

Content of Variable-scale Maps

PhD Research Proposal

Radan Šuba, MSc

GISt Report No. 64

January 2013

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Summary

This PhD research proposal focuses on vario-scale geo-information. Vario-scale is a new approach for creating maps offering an infinitely number of scales, minimum redundancy and a data structure for progressive transfer. A lot of knowledge has to be implemented in the generalization process to populate good quality vario-scale data. I will try to make a paradigm shift towards dynamic vario-scale geo-information. Some of the research topics are motivated by discussion with the Users Committee of the Technology Foundation STW.

The PhD research will be conducted as follows. Firstly of all, the motivation for this research and an overview of state-of-the-art technologies are presented. Secondly, the whole principle of vario-scale, the current status of research and the applications are described. Thirdly, open problems and new challenges are discussed.

The most important part is chapter 4 where the plan of the PhD research is described. In my PhD research, I will start exploring the whole process chain of creating and using vario-scale maps. Later on I will develop knowledge about different classes leading to an indication of improved generalization actions depending on the classes. For the improvement of the generalization model, including pattern recognition to enrich input data, generalization decisions or improvement of generalization operators are needed. After that, I will solve the problem how to deal with large data sets containing millions of records. Finally, the design and implementation of a more dynamic structure - where updating, changing, replacing or modifying is possible - will take place.

The last part of proposal focuses on practical issues such as appropriate data sets for research or financing and research output.

ISBN: 978-90-77029-38-1

ISSN: 1569-0245

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Chapter 1

Introduction

The research will focus on variable-scale (vario-scale for short) geographic vector information. It will explore current situations and problems. It will start with testing and assessing a current implemented vario-scale structure. The content of the PhD research will be extended with earlier research analyses and will identify limitations. It will also conduct and further develop the proposed structure based on several new ideas, e.g. higher generalization quality and dealing with large data sets. The goal of the research is to improve current vario-scale structures and to extend knowledge of vario-scale maps.

1.1 Motivation

For planning business or family trips paper maps were used in the past. Basically we needed two maps: one for planning the whole trip, the small scale map and the second more detailed one for finding the final destination, the large scale map. Not much has changed since those days. We have started to use digital maps at map portals on the internet instead of paper maps, but the principles remain the same. When we zoom in or out it is just like "switching" from one map to the other.

Everybody knows map portals like Google Maps, Microsoft Bing Maps and the recently, much discussed, Apple Maps. These "traditional" map portals and their maps look like the vario-scale maps, but they are not. Because they are based on a limited number of scales, we cannot choose variable-scale. These maps are only providing the feeling of vario-scale by supporting smooth zoom or other features. The other disadvantage of these maps lies in the fact, that every scale (layer) is stored separately in the database. This results in a lot of data redundancy and makes it also more difficult to keep the data up-to-date. Last but not least there exists a data transfer problem. The user receives more data than he actually needs.

However, if we would have a map with an almost infinite number of scales with minimum redundancy it would become possible to use this map for progressive data transfer from the server to the end-user. In that case we would have a better map than at any other time. Navigation and orientation would not only be clearer (Munzner, 2009), but with real smooth zooming it will also be faster (Midtbø and Nordvik, 2007). In addition improvement of consistency between scales raises data quality. Last but not least, if we are charged the volume of data which we receive through the internet, we would have to pay less for the usage of these maps.

1.2 State-of-the-art Technologies

Digital maps are still under development. The vector data on the internet have been very exceptional five years ago (Meijers, 2008), but the big technology jump has been made from this date on. Data are available in a vector format nowadays, moreover they are available online and updated. Smart phones and tablets have been developed. "Technology has simultaneously raised users expectations of the instant, tailored maps, delivered through any media and device and provided by the database technology needed to support the creation, integration and maintenance of data to support for such delivery" (Mackaness et al., 2007, p. 316).

We can mention again two well-known examples of the state-of-the-art technology: Google Maps and Apple Maps. The first one, world famous maps from Google, is a classical multi-scale representation map. About twenty different layers are included in the Google's map server, which is large number. When the user is zooming in or out there is a very fast switch from one layer to another. Unfortunately, everything is based on principles appropriate for raster data. The data stored by Google are stored as vector, but are transferred to raster for transition and sent to the user as images. All operations are done brute force on the server side and the user is just receiving the data. The transfer is fast, but features which offer vector data are basically eliminated.

The second one, a new version of Apple Maps, has been published recently. When Apple put the new version of maps on the market, a large discussion about content started. However, they also present the dramatic improvement of map visualization. The visualization is becoming more dynamic and the user is receiving the data in vector format. The maps are still multi representation, but the user has a feeling of gradual changes especially because of dynamic map labelling. The maps make higher demands on the client side of architecture, whereas the maps are especially developed for smart phones and tablets. It brings more computation power for visualization and other abilities, e.g. providing voice-guided directions, 3D models of buildings or up-to-date points of interested.

These examples show the state-of-the-art technologies and how progress has been made in the last few years. The development will be faster in the future (Farmer

and Pozdnoukhov, 2012). According to (Weibel and Burghardt, 2008) the automated generalization technique in real time (on-the-fly) will have priority. It will be intimately linked to highly interactive cartographic applications such as web mapping, mobile mapping and real-time decision support systems that involve multiple spatial scales.

There is a requirement of real-time map delivery. These mapping applications demand adaptation and personalization of the thematic map content to the given user query and context, which is needed to deal with. There are two existing approaches to the right direction: multiple representation database (MRDB) and hierarchical structures (vario-scale) (Weibel and Burghardt, 2008). These two approaches will be introduced later, but this thesis research mainly focuses on vario-scale.

Chapter 2

Related Works

Large amount of data are stored in databases. Data-sets are created for a sense of scales. The different map scales can be obtained and maintained by two main approaches which differ considerably. The first is the multiple representation approach (Mackaness et al., 2007), the second is the vario-scale approach (Meijers et al., 2012).

The remainder of this chapter is organised as follow: § 2.1 presents multiple representation databases and § 2.2 introduces vario-scale databases. In § 2.3 their main differences are described followed by the current status of vario-scale research in § 2.4 and § 2.5. Finally, one practical application of vario-scale will be discussed in § 2.6.

2.1 Multiple Representation Databases

The first approach is multiple representation maps or multiple representation databases (MRDBs). The name is derived from the database structure in which several representations of the same geographic entity or phenomenon, such as buildings or lakes, are stored as different objects in a database and linked to each other. A MRDB consists of various representation levels with different degrees of geometric or semantic abstraction providing a set of different views of the same object. The different representations are stored at different levels of detail. The utility and flexibility of MRDB lies in its ability to define different types of maps from the representation levels of a MRDB, using generalization methods (Mackaness et al., 2007).

Mackaness et al. (2007) point out that the benefits of a MRDB can be summarised as:

- data redundancy in one level is avoided since each object is stored only once;
- the links between objects at different representation levels can provide a basis for automatic consistency and error checking. Unfortunately, in most of the MRDBs these links are missing;

- the speed of information access can be quicker (for example, in mobile applications with low bandwidth an MRDB can be used to quickly access relevant information as the user zooms);
- MRDBs can be used for multi-scale analysis of geographical information, to compare data at different resolution levels, for example in route finding;
- it is possible to derive application-dependent generalized outputs needed for a variety of media (such as printed maps or map series, screen maps and on-the-fly maps for internet and mobile use).

