A typology of operators for maintaining legible map designs at multiple scales

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ABSTRACT

The potential for and ubiquity of multiscale mapping is growing as a result of contemporary research and development efforts in digital cartography. Past work on multiscale mapping discusses use of the ScaleMaster diagram, a conceptual schematic for organizing, maintaining, and sharing the scale-dependent design specifications of a multiscale mapping project. Here, we present a typology of multiscale mapping operators that can be implemented at the decision points identified within the ScaleMaster diagram in order to maintain legible map designs when changing scale. The ScaleMaster typology of multiscale mapping operators draws in part on extant literature on generalization, which primarily focuses upon changes to the geometry of map features. We argue that this past work on generalization should be appended with other work in map design to generate a comprehensive list of decisions available to a cartographer when changing scale. This extension results in four higher-level categories of multiscale mapping operators: content, geometry, symbol, and label. In the following, each operator in the ScaleMaster typology is introduced and explained, with discussion organized according to the four higher-level categories. For each operator, we include a formal definition, a standard two-character code for use in the ScaleMaster diagram, a sample illustration, a description of its use in the cartographic literature, and our approach to reconciling contradicting uses (where appropriate). The key contribution of this work is the synthesis and integration of existing generalization and map design research into a logical framework for use as a classroom teaching tool, a pragmatic guide for completing multiscale mapping projects, and a conceptual foundation for future scientific research.

KEYWORDS: cartography multiscale mapping, generalization, scale, ScaleMaster, map design

INTRODUCTION: FROM GENERALIZATION TO MULTISCALE MAPPING

Generalization is the process of meaningfully abstracting the infinite complexity and diversity found in the real world into a single, targeted cartographic representation that is usable and useful for the given map scale and purpose (Müller and Wang 1992). As any well-trained cartographer will tell you, there is no one-click solution that automatically discriminates essential geographic information from irrelevant or excessive detail. Instead, generalization requires a comprehensive rethinking of how geographic data layers are maintained and displayed, and sometimes even how they are collected (Stoter et al. 2009). Further, it requires a wide variety of potential generalization solutions to customize the resulting map for a specific theme and purpose, and a cartographer with the knowledge to apply these solutions suitably to ensure that the map is an appropriate representation of the portrayed geographic phenomena. Although generalization is a formidable cartographic task, it is this very task that gives the map its power, allowing the cartographer to emphasize particular geographic phenomena and processes while deemphasizing others. As the distinguished academic cartographer Arthur Robinson and his colleagues (1995: 42) note, "the act of generalization gives the map its *raison d'être*."

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Multiscale mapping describes the cartographic practice of generating integrated designs of the same geographic topic at multiple (or perhaps all) cartographic scales (Spaccapietra et al. 2000). Although long a topic of critical importance, research and development on generalization has drawn increased attention in the past decade both within and beyond the discipline of cartography due to the broad potential and increasing ubiquity of multiscale maps. While closely related, multiscale mapping and generalization are not the same. Multiscale mapping describes the full set of map design decisions made across the range of supported map scales, with the primary goal of maintaining map legibility as scale changes. Generalization traditionally describes the design decisions made for a single scale, with the primary goal of meaningfully reducing detail once scale is fixed (Brewer and Buttenfield 2010). It could be said that generalization is the process that occurs at each output map scale in a multiscale mapping project; however, as we discuss in this article, alterations beyond "generalization" also can be applied to maintain legible map designs as scale changes.

Multiscale mapping is fundamental to at least three contemporary cartographic research and development efforts:

(1) Multiple Representation Databases: Multiple representation databases (MRDB) link several representations of the same geographic entity across scales, resolutions, or purposes (Kilpeläinen 1997; Sarjakoski 2007). For applications of MRDB for multiscale mapping, each individual representation is generalized for use at a particular range of scales. MRDB offers a technical solution for partially automating the multiscale mapping process and promises tighter integration of geographic data and map design, leading to easier map updates and a more consistent cartographic design across scales. MRDB functionality is continuing to improve in GIS software (e.g., the software product 1Spatial; **http://www.1spatial.com/**), and its increased implementation can be expected to support production cartography.

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(2) National Mapping Agencies: The earliest multiscale maps were national mapping efforts chartered to catalog features in the natural and built landscape, with the U.S. Geological Survey (USGS) topographic series being one example. Today, many national mapping agencies (NMAs) are executing plans to construct consolidated repositories of digital geographic information and associated online map viewers for their national mapping products, integrating public domain datasets across themes and scale levels for general consumption (Stoter 2005). The goal of the current United States effort, referred to as *The National Map* (Clarke et al. 2003), is the release of harmonized government and volunteered datasets for multiscale display and download in *The National Map Viewer*. Prior work to extend a limited set of national hydrography datasets (NHD) with topologically coherent flow networks and enriched attributes is one contribution to the multiscale vision of *The National Map* (Buttenfield et al. 2010).

(3) Web Mapping Services: The popular on-demand web mapping services, and the associated web map mashups built atop these services, are at their core multiscale maps (Roth and Ross 2009). It is arguable that no development has increased the visibility of multiscale maps, and perhaps even cartography, more than web mapping services. Such services have empowered the general public to move beyond the "one-map" solution (Monmonier 1991)—or generation of a single, optimal map design emphasized within the communication paradigm—allowing them to navigate the world freely through a set of integrated multiscale designs and related interface conventions. The recent ability for users to edit cartographic styles across scales through such services as OpenStreetMap and Google Maps is a further step towards the democratization of cartography in which anyone can be a mapmaker and calls into question the degree to which multiscale mapping choices should be constrained by expert knowledge (Wallace 2010).

Despite its fundamental relationship to these three contemporary efforts within cartography, research on multiscale mapping is still in its infancy, with current practice outpacing scientifically-derived guidelines. Specifically, connections between cornerstone cartographic research on generalization and recent challenges in multiscale mapping have been limited or implicit in nature. This article is designed to bridge this gap directly, connecting past work on generalization to current problems in multiscale mapping. The work reported here builds upon and formalizes past work on the ScaleMaster diagram, a schematic used to describe and organize multiscale mapping projects (Brewer and Buttenfield 2007; Brewer et al. 2007; Stryker et al. 2008; Roth et al. 2008; Brewer and Buttenfield 2010). Specifically, a comprehensive literature review was conducted to synthesize and organize extant literature relevant to multiscale mapping. This literature review appends research on generalization with research on map design, as multiscale mapping is broader than generalization alone. This review then was used to develop a typology of multiscale mapping operators for use with the ScaleMaster diagram, which includes four higher-level categories: content, geometry, symbol, and label. The purpose of the ScaleMaster typology, and associated literature review, is to provide a more complete understanding of how map appearance must change across scales to maintain readability and usefulness. The ScaleMaster typology is prepared so that it can be used as a classroom teaching tool, as a pragmatic guide for completing multiscale mapping projects, and as a conceptual foundation for future scientific research. Although description of a case study application of the typology is outside of the scope of this paper, the proposed typology successfully was applied and evaluated in concurrent ScaleMaster work (see Brewer et al. 2010).

The paper proceeds with four additional sections. In the following section, we briefly introduce the ScaleMaster diagram and its relationship to the work in multiscale mapping presented here. We then provide an extended review of key research on generalization; the focus in this review is upon research containing either informal lists or formal typologies of generalization operators. In the fourth section, we integrate this review on generalization with other work on map design and offer our primary contribution: the ScaleMaster typology of multiscale mapping operators. We conclude by offering summary remarks and future directions.

CONTEXT: THE SCALEMASTER DIAGRAM AND MULTISCALE MAPPING OPERATORS

The broader context of this paper is the *ScaleMaster diagram*, a conceptual schematic for organizing, maintaining, and sharing the scale-dependent design specifications of a multiscale mapping project. Originally presented in 2003 at an Esri planning talk by Senior Cartographer Charlie Frye, the ScaleMaster concept was extended during a seminar offered by Cynthia Brewer in 2004 at Penn State and later formalized in a trio of publications by Brewer, Buttenfield, and colleagues (Brewer et al. 2007; Brewer and Buttenfield 2007; Brewer and Buttenfield 2010). The ScaleMaster diagram represents each feature type as a stack along the vertical axis and the range of project scales along the horizontal axis. Scales are marked along the horizontal axis that contain *anchor data*, such as a different data capture or a pre-processed generalization of the dataset (referred to as a level of detail, or LoD), or a *decision point* (i.e., a scale at which the map design requires modification). Each feature type, grouped by theme, has an

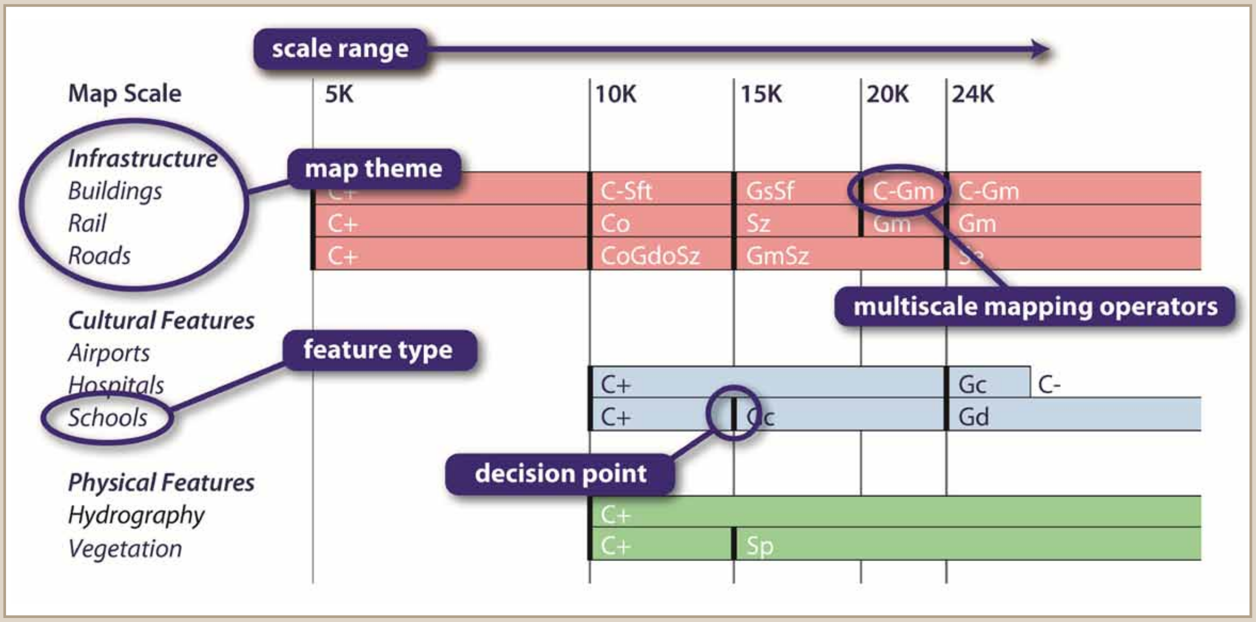

Figure 1: An example ScaleMaster diagram.
This figure shows a portion of a ScaleMaster diagram constructed for a multi-scale mapping project in Portland, OR. In the example, the ScaleMaster design is shown through 1:24K for simplicity, although the complete multiscale mapping project extended through 1:1M. Meanings of the two-letter codes are provided in Figure 3..

associated rectangular bar that extends across the range of scales for which it is used. Decision points are labeled with two-letter codes indicating the necessary *multiscale mapping operators* (the actual design alterations) that must be applied in order to maintain map legibility. Thus, the ScaleMaster diagram itemizes the multiscale mapping operations that need to be applied given the desired scale for map use. Figure 1 shows an example ScaleMaster diagram taken from a multiscale mapping project for Portland, Oregon. Additional details about ScaleMaster can be found at **http://www.scalemaster.org**.

The contribution to research on the ScaleMaster diagram reported in the following is the theoretically-informed enumeration of the available multiscale mapping operators that can be applied at each decision point to maintain a legible map design. Before presenting the ScaleMaster typology and associated literature review, we first must justify investigation at the operator level, rather than at the algorithm level. A distinction between operators and algorithms commonly is accepted in the generalization literature. An *operator* is an abstract or generic description of the type of modification that can be applied when changing scale, while an *algorithm* is a particular implementation of the operator (Regnauld and McMaster 2007). The operator articulates how the cartographer conceptualizes the cartographic design decision (e.g., “I want to simplify this line”), while the algorithm articulates how the cartographer executes the decision (e.g., “I maintained every fifth point, deleting those falling in between”).

