Spatial Information Management -- A Survey

Martin Tuori
D.C.I.E.M.
PO Box 2000, Downsview,
Ontario, Canada M3M 3B9

This is DCIEM Research Paper No. 82-P-09

Abstract

This paper is a survey of research in Spatial Information Management. Research is reviewed from a variety of application areas, including Geographic systems, Computer Aided Design and Manufacturing, Image Processing, graphical interfaces to Data Base Management Systems, and general techniques for the representation of spatial information. Significant issues are outlined, and areas suggested for further research.

Keywords: spatial information, computer graphics, cartography, image processing, data base management, interactive systems, pictorial systems, information management.

1) Introduction

The use of pictures as an information medium predates the use of text, yet the application of computers in managing visual information has been delayed by conceptual and technological problems. Computers were originally developed for numerical applications, but were quickly adapted to more general, symbolic textual applications. More recently, they have been adapted to the storage and processing of pictorial information. Similarly, integrated Data Base Management Systems (DBMS's) were originally developed for alphanumeric use, but are now being adapted for use with pictorial data.

Spatial Information can be defined as information which is inherently visual, or which represents positional and topological relationships among objects situated in space. Spatial Information Management is the application of techniques in data representation, storage and management for the purpose of handling spatial information. It includes input techniques, manipulation, analysis, and visual display of such information. Research in this area uses techniques developed in Data Base Management, Computer Graphics, and Image Processing, while providing solutions to problems in CAD/CAM, Cartography, Urban Planning, etc. While not all such information is stored as pictures, per se, nonetheless pictures dominate most applications.

2) Survey of Research by Application Area

2.1) Geographic and Cartographic Systems

Work in Geographic and Cartographic systems has been quite extensive, with much of it coming from Government and University labs. The research reported typically seeks to utilize existing specialized data sources, and much of it is directed towards production of map products, with less emphasis on the use of a computer system as a visual problem solving tool. Typical of groups active in this area are the US Bureau of the Census, [USBu70], the US Defence Mapping Agency [Vite80], [Berg80], Statistics Canada, Energy Mines and Resources Canada (Surveys and Mapping Branch) [Harr72], the National Land Survey of Sweden, Harvard University Laboratory for Spatial Analysis and Computer Graphics [Harv79], and Carleton University Cartographic Research Unit [Tayl74], [Tayl80]. For surveys of this aspect of Spatial Information Management, see [Nagy79] and [Dutt78].

There are several commercial products relating to this area, ranging from software plotting packages to complete map storage and production systems. Other areas of research include digital production of conventional map products, customized map production, especially thematic maps (display of some variable over a surface, via colour, shading, prism height, etc.), and the study of basic algorithms for graphical input, analysis, manipulation, and presentation. It is worth noting that much of the research has been applied in the processing of specific data files, rather than in the use of more general tools, such as provided by a DBMS. Thus existing data sources cannot easily be applied to new problems by extending them with other forms of information.

2.2) CAD/CAM

Computer aided design and manufacturing has a somewhat separate history, although some of its problems and solutions have parallels in the other areas. For an excellent bibliography on Geometric Design in CAD, see [Bars81]. The imagery used in CAD is usually synthetic (little use is made of scanner input), and the analyses called for are specific to the product area being addressed. As a result, CAD/CAM systems have often evolved in industrial settings, and may be inaccessible or inappropriate for use in solving problems in other application areas.

High level modelling languages have been devised, with which a designer can build complex 3-dimensional physical systems [East77]. While such a system might concentrate on the shape and appearance of equipment or buildings under design, a companion system can hold ancillary information, such as building specifications [East80]. Again, much of the work in the CAD/CAM field relies on data structures which are designed for the specific application at hand, rather than by a view of the data as a general shared resource. A common view of DBMS's is that they are unsuitable for storing and manipulating spatial information [Lees79, Chie80]. This view is well taken, not because spatial entities do not have properties which can be listed, but because those attributes may be difficult to store using the data types a DBMS provides. Polygon outlines, for example, require variable length lists of floating point values, and many DBMS's do not support variable length fields. Moreover, appropriate spatial operators must be provided. Where a business application might ask for employees earning $10,000 < salary < $20,000, a spatial application might ask for employees whose home address is *inside* a given polygonal area. This, and other spatial operators should be added if a DBMS is to be used for spatial queries. More recently, attention is being given to the development of DBMS's specifically aimed at CAD/CAM. Ulfsby et al [Ulfs81] describe a CODASYL-type network DBMS; however, it is not clear from that report in what ways such a DBMS differs from one intended for more conventional applications.

