metaphor. A “pile” metaphor encourages the thinking of an office desk as a number of piles of documents, each pile holding similar documents. If a document is related to more than one pile, it is put between those, closest to the most relevant pile. The pile metaphor is based on the notion that people often use piles for casual arrangement of documents. This pile metaphor has been developed into a content awareness information retrieval interface and implemented in VIBE system (Olson et al. 1993). VIBE is most appropriate for vector space models handling queries involving multiple reference points, but has also been extended to handle Boolean queries.

One of the common characteristics of InfoCrystal and VIBE is that they all use spatial layout of icons to indicate semantic closeness, much like organizing files on a desktop.

5 Designing Visual Environment For Retrieving Geographical Information: Some General Guidelines

Our discussions above lead to a few design principles.

[Guideline I] Integrating multiple document surrogates

The dual nature of geographical documents requires two separate document surrogates, one defined in spatial subspace (perhaps using geographical “footprints”) and the other defined in thematic subspace (perhaps using term vectors). The process of deriving these surrogates is defined as the mapping from the literal spaces to the two semantic subspaces. Retrieval of relevant documents in relation to a query should be based on the combined similarity measure that reflects the way that human users interpret document relevancy according to thematic similarity and spatial proximity.

[Guideline II] Integrating multiple views

When people approach digital libraries with their information needs, they are likely to have only fragmented and vague clues of “where” and “what” they are looking for. Accordingly, their searching attempts will also be fragmented, using geographical search for a while and then switching to thematic search, and back and forth. Natural metaphors for interactive browsing and retrieval should include coordinated multiple views (Masui et al. 1995, North and Shneiderman 1997) to facilitate visual and interactive filtering and navigation. Each view facilitates the understanding of the structure and contents of a geographical information space in different but complementary ways, for
example, one generates spatial structure of the information space, and the other generates a conceptual structure of the information space.

[Guideline III] User Controlled Visual Environment

Visual environment should enable user’s self-guided sense-making process for understanding the document space and support relevance judgments. Previews and overviews, when combined with coordinated multi-views and zoomable utilities, can provide aids to human’s visual thinking process.

6. A Design Example

In order to explain how the principles developed above can be put into design practice, I will cite my own work on a visual interface, GeoVIBE (Cai 2001). The main feature of GeoVIBE is that it supports visual interaction with the document space utilizing the user’s common-sense geographic knowledge as well as thematic concepts. Figure 1 shows a snapshot of the GeoVIBE system. The display consists of two opened views of the document space. The sub-window at the left is the GeoView, which shows a multi-layered map with clickable icons of different shape and sizes linked to document items. The window is the VibeView, where all the documents are presented in a coordinate system defined by Points of Interest (POI) on the display. In the following discussions, we will show how the two views of the document space work together.

6.1 GeoView

GeoView imposes a geographical order on the underlying document space. In this information space, documents are represented by the cartographic characterization of their geographical scopes, and are visualized as a multilayered map that places document “footprints” within a comprehensible context established by a number of “base” map layers. GeoView has a number of functional regions: a map view region, a tool tip region, a spatial query mode region, and a toolbar region (see Figure 1). The toolbar region provides many of the standard desktop GIS tools for manipulating a map view, such as ‘zoom in’, ‘zoom out’, ‘identify’, and ‘pan’. In addition, it includes tools for drawing query shapes (point, rectangle, polyline, and polygon) so that users can formulate geographical and spatial queries. GeoView currently supports point-in-polygon queries and region queries for selecting and filtering documents, but more queries types (as discussed by Larson (Larson 1996)) are planned for future extensions.

Besides spatial query functions, GeoView also provides users with preview and overview of the document space. An example of preview maps can be observed in Figure 2, where the map view clearly shows the geographic “footprint” of a document (titled “Former Congressman Urges….”) when a user clicks on it in the document list window (lower right corner). The map is color coded to show different degrees of relevance of the document to any location on the map. To resolve the difficulties of interpreting color codes, GeoView implements a tooltip, called “Frequency”, which shows the associated frequency measure of a document on a location when the user moves the cursor to that location. There are two frequency readings (separated by a comma) in the “Frequency” field: the first reading is the frequency of the currently selected document, and the second reading is the total frequency measure of all the documents. The ratio of these two frequencies gives the reader the sense of the relative strength of the binding of the current document in relation to other documents.