Despite so many benefits, the maintenance, updating and redundancy of a stack of Level of Details (LoDs) in databases is still a major problem (Mackaness et al., 2007, p. 24, p. 178). Also, they are not suitable for progressive data transfer (van Oosterom, 2005). E.g: If the user zooms in receives new sets of data. Nevertheless the MRDB remains an active and important research area (Weibel and Burghardt, 2008) and there are lot of publication at present e.g.: (Mackaness et al., 2007, p. 177, Zhang, 2012). In addition, many public and private mapping organizations have large holdings of digitized maps at different scales. For this reason they are interested in linking these maps together so that updates can be propagated automatically from detailed to less detailed representations, allowing updates for maintenance (Weibel and Burghardt, 2008).

2.2 Vario-scale Databases

The second approach for obtaining and maintaining data-sets at different map scales is vario-scale (Meijers et al., 2012, Weibel and Burghardt, 2008). The vario-scale approach offers the possibility to derive a map at an arbitrary map scale. It is based on the vario-scale data structure. In this way the redundant data storage - typical for multiple representation using a stack of LoDs is avoided (Weibel and Burghardt, 2008).

Storage of vario-scale is based on data structures, quite often hierarchical. The most detailed data is stored once, and an incremental object by object generalization process is run and represented in a data structure, which can afterwards be used to efficiently obtain any arbitrary scale on the fly (Meijers et al., 2012).

The main advantages of vario-scale can be described as (van Oosterom, 2005):

- the minimal redundancy of data stored in the structure thanks to the tree structures;
- vario-scale maps are convenient for dynamic data transfer: The user is receiving only the data which really is demanded. E.g.: at first, the user receives the most

important data such as the perimeter of the state, then - when user zooms in - more detailed data such as the subdivision of the state is received;

- the vario-scale maps are also suitable for on-the-fly generalization in a web environment;
- vario-scale maps are also appropriate for dynamic zoom operations because their structures represent a 2D space plus a 1D scale as a 3D space partition.

The main disadvantage is that there is no solution in practice and sufficient experience these days. There exists a prototype, but it is still mainly an academic research topic. The next step for vario-scale research is to test it on practicality (Meijers et al., 2012).

2.3 Vario-scale vs Multiple Resolution / Representation Databases

Storing and maintaining the spatial data are a priority for both approaches. Both were designed for this purpose. However, implementations are different. The vario-scale approach is focused on object consistency, minimum redundancy, smooth zooming functionalities and data transfer. On the other hand the multiple representation approach is focused on maintaining maps at predefined fixed and independent map scales. That means that vario-scale ensures the lowest redundancy and the highest consistency among scales. On the contrary, the multiple representation approach keeps the redundancy under control in a discrete fashion (Meijers et al., 2012) and other redundancy can be managed by supporting links between layers.

The big question has been raised: Can the vario-scale approach replace the multi representation approach? Could a vario-scale approach be considered as a tool for automated generalization of topographic data? Meijers et al. (2012) try to find the answer for these questions and mention that the multiple representation approach of NMAs could be seen as an intermediate solution awaiting the successful ultimate vario-scale solution. The paper also shows that the specific application areas are different and can be used to solve certain parts of the generalization process of topographic maps. So far the vario-scale solution by itself is not suitable to solve all the issues of multi-representation maps.

Further research is needed. A lot of cartographic knowledge has to be implemented in the generalization process to populate good quality vario-scale data structure (Meijers et al., 2012). However, there are some problematic issues, such as how to deal with large data sets or updates of the structure, which will be discussed more detail in Chapter 3 and 4.

2.4 Current Status of Research

Nowadays there exists a true vario-scale data structure called tGAP (topological Generalized Area Partition) (van Oosterom, 1995, 2005, Meijers, 2011). The structure is based on the creation of a structure. In the beginning we have the most detailed level including all features (largest scale). Next the least important object based on classification and geometry (size) is selected, and then merged with its most compatible neighbour based on class compatibility and geometry (topology). This is repeated until only a single object remains. The merging process is recorded into the tGAP tree structure. The last 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 the required level in the tree, see Figure 2.1. Geometry of the objects is stored only in the most detailed level, all other objects (created by merging) are only links to the part of the object in the more detailed level. The redundancy of structure is minimal because no new geometry is created.

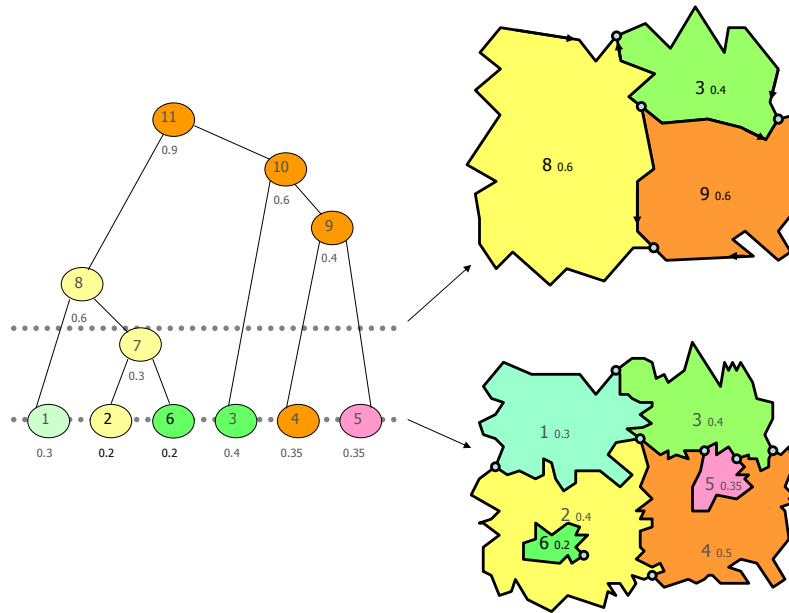


Figure 2.1: The principle of the tGAP structure: the objects are aggregated, based on importance value and data can be visualized at any arbitrary level (taken from (Meijers et al., 2012)).

In recent years the tGAP structure was further developed. The constrained tGAP (Haunert et al., 2009) was proposed: The way how to reach results of integrating large- and medium-scale data into a unified data structure to improve cartographic quality.

As last improvement the structure was extended for other generalization operators: The collapse/split (Ai and van Oosterom, 2002) which is assigned to parts of the object based on its skeleton and topologically-safe line simplification that simplifies the boundaries of faces (Meijers, 2011).

2.5 Smooth tGAP

The idea of the tGAP structure has been developed even further. The concept of the smooth tGAP structure exists (van Oosterom and Meijers, 2012). It is presented as a space-scale partition, which is termed the Space-Scale Cube (SSC), see Figure 2.2. Figure 2.2a gives an idea how map generalization is represented via extrusion of data into an additional dimension. The scale is taken as an additional dimension. The resulting vario-scale representation for 2D map objects is a 3D structure. The 2D area object is now represented as a 3D volume. However, despite the 3D representation in the tGAP structure, there still remain a large amount of discrete steps. A split and merge operation can still cause a sudden local "shock". A small change of scale does not result in a small change of geometry. It is even possible that some features disappear. This cannot happen in the Space-Scale Cube of the smooth tGAP, see Figure 2.2b. All actions with geometry must lead to a smooth SSC. If we make a smooth shift of slicing (horizontal slices) from the top of the cube downwards, an object will not suddenly appear or vanish. All changes are smooth. A small change of scale means a small change of geometry.