2.3) Data Base Techniques in Image Processing

Two volumes from the Springer-Verlag series *Lecture Notes in Computer Science* [Chan80, Blas80] provide an excellent introduction to the topic of Information Management in Image Processing. While most of the work reported is directed towards the maintenance of libraries of scanned images, some insights are offered on methods for representing image contents found by segmentation, classification, etc. Material discussing techniques for representing and processing visual information in computer vision systems can be found in [Tani80]. A brief survey of methods in processing Earth Resources Imagery can be found in [Teic78], while more thorough coverage of the same topic is offered in [Moik80].

Various authors suggest ways in which a DBMS might be used to reference collections of images [Chie80, Zobr80]. At the low end, image files can have headers prepended to them, containing name, geographic position, and other attributes (i.e. no real use of a DBMS). A more powerful scheme would use a DBMS to store references to the picture files, including relationships among different pictures and subpictures. At the high end of this spectrum, a DBMS might be used to store a symbolic representation of image contents, giving the subdivision of each image into composite parts (areas of constant texture, edge boundaries, etc). At this extreme, the DBMS would actually contain the image data, not just references to it.

2.4) Graphical Interfaces to DBMS's

The use of interactive graphics as a component of the user interface to a DBMS is a recurring theme. For example, [Lapc77] describes a system, built as a user interface to the OMEGA DBMS. With this interface, the user combines predefined elements in a diagrammatic representation of the desired query. The diagram is translated into a written query language (LSL), so that it can be parsed, and carried out. A similar effort is described by McDonald and Stonebraker [McDo74], [McDo75]; in a system called CUPID the user draws query diagrams on a graphics display, which interfaces through the QUEL query language to the INGRES DBMS. The authors cite several advantages of such an interface, including a reduction in typographic errors, simplified parsing, expressive power equivalent to the underlying query language, and user-friendliness. In both of these systems, only the interface is graphical -- the information stored in the data base would normally be alphanumeric.

A system described by Herot et al [Hero80a], [Hero80b] also employs a graphical interface to the INGRES DBMS, but the data contained in the data base is visual. Diagrams, text, and photographs are arranged in a large visual space, around which the user may browse. One may ask for more information about a visual entity by zooming in on it. The visual display then takes on a more detailed appearance, as more information is provided about that entity. A casual user may probe the data base for information, without having to learn a formal query language. A similar browsing capability is provided in the Movie-Maps system implemented by MIT's Machine Architecture Group [Lipp80]. In their prototype use of the system, their data consisted of real-world views of a small town. Stored on random access videodisc and available at an interactive graphics display, these views permit a would-be visitor to take a simulated *drive* through the town, controlling route, speed, and direction of view. In addition to the real-world views, scenes from a synthetic model of the town are available, as well as other information about historical buildings and locations. The system provides a very rich exploration of an unfamiliar place.

Recent work by McDonald [McDo80] also suggests the use of videodisc as a tool for a browsing interface to a DBMS. In this system, the sample data is a hospital stores catalogue. The system she describes permits the user to browse through recorded images of the storeroom, catalogues, etc., and to select an item therein for more information. Traditional query language tools would also be available; the visual interface is intended to facilitate casual perusal, and to capitalize on conscious/unconscious visual associations, such as the knowledge that a desired item is stored near a particular door.

Another system which uses videodisc to facilitate the study of spatial information is described in [Bolt81]. The user is presented with a large-format video display containing upwards of 20 active windows, each potentially an ongoing movie, in sound and colour. The use of an eye-tracking device permits the system to determine where the user's attention is focused, and thus direct the flow of information accordingly. While some of the windows would be live sources from television stations, others might be recorded messages, etc. Thus some of the windows will continue silently if not viewed directly, while others may stop, and await the viewer's gaze before continuing. This research is unusual in that it views information as a stream, and seeks to provide the user with flow controls; in most conventional DBMS's the user's tools permit the definition of discrete batches of information.

