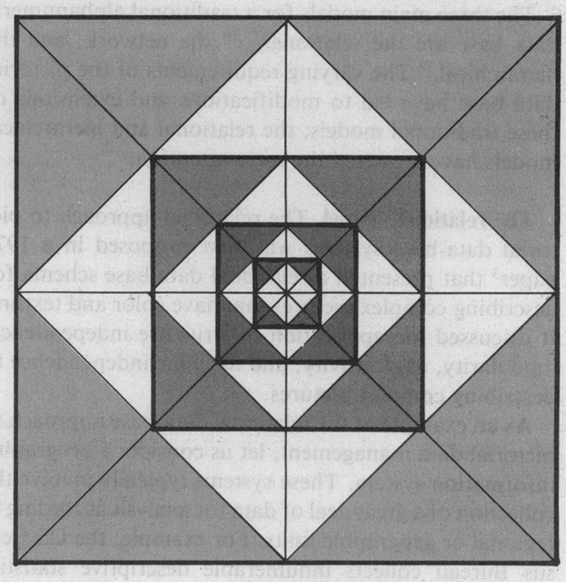
New applications in digital picture processing—notably in handling geographic data and in computer-aided design—have prompted development of a variety of pictorial data-base systems.

Pictorial Data-Base Systems



Shi-Kuo Chang
University of Illinois at Chicago Circle

Tosiyasu L. Kunii
University of Tokyo

A pictorial data base is a collection of sharable pictorial data encoded in various formats. A pictorial database system, or PDBS, provides an integrated collection of pictorial data for easy access by a large of number of users. The PDBS is the core of a pictorial information system.

Until recently, little attention has been paid to the management of nonalphanumeric information such a digitized images,[1] which require large amounts of storage—even for pictures of average complexity.[2-6] The list of new applications in digital picture processing has grown to include interactive computer-aided design,[4,7] geographic data processing,[8] remote sensing of earth resources,[9,10] regional economic and health data processing, and cartographic and mapping applications. Efficient and economical storage, flexible retrieval, and the manipulation of a vast amount of pictorial information have become problems that require careful consideration.

Formats

Two common formats are used in representing pictorial information. Computer cartography, topography, and spatial analysis in geographic information systems have traditionally used a *vector format*.[11,12]

More and more data, however, are becoming available via new image capture devices that generate data in *raster format*. Examples are Landsat imagery and drum scanner output. Advanced technologies in computer graphics, such as video frame-buffer memories and improved CRT resolution, have made feasible the increasing use of raster-scan displays as interactive graphics terminals.[13-15]

Algorithms and data structures for manipulating raster-formatted spatial data have also been explored. Recursive description and processing hierarchically structured pictorial data in a raster format has been proposed, and its implementation reported.[4] The logical basis of raster-format processing has also been established.[16] These recent advances have led to the development of pictorial data-base systems capable of managing pictorial data encoded in various formats.

Design challenges

Chang, Reuss, and McCormick[2] have defined two basic tasks that face designers of pictorial information systems. The first is the storage, retrieval, and processing of a large number of pictures; the second is the storage, retrieval, and processing of a very large picture or pictures of great complexity. Another consideration is the intended use of the system. Is it mainly for retrieval of pictures, or mainly for processing and manipulation of pictures? These considerations can have a profound effect on the design of a system.

Two central issues are common to all these design problems: (1) How does one provide a unified approach to retrieve and manipulate pictorial information? and (2) How does one utilize data structures to improve and develop algorithms for pictorial information retrieval and manipulation?

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In the following sections, we will survey a variety of responses to these problems and issues.

Relational and hierarchical pictorial data bases

The three main models for a traditional alphanumeric data base are the relational,[17,18] the network, and the hierarchical.[19] The varying requirements of the pictorial data base have led to modifications and extensions of these traditional models; the relational and hierarchical models have attracted the most attention.

The relational model. The relational approach to pictorial data-base systems was first proposed in a 1974 paper[3] that presented a relational data-base schema for describing complex pictures that have color and texture. It discussed the application of structure independence, modularity, associativity, and machine independence to describing complex pictures.

As an example of the relational data-base approach to pictorial data management, let us consider a geographic information system. These systems typically involve the collection of a great deal of data for analysis according to regional or geographic units. For example: the US Census Bureau collects innumerable descriptive statistics about population and housing by various political units; marketing companies collect data by zip codes, to determine target areas for advertising campaigns; land-use planners require information on soil type for each parcel of land.

