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Graphics or Geometry

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Computer Assisted Cartography: Graphics or Geometry?

By Andrew U. Frank[1]

Abstract: A classification of interactive graphic systems, currently used to prepare plans and maps in surveying practice, is presented. The first generation of systems are graphics editors storing drawings that can be graphically changed and redrawn. A second generation of systems provides the same functionality as the first, but the user can add certain types of information to the graphical elements (e.g., tube diameter or material). The state-of-the-art third generation of systems internally stores models of reality. Drawings and reports produced in varying formats are just operations to make these internal models visible to the user. Such systems can automatically maintain constraints on the model during changes. This classification seems to reflect a very general trend in computer applications toward systems that integrate an increasing amount of knowledge about reality.

Introduction

In surveying, computers were first used for solving complicated calculations. Today, surveyors use computers increasingly to draw maps. This trend is a shift from the exclusive use of computers as powerful calculators to their use as more versatile, multipurpose machines for all kind of treatment of data, including long term storage of results and producing output as legible, hopefully pleasing, reports and maps.

This paper will discuss, in very general terms, the ways in which the computer can be used to produce maps. It will present basic concepts in graphic data processing and will link these concepts to database management for geometric data and to the future expert systems of the so-called "fifth generation" computers (5).

Using these concepts to classify present systems, three generations are proposed:

1. 1st generation.—Purely graphic systems—electronic drafting tables.
2. 2nd generation.—Annotated, multilayered, storage-oriented systems.
3. 3rd generation.—Database-oriented, intergrated systems that manage complex models of reality and provide different renderings.

Practical criteria are given to classify the different software packages, as they were developed over the last decade, into the foregoing generations. The concepts associated with these generations will be detailed in order to understand their functionality and limitations.

The writer will not discuss the single packages that are offered in the marketplace. Given the fast changes in the products, this review would be a futile endeavor. It is more important that the underlying concepts of the 3 generations are understood. It is then simple to ask a vendor

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certain questions to find out to which generation a system belongs, thus clarifying limitations in functionality.

This basic information should enable the practitioner to assess systems in relation to his needs and to find the one most appropriate to his situation. The appropriate system is not necessarily the most sophisticated one, since additional functions increase the cost of a system but are often a burden in daily operation.

This paper is, therefore, not intended as a buyer's guide and will not touch on some practical topics that are very important to the buying surveyor (e.g., prices), but will concentrate on concepts and functionality. The typical hardware considerations that dominate many discussions are excluded, and emphasis is put on software functionality.

Before we can start describing the different generations of interactive graphics systems used for map drawing, we must explain the fundamental principles of the ways in which maps relate to the real world. Then, we will present the three generations and the concepts upon which this classification scheme is based, in order to discuss their functionality.

A final chapter will relate the developments in these computer systems to a trend in the development of computer applications in general.

Maps and Reality

Maps usually describe an external, real world situation in a past, present or possible future form. An attentive reader notices that we assume the existence of an exterior world independent of the observing subject. Without that assumption, a meaningful discussion of maps is not possible.

Maps are a specific class of data collections that describe special aspects of the world. First, we can analyze the more general case of data collections that describes the real world. Physical objects in the world are perceived by the observer with his sensors (eyes and ears, to name the most important ones). This perception of reality is not objective, but regulated by the result of the subject's experience, expectations, task, etc. From this perception, the subject builds a conceptual model in his mind. In order to communicate this mental conceptual model to other individuals, the observer must use some observable physical phenomena (sound, color on paper, etc.) to express its content. The rules of representation for mental concepts are conventions between the parties involved. They define how mental concepts are transformed into observable and interpretable patterns and communicated. The receiver must understand these rules in order to interprete the message and create his own mental, conceptual model. It is inevitable that the conceptual model of the receiver is different from that of the sender. Standardization of encoding and education are the two most important methods to keep these differences small enough so that they do not interfere with the goal for which the information is needed (7).