The operator level was chosen for the ScaleMaster typology for four reasons. First, there is a strong tradition in the generalization literature of using operators to describe the generalization processes when the complex details of the transformation algorithms are not necessary (for example, see the acceptance and permutation of the McMaster and Shea, 1992, paradigm in American cartography described in the following section). This suggests that cartographers conceptualize map generalization during the planning stages of map design in a much more abstract form than how they eventually execute their decisions. Because one purpose of the ScaleMaster diagram is to support the planning stages of a multiscale mapping project, annotations at the operator level are more appropriate. Second, there are many algorithms that implement the same operator. For example, the simplify operator, found in all existing generalization typologies, can be accomplished by many algorithms, including simple nth point, the Douglas-Peucker algorithm (Douglas and Peucker 1973), the Walking algorithm (Müller 1987), ATM filtering (Heller 1990), optimization simplification (Cromley and Campbell 1992), the Visvalingham-Whyatt algorithm (Visvalingham and Whyatt 1993), and the modified Visvalingham-Wyatt algorithm (Zhou and Jones 2004; Bloch and Harrower 2006), among many others. Specific algorithm names and parameters can be stored in an ancillary document associated with the ScaleMaster overview. Third, the plethora of algorithms is complicated further by a lack of consistency in algorithm name, with different software packages often employing different naming conventions. To ensure that the ScaleMaster typology is useful to expected users, it is important that the ScaleMaster diagram can be applied equally well across software environments. Again, software-specific terminology can be stored in an ancillary document. Finally, if the algorithm level is the elemental decision choice in the ScaleMaster diagram, the proposed typology quickly may become out-of-date and therefore irrelevant as new algorithms are developed.

LITERATURE REVIEW: A SURVEY OF GENERALIZATION TYPOLOGIES

Research on generalization was used as a starting point for constructing an initial typology of multiscale mapping operators for use in the ScaleMaster diagram. We specifically focused upon research offering either informal lists or formal typologies of generalization operators, extending the summary of typologies offered in Li (2007). Given the goal of supporting *The National Map* effort in the United States, our review focuses primarily upon American scholarship, although a targeted subset of contemporary European frameworks are reviewed for comparison. The reviewed generalization typologies are compared in Figure 2. The dark blue depicts the first appearance of a generalization operator in a typology (not the first time it is used independently in the literature) and the light blue depicts its subsequent mention in other typologies. It is important to note that many of the authors used different words to describe a similar action or the same word to describe very different actions; these inconsistencies are marked with notes in Figure 2. The large number of inconsistencies supports the findings of Rieger and Coulson (1993), who reported that experts in map generalization do not make use of a common lexicon and that many of the terms in the literature are used in multiple, sometimes contradictory ways by educators and practitioners. Further, of the seventeen generalization operators identified in Figure 2, only simplification is acknowledged throughout, illustrating the overall lack of agreement among the typologies. Finally, it is important to recall the distinction between multiscale mapping and generalization made in the introductory section; while extant generalization literature provides a theoretical basis, it should not be accepted as the full space from which to gather multiscale mapping operators, as discussed in the next section.

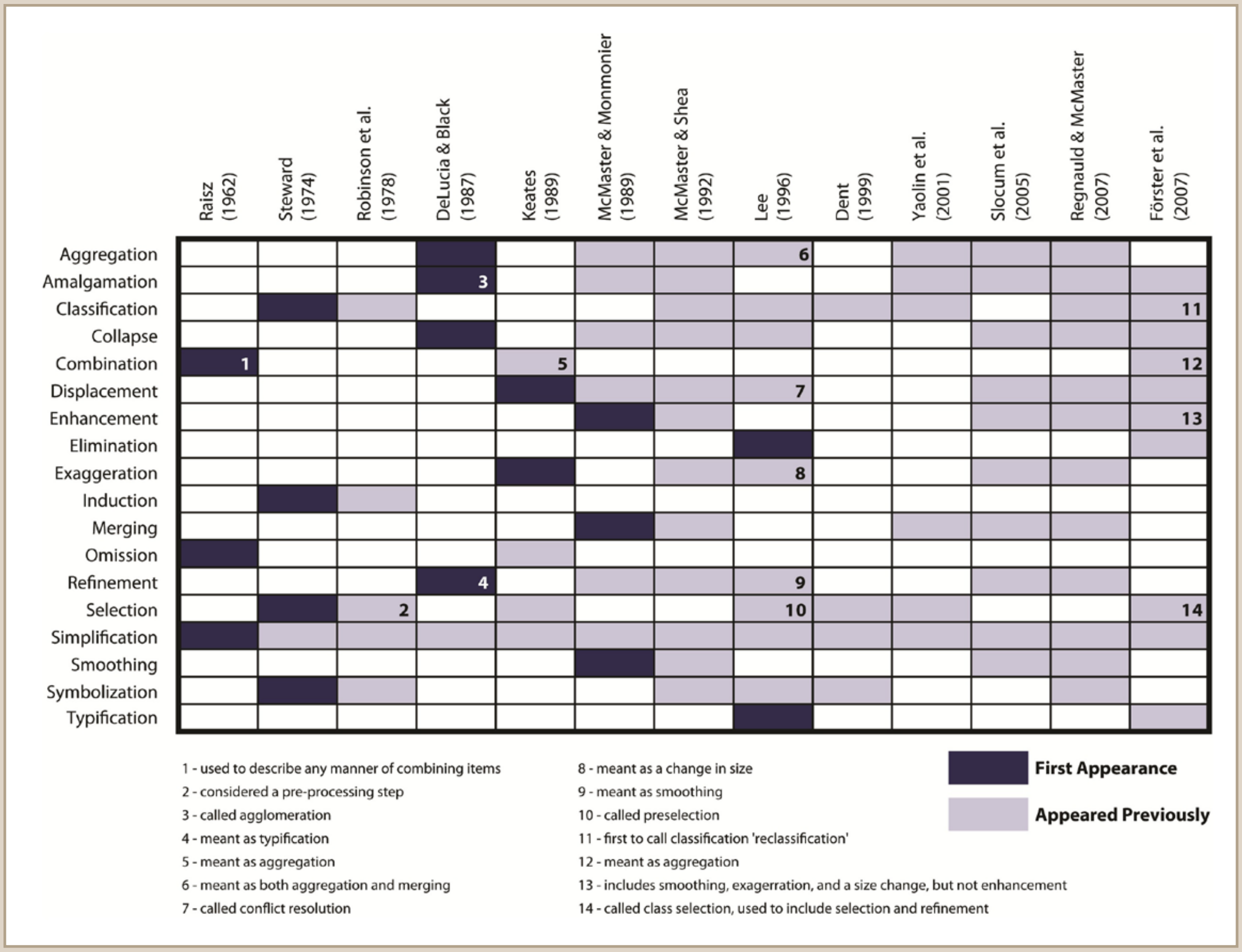

Figure 2: A comparison of generalization operator typologies.

Two of the earlier typologies were purposefully broad in their categorization of the generalization process. Raisz (1962) identified three basic categories of generalization: omission, combination, and simplification. Raisz's omission described the removal of a geographic phenomena or process from consideration for mapping, his combination included any method for representing multiple real world objects with a single map object, and his simplification involved any action that eliminates detail from the representation of a single feature. Robinson et al. (1978), following previous work by Steward (1974), divided mapmaking into two higher-level categories: selection and generalization. Selection, to Robinson and his colleagues, was the determination of the map features necessary for support of the map theme and was considered a pre-processing step for generalization; Robinson et al.'s selection perhaps can be considered the inverse of Raisz's omission. Generalization then was further subdivided into four "elements": simplification, classification, symbolization, and induction. Robinson et al.'s simplification described the retention of the character of a feature while removing unneeded detail (similiar to Raisz's use of simplification); classification involved organizing selected features into categories; symbolization described the graphic representation of selected features or classified groupings by abstract symbols; and induction summarized further transformations of the data into summary information graphics, and then into knowledge by the map reader. Interestingly, Robinson et al. did not include Raisz's combination, an operator given heavy attention by later scholars. The Dent et al. (2009) textbook adopts four of the five Robinson et al. generalization operators, dropping induction (a category not supported by scholars following Robinson et al.).

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Several subsequent typologies further discriminated these broader categories, primarily focusing upon Raisz's (1962) combination and Robinson et al.'s (1978) simplification. DeLucia and Black (1987) divided Raisz's combination into three operators according to geometric dimensionality: agglomeration, aggregation, and collapse. To DeLucia and Black, agglomeration described the combination of multiple features into one feature without a change in dimensionality (points-to-point, lines-to-line, areas-to-area); aggregation described the combination of multiple features into one feature using an upward conversion in dimensionality (points-to-line, points-to-area, lines-to-polygon); and collapse described the combination of multiple features into one feature using a downward conversion in dimensionality (areas-to-point, areas-to-line, lines-to-point). DeLucia and Black also used collapse to describe the downward conversion in dimensionality of a single feature (e.g., a single area into a single point), a definition that does not fit with Raisz's original definition of combination, which included only many-to-one conversions. Finally, the DeLucia and Black typology included simplification, as defined by Robinson et al., and distribution refinement, defined as the deletion of a subset of the total features in a data layer based on spatial proximity in order to produce a representative sampling (a concept also fitting Stanislawski's, 2009, usage of pruning).

McMaster and Monmonier (1989) continued the partition of Raisz's (1962) combination and Robinson et al.'s (1978) simplification, and also offered several new, unrelated operators. Unlike their predecessors, McMaster and Monmonier organized their generalization operators by geometric dimension, separating operators based upon their applicability to point, line, areal, and volume features. This approach generated some redundancy, most notably their distinction between amalgamation and merging. Both operators referred to the combination of many features into a single feature without a change in dimensionality, similar to DeLucia and Black's (1987) agglomeration; these two operators differed only in that amalgamation referred to a combination of area features while merging referred to a combination of linear features (there was no operator given for a combination of point features). This distinction was retained by McMaster and Shea (1992), Yaolin et al. (2001), Slocum et al. (2005), and Regnauld and McMaster (2007). McMaster and Monmonier also refined Robinson et al.'s conceptualization of simplification, differentiating between smoothing, defined as the removal of small crenulations along a line, and their own version of simplification, defined as the removal of the number of points constituting the line. Finally, McMaster and Monmonier offered the operators displacement, defined as the positional adjustment of a feature to avoid coalescence with other features (after Keates, 1989); enhancement, defined as supplementary graphic marks to clarify or elevate the message imparted by a symbol; and refinement, an alteration of DeLucia and Black's usage referring to the elimination of a subset of features based on attribute, rather than on spatial characteristics.

The McMaster and Shea (1992) text synthesized work from a previous Shea and McMaster (1989) proceedings paper along with the McMaster and Monmonier (1989) framework described above. A key addition of the McMaster and Shea typology was the broader-level distinction between spatial transformations and attribute transformations. Spatial transformations referred to generalization operators that alter the geographic or topological positioning of a feature, while attribute transformations referred to generalization operators that manipulate the statistical characteristics of a feature. As with most of the prior typologies, greater attention was given to the spatial transformations. Spatial transformations included the nine operators from the McMaster and Monmonier typology appended with Keates' (1989) exaggeration, defined as the amplification of a portion of an object to emphasize or maintain a characteristic aspect of it. Attribute transformation included the Robinson et al. (1978) operators of classification and symbolization. The ten spatial transformation operators from McMaster and Shea were offered by Slocum et al. (2005) as a typology of vector-based operations. All twelve operators were adopted by Regnauld and McMaster (2007), although the ten spatial transformations (i.e., not classification and symbolization) were considered the "fundamental" generalization operators. Because of these mainstream reproductions, the McMaster and Shea (1992) paradigm is perhaps the most popular generalization typology in American cartography today.

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In contrast to the American typologies, Foerster and colleagues (2007; 2010) offered a classification of operators organized according to Gruenreich's (1985; 1992; 1995) division between model generalization and cartographic generalization, a dominant dichotomy in the European generalization literature. Model generalization describes the manipulation of the digital representations of geographic information stored in the database, while cartographic representation involves the manipulation of the graphic representations on the map page (Weibel and Dutton 1999). In the Foerster et al. typology, many of the operators present in the McMaster and Shea (1992) paradigm were identified as either model generalization or cartographic generalization; the amalgamation operator was included in both. Cartographic generalization operators included class selection, reclassification, collapse, combination, simplification, and amalgamation, while model generalization operators included enhancement, displacement, elimination, typification, and amalgamation.

Foerster et al.'s (2007) class selection appended Robinson's et al.'s (1978) use of selection with McMaster and Shea's (1992) use of refinement, describing this action as filtering of features based upon an attribute hierarchy. Foerster et al. used the term reclassification in a similar manner as Robinson et al.'s classification, adding the prefix to emphasize that the reclassification always is based upon an existing data model. Class selection and reclassification are executed first and followed by the model generalization operators collapse (similar to the DeLucia and Black, 1987, usage), combination (similar to DeLucia and Black's aggregation operator), amalgamation (similar to the DeLucia and Black usage), and simplification (similar to the McMaster and Monmonier, 1989, usage). Interestingly, Foerster et al. eliminated the distinction between amalgamation and merging present in the McMaster and Monmonier typology. The cartographic generalization operator enhancement combined Keates' (1989) and McMaster and Monmonier's smoothing along with the squaring of buildings and enlargement of features. Foerster et al. borrowed the operators elimination and typification from the Lee (1996) Esri white paper, which described the removal of a graphic from the display and the replacement of a set of features with a representative subset respectively. Finally, Foerster et al.'s amalgamation matched the DeLucia and Black definition of the term, and displacement matched the Keates definition. Foerster et al. did not consider symbolization as a fundamental operator.

