Research Article

Spatialized Browsing in Large Data Archives

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Abstract
Exponentially growing data archives emphasize the need for efficient techniques and novel approaches to find and extract information. Information visualization has emerged in the Information Retrieval domain to facilitate access to large databases. This development acknowledges the need to focus on higher level cognitive processes in information seeking. Graphic depictions of large databases are increasingly based on the spatial metaphor. These representations are also known as spatialized views or information spaces. Whereas space as a data property has implications for the design and implementation of spatial information systems, this paper explores whether commonly used spatial concepts could be used as browsing metaphors to explore a digital library catalog. A proof of concept is provided that illustrates how spatial metaphors might be embodied in a query interface to visually explore the catalog of the Alexandria Digital Library. This experimental interface includes an information landscape that is based on three spatial concepts, distance (similarity), arrangement (dispersion and concentration), and scale (level of detail).

1 Introduction

In the popular mythology the computer is a mathematics machine: it is designed to do numerical calculations. Yet it is really a language machine: its fundamental power lies in its ability to manipulate linguistic tokens – symbols to which meaning has been assigned (Winograd 1984, 131).

The advent of computer networking technologies, such as the Internet and the World Wide Web, has had a considerable impact on how we access, store, and exchange information. Access to information is a key element to the economic, environmental

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and social well being of a nation (National Research Council 1994). While the global information infrastructure (GII) launched by Vice President Gore promises increasing amounts of data available at our fingertips, the need for techniques and methods to efficiently extract information becomes crucial (Gershon and Brown 1996a).

Although the computer has enabled 'knowledge workers' to process large amounts of information, for example relying on efficient algorithms for searching, sorting and indexing, as well as by reducing data retrieval times, the bottleneck in information processing seems to lie in the user interface, restricting the potential of today's computational and communications technologies (Buxton 1990, 405). Unfortunately, many of the current query user interfaces provide insufficient guidance for the information seeker, and queries often return a huge set of undesired results (Doan et al 1996). Put more directly by Norman (1990, 210): 'The real problem with the interface is that it is an interface. Interfaces get in the way.'

Mark Weiser (1991, 94), who proposed *ubiquitous computing* points out that 'The arcane aura that surrounds personal computers is not just a user interface problem', but that 'most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable.' Weiser proposes that such disappearance is not a fundamental consequence of technology, but of human psychology. Moreover, to understand the invisibility of technology the humanities and the social sciences are especially valuable, because they specialise in exposing the otherwise invisible (Weiser 1994).

Traditional information retrieval is being superseded by interactive information seeking strategies, based on powerful graphical direct manipulation user interfaces. The term knowledge discovery in databases (KDD) (Fayyad et al 1996), for example, encompasses strategies for finding useful patterns and extracting knowledge from digital records stored in huge data archives, such as data warehouses. Knowledge generation from large databases involves several steps, ranging from data manipulation and retrieval, to mathematical and statistical inference, as well as search strategies and human reasoning processes. A particular step in this knowledge discovery process referred to as data mining, which refers to specific algorithms for extracting patterns (models) from data sets (Fayyad et al 1996, 28). Other examples utilizing exploratory information access techniques based on high resolution colour displays are data browsing and filtering (Shneiderman 1998), or information visualization and information foraging (Robertson et al 1993, Pirolli and Card 1995).

2 Sense-making in Information Access

In the process of information use Gershon and Eick (1996) distinguish four phases: information must be sifted and pertinent material must be found, accessed, and understood. Moreover, information should be represented in a form that matches human capabilities best (Gershon and Brown 1996b, 61). People's interaction with a large data archive will probably be more efficient if some sort of graphical display is provided while they are searching for information. As graphical representations are compelling and easy to understand, one can expect that a visual overview of the information space will help people understand the content of the available data. A visual approach is also desirable during query formulation. Instantaneous graphical feedback helps users to understand the query process and to select appropriate query

terms. Likewise, a graphically oriented presentation of query results will help the information seeker to 'see' results quickly and to successfully retrieve desired documents. It has been shown that humans have powerful visual thinking abilities, and physical, spatial and visual representations are easier to learn, understand and communicate than abstract numeric or textual information (Arnheim 1969, Tufte 1983, 1990, 1997).

