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SUPPORT CONCEPT-BASED MULTIMEDIA INFORMATION RETRIEVAL: A KNOWLEDGE MANAGEMENT APPROACH

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Abstract

Identified as an important management concept five years ago (Garner 1999), knowledge management (KM) aims to enable organizations to capture, organize, and access their intellectual assets. This paper proposes a prototype system that applies a knowledge management approach to support concept-based multimedia information retrieval by integrating various information analysis and image processing techniques. The proposed system uses geographical information as its testbed and aims to provide flexibility to users in terms of specifying their information needs and to facilitate parallel extraction of information in different formats (i.e., text, image). Our testbed selection is based not only on the fact that geographical information has become an important resource supporting organization decision making, but also on the diversity of its information media and the fuzziness of geo-spatial queries. We hope that the proposed system will improve the accessibility of geographical information in different media and provide an example of integrating various information and multimedia techniques to support concept-based cross-media information retrieval.

1. INTRODUCTION

Identified as an important management concept five years ago (Garner 1999), knowledge management (KM) aims to enable organizations to capture, organize, and access their intellectual assets. Coates (1999) identifies several situations in which KM is a solution. One example is that the islands of knowledge and expertise within a large organization do not communicate with each other. Other examples include the failure of learning from past failures, difficulty in identifying the needs of market, and the inability to appreciate the expertise or knowledge of employees (Coates 1999). KM promises to be an effective tool to address these important issues.

One of an organization's most important knowledge resources is its information in various media types. According to the GartnerGroup Report (1998), knowledge retrieval is one of the important processes within the architecture of KM. The goal of knowledge retrieval is to extract helpful information and create a "concept yellow page" by using various information analysis techniques. The basic knowledge retrieval approach includes extracting data, understanding the semantics of information in different media types, creating a thesaurus or dictionary about information, and applying a clustering algorithm to categorize information and to generate the table of contents. The entire process aims to connect various information sources and accelerate the information or knowledge seeking process within an organization.

However, according to Larson (1996), information seeking is typically probabilistic and performs partial matches of relevant documents (text, images, maps, video, etc.) using fuzzy, natural language queries. The judgment of relevance is often subjective because it is based on a user's expectations, background, and needs. Networked information systems and multimedia technologies popularized by the Internet and the Web have opened a floodgate of user expectations for multimedia concept-based information access and analysis

This paper proposes a prototype system applying this knowledge retrieval approach to support concept-based and cross-media information retrieval. The system consists of several knowledge sources that interact with each other to support interoperability. Each knowledge source supports information retrieval in one media type by using various information analysis techniques including automatic indexing, co-occurrence analysis, associative retrieval (Chen et al. 1998), self-organizing map (SOM) (Kohonen 1995) and image processing techniques such as image representation and image compression. The prototype system utilizes geographical information as its testbed and aims to provide flexibility to users in terms of specifying their information needs and to facilitate parallel extraction of information in different formats (i.e., text, image). We have also conducted two experiments to evaluate the performance of the proposed system.

Geographic collections have almost as long a history as any subject collections. Our selection of testbed was based not only on the fact that geographical information has become an important resource for supporting organization decision making, but also on the diversity of geographical information media and the fuzziness of geo-spatial queries. For instance, house owners and developers can use digital elevation model, census data, aerial photos to evaluate construction projects and perform feasibility studies; airlines need weather information to arrange flight schedules; and oil and gas companies utilize geo-science documents to guide their future plans.

The two primary classes of geo-spatial queries are "What's there?" and "Where's that?" Both of these involve describing geographic location ("where"), using either precise (e.g., coordinates) or fuzzy place names such as place names or features (e.g., river, Santa Barbara County). In addition, the describing of geographic attributes such as temperature, vegetation, or land surface type and geographic phenomena such as rainfall, earthquakes, or wind ("what") becomes even more complicated. In terms of text-based geographical information retrieval (GIR), using subject terms for description represents a classical difficulty in information retrieval: it suffers from the vocabulary difference problem (Chen and Ng 1994; Lancaster 1979). The description of "what" becomes even more difficult for image-based GIR. To counteract the non-scalability of traditional algorithms that use textual annotation to represent images, most current image retrieval systems represent images by their low-level features such as texture, color, and shape (Flickner et al. 1995; Manjunath and Ma 1996; Pentland, Picard and Sclaroff 1994). This requires users to have knowledge about low-level image features in order to describe what, which usually is not the case.

In this regard, we hope that the proposed system could increase the accessibility of geographical information in different media and provide an example of integrating various information and multimedia techniques to support concept-based cross-media information retrieval. The paper is structured as follows. We will review the techniques of information analysis and image process used in our prototype system in the next section, followed by the description of our system architecture. We then present a prototype system that implements the proposed architecture in section 4 and describe two experiments evaluating the performance of the system in section 5. We discuss how to apply the proposed approach to other domains and provide a conclusion in section 6.

2. TECHNOLOGY OVERVIEW

2.1 Automatic Indexing, Co-occurrence Analysis, and Associative Retrieval

The application of automatic indexing, co-occurrence analysis, and associate retrieval aims to alleviate search uncertainty, which refers to generating the right terms to retrieve the information of interest. A detailed description of this technology can be found in Chen and Lynch (1992).

Indexing refers to representation of the content of textual documents with indexed key words. Evidence suggests that different indexers, well trained in an indexing scheme, might assign index terms for a given document differently. It has also been observed that an indexer might use different terms for the same document at different times (Jacoby and Slamecka 1962; Stevens 1965). The purpose of automatic indexing is to automatically identify the content of each textual document. Chen et al. (1998) applied a revised automatic indexing technique (Salton 1989) to a large-scale test collection of over 400,000 documents, which we have adopted to represent textual documents in our proposed system.

Co-occurrence analysis creates a concept space by identifying relationships among the terms. The created concept space can help a user to refine a query by providing a set of related terms to the keyword provided by the user. This technique has been applied in different domains, including Russian computing (Chen and Lynch 1992) and group support systems (Chen et al. 1993).

An associative retrieval technique, such as the Hopfield algorithm, has been shown to be ideal for concept-based information retrieval (Chen and Lynch 1992). Each term in a network-like thesaurus is treated as a neuron and the asymmetric weight between any two terms is taken as the unidirectional, weighted connection between neurons. Using user-supplied terms as input patterns, the Hopfield algorithm activates neighboring (i.e., strongly associated) terms, combines weights from all associated neighbors (by adding collective association strengths), and extracts the information that satisfies the user's information need.

