ScaleMaster2.0: A ScaleMaster Extension to Monitor Automatic Multi-Scales Generalisations

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Abstract. Little by little, the co-existing geographical datasets are integrated into Multi-Representation Databases, where the datasets represent different level of detail, or different point of views for the same geographical features. The ScaleMaster model from Brewer and Buttenfield (2007) allows formalising how to choose the features to map from the different datasets. The paper proposes an extension of the ScaleMaster model that drives automatic generalisation rather than guidelines for manual mapmaking. This ScaleMaster2.0 has been implemented and is tested for a use case with real data.

Keywords: Generalisation, ScaleMaster, Multi-Representation Database

1. Introduction

The progress of geographic information capture and the emergence of volunteered geographic information allow more and more to command multiple datasets on the same territory (Baella et al. 2012). These datasets have different level of detail or perspective. As a consequence, space may be represented differently in each dataset. The dataset variety makes mapmaking at different scales easier, relating a dataset level of detail to a visualisation scale. For instance, IGN (French national mapping agency) BDTOPO® can be mapped at the 1:15000 scale. However, making maps between the existing scales is necessary as it would greatly improve geoportals (no big gap between representations through zooming) and on-demand mapping (i.e. a default user may need a scale different than the pre-existing ones). Added to that, making maps that combine datasets is also necessary, even if the levels of detail (LoD) are not the same. For instance, a map for boat shuttles may require information from a topographic dataset in order to map the coast, and information from a bathymetric dataset to map the sea. Both issues require cartographic generalisation.

Therefore, a model is required to describe and produce smooth or continuous transitions between scales, using multiple data sources, in order to make legible generalised maps for a given non standard scale. To be integrated in mapmaking procedures, it should provide automatic generalisation whatever the scale of the map is. The ScaleMaster, proposed by Brewer and Buttenfield (2007), provides a model to describe such smooth transitions, but maps are produced interactively by a cartographer that reads the ScaleMaster. The paper proposes an extension of the ScaleMaster, called ScaleMaster2.0, which is readable by a generalisation system to provide automatic generalisation.

The next part details the problem of multi-scales generalisation and presents related work. The third part describes the proposed extension of the ScaleMaster model.

Then, experiments carried out on real data are presented and discussed. Finally, the fifth part draws some conclusions and explores further work.

2. Models for Multi-Scales Generalisations

2.1. MRDBs and Multi-Scales Generalisations

We call a Digital Landscape Model (DLM) a geographic dataset that has not been transformed for mapping purposes, and Digital Cartographic Model (DCM) a dataset that can be mapped at a given scale thanks to generalisation (Meyer 1986). Producing maps is thus the creation of a DCM from a DLM, using generalisation.

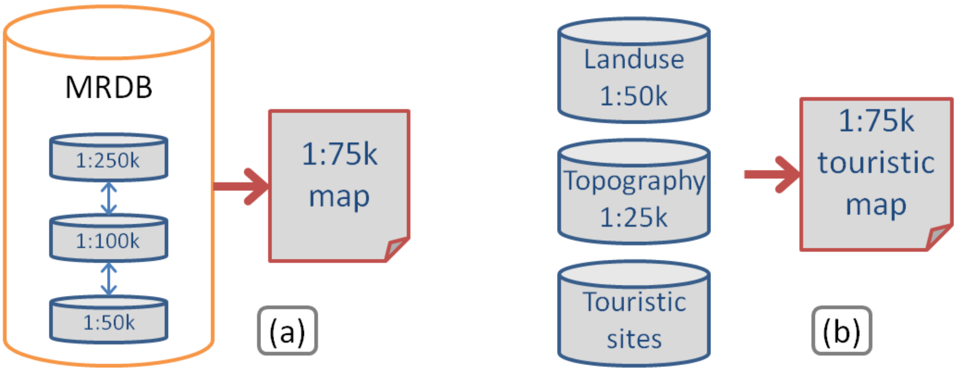

Figure 1. (a) Multi-Scales generalisation from MRDB. (b) Multi-Scales generalisation from unrelated DLMs.

The aim of the paper is to carry out multi-scales generalisation, which is the creation of a DCM adapted to a target scale chosen by a user in a continuous range of scales, i.e. the user can pick whatever scale he wants. For instance, the system we aim at developing can automatically create either a 1:75k map or a 1:165k map from detailed DLMs. Multi-scales generalisation can be achieved by the use of a multiple representation database (*Figure 1a*), where the multiple representations of features correspond to different LoDs or scales. But multi-scales generalisation can also be achieved by the use of unrelated databases (*Figure 1b*) that contain complementary information that is generalised and mixed in the DCM (consistency between datasets should be achieved by another process). In both cases, the tricky problem is to produce DCM for in-between scales, which do not correspond to the LoDs of the DLMs.

