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IMAGE DATABASES: PROBLEMS AND PERSPECTIVES

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ABSTRACT

With the increasing number of computer graphics, image processing, and pattern recognition applications, economical storage, efficient representation and manipulation, and powerful and flexible query languages for retrieval of image data are of paramount importance. This paper examines these and related issues pertinent to image databases.

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1. Introduction

With the rapid advances in the Image Processing/Pattern Recognition and Computer Graphics fields, Image Database (IDB) systems have recently attracted the attention of many researchers. The recent special issue of IEEE Transactions on Software Engineering (IEEE 88) attests to this fact. Even though there has been considerable research activity on issues such as image compression, hierarchical data structures for storing complex images, and various similarity measures for efficient retrieval of the images with partial specifications, but not until recently has serious thought been given to integrating these results and techniques into a unified framework for efficient storage, processing, and retrieval of complex images. Many of these techniques were used in several applications to varying degrees such as Desktop Publishing/Office Automation, Cartographic and Mapping Applications, Interactive Computer-aided Design (CAD), Geographic Information Systems (GIS), Spatial Database Management Systems (SDMS), Message Management Systems(MMS), and Remote Sensing (RS) of earth resources.

This paper examines some issues and techniques for designing image databases and provides a survey of some existing systems. The outline for the remainder of the paper is as follows. Section two provides a historical perspective and sets the terminology. Various existing design paradigms for image databases are examined in section three. Future outlook and conclusions are given in section four.

2. Historical Perspective and Terminology

The disadvantages of traditional file processing were recognized early in the seventies. Several database management systems (DBMS) were proposed and implemented in the later years for efficient storage, retrieval, and management of alphanumeric data. Enormous amounts of storage are required for storing images/pictures. A sharp decline in hardware prices coupled with advances in processor speeds and mass storage devices paved the way for integration of image data with alphanumeric data in several application areas. These systems capable of managing both alphanumeric and image data came to be known, depending on the application area and the extent to which facilities are provided by the system for managing image data, as Pictorial Database Systems (PDBS)(Chan 81) (Yang 87), Integrated Database Management Systems (IDMS)(Tang 81), Image Database (IDB) systems (Tamu 84), Geographic Data Processing (GDP) Systems (Nagy 79), and Geographic Information Systems (GIS)(Fran 88). Parker (Park 88) lists many other terms used synonymously with GIS. Some of these systems are not functionally distinct in the sense that some complement each other and some are supersets of others. This nomenclature problem is not uncommon for a broad and rapidly evolving discipline such as the one under discussion.

There are two basic approaches to the processing of pictorial data (Tamu 84). The first one is image processing/pattern recognition and emphasizes analysis, transformation, and recognition to yield other images or a symbolic description of the images. The second approach is computer graphics which synthesizes images from given descriptions. For computer graphics, data structures are of paramount consideration, whereas for image processing/pattern recognition, processing is of primary consideration. In other words, these two approaches vastly differ in the processing methods involved and data structures employed. Therefore, image database design concepts also differ. Graphic oriented pictorial databases are suitable for applications such as CAD/CAM which involve pictorial data of great complexity. Modeling, 3D object representations, and complex data structures/formats are of primary concern. Image processing oriented pictorial databases are suitable for applications based on LANDSAT imagery. The primary concern here is for efficient storage techniques and use of pattern recognition techniques for retrieval. Pictorial databases refer to both graphic oriented and image processing oriented databases. Tamura and Yokoya (Tamu 84) refer to these database systems as image databases and so does this author.

Tamura (Tamu 80) classifies image database systems into five types. Type one refers to a large collection of images systematically collected and made available to several users. Remote sensing data centers databases fall into this category and require no explicit image database management system. Type two refers to databases for retrieval of secondary information such as date of acquisition, quality, altitude, etc. A conventional DBMS can be used for this type for storage and retrieval of secondary information which is inherently alphanumeric. Type three systems are characterized by the existence of a management system for imagery and map data for spatially-oriented processing. Type four systems store structural information describing pictures or scenes. Type five systems constitute a set of library images which are intended to be used as benchmarks for evaluating and comparing new algorithms. This classification is mentioned for historical interest and has no relevance for classifying today's systems.

