CO-331

METHODS FOR EVALUATING THE RESULTS OF AUTOMATED GENERALIZATION

PUNT E., WATKINS D., BRIAT M.O., MONNOT J.L.
Esri, Inc, REDLANDS, UNITED STATES

ABSTRACT

Cartography is concerned with representing reality as clearly and faithfully as possible at a given scale. Mapping a continuum of scales requires a smooth and logical transition of the amount of detail shown while retaining a clear and representative depiction. One of the challenges of generalizing data for cartographic display is verifying that the changes made are valid and appropriate.

There is a need for automated verification of generalization results. Despite advances in the automation of various generalization processes, the evaluation of the results is still often left to the visual scrutiny of cartographic experts. As larger data sets are being generalized automatically, visual evaluation of the results across the entire data set becomes less feasible. Simple automated checks, such as ensuring that features are not spaced too closely, are inadequate if they give increasingly positive feedback as results become overly generalized.

In ArcGIS 10, Esri released tools to perform automated contextual generalization of roads and buildings. Research continues at Esri now to leverage a partitioning approach to process very large datasets with these tools. Evaluating the results of such expanses of data proves difficult with only interactive, visual methods.

To support the verification of generalization results, a suite of in-house automated quality control tools are being developed. These tools check the degree to which multiple—sometimes conflicting—constraints are respected and also verify that the resulting data meets requirements for further generalization processing. The tools validate both the integrity and display of geographic data, focused primarily on the resulting characteristics of road networks and building polygons.

Just like the generalization tools themselves, the in-house quality control tools leverage ArcGIS's geoprocessing framework. The checks are implemented as individual geoprocessing tools that accept the resultant, generalized layers as inputs. The quality control tools that are concerned with meeting display specifications include parameter inputs defining these guidelines. Other tools are more concerned with validating the geometric integrity of the output. These tools compare the resultant layer with an input or other reference layer. The outputs of the quality control tools are points, lines, or polygons which can be drawn or queried to highlight areas of potential concern. Categorized issues are indicated through attribution on these features.

This suite of tools has allowed Esri to improve their generalization tools and ensure that they function well in a complex cartographic workflow. Using a combination of all these automated checks provides a method for evaluating the quality of the results of automated generalization processes and validating complex workflows. As the suite of ArcGIS generalization tools grows in future releases to address more data configurations, quality control tools will become even more invaluable. Consideration will be made whether to make them available to users in a future ArcGIS release.

1 INTRODUCTION

ArcGIS is Esri's platform for building, managing, and sharing geographic information and analysis; it includes generalization tools to process detailed data for display on Web and print multi-scale maps. ArcGIS 10 introduced a new set of contextual generalization tools for transportation networks and building features. These tools support thinning, offsetting, merging, and de-confliction of roads and buildings [Punt & Watkins 2010]. Since these tools consider adjacent features from multiple themes contextually, they can process only about a single map sheet's worth of data at a time before encountering memory limitations. In a forthcoming release of ArcGIS, these tools will be scaled to process much larger data sets. A partitioning approach is introduced in which a polygon layer can be used to subdivide the processing into manageable portions. One formidable implication of this advancement is that evaluating the quality and integrity of large amounts of resulting generalized data becomes a daunting task.

Up to this point, in-house quality control measures have been largely manual and ad-hoc. Experienced cartographers visually inspect the results of generalization processing in comparison to unprocessed data. Areas of concern are identified and reported back to the development team for further decision and resolution. This collaborative approach can be effective and successful on a single map sheet, but does not scale well to the large datasets.

Assuring the quality of generalization processing and the integrity of the resulting datasets is only feasible if it is accompanied by an automated way to evaluate the results. To address this, Esri is developing a series of in-house tools and procedures to evaluate the results of automated generalization.

2 GENERALIZATION IN ARCGIS

As new demands have arisen for automated multi-scale mapping, Esri has been providing and improving solutions to simplify road networks and building arrangements and resolve graphical conflicts associated with their distribution and display at smaller scales. These solutions were first implemented as geoprocessing tools in ArcGIS 10 and are intended to work together in a workflow [Punt & Watkins 2010].

