AN INFORMATION SYSTEM FOR GEOSCIENCES: DESIGN CONSIDERATIONS

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ABSTRACT

The geosciences, and particularly those involved in resource evaluation, are confronted with data handling problems which involve highly complex three-dimensional objects. This complexity demands advanced object representations and data organizations which the conventional GIS is not designed to deal with. The ability to efficiently store, analyze, and update complex geo-information, together with the ability to plan resource explorations, has been the subject of two years of research here at the University of New Brunswick. This paper describes an integrated spatial information system which has been produced as a result of this research.

The system employs various data representations in order to characterize point, line, surface, and solid type geo-objects. These objects can be highly irregular, fragmented, and non-homogeneous. Both geometric shape and the spatial distribution of attributes are known to the system through an extended octree indexing scheme. This organization of the information permits efficient spatial and attribute queries, including boolean operations and queries which involve object topology. Software was written to utilize these abilities within an interactive graphics session.

Date sets were provided by local mining firms in order to assess the suitability and efficiency of the extended octree structures for geo-applications, and the practical utility of the system. Additional applications software was included to perform geostatistical analyses, and operations involved more specifically in the design of a mine. Details and experiences from the practical assessments are also reported in the paper.

1. BACKGROUND

There has been an increasing use of digital technology in the geosciences during recent years. Similar trends have been observed in the areas of resource evaluation and mining but at a slower rate. The main reason for this lag in development rests with the complexity of the problems addressed. Large amounts, and differing types of spatial information compound these problems. The automated collection of digital survey data and use of computerized drafting systems speeds-up laborious work but contributes very little to resource management and efficient mine planning - a complicated task for the geologist and the mine engineer. There is a demand for a geo-information system which efficiently represents, organizes and stores the complex geometry and geology of natural objects so that analyses and updates can be readily performed.

In the mining context, the system should enable the user to store, retrieve, manipulate and display information about:

- the attributes of any point in the mine
- the shape and volume of the entire ore body or parts of it
- the network of excavations and utilities
- the intersection between mining objects such as the ore body and the stopes
- the shortest distance between objects

- the cross sections, profiles and projections of any objects.

In addition, the system should be designed in a flexible and expansible way so that it can accommodate the variety of shapes and attributes involved in all geo-applications. The information-system approach can satisfy the geoscientific needs in a more integrated way than general purpose computer graphics or CAD systems. A number of smaller computer graphics systems developed for certain geo-applications only (e.g. mining), are also very limited in their capabilities because their design has been aimed at the automation of operations which were performed manually in the past. Conceptually, their procedures are still the same, only a lot faster. Such systems solve the specific problems that they were designed for. Expansions are difficult and often impossible, due to simplistic object modeling and data structures.

This paper describes the characteristics of an information system designed for general geoscientific applications. Particular emphasis was given to mining applications as they are very complex. The research and its implementation were done in conjunction with CARIS- a Computer Aided Resource Information System (Masry, 1982; Lee, 1983), which is in use at the Digital Mapping Laboratory of the University of New Brunswick. As a result of this research, a prototype system, known as *Daedalus*, was developed. The most important aspects of the Daedalus design are:

1. The selection of internal representations for the 3-D spatial geo-objects.

2. The way these representations are created, organized and accessed by the system.

The first aspect is the subject of the next section of this paper. Section 3 presents the overall system design with emphasis on the data structure. Results from the practical assessments of the system are reported in section 4.

2. REPRESENTATION OF SPATIAL GEO-OBJECTS

The system developed distinguishes between geometric and attribute geo-information. Geometry relates to the location and shape properties of spatial objects, and consists of metrics and topology. Attributes consist of textual information not related to the shape definition of the objects involved. Geometry and attributes are stored separately.

The system classifies geo-objects into four different geometric types, according to their complexity:

- point type (stations, control points, elevation points),

- line type (utilities, drill-holes, ventilation/power/water lines, transportation, etc.)

- regular solid type (shafts, drifts, ramps, stopes, etc.)

