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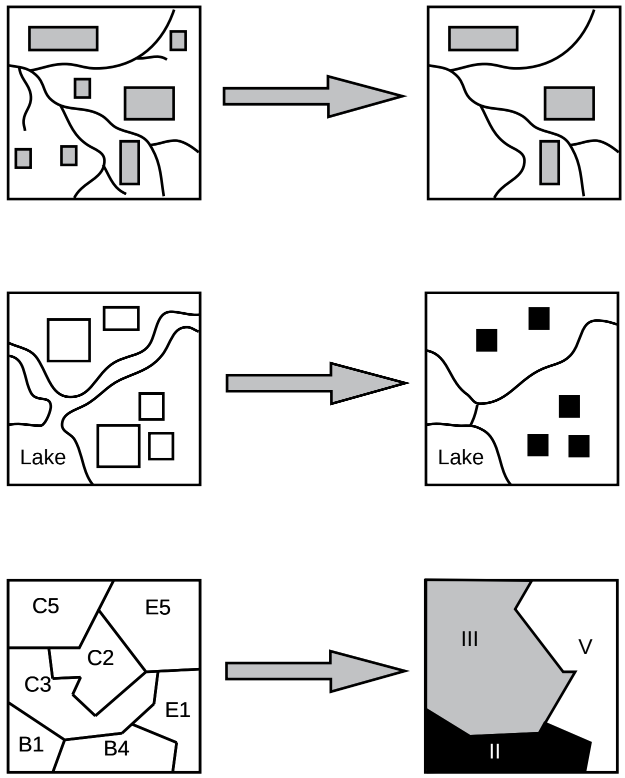


# Automation of Map Generalization

*The Cutting-Edge Technology*

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# Automation of Map Generalization—the Cutting-Edge Technology

## An ESRI White Paper

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# Automation of Map Generalization—the Cutting-Edge Technology

Digital generalization, rooted from conventional cartography, has become an increasing concern in both geographic information system (GIS) and mapping fields. This paper is intended to briefly review the state of the art of the new technology and to help understand the needs and plans for the implementation of digital generalization capability for Environmental Systems Research Institute, Inc. (ESRI), products.

## Generalization—Traditional Way and Modern Technology

Generalization is an essential component in mapmaking. The process of generalization extracts and reduces information from reality or source maps and portrays it to represent a specific theme and/or at a smaller scale, while meeting cartographic specifications and maintaining the representative integrity of the mapped area. Manual generalization, as the traditional means, is extremely subjective and time consuming. Cartographers draw a reduced map by hand. They eliminate unimportant features, simplify lines and boundaries, combine area features, and resolve conflicts as they draw. The result is, no doubt, operator-dependent.

As geographical databases are constantly built, the request for automation of generalization capability for multi-purpose output is in demand. The field of generalization has extended to include GIS applications. Noticeable efforts have been made by researchers and some GIS/mapping software vendors to define digital generalization problems and to develop solutions. However, none of the existing GIS/mapping systems has provided a set of tools that fully satisfies digital generalization needs.

### Review of Digital Generalization Research and Activities

Although principles and guidelines of generalization can be found in cartographic literature and among mapping organizations, there has not existed a set of universal rules that explicitly defines how generalization should be performed. Manual generalization depends on operator's experience and judgment and therefore produces inconsistent results. The lack of fully understanding the process and the lack of technical means that mimic human analysis, decision-making, and actions make the automation of generalization a difficult task. However, the evolution of developing digital generalization technology has gone on for decades. Major efforts and achievements in this field are summarized below:

- In the 1960s and 1970s, isolated research was attempted to develop simple techniques that reduce data complexity. Examples of the few named algorithms are Douglas-Peucker's (Douglas and Peucker, 1973) and Lang's (Lang, 1966) line simplification algorithms; and Brophy's (Brophy, 1972) and Chaiken's (Chaiken, 1974) line smoothing routines.