Utilizing sophisticated graphical imaging technology and relying on the concepts taken from scientific visualization to 'see the unseen' (McCormick et al 1987), information visualization has emerged in the human computer interaction domain to facilitate information access to large distributed data archives (Robertson et al 1993, Ahlberg and Shneiderman 1994).

Research on information visualization has produced novel data access tools to cope with the fast growing demand to retrieve, store, manipulate, and understand large amounts of data (Robertson et al 1993). Information foraging and sense-making research have taken a cognitive, user centered approach to tackle the information explosion. One of the main themes in sense-making is the process of searching for an optimal representation and encoding data in that representation to answer task-specific questions (Russell et al 1993, 269). Dervin (1983) suggests that information seeking and use is central to sense-making, and that sense-making is both a cognitive internal process as well as externalised overt behaviour. For example, making sense of a large body of data by visual means is a crucial analysis task in any type of activity within an information rich environment. Concepts taken from cognitive science and psychology are combined with principles from human computer interaction, not only to design better interactive information retrieval systems, but also to optimise the user's cost of operations in a general sense of information use (Russell et al 1993).

Information foraging specifically applies biological foraging strategies to the processes of information gathering. Trade-offs in the value of information gained against the costs of performing information-seeking tasks are analyzed and evaluated (Robertson et al 1993, Pirolli and Card 1995). Russell et al (1993) have identified data extraction as one of the most time consuming tasks in sense-making, and suggest automated clustering techniques to lower the costs of information extraction within the larger domain of information processing. Nelson (1990) suggests the term conceptual *structure design* to represent the true structure and interconnectedness of information. By using uniform or systematic spaces, such as geographic space for example, multidimensional connections can be revealed. Discrete connectedness can be achieved by mapping individual and disparate interconnections through hyperlinks (Nelson 1990).

Card (1996) suggests substituting the term 'information perceptualization' in place of information visualization to imply a richer use of many senses (i.e. vision, sound and touch) to increase the rate at which people can assimilate information. Information perceptualization might be expanded into 'information cognitization' to emphasise the internal, mental process of information use over the psychophysical aspects of seeing an information representation.

3 Spatial Metaphors

Spatialized views rely on the use of spatial metaphors to represent data that are not necessarily spatial. Spatial metaphors constitute a fundamental part of human

cognition (Lakoff 1987). Lakoff (1987) defines the *Spatialization of Form Hypothesis*, which requires a metaphorical mapping from physical space into a conceptual space. Consequently, image schemata which structure space are mapped into the corresponding abstract configurations, which structure concepts (Lakoff 1987). The way books are shelved in a library could serve as an example. For instance, the fundamental near-far image schemata (Johnson 1987, 126) can be used as a source domain and mapped into the abstract target domain of similarity. Typically, a library user looking for plays by Shakespeare will find the items of interest in the English Literature section, where other books by English authors and or English plays will be placed on nearby shelves.

The user's understanding of spatialization is based on envisioning and comprehending spatial properties. Among the most basic properties of space are location, distance and direction. Golledge (1995) discusses a set of primitives for building those spatial concepts, such as identity, location, magnitude, and time. Distance, angle and direction, connection and linkage (nearest neighbor, proximity, similarity, etc) can be derived from the basic concept location. Derived concepts can be combined to build higher order spatial concepts. Location, magnitude, and connectivity can be combined to obtain the concept of hierarchy, for instance. An ordered tree (hierarchy) provides a useful metaphor or data model for the concept of scale. Similarly, (local) density, which is connected to the concept of dispersion, may be constructed by combining location with magnitude.

Both Lakoff and Johnson (1980) and Lakoff (1987) point out that spatial schemata seem to be at the core of cognitive structures and form a basis for many less concrete domains. 'Spatialization metaphors are rooted in physical and cultural experiences', and 'much of how we think in later life is based on what we learn in early life about the world of space' (Lakoff and Johnson 1980, 17–8). These linguistic definitions of spatialization exemplify why spatial metaphors may play an important role in the human-computer interaction domain and more specifically within user interface design. Spatialization serves the user's need to organise abstract concepts coherently (i.e. a computer operating system) and to ground them in familiar experiences (i.e. an office desk) (Kuhn and Blumenthal 1996, 57). A metaphor's primary function is to provide a partial understanding of one kind of experience in terms of another kind of experience (Lakoff and Johnson 1980). Consequently, because spatial experience is so fundamental to humans, spatial metaphors act as fundamental sense makers for abstract domains.

