OBJECT-ORIENTED GIS AND REPRESENTATION OF MULTI-DETAILED DATA

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PURPOSE

Object-Oriented Geographic Information System can be named as a system in which DBMS is used for restoring of cartographic representation in a required level of detail corresponding to determined scale of map with the minimum data duplication and data reduction. The concept of multi-detailed data directly connects with a concept of map generalization.
The present article deals with the problem of creation of a Multi-Detailed Object-Oriented GIS (MGIS). Main attention will be paid to problems of implementation of cartographic generalization (CG) in GISs. While designing any MGIS, it is proposed to use Object-Oriented Approach (OOA), the latter being the most appropriate tools for implementation of methods of CG in GISs. Issues of utilizing OOA properties at various stages of generalization decision-making are discussed. The inner structure of the object-oriented model of MGIS spatial objects has been considered. Attached is a flow-chart which reflects the main components and data interface of the MGIS. A number of MGIS object classes is studied in detail, interface between MGIS objects and CG methods is presented. OOA can not sometimes be applied to description of CG processes. That is why besides OOA it is necessary to use other intellectual approaches, as noted below.

INTRODUCTION

Basing on personal experience and various works on ACG and multi-detail imaging in MGIS, it becomes evident that there is a need of supporting a unified model of a single object in the GIS data base (Aasgaard,1992, Beard,1991, Govorov,1994,1995, Grunreich,1993, Jones,1991, Khorev, 1996, Buttenfield,1991, van Oosterom,1995, etc.).
The problem of creation of MGIS is directly connected with the problem of automation of cartographic generalization (CG).
Digital CG is utilization of the mechanism of abstraction as applied to real-world objects with the idea to formulate a reality image with the use of simplification and supplement. This abstraction is of multi-factor character. That is why the CG process in GIS can be automated only with the use of methods of data processing utilized in intellectual systems (Buttenfield,1991, Govorov,1995, Zhang,1993). Attempts to model cartographic generalization within the framework of geo-relational approach lead only to development of interactive cartographic generalizator designed for creation of cartographic image of an object, not of a whole digital cartographic model of the related phenomenon (Govorov,1995). In a relational model are stored relations not between separate objects but those between types of data. Different data types imply different tables.
One of the most applicable approaches can be object-oriented approach (OOA) (Gunter,1994, Milne,1993, Rumbaugh,1991, Vijibrief,1992, etc.). Such approach does not presupposes mere usage of OO programming technologies, but also application of such technologies to such areas as OO DBMS, system CADs; representation of knowledge; user graphic interface and OO analysis technique (Helokunas,1994).
Development or extension of a specialized OO DBMS can become the basis of creation of a MGIS. An OO database is a base not only developed in the OO language but also a base storing objects with all their attributes, methods and interobject relations (Cattell, 1994). Such a base practically does not require DBMS because all information about behavior of objects is contained in the objects themselves as methods.
Usage of OO DBMS in conjunction with a decision-making system (DMS) will enable construction of a unified MGIS. Such a system will enable it to evaluate the use of OO DBMS objects and to create necessary imaging models disregarding the tasks set forth.
Application of OOA for description of CG processes in digital media is justified by the fact that many OOA characteristics can easily describe the process of abstraction of an OO entity in a map. Here the very notion of a CG process is understood as design of an OO model of a geophysical phenomenon and OOA to actual implementation of cartographic modeling during visualization.

OBJECT-ORIENTED APPROACH IN GIS

The concept of OOA is widely used in program languages, DBMS, information systems, etc. Such concept is also used at GIS construction (Gunter,1994, Milne,1993, Helokunas,1994, Stonebraker,1986, Vijidrief,1992, etc.).
Main characteristics of OO GIS are as follows:
1) object-centered data model;

2) presence of object operations and behavior functions in the data model;
3) inherent links between object classes.
Completeness of OOA in GIS is described by (Helokunas,1994):
- object-based system. Information is presented as a geographic object (GO), not as layers or tiles as in case of traditional GISs;
- object-centered system. As types of objects we have geometrical primitives and their topological varieties, as well as other geographical entities and phenomena;
- OO graphic user interface;
- usage of OO programming principles;
- object-oriented data base.

The main notion of OO GIS is an object. The paradigm of an object is described by the following notions: encapsulation, identity, classification, relationship, inheritance, aggregation, grouping, polymorphism.

