Visualizing Metadata for Environmental Datasets

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Abstract

Data growth in the environmental sciences has resulted in multidimensional datasets that are heterogeneous and extensive. Scientific academic research includes scalar, sensor, or vector data, which may be publically available. The datasets generated extend to local environmental groups whose trained citizens contribute to the surveillance of local habitats and ecological conditions that can potentially enhance various data analyses on a national and international level. While the abundance of environmental data is growing, tools to select, compare, and utilize the growing number of datasets generated from multiple institutions and groups are not keeping pace. This paper focuses on planning the construction of a dataset visualization that concentrates on the use of metadata to facilitate the identification, selection, and comparison of dataset information. It is presented in the visualization framework at the School of Information Sciences called VIBE (Visual Information Browsing Environment) and plans to adapt the Dublin Core Metadata Element Set as a basis for its development. In the long term, visualization may emerge not only as a primary tool for modeling environmental scientific metadata, but also as a mechanism used at the incipience of environmental scientific discovery.

Keywords: information visualization; metadata; environmental data; visualization technology; dataset management.

1. Introduction

Information visualization refers to the graphical display of abstract entities. The use of new visualization tools to represent electronic databases in ways that can render them useful to the public and informative for environmental scientists across a broad spectrum of disciplines is a viable area of exploration. Environmental science has an active history that brings significant attention to issues such as climate change, toxicity levels, and habitat changes whose importance extends beyond academia to the general public. Environmental scientific research demonstrates an increasing impact on current and future life quality that is recognized by the general public. Researchers in disciplines such as ecology, climatology, geoscience, and biology generate an abundance of data to construct hypotheses, monitor changes, and examine ecological patterns on local, national, and international levels. Data collections emerge not only from academic research, but also from environmental groups whose trained citizens collect environmental measures on a local level and whose data collections remain underutilized. While the abundance of environmental data is growing, visual techniques to select, compare, and concatenate the growing number of datasets generated from both citizen-based environmental groups and scientific researchers are not.

From the researcher's perspective, the initial phase of scientific data analysis involves the selection of an appropriate dataset or datasets based on a research question's criteria. The datasets involved are multidimensional and are comprised of a range of variables including language, version, creator, and file format. Data sources are variable since data are generated from multiple disciplines, institutions, and environmental groups. Sources such as the U.S. Environmental Protection Agency's data and data.gov provide publically available datasets for analysis. A dataset may be found through a standard information retrieval search that yields textual result lists devoid of dataset relationships and selection grouping. Dataset attribute search is predominantly linear without context and this textual approach does not render a visual path through dataset information. For example, researchers may explore more associative queries such as: Are there a number of relevant datasets for exploring Research Question X? Do they share any commonalities for potential concatenation? Are they available in French? Are the data collected from the southern states of the United States? A visualization that displays dataset relationships can provide more context and information than answering a single query.

As outlined in the National Science Foundation's (NSF) Visualization Research Challenges, one of the greatest scientific challenges is no longer collecting enough information, but to render it useful (Johnson et al., 2006). Decisions for the selection of potential datasets could benefit from an aggregate visual representation to facilitate data understanding and an efficient selection process that improves scientific communication, collaboration, and discovery. The model proposed enhances the retrieval and display of datasets by using visualization techniques to provide a metadata context in order to parameterize and compare dataset information. The primary research questions, which guide the development of this model include: which variant of the visualization technology application will render dataset processes more effective for end users? and how does the application of basic DCMI metadata adapt to the visualization of a dataset?

The potential of using an innovative visualization method to solve the problems associated with dataset collections, namely their underutilization, selection, and sharing among environmental researchers is challenging. A tested visualization environment is used; however, the application of environmental science metadata visualization is new. The dataset problem is common to many scientific fields, but given the recent activity among environmental researchers and its multidisciplinary nature, it presents interesting issues for planning dataset visualization. This paper is organized as follows: section 2 reviews related work, section 3 discusses the adaptation of metadata, section 4 examines the research application and future testing plan; and section 5 presents the conclusions.