- irregular solid type (most geological objects, stopes, etc.)

The geological information comes primarily from drill-hole data, whilst the input information for the rest of the geo-objects is obtained using standard surveying techniques.

The traditional method of representing 3-D objects is to use multiple orthogonal projections of their surfaces. This method may be sufficient in the case of simple objects, but does not efficiently represent complex objects. In practice, complex objects almost always have to be treated as assemblies of components. Forrest (1978), gives a general complexity measure for objects where:

- *embedding* complexity refers to the dimension of the euclidean space in which the modeled objects are embedded;

- *geometric* (component) complexity refers to the geometry of a component;
- *combinatorial* complexity refers to the number of components in an assembly.

Being irregular and possibly non-homogeneous or fragmented, solid-type geo-objects (geo-solids), such as ore bodies, are the most difficult to model. Man made objects usually have a more regular shape. Utilities (point and line type geo-objects), are easier to handle since, in practice, they are of network type and of constant dimensions. Geo-objects (regular or irregular) present high combinatorial complexity. Therefore, many of the geometric operations to perform involve a large number of components and, as such, give rise to significant computational problems.

Considering the complete representations for solid objects (Requicha, 1980), we are mainly interested in the following two:

- *boundary* representations where the surface which encloses the solid object is modeled
- *volume* representations where the solid's interior is represented as a collection of volume primitives of different size.

In the system developed, a simple and robust volume representation - known as *Linear Octree Encoding*, is used to represent the shape of geo-solids and the spatial distribution of their attributes. The Linear Octree is a hierarchical tree structure proposed by Gargantini (1981). Octrees (Samet, 1984), have found many applications in computer graphics and lately in solid modeling (Meagher, 1982). Very recently, they have also been used to represent topography and geology, (Kavouras, 1985; Mark & Cebrian, 1986). In the octree scheme, the areal extend of the application (such as an entire mine), is enclosed in a large cuboid called "universe". The cuboid universe is subdivided into eight subcuboids (octants) of equal size which are indexed in a specific encoding scheme. If octants contain volume of importance (as in solid modeling), they are called *voxels* (volume elements). Each voxel is attached a color depending on whether it lies inside (BLACK), outside (WHITE), or at the border (GREY) of the geo-solid. The subdivision continues recursively only for the GREY voxels, and terminates when either no GREY voxels remain or when a preset resolution is reached. The smallest elements after the Nth subdivision are called *resolution voxels*. The GREY resolution voxels are of importance because they lie on the surface of the geo-solid.

Due to the spatial coherence of nature, neighboring elements are likely to consist of the same material. By aggregating them into homogeneous regions within an octree structure, and by storing only the BLACK and GREY voxels, substantial storage compression can be achieved. More importantly however, such a compression, in contrast to other techniques (Comeau & Holbaek-Hanssen, 1983), does not suppress the topology of the uncompacted data.

Octree modeling has a number of advantages that make it an attractive scheme for modeling ore bodies in underground or open-pit mines, water reservoirs, caverns, and other geo-solids. Some of the perceived advantages are:

- It creates complete and valid representations.
- It can represent arbitrarily irregular or fragmented geo-solids.
- It stores geometry and basic geology in the same scheme.
- It can also represent the interior of non-homogeneous geo-solids such as ore bodies with variable distribution of grades and other properties. It therefore relates easily to geostatistical block estimations and mine planning.

- Rigid and homogeneous ores can be very concisely represented by exploiting their spatial coherence.

- Its hierarchical nature makes the generalization of geo-solids to variable resolutions very simple.

- Geometric operations useful in geology and mining are easy to perform due to the efficiency of algorithms facilitated by the octree scheme itself.

- Both full and void space can be stored in the same scheme, making volume computations for ventilation analyses trivial.

- Octree modeling can be used in the finite element method, being therefore useful in deformation analysis and rock mechanics, (Chrzanowski et al., 1983).

- The scheme maintains adjacency relations so that different geo-objects (such as ore bodies, excavations and utilities), can be spatially related without extensive searches in an extended data base.