As space plays such an important role in human cognition, spatialization might profoundly influence the quality of the design of interactive information access user interfaces. Lastly, spatial metaphors suggest a rich source for affordances (Kuhn and Blumenthal 1996). Gibson (1979) coined the term *affordances* to describe values and meanings of objects which humans can perceive while they interact with them in everyday life. In other words, affordances are properties of things *taken with reference to an observer*, but not of the *experiences of the observer* (Gibson 1979, 137; italics in original). For example solid substances have perceivable surfaces, with individual characteristics. If the surface is flat and extended, it affords support. According to Gibson, the ground literally 'affords' the base support for human behaviour in space and perception thereof.

4 Information Access using Spatial Metaphors

The World Wide Web is a good example of how spatial metaphors are used. For example, Web surfers navigate from site to site on the *infobahn* to explore cyberspace. Information seekers search the *infosphere* for information and access it through the *docusphere* or the *docuverse*.

The graphical user interface of a query system could also be seen as an interaction 'space' affording an information seeker the opportunity to interact with objects on the display in order to find information. Norman (1988) utilises the concept of affordances, to study the effectiveness of design of everyday things, such as doors, light switches, VCRs, etc. Gibson's (1979) and Norman's (1988) affordance concepts can be transferred into the human computer interaction domain, to enhance the effectiveness of graphical user interfaces. Prototypical interactions of an information gatherer with a query system are formalised in Table 1, using Shneiderman's (1998, 510–3) *task action* taxonomy, within an *object-action* interface framework.

Task-centered user interface design (Lewis and Rieman 1994) emphasises the identification of representative information access tasks an information seeker wishes to perform while accessing a large data repository, for example the Alexandria Digital Library (ADL, on the Web at http://www.alexandria.ucsb.edu). There are two ways to query the ADL in the current interface. First, specific keywords can be entered in text entry fields to issue a combined search in the gazetteer (geographic search) and the catalog (attribute search). Second, one can use the map browser to graphically refine the search area, by zoom and pan. Relating to Sheiderman's task action taxonomy (see Table 1), only *known-item-searches* are available, thus restricting a user to specific keywords or geographic areas as query inputs.

Although the system handles specific fact finding well, exploratory information access through open-ended browsing is not adequately supported. Some users might not have a well-defined information need, and might desire to gain an overview of the entire collection first, before querying it with a specific keyword. Other information seekers might be interested in discovering new relationships among items of interest in the database, which would assists them in formulating queries they would not have previously considered.

What might a visual information gathering process look like in ADL? Exploratory information seeking could be built upon what Shneiderman (1998, 523) calls the visual-information-seeking mantra. The mantra includes three parts: 'Overview first, zoom and filter, then details-on-demand'. Users can directly manipulate visual components provided in the interface, to refine a query. Dynamic queries are carried out by 'point and click' as well as 'drag and drop', using tools and buttons, sliders, scroll bars and check boxes. Linked windows allow an immediate graphical response by the system. The general interaction schema in Figure 1 outlines how information seekers might be able to interact with ADL's collection.

5 Spatialization

Spatialization, which combines powerful visualization techniques with spatial metaphors, has a great potential to overcome current impediments in information access and retrieval. Spatialization is utilised to create lower-dimensional digital

Table 1 Information Access Tasks in a Digital Library (after Shneiderman 1998)

