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A TYPOLOGY OF MULTI-SCALE MAPPING OPERATORS

developing a comprehensive list of available multi-scale mapping operators for the ScaleMaster diagram

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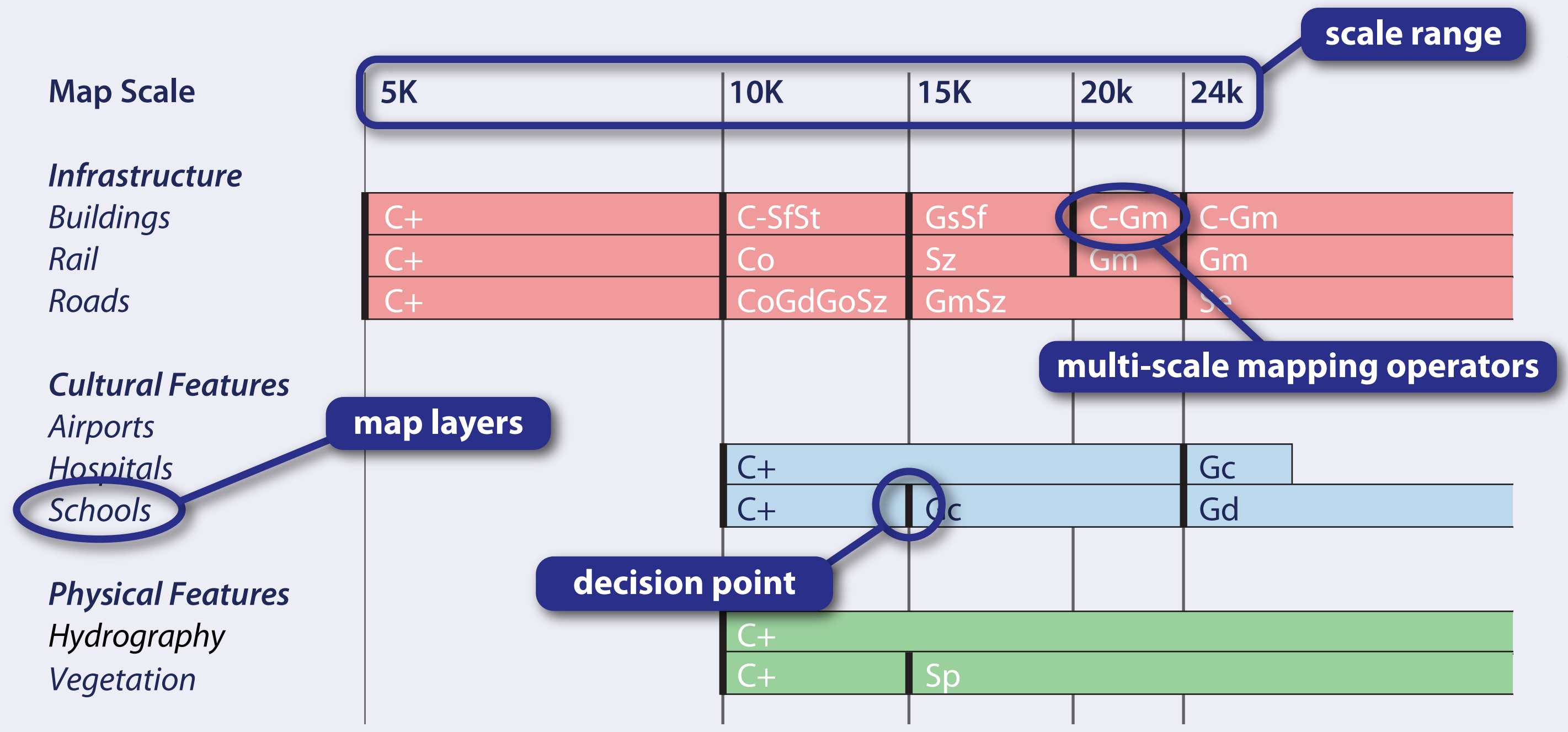
CONTEXT: multi-scale mapping

Multi-scale mapping describes the cartographic practice of producing integrated, legible designs of the same geographic themes at numerous scales (Spaccapietra et al. 2000). The importance of multi-scale mapping is being realized as multi-resolution databases (MRDB) and on-demand web mapping services continue to improve. This powerful technology allows users to request a customized map display at a specific screen resolution and scale. Unfortunately, scale generalization and map redesign are difficult and time-consuming, and, in many cases, still require tedious manual adjustment to achieve legible results at each output scale. However, the efficiency and quality of a multi-scale mapping project can be improved by identifying the key scales, termed ***decision points***, at which one or several kinds of modifications, termed ***multi-scale mapping operators***, must be applied to the display to ensure legibility. The ScaleMaster diagram, and an associated typology of multi-scale mapping operators, is an important first step towards attaining simple and easy multi-scale mapping.

what is the SCALEMASTER diagram?

The ***ScaleMaster diagram*** is a schematic for guiding multi-scale map design decisions and describing scale-dependent design specifications. Originally presented in 2003 at an ESRI planning talk by Senior Cartographer Charlie Frye, the ScaleMaster concept was extended during a seminar offered by Dr. Cynthia Brewer in 2004 at the Pennsylvania State University and later formalized in a pair of publications by Brewer and colleagues (Brewer and Buttenfield 2007; Brewer et al. 2007). The ScaleMaster diagram stacks each map layer along the vertical axis and the range of represented scales for the map layers along the horizontal axis. Each map layer, grouped by theme, has an associated rectangle that extends across the range of scales for which the layer is used in the multi-scale mapping project. Decision points for each map layer are marked and labeled with an abbreviated code indicating the multi-scale mapping operators that need to be applied. The following figure shows an example ScaleMaster diagram.

