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MetaViz: Visual Interaction with Geospatial Digital Libraries

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Technical Report
TR-99-017

October 1999

Abstract

Recent initiatives to geospatial digital libraries provide access to a wealth of distributed data, but offer only basic levels of interactivity and user assistance. Consequently, users find it difficult and time-consuming to browse through data collections and locate those data sets that meet their requirements. The MetaViz project addresses two of the major barriers preventing the extensive use of digital libraries: lack of usability and information overload. This research focuses on geospatial data, making it possible to develop effective visualization and interaction methods that are based on familiar spatial metaphors. The visualization methods developed employ three-dimensional techniques, combining several characteristics or dimensions of metadata into single graphical views. As those visualizations are based on map and landscape metaphors, they are easy to understand and provide instant overviews of complex data characteristics. The visualization methods have been integrated into MetaViz, an interactive system for browsing and searching geospatial data. In MetaViz, graphical views of data characteristics can be created and combined dynamically, levels of detail can be adjusted and the data sets found can be previewed and accessed. MetaViz helps users to locate and select appropriate geospatial data from various sources and to combine and use them in an effective way.

1 Introduction

1.1 Geospatial Data

1.1.1 Types and Use

Geospatial data contain information about the location, shape, and characteristics of real-world geographic features. There are three main types of geospatial data, *vector data*, *raster data* (see Fig. 1) and *georeferenced data*. Vector data store the location and shape of geographic features as geographic coordinates, lines and polygons. Examples of vector data are digitized maps and road databases. Raster data are based on a cellular data structure composed of rows and columns for storing images. Groups of cells with the same value represent features. Examples of raster data are scanned maps and digital satellite images.

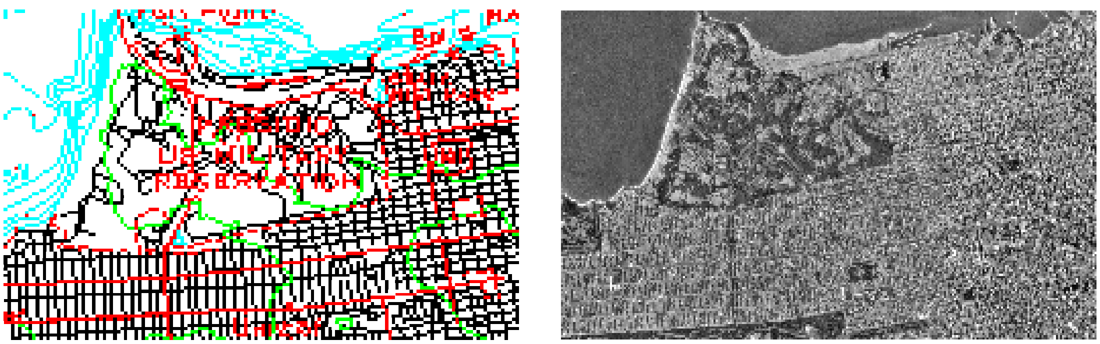

Fig. 1: Vector data and raster data.

Georeferenced data describe the characteristics of geographic features. They are typically stored in a tabular format and linked to a vector base data set. Examples of georeferenced data are census data, linking statistical values to census blocks.

Geospatial data are used in a variety of ways. Road databases are the data source for various simple mapping tools in the World-Wide Web that provide customized maps and driving directions. Road databases also support GPS-based car navigation systems. In the public and commercial sectors, geospatial data have been used much longer for advanced mapping and planning tasks, such as regional planning and environmental management. Research in earth sciences and life sciences is another field that makes extensive use of geospatial data.

1.1.2 Characteristics and Metadata

Geospatial data have complex characteristics of content, context, and access. To make valid and effective use of the geospatial data, it is important to know and observe these characteristics.

Content characteristics specify the domain and themes covered by a data set.

Context characteristics specify the spatial and temporal context of the data and may include

- the geographic area covered by the data set,
- the time period covered by the data set,
- data quality properties, e.g. location accuracy, and
- the scale of the data set.

Access characteristics specify the valid ways to access and use the data. They may include

- access paths to the data set,
- data set formats, e.g., raster and vector formats,
- the cost of the data set,
- the data set size, and many other characteristics.

Metadata are a way of formalizing and storing these characteristics. Usually, a geospatial data set will be accompanied by a metadata record in one of a number of standards. In the US, the best known of these standards is the Federal Standard for Digital Geospatial Metadata [14], in effect since 1994. Other standards are used in Europe [9] or are proposals for ISO norms [21].

1.2 Searching Geospatial Data

1.2.1 Geospatial Digital Libraries

Geospatial digital libraries organize large repositories of geospatial data and provide support for searching and retrieving geospatial data. Digital libraries may contain several *repositories* that can be physically distributed and connected over a network. The individual repositories typically contain a number of *collections* of thematically related data. Individual collections consist of *spatial information objects* (SIOs), which form the basic information unit [3]. Some examples of SIOs are aerial photographs, vector data sets of national park boundaries, and seismic data sets.

Metadata are widely used to support search, retrieval, transfer and evaluation of geospatial data in digital libraries. In addition to the metadata for individual SIOs, geospatial digital libraries also contain metadata for other levels, e.g. collection level metadata.

A well-known example of a geospatial digital library is the Alexandria Spatial Digital Library [7], located at the University of California at Santa Barbara. ADL is a 4-year research project within the NSF digital library initiative. Currently, the ADL repository includes the following collections [2]:

- the ADL Catalog, a collection of maps, aerial photographs, satellite photographs and databases (300,000+ SIOs),
- the ADL Gazetteer, a collection of geographic place-names (6,000,000 SIOs),
- the Earthquake Data Collection (300+ SIOs), and
- the Volcano Data Collection (1,500+ SIOs).