THE SCALEMASTER TYPOLOGY

The above review on generalization was used as a theoretical foundation for the development of a typology of multiscale mapping operators for use in the ScaleMaster diagram. In this section, we first introduce a higher-level framework for organizing the operators, which includes four categories: content, geometry, symbol, and label. This higher-level categorization takes a "cartographer-oriented" view of multiscale mapping, describing broader groupings of decisions available to a cartographer to maintain map legibility when shifting scales, compared to what could be termed "automation-oriented" or "computation-oriented" views presented by other, geometry-centric offerings in the generalization literature. After discussing the higher-level categorization, we then introduce each multiscale mapping operator included in the typology. It is important to note that we expect this set of operators to expand as practice and technology evolves, although we also expect the higher-level distinction to remain a useful framework for conceptualizing and organizing multiscale mapping operators.

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IDENTIFYING HIGHER-LEVEL CATEGORIES OF MULTISCALE MAPPING OPERATORS

We were interested to find that many scholars organized their proposed generalization operators into a two-level hierarchy, with the operators classified into a set of higher-level categories. For instance, Robinson et al. (1978) distinguished between the higher-level categories of selection and generalization; McMaster and Monmonier (1989) organized operators according to dimensionality; McMaster and Shea (1992) distinguished between attribute and spatial transformations; and Foerster et al. (2007) organized operators according to model versus cartographic generalization. Such a higher-level categorization emerged as we reconciled the existing generalization typologies and considered the generalization operator descriptions in the context of multiscale mapping. We identified four higher-level categories in total: geometry, content, symbol, and label; each is described in the following section.

The majority of generalization typologies focus upon geometric transformations (Foerster et al., 2007, also note this emphasis). The *geometry* category of the ScaleMaster typology follows Regnauld and McMaster's (2007) "fundamental geometric generalization operators" and includes any manipulation of the points, lines, or polygons constituting a map feature. The prevalence of geometry operators perhaps is a result of the amount of attention given to Raisz's (1962) combination and Robinson et al.'s (1978) simplification by subsequent scholars, and the associated promulgation of the McMaster and Shea (1992) paradigm. This prevalence also may be due to a past emphasis on developing computational techniques to automate the generalization process. However, manipulation of the vector linework alone is insufficient to produce a legible map in most mapping contexts, as Raisz and Robinson et al. identified early in the generalization literature.

Many scholars acknowledge in their typologies the impact that the content included in the map has on the map's legibility. The *content* category of the ScaleMaster typology, a term borrowed from Monmonier (1996), describes the choices made to identify and organize the features for inclusion on the map. The content category expands Robinson et al.'s (1978) notion of selection to include other map organization operators, such as the classification of features into nominal or hierarchical categories and the stacking of feature types for display. Many of the reviewed generalization typologies included some form of content manipulation.

The third category is the fundamental component of cartographic representation: map symbolization. The *symbol* category of the ScaleMaster typology follows Robinson et al.'s (1978) broad symbolization operator and is defined as the graphic encoding of a feature on the map page. Symbolization is often missing from extant generalization categories (e.g., Raisz 1962; DeLucia and Black 1987; McMaster and Monmonier 1989; Foerster et al. 2007) or is considered to be something entirely different from the core set of generalization operators (e.g., McMaster and Shea 1992; Regnauld and McMaster 2007). Brewer and Buttenfield (2007; 2010) and Brewer et al. (2007), however, demonstrated that for intermediate scale ranges, legible designs can be maintained by adjusting the map content and symbols alone. Regardless of whether symbol operators are considered to be a form of "generalization," they are invaluable for multiscale mapping and thus are included in the ScaleMaster typology. Many of the symbol operators are related to Bertin's (1967|1983) visual variables, although it is important to note that the usage of these operators does not necessitate that the visual variables directly encode data attributes; a comparison of visual variable typologies is provided by Tyner (2010).

As with map symbolization, map labeling, or typography, also has received a great deal of attention by cartographers. Also, like map symbolization, much of the work on map labeling is not considered in the context of generalization

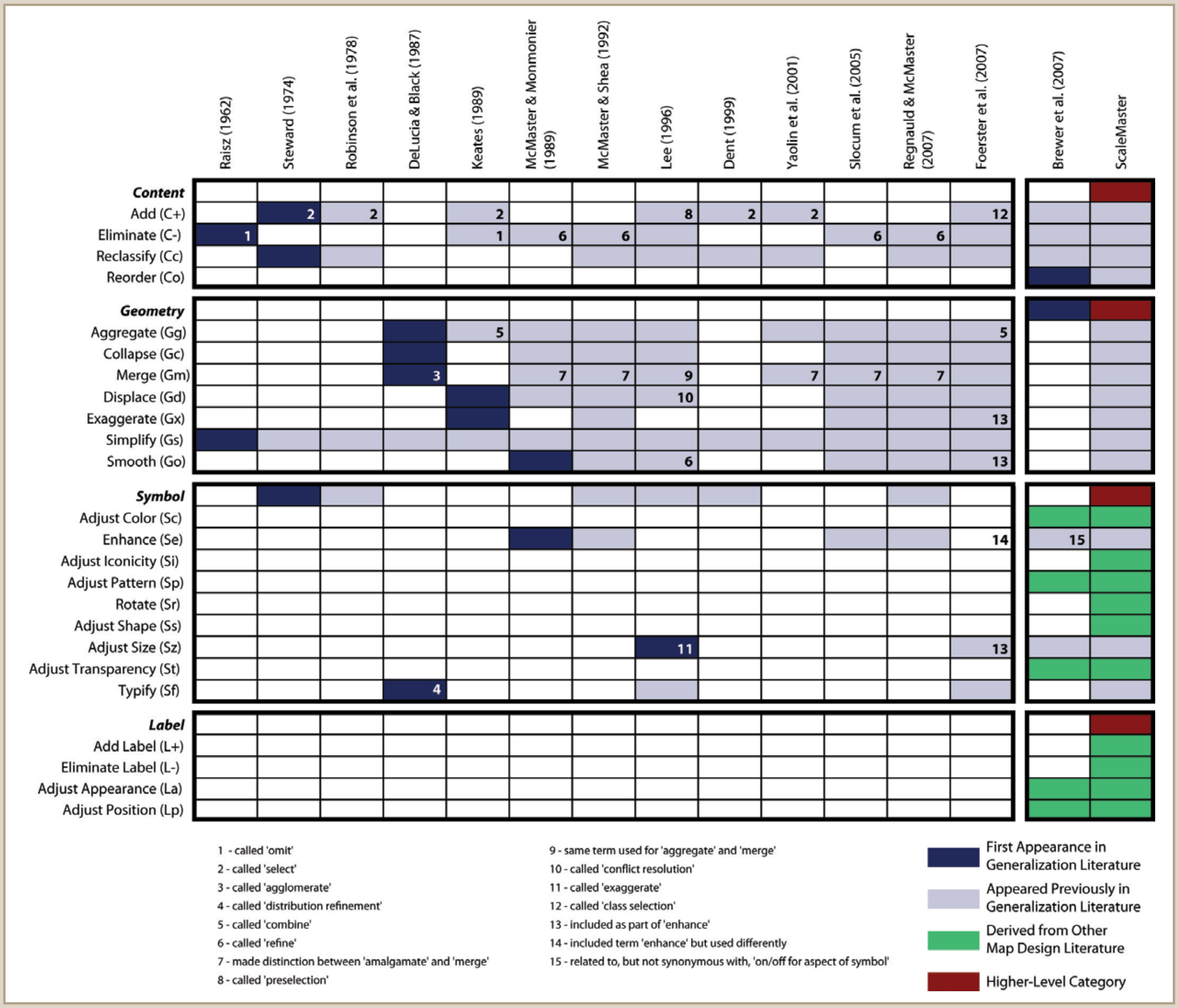

Figure 3. The ScaleMaster typology of multiscale mapping operators, with the higher-level categories of Content, Geometry, Symbol, and Label. The ScaleMaster typology is compared to the generalization operator typologies presented in Figure 2 (note: operators in the generalization typologies have been reordered from Figure 2 to conform to the ScaleMaster typology).

and multiscale mapping; see Stroh et al. (2010) and Butzler et al. (2011) for recent examples that do consider labeling for multiscale mapping projects. The *label* category of the ScaleMaster describes the rules for adding text to the map in order to explicate or replace the included map symbols. Early applications of the ScaleMaster diagram treated labeling as a meta-operation performed on each feature type, with adjustments to labeling represented by a thinner, secondary bar stretching across the scales at which the feature type is labeled. This secondary bar was placed directly beneath the primary horizontal bar that indicated the multiscale mapping operators applied to the feature type (see Brewer et al., 2007, for an example). However, more recent work by Brewer et al. (2010) dissolves this distinction for visual clarity in the ScaleMaster diagram, placing notes on label adjustments in the primary bar along with other multiscale mapping operators in the ScaleMaster diagram, and considers labeling as its own category of multiscale mapping operators. Although multiscale design generally begins by applying content operators, followed by geometry, then symbol, and finally label operators, it is important to note that multiscale design is an iterative process, with the application of any operator requiring the cartographer to revise the application of previously applied operators.

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DESCRIPTION OF MULTISCALE MAPPING OPERATORS IN THE SCALEMASTER TYPOLOGY

Figure 3 groups the operators from Figure 2 according to the four aforementioned higher-level categories. In the ScaleMaster typology, we identify four content operators (add, eliminate, reclassify, reorder); seven geometry operators (aggregate, collapse, merge, displace, exaggerate, simplify, and smooth); nine symbol operators (adjust color, enhance, adjust iconicity, adjust pattern, rotate, adjust shape, adjust size, adjust transparency, and typify); and four label operators (add labels, eliminate labels, adjust appearance, and adjust position). Each of these operators is described in the following subsections. For each operator, we include a formal definition, a standard two-character code for use in the ScaleMaster diagram, a sample illustration, a description of its use in the literature, and our approach to reconciling contradicting uses (where appropriate).

(1) CONTENT OPERATORS

Add (C+): *insertion of features*

The *add operator* (Figure 4) inserts new features to the map display once a scale is reached that is appropriate for their display. This operator relates to the notion that anchor data is useful at a finite set of scales in a multiscale mapping project. Further, geographic phenomena and processes often are conceptualized to occur at a particular scale or set of scales (e.g., it does not make sense to represent a mountain range at a large cartographic

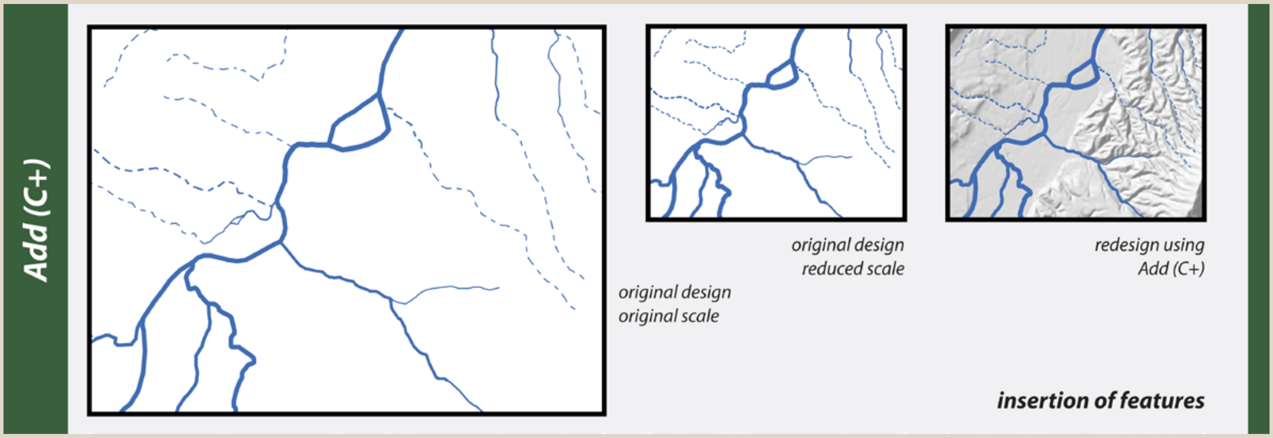

Figure 4. Add (C+)

scale). Thus, the add operator inserts features only at the scale at which they are conceptualized and measured. It also is common to add new layers as scale changes due to the associated change in map extent (e.g., different kinds of features now may be in view); Figure 5 modifies Figure 4 to show how changes to the map extent impact application of the add operator. The add operator may be coupled with the elimination of more detailed features in a similar theme or the elimination of other features that previously caused map legibility issues with the newly added features. The add operator is similar to Robinson et al.'s (1978) selection, but differs in that it is not solely a preprocessing step; it instead can be implemented at any scale in the multiscale mapping project. The add operator is the inverse of Raisz's (1962) and Keates' (1989) omission and the ScaleMaster eliminate operator (C-).