OO GIS contains varied objects, including entity model - a geographical object (GO). Similar objects can be grouped into object classes. The structure of classes is defined by all characteristics of grouped objects. The object classes can present a strict hierarchy, i.e. an object of a certain class is automatically accounted for in the upper classes. Objects of the hierarchy, as a rule, inherit characteristics of the upper classes. Non-hierarchical classification of objects and classes of objects is also possible. In such case encapsulation of object-related methods from other classes of objects is being performed, in accordance with user-designed links between objects.

There exist two types of object description in OO DBMS:
- structural object orientation. In such case the data model supports designing of complex structural object classes;
- behavior object orientation. In such case the data model supports designing of user-defined object classes.

MAJOR TYPES OF OO GIS OBJECTS

Object classes used in GIS, can be divided into two types (ESRI,1994):
- abstract classes. Such object classes do not contain any concrete specimens of an object. They provide general methods and attributes which are inherited by sub-classes;
- concrete classes. Such object classes contain full specimens of objects.

This is the system view on the classification of object's classes.

OO DBMS presents the following major groups of objects:

1. Theme objects and GOs. In OO DBMS geographical information is presented with the help of theme objects, which represent information of the real world. Theme objects can be simple and complex, i.e. consisting of other theme objects. Theme objects can possess various attributes presenting theme characteristics. The characteristics are as follows: simple attributes; complex attributes; reference attributes.
One of the sub-types of theme objects are GOs. Such objects are characterized not only by these attributes, but also by containing geometrical objects. I.e., GOs are characterized by theme content and spatial characteristics. Such objects are in fact abstract object, as they may contain no data of theme content, but encapsulate these from other classes.
2. Geometrical objects. Geometrical objects are used to describe geometrical essence of geographical objects. A geometrical object consists of elementary geometrical objects (nodes, label point, vertex, etc.). Such geometrical objects present a class consisting of sub-classes, such as a point, a chain and a polygon. There may be topological relations between these classes: a polygon can have a chain border, one chain can belong to a multitude of polygons, etc. A geometrical object can be simple, i.e. comprising only a point, a chain or a polygon. Also a geometrical object can be complex, and comprise a multitude of geometrical objects. Such description makes it possible to describe geometry of any GO of free form with the preserved in the geometrical objects, as a rule, in full, that is why such objects can be called concrete.
3. Graphic objects and cartographic objects. Graphic objects are designed to represent theme objects. A graphic object is characterized by such attributes as color, type of line, font, etc. Also a graphic object can import image objects from data tables, raster and vector objects of other GISs, multi-media objects, etc. A graphic object can be part of a theme object. A component of the graphic object is a cartographic object. Cartographic objects contain methods defining GOs characteristics. In particular, cartographic methods encapsulate CG methods of GOs. Cartographic objects are also related in their major part to abstract objects.
4. Other objects. There exist object classes designed to organize interactive access to geodata, objects to organize user interface, objects to provide import of components from other informational systems, etc.

GENERALIZATION KNOWLEDGES ON ENTITY AND OOA

CG process in GIS media can be divided into two stages:
1. Acquiring of spatial multi-detail model of a geographical object in digital form (OOSMDM).
2. Cartographic representation of OOSMDM in the required detail scale (OOCR).

Main requirements for creation of CG can be divided into four groups (Buttrnfield,1991):
1) phenomenon-based factors which are caused by the conceptual nature of the modeled entity (the essential of the phenomenon analyzed; peculiarities of the area; relations among entities, etc.);
2) purpose-oriented factors (user needs and purposes; contents; scale; technology of map compilation, etc.);
3) graphic media and format factors (visualization purpose; technology of map compilation; types of cartographic objects; methods of cartographic representation; rules for map design, etc.);
4) computational factors (efficiency of introduction of the information system).

Factor 1 and 4 are of most importance at the first stage of CG. Factors 2 and 3 are accounted for during the second stage, with influence of factors 1 and 4 also felt here. Here factor 1 has the highest priority during realization of interactive processes, during conflicts at the 2nd stage of CG.

According to the above-mentioned requirements we should be able to pinpoint the following types of knowledges needs for implementation of ACG (Buttrnfield, 1991): 1) structural knowledge; 2) geometrical knowledge; 3) procedural knowledge; 4) application requirements.