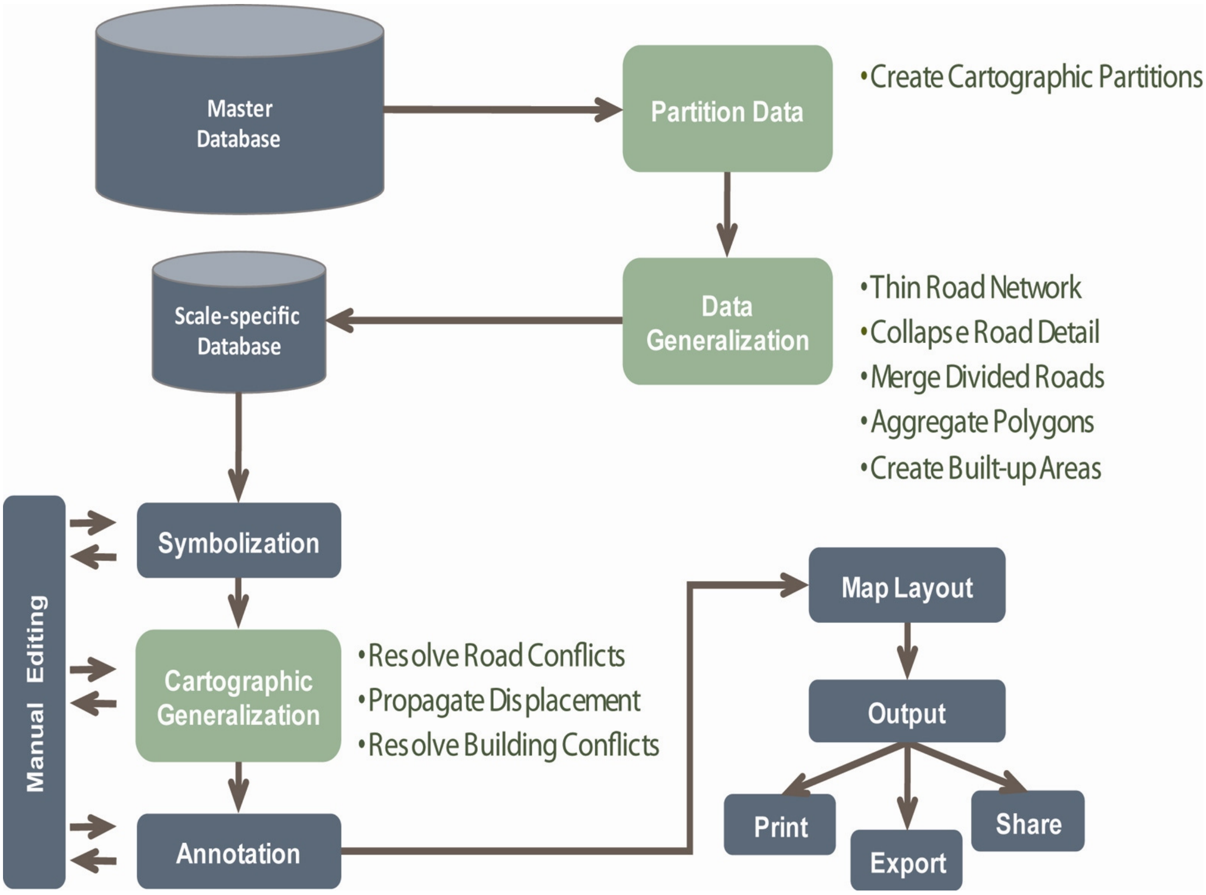

Figure 1: A simplified version of a typical cartographic workflow for generating data to be displayed at smaller scales. The primary generalization and conflict resolution tools of the ArcGIS geoprocessing framework are listed.

To modify the display of roads for multi-scale mapping, a variety of tools have been introduced. The Thin Road Network tool eliminates road features from display to create a simplified arrangement of roads that maintains connectivity as well as representative pattern and density of the original structure. The Merge Divided Roads tool creates single roads from matched pairs of parallel-trending, equal classification roads. The Resolve Road Conflicts tool modifies the shape of roads to separate them where they graphically conflict when symbolized at scale. The Propagate Displacement tool reestablishes spatial relationship between features after running the Merge Divided Roads or the Resolve Road Conflicts tools by propagating the displacements captured by these tools to proximate features.

3 EVALUATION OF GENERALIZATION RESULTS

Esri has been eager to automate the evaluation of generalized results because doing so adds a degree of objectivity to the process. As Harrie and Weibel state, “the level of constraint satisfaction in the final generalized map can be used as an indicator of success” [Harrie & Weibel 2007]. Automated checks can be run repeatedly with the assurance that the same evaluation will take place each time, and they can be used to evaluate large areas. As the amount of map content continues to grow, especially to support Web maps, automated generalization is being used with increasingly larger data sets. But, in spite of the advantages “it is remarkable that the automation of quality assessment still lacks in techniques” [Burghardt et al 2008].