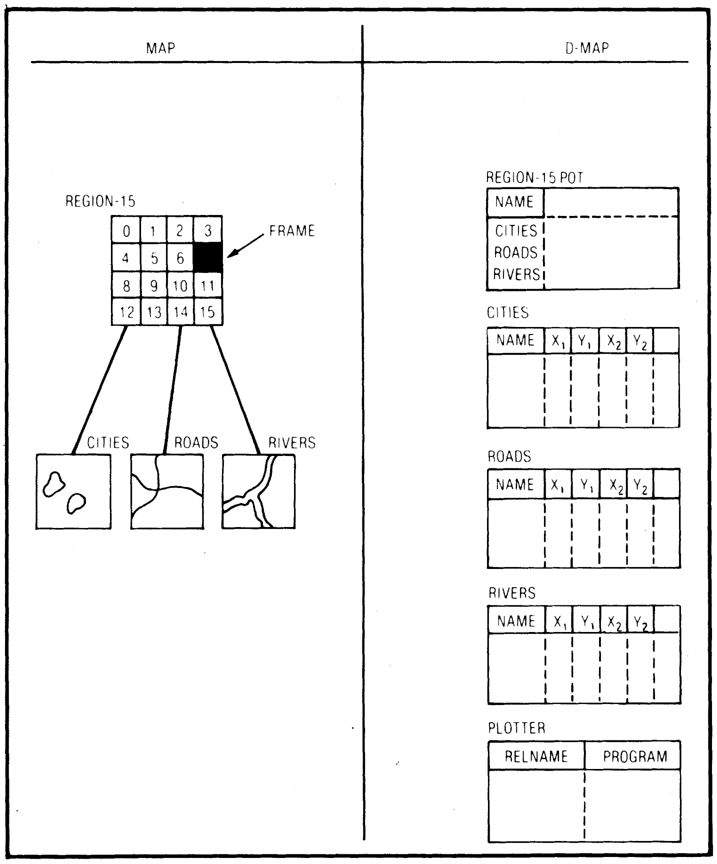

Figure 1. A pictorial relational data base and its materialization.

Storage of this type of data—attributes for each geographic unit—lends itself to the development of a relational data base. It allows the user to algebraically manipulate the data to answer complex questions and generate new information, which can be converted to pictures. Several papers[20,21] have suggested using the relational data base as the underlying structure for a geographic information system with cartographic output. The structural power of a relational data base requires data aggregated by and associated with geographic units. An image divided into frames is shown at the left of Figure 1; the corresponding pictorial relations are shown on the right. In Chang, Lin, and Walser,[22] the image is called a *map;* the pictorial relational data base is called the *d-map.* The process of converting a map into a d-map is called *abstraction.* The inverse, converting a d-map into a map, is called *materialization.*

Extensive results for integrated relational data-base design led to the conclusion that the traditional relational algebra is insufficient to manipulate tabular, graphical, and image data.[22,23] The traditional algebra could not, for example, analyze spatial relationships among various picture objects. A set of picture operations, called *picture algebra,* was designed for storage, retrieval, manipulation, and transformation of spatial data.[24]

An integrated pictorial data-base management system was developed in the late 1970's.[22,23] It combines a relational data-base management system, Rain, with an image manipulation system. This enables the user to perform various pictorial information retrieval functions by zooming, panning, and using spatial relation analysis operations to manipulate the pictorial data base. This data base contains pictorial data in two forms, relational table and raster image. The user can specify his picture query in Grain language, which is imbedded in the Dimap—distributed image management and projection—system. A hierarchical collection of picture objects is organized so as to allow logical zooming, which is used to navigate into the detailed description or to browse through picture objects that are similar to the picture of interest. This concept can be applied to the storage and manipulation of a large number of pictures, some of which can be very complex. A query language was developed for pictorial information retrieval. It uses a pictorial data-base skeleton as its knowledge model.

In another approach to pictorial query translation, Chang and Fu[25,26] describe a relational data-base system that is interfaced with an image understanding system. They also describe an algorithm to convert a relational graph into a relational data base and the design of a flexible query language for pictorial information retrieval based upon Zloof's query-by-example approach.[27] They emphasize the importance of spatial operations as the clue to retrieving images from a pictorial data base.