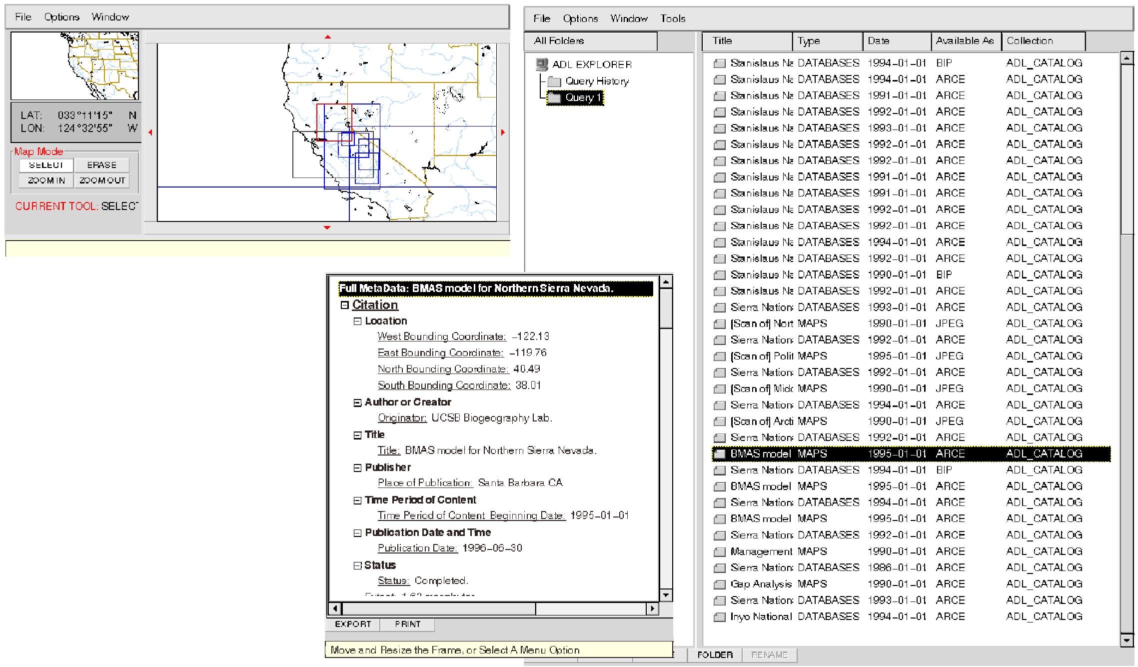

Fig. 2: Browsing search results with the Alexandria Spatial Digital Library

1.2.2 The Problem: Ineffective Search Process

An interesting feature of the ADL is a Java-based graphical search interface that can be used over the World-Wide Web. Users can select a geographic region of interest in a map browser, specify a collection name, metadata attribute values or value ranges and retrieve a list of matching SIOs (see Fig. 2).

ADL contains a detailed metadata schema of over 400 attributes. Users that search for geospatial data with very specific criteria in mind can use this schema to formulate precise queries. The result set of these queries will generally be rather small and matching SIOs can be identified quickly.

However, users often do not have detailed and specific criteria in mind when searching for geospatial data sets. Instead, there are a number of constraints that need to be satisfied, such as the geographic region of interest and thematic constraints. The user would specify these constraints as search parameters, start the query, study the result set of the query to get an overview of the contents of the collection, probably refine the search criteria or add new ones, start another query, study the new result set, and so on.

In a nutshell, this search process will be rather repetitive and involve the following steps:

1. Specify search parameters and start query
2. Browse through result set (reading through a list of values)
3. For promising SIOs read and compare metadata (reading through a list of values)
4. Redefine query and start over

If the result set of the query is large, this search process can be quite ineffective. In many cases, the result set will be large (several hundreds of SIOs) or huge (over a thousand SIOs). In the ADL search interface, the result set would be displayed as a large list of metadata attribute values for the individual SIOs (Fig. 2, left window). To browse through the result set, the user would scroll through this list, looking for promising SIOs, identifying them by specific attribute values. For every promising SIO, the user would then retrieve the complete metadata set (Fig. 2, middle window) and study the attribute values in detail.

1.2.3 Related Work: Visualizing the Result Set

This search process is ineffective, because both, steps 2 and 3 involve reading through potentially large lists of values, comparing these values and identifying specific occurrences of values. These tasks could be made much more effective, if the data was not shown in lists but presented in a graphical form. Information Visualization has been used for some time to transform data sets into images that are easier to interpret for users. Often, graphical representations reveal features not visible in the original tabular displays [5, 31, 35].

Various researchers in Information Visualization have shown that result sets of queries should be presented visually [1, 20, 30]. With the *TileBars* system [19], Hearst showed that it is important to show many, if possible all, parameters of the result set simultaneously and compactly. Beard [4] introduced graphical views of geospatial metadata and argued that these views should facilitate the quick comparison of individual SIOs in the result set. Various experiments have shown that computer-generated 3D scenes can be very intuitive and effective setting for interacting with digital libraries [10, 12]. These findings from related areas of research form the basis for the MetaViz project.

1.3 The MetaViz Project

1.3.1 Motivation

Distributed digital libraries offer a degree of information accessibility never reached before. However, having access to large collections of data is of little use unless people are able to find the information they need and also know how to use it. Locating, selecting and using information effectively is especially demanding in the case of geospatial data, with their manifold characteristics of scale, quality, cost, format, and thematic coverage. Recent initiatives to geospatial digital libraries (GDLs) provide access to a wealth of distributed data, but offer only basic levels of interactivity and user assistance.

Current search interfaces for geospatial data are mainly list-based and users have to go through a tedious process to find and compare spatial information objects (SIOs). Several steps in this process are ineffective because of the textual representation of metadata involved. Research in information visualization provides several clues on how to improve this process. Some important recommendations on presenting result sets are:

- always present the result sets visually
- present as many attributes of the result sets as possible
- facilitate quick comparison of individual SIOs

1.3.2 Goals

The MetaViz project addresses two of the major barriers preventing the extensive use of digital libraries: lack of usability and information overload. The research is focused on geospatial data, making it possible to develop effective visualization and interaction techniques that are based on familiar spatial metaphors like maps, landscapes and city models. The goals of this project are

- To find adequate visualization techniques for spatial metadata.
- To develop interaction metaphors for query result sets in GDLs.
- To create a GDL interface for visualizing, browsing, and interacting with query results.

1.3.3 Project Outline

The MetaViz project is centered around a set of visualization methods for geospatial metadata. Geospatial metadata are key to browsing and interaction in geospatial data libraries, as they describe characteristics of data sets typically used to formulate queries. The visualization techniques developed transform result sets of GDL queries into a visual form: so-called result scenes. In this transformation process, a number of mappings from metadata attributes to visual attributes of the result scene are performed making sure that metadata attributes can be processed effectively and correctly by the human visual system.