There have been several methodologies proposed for the evaluation of generalization results. Weibel proposed that "evaluation methods are an important component and even a prerequisite of knowledge acquisition." He determined that evaluation was needed at three stages of the generalization process. A priori – prior to the knowledge acquisition step, a posteriori – including a comparison of the different generalization alternatives, and ad hoc – to control the automated generalization as a means of continuous evaluation [Weibel 1995].

João also proposed a three-stage process: evaluating the need for generalizing before generalization begins, control of "how and how strongly" features are generalized, and "quantification and storage of the transformations caused be generalization" after generalization has taken place. The idea being that these final results can be used as metadata when performing subsequent analysis with the data [João 1995].

Bard proposed "an assessment model based on (1) characterization of the data in their initial and final states at different levels of analysis; (2) a data quality assessment by comparison of the two characterizations; and (3) aggregation of the various assessment results to summarize data quality." He defines three types of assessment functions:

1. Threshold respect functions: to "check if the assessed property is over or under a threshold of legibility at the final scale."
2. Property evolution analysis functions: to "assess if a property has evolved as expected."
3. Qualification functions: "the aim…is to make evaluation results comparable. Clearly, the normalization of values is not sufficient, and values must have the same meaning" [Bard 2004].

Mackaness and Ruas acknowledged that, "Evaluation is a fundamental part of the automation process" and propose three types of evaluation: evaluation for controlling, in which evaluation occurs during generalization, evaluation for tuning where evaluation occurs prior to generalization, and evaluation for assessing the quality of generalized data after processing [Mackaness & Ruas 2007].

In addition to these methodologies, there has been research into practical implementations of methods for evaluating the results of generalization. Almost all of these implementations have included expert evaluation of results. With the complexity and subjective nature of generalization, ad hoc review has proven to be the most practical method for verifying that any automated checks have returned valid results [Skopeliti & Lysandros 2001]. Surveys have also been developed and used as a means to standardize expert assessments. An initial comprehensive survey was part of the AGENT project [AGENT 2000]. This survey was referred to and extended for use in additional studies and practical evaluations [Ruas 2001, Burghardt et al 2008].

Many of the practical evaluation tests have focused on one layer or theme. For example, Skopeliti and Lysandros' study focused on the evaluation of "line shape descriptions" [Skopeliti & Lysandros 2001]. Brewer and Buttenfield have worked in conjunction with Stanislawski on the evaluation of generalization using hydrographic features [Brewer et al 2009, Stanislawski et al 2010]. Few have tackled the task of generating an overall aggregation as Bard suggested [Bard 2004]. The most comprehensive review was conducted as part of the EuroSDR evaluation, State-of-the-Art of Automated Generalization in Commercial Software [Stoter et al 2010]. This evaluation, using results from four different vendors, combined expert evaluation, automated tests of constraints, and a comparison between results, in an attempt to provide an overall measure of generalization quality. [Burghardt et al 2008, Stoter et al 2010].

The conclusions drawn from the EuroSDR study included "that a map that is produced by strictly applying a set of regulations will always differ from an interactive generalized map. Cartographers can allow themselves some freedom in applying regulations, even in adhering to threshold values" [Stoter et al 2010]. Herein lies the difficulty of automating generalization evaluation. The rules are not always observed when a cartographer generalizes manually. Stoter concludes that we need more detailed specifications than those that are meant to be interpreted by humans if we are going to be able to get better automated checks [Stoter et al 2010].

Methodology

At Esri, the majority of generalization processing results has been traditionally evaluated by visual inspection alone. The need for diagnostic tools to quantify and validate generalization results arose with new capabilities to process large datasets. A practical solution needed to be implemented within the constraints of the current system. An assessment of the current framework and the types of errors that were frequent or difficult to detect with a visual review identified requirements for tools that assess the geometric integrity of resulting datasets, tools that validate the connectivity of resulting road networks, and tools that check the proximity of symbolized features at scale. Tools of this nature could both validate visual reviews and assess the quality of much larger data sets without the need for a comprehensive visual check.