2.2. Related Work

Producing maps at different scales with or without MRDB structures has been a research topic for several years, as generalisation techniques were improving. The first approach considers some well defined scales or LODs at which new DLMs or DCMs have to be derived from the existing DLMs. It is the standard approach of National Mapping Agencies that often produce one or two detailed DLMs and want to derive new products at smaller scales (Trévisan 2004). Two strategies coexist in this approach, the star and the ladder architecture (Stoter 2005). For instance, the ladder approach is used in Catalonia (Baella et al. 2012) and the star approach at the Ordnance Survey (Regnauld et al. 2012). Buttenfield et al. (2011) compared both strategies for the generalisation of several hydrographical DLMs. The paper concludes that both strategies lead to similar results for river network simplification, when the scale change is not too significant (200K to 500K), but the star strategy may cause problems when the scale change is large (e.g. 200K to 2M). However, this approach does not prevent from problems when in-between scales are required.

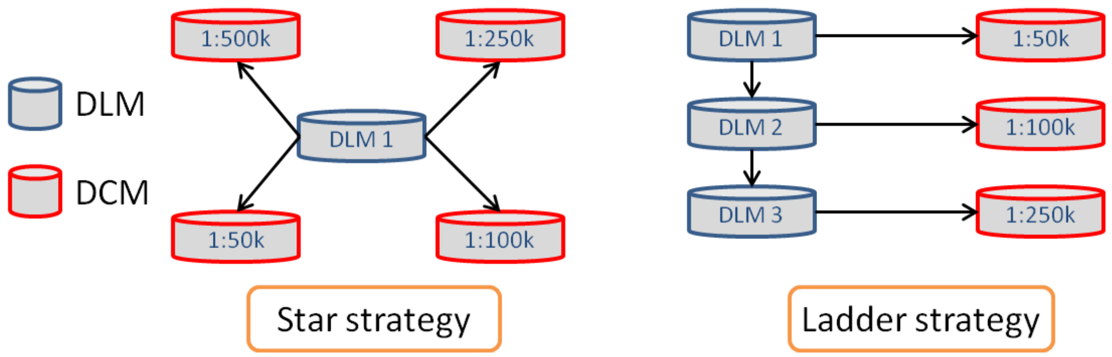

Figure 2. The Star and Ladder strategies to generalise predefined DCMs.

Otherwise, research tried to define models that enable smooth or continuous generalisation, i.e. data can be derived at any scale. The ScaleMaster model (Brewer & Buttenfield 2007) allows the description of continuous rules to map a theme at a given scale in a timeline style where scale replaces time. The ScaleMaster model was used in a framework for building MRDBs, where it helped to balance workloads between all generalisation tasks (Brewer & Buttenfield 2009). It has also been used in a project for multi-scales generalisation of US toponyms (Brewer et al. 2011). The ScaleMaster is not an interactive tool, but a formal way (Excel sheets) to record symbol changes for manual map design.

In order to produce maps with variable scales (e.g. large scale around user's location and small scale far from the user), Harrie et al. (2002) proposed continuous distortions of map features from large scale to small scale.

Finally, the vario-scale model (van Oosterom 2005, van Oosterom & Meijers 2011) is an attempt to structure features with continuous representations through scales. The vario-scale was successfully carried out on partition map features (Meijers 2011).

This literature provides different methods for multi-scale mapping but do not rely on the same hypotheses on initial data. We are interested in multi-scale mapping from existing DLMs at different resolution, so the ScaleMaster framework (Brewer & Buttenfield 2007) seems the most appropriate starting point. The ScaleMaster has a Condition-Action view of generalisation (Harrie & Weibel 2007) whose limitations, compared to the Constraint-Based view, are discussed in section 4.4. However, multi-scale mapping is more at the 'Global Master (Ruas & Plazanet 1996) level, which is a Condition-Action scheme that encapsulates Constraint-Based generalisation procedures like AGENT (Barrault et al. 2001) or Least Squares (Harrie & Sarjakoski 2002, Sester 2005). Thus, the ScaleMaster framework can be a way to encapsulate Constraint-Based processes as well when necessary. The next part describes our proposed extension of the ScaleMaster that allows automatic derivation of DCMs at multiple intermediate scales.

3. A ScaleMaster Formalisation and Extension, the ScaleMaster2.0

3.1. From ScaleMaster to Automatic Generalisation

The ScaleMaster framework is a very rich tool, but it is designed for manual mapmaking on standard GIS. In order to extend the framework to enable automatic multi-scale map production, some issues have to be overcome. First, the ScaleMaster is dedicated to standard symbolisation and generalisation operations that can be triggered from a GIS (Figure 3). But, map generalisation often requires complex processes (see an overview in Harrie & Weibel 2007) that may combine multiple operations. So, the extension has to handle both complex processes as standalone operations and the use of several processes for the generalisation of a given theme.

