Smooth Generalization for Continuous Zooming

Marc van Kreveld

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Abstract

Most research efforts on cartographic generalization have focussed on producing a map at a less detailed level than the input map or the input data. Only the final outcome is of interest. In this paper we study how the changes made to a map during generalization can be visualized such that it looks smooth, that is, without sudden changes. This is necessary for continuous zooming during interactive mapping. We analyze the possibilities and identify various complications that arise.

1 Introduction

Cartographic generalization is the process of transforming a map at a certain scale to another, smaller scale. Automated cartographic generalization attempts to derive the map at the target scale from the source scale in a fully automated manner. The generalization process involves changes that are thought of as operators: selection, elimination, merge, displacement, aggregation, symbolization, and more. Automated generalization has received considerable attention in the last decades, which has resulted in many papers and several books (Buttenfield and McMaster (1991); McMaster and Shea (1992); Müller et al. (1995)).

To pursue the goal of fully interactive automated cartography, generalization should be considered a continuous process of change. Zooming out on a map requires gradual changes in which cartographic generalization is performed. So, unlike in the usual automated cartographic generalization, the intermediate scales between the source scale and the target scale of the map are important too. This is also called dynamic, or on-the-fly generalization, where generalization is done for temporary maps on a computer screen (van Oosterom (1995); Mackaness and Glover (1999)).

This paper makes a step towards a the visualization of continuous scale change, which can also be though of as cartographic animation (MacEachren and Kraak (1997); Kraak and MacEachren (1999); Robinson et al. (1995)). It is a type of non-temporal animation, because the variable of change that triggers the animation is not time but scale. Visualization of continuous scale change of maps is already possible on modern computers, and with the technical developments of the internet, it will also soon be feasible for web cartography (Kraak and Brown (2001); Cartwright et al. (1999)).

We study the common cartographic generalization operators and what continuous, or smooth versions of it can be designed. For example, a smooth version of line simplification would be the morphing of a polygonal line to a straight line segment (the simplest respresentation on a very small scale map). Morphing is well known in the context of computer graphics. Another example is elimination, in which a map feature can be faded slowly into the background, or shrunk to a point and vanish. In the paper we also study the other, more complex generalization operators and their smooth counterparts.

The use of smooth changes in the interface has also been one of the changes between Windows95 and Windows98, and Office97 and Office2000. In the newer versions, the pull-down menus don't suddenly appear any more, but they scroll down from the menu bar. This is considered to be more natural or aesthetical.

The importance of having the appearance of a smooth change is mainly ease of reference. Sudden changes during zooming on a map are distracting to the user, and may also result in losing track of the objects the user is interested in. The other reason is for aesthetics.

It appears that a distinction must be made in intermediate, transitional maps that appear during zooming, and the resulting map, which is steady. It is required that the stationary map gives a proper map without, for instance, partially faded map features, whereas fading could be used in the transitional maps. Since the target scale during an interactive zoom is not known beforehand, special attention must be paid to assure a properly generalized stationary map when the user stops zooming.

In Section 2 we analyse the different ways of visually continuous changing a map to a more generalized version. We study which operators can be performed by which types of visual changes.

In Section 3 we discuss requirements for the intermediate maps that are changing. Therefore, the requirements can be less strict that for a stationary map, like it is shown when zooming is stopped. We study possibilities of proceeding the transitions from a transitional map to end up quickly in a properly generalized stationary map.

In Section 4 we elaborate on the issue of scale dependency and rate of change.

In Section 5 we consider how the visually smooth changes can be implemented. In particular we present a few easy ways of morphing.

In Section 6 we study some examples of generalization operators and their smooth implementation.

Section 7 gives some conclusions and possibilities for further research.