The spatial metadata visualization methods are augmented by a set of interaction metaphors and techniques for GDL query result sets. These interaction techniques operate on the result scenes. Specific interaction techniques let users explore both detail and context of a result scene, compare individual SIOs effectively, or use the result scene to refine the query.

Both, the metadata visualization and interaction methods are integrated into an interactive system for browsing and searching geospatial data. In this interactive system graphical views of data characteristics can be created and combined dynamically and the data sets found can be previewed and accessed.

2 Geospatial Metadata Visualization

2.1 Visualization Paradigm

The geospatial metadata visualization techniques developed transform result sets of GDL queries into a visual form: so-called *result scenes*. In this transformation process, a number of mappings from metadata attributes to visual attributes of the result scene are performed. These mappings make sure that metadata attributes can be processed effectively and correctly by the human visual system [5, 13, 22, 28].

Geographic space is mapped to the *xy* plane of the result scene, since this is both a natural and a very effective mapping. It is natural, because it preserves the familiar landscape or map metaphors that make it easy for users to spatially orient themselves in the result scene. The position in the *xy* plane is also the most effective visual variable to encode quantitative data [5]. Encoding the geographic context of geospatial data effectively is important, because it is the most important search criterion for users [32].

Temporal attributes of the metadata are preferably mapped to the *z* plane of the result scene. This is also an effective mapping, reflecting the fact that users rate the temporal context of geospatial data as the second most important search criterion.

Quantitative attributes of the metadata are mapped to color intensity and/or hue. Color intensity is the most effective visual variable for quantitative attributes such as cost and size. Color hue is also very effective, if the succession of hues is perceived as natural [8, 29, 36]. The “hot iron” and the “spectrum” scales used in the example visualization are effective for quantitative data.

Categorical attributes of the metadata, e.g. data set formats, are always mapped to different color hues.

2.2 Test Data

The metadata used in the example visualizations has been extracted from the California Environmental Information Catalog [10] and various other sources [15]. Metadata attributes covered in the visualizations are:

- *Geographic Region* - the bounding box of the Spatial Information Object (SIO) described. (Metadata records that define a bounding box larger than a certain threshold or no bounding box at all are not shown.)
- *Time Period* - the period covered by the SIO
- *Publication Date* - the date the SIO was originally published
- *Update Frequency* - *continually, daily, weekly, monthly, annually, biannually, as needed, irregular*, or, *none planned*
- *Size* - the size of the SIO in megabytes
- *Scale* - the map scale, e.g., 1:24,000

2.3 Surface Plots

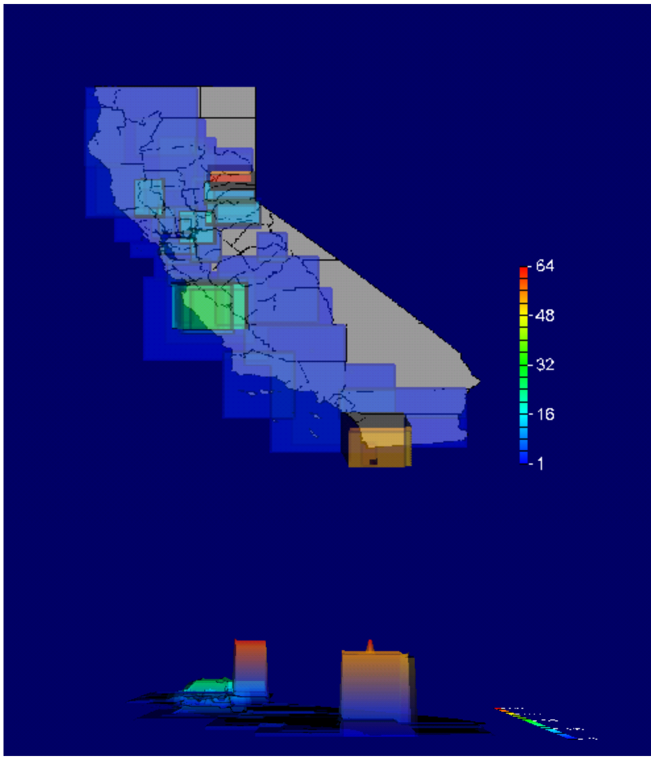

Fig. 3

Technique:
Surface Plot

Attributes:
Number of SIOs:
mapped to height and color

Examining the result set of a search, one of the basic tasks is to get an overview of the spatial distribution of SIOs matching the search. A surface plot gives such an overview, mapping the absolute number of SIOs covering a point on the plane to both the height of the surface above this point and to the surface color. In Fig. 3, two different views of the same surface plot are shown, one from above, and one from the south side of the plane looking north. The surface plot makes it easy to identify several general properties of the result set's geographic distribution: there are four geographic areas with a high density of SIOs in this search: Greater San Diego, the Monterey Bay, Lake Tahoe and the San Francisco Bay. Other areas, such as the Mojave Desert are not covered at all. Locating these areas is made easy by rendering the surface transparently on a reference map as a backdrop.

2.4 Box Piles

Fig. 4

Technique:
Box Pile

Attributes:
Geographic Region

Surface plots show the spatial distribution of SIOs but give little information about the spatial extent of individual SIOs. A technique that portrays the numerousness of SIOs at certain regions but also shows the spatial extent of each single SIO is a box pile (see Fig. 4). In this visualization method, each SIO is represented by a flat box. The *x* and *y* size and position of the boxes correspond to the geographic region attribute. Boxes that would overlap in the *xy* plane are simply stacked on top of each other.

In box piles the color of the individual boxes can be used to map another metadata attribute. Fig. 5 maps the publication date to the box color; a logarithmic scale has been used. Fig. 6 maps the update frequency, a categorical attribute, to the box color. The plots make it easy, for example, to identify areas with SIOs that are recent or that have a high update frequency.