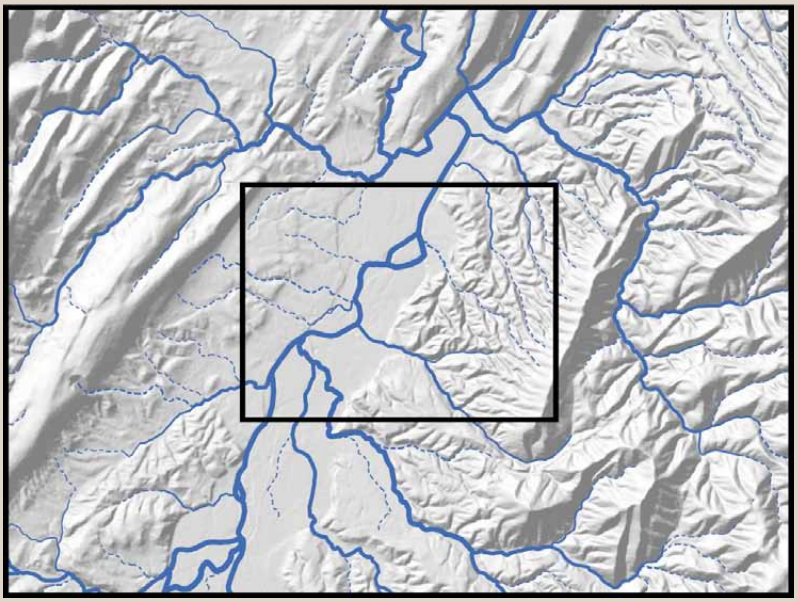

Figure 5. One reason for applying the add operator is due to the change in map extent that occurs as scale changes. This figure modifies Figure 4 to show the new map extent at the smaller scale. There are now prominent ridges included in the map extent, increasing the importance of terrain representation to the map theme. Inclusion of terrain representation at the smaller scale, and not at the larger scale, additionally is justified due to the spatial resolution of the underlying elevation data.

Eliminate (C-): *removal of features*

The *eliminate operator* (Figure 6) removes features once a scale is reached where they become illegible or no longer fulfill their intended purpose. The eliminate operator may be implemented if: (1) the data has too detailed a resolution and precision, providing unnecessary detail, (2) there are too many feature types represented for a given scale, causing illegibility, or (3) only the most significant features in a grouping are required to convey the message. The eliminate operator is similar to Raisz's (1962) and Keates' (1989) omission, and it is the inverse of Robinson et al.'s (1978) selection, Foerster et al.'s (2007) class selection, and the ScaleMaster add operator (C+). A special case where a subset of features is eliminated from a larger whole based on a hierarchical ordering was distinguished by DeLucia and Black (1987)

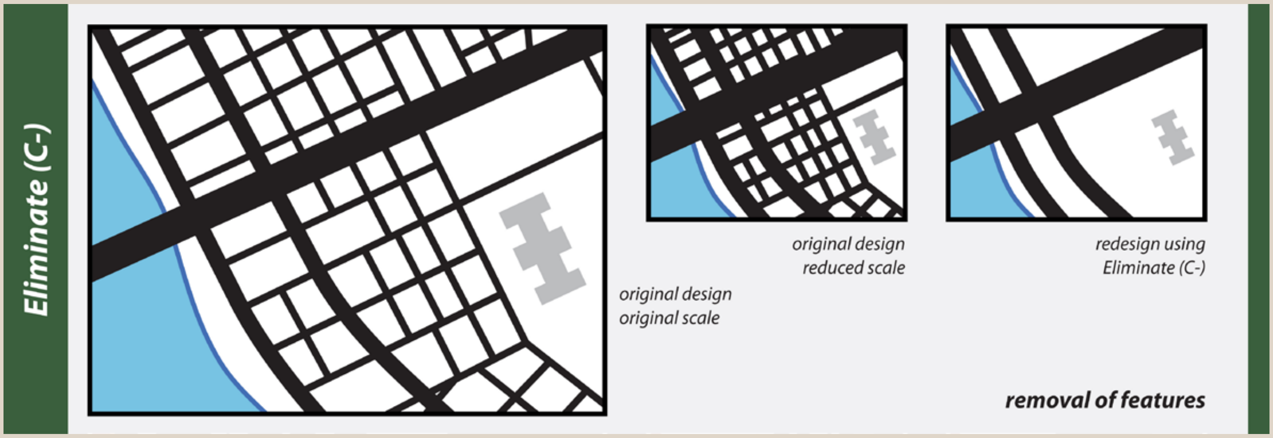

Figure 6. Eliminate (C-)

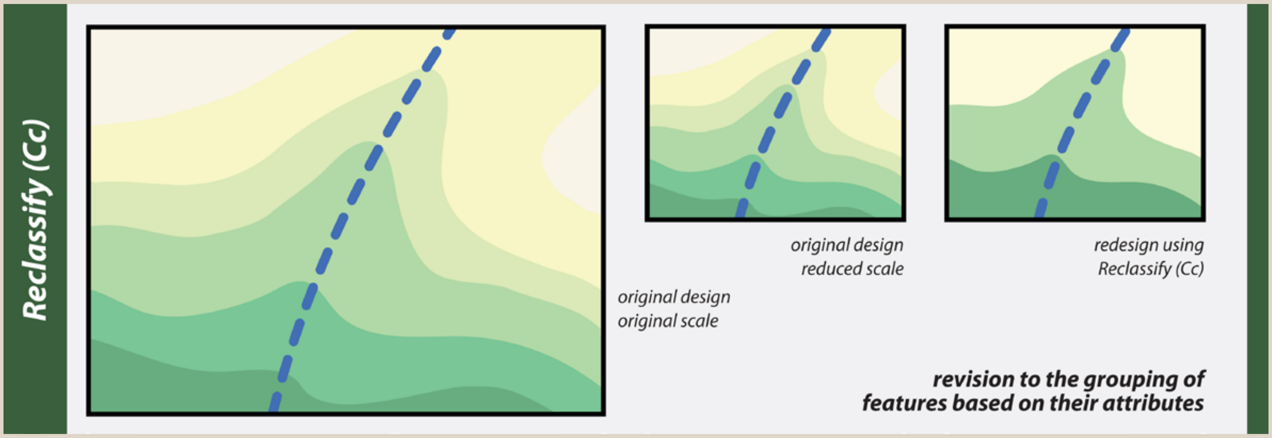

Figure 7. Reclassify (Cc)

and McMaster and Shea (1992), terming this special case refinement. The ScaleMaster typology does not follow this distinction because it is a function of the structure of the data and does not produce a different kind of change to the map (i.e., it is more similar to two multiscale mapping algorithms that implement the same multiscale mapping operator, rather than conceptually separate multiscale mapping operators).

Reclassify (Cc): *revision to the grouping of features based on their attributes*

The *reclassify operator* (Figure 7) alters the way that features are organized in the representation based upon their attributes in order to improve map legibility. The reclassify operator may be implemented in several ways: (1) a revision to the total number of classes represented, (2) a revision to the composition of existing classes (by using different class breaks or classifying by a different attribute), or (3) a combination of both. The reclassify operator was defined in a similar manner by Robinson et al. (1978), Nyerges (1991), and McMaster and Shea (1992), all using the term classification. The term reclassify, first used by Foerster et al. (2007), is preferred over the term classify to emphasize that the same data may be classified differently at different scales.

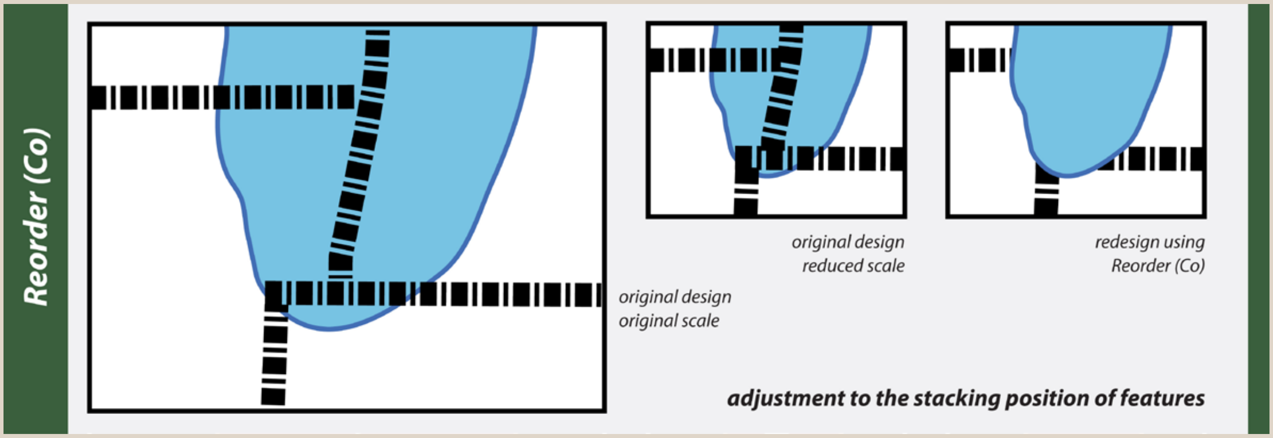

Figure 8. Reorder (Co)

Reorder (Co): *adjustment to the stacking position of features*

The *reorder operator* (Figure 8) changes the stacking order of features when one feature becomes sufficiently obscured by another. The reorder operator is recommended when use of the adjust transparency or displace operators yield an unsatisfactorily legible solution to feature overlap. Reordering also may be used to make some features less visually significant because they are less important to the map's message at smaller scales (e.g., the graticule may be moved behind land areas at smaller scales, at which precise measurement is unlikely). Reordering often is required when other operators cause feature conflict. For example, an aggregation of a set of related point features into a single polygon feature may require reordering of the new polygon feature beneath all other point and line features so that they remain visible. The reorder operator was defined in a similar manner by Brewer et al. (2007).

(2) GEOMETRY OPERATORS

Aggregate (Gg): *replacement of many related features with a representative feature of increased dimensionality*

The *aggregate operator* (Figure 9) captures the spatial extent of multiple features with a single feature of increased dimensionality (i.e., lines-to-polygon, points-to-polygon, or points-to-line). The aggregate operator is the inverse of the collapse operator, which produces a downward conversion in geometric dimension (i.e., polygon-to-line, polygon-to-point, or line-to-point). The aggregate operator commonly is confused with the polygons-to-polygon instance of the merge operator, which does not change dimensionality (e.g., Lee 1996; Monmonier 1996). The aggregate operator was defined in a similar manner by DeLucia and Black (1987), McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007). The aggregate operator also was referred to as area conversion by Monmonier (1996), combination by Foerster et al. (2007), and regionalization by Li (2007).

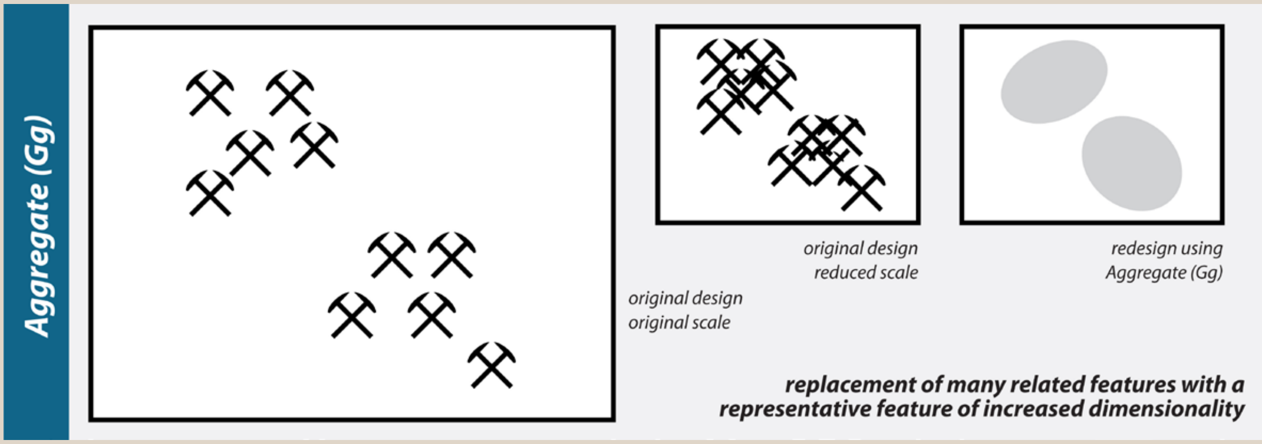

Figure 9. Aggregate (Gg)

Collapse (Gc): *replacement of a feature with a representative feature of lower dimensionality*

The *collapse operator* (Figure 10) reduces the complexity of one or more features with a downward conversion in dimensionality (i.e., polygon-to-line, polygon-to-point, or line-to-point). It is this reduction in dimensionality that differentiates the collapse operator from the ScaleMaster adjust iconicity operator (Si), where the represented feature itself maintains the same geometric dimension regardless of how the new symbol design appears. The collapse operator is the inverse of the ScaleMaster aggregate operator (Gg), which produces an upward conversion in geometric dimension (i.e., lines-to-polygon, points-to-polygon, or points-to-line). The collapse operator was defined in a similar manner by DeLucia and Black (1987), McMaster and Shea (1992), Slocum et al. (2005), Regnauld and McMaster (2007), and Foerster et al. (2007). The collapse operator also was referred to as point conversion by Monmonier (1996).