Pictorial data includes a typical case in which the number of different relations is almost equal to the number of data instances.[2] Here the relational model originally proposed by Codd[17,18] is not convenient, because it assumes that each relation has a reasonably large number of instances. Codd[28] subsequently proposed extended relational schemas to handle this case, but it would be better to generalize the relational model. This would allow the relations themselves to be accommodated in a data base as data-base instances. The designers of the Elf system at the University of Tokyo seek to accomplish this by allowing certain attributes to be names of other relations.[29]

Hierarchical systems. Sties, Sanyal, and Leist[30] describe an image information system in which an object is described in terms of shape, symbolic description, and relations with other objects. Objects in a picture can be retrieved in terms of symbolic description and/or object relationships.

Early in 1977, McKeown and Reddy[31] presented Midas, a multisensor image data-base system capable of image understanding and knowledge acquisition. They chose a hierarchical data structure, primarily in order to store symbolic representation in the pictorial data-base system. Images are stored hierarchically with different resolutions, in what is called an *iconic* data structure.[32] Partial image description is stored in a relational data base, which is used for performance evaluation.

Klinger et al.[33-35] have proposed a hierarchical data structure scheme for storing images by regular decomposition of pictures into adjacent quadrants with differing resolutions. Each quandrant corresponds to a node in a tree, called the Quad-tree. This structure is in keeping with the theories on data-base design.[19,36] It facilitates accessibility to pictorial data in storage, flexibility in pictorial data storage, pictorial data independence, redundancy reduction in multilevel structured data, and efficient analysis of small portions of a picture. A further generalization of Quad-tree structure to iconic/symbolic tree structure has been proposed.[32]

The relational approach can be combined with the hierarchical approach.[22] Figure 2 illustrates such a combination. Each node in the hierarchical structure on the left corresponds to an image that can be materialized from a collection of pictorial relations of a corresponding node on the right. Logical zooming can be used to retrieve information from this hierarchical structure.

Data base supported computer graphics and image processing

There are differences and similarities between computer graphics and image processing.[37] While computer graphics generally involves synthesis techniques, image processing is mostly analysis. Still, the hardware for computer graphics, and even for alphanumeric displays, more and more frequently employs raster-scan techniques; such displays are suitable for image processing. Likewise, image processing equipment can be used to draw vectors and write texts, as well as output images. This has spurred considerable interest in combining interactive graphics and image processing techniques on the same display screen. This, in turn, has prompted an examination of their software and data structures.[38] The concept of data-base systems is applicable to the design of graphics and image-processing software and data structures.

Computer graphics and spatial data structures. Graphics technology is obviously concerned with spatial data structures.[3,13,39,40] A general spatial data structure that can be used to represent spatial objects has been proposed by several authors.[4,16,41]

Shapiro and Haralick[41] offer a structure consisting of a set of N-ary relations, often including an attribute-value table. The entries in the table and the objects on which the relations are defined can also be spatial data structures. This approach emphasizes the description of spatial structure. Retrieval processing is through the attributes of spatial data. A semantic table set up for spatial relation analysis speeds the retrieval process. Data-base updating is somewhat complicated.

Infads. Graphics software packages often pay little or no attention to data-base management facilities.[42-46] Recently, the rapid development in data-base technology has been a major factor in the development of graphic systems.[7] Most papers in this area describe the techniques used to build pictures.[4,42,47-49]

Kunii and his group,[4] working at the University of Tokyo and at the Fujitsu Corporation, designed Infads, an interactive design system with hierarchical picture-building tools and a relational data base as integral parts. It can handle both lines (including vectors and free curves) and areas with color and texture; texture can be nested. In Infads, an attribute of a relation can have a graphical interpretation. Thus, an attribute can contain a