The octree representation scheme has also its disadvantages. It is shift and rotation variant; it is not suitable for surface analysis; and it always involves some approximation when converted to a boundary representation. These disadvantages would be serious in many industrial applications. In geo-applications however, they do not seem to be crucial, and are outweighed by the advantages. For those special geo-applications where both accurate surface description and knowledge of the solid's interior are important, either multiple or hybrid representations (Carlbom et al., 1985; Kavouras, 1986) have to be employed.

In Daedalus, block models are computed from geological sections and polyhedra, (Smart, 1986)(Fig. 1). The system can also utilize block models which have been estimated from a geostatistical package. Octrees are then easily generated by reducing the block models. The procedure for creating representations for ore bodies or other geosolids, can be outlined as follows:

High level programs are used to format and store the geometric and geological core data derived from drill-holes. If a geostatistical block estimation for the entire mine area, already exists, a special octree aggregation/classification procedure (Kavouras, 1986), can be directly used to define the ore body. If this is not the case, a number of interactive steps have to be followed:

-- The geologist retrieves selectively all the drill-hole information which lies within a particular section of certain thickness. He then, semi-interactively defines the ore-waste contact. From correlation of parallel adjacent sections, a complete boundary model of the ore is computed. Next, the boundary model is converted to block data (spatial enumeration arrays), (Smart, 1986).

-- The geological sections can be simple polygons, in which case, no grade variations are distinguished inside the ore. If the ore body is indeed homogeneous, then all blocks carry the same geological attributes. If however, there is an important variation of ore quality, geostatistics can be used to estimate accurate grade values for all generated blocks.

-- The generated blocks are finally converted to the octree voxel representation using the octree aggregation/classification procedure. Both grade values and their estimated accuracy are used to classify ore zones of certain richness.

Whereas modeling of irregular geo-solids is a complex problem, the modeling of regular solids and point/line type utilities is much easier. In Daedalus, the internal representations for regular solids and other utilities consist of the coordinates of characteristic points of the object's axes, and a short list of other geometric (usually cross-sectional) parameters. Namely, the solid is not represented explicitly as in the case of octrees, but only implicitly by some parameters. The actual solid in an octree or other form, may be computed locally when some geometric problem, such as an intersection, has to be solved.

Surface type geo-objects (geo-surfaces), can be treated as thin solids, and be discretely represented as octrees. Some applications however, may require an explicit surface description. The data structure of Daedalus has been designed to accommodate simplicial composite surfaces with planar polygonal faces, and full topological surface-face-vertex description (Baumgart, 1975). Complex handling however is still under development.

3. SYSTEM DESIGN - DATA STRUCTURE

In order to explain the different modules of the system, consider the logical system design, as shown in figure 2a.

At the lowest level of the system stands the data base. It consists of the digital shape representations of all objects, their attributes, and nothing else.

At the next higher level - the data structure of the system, there exist a number of basic facilities for organizing new information in the data base or for accessing previously stored data. This organization also ensures the integrity of the information (such as validity of representations). Spatial searches in given locations and their neighborhood are facilitated here. Elementary but robust operations on data base entities, such as octree aggregation of neighboring voxels, also belong to this level.

The next level contains modeling and low level general operations. Here internal representations of geo-objects are created and/or converted. Geometric operations perform volume/surface computations, projections, sections, and transformations on the stored objects. Set (boolean) operations perform union, subtraction or intersection on octree encoded objects (Reeler, 1986).

At the highest level, there are operations to answer complex metric, topological and attribute queries. Other algorithms perform hidden surface removal on selectively displayed mine sections. Finally, application programs can perform user requested operations, such as contouring, volume computations, geostatistical evaluations, interference/adjacency analysis, and so on.

In order to provide the necessary efficiency, the data structure of Daedalus consists of five sub-structures, (Fig. 2b):

-- The VOXEL structure which contains data files and access methods to the octree representations of all geo-solids. Voxel geometry and basic geology can be stored together, whilst additional attributes are kept in the attribute files. The file structure allows for direct accessing of single voxels and their attributes. The so far experience with geo-applications shows that direct accessing to single pieces of information is essential and always requested by the users.