These tools can compare datasets before and after processing, compare data to a reference generalized dataset, or can compare two discrete runs of a tool for regression testing. They return objective measurements and features that can be queried to locate areas of concern that might not be visibly obvious or easy to locate in a very large dataset. Evaluation of results can be a combination of evaluating numbers returned, checking the number of features created, and setting up queries for specific anomalies.

4 QUALITY CONTROL TOOLS

4.1 Perform Geometry Checks tool

The contextual generalization tools in ArcGIS each run a series of geometry checks during processing to ensure that the geometric and topological integrity of the data is adequate to assess the connectivity and spatial relationships between all features considered. The Perform Geometry Checks tool allows these diagnostics to be run either before processing—as an easy way to gauge data integrity before running a long process, or after processing to ensure that the results of a tool are acceptable as inputs for a subsequent tool in a workflow. The output is a point feature class that flags by attribute and location empty geometry, multipart geometry, shared segments, self connections, and unsplit intersections, each of which will potentially cause problems in generalization or conflict resolution processing.

4.2 Calculate Polygon Size tool

The Calculate Polygon Size tool provides metrics to express the size of individual polygon features after generalization processing has taken place. Map specifications often include minimum allowable size of certain features but these measurements are not easy to visually ascertain or even to query directly from the data, so this tool performs calculations and reports relevant measures for each feature.

Three fields are added to the feature class attribute table, representing three expressions of polygon size, depth and the dimensions of the minimum bounding box. This tool is commonly used to ensure that the resulting buildings from the Resolve Building Conflicts tool meet the required size specifications.

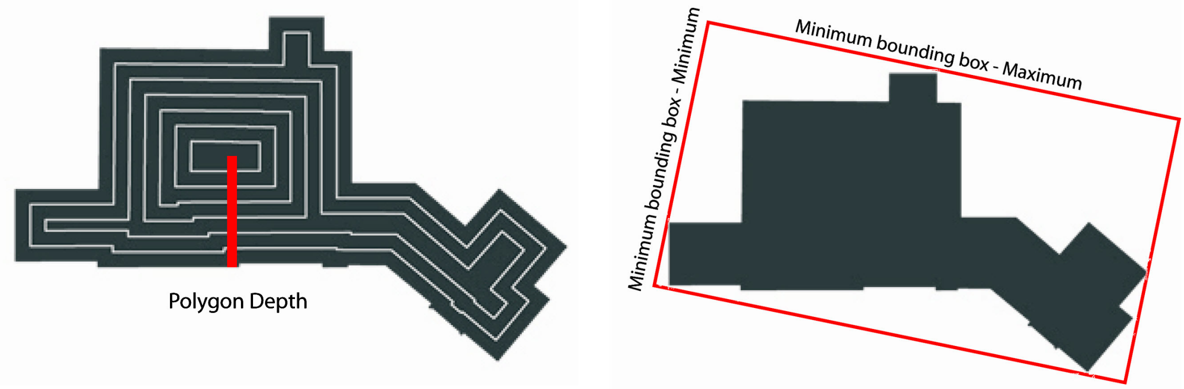

Figure 2: The Calculate Polygon Size tool stores three measures that can be used to define the size of a polygon in addition to feature area.

4.3 Check Spatial Relationships tool

The Check Spatial Relationship tool is used to report significant differences in the relative change in position of features following conflict resolution processing. An output line feature class stores connections between any features whose relative position has changed significantly. This tool is used to ensure that conflict resolution processes aren't skewed in favor of meeting constraints at the expense of retaining faithful representation of feature arrangement.

The spatial relationships of pre- and post-processed pairs of features are compared. Significant changes in their relationship, expressed as a change in angle, are indicated by output line features. The degree of change is categorized by the angle of change, allowing the reviewer to symbolize the lines to highlight the most severe infractions.