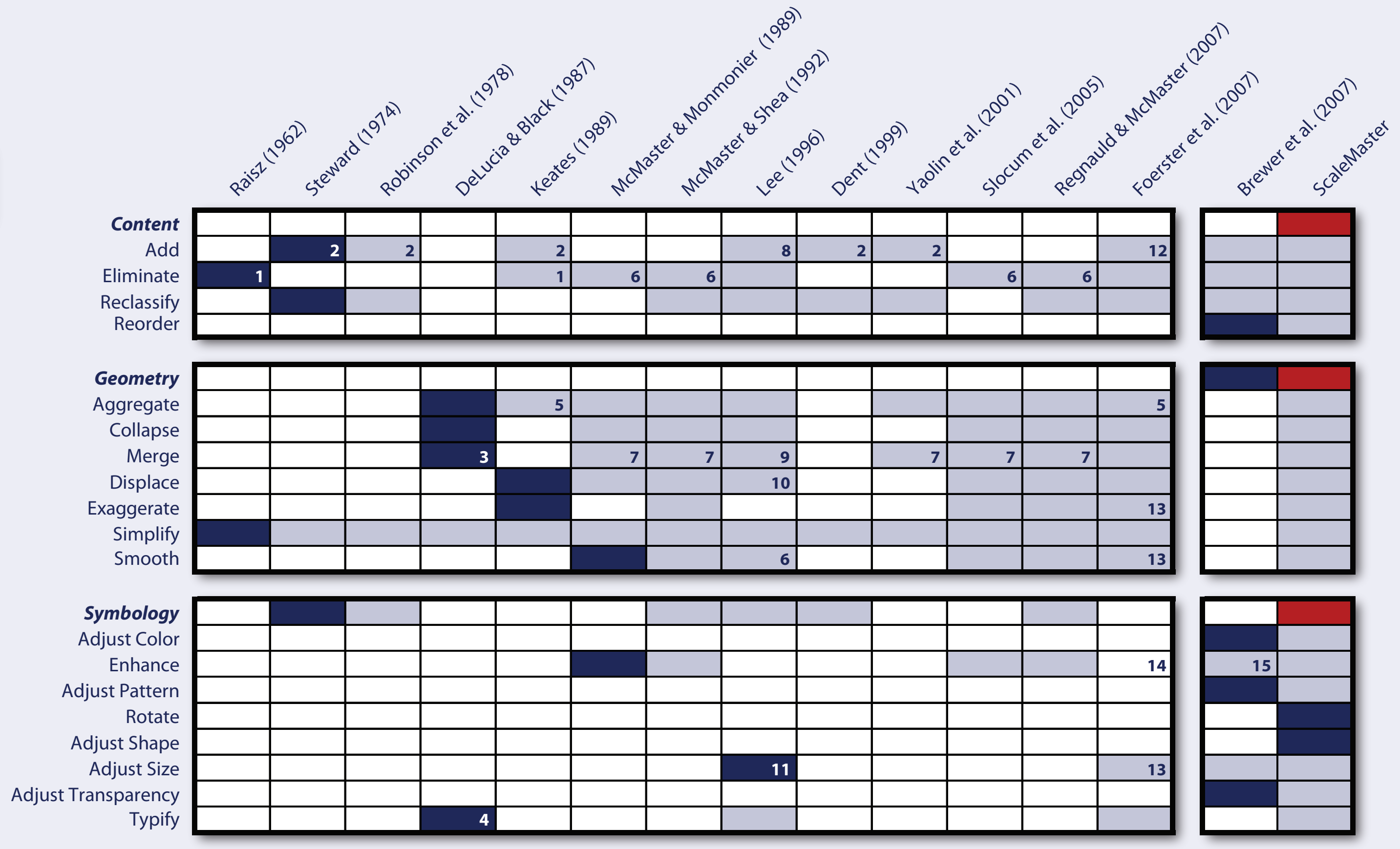


MACRO-LEVEL and MICRO-LEVEL

The primary contribution of this poster is the development of a comprehensive typology of multi-scale mapping operators available for use in the ScaleMaster diagram. A logical starting point is a review of generalization typologies offered in the cartographic literature. Such typologies commonly organize the basic, ***micro-level*** units by broader, ***macro-level*** categories. The provided macro-level distinctions vary greatly, including pre-processing versus generalization (Robinson et al. 1978), attribute versus spatial transformations (McMaster and Shea 1992), spatial dimensionality (McMaster and Monmonier 1989; Monmonier 1996; Li 2007), and model versus cartographic generalization (Weibel and Dutton 1999; Foerster et al. 2007). Despite this inconsistency in macro-level categorization, only operators or algorithms are used as the micro-level unit. An ***operator*** is an abstract or generic description of an action or modification, while an ***algorithm*** is a particular programmatic implementation of an operator (Regnauld and McMaster 2007). Exhaustive classifications of generalization algorithms are provided by the AGENT report (1999) and Li (2007). However, most generalization typologies use the operator as the micro-level unit because: (1) many algorithms implement the same operator, multiplying the number of entities in the typology, (2) the naming of algorithms is often software dependent, complicating the identification of unique micro-level units, and (3) typologies using the algorithm as the micro-level unit quickly become out-of-date as new algorithms are developed. For these reasons, the ScaleMaster typology uses the operator as the micro-level unit.

the SCALEMASTER TYPOLOGY of multi-scale mapping operators

The ScaleMaster multi-scale mapping typology organizes operators into three macro-level categories: (1) content, (2) geometry, and (3) symbology. The ***geometry*** macro-level category, following Regnauld and McMaster's (2007) fundamental geometric generalization operators, is defined as the set of operators that modify the spatial geometry of mapped features to maintain legibility when changing scale. Many of the operator typologies offered since the late 1980s focus solely upon the role of geometry alterations to maintain legibility (e.g., DeLucia and Black 1987; McMaster and Shea 1992; Foerster et al. 2007). However, Brewer and Buttenfield (2007) contend that alterations of the content or symbology can result in an equally legible representation at a reduced scale, often requiring a smaller required workload for the cartographer or higher computational efficiency for automation. The ***content*** macro-level category, following Monmonier's (1996) content generalization and combining Robinson et al.'s (1978) selection and classification, is defined as the set of operators that revise (i.e., add or eliminate map layers) or reorganize (i.e., reclassify or reorder map layers) a portion or all of the content to be mapped in order to maintain legibility when changing scale. Finally, the ***symbology*** macro-level category, following Robinson et al.'s (1978) symbology, is defined as the set of operators that alter the graphic encoding of mapped features to maintain legibility when changing scale.



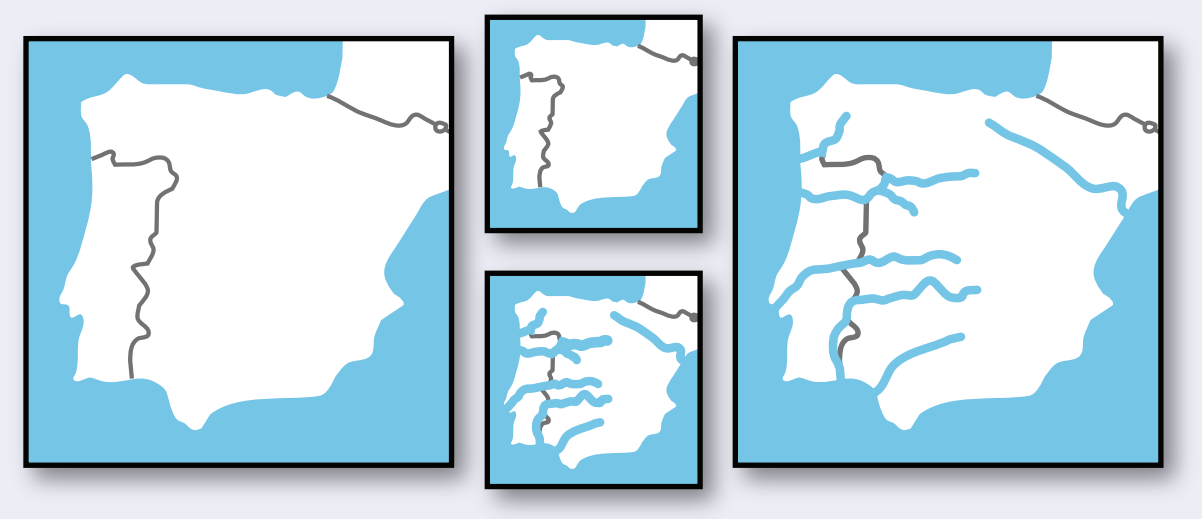
	Raisz (1962)	Steward (1974)	Robinson et al. (1978)	DeLucia & Black (1987)	Keates (1989)	McMaster & Monmonier (1989)	McMaster & Shea (1992)	Lee (1996)	Dent (1999)	Yaolin et al. (2001)	Slocum et al. (2005)	Regnauld & McMaster (2007)	Foerster et al. (2007)	Brewer et al. (2007)	ScaleMaster
Content															🟥
Add		■ 2	▨ 2		▨ 2			▨ 8	▨ 2	▨ 2			▨ 12	▨	▨
Eliminate	■ 1				▨ 1	▨ 6	▨ 6	▨			▨ 6	▨ 6	▨	▨	▨
Reclassify		■	▨				▨	▨	▨	▨		▨	▨	▨	▨
Reorder														■	▨
Geometry														■	🟥
Aggregate				■	▨ 5	▨	▨	▨		▨	▨	▨	▨ 5		▨
Collapse				■		▨	▨	▨			▨	▨	▨		▨
Merge				■ 3		▨ 7	▨ 7	▨ 9		▨ 7	▨ 7	▨ 7	▨		▨
Displace					■	▨	▨	▨ 10			▨	▨	▨		▨
Exaggerate					■		▨				▨	▨	▨ 13		▨
Simplify	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨
Smooth						■	▨	▨ 6			▨	▨	▨ 13		▨
Symbology		■	▨				▨	▨	▨			▨			🟥
Adjust Color														■	▨
Enhance						■	▨				▨	▨	14	▨ 15	▨
Adjust Pattern														■	▨
Rotate															■
Adjust Shape															■
Adjust Size								■ 11					▨ 13	▨	▨
Adjust Transparency														■	▨
Typify				■ 4				▨					▨		▨

