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Generalisation of framework data: a research agenda

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ABSTRACT

Generalisation of framework data is studied by many research groups. The research on generalisation at ITC aims at contributing to this research community. Therefore we want to place our research on generalisation within current developments in both research and practice. This paper sketches our research agenda for the coming years. To come to this agenda we firstly describe the changing role of framework data over time and we give examples from practice by describing generalisation practice within the Dutch Topographic Service (which is the main test case in our research) and by describing two examples of commercially available generalisation software.

1 INTRODUCTION

One of the main wishes of National Mapping Organisations (NMO’s) and other producers of framework data is to produce and maintain one single geo-database from which it is possible to derive a broad range of products on demand. Databases filled with large-scale geo-data are now reality and tools to derive automatically small-scale products out of these data sets are evolving. One of the main challenges to generate derived products from a single very detailed database is to have appropriate generalisation techniques that address both database as well as cartographic aspects (Regnauld, 2003). But what does appropriate mean? Appropriate generalisation techniques that serve one application or the framework data set of one country could not be appropriate for other applications or other framework data sets. Can the appropriateness be measured?

The issue of generalisation of framework data focusing on both geometric (cartographic) generalisation and conceptual (database) generalisation is a fundamental issue in geosciences that has been studied and discussed extensively since early history of GIS and has yielded promising results (see for example Douglas and Peucker, 1975; Richardson, 1993; Oosterom and Schenkelaars, 1995; Oosterom, 1995; Peng, 1997; Weibel and Dutton, 1998; Ruas, 2000a; Yaolin, 2002; Smaalen, 2003; Hampe et al. 2003). However current practice is that generalisation still has to be performed partly interactively and can therefore not be performed on the fly. Most NMO’s have ad-hoc processes that mix automation (for some tasks) and interaction (for other tasks or to correct mistakes).

The aim of this paper is to outline the research agenda on generalisation of framework data at ITC, Department of Geo-Information Processing. The aim of our research is to study the generalisation requirements that are met in practice and to come to solutions and recommendations to meet these requirements. Our research will focus on solutions that are not country or application specific in order to meet the growing need of using the same framework data by more and more users and in order to meet the need that framework data operates within National and International Spatial Data Infrastructures (SDI's).

Framework data as used in this paper has a broader meaning than the topographic data that is traditionally produced by NMO's. These traditional data sets are mainly used to create topographic maps at different scales and therefore it includes information on infrastructure, hydrography, buildings, and land use. In today's perception on what should be included in a basic dataset that can be used to support a broad range of geo-operations one would include, next to the fundamental topographical objects, geodetic control data, digital elevation models, orthophotos, administrative boundaries, official geographic names etc. This basic set is in this paper referred to as framework data. In literature one sometimes refers to this data set as core data or foundation data. Although in the discussion on generalisation we will concentrate on the 'classic' topographic data we have to keep in mind that because of technological developments (data acquisition techniques - satellites, lidar, location based services, etc) and the demand from the user (up-to-date; multi-dimensional etc) the traditional function of the topographic data is likely to change.

In this paper we will first describe the evolving role of framework data, which has its influence on the requirements of generalisation (section 2). The generalisation approaches that are both currently practiced, and needed in the future, pushes the research on generalisation. In section 3 the technological outline of research on generalisation is illustrated by examples from practice. It starts with a description of generalisation within the Dutch Topographic Service. Section 3 also describes two examples of commercially available software. We will end this paper by a discussion on the research direction that is needed to facilitate generalisation of framework data that meet user requirements in the medium to long-term future. This will be the main drive for our research on generalisation (section 4).

2. CHANGING ROLE OF FRAMEWORK DATA

The requirements for generalisation are influenced by the changing role of framework data. How the production, maintenance, characteristics and use of framework data have changed over time, and how this changing role influences the requirements for generalisation will be described in this section. In the description below one should realise it describes the general trend in generalisation of framework data. At the different NMO's the implementation of any of the phases has been adapted to the local situation. Figure 1 schematically portrays the changing role of framework data.

In the past (figure 1a), when only paper maps existed (before the eighties), generalisation was a manual operation. Cartographers distinguished between graphic and conceptual generalisation. The first would mainly deal with the geometry and the second would in addition result in a change of the legend items as well.

