A System Approach to Automated Map Generalization[1]

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Abstract

This paper presents a system approach to tackle problems involved in automated map generalization. The system combines database generalization and dynamic object generalization capabilities and is coupled with a map agent on top of a map object. The map agent is for the construction of navigating maps, performing tasks on behalf of, and communicating with, users. The object classes are topologically and geometrically structured with the dynamic VMO-tree (Voronoi Map Object Tree). Experiences show that such a system looks promising for providing desirable solutions.

1. Introduction

We present a system approach to tackle problems involved in automated map generalization. The objectives are to combine database generalization and dynamic object generalization capabilities in the system, and to couple a map agent on top of a map object which constructs navigating maps, performs tasks on behalf of, and communicates with users. The object classes are topologically and geometrically structured with the dynamic VMO-tree (Voronoi Map Object Tree). This approach is based on a popular consensus that automated map generalization is actually a part of fundamental problems in GIS development, and the satisfactory solution of it cannot be achieved without an integrated consideration of database modelling, artificial intelligence methods, individual object generalization algorithms, and object-oriented technology.

2. The Schematic View of Automated Map Generalization

Automated map generalization is a complex decision-making process which must be intelligently steered by goals and rules from the geographical application domain, such that the generalized representation conveys knowledge consistent with reality. Taking generalized map production as an integral part of a GIS, it can be started as early as during the geo-database modelling, and ended with the interactive process of querying and presenting in a problem-solving environment where a map is intelligently used (Figure 1).

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[1] This paper was not scheduled for presentation due to its late arrival. The abstract of the paper is added by the editors.

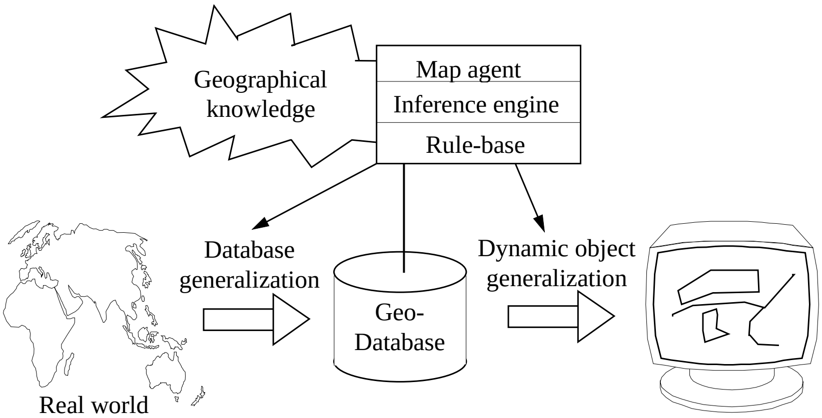


Figure 1. A schematic view of generalization

3. Database Generalization

Database generalization utilizes data modelling formalisms to capture the map structure of applications at a given point of time. The formalism describing geometric objects and their relationships is depicted grammatically in Figure 2.