1 - called 'omit'
2 - called 'select'
3 - called 'agglomerate'
4 - called 'distribution refinement'
5 - called 'combine'
6 - called 'refine'
7 - made distinction between 'amalgamate' and 'merge'
8 - called 'preselection'
9 - same term used for 'aggregate' and 'merge'
10 - called 'conflict resolution'
11 - called 'exaggerate'
12 - called 'class selection'
13 - included as part of 'enhance'
14 - included term 'enhance' but used differently
15 - called 'on/off for aspect of symbol'

■ First Appearance
▨ Appeared Previously
🟥 Macro-Level

add (C+)

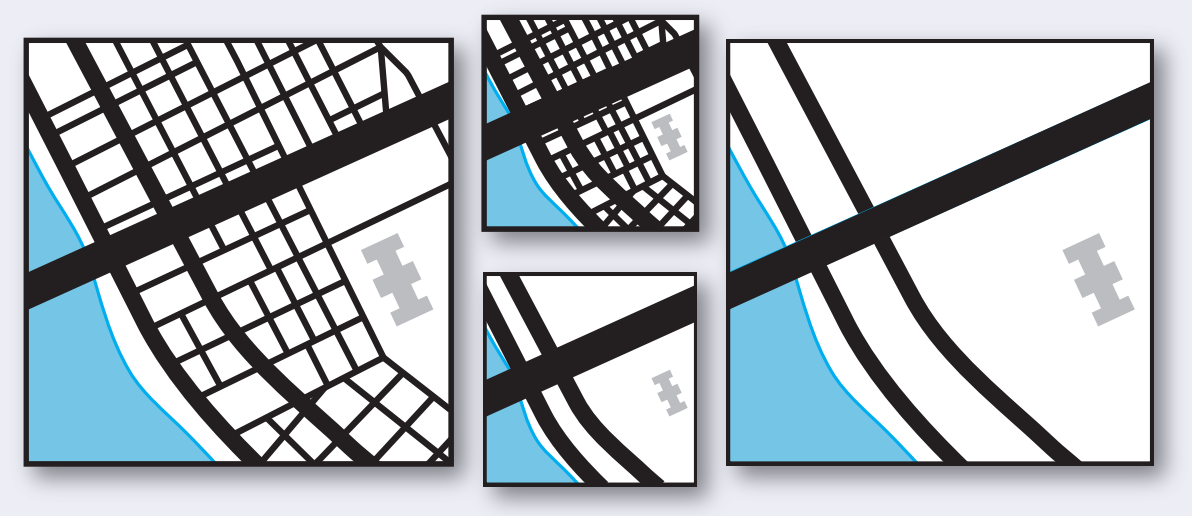
insertion of features



The ***add operator*** inserts new features to the map display that are only appropriate for representation at smaller scales. Such layers may be useless, and even deceiving, at large scales, but can be included in the representation once the scale has been reduced to a sufficient level. Use of 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 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 a preprocessing step; it instead can be implemented at any scale in the multi-scale mapping project. The add operator is the inverse of Raisz's (1962) and Keates' (1989) omission and the ScaleMaster eliminate operator.

eliminate (C-)

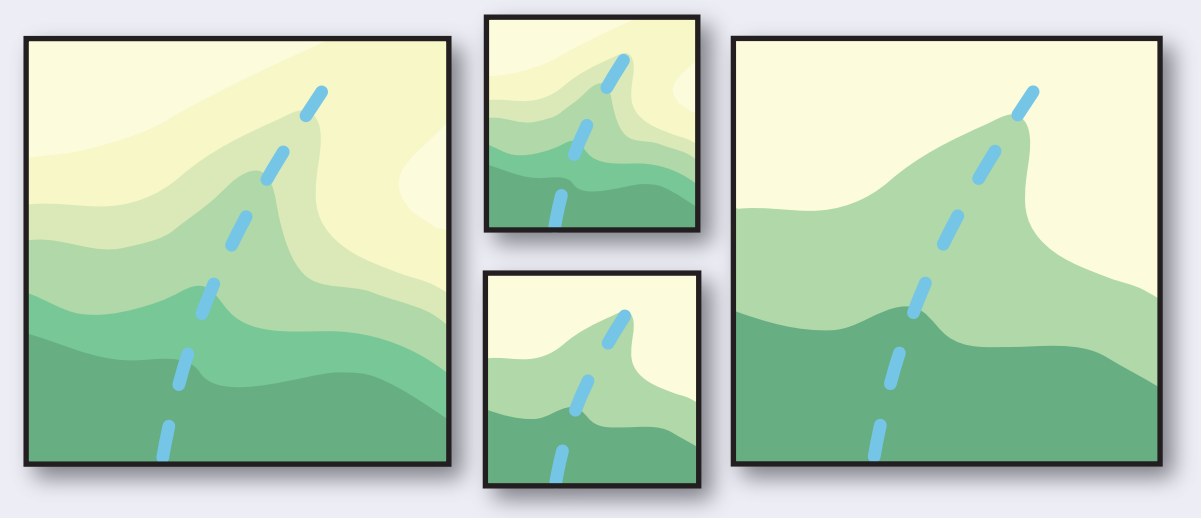
removal of features



The ***eliminate operator*** removes features when they become illegible or no longer fulfill their intended purpose. The eliminate operator may be implemented if (1) the data has a resolution and precision too coarse for the viewing scale, causing significant mismatch with other layers, (2) the data has too detailed a resolution and precision, providing unnecessary detail, (3) there are too many different layers represented for a given scale, causing illegibility, or (4) 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 is the inverse of Robinson et al.'s (1978) selection, Foerster et al.'s (2007) class selection, and the ScaleMaster add operator. A special case where a subset of features is eliminated from a larger whole based on a hierarchical ordering is distinguished by DeLucia and Black (1987) and McMaster and Shea (1992), terming this special case refinement; the ScaleMaster typology does not follow this distinction because it is only a function of the structure of the data and does not create different results.

reclassify (Co)

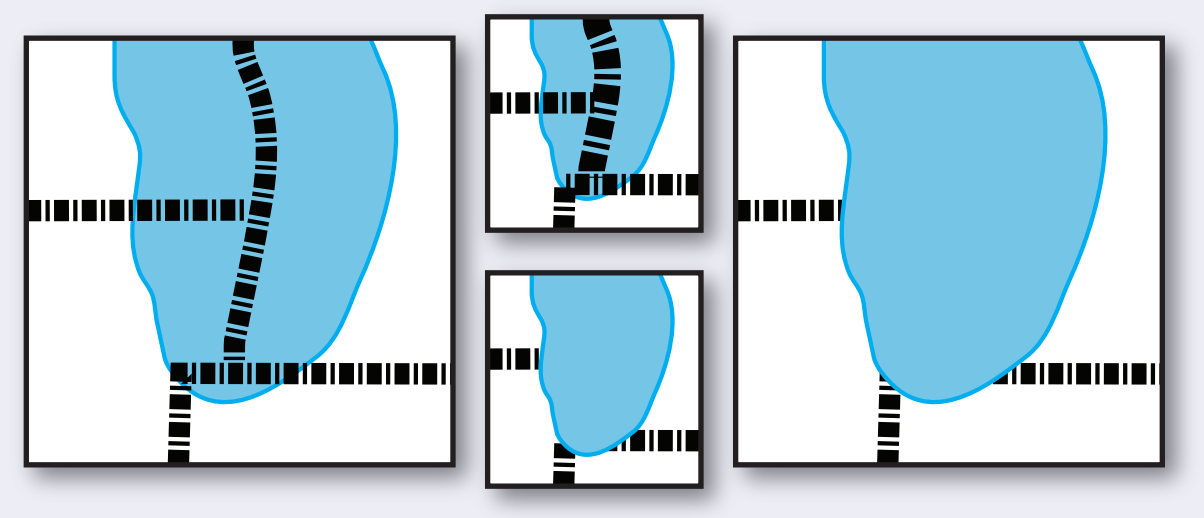
revision to the grouping of features based on their attributes



