GIS TECHNOLOGY

Variable-Scale Geo-Information

PhD Research Proposal

Ir. B.M. Meijers

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TU Delft

OTB Research Institute for Housing, Urban and Mobility Studies

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Abstract

Since the early days of (analogue paper) maps humans have been using the concept of map scale. When moving to a digital environment, the old fixed map-scale concept was maintained. However, this is not necessary anymore, as with digital devices users can zoom in and out and with well structured databases it is not needed any more to store the geographic data for every map-scale independently. There are already (commercial) map user interfaces providing the feeling of variable scale by supporting smooth zoom. However, this is just an illusion as the solution behind the 'curtains' is still based on a number of fixed scale-maps representations. This research wants to provide a true solution and deals with storage, maintenance and dissemination of variable-scale geographic vector information. The overall goal of the PhD research project is to make more dynamic variable-scale map solutions possible. The central question that drives the research is: How can we realize a paradigm shift towards dynamic variable-scale geo-information with minimal redundancy? The start of the PhD research is the variable-scale data structure called tGAP (topological Generalized Area Partition; see Appendix 5.3 for further details), of which recently a static version has been implemented for the first time ever (Meijers, 2006). However, there are many research challenges waiting to be solved: formalization of the tGAP data structure, support for point and line objects (besides area objects), better cartographic generalization quality (support for more type of generalization operators), ability to handle massive data sets (over 100 million features), support for dynamic updates, etcetera. The utilisation of this research is proposed along two lines. First, the geographic data producers can migrate from their current independent geographic data sets for a fixed number of given scales towards an integrated variable-scale geographic data set. This will have great benefits for the efficiency of geographic data production as only one product line has to be maintained. From this product it is then possible to produce a representation at any required scale (of course within reasonable limits), including the traditional map scales. Second, for the Geo-ICT industry this research will indicate development directions in order to support the concept of variable-scale geographic information. This will cover the storage structures, but also visualization (smooth zoom and pan). For the end-users, this will provide an improved look-and-feel map interface, with high performance. Because all representations are derived from the same variable-scale structure, there can be no inconsistencies between the map-scales any more.

Chapter 1

Motivation and background

This research deals with storage, maintenance and dissemination of variable-scale geographic vector information. The overall goal of the PhD research project is to make more dynamic, digital map solutions possible. In this section it will be described what problems are to be dealt with within the project context, what the background to these problems is and what solutions are being considered.

1.1 Problems

From a user point of view, we see an increase in the use of digital maps in a networked environment. This is true for the desktop environment, but also in mobile context of map use. In the case of using digital maps via a network, the original information can be kept at the source. Then it might be easier for a user to retrieve up-to-date information. Also a fair-pricing mechanism, e.g. based on usage, can be created (cf. Van Oosterom, 2001). However, most current mobile map solutions are based on static copies of maps at the client side (e.g. supplied to a mobile device). There are severe limitations involved with this situation: the copies are limited in size (e.g. only a specific region, and not the whole world), limited in up-to-dateness (the date the copy was produced), limited in the available scales (level of details, at best there are different copies for different scales) and limited with respect to integrating maps (geo-information) from multiple sources.

Computer and mobile phone screens have changed the way people are allowed to work with geographic information: users can zoom in or out to the desired level of detail their tasks require. There is not really a need for a fixed map scale as is the case with paper maps made by specialists.

Another possibility is that users can get a coarse overview first and then a finer overview refined at the same scale later on, without waiting too long (users are impatient while waiting for information delivery). This calls for progressive transfer. Raster images can accommodate progressive transfer nicely with techniques like wavelet compression and data pyramids. Using the data structures, first a coarse representation can be sent and later on refined ones with more details. It is more difficult to obtain those effects with vector data, as these require more advanced data structures.

In summary, the current digital (mobile) vector map solutions are not dynamic and the user interfaces are insufficient.