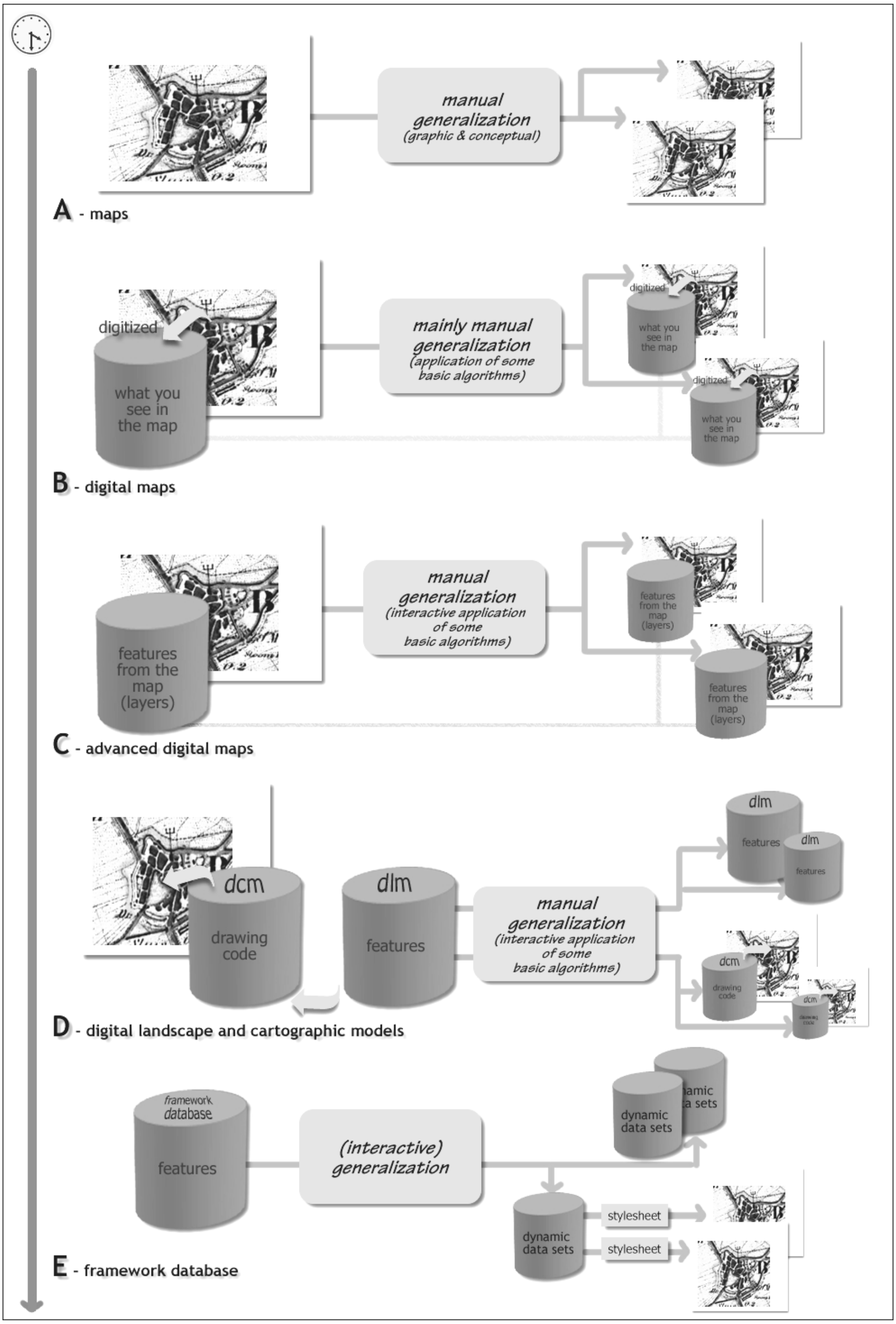


Figure 1. Development of the generalisation of topographic framework data: a) manual; b) digital maps; c) advanced digital maps; d) digital landscape model and digital cartographic model; e) single framework database and dynamically derived products.