The ***reclassify operator*** alters the way that features are organized in the representation based upon their attributes in order to improve legibility. The reclassify operator may be implemented in one of three fashions: (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 is 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 data may be reclassified multiple times and at any scale given its appropriateness.

reorder (Co)

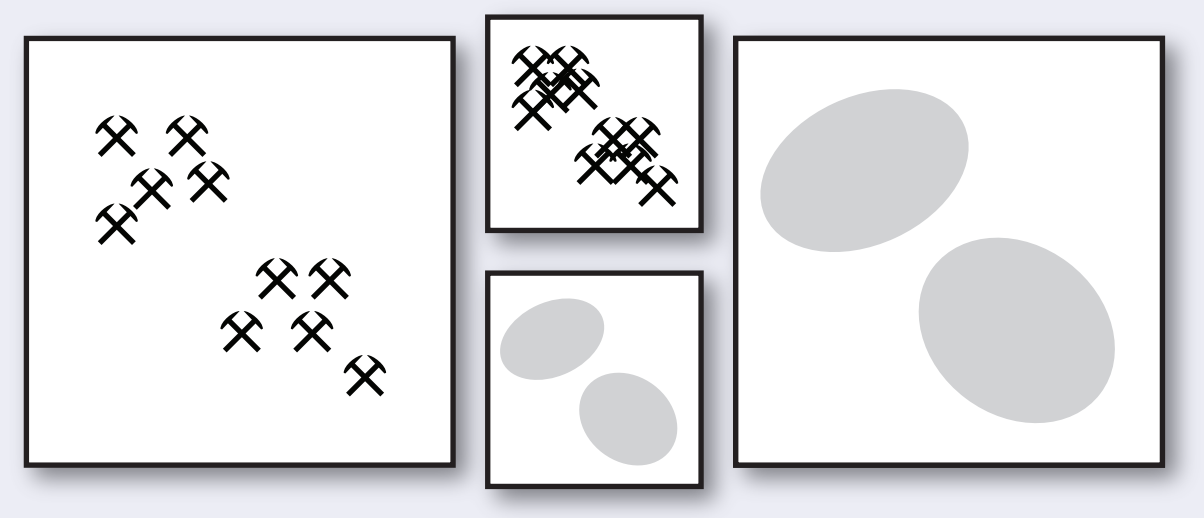
adjustment to the stacking position of features



The ***reorder operator*** changes the stacking order of features when one feature becomes sufficiently obscured by another. The reorder operator is recommended when the use of the adjust transparency or displace operators yield an unsatisfactorily legible solution to feature overlap. Reordering is often 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 is defined in a similar manner by Brewer et al. (2007).

aggregate (Gg)

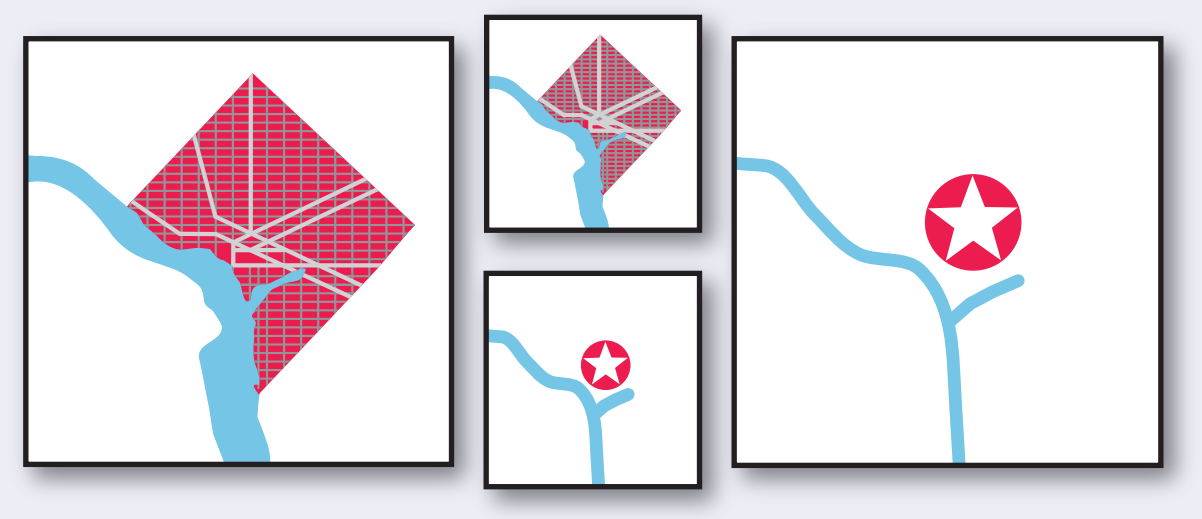
replacement of many related features with a representative feature of increased dimensionality



The ***aggregate operator*** 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 is commonly confused with the polygons-to-polygon instance of the merge operator, which does not change dimensionality (see Lee 1996; Monmonier 1996). The aggregate operator is defined in a similar manner by DeLucia and Black (1987), McMaster and Shea (1992), Slocum et al. (2005), and Regnault and McMaster (2007). The aggregate operator is also referred to as area conversion by Monmonier (1996), combination by Foerster et al. (2007), and regionalization by Li (2007).

collapse (Gc)

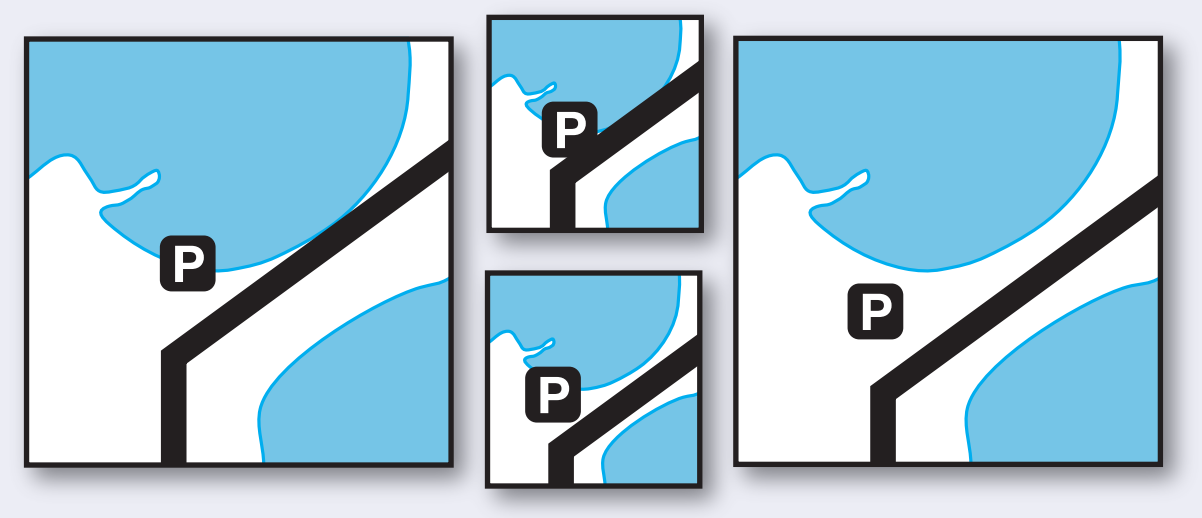
replacement of a feature with a representative feature of lower dimensionality



