Large scale road network generalization for vario-scale map

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Abstract The classical approach for road network generalization consists of producing multiple maps, for a different scale or purpose, from a single detailed data source and quite often roads are represented by line objects. Our target is the generalization of a road network for the whole scale range from large scale, where roads are represented as area objects, to mid and small scales, where roads are represented as line objects. Crucial in our approach is that we use the specific data structure where for all map objects a range of valid map scales is stored. Instead of targeting predefined discrete map scales, we offer a whole range of map scales (where the process of map generalization was captured for). So far the structure has been used exclusively for area features. The exception to this was recent research where line feature (roads) have been included in the implementation for the first time. However, this was applied to smaller scales only. Therefore in this paper we will address the first part of the process, the generalization of large scale road objects, when (road) features change there representation from areal to linear segment. In our suggested gradual approach this representation change may happen at different 'scale' moments for individual roads (even of the same road element), in contrast to current practices. This is the first time ever that this aspect is discussed in more detail.

1 Introduction

Automated, continuous map generalization is the focus of this discussion paper. We use incremental generalization stored in the vario-scale data structure, which ac-

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commodates a complete scale range for every map object. Therefore it offers flexible storage for maps with arbitrary map scale instead of a sequence of maps with different levels of detail (LOD) as has been common so far. In previous research we mainly focused on areal map features such as buildings, forests, fields, etc. Now we want to cover another important part of features present on topographic maps: road networks. The reason for this: The roads as a part of the infrastructure objects make the ‘backbone’ of many map types. They improve the legibility of maps and help users to orient and recognize the real world situation, depicted in maps, much more easily. Similar transitions, from area to line representation, are also relevant for the hydrology network. Road and hydrology processing has the potential to provide a big influence on the whole generalization process and improve the quality of the final result.

Our ultimate goal is to support input data, where roads are modelled as areas (large scale) and progressively are collapsed into lines (small scale). Our previous research already covers the later part of the process where roads are already modelled as lines (mid-scale, 1:50K, to small scale). This paper covers the first part of this problem (large scale road network generalization only) and the transition from area to line representation.

Fig. 1: Two map fragments of different scale show city centre of Leiden, The Netherlands. First (left), the base map (in Dutch:Basisregistratie Grootschalige Topografie) intended for use at a 1:500 - 1:5,000 map scale. Note that only linear features are displayed. Second (right), a road network dataset of the Netherlands was used (in Dutch: Nationaal Wegen Bestand). This is a dataset intended for use at a 1:25,000 map scale.

To be more specific, Figure 1 shows examples where roads are represented by area features in one scale and modelled as lines in another. It is evident that for a map series the transition from large to middle scale must be performed somewhere. Most of the time this happens in the generalization processing and only the final result is stored; it is often the same type of representation (line or area) for all instances at the same road class. However, when we accept the fact that vario-scale approach can accommodate storing a scale range for every map object (or object part) it leads us to the idea that new scales can be introduced between large and small scale maps.

This can give in theory a better impression to the user about the transition from one scale representation to another. To accommodate this non-trivial principle it requires closer investigation. Therefore, this will be the main focus in this paper.

The remainder of this paper is structured as follows: Section 2 reviews related work and explains the vario-scale data structure in more detail. Followed by Section 3, which explains our method to deal with generalization of roads modelled as areas. Finally, Section 4 concludes the paper and presents some open questions.

2 Related work

Brewer and Buttenfield (2007); Touya and Girres (2013) describe an interesting tool called ScaleMaster, which allows automatic multi-scale generalization. It is based on the model where it is possible to formalize how to generalize map features from different data sets through the whole range of targeted scales. Despite the fact that the tool is focussed on generating a multi-scales/ multi-representation solution the idea of defining generalization actions for a whole scale range is similar to our approach. We also see the generalization process as the process through map scales where some generalization actions take place only in a specific range, e.g. the collapse of the roads should be possible only for the transition range of scales between large and small map scale (e.g. between 1:5,000 and 1:25,000).

The structure used for the vario-scale approach is known as tGAP (topological Generalized Area Partition) (van Oosterom, 2005; van Oosterom et al., 2014). The principle of the tGAP structure can lead to smoother user interaction, for which the concept has been introduced by Meijers and van Oosterom (2011); van Oosterom and Meijers (2011). It allows a single real world feature to have a single database representation, by contrast with the discrete scales approach which not only has different representations, but these are often separately maintained.