-- The SURFACE structure which contains data files and access methods to the simplicial composite surface representations of all geo-surfaces. Integration of this structure into the Daedalus system is still in progress.

-- The CARIS data files and access methods to all representations of point, line, and regular solid type geo-objects. The CARIS structure can handle high densities of utility data with very satisfactory performance.

-- The CUBEL space subdivision indexing scheme which points to all point, line, surface or regular solid type objects of each specific CUBoid ELement in the application universe. The cubel size is based on the density of spatial information. Global density criteria result to a fixed cubel size. Local density criteria require a dynamic and variable cubel size which has to be updated as information is added or deleted from the data base. Empty

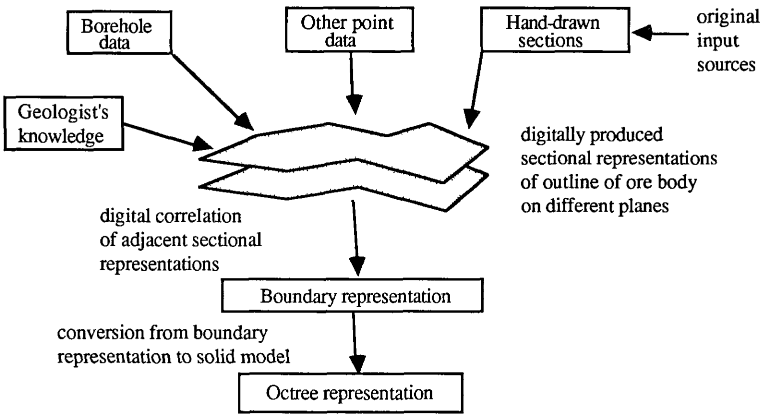


Figure 1 : From Sectional to Octree Representations, (from Smart, 1986).

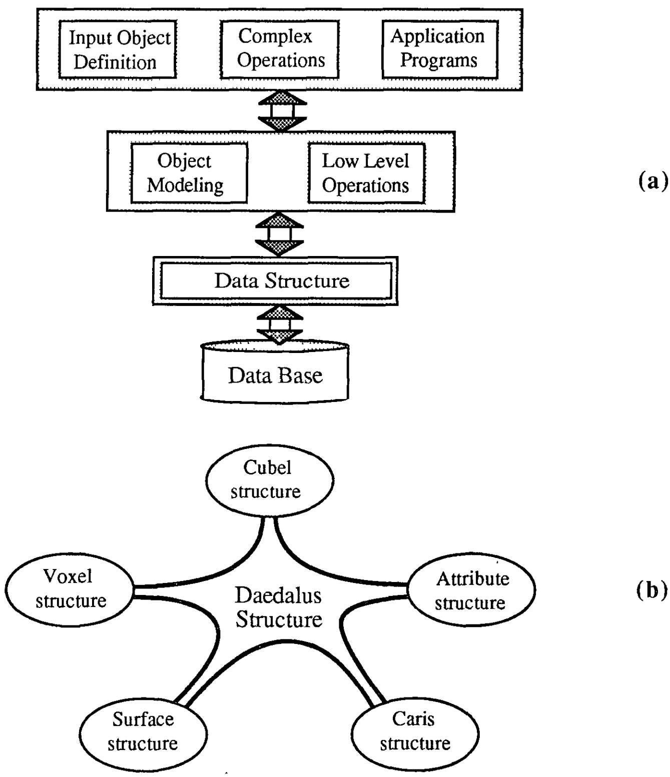


Figure 2: System Design: Daedalus Modules (a) and Structure (b).

cubels are not stored. By basing it on a similar octree-encoding-scheme, the cubel structure is implicitly linked to the voxel structure through the use of linear keys. Results from most applications with a fixed cubel size have been satisfactory. More analysis is however still required in order to determine the optimal cubel size for variable densities and operations.