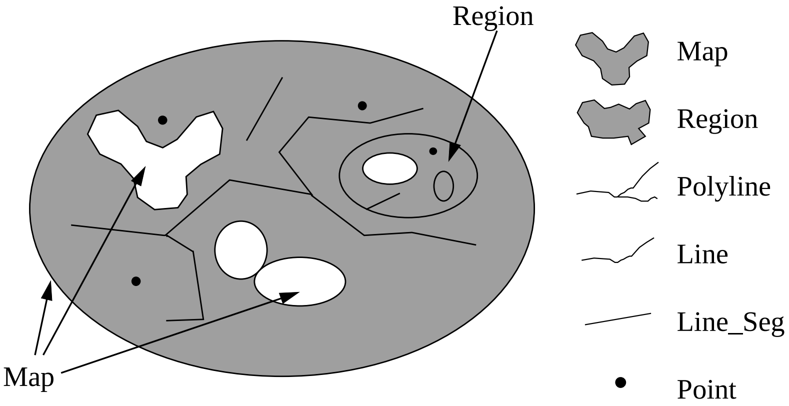


Figure 2. Geometric object classes

Six classes of geometric objects are accommodated with the formalism: maps, regions, polylines, lines, line-segments, and points. The definitions of these classes and their spatial relationships supported by the formal model are descrbed in Yang [1997]. The similarities and differences between maps and regions are worth explaining. Both maps and regions are aggregates of the six object classes. For this reason, they can be thought as container objects. The difference is that the internal structure of a map object is hidden from its container subspace while that of a region object is visible. The interior of a map object within a container constitutes a hole. The reasons for having a map object class, in addition to the region object class, are: 1) the data describing the internal structure of a map may temporarily be unavailable (in networked applications); 2) the internal structure may have a different format (for multimedia representation and heterogeneous databases); and 3) for hierarchical representation and management of large quantities of spatial objects.

The topological and geometric structures of the formalism is implemented with the VMO-tree [Yang and Gold 1996] which is based on the incremental and dynamic Voronoi diagram for points and line segments [Gold 1990; Roos 1991; Gold et al. 1996], and the dynamic spatial object condensation technique (partitioning and merging Voronoi diagrams and saving subsets onto disk pages) [Yang and Gold 1995]. The construction of the VMO-tree reflects an information abstraction process in which higher level objects represent outline views of geographic spaces and details can be examined in lower level objects with successively finer resolutions (Figure 3).

An important step to construct a generalized geographical database is to recognize geometric structures that correspond to geographical phenomena [Mark 1989]. This requires applying on-line knowledge representation techniques to catch structural and process knowledge [Nyerges 1991]. Inference rules need to be devised for generating structural knowledge [Buttenfield 1991] based on neighbourhood reasoning in a geographical context. The dynamic feature and the object-oriented design of the VMO-tree enhance triggering appropriate procedures and rules at the right time and place. The Voronoi diagram is proved to be a reliable local structure to reason and extract perceptual structures from atomic objects [Ahuja and Tuceryan 1989]. An experiment of utilizing the Voronoi diagram for analyzing building clusters was reported recently [Regnauld 1996].