- Evaluations of existing algorithms have been carried on since the early 1980s (McMaster, 1983; Visvalingam and Whyatt, 1990; Beard, 1991). More comprehensive techniques for automated generalization were continuously explored; modeling and rule-based generalization became an increasing interest in the late 1980s (Nickerson and Freeman, 1986; McMaster and Shea, 1988, and so on).

- Significant progress in digital generalization has been made worldwide in the 1990s. A number of international organizations have been established (see below) to coordinate digital generalization research projects and special meetings. The main focus is to formalize digital generalization in theory and practice it in reality. The availability of more comprehensive generalization systems has provided cartographers with experimental environments.

In order to stimulate and formalize the research activities on digital generalization, the following organizations and working groups have been established:

- The Working Group on Map Generalization under the International Cartographic Association (ICA), as part of the Commission on Advanced Technology, was formed at the fifteenth International Cartographic Conference (ICC) in Bournemouth, United Kingdom, in 1991. It has played an important role in providing a forum for exchanging ideas, supporting a network communication among people and institutions in map generalization, and coordinating activities with other research groups. The most recent significant activity was the three-day workshop on Progress in Automated Map Generalization held prior to the seventeenth ICC in Barcelona, Spain, in 1995. More than thirty active researchers and users presented their work and discussed the short- and long-term research directions and focuses. Another workshop was planned to be held in conjunction with the eighteenth ICC in Stockholm, Sweden, in 1997.

- The Working Group on Automatic Generalization under the Organization Europeenne des Etudes en Photogrammetrie Experimentale (OEEPE) is largely connected to national mapping agencies (NMA). Their research focus is to find solutions for practical problems. The initial project of this group concentrates on developing criteria for the evaluation of the quality of generalization results and on evaluation of commercial generalization software.

- The European Science Foundation has organized a research program called GISDATA. Part of the GISDATA activities is the creation of various task forces that are responsible for the organization of specialist meetings on various issues related to GIS. One of the task forces is on the topic of generalization. A specialist meeting was held in Compiegne, France, in December 1993. As a result of this meeting, a book (edited by Muller, et al., 1995) was published as a collection of articles that represent and describe the state of the art of digital map generalization.
- The U.S. National Center for Geographic Information Analysis (NCGIA) held the Symposium on Map Generalization at Syracuse University in mid-April 1990, funded jointly by Syracuse University. One of NCGIA's research initiatives is "Formalizing Cartographic Knowledge." A specialist meeting was held in October 1993, addressing generalization and other digital cartographic issues.

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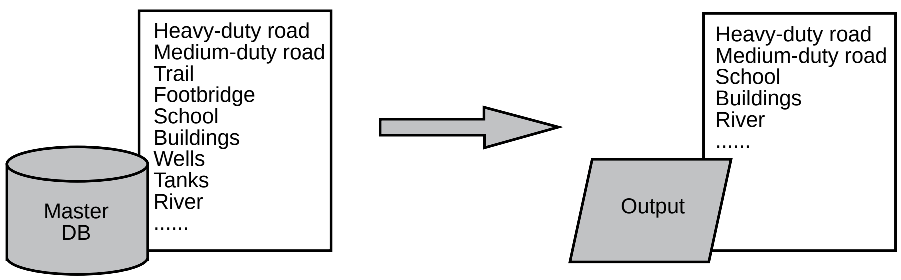
## Generalization Operators

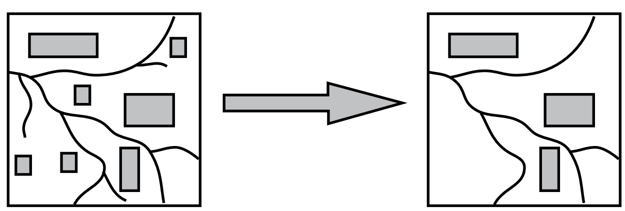
Generalization involves a great deal of human analysis of the geographic data and decisions on what to generalize, how to generalize, and how to resolve symbol conflicts. It would be very difficult to fully automate this process due to the subjective nature of it and the lack of well-defined rules to guide the decision making. The alternative is to automate the computational work as much as possible and leave the decision making to the users, that is the computer-assisted solution.