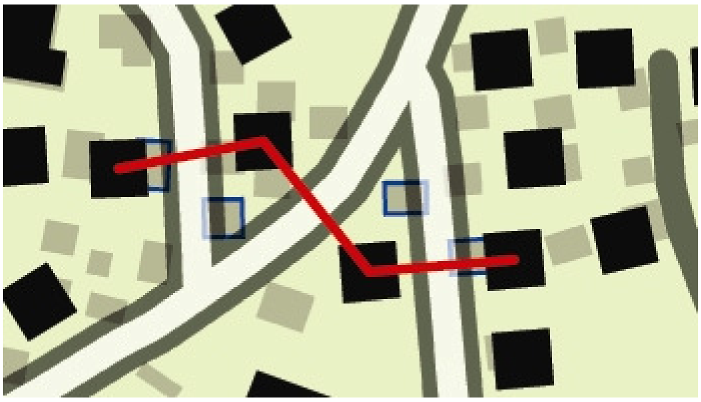

Figure 3: The original size, shape, and location of the four identified buildings before processing with the Resolve Building Conflicts tool are shown with a blue outline. The arrangement of these four buildings after processing has been identified with a red line by the Check Spatial Relationships tool. In this case, the results could be valid as the two acute angles of the roads force the buildings near the apexes to be moved significantly away from their original locations in order to meet the minimum size and minimum spacing requirements.

4.4 Compare Feature Geometries tool

The Compare Feature Geometries tool quantifies how much the morphology of a feature has changed during generalization processing. Measurements stored include the maximum distance between corresponding vertices, differences in the angle or deflection between segments, and any translation, rotation, and inflation transformations that have taken place. The Compare Feature Geometries tool is used most commonly to identify displacements that have created sharp angles, feature distortion, and areas of too much displacement.

Figure 4: Significant changes in deflection and translation identified by the Compare Feature Geometries tool after conflict resolution processing is performed by the Resolve Road Conflict tool. Original roads are shown in light grey. Orange points identify road segments that have been translated beyond an acceptable threshold (the query used on the output data in this case was translation greater than 30m.) The purple point identifies a road segment whose deflection has changed by more than an acceptable amount (beyond 35° in this case.)

4.5 Check Isolated Groups tool

The Thin Road Network tool seeks to eliminate relatively insignificant roads while retaining the character and connectivity of the original network. It is undesirable in this process to create isolated groups of roads that are unattached to the rest of the road network. The Check Isolated Groups tool identifies collections of roads that are no longer connected to the overall network. This is most commonly a problem along partition edges where improper Thin Road Network tool processing in adjacent partitions can apply a contradictory result on a common road segment.

Figure 5: The Check Isolated Groups tool produces output features that identify isolated collections of roads after processing with the Thin Road Network tool. The vertical red line is a partition boundary.

4.6 Check Network Connectivity tool

The Check Network Connectivity tool verifies that the road network created by generalization processing retains geometric integrity. It compares the geometry of a processed dataset to a reference dataset. Inconsistencies are reported as point features with a field containing the error type:

- Connectivity not preserved, which identifies features that are connected in the reference network but are connected to the wrong feature in the output. The relationship of the original connection is not preserved. A point feature is placed at the reference node location.
- New dangling feature, which identifies dangling features in the processed network in areas where no dangle exists in the reference network.
- Unable to find reference node, which indicates that a match could not be made from the processed network to the reference network for the identified vertex.
-

These point features can be symbolized by type and displayed along with the two datasets to highlight areas of concern.

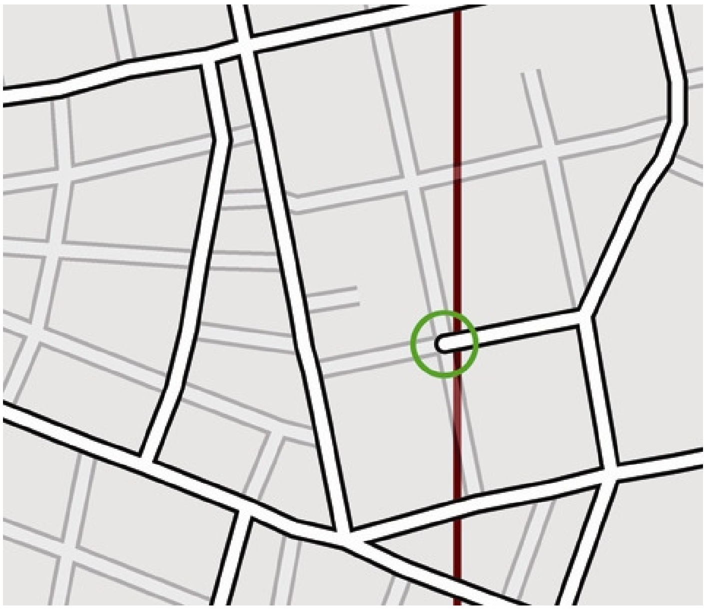

Figure 6: A dangling feature created after running the Thin Road Network tool to thin the density of a network of streets. Original roads are shown in grey; processed roads are white. The vertical red line is a partition boundary, and the green circle symbolizes a point feature generated by the Check Network Connectivity tool that represents the end of an erroneous dangling arc.