2 Visually continuous generalization

There are several ways in which a map can change gradually and which appears to be a visually smooth process. Five gradual changes are *moving* (displacement), *rotating*, *morphing* (deformation), *fading*, and *appearing* (inverse of fading). We use terms like moving and morphing to avoid confusion with closely related generalization operators. When moving is compared with displacement, not only the initial and final positions of an object that are of interest, but also all positions in between. In other words, the path the object follows during moving is relevant. When morphing is compared with operators like simplification, enhancement, exaggeration, not only the initial shape and the final shape are of interest, but also the shapes in between are of interest.

In the continuous process of fading, an object gradually loses its color or pattern and dissolves in the background. This can be a visually continuous way of eliminating map features. The inverse process of fading is appearance, which can also be necessary in generalization. For example, an oil field can appear to replace a collection of separate oil wells during generalization.

The well-known cartographic generalization operators can all be implemented by the above-mentioned gradual changes. Sometimes, more than one possibility exists. We next review several of the generalization operators and how they can be done in a visually continuous way.

Elimination. A feature can be eliminated gradually either by letting it shrink, that is, morph to a point and vanish, or by fading it into the background.

Simplification, smoothing, enhancement, refinement, exaggeration. These operators operate on linear features, or boundaries of areal features. They can all be performed using morphing. It is also possible to fade a linear feature and let its simplification appear at the same time, but this is an unnatural way of gradual change.

Displacement. The obvious choice for displacement in a continuous way is moving. Again, the possibility of simultaneous fading at the old position and appearance at the new position exists but is unnatural.

Merging, aggregation, dissolution. Merging two line features into one is done best by morphing the two line features to a new, intermediate position. Aggregating two areal features can be done either by morphing the two shapes to one new areal feature, or by letting the connecting area that makes the two areas become one appear from the background. Dissolution of an areal feature in a subdivision can be done morphing the neighboring areal features such that feature to disappear shrinks to a point, or by letting the areal feature fade while the neighboring areal features have their new region appear in the disappearing region.

Collapse. Collapsing an areal feature to a linear feature can best be done by morphing the opposite boundaries of the areal feature to a common centerline. Collapsing an areal feature to a point (symbolization) can be done by morphing the area to a point (or symbol). In case of a complex symbol shape, it can appear from the background while the areal feature shrinks or fades.

Typification. Typification is a difficult operator to convert to a smooth version. When replacing an equally-spaced row of nine houses by an equally-spaced row of six houses, the objects in the initial situation are not explicitly related to those in the final situation, but only as typical replacements. At least five different ways of gradual change are possible, even when we assume a fixed initial and final situation. Suppose that we have an equally-spaced row of nine square houses that should be displayed as an equally-spaced row of six houses of the same size. Then one could show the transition as: (i) fading the nine houses while letting the six appear simultaneously; (ii) moving all nine houses to the closest of the six final positions; (iii) moving six of the nine houses to the closest of the six final positions, while simultaneously letting the three other houses fade; (iv) same, but now the three other houses shrink to a point and vanish; (v) shrinking the nine houses to points while letting the six new houses appear.

Often the new row of houses must be moved away from the adjacent roads, and the houses must be exaggerated somewhat. An example of this combination, together with one stage in the first option of gradual change, is shown in Figure 1.