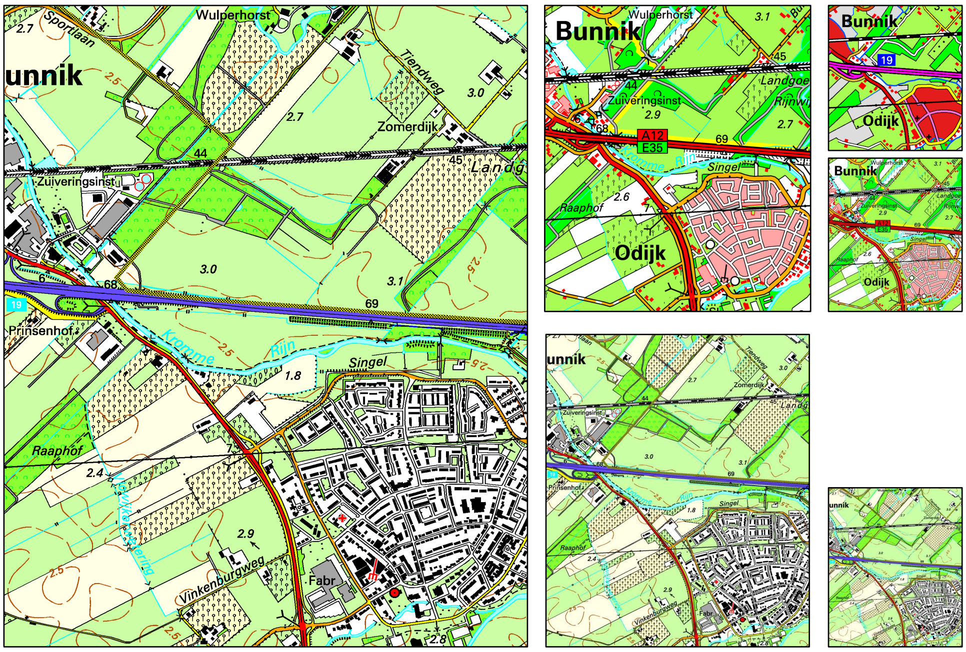

Figure 1.1: Scale reduction of a map with and without generalization applied (maps courtesy of Dutch Topographic Mapping Agency).

From a producer's point of view, there are different challenges ahead in the (near) future. Due to the increased usage of geographical information, there is a higher demand for updates. In The Netherlands, for example, law (on 'key registers') requires governmental mapping agencies to deal with higher update cycles of the geographic vector data sets produced. To cope with this increasing update cycle, it is needed to overcome certain problems, like:

- Inadequacies between different map scale series (maintaining multiple consistent levels of detail). A new map series at a smaller scale, with lower level of detail, is either produced on the basis of an existent larger scale series, or based on a new survey with other surveying rules from the field. Both approaches suffer from problems with updating and possible inconsistencies.

- Update propagation: propagating update from larger scale datasets to smaller scale datasets, cf. Uitermark et al. (1999).
- Take user perspective into account for geographic information delivery. When manually generalizing for paper map production, cartographers take into account a lot of variables, among others: target user group, target use, spatial patterns and surroundings of represented geographic objects. It is difficult to combine those (sometimes contradicting) requirements in an automated system (completely automated generalization).

Summarized, producers and maintainers of geographic information are looking for automated solutions to keep information at multiple levels of detail up-to-date.

1.2 Possible solutions

Basic idea of generalization is that large scale maps are simplified and filtered to represent the same area at a smaller scale, while preserving the characteristics of the information available at the larger scale. On the fly generalization, in which a generalized map is derived from the base data for an arbitrary target scale, is not considered as an option, due to the overly complex nature of the problem (imposing too many conditions for the result) and requiring too much time for generating a map in an online delivery scenario. On the contrary, the following solutions to the aforementioned problems are considered.

1.2.1 Multiple resolution/representation databases

Multiple resolution/representation databases (MRDBs) try to overcome the problem by explicitly linking two or more geographic datasets (mostly the case with map series from national mapping organisations). In these data structures links between corresponding objects of the different resolution levels are explicitly stored, to offer consistency during the use of the data (Hampe et al., 2003). Based on these links, updates can be made also to the other representations. Advantage of this solution is that geographic information is stored with a lot of thematic semantics (thematic attributes) and is available at multiple levels of detail. Disadvantage of this solution is that redundancy exists between these different levels in the database. Another drawback of the structures is that they are not suitable for progressive data transfer, because each resolution level requires its own graphic representation to be transferred.

Furthermore, these MRDB efforts seem suitable for map production at fixed, multiple (discrete) levels of detail, but can not really cope with the changing requirements of delivering a map in real time, at an arbitrary (continuous) level of detail, dependent on the context of a user: Using an MRDB solution discontinuities (‘shocks’) will be visible, while zooming interactively and the content of the map is not very well adjusted to the level of detail the map has, if the database lacks this level.

So, although these structures make the situation of updating better (by storing links), they still have their downsides from a data management point of view: redundancy of data at different levels and they can not really cope with (a) direct delivery of a map that is not stored in the data structure (thus not being one of the fixed levels, thus an arbitrary scaled map), (b) user context while delivering information and (c) progressive transfer.

1.2.2 Variable scale data structures

Another solution that is considered to overcome the problems associated with multiple representation databases is to use variable-scale data structures in a geographical Database Management System (geo-DBMS). These structures are subject of this research.

The purpose of the variable-scale data structures is to store the geographic data only once. Redundancy of geometry is avoided by storing references to composing elements of highest level of detail (LoD) for any other element of lower LoD. Next to the references an importance value for all objects is stored and based on this importance different representations can be derived on the fly from the structure according to the LoD needed.

In earlier research both the theoretical and practical (prototype implementation) aspects of an example of such a more advanced data structure, the tGAP structure (topological Generalized Area Partitioning) have been described (see Van Oosterom (2005) for the theory and Meijers (2006) for the practical aspects).

