2D vario-scale representations based on real 3D structure

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Abstract

This paper focuses on 3D data structures supporting an alternative approach for creating 2D vario-scale maps. The smooth animated zooming functionality have lead us to investigate a volumetric representation of gradually changing vario-scale objects. In this paper, the principle of vario-scale maps with theoretical knowledge about 3D representation (2D space plus 1D scale) is briefly introduced, followed by a description of our initial implementation efforts for creating a development environment for our research, which is based on the conversion from the classic tGAP data structure through tetrahedralization to a volumetric representation. The current results and examples of this volumetric representation with real world data and plans for future improvements are presented.

1 Introduction

This paper reports on on-going research for using vario-scale maps for smooth zoom functionality. The vario-scale approach is an alternative for obtaining and maintaining geographic data sets at different scales. It offers the possibility to derive a map at an arbitrary map scale from a data structure with minimum redundancy. The principle of vario-scale is based on storing only the geometry of the most detailed layer and the additional objects that are created in a generalization process are stored by links to the original data. All objects are stored as a 2D object in a topological data structure extended with scale ranges, the so-called topological Generalized Area Partition (tGAP). Up to now, the data have been stored and visualized as 2D maps, but this did not yet result in very smooth zooming operations (still shocks are visible during use). Therefore a 3D structure called the Space-Scale Cube (SSC) (Meijers and van Oosterom, 2011) has been proposed, but this theoretical concept has not yet been implemented.

This paper presents our experiments with using for the first time a real volumetric representation of the vario-scale data structure, where objects are represented as 3D geometric objects (2D geometry + 1D scale). It is motivated by replacing a number of discrete 2D representations by a 3D representation connecting the different scales which offers us a research environment that is useful for developing, debugging and visualization of vario-scale data, by employing standard 3D geometric modeling tools.

The remainder of this paper is organised as follows: §2 describes the principles and applications of the vario-scale approach. The steps which have been taken during implementation are explained in §3. §4 describes the results of converting topological vario-scale data to 3D geometry, followed by conclusions in §5. Finally, the future work is discussed in §6.

2 Related work

The classic multiple representation databases (MRDB) approach is widely applied, but is suffering from a discrete number of Level of Details (LoDs), potential inconsistency and redundancy, which they are trying to keep under control by storing links between objects from different map scales.

On the other hand, as was mentioned by van Oosterom (1995, 2005), Meijers (2011), the vario-scale approach offers minimum redundancy, smooth zooming functionality and progressive data transfer. The next subsections focus on the explanation of the vario-scale data structure, where these benefits are supported explicitly.

2.1 topological Generalized Area Partition

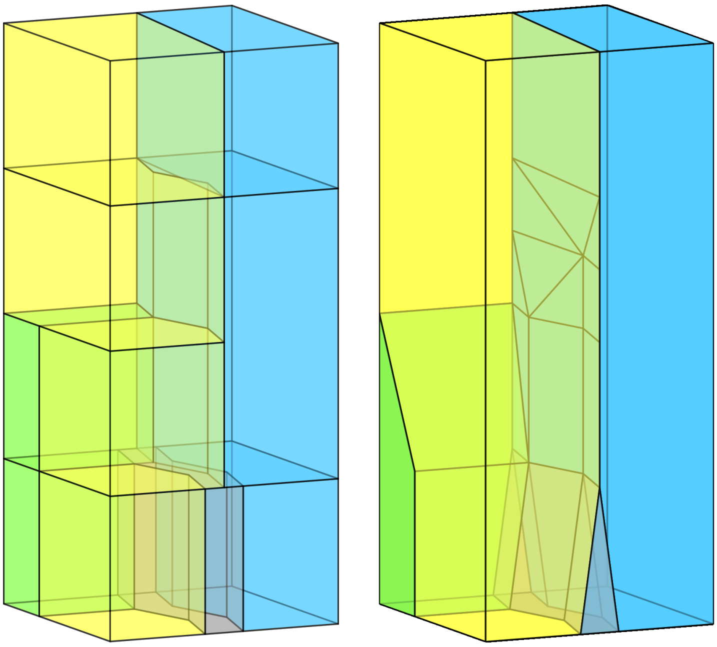
Nowadays there exists a vario-scale data structure which is called tGAP (topological Generalized Area Partition) (van Oosterom, 1995, 2005, Meijers, 2011). The principle of this structure is based on the creation of a tree structure.