For the most part, these browsing systems treat images as atomic entities, having various relationships to other single frames, but no internal structure. By contrast, systems described in the previous section on Image Processing often seek to describe the contents of images, providing successively detailed information about attributes and relationships. The *level of representation* supported by a spatial information system is a fundamental characteristic of its generality, and of the kinds of applications for which it is appropriate.

2.5) Techniques for Representing Spatial Information

Developing or selecting appropriate data representations is of central importance in dealing with any form of information. The earliest computer graphics systems were based on the vector-drawing model of the oscilloscope. Data structures evolved, called display files, which offered the right blend of function and performance for the tasks involved in refreshed vector graphics. They proved inappropriate, however, for many other application tasks that are required when dealing with drawings. Many specialized data structures have been developed, each with its own strengths and weaknesses.

A spatial information system should provide data independence to application programs. In Computer Graphics, device independent programming packages and intermediate display files (sometimes called metafiles) provide some freedom from the details of device and data formats [Ende78], [Hors76], [Warn79a], [Warn79b]. Similarly, standardized formats have been proposed for the encoding and exchange of geographic information [Good79], [USBu70]. But while these formats provide a convenient means for exchanging or displaying images, they may still not be the preferred representation for analysis.

More recently, graphics systems have evolved, not from the oscilloscope, but from the television. Rather than controlling the electron beam in an arbitrary path across the face of the CRT, these systems use the beam in a regular scanning motion, from left to right, and top to bottom of the screen. This *raster* technique is central in the television-like scanner technology used by the Image Processing community. It is not surprising, then, that that community shows a strong preference for scanned raster representations of spatial information; such representations permit numerous powerful transformations, often with the aid of parallel computation architectures. Computer Vision research [Tani80] is concerned with extracting from such scanned images information about objects seen in the images, and their attributes and relationships. This derived information may be stored in vector form (boundaries), or as relational tables or semantic nets (topological relationships, meaning, etc). Some authors suggest, however, that a pure raster system can be used as the basis for handling all forms of spatial information [Peuq76, 77]. This attitude is supported by raster systems which extend the notion of a pixel to include fields other than scanner components. This hybrid technique [Zobr80], [Blai81], is able to treat vector and other information as an attribute associated with each pixel; each pixel contained within some boundary, for instance, contains a field to refer to that boundary attribute.

Others have suggested that graphical information be stored in a conventional DBMS, thus avoiding some of the problems of data representation and data independence. This notion can be applied to whatever extent is appropriate, from using the DBMS to store references to picture files [Hero80a], to storing an active vector refresh display file in the DBMS [Moor76], [Pale79], [Well80]. While the latter extreme offers some useful insights into the DBMS services that can be offered to graphics applications (the *pick* operator, for instance), it may be difficult to support the performance constraints of a comfortable interactive user interface. One possibility is to archive the image in a DBMS, but take a workspace copy (in an appropriately efficient form) for use during an interactive graphics session. By using hybrid representations, or different representations for different stages, the system designer can capitalize on their individual strengths while avoiding their weaknesses.

3) Major Issues and Suggestions for Further Research

The major issues to be faced in developing improved systems for managing spatial information can be summarized under several topics: selection of appropriate representation(s), identification of the functionality that should be included, design of powerful user interfaces, and achievement of suitable performance. Although we expect to see new ideas evolve in specific application areas, we consider a primary current issue to be the integration of existing tools and techniques. A single system that encompasses the best capabilities of the various systems surveyed above would be very powerful indeed.

Depending on the applications for which it is to be used, a comprehensive spatial information system will have to provide storage and access mechanisms to data that is visual (vector and raster), alphanumeric, and semantic (expressing the meaning and significance of the various data to the task at hand). The goals in designing this aspect of a spatial information system are largely in common with the goals of strictly alphanumeric DBMS's -- the data should be independent of the programs that access it, the data should be sharable, it should be possible to add new data and new relationships, data redundancy should be controlled, etc. It seems prudent to employ a DBMS to satisfy this component of our task. Two problems arise. First, the primitive data types available in existing DBMS's may not be sufficient to construct simple, appropriate representations. There is therefore a need to re-examine popular spatial data structures, in order to catalogue their relative merits, and to determine means of representing them within a DBMS, and means of converting from one to another, where necessary. Secondly, the operations provided by existing DBMS's should be extended to include spatial operators such as intersections and unions of geometric entities (points, lines, polygons, etc.), radial distance measurements, etc. This set of operators needs to be compiled in a consistent framework.

