A REVIEW OF MAP AND SPATIAL DATABASE GENERALIZATION FOR DEVELOPING A GENERALIZATION FRAMEWORK

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ABSTRACT:
Technological development in the field of map and spatial database generalization is very fast, following the trend from manual cartography to computer-based cartography. Map generalization is an integral part of spatial data collection, representation and access. Most generalization algorithms developed and employed by the GIS industry and the computer science community have been tailored for map production. This paper firstly introduces "derivative mapping" from a seamless database as a very active research and development topic. This is an area of interest to many national mapping agencies, academia, map and spatial data providers and users across the spatial industry. It deals with a derivation of smaller scale map products from a detailed single master database. Then the paper provides a brief review of "generalization". This covers the concepts of cartographic generalization, model generalization and generalization operators. It also highlights existing generalization software packages. Finally, it presents a framework to generalize a road network database from GEODATA TOPO-250K. The framework will be used to produce small scale maps at 1:500,000 and 1:1,000,000 using generalization operators from ArcGIS. The overall aim is to integrate generalization algorithms with cartographer's intuition and skills in order to derive acceptable results.

1.0 INTRODUCTION

National mapping agencies (NMAs), spatial data providers and map producers often maintain several databases at different scales, to represent the geographic world (Lee, 2003; Kazemi, 2003). Maintaining multiple databases (e.g. small scale to large scale) is resource-intensive, time consuming and cumbersome (Arnold and Wight, 2003). In order to serve multiple-purpose and multiple-scale applications via these databases, automated generalization is a key solution to be built into modern Geographic Information System (GIS) software. The aims of this paper are: 1) to highlight the need to the maintain one master database in order to reduce data handling and data duplication, and 2) to describe how desired products and databases should be dynamically developed "on-the-fly" from the single database using an automated generalization procedure. The goal is to collect once, and maintain or use at different levels based on requirements.

Automatic generalization refers to the generation of abstract features from a rich database through computer algorithms rather than a human's judgment. It is commonly used for individual objects such as lines or polygons. Researchers (e.g. Ruas and Plazanet, 1996; Meng, 1997; Lee, 2002) believe that NMAs and other spatial information providers/users should work with GIS software developers to build a universal generalization tool.

The automatic generalization discipline is a fertile research area. NMAs are committed to maintaining a set of cartographic data with different scales and to synchronize the updates with other multiple scale data (Haire, 2001). This is a major challenge for NMAs and other map/spatial data producers (e.g. Kilpelainen, 1997; Lemarie, 2004). A multi-purpose seamless master database should offer capabilities to derive different maps at different scales from objects (e.g. topographic objects), say at scale ranges from 1:250,000 to 1:10,000,000. This capability is referred to as a "derivative mapping".

Over the last three decades tremendous efforts have been made to derive numerical methods (Lee, 2003) applicable to automatic generalization, in order to generate maps at different scales by utilizing advanced GIS-based technologies (McMaster and Shea, 1992; Baelia *et al.,* 1995; Joao, 1998). Release of commercial GIS generalization tools has been well received by major NMAs (Kilpelainen, 1997; Lee, 2003). Better qualification of generalization tools in finding reasonable solutions for deriving multiple scale data from a master database (e.g. Peschier, 1997; McKeown *et al.,* 1999; Thomson and Richardson, 1999; Jiang and Claramunt, 2002) and full integration of the generalization capability for deriving new datasets and compiling cartographic products has become inevitable (Lee, 2003). Derivative mapping is composed of several stages, that include data loading into the generalization software package. A user needs an identification to adapt and give priority to constraints for each generalization. Data enrichment refers to the creation of structural objects such as roads, urban blocks, generalizations of such objects, and evaluations of the generalization results (Ruas, 2001; Ruas and Lagrange, 2003).

The remainder of this paper is organized as follows. In Section 2, differences between the database (model) generalization and the cartographic generalization in a GIS environment are described. In Section 3, the relevant literature on generalization operations with special emphasis on linear features (e.g. roads) is highlighted. In Section 4, generalization frameworks are reviewed and a conceptual generalization model is briefly proposed for derivative mapping from a master database with particular reference to road networks. This is followed by an overview of generalization software (Section 5). Finally, Section 6 concludes the paper and indicates research directions for future work.