The first two types of knowledge can be used during the first stage of CG. Here the four types of abstraction of a GO into its digital representation are used: classification, association, generalization and aggregation (Buttrnfield,1991). All these types of abstraction are well described by the OOA. OO multi-detail GO model supports such types of relations as generalization (inheritance), aggregation (composition) and multiplicity of association. Such characteristics can be applied for multi-detail representation of a GO at: grouping (aggregation) of various types; progressive refinement of subclasses in the form of hierarchy structures with inheritance of characteristics and behavior from a superior class; introduction of semantic multiple links between objects of the same level.

Besides, as it is supposed that GO is composed of geometrical subjects, such characteristics of the OOA as structural OO and encapsulation are of utmost importance. Such traits of the OOA support design of complex objects and representation thereof or their components at various stages of activities.

The set of GO classes has not been pre-fixed and a user shall be able to extend it. And such properties of OOA as overloading, polymorphism, behavioral and late binding can enable this.

One of the important traits of OOA for support of multi-detail representation of GOs is dynamic binding. This characteristic of OOA enables real-time transfer of changes performed at base level of the entity model, to lower-detail levels that are used as applications.

At the second stage a symbol model of a GO utilizing 3rd and 4th knowledges, can be created on the basis of the OO model of a geographical model, having such traits as inheritance, association, aggregation, encapsulation, overloading, polymorphism, etc. Here OOSMDM is used for multi-scale analysis of data and OO cartography modeling. As a result of analysis of OOSMDM a user should be able to get a map of the required scale.

A GO exists in the OOGDB based on the principle of OOA identification. This principle means unique properties of each object and existence of each object apart from its notions.

During design of a CO of a certain level of details which would comply to the prescribed scale, the message mechanism of OOA is very important. Thanks to these characteristics, a OOA object is able to communicate with PC and other objects, and to perform all computations needed for its scale representation and solving of graphic and semantic conflicts between adjacent objects during cartographic visualization.

The following chapters reflect structural MGIS schemes and some of the groups of its classes. The links between classes are based on the above OOA principles. This overview of MGIS classes is illustrated by the following notions ⟶ generalization, ⟷ aggregation, —— association (one to one), ⟶ association (one to many) (Rumbaugh,1991).

THE OBJECT-ORIENTED MODEL OF MGIS SPATIAL OBJECTS

The MGIS Spatial objects can be divided into abstract and conceptual ones. This is application approach to the classification of object's classes.

A geographic object is simulated in MGIS with the aid of spatial objects of five hierarchical classes:

- inner or elementary geometric objects;
- simple geometric objects;
- complex geometric objects;
- digital models of geographic objects (GO);
- cartographic objects.

The spatial objects of the first three classes belong to abstract spatial objects, but acc. to their type, they belong to concrete ones. The digital and cartographic model of a geographic object is formed of the spatial objects of the geometric classes.

Each object at a basic level is formed of two essences: records and relations, the above-mentioned level being no object-oriented level but, as a matter of fact, a semantic network.

A record can have an arbitrary structure; in such a case the DBMS has no idea about its content. The record can change its dimensions. Anything can be stored in it, including executed code, generalized line-tree (Jones,1991, van Oosterom,1995), R-tree, etc. To gain access to the record, methods - procedures are available (e.g. methods of implementing generalization techniques, determination of generalization conflicts, plotting of implicit Delaunay pyramid, etc.).

Record are joined by relations. A relation indicates two records, and is characterized by a direction and type. Each record has references to all its relations. Each relation has a unique identifier. A type of relation also represents a record. The latter can be modified, too. A type controls records belonging to it.

A special record - procedure contains a set of operations for a definite type. It is connected with this type by a relation of a respective kind. While dealing with a record belonging to a definite type the respective procedure is recalled from the set of operations. The procedure works at the contents of the records.

Inheritance is realized through types and relations. One type is related to another in a hereditary way. The system recalls operations: first for the derivative type, then for the basic one. Inheritance can be plural.

The indexing of records is carried out by inserting a special index record-type ensuring fast execution of an inquiry.

The object can belong to several types, and change a type. It must not necessarily belong to a definite type.

The conceptual data model is formed of abstract and concrete objects and methods (permissible operations with objects), and is object-oriented. Conceptual objects are realized by writing the respective set of procedures processing inquiries to records of the given type (e.g. inquiry about the value of the field or as to the possibility of changing the value of the field).