2. Related Work

Researchers have examined technological and communication issues that surround the topic of data abundance. Visualization techniques primarily focus on the scientific visualization of data within the dataset and less attention is given to a visual approach for evaluating two or more datasets. Tools are not readily available which enable a scientist from a given discipline to have a 'snapshot' of relevant datasets from related fields. Further, there have been no efforts to work out how to present these complex datasets in ways which will be useful for non-scientific groups such as local citizen environmental groups. The predominant themes of previous work relating to this topic include scientific visualization, dataset metadata, and information visualization. The following is a critical summary of the publications that provide a foundation for this topic.

Scientific visualization refers to the visualization of physical objects with spatial properties. Data collected in large datasets represent values of the dataset attributes (Card et al., 1999; Chen, 2004; Bak et al., 2009). High dimensionality is explored by investigators whose work elicits characteristics about dataset structures (Wood et al., 2007; Ren et al. 2006, Dennis and Healy, 2002) and visualization systems have been developed that demonstrate various approaches to depicting large scale data including star plots, tree techniques, and maps to visually process and depict large sets of data collections (Smith et al., 2006; Callahan, et al., 2006; Chen and Tian, 2009; Scheidegger et al., 2007; Elmqvist et al., 2007). Some of these systems are domain dependent and offer specific approaches to data generated in different scientific fields (de Leeuw et al., 2006; Kehrer et al., 2008; Weber et al., 2007). Scientific visualization offers high dimensional displays of database contents, however insufficient attention is being paid to the meta-analysis of datasets in a visualized way.

Issues surrounding the type of external or internal metadata of scientific datasets in either structured or unstructured formats are examined from a meta-repository creation perspective along with the appropriate utilization of existing datasets for potential meta-analysis (Ordonoz et al., 2007; Mair et al., 2005; Albertoni, et al., 2005). Dataset characteristics such as time-limited interest, sharing, and metadata formulation are examined in the context of local data storage for large scientific datasets (Vazhkudai, et al., 2006). This work contributes to the understanding of meta-evaluation, but the application of visualization techniques to analyze problems at a metadata level are not apparent.

Information visualization originates from scientific visualization practices and offers a visual representation of abstract entities without inherent spatial properties. The procedures required for processing scientific datasets conform to elements of information visualization taxonomic task structures. Visual operations such as the ability to visually "associate", "compare", "distinguish", and "categorize" are found in several researchers' work and are not bound to a particular domain (Wehrend and Lewis, 1990; Zhou and Feiner, 1998; Valiati et al., 2006, Morse et al., 2000). Taxonomies have developed focusing on data types and dimensionality (Shneiderman, 2003), and in one model these factors are integrated into a three pronged framework based on data types, display mode, and interaction (Keim, 2002). The significance of visualization task taxonomies is their comparable elements between the information and scientific visualization domains that are amenable to the construction of meta-dataset analysis in the environmental sciences.

This approach offers a comparative platform for visual dataset assessment. Dataset visualization relies upon external metadata for research selection and potential concatenation. The research issue may be viewed as an information retrieval problem where several visualization techniques have been applied and tested for the identification and retrieval of relevant information. Work in the visualization field incorporates the display of information through treemaps and hyperbolic trees based on hierarchical data, visual clustering, radial layouts, focus+context techniques and hybrid methods (Shneiderman, 2003; Rivadeneira and Bedersen, 2003; Pirolli et al., 2001; Morse et al., 2002; Draper et al., 2009). Information visualization has an established foundation of techniques and exploration is required to build the dataset requirements at a metadata level.

3. Metadata Adaptation

In accordance with the basic DCMI metadata elements, an external metadata template for creating a meta-dataset will incorporate metadata terms such as: organization, topic, location, data collection time period, file format, file size and so forth. External metadata refers to descriptive elements about the dataset. Many visualizations primarily depict patterns of data values within large datasets. Metadata elements may be structured according to data type and a list of internal metadata will be compiled for supporting the detailed visualization option of the Shneiderman visual information seeking mantra (Shneiderman, 2003). Lexical issues will be considered to achieve metadata representation and consistency. Table 1 delineates the basic DCMI metadata terms, their definitions, and their adaptation to dataset metadata as evidenced in the literature on large datasets.