2.6 Mixed-scale Map

Only the horizontal slice parallel to the bottom and top of the cube has been presented until now. In that case the result of horizontal slicing is a map with a homogeneous scale, but in principle it is possible to take non-horizontal slices, see Figure 2.3. The result will be a mixed-scale map where most detailed objects, from the bottom of the SSC, will be combined with less detailed objects from the top of the SSC. It can be used, for instance, in navigation, where a user receives detailed information close to his position and less detailed information farther away from him. In addition, the mixed-scale map can be created by slicing with a non-planar plane, e.g.: a surface of a cone or a bellshape surface. The mixed-scale map gives us an example of the application of vario-scale, which can be further explored and develop in the future.

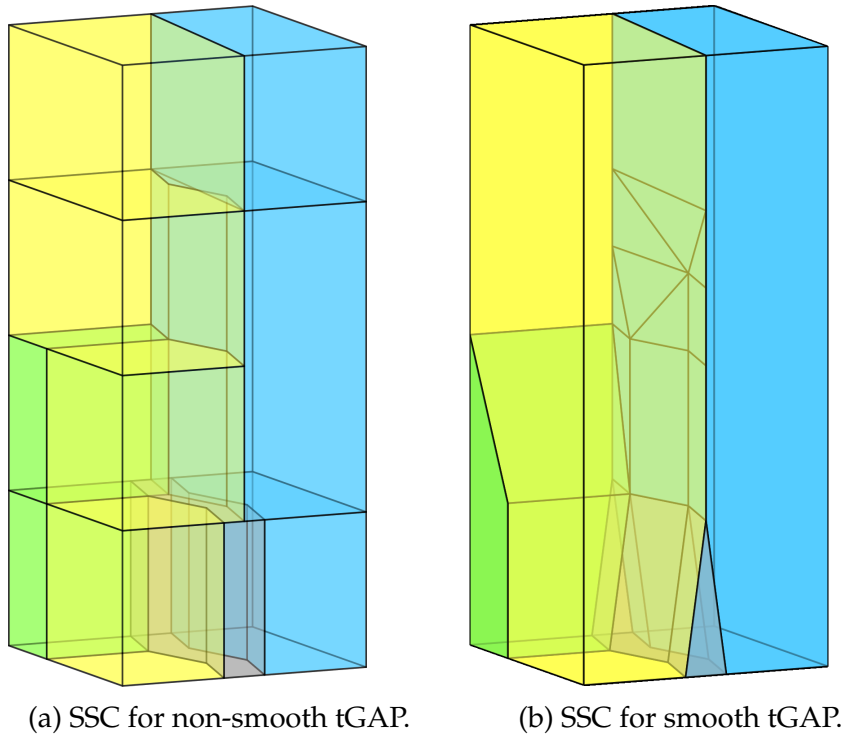


Figure 2.2: Space-Scale Cube (Meijers, 2011).

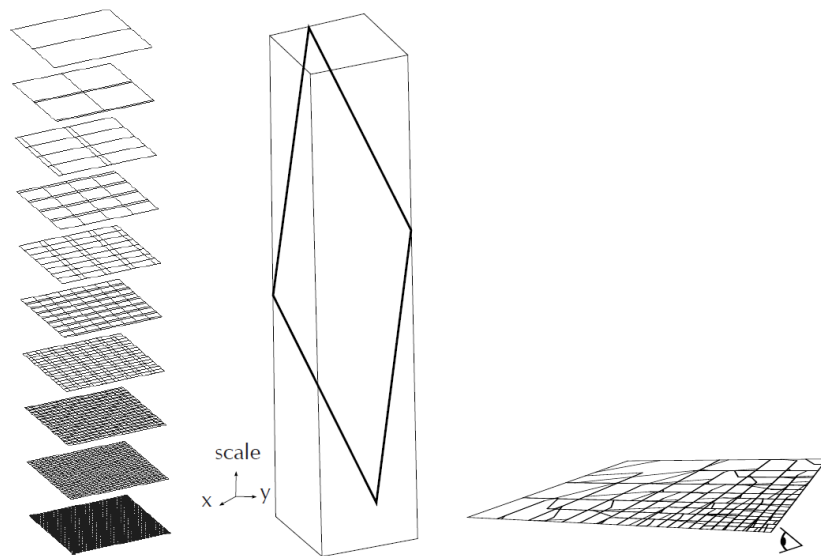


Figure 2.3: A mixed-scale map of the non-smooth tGAP structure (van Oosterom and Meijers, 2012). A stack of horizontal slices (on the left); a non-horizontal slice (in the middle); and a mixed-scale map (on the right).

Chapter 3

Research Questions

The research should bring new ideas, improvements, implementations, testing with real data and assessment in the field of vario-scale. The general aim which I work towards is "How can we realize a paradigm shift towards dynamic vario-scale geo-information with minimal redundancy, supporting the delivery of representations at an arbitrary scale for different user contexts and progressive transfer for the delivery of refinements?" This research question is too general and needs to be refined for the PhD research. Below a list of open problems (which comes mostly from (van Oosterom and Meijers, 2012, Meijers et al., 2012, Meijers, 2011)):

1. It will be necessary to verify theoretical knowledge about SSC more practically. Further to test whether it is necessary to create and store SSC as a 3D structure or is it possible to work with only the 2D representation?
2. Explore new possibilities of creating maps by slicing. It should be possible to create a map with a slice, which is not even horizontal. It would lead to a "mixed-scale" map.
3. The current structure only explicitly supports area features. Line and point features are not yet included explicitly in the storage structure. However these type of objects are produced during the creation of the tGAP structure. The collapse process is a good example. When the long feature is collapsed to a skeleton it changes dimension, e.g.: from dimension 2 to dimension 1, from an area feature to a line. It is convenient to store information about the collapsed feature. The explicit dealing with points and lines should be part of the structure in the future.
4. Labels are an important part of maps, but are not included in the structure. Objects in the map need a label and every label in the map takes space. It is a classical cartographic problem: each object that has to be labelled allows a

number of positions where the corresponding label can be placed. However, each of these label candidates could intersect with label candidates of other objects. It is possible to find the right solution for just one predefined selected scale, but how can we find the right solution for the variable-scale?

5. Larger real world data sets should be tested (to further assess the potential of vario-scale maps). How should we deal with millions of records? This huge amount of data does not fit into the memory. It could be split in smaller parts. After that every part has to be computed separately and in the end these have to be merged together. How to make the whole process manageable?
6. One merge operation at the same time is supported in the structure. More generalization actions could run at the same time. E.g.: a parallel merging process could be an improvement with objects involved at different locations.
7. Make the structure more dynamic. The current tGAP structure is a static one. It cannot handle change of data. If a small change of data takes place in the structure, the whole structure has to be recomputed.
8. Consider the thematic semantic aspect better, because the selection of an object is based on area and class of object. It deals the same with all objects. There is no approach that would take into account the feature type of the objects, e.g.: linear or areal.