2.0 GENERALIZATION THEMES

Weibel and Jones (1998) classified generalization into two main approaches, known as the *cartographer driven* (cartographic generalization) approach and the *feature reactive* (database or model generalization or conceptual generalization) approach. This perspective is revisited here by considering other researchers' points of view.

Database generalization filters the data through a scale reduction process, whereas the cartographic generalization deals with representation or visualization of the data at a required scale (Weibel and Jones, 1998). A geographic database is usually richer than cartographic information. The database should offer multiple map generations in a continually varying range of scales. The latter method uses an object-oriented data model utilizing data modelling formalisms to capture the map structure of applications at a given point in time (Yang and Gold, 1997), since this requires a highly structured dataset (Brooks, 2000). The object-oriented technology enables feature definitions and storage as objects with intelligence to represent natural behaviour of the objects and the spatial relationships of features. This is based on varying scale in one

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representation by displaying certain object dynamically “on-the-fly” (Zhou *et al.,* 2002; Lee, 1993 and 2002). This type of database can be called scale-less or scale-free with a single maintenance procedure (Muller, 1995) that is appropriate for multi-purpose applications. In this regard, derivative mapping is considered the most cost effective and efficient method to derive multiple scale maps and GEODATA, from a master detailed database to satisfy the map content requirements of a specific application (Kazemi, 2003).

A major advantage of database generalization is reduction in the cost and workload of the manual process once the database is highly structured and attributed. It selects the set of features or attributes and chooses an approximate level of generalization, then employs generalization operators/algorithms, and finally post-processes the dataset. This limits the degree of human intervention. However, cartographic generalization renders the features for display/visualization as a means of communication that is a subjective process since cartographers should satisfy the basic requirements for graphic clarity and legibility, as well as analyzing the relevance of map features, including their geometric and semantic attributes by applying generalization operations (Meng, 1997). Furthermore, reducing the number of features in database generalization is a key task that can be accomplished by six major operations based on the geometric, semantic relationships, and database constraints that are well documented in the literature (e.g. McMaster and Shea, 1989 and 1992). These include simplification (line generalization), aggregation (combination geometrically and thematically), symbolization (for line, polyline and point), feature selection (elimination and delete), exaggeration (enlargement) and displacement or moving objects (Oosterom, 1995).

In cartographic generalization a cartographer chooses features from a larger scale map to be shown on a smaller scale map through modifications to filter out detailed information, while maintaining a constant density of information by considering purposes of the map (Davis and Laender, 1999). A drawback of this approach is that this generalization is based on a cartographer’s skills, including his/her visual/aesthetic sense (e.g. clarity, readability, ease of interpretation) and the lack of extensibility for multiple representations in GIS. The way forward is incorporation of a data modelling process, as it provides a detailed description of the database structure, or the so-called *schema*. A main advantage of this approach is a reduction in spatial and semantic resolutions, which permits both a spatial analysis and map production. For example, Jiang and Claramunt (2002) proposed a generalization model of an urban street network that aims to retain the central structure of a street network by relying on a structural representation of this data employing graph modelling principles (e.g. Gross and Yellen, 1999). The proposed method provides a flexible interactive solution to a street network because it incorporates the concept of a hierarchy-based generalization in terms of connectivity to an average path, length and measures. Peter and Wiebel (1999) identified several measures, such as size, distance and proximity, shape, topological, density, distribution, pattern and alignment, as a set of generic constraints that need to be applied to database generalization. Therefore it is suggested that selection of appropriate algorithms and prioritizing of constraints needs to be studied. A series of selection rules emerged for road networks, such as if the average segment length of a street is less than a given threshold, then keep it in a database, otherwise delete it. Shortcomings of the graph theory approach are geometric aspects of coalescence as well as imperceptibility, and semantic perspectives (e.g. avoiding large detours that are not clearly explained). Kreveld and Peschier (1998) used this method for road network generalization.

In this regard, multi-resolution spatial databases provide the ability to represent objects in multiple representations tailored towards the requirements of different users, especially for web applications. It should preserve spatial relations throughout scale changes (Tryfona and Egenhofer, 1996). Generally there is a direct linear relationship between scale changes and the amount of generalization (Kerveld, 2001). Continuous map scale change is already operational on modern computers and so technological developments will soon provide this capability for web cartography (Karaak and Brown, 2001; cited by Kerveld, 2001). With reference to linear features, note that a consistent representation of networks such as roads needs to be considered through two major criteria, including: (a) when small changes take place from the one level to the next, and (b) when long changes accrue (Tryfona and Egenhofer, 1996). An example of such change is presented by Kazemi (2003). Ibid (2003) commented on the potential for developing a conceptual model for an object-oriented continuous master database, multi-scale and multi-purpose database that enables derivative mapping.