However, the current tGAP data structures are currently geometry based and are still in their infancy. For example, the structures are static: if the base geographic data changes, there is no other way than completely rebuilding the structures from scratch. Further more, the structures are not formally described, e.g. with axioms, limited to area features only and with the structures a 'suboptimal' cartographic generalization can be reached. Also, they have very limited support for taking into account the thematic semantic aspects (e.g. there are semantic compatibility and importance functions, but they do not introduce new classes of objects when moving to smaller scales).

In this chapter background and motivation for the project was given. In chapter 2, the objective of the research, the research questions, the scope, limitations and relationships with other projects of the research are given. A concise time planning for the research and the strategy that will be followed can be found in chapter 3. Needed material and tools are given in chapter 4. Finally, for a description of what should be delivered during the project, refer to chapter 5.

Chapter 2

Conceptual design

2.1 Research objective

The problem of managing, storing and disseminating variable-scale geo-information is defined as the lack of an environment that can accommodate real time delivery of geographic data at variable-scale and takes semantics of the geographic data into account.

A variable-scale geo-information environment will be an environment that also works under these specific conditions:

1. Enables real time access to geographic vector data;
2. Makes it possible to store, maintain and disseminate data at variable scale (not only pre-defined scales at the producers site, but with continuous levels of detail);
3. Supports one base dataset and multiple 'outlets' with thematic emphasis, which can take different user perspectives into account;
4. Takes semantics of the geographic data into account (meaningful information);
5. Allows for other than area features, e.g. point and line features;
6. Allows progressive transfer and smooth zoom.

Given this problem the objective of this research is to develop extensions to the original tGAP variable-scale data structures , to get to representations of the real world with continuous levels of detail, instead of representations with discretised levels of detail (in multiple layers, each layer only representing one resolution level). This includes storage methods, semantics, progressive transfer of data over networks and smooth zoom and pan, e.g. geo-morphing at the client side (where probably techniques can be used described by Hoppe, 1998, Cecconi and Galanda, 2002, Sester and Brenner, 2004).

2.2 Research issues

The research objective should be reached by studying existing solutions, designing and engineering new solutions, giving formal descriptions of the new solutions and running experiments and tests on created prototypes (more details can be found in chapter 3). To guide this process, a central question, which should be answered during the course of the research, and several sub-questions questions have been formulated. The central question that drives the research is:

How can we realize a paradigm shift towards dynamic variable-scale geo-information with minimal redundancy?

The following list of sub-questions is an indication for the direction in which the research will be heading.

General questions

1. How can we theoretically combine the strong points (like the ability to implement a MRDB and generalization quality) from both MRDB & variable-scale data structures to make one variable-scale environment?
2. How can we store point and line objects in the data structures? Should we organize this data in different layers?
3. Based on a feature model: is it possible to introduce 'collapsing of objects', so that at a certain level of detail an object is represented by another kind of geometric object (from area to line, area to point or line to point)?
4. How should we store importance of objects, so that we can relate the objects to a certain scale and how should this relation look like in case of variable scale?
5. How can we efficiently realize a variable-scale server (see section 5.3 for what is considered efficient)?

Questions related to managing dynamic data with the structures

1. How can we make the data structures suitable for updates and deletes, while controlling the locality of updates (e.g. by taking natural boundaries, like roads, into consideration while performing the update)?
2. How to describe the data structures formally (e.g. with usage of axioms)?
3. What is needed to formalize the structures (e.g. avoid global optimization)?

Questions related to thematic semantics (amongst others: classification and alphanumeric attributes) and user tasks and context

1. How can the current structures be made aware of thematic semantics of objects?
2. In which way should we incorporate a feature model on top of the tGAP structure, to allow generalization algorithms to take this information into account?
3. The current data structures make use of the generalization operators aggregation, simplification and selection. How can we make other generalization operators work with the data structures, like typification, displacement and exaggeration? Does the result of these operators fit in the structures and how should an algorithm fill the structures?
4. Is it useful to create an ontology of the geographic dataset that is loaded into the variable-scale environment?
5. Is it possible to use another, completely independent dataset for constraining the way the tGAP structure is filled (like Haunert et al. (2007), who used a derived smaller scale dataset of the large scale base dataset, but then use a completely independent dataset as constraint)?

Questions related to real-time delivery of variable scale data

1. How to smoothly zoom in, out and pan with a client using the data structures?
2. How to derive increments from the data structure, i.e. how should progressive transfer in a server-client set-up look like with respect to increments and communication?

2.3 Scope

The scope for the research is set by the research objective and the research questions. Additional requirements are described here, to guard the scope of the project:

- The project will be driven by a use case. The outline of this use case is as follows: A networked user zooms in or out or pans on a topographic dataset. Progressive transfer is accomplished by the system, therefore the user should not get lost, and should have a sense of high-responsiveness of the system. The amount of zooming will be varied (e.g. in small steps or in one extreme step). It will be tried to have constant time for the zoom and pan operations (and thus keep the amount of data the same – e.g. constant number of objects and coordinates is measured). The reaction speed of the system should be independent from the screen size of the user (mobile user / desktop user).