We start with the most detailed data level that includes all the features (the largest map scale). Next, the least important object is selected, and merged with its most compatible neighbour, based on area, classification and the length of the shared boundary. This is repeated until only a single object remains. The merging process is recorded into the tGAP tree structure. The last remaining object is the top of the tree. Later on, when using the structure, it is possible to choose any required level of detail by selecting this level of detail in the tree. Geometry of the objects is stored only in the most detailed level, all other objects (created by merging) are merely links to the parts of the object in the more detailed level. The redundancy of the structure is minimal, because no new geometry is created.

Every object stored in the database has two attributes defining the valid scale range of the object. At a given scale, these attributes say which objects are visible/exist. The geometry and the scale range attributes of an object are used as a starting point for creating the volumetric object.

2.2 Smooth tGAP

The principle of the tGAP structure can lead to smoother user interaction, for which the concept of the smooth tGAP structure has been introduced by van Oosterom and Meijers (2012). It is presented as a space-scale partition, which is termed the Space-Scale Cube (SSC) in which prism based representations for objects are stored, see Figure 1(a). Figure 1(a) gives an idea of how map generalization is an extrusion of the original data into an additional dimension connecting the discrete scales (without topology errors). Map scale is seen as an additional geometric dimension. The resulting vario-scale representation for 2D map objects is a 3D structure. The 2D area object is now presented as a 3D volume. However, despite the 3D representation in it, the tGAP structure is still based on a large amount of discrete steps. A split or merge operation still causes a sudden local change in map ("shock"). A small change in the map scale does not automatically result in a small geometry change. This situation however will not happen in the gradual Space-Scale Cube representation of tGAP, a smooth transition based representation, see Figure 1(b). All generalization actions must lead to a smoothly changing map. We can imagine it as: if we are making a gradual shift of a slice plane (where we take a horizontal slice) from the top of the cube downwards, there will not be any object suddenly appearing or vanishing. All changes result in a smooth changing 2D map: a small change in the map scale means a small change of geometry in the resulting map.