In contrast to preview maps that visualize geographical footprints of a single document, an overview map is the one that shows an overall picture of how a collection of documents is related to different parts of the geographic space. An example of overview maps is presented in Figure 1. Again, the degree of association between a document collection and a particular locality is visualized by a color coded frequency map, where darker colors mean higher frequency, in general. Users can also get a reading of the frequency value on any location simply by moving the cursor over it. In the GeoView of Figure 1, the frequency field reads 276 while the cursor is over a location within California.

Central to understanding and using previews and overviews in GeoView is the concept of “document-location frequency” (DLF). DLF is a measure of what the system believes is the degree of relevance of a document (or a set of document) to a geographical location or region. A DLF of zero indicates no association between the document(s) and the location, and higher DLF indicate higher degree of document-location association. DLF can be calculated from the geographical indexing structure of GeoVIBE, represented as document-shape frequency matrix, which will be formally introduced later in Section 3.
GeoView enables users to judge relevance in a rich geographical context. It adopts the abstract sense of the world (places and locations) as a user interface metaphor for browsing a large number of documents. When documents are put into the context of the geographical world, the potential spatial interactions between places (diffusion, movement of information through space) and/or the spatial patterns of document distribution provide rich clues for judging relevance of a document in its associated geographical context.

6.2 VibeView

VibeView is similar to the interface of the VIBE system (Olson et al. 1993). First, the visual space in the view is a coordinate system that is established by defining a set of points of interest (POI) on the display. Each POI consists of a vector of key values describing a subject of interest to the user and a unique icon placed on a position within the VibeView window. Currently, VibeView allows up to four (4) POIs to be specified by a user through entering salient keywords, but theoretically the number of POIs can be more or less and each POI may be chosen to be any of the following: (1) user queries expressed in vector space model; (2) personal interest profiles; and (3) some known documents. After POIs are defined, the placement of a document icon is determined by the relative similarity of the document to the POIs. The position of a document icon gives an indication of the contents of that document. The size, color, and shape of a document icon may vary according to a user-defined function (e.g., the length of the document). Document visualization through VibeView is especially useful for identifying groups of interesting documents in a collection that does not fit a hierarchical structure.

VibeView supports exploration of the content structure of a document space by providing an effective spatial “overview map”. This overview can easily be understood because it is based on the familiar “desktop” metaphor as its information organizing principle. The “desktop” metaphor encourages the thinking of a computer screen as an office desk that organizes information spatially as a number of piles of documents, each pile holding similar documents. If a document is related to more than one pile, it is put between those, closest to the most relevant pile. The desktop metaphor allows people to manipulate digital documents just as they manipulate piles of files on their desks. Desktop metaphors have been widely used in developing content awareness information retrieval interfaces, such as the VIBE system (Olson et al. 1993) and the InfoCrystal (Spoerri 1993).

VibeView implements a subset of the functions of the VIBE interface (Olson et al. 1993). A common user session of VibeView starts with a user entering 2 to 4 keywords (known as POIs) and then clicking on the “Search” button. This will cause the system to search for documents that contain at least one of those keywords, and generate a new display. The VibeView window on Figure 1 shows a screen layout after a user enters four keywords: “democratic,” “republic,” “arm,” and “election.” Clusters of document icons indicate groups of similar contents in relation to the four points-of-interest (POIs). The closer an icon is to a particular POI, the more similar the document is to the meaning of the POI term.

The spatial encoding of document icons within VibeView is designed to exploit human spatial reasoning capabilities in judging document similarities and relevancy. Here the size of a document icon indicates the size of that document, but it can also be used to describe other attributes of the document, such as how recent the document is. Individual POIs can be dragged and re-placed to another location by the user, and the layout of document icons are updated automatically.