Communication of mental concepts is not only possible between two persons in a face-to-face situation, but also between persons, separated by time and space. Different machines may be used to transform the encoded ideas, which are called data. The most versatiles are computers, but printing and copying machines must also be considered. Only human beings can interpret the data and form a mental model. Computers are strictly limited to processing the data and will never understand what the data mean in real world terms. However, the rules (the programs) employed by a computer enables it to perform sophisticated operations on the data rather than on the ideas implicated. If, in the sequence, we use terms such as "the computer knows," we mean that there are programmed rules that embody certain aspects of a human being's understanding of a situation and allow the computer to imitate reasonable behavior in treating the data.

Maps are, from this point of view, nothing more than graphic notations of spatial concepts about the real world. For the following classification, these specific properties are of a lesser importance than their general properties.

First Generation: Graphic Editor

Shortly after computers were invented, they were used to produce graphic output, maps, and other sorts of diagrams.

A first type of packages of programs allowed one to store, manipulate, and draw maps and similar diagrams. The internal model of a map in this type of package is the map drawing. These packages treat the graphical elements (lines, symbols, etc.) on the final output as units and allow the user to manipulate these units; he can erase lines, move them from one point to another, copy them from one place to another, rotate and scale parts of the drawing, etc. This versatility is quite impressive and can accelerate the production of maps. However, for the system, the drawing is a collection of graphical elements (lines, symbols, texts) without any meaning and without connection between them.

This limitation may lead to results that are quite surprising and annoying to the user, but clearly understandable when one bears in mind the type of internal model used.

The following examples illustrate how limitations in the program's model appears during operations and cause demand for additional adjustment by the human user.

In Fig. 1(*a*), the user notices that the length of the west/east streets is too short and intends to make them longer by moving the eastern north/south road. To his surprise, this results in Fig. 1(*b*), and it takes six tedious operations to make all the lines for the roads longer. What is missing in the computer's model is the topological information. The storage of unconnected lines is insufficient, and the fact that the road lines are connected must be included in the internal model.

Fig. 2 shows that an object may be moved without automatically carrying with it the accompanying text.

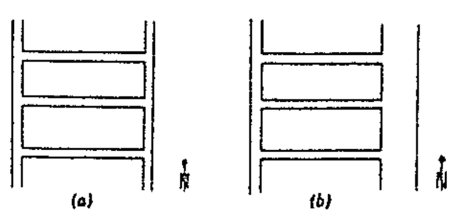

FIG. 1.—Moving Line Instead of Object

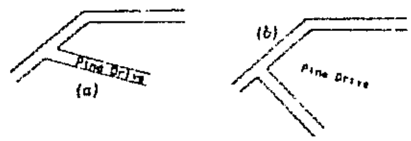

FIG. 2.—Moving Object Without Accompanying Text

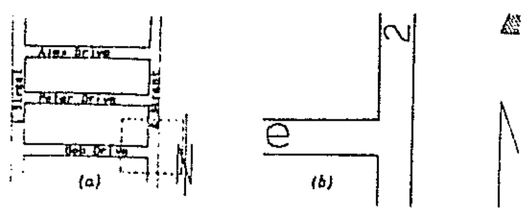

FIG. 3.—Graphic Zoom Deleting Text

These examples should delineate what is meant by "unconnected" graphic elements.

These systems also treat graphic objects without meaning. There is no internal difference between a line representing a street center line and the borderlines of the drawing. This limitation becomes obvious when simple changes in the map presentation are required. Since the system does not "know" what the lines mean, we cannot simply eliminate all buildings or change the line style for all street center lines; the operator must change each line individually, because only he can interprete the drawing to separate the borderlines from the street lines.

Similarly, a scale change is a change of the size of all objects (Fig. 3), including symbols and text, and the result is often not the intended one.

All the preceding errors can be changed by graphic editing, but require manual, labor-intensive operations. The human operator is capable of doing them because he interprets the drawing and can add the information that is missing in the computer model.

Topological Relations in Surveying

Topology is, to express it in a nonmathematical way, that which is left from geometry if you make your drawings on a balloon. Topology is a branch of mathematics dealing with two types of objects, namely points (called nodes) and lines (called edges), and one type of basic relation between them (called incidence).