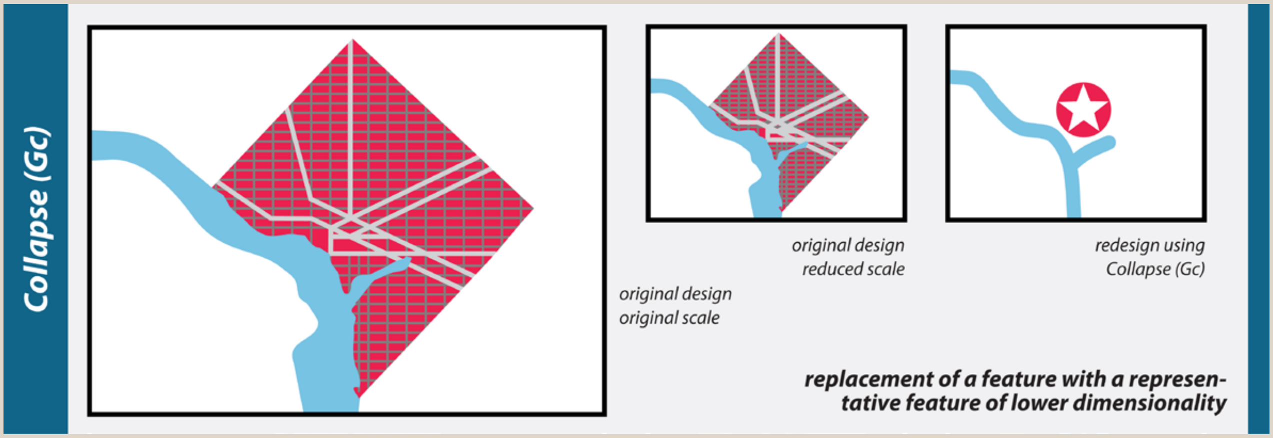

Figure 10. Collapse (Gc)

Merge (Gm): *replacement of a feature with a representative feature of equal dimensionality*

The *merge operator* (Figure 11) combines an array of related features into a single representative feature without a change in dimension. In the literature, this definition of the merge operator often was called amalgamation. McMaster and Monmonier (1989) divided DeLucia and Black's (1987) initial usage of amalgamation into two operators: the term amalgamation was used to describe the combination of multiple areas into a single area and the term merging was used to describe the combination of multiple lines into a single line. This distinction was adopted by McMaster and Shea (1992), Yaolin et al. (2001), Slocum et al. (2005), and Regnauld and McMaster (2007). We remove this distinction to reduce redundancy, following Foerster et al. (2007). In addition, this distinction is removed because the merging operator also may be applied

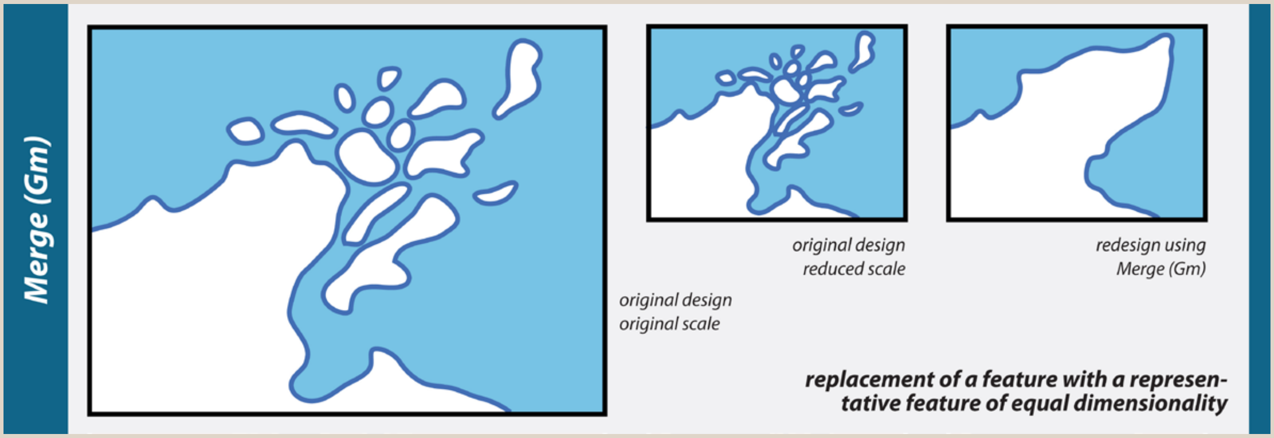

Figure 11. Merge (Gm)

to points, where a field of points is represented by only a single point (e.g., the geographic mean). The term merge is adopted rather than amalgamate because amalgamation commonly is confused with the term aggregate. The merge operator also was referred to as dissolving and merging by Tomlinson and Boyle (1981), agglomeration by DeLucia and Black (1987), dissolution by Monmonier (1996), and fusion by Foerster et al. (2007).

Displace (Gd): *adjustment to the location of a feature to avoid coalescence with adjacent features while maintaining topology*

The *displace operator* (Figure 12) shifts the position of one feature away from another feature to avoid overlap. The displace operator should be implemented in a way that retains the topological relations among the adjusted features as much as possible. The displace operator is different from the exaggerate operator in that displacement is not implemented to place an emphasis on the repositioned feature. The displace operator was defined in a similar manner by Keates (1989), McMaster and Shea (1992), Slocum et al. (2005), Regnauld and McMaster (2007), and Foerster et al. (2007). The displace operator also was referred to as conflict resolution by Lee (1996).

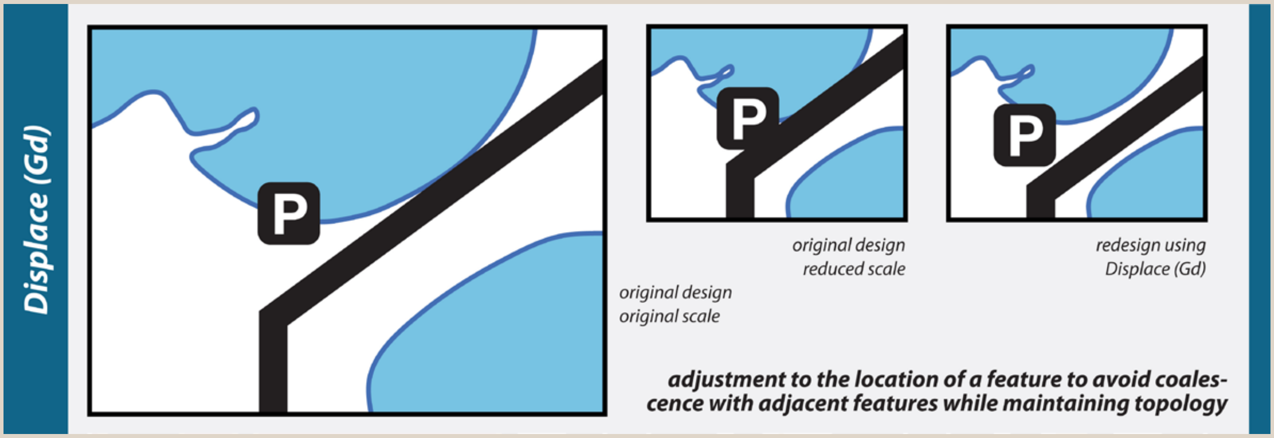

Figure 12. Displace (Gd)

Exaggerate (Gx): *amplification of a portion of a feature to emphasize a characteristic aspect of it*

The *exaggerate operator* (Figure 13) ensures that an important aspect of a feature is legible at all viewing scales. Muehrcke (1986) identified such amplification of characteristic aspects of features as vital to the cartographic abstraction process. Unlike the enhance operator, which adds graphic marks atop or around the symbolization of a feature to emphasize an important aspect of it, the exaggerate operator amplifies the important aspect by changing the geometry of the feature. Unlike the displace operator, maintaining topology and general legibility of all map features is not the purpose of the exaggerate operator. The exaggerate operator was defined in a similar manner by Keates (1989), McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007). The exaggerate operator also was referred to as partial modification by Li (2007).

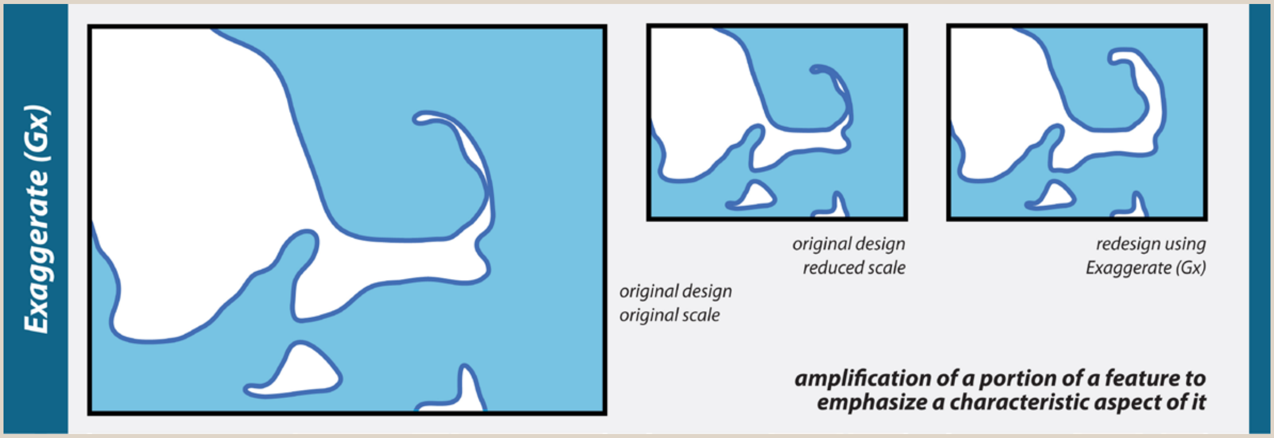

Figure 13. Exaggerate (Gx)

Simplify (Gs): *reduction of the number of points constituting a feature*

The *simplify operator* (Figure 14) reduces the number of points that constitute a line or polygon feature while retaining its overall character. Although simplification is one of the most commonly recognized operators, its use in the literature has evolved from a more generic descriptor of any action that reduces detail or data volume (Robinson et al., 1978) to its present-day, narrow focus on eliminating points. The simplify operator was defined in a similar manner by DeLucia and Black (1987), Jenks (1989), McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007). The simplify operator also was referred to as point reduction by Li (2007).

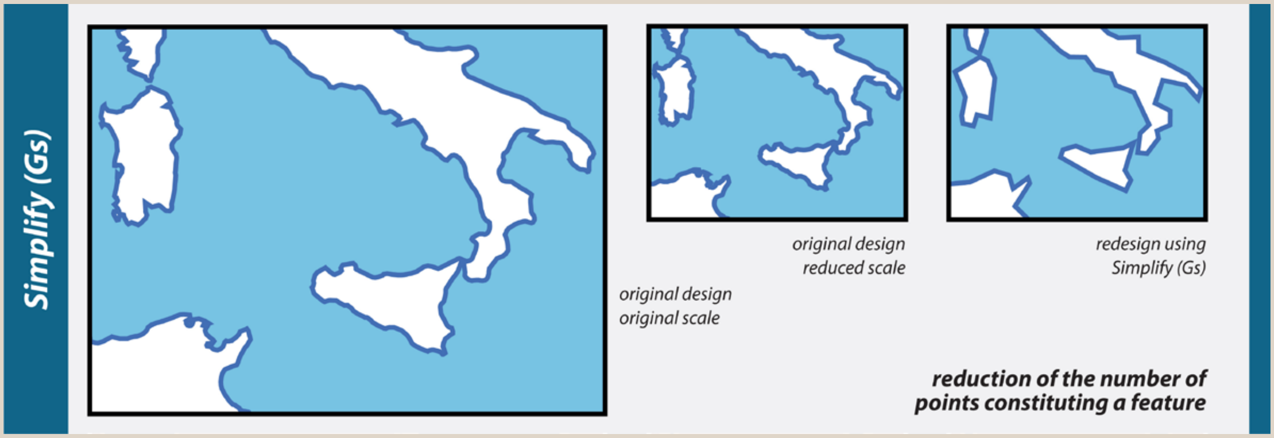

Figure 14. Simplify (Gs)

Smooth (Go): *removal of small variations in the geometry of a feature to improve its appearance*

The *smooth operator* (Figure 15) produces a more aesthetically pleasing (i.e., less angular or jagged) version of the original line by shifting the location of original points, adding intermediate points between the original points, or allowing the connection between points to be non-linear. While McMaster and Shea (1992) described the smooth operator as a process that maintains the original number of points, this definition is expanded here due to the large number of algorithms that increase or decrease the point total. Because the simplify and smooth operators often are synergetic, many compound algorithms implement these operators in tandem (McMaster, 1989). The smooth operator was defined in a similar manner by McMaster and Monmonier (1989), McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007).