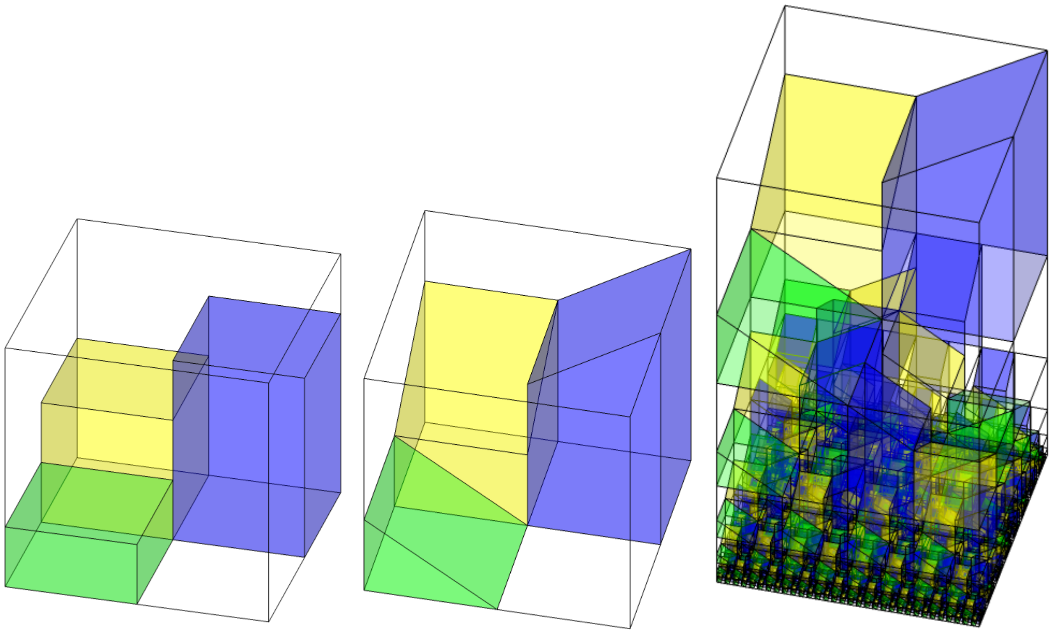


(a) SSC for classic tGAP (b) SSC for smooth tGAP

Figure 1: Space-Scale Cube

2.3 Mixed-Scale map

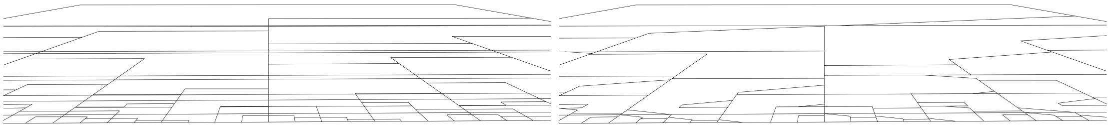
Besides smooth zoom with gradual changes, another more advanced usage of tGAP or smooth tGAP is creating a mixed-scale map. Only the horizontal slice plane parallel to the bottom of the cube has been mentioned until now. In that case the result of a slice is a map having homogeneous map scale, but in principle it is possible to take non-horizontal slices through the 3D cube. The result will be a mixed-scale map with multiple map scales combined in one picture, where the most detailed objects which stem from the bottom of the SSC, will be combined with less detailed objects from the top of the SSC. It is then possible to see the smooth transition from detailed to coarse representation. This is useful for 3D perspective views, where a user receives detailed information close to his position, while less details are generated further from him. In addition, the mixed-scale map can be created by slicing with a non-flat plane, e. g.: a bellshape surface (Harrie et al., 2002, Hampe et al., 2004) to provide a fish-eye lens type of map (to magnify an important part of the map).



(a) The example of discrete merge operation. (b) The example of smooth merge operation. (c) The dataset created from artificial data 2(b).

Figure 2: The artificial data examples of tGAP in SSC. The prism based approach representing four objects: yellow, green, blue and transparent white. In Figure 2(a), the transparent/white object is taking over space from green, yellow and from purple neighbour and the whole area has become white. In Figure 2(b), it illustrates the same process, but now using a gradual, smooth transition. Figure 2(c) illustrates the whole artificial dataset for creating a mixed-scale map.

The classic tGAP (with "shocks") represented in the SSC is basically an extrusion of the geometry faces from their starting scale to their ending scale (prisms). The principle of classic tGAP structure can already be used for creating a mixed-scale map. Figures 2 and 3 show that. The objects their boundaries have been used: It results in lines that represent the boundaries of the objects in the final map, see Figure 3. The final map is obtained by intersecting the boundaries of the objects with a curved surface. Hence, we can see only lines. For a better final map, where areal objects will be present and can be given a colour, the volumetric representation of the space-scale objects is needed,



(a) The mixed-scale map of artificial dataset composed from discrete classic tGAP 2(a).

(b) The mixed-scale map of artificial dataset 2(c) composed from smooth tGAP 2(b).

Figure 3: Example of mixed-scale maps. The maps have been created by diagonal slicing of artificial dataset. The lines are intersections between the slicing plane and boundary of objects. We can observe that the detailed object have been sliced near to bottom and less detailed (more generalized) object have been sliced on top.

because then the intersection would be an area and not a line.

3 Implementation

To be able to experience smoothly changing data, we have investigated a conversion procedure of already existing tGAP data and the use of 3D geometric modelling tools. Here we report on our findings of the resulting workflow and our current research platform, which uses as much as possible standard and open source 3D geometric modelling tools.

Developing the 3D representation of vario-scale objects requires the possibility to load a 3D representation, should offer a slicing tool, where the result of taking a slice is a collection of area objects and should also offer a possibility for simulating smooth zooming functionality to inspect the content of the 3D data structure.