Then, complex processes but also simple generalisation algorithms require the definition of specific parameters to work properly and derive legible data at a given scale. In order to be triggered automatically from the ScaleMaster, the processes to be used have to be described including the parameters and their values for each scale range (e.g. between 1:50k and 1:100k, use *process1* with *parameter1* = 12), which is not the case in the current ScaleMaster framework (Figure 3).

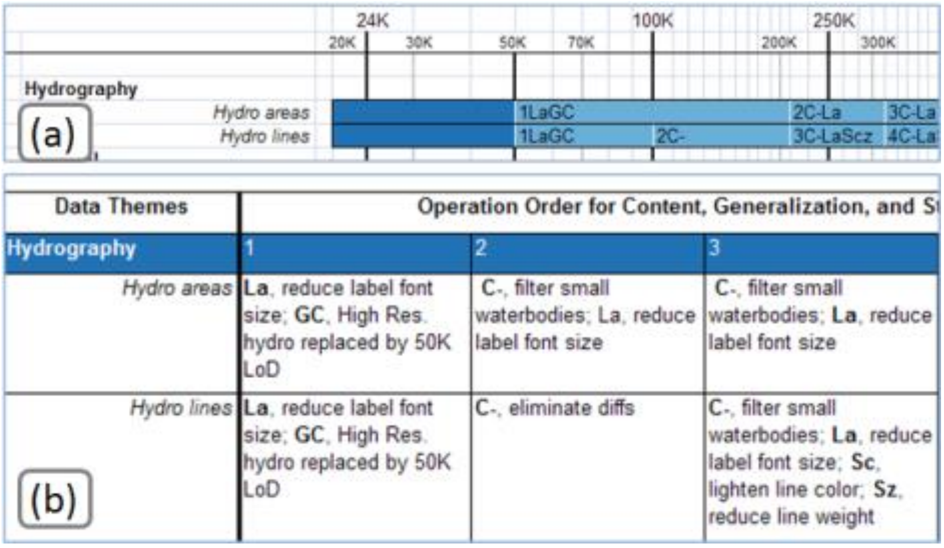

Figure 3. (a) extract from a ScaleMaster for hydrography data. (b) the operations related to the keys used in the ScaleMaster extract.

Moreover, if several processes can be dedicated to the generalisation of a theme, a processing order (i.e. priorities) has to be included in the ScaleMaster extension. For instance, to generalise the built-up area parcels from 1:100k to 1:250k, first merge the adjacent features, then select the ones bigger than 10 km². If the processes are applied the other way round, the result is completely different (Figure 4).

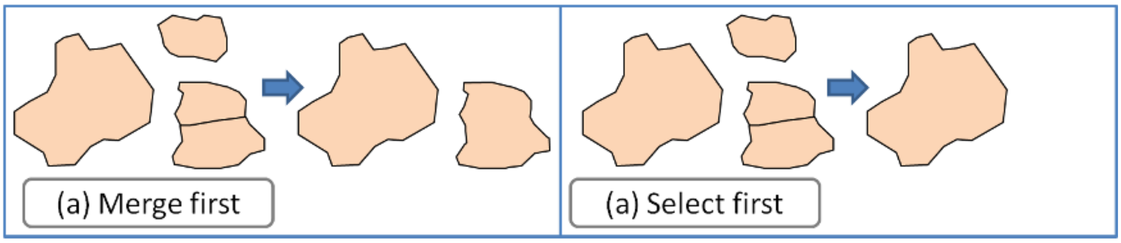

Figure 4. Illustration of the importance of processing order in map generalisation: it greatly impacts the results.

Finally, map generalisation is highly context dependant and initial data often has to be enriched with implicit patterns and structures to be properly generalised (McMaster & Shea 1988, Mackaness & Edwards 2002). For instance, road network selection requires the identification of complex junctions like roundabouts. So, the ScaleMaster extension needs to handle the definition of required enrichment for some themes.

3.2. The ScaleMaster2.0 model

Considering the issues presented in the previous section, we propose an extension of the ScaleMaster framework that enables automatic multi-scale generalisation, the ScaleMaster2.0 model. It takes up the components of the ScaleMaster framework, enriching them to overcome the issues of automation (Figure 5).