Although the detailed functionality of any specific spatial system will depend on its context, some general insights are possible. Such systems can be expected to offer more than mere archiving of data, to be retrieved in the same chunks in which it was submitted. Such systems should offer casual browsing, and the formulation of new queries in solving unanticipated problems. The need to develop general spatial systems is expressed in [Chan81], where existing systems are surveyed, and future directions proposed. Ignoring for the moment any specific application, we can view a spatial information system as a collection of functional modules, providing visual and textual access to a shared information pool, such that textual queries, sketching, data base to data base conversion, image processing, and other applications can be carried out. The underlying layer in such a model is a DBMS capable of supporting the data types and operators mentioned in the previous paragraph. The extent to which such operations should be in the DBMS, or in application modules, is a question that deserves more attention.

The fields of Graphic Design and User Interface Design are both concerned with aspects of the same problem -- interaction between a person and information. It has been suggested [Marc81] that much of computer-generated graphics lacks the rudiments of good graphical style. An information system offering visual output should assist in the choice of symbolism, colour, and composition; it should encourage the designer to create simple, yet effective visual communication. Where these choices have traditionally been manual decisions made on the basis of aesthetics and consistency, guidelines need to be identified and codified for inclusion in spatial information systems. The use of generalization and labelling in map design are examples of how hard these choices can be. Although some work has been reported in this area [Craw76], [Phil79], [Muel78], further study of these issues is required. Similarly, careful study of the user interface for controlling such systems is important. It would appear that most of the user interfaces to existing computer graphics systems have evolved in an ad-hoc manner. Controlled studies of design alternatives are possible [Mora81], if somewhat expensive. Given that generalized spatial information systems will present the user with considerable complexity, it seems that careful design and analysis of the human interface is essential to making such systems usable. Of particular concern is the need for input and editing tools that make appropriate use of the individual capabilities of man and machine. Known algorithms can perform much of the work of processing, analysing, and abstracting visual material; with a person on hand to guide it, the software can better be directed, so as to ignore areas of little interest, back out of dead ends, etc.

The question of performance refuses to be ignored. While the goal of a fully general spatial information system is enticing, it remains to be seen whether such a system could perform at a reasonable level on specific applications. The generality and advantages of a powerful DBMS cannot be had without some payment in performance. Consider, for example, the sheer volume of data that is involved. One Landsat Satellite produces about 4 gigabytes of data per day, just in its coverage of North America. Digitized top maps (1:50,000 scale) from Energy Mines and Resources Canada (EMR) occupy about a megabyte per map sheet, and it takes 13,000 map sheets to cover Canada. Storage and access overheads must be controlled, and interactive use may dictate the need for highly parallel hardware architectures. Supporting these classes of spatial information will place heavy demands on a DBMS.

Hopefully, this brief survey offers some insight into those areas which contribute to the fairly new field of Spatial Information Management. There is considerable recent literature that suggests a movement towards the integration of techniques from Computer Graphics, Image Processing and Data Base Management, in solving spatial problems. The process of collecting and combining those techniques will be a central issue over the next few years.