For visualization of the resulting data we have selected a combination of the VTK library (Visualization Toolkit) (Kitware and Avila, 2012) followed by visualization in Paraview (Paraview, 2012). First, VTK is an open source tool for three-dimensional computer graphics, image processing, and visualization. The VTK file format is part of the VTK specification. Second, ParaView is an open-source, multi-platform application designed for the visualization of data sets of size varying from small to very large, with its main focus on scientific visualization. The combination of VTK/Paraview offers both the visualization possibilities as well as a powerful slicing tool.

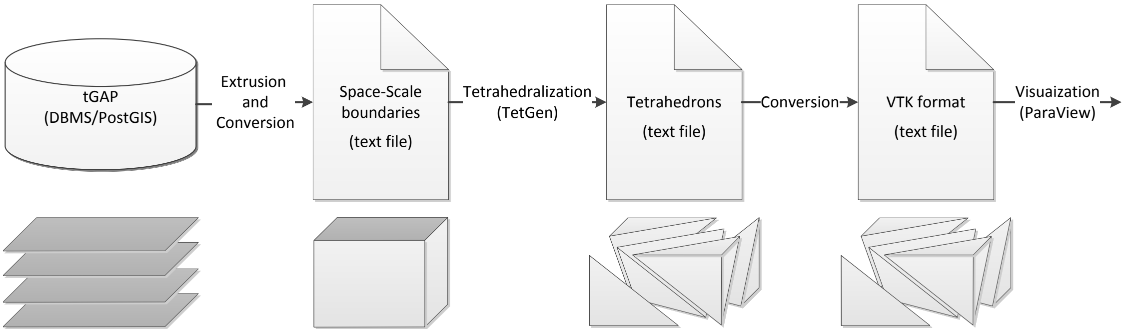


Figure 4: The diagram of process chain.

Figure 4 shows the whole pipeline from the classic tGAP structure to the visualization. The process chain starts in the database (we use a PostGIS enabled PostgreSQL database) where the classic tGAP structure is stored and all vario-scale representations can be obtained. The objects are converted from areas stored in the tGAP structure to Space-Scale objects; these objects are prisms composed of horizontal and vertical faces. For obtaining a dataset that can be visualized, a conversion from the tGAP representation to tetrahedrons (a tetrahedron is a geometric object composed of four vertices and four triangular faces) takes place. TetGen, a tetrahedral mesh generator, has been used for that (Si, 2006). The output from TetGen has been converted to a VTK file (Schroder et al., 2000). The resulting Space-Scale boundary objects are currently stored in text files (in VTK format), but our intention is to use a database for storage later. The VTK file is opened in Paraview.

The whole 3D dataset with tetrahedrons represents a set of Space-Scale volumes (composed of 2D geometry and 1D scale). The slice plane for slicing can be controlled interactively in Paraview and the resulting 2D area objects are computed in real time. This makes it possible to analyse and illustrate the smooth zoom experience. The tetrahedrons that are sliced with the slice tool in Paraview lead to 2D area objects (triangles) and these can subsequently be colored based on the attribute that is associated with the tetrahedrons; This is the reason why the Space-Scale volumes are decomposed into tetrahedrons.