2.2 Self-organizing Map (SOM)

After examining several neural network algorithms in previous research (Lippmann 1987), our research group concluded that a variant of the Kohonen self-organizing feature maps (SOM) appears to be the most promising algorithm for organizing large volumes of information. As an information categorization and visualization technique, SOM was first proposed by Kohonen (1995), who based his neural network on the associative neural properties of the brain. The network consists of an input layer and an output layer. The number of the input nodes equates to the number of attributes associated with the input. After all of the input is processed, the result is a spatial representation of the input data, organized into clusters of similar regions. SOM is defined as a mapping from a high-dimensional input space into a two-dimensional array of output nodes, and the output nodes that are topographically close are considered to be similar to each other. In addition, its two-dimensional output makes SOM an ideal candidate for information visualization. Several recent studies adopted the SOM approach to textual analysis. Examples are the DISCERN (Distributed Script processing and Episodic memory Network) developed by Mikkulainen (1993) as a natural language processing system, the WEBSOM system developed by Kohonen's group for newsgroup classification (Honkela et al. 1996), and the multilayered SOM system developed by the Arizona Artificial Intelligence Group for Internet home page categorization (Chen et al. 1996). Their work suggests a high applicability of the SOM approach to large-scale classification.

Table1 outlines how the Kohonen SOM algorithm was modified to create textual category maps and image-based visual thesaurus.

2.3 Image Representation

The traditional algorithm for representing an image is based on its author, date, and content. However, this approach is unable to capture the complete content of an image and requires manual effort to define and enter the necessary annotation. Therefore, another approach, searching images based on their low-level features, has been introduced and become a promising research alternative, evidenced by several recent prototypes such as the Photobook system at MIT (Pentland, Picard and Sclaroff 1994) and by commercial systems such as IBM's QBIC system (Flickner et al. 1995). A variety of algorithms can be employed to extract low-level features in image retrieval systems. For instance, QBIC calculates the texture features of an image according to the coarseness, contrast, and directionality. Photobook consists of three parts: the Appearance Photobook, the Shape Photobook, and Texture Photobook. In the Texture Photobook, Wold-based representations are used to extract the texture features of an image. In the prototype system for the Alexandra Digital Library Project, Manjunath and Ma (1996) used Gabor filters to extract texture features of an aerial photo. The selection of an algorithm for image representation varies with the image type. In our prototype system, since we used aerial photos as the input of the prototype system, we employed Gabor filters as our image representation algorithm. As indicated in Manjunath and Ma, Gabor filters perform better than the other image representation algorithms in representing an aerial photo.

Table 1. The SOM Algorithm Used in Textual Category Map and Visual Thesaurus Generation

- **Present each document or image in order**:
  Represent each document or image by a vector of N features and present to the system.

- **Compute distances to all nodes**:
  Compute distance d_j between the input and each output node j.

- **Select winning node j* and update weights to node j* and neighbors**:
  Select winning node j* as that output node with minimum d_j. Update weights for node j* and its neighbors to reduce their distances (between input nodes and output nodes).

- **Label regions in map**:
  After the network is trained through repeated presentation of all inputs, submit unit input vectors of single terms to the trained network and assign the winning node the name of in put feature. Neighboring nodes that contain the same features then perform a concept or topic region. The resulting map thus represents regions of important terms or image patterns (the more important a concept, the larger a region) and the assignment of similar documents or images to each region.

- **Apply the above steps recursively for large regions**:
  For each map region that contains more than *k* (e.g., 100) documents or images, conduct a recursive procedure of generating another self-organizing map until each region contains no more than *k* documents or images.

2.4 Image Compression

Users often expect an image retrieval system to return a set of images that match their queries. Maintaining a hierarchical resolution of images will enable the system to meet this user requirement without sacrificing performance, especially under the circumstance of web-based image retrieval. The system first returns a set of low-resolution images and then presents the high resolution version of the image according to a user choice. The image knowledge source of the prototype system applies the Joint Photographic Experts Group (JPEG) compression, a popular image compression algorithm, to compress an original image into a set of images of varied resolutions. A useful feature of JPEG is that it permits a trade-off of image size against image quality, allowing adjustment of image quality by changing the compression parameters.

3. A CONCEPT-BASED MULTIMEDIA SYSTEM DESIGN

Figure 1 shows a schematic diagram of the proposed architecture. The architecture includes a top-down ontological view of knowledge structure development and a bottom-up, inductive approach to extracting desired information from textual and image databases. In the diagram, knowledge sources or structures are depicted by ovals and processes and techniques are represented by rectangular boxes. The resulting body of integrated information (the dotted oval) is shown as loosely-coupled networks of knowledge sources. In the current prototype system, there are three types of knowledge sources; textual knowledge sources, image knowledge sources, and numerical knowledge sources.

- A *textual knowledge source* is a set of concept spaces derived from textual documents from different domains. A textual knowledge source uses automatic indexing to represent the content of a document with terms and applies co-occurrence analysis to identify relationships among the extracted terms. The concept space created thus has the capability of understanding the query terms given by a user and returns a list of related terms. The user then can refine the information request by selecting more precise terms. In addition, with the associative retrieval technique, the textual knowledge source may activate some other terms related to the query terms given by a user to retrieve more complete information.

