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The Geographic Information System and Its Use for Valuation*

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In order to evaluate and assess real estate property information properly, it is necessary to describe the property. The major part of this information is necessarily space related, that is, related to the land it describes. Geographic information systems (GISs) are computerized systems to manage large amounts of spatial information and could, therefore, be good tools for assessors. The uses of GIS can be classified as planning or operational; these uses have very different requirements for the quality of the data in the system. The two primary architectures for GIS, file and data base oriented, can be linked to these use classes. Systems for valuation purposes should be data base oriented.

Introduction to Geographic Information Systems

The concept underlying geographic information systems (GISs) is integration. Data collected with respect to a location in space can be combined and shared. In any local government or utility, most departments use the same data sets, which they combine with data specific to their own tasks. Efforts to collect and update continuously the data sets are large and duplicated (Wisconsin Land Records Committee 1987). If only one group were to maintain the data base, considerable savings could be realized, and problems caused when two departments reach contradictory deci-

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sions about a parcel based on the use of different information would be reduced. This concept of integration and sharing of data based on location is often illustrated with a set of layers, which may include buildings and streets, soil types, parcels, and so on (see figure 1).

GISs manage space-related information, information that is related specifically to a place on earth. Space-related information ranges from the description of utility lines, description of legal parcels, and land use data at all scales to socioeconomic data that are related to towns or counties or data describing the ecology in a watershed.

GISs are a special type of spatial information system. Spatial information systems include all systems that manage information related to a location in space and support using this information in a spatial context. GISs manage spatial data, which can be separated into two pieces, the nongeometric, descriptive part and the geometric part (Frank 1980). The descriptive part can usually be expressed in alphanumeric form—but need not be stored this way—and is, therefore, sometimes called "alphanumeric" data. The geometric part must describe both the location of the land to which the descriptive data relate and the extent and shape of the land.

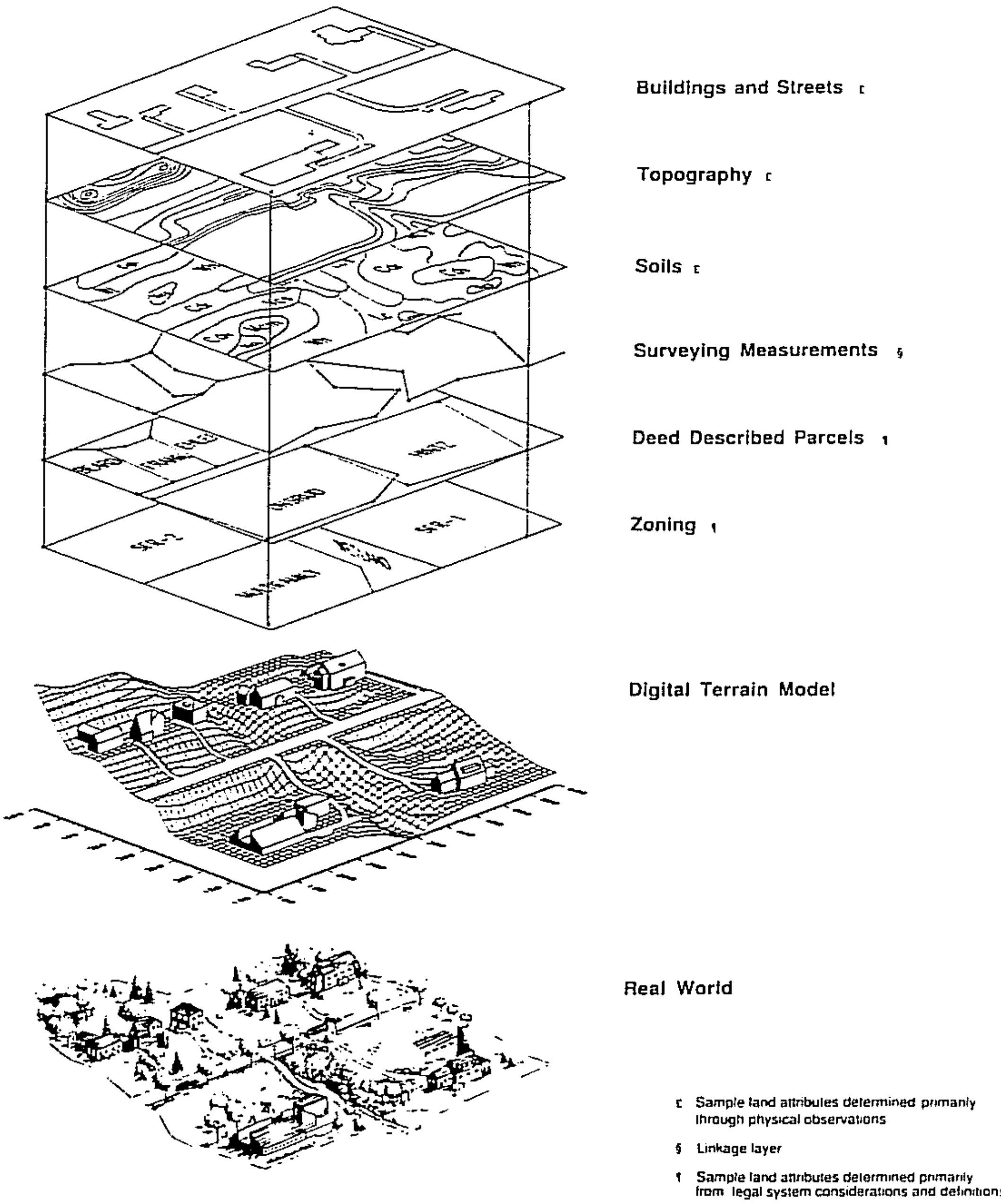
A spatial information system must contain methods to exploit the data with respect to their geometric properties. For example, the query language must allow selection of data based on location in space: it must be possible to select all properties within a certain distance from a given point, and so on. Spatial information systems are used for computer-aided design (CAD), where the parts of mechanical construction or the cells of a very large-scale integrated (VLSI) chip are designed. Such systems deal with the space of a machine or a chip, thus are certainly spatial, but do not refer to location on the earth.