- Focus of the project will be mostly on technique, only limited attention will be given to human factors (i.e. taking into account the users perspective). Current state-of-the-art is to use a rasterized canvas, blow up pixels and if a user stops zooming, data is retrieved. Intention is to use only vector data, which is blitted to a raster screen. Smooth zooming is accomplished by creating intermediate versions, based on the vector data.

- Although there is a strong link related to visualization in the project, the focus is on (correctly functioning) data structures and algorithms. Still, visualization is regarded in this project as a powerful tool and will be used. Visualization can be split in two parts: visualization that can very much help the developer of the data structures, to see if the structures work as intended ('process visualization'). This opposed to 'user visualization', which is used in graphic user interfaces, where usability techniques are used to test cartographic quality and efficiency of a system for a user's task. User visualization is not considered within this project.

- The focus of the project will be on a geo-DBMS environment; as such an environment should be suitable for storing large amounts of geographic data, structured for access of many users and with some sort of security mechanism in place. This way data can be kept at the source (e.g. within the producing organization).

- Within this geo-DBMS context it is also important to investigate the separation on the Digital Landscape Model (DLM) and Digital Cartographic Model (DCM), which is considered as state of the art. In theory the DLM consist of object instances and the DCM describes rules on how to transform these instances for a visualization (the DCM thus does not contain instances). In practice, for DCMs separate objects are instantiated and maintained. A preliminary conclusion can thus be that a strict separation of the two models leads to more redundancy in a multi-scale approach and makes it more difficult to automate the process of generalization. For the tGAP structures it probably makes sense to integrate DLM and DCM in one model and also store the result of changes with a more cartographic nature in the landscape model. This could result in less accurate results while querying datasets. It is foreseen that as people consider querying, a different tGAP data set could be created, with different rules (i.e. content of the structures will be different, as well as the algorithms that fill the structures, but the structures will not change; the same setup will be applicable). Therefore, the initial start will be to integrate the two models.

- Data in the project will be two dimensional. At most, data used will be a $2\frac{1}{2}$ dimensional representation of the real world.

2.4 Limitations

In this section the most important limitations to the research will be described. Most import limitation of the research is that the result won't be a complete solution for the generalization problem, as this is a long standing problem. Other things that are considered out-of-scope of the research are:

- A client that does a good job with respect to geo-morphing or that has full support for progressive transfer;
- Implementation of smooth zooming at a client;
- Non-topographic data themes, like continuous phenomena, such as weather and ocean floors;
- Generalization of 3 dimensional models;
- Formal reasoning with geographic information;
- Machine learning from human generalization as input (1. map series and different scales or 2. capturing iterative sessions conducted by an editor);
- Compression techniques for data storage and transfer.

2.5 Relation with other generalization projects

Within this section the relation with other on-going generalization projects of the research will be described. This research aims to contribute to solving long standing issues in generalization research (cf. Töpfer and Pillewizer, 1966, Nickerson and Freeman, 1986, Shea and McMaster, 1989, Lam et al., 2004): it tries to find one integrated model of the world, suitable for querying, updating and visualization, in which non-predefined scales can be accommodated and from which multiple visualizations can be derived. The results of the research probably will contribute to other projects, and the research might benefit from on-going projects.

It is becoming more important to serve geo-information over networks. Therefore, results probably will contribute to the BSIK RGI project 'Usable and well scaled mobile maps' (MobiMaps) that tries to find solutions to problems related to human factors of mobile mapping (especially focussing on generalization for devices equipped with small displays). The structures will allow different kind of access than traditional methods. Key registers ('basisregistraties' in Dutch) is another good example for which variable-scale geo-information could be important: as it will require a lot of effort from the producers to cope with the higher update cycles, and different usage at different levels of detail that cannot be foreseen beforehand. Another area where results might be used is Spatial Information Infra structures (SII), like at European level with the INSPIRE initiative. Data exchange and sharing might benefit from having variable-scale solutions available that can switch to different levels of detail easily. Last, another project is the IMTOP project carried out at the Netherlands' Cadastre that is concerned with modelling for multiple LoD's (to unify the models used for the different scales).

The research itself might benefit from several on-going projects, co-operations and developments. Current BSIK RGI projects, like MobiMaps and base maps for spatial planning might deliver interesting results to take into account during the research. Further, from co-operation with industry partners, like ESRI and 1Spatial spin-off can be expected in terms of ideas, usage of existing and, probably, development of new software products.

Chapter 3

Research planning

In this chapter a clear and consistent planning of the research will be given. The time frame in which the research takes place is: 1 July 2007 – 30 June 2011. This means that 48 months in total is available. The time will be divided as follows: 90% of the time is available for doing research, writing articles and producing a PhD thesis and 10% for administrative purposes, e.g. helping with education. It will be tried to do writing intermingled with research activities, so that writing will not be an end in itself.