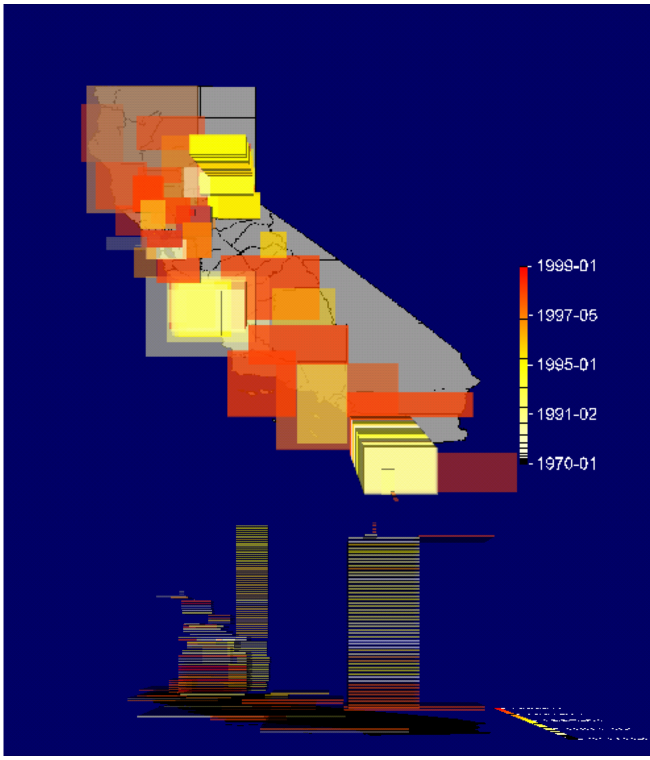

Fig. 5

Technique:
Box Pile

Attributes:
Geographic Region
Publication Date:
box color

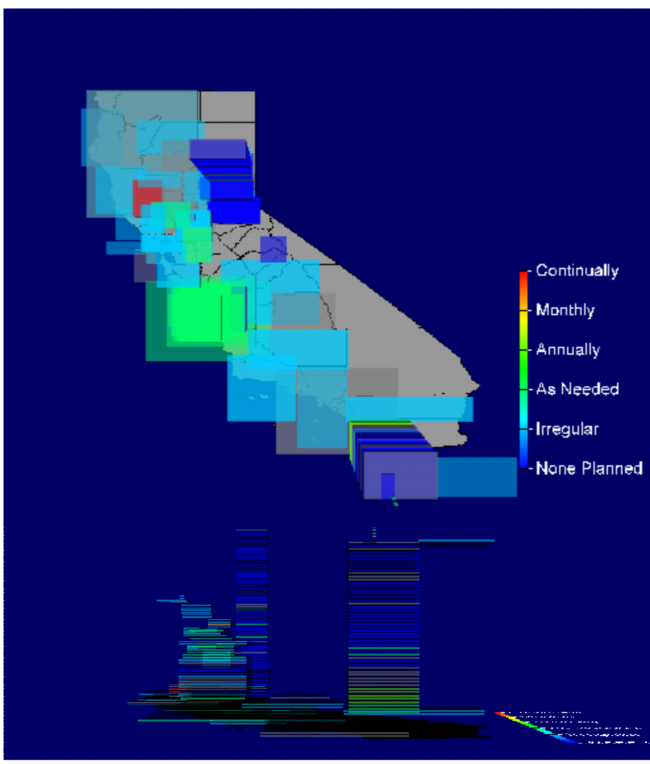

Fig. 6

Technique:
Box Pile

Attributes:
Geographic Region
Update Frequency:
box color

2.5 Temporal Box Plots

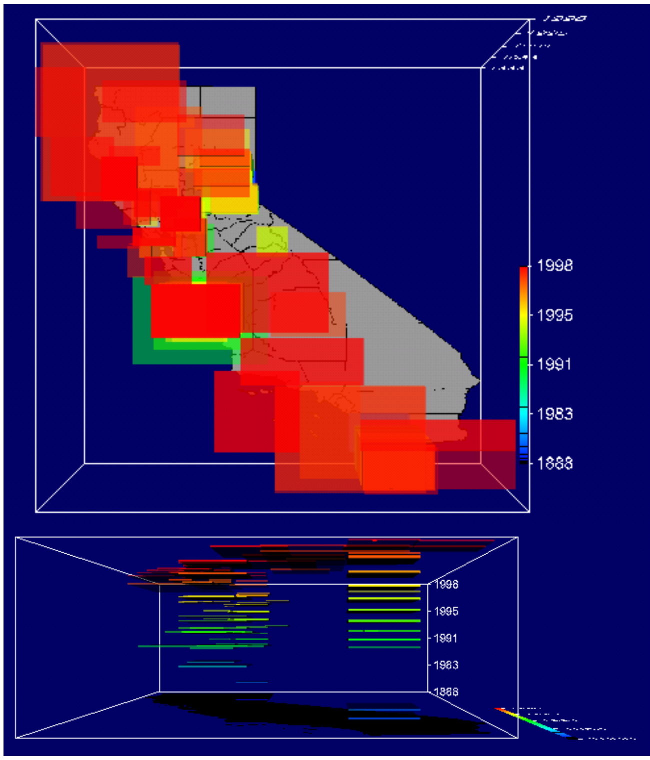

Fig. 7

Technique:
Temporal Box Plot

Attributes:
Geographic Region
End of Time Period:
vertical box position and box color

The box pile technique stacks boxes on top of each other to prevent them from overlapping. Thus, the vertical positions of the boxes are assigned randomly. Temporal box plots use the vertical position in a different way: to express one of the temporal attributes of the SIOs. In Fig. 7, the end of the time period of the SIO is mapped to the vertical position.

A problem with the temporal box plots is that boxes can overlap. Even though the box material is transparent, some boxes may be obstructed or barely visible.

Again, the color of the boxes can be used to express an additional attribute. In Fig. 8 the scale of the SIO is mapped to the color. Those SIOs that do not have the scale attribute are shown in gray.

2.6 Space Time Plots

In the Temporal Box Plots above only points in time can be mapped. Space Time Plots are a generalization of that technique also permitting time periods to be mapped. Here the boxes are no longer uniform in height; instead, the height corresponds to a duration. Fig. 9 shows a Temporal Box Plot of search result set. Examining the scene in 3D makes the temporal characteristics of the SIOs visible, e.g., those SIOs can be identified that cover a very long period in time.