Following the terminology proposed by Dale and McLaughlin (1988), GIS is the term used to describe all systems that deal with data related to the earth. In the surveying and mapping literature, the term land information system (LIS; Federation Internationale 1981) is often used as a synonym for GIS. Sometimes LIS is used to indicate a focus on data as used in town, county, or public utility administration, whereas GIS is thought to emphasize systems that deal with data for large areas or socioeconomic data as produced by the census. Public utilities use the acronym AM/FM (Automated Mapping/Facilities Management) for systems that are similar to GIS.

Cadastral systems are another important type of GIS and deal primarily with data describing ownership of land and other legal rights. It is often assumed that the ownership parcels form a useful base to record information in addition to ownership. The influential reports by the National Academy of Sciences (National Research Council 1980; 1983) describe the construction of a multipurpose cadastre by expanding the data sets for

FIGURE 1

Model of a Multipurpose Cadastre



legal purposes with data for other purposes such as fiscal or planning purposes. The "multipurpose cadastre" stresses an aspect common to all GISs, namely that the same spatial base information, here the so-called "parcel layer" can serve many purposes. Nevertheless, the term multipurpose cadastre seems to be less often used. Today, the term geographic information systems appears to be used broadly and without intending a differentiation.

GIS does not imply the technical means used to build, manage, and use the data collections, and the term includes traditional manual systems as well as modern, computer-based systems. However, it becomes increasingly clear that the full benefits of integration and sharing can be achieved only by using computerized data processing equipment. Thus, for all practical purposes, GIS most frequently implies computerized GIS.

Computer systems are often used to manage data sets that represent maps. Such data sets are either collected during an effort to map an area (for example, when new town maps are established) or digitized from existing maps. Programs to maintain maps are easy to use and help to update the map and produce new versions after changes. Such cartographic data bases are useful and cost effective as a means to maintain up-to-date maps. However, they do not provide all the benefits of a truly integrated GIS. The major difference is that cartographic data primarily represent the map as it is drawn, whereas a GIS must attempt to model reality (Frank 1984a). The difference becomes apparent when users query a cartographic data base, and information that can be easily seen on the map (such as the length of the frontage of a parcel) cannot be retrieved from the data base because the relevant concepts are not included in the data. Such systems are useful in the production of maps from the graphical data they contain. However, as the data are not organized by topics, it is difficult to produce lists and reports. A true GIS furnishes data in both graphical and alphanumerical formats.

Use Classes for GIS

As with other information, geographic information can be used for both planning and operations (Frank 1980). Even if the base data, for example, population or land use data, seem very similar in many instances, there are different requirements for the data for these two classes of activities; these requirements affect the design and operation of a GIS.