3.0 GENERALIZATION OPERATIONS

There are no standard definitions for generalization operations, and each researcher has defined them based on his/her perspectives or application area (Cecconi *et al.,* 2000). However, McMaster and Shea (1992) defined twelve operations, with special emphasis on digital cartography, with the first ten operators based on graphical representations, with the last two operators are attributes of the spatial objects. The applications of some of these operations define generic rules, whereas some are just used by cartographers in a subjective manner (Davis and Laender, 1999) due to different feature type geometry. Thus, a definition of each of the operators could have different meanings in terms of the feature type, e.g. area elimination of vegetation features and elimination of hydrographic features. Lee (1993) examined operational consequences and developed criteria through formalizing workflow using the MG Integraph software product for generalization of areal, linear and point features. Results are presented at 1:100,000 scale, by which the amount of information kept in the final map was comparable to the real work. Again, there is no holistic or even ideal sequence for the utilization of these operations. However, Monmonier and McMaster (1991) claimed there are sequential effects of the operations in cartographic line generalization, but have not received much support from others as each of the operations may serve a specific generalization problem. Typically the intention is to break down the generalization process into sub-processes, and later combining several operators to build a more robust generalization workflow. Also Cecconi *et al.,* (2000) evaluated and integrated generalization operations to improve automated generalization for on-demand web mapping from multi-scale databases. This is an excellent example of recent work on combining existing generalization algorithms for an operational environment for on-the-fly map generalization. To date commercial GIS tools have incorporated many of these operations, but some of these operations (e.g. displacement, exaggeration) are still in an experimental form since they are strongly based on a cartographer’s intuition. For example, ESRI’s recent object-oriented ArcGIS software (version 9.0) provides a spatial framework to support generalization needs by introducing geoprocessing concepts and map generalization tools that have been enhanced and implemented in a geoprocessing framework (Lee, 2003).

Typically current GIS software applications offer both line generalization and area generalization algorithms. Since the focus of this research is on road network generalization, this paper only highlights some of relevant literature on linear features (Skopeliti and Tsoulos, 2001). Linear feature generalization plays an important role in GIS (Barrault, 1995; Forghani, 2000; Skopeliti and Tsoulos, 2001). Several algorithms have been developed to simplify lines. McMaster (1989) classified the processing of linear features into five major algorithmic categories: (a) independent point algorithms of map generalization where a mathematical relationship between neighbouring pairs of points is not established; (b) local processing routines that apply the characteristics of immediate neighbouring points to determine selection; (c) extended local processing routines that apply distance, angle, or number of points to search beyond neighbouring points; (d) extended local processing routines that use morphologic complexity of the line to search beyond neighbouring points; and (e) global routines that take into account the entire line or specified segment. However, none of these methods leads to an automated generalization mechanism.

One of the revolutions in generalization was the development of an algorithm by Douglas and Peucker (1973) and Duda and Hart (1973) (iterative endpoint fit). This algorithm is regarded by many as the best of the line generalization algorithms incorporated into GIS tools (e.g. Visvalingham and Whyatt, 1993). It should be noted that the underlying concept of the Douglas and Peucker algorithm comes from Attneave's (1954; cited by Visvalingham, 1999) theory that curvature conveys informative points on lines. Many other pieces of research have subsequently enhanced Douglas and Peucker's algorithm (e.g. Wang and Muller, 1993 and 1998; Visvalingham and Whyatt, 1993; Ruas and Plazanet, 1996) in the area of curvature approximation applying various thresholds. Oosterom (1995) criticized these types of algorithms as time-consuming, so he introduced the reactive-tree data structure for line simplification that is applicable to seamless and scale-less geographic databases. There is still, however, a need for the cartographer's interaction in generalizing lines/curves to make them "fit-for-use".