3.1 Time planning

The research will be driven by milestone packages. The time planning below does mention rough time phases for the milestones from the research strategy (see section 3.2). The order in which milestones are worked on might change, if this is useful (e.g. due to co-operation):

Phase 1, 2007 Research setup; Starting up

Phase 2, 2008 tGAP versus MRDB; Real-time delivery of variable scale data; User's perspective

Phase 3, 2008, 2009 Managing dynamic structures; Managing large dynamic structures; Formalization

Phase 4, 2009, 2010 Thematic semantics, an object model, using the object model and advanced semantic modelling; Formalization

Phase 5, 2011 Creation of the final dissertation (some parts will be written earlier on), improving the thesis and preparation for the PhD defence.

Later on in the project it will be decided, if some time will be spent at a university abroad to co-operate on topics of the research. This should be a university or institute doing MRDB and/or map generalization research.

3.2 Research strategy

The milestone packages are described in this section. For each package a general description of the outcome is given. However earlier outcomes might influence later packages and changes might be necessary. So, to be able to adapt to these changes an iterative approach is followed for doing research (based on Schwaber and Beedle (2002)).

All wishes and work for the research will be captured in a research backlog (a priority queue of features and directions in which the research should evolve). Research will be carried out in periods of 30 days (a sprint). At the start of such a sprint, the most important features will be taken from the research backlog to the research sprint log. This is a queue of work that should be finished at the end of the period. To avoid taking too less or too much work, estimates will be given to each feature on the research backlog. This backlog will also capture knowledge, on how much time is still needed for finishing the remaining parts of a certain milestone package.

When a start is made with a new milestone package an inventory takes place what should happen to set the scene for this package, i.e. features and directions are made more concrete and inserted as work entities in the research backlog. After setting the scene, these concrete ideas will be worked out in an iterative way, i.e. ideas will be tried, refined, tried, refined, and so on.

Research setup Create the research proposal, this includes the conceptual design and technical design of the research. Also, setup the research backlog to capture all features, requirements and directions.

Deliverable: (this) research proposal and a research backlog system.

Starting up Tools and data will be setup in this stage.

To learn Python, Cython or C++ and how to glue those programming environments together two experiments will be carried out: (a) program an R-Tree in Cython or C++ and allow use in Python, and (b) create a topology builder based on what is available in Grass (this builder should do cleaning of geometry and create explicit left/right, centroid/node and start/end node references).

Setup data in an MRDB way. Load a number of layers (a layer contains a number of map sheets with the same scale) for the same area and then glue together the sheets (dissolve artificial boundaries) and create links between features at different layers. Also geometry should be cleaned, so that correct, explicit topology can be obtained.

Further, it is necessary to choose libraries already available for programming, like the GEOS library, and the OGR library. Also learn about other programs, like Grass, qGIS, FME, Oracle, PostGIS and Radius Studio.

Deliverables: After this milestone test data, the feature classification hierarchy, as well as documents for generalization rules and workflow (via topographic survey) and knowledge how to operate the diverse tools should be available.

tGAP versus MRDB Based on the dataset from the 'starting up' milestone, we can build a geometry only tGAP structure based on the largest scale of the MRDB. Further, an experiment can be run to create a constrained tGAP structure, based on the remaining MRDB layers.

Deliverables: tGAP creation software prototype and two tGAP datasets.

Real-time delivery of variable scale data Create a client near the database for visualizing information out of the data structures. This client can also be used for experimenting with 'local' progressive transfer of data to the drawing canvas. This can be the basis for more elaborate solutions based on network protocols and transport (e.g. based on WFS or SOAP).

Deliverables: prototype implementation of a local client with progressive rendering possibilities of vector information.

Managing dynamic structures As the tGAP structures are not dynamic, it is necessary to look into how updates can be propagated in the structures after a change to the base data has occurred. Updates are related to time, so probably it is useful to store start and end time attributes with the objects in the tGAP structure.

Deliverables: an initial update algorithm for small data sets (might re-organize the complete contents of the data structures).

Managing large dynamic structures As the previous milestone focussed on a simple algorithm for updates, here we will focus on a more advanced updating mechanism. It is necessary to define locality or come up with an algorithm that does some things more local, than the global criterion of least important face. A divide and conquer strategy might be necessary, like a field tree approach (overlay data with a changing grid) or dividing the dataset in subsets by using linear features, like road and water ways. Another option might be the 'partial re-generalization' approach (described by Ellsiepen, 2007): find smallest feature on a local measure, instead of a global measure.

Deliverables: sophisticated update algorithm for large(r) data sets.

Thematic semantics, an object model Design of an object model with the existent data structures. The thematic semantics are not very well represented at this moment. Only a flat list of possible classes is stored. A hierarchical approach might be better: The advantage of having the thematic attributes also available in this way may influence the quality of the algorithms filling the tGAP structures.