Both public and private organizations need daily spatial information for their operations. In many instances such information is collected on the spot by inspection, for example, for building permits. In other circumstances, where similar decisions are frequently required, files are collected and maintained. Organizations have established standard administrative procedures (sometimes called standard operating procedures, or SOPs) that describe what type(s) of information need to be considered to reach a specific decision and how it is to be used (Obermeyer 1989). This guarantees equitable treatment of similar cases. The standard administrative procedures for operational decisions are generally streamlined and do not require much individual judgment. The information input is standardized to data that are readily available and objectively assessable, preferably measurable (for example, size of parcel or number of bedrooms). The requirements for the quality of the information used is generally high: the information must be correct, accurate, and up-to-date.

Public and private enterprises occasionally need to make policy and planning decisions regarding land and its use. These decisions have far-reaching consequences and require considerable individual judgment. If standard procedures exist, and very often they do not, they usually prescribe procedures but not the information that must be considered. Essentially all data relevant to the decision should be used, including measurable data such as the population per town and subjective assessments such as the character of current land use. Decisions most often affect large areas, which makes the collection of precise data more difficult. On the other hand, statistical laws indicate that individual errors may cancel each other out in an aggregate that is large enough, thus allowing the use of less precise data. The decision is reached through a complex weighting of different factors, and no single element is clearly decisive; thus errors, imprecision, and some degree of subjective judgment can be tolerated in the data used. The data may also be slightly out of date without adversely affecting the validity of the decision. In public organizations, decisions can be revised by a higher unit of government but private enterprises must often submit decisions for approval by a public body.

Understanding these two use classes and their requirements for data quality is important for GIS. The cost of data collection and maintenance increases rapidly with rising data quality requirements. Data collected for one application cannot always be used for another application which needs the same data sets but has different quality requirements. Differences may exist not only in the level of precision required, but also in the level of completeness of coverage or timeliness of the updates. In general, data quality is a multidimensional characteristic not yet well understood. Problems appear where data collection mechanisms designed for one purpose are used for others, for example, when census data on population, which are collected for statistical and planning applications, are used for the distribution of federal aid, an administrative use.

If a GIS integrates data for different purposes, there must be agreement on the data sets to be included and on the data quality needed. It is often appropriate to put the group that has the highest requirements for data quality in charge of the collection and maintenance of the data. This leads to a better balance between cost and requirements and assures that the data collected are useful for the most demanding application. Applying this principle may well lead to town assessors becoming responsible for collection and maintenance of significant parts of a GIS.

The data for a GIS needed for a policy decision can be collected and aggregated from one or several GISs used for operations. One must establish standards for exchange of data, either using the new national standard or one of the widely used formats from the major vendors of GIS technology. In all cases, it is important to understand fully what the original purpose was and how the data were collected, as this may introduce a bias in the data that makes them unsuitable for certain uses. Combining or comparing data gathered from different sources or collected for different purposes demands careful assessment. GISs are powerful tools possessing almost all the dangers for abuse that we know from statistics.

Unfortunately, data quality is currently not yet well understood and it is difficult to describe the quality of a data set (Robinson & Frank 1985; National Research Council 1983). Data quality is affected by the data processing in the GIS, but it is currently not possible to link the quality of a GIS output to the quality of the input, nor do we understand how to measure the exact data quality requirements for a specific decision process. The current answer is too often "as precise as possible," meaning that the data should be collected with the highest quality technically and economically feasible. This is an active area of research (Abler 1987).

Components and Architecture of a GIS

Several vendors offer software or complete systems to establish a GIS. These systems are designed for one or the other application area and use class. Two different types of architecture designed about ten years ago by research groups influence today's commercial offerings.

Coverage Oriented Systems

The idea of GIS was greatly influenced by the work done at the Harvard Laboratory for Computer Graphics and Spatial Analysis (Dutton 1978). The *ODYSSEY* system designed there and later distributed was one of the first sets of viable GIS software and was widely used. Its architecture has influenced many of the commercial systems available today.

The "Harvard" architecture for a GIS is built with files that contain a spatial data set (Chrisman 1987) and processes (programs) that operate on these files (figure 2). A data file, or coverage, contains the data for one topic for the whole area covered, for example, parcel definitions or soil types. The major operation is the "overlay" that combines two data sets in a way that is similar to the overlaying of two map themes drawn on transparent material. For example, one coverage may contain all parcels of farm land in a town and another coverage may show the soil types for the same town. The overlay process permits the determination of the area from each farm of each soil type, and the result can be a map or a report.