-- The ATTRIBUTE structure, which contains textual information not directly related to the geometry of the spatial objects. Any attribute information, such as utility maintenance records, land ownerships, detailed geological descriptions, and exploitation history are stored in attribute files and are accessed via a commercially available DBMS.

4. PRACTICAL ASSESSMENTS

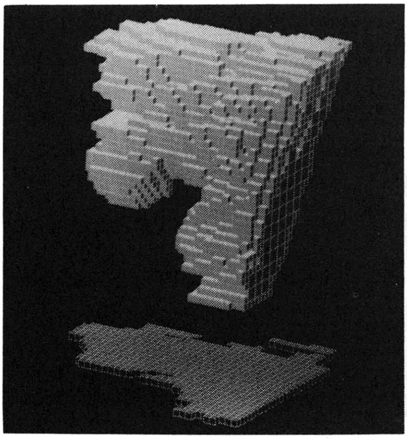
The system has been assessed using data sets provided by local mining firms. The assessment was based on various mandatory requirements for a suitable spatial information system. A summary of those requirements were:

- Suitability of the selected schemes in representing point, line, and regular-solid type geo-objects.
- Suitability of the octree scheme as a representation of irregular geo-solids, and particularly ore bodies with variable distribution of ore quality.
- Sufficient compaction for homogeneous and non-fragmented ore bodies.
- Fast access to any piece of spatial information, without extensive searches.
- Efficient interactive geometric manipulations on block models which involve up to hundreds of thousands of blocks. In particular, boolean operations, sectioning, and volume computations are very essential to mine design and planning.
- Integration with all mining objects and surface topography.
- Attribute analysis based on user specified criteria.

We present below a real mine test case of an underground gold ore deposit. The block grades and their accuracy had been previously estimated using geostatistics. The block model consisted of cubic blocks (20x20x20) cubic feet, and the areal extend of the estimation was (3800 x 1600) square feet, with a vertical thickness of 840 feet. Therefore, the model consisted of (190x80x42) = 638,400 single blocks. The range of block grades varied (non-uniformly), between 0.000 and 5.368 ounces of gold per ton.

Being quite fragmented, the ore body could not be modeled by a boundary representation, and the octree scheme was ideal to use as an internal representation. Using a cut-off grade of 0.100 ounces/ton, the blocks were classified as waste (below cut-off grade), or ore (above cut-off grade). The resulted ore body consisted of only 30,412 blocks. A subsequent octree aggregation based only on adjacency, resulted in an ore body of 17,007 voxels of different sizes (Fig. 3). The ore grades varied between 0.104 and 5.368 ounces/ton, with a mean single block grade of 0.504 ounces/ton, and a standard deviation of 0.286 ounces/ton. Since the number of voxels is directly proportional to the surface area of the encoded solid (Meagher, 1982), the compaction would have been much higher if the ore body was not so fragmented.

In order to assess effectiveness and efficiency of geometric operations, excavations were then designed in the form of shafts, ramps, drifts and stopes, for three major levels (Fig. 4). The surface topography was also encoded in the data base (Fig. 4). Intersections were then computed among excavations, the ore body, and the drill-holes. In this way, any undesirable interference was avoided, and the stopes were optimally positioned with respect to the ore body (Fig. 5). Volumes of recoverable ore and of void space were then



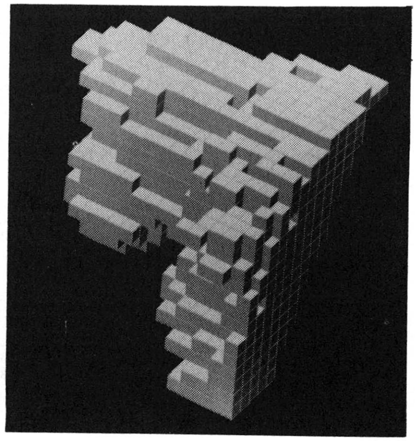


Figure 3 : A Portion of the Ore Body, Detailed and Generalized.