As soon as computers became available (from the beginning of the eighties) national mapping organisations started to use them to automate their mapping process (figure 1b). The existing maps were digitised. One actually only incorporated the features seen on the map because the objective was to speed up the map production process. This could lead to a situation where customers asking for the digital hydrographic data (e.g. water boards) would end up with rivers and canals with many gaps on those locations where road or railroads would cross. Automatic generalisation was performed only at an experimental level and required much interactivity e.g. every object needed individually to be generalised with either specific or non-specific generalisation algorithms. Looking at spatial relationships between objects was not of primary interest in this phase. Small-scale databases, still primarily meant for topographic mapping, were created by digitising the main part of the small-scale maps themselves.

In a more advanced digital map environment, starting to become of interest from the beginning of the nineties, the database became slightly more structured and often layer oriented (figure 1c). A full hydrography layer would now exist, but still structured in such a way that the paper maps could be generated easily. GIS users were still not yet seen as prime customers. Generalisation, still aiming at producing small-scale maps, was done partly manually, but one could apply algorithms on a set of objects (e.g. a specific thematic layer) that required less interaction. The algorithms still focused on simplifying individual objects. Afterwards the layers needed to be combined manually in a single map.

The last decade GIS matured by which the need was recognised for a different approach to the data structures behind the topographic maps (figure 1d). In fact, the map is just one of the products that can be generated from framework datasets. Framework data is nowadays also required for:

- input in noise prediction models (location of noise producers such as railways and roads) (Kluijver and Stoter, 2003);
- water and road maintenance systems;
- input for plan studies (e.g. location of dwelling-areas);
- input for network calculations, e.g. route-planning.

These applications demand specific requirements on the contents of framework data compared to the content that was available in traditional (digital) maps, for example:

- It should be possible to select and identify objects in the data set that represent objects in the real world, e.g. select all segments that form the highway ‘E13’.
- The location of objects should represent the real location and should not be replaced at smaller scales.
- The width of roads and railways should represent the real width of these objects instead of e.g. the importance of these objects as in (digital) maps.
- It should be possible to relate objects to objects in different databases.

For these new requirements, road and water objects needs to be identified and available using both line geometry for network calculations and polygon geometry for input in spatial models and maintenance applications. This in contrast to the traditional cartographic data sets in which it may be possible that line-shaped objects of the same class are represented as lines when they are smaller than a threshold value and as polygons when they exceed this threshold value (e.g. canals smaller than 3 meter are represented with linear geometries and canals wider than 3 meter are represented as with polygonal geometries).

In this phase the distinction between the digital landscape model (DLM) and a digital cartographic model (DCM) is most obvious. The rise of GIS has changed the focus of generalisation, because of the importance of the database (DLM) behind the map (DCM). Many databases with framework data are nowadays still somehow map based or are in the process of turning into a less map-oriented database. However, generalisation is increasingly split into database generalisation and cartographic generalisation. The first leads to a new dataset ('derived landscape model') for instance for use in a GIS environment or can be the base for a new cartographic model. The second is applied to a landscape model to generate proper map output. Generalisation is executed using many individual algorithms available. Because these algorithms can be organised in batch processes, the generalisation requires less interaction then in the previous phases. However, the generalisation process is more complex since generalisation is no longer only used to produce readable small-scale maps. In this phase we also see that generalisation algorithms are improved by generalising objects using their geographical context, taking topological relations and other spatial relations as well as constraints into account. Also in this phase manual (on-screen) work is still required to obtain satisfactory products. This phase is currently practiced in most NMO's.