The *ODYSSEY* system worked with data sets wherein each area was described by the separating boundaries, using a coordinate system and topological relations. Such systems are called vector based. The same architecture is very often used with raster based systems, in which average values for an attribute are recorded for regular square areas. The typical application of raster based systems is remote sensing, where the data, as collected by the satellite sensors, are already rasterized.

The power of the architecture is that most processes produce coverage files that can be used as input to other processes—mathematically speaking we have a closed algebra. Thus, very complex spatial data processing becomes feasible by combining these basic processes in the correct sequence, the map algebra of Tomlin (1983). The overall design is reminiscent of the UNIX toolset to manipulate text files.

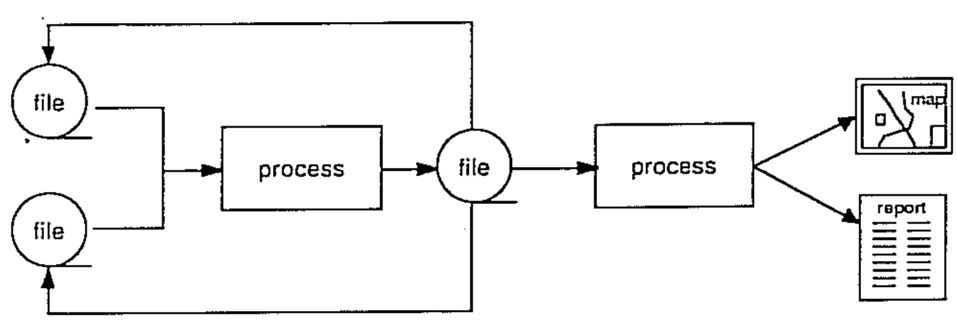
In addition to the processes that combine coverages and produce new coverages, there exist programs to draw maps from these files or produce reports in various formats. There are also utility programs that help to edit coverages for small changes. The processes to combine coverages can be used for purely graphical purposes, but much more powerful and sophisticated analytical tools can be provided.

The organizational environment that influenced the Harvard architecture is the project as used in urban or regional planning. In order to plan for a given area, all the relevant data sets are collected. They are then combined to produce material that helps to reach a decision or that documents why a certain decision was reached.

The architecture has some problems dealing with data sets that must be maintained and updated. Each coverage is thought of as independent of any other, and, if dependencies exist, the responsibility to update all

FIGURE 2

Harvard Architecture



related coverages remains with the user. The system does not manage consistency constraints nor automatically enforce them. Similarly, the system does not differentiate between original data coverages and coverages that are deduced from them. Thus, if base data change, the user must decide which deduced coverages must be reconstructed and what processes to use.

Data Base Oriented Architecture

A completely different line of thought started with the critique of file oriented data processing during the 1960s and 1970s. In large data processing operations, such as banking or insurance, it was observed that the traditional input-process-output model of data processing led to arrangements that were difficult to maintain. Each process required specifically structured input files and produced its own output files; changes in one process spread immediately to others by requiring changes in the files used to exchange data. The Harvard architecture avoids this problem, as all the files have the same basic format, and the processes are standardized and mostly application independent. Another disadvantage of a file oriented structure is that access to information distributed over more than one file is difficult and requires special programs. It was observed that much information vital to management was indeed stored in some files, but it was not possible to use the information in a timely manner.

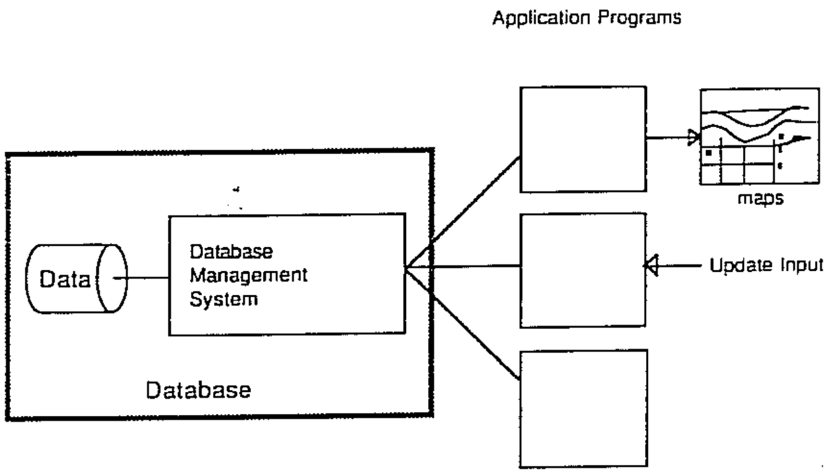
The data base concept attempts to collect all the data in a single repository where it can be accessed by all the different programs that use it (figure 2; Date 1986). This became technically feasible as large and fast random access storage systems, typically hard disks, became economical. File oriented data processing could store its data on magnetic tape with sequential access; data base technology needs random access.