A majority of map features are represented as lines or polygons that are bounded by lines. Skopeliti and Tsoulos (2001) developed a methodology for the parametric description of line shapes and the segmentation of lines into homogeneous parts, along with measures for the quantification of shape change due to generalization. They stated that measures for describing a positional accuracy are computed for manually generalized data or cartographically acceptable generalization results. Muller *et al.,* (1995) imply that ongoing research into line generalization is not being managed properly. Most of the research in generalization has focused on single cartographic line generalization instead of working on data modelling in an object-oriented environment to satisfy database generalization requirements. In contrast, other researchers (e.g. Visvalingham and Whyatt, 1993) have highlighted a need to evaluate and validate existing generalization tools rather than developing new generalization algorithms and systems. So far standard GIS software applications do not fully support automatic generalization of line features. This research focuses on integration and utilization of generalization operators using the ArcGIS 8.2 Generalize tool in order to generalize a road network database from GEODATA TOPO-250K Series 2 to produce smaller scale maps at 1:500,000 and 1:1000,000.

4.0 GENERALIZATION FRAMEWORKS

An excellent classification of generalization assessment tools based on measures, conditions and the interpretation of generalization result is provided by Skopeliti and Tsoulos (2001). Peter and Weibel (1999) presented a general framework for generalization of vector and raster data to achieve more effective translation generalization constraints into assessment tools to carry out the necessary generalization transformation. Peter (2001) developed a comprehensive set of measures that describe geometric and semantic properties of map objects. These are the core parts of a generalization workflow from initial assessment of the data and basic structural analysis, to identification of conflicts and guiding the transformation process via the generalization operators, and then qualitative and quantitative evaluation of the results. The following discussion provides a critical review of the relevant generalization research based on measures, constraints or limitations, and integration of measures into the generalization process.

In connection with generalization constraints, Peter (2001) categorized constraints based on their function (graphical, topological, structural and Gestalt) and spatial application scope (object level – micro, class level – macro, and group of objects/region/partition of the database level – meso). The constraints relevant to the micro level (object) include minimum distance and size (graphical), self-coalescence (graphical), separatability (graphical), separation (topological), islands (topological), self-intersection (topological), amalgamation (structural), collapsibility (structural), and shape (structural). To assess generalization quality for linear features, constraints have been employed (Peter and Weibel, 1999; Yaolin *et al.,* 2001). Constraints for the micro level (object classes) include size ratio (structural), shape (structural), size distribution (structural) and aliment/pattern (Gestalt). Finally, Peter (2001) divided meso level (objects groups) constraints into neighbourhood relationships (topological), spatial context (structural), aggregability (structural), auxiliary data (structural), alignment/pattern (Gestalt), and equal treatment (Gestalt). For a detailed description of the above constraints readers are referred to Peter and Weibel (1999); Skopeliti and Tsoulos (2001); Peter (2001); and Jiang and Claramunt (2002).

In relation to application of measures for the evaluation of generalization results, there are several measures to assess performance. These can be classified as being either qualitative and quantitative methods. To date most of the generalization transformation results have been evaluated qualitatively based on aesthetic measures. Recently Skopeliti and Tsoulos (2001) developed a methodology to assess linear feature integrity by employing quantitative measures that determine if specific constraints are satisfied. Researchers began to develop formal approaches that integrated generalization constraints and measures for development of coherent frameworks and workflows (e.g. Peter and Weibel, 1999; Yaolin *et al.,* 2001). In this regard, Skopeliti and Tsoulos (2001) incorporated positional accuracy measures to quantitatively describe horizontal position and shape, then to assess the positional deviation between the original and the generalized line, and to relate this to line length after and before the generalization. A technique such as cluster analysis (qualitative assessment) was used for the line shape change and the averaged Euclidean distance (quantitatively assessment). Also, McMaster (2001) discussed two basic measures for generalization that include procedural measures and quality assessment measures. These measures involve a selection of a simplification algorithm, selection of an optimal tolerance value for a feature as complexity changes, density of features when performing aggregation and typification operations, determining transformation of a feature from one scale to another such as polygon to line, and computation of the curvature of a line segment to invoke a smoothing operation.

It should be noted that quality assessment measures evaluate both individual operations, e.g. the impact of simplification, and the overall quality of generalization (i.e. poor, average, excellent). Despite all these efforts there is no comprehensive, universal and concrete process for generalization measurement techniques. However, Ibid (2003) provided a review of existing measurement methods for automatic generalization in order to design a new conceptual framework that manages the measures of intrinsic capability, in order to design and implement a generalization measurement library. To apply quantitative measures, Kazemi (2003) used two methods of the Radical Law (Pfer and Pillewizer, 1966; Muller, 1995) and an interactive accuracy evaluation method to assess map derivation. The Radical Law determines the retained number of objects for a given scale change and the number of objects of the source map (Nakos, 1999).