The ***collapse operator*** reduces the complexity of a feature 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 adjust shape operator, where the represented feature itself maintains the same geometric dimension regardless of how the new symbol shape appears. The collapse operator is the inverse of the aggregation operator, which produces an upward conversion in geometric dimension (i.e., lines-to-polygon, points-to-polygon, or points-to-line). The collapse operator is defined in a similar manner by DeLucia and Black (1987), McMaster and Shea (1992), Slocum et al. (2005), Regnault and McMaster (2007), and Foerster et al. (2007). The collapse operator is also referred to as point conversion by Monmonier (1996).

displace (Gd)

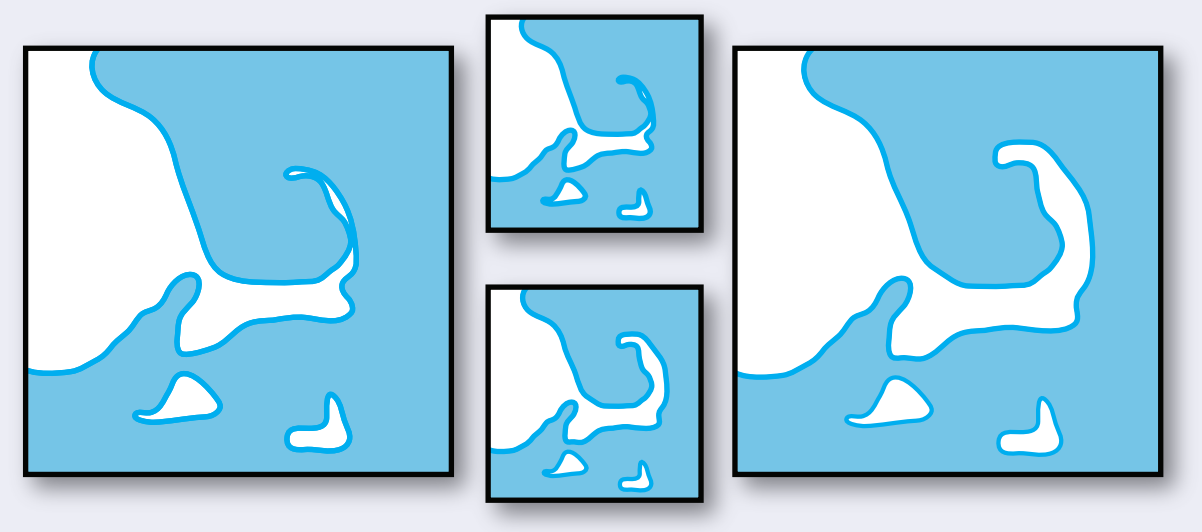
adjustment to the location of a feature to avoid coalescence with adjacent features



The ***displace operator*** shifts the position of one feature away from another feature to avoid coalescence. The displace operator systematically shifts all x- and y-coordinates comprising a feature, altering the absolute location of the feature while maintaining its relative, topological relations with surrounding features. The displace operator differs from the exaggerate operator, which also shifts x- and y-coordinates, in that the displace operator translates the entirety of a feature in a single direction, while the exaggerate operator only repositions the subsection of the feature that requires emphasis. The displace operator is 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 is also referred to as conflict resolution by Lee (1996).

exaggerate (Gx)

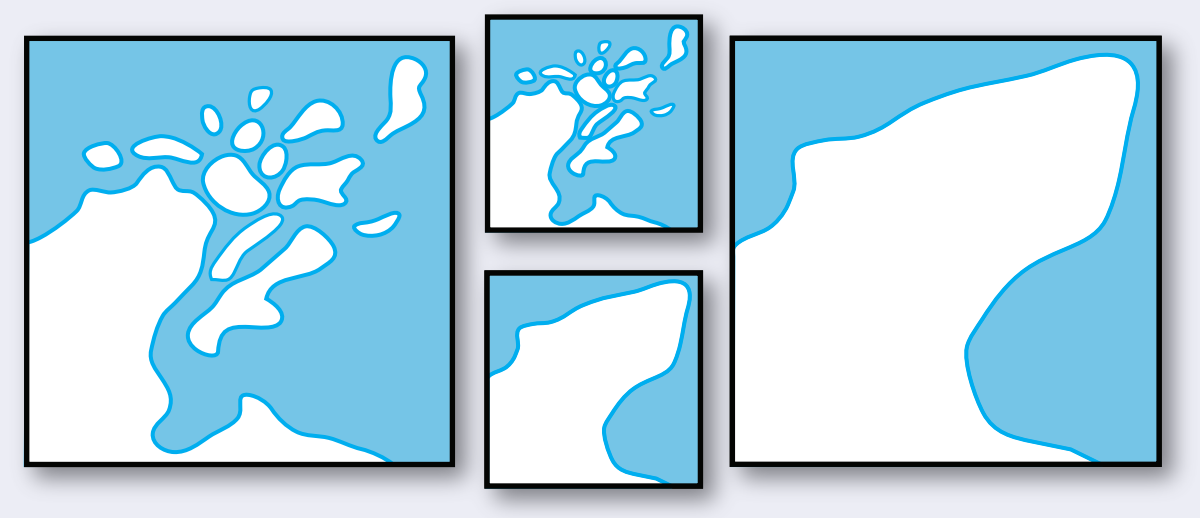
amplification to a portion of a feature to emphasize a characteristic aspect of it



The ***exaggerate operator*** ensures that an important aspect of a feature is legible at all viewing scales. Muehrcke (1986) identifies such amplification of characteristic aspects of features as vital to the cartographic abstraction process (McMaster and Shea 1992). Unlike the enhance operator, which adds graphics 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, which systematically offsets the coordinate location for every node in a feature, the exaggerate operator only offsets a portion of the total coordinate pairs, leaving the majority of the feature in its original position. The exaggerate operator is defined in a similar manner by Keates (1989), McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007). The exaggerate operator is also referred to as partial modification by Li (2007).

merge (Gm)

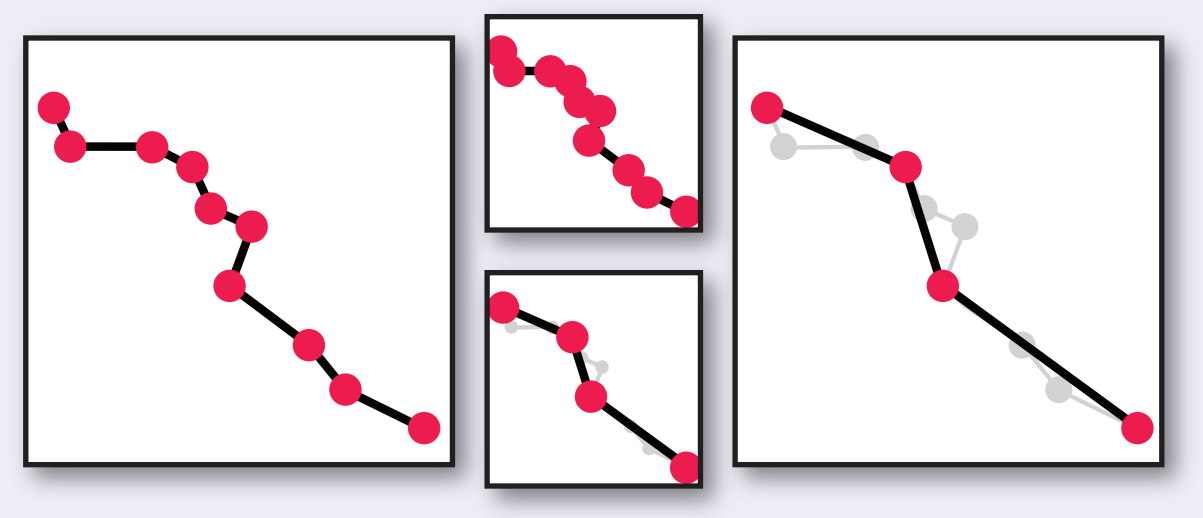
replacement of a feature with a representative feature of equal dimensionality