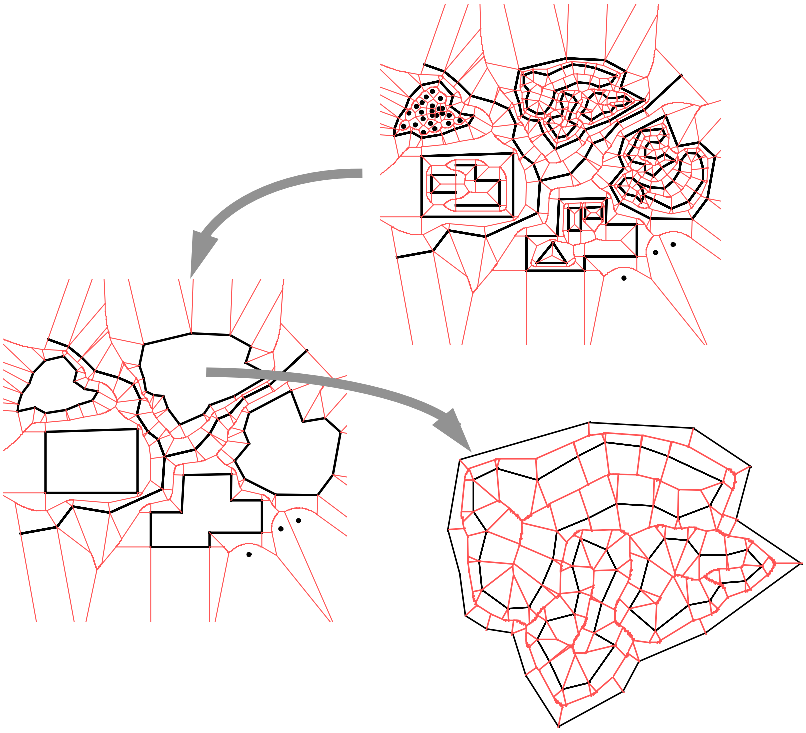


Figure 3 Hierarchical generalization of VMO-tree objects

4. Map Agents

The off-line database design incorporates geographical domain knowledge and cartographers intuition on the structures and constraints of maps. The dynamic database generalization process would rely on both declarative and procedural knowledge and especially, the mechanism to integrate and enrich both types of knowledge through the evolution of the database. A map agent serves as the mechanism in an interactive environment. An artificial agent is an object which possesses formal versions of a mental state, and in particular formal versions of beliefs, capabilities, choices, commitments, and possibly a few other mentalistic-sounding qualities [Shoham 1994]. Autonomous agents are primarily developed from the field of distributed artificial intelligence (DAI) and play active roles in a dynamic environment of a complex system which involves multiple, co-operative decisions by different autonomic components with goals.

The map agent is an object class whose state is a repository of declarative metadata about the mapping classes and rules derived from geographical and cartographic expert knowledge. An example of generalization rules about a bay is given in Mark [1991]. Functions of a map agent constitute the inference engine conducting knowledge collection and representation. The inference engine contains the logic to control and direct search and reasoning techniques. The logic techniques can be characterized as having four basic operations [Michaelsen et al. 1985]: 1) selection of the relevant rules and data elements; 2) matching the active rules against data elements to determine which rules have been triggered, indicating they have satisfied the antecedent condition; 3) scheduling which triggered rules should be fired; and 4) executing (firing) of the rule chosen during the scheduling process. The choice of an appropriate control strategy to address these four actions is dictated by the problem under consideration, the content of the object database, and the structure of the knowledge base.

There is also a technical reason for coupling a map agent on top of the geo-database. A geo-database have classes of geometric objects as well as thematic objects. It is desirable that complex geometric objects are implemented with generalization capabilities so that they know how to generalize themselves before being presented graphically with a given scale. It would be inappropriate to include geographical knowledge in the generalization procedure because one geometric object may be dynamically associated with different thematic objects. On the other hand, a thematic object is a conceptual one which refers to, but is not, a geometric object. It would be awkward to include specific generalization rules in the thematic object because of loss generality. A map agent understanding both thematic and geometric models serves as the coordinator between them.

In the context of map generalization, the primary role of the map agent is to control, schedule, and validate dynamic generalization operations enacted by objects. Another role of the map agent is to aid map uses. To achieve success in automated map generalization, the purposes of mapping must be understood and targeted users must be integrated. Typical uses of maps include navigation, measurements, visualization (of landscape patterns), spatial analysis, planning, designing, simulation, and decision making. Any map use can be transformed as a model of navigating a map. This model would require defining objectives and performing interchangeable outline and concentration processes. The navigation model should help users being persistent on their objectives, with less distraction, and finishing tasks with non-surplus and sufficient information.

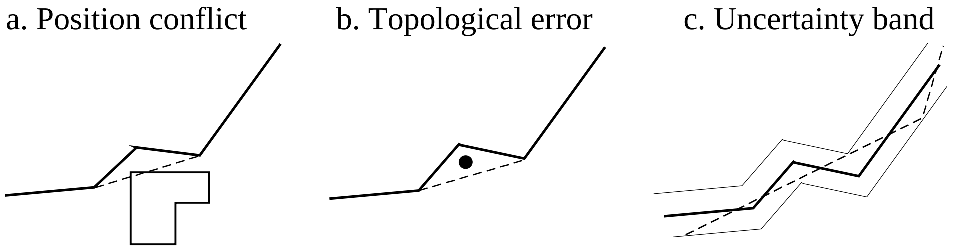
Generating a schedule for a generic navigation model in an autonomous fashion would be a highly desirable goal of the map agent. For this purpose, the map agent needs to perform communication. This includes communication between computer systems, between a system and humans, and among humans with various levels of knowledge. Studies show a strong dissatisfaction concerning current maps to convey knowledge. The impedance between the functional abilities of geographical information systems and the expectations of users is tremendous. Maps developed in current spatial databases may not be the same as those understood by a user. For a specific task, a user may have her/his own interpretation of the space and construct her/his own mental models for the task. The mental models or mental maps are centered with respect to the observer. With a goal specified, a mental map is constructed through a repetitive process, exchanging and updating information between the short term and long term memory spaces. Psychological studies show that cognitive models of spaces in a human brain form some hierarchical structures and that a more generalized perception is obtained by moving his eyes along more detailed small parts of the space.