Topologic data can be understood as the opposite of metric data. To analyze topological relations, the exact location of the nodes and the form of the edges are of no importance; only the fact that two points are connected by a line is relevant. In topology, the two Figs. 4(*a–b*) are equivalent.

The metric (in the original sense of measurable, rather than referring to the measuring units) data describe measurable properties, or more precisely, distances between points. Therefore, the metric information in Figs. 4(*a–b*) are very different.

Metric and topological data together are represented in a map. To register the extension of a plot of land, it is not sufficient (but necessary)

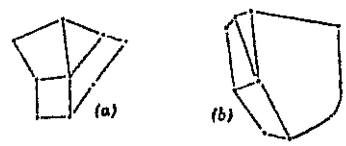

FIG. 4.—Two Topologically Equivalent Figures

to record the relative positions of the corner points (these are the metric properties), but we must record also the topologic information indicating how these points are connected by the lines.

Topology also includes reasoning about adjoining properties. Surveyors have always represented topological and metric information together in their maps. When computers were mainly used for the computation of metric data, dealing with topological relations continued in the traditional graphic way. If today, computers are used to support that part of the surveyors work, they must be capable of dealing in a natural way with both metric and topological data.

Since it is possible to produce a complete map using metric information alone, one cannot tell by looking at a finished map whether the system treats topology or not. In the operations, however, differences regarding ease of use are noticeable.

Second Generation: Graphics With Attached Meaning

In the course of developing graphic systems, users of spatial data management systems came to expect their systems to be more than expensive and complicated copying machines able to faithfully reproduce an original, which was at one time, digitized, a time-consuming method that provided only slight flexibility in updating the data.

System builders not only improved the methods of treating the graphic elements and added some topological ideas (e.g., polygons as a sequence of connected lines), but also allowed the user to attach additional data to the graphical features of the map.

Graphic lines can now be annotated with the properties that characterize a physical object, such as the material, pipe diameter, and age of utility lines.

Those improvements have enabled operators to use data for different representations on maps, as well as for making lists of pipe qualities, etc. If the system features a user-friendly query language, we may even get answers to questions such as, which pipe is the oldest; how many pipes have a certain diameter, *x*; and how long are the pipes of copper, with a certain age in years.

Such systems were primarily built for keeping track of utility lines, updating pipe plans, and at the same time, allowing additional use. They were successful, because utility lines can be represented with a single graphic object (e.g., the black stretch of line) that stands for a real world object, and additional data can be attached to this graphical object.

Some systems even exploit the topological properties. Here again, the simple topological structure of utility networks did help, when topological information was reconstructed from metric data.

Those systems typically do not fare well if we want to store information on objects that are not represented by simple graphics. A parcel is limited by its boundaries, which at the same time limit its adjoiner. There is no "natural" graphic object for the lot. An often-used solution seems to be to add a point within the lot (a so-called centroid) and attach all of the lot data to this point. To logically connect this point to the boundary has proven difficult. Not all of those systems can select just one lot with all its boundaries and nothing else, or can print a list of the coordinates of the corner points of a lot. In addition, some systems cannot detect whether two lots overlap.

At the same time, a number of traditional techniques of graphic map drawing were computerized and integrated.

1. Overlays.—When map makers are faced with the problem that different users want to represent different data on the same base map, they often use overlays. Each piece of user data is put on a transparency, and combinations of base map and overlays are made.

A computer can handle a great many more overlays than a draftsman would ever dare (60 or more are current upper limits). It is, however, not clear whether an increase in the number of layers makes this primitive structuring method any more flexible. A user may be unable to organize data in a large number of layers without becoming confused.

2. Flexible symbol selection.—Instead of storing symbols as lines, they may be stored as references into a symbol table. This method allows more flexibility in the production of maps for different users, since the symbols can now be selected immediately before printing and can, therefore, be varied for different users.

3. Joining of map sheets.—As the basic organization of the stored data remains in map sheets, a computer-assisted method of joining two (or more) adjoining map sheets into one is required.

Data Structures and Consistency Constraints

To manage large data collections, especially if they contain spatial information, has been proven difficult and time consuming (4). A multitude of small errors and discrepancies tend to creep in undetected during update operations, and subsequent problems in processing the data lead to their detection and ultimate correction. (This can be seen as an application of the third law of thermodynamics, applied to data collections.)