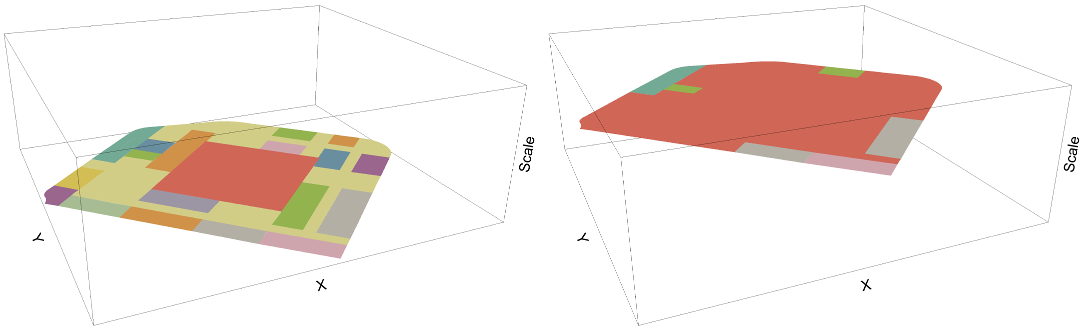
4 Results

Figure 5 and 6 demonstrate the space-scale volumes of real world data in Paraview. In Figure 5, the volumes represent real map objects from the CORINE Land Cover dataset of the Netherlands, stored in the SSC. The first two pictures 5(a) and 5(b) present slices of SSC. The clip of SSC in combination with some selected objects is shown in Figure 5(c). Only objects of the initial map scale have been selected for this illustration. Merged objects have not been visualized. The height of the prisms corresponds with the scale range for which the object is valid. More important objects remain to smaller scales and consequently are higher than less important objects. The red object, for instance, has highest importance and all merge operations end in the red object.

Figure 6 shows a subset of medium scale ATKIS data (1 049 tGAP objects, start scale 1:50,000) where Figure 6(a) illustrates the horizontal slices (detailed slices low, medium and overview slice high) in combination with a clip of the SSC and Figure 6(b) presents a tilted plane slicing through all Space-Scale volumes resulting in mixed-scale map. Note that quite some ‘horizontal’ lines in this slice can be observed. This is the result of slicing the stacked prisms with the tilted slice plane and will not occur when a smooth SSC is sliced.

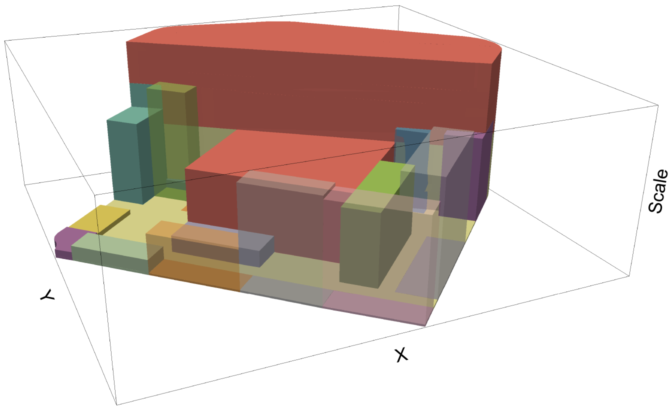
The number of resulting elements can give us some idea how efficient the storage is. The small subset of CORINE presented in Figure 5 contained 45 faces in the tGAP structure and results in 228 tetrahedrons. The example of ATKIS dataset in Figure 6 has 1 049 objects in the tGAP structure and 266 167 tetrahedrons in VTK.

The results so far have illustrated ‘prism-based’ Space-Scale objects. Figure 7 illustrates our first attempt at implementing a generalization algorithm that generates smooth output, performed for only one object: The boundaries of the detailed version of the ob-