While the majority of developed frameworks for the generalization of cartographic data, such as those by Lee (1993), Brassel and Weible (1998) and Ruas and Plazanet (1996), deliver generic procedural information (Peter and Weibel, 1999), the one briefly discussed in this paper is designed more specifically for the derivation of multiple scale maps from a master road network database (see Kazemi, 2003). Large portions of Kazemi's proposed framework may be considered generic (e.g. conditions/parameters/constraints definition). However, most parts deal specifically with road generalization. Generalization operators in the ArcGIS software are tested to generalize roads above the conceptual generalization framework for derivative mapping. The method is empirically tested with a reference dataset consisting of several roads, which were generalized to produce outputs at 1:500,000 and 1:1,000,000 scales (Ibid, 2003). According to visual interpretation, the results show that the derived maps have high correlations with the existing small-scale road maps such as the Global Map at 1:1,000,000 scale. As the methodology is only tested on roads, it is worthwhile to extend it to various other complex cartographic datasets such as drainage networks, power lines, and sewerage networks, in order to determine the suitability of the methodology proposed here. Additionally, various kinds of linear, areal and point cartographic entities (e.g. coastlines, rivers, vegetation boundaries, administration boundaries, land cover, localities, towers, and so on) should also be studied.

There is no universal semi-automatic cartographic generalization process (Costello *et al.,* 2001; Lee, 2002), because off-the-shelf tools do not provide an aesthetically robust and pleasing cartographic solution. The current ArcGIS map production tools are significantly better than the map production systems of the 1990s in finding a reasonable solution to the challenge of deriving multiple scale data from a master database (Lee, 2003), and hardware performance and cost makes them suitable for implementation in a full production setting (Forghani *et al.,* 2003). For example, ESRI's current object-oriented ArcGIS software (version 9.0) provides a spatial framework to support generalization needs, by introducing geoprocessing concepts and map generalization tools that have been enhanced and implemented in the geoprocessing framework (Lee, 2003). The issue is still the incorporation of cartographer knowledge into the generalization process, as well as finding situations where high accuracy and other automatically derived information are both useful and valuable.

5.0 OVERVIEW OF MAJOR GENERALIZATION SYSTEMS

Despite considerable R&D efforts directed toward automation of cartographic generalization by academics and the GIS industry, existing software tools are not able to play a more significant role than graphic editing and statistical calculation (Meng, 1997). This is due to inadequate "intelligence" (compared to cartographers), in determining 'how' and 'when' to generalize (McKeown *et al.,* 1999; Iwaniak and Paluszynski 2001). However, to remedy this shortcoming, rule-based systems were introduced to incorporate topological, geographical and cartographical expert knowledge in order to build a map generalization expert system. Examples of such expert systems (eg for generalization of roads) are given in Peschier (1997) and Skopeliti and Tsoulos (2001). This implies a lack of fully automated generalization tools. A number of commercial GIS vendors (e.g. Intergraph, ESRI, and LaserScan) have worked with various mapping agencies to use these generalization tools for the production of maps at various scales (e.g. Kilpelainen, 1997; Meng, 1997) while developing tools to automate generalization.

ESRI's recent ArcGIS (version 9.0) product offers a spatial framework to support GIS and mapping needs. Geoprocessing, combining its earlier command operation with a modern user interface, has become an important part of upcoming software releases. Developing generalization tools within a geoprocessing framework has opened opportunities to explore new technology and data models, and to make enhancements using better techniques (Lee, 2003). In principle, it embedded the Douglas & Peucker algorithm for line generalization. However research shows that ArcGIS (versions 8.1-8.3) Generalize does not provide total solutions for generalization (Limeng and Lixin, 2001; Kazemi, 2003), because after the point, line and the feature are simplified, manual editing was still required. The reason is that topological errors are produced when applying the Generalize tools, such as line crossing and line overlapping; for polygon coverage, errors such as no label or multiple labels were introduced. To deal with these problems manual editing is necessary (Limeng and Lixin, 2001; Kazemi, 2003). Detailed generalization capabilities of this product are described by Lee (2002, 2003).

The CHANGE software developed by the Institute for Cartography of Hanover University is capable of generalizing building and road objects at a scale ranging from 1:1,000 to 1:25,000. The CHANGE software generalizes buildings through its sub-program of CHANGE-Buildings, and for roads CHANGE-roads (www.ikg.uni-hannover.de).