To every surveyor, it is obvious that a subdivision plat must look something like Fig. 5(*a*). For many reasons, Fig. 5(*b*) cannot depict such a plat.

Knowledge of spacial information must somehow be built into a program to make it impossible to enter data that violate those rules. It is much easier and cheaper to prevent errors than to make labor-intensive corrections.

That problem is ubiquitous in all large data collections. The addition of so-called plausibility tests during data entry, in order to catch as many of the errors as possible, is common practice in data processing. The same methods must be applied to collections of spatial data.

A stringent analysis of these problems in database theory has shown

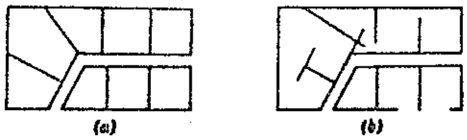

FIG. 5.—Consistent and Inconsistent Subdivision

that data processing programs generally rely on certain properties in the data set. If these properties are violated, as in Fig. 5(*b*), processing of the data is not possible, and processing errors and incorrect output results. It is, therefore, necessary to define the set of rules that must be fulfilled by the data. These rules are called "data consistency constraints" or "data integrity rules."

Those rules do not necessarily capture all restrictions imposed on the data from the real world situation, but only a minimal set needed for orderly processing.

If we want to catch as many errors as possible during data entry and create useful "error free" data sets, the relations between different data parts must be analyzed and constraints formulated.

Unfortunately, the formulation of integrity constraints for geometric data is quite complicated, and not much research has been done in this area (1,3,7). However, it is feasible, and some early attempts, most notably by the Bureau of Census (2), have shown that this procedure is the only way to achieve usable "error-free" data sets, without unacceptably high expenditures for error correction.

Third Generation: Database Management Systems

The fundamental idea in database management systems is the separation of data storage and retrieval from the use of the stored data. The database storage and retrieval programs are centralized and separated from the applications programs. These programs use a number of standardized methods to retrieve and update the stored data. No application program is allowed to directly access the stored data.

The central database management program contains a description of the data on the conceptual level and checks all updates against the stated integrity constraints. Having one program set contain all the routines to access the physical data storage (disk) also makes maintainance more economical and easier. For commercial applications, generalized database management systems have been developed; such program systems

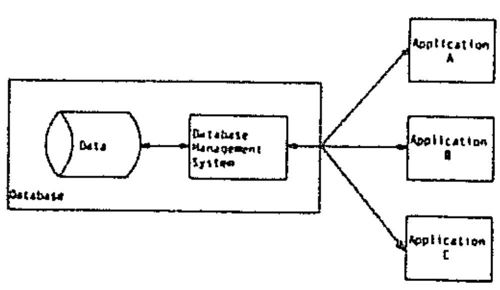

FIG. 6.—Data Base Management System

can easily be adopted to manage the data for arbitrary areas of application. Those systems are, unfortunately, unable to treat geometric data fast enough.

Furthermore, database-oriented systems concentrate the description of the data in one place. As a consequence, changes to the data description due to changing requirements are easy to apply.

The primary advance in database-oriented systems lie in the additional possibilities of structuring data. The data structure can be modeled as closely as possible to render the real world situation. Nongeometric data can be attached to graphic data, and may also exist on its own and may be structured to best fit the application. The more powerful data-structuring tools also allow one to model the geometric situation better and to join topologic and metric information.

Modeling the real world situation in an accurate manner and capturing more data opens additional potential for new applications. The base data stored in the database cannot only be used to create maps of varying scale and symbols for different users, but the data can also be used for simulation programs. The most obvious examples are network flow calculations for electric utility nets, calculation of flow in sewer lines during heavy rain, etc. These applications are only possible if a meaningful model of the world, and not only graphics is stored.

This understanding of the situation is relatively new. It started in database theory and took a long time to be applied to graphic and geometric problems. Because the high performance requirements in these areas seemed difficult to meet, reluctance to apply these concepts can be found among the designers of computer-aided design systems. This point of view is limited and should be replaced by more global considerations.