Future use of framework data requires a new approach of generalisation. In figure 1e the situation is shown that will most probably be the environment that need to be faced in the coming years. A national mapping organisation is responsible for a single large-scale up-to-date object oriented database. From this framework database any or at least a broad variety of demand(s) for topographic information can be fulfilled, either for map products but also for other purposes.
The datasets derived from the framework database are preferably dynamic datasets and are uniquely generated for the particular application at hand. They can be seen as the former derived landscape models and can be described in formats that integrate with Web technologies and tools to work within (N)SDI's, e.g. xsd (for the datamodel) and xml (for the actual data).
The derived data sets are generated via a *database* generalisation process that requires no or a limited amount of interactive intervention and that is implemented within the SDI. The dynamic data sets can be used in any geo-application like for instance car navigation systems that might not even require a map at all. Maps can still be created from the dynamic data sets. This includes the data model, the data itself, the symbol catalogue and the actual drawing code in for example SVG (Scalable Vector Graphics) for 2D data or X3D (Extensible 3D) for 3D data. The process of going from the derived landscape model to the cartographic product includes the *graphic* generalisation.
The database with features in this phase is actually similar to the landscape model in the previous phase. The generalisation in this phase could build on the progress made in separating the model and graphic aspects of the problem in the previous phase (figure 1d) distinguishing between generalisation aiming at good cartographic products and database generalisation. The cartographic product will be just one of the many geo-applications.

3. GENERALISATION OF FRAMEWORK DATA: EXAMPLES OF CURRENT PRACTICE

To illustrate current practice of generalisation we will describe the generalisation procedure within the Dutch Topographic Service (section 3.1). In section 3.2 we will briefly describe two examples of commercially available generalisation software.
The reason why we selected the Dutch Topographic Service is not because it maintains an advanced or primitive system, but because of the easy access to data and our knowledge about

this particular organisation. The aim of this description is to show how a West European country is dealing with generalisation and what problems it meets. It is not the aim of this example to give an overview on the state-of-the-art of generalisation within mapping agencies in general. Therefore an extensive research including several case studies would have been needed, which would definitely be very helpful in research on generalisation.
The examples of generalisation software are an illustration of the software that is directly available. To meet specific needs, many (semi) user-defined implementations are available. However here we focus on two commercial products.

3.1 Generalisation in practise: the Dutch case

Topographic products of the Topografische Dienst

The Topografische Dienst in the Netherlands (Topografische Dienst Kadaster, 2004) is responsible for the topographic data in the Netherlands (see figure 2). The Topografische Dienst finished the process of digitising paper map sheets in 1997 for the complete national coverage at scale 1:10 000, stored in a database called TOP10vector. This database serves as a direct source for the 1:10 000 and 1:25 000 paper maps. The 1:25 000 product is scanned to produce a digital raster version (TOP25raster). Through interactive on-screen generalisation of the TOP10vector database, a second topographic database is derived: the TOP50vector. Products based on this database are the 1:50 000 paper map sheets and a scanned raster version (TOP50raster). Interactive generalisation of the TOP50vector database leads to a 1:100 000 database, the TOP100vector (primarily used for printing a 1:100 000 paper map for military purposes), and a 1:250 000 database, the TOP250vector. From the latter database a road map of the Netherlands is produced, which is also available in a scanned raster version (TOP250raster). Finally, the TOP250vector database is again interactively generalised to produce a 1:500 000 database (TOP500vector), which is used for printing a 1:500 000 paper map for military purposes. The TOP10vector, TOP50vector and TOP250vector databases are regarded as the most important base data sets and these data sets are primarily maintained for map products. The TOP100vector and TOP500vector databases are only in use for military map production.

Figure 2: Examples of topographic datasets in the Netherlands: TOP25raster (which is based on the Top10 data set), TOP50raster and TOP250raster

Recently the Topografische Dienst has merged with the Netherlands' Kadaster into one organisation. Consequently, the Large Scale Map of the Netherlands (GBKN) (ranging from 1:500 to 1:2000) is also one of the topographic products of the Topografische Dienst Kadaster.

To meet changing (GIS) user-needs and changing technologies, the Topografische Dienst started a research in 2000 to come to a new object oriented data structure and data model for their vector products (Bakker and Kolk, 2003; Knippers and Kraak, 2002). The first goal of this research project is to reengineer the data model of the TOP10vector,
Other partners in this project are the Centre for Geo Information of Wageningen University (user requirements and evaluation), ITC (our Department, responsible for the conceptual data model) and the Technical University of Delft (translation of the conceptual model into a technical model). The research project is part of a larger program to improve the products and production environment of the Topografische Dienst.