The ***merge operator*** 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 is often called amalgamation. McMaster and Monmonier (1989) divide DeLucia and Black's (1987) usage of amalgamation into two operators: the term amalgamation is used to describe the combination of multiple areas into a single area and the term merging is used to describe the combination of multiple lines into a single line. This distinction is adopted by McMaster and Shea (1992), Yaolin et al. (2001), Slocum et al. (2005), and Regnauld and McMaster (2007). We remove this distinction, following Foerster et al. (2007), because the merging operator may also be applied to points, where a field of points is represented by only a single point. The term merge is adopted rather than amalgamate because amalgamation is commonly confused with the aggregate operator. The merge operator is also 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).

simplify (Gs)

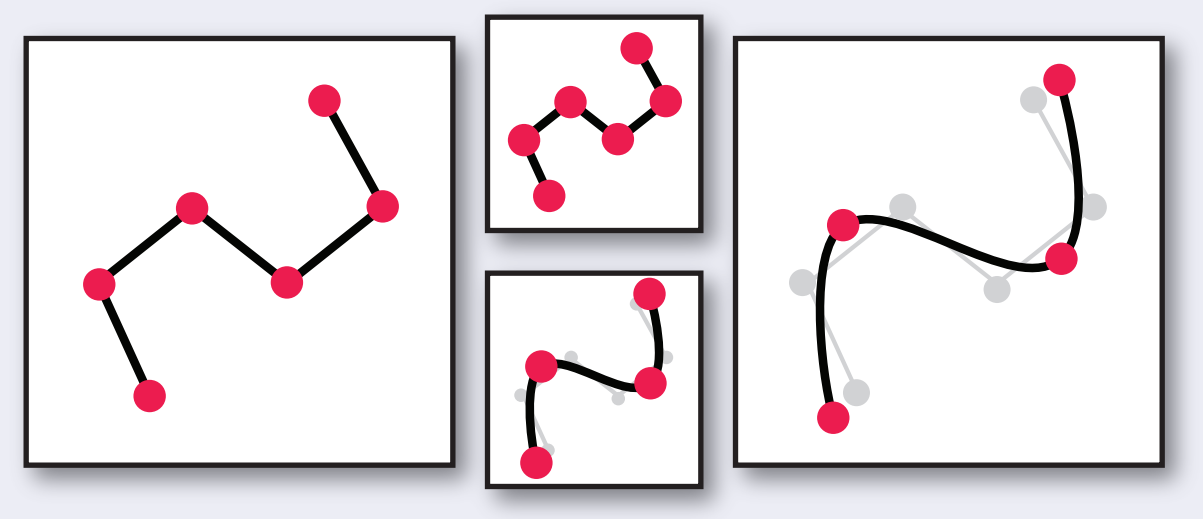
reduction of the number of points constituting a feature



The ***simplify operator*** removes the number of points that constitute a 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 (e.g., Robinson et al. 1978; Lee 1996) to its present-day, narrow focus on eliminating points. The simplify operator is 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 is also referred to as point reduction by Li (2007).

smooth (Go)

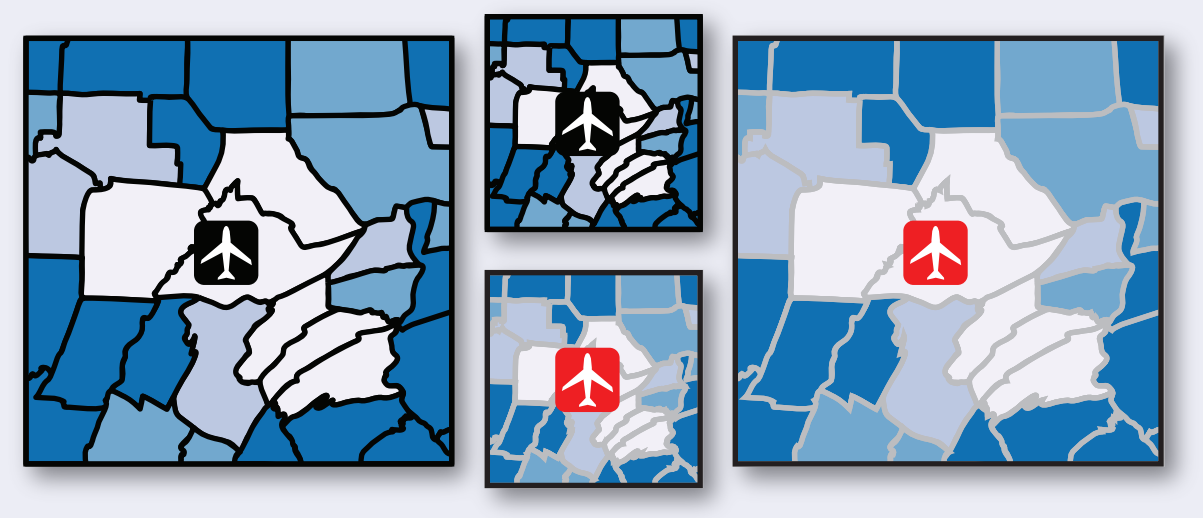
removal of small variations in the geometry of a feature to improve its appearance



The ***smooth operator*** 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) describe the smooth operator as a process that maintains the original number of points, this definition is expanded due to the plethora of algorithms that increase or decrease the point total. Because the simplify and smooth operators are often synergetic, many compound algorithms implement these operators in tandem (McMaster 1989). The smooth operator is defined in a similar manner by McMaster and Monmonier (1989), McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007).

adjust color (Sc)

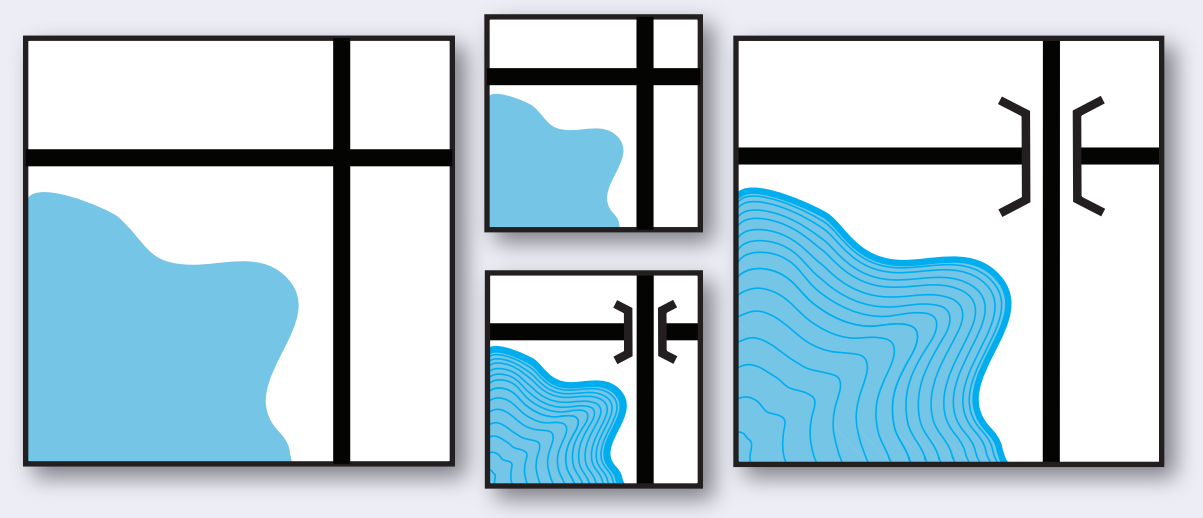
adjustment of the symbol color to ensure legibility of the feature or surrounding features