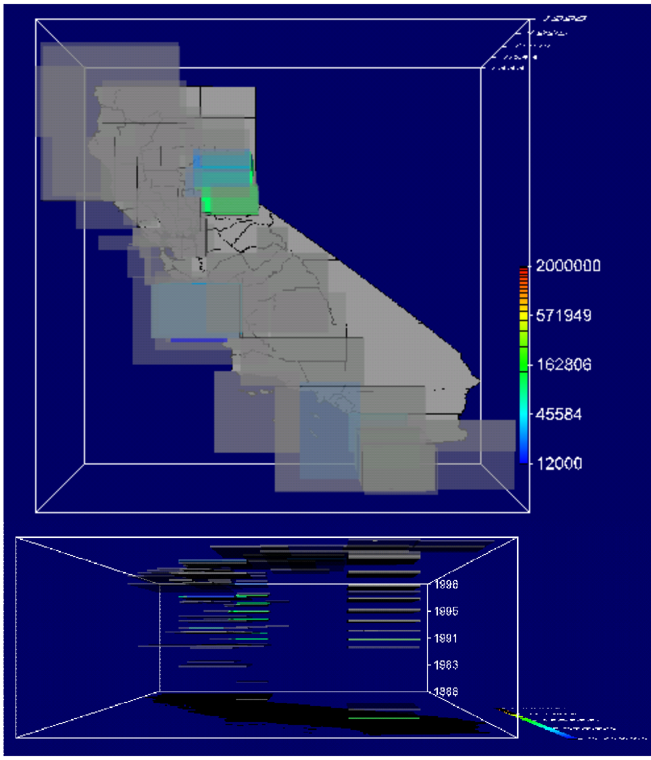

Fig. 8

Technique:
Temporal Box Plot

Attributes:
Geographic Region
End of Time Period:
vertical box position
Scale:
box color

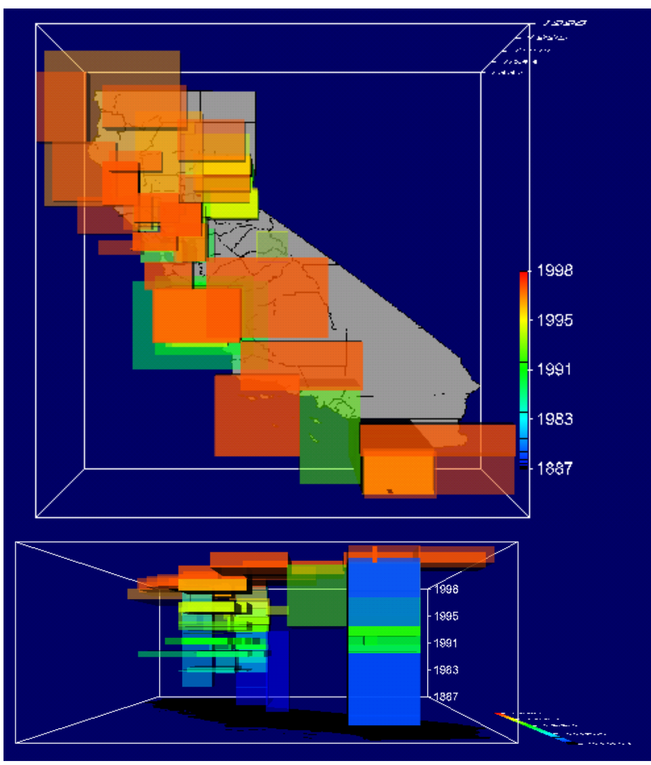

Fig. 9

Technique:
Space Time Plot

Attributes:
Geographic Region
Time Period:
vertical box position and size
Start of Time Period:
box color

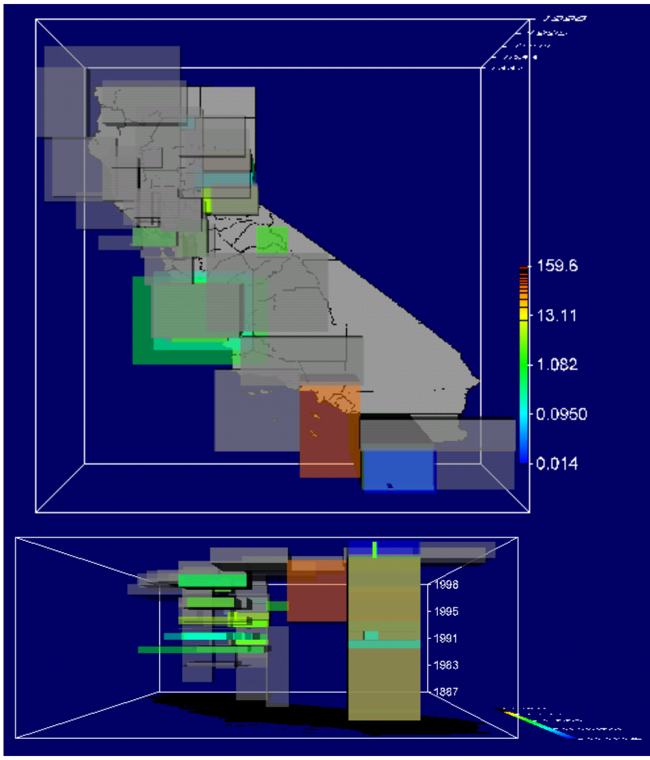

Fig. 10

Technique:
Space Time Plot

Attributes:
Geographic Region
Time Period:
vertical box position and size
Size (MB):
box color

As in the other visualization techniques, the color of the boxes can be used to express an additional attribute. In Fig. 10 the scale of the SIO is mapped to the color. Those SIOs that do not have the scale attribute are shown in gray.

2.7 Glyph Plots

A shortcoming with both, temporal box plots and space time plots is that boxes can overlap. Some boxes may be obstructed or barely visible. It can be especially hard to spot the numerousness of SIOs that have identical bounding boxes and time periods.

Glyph plots avoid this shortcoming by mapping a compact “glyph” (simply a sphere in the example visualizations) at or near the centers of the SIO bounding boxes. If two bounding box centers are identical one of the glyphs will be slightly displaced in the scene. The area of the bounding boxes can be mapped to the glyph size and/or color.

Fig. 11 shows a glyph plot of a result set where glyph size and color correspond to the geographical area covered by the SIOs and the vertical glyph position corresponds to the end of the time period covered. In Fig. 12, the glyph color shows an additional attribute, the size of the SIO.