These open questions give us an idea what the PhD research will be about. However, the amount of problems which I will have to face is quite large and the research time is limited. The original vario-scale research project (§ 5.1), discussion with the STW Users Committee (§ 5.1), a logic order and urgency in the vario-scale research were reasons why only some of the problems have been chosen and have been used for defining the main research parts as discussed in chapter 4.

It is also important to say what is not in my scope of the research. Some of the problems have been eliminated based on reasons presented above, the current status of research (e.g.: the structure is not ready for it), they do not fit into scope of the research or more important things have to be done first (e.g.: the content of map has to be improved before visualization). The problems which I will not deal with are:

- improving data transfer from the server to the end-user and tuning the progressive transfer on demand;
- developing an appropriate visualization technique to test graphical user interfaces supporting smooth zoom visualization;
- exploring and improving the application and usability of vario-scale approaches to test end-user behaviour with the vario-scale map;

- including labels of objects in the presentation;
- supporting 3D input data;
- supporting classification change during scale change. The idea of vario-scale as a "delta scale, delta map" applies to the geographic feature, the same applies to the object re-classification.

Chapter 4

Research Plan

The research is planned to run for four years. Therefore this period is divided into smaller parts, blocks. Figure 4.1 gives an overview of the research. Although every block has been designed separately, the blocks are connected and together they create the whole research. The blocks of research are: Setting the Environment, Experiment and Testing, Better Generalization Results based on the Classes, More Advanced Generalization Process, Large Data set and Data Update. Every block is presented below. The remaining blocks without detailed information are PhD plan and Writing PhD thesis, which do not need a description.

2012			2013			2014			2015			2016											
1 st Semester			2 nd Semester			1 st Semester			2 nd Semester			1 st Semester			2 nd Semester								
September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August
PhD plan	4.1.1 Setting the Environment	4.3 Better Generalization Results based on the Classes					4.1.3 Testing	4.2 Reflection	4.5 Large Data set					4.1.3 Testing	4.2 Reflection	Writing PhD Thesis							
	4.1.2 Experiment	4.4 More Advanced Generalization Process					4.1.3 Testing	4.2 Reflection	4.6 Data Update					4.1.3 Testing	4.2 Reflection								
	4.1.3 Testing											4.1.3 Testing	4.2 Reflection										

Figure 4.1: Timetable of the research.

4.1 Setting the Environment, Experiment and Testing

This is the first period (block) of the research. I will explore and implement the whole process chain of creating vario-scale maps. I will develop the whole process chain

from input data and creating the tGAP structure until creating a 3D representation and using this for 2D visualizing the results. This block takes place during the period December-March. The functionality will be a priority and less focus will be given to the cartographic quality or performance. This initial result and experiment will be used as a starting point of the research, which will be improved in the future. The initial implementation should include the use of a database.

The result of the initial stage of the research will be: an initial structure, a code for loading data, a tool for visualization of the results, timings and statistics, information about the quality of the results and a list of most significant problems and possible improvements. Results can be used for a presentation at the STW Users Committee Meeting, see § 5.1.

4.1.1 Setting the Environment

Setting the environment will be an important initial step. As van Oosterom and Meijers (2012) pointed out the interface supporting smooth zoom visualization is still missing. I will explore potential tools and software which could be used, see § 5.9 and I will try to find the visualization environment for smooth tGAP, which could be used for debugging, tuning or visualization of mixed scales. It will explore suggested possibilities (as described in § 5.9) and I will choose the best one or combinations of them for more convenient development in the future.

4.1.2 Experiment

This block will focus on getting a feeling for the whole process. In particular I pay attention to the transition from the classic tGAP structure to a smooth representation, where horizontal faces do not exist. I will propose some approaches and demonstrate them with some examples.

The gradual transition between scales gives better orientation for users (Midtbø and Nordvik, 2007). The user can simply follow the objects of interest. A good gradual transition can be realized by a merge operation or simplification in the smooth tGAP structure. During improper transitions into the smooth tGAP structure some objects could be deformed or misrepresented and the resulting map (slice of the smooth tGAP representation) might become chaotic. E.g.: a simple object can be represented by many parts of the same object (multi-parts). If multi-parts exist it is still possible to read the map, but it is more difficult. For these reasons our intention will be to represent every face in one piece and avoid multi-parts when the input was a simple object.

The merge operation in smooth tGAP should be presented as a tilted face. For simple convex faces it is possible to use a single flat plane as a tilted face. Figure 4.2 shows an example: the red object is the least important face and merges with

the blue object which takes over the space. The tilted plane is defined by the shared boundary and the furthest point from the shared boundary which is the point of the least important object.

When a shared boundary is not a straight line (see Figure 4.3a) or a shared boundary has multiple parts (see Figure 4.3b) then there will be some challenge. In the first case, despite being a direct neighbour point/area for a while nothing changes here (while other direct neighbour areas are already in transition). In the second case, two possible orientations of tilted faces exist (yellow and green arrows). The object that has to be removed can still be represented as a single plane. However, the orientation of this face will be another problem which has to be solved.

Figure 4.2b represents an example of the introduction of multi-parts. If we make a horizontal slice in the middle of the volumes we will receive two fragments of the blue object instead of one. The single plane is not optimal for these non-complex faces. Making segments of the least important area and creating a tilted face for every segment could be a solution. The triangulation of an object could be used for segmentation.

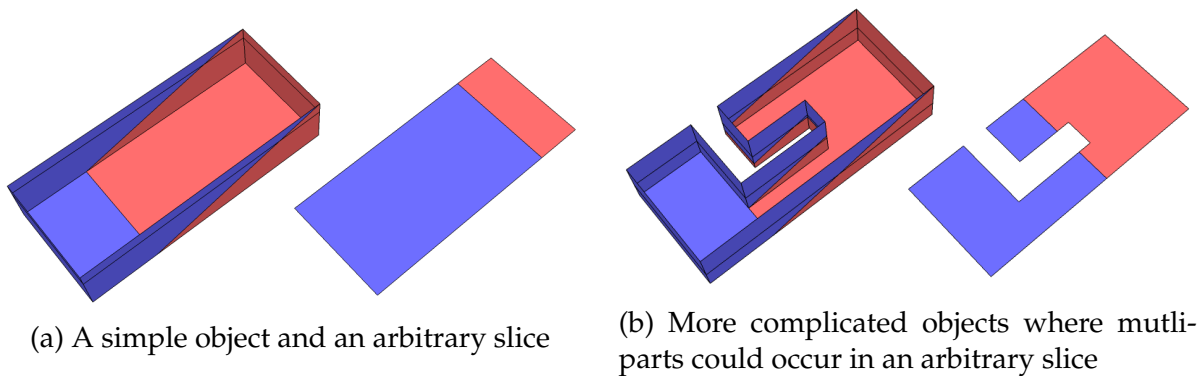
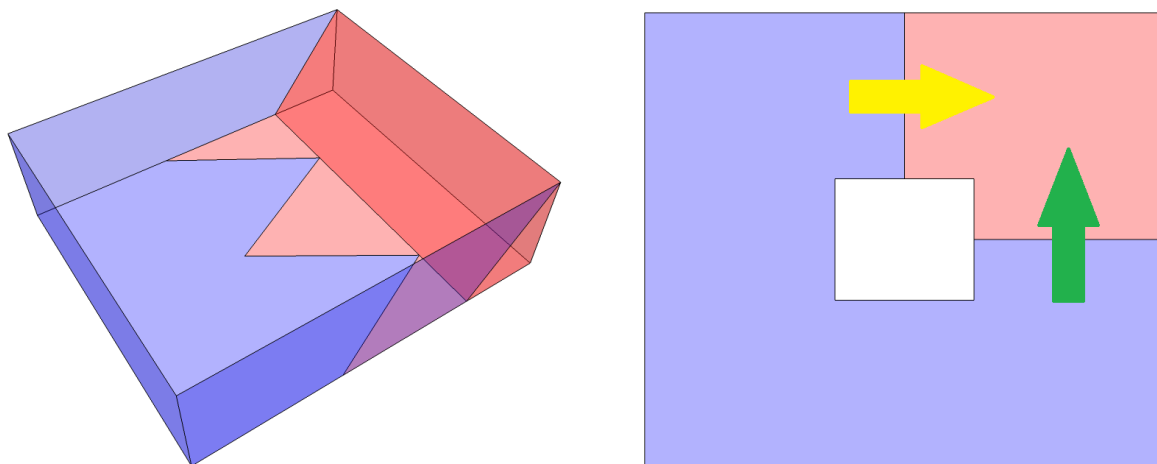