Bibliography

1) Ahuja, Narendra and Schachter, B.J., **Image Models,** Computing Surveys, 14, 3, pages 373-398, (Dec, 1981)
2) Baer, Adrian and Eastman, Charles M., **The Consistency of Integrated Databases for Computer Aided Design,** Proceedings of a Workshop on Computer Representation of Physical Systems, Carnegie-Melon University, (Aug, 1976)
3) Barsky, Brian A., **Computer-Aided Geometric Design: A Bibliography with Keywords and Classified Index,** IEEE Computer Graphics and Applications, 1, 3, pages 67-109, (Jul, 1981)
4) Bentley, Jon Louis, **Multidimensional Divide-and-Conquer,** Communications of the ACM, 23, 4, pages 214-229, (Apr, 1980)
5) Blair, Greg and Moon, George, **CML Virtual Grid Techniques,** Private Communication, (1981)
6) Blaser, A., Editor, **Data Base Techniques for Pictorial Applications,** 599 pages, Springer-Verlag, (1980)
7) Board, C., **Maps as Models,** pages 671-725, in *Models in Geography,* (1967)
8) Bolt, R.A., **Filing and Retrieval in the Future -- Spatial Data Management,** Proceedings of the Infotech Conference on User-Friendly Systems, London, March 1979, (1979)
9) Bolt, Richard A., **Gaze-Orchestrated Dynamic Windows,** Computer Graphics, 15, 3, pages 109-119, (Aug, 1981)
10) Boyle, A. Raymond, **The Requirements of an Interactive Display and Edit Facility for Cartography,** The Canadian Cartographer, 13, 1, pages 35-59, (Jun, 1976)
11) Brachman, Ronald J., **On the Epistemological Status of Semantic Networks,** pages 3-50, in *Associative Networks,* (1979)
12) Brassel, K., **A Survey of Cartographic Display Software,** Report, No: Report R-77/3, Geographic Information Systems Laboratory, State University of New York, Buffalo, (1977)
13) Buchmann, A.P. and Kunii, T.L., **Evolutionary Drawing Formalism in an Engineering Database Environment,** Proceedings of Compsac 79, pages 732-737, (Nov, 1979)
14) Center for Advanced Computation, Univ of Illinois, **NARIS A Natural Resource Information System,** CAC document number No: 35, (Aug, 1972)
15) Chamberlin, D.D., **Relational Data Base Management Systems,** ACM Computing Surveys, 8, 1, pages 43-66, (1976)
16) Chang, N.S. and Fu, K.S., **A Relational Database System for Images,** Technical Report No: TR-EE79-28, Purdue University (May, 1979)
17) Chang, Ning-San, **Image Analysis and Image Database Management,** 146 pages, UMI Research Press, (1981)
18) Chang, S.K. and Fu, K.S., Editors, **Pictorial Information Systems,** 445 pages, Springer-Verlag, (1980)
19) Chang, S.K., Guest Editor, **Pictorial Information Systems,** IEEE Computer, 14, 11, pages 1-67, (Nov, 1981)
20) Chien, Y.T., **Hierarchical Data Structures for Picture Storage, Retrieval and Classification,** pages 39-74, in *Pictorial Information Systems,* 445 pages, Springer-Verlag, (1980)
21) Crawford, P.V., **Optimal Spatial Design for Thematic Maps,** The Cartographic Journal, 13, 2, pages 145-155, (Dec, 1976)
22) Davis, J.C. and McCullagh, M.J., **Display and Analysis of Spatial Data,** John Wiley and Sons, (1975)
23) Donato, N., McCormick, B.H., Reuss, J. and Rochetti, R., **A Relational Database System for Pictures,**
24) Donelson, W.C., **Spatial Management of Information,** SIGGRAPH Proceedings, (1978)
25) Dueker, K.J. and Noynaert, J.E., **Interactive Digitizing, Editing, and Mapping: Software and Data Structure Considerations,** Technical Paper 92, Intitute for Urban and Regional Research, University of Iowa (Jul, 1977)
26) Dueker, K.J., **Cartographic Data Structures: Alternatives for Geographic Information Systems,**

Computer Graphics, 10, 2, pages 167-172, (1976)

27) Dutton, G.H. and Nisen, W.G., **The Expanding Realm of Computer Cartography**, Datamation, pages 134-142, (Jun, 1978)

28) Eastman, C.M. and Fenves, S., **Design Representation and Consistency Maintenance Needs in Engineering Databases**, Proceedings of a Conference on Engineering and Scientific Data management, Hampton, Va., (May, 1978)

29) Eastman, C.M., **Prototype Integrated Building Model**, Computer Aided Design, 12, 3, pages 115-119, (May, 1980)

30) Eastman, Charles M., **Databases for Physical System Design: A Survey of U.S. Efforts**, Proceedings CAD76 Conference, IPC Science and Technology Press, Guildford, England, (Mar, 1976)

31) Eastman, Charles M. and Henrion, Max, **GLIDE: A Language for Design Information Systems**, Computer Graphics (Proceedings SIGGRAPH 77), 11, 2, pages 24-33, (Summer, 1977)

32) Edson, D.T. and Lee, G.Y.G., **Ways of Structuring Data within a Digital Cartographic Data Base**, Computer Graphics, 11, 2, pages 148-157, (1977)