User		Interface	
tasks actions	representative tasks	objects	affordances
Specific fact finding	Find a USGS digital orthophoto quad of Boulder, CO	resizable windows, data entry fields, menus, selection lists, scroll bars, buttons, check-boxes	point and click, type, select, scroll, use slider, check mark
Extended fact finding	Are there orthophoto quad series available in CO to study landuse change along the South Platte River?	linked windows, visual and textual query tools, i.e. information spaces, dynamic graphs, keyword trees, sliders, graphic footprints	drag and drop, select, compare and match, scroll, use slider, link, jump, animate, graphic Boolean queries, zoom-ins, lasso, transect
Open-ended browsing	Hikes to 14-ers in Coloraodo?	linked windows, visual and textual query tools, i.e. information spaces, dynamic graphs, keyword trees, sliders	drag and drop, select, compare and match, scroll, use slider, link, jump, animate, graphic Boolean queries, zoom-ins, lasso, transect
Exploration of availability	What types of maps of Boulder, CO are available?	linked windows, visual and textual overview of available items according to selected keywords, i.e. information spaces at multiple scales, keyword tree lists, dynamic graphs, sliders, graphic footprints.	drag and drop, select, compare and match, scroll, use slider, link, jump, animate, graphic Boolean queries, zoom-ins, lasso, transect

representations of higher-dimensional data sets, whose characteristics are often quite complex. These digital data sets may not be spatial in nature. Common spatial concepts such as distance, direction, scale and arrangement which are part of the human's experience in everyday life are applied, to construct abstract information spaces. Spatialization offers the field of geography, which investigates space and spatial relations, opportunities to apply the body of knowledge to other non-spatial domains.

Egenhofer and Mark (1995, 4) coined the term Naive Geography to describe '[...] the body of knowledge that people have about the surrounding geographic world.' They argue that spatio-temporal reasoning is so common in people's daily life that it is
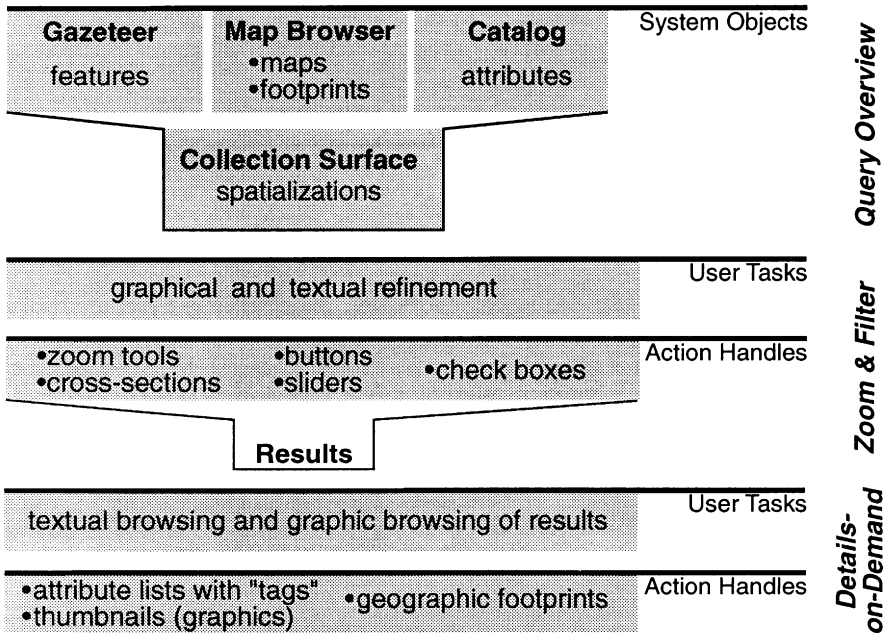
Figure 1 Visual Browsing Query Process (Fabrikant and Buttenfield 1997, 688).

rarely noticed as a particular concept of spatial analysis. Naive Geography, in their words, focuses on formal models of common-sense knowledge of geographic spaces (Egenhofer and Mark 1995, 3).

Why is spatialization important for the geographic information science community? As geographers, cartographers and GIS users, we are familiar with the use of spatial metaphors. Relying on sound graphic design principles from a long standing cartographic tradition and spatial modeling concepts developed within analytical geography, the GIS community has a strong background to offer, in helping to design these new representations for non-spatial data. The reduction of real world complexity through cognitive processes like selection, abstraction and generalization is a key process in spatial data handling, to extract and communicate meaning about the multidimensional world. Moreover, there still seems to be little formalised knowledge on how humans develop concepts and reason about geographical space. Geographic Information Systems, being a special case of information systems, deal explicitly with the representation of space. However, Medyckyi-Scott and Blades (1992) point out, that the increased sophistication of GIS has not always been accompanied by an improvement of usability. Unfortunately, the user has to learn an abstract formalised spatial language, and adapt to the system's terms of representing space, instead of the system reflecting how the users themselves represent and reason about space. This is a fundamental impediment from the perspective of usability.