The research project has resulted in a prototype TOP10NL, which is now being tested and evaluated, and which will become a final version in the summer of 2004. It is expected that TOP10NL will come into production in 2005. The main characteristics of the new structure are: an object-based data structure, unique ID's, more attributes, change-only updates, seamless database, multiple geometries and linking possibilities with other geo-databases. ISO and OpenGIS Consortium standards (e.g. Geography Markup Language) are adopted for the exchange of the data.

Generalisation wishes of the Topografische Dienst

For the short to medium term future the need for generalisation within the Topografische Dienst comprises three aspects:

- generalisation of buildings from the GBKN to be inserted in TOP10NL (see figure3)
- generalisation of TOP10NL to produce small-scale data sets ranging from 1:50 000 to 1:500 000
- generalisation of GBKN to come to a reference data set that can be used to generate (semi-)automatically small scale data sets (1:10 000 and smaller)

At this moment, no automatic generalisation procedures exist within the Topografische Dienst. The topographic data sets at different scales (TOP10vector, TOP50vector and TOP250vector) are maintained independently from each other and when updates occur, all data sets need to be updated separately. Obviously, this has many disadvantages (risk of inconsistencies, update-work has to be carried out more than once, data sets are not of the same date and therefore not as up-to-date as possible). Consequently the Topografische Dienst is looking for automatic generalisation procedures in the future that can be performed on the fly. If it turns out that on the fly generalisation is too complex, an intermediate solution will be support of multiple representations. This means that the existence of more than one representation of real world objects (i.e. multiple representations) is supported by the database by maintaining links between the different representations and by supporting appropriate update mechanisms e.g. an update in one data set has consequences for the other data set (see also Frank and Timpf, 1994; Friis-Christensen et al. 2002; Spaccapetra et al., 2000).

As part of the Top10NL project, a research has started on how to create data sets ranging from 1:10 000 to 1:500 000 out of the Top10NL. Going to a smaller scale may change the geometry, the symbolisation as well as the object definition. In some cases this lead to a re-classification of objects e.g. reclassification of different kinds of forest types that are distinguished at a large scale to one type 'forest area' at a smaller scale.

Figure 3: Using buildings from the Large Scale Map in the TOP10vec requires generalisation of the objects.

In order to incorporate generalisation in the data model of the Top10NL itself, the data model of the Top10NL data set is being extended with 'generalisation characteristics' that indicate for homogenous class of objects, e.g. buildings, roads, water elements (Knippers and Kobben, 2003):

- the scale of the generalised result (1:50 000, 1:100 000, 1:250 000 etc)
- which actions have to be taken to effectuate the generalisation (selection, reclassification, simplification, displacement, merging, exaggeration, symbolisation)
- rules of generalisation, e.g. 'separate buildings within a city area at scale 1:50 000 will preferably be joined to one built area'
- whether the generalisation can be performed automatically (e.g. selection), semi-automatically or has to be done manually
- the algorithm that is needed for the generalisation

Rules that are specific for objects can be defined at object-level. For one object, many entrances of generalisation characteristics may occur. For example a building defined in TOP10NL may be simplified, displaced and exaggerated at scale 1:50 000, and reclassified and merged at scale 1:100 000. The generalisation characteristics are based on generalisation directions (already defined within the Topografische Dienst, see Topografische Dienst, 1998 and Topgrafische Dienst, 1996), such as 'select only those elements that are needed for the purpose and the scale of the data set', 'emphasise important objects and remove less important objects', 'when displacing objects, take into account the priority-order of objects'.

Once the Top10NL data model has been finalised, the generalisation characteristics can be inserted for every object class. However, first the Top10NL data model needs to be extended with object classes that occur at smaller scales but that do not occur in the Top10NL.
Incorporating generalisation characteristics in the data model of Top10NL only covers the conceptual part of generalisation. The next (and very challenging) issue is how to perform the actual generalisation, which needs to be further studied.

3.2 Two examples of commercial software

To actually perform generalisation within NMO's, algorithms need to be implemented in commercially available software. In this section two examples of generalisation software that are available in the market are briefly described.