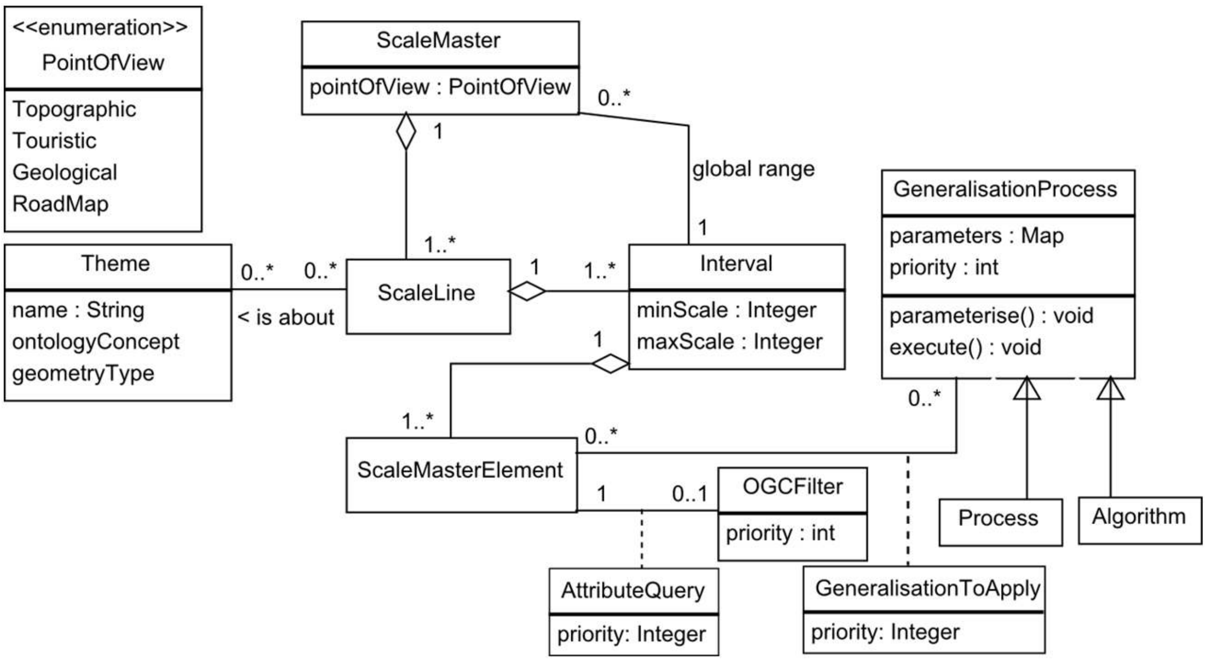

Figure 5. UML class diagram of the ScaleMaster2.0 model.

Like in the initial model, where different ScaleMasters were defined for topographic, road or geological maps, a ScaleMaster has a unique *point of view*, using the MRDB vocabulary. A ScaleMaster is defined on a global scale range and is composed of *ScaleLines* (in analogy to timelines).

A *ScaleLine* described the generalisation rules for one data theme across the scales. In the proposed model, it is composed of scale intervals (e.g. 1:25k to 1:50k) where several *ScaleMasterElement* instances are defined, each one monitoring the generalisation of a source from which the theme is derived. For instance, the "river line" theme can be derived from river lines from a dataset and river areas from another, and each case is monitored by a different *ScaleMasterElement*.

The *ScaleMasterElement* is the key component of the model as it holds the generalisation rules. It is composed of required enrichments, an attribute based query that selects the appropriate data for the scale interval (described with the OGC Filter norm) and of several generalisation processes, described with the parameter values. Priorities are set on the filter and on each process.

In order to allow the re-use of previously computed generalisation, the ScaleMaster2.0 model adds a MRDB n:m link between initial and generalised features.

3.3. Ontologies to Control the ScaleMaster2.0

ScaleLine instances of the ScaleMaster2.0 model describe the derivation rules to display a given theme on the map (e.g. road lines, building points or water areas). Thus, the theme of the ScaleLine is composed of a geographic concept (e.g. road) and a geometry type (e.g. line). In order to guarantee the interoperability of the ScaleMaster2.0, a geographic concepts ontology is required to control the geographic concept of the theme only with ontology concepts. Several ontologies describing geographic concepts exist and we used the one produced at IGN France, by Abadie (2009).

Moreover, an ontology of generalisation *algorithms* and automatic *processes* is necessary, in order to fill the ScaleMaster elements for a given scale interval. *Algorithms* are implementations of one generalisation operation like displacement, simplification or aggregation. For instance, the well-known Douglas & Peucker (1973) algorithm that filters the vertices of a polyline, is an implementation of the 'filter' operation. *Processes* are complex computer programs that orchestrate the use of multiple operations. The Least Squares generalisation from (Harrie & Sarjakoski 2002) and CartACom (Duchêne 2003) are different examples of the processes that need to be listed in the ontology.

The ontology thus needs to rely on one of the existing generalisation operators taxonomies (Mustière, 2001; Foerster et al, 2007; Roth et al, 2011). The taxonomy from Mustière (2001) is chosen as it is simple and the vocabulary used to name operators is not ambiguous (*Figure 6*).