Vector format and raster format are the two principal formats used for storing images. Applications such as cartography, topography, and spatial analysis or GIS use vector format. Spatial data are represented by using point, line or segment, and polygon data types. Applications using LANDSAT imagery use only point data type. Also, the output produced by many modern image capturing devices is inherently in raster format. Since raster format stores images as a collection of points along with their attributes, this leads to enormous storage requirements. However, several image compression techniques for compressing raster image data are reported in the literature (Yang 87) (Barn 88). Of course, compression techniques consume computational time for encoding and decoding of images. In addition to the vector and raster formats, there are several other formats (Chan 81).

3. Design Paradigms

Image data models, image data types, image data structures, mechanisms for describing image features, storage/compression techniques, and a flexible query language are integral parts of an image database system. A system to integrate and coordinate the functionalities of these components is an image database management system. In the following sections, each of the component structures is examined in detail.

3.1 Image Data Models

A data model for image databases should provide a uniform framework for handling both alphanumeric and image data. The associated management system is expected to store, retrieve, and process a large number of pictures of great complexity. There exists three main data models for managing alphanumeric data, namely, hierarchical, network, and relational models. It may seem natural to extend the concepts and techniques of conventional DBMS to bear with image database systems. This approach has two main disadvantages (Econ 83). Since conventional DBMS are geared to handle structured alphanumeric data, the resulting image databases are inefficient and cumbersome with unnatural query languages. Secondly, these query languages are very complex because they emphasize low-level descriptions of images.

Design characteristics of an image database depend on the intended functionality, types of images, and the extent of data abstraction and image data structures. An archival system for LANDSAT imagery is more concerned about efficiency of storage and retrieval than the processing methods and data structures. On the other hand, a system for map database applications focuses on efficient data structure design, ease of update, coloring, and overlays rather than storage requirements. Some applications may impose significant data abstraction. For these applications, image features are completely symbolized and the symbolic information, not the original images, is stored and managed. On the other extreme, are the cases where the images are stored without compression and the management system simply maintains pointers to these locations. Between these two extremes are a number of other possibilities.

There are three basic approaches to image database design. The first approach is to simply extend the conventional database by adding images as a standard data type and extending the query language. ADM (Aggregate Data Manager) (Taka 80) is an example of this kind. Its architecture is based on a relational database management system, System-R. System-R's query language, SEQUEL is suitably modified to handle image data. A second approach is to add database capabilities to an existing image processing system. EIDES (ETL Image Database for Experimental Studies) (Tamu 80) and MIDAS (Multi-sensor Image Databases System) (McKe 77) are two examples of this approach. In addition to these two, there are several approaches from application fields such as geographic data processing, medical imaging, remote sensing, and fingerprint analysis (Tamu 84).

In general, a relational data model is widely used in experimental image database systems because of its mathematical simplicity. GRAIN(Graphics-oriented Relational Algebra Interpreter) and REDI(Relational Database System for Images) are two examples of early implementations (Tamu 84). Unfortunately, relational model has several shortcomings for modeling pictorial data (Moha 88). A relational model is inherently suitable for representing one-dimensional data in the tabular form but pictorial data is two-dimensional. Hierarchical structured data cannot be easily represented using a relational model. Many tables are required for representing hierarchy links. It is not possible to explicitly specify semantic information about relationships. Since most of the semantic information is distributed over several hierarchy link relations, meaning has to be guessed by the user before performing any operation.

3.2 Data Types, Data Structures, and Storage Techniques

Spatial data are inherently multi-dimensional (Oren 88). Also, notions of spatial data tend to vary from one application to another.

Geographic applications require two-dimensional data, geological applications require three-dimensional data, and some solid modeling applications require four-dimensional data. Spatial operations and representations are highly application dependent. And for this reason, many models that are implemented are application specific including query languages (Jose 88).

Image data can be viewed as a matrix of gray levels or two dimensional signals in raster format. In vector format, image data is encoded by simple data structures such as points, line segments, and polygons or regions. Quadtrees, Octtrees, and Pyramid representations are some data structures proposed for storage efficiency (Tamu 84). Cheng and others (Chen 88) recently proposed a method for compressing binary digital images using irreducible covers of maximal rectangles. Barnesley and Sloan (Barn 88) describe a method for compressing images based on fractal encoding. Only iterated function system (IFS) codes are stored rather than the original images. This approach seems promising for automatic image analysis because the combinatorial search space for feature extraction is dramatically reduced.