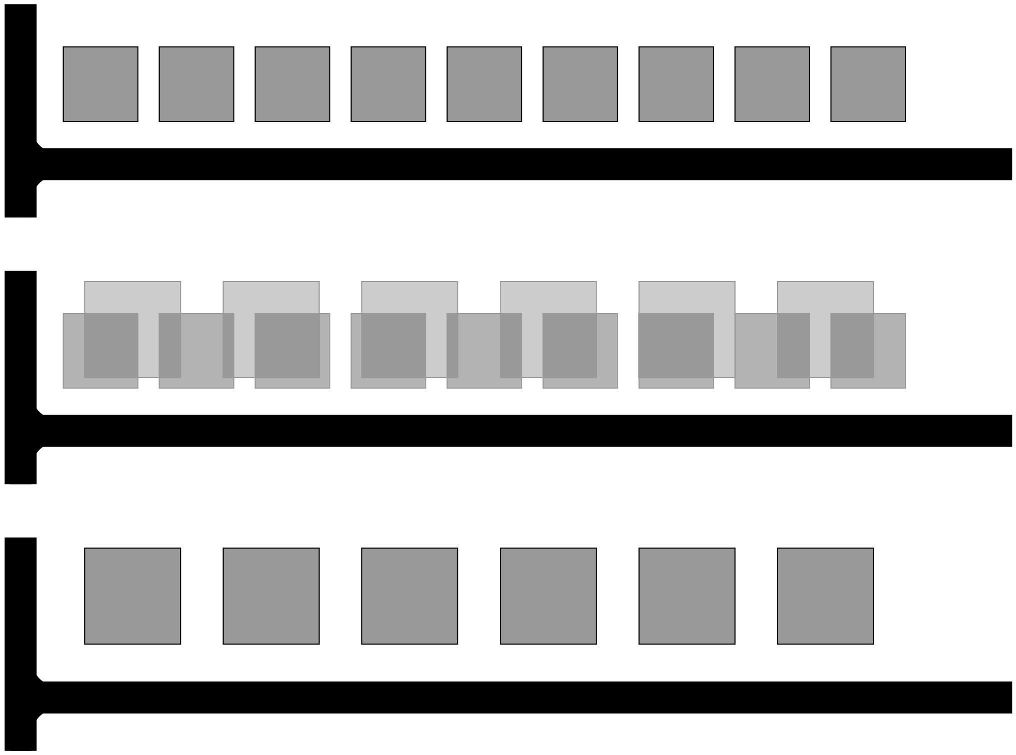

Figure 1: A row of nine houses, replaced by a row of six slightly larger houses with more spacing between features.

Classification. When a classified subdivision is generalized to a subdivision with fewer classes, some classes are merged while the boundaries between the now equal classes diappear. For instance, deciduous and coniferous forest classes may be combined into a new, generalized class forest. Visually, this can be done by changing the colors of the areas with deciduous and coniferous forests into the color of the new class forest, while at the same time the unnecessary boundaries are also faded into this color.

3 Requirements for transitional and stationary maps

In an interactive mapping environment, we call a map *stationary* if it is displayed on a screen without changing, until the user invokes an action. We call a map *transitional* if it is displayed on a screen but it is undergoing changes, regardless of the user invoking actions or not.

For the usual static, or stationary maps, a number of quality conditions can be listed. In particular, such conditions may relate to cartographic generalization. McMaster and Shea (1992) list a number of conditions that indicate the need for generalization, including congestion, coalescence, and imperceptibility. The absence of such conditions implies that no further generalization is needed. Similarly, Weibel (1996) classifies the conditions for generalization as geometric, topological, semantic and Gestalt. All such conditions are requirements for a stationary, generalized map. For a transitional map, some of these conditions can be relaxed. For example, a certain amount of congestion may be present, as long as it is removed when the map becomes stationary. Similarly, two features may coalesce on a transitional map, provided it is resolved later. On the other hand, topological inconsistencies should be avoided on both stationary and transitional maps.

A different type of difference in requirement for transitional maps and stationary maps comes from the process of smooth change itself. When a feature is eliminated by fading, a partially faded object may of course be present on a transitional map, but not on a stationary map.

4 Dependency on scale

In a standard, isolated generalization case, a (detailed) feature is given together with a target scale, and a representation of the feature at the target scale is computed. This is of course a valid representation for a stationary map, because there is no concept of transitional map in this case. When a smooth transition is needed, the feature will go through representations that are only valid on a transitional map.