To gather geometric data describing lots, names, utility lines, etc. is very expensive. To maintain that type of data collection requires permanent effort, which can only be justified if many different users can use these data without new measurements. If a true multipurpose cadastre emerges (8), which answers many needs, then the maintenance cost of the database can easily be covered. This multiuser solution is only possible if the data collection is flexible enough to be used by different users. This flexibility is hardly possible in a conventional graphic system on paper, even with overlays, and is not much easier in a system of the first or second generation, which imitates the conventional methods.

If the objects manipulated by the system (graphic lines) are different from the categories management is interested in, the users have to learn to translate their requirements in terms of the objects handled by the system, making it difficult for managers to predict which tasks can be carried out by the system. Very similar tasks, in terms of the user's model, may be very different in terms of the system's model. Such unpredictable behavior, is frustrating and limits the use of the system. Even tasks that could be carried out are not done for lack of understanding. Similarly, large differences between the user's model (real world objects) and the system's objects (line drawn) result in problems for the operators, who are constantly forced to translate their objectives into the realm of the system's actions. This translation makes their task harder, more error prone, slower, and requires more extensive training.

Longer Term Trend

The development in these systems is quite typical of the development of computer application in general. An understanding of this trend can help us to foresee the immediate future.

1. Increased use of computers to other ends than calculations (number crunching). Computers can also profitably be used for long-term storage and retrieval of data. They allow one to structure the data according to different points of view and to retrieve them in different contexts.

2. A trend toward using interactive, direct communication between user and computer, while restricting "batch" processing to special cases. Graphic output can improve man-machine communication considerably.

3. A trend away from treating a very limited share (drafting) of a complex application area towards an integrated approach (multipurpose cadastre). The intermediate step of using a computer system to simulate traditional technical solutions (drafting and overlay) is very common and helps the user to understand the systems operation. This intermediate step seems less successful in drafting applications, since graphics treated by the machine and the interpretation by the human operator are semantically closely coupled, but may be differently modeled. A desire for adding more information, however, destroys the simple metaphor of the drawing and makes the system complicated to use.

4. Most important is the trend toward using more realistic models in the computer. More and more knowledge about the real world situation is embodied into the computer programs, and the programs can consider an increasing number of aspects and rules.

At the extreme frontier are systems that store arbitrary facts and logical deduction rules, and are then able to make reasonable conclusions on their own. Such systems expose a nearly intelligent behavior. Much research has been done in the past, and we are now slowly beginning to see the practical fruits of these efforts (5).

For commercial applications, "fourth generation" languages appear on the market that contain some knowledge about their field of application and allow one to instruct computers to produce desired results almost without programming and with very little training (for an application to mapping see Ref. 6).

"Expert system" (also called "decision support system" of "knowledge bases") becomes feasible. Those systems contain not only a description of real world situations, but also the rules used by experts to deal with them. Such systems support human experts by making the advice of other experts available to them, helping them to follow complex administrative or technical procedures, keeping track of complex situations, and permitting one to explore "what . . . if . . ." questions. It seems obvious that those ideas can profitably be applied in the area of zoning, environment, and resource management.

Conclusion

Different stages in the development of spatial data management systems needed for a multi-purpose cadastre have been identified. It becomes apparent that systems develop: (1) To incorporate ever-increasing amounts of data about the world; and (2) to include rules about using these data. Those systems appear to behave more "intelligently," become easier to use, and produce more useful results. Today's database-oriented systems are an intermediate step. They allow one to capture the complex reality more adequately and are more flexible in using the stored data. The next generation of systems will incorporate expert knowledge about the surveying profession. They will be easy to adapt to changing requirements, and should be easy to use with little training.

In spite of this development, the surveyor must decide if he wants to use today's systems. There will always be better systems just around the corner. Decisions today should be based on a clear understanding of present systems' range of application and their limitations. Only if the requirements and the system's ability match closely may profitable operation be expected.