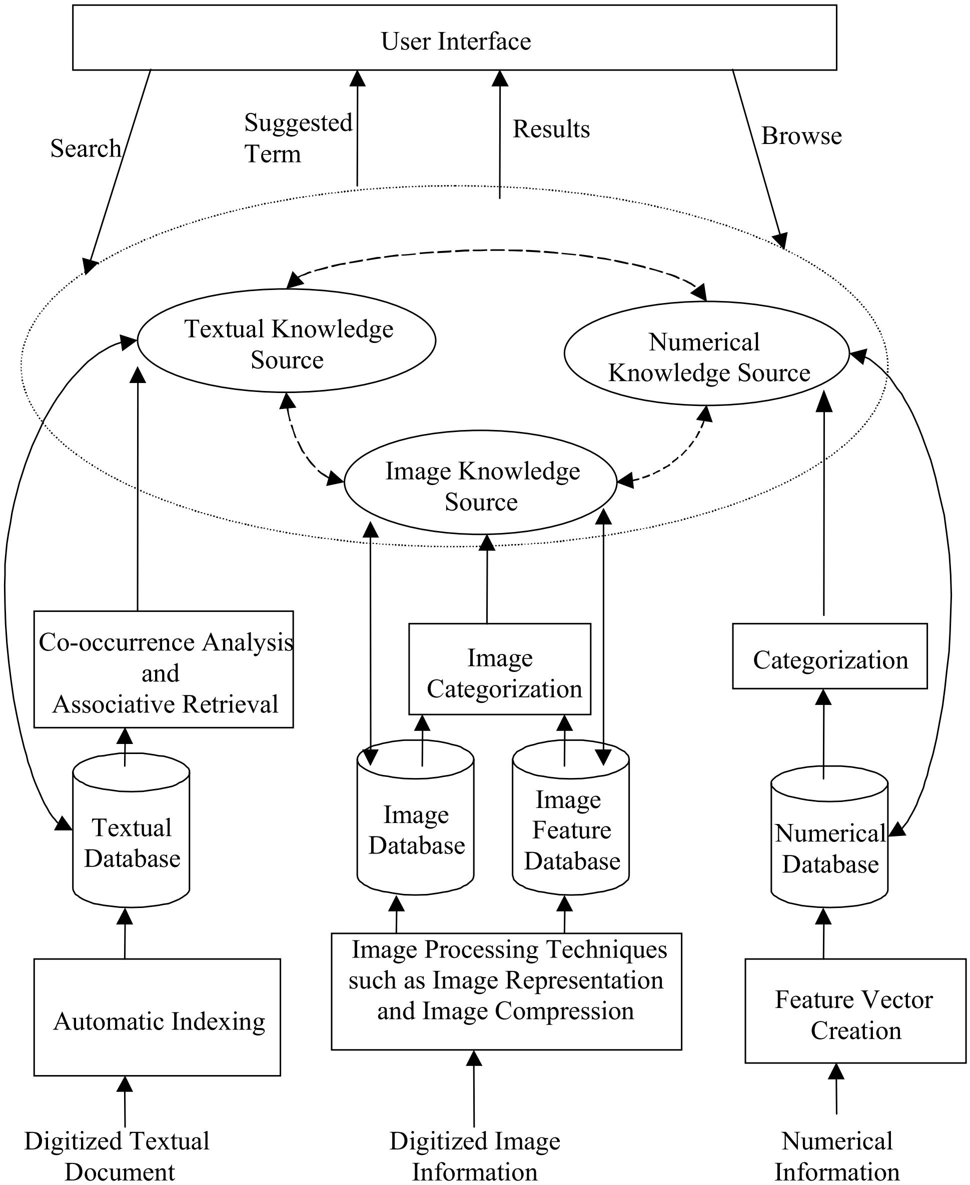

Figure 1. The Proposed Architecture

- Applying an image representation technique, the *image knowledge source* represents an image with its low-level features such as color, shape, and texture. SOM is then applied to the extracted features to categorize images. The image knowledge source uses an image as the label of each created category and employs the two-dimensional output of SOM as its interface. Thus the interface of an image knowledge source is a graphical representation of image categorization. A user can specify a query by selecting one of the label images and can browse images by choosing the category of interest.

- The *numerical knowledge source* creates feature vectors to represent the content of the numerical information and applies the SOM to categorize the created feature vectors. The numerical knowledge source supports numerical data information retrieval based on the categorized information.

4. THE IMPLEMENTATION OF PROTOTYPE SYSTEM

We applied different technologies to create the textual knowledge source, the image knowledge source, and the numerical knowledge source. Each knowledge source had its input information in one media type. The textual information used by the textual knowledge source included 50,000 geo-science-related abstracts from Compendex geographic category provided by Engineering Information Inc., 20,000 Georef records with abstracts from the American Geological Institute, and 800,000 petroleum abstracts from the University of Tulsa. The tested image input to the image knowledge collection was a collection of 800 aerial photos provided by the Map and Imagery Laboratory of Davidson Library at the University of California, Santa Barbara (UCSB). The coverage and location of each image had been checked and corrected against a digital coastline supplied by the CIA World Data Bank and the World Vector Shorelines via Generic Mapping Tools software. The numerical information input to the prototype system was the Advanced Very High Resolution Radiometer (AVHRR) data from the National Aeronautics and Space Administration (NASA), which provides the information about the vegetation density of land surfaces and surface air temperature.