As has been mentioned, our intention is to model the transition from one map scale to another as gradually as possible. That is why a single generalization action should run for small segments which change map as little as possible. We chose to perform this for segments of roads. If we chose even smaller segments more storage will be required with limited additional value for users. Later we apply remove/merge, collapse/split and simplification generalization operations for these segments, which can result in a road object composed from segments represented by lines and faces together, see Figure 2. From a cartographic point of view this is classified as less favourable but from a vario-scale point of view is a completely valid operation which occurs only temporarily (for time of transition) and gives better understanding to user.

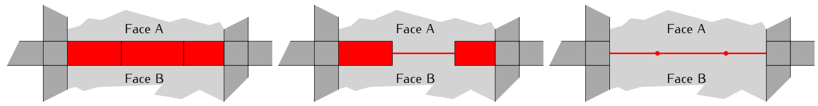


Fig. 2: Side effect of gradual transition from one scale to another (from the left to the right). For some reasons (may be different attributes; e.g. road surface type) the red road consists of 3 parts. To achieve the gradual transition the individual parts are generalization separately. It changes representation from areal on most detailed scale (in left) to semi-linear on 'halfway' scale (in the middle) to linear on final scale (in the right). Be aware of the fact that the road object in one moment of process is represented by areal and linear features at the same time. Note that one of the consequences is topological change, where *Face A* and *Face B* become adjacent.

3 Continuous generalization for roads modelled as areas

The number of elements involved in generalization operations differs from one object to a set of objects to a whole hierarchical class. We call this degree of selection the *granularity*. We distinguish three following levels of *granularity*, see Table 1:

- Global / coarse – The whole hierarchical class is generalized e.g. all highways or all provincial roads.
- Middle / medium – Only specific group of features are generalized, e.g. road consists of multiple parts and crosses multiple others (stroke[1]).
- Local / fine – Particular individual part, object or segment is selected e.g. road segment between two junctions, segment with a different speed limit or different geometrical / topological configuration (dead-end).

Table 1: Different types of granularity

Granularity type	Example	+	−
Coarse	hierarchy class / subclass	easy to read	content shocks, computationally expensive, complex problem
Medium	object feature level (instance)		
Fine	part / segments	as gradually as possible, easier compute, implicit history of steps, features links	can be disturbing

Table 1 shows positive and negative aspects for every type of granularity with respect to our designed goal for vario-scale maps. The pros and cons of the first and second rows are merged, because they are similar.

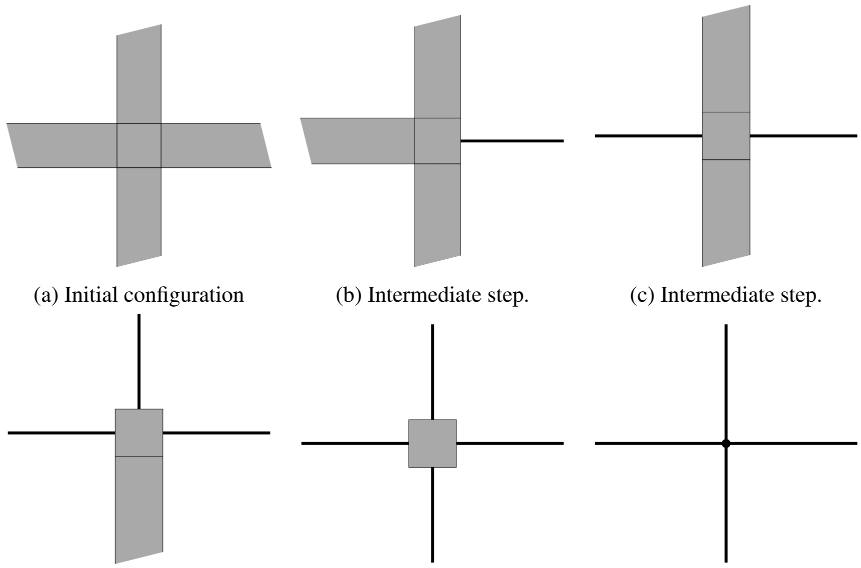
[1] The strokes approach groups road segments into bigger elements (longer lines) based on some criteria (e.g. angle between segments) Zhou and Li (2012); Li and Zhou (2012); Thomson and Richardson (1999).