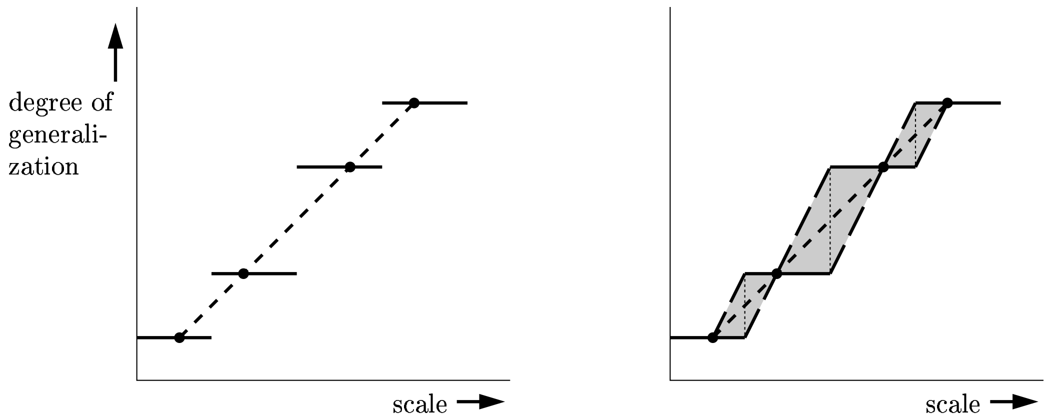

Figure 2: Graph showing the relation between scale and amount of generalization.

Figure 2 shows a graph with on the one axis the scale (or zoom factor) and other the other axis the amount of generalization, expressed in the scale to which such an amount of generalization corresponds. The graph applies to a single feature, and a point in the graph shows for a certain scale the amount of generalization. We assume in smooth generalization that for each feature, there is an amount of generalization to which it corresponds, although the visualization of it may not be valid on a stationary map. So for continuous zooming, the amount of generalization changes linearly, along the line $y = x$, shown left as a dashed line. However, when the user stops zooming and the feature in transition is not valid on a stationary map, we should get to an amount of generalization that would be valid, and as quickly as possible. So we could imagine that some points (or whole intervals) on the line $y = x$ are valid amounts of generalization for stationary maps at those scales. The other positions on $y = x$ are correspond to transitional features that are not valid on stationary maps. When zooming stops, the scale cannot be changed, but the amount of generalization can. This corresponds to a vertical motion from the current [scale,generalization] pair to a position on one of the solid horizontal segments. For every scale, there must be an amount of generalization that yields a valid stationary representation of the feature.

The right part of Figure 2 shows all positions in the graph that can be reached during zooming and stops in zooming. Solid lines of the graph show valid [scale,generalization] pairs for the feature on stationary maps, and grey parts show possibly occurring (scale:generalization) pairs for the feature on transitional maps.

The rate of change of transitions after zooming stops can be chosen the same as during the continuous zooming. This implies that if the zooming continues, the rate of change can be up to double the normal rate of change, which appears as the steeper sloped boundaries of the grey regions.

Using a fixed scale where generalization of a feature is always continued beyond and backed up before, means that a user who alternatingly presses zoom in and zoom out can see transitions back and forth all the time. If this is considered a problem, one could use a different cut-off scale for zooming in and zooming out.

As an example, consider generalizing a lake or other natural shape. One could let it first shrink with a factor equal to the zooming factor (scale of the map), then letting it shrink at a reduced rate since otherwise it would become to small (so this is exaggeration), and when it really becomes too small for the scale of the map, letting it shrink at accelerated rate (and continuing even if zooming stops). This final shrinking could be morphing to a point, or morphing to the main part of the skeleton (which should be defined appropriately). When generalizing a city outline, it makes sense to shrink it to a point or small circle in the third stage, so the symbolization as a point symbol appears more natural.

5 Implementing smooth changes

This section gives suggestions of ways to perform the smooth changes. Since we are dealing with changes on temporary maps, we are not looking for most aesthetical solution, but rather for simple solutions that work well in most of the cases that will arise.

5.1 Ways of moving

When the initial and final position of a feature at two different map scales is known, the obvious choice for moving is translation along a straight line at constant speed. This may cause, however, coalescence and overlap of different map features during the move. Since the amount of displacement is generally quite small, and hardly any features will be in conflict with the intermediate positions of the moving feature, it is not worthwhile to go for more elegant solutions in which conflict-free trajectories are computed. This would lead to problems considered in coordinated motion planning for multiple robots, and these problems are computationally very hard.