Exploring the use of familiar spatial metaphors to represent large, non-spatial data sets for information access might help the geographic information science community to learn more about human spatial reasoning and decision-making. Consideration of spatial cognition is not only important for the development of spatial information

theory, but also the focus on the user's view of space will play a significant role in the design of more intuitively usable geographic information systems.

Successful spatialization examples demonstrate that graphical displays based on spatial properties can reveal patterns and structures within the data base. For example, Chalmers (1993) creates a landscape of conference proceedings articles, which are organised spatially, depending on their similarity in content. Skupin and Buttenfield (1996, 1997) construct a 'newspaper article space' representing the thematic content of news articles in two issues of the New York Times. Atkins (1995) describes the periodic table of the elements as a geographic landscape. Based on element characteristics, Atkins divides the chemical elements into landscape regions. Subsequently, he creates a terrain of the chemical elements in terms of altitudes that represent different element features or characteristics such as atomic masses, diameters, or densities.

Spatialized user interfaces emerged over the past few years, first popularised by spatialized operating systems (i.e. Apple Macintosh's Finder) and then spreading into virtual environments, multimedia applications and computer game worlds (Kuhn and Blumenthal 1996). User interfaces based on spatial metaphors also found their way into the information visualization domain, for example Wise et al (1995) implemented *Themescape*, an information retrieval interface depicting surfaces of document collections, organised spatially by similarity of term co-occurrences (see Fabrikant (1999) for more examples described in related work to represent abstract, multidimensional databases with spatial metaphors). Although awareness of the potential benefits of spatialization is growing, there seems to be a lack of systematic treatment (Kuhn and Blumenthal 1996, Skupin and Buttenfield 1996).

The use of spatialization is not restricted to the larger domain of information use, but touches on a wide variety of human related activities, including cognitive, aesthetic, social, legal, educational, as well as commercial aspects (Kuhn and Blumenthal 1996, 3). Whereas aesthetic aspects focus on aesthetically pleasing and comprehensible designs for the visualization of space, social and educational components are centered around the user community using spatialized displays. At a higher societal level, legal aspects become crucial, if access and security issues are involved in the general information use domain. This paper focuses mainly on cognitive aspects of spatialization (and to a small extent on aesthetic issues), and how they may relate to widely used concepts and techniques in geography and cartography, to comprehend large bodies of non-spatial data by visual means.

6 Spatialized Browsing

This section describes a proof-of-concept of an experimental query interface to visually browse the data type catalog of the ADL. The design of this direct manipulation interface is based on three spatial concepts, including distance (similarity), scale (level of detail), and arrangement (dispersion and concentration).

As noted in an earlier section, Lakoff (1987) defines metaphors as mappings from a source to a target domain, or in other words metaphors allow us to partially understand one thing in terms of another (Kuhn and Blumenthal 1996, 16). Moreover, spatial metaphors include affordances. Affordances call for opportunities of interaction between a human and entities populating an environment (Gibson 1979, Norman 1988, Kuhn and Blumenthal 1996). Table 2 lists relevant spatial image schemata extracted

Table 2 Spatial Image Schemata and Cognitive User Tasks

Spatial Image Schemata	Source Domain (library collection)	Target Domain (collection landscape)	Cognitive User Tasks (spatial abilities)
Container	data archive	landscape of documents	recognise and associate regions to items in the collection
Link	cross references between items	cross sections in landscape	associate and relate items of interest by similarity in content
Near-Far	similarity between items	distance between items	estimate distance between documents, based on content similarity
Surface	library collection	landscape of keywords	recognise and associate landscape features to structure of documents
Scale	hierarchy of documents	level of detail in landscape	organise and rank documents
Part-Whole	clusters of related documents	regions in landscape	differentiate, recognise, and detect regions of related documents.

from Johnson's (1987, 126) image schemata taxonomy, which form basic structures based on our everyday experiences interacting with the environment and relate them to cognitive user tasks in the information access process.