Figure 4.2: The process of merging in smooth tGAP

These are initial ideas of transition between the classic tGAP structure and smooth tGAP. On the one hand the advantages of single flat plane are that the remaining area object grows with constant speed and that computation of tilted face is easy. On the other hand it cannot be used very well for not-convex objects and more complex implementations. The general solution for every face needs to be developed. These ideas will be continuously explored further in future research.

4.1.3 Testing

On the base of suggestions made in the Users Committee Meeting, see § 5.1, it has been decided that it is important to include some evaluation and testing with real data into the research. The testing could give evidence that results of research are as good as we



(a) The object without a straight line as a shared boundary

(b) The object with two possible orientations of tilted plane

Figure 4.3: The process of merging in smooth tGAP.

hope. It also brings motivation and/or new questions for future research. E.g.: we can measure how fast the implementation is and try to improve its speed.

There will be five testing blocks, that is, one after each iteration of the research and associated vario-scale prototypes. The improvement of the maps will be subject of first testing. The result of first testing will be focused on solving three most urgent problems in generalization. It will give an indication for the next research blocks, especially for the "Better Generalization Results based on the Classes" block. The content of other testing blocks will be evaluated by the previous research blocks and brings starting points for the next one. This is the reason why every testing block takes place behind every block of research.

4.2 Reflection

The first year is planned relatively detailed. The remaining part of the research is not so explicit defined for a number of reasons. Firstly, nobody can say right now what the status of the research will be the coming years. Secondly, new challenges and problems which have to be solved may occur. Thirdly, it is important to check if the research still follow the predefined problems and goals. For the above mentioned reasons this reconsideration phase (not the same as the other five real research blocks) is included in the plan. At that time the evaluation of the previous and future research should take place and/or order of the blocks can change. I will stick to the plan as much as I

can, but slight modification of the plan for the remaining part of the research should be possible.

4.3 Better Generalization Results based on the Classes

The main goal of this block will be to use object/thematic knowledge, which is already explicitly available, to get better generalization results. It means dealing with classes which are already available in data sets and not to create new ones.

In the multi-representation approach the map object changes through scales such as switching the classification or changing a dimension. For instance, a set of buildings and gardens creates a block of buildings or an area object of a river collapses into the line feature. While in the multiple-representation approach the "place of change", in which scale the change has been taken, is irrelevant and every scale contains just a predefined type of classes, in vario-scale this information is crucial. We still have to keep in mind the principle of vario-scale where objects are gradually changing but not suddenly appear. On the other hand the definition of gradual appearing in smooth transition can be a real problem especially for classes. For instance, where do buildings become blocks of building? Furthermore, the new appearing class, e.g. farmland, is basically wrong from the vario-scale point of view. All classes should be present in the entire generalization process. In contrast to this, vario-scale gives us an extra advantage making it possible to define the composition of less detailed objects in an easy way. All predecessors of the object are stored in the tree structure and we can easily get them.

As mentioned in Chapter 2, the initial generalization approach for tGAP has been developed. The most important face is merging with the most compatible one. Unfortunately, the resulting map was not sufficient. The other approach comes with the constrained tGAP (Haunert et al., 2009). Haunert et al. (2009) presents the process of generalization based on using existing medium scale data (1:10 000) as a constraint. All generalization actions try to reach this constraint and the final generalized product is a same representation as referenced medium scale. Also, this approach is working with classes of objects. The constraint medium scale is a limitation of the whole process and together with the classification of objects there are aspects which I would like to improve.

A clue how to improve the generalization process is given by (van Smaalen, 2003): concentrating on non-graphic operations and large generalization steps, i.e. big scale changes. Whereas most existing methods work towards a clear end result, this approach does not. Instead, it is entirely based on the input data. Minimizing generalization errors has priority and assessment of the generalization results are also an issue to consider. The goal of the paper was to develop a system for the generalization of

object- and vector-based categorical maps, such as large-scale topographic data (van Smaalen, 2003).

In addition, the principle of generalization using the tGAP structure is based on the uniform solution for every object in the data set where all classes are processed in the same way. For better generalization results most likely a non-uniform solution where different classes will be processed in a different manner, e.g. linear / infrastructure features, buildings / constructions, other areal features (terrain, water coverage), will be chosen.

The first step of this research will be an experiment with feature classes of various scale objects. The feature type, such as a linear or a areal, can cover every object in the data set. E.g.: the area object representing a road is a linear feature type. The forest is an areal feature type. This makes it possible to deal with each main feature type in different ways. The result of the experiments should be the detection how far we can get with this approach (same classification / legend for all scales) respectively how far the map is still meaningful for reader. Later experiments will be more complex and complicated.

The result of this research block is a recipe which can be used in the process of creating the tGAP and reach better cartographic solutions for the final map generalization. However, it is not sufficient because we did not take spatial more complex patterns about objects into account. Therefore in the next subsection I will discuss how the knowledge of classes and patterns can be used to improve the generalization process.

4.4 More Advanced Generalization Process

I would like to improve the model of generalization with respect to spatial configuration. The spatial configuration and relations among objects play a significant role, e.g. buildings which are standing in row should be displaced together. If we want a good generalization result we will have to include this information of data into the process. However, the object/thematic knowledge still plays a significant role and it should be also included. E.g.: for objects detection standing in the row would be used only the class of buildings.

Two main approaches for generalization of multi-representation maps exist. The first is based on principle where the most detailed data set is used as input for the process to generate all levels of details. Although each single data set is well generalized, the obtained sequence of data sets does not conform to the idea of gradual refinement, for example, a line boundary that appears at a smaller scale may not be present at a larger scale (Haunert et al., 2009). The second is known as an agent based approach which is based on the "satisfying the conditions" (Lamy et al., 1999). For instance, the process of merging is going on until only one face remains. The tGAP structure is more

similar to the second approach. We have a set of generalization operators and each of them has conditions which has to be "satisfied" for reaching the result.