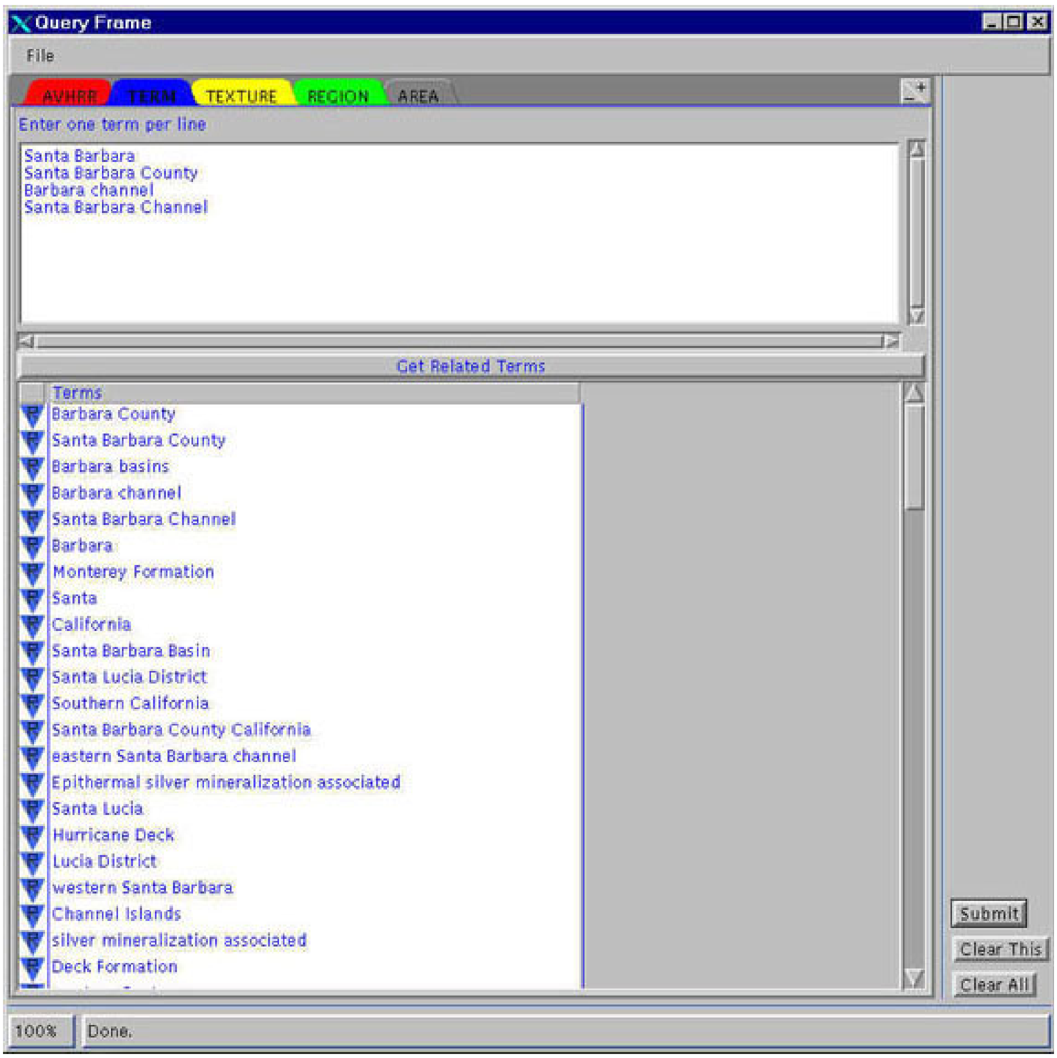

Figure 2. The Query Frame when the tab "TERM" is clicked. On this figure, the term "Santa Barbara" is entered and the system suggests 40 related terms in the panel named "Get Related Terms." A user could select more than one related term by clicking on it.

In our prototype, the textual knowledge source applies automatic indexing, co-occurrence analysis, and associative retrieval to its input textual information. The image knowledge source divides an image into small tiles and represents each tile by using the algorithm of Gabor filters. It then categorizes the created image features by utilizing the SOM method. Similarly, the numerical knowledge source also employs SOM to categorize its input numerical data. Moreover, the three created knowledge sources interact by using the Geographical Names Information System (GNIS) from the U.S. Geological Survey (USGS), a useful knowledge source for identifying relationships between precise coordinates and fuzzy place names.

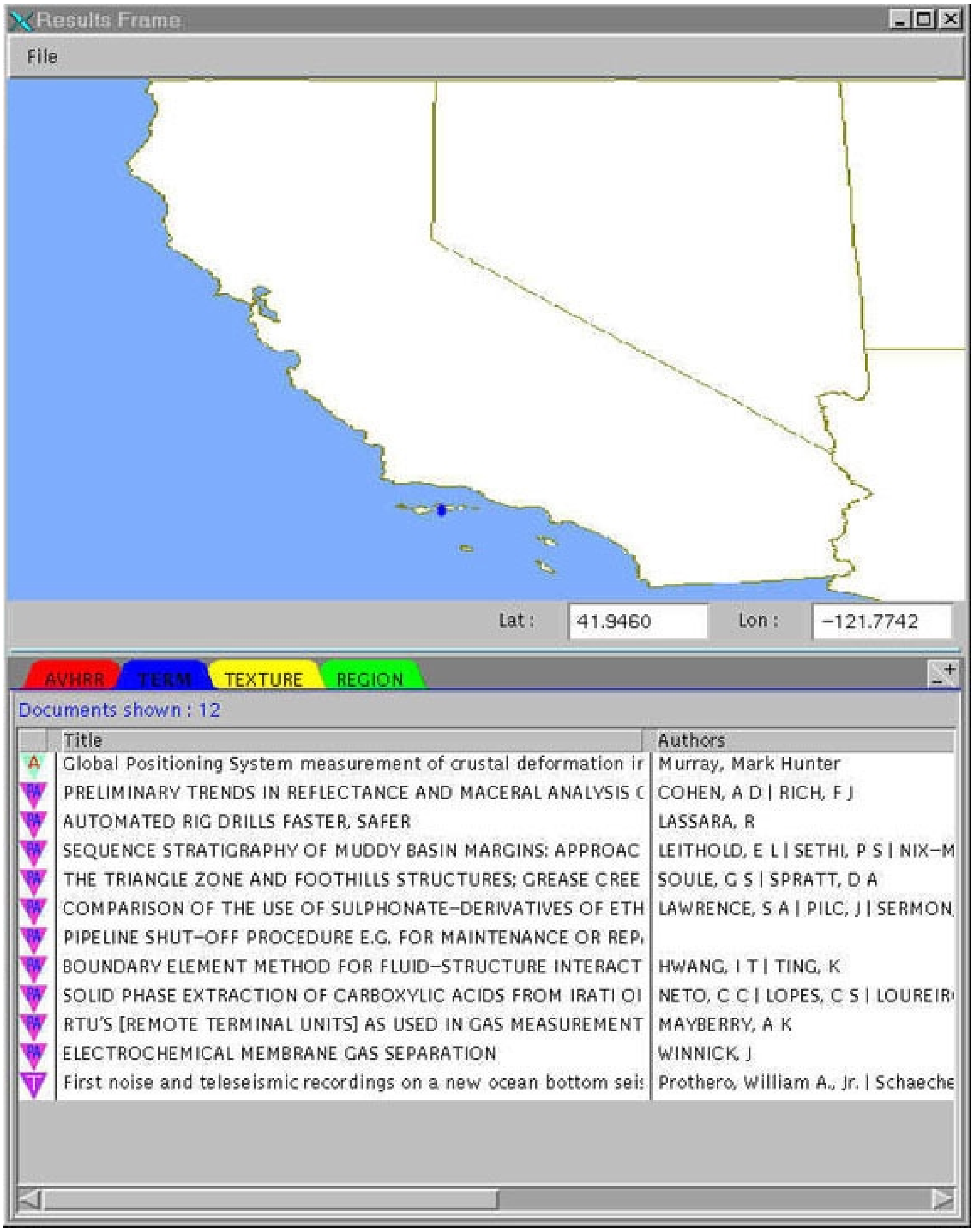

Figure 3. The Result Frame when the tab "TERM" is clicked. On this figure, 12 documents are retrieved from the textual knowledge source. Their locations are calculated and presented as blue dots on the map. In this case, only one location has been acquired. The numbers in the fields "Lat" and "Lon" indicate the latitude and the longitude of the point on the map pointed to by the mouse cursor (not shown on the figure).