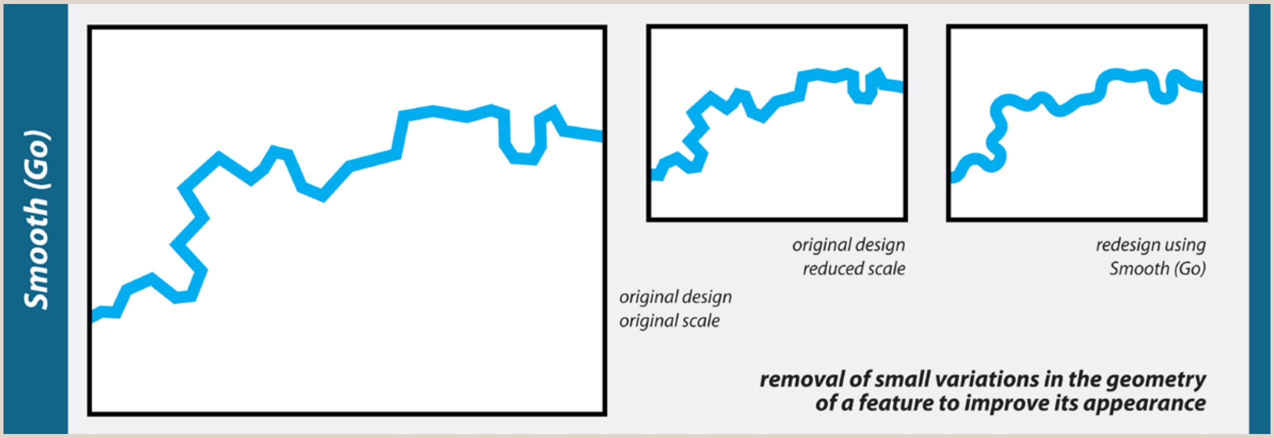

Figure 15. Smooth (Go)

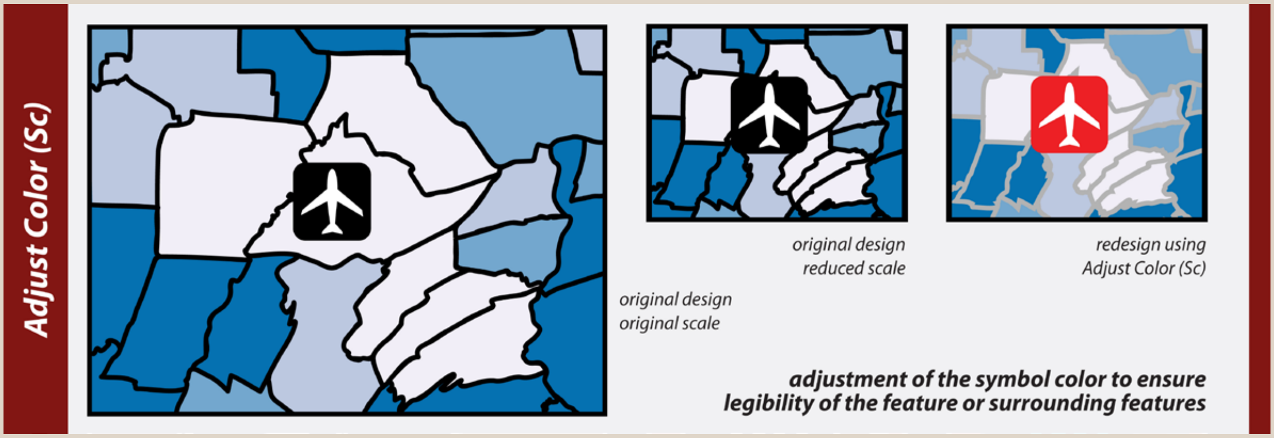

Figure 16. Adjust Color (Sc)

(3) SYMBOL OPERATORS

Adjust Color (Sc): *adjustment of the symbol color to ensure legibility of the feature or surrounding features*

The *adjust color operator* (Figure 16) alters the hue, lightness, or saturation (or a combination of any two or all three) of a feature so that it remains legible across multiple scales. Hue and lightness are two of Bertin's (1967|1983) original visual variables; Morrison (1974) added saturation, the third component of color, to this list. A change in scale may adjust the color distribution on the map enough to produce situations of simultaneous contrast or color illegibility not present in larger scale versions. The adjust color operator may be implemented for two reasons: (1) to increase the position of a feature in the visual hierarchy by increasing its contrast or distinctiveness or (2) to increase the position of surrounding features in the visual hierarchy by decreasing the resymbolized feature's contrast or distinctiveness. The adjust color operator was defined in a similar manner by Brewer et al. (2007).

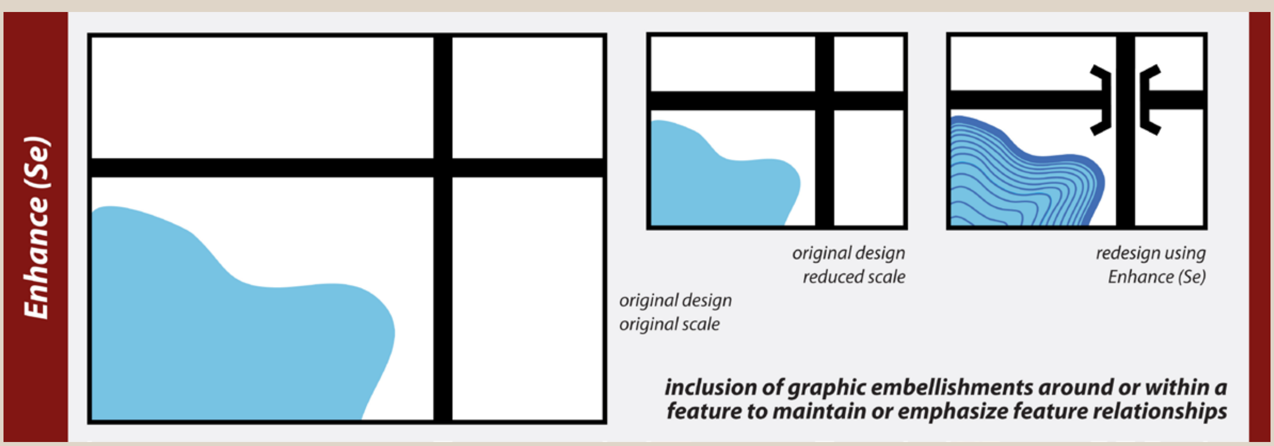

Figure 17. Enhance (Se)

Enhance (Se): *inclusion of graphic embellishments around or within a feature to maintain or emphasize feature relationships*

The *enhance operator* (Figure 17) provides additional graphic marks to accentuate and clarify an important aspect of a feature or an important relation among features. The common example is a bridge symbol placed where two roads cross, but the enhance operator also includes simple embellishments such as line casings for major roads, drop shadows on point symbols, and waterlining (Huffman, 2010). The enhance operator differs from the other symbolization operators that manipulate visual variables, including color, pattern, shape, size, and transparency, in that it adds or removes extra symbols around or atop the original symbols, rather than manipulating the symbols already present. The enhance operator differs from the displace and exaggerate operators in that the added embellishments do not transform the underlying geometry. The enhance operator was defined in a similar manner by McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007). The enhance operator also is related to, but not synonymous with, Brewer et al.'s (2007) use of on/off toggling.

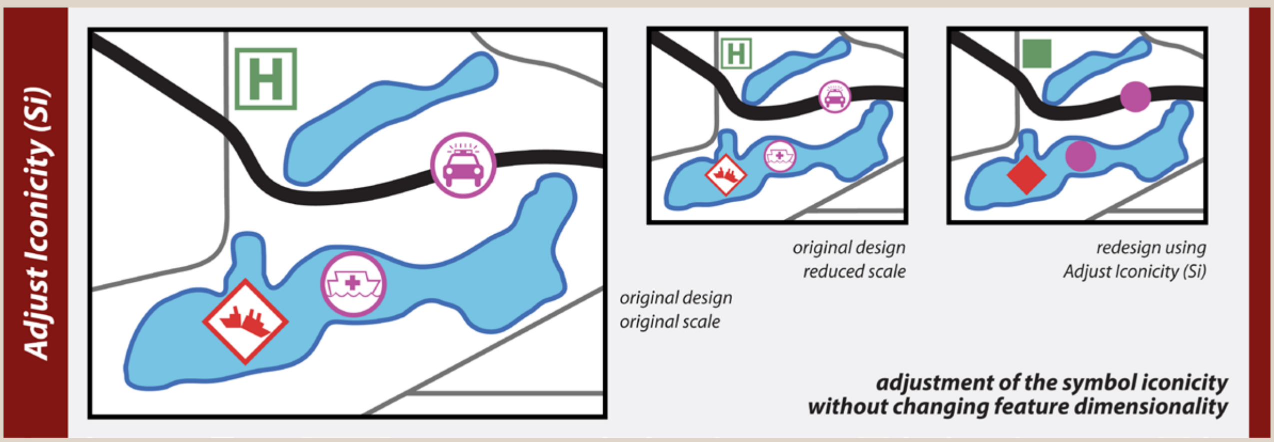

Figure 18. Adjust Iconicity (Si)

Adjust Iconicity (Si): *adjustment of the symbol iconicity without changing feature dimensionality*

The *adjust iconicity operator* (Figure 18) adjusts the degree to which a symbol resembles the feature it represents. Iconicity often is conceptualized as a continuum between mimetic/pictorial symbols and arbitrary/geometric symbols (MacEachren, 1995). Mimetic or pictorial symbols take a form similar to the feature they represent, while arbitrary or geometric symbols are abstractions with little or no visual relation to their referent. During the change to a smaller map scale, it is often necessary to swap detailed, unambiguous mimetic symbols for simplified geometric primitives whose interpretations are reliant upon a legend or label; a multiscale examine of

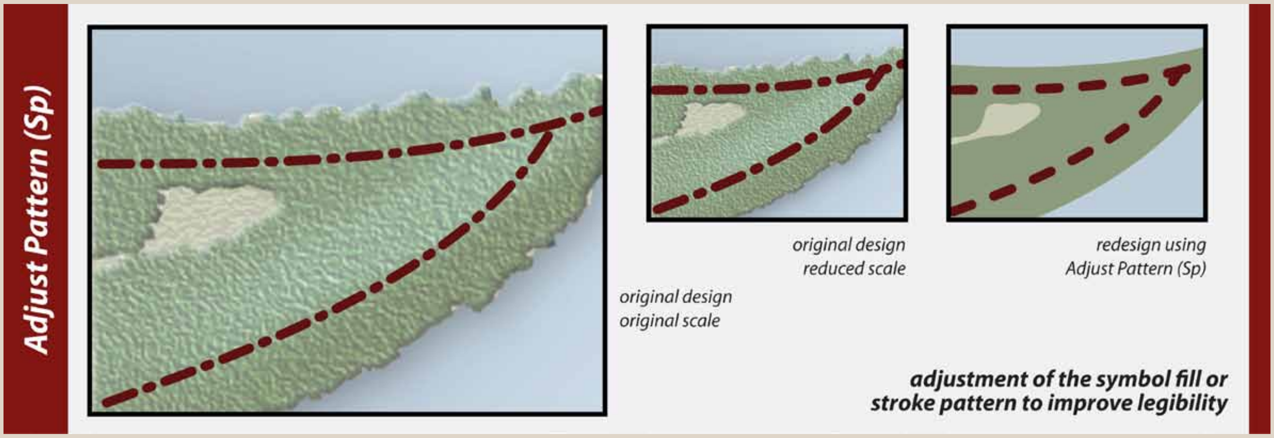

Figure 19. Adjust Pattern (Sp)

iconicity adjustment across scales is provided by Kostelnick et al. (2008). The adjust iconicity operator differs from the simplify, smooth, and collapse operators in that the underlying geometry is not altered.

Adjust Pattern (Sp): *adjustment of the symbol fill or stroke pattern to improve legibility*

The *adjust pattern operator* (Figure 19) adjusts the complexity of a symbol by changing the pattern. Although pattern and texture sometimes vary in definition, we are using the two terms synonymously. Texture was one of Bertin's (1967|1983) original visual variables and was theorized by Caivano (1990) to have three dimensions: (1) directionality of the texture units, (2) size of the texture units, and (3) density of the texture units. The adjust pattern operator is different from the exaggerate operator because the pattern is not created by the feature geometry and it is also different from the typify operator because the adjusted pattern does not mimic the overall distribution of an underlying set of features. The adjust pattern operator was used in a similar manner by Brewer et al. (2007).