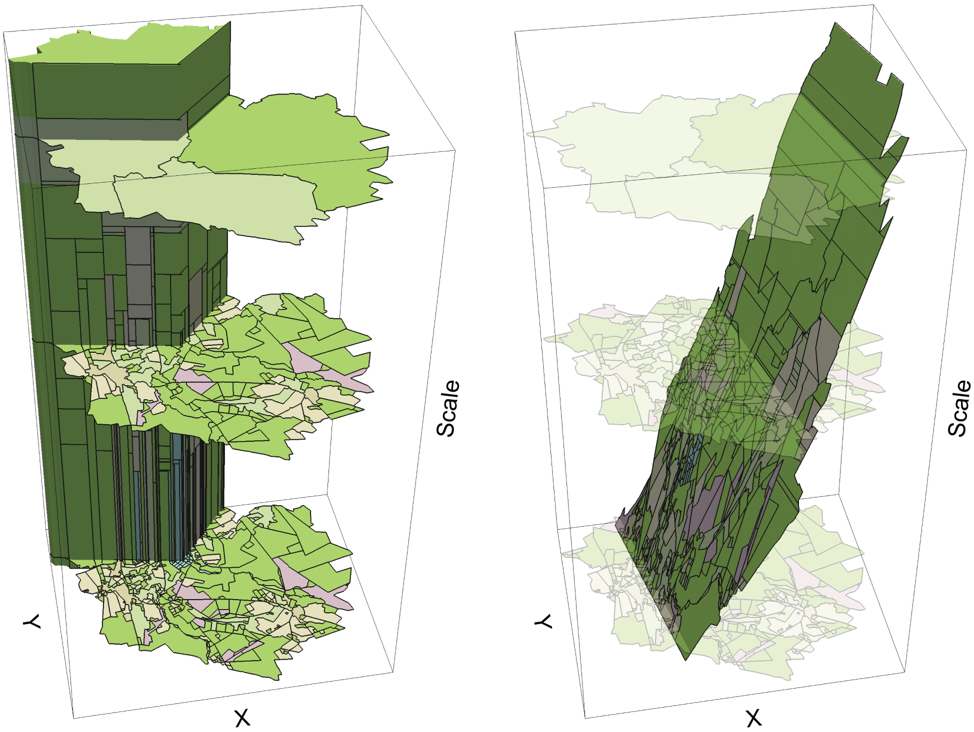
(a) A detailed slice

(b) a overview slice



(c) a objects selection in combination with the clip of SSC

Figure 5: A small subset (45 faces) of real data represented as space-scale volumes. The colours are randomly assigned.



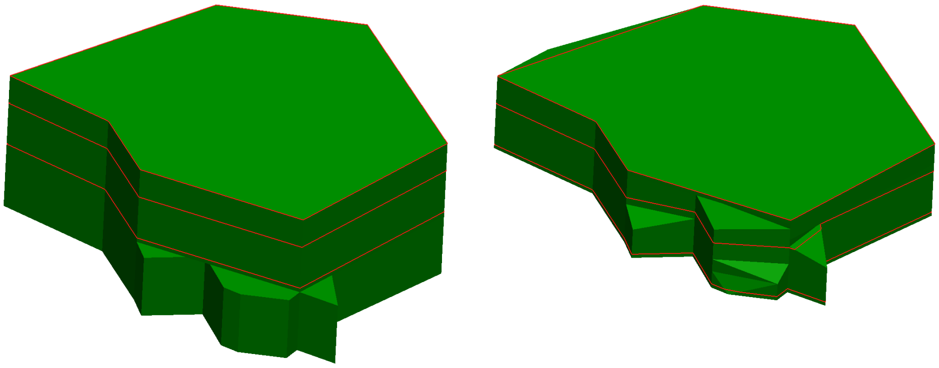
(a) The clip and horizontal slices of dataset. (b) The non-horizontal slice.

Figure 6: 1 049 objects of Atkis in SSC.

ject are simplified with the Visvalingham Whyatt algorithm, leading to a coarser object. The order in which the vertices are removed from the line by the algorithm are stored in a binary tree structure (the so-called Binary Line Generalization tree, BLG tree). This tree structure provides enough information to construct a 3D volume for the object. The faces that are extruded in the scale dimension are now not necessarily all vertical faces. The resulting volume is tetrahedralized, and the tetrahedrons are loaded in Paraview. Now, slices can be taken through this object. For comparison reasons, also the object is shown but now constructed based only on the simplified boundary. The smoothly changing resulting slices can be compared to the slices that stay the same for all intermediate map scales.

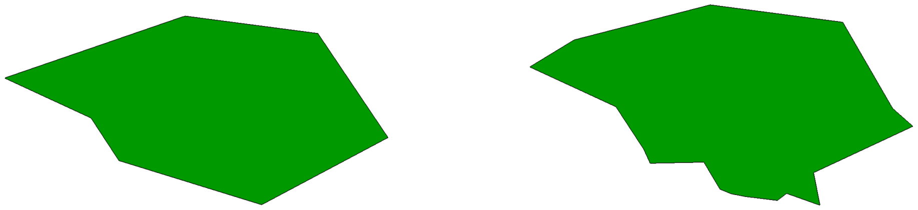
5 Conclusion

This paper presented the whole process chain from converting classic tGAP storage to a 3D SSC, which gives us an idea how useful this visualization approach is and which tools we can use in our future research. The 3D representation offers easy visualization of the result of the generalization process, a possibility to simulate smooth zooming and gives an idea how mixed-scale map can be constructed and derived from the data structure. Every object from the tGAP structure is converted to a prism-based Space-Scale boundary representation, then the tetrahedrons are generated and finally sliced and