5.2 Ways of fading and appearing

Fading and appearing are basically color changes of areal features and their boundaries. They can therefore be done at the pixel level and at the vector or object level. At the object level, we would need a way to represent the display of two objects that both occupy the same space, and both influence the color at that space.

5.3 Ways of morphing

The topic of morphing between two shapes or images has been studied extensively in the computer graphics community. It is used, for instance, to produce frames in between key frames.

In the context of cartography, the most important type of morph is probably simplification. Since the most drastic simplification of a polygonal line is a straight line segment connecting the endpoints of the polygonal line, we present two simple ways to morph to a line segment, which can be used for smooth generalization.

Consider a polygonal line P defined by $p_0, \ldots, p_n$, to be morphed to the line segment $\overline{p_0 p_n}$ connecting p_0 and p_n. Take $n-1$ of equally-spaced points $p'_1, \ldots, p'_{n-1}$ on the line segment $\overline{p_0 p_n}$. Now let the $n-1$ points $p_1, \ldots, p_{n-1}$ move simultaneously to the points $p'_1, \ldots, p'_{n-1}$ along a straight line, at such relative speeds that each point p_i eaches its destination p'_i at the same time. The moving control points of the polygonal line P gradually simplify, or morph it to a straight line segment.

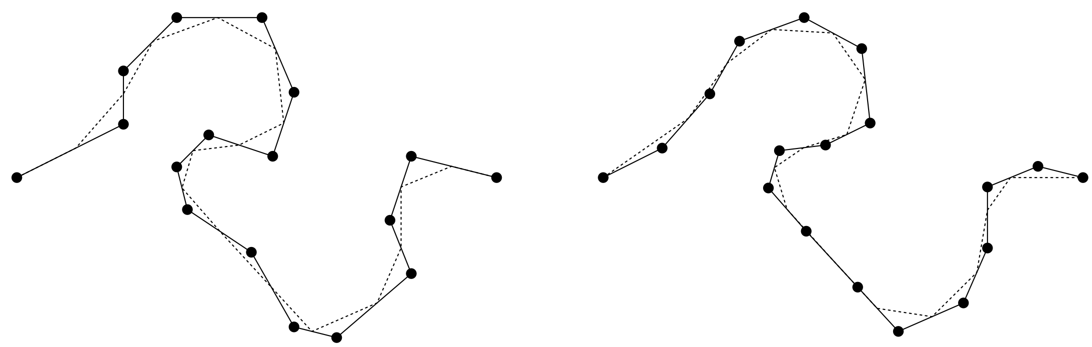

Figure 3: Two steps in morphing a polyline for simplification.

A second way of morphing to a straight line segment is reminiscent of Casteljau's spline evaluation method. For the first step and every other odd step, choose the midpoint of every segment $\overline{p_i p_{i+1}}$ of P. Connect these midpoints to form a slightly simplified polygonal line P_1, and morph P to P_1 in the obvious way. To compute P_2 from P_1, and in every other even step, again take midpoints but not of the first and the last segments on P_1, and morph P_1 in the obvious way to P_2. The polygonal lines $P, P_2, P_4, P_6, \ldots$ have the same number of control points. Every next polygonal line P_{i+1} is shorter than the polygonal line P_i from which it was created, and after a few dozen steps it looks like a straight line segment.

The same processes can be used for polygons. To make a polygon shrink, we can move its control points simultaneously to a single point as in the first way of morphing. This changes the size of the polygon, but doesn't simplify it, however. The second way of morphing, connecting the midpoints of all segments of the polygon and connecting these, reduces the perimeter of the polygon in every step, although the area may increase in some steps. So at the same time the shape of the polygon in simplified and it is reduced in size (perimeter), see Figure 4. Eventually, the polygon will look like a point.