These operators currently work with one pair of objects at the same time. E.g.: one area object merges with an other area object, in spite of the fact that area objects touching each other could be processed together. For instance, we can extend a previous example of the buildings which are standing in row. Every building has touching area objects representing its sheds. Firstly the buildings should be merged with their sheds, secondly the row of buildings should be displaced together. However, this enrichment of source data in automatic generalization is difficult and bad recognition could affect the whole generalization result.

From these difficulties the process of creating map generalization can be divided into three steps:

1. data enrichment;
2. including new / more generalization operators;
3. including in the smooth tGAP / SSC structure.

The first step, to enhance knowledge about source data, should obtain the recognition of final objects in the large-scale map, like the recognition of buildings standing in the row or other patterns (Zhang, 2012). Based on this recognition we could select the appropriate generalization operations in step two and finally, the all processes take the action in step three. On the other hand, new questions came up with this three-step-process:

- firstly, when should we use the reached data from step one? Either we can use them for pre-processing or we can use them during the process;
- secondly, can we arrange parallel generalization? For instance, all area objects of sheds are merging, but other faces in the remaining part of the data set are still waiting for processing. It would be more suitable to display the data afterwards. The user has the feeling that the generalization process takes place at multiple locations (north and south are treated in parallel and do not wait for each other);
- thirdly, how can we use classification enriched knowledge as mentioned in § 4.3 for each class? The buildings, linear features (roads) and other objects (forests, fields), for example, would be processed separately with a different generalization operator.

Also, the new generalization operators or the entity could be included in the process, such as the area object of a road become a line, but attributes about a road should stay with the object (not implemented yet). Finally, all these improvements should bring better generalization results than before.

4.5 Large Data set

In van Oosterom (2005), Meijers (2011), van Oosterom and Meijers (2012), Meijers et al. (2012) mentioned that dealing with large data sets containing millions of records is a real problem. The large data set does not fit into the computer main memory. There are two aspects which we have to face. The first is the limitation of hardware, e.g. how big the memory is. The second is topology correctness of the data, e.g. if we split the data set into smaller pieces, the data on the borders still have to fit together. I will try to deal with these problems in this section.

Firstly, the large data set must be stored somewhere, but it must be processed somewhere else. The strategy for dealing with this would be to reduce the size of data to load from the disk, region-of-interest extraction. We must ensure that the amount of data to be loaded for each time step remains reasonably small (Dussel et al., 2009).

Secondly, if we cut data into smaller pieces and process them separately, we still have to deal with relations among the data. We have to consider the neighbouring faces if there are any. E.g.: one part of the huge data set has been selected and processed separately, but neighbours of a face at the border of the chunks are still relevant, because it can affect the result of generalization.

In addition, the merging process could be speed up if we merge faces on different places at the same times on the multiple CPUs. The merging process can run in parallel. These questions and challenges would be necessary to explore and to deal with.

4.6 Data Update

The last block at the plan is data update. The block is last because the knowledge received in previous years will be applied here (especially handling large data sets in parts). The updating, changing, replacing or modification will be content of this block.

The geometry of all objects are stored just once in the tGAP structure on the most detailed level. The modification part of data should be done only on this level. Currently, the whole process of creating the tGAP structure has to be recomputed. The change of only a particular area without recomputing and recreating structures of the whole data set again as it have been mentioned in (van Oosterom, 2005) will be my objective in this block. The data update is also required by the STW Users Committee Meeting (§ 5.1).

We should still keep in mind the idea of the vario-scale structure. Every object is merged and it is a predecessor of the other object. It means that every object is a node of the tree structure and has a relationship with other nodes. The data update is related to a walk from graph theory. The update would be the walk through the tree structure and/or replacing a part of the structure. If we are changing the areas where we want to modify, we are changing the part of the tree. From that perspective the local or global

effects need to be considered. It is necessary to consider how large the modification of tree has to be done. The computation difficulty grows with the size of the modification.

Another complication comes with the principle of the smooth tGAP, where every object on the map is represented as a 3D volume in the SSC cube mentioned in Chapter 2. The horizontal faces should not exist and objects are defined as a polyhedral volume. On the one hand it will be easier to see what is related in 3D space and making definitions of the objects that should be modified will be easier. On the other hand filling the gap with new objects in 3D can be more complicated. E.g.: one object replaces two objects. The new object must still fit into the SSC cube and its polyhedron must be the same as the previous two polyhedrons together.

That are dilemmas which I will have to solve, but the main dilemma is a spread of update. How far will the change be acceptable? The update of data without limitation can involve all data in the data set and can cause collapse of efficiency. The definition of spread will be crucial.

Chapter 5

Practical Issues

The research related topics have been discussed so far. This chapter focuses on practical research issues. It starts with the description of the project of which this research is part of. In § 5.2 and § 5.3 information about supervision as well as tools for monitoring of the research are given, followed by the education part that is included in this research project. § 5.5 presents the potential research visits. Deliverables, conferences and journals are described in § 5.6, 5.7 and 5.8 followed by § 5.9 about tools which can be used. The chapter concludes with a data set selection for this research.

5.1 Project

The research is part of the bigger project. This project is called "Vario-scale geo-information" (project code 11185) and it is funded by the Technology Foundation STW. The research objectives fit within the definition of this project.

The aim of the Technology Foundation STW is to realise knowledge transfer between technical sciences and users. To this end, STW brings researchers and (potential) user together. The instrument par excellence in this respect is the user committee which is also the primary valorisation instrument. The user committee meets twice a year and gives feedback (reflection on the research results and suggestion for further direction of the research). The members of the committee are Dutch geographic data producers: Kadaster, RWS-CIV and the municipalities of Amsterdam, Rotterdam and Den Haag and Geo-ICT industry: Bentley System Europe B.V., ESRI Nederland B.V., 1Spatial Group Ltd., Oracle and TomTom.

The "5D data modelling: full time integration of 2D/3D space, time and scale dimension" project (project code 11300) is closely related to this research. The nD data modelling approach, which is also studied within the GIS Technology Section will lay a foundation for higher dimensional modelling in GIS. This new way of spatial data modelling will enable full integration of the separate dimensional aspects of GIS.

The resulting multidimensional partitioning will contain a highly formal definition of the dimensional concepts of geo-data allowing optimal flexibility to define specific semantics for each feature type and each dimension separately. For example these ideas are presented in (Stoter et al., 2012). It will also involve the work of Jantien Stoter, Hugo Ledoux, Ken Arroyo Ohori and Filip Biljecki. The project is very related to the vario-scale project and cooperation will be useful during the research.

5.2 Supervision

The supervisor of this PhD research is prof.dr. P.J.M. van Oosterom. The coach is dr. B.M. Meijers. During a so-called "Progress Meeting" I meet my supervisor and coach every two weeks. Every meeting problems and questions with respect to the on-going research are discussed. After every meeting the PhD researcher creates an overview from the meeting. Topics and problems, which have been discussed, tasks, which will be relevant are included in this overview. Before every Progress Meeting an agenda is prepared by PhD researcher. The agenda contains tasks dealt with by the PhD researcher and open questions or topics, which the PhD researcher would like to discuss. In case of problems the first contact person is the coach.

5.3 Monitoring tools

The development during the research must be monitored and recorded. There are four main tools for monitoring: two weekly Progress Monitoring, Doctoral Monitoring Application, twice a year the Result and Development Cycle and twice a year the STW Users Committee Meeting. Each from these four is provided for different reason.