The ***adjust color operator*** alters the hue, value, or saturation (or a combination of all three) of a feature so that it remains legible across multiple scales. Hue and value are two of Bertin's (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 and color illegibility not present in larger scale versions. Therefore, 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 is defined in a similar manner by Brewer et al. (2007).

enhance (Se)

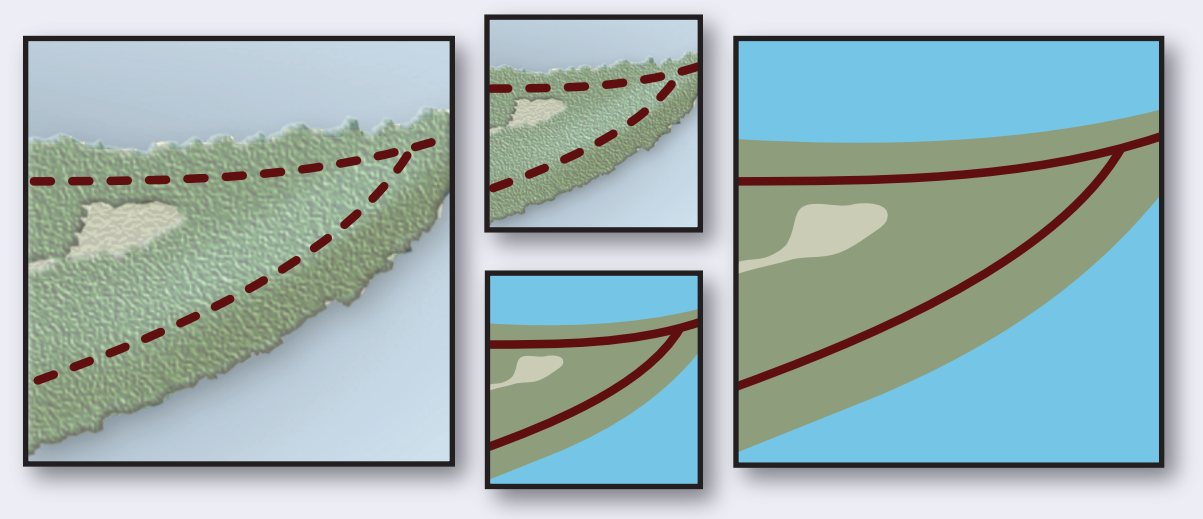
inclusion of graphic embellishments around or within a feature to maintain or emphasize feature relationships



The ***enhance operator*** 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 contouring of water features. The enhance operator differs from the other symbology 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 symbology, 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 is defined in a similar manner by McMaster and Shea (1992), Slocum et al. (2005), and Regnauld and McMaster (2007). The enhance operator is also referred to as on/off toggling by Brewer et al. (2007).

adjust pattern (Sp)

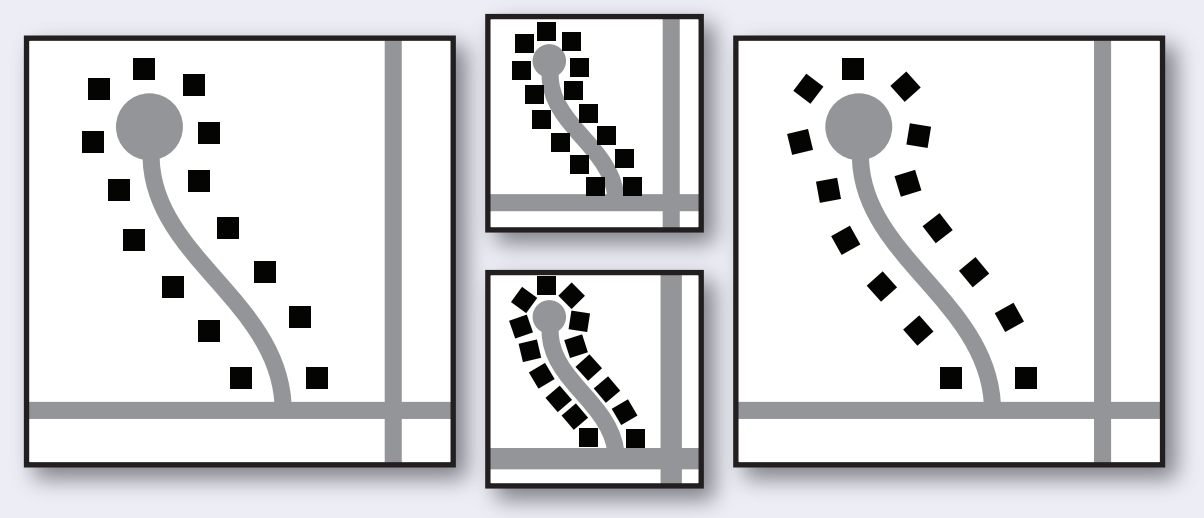
adjustment of the symbol fill or stroke pattern to improve legibility



The ***adjust pattern operator*** reduces 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 is one of Bertin's (1983) original visual variables and is 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 associated with 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 is defined in a similar manner by Brewer et al. (2007).

rotate (Sr)

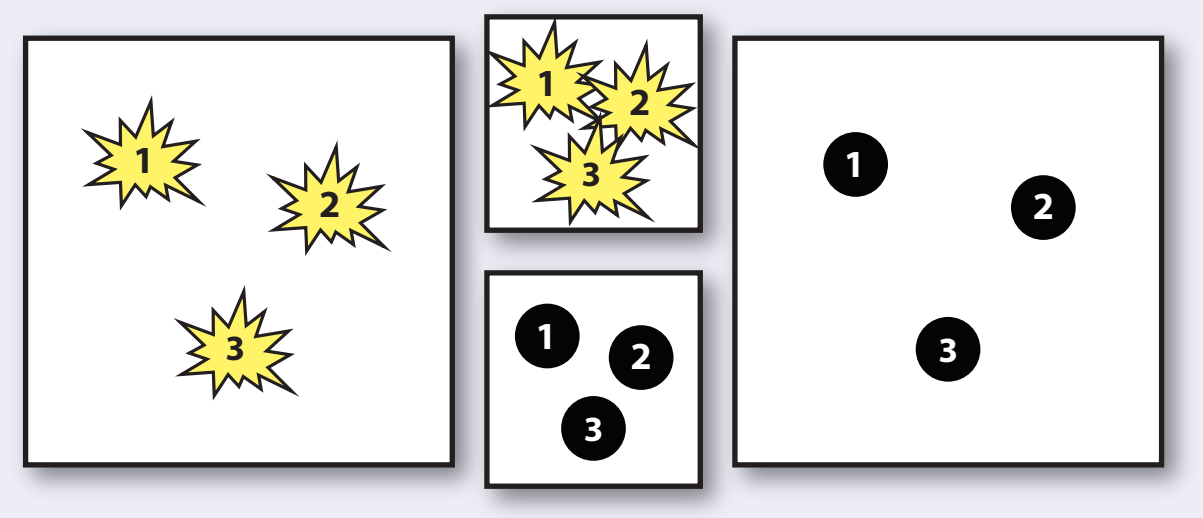
adjustment of the symbol orientation to maintain or emphasize its relations to other features



The ***rotate operator*** adjusts the orientation of one feature in relation to other features. Orientation is one of Bertin's (1983) original visual variables, describing the 360-degree rotation of a symbol. 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 it is not considered a unique operator.

adjust shape (Ss)