Major problems remained with the development of the necessary data base management software. The complexity of the problems involved became manageable only with a strict separation of the conceptual design of the application-related aspects from the design of the general data base (ANSI/X3/SPARC 1975). The resulting reduction in efficiency of data processing became affordable when faster central processing units were produced—it helps to remember that today's personal computers are considerably more powerful than yesterday's mainframes. However, progress in software engineering and programming practice was slow to provide tools to tackle the full complexity of large integrated information systems.

The "Zurich" architecture resulted from studies started at the Swiss Federal Institute of Technology in 1978 to use standard commercial data base management systems for the emerging LISs. The group intended to integrate all the data for an LIS as used by the administration of a town and store it in a single data base. Access to and update of the data were

FIGURE 3

Zurich Architecture



expected through interactive terminals which would produce both alphanumeric reports and map graphics. (Nicholas R. Chrisman told me that the group at Harvard Graphics Lab had considered this architecture earlier and decided it was not viable at that time.)

Many problems were encountered. It is more difficult to organize and manage spatial data than administrative data, and some additional program components were necessary. The major additional software components not found in administrative nonspatial data bases are as follows:

- Every data base management system needs a query language permitting users to access the data in an interactive ad hoc fashion without the need for formal programming. The standard query languages (for example, the widely used SQL) lack provisions for selection of data based on spatial properties and relations (ANSI/X3H2 1985). It is also necessary to give users methods to select the most appropriate method for display (Egenhofer 1989; Egenhofer & Frank 1988; Frank 1982; Frank 1984b).
- The data models used in administrative data bases, mostly the relational model (Codd 1970), are too restricted for modeling spatial data. Extensions have been investigated, and we expect that the emerging object-oriented methods to describe data will contribute to the solution of the software engineering problems encountered (Dittrich 1986).
- Representing geometry in a formal system in a finite computer was a surprising challenge (Franklin 1984). Traditional Euclidean geometry is not a sufficient base, and we had to resort to combinatorial topology (Frank & Kuhn 1986).

- The data base needed extended methods to structure spatial data that would permit fast retrieval for interactive display of maps (Barrera & Frank 1989; Frank 1980; Frank 1983).

Despite these technical problems, not all of which are completely resolved, commercial systems built around this architecture now appear on the market. Indeed, most of the current systems appear to migrate towards a data base architecture (Herring 1989). The data base architecture forces more integration of the data when they are entered in the system. The possibility to check automatically for consistency between data entered reduces the potential for errors.

The data base oriented (Zurich) architecture is clearly advantageous in cases where data are used for extended periods of time and must be updated to reflect changes occurring during the time of use. Spatial information necessary for operational activities as prescribed by standard operating procedures should be included in a GIS with a data base architecture, and linkage of the GIS to other administrative data bases should be explored.

Using data base technology opens the potential of methods developed for data base management systems in general. Multiuser systems allow many users to access or even to update the same data base without creating conflicts. In a distributed data base, not all the data must be stored at the same location. Indeed, it is often more advantageous to store the data where they are needed and use computer communication networks to access them.

On the other hand, the file oriented (Harvard) architecture is suitable to manage and process data for projects that occur rarely and where there are no clear needs to maintain the data for future use. The Harvard architecture is flexible enough to adapt to the ad hoc nature of such studies, where the need for additional data sets appears only after initial investigations are carried out. Transfer of base data necessary for a project from an operational GIS for administrative use, which is based on a data base, to a project oriented system, is technically possible. Other data may come from the U.S. Geological Survey or the Bureau of the Census, both of which distribute spatial data in a computer readable format. Recently, remote sensing data with very high resolution (30 feet) have become available from SPOT, the French earth observing satellite; such data have been used successfully to detect new roads and to update maps (Ehlers 1989).

Integrated GIS for a Municipality

The data in a GIS should be considered a valuable corporate resource and should be maintained for long-term use. This means we should establish administrative methods to assure that once collected, the data remain up-to-date, but also that we should plan to maintain data for long-term use only when we can organize its actualization. For certain types of data, where we can tolerate a lag, it may be viable to plan regular full collections.