Positive aspect for these types is legibility for a user, mainly because it is commonly applied and a well known solution so far. More practical, all roads of the same classification have identical representation on specific scale (throughout whole domain), which is easy for map reading (at this fixed scale). However when changing the scales, changing all roads (of certain type) from area to line (or vice versa depending on zoom in and out) causes a visual ‘shock’. Additionally, since multiple objects or classes influencing each other are involved in the process, the situation is complex (topology / geometry wise) and computational expensive. e.g. collapse of a complete highway network for producing a European base map.

On the other hand, processing data in small steps, part by part, gives an impression as gradually as possible to the user. He can observe, for instance, complicated road junctions collapse in a sequence of steps into the set or connecting lines which are replaced by a center point later. One can argue that this functionality can be disturbing for a user. Especially the situations when the road is represented by both types; the line and areal segment, see Figure 2. Nevertheless, this situation can be fixed by applying proper styling, when the line segments are represented by lines of same thickness equal to the width of the adjacent area object. Furthermore, the fact that the generalization process is preformed in smaller steps for small region of data at the time leads to simpler problems easier to compute or implemented. Moreover, some existing algorithms already perform a sequence of incremental steps, e.g. thinning of roads or computation with strokes (set of road segments where computation is done incrementally per segment). The only difference is that these methods only store the final result. Another advantage comes with the fact that the history of steps is stored explicitly and implies the links between generalized and original objects. To sum up, from our vario-scale approach perspective the third type of *granularity* is the most feasible. It fits the gradual way of thinking. In the future, usability tests should be conducted in order to have more scientific proof of human interaction, appreciation / behaviour / performance of work with the different scale transition approaches.

Granularity is one aspect of our approach but an obvious danger is that some overall recipe is missing. Figures 3 and 4 demonstrate some possible generalization sequences. From Figure 4 it is obvious that every action has to be in correct sequence to give the best possible impression at the end. Therefore we introduce a global strategy how to deal with large scale road network generalization.

Our initial assumption is to use just the well-known remove/merge and collapse/split operations. These should give enough options to achieve reasonable results. Additionally, we assume input data is represented as a space partition (no overlapping features and no gaps in the modelled domain) and stored in a topological data structure, which means that we have explicit nodes, edges and faces representing the map. Note that all features start as faces (road included). Another working assumption is that for the time being the whole domain is composed from two types of objects only; the roads and all other non-road features (both represented by areas). This will drop the number of superclasses in the dataset to two which makes decisions more obvious, easy and transparent. All other non-road features from the second category are just merged if possible (independent from which



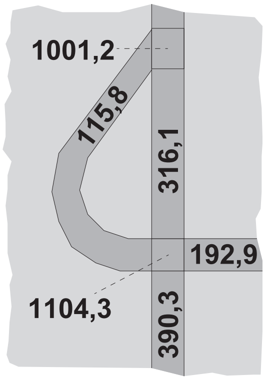
(a) Initial configuration (b) Intermediate step. (c) Intermediate step.

(d) Intermediate step. (e) Intermediate step. (f) Final result.

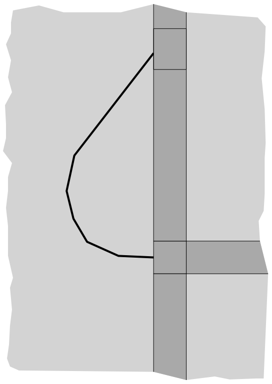
Fig. 3: Example of our new approach for simple crossing (all faces in the dark grey). All faces are equally important.

subclass they belong to). The road objects from the road superclass are classified into two subclasses; road junctions and road connections. The first subclass, road junctions, see Figure 5a, are simply adjacent to more than two other road areas. The second subclass, road connections, connects to two other road areas, see Figure 5b. Roads (junctions / connections) may be further classified, such as being part of highway, provincial road, local road, etcetera (using a known road hierarchy). Then every face / area feature in the structure gets importance value based on feature class (subclass) and size (area) of the feature. Based on importance value for every face, the process starts picking one face after another and performs specific actions based on the type. The face with the lowest importance value is processed first. The options for a selected face are the following:

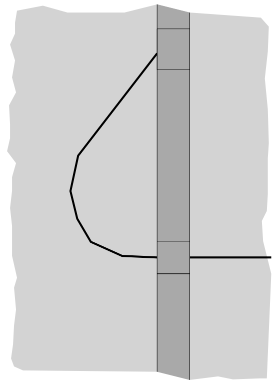
- The selected face is non-road area and will be merged with another adjacent non-road area, if there is any. If this is not possible, then the importance is raised and the face is put back in the queue.
- The selected face is road junction and will be preserved until all adjacent road connection are collapsed. If so, the face itself can be collapsed. If not, then the importance is raised and the face is put back in queue.
- The selected face is road connection and will be merged with the adjacent road connection. If there is no such a face then it is collapsed to a line feature.