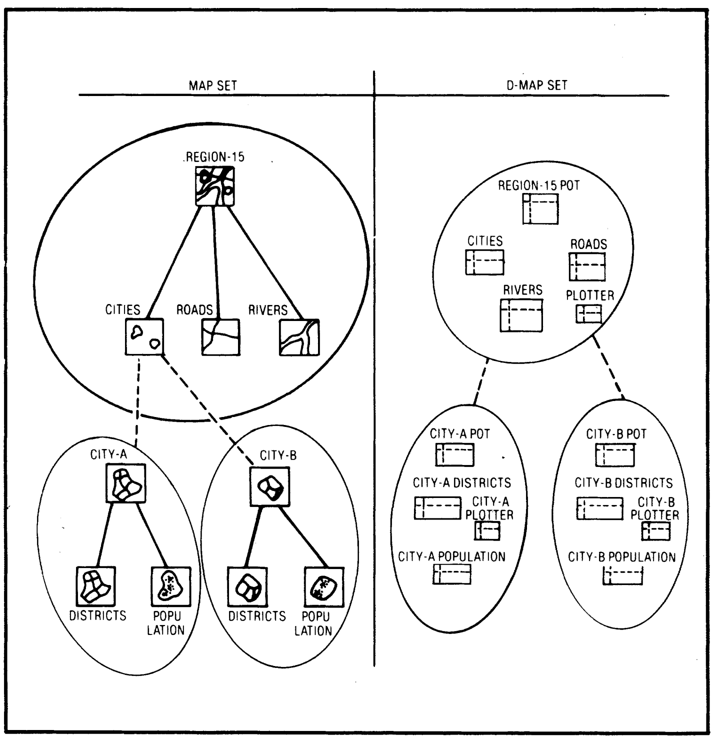

Figure 2. A hierarchical structure of pictorial relational data bases.