The Intergraph Corporation developed the MGE DynaMap Generalizer as an interactive platform that works under Unix and Windows NT. It deals with small-scale derivation from large-scale databases, theoretically without limitation of scale range. A number of visualization tools in DynaMap Generalizer are also available to assist the interactive generalization processes (Lee, 1993). Iwaniak and Paluszynski (2001) combined the expertise of a cartographer with DynaMap Generalizer in batch mode to perform the actual map transformations, and a rule-based system for controlling the process. They noted that this system does not have a mechanism for controlling topology. Unlike CHANGE, when making essential decisions in DynaMap Generalizer (such as tuning generalization sequence), system users must select parameters for each algorithm and the number of iterations to be applied for each particular task. DynaMap Generalizer has been tested for different generalization tasks in several countries, the USA, UK, Germany, Spain, Sweden, the Netherlands, and China. In Spain, for example, DynaMap Generalizer is used to derive a topographic map at 1:100,000 from 1:50,000 scale data, and to produce an atlas composed of different maps at different scales (Baella *et al*., 1995).

Since 1990, LaserScan has been developing an Open Systems object-oriented Application Development Environment (ADE) named "Gothic". Since 1994, LaserScan has been developing a new generation Mapping and Charting application using the Gothic ADE. The new application, named LAMPS2, uses a central database of map data to generate a range of products. Operations are performed in two phases: compilation (database creation and maintenance from a range of sources), and product generation (extraction, symbolization and generalization).

6.0 REMARKS AND CHALLENGES

A review of the literature demonstrates that future research and development work on automatic generalization should focus on the following major streams. This judgment is supported by other researchers in the field of map generalization (Meng, 1997; Costello *et al.,* 2001; Lee, 2002 and 2003). To build an automatic generalization tool, Lee (2002) and Kazemi (2003) highlighted a number of major streams:

- A need to evaluate and validate existing generalization tools as identified by researchers (e.g. Visvalingam, 1999), as well as improvements in editing tools (e.g. Muller, 1995) for both area generalization and line generalization applications. To fulfill the need to evaluate and validate existing generalization tools, the authors' research will focus on the development of a detailed generalization framework to derive multi-scale GEODATA. It focuses on integration and utilization of generalization operators as well as cartographer's intuition/skills using the ArcGIS 8.3 Generalize (and possibly DynaMap Generalizer) software in order to generalize a road network database from GEODATA TOPO-250K Series 2 to produce smaller scale maps at 1:500,000 and 1:1000,000.
- Maintaining a single sophisticated database that supports many applications (rather than multiple simplistic map layers), as well as a well-designed database, provides a platform to support data derivation, generalization, symbolization, and updating (Lee, 2002). The idea is to associate geographic objects/features to multiple scales and maintain the cartographic quality of spatial data products. This requires the development of data models that support derivative mapping concepts. Many geographic objects vary in their appearance with scale, so that it is difficult to encapsulate all possible details for all probable scales within a single data model. The way forward is to model data in an object-oriented solution
- Development of universal guidelines to derive smaller scale products from a master database. As NMAs (e.g. Land Information New Zealand, Geoscience Australia, and Ordnance Survey) migrate their dataset into multi-scale national seamless coverage, it is essential to develop guidelines and tools to derive smaller scale products from their fundamental spatial information (e.g. GA's "GEODATA TOPO-250K" national coverage) at a consistent level, as well as providing a basis for generalizing other data sets at different levels of generalization. The guidelines should also highlight both essential and desirable steps for generating smaller scale maps in line with a production environment focus. These

include topological relations between the object types and classes, how the objects have to be selected, how to generalize, when to smooth, when to delete, when to merge, how to do reclassification of roads, and so on.

- A set of automatic generalization tools and a set of efficient post-editing and cartographic editing tools is needed (Lee, 2002). For example, ESRI has begun developing a set of commonly used generalization tools for simplification, aggregation, displacement and so on. These tools will be available as Component Object Model (COM) Objects for users to access, but they are also making them available as batch functions within GeoProcessing modules, and will implement them as interactive editing tools. The GeoProcessing module will have a ModelBuilder, which allows the user to chain a number of steps together and process them in a logical sequence. This will help users to model and fine-tune the generalization process. It should be noted that all the above developments and improvements will not be possible without a close co-operation between universities, map producers, GIS software vendors and NMAs.

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