Orenstein and Manola (Oren 88) proposed a new approach to extend the database system functionality for spatial data modeling and query processing. Extensibility is built into their object-oriented data model, PROBE, thereby making the model flexible enough to be adapted to a different number of applications. They also show how their system can be used for spatial data modeling and querying for image database applications. Economopoulos and Lochovsky (Econ 83) have designed and implemented an image data model which represents images in terms of high-level semantic descriptions rather than a pixel-oriented description. This system is a component of a larger prototype system, Message Management System (MMS), intended for intelligent communication and processing of messages.

Joseph and Cardenas (Jose 88) describe the requirements for a generalized pictorial database management system (PDBMS) to provide data heterogeneity transparency over pictorial and non-pictorial data. The data manipulation capabilities that are expected of a generalized PDBMS are classified into six categories such as image manipulation operations, pattern recognition operations, spatial or geometric operations, function operations, user defined functions and programming language interface, and input/output operations. The proposed architecture has two database management system components, one to manage the pictorial data, called PICDMS, and the other to manage conventional data, referred to as non-pictorial database management system. Similarly, the query language has two components to manipulate and access pictorial and non-pictorial data. A notable thing about this system is that it allows a user to define his own pictorial data types in addition to the point, line, and region data types provided as standard pictorial data types.

3.3 Image Retrieval and Query Languages

There are three levels of retrieval: retrieval by an identifier, retrieval by conditional statements, and similarity retrieval by a given sample. Retrieval by an identifier corresponds to physical retrieval of an image corresponding to the given identifier. Retrieval by conditional statement is based on the image features. Image features can be precomputed or computed dynamically.

Many query languages implemented up to 1980 have been summarized (Chan 81). The majority of the query languages developed till today are command-oriented languages. Some query languages are newly designed with emphasis on registration, editing, and display of images. Other query languages are simple extensions of data manipulation languages for image file management.

Chang and Fu[Chan80] developed Query-by-Pictorial-Example (QPE), a query language for a relational database system for images (REDI). Image processing and pattern recognition techniques are used to extract structures and features from images. These extracted features are integrated and used in query processing. Original image data is retrieved and processed only when the feature data are insufficient and/or imprecise to process a query. The graphical interface for querying is similar to the well known relational query language, Query-By-Example (QBE).

PICQUERY (Jose 88) is a pictorial query processing language for PICDMS (mentioned above). PICQUERY has an open-ended design to interface with other robust PICDMS also. PICQUERY provides a fundamental shell on which user defined operations for pictorial data may be built. PSQL, a query language for the manipulation of pictorial databases, allows pictorial domains to be represented in their analog form (Rous 88). The associated database can perform direct spatial search and computation by using efficient data structures, R- and R+ trees.

The most desirable feature of a query language for image database applications is the ability to retrieve images from a large image database based on a partial description of the image content. Rabitti and Stanchev proposed a formalism based on fuzzy set theory for this task. There are four stages involved: element recognition, segmentation object recognition, added information definition, and image clustering. During the element recognition stage, the system tries to match the image elements with the terminal symbols of an adapted grammar. Fuzzy formalism helps when the system is unable to find an exact match with the stored representations (all possible elements the system is likely to encounter are stored to start with). More than one match is assigned with different certainty factors.

Objects correspond to nonterminal symbols of the adopted grammar, and applying the production rules of the grammar recursively, objects are identified starting with the image elements. During the added information definition stage, a user can add more information to the object description. The image interpretation obtained is compared with all the given class descriptions during the last stage. The class assignment is made on the basis of distance measures.

A model based on object-oriented knowledge representation for spatial information has been reported as flexible enough to capture any type of information one wishes to represent about a given pictorial world (Moha 88). The visual user interface for map information retrieval has been reported in (Tana 88). The system is designed to reduce the semantic gap between the user's view and the system function.