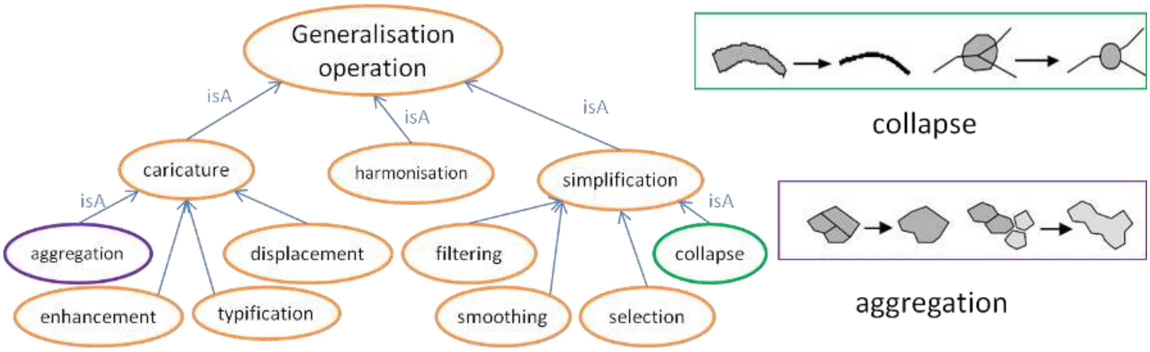

Figure 6. Extract of the generalisation operators ontology, two of the operators being illustrated with examples.

The ontology of algorithms and automatic processes is based on the operators' one. Existing ontologies (Gould & Chaudhry 2012, Touya & Duchêne 2011) were used as a basis but the proposed one differs as it is not intended to be used the same way. *Figure 7* shows how the ontology is modelled centred on the concepts *algorithm* and *process*. An *algorithm* (or a *process*) works on a *geometryType*, applies to *geographic entities* and has *parameters*. An algorithm implements one (or several) operation(s), while a process triggers algorithms (e.g. CartACom process (Duchêne 2003)) or operations (e.g. least squares (Harrie & Sarjakoski 2002) that triggers displacements).

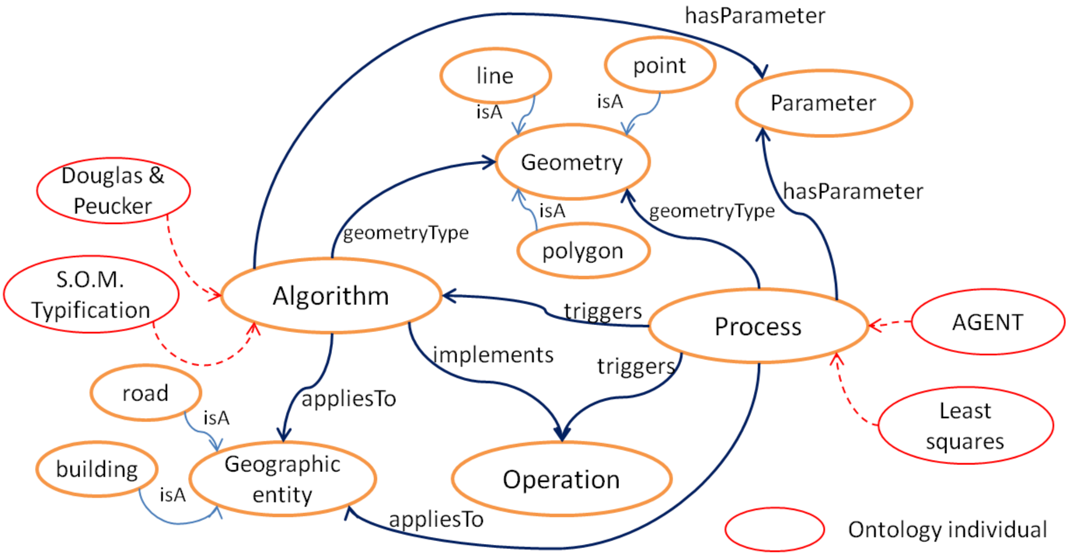

Figure 7. Extract of the generalisation algorithms ontology.

3.4. How to Automatically Process a ScaleMaster2.0

The aim of the ScaleMaster extension is to provide automatic generalisation for every scale within the ScaleMaster range. As a consequence the ScaleMaster2.0 needs an engine that interprets the information contained in a ScaleMaster2.0 and carry out automatic sequences of generalisation procedures. *Figure 8* shows the algorithm used by the engine to carry out automatic generalisation. It's a pretty straightforward algorithm that reproduces the task made by the cartographer in the initial ScaleMaster: themes are generalised from top to bottom of the ScaleMaster, whose order should follow the principle "from the ground up" (Brewer & Buttenfield 2007), i.e. first terrain, then hydrography, then transportation, etc.