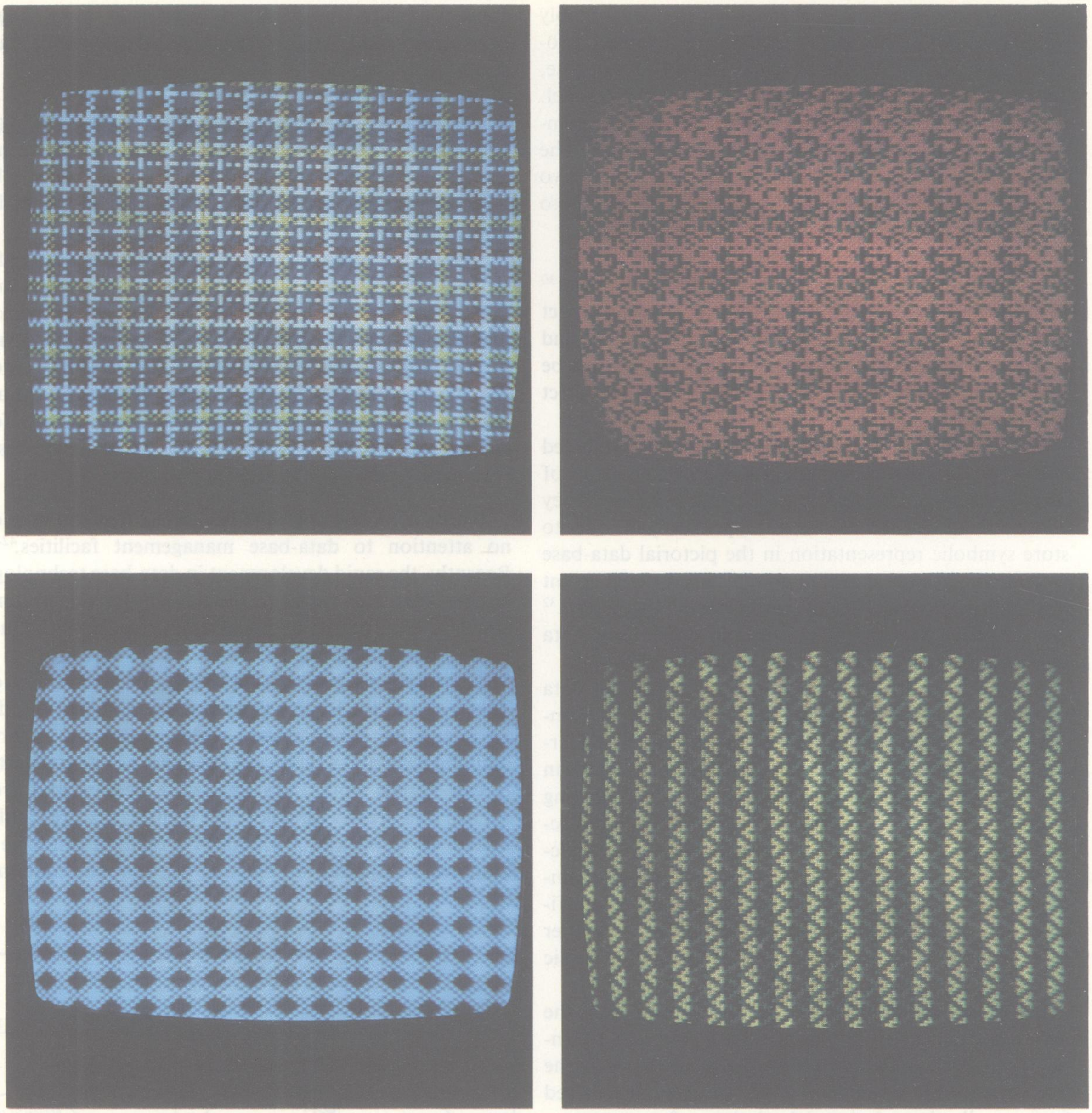

Figure 3. Examples of weaving textures created by Infads.

call to another relation. The called relation can be another standard tabulation relation in the data base or a procedural relation (i.e., a normal program).[3]

This abstracting of pictorial data is very convenient in implementing the pictorial data base. For example, it makes storage and update of the free curves and textures much simpler than directly storing the values of all the picture points in terms of all their coordinates and colors. Each free curve C is implemented as a pair of points P that characterizes the curve and a call to an interpolation procedure I. Thus, $C = (P,I)$. Likewise, each texture T is implemented as a pair of texture elements E and a set of calls to their distribution procedures D. Thus, $T = (E,D)$. Updating the representation of the free curve from polygon approximation to B-spline is just a matter of replacing the call to an interpolation procedure. Direct storage of the data values without the data abstraction level obviously causes a major data-base update of all data values of the curve. The same benefit is gained from texture storage at the abstract level. When changing the weaving texture of cloth, for example, from satin to twill, the abstraction can save the spatial value update, requiring only the switch of the procedure call from the satin distribution procedure to the twill distribution procedure. Computer graphics-displayed weaving textures created and abstractly stored in the pictorial data base by Infads are shown in Figure 3.

Relational data base interface to graphics has also been considered by Joyce and Oliver[50] and by Lorie, Casajuana, and Becerril.[51]

PBS. William and Gridding[49] at IBM designed a picture-building system, or PBS, based on ideas similar to those of Kunii et al.[3,4] They found that tuples in a relation must sometimes be ordered if pictorial data is to be stored in relations or tables. They suggest that duplicate tuples be allowed. Such features are in violation of the classical relational data-base concept, but are needed for PBS.

Ocean data base and Divisrs. McCleary[14] of the US Naval Ocean System Center has described an interactive computer program developed to display data for large ocean areas in color on a raster-driven CRT. Typical user commands allow the user to select geographic areas and types of annotation.

Myers[52] has described a general-purpose system that generates, stores, retrieves, processes, and displays raster-formatted images. It is called the digital video information storage and retrieval system, or Divisrs. Developed by the Computer Graphics Research Group of Ohio State University, this system is designed to handle static and dynamic images from multiple sources, as well as system-synthesized images. Run-length encoding is used to improve storage efficiency. The emphasis of this design is on hardware capability; no data-base concept is built in.

Dids. The domestic information display system, or Dids,[53] is an interactive, menu-driven software system. It produces single and bivariate chloropeth maps of socioeconomic data by county at the national and state level and by census tract for standard metropolitan statistical areas. Selected subareas of national and metropolitan maps can be dynamically enlarged to show greater detail. Histogram displays are available to show statistical as well as geographic structures. This minicomputer-based system utilizes the image manipulation capabilities of a raster-scan color graphics terminal designed at NASA/Goddard as part of the Atmospheric and Oceanographic Information Processing System.[54]

A-Idas. Uno and Matsuka[55] proposed a system called A-Idas—advanced integrated designer's activity support system. It provides a relational data base to store geographic, geometric, and engineering data. This system also provides a graphic management facility that manipulates not only pictures drawn with lines, but those drawn as areas. Areas are represented by colors, cross-hatching, or texture and scenery.

The system controls both vector and raster graphic display devices. When pictures are drawn with lines, these devices are supported through a device-independent user interface. The graphic management facility is extended to include image manipulation functions. Functions for image-data manipulation include background processing, image deformation, domain extraction, and image composition.

Image processing. Researchers have begun to investigate various problems in data management for image processing and picture description.[5,56] The query-by-pictorial-example approach is discussed by Chang and Fu in the second paper of this issue, pp. 23-33. Other important results are summarized below.