Table 1: Dublin Core metadata elements for dataset adaptation.

Metadata Term	Definition	Adaptation to Dataset Attributes
Contributor	An entity responsible for making contributions to the resource.	An entity responsible for making contributions to the dataset.
Coverage	The spatial or temporal topic of the resource, the spatial applicability of the resource, or the jurisdiction under which the resource is relevant.	The location coordinates of the dataset or the time period.

Creator	An entity primarily responsible for making the resource.	The person(s), department, or organization who created the dataset.
Date	A point or period of time associated with an event in the lifecycle of the resource.	The point in time in which the dataset is created.
Description	An account of the resource.	Description of the dataset and attribute summary.
Format	The file format, physical medium, or dimensions of the resource.	Denotes the electronic file format of the dataset (e.g. .cvs, .xlsx).
Identifier	An unambiguous reference to the resource within a given context.	The identifier may be used to generate a formal reference to the dataset.
Language	A language of the resource.	Describes the language of the data.
Publisher	An entity responsible for making the resource available.	Refers to the entity, who made the dataset publically available.
Relation	A related resource.	A related resource to the dataset.
Rights	Information about rights held in and over the resource.	Specifies the uses allowed with the dataset and user rights.
Source/ Origin	A related resource from which the described resource is derived.	Refers to the geographic location from which data are collected or affiliated or may be renamed origin to indicate the institution providing the data.
Subject	The topic of the resource.	The topic of the dataset.
Title	A name given to the resource.	A name given to the dataset.
Type	The nature or genre of the resource.	The nature or genre of the dataset.

Source: Dublin Core Metadata Element Set, v. 1.1 http://dublincore.org/documents/dces/

Each metadata term may be rendered as a Point of Interest (POI) in the visualization framework that is presented next.

3. VIBE (Visual Information Browsing Environment) Framework

VIBE (Visual Information Browsing Environment) was developed as a desktop prototype system by researchers at Molde College, Norway, and at the School of Information Sciences, University of Pittsburgh. The VIBE system was comprehensively tested for usability and it is amenable to further development for visualization research and testing (Koshman 2004, 2005). The system has been utilized for several purposes including an early research project for meta-information extraction from a scientific bibliographic database funded by the Department of Energy's Office of Scientific and Technical Information (Olsen, et al., 1993). Its original implementation had a strong impact on the direction of information visualization for over a decade (Olsen et al., 1993; Korfhage, R., 1997; Heidorn, 2000; Christel and Huang, 2001; Morse et al, 2002; Koshman, 2004, 2005; Ahn et al, 2006). VIBE's initial desktop prototype is available in C and runs on Unix and Windows. A more current prototype was built in Java at the School of Information Sciences. The most recent version of VIBE is a mobile adaption written in JavaScript called Mobile VIBE (MVIBE) (Koshman and Ahn, 2009). The selection of VIBE for this framework was based on: 1) its wide implementation that reduces the uncertainty associated with general visualization system effectiveness and use, and 2) its well developed set of features that can be customized for dataset visualization.

The basic elements of the VIBE interface include a visual query that features round circular icons, which represent Points of Interest (POIs) or user selected terms. The resulting document set is depicted as rectangular polygons that are plotted in proximity to the POIs according to a term frequency distribution algorithm. Color, shape and size comprise the icon attributes. The larger the document icon, the more frequent occurrence of terms related to the document. VIBE uses key terms to calculate a document score and a positioning algorithm places the document icons in relation to the POIs on the display (Figure 1).