Clarity, Laser-Scan

Clarity (Laser-Scan, 2003) is a commercial product that is based on the AGENT (Automated Generalisation New Technology) research project (Ruas, 2000b). Laser-Scan joined the multi-national consortium as the software supplier. Other members included IGN (the French national mapping agency in Paris) in the lead role, and three universities: Zurich and Edinburgh (for their expertise in geography and cartography), and Grenoble (for its work in artificial intelligence). Three years of research and development resulted in a prototype agent-based generalisation system, based on Laser-Scan's Gothic LAMPS2 object-oriented database. The system (AGENT) uses the generalisation model of Ruas (Ruas, 1998; Ruas, 2000a). The final version of the AGENT prototype contained twenty-five generalisation algorithms, eight algorithms of control and twenty-nine algorithms of measurements, which indicates the complexity of a generalisation procedure that is based on user requirements. This complexity means that the software can only be used appropriately by skilled users.

In the system, individual topographic objects such as houses and roads become active agents and co-operate through simplification, typification and displacements of themselves to achieve an acceptable generalised result. Geo-agents can be generalised taking into account their particular situation, with similar features potentially having quite different operations applied to them. An agent does not try all solution and take the best but it uses knowledge to optimise the convergence (see also Ruas 1998 and Ruas, 2000). Each agent computes its state and according to this information it filters appropriate algorithms to be tried. The AGENT prototype was made available in the commercial LAMPS2 Generaliser product and has been extended for production use at several National Mapping Agencies including KMS Denmark (Sheehan, 2001) and IGN France (Lemarié, 2003). Clarity is the next version of the LAMPS2 Generaliser and is also based on the Gothic object-oriented database.

During generalisation, micro-agents are used that define generalisation rules for individual objects (to avoid the inappropriate use of the same tools globally throughout a data set), meso-agents that define generalisation rules between individual objects to avoid consequential conflicts and macro agents to retain the overall coherence of data. A generalisation procedure comprises the following aspects:

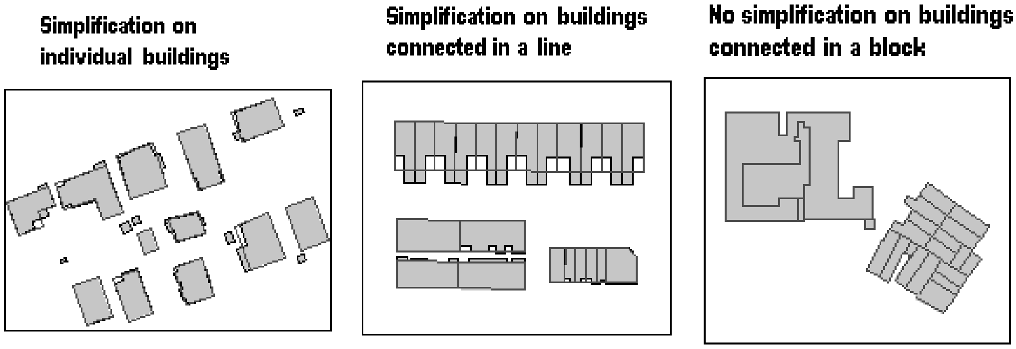
- measures, e.g. how big is this object? what is the distance between objects?
- constraints, e.g. the minimal object area at a given scale
- algorithms, a core set of algorithms is included, such as scale a polygon by a given factor, replace a building geometry with the Minimum Bounding Rectangle, apply Gaussian smoothing to a line geometry etc.

- plans, which determine the choice and order in which algorithms are executed
- re-evaluate to determine (by using measures and constraints) if the previous plan was a success or not, and if not the state will be backtracked in order to try another plan.

Generalisation within ArcGIS

ArcGIS is a widely used system in GIS applications and also within topographic services and mapping agencies. The generalisation tools that are supported in the ArcToolbox of ArcGIS 8.3 are (Esri, 2004):

- Create Centerlines: Produces centerlines (single lines) from dual-line features, such as road casings, based on specified width tolerances.
- Dissolve: Merges adjacent polygons, lines or regions which have the same value for a specified item.
- Dissolve Regions: Creates a region subclass by merging polygons or regions that have the same value for a specified item.
- Find Building Conflicts: Searches a data set for overlapping and closely together buildings, based on a specified distance, and records the occurrences.
- Simplify Buildings: Simplifies the footprint of buildings and creates a preliminary region for each simplified building (see figure 4).
- Simplify Lines: Reduces details from lines based on a specified tolerance and simplification method.