In order to develop the computer-assisted solution, it is necessary to understand what exactly happens when a cartographer generalizes a map, and to make the operations explicitly defined for digital implementation. A complicated generalization process can be decomposed into the following operation categories, which are described in digital generalization terminology:

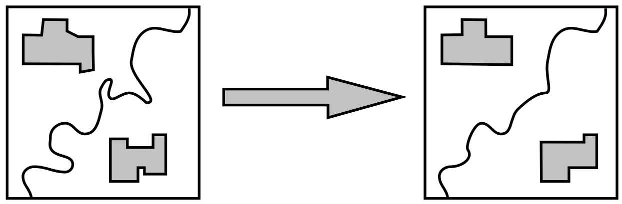
**Preselection—**Selecting certain feature classes from a master database for the inclusion in the final map. What to be selected depends on the target map scale and purpose. The preselected features will participate further generalization operations.



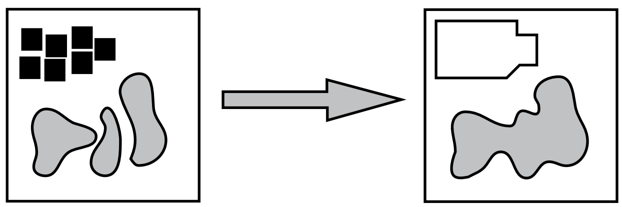

**Elimination—**Selectively eliminating features that are too small, too short, and too insignificant to be presented in the final map; for example, small islands, short roads, little villages, and so on.



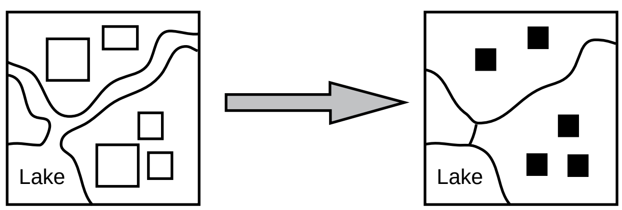
**Simplification—**Removing unnecessary detail, such as extraneous bends and fluctuations, from a line or an area boundary without destroying its essential shape.



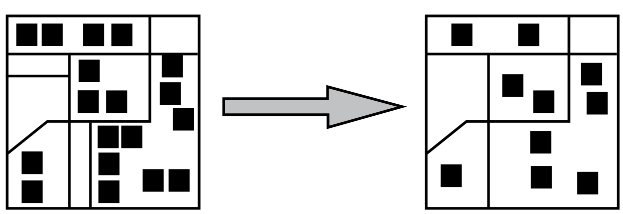
**Aggregation—**Combining features in close proximity or adjacent features into a new area feature; for example, forming a built-up area from a cluster of buildings or joining patches of crop fields into a large agricultural area.



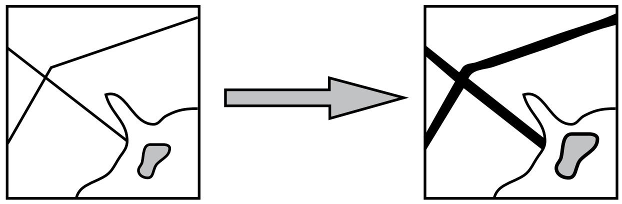
**Collapse—**Reducing a feature dimension or the representation of its spatial extent; for instance, changing an area feature to a linear or point feature, changing a multiple-line feature to a single-line feature, and so on.



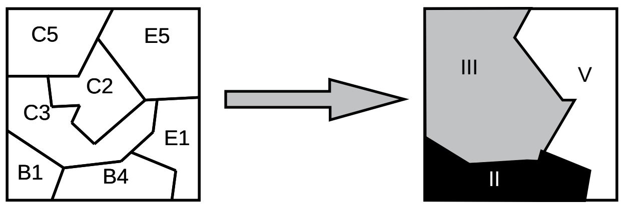

**Typification—**Reducing feature density and the level of detail while maintaining the representative distribution pattern and visual impression of the original feature group; for example, reducing the amount of detail in a drainage network without losing the impression of its structure.