Appendix.—References

1. Burton, W., "Logical and Physical Data Types in Geographical Information Systems," *Geo-Processing I*, 1979, p. 167.
2. Corbett, T., and Fransworth, G., "Theoretical Bases of Dual Independent Map Encoding (DIME)," *Proceedings of the International DIME Colloquim Conference*, Census Bureau, Washington, D.C., 1973.
3. Cox, N. J., et al., "A Relational Data Base System and a Proposal For a Geographical Data Type," *Geo-Processing I*, 1980, p. 217.
4. Cranford, G. F., "Editing and Updating Geographic Base Files—A Discussion of Practical Processing Alternatives," *First International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems*, Harvard University, Cambridge, Mass., 1978.
5. Feigenbaum, E., and McCorduck, P., "The Fifth Generation: Artificial Intelligence and Japan's Computer Challenge to the World," Addison-Wesley Publishing Company, 1983.
6. Frank, Andrew, "MAPQUERY: Data Base Query Language for Retrieval of Geometric Data and their Graphical Representation," Proceedings, SIGGRAPH '82 Conference Proceedings, *Computer Graphics*, Vol. 16, No. 3, July, 1982.
7. Frank, Andrew, "Data Structures for Land Information Systems—Semantic, Topological, and Spatial Relations in Data of Geological Sciences," thesis presented to the Swiss Federal Institute of Technology, at Zurich, Switzerland, in 1983, in partial fulfillment of the requirements for the degree of Doctor of Technical Sciences.
8. *Need for a Multipurpose Cadastre*, National Research Council, National Academy Press, Washington, D.C., 1980.

REPORT: Surveying Engineering Publications and Reprints
The following reports were published and are available upon request

1. Defining the Celestial Pole, A. Leick, Manuscripta Geodetica, Vol. 4, No. 2.

2. A New Generation of Surveying Instrumentation, A. Leick, The Maine Land Surveyor, Vol. 79, No. 3.

3. The Teaching of Adjustment Computations at UMO, A. Leick, The Maine Land Surveyor, Vol. 79, No. 3.

4. Spaceborne Ranging Systems - A useful tool for network densification, A. Leick, The Maine Land Surveyor, Vol. 80, No. 1.

5. Potentiality of Lunar Laser Range - Differencing for Measuring the Earth's Orientation, A. Leick, Bulletin Geodesique.

6. Crustal Subsidence in Eastern Maine, D. Tyler, J. Ladd and H. Borns; NUREG/CR-0887, Maine Geological Survey, June 1979.

7. Land Information Systems for the Twenty-First Century, E. Epstein and W. Chatterton, Real Property, Probate and Trust Journal, American Bar Association, Vol. 15, No. 4, 890-900 (1980).

8. Analysis of Land Data Resources and Requirements for the City of Boston, Epstein, E.F., L.T. Fisher, A. Leick and D.A. Tyler, Technical Report, Office of Property Equalization, City of Boston, December 1980.

9. Legal Studies for Students of Surveying Engineering, E. Epstein and J. McLaughlin, Proceedings, 41st Annual Meeting, American Congress on Surveying and Mapping, Feb. 22-27, 1981, Washington, D.C.

10. Record of Boundary: A Surveying Analog to the Record of Title, E. Epstein, ACSM Fall Technical Meeting, San Francisco, Sept. 9, 1981.

11. The Geodetic Component of Surveying Engineering at UMO, A. Leick, Proceedings of 41st Annual Meeting of ACSM, Feb. 22-24, 1981.

12. Use of Microcomputers in Network Adjustments, A. Leick, ACSM Fall Technical Meeting, San Francisco. Sept. 9, 1981. (co-author: Waynn Welton, Senior in Surveying Engineering).

13. Vertical Crustal Movement in Maine, Tyler, D.A. and J. Ladd, Maine Geological Survey, Augusta, Maine, January 1981.

14. Minimal Constraints in Two-Dimensional Networks, A. Leick, Journal of the Surveying and Mapping Division (renamed to Journal of Surveying Engineering), American Society of Civil Engineers, Vol. 108, No. SU2, August 1982.

15. "Storage Methods for Space Related Data: The FIELD TREE", A. Frank in: MacDonald Barr (Ed.) Spatial Algorithms for Processing Land Data with a Minicomputer. Lincoln Institute of Land Policy 1983.