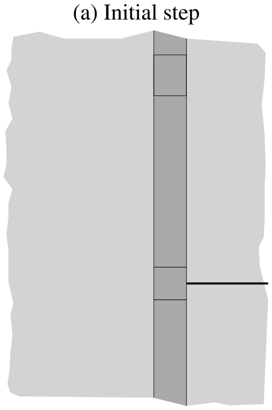
(a) Initial step



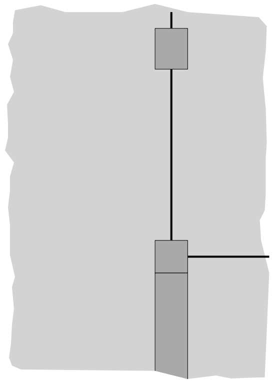
(b) The slip road collapsed.



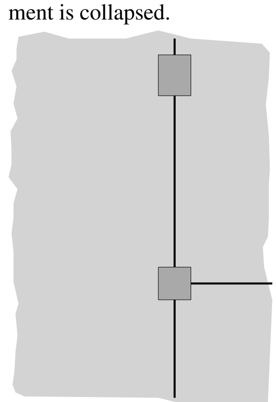
(c) Other lest important segment is collapsed.



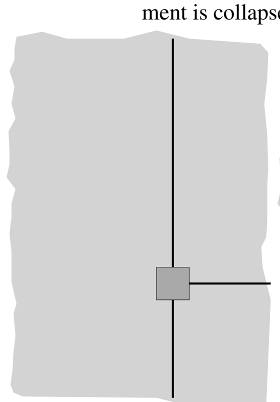
(d) The slip road is removed, because it lies between two merged faces.



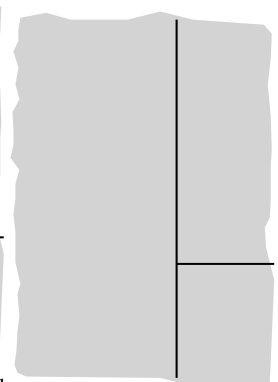
(e) Other lest important segment is collapsed.



(f) The faces defined as road junction should be removed the last.



(g) The faces defined as road junction should be removed the last.



(h) Targeted result of the transition.

Fig. 4: Example of our new approach for more complicated crossing, a highway with exit to provincial road (all road faces in the dark grey). We assume the road going from north to south (the highway) is the most important. The numbers in upper left Figure 4a indicate importance values for the roads features.

This continues for all faces of the dataset in the structure until all roads represented by areas are gone (only road lines exist). This simple recipe should guarantee that the roads can be generalized in a meaningful way for large scale.

An other issue is related to the fact that the simple delete / merge operation could be more advanced. Figure 6 shows two different option for better performance of merge operation. Either the grass in the middle is merged with both road neighbours into one or collapsed/spit (and parts assigned to both neighbours). Anyway both methods are completely valid and there is no reason to prefer any one of them. Therefore it would be necessary to involve some other criteria.

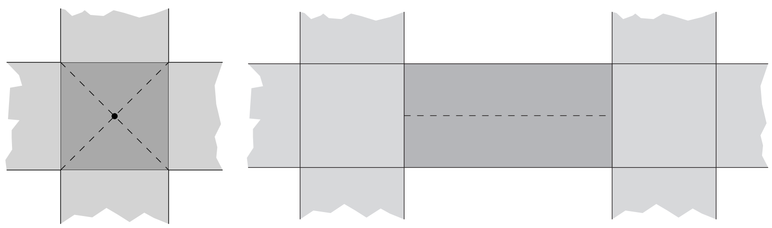
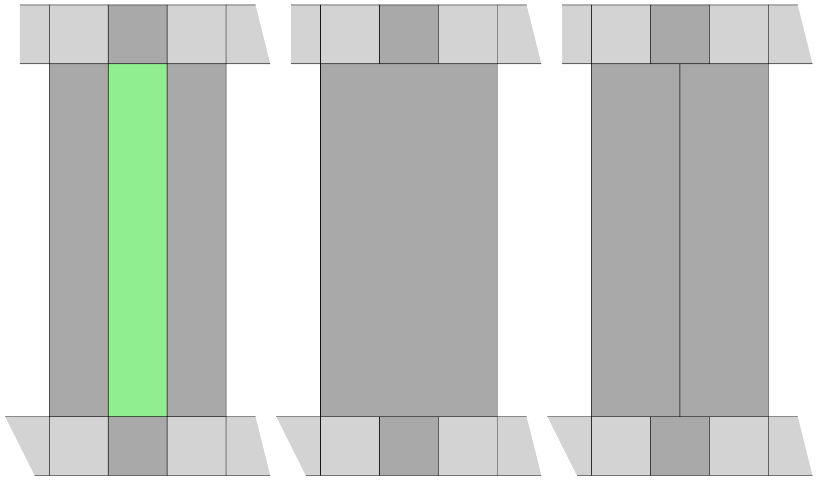