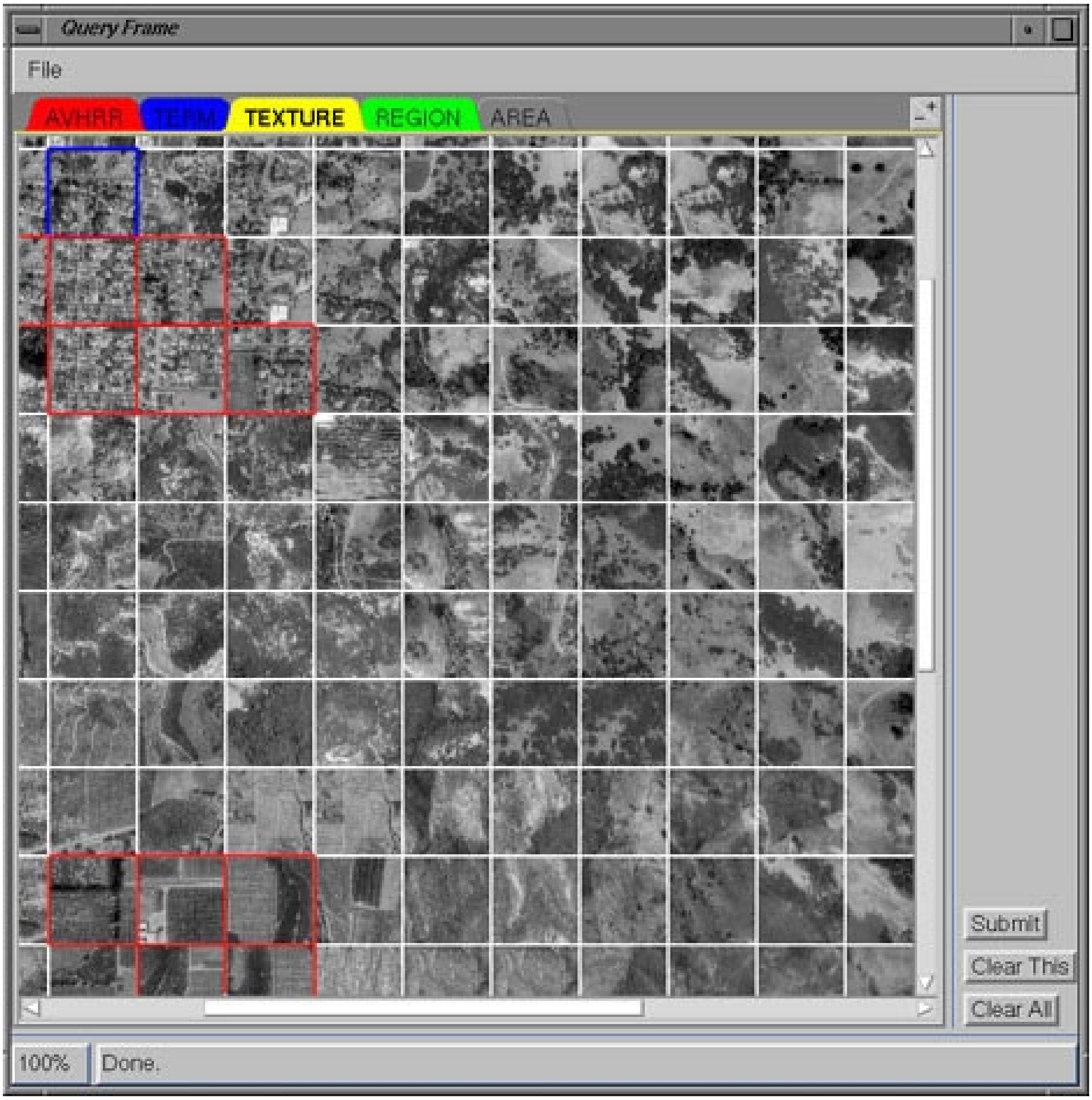

Figure 4. The Query Frame when the tab "TEXTURE" is clicked. User-selected tiles are highlighted in red. A blue tile is the one under inspection.

The interface of the prototype system contains query frame (Figures 2 and 4) and result frame (Figures 3 and 6). At the top-left corner on the query frame are five tabs named AVHRR, TERM, TEXTURE, REGION, and AREA. Tabs of TERM, TEXTURE, and AVHRR are associated with the textual knowledge source, the image knowledge source, and the numerical knowledge source, respectively. Such an interface structure enables users to retrieve information from all knowledge sources simultaneously. A user can click on more than one tab to specify a query in different formats. For instance, a user can click on the TERM tab to enter textual term query (Figure 2), click on the TEXTURE tab to query image texture (Figure 3), click on the AVHRR tab to query vegetation temperature type in numerical format, and click on the AREA tab to indicate the corner coordinates the area of interest. A "Submit" button on the query frame permits a user to submit a query. The information retrieved is displayed in the result frame (Figures 3 and 6), which is divided into two parts, with one being a California map and the other displaying the list of query results. Between these two parts are five tabs that have similar functionality to the tabs in the query frame. Places with the attributes specified by the user can be displayed on the map, while the user can browse the geographic features of the area of interest by clicking on the tabs in the result frame. The two frames allow a user not only to specify "where" in the query frame and have the associated "what" displayed in the result frame, but also to enter "what" in the query frame in more than one format (textual, image, or numerical) and have distribution of "what" on the map returned.

Figure 2 displays the query frame of the prototype when the tab TERM is clicked. As shown in Figure 2, after entering "Santa Barbara" as the initial search term, the system suggests "Santa Barbara County," "Santa Barbara Basin," "Santa Barbara Channel," etc., as relevant concepts. After deciding on appropriate search terms, a user can then submit a query and the results will be displayed on the result frame (Figure 3). The user can draw a square on the map to choose place of interest and then browse its geographic attribute by clicking on different tabs. In Figure 3, the TERM tab was clicked and the system returned a list of textual documents related to the place of interest.