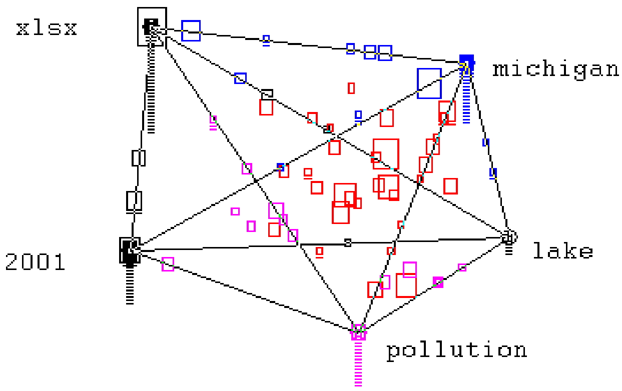


FIG. 1. VIBE display using the net feature and color. (Source: VIBE Software)

The advantage of the VIBE visualization in Figure 2 is demonstrated with the following example in environmental sciences adapted from (Olsen et al., 1993). The following is a three topic-based request.

1. pollution and rivers and toxicity
2. pollution and rivers
3. pollution and toxicity
4. rivers and toxicity
5. pollution
6. toxicity
7. rivers

The salient premise in VIBE's design is that queries and resulting items can be visualized in one display for user browsing. Figure 2 shows that a VIBE display encapsulates the preceding variations. The polygonal icons located in the display center support condition 1, which contains all three POIs. The polygonal icons located upon the axes between two terms denote the two term relationship found in conditions 2, 3, and 4. Tails or a vertical stack of dashes found underneath individual POIs indicates icons that contain only that term (conditions 5, 6, and 7). Overall, users may make inferences about the document icons (in this model, datasets) based on their position relative to the POIs or metadata elements in the display.

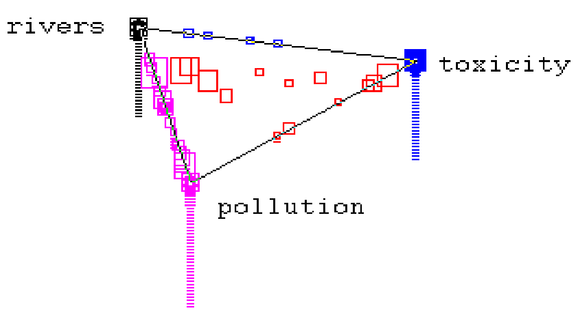
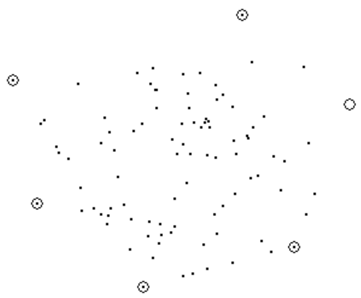


FIG. 2. VIBE's data display. (Source: VIBE Software)

Users may drag, add or remove POIs (terms) from the display so a number of metadata attributes may be selected for the display. In Figure 2, color is used to distinguish POIs and resulting document icons. If two POIs are assigned different colors, then the combined document set that contains both terms turns red. Relationships between the POIs and the document icons can be depicted using the "lines" or "net" feature and users can select display options such as the "astro" view, which is useful for attaining an overview of a larger number of dataset items (Figure 3a). The astro view containing the lines feature and color offers a more aesthetic overview in Figure 3b. The first comprehensive usability study of the VIBE system indicated that VIBE was a learnable information visualization system and that users could find features to resolve their information tasks (Koshman, 2004, 2005). VIBE's appeal and usability was established among general users, hence its features are robust and customization is achievable and relevant to the environmental dataset context.



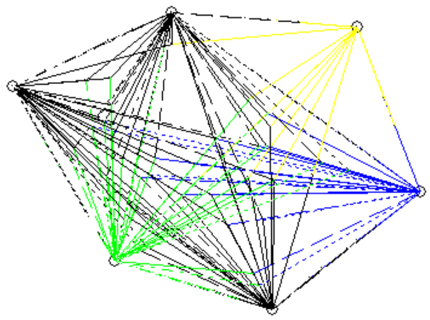


FIG. 3. (a) VIBE's astro view for high density displays. (b) VIBE's astro view with the lines feature. (Source: VIBE Software)

4. Research Application and Future Testing Plan

From a theoretical perspective, VIBE's browsing-based display promotes increased understanding of connections between multiple datasets displayed as polygonal icons for the end user. Customization of the VIBE framework for dataset tasks would include the following requirements.