For the data that must be maintained, a locus of responsibility for maintenance must be decided. Only a designated group may be permitted to update, and then only according to fixed rules. Maintaining valuable data requires strict controls for errors; the data base management system with its integrity or consistency constraints can contribute to the effective maintenance of data. Sharing of data among various groups is possible only when the groups agree on standards for data quality and a distribution of the cost of collecting and maintaining the data.

On the other hand, sharing data may contribute to a reduction of the effort necessary for maintenance. One department's activities may deal with changes that affect the data sets used by many others. Traditional administrative organizations then have the originating group send copies of their information to other groups that may be interested. Town or county administrations usually have copies of building permits or deeds registered sent to the assessor's office. In an integrated system, the activities in one group automatically signal another group to assess the situation and update their specialized data if warranted.

GIS for Valuation

Valuation in the United States uses considerable amounts of spatial data. Assessors' departments maintain large files that describe each property and the relevant attributes used to determine its value and an equitable tax. Often, however, assessors lack the tools to deal properly with the spatial aspects of their data. Tax maps are updated using information from registered deeds, but the updates are "penciled in," and, within a few years, new maps need to be drawn.

Similar data sets are used for other services in a municipality, and it appears that sharing of these data sets could be mutually beneficial, provided agreements on data quality, responsibility, and cost sharing can be resolved.

The data that assessors need, and therefore maintain, are valuable for other departments. The GIS technology is the means to maintain not only the registers but the geometric data as well. It becomes feasible to keep the town map up-to-date so that all departments in a municipality may use it. Between the registry of deeds and the assessor's office the information necessary is collected, and methods to use it systematically must be arranged. The technology is certainly available.

Conclusion

GIS technology has matured enough to be used for standard operational tasks in municipal government. The long-term maintenance of information in a data base is a cost-effective and standard practice in most administrations. GIS technology provides a tool to extend the data base concept to the spatial information used for assessment of properties.

Standard operational use of spatial data for assessment and other tasks in a municipality is different from its use for planning and policy decisions. Commercially available GISs are sometimes better suited for project work (the file oriented, or Harvard, architecture) and sometimes for operational use (the data base oriented, or Zurich, architecture). Municipalities will use both and will need systems that allow them to transfer data from the operational GIS to GISs that are established for special projects.

Assessors use and collect large amounts of spatial data but often lack the tools to maintain it properly. GIS is the tool to help with this aspect of their task. The result is a town map which is always up-to-date and thus valuable to many services in a town or county. For the most part, the data have been collected and the technology is available.

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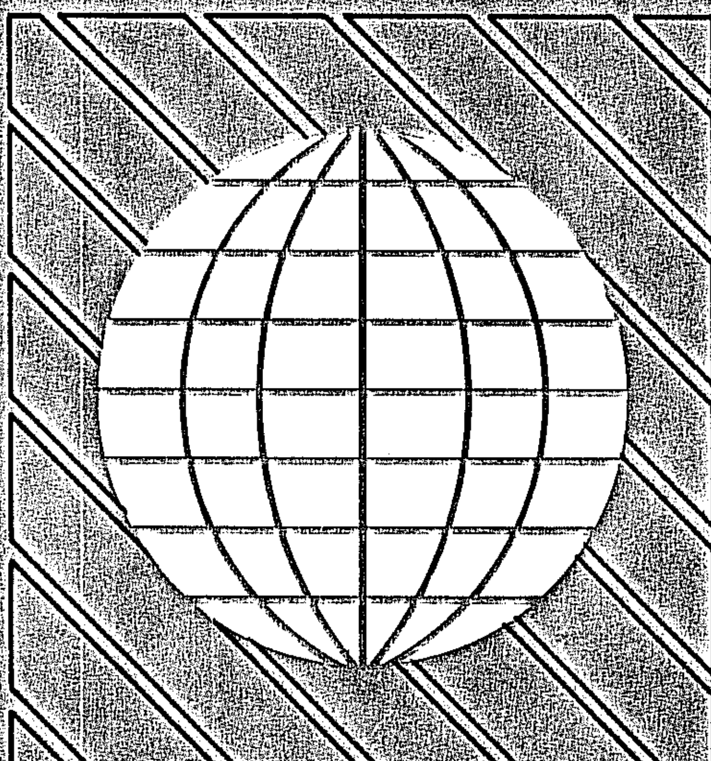

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