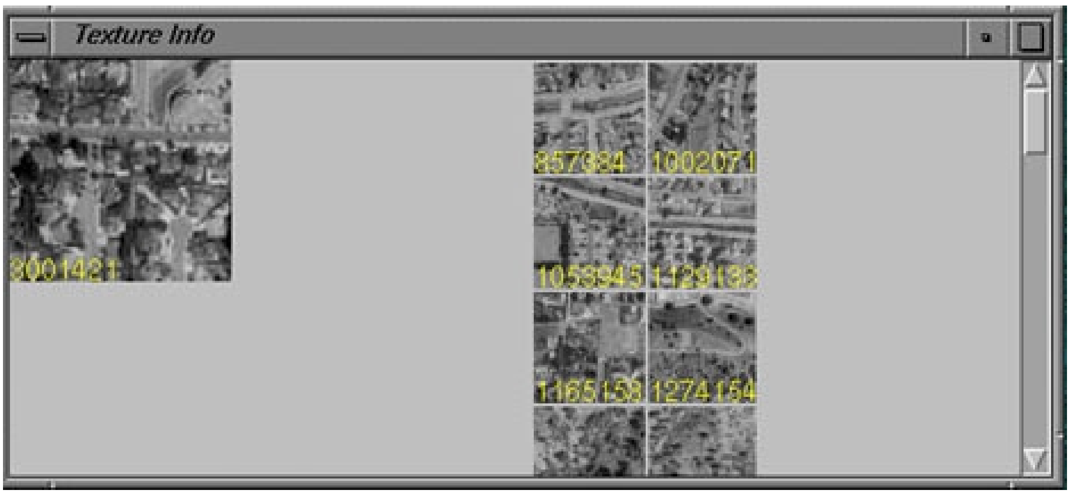

Figure 5. The interface that displays the full resolution (128 × 128) of the selected image tile and its similar tiles. The yellow number on each tile represents the tile number of that tile.

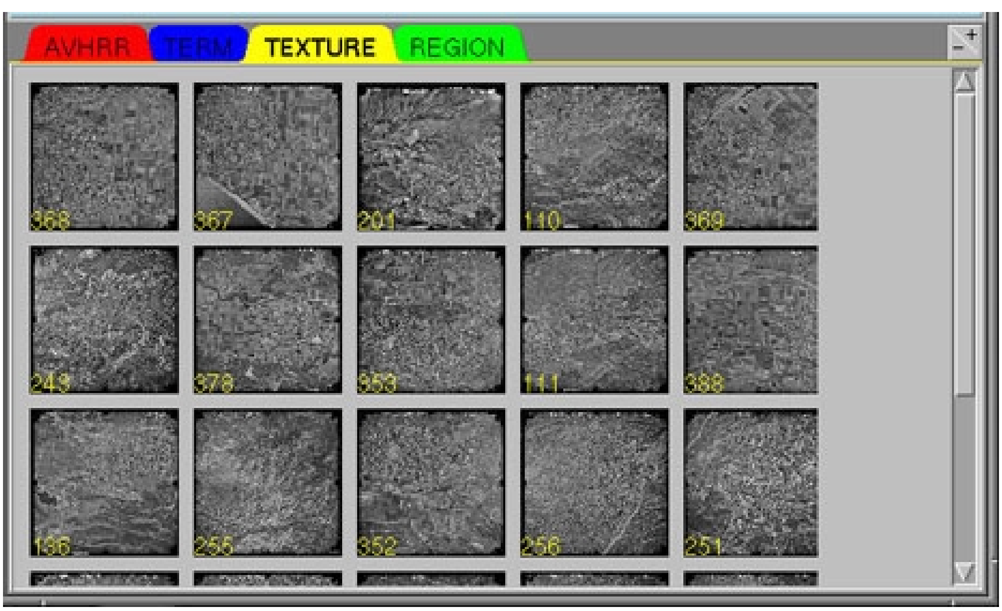

Figure 6. The Result Frame when the tab "TEXTURE" is clicked. The yellow number at the left bottom is the image number. A set of images with low resolution is displayed in this frame. The images are ranked according to the number of tiles that match user queries.