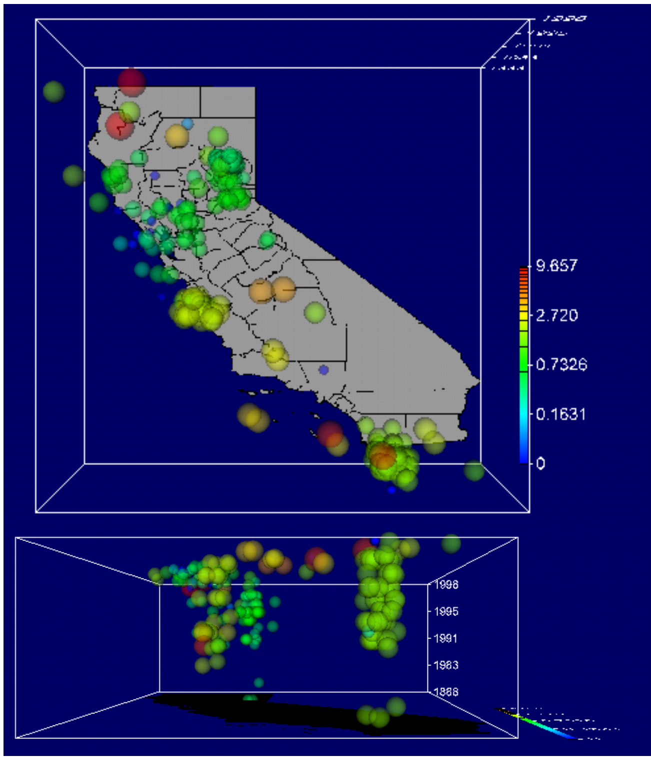

Fig. 11

Technique:
Glyph Plot

Attributes:
Center of Geographic Region:
glyph position
Area of Geographic Region:
glyph size and color
End of Time Period:
vertical glyph position

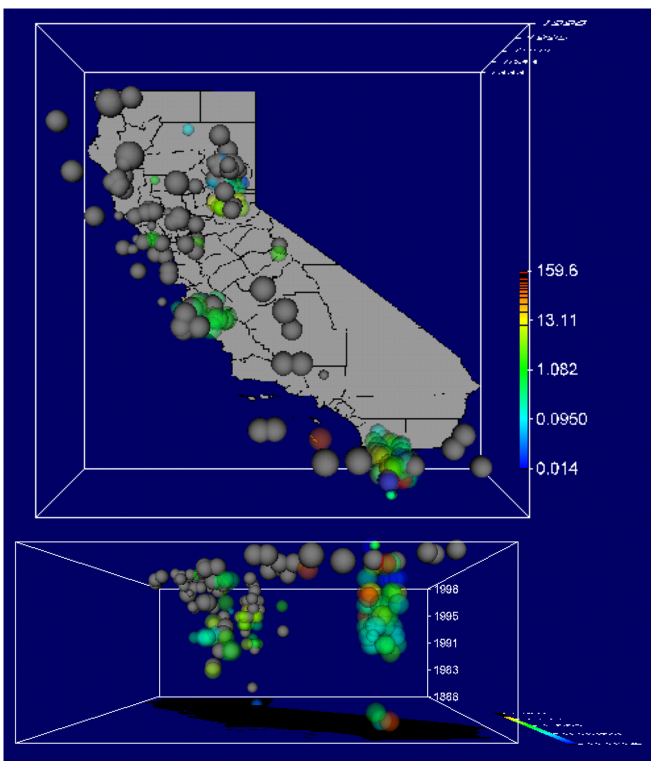

Fig. 12

Technique:
Glyph Plot

Attributes:
Center of Geographic Region:
glyph position
Area of Geographic Region:
glyph size
End of Time Period:
vertical glyph position
Size (MB):
glyph color

2.8 Aggregation Plots

Glyph plots can show a large number of SIO attributes simultaneously and therefore give a compact overview of the characteristics of the result set. However, they can get crowded when the result sets are very large. They also do not show the exact spatial extent of each SIO but only map the geographical area covered to the glyph size.

A way to reduce the number of glyphs in a result scene is to show only a single glyph for a number of different SIOs that have very similar characteristics. Aggregation plots (see Fig. 15 on page 16) aggregate all SIOs of a result set that cover the same geographic area and time span (plus/minus a small delta) and that have the same values for all other attributes shown in the scene (e.g., the same publication dates in Fig. 15). Aggregation plots use two different types of glyphs: cubes for individual SIOs and spheres for aggregated SIOs. The size of the sphere is proportional to the number of SIOs aggregated in one glyph. Aggregation plot glyphs also use thin lines to show the exact width and height of the geographic area covered.

3 MetaViz

MetaViz is an experimental system for searching and browsing geospatial digital libraries. MetaViz is based on the geospatial metadata visualization methods presented in chapter 2. It augments these methods with dynamic interaction techniques for the result sets. Specific interaction techniques let users explore both detail and context of a result scene, compare individual SIOs effectively, or use the result scene to refine the query. MetaViz also provides a user interface for specifying GDL queries.

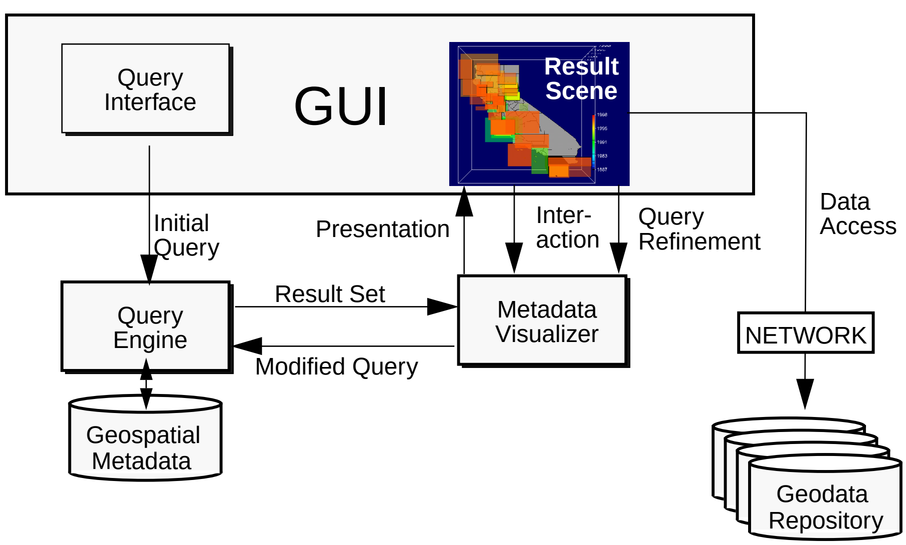

Fig. 13: MetaViz architecture.