33) Enderle, G., Geise, I., Krause, M. and Meinzer, H.P., **The AGF Plotfile - towards a Standardization for Storage and Transportation of Graphics Information**, Computer Graphics, 12, 4, pages 92-113, (Dec, 1978)

34) Fischler, Martin A. and Bolles, Robert C., **Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography**, CACM, 24, 6, pages 381-395, (Jun, 1981)

35) Forbes, B., **The Design of an Information retrieval system for Computer Graphics**, CAD80 Proceedings, (1980)

36) Giddings, Gary M. and Carlson, Eric D., **An Interactive System for Creating, Editing and Displaying a Geographic Base File**, Research Report No: RJ 1288, IBM 30 pages, (Oct, 1973)

37) Gillespie, R. and Davis, W.A., **Tree Data Structures for Graphics and Image Processing**, Proceedings of the 7th Canadian Man-Computer Communications Conference, pages 155-162, (Jun, 1981)

38) Goodenough, D.G., O'Neill, K.J., Gordon, L.A., Yan, J., Fisher, T., MacDonald, C.L. and DesRochers, A., **Standard Format for the Transfer of Geocoded Polygon Data**, Research Report No: 79-3, Canada Centre for Remote Sensing / Energy Mines and Resources(Dec, 1979)

39) Hardwick, Martin, **Graphical Data Structures**, Computer Graphics, 15, 4, pages 376-404, (Dec, 1981)

40) Harris, Lewis J., **Automated Cartography in Federal Mapping in Canada**, The Canadian Cartographer, 9, 1, pages 50-60, (Jun, 1972)

41) Harvard University Laboratory for Computer Graphics, **The Harvard Library of Computer Graphics Mapping Collection, Volumes 1-11**, (1979)

42) Herot, C.F., Carling, R., Friedell, M. and Kramlich, D., **A Prototype Spatial Data Management System**, Computer Graphics, 14, 3, pages 63-70, (Jul, 1980)

43) Herot, Christopher F., **Spatial Management of Data**, TODS, 5, 4, pages 493-514, (1980)

44) Horsley, Tom and Reeves, Bill, **GSFORMAT -- Graphics Standard Format**, University of Toronto, Computer Systems Research Group -- UNIX Programmer's Manual, (Jan, 1976)

45) IBM, **Distribution Facilities Information System, Volumes 1, 2, and 3**, IBM Publication numbers GE20-0672, GE20-0673, GE20-0674 pages 1-105, (1980)

46) Jacobsen, J.D., **Geometric Relationships for Retrieval of Geographic Information**, IBM Systems Journal, 7, 3 and 4, (1968)

47) Keith, R.E., **Map Models: Concepts and Applications**, Bureau of Municipal Research and Service, University of Oregon, (1967)

48) Kunii, T.L. and Kunii, H.S., **Architecture of a Virtual Graphics Database System for Interactive CAD**, Computer-Aided Design, 11, 3, pages 132-135, (May, 1979)

49) Kunni, T.L., Weyl, S. and Tenebaum, J.M., **A Relational Database Scheme for Describing Complex Scenes with Color and Texture**, Proc. Second Int. Joint Conf. on Pattern Recognition, Copenhagen, Denmark, pages 310-316, (Aug, 1974)

50) Lafue, Gilles, **Design Data Base and Data Base Design**, Proceedings CAD78 Conference, IPC Science and Technology Press, Ltd., Guildford, England, (1978)

51) Lapczak, Olga L., **An Interactive Graphical Facility for Interacting with LSL**, MSc thesis, University of Toronto pages 1-124, (1977)

52) Lee, Edward T., **Similarity Retrieval Techniques**, pages 128-176, in *Pictorial Information Systems*, Springer-Verlag, (1980)

53) Lee, Ronald M., **Towards Managing the Non-Typographic Data of the Office**, Working Paper Dept of Decision Sciences, The Wharton School, University of Pennsylvania 9 pages, (Mar, 1979)

54) Leesley, Michael, Guest Editor, **Special Issue: Databases**, Computer Aided Design, 11, 3, pages 113-192, (May, 1979)

55) Lin, B.S. and Chang, S.K., **Picture Algebra for Interface with Pictorial Database Systems**, Proceedings, Compsac 79, pages 525-530, (Nov, 1979)