CONCEPT OF THE OBJECT-ORIENTED MULTI-DETAILED GIS

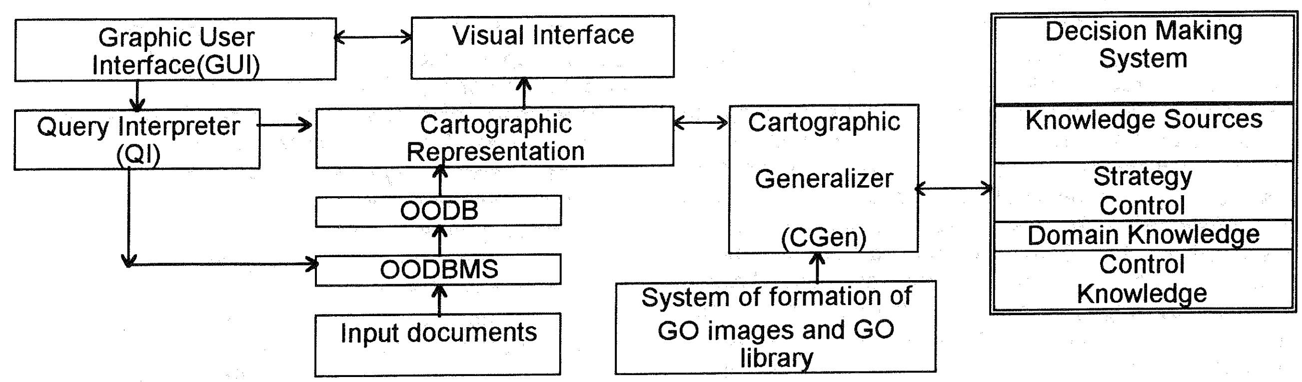

Figure 1 Structural scheme of OOMGIS

The details of the concept of the Object-Oriented Multi-Detailed GIS were proposed in (Khorev,1996).

STRUCTURE OF GO CLASSES

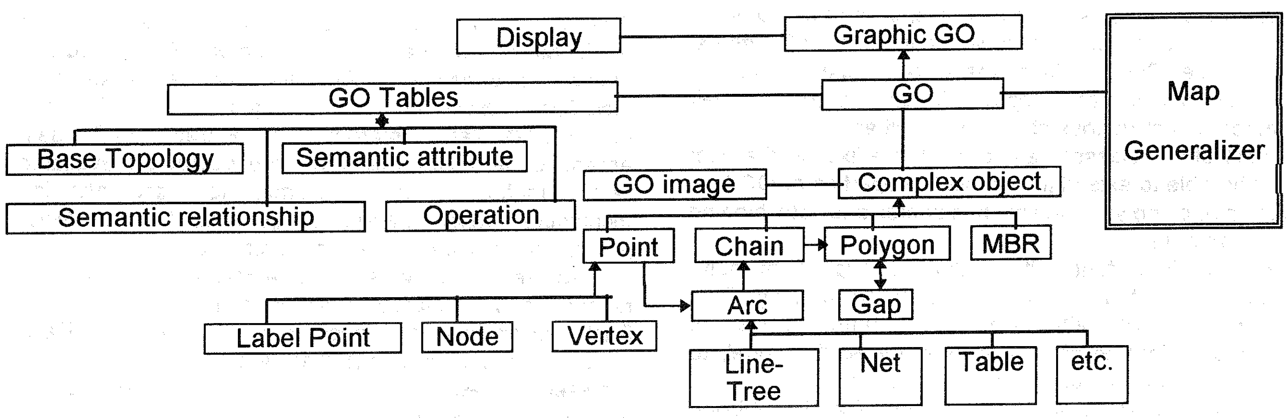

Figure 2 Scheme of GO classes

Entity is a type of phenomenon. GO is and entity model in OODB. Geographical object is a spatial object. Geographical object encapsulates behavior and data associated with geometric figures and their composition. Geographic tables stores geographical objects. Arc can be represented as certain data structures. The latter cab be chosen depending on the efficiency of restoration of multi-detail representation of an arc as a GO element. This is done with the help of CG which also accounts for the type of entity while choosing the structure of GO geometry. To do this, CG exchanges messages with the DMS. The GO images library contains description of structures of various types of entities, and can be expanded depending on the requirements of a user.