Deliverables: design document of how object model should be incorporated in the data structures.

Thematic semantics, using the object model Build a tGAP structure on top of the object model and take information from the object model into account while filling the tGAP structure.

Deliverables: software prototype implementation of an object model with the current tGAP structures.

Thematic semantics, advanced semantic modelling Using ontology and semantic rules in the object environment. Taxonomies, hierarchies of rules and ontologies may be helpful for better modelling the outcome of the build process of a tGAP structure. For example, Stoter et al. (2007) explain different approaches for modelling with multiple fixed levels of detail in which object hierarchies are considered. It might be necessary to introduce a way to go from model rules to implementation (e.g. specify rules/formal semantics once in a modelling environment and use them while building).

Deliverables: design document and probably prototype implementation of using ontology related to the object model.

User's perspective Taking into account the user's perspective: using different parameters to fill the structures with the same base data.

Deliverables: From the data structure different maps should be derived, based on parameters that represent the user's perspective.

Formalization Formalization of the data structures, probably by means of specific languages suitable for this purpose (e.g. Common Algebraic Specification Language, CASL, or propositional logic).

Deliverables: formalization of the data structures.

The dissertation Writing and creation of a dissertation.

Deliverables: PhD Thesis summarizing the results, conclusions and future directions.

3.3 Supervision

The project will be promoted by Prof. Dr. Ir. P.J.M. van Oosterom and co-promoted by Prof. Dr. M.J. Kraak.

The promotor will act as daily supervisor. It is agreed to meet at least once per month with the promotor. This monthly meetings will be about progress, opportunities and problems of the research. Martijn will distribute an agenda before the meeting and take notes during the meeting. These notes will be made available afterwards as minutes. At least once per year a meeting takes place with the promotor, co-promotor and the PhD student.

During the sabbatical leave of the supervisor (planned in 2008), the monthly meetings will take place at a distance by means of a telephone or online conversation medium.

3.4 Involvement in other projects and education

As the PhD project can benefit from other projects and their findings, it is tried to co-operate in current on-going projects, like MobiMaps and modelling for the new TOPNL geographic datasets (more on this in section 2.5).

To find out more about semantic web technologies the course 'Intelligent Web Applications' lectured at the Faculty of Sciences, Free University of Amsterdam will be attended. To broaden the PhD student his knowledge, he will also take part in the courses 'Getting started in a PhD project' (PROM-1) and Scientific Writing in English (PROM-4), both taught at Delft University of Technology at the Faculty of Technology, Policy and Management. If more training is needed, this will be discussed with the supervisor.

Chapter 4

Research material

Which material is needed to address the research issues is described here.

4.1 Data / material

1. Large, mid- and small-scale geographic datasets: topographic data of the Dutch Topographic Mapping Agency (Topografische Dienst Kadaster), scale 1:10,000 - 1:500,000 (and all levels in between, datasets should have the same geographic extent, to make comparison of a MRDB to a variable scale dataset possible).

2. Optional: soil data and height data might be worth investigating later on in the project, as they have different characteristics from the topographic datasets.

3. Guidelines and workflow for generalization, i.e. a rule base for generalization and formal constraints on the results of the process.

4.2 Tools

What exists with respect to a variable-scale environment is a prototype implementation of the initial theoretic ideas (Meijers, 2006). This prototype supports storage of two dimensional area partitions, only storing the geometrical representation. As input data the geometry of cadastral parcels was used. By Haunert et al. (2007) an extension was described and a prototype was created to use another dataset with smaller scale to influence the results based on this dataset (with what they termed a constrained tGAP structure). These prototypes can be used as a start for this research.

For further development of the prototypes preferably open source tools will be used and commercial ones as no equivalent open source solutions exists. Having the source available most of the time means easier practical problem solving. Prototypes built will be eventually released as open source as well.

1. Programming: Python, Cython, PyRex, ShedSkin, C and/or C++;
2. Relevant libraries for handling spatial data, like GEOS and GDAL / OGR;
3. Relevant libraries for creating web services;
4. Eclipse (Integrated Development Environment) and Subversion (source code management);
5. DBMS environment (Oracle, PostGIS and/or MonetDB);
6. GIS environment (for visualization and generalization): FME, GRASS, uDIG, OpenJump, ArcGIS, Manifold, 1Spatial Radius Studio and software for generalization from University of Hannover;
7. Formal semantics software (like Protégé and Racer);
8. UML Modelling software with Object Constraint Language support (like Enterprise Architect);
9. LaTeX for (scientific) writing.

Chapter 5

Deliverables

In this chapter the main deliverables of the research project are described. Deliverable products are split into three categories: prototypes, writings and PhD thesis.

5.1 Prototypes

Prototypes will consist of software and data. Eventually these prototypes will be released under an open source license, so that the source code will be available as implementation of the ideas.