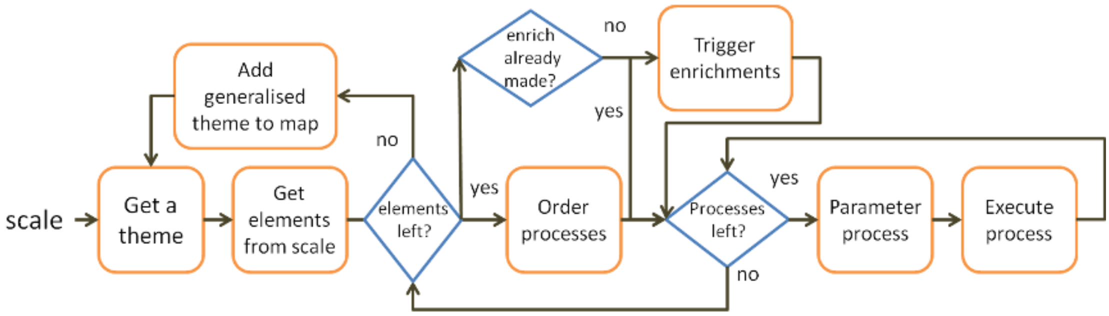

Figure 8. Automatic process of the ScaleMaster2.0 to produce a DCM at a given scale.

Themes and related ScaleLines are picked iteratively from top to bottom of the ScaleMaster. Then, the elements corresponding to generalisation scale are fetched and processed iteratively. For a given element, the processes and the attribute query are ordered by priority, while the required enrichments are carried out if it has not been done for a previous element (several processes may use the same enrichment). When enrichments are made, each process is parameterised and executed on the features described in the element. There is no risk of infinite loop as the number of elements by theme, and the number of processes by element, are finite, as defined by the user in the ScaleMaster.

4. Experiments

4.1. Model Implementation

To implement the ScaleMaster2.0, the CartAGen library (Renard et al. 2011), developed since 2009 by the generalisation team of the COGIT lab, is used. The availability of a large number of generalisation processes and the possibility to manage different databases in the same time justifies the use of this Java platform. The ScaleMaster2.0 implementation is Open Source as part of the GeOxygene project (Bucher et al. 2012).

To facilitate the parameterisation of the model, three XML interfaces are associated to the Java core: the ScaleMaster.xml, Parameters.xml, and Symbology.xml files, as illustrated in Figure 9.

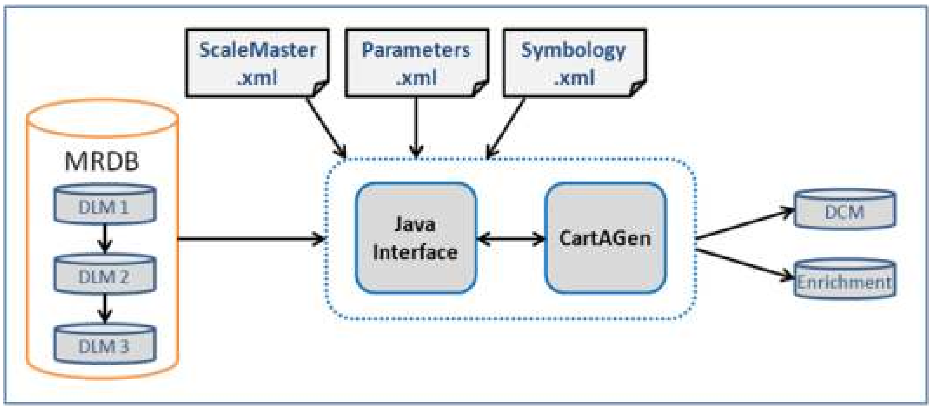

Figure 9. Implementation of the ScaleMaster2.0 model using the CartAGen library

The ScaleMaster.xml file is the XML transcription of the ScaleMaster2.0. As presented in Figure 5, the operations are organised in attribute queries and generalisation processes, for a given scale interval in a ScaleLine. Attribute selection queries are formalised using OGC filters and generalisation processes are structured as a list of processes, involving a series of parameters. These operations are classified by priority order to facilitate the scheduling of the generalisation procedure.