STRUCTURE OF SYMBOL CLASSES

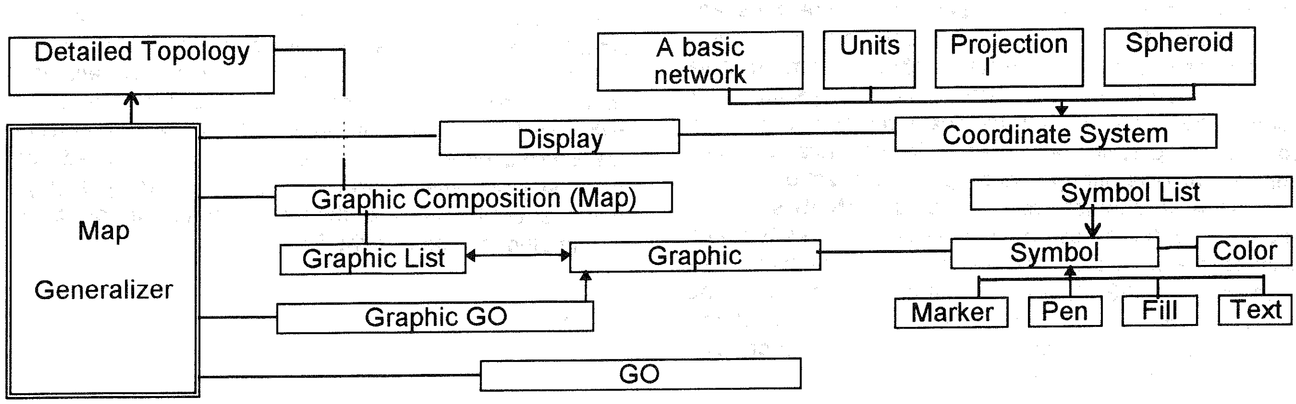

Figure 3 Scheme of symbol classes

A display encapsulates a coordinate system and the knowledge of how to place objects onto a portion of the physical computer screen. A graphic tool is and objects that "knows" how to draw a GO on a display with a certain set of symbols. CGen interferes with the process of cartographic representation two times. First time, CGen enables it to restore the generalized image of GO in the required level of details depending on entity characteristics as prescribed in the multi-detail model. During the next stage CGen solves conflicts: geometrical (too small, too narrow, too short, too close) (Mackaness, 1994) and semantic, which are based on the nature of an entity and links between entities (e.g., a road crosses a river, the latter being over 2 m deep; here a third entity must be shown - a bridge). During such conflicts solving interference of an operator can be needed, so an exchange of messages between CGen and the user's display is required.

GO topology of two types can be supported: local neighborhood topology and Delaunay triangulation. Support of base topology and creation of "on flight" topology for intermittent detail level can be useful while solving conflicts at visualization of cartographic images of entities and control of adequacy of CG processes.

CONCLUSION

The representation methods of various generalization techniques of multi-detailed objects, the results of the inventory of existing guidelines of Russian cartography, the operation and corresponding map generalization techniques were investigated in early works (Govorov,1994,1995, Khorev,1996). Also, CG methods for the 1st and 2nd levels MGISs have been identified and systematized.

The defined objects of MGIS can be used as: 1) functions for object-oriented model of features; 2) principles for construction multi-detailed structures of the features or geometrical objects; 3) selection techniques of suitable algorithms for cartographic generalization.

It must be noted that the proposed approach to creation of MGIS and the developed complex of software, has as its prerequisite the ability to re-construct and interchange components of the system. Also for realization of MGIS it is proposed to use such modern technologies as OLE and DDE data exchange.

To make up the full package of the system it is proposed to use the GO library sets for various theme applications, including industrial DMS and CG.

Further research efforts will be concerned with development of spatial access mechanism by means of the overlapping region's scheme; the questions of integrity of multi-detail representation data base; methods of maintenance of topological objects relationships; object-layer organization and linking; tiling and edge-matching solutions.

The proposed approach is taken as the main principle for development of an object-oriented geographic information system "SOCRAT-GEO". The "SOCRAT-GEO" uses BORLAND C++ 4.51 compiler, tool kit for creating a "client-server" application - DELPHI95, and other programming tools.

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