Ibis. Ibis, the image-based information system developed at the Jet Propulsion Laboratory, was built upon an existing image-processing system called Vicar, for video image communication and retrieval system.[15,57] It can handle both raster-formatted Landsat images and vector-formatted census data, which it stores in two separate data bases.

IMDS. Lien and Schroff[58] have designed IQ, an interactive query language, as a user interface for an image data-base management system. Through this query language, the user can define a false color function, a pixel value transformation, an overlay function, a simple physical zoom function, and a window. The user manipulates the images (in raster format) through generic functions. He can direct images to display devices for visual and qualitative analysis. Image histograms and pixel value distributions can be computed to obtain quantitative analysis of images.

Pictorial data-base applications

Geographic data processing has traditionally required pictorial data-base support. Both vector-formatted and (to a lesser extent) raster-formatted geographic data-base systems have been developed.

Nagy and Wagle,[8] in their comprehensive review of geographic data processing, discuss geographic input/output mechanisms, range of applications, coordinate systems and base maps, data organizations, and processing. They identify *cellular* and *linked* data organizations as the most important.

Cellular organization (matrix representation) is more suitable to software developments such as geographic operations related to location and distance measure. Its disadvantage is its waste of computer storage for spatially spare data.

Linked organization (line-segment representation) has the advantage of storage efficiency. Its drawbacks are the complexity of its software for editing and updating geographic data and the increased difficulty of applying set algebraic and distance-related operations.

Vector-formatted geographic data base. Vector format is only one of the formats of spatial data. It represents areas by their boundaries and has the advantage of a very compact representation.

Many cartographic data systems[8,11,59] use the *topological data structure* for computer handling of spatial data. In this approach, a polygon or region is encoded by boundary chains or line segments. Each chain consists of beginning and ending nodes, which are indicated by their coordinates.[60,61] The Canadian geographic information system of the Canadian Ministry of Environment, the dual independent map encoding of the US Census Bureau, Polyvrt of the Harvard Laboratory for Computer Graphics and Spatial Analysis, and the Polygon Information Overlay System of San Diego county all use the topological data structure. The disadvantage of this structure is that it requires time-consuming algorithms to handle polygon overlay and polygon merge.[57,62]

CGIS. The Canadian geographic information system[59,63] is one of the earlier successful geographic information systems. It includes a command language, an assessment language, overlaying of maps, interactive graphics, and input from a drum scanner or an *x-y* digitizer. It represents regions as polygons. Two types of files are used: the image data set, which contains the line segments that define the polygons; and the descriptive data set, which contains the user-assigned identifiers, centroids, and area. Each polygon in the image data set points to its representation in the descriptive data set, and vice versa.

Dime. In the dual independent map encoding files,[64] the basic element is a line segment. Each segment is defined by two end nodes plus pointers to the polygons on the right and left of the segment. In this system, the data structure has been kept simple, at the expense of extra processing time for certain operations that require searching the data base. These operations include determining which line segments share a node and finding the whole outline of a polygon. The structure can adequately represent topological spatial relations between regions.

Gads. The geodata analysis and display system, under development at IBM since 1973, is an ambitious attempt to design a geographic information system that provides flexible and interactive problem-solving capabilities. This system has data-base management facilities and supports data-base integrity, as well as various user views of the pictorial data base.

Geograf. Geograf is a system proposed by Peucher and Chrisman[11] to handle both planar and surface data. The system includes the concepts of

(1) the least-common geographic unit (an area that cannot be partitioned further);
(2) the chain group (a set of chains forming a boundary of two regional units of a given polygon class); and
(3) the attribute cross-reference table.

To handle surface data, the system has a two-part data base that includes both a triangle structure and a set of points that lie along lines of high information content. The triangle structure is a low-level structure, comparable to the image data set of the CGIS. The points in the second set consist of peaks, pits, and passes. This set, in a way, corresponds to the descriptive data set of CGIS.

Raster- and grid-formatted geographic data bases. These approaches to formatting the representation of spatial data are mainly used in image processing and raster graphics display.