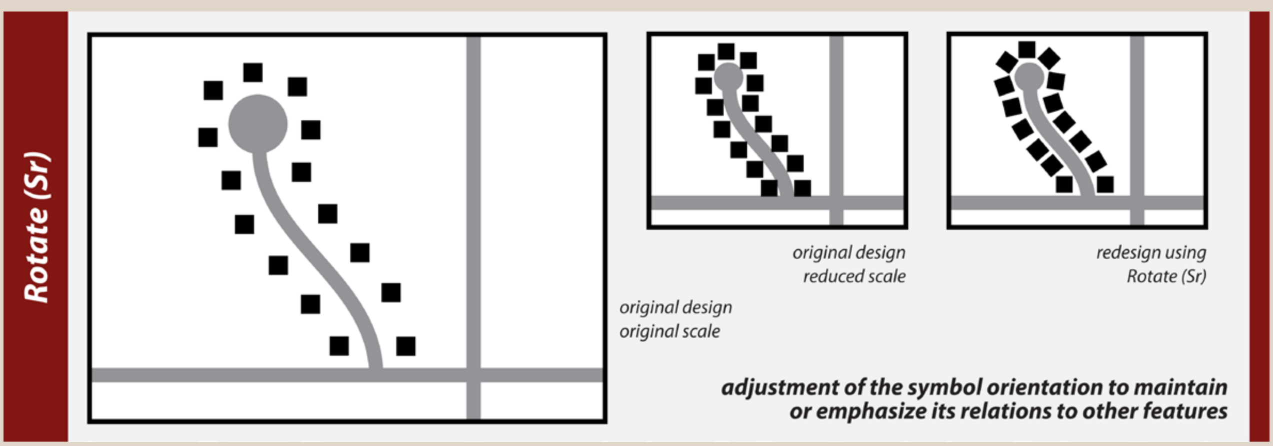

Figure 20. Rotate (Sr)

Rotate (Sr): *adjustment of the symbol orientation to maintain or emphasize its relations to other features*

The *rotate operator* (Figure 20) adjusts the orientation of one feature in relation to other features. Orientation was one of Bertin's (1967|1983) original visual variables, describing the 360-degree rotation of a symbol around its center. The rotate operator is different from the displace operator, which adjusts the spatial location of a feature but not its orientation, and the exaggerate operator, which may rotate a subsection of a symbol, but not a symbol in its entirety. The most common example of the rotate operator is the alignment of building symbols to a road after the buildings are collapsed or the road is simplified (Duchêne et al. 2003). The rotate operator is defined in a similar manner by Regnauld and McMaster (2007), although they do not consider it as a separate operator.

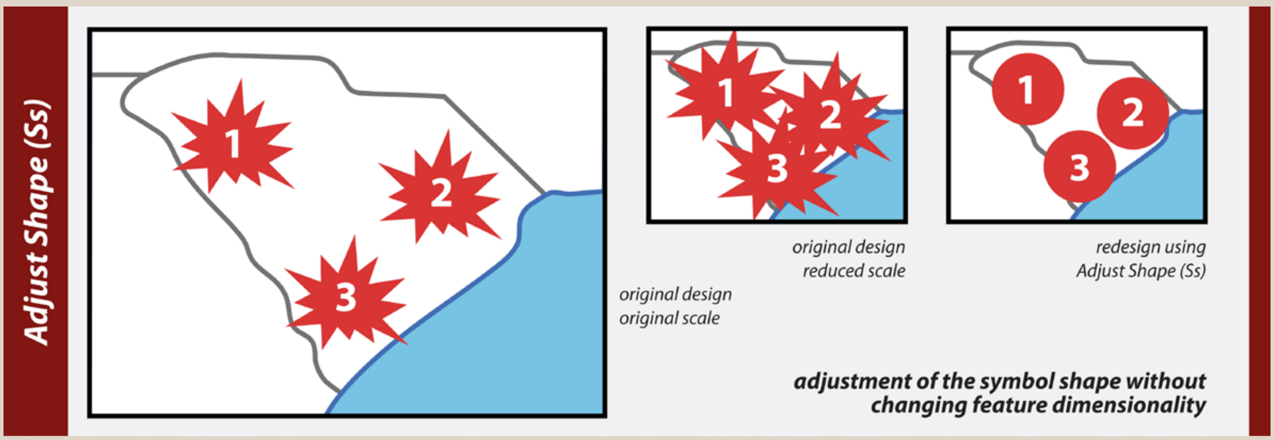

Figure 21. Adjust Shape (Ss)

Adjust Shape (Ss): *adjustment of the symbol shape without changing feature dimensionality*

The *adjust shape operator* (Figure 21) replaces a symbol that has a complex, irregular shape with one that is more compact, or vice versa. Shape is one of Bertin's (1983) original visual variables. The adjust shape operator is different from the collapse operator in that it does not change the underlying feature geometry. While point symbols are the most common example of shape adjustment, it may also be extended to the symbols placed along lines and polygons; the symbols used to represent fronts on weather maps are an example of a geometric shape variation for lines.

Adjust Size (Sz): *adjustment of the symbol size without changing feature dimensionality*

The *adjust size operator* (Figure 22) alters the size of a symbol so that it remains legible when transitioning to a smaller scale. Size was one of Bertin's (1967|1983) original visual variables. While the most common

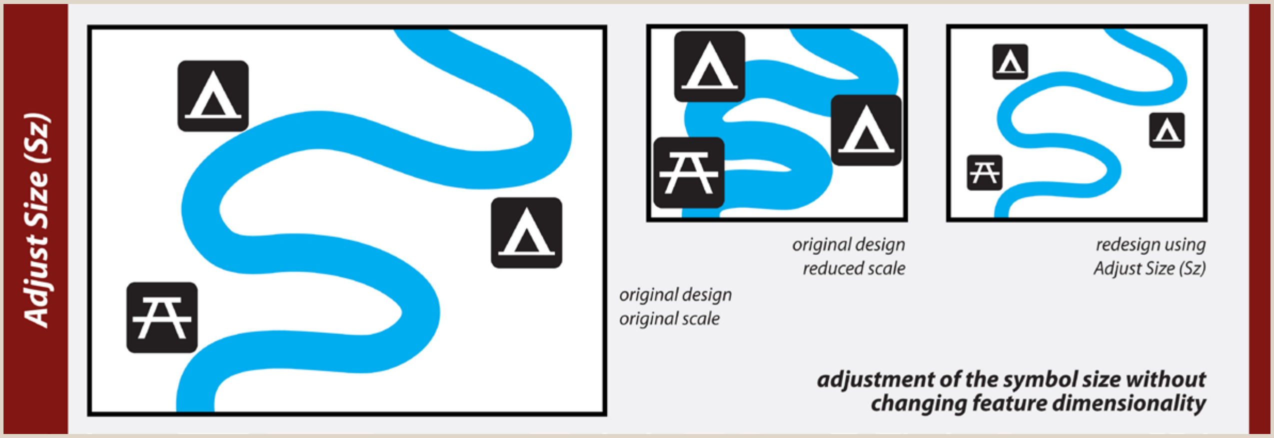

Figure 22. Adjust Size (Sz)

example of adjust size operator is for point symbols, it also can be applied to the stroke weight of lines or polygon outlines or area fill patterns. The adjust size operator differs from the exaggerate operator because it does not change the underlying geometry of any part of the feature. The adjust size operator was defined in a similar manner by Brewer et al. (2007). The adjust size operator also was called exaggeration by Lee (1996), magnification by Li (2007), and enlargement by Regnauld and McMaster (2007).

Adjust Transparency (St): *adjustment of the symbol opacity to improve the legibility of the feature or underlying features*

The *adjust transparency operator* (Figure 23) modifies the degree to which one feature obscures another so that both are visible at one time (increased transparency) or an underlying feature is no longer visible (reduced transparency). MacEachren (1995) extended the list of visual variables to include transparency, originally called fog, as part of the visual variable clarity. Roth et al. (2010) discuss how transparency can be used as a visual variable, noting that it often produces a similar effect to color change.

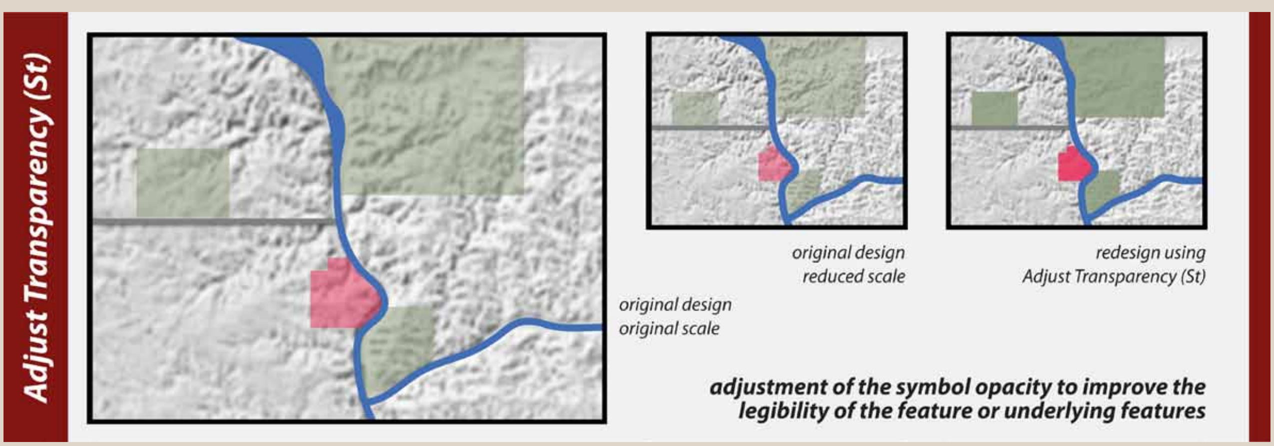

Figure 23. Adjust Transparency (St)

The common application of the adjust transparency operator is when it is necessary to portray two areal features (e.g., shaded relief along with land cover). The adjust transparency operator was defined in a similar manner by Brewer et al. (2007).

Typify (Sf): *replacement of a related set of features with a sparser, representative arrangement of symbols*

The *typify operator* (Figure 24) replaces a large collection of related features with a smaller set of symbols. The typify operator can be applied to a distribution of points (Regnauld, 2001), internally to an individual line (Lecordix et al., 1997), a network of lines (Regnauld and McMaster, 2007), and a distribution of polygons (Li, 2007). Unlike the eliminate operator, which may remove a number of features from a group but leave others based on a hierarchically-ordered attribute, the typify operator uses only the spatial characteristics of the features to generate the new arrangement of symbols that were not from the original set. The symbols created by the typify operator may be referenced spatially and assigned attributes (making it a geometry operator), although most current implementations only generate a new symbol set, much like an pattern swatch, rather than manipulating the original geometry of the spatial data (the reason it is currently included as a symbols operator). The typify operator was defined in a similar fashion by Lee (1996) and Foerster et al. (2007) where appropriate).

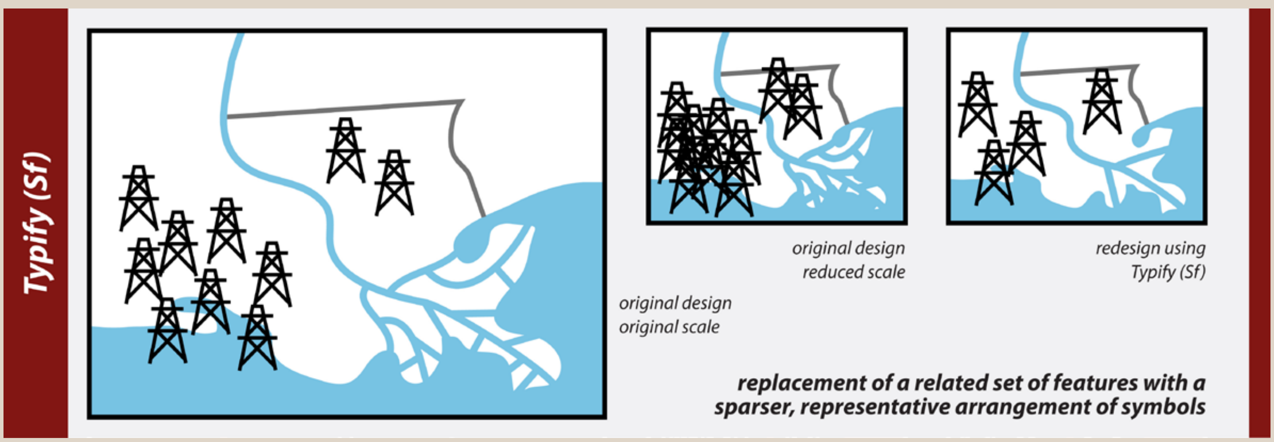

Figure 24. Typify (Sf)

(4) LABEL OPERATORS

Add Label (L+): *insertion of labels*

The *add label operator* (Figure 25) inserts new labels to the map display once a scale is reached that is appropriate for their inclusion. The add label operator is conceptually similar to the ScaleMaster add operator (C+), but is included as a separate operator because the inclusion of a new feature type

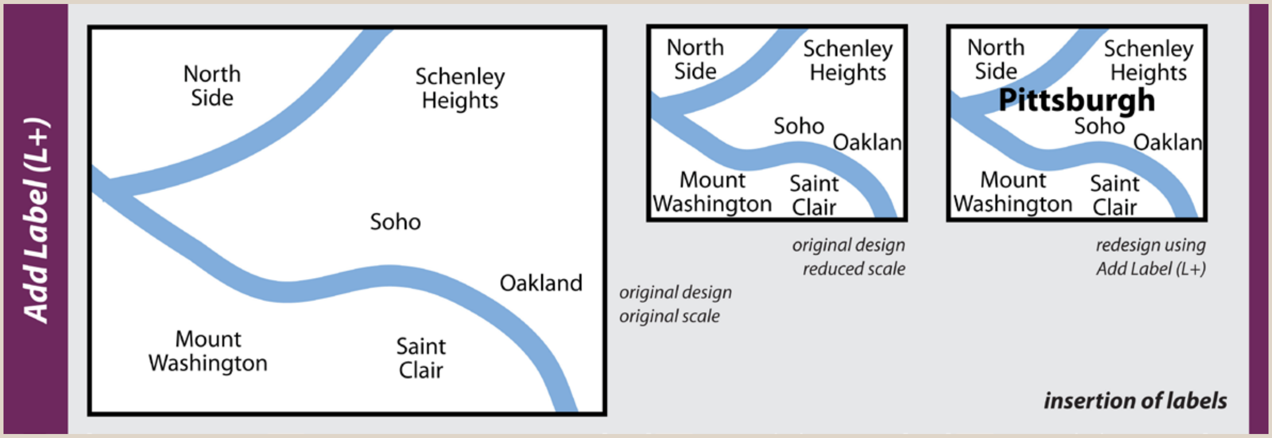

Figure 25. Add Label (L+)

often does not require addition of associated labels, particularly when the features are represented by highly mimetic symbols or when the features are of only secondary importance to the map message when compared to other map features, and therefore are low on the visual hierarchy. Like the add operator, the add label operator commonly must be applied due to changes in the map extent. Figure 26 modifies Figure 25 to show how changes to the map extent impacts application of the add operator.