4.7 Check Minimum Gap tool

The Check Minimum Gap tool analyzes the spatial relationships between the features of one or more layers to identify features whose scaled, symbolized depictions are too close together. Map specifications of this nature are particularly difficult to detect because they rely on an analysis of the footprint of symbols at a particular map scale, which is not necessarily coincident with feature geometry. Trying to visually identify minimum distance infractions across thousands of small features on a map, like buildings, is even more challenging.

The Check Minimum Gap tool outputs a feature class of lines, classified by the severity of the minimum distance infraction. Actual symbol overlaps are also reported. A common way that this tool is used is to review the results of the Resolve Building Conflicts tool, which modifies the shape and position of building features with respect to other buildings and one or more barrier layers.

Figure 7: The Check Minimum Gap tool identifies features that are too close together, based on a distance parameter. In this example, only building-to-building distances were assessed, using a minimum distance of 15m apart. Green lines indicate very minor infractions, where two buildings are within 95% of the allowable distance, between 14.25m and 15m. Purple lines indicate infractions of the minimum distance that are between 50% and 95%, where buildings are between 7.5m and 14.25m apart. Blue lines show the most severe infractions, where the distance between buildings is less than 50% of the minimum allowable distance, or less than 7.5m apart.

4.8 Detect Line Overlap tool

The Detect Line Overlap tool verifies the correct proximity of symbolized lines at scale, especially those running parallel to each other, resulting from processing the Resolve Road Conflicts and Merge Divided Roads tools. The Check Minimum Gap tool leverages the same classification fields that those tools use during processing to ensure that the different classifications of roads are assessed properly.

When the Detect Line Overlap tool is used to assess the results of the Resolve Road Conflicts tool, the same road hierarchy field that was used in conflict resolution processing is used. This indicates that the spacing distances that are inherent in the Resolve Road Conflicts will be assessed.

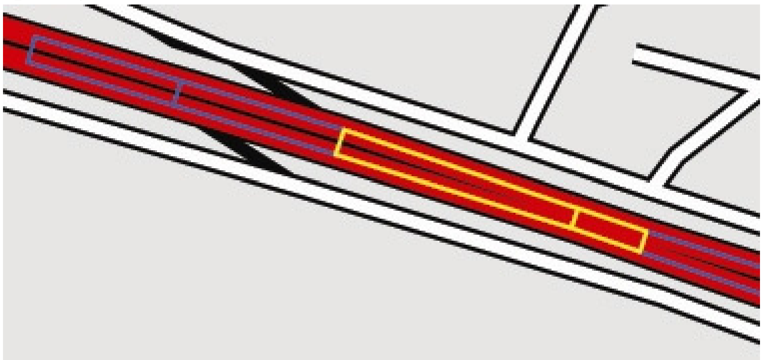

Figure 8: This example shows two different degrees of infraction when the Detect Line Overlap tool is used to assess the results of the Road Conflicts tool. Two parallel red highway lanes of equal hierarchy value have been flagged along a portion of their length. The yellow polygons indicate areas where the distance between the two line symbols are 50 to 80% the size of the expected gap. The blue polygons indicate areas of separation that are between 80 and 100% of the expected size.

When the Detect Line Overlap tool is used to assess the results of the Merge Divided Roads tool, the same merge field that was used in processing is used, along with the same merge distance value. Only parallel road segments of equal classification will be assessed by the tool. The primary role of the Detect Line

Overlap tool when used with the Merge Divided Roads tool is to verify that no non-merged parallel candidates remain after processing.

Figure 9: The pink polygons created by the Detect Line Overlap tool indicate areas in the output of the Merge Divided Roads tool where parallel, equal classification roads remain unmerged.

5 CONCLUSIONS AND FUTURE RESEARCH

The subjectivity of retaining the representative character and patterns of a place while simplifying it for display at a smaller scale is what makes generalization so difficult to validate, especially in an automated fashion that can be applied to all places. As generalization processes become increasingly automated, the related parameters and specifications become more quantifiable. While this alleviates some of the subjectivity in the validation process, automated checks that assess a single variable remain inadequate if they give increasingly positive feedback as results become overly simplified to meet generalization requirements.