16. "Structure des données pour les systèmes d'information du territoire", (Date Structures for Land Information Systems), A. Frank in: Proceedings 'Gestion du territoire assistee par ordinateur's, November 1983, Montreal.

17. "Semantische, topologische und räumliche Datenstrukturen in Landinformationssystemen (Semantic, topological and spatial data structures in Land Information Systems) A. Frank and B. Studenman, FIG XVII Congress Sofia, June 1983. Paper 301.1.

18. Adjustment Computations, A. Leick, 250 pages.

19. Geometric Geodesy, 3D-Geodesy, Conformal Mapping, A. Leick.

20. Text for the First Winter Institute in Surveying Engineering, A. Leick, D. Tyler, 340 pages.

21. Adjustment Computations for the Surveying Practitioner, A. Leick, (co-author: D. Humphrey, Senior in Surveying Engineering).

22. Advanced Survey Computations, A. Leick, 320 pages.

23. Surveying Engineering Annual Report, 1983-84.

24. Macrometer Satellite Surveying, A. Leick, ASCE Journal of Surveying Engineering, August, 1984.

25. Geodetic Program Library at UMO, A. Leick, Proceedings, ACSM Fall Convention, San Antonio, October, 1984.

26. GPS Surveying and Data Management, A. Leick, URISA Proceedings, Seatle, August, 1984.

27. Adjustments with Examples, A. Leick, 450 pages.

28. Geodetic Programs Library, A. Leick.

29. Data Analysis of Montgomery County (Penn) GPS Satellite Survey, A. Leick, Technical Report, August, 1984.

30. Macintosh: Rethinking Computer Education for Engineering Students, A. Frank, August, 1984.

31. Surveying Engineering at the University of Maine (Towards a Center of Excellence), D. Tyler and E. Epstein, Proceedings, MOLDS Session, ACSM Annual Meeting, Washington, March, 1984.

32. Innovations in Land Data Systems, D. Tyler, Proceedings, Association of State Flood Plain Managers, Annual Meeting, Portland, Maine, June 1984.

33. Crustal Warping in Coastal Maine, D. Tyler et. al., Geology, August, 1984.

34. St. Croix Region Crustal Strain Study, D. Tyler and A. Leick, Technical Report submitted to the Maine Geological Survey, June 1984.

35. Applications of DBMS to Land Information Systems, A. Frank, in: C. Zaniolo, C. Delobel (Ed.), Proceedings, Seventh International Conference on Very Large Databases, Cannes (France), September, 1981.

36. MAPQUERY: Database Query Language for Retrieval of Geometric Data and Their Graphical Representation, A. Frank, Computer Graphics Vol. 16, No. 3, July 1982, p. 199 (Proceedings of SIGGRAPH '82, Boston).

37. PANDA: A Pascal Network Data Base Management System, A. Frank, in: G.W. Gorsline (Ed.). Proceedings of the Fifth Symposium on Small Systems, (ACM SIGSMALL), Colorado Springs (CO), August, 1982.

38. Conceptual Framework for Land Information Systems - A First Approach, A. Frank, paper presented to the 1982 Meeting of Commission 3 of the FIG in Rome (Italy) in March 1982.

39. Requirements for Database Systems Suitable to Manage Large Spatial Databases, A. Frank, in: Duane F. Marble, et. al., Proceedings of the International Symposium of Spatial Data Handling, August, 1984, Zurich, Switzerland.

40. Extending a Network Database with Prolog, A. Frank, in First International Workshop on Expert Databases Systems, October, 1984, Kiawah Island, SC.

41. The Influence of the Model Underlying the User Interface: A Case Study in 2D Geometric Construction, W. Kuhn and A. Frank.

42. Canonical Geometric Representations, A. Frank

43. Computer Assisted Cartography - Graphics or Geometry, A. Frank, Journal of Surveying Engineering, American Society of Civil Engineers, Vol. 110, No. 2, August 1984, pp 159-168.

44. Datenstrukturen von Messdaten, A, Frank and B. Studemann, paper presented at IX International Course for Engineering Surveying (Graz, Austria) September 1984.