56) Linders, J.C., **Computer-Assisted Cartography and Geographic Data Bases**, Proceedings of an ACM Workshop on Data Bases for Interactive Design, New York, pages 161-168, (1975)

57) Lippman, Andrew, **Movie-Maps: An Application of the Optical Videodisc to Computer Graphics**, Computer Graphics, 14, 3, pages 32-42, (Jul, 1980)

58) Lorie, R.A., Casajuana, R. and Becerril, J.L., **GSYSR: A Relational Database Interface for**

Graphics, Research Report No: RJ2511, IBM (Apr, 1979)
59) Marcus, Aaron, **Graphic Design and Computer Graphics, a seminar presented at the University of Toronto,** (Mar, 1981)
60) McDonald, Nancy and Stonebraker, Michael, **CUPID -- The Friendly Query Language,** Memorandum No: ERL-M487, UC Berkeley Electronics Research Lab pages 1-18, (Oct, 1974)
61) McDonald, Nancy, **CUPID: A Graphics Oriented Facility for Support of Non-Programmer Interactions with a Data Base,** Memorandum No: ERL-M563, UC Berkeley Electronics Research Lab pages 1-171, (Nov, 1975)
62) McDonald, Nancy H., **Videodisc: A New Technology for Human Factors,** pages 1-8, (Unpublished, 1980)
63) Meder, H.G. and Palermo, F.P., **Data Base Support and Interactive Graphics,** Proceedings of the Third International Conference on VLDB, pages 390-402, (Oct, 1977)
64) Moik, Johannes G., **Digital Processing of Remotely Sensed Images,** 330 pages, NASA Scientific and Technical Information Branch, (1980)
65) Moorehead, W. Gerald, **GXRAM, Relational Database Interface for Graphics,** Research No: RJ1935, IBM (Feb, 1976)
66) Moran, Thomas P., Guest Editor, **Special Issue: The Psychology of Human-Computer Interaction,** ACM Computing Surveys, 13, 1, pages 1-141, (Mar, 1981)
67) Morse, S.P., **Concepts of Use in Contour Map Processing,** Communications of the ACM, 12, 3, pages 147-152, (Mar, 1969)
68) Mueller, Guenter, **Graphical Information Representation In Business Systems,** Research Report No: RJ2406(31818), IBM Research Laboratory pages 1-38, (Nov, 1978)
69) Mylopoulous, John, **An Overview of Knowledge Representation,** Proceedings of a Workshop on Data Abstraction, Databases and Conceptual Modelling, pages 5-12, (Jun, 1980)
70) Nagy, G., **Digital Image Processing Activities in Remote Sensing for Earth Resources,** Proceedings IEEE, 60, pages 1170-1200, (1972)
71) Nagy, George and Wagle, Sharad, **Geographic Data Processing,** ACM Computing Surveys, 11, 2, pages 139-181, (Jun, 1979)
72) Palermo, Frank and Weller, Dan, **Picture Building System,** Research Report No: RJ2436(32247), IBM pages 1-9, (Jan, 1979)
73) Parker, James L., **Information Retrieval with Large -Scale Geographic Data Bases,** ACM SIGFIDET Workshop on Data Description, Access and Control, pages 325-347, (Jun, 1971)
74) Peuquet, D.J., **Raster Data Handling,** Report, No: Report R-77/7, Geographic Information Systems Lab, State University of New York, Buffalo, (1977)
75) Peuquet, Donna Jean, **Rater Processing of Spatial Data, PhD Proposal, Dept. of Geography, State University of New York at Buffalo,** pages 1-16, (1976)
76) Phillips, Richard J., **An Experiment with Contour Lines,** The Cartographic Journal, 16, 2, pages 72-76, (Dec, 1979)
77) Rhind, D.W., **Computer Aided Cartography,** Transactions of the Institute of British Geographers New Series, 2, 1, pages 71-96, (1977)
78) Rosenfeld, A. and Kak, D., **Digital Picture Processing,** Academic Press, (1976)
79) Shapiro, Linda G. and Haralick, Robert M., **A Spatial Data Structure,** Technical Report #CS7900S-R No: 12, Dept. Computer Science, Virginia Polytechnic and State University (Aug, 1979)
80) Sloan, K.L., Jr. and Tanimoto, S.L., **Progressive Refinement of Raster Images,** IEEE Trans. Computers, C-28, 11, pages 871-874, (Nov, 1979)
81) Srihari, Sargur N., **Representation of Three-Dimensional Digital Images,** Computing Surveys, 14, 3, pages 399-424, (Dec, 1981)
82) Tanimoto, S. and Klinger, A., Editors, **Structured Computer Vision,** 234 pages, Academic Press, (1980)
83) Tanimoto, S.L. and Pavlidis, T., **A Hierarchical Data Structure for Picture Processing,** Computer Graphics and Image Processing, 4, 2, pages 104-119, (Jun, 1975)
84) Taylor, D.R.F., **The Canadian Cartographer and the Computer/ Present Trends and Future Challenges,** The Canadian Cartographer, 11, 1, pages 33-44, (Jun, 1974)
85) Taylor, D.R. Fraser, Morrison, Joel L., Rhind, David, Boyle, A.R., Harris, Lewis J., Ottoson, Lars, Rystedt, Bengt, Bie, Stein W., Gold, Christopher, Broome, F.R., Witiuk, S.W., Waugh, T.C. and Bickmore, D.P., **The Computer in Contemporary Cartography,** 252 pages, John Wiley and Sons, (1980)
86) Teicholz, E., **Processing Satellite Data,** Datamation, pages 117-132, (Jun, 1978)
87) Tomlinson, R.F., **Geographic Information Systems, Spatial Data Analysis and Decision Making in Government,** PhD Dissertation, University of London, (1974)
88) Tomlinson, R.F., **Environment Information Systems,** in *Proceedings UNESCO/IGU First Symposium on Geographical Information Systems,* (1970)
89) Tomlinson, R.F., **Geographical Data Handling,** Report, No: Vols 1 and 2, IGU Commission on Geographical Data Sensing and Processing, Ottawa, Ontario, (1972)
90) Tomlinson, R.F., **Computer Handling of Geographical Data,** UNESCO Press, (1976)
91) U.S. Bureau of the Census, **The DIME Geocoding System,** Report, No: 4, Census Use Study