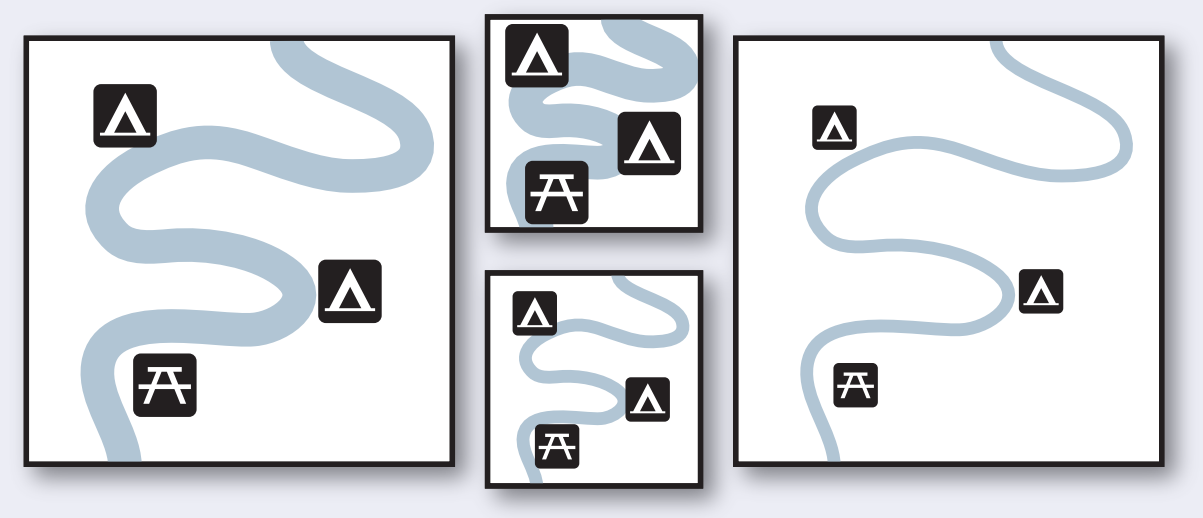
adjustment of the symbol shape without changing feature dimensionality



The ***adjust shape operator*** replaces a symbol that has a complex, irregular shape with one that is more compact for legibility. Shape is one of Bertin's (1983) original visual variables and is a primary contributor to the difference between mimetic/pictorial versus arbitrary/geometric icons (MacEachren 1995). Mimetic or pictorial symbols take a similar form to the feature they represent, while arbitrary or geometric symbols are abstractions with little or no visual relation to their referent. During a change in scale, it is often necessary to swap detailed, unambiguous mimetic symbols for simplified geometric primitives whose interpretations are reliant upon a legend. While point symbols are the most common example of shape change, it may also be extended to the symbols along lines and polygons; the symbology used to represent fronts on weather maps are an example of a shape variation for lines. The adjust shape operator differs from the simplify, smooth, and collapse operators in that the underlying geometry is not altered.

adjust size (Sz)

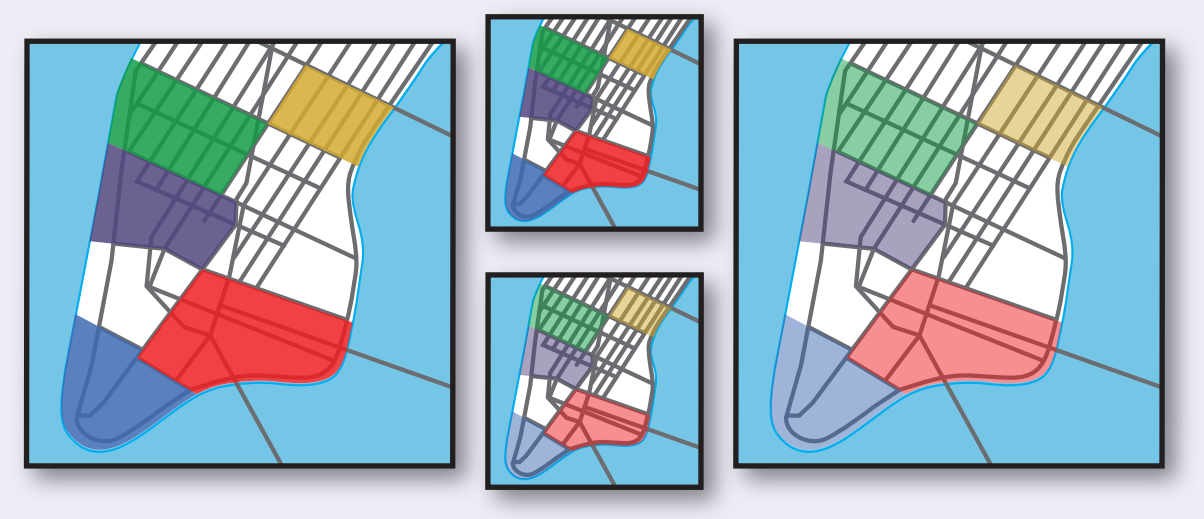
uniform adjustment of the symbol size without changing feature dimensionality



The ***adjust size operator*** alters the size of a symbol so that it remains legible when transitioning to a smaller scale. Size is one of Bertin's (1983) original visual variables. While the most common example of adjust size operator is for point symbols, it can also be applied to the stroke weight of lines or polygons. 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 is defined in a similar manner by Brewer et al. (2007). The adjust size operator is also called exaggeration by Lee (1996), magnification by Li (2007), and enlargement by Regnauld and McMaster (2007).

adjust transparency (St)

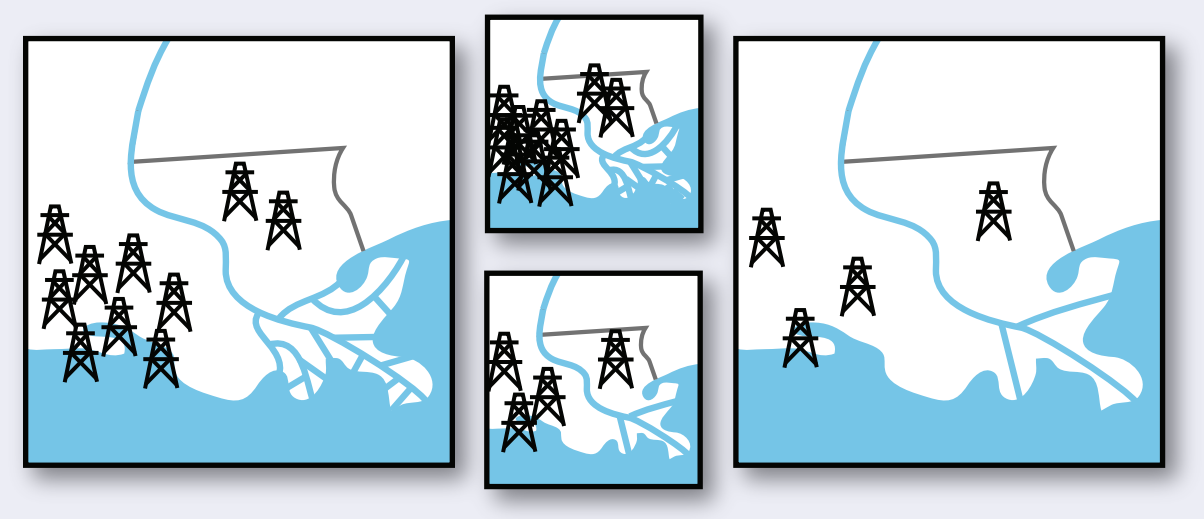
adjustment of the symbol opacity to improve the legibility of the feature or underlying features



The ***adjust transparency operator*** 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) extends the list of visual variables to include transparency, originally called fog, as part of the visual variable clarity. Common usages of the adjust transparency operator include the removal of transparency when a layer lower on the visual hierarchy is deleted by the elimination operator and the application of transparency when a layer higher on the visual hierarchy is included by the add operator. The adjust transparency operator is 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*** replaces a large collection of related features with a smaller set of symbols. The typify operator can be conducted on 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 geometric of the spatial data (the reason it is currently included as a symbology operator). The typify operator is defined in a similar fashion by Lee (1996) and Foerster et al. (2007).