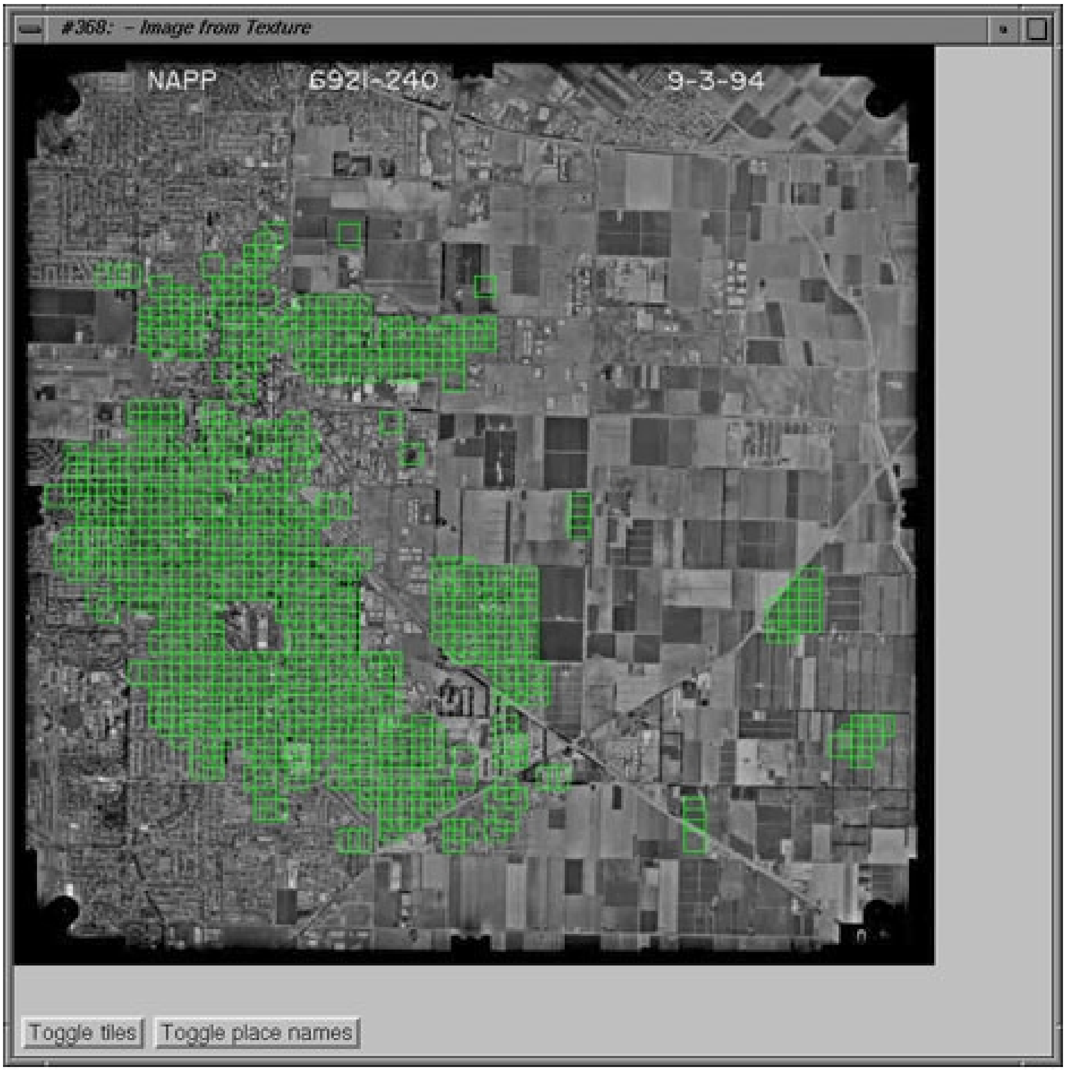

Figure 7. The Texture Frame of the image knowledge source. In this figure, high resolution version (700 × 700) of image 368 is displayed. The location of interested tiles are highlighted with green squares.

Figure 4 is an example of the query frame of the prototype system when the tab TEXTURE is clicked. The frame displays the representative tiles generated by SOM. Each tile is in low-resolution (64 × 64 pixels). A user can get a close look at a tile of interest by right clicking on it, upon which the system highlights the tile clicked in blue and brings up the "Texture Info" frame (Figure 5) to display the full resolution version of that tile and other tiles within the same group. The user can select more than one representative tile on the query frame as his or her query by left clicking on them. At the same time, all the selected tiles will be highlighted in red (Figure 4). For instance, in Figure 4, the user selected some tiles with an urban pattern and some tiles with a farm land pattern. After this user clicked on the submit button on the Query Frame, the system displayed a list of thumbnails of retrieved images in the results frame (Figure 6) where the tab TEXTURE had been clicked. The locations of the retrieved images are also displayed on the map, which has been truncated in figure 6 in order to improve the visual quality of the figure. The images in this list were sorted according to the numbers of related tiles they contained. The Results Frame displays a set of the retrieved images in low resolution, from which the user can select any image in the list to activate the system to present a high-resolution version (700 × 700) of that image in the Image Frame, along with the related tiles highlighted in green (Figure 7). In addition, the system can also display the place names associated with this image (Figure 8) by cross-referencing with the GNIS gazetteer. Place names provide rich and important contextual information for aerial photo browsing.

Due to the limitation of space, we do not present the query frame of the prototype system when the tab AVHRR is clicked, where a user can query vegetation-temperature. The results can be displayed in the result frame, where the places with the vegetation-temperature pattern that matched the user's query were displayed in the map. The user can draw a square on the map to indicate the place of interest and the system will bring up the seasonal changes of vegetation and temperature of the place selected.

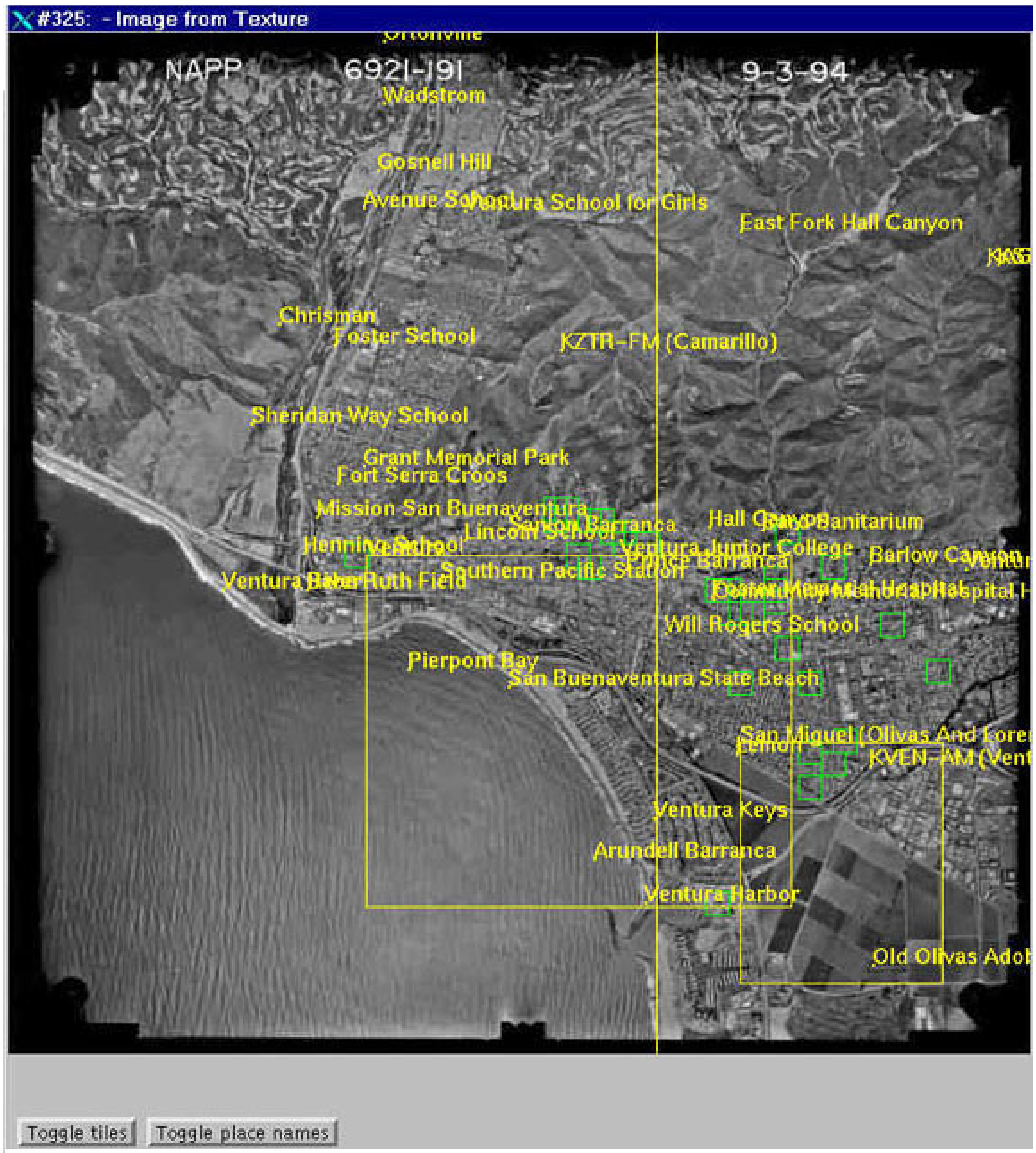

Figure 8. The Texture Frame of the image knowledge source. In this figure, place names associated with the presented image are extracted from GNIS and are displayed on the image according to the locations.