Figure 26. Like the add operator, the add label operator often is applied due to the change in map extent that occurs as scale changes. This figure modifies Figure 25 to show the new map extent at the smaller scale; administrative boundaries also are added. At the original scale, the entirety of the map was within the Pittsburgh city limits, resulting in labeling of neighborhoods and not cities ("Pittsburgh" would instead be in the map title). Due to the expanded map extent at the smaller scale, city labels must now be added.

Eliminate Label (L-): *removal of labels*

The *eliminate label operator* (Figure 27) removes labels once a scale is reached when they are no longer readable or no longer are needed for the intended map purpose. The eliminate label operator is conceptually similar to the ScaleMaster eliminate operator (C-) found in the content category, but again is included as a separate operator because removal of labels does not require the removal of the associated map features. The eliminate label operator may be implemented if (1) there are too many labels on the map, producing a cluttered, illegible design, (2) the applied geometry operators have adjusted the semantic meaning of the map features (e.g., many points collapsed into a single polygon), making the prior labels no longer appropriate, (3) the iconicity of the applied symbols has increased and can now be interpreted without a label, or (4) the map features with which the labels are associated have been removed from the map. Labels need not be removed, however, when symbols are removed; they may remain the sole indication of feature location (e.g., summit labels at intermediate map scales).

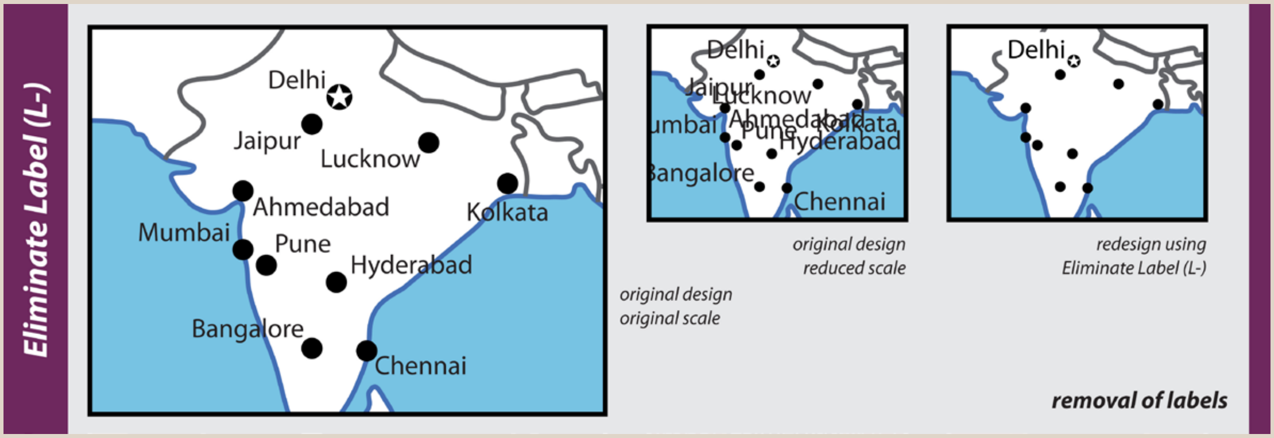

Figure 27. Eliminate Label (L-)

Adjust Appearance (La): *modification of the styling applied to a set of labels*

The *adjust appearance operator* (Figure 28) changes the styling of the labels without changing their positioning. Label styles that can be manipulated across scale include the typeface or font, color, posture/emphasis (e.g., roman, italic, bold), size, leading (spacing between lines of text), tracking (spacing between characters), and any character enhancements such as casing or shadows (Brewer 2005). A comprehensive review on these label styles, and their impact on the look of the overall map, is provided by Sheesley (2007).

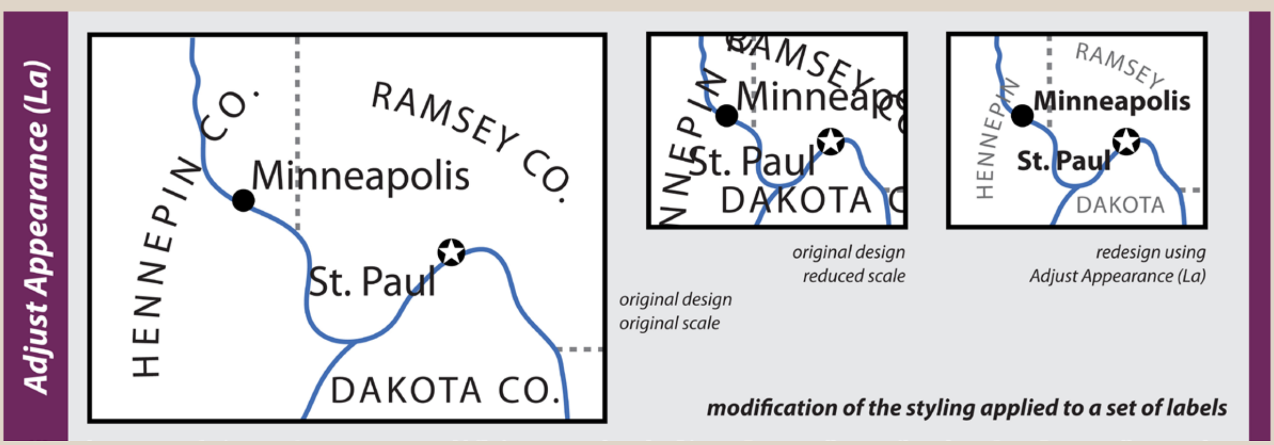

Figure 28. Adjust Appearance (La)

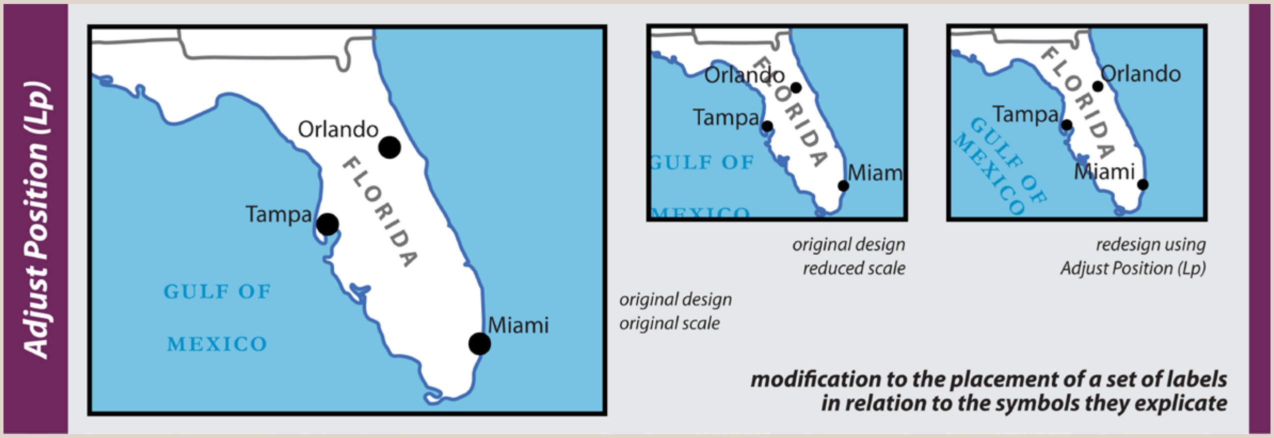

Figure 29. Adjust Position (Lp)

Adjust Position (Lp): *modification to the placement of a set of labels in relation to the symbols they explicate*

The *adjust position operator* (Figure 29) changes the position of the labels in relation to their associated map symbols without changing their styling. The adjust position operator includes a change to both the location of a label (e.g., a point symbol label moved from the top-right position to the center position) as well as the orientation of the label (e.g., a horizontal label reoriented to match the maximum axis of a polygonal feature); the latter also may include a change from a straight to a curved baseline, or vice versa, and the use of a leader line. A comprehensive review on label placement by dimension is provided by Imhof (1975). Because most changes in scale require adjustment to the position of labels, the use of this operator often refers to the position parameters of automated labeling engines, such as Maplex (**http://www.esri.com/software/arcgis/extensions/maplex/index.html**), which generate optimal solutions given the placement constraints. Automated position changes in these environments may be suitable for multiscale mapping (e.g., changing the distance a label can overrun an associated map feature).

CONCLUDING REMARKS AND FUTURE DIRECTIONS

In this article, we described work to improve the utility of the ScaleMaster diagram in support of multiscale mapping projects. Specifically, a comprehensive literature review on cartographic generalization was conducted in order to construct a theoretically-informed typology of multiscale mapping operators that can be inserted at decision points in the ScaleMaster diagram, and thus that can be applied to maintain map legibility across scales. Related literature on map design (e.g., visual variables, typography) was integrated into this review to generate the final ScaleMaster typology of multiscale mapping operators, which includes four higher-level categories: content, geometry, symbol, and label. We anticipate the typology, and its associated review of past work, to be useful in three ways: (1) as a classroom teaching tool, (2) as a guide for multiscale mapping practitioners, and (3) as a conceptual foundation for future scientific research. As stated above, we expect the set of operators to increase as technology and practice evolves, although we also expect the higher-level categorization to remain a useful framework for conceptualizing and organizing multiscale mapping operators.

Multiscale mapping is a topic of increasing importance to academic and practicing cartographers, with application to such contemporary cartographic efforts as MRDB, national mapping agencies, and web mapping services. The ScaleMaster diagram, and the associated multiscale mapping typology described here, has much promise to facilitate these efforts. However, key technological and scientific improvements remain, such as:

ScaleMaster as a Service: While the ScaleMaster diagram has proven to be a useful organization tool, its construction is not straightforward and often completed in an informal manner (e.g., in Excel or using pen/paper). A potential advance is to provide a service to formalize and expedite the ScaleMaster diagram construction process and also allow for digital notes to be included describing the algorithmic or design parameters for each applied multiscale mapping operator. Such a service should leverage existing geocollaboration technologies, allowing team members to construct, review, and annotate their project's associated ScaleMaster.

ScaleMaster as an Interface: Perhaps the ultimate vision of the ScaleMaster diagram is integration with desktop GIS software that offers multiscale mapping functionality. Here, the ScaleMaster diagram becomes an interface for manipulating multiscale map design, rather than an ancillary document for recording the design decisions. A logical interface metaphor for the ScaleMaster diagram would be a horizontal interface associated with each layer in the vertical layer stack, allowing users to insert decision points and apply operators interactively. As online mapping matures, ScaleMaster could alternatively be viewed as an interface to a map delivery source that allows the user to retrieve maps (or the underlying data) suited for a particular scale or resolution.

The Science of ScaleMaster: A by-product of developing ScaleMaster services and interfaces is that trained and untrained cartographers alike would be able to generate inappropriate multiscale map designs more quickly and more easily. Likewise, no single ScaleMaster provides a 'best' solution; there are trade-offs among pairs of operators that need to be considered when finalizing a multiscale map design (Cecconi et al. 2002). For example, geometry operators, which leverage the computation power of a computer, may generate cartographically suboptimal solutions in comparison to symbol operators, which generate tailored solutions but require a large amount of manual adjustment and cartographic license. The science of multiscale mapping needs to catch up to its practice in order to understand how best to apply the available multiscale mapping operators across map scales and map themes; the multiscale mapping typology described here could be used as a framework for such testing. A result of this work would be a set of design guidelines for multiscale mapping projects.

Multiscale mapping is an aspect of mapmaking growing in use and inviting innovation. Through the new discussion forum of *Cartographic Perspectives*, we invite feedback about the ScaleMaster typology of multiscale mapping operators offered here and ideas for expanding the utility of the ScaleMaster diagram in support of multiscale mapping projects.

ACKNOWLEDGEMENTS

We are grateful for the advice on this typology that was provided by Barbara Buttenfield, Charlie Frye, and E. Lynn Usery. We would also like to thank Carolyn Fish and Douglas Schoch for their assistance with the Portland multiscale mapping project posted to the ScaleMaster website (**http://www.scalemaster.org**), and the associated ScaleMaster diagram used in this paper. Finally, we would like to thank Jess Acosta, Mamata Akella, and Chelsea Hanchett for their help in refining the ScaleMaster concept.

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