- Progress Monitoring - Reporting of my research results every two weeks. This clarifies the progress of my research. My supervisor and coach get an overview of the research situation and they can intervene if necessary. I get regular feedback and new suggestion for next steps. Results from regular meetings will be used as a source for annuals reports.
- Doctoral Monitoring Application (DMA) concerning tracing training and courses for Doctoral Education organised by the Graduate School Delft University of Technology. The arrangements (contact frequency with daily coach, educational tasks) are also recorded. It is made during a period of 3, 6, 9-15, 24 and 36 months. The Graduate School, the supervisor and the coach benefit from it.
- Result and Development cycle (R&D cycle) concerning Annual Agreements. It is a more official agreement among me, as an employee, and my assessors. Me, the supervisor and Human Resources make use of it.

- STW Users Committee Meeting organized for transfer of knowledge. It gives an opportunity to "users" to keep track of the research and to be informed of its results. This is a platform for exchanging information, contributing to the research and making suggestions for the further direction of the research. For the researchers, participation is important, partly because they can identify which developments are commercially interesting and how the results can be applied in a product or industrial process. Furthermore, researchers have the opportunity to familiarise themselves with industry and everyone from the committee have a usage from that.

5.4 Education

The necessary conditions for the PhD requirements are defined by the Graduate School (GS). The PhD researcher must finish at least 45 Graduate School credits (GS) in three categories over four years:

- discipline-related skills (a minimal of 15 GS credits);
- transferable skills (a minimal of 15 GS credits);
- research skills called as "Learning on-the-Job Activities" (a minimal of 15 GS credits).

The research requires multidisciplinary knowledge and skills. English writing skills, software developing and computer geometry are the main ones. Figure 5.1 shows an overview. During the study I will follow English courses for improving English. The Data visualization course and the Geometric algorithms course will be attended for improving knowledge related to the research. A programming course will not be attended. Programming skill will be learned on-the-job.

The Data visualization course and the Geometric algorithms will be included into the discipline-related skills category. Mandatory courses, The PhD StartUP and Preparing the Next Step in your Career, from GS will be included into transferable skills. The English courses will be there too.

5.5 Research visit

The research focuses on new ideas and/or further development of existing ones. A research visit can be useful to develop a new idea or to get a different perspective on existing technology. Sometimes it is very useful to change environment or to discuss the research with new people. New ideas or just comparison with situations somewhere

		2012							2013							2014							2015							2016							
		1 st Semester				2 nd Semester			1 st Semester				2 nd Semester			1 st Semester				2 nd Semester			1 st Semester				2 nd Semester										
		September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August
Training & Self-study																																					
Discipline-related skills																																					
IN4086 Data visualization*	6																																				
Geometric algorithms - Utrecht*	7,5																																				
Research visits	?																																				
Conferences and papers:																																					
0 th paper (extended abstract for GIN symposium)	?																																				
GIN Symposium	?																																				
PhD proposal	?																																				
16th AGILE(14-17 May 2013) - Full papers: November 9, 2012	?																																				
29TH URBAN DATA MANAGEMENT SYMPOSIUM(29-31 May)	?																																				
1 st conference paper	?																																				
2 nd conference paper	?																																				
AutoCarto 2014, USA	?																																				
16th ICA Generalization Workshop	?																																				
3 rd conference paper	?																																				
ICA ICC, Brazil, Rio de Janeiro (23–28 August 2015)	?																																				
4 th conference paper	?																																				
1 st journal article	?																																				
2 nd journal article	?																																				
C5.M2 Writing a dissertation	3																																				
PhD theses																																					
subtotal (a minimal of 15 GS credits)	16,5																																				
Transferable skills																																					
PhD Start-up - mandatory	3																																				
C10.M1 Career Development - Preparing the Next Step in your Career	1																																				
C11.M3 English for academic purpose (EAP-2)	3																																				
C11.M4 English for academic purpose (EAP-3)	3																																				
C11.M6 Pronunciation	3																																				
C11.M5 English for academic purpose (EAP-4)	3																																				
option:																																					
C11.M7 Spoken English for Technologists-1	3																																				
C11.M8 Spoken English for Technologists-2	3																																				
subtotal (a maximum of 4 GS credits via language courses)	4																																				
Dutch course (not at TU Delft)	?																																				
C8.M3 Self-management Strategies	2																																				
C13.M1 Presenting Scientific Research	3																																				
C13.M5 Writing a Scientific article in English	3																																				
subtotal (a minimal of 15 GS credits)	16																																				
Total (a minimal of 30 GS credits)		32,5																																			
Research skills (= "Learning on-the-Job Activities")																																					
Scientific Presenting & interacting																																					
Addressing a major international audience	1																																				
Poster presentation, major international audience	1																																				
Writing and publishing																																					
Writing a research proposal (2-4)	3																																				
Writing (first) journal article (2-4)	3																																				
Teaching & supervision																																					
Teaching assistance: providing technical/material support for lectures,	3																																				
Total (a minimal of 15 GS credits)		11																																			
Total of total (a minimal 45 GS credits)		44																																			

* 1 ECTS = 1 GS

X = a modification of paper

Figure 5.1: Timetable of courses and writings - The numbers of credits are only estimated.

else can bring benefits. Therefore a research visit is considered during the research. The decision where and why to go will be made in the future. The hypothetical research visit is planned in the second or third year of this research.

A potential research visit can be at an other university. Wuhan University in China is a good candidate for two reasons. Firstly, on 12.11.2012 representatives of the Wuhan University and the Delft University of Technology signed an agreement with which the 'Wuhan University-TU Delft Joint Research Centre on Spatial Information' was formally established. Secondly, Wuhan University is a significant contributor in the map generalization research field. A research visit for several months is possible.

Research visits can also be organized for a shorter period at a company. Companies which can be most likely included are ESRI Nederland, Bentley System Europe B.V., 1Spatial Group Ltd., Oracle and TomTom. These companies are involved in STW project and their delegates participate in the STW Users Committee.

Also, a collaboration is possible. Especially with ESRI or 1Spatial, because ESRI has many tools which could be used and 1Spatial offers interesting topology products. Both companies are also focused on automatic generalization.

5.6 Deliverables

The main deliverables of this research are journal articles, conference proceedings, developed prototype implementations and finally a PhD thesis. The deliverables could be classified and described as follows.

- It is planned to write two journal articles (in the second and the third year of the research).
- It is also planned to write conference papers during the study. The content of the first three conference papers can be described as:
 - publication 0: Extended abstract for the GIN symposium + poster (October 2012);
 - publication 1: Testing, initial setting up the environment and experiments (March 2013).
 - Publication 2: The implementation of The Corine Land Cover data set and the improved generalization steps based on classes will be included (July 2013).
- Finally a regular PhD Thesis will be written for the doctoral defense.

Figure 5.1 gives us an overview, when which paper will be written.