4. Future Outlook and Conclusions

Image database systems started as application specific systems and are gradually evolving toward more general-purpose systems. The advances are in two specific directions based on the two basic approaches for processing of pictorial data. For the approach based on computer graphics, commercial systems such as ARC/INFO are already available and provide a uniform framework for GIS applications. Even though ERDAS is a general-purpose commercial image processing system, it is far from ideal.

Substantial research into proposing and demonstrating a unified framework for image database management systems is required. This framework is expected to provide a pictorial data model that truly provides data independence and captures all the implicit semantic information in the pictorial data. This framework is also expected to provide flexible query languages for the partial specification of queries based either on precise or imprecise image description or the image itself (specified in the format). Advances in this area will have a profound impact on providing intelligent graphical user interfaces for applications.

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References

(Barn 88) Barnsley, M.F.; Sloan, A.D., A Better Way to Compress Images, BYTE, 1988, January, 215-223.

(Chan 80) Chang, N,; Fu, K.S., Query-by-Pictorial Example, IEEE Transactions on Software Engineering, 1980, November, 519-524.

(Chan 81) Chang, S., Pictorial Information Systems: Guest Editor's Introduction, Computer, 1981, November, 10-11.

(Chan 81a) Chang, N.S.; Fu, K.S., Picture Query Languages for Pictorial Data-Base Systems, Computer, 1981, November, 23-33.

(Chen 88) Cheng, Y.; Iyengar, S.S.; Kashyap, R.L., A New Method of Image Compression Using Irreducible Covers of Maximal Rectangles in [IEEE88].

(Econ 83) Economopoules, P.; Lochovsky, F.H., A System for Managing Image Data, Proceedings of IFIP Congress, 1983.

(Fran 88) Frank, A., Requirements for a Database Management System for a GIS, Photogrammetric Engineering and Remote Sensing, 1988, November, 1557-1564.

(IEEE 88) IEEE Transactions on Software Engineering Special Issue on Image Databases, 1988, May.

(Jose 88) Joseph, T.; Cardenas, A.F., PICQUERY: A High Level Query Language for Pictorial Database Management in [IEEE88].

(McKe 77) McKeown Jr., D.M.; Reddy, D.R., A Hierarchical Symbolic Representation for an Image Database, Proceedings of 1977 IEEE Workshop on Picture Data Description and Management, 1977, 40-44.

(Nagy 79) Nagy, G.; Wagle, S., Geographic Data Processing, Computing Surveys, 1979, June, 139-181.

(Oren 88) Orenstein, J.A.; Manola, F., PROBE Spatial Data Modeling and Query Processing in an Image Database Application, IEEE Transactions on Software Engineering, 1988, May, 611-629.

(Park 88) Parker, D.H. The Unique Qualities of a Geographic Information System: A Commentary, Photogrammetric Engineering and Remote Sensing Special GIS Issue, 1988, November, 1547-1549.

(Rous 88) Roussopoulos, N.; Faloutsos, C.; Sellis, T., An Efficient Pictorial Database System for PSQL in [IEEE88]

(Taka 80) Takao, S.; Itoh, S.; Iisaka, J., An Image-oriented Database System, Database Technique for Pictorial Applications, A. Blaser, Ed., Springer-verlag, 1980, 527-538.

(Tamu 80) Tamura, H., Image Database Management for Pattern Information Processing Studies, Pictorial Information Systems, S.K. Chang and K.S. Fu, Eds., Springer-Verlag 1980, 198-227.

(Tamu 84) Tamura, H.; Yokoya, N., Image Database Systems: A Survey, Pattern Recognition, 1984, 17, 29-43.

(Tana 88) Tanaka, M.; Ichikawa, T., A Visual User Interface for Map Information Retrieval Based on Semantic Significance in [IEEE88].

(Moha 88) Mohan, L.; Kashyap, R.L., An Object-oriented Knowledge Representation for Spatial Information in [IEEE88].

(Tang 81) Tang, G., A Management System for an Integrated Database of Pictures and Alphanumeric Data, Computer Graphics and Image Processing, 1981, 16, 270-286.

(Yang 87) Yanguang, W., The Research of Digital Picture Storage Methods for Picture Database, 38th Congress of the International Astronautical Federation, Brighton, UK, 1987, October, 1-23.