7 Representations of Spatial Metaphors in a Query

Applying spatial metaphors to the visual-information-seeking mantra discussed earlier a spatialized information gathering session in ADL could be envisioned as follows. An information seeker will encounter a direct manipulation interface with linked windows (Figure 2). Dynamic queries are carried out by buttons, sliders and check boxes, which trigger an immediate graphical response by the system. Items selected in the lists will be highlighted in the spatialized views and vice-versa.

To envision the distance concept, for instance, a series of spatial metaphors might be possible, spanning from the abstract to the concrete, such as point clouds, bar graphs, spaces, pin-point maps, block diagrams, stepped surfaces, continuous surfaces, etc. Also mimetic representations could be utilized, such as a city metaphor with skyscrapers and connecting streets, a transportation network with stations and paths, or perhaps a library metaphor with rooms, shelves and documents. The scale metaphor could be envisioned as different types of hierarchical trees, hierarchical networks, dendograms or color-coded layers.
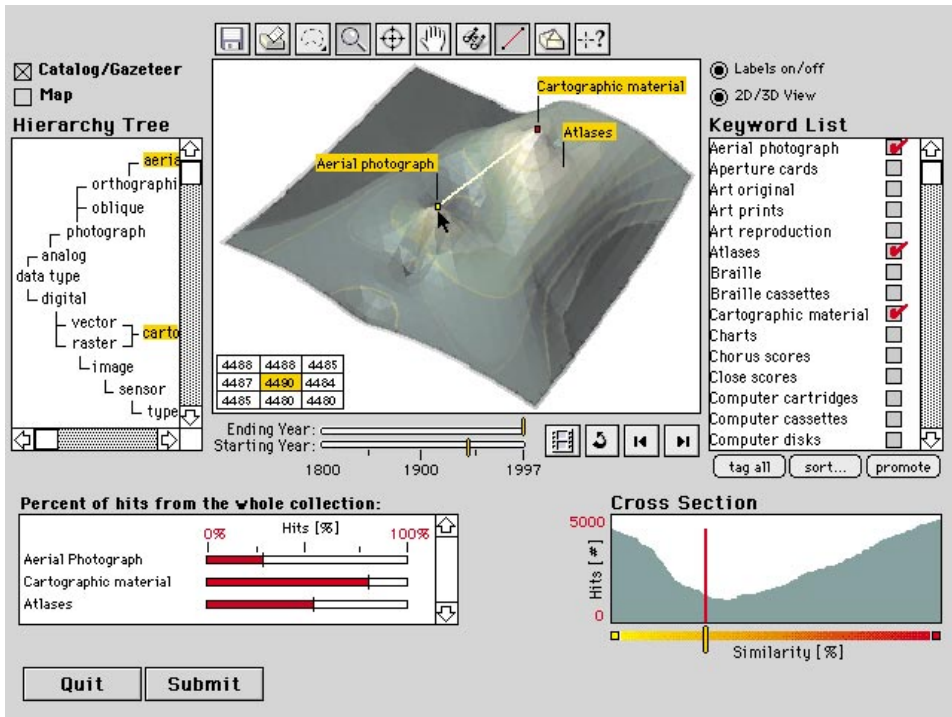
Figure 2   Spatialized Query User Interface (modified from Fabrikant and Buttenfield 1997, 689).

Figure 2 presents a landscape of keywords representing ADL's data type catalog index. The distance metaphor is applied to keywords describing documents in the archive, relying on Salton's (1989) vector space model. Multidimensional scaling (MDS) is utilised as the projection method to create a surface of keywords (Skupin and Buttenfield 1997). The landscape of catalog items that were returned by a query is visualised in Figure 2, in the centre window. In this abstract data space the physical distance concept (source domain) is mapped into the abstract document similarity concept (target domain). Documents characterised by similar keyword sets are placed closer together in the landscape than documents which have few keywords in common. This landscape affords a user to:

- look at the surface and get a sense of the structure of the library space (overview first)
- navigate in this landscape to discover items of interest
- selectively perceive the landscape by changing the level of detail of the document space (zoom and filter)
- select individual documents or groups of documents
- discover relationships between documents (details-on-demand).