Fig. 5: The examples of two types of road area (in dark grey). The dashed line represents the 'optimized skeleton'.

4 Discussion

In this discussion paper we have presented our idea for upcoming research. We have suggested some possible scenarios and introduce some strategies and solutions. However there are still some open issue to be answered. Our other questions include:

- We assume part by part granularity as the best for vario-scale approach, but what would be the real gradual imprecision for a user? This would require some usability study / tests.
- With the currently implemented operation we can cover a large part of the generalization process for road network generalization. The main problem is not the performance and ability to represent / store the vario-scale structure, but steering the process in a good way. The automated decisions what to do in specific situation is hard to define.
- It is challenging to oversee all consequences of this new idea. Since there are more combinations possible, even the implementation of a simple operation like merge becomes less straightforward.
- Generalization of a dataset with class granularity the computations could be really complex and expensive and a bit similar to the complete road feature generalization, consisting of many parts, where must be done analyses beforehand



(a) Initial situation (b) Grass is merged. (c) Grass is split.

Fig. 6: The examples of two types of merge operation. The initial situation in left where the road faces (in dark grey) are separated by face of grass (in green). There are two possible scenario how to correctly generalize the grass area in the middle; First (in the middle) where the resulting road is merged original faces all together. Second (on the right), where the resulting roads are composed from two road faces with spitted part of the grass.

containing triangulation for such an application as well as finding clusters in the data. Would be possible to perform same result without complex analyses for part to part granularity?

Acknowledgement

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References

Brewer, C. A. and Buttenfield, B. P. (2007). Framing guidelines for multi-scale map design using databases at multiple resolutions. *Cartography and Geographic Information Science*, 34(1):3–15.

Li, Z. and Zhou, Q. (2012). Integration of linear and areal hierarchies for continuous multi-scale representation of road networks. *International Journal of Geographical Information Science*, 26(5):855–880.

Meijers, M. and van Oosterom, P. (2011). The space-scale cube: An integrated model for 2d polygonal areas and scale. In *28th Urban Data Management Symposium*, volume 38 of *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, pages 95–102.

Thomson, R. C. and Richardson, D. E. (1999). The 'good continuation' principle of perceptual organization applied to the generalization of road networks. In *Proceedings of the 19th International Cartographic Conference*, pages 1215–1225. Ottwawa.

Touya, G. and Girres, J.-F. (2013). ScaleMaster 2.0: a scalemaster extension to monitor automatic multi-scales generalizations. *Cartography and Geographic Information Science*, 40(3):192–200.

van Oosterom, P. (2005). Variable-scale topological data structures suitable for progressive data transfer: The gap-face tree and gap-edge forest. *Cartography and Geographic Information Science*, 32(11):331–346.

van Oosterom, P. and Meijers, M. (2011). Towards a true vario-scale structure supporting smooth-zoom. In *Proceedings of 14th ICA/ISPRS Workshop on Generalisation and Multiple Representation*, pages 1–19, Paris.

van Oosterom, P., Meijers, M., Stoter, J., and Šuba, R. (2014). *Abstracting Geographic Information in a Data Rich World: Methodologies and Applications of Map Generalisation*, volume 2014 of *Lecture Notes in Geoinformation and Cartography*, chapter Data Structures for Continuous Generalisation: tGAP and SSC, pages 83–118. Springer.

Zhou, Q. and Li, Z. (2012). A comparative study of various strategies to concatenate road segments into strokes for map generalization. *International Journal of Geographical Information Science*, 26(4):691–715.