Programming a map agent in order to mimic map users presents a long-standing challenge. Although the geo-database briefly described earlier represents progressively generalized views of the world, it reflects only one state of limited expert knowledge. How to navigate through the structure and construct different views to present to various users can not be answered very easily. We hope that understanding and developing map agents will lend a hand to solve such problems.

5. Dynamic Object Generalization

Dynamic object generalization is the process activated before an object is drawn on media. How many and what objects to draw is the decision of the map agent in accordance with the purpose of the map use. When an object receives the message to draw itself, it invokes the built-in generalization procedure to prepare the graphics data. The container map object controls the generalization by providing search functions to detect any positional conflicts (Figure 4.a), or topological errors (Figure 4.b) of a proposed generalization with other existing objects decided to be drawn. Futhermore, if an object has a property describing its certainty, an uncertainty band (corridor) can be superimposed to control the quality of the generalization (Figure 4.c). Searching and corroding functions can be performed easily with the support of native geometric and topological structures (in this case, the Voronoi diagram). The function and data flows of the dynamic object generalization process may look like the one in Figure 5.

One of the advantages of having dynamic object generalization is that a map can have varying scales in one representation, that is, more details in the area of interest with a more outlined global picture elsewhere to visualize landscape patterns. Because generalization procedures are built in each geometric object, individual messages concerning resolutions of a generalization can be passed to the object concerned.



a. Position conflict b. Topological error c. Uncertainty band

Figure 4. Detecting conflicts and errors, and controlling uncertainty in dynamic object generalization

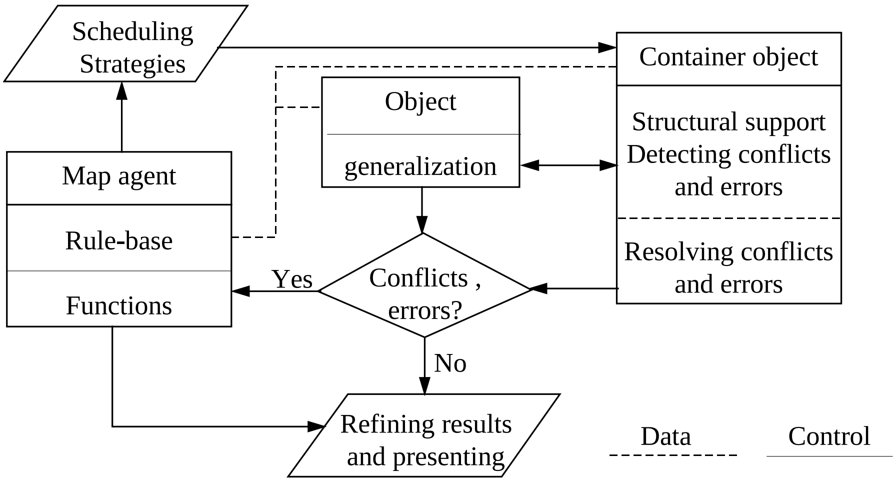


Figure 5 Function and data flows of dynamic object generalization

6 Conclusion

Although the problem of automated map generalization appears to from the “hardware” limitation of mapping media, it has in fact a strong intellectual background and the true solution of it is never simple. The system needs to include individual generalization techniques and more importantly, a mechanism of representing and inducing inference rules to support choice of decisions when one individual method alone fails. The final result, i.e., a generalized map (which may even not need be drawn), must convey an understandable message to help the user completing tasks. The system approach incorporating database generalization through off- and on-line data modelling, dynamic object generalization, and map agents looks promising for providing desirable solutions.

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