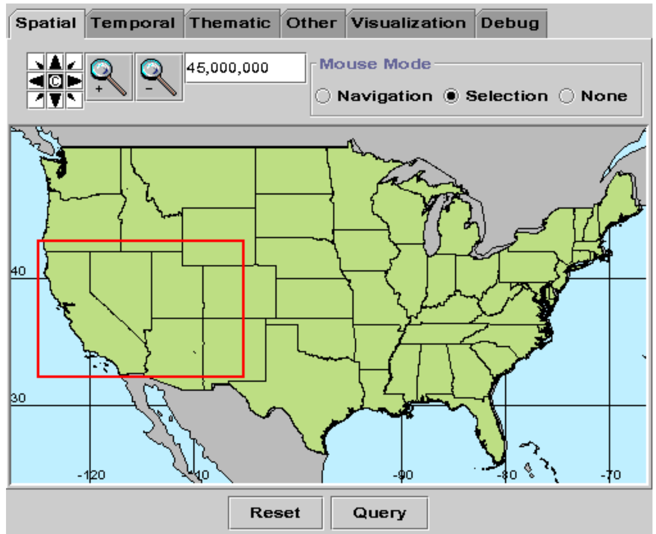

Fig. 14: MetaViz: spatial query window.

3.1 Architecture and Implementation Notes

Fig. 13 shows the architecture of MetaViz. At its core the system has a database of geospatial metadata and a query engine on top of it. Users can specify queries in the graphical query interface which is imbedded into the GUI. To specify the geospatial constraints of the query, MetaViz offers a map interface (Fig. 14), other constraint types offered are temporal constraints (time period, publication date, metadata date), thematic constraints (collection name, themes, keywords), size, scale, and format. Once the query has been started, the query engine creates the result set metadata and hands it over to the metadata visualizer. The visualizer transforms the metadata into a three-dimensional graphic representation, the result scene. A 3D viewer window in the GUI renders the result scene and lets users interact with it (see Fig. 15). Once the user decides to access one of the SIOs in the result scene, a network connection to the geospatial data repository is created and the SIO is retrieved and displayed.

MetaViz is a Java 2 application that makes use of the Java 3D extension. The geospatial metadata is stored in an mSQL database and accessed through the JDBC interface.

3.2 Interacting with the Result Set

3.2.1 Navigation and Selection

MetaViz offers several ways of interaction with the result set. The most basic interaction technique is navigation. Users can examine the scene by modifying the viewing parameters, rotating the scene, etc. In addition to this basic viewer navigation, users can also select one of the glyphs or boxes of a result scene to display a window listing all the attributes of the corresponding SIO (see Fig. 16). Both, the result scene window and the attributes window offer hyperlinks that can be fol-

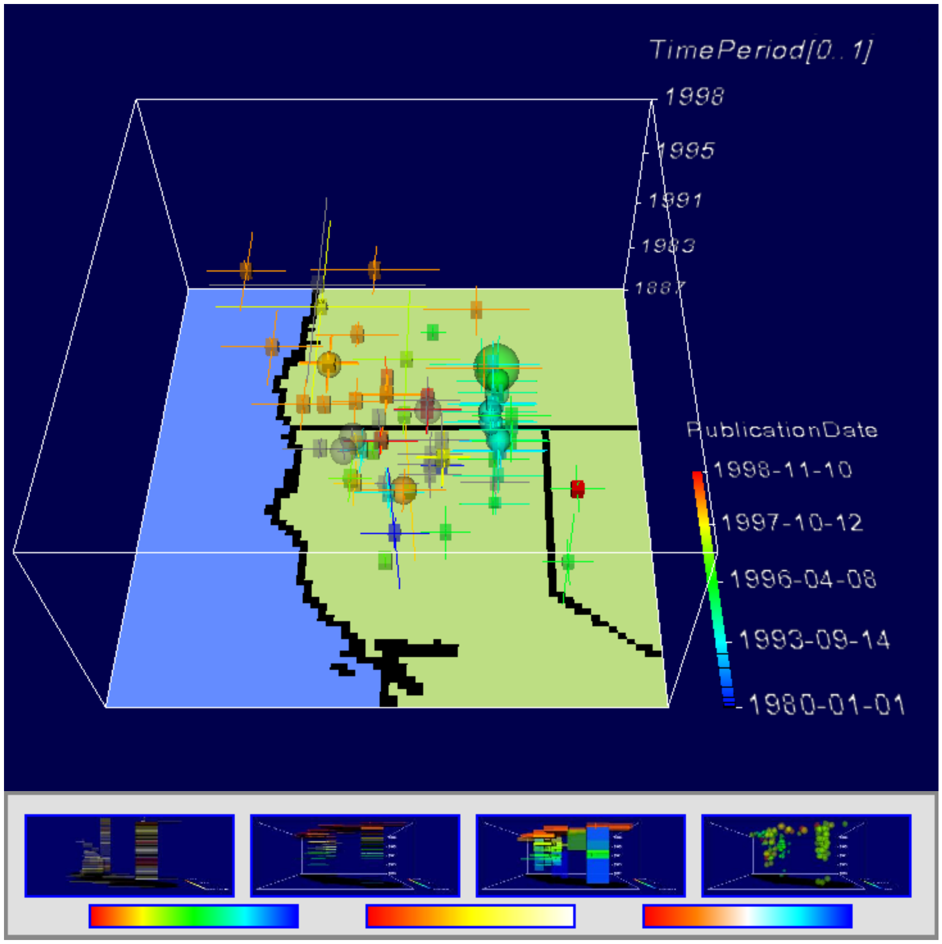

Fig. 15: MetaViz: result set.

lowed to modify parameters of the visualization. Following one of the icons in the result scene window triggers the generation of a new result scene with a different visualization technique or color map being used. Following one of the attribute name hyperlinks triggers the generation of a new result scene that maps the attribute to a visual variable, e.g. color.

3.2.2 Keyword Searches

Following one of the keyword hyperlinks in the attribute window triggers a new query for this keyword. For multiple keyword searches, MetaViz computes a score function for each SIO in the result set and maps this function to a visual variable, e.g. color. Fig. 17 shows an example of such a result set with a score function. The keyword search that lead to this result set was “boundary OR wildlife OR refuge OR bay”. Matching SIOs were found all over the US but the score was significantly higher for SIOs in the New England states.