To morph a polygon to a simplified shape without shrinking it can be done too. We can compute a simplified polygon with any existing algorithm and use the first way of morphing to simplify the original polygon. Or, we can use the second way and after each simplifica-

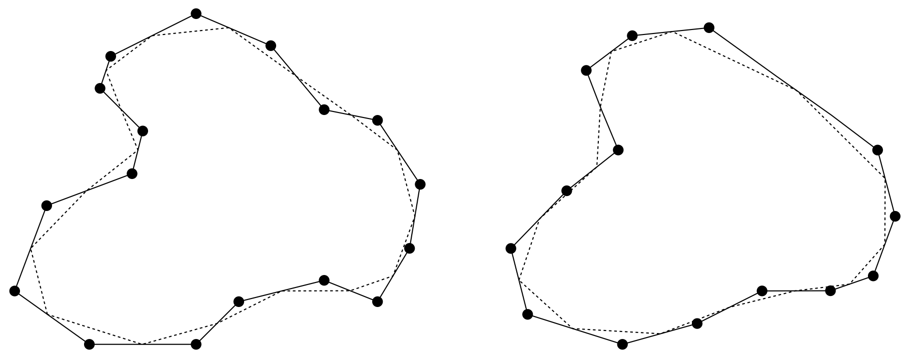

Figure 4: Two steps in morphing a polygon for simplification and shrinking.

tion/shrinking step, scale the polygon so that it keeps the original area. Scaling preserves the shape, so the simplification is the only effect.

6 Implementation possibilities of smooth operators

In Section 2 we reviewed a couple of generalization operators and which smooth changes could be done for them. In the case of typification for a row of houses, we noted that at least five different options are possible. In this section we analyse a few more cases in which there are several options for smooth change. Even when a smooth change is done by morphing, for instance, there are still various possibilities of how to morph.

Drainage network generalization. For drainage network generalization, we may choose streams to eliminate by their Strahler or Horton order. Elimination of such a stream can be done nicely by a special type of morph called retraction. A stream of lesser importance can be shrunk from its source to the place where it enters a larger stream.

Road network generalization. In road network generalization, eliminating road of lesser importance cannot be done naturally by retraction. The only reasonable type of smooth change is fading in the background. Simplifiying the roads that remain can be done by one of the morphing methods described before.

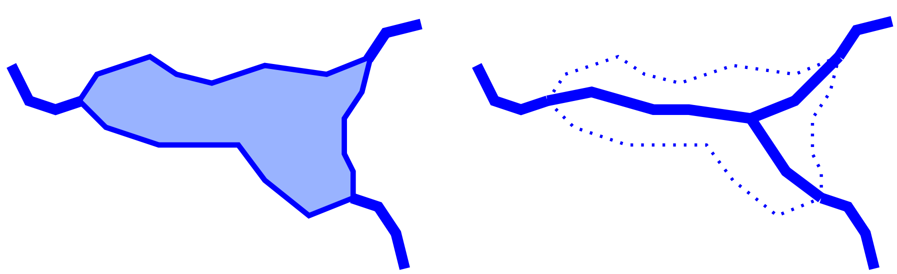

Figure 5: Collapsing an elongated lake into rivers.