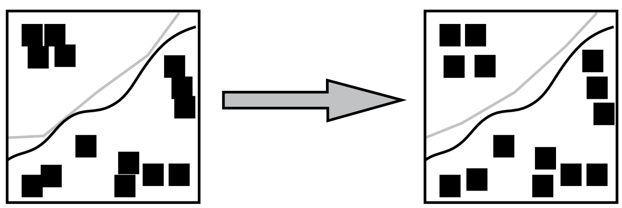
**Exaggeration—**Increasing the spatial extent of a feature representation for the purpose of emphasis and legibility; for example, enlarging the size of an island, which is otherwise small enough to be removed, to include it for its significance as a navigational point of reference.



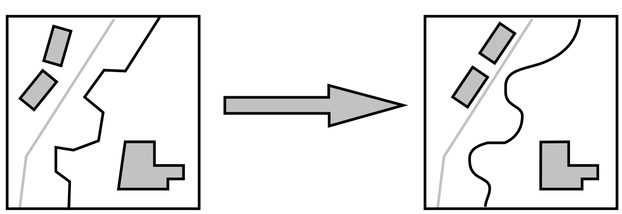
**Classification and Symbolization—**Grouping features sharing similar geographic attributes into a new, higher-level feature class and representing it with a new symbol.




**Conflict Resolution (Displacement)—**Detecting feature conflicts and then repositioning the less important conflicting features or adjusting feature extents to satisfy the threshold of separation and other cartographic specifications.



**Refinement—**Altering and adjusting a feature's geometry or appearance to improve its aesthetic (visual) impression and to ensure its agreement with reality. Some examples are smoothing a line, squaring a corner, changing the orientation and alignment of a point symbol, correcting the intersecting angles of a contour and a river, and so on.



Based on the above definitions, a set of generalization operators are to be created to automatically perform these operations and produce desired results. For example, under the category Collapse, one of the operators should collapse an area feature to a point feature, if the area size is smaller than a tolerance; under Aggregation, one of the operators should combine a cluster of point features into an area feature when space no longer permits point features to be presented individually.

## ESRI's Goals and Plans

To enhance ESRI's GIS/mapping software solutions such that the users can produce multiple-scale and multiple-subject output more efficiently, digital geographic data generalization must be addressed. There are two major areas where generalization should take place when manipulating geographic data. One is to generate thematic data sets for multiple-level, comprehensive GIS analysis; the other is to produce cartographic output. Both require the extraction of a subset of data from a GIS database and the reduction of the amount of detail to meet desired output specifications. Digital generalization tools are to help automate this process as much as possible and bring long-term efficiency and savings in GIS/mapping database maintenance and applications.

Building generalization capability into the ESRI product environment will be a challenging task. The preliminary design of generalization functions and a demonstration of currently available generalization operators, including a new line generalization operator, will be presented at the ESRI User Conference in 1996.

### Short-Term Plans

Focus our research on careful design and selection of the most practical approaches for the most needed generalization operators such as the following:

- Feature elimination by size, length, and other criteria
- Simplification of building or other man-made feature outlines
- Collapse of dual-line to single-line and area features to linear or point features
- Aggregation of areal or point features into areal features
- Basic feature conflict detection and resolutions

Implement a generalization function library and build a user-friendly interface that enables GIS users and cartographers to easily access this library and efficiently perform generalization sessions on their data or to customize the interface according to their needs.

Gain feedback from customers quickly and acquire knowledge and experience for further long-term development.

### Long-Term Goals

- Integrate an advanced, comprehensive system for digital generalization into ESRI products.

- Provide fully operational generalization solutions for efficient production of multiple-purpose output.

As we progress, ESRI will participate in major conferences and worldwide activities with presentations and demonstrations. We encourage users to send us requirements and suggestions.

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