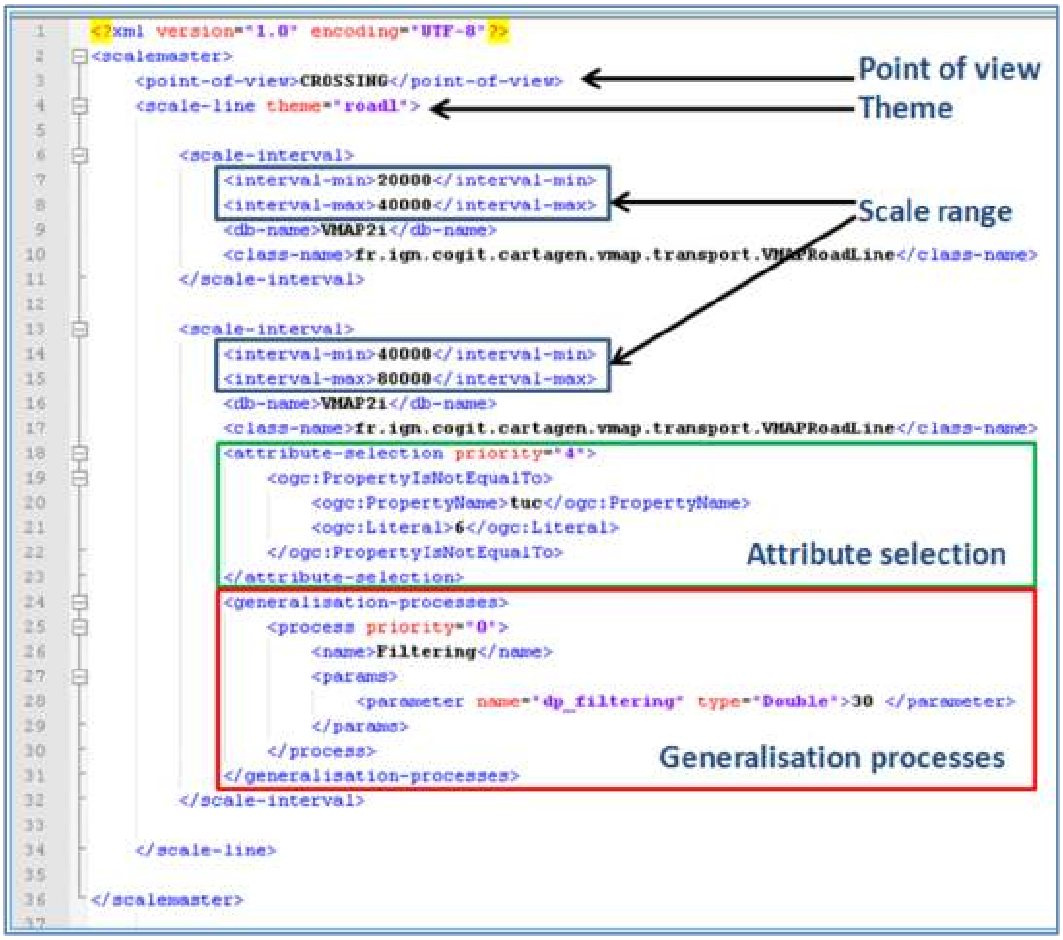

Figure 10. Structure of the ScaleMaster.xml file

The Parameters.xml file defines the map final scale and what DLMs (or layers of a DLM) are available to be used as sources. Finally, the Symbology.xml file is proposed to describe how map themes are displayed. The formalisation of symbology in this XML file follows the SLD (Styled Layer Descriptor) standard.

At the moment, the edition of these three XML interfaces is only available using classical text editors. Nevertheless, an interactive editor, as exposed in figure 10, is also being developed in order to facilitate the parameterisation by the user.

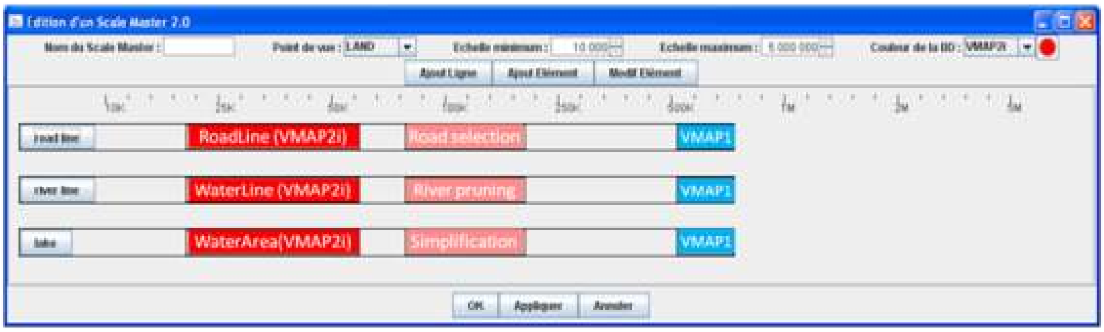

Figure 11. An interactive editor for the ScaleMaster2.0 model

4.2. Use Case

The ScaleMaster2.0 model is experimented using the VMAP MRDB, exploited as part of a research project conducted by the COGIT Lab. The Vector Map (VMAP) is a

MRDB providing a large variety of themes at three different levels of details: VMAP0 for small scales (~1:1000k), VMAP1 for medium scales (~1:250k) and VMAP2 for large scales (~1:50k).

The study area (Figure 12) used for the experiment is located in the region of Abéché (Tchad). Its surface is 1 sq.degree, which is about 12000 km².