5. SYSTEM EVALUATION

In order to validate the performance of the prototype system, we conducted two experiments to determine how helpful our system could be in facilitating concept-based information retrieval. We evaluated the performances of the textual knowledge source and the image knowledge source separately. We did not conduct an evaluation of the numerical knowledge source because both the numerical and the image knowledge sources apply the same technique, SOM, to categorize their input data. In addition, after representing an image with its Gabor features, the image knowledge source actually uses a set of numbers to represent each image. Applying SOM to the extracted features is similar to applying SOM to other numerical data.

5.1 Evaluating the Textual Knowledge Source

The purpose of evaluating the textual knowledge source was to discover whether the use of automatic indexing, co-occurrence, and associative retrieval could improve the recall and precision of geo-science information over using only the searcher's keywords. Precision represented the relevance of the retrieved information, while recall indicated how much of the relevant information in the database was retrieved (Salton and McGill 1993). Although research indicates that the use of keyword searching alone leads to satisfactory results (Tillotson 1995), our goal was to improve upon keyword searching by complementing it with concept space searching. Twelve subjects with geo-science backgrounds participated in the study for a small monetary reward. Of the subjects, two were from the geo-science specialties of hydrology and environmental engineering, seven were geology students (master's and doctoral levels), and three were professionals with the United States Geological Survey. Each subject performed four searches on two different queries, so each query was used to perform a keyword *and* a concept space-based search. For example, if a search used the keywords "Clastic Sediments" and "fossils" to access the abstracts, the system returned abstracts that were related to the query. The query would be repeated using the same keywords to enter the concept space, the system returned a list of related terms, and the subject would be allowed to select terms to broaden or narrow the search. The order of searching method was alternated so that results were not confounded by method order; if the first search started with a keyword, the second search was begun with a concept space search and vice versa. In addition, the searching order was alternated between subjects; seven started the first search with a keyword search and five started with a concept space search. At the end of a concept space or keyword search, the abstracts were retrieved for examination. The subjects were asked to examine the abstracts, determine each document's relevance, and briefly comment on why the document was or was not considered relevant to the particular query.

The result analysis of this evaluation indicated that the concept space significantly improved identification of relevant textual documents from a pool of potentially relevant textual documents. A majority of the subjects reported liking the concept space search tool better than the keyword search tool, since they found the ability to narrow down searches by using concept space terms to be very helpful. Hauck et. al (1999) provide a detailed description of the evaluation process and results analysis.

5.2 Evaluating Image Knowledge Source

We designed an experiment to evaluate the performance of the image knowledge source. We used 10 images in the experiment and 10 subjects participated. Every human subject worked with one image that was categorized by using the SOM algorithm. We used the system-selected representative tiles as suggested categories. Human subjects categorized the image by selecting all of the tiles in the image into one of the suggested categories. An expert who had three years of experience in remote sensing image analysis also participated in this experiment, during which the system, the subjects, and the expert accomplished the same tasks. We used the expert's results as the benchmark against which to evaluate the performances of both the other human subjects and the system, hoping to determine how useful the image knowledge source would be in helping a non-expert user in image retrieval. The quality of the performances of subjects and the system was measured by the values of precision and recall.

The results of this of the experiment are listed below. A more detailed description of the experiment can be found in Zhu and Chen (1999).

- The system did at least as well as human subjects in image categorization. The precision and recall comparisons indicated that there were no statistically significant differences between performances of the human subjects and of the system (subject recall = 40.00%, system recall = 41.60%, subject precision = 35.08%, system precision = 33.88 %).
- Both human subjects and the system did well with tiles of distinguishable texture and had difficulty in dealing with tiles having no apparent texture pattern.
- Most of the subjects complained that there were too many suggested categories and that some of the representative tiles were similar to each other. This is probably due to the small size of the input data. A set of 192 tiles was too small for the adaptive SOM algorithm. However, the pilot studies indicated that 192 tiles were as many as human subjects could handle with the assistance of the interface.

6. CONCLUSION AND DISCUSSION

Developing scalable techniques to support fuzzy, concept-based, multimedia information retrieval has been considered one of the most pressing research questions for knowledge management. Our project aimed to investigate knowledge retrieval technical and research issues using an integrated and scalable artificial intelligence approach.

In this paper, we presented a prototype system that integrates multiple multimedia (textual and image) knowledge sources to support concept-based geographic queries and analysis. Based on semantic network and neural network representations, the proposed system loosely couples different knowledge sources and adopts spreading activation algorithms for concept-based knowledge reasoning. Since geographical information has become an important resource for organizations' decision-making processes, we used it as the testbed of our prototype system, hoping to increase the its accessibility in addition and provide an example of a concept-base multimedia information retrieval system.

The same concept-based cross-media approach can be applied to other domains where information is stored in various media types. Examples include medical information, where the records of patients may be texts, images, or numbers, and engineering information, where both design drawings and documents need to be accessed efficiently. In addition, the approach proposed can also support organizational memory, an important knowledge source of an organization. Confronted with down-sizing and intenationalization of personnel, organizations are searching for more efficient ways to access and to maintain their intellectual assets. According to Walsh and Ungson (1991), organizational memory is usually stored in six places: individuals, organizational culture, organizational transformations, organizational structures, organization ecology, and external archives. As indicated in Ackerman (1994), information technology can support organizational memory by enhancing the accessibility of recorded knowledge. Conventionally, such knowledge within an organization is stored in textual or numerical type. The occurrence of the Internet and video conferencing leads to information in image type. However, the prototype system proposed uses GNIS gazetteer to connect geographical data in different media types. Before applying the same approach to other domains, we need to create knowledge structure and meta data that allow us to map information in different media types.

Our future work will include validating the enhanced accessibility of geographical information by using the prototype system, evaluating the usability of the prototype system, and applying the same techniques to information in other domains.

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