5.2 Scientific writings

The publication goals for the project are set as follows: a number of conference papers (two per year), one/two journal paper(s). Papers might be joint work with colleagues. Possible working titles of papers can be (those are certainly not fixed and are subject to change):

1. Updating in a variable-scale geo-information environment.
2. Incorporating thematic semantics in a variable-scale geo-information environment.
3. Updating in a variable-scale geo-information environment with the use of semantic information.
4. Defining locality (how large is an influencing area) in a variable-scale geo-information environment.

5.3 PhD Thesis

The initial PhD thesis contents looks as follows:

Introduction Introduction of the work, a guide for reading.

Background Setting the scene of the research. Describing the motivation and the background.

Dynamic data structures Updating structures. Divide and conquer approach. Formalization of the data structures with respect to updates.

Semantics and objects Semantic modelling, ontologies. Formalization of the data structures with respect to semantics and objects.

Prototype development and testing Outcome of the prototype developments, together with test results and conclusions.

Conclusions Conclusions, future research directions.

This is a concept table of contents: after a year this table of contents should be made available in more detail (as some parts of the research will be clearer then) and further on in the process refined even more.

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Definition of concepts

The main concepts of the research objective and the research issue are defined, refined and made concrete here. These concepts are the variables researched, together how they are made operational.

Terms

Geo-Database Management System A software system that lets users create, manage and access data in a database and that has been extended with capabilities to store geographic objects with their geometry (e.g. points, lines and polygons), functions for querying and processing this geometry (e.g. distance and buffer functionality) and multi-dimensional access methods for fast retrieval (e.g. a R-Tree mechanism).

Geo-morphing Inserting new vertices along existing edges in a vectorized terrain representation and smoothly moving those vertices to their final position (over a small time span). This way the terrain is morphed to its final look.

Generalization A simplification of data, so that information remains clear and uncluttered when the representation scale is reduced. It usually involves a reduction in detail, a resampling to larger spacing or a reduction in the number of points in a line. (McDonnell and Kemp, 1995)

Generalization operators Generalization operators (or generalization operations, generalization procedures, depending on the author) designate transformations in the generalization process on a conceptual level. (Galanda, 2003)

Multiple resolution/representation database (MRDB) A spatial database, which can be used to store the same real-world-phenomena at different levels of precision, accuracy and resolution (Devogele et al., 1996). In an MRDB, different views on the same physical objects or phenomena can be stored and linked (Hampe et al., 2003).

Level of detail Complexity of the representation of an object (set). Based on the level of detail it is decided which granularity should be used when an object is visualized. Also the thematic attribute values of object classes can be generalized based on the level of detail (e.g. the classes 'deciduous forest' and 'evergreen forest' become 'forest' at a certain scale).

Progressive transfer Transfer of geographic data over a network, where initially a coarse representation of the geographic objects is transmitted and later on this representation is refined with more details.

Scale The ratio between the size of the current representation of the object (e.g. size of object on a visualization) and the reference object (e.g. size of object in the real world).

Smooth zoom and pan To smoothly adjust the contents of a map and the symbolization used to a target scale as a result of a zooming, i.e. scale change, or panning, i.e. geographical extent change, operation (after Cecconi and Galanda, 2002).

Thematic semantics Theme stored with geographic objects, i.e. the non-spatial attributes and their meaning (e.g. height means absolute height according some reference system, or means height above the field level).

Variable-scale Allowing access to digital geographic data at an arbitrary and not predefined level of detail.

Research variables

Efficient dynamic data structures Data structures that allow modification of the contents stored, after initial creation of the structures. Efficiency can be expressed in terms of the amount of change of the data structure after an update and how stable the results of an update operation are, i.e. how dependent the result of the updates are on the order of data import, updating and editing.

Efficient realization and use of data structures Efficient realization and use could be given in terms of: the implementation time needed, the running time (during use), required disk space for storing the information, the size of data that needs to be transferred to a client to create a visualization of the data stored, i.e. number of bytes sent and the time that is needed for retrieval and visualization.

Locality of updates Effect of an update, measured in amount of change of the structures: how much of the contents of the data structures changes after the tGAP data structure update has taken place as a consequence of a change in the real world.

Quality of tGAP visualization result Quality will be measured in terms of efficiency (see above). Visual appearance will be judged in terms of how good the resulting map obeys certain constraints (e.g. minimal size of an area object at a certain level of detail). Further, visual appearance will be compared with alternative approaches (like MRDBs). However, it will not be tried to measure quality with respect to human factors (i.e. no usability research will be conducted).