5.7 Conferences

Conferences are a good opportunity to present my research, to share knowledge, to meet people from the same field and to get new ideas. Figure 5.1 also includes the timetable of conferences. The currently known conferences which I would like to attend are:

- GIN Symposium - Geo-information Netherlands, 15 November 2012;
- 16th AGILE - the Association of Geographic Information Laboratories for Europe, 14-17 May 2013;
- 29th Urban Data Management Symposium 29-31 May 2013;
- 16th ICA Generalization Workshop, 2013;
- AutoCarto - Automated Cartography International Symposium, 2014;
- ICA - ICC - International Cartographic Association - International Cartographic Conference, 2015.

5.8 Journals

Several relevant journal are presented. The impact factor is up to date based on the publishing companies Elsevier B.V, Springer, Taylor & Francis or the web pages of journal.

- ACM Transactions on Graphics (TOG) - Computer graphics, related to SIG-GRAPH. Impact factor: 5,070.
- Computational Geometry: Theory and Applications - Computational geometry. Impact factor: 0,725.
- Computers & Geosciences - New computation methods for the geosciences. Impact factor: 1,429.
- Computers & Graphics - Research and applications of computer graphics techniques. Impact factor: 1,000.
- Discrete & Computational Geometry (DCG) - Computational geometry. Impact factor: 0,938.
- GeoInformatica - Computer science and geographic information science. Impact factor: 1,143.

- IEEE Computer Graphics and Applications (CG&A) - Computer graphics. Impact factor: 0,82.
- International Journal of Geographical Information Science (IJGIS) - GIS science and geocomputation. Impact factor: 1,472.
- International Journal of Computational Geometry and Applications (IJCGA) - Computational geometry. Impact factor: 0,580.
- ISPRS International Journal of Geo-Information (IJGI) - Open access journal on geo-information. Impact factor: n/a.
- Journal of Spatial Information Science (JOSIS) - Open access journal on spatial information science. Impact factor: n/a.

5.9 Tools

For research it will be necessary to use a development environment, software and tools. Useful tools are:

- programming language Python;
- The Eclipse software development kit, with plugins PyDev, Mercurial;
- the pprepair and the prepair tools for repair planar partitions data (Ohori et al., 2012);
- Oracle Spatial or PostgreSQL with extension PostGIS as a DBMS environment;
- ArcGis and/or Quantum GIS (QGIS) and/or 1Spatial for visualization, managing, editing and analysing spatial data;
- Vector graphic software for creating the research output: GIMP, Corel, Adobe Illustrator or Adobe InDesign;
- Jabref for managing bibliography;
- L^AT_EX for scientific writing (Texmaker).

In Chapter 2 van Oosterom and Meijers (2012) mentioned that the vario-scale data needs to be visualized. Finding the software for visualization and debugging will be a priority. There are some possibilities, but it is important to select the software which fits best our requirements. We can sum up these needs following:

- free software;

- to could do slicing continuously.

Software which could be used:

- DeVIDE (Delft Visualisation and Image processing Development Environment) (Botha and Post, 2008);
- OpenDX;
- Khoros;
- ParaView.

DeVIDE is a tool for rapid prototyping of visualisation algorithms developed by TUDelft Graphics Group. It could be useful and most likely it will be used in my research for the following reasons:

- firstly it is an open source dataflow application builder;
- secondly DeVIDE is based on Python;
- thirdly it combines an event-driven and demand-driven scheduling in a hybrid scheduling approach that adaptively offers the efficiency and scalability of a demand-driven execution and the programming simplicity of an event-driven execution;
- fourthly the implementation of new visualization modules should be easy;
- fifthly the tool has been developed by the TU Delft Graphic Group, which has interest in cooperation;
- sixthly it supports vector data and it should be possible to do slicing with it.

5.10 Data

The classical map generalization problem has many ways how to deal with (Haunert et al., 2009), but some parts of the process are more difficult than others. The generalization from large to middle scale is more difficult than from medium to small scale. These aspects play an important role in the selection of data sets.

The order of data sets, in which we will use them, is also important. At first it is better to use only a small set of data and verify that everything works. Later on more complicated data sets can be added. The data from real world could be included at the end. This is important to consider during selecting appropriate data for the research.

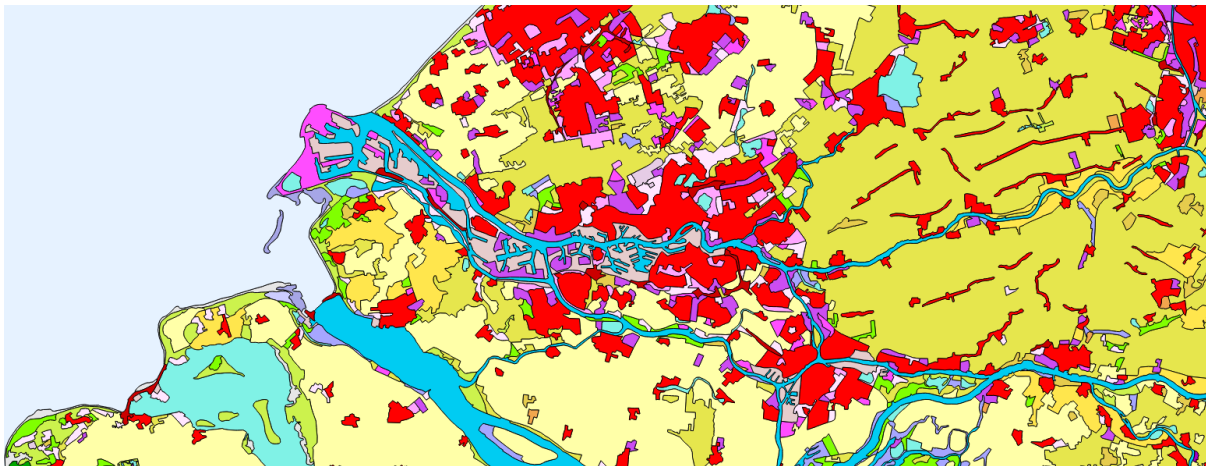


Figure 5.2: The extract of the Corine Land Cover data set with 3 level legend for region around Delft, the Netherlands.

For this research a topographic vector data set on a small scale will be needed, such as 1:100 000. On a large scale we think about 1:1 000. Both with area partition. The data set should contain a large number of classes. The data should be on a high level of detail and should have a rich set of attributes. The emphasis should be also placed on planar partitions. It should be as error free as possible. Unfortunately, most of the time spatial data contain some topological errors. For that reason, the data will be checked and repaired. The data will be most likely repaired by the tools `prepair` and `prepair` (Ohori et al., 2012).

The Corine Land Cover data set of the Netherlands will be used during the initial stage of the research, see Chapter 4. The Corine Land Cover (Coordination of Information on the Environment Land Cover) is a seamless vector database (1:100 000) produced by the European Environment Agency (EEA) and has a convenient classification hierarchy where the level 3 is the most detailed one and will be used. As shown in Figure 5.2, the data set is composed from area features only and contains more than 2 000 000 records which would be a sufficient number. It will be used twice. Firstly, the small subset of Corine will be used for the initial stage of the research. It will be a small amount of data for setting up the environment, developing and initial testing. It will be probably a small region around Delft presented in Figure 5.2. Secondly, a larger subset of the Corine data set will be used in the period of March to July, and this will give an impression how to deal with real data, will develop knowledge about different classes and will lead to an indication of improved generalization actions depending on the classes. Later, the large scale data set will be used. It will probably be provided by one of the members of the STW Users Committee, i.e. a municipality.

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