(1970)

92) Ulfsby, S., Meen, S. and Oian, J., **TORNADO: a DBMS for CAD/CAM systems,** Computer Aided Design, 13, 4, pages 193-197, (Jul, 1981)

93) Vitek, Richard L., **Data Base Requirements for Geographical Mapping,** pages 1-13, in *Data Base Techniques for Pictorial Applications*, Springer-Verlag, (1980)

94) Warner, James, **Device-Independent Intermediate Display Files,** Computer Graphics, 13, 1, pages 78-109, (Mar, 1979)

95) Warner, James, **Status Report of The Graphics Standards Planning Committee, Part IV: The GPSC Metafile Proposal,** Computer Graphics, 13, 3, (Aug, 1979)

96) Waugh, T.C. and Taylor, D.R.F., **GIMMS/ An Example of an Operational System for Computer Cartography,** The Canadian Cartographer, 13, 2, pages 158-166, (Dec, 1976)

97) Weller, D. and Williams, R., **Graphics and Data Base Support for Problem Solving,** Computer Graphics, 10, pages 183-189, (1976)

98) Weller, D. and Palermo, F.P., **Database Requirements for Graphics,** pages 231-234, in *Proceedings of IEEE Compcon 79*, (Feb, 1979)

99) Weller, D.L., Carlson, E.D., Giddings, G.M., Palermo, F.P., Williams, R. and Zilles, S.N., **Software Architecture for Graphical Interaction,** IBM Systems Journal, 19, 3, pages 314-330, (1980)

100) Wild Leitz Canada, Ltd. and Synercom Technology, Inc., , **Informap and Infodraft Sales Literature,** (Nov, 1980)

101) Yen, Elizabeth H., **A Graphics Glossary,** Computer Graphics, 15, 2, pages 208-229, (Jul, 1981)

102) Zobrist, Albert L. and Bryant, Nevin A., **Designing an Image Based Information System,** pages 177-197, in *Pictorial Information Systems*, Springer-Verlag, (1980)

103) Zobrist, Albert L., **Mapping with Census Data and LANDSAT Imagery,** pages 49-64, in *Data Base Techniques for Pictorial Applications*, Springer-Verlag, (1980)