	Ceres:IR0575
GeographicRegion	[-119.8848,37.4933 -119.1951,38.1856]
TimePeriod	[1995-01-01 1995-12-31]
PublicationDate [H]	1996-01-01
MetadataDate [H]	1998-08-09
Scale [H]	
SizeMB [H]	1.7
UpdateFrequency	1
Format	ARC/INFO Export
Title	Yosemite National Park Wilderness Boundary
Keywords	boundary; park
Themes	Wilderness areas

Fig. 16: MetaViz: SIO attributes.

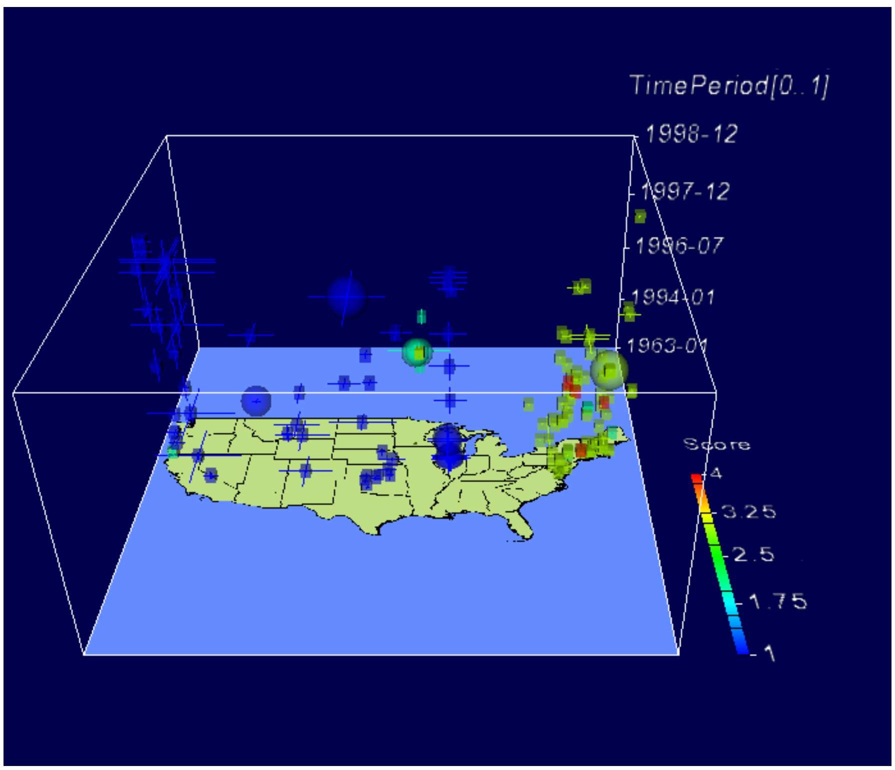

Fig. 17: MetaViz: Result Set for Keyword Search

3.2.3 Geographical Zoom

An important interaction technique for result sets is the geographical zoom function. Users can select a point on the base map and zoom in or zoom out around this point. In general this will trigger a new query with a different (smaller resp. larger) geographic region of interest. For aggregation plots this will generally result in fewer SIOs being aggregated (and consequently more detail being shown) for zoom in and in more SIOs being aggregated (less detail being shown) for zoom out.

4 Discussion

4.1 Summary

Distributed digital libraries promise a level of information accessibility never reached before. However, having access to large collections of data is of little use unless people are in a position to find the information they need and also know how to use it. Locating, selecting and using information effectively is especially demanding in the case of geospatial data, with their manifold characteristics of scale, quality, cost, format, and thematic coverage. Recent initiatives to spatial digital libraries provide access to a wealth of distributed data, but offer only crude levels of interactivity and user assistance. Consequently, users find it difficult and time-consuming to browse through data collections and locate those data sets that meet their requirements.

This project addresses two of the major barriers preventing the extensive use of digital libraries: lack of usability and information overload. The research was focused on geospatial data, making it possible to develop effective visualization and interaction techniques that are based on familiar spatial metaphors like maps, landscapes and city models.

In the first phase of the project a set of visualization methods for spatial metadata have been developed. Spatial metadata are a key to browsing and interaction in geospatial data libraries, as they describe characteristics of data sets typically used to formulate queries. Employing three-dimensional visualization techniques, several characteristics or dimensions of metadata can be combined into single graphical views. As those visualizations are based on map and landscape metaphors, they are easy to understand and provide instant overviews of complex data characteristics.

In the second project phase these metadata visualization methods were integrated into an interactive system for browsing and searching geospatial data. In this interactive system, graphical views of data characteristics can be created and combined dynamically and the data sets found can be previewed and accessed.

4.2 Conclusions and Further Work

MetaViz is an experimental system that demonstrates the use of information visualization techniques to interact with result sets of geospatial data searches. MetaViz offers users of geospatial digital libraries a graphical view of search result sets. Compared to traditional, list-based presentation of result sets, graphical views make it much easier to gain a quick overview over the results, taking into account many different attributes of the SIOs. Other tasks are easier to perform visually as well, such as the comparison of attributes for SIOs, detection of patterns in the SIO distribution, or the identification of promising candidates for more detailed inspection.

An interesting area for further research would be a detailed usability evaluation of graphical interfaces to result sets, such as MetaViz, in comparison to list-based interfaces, such as the current ADL interface. A number of psychological tests could be devised, where the performance (speed, accuracy) achieved with both interfaces would be measured and compared for a number of test users.

There are many ways of extending the system, both by integrating new visualization methods and by developing other interaction techniques. In the current state, temporal attributes are only mapped to two of the visual variables, the vertical position and/or the color of glyphs. Other mappings might involve animating the result scene or using further visual variables [25, 27]. Non-spatial visualizations (where the geographic space is not mapped to the *xy* plane of the result set) should also be supported when the other attributes of the SIOs are more important to the user.

Navigation in the result scene could be improved by providing a directed-flight option and dynamic glyphs. With the directed-flight option, users could click on one of the glyphs to start a smooth flight that takes them close to the glyph to show its neighborhood in detail. Aggregation glyphs could also be made dynamic in a way that they automatically expand to the individual glyphs (to a higher level of detail) as users move close to them.

Acknowledgements

This work has been made possible by a scholarship from the German Academic Exchange Service (DAAD).

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