Several components of the interface are provided to envision the level of detail of the data base. For example, tools for zooms are available and a window visualises the hierarchical structure of the keywords. Direct manipulation of the spatialized views follows previous work demonstrating ease of learning interface tools (Shneiderman

1983, Tsou and Buttenfield 1996). For example an information seeker might be interested in the availability of aerial orthophotographs of Boulder, Colorado. While selecting the data type keywords 'cartographic material' and 'aerial photograph' in either the Hierarchy Tree Window or the Keyword List Window their place in the data space and the magnitude of documents associated with the selected keywords will be displayed dynamically in the landscape window.

The information foraging principle is included as well, which refers to the optimal use of knowledge about the expected information value and about the expected costs of accessing and extracting the relevant information (Pirolli and Card 1995). For example, a window is provided which reacts to keyword selections by displaying dynamic bars showing the relative percentage of hits that would be associated with each keyword. This graphic display supports people in their query refinement and indicates the magnitude of results to expect.

The Cross Section Window combines the scale with the distance and direction metaphors. The gray area under the curve predicts the magnitude of related documents to be expected along the transect line drawn in white across the landscape window. The transect is determined by a source and target keyword (white and dark gray square). By moving the slider below the x-axis of the Cross Section Window, the location of keywords along the transect line in the landscape window will be highlighted.

The 'collection surface' embodies the concept of arrangement. Peaks and valleys of documents offer a graphic overview of the queried items. As users dynamically select keywords in a Keywords List Window, the Landscape Window reveals their position within the collection, in relation to each other, based on their content. The 'looking glass' tool allows a user to examine the surface in more detail. The 'three-by-three pixel' window at the lower left corner of the landscape window displays the exact number of hits retrieved at the mouse location (black arrow in Figure 2).

8 Conclusions and Future Work

Cognitive, user centered approaches are increasingly used in Information Retrieval to tackle the information explosion. Information visualization has emerged within the human-computer interaction field to facilitate access to fast growing, complex data archives by combining cognitive approaches with graphical imaging technology. Graphic representations of vast databases are increasingly based on spatial metaphors. Spatial concepts are viewed as a useful metaphor to graphically depict large complex databases because concepts about space are easily accessible to human cognition. This article explored whether spatial concepts could be utilized as browsing metaphors to make better sense of the contents of a large digital data archive. Grounded in cognitive theory on space and spatial metaphors, a proof-of-concept for a direct manipulation interface has been described that relies on a set of spatial primitives to envision the catalog of a digital library such as the Alexandria Project. Basic spatial concepts such as distance (similarity), arrangement (dispersion and concentration), and scale (level of detail) are applied to create a landscape of keywords of a hierarchical library catalog. The use of spatialized views to represent the holdings of a digital library has not been implemented to date. As argued in this paper, spatialized views to represent the catalog of a digital library would help people to browse large document collections.

Further research could include several steps. Firstly, spatial concepts embedded in the mock-up interface should be tested with users to provide empirical evidence on the appropriateness of the described metaphors for visualization. Users' metaphor comprehension might not only vary depending on the information need, but also depending on the types of documents available in the collection. Usability evaluation should include query scenarios based on representative information seeking tasks and real-world data. Multiple versions of the information landscape can be tested depending on the organisation principle applied to store the data. Information spaces can be constructed that depict the temporal structure of items in the archive (e.g. acquisition date, lending date, etc), their geographical location (e.g. storage location, geographic descriptions within documents, etc), their administrative status (e.g. document type, availability, popularity, etc) or their semantic content (e.g. depending on type of subject index).

Secondly, insights gained through usability evaluation should lead to system implementation, using an existing library collection that is based on a real document catalog. A host of design challenges need to be addressed that lie beyond the scope of this paper. For example, real time visualizations of dynamic online databases, direct manipulation interfaces that allow instantaneous query feedback from distributed databases, or the application of spatial metaphors in virtual, immersive environments. Technological challenges will have to be considered as well. Issues, such as data base scalability, data access, update and maintenance aspects in a distributed environment (e.g. Internet), and efficient data retrieval algorithms (e.g. precision and recall) beg for an increased, collaborative research effort across disciplines.

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