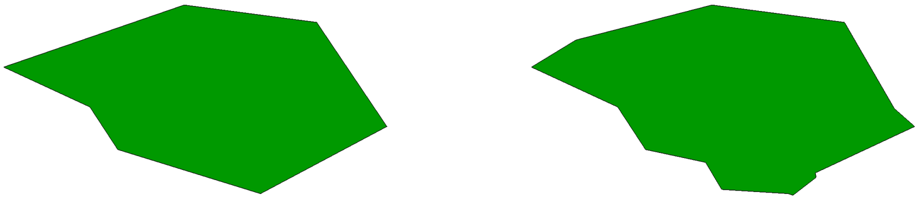
(a) 3D perspective view (*without* smooth boundary simplification). The lower part of the object is result of previous step. It is used as input for simplification.

(b) 3D perspective view (*with* smooth boundary simplification)



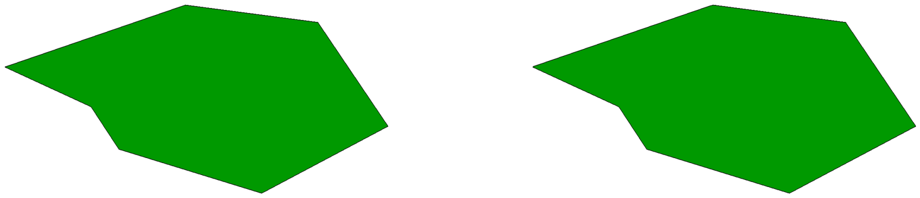
(c) 2D horizontal slice (detailed) – without smooth simplification

(d) 2D horizontal slice (detailed) – with smooth simplification



(e) without smooth simplification

(f) with smooth simplification



(g) (less detailed) – without smooth simplification

(h) (less detailed) – with smooth simplification

Figure 7: Two Space-Scale volumes with (right column) and without (left column) smooth line simplification and some derived slices. The red lines indicate the position of the slices.

visualized in Paraview. This workflow gives us an initial procedure for obtaining a true volumetric representation, but has to be tuned in the future.

6 Future work

The smooth tGAP where horizontal faces do not exist in gradual SSC and where dynamic zooming presents gradually smooth changing geometry is the next logical step. We have shown our first steps in this direction for performing line simplification, but for merging and/or splitting area objects this principle has only been described in theory, but has not yet been implemented. Some theoretical algorithms for smoothly merging and splitting area objects have been described (van Oosterom and Meijers, 2012), but these need to be implemented, tested and the results should be verified with real data.

Another concern is the storage aspects of the 3D data structure. Minimum redundancy is one of the main principles of vario-scale, but our current encoding of Space-Scale volumes takes significant storage (the number of tetra needed is quite big). How can we keep redundancy at a minimum also for explicit 3D storage and is explicit 3D storage really needed? Storing the data in a 3D topology data structure could be one option. Another option could be to derive what is needed from the tGAP data structures that store more or less separately the 2D geometry and 1D scale range and create the 3D representation when needed, e. g. at client side (as is done in this paper with tetrahedralization), because the current tGAP data structure implicitly contains 3D data, but does not store it as such.

Furthermore, we intend to investigate other generalization operators and how the result of these operators can fit in the 3D structure. For example, the split operation can cause that the object defined in the SSC is composed of a volume and a set of polygons. For instance, the road represented by the grey object in Figure 1(b). The road collapses to a line and should still be present in the generalized map (but now as line). For such an object it is not sufficient to represent the object as a set of tetrahedra alone (although we could attach the object information to the bounding triangles of the tetra for the smaller scales).

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