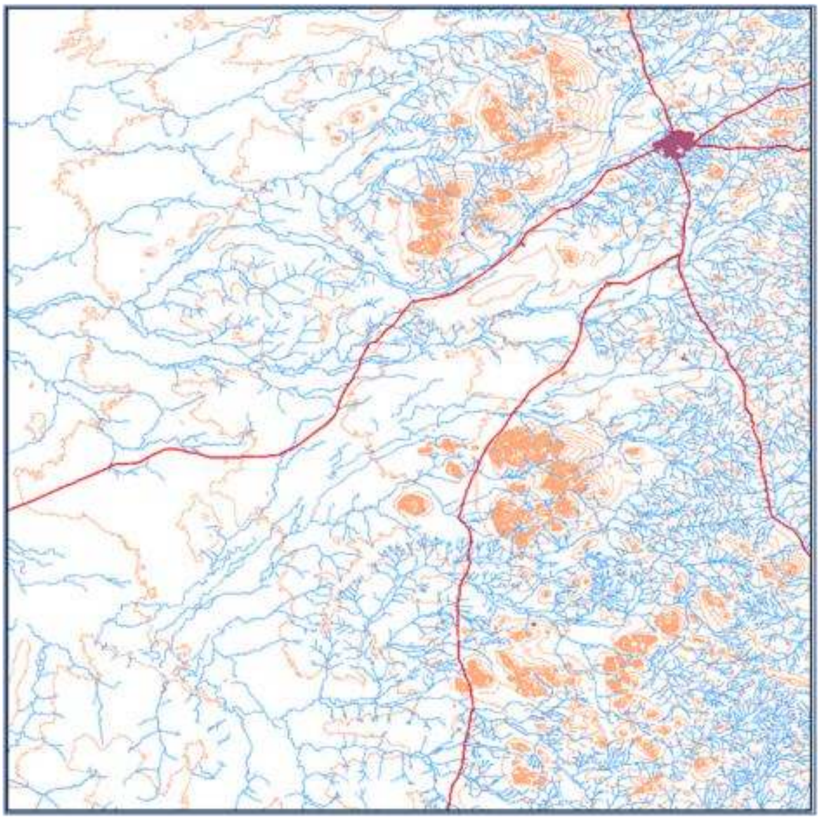

Figure 12. Study area experimented with the ScaleMaster2.0

The following themes are generalised: roads, rivers, lakes, contours, and built-up areas. At the moment, only basic generalisation processes are carried out by the ScaleMaster2.0: Douglas-Peucker filtering, Gaussian smoothing, polygon merging, polygon skeletonization, strokes-based road selection and contours selection.

The main issue of the ScaleMaster2.0 editing deals with the parameterisation of the different algorithms used for generalisation. Indeed, experiments by trial and error need to be previously carried out, in order to define the appropriate value of the parameter according to the target scale. To set these values, specifications of the derivation rules from VMAP2 to VMAP1 DLMs, and VMAP1 to VMAP0 DLMs were used.

For example, from VMAP2 (~1:50k) to VMAP1 (~1:250k), only 1 contour out of 5 is preserved. Thus, to derive contours at the scale 1:100k, 1 contour out of 3 is preserved, and at the scale 1:200k, 1 contour out of 4 is preserved.

4.3. Results

To experiment the ScaleMaster2.0 model, we propose to derive DCMs at three target scales from the VMAP MRDB: 1:100k, 1:200k (from VMAP2) and 1:500k (from VMAP1). The 1:250k results are just VMAP1 extracts for comparison purposes.

The derivation of the road theme is mainly based on attribute filtering (important roads are kept) and strokes-based selection (Thomson & Richardson 1999), with Douglas-Peucker filtering (Figure 13).

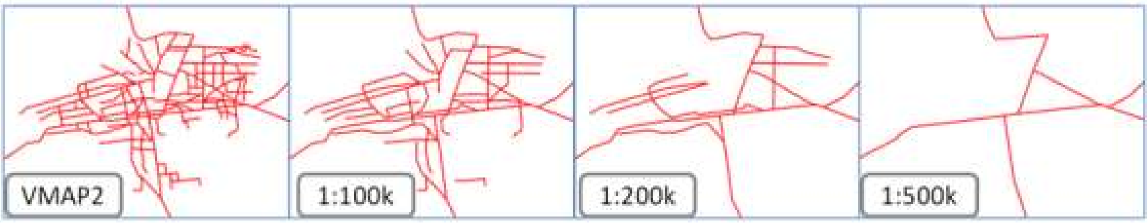

Figure 13. Derivation of roads from VMAP MRDB.

The derivation of rivers for the three target scales also relies on attribute selection and geometrical filtering. Figure 14 clearly demonstrates that the use of the ScaleMaster2.0 model allows the automatic generation of continuous representations of a theme with smooth changes in the level of details.