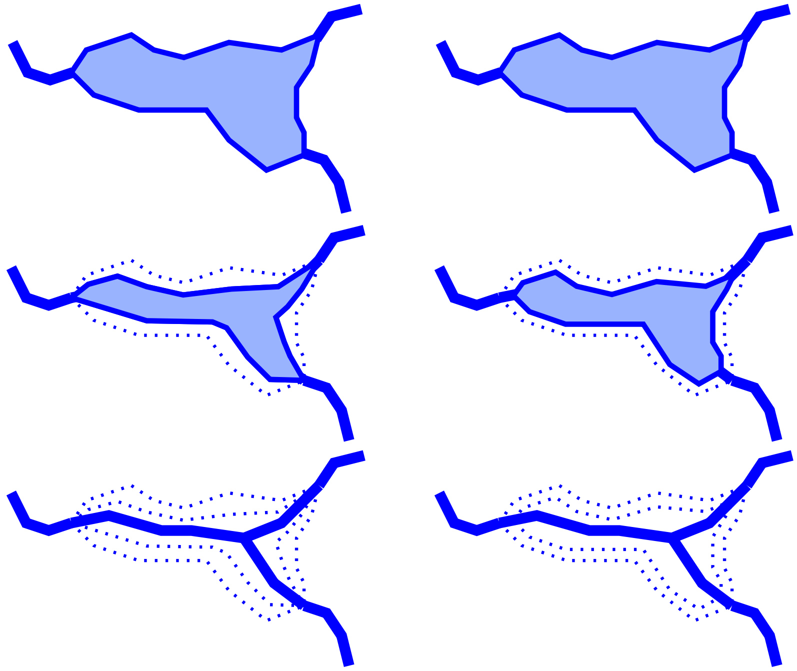

Figure 6: Collapsing an elongated lake into rivers by morphing.

Area collapse. Area collapse of a lake in a river can be done by chosing a skeleton or center line in the lake (polygon), and using the parts that lead form the inlets to the outlet only, see Figure 5. Such a collapse can be done by fading or morphing. In the case of morphing—which seems more natural than fading—, there are two natural ways, see Figure 6. Firstly, one could shrink the lake by parallel lines (buffering) until the skeleton remains. Alternatively, one could translate the control points of the lake boundary to an appropriate position on the skeleton, such that all control points reach the skeleton at the same moment. The second option gives a more narrow lake in the intermediate steps than the first option.

Building simplification. When simplifying the shape of a complex building, standard simplification cannot be used because the rectilinear orientations of the edges need be preserved. Generalized versions of buildings can be computed by shifting an edge, while shortening or making longer the adjacent two edges, until the number of vertices of the building is reduced. This in itself is a smooth process and yields nice results in many cases, see Figure 7.

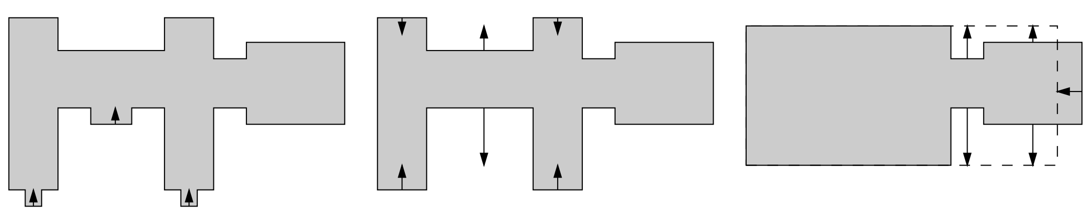

Figure 7: Simplifying Sanford Hall, University of Minnesota, smoothly by shifting edges in stages.

7 Conclusions

This paper studied the issues involved when generalization is done during continuous zooming. Smooth generalization implies:

- Accepting that transitional maps don't satisfy traditional map constraints.
- Accepting that changes for generalization continue after the user stops zooming.
- Accepting that either the stationary map obtained after zooming is not perfect at the given scale, or that considerable changes, and perhaps even undesirable changes, are made after stopping the zooming.

There are many directions for further research. It should be studied which smooth versions of the generalization operators are most pleasing and most effective. It should be studied how smooth generalization can be performed efficiently on a stand-alone computer and via the internet. How should the data be organized so that smooth generalization can be performed? What intermediate representations of features should be used to allow for smooth generalization between them? And how can several smooth changes be incorporated into a whole to get a pleasing overall result? These are some of the questions that arise in the context of this paper.

Implementations of the various options of smooth change are needed to examine how they look. This is planned in the near future. Also, the idea of smoothly undoing a smooth generalization step if it has just started and the user stops zooming, should be implemented to judge its naturalness.

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