Weber's approach. The advantages and drawbacks of a grid-formatted data structure are almost perfectly complementary to those of the vector-formatted structure (i.e., the topological or polygonal data structures). Therefore, Weber[65] has proposed a locational and grid-formatted data structure. The operations working on this data structure are hierarchically defined such that the transition from grid-formatted to vector-formatted representation is merely the last step in a process of successive refinements defined by the nesting of squares of different sizes. Weber states that his locational data structure is well suited to automated cartography. He does not, however, provide defined operations to go through this data structure, and he does not explain how to store those vector-formatted and grid-formatted representations.

Other relational geographic information systems. The Geo-Quel system developed at the University of California-Berkeley uses a relational data-base approach to manipulate geographic data.[66,67] A basic entity in Geo-Quel is a map, which is a collection of points, lines, line groups, and zones (collections of polygons). A map is stored in the Ingres data-base system as a relation. A query language, Quel, which is similar to Sequel,[19] is used to interrogate the data base. The system can handle simple queries about a map and can display information from a map. Except for Codd's conventional relational calculus, picture operators are defined to handle retrieval and manipulation of different picture entities: regional features, linear features, and point features. Modeleski[68] has proposed additional relational attributes to permit topological manipulation of geographic files. He emphasizes the storage of chain files in relational structure, topological access, and the use of topological information to enhance Geo-Quel's recognition of the graph-theoretic properties of a geographic file stored in relational form.

Computer-aided design applications

Computer-aided design is emerging as an important pictorial data-base application area. Systematic research on CAD data-base systems has just begun.[69-72]

A joint effort carried out in Tokyo and Texas by Harada,[69,70] Buchmann,[71] and Kunii[72] has resulted in systems with user-friendly interactive computer graphics at the front end. Their CAD data-base system, named Sid—system for interactive design—formalizes design specifications and design processes through recursively structured graphs and the relational data model. Their systems also support design evolution from one level of detail to another. The very basic logic for data-base-supported design evolution is called the design engine.[73] Applications include computer-aided design of software and electronic circuits and engineering drawing evolution.

Similar activities are beginning at many research laboratories and universities in the US.

Conclusions

It is generally recognized that a flexible pictorial data-base system should support pictorial data encoded in various formats and provide automatic conversion among variously formatted pictorial data. Standardization will undoubtedly facilitate the design of future systems with versatile format-conversion capabilities.

It is also generally recognized that pictorial data at various levels of abstraction must be stored in a pictorial data-base system. The distinction between logical picture and physical picture in a pictorial data base is similar to the distinction between logical record and physical record in a traditional alphanumeric data base.[22]

The formatting problem is a main issue in physical pictorial data-base management; it can probably be solved through increased standardization. This is also the case for logical pictorial data-base management. The main issue here is whether a commonly acceptable framework for defining logical pictures can be established.

The relational model and the hierarchical model each has its appeal. Whether they can be combined into a commonly acceptable framework remains to be seen.

For the relational pictorial data-base system, the classical relational model must be generalized to accommodate pictorial data. Various proposed extensions have been reported, and future research could lead to the development of more sophisticated pictorial relational models. Their usefulness must be proven in practical applications.

Flexible user interface, as well as system interface, must also be developed.[22,26] This will facilitate the incorporation of a pictorial data-base system into a pictorial information system for general problem solving, image processing, and image understanding. The rapid advances in office information systems will cause intelligent user interfaces for multi-media data-base systems to receive even more attention in research and development.

Finally, new computer architecture for pictorial information systems will necessarily have an impact not only on image processing techniques, but also on techniques for the storage and retrieval of pictorial data. ■

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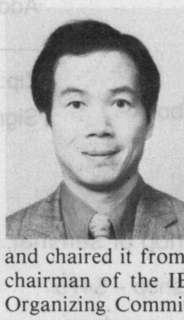
Shi-Kuo Chang is the guest editor of this issue. His biography appears on p. 11.



Tosiyasu L. Kunii is a professor in the Information Science Department of the University of Tokyo. He has been active in computer graphics, data-base systems, and software engineering since 1967. He is on the IFIP Data-Base Working Group and the IFIP System Modeling Working Group. He organized the Technical Committee on Software Engineering in the Information Processing Society of Japan and chaired it from 1976 to 1981. Since 1979, he has been the chairman of the IBM Japan Computer Science Symposiums Organizing Committee. He has authored and edited a dozen computer science books and published 60 refereed academic/technical papers in computer science and applications.

Kunii received BSc, MSc, and DSc degrees in chemistry in 1962, 1964, and 1967, respectively, all from the University of Tokyo.