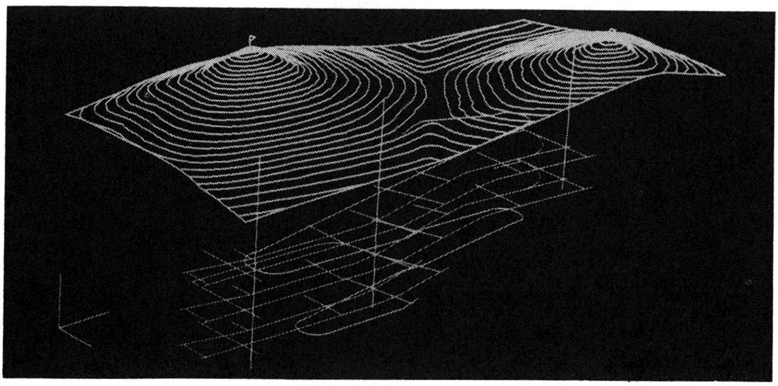


Figure 4 : Surface and Portion of Underground Utilities.

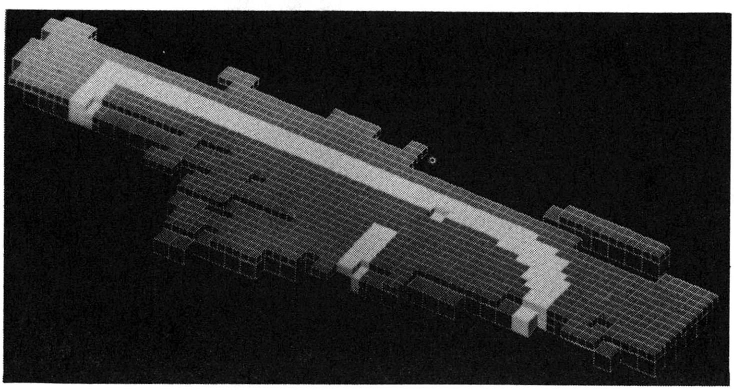


Figure 5 : Embedded Excavation in the Ore Body.

computed. The first volume computation serves the production planning, and the second serves the ventilation analysis. The above operations were performed in the area of interest each time (e.g. stopes and ore of one level at a time), without involving other parts of the data base. This significantly increased the efficiency of the operations.

Attribute analysis was also assessed, in which queries such as: "Retrieve all blocks which are of certain size and have an ore grade between z1 and z2 ounces/ton", were invoked. Such a query generates an attribute report where a summary of all blocks found is listed, along with their position with respect to the rest of the ore. Volumes and statistics are also displayed on a graphics screen or printed. Other queries, such as: "Find the shortest distance between certain drifts/stopes and the rich blocks of the ore", were also assessed.

The overall assessment showed that the selected schemes and particularly the octree encoding, are suitable to represent a wide variety of mining geo-objects. Geometric operations - essential to mine design, are performed efficiently. Attribute analyses are also satisfactory. All these queries can be performed comfortably in an interactive session. There are however, a number of optimizations which are required, in order to make the prototype system a production system:

- Daedalus structure has to be fully integrated with the CARIS structure and peripheral utility programs.

- Additional tests and assessments with other mining conditions, or geo-applications are also needed.

- The main system should include some additional peripheral utility programs, such as 3-D network analysis for route selection in mine planning, some aided-design functions, and more sophisticated display programs. Integration with a digital terrain modeling and analysis package also appears to be desirable.

5. FINAL REMARKS

A prototype Spatial Information System for mining applications has been developed and tested at the University of New Brunswick. Its sophisticated design proves to be flexible and expansible in its handling of geo-applications. Development will still continue in order to optimize certain system modules, and add some peripheral utilities. Results have been very satisfactory and local mining firms have expressed a strong interest in adopting a production system.

In order to satisfy as many adverse applications as possible, future research will be directed towards the incorporation of complete surface representations in the Daedalus system. Also, the complexity, usefulness, and potential implementation of hybrid and multiple representations will be investigated.

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