- The descriptive metadata approach to **dataset characteristics** represented in POIs will comprise the dataset icons for which metadata frequencies will need to be calculated. Dataset POIs may be presented in a visual carousel where each plane represents a metadata dimension to aid visual query building. User control of the number of metadata elements will be explored.
- **Metadata similarity measures** will be tested and will operate in VIBE's vector-based framework. The standard representation is as follows, if *x* and *y* are two dataset objects in a vector space,

  $x = (a_1, a_2, a_3, \ldots, a_n)$

  $y = (b_1, b_2, b_3, \ldots, b_n)$

  $S(x,y)$ then represents the similarity (Zhang, 2008).

  Testing will determine if the number of metadata elements is sufficient in consistency and number to provide useful similarity calculations for dataset object positioning and user selection.
- **Visualization overviews** such as a radial diagram will be designed to complement the astro overview of the datasets (Tominski, et al., 2004; Draper et al., 2009).

- **Color** will be used for highlighting datasets that share common attributes and will draw upon the users' visual processing for selecting and exploring target item groups (Ware, 2004). Individual metadata POIs may be colored resulting in a set of pop-out dataset polygons that uses visual discriminatory processes. Supplementary techniques, such as icon line thickness, will be incorporated to support non-color discriminating users.
- **Spatial proximity** through positioning functions will be maintained for visually assessing dataset relationships (e.g. geographic locations, topic commonalities). Gestalt theory supports the use of proximity for visually ascertaining item relationships. For example, VIBE's "net" feature offers the Gestalt-like connectivity feature to show lexically related items contained in the resulting set.
- **Dataset attributes** will be detailed when the polygonal dataset icon is clicked upon. Initially, an attribute listing will be presented. An alternative multi-point shape (e.g. a star plot, folded parallel coordinate diagram) may also be explored to replace rectangular polygonal icon shapes to visually distinguish dataset characteristics (such as Elmqvist, 2007). Detailed attributes may be presented through semantic view techniques, which provide users with a new representation upon zooming (e.g. presenting visual and text information).
- An issue observed from previous VIBE testing is the aggregation of data items in the center of the display, which results in visual complexity for the end user. A fish-eye technique has been developed for the VIBE display to magnify icons as they are browsed. **Space limitation techniques** such as suppression and overview & context will be tested for enhancing display clarity and usability (Spence, 2007).
- Visual **filtering** may be introduced to enable users to create a static dataset request. As the system is updated with new datasets, the query results will be updated according to the request parameters. Other datasets that do not match the user's request will be suppressed. This technique can reduce visual clutter as well as permit constant user-based dataset selection for decision-making (Ellis and Dix, 2007).
- **Progressive testing** with users from various disciplines throughout the model implementation will address the following factors: 1) the granularity in dataset attributes in rendering a meaningful dataset display for users, 2) the visualization's ease of use – understanding the display, locating appropriate system features, 3) timing the users' dataset decision-making tasks, 3) the amount of new dataset exploration by users, 4) the completeness of assigned tasks, 5) subjective satisfaction, 6) dataset scalability, and 7) measuring feature use. The significance of using visualized DCMI metadata for dataset exploration will be tested and evaluated.

5. Conclusions

The use of metadata has long referred to primary features of interoperability and standardization. If dataset attributes can be mapped to a known metadata standard, then the visualization that transforms the meta dataset can be rendered. To evaluate the operational implementation, dataset samples will be needed to provide an initial comparison and data will be structured to be usable within the VIBE visualization's framework. Visualization is a known technical solution for multi-disciplinary domains since its perception-based representations offer the opportunity to use visual pattern identification and pre-attentive processes to efficiently present data for a range of users. Adopting this approach to dataset metadata retrieval in the environmental sciences domain offers not only the opportunity to move forward in an increasingly important scientific area, but also to contribute to potential collaborative and formative scientific discovery in the environmental sciences.

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