Explanation of the existing variable-scale data structures

The existing variable-scale data structures are based on explicit topological data storage. Several data structures are used to allow variable-scale data access. The GAP face tree is a tree structure that stores information on generalization of topological faces, i.e. making the selection of faces possible that are important enough for a certain level of detail. Because a planar area partition is used (i.e. no gaps and no overlaps are allowed in the two dimensional domain), it is not possible to just remove faces for a lower level of detail, as this would leave gaps in the area partition. Therefore, on higher importance levels, the areas belonging to the least important faces are assigned to their most important and most compatible neighbouring faces. For deciding which face will be removed and assigned to a neighbouring face, both an importance and a collapse function are needed. The importance function will return the least important face in the complete area. With the collapse function, it is decided to which neighbouring face the area of the face will be assigned. Within the GAP face tree, each face has an importance range assigned. The importance range consists of two stored values that define a range: low importance and high importance. Based on the intersection of an importance level with the importance ranges of the faces, the faces that are valid for that importance level can be selected. Via this selection the amount of faces can be reduced, because less faces reside higher in the tree. So far, one part of generalization can be accommodated with the data structures, i.e. a selection can be made which faces to show on lower levels of detail. For simplification of the geometry of the faces, other data structures are needed. Each topological face consists of a collection of edges and nodes that form the face. To simplify the appearance of the face, a simplification of the geometry of the edges is needed. With this simplification, the amount of coordinates associated with the edges is reduced. This is accomplished by using a binary tree structure that is called the Binary Line Generalization (BLG) tree. The result of the Douglas Peucker algorithm can be mapped to the contents of a BLG tree. If this tree structure is used, one can query the tree to get the right amount of edge detail by using the threshold values stored with the vertices, instead of having to calculate all distances over and over again. Selection of detail is based on the vertex tolerances

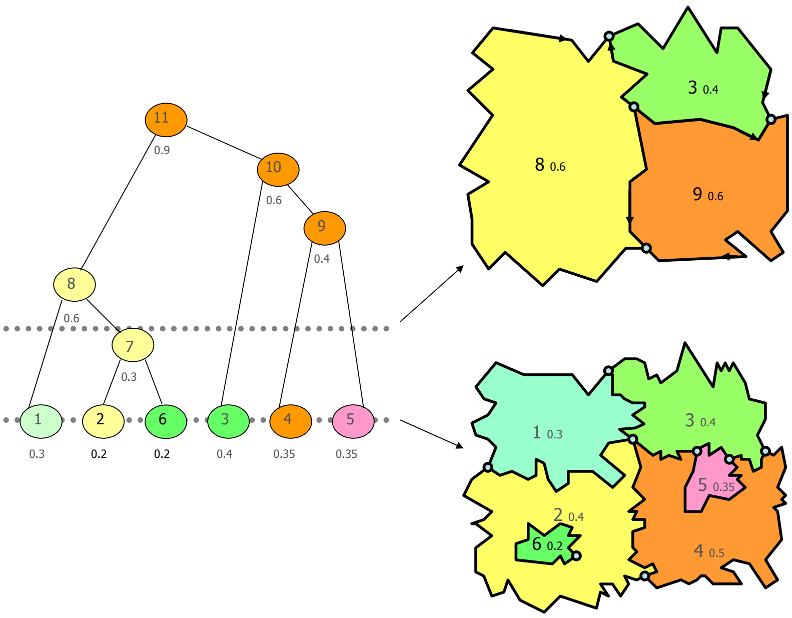

Figure 1: Illustration of the working of the current tGAP structures: Based on the importance value of the objects, the data structures can be queried.

from the Douglas Peucker algorithm that are stored in the BLG tree. Vertices having larger threshold values are mostly stored closer to the root of the tree (i.e. higher in the tree). In general, a vertex residing lower in the tree has the same or a smaller tolerance than its parent in the tree. To get a particular amount of detail for the edge geometry, the BLG tree is descended, until the wanted detail, given by the threshold value, is reached and one can stop with descending the tree in that direction. Edges in the structure can thus be simplified, with the use of the BLG tree. But another problem has to be solved: With each merging step of faces in the GAP face tree, the boundary edge(s) between two faces that are merged will be removed. This removal may leave two edges with one node as a junction, where this junction node then has an incidence relationship with only the two edges that are still left. The two edges should be joined to form a new edge, also enabling simplification for the joined pair. By joining the edges into a new edge, the geometry would be duplicated. Therefore, if the two edges their corresponding BLG trees are joined by making a reference to the two old BLG trees, it is possible to make the edge data structure without geometrical redundancy. However, for the junction node then no information is available on how to simplify the new edge, as opposed to the rest of the vertices, which all have a threshold value assigned (stored in the BLG tree). This threshold value has to be computed when building the GAP face tree, just as is the case in the first initial step of the Douglas Peucker algorithm. This process of joining edges takes place with building the GAP face tree. Selection of how much detail is needed can be done in the same way as with the original BLG trees, although the accuracy measure of the junction node is then a worst case estimate value. Joining of the edges will extend the existing BLG trees into larger trees. However, because boundary edges will be removed, multiple root nodes, starting multiple trees, will exist for the edge data structures after building the GAP face tree. This edge data structure is therefore called, the GAP edge forest.

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