Querying documents in VibeView involves only simple user actions such as clicking and dragging. A double-click on a single document icon brings a preview on the document ID number. A double-click on a group of document icons will bring up a document list enumerating all the documents clustered in that display region. A user can drag a rectangle box to select a set of documents into a document-list dialogue window. An example of the document-list dialogue window is shown in Figure 2 (the window on top of GeoView window). This window allows the user to focus attention on individual documents. Clicking the “View” button will bring up a separate window that shows the original content of the highlighted document. If a user decides to focus only on the documents in the list window and remove other documents, (s)he can simply click on the “Focus” button.

6.3 Coupling GeoVIEW and VibeVIEW

Although GeoView and VibeView each provide preview, overview, and query functions for interacting with the document
collection, it is the tight coupling of these two complementary views that constitutes the uniqueness of the GeoVIBE environment. Some of the unique features that are available only in GeoVIBE are:

(1) **Simultaneous Spatial and Thematic Overview.**

The graphical overviews of the document space presented by GeoView and VibeView can convey immediate understanding of the size and extent of the content coverage, as well as how documents relate to each other. The tight coupling of GeoView and VibeView allows users to interact with the same subset of documents through interpreting and manipulating two overviews, a capability that provides a much higher value to the users than the simple sum of the values of individual overviews. With GeoVIBE, it is possible for the user to make inferences on both the geographical and thematic structures of the document collection with great ease. For example, Figure 1 is a coupled overview map of documents selected by the four keywords: “democratic,” “republic,” “arm,” and “election.” Because both views can be directly manipulated by users through zooming in geographic view and changing search keys in VibeView, GeoVIBE allows users to focus on their complex information problem at hand.

(2) **User Controlled Spatial-thematic Navigation.**

The spatialization of document space representations in GeoVIBE attempts to maximize the transfer of users’ skills and knowledge in learning and navigating a natural spatial environment to facilitate their ‘navigation’ in digital information space. When interacting with GeoVIBE, users’ information searching process typically involves interweaving of overview, preview, and query activities - a sequence guided only by users’ focus on learning about the document space. GeoVIBE allows users to switch their mode of interactions freely among the following alternative modes: thematic overview; thematic query; thematic preview; spatial overview; spatial query; and spatial preview. As an example, Figure 2 demonstrates a small section of a user’s session, where a user starts with an overview in VibeView, followed by a selection query in VibeView, which in turn invokes a document selection list dialogue. From this time, a user can go to the preview mode in GeoView by selecting individual documents in the document list dialogue, or see a geographical overview of selected documents in GeoView. In summary, GeoVIBE facilitates users’ efforts to learn about the information structure of a geographical document collection.

(3) **Progressive Spatial and Thematic Focusing.**

In many cases, a document collection is so large and so widely dispersed in its content that using either geographical constraints (in GeoView) or thematic constraints (in VibeView) in isolation will still leave a large number of documents undecided on their relevancy. The successful linking of GeoView and VibeView in GeoVIBE enables the user to quickly focus on the relevant documents in two easy steps: one thematic query, followed by a spatial query, all through direct manipulation.

### 7. Conclusions

This paper analyzed the challenge of providing information services on multimedia geographical documents, and argued the role of visualization to support user-controlled knowledge discovery. Based on theories from geographical information sciences, information retrieval, and visualization, a few design principles were proposed, which opens many new design opportunities. As an example, GeoVIBE system was used as a representative of this new class of visual interfaces for digital geospatial libraries. The most important contribution of GeoVIBE is the tight coupling of two visual interface representations, a GeoView and a VibeView, which work in coordination to provide overview, preview, and query functions through direct manipulation. GeoVIBE represents a systematic application of the principles on the choice of document surrogates, which led to the use of two complementary surrogate sets. We expect to see growing efforts in the future on the design of visual information environment, and these practices should benefit from the multi-disciplinary perspectives and principled approach as used in this paper.

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