Simplification on individual buildings

Simplification on buildings connected in a line

No simplification on buildings connected in a block

Figure 4: Simplifying buildings in ArcGIS

Although generalisation procedures can only be performed on a whole dataset, the algorithms in the ESRI software take in some way the geographical context into account. For example when topological errors are encountered in the SimplifyLine process (e.g. line-crossing, line-overlapping or zero-length lines) lines are 'undersimplified', using smaller tolerances, avoiding line errors. ESRI is working on incorporating spatial constraints in generalisation algorithms e.g. to preserve the relative position of features and to avoid undesired interferences. For instance a gas station on one side of the road should not end up on the other side

ESRI announced that in version 9 (since a few weeks available) Database Cartography will be introduced (ESRI, 2004). Cartographic layers will be stored in the geodatabase with rules that define it. So, along with the base GIS data, cartography as another set of layers will be stored. The cartography will be linked to the underlying GIS data. According to ESRI, this will solve many problems (e.g. map series, generalisation, multiple representation, and multiple scale) (ESRI, 2004).

4. CONCLUSION: ITC RESEARCH AGENDA ON GENERALISATION

This paper sketched the background of the research on generalisation. In section 2 the changing role of framework data was described. It was concluded that the developments of framework data, at least from the user-requirements perspective, are towards maintaining one single data database within a SDI, from which a broad variety of datasets sets can be derived (preferably) on the fly. These data sets include sets to produce (digital) maps, but also specific selections of the base data set (e.g. only the road network or objects that fulfil a specific condition), low resolution data sets, data sets fused with other data, semantically transformed data sets etc.
As was seen in section 3, current practise is still not totally ready to support generalisation of framework data within a SDI and research is needed to be able to support such an environment and to see how far such an environment is realisable, which is an important first step.

Our long-term research will have the optimal environment in mind because in this environment framework data can be optimally used and the generalisation of framework data can be adjusted to the changing user-requirements. We will define intermediate steps in order to adjust the concepts to technological possibilities and to achieve intermediate results that *are* supported by techniques. Therefore we aim at prototyping parts of the concept in order to give insight into possible solutions and (temporarily) bottlenecks.
Our research will include the following activities:

- Design a core data model of framework data from which a broad variety of data sets can be derived, first at national level but preferably it should be a data model that is not (or as less as possible) application or country specific. The data model should take into account (changing) user requirements of framework data as well as technological possibilities;
- Make inventory of generalisation in practice within organisation that are producers of framework data, e.g. by organising a workshop and by visiting several national mapping organisations. The aim is to get an overview of general generalisation problems and requirements.
- Evaluate current (commercial) implementations of generalisation by designing appropriate methodologies for evaluation and comparison of algorithms and approaches, e.g. how to measure the appropriateness of a generalisation implementation;
- Extend existing software to fill gaps and to show limitations and possibilities of technology;
- Design a general generalisation process, at least at the conceptual level, that is appropriate for any generalisation problem of framework data, the result of this will be a more concretised and better argued version of the architecture sketched in figure 1e;
- Define the theoretical formalism of data models and structures to support the architecture that we described in figure 1e and design the needed concepts to implement the environment of figure 1e;
- Build prototypes that implement (part of) the concepts of the previous two steps to evaluate the designed concepts and, if needed, to adjust the designed concepts.

We will use the Dutch case as example in our research, although we will also look at other countries, both within and outside Europe. It should be noted that many minor differences are present between framework data from different countries and between producers of framework data due to different organisation, different implementation history but also differences in landscape in different countries. However our research will focus on generalisation in a context of growing communities that make use of the same framework data within national and international SDI's.

As was seen in this paper, the processes involved going from a large-scale data set to a (or preferably any) small-scale data set are very complex. Thus, it is obvious, that (at least today) the generation of a data set in arbitrary scales can not easily be solved without pre-generalised data sets that have been produced by using (semi-) automatic and manual methods. Therefore, intermediate solutions should support multiple representations of framework data at several scales. Therefore our research will intermediately focus on multiple representations in DBMS (data structure, data models, constraints, spatial operations in such an environment, maintaining interrelationships between different representations of same real world objects, update propagation).

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