The automated quality control tools that Esri has developed for internal use have proven to be a valuable part of a workflow that is used to assess a variety of aspects of generalization output, including degree to which display specifications are met, and the geometric integrity of the results. Leveraging these tools throughout a period of iterative testing and software development has allowed Esri to improve the generalization offerings in ArcGIS and further ensure that they participate effectively in a complex cartographic workflow.

Research continues at Esri, not just with respect to generalization functions but also in continuing to assess and validate the quality of the results that generalization tools produce. As the suite of ArcGIS generalization tools grows in future releases to address more data configurations and themes, quality control tools and procedures will become even more indispensable. Yet, in order to meet the need of a growing generalization workflow, these tools will need to become more generic in order to better automate and apply quality assurance procedures to a wider variety of data styles at a wider array of scales. There is also a distinct opportunity to develop better approaches to ensuring that the representative character of geographic formations is faithfully retained as scale and complexity decreases. This is perhaps the most subjective and therefore difficult aspect of evaluating generalization results. Assuming the quality tools and procedures become more robust in the future, consideration will be made whether to expose and support them in a future ArcGIS release.

ACKNOWLEDGMENTS

This research has been developed and supported by the Esri Multi-scale Mapping team where the work of engineering solutions to multi-scale mapping problems is achieved. The authors extend a special thank you to Jamie Conley, Shara Suhasini, and Anna Vetter who have been instrumental to the on-going development and testing process.

BIBLIOGRAPHY

AGENT (2000), Map generalisation by multi-agent technology, http://agent.ign.fr/

Bard, S. (2004), Quality Assessment of Cartographic Generalisation. Transactions in GIS, 8(1): 63–81.

Brewer, C.A., Buttenfield, B.P., E. Lynn Usery, E.L. (2009), Evaluating Generalizations of Hydrography in Differing Terrains for The National Map of the United States, Proceedings, 24th International Cartographic Conference, Santiago, Chile, 2009

Burghardt, D., Stefan Schmid, S., Duchêne, C., Stoter, J., Baella, B., Regnauld, N., Touya, G. (2008), Methodologies for the evaluation of generalised data derived with commercial available generalisation systems, Workshop of the ICA Commission on Generalisation and Multiple Representation, Montpellier, June 20-21, 2008.

Harrie, L. and Weibel, R. (2007), Modelling the overall process of generalisation. In: Ruas, A., Mackaness, W.A. and Sarjakoski, L.T. (eds.). Generalisation of Geographic Information: Cartographic Modelling and Applications, Series of International Cartographic Association, Elsevier, pp. 67–87.

João, E.M., (1995), The importance of quantifying the effects of generalization. In Müller, J.C., Lagrange, J.P., Weibel, R. (eds.) GIS and Generalization: Methodology and Practice. London, Taylor and Francis, pp. 183-193.

Mackaness, W.A. and Ruas, A. (2007), Evaluation in the map generalisation process. In: Ruas, A., Mackaness, W.A. and Sarjakoski, L.T. (eds.). Generalisation of Geographic Information: Cartographic Modelling and Applications, Series of International Cartographic Association, Elsevier, pp. 89–111.

Punt, E., and Watkins, D. (2010), User-directed Generalization of Roads and Buildings for Multi-scale Cartography. 13th Workshop of the ICA commission on Generalisation and Multiple Representation, 2010 Zurich

Ruas, A.(2001), Automatic Generalisation Project: Learning Process from Interactive Generalisation, OEEPE Official Publication n°39.

Skopeliti, A. and Lysandros, T. (2001), A methodology for the Assessment of Generalization Quality. Fourth Workshop on Progress in Automated Map Generalization, Beijing, China.

Stanislawski, L.V., Buttenfield, B.P., Samaranayake, V.A. (2010), Generalization of Hydrographic Features and Automated Metric Assessment Through Bootstrapping, 13th Workshop of the International Cartographic Association commission on Generalisation and Multiple Representation, Zurich, Switzerland, September 12-13, 2010.

Stoter, J., Baella, B., Blok, C., Burghardt, D., Duchêne, C., Pla, M., Regnauld, N., Guillaume, Touya, G., (2010), State-of-the-art of automated generalization in commercial software, EuroSDR publication, March 2010.

Weibel, R., (1995), Three essential building blocks for automated generalization. In Müller, J.C., Lagrange, J.P.,Weibel, R. (eds.) GIS and Generalization: Methodology and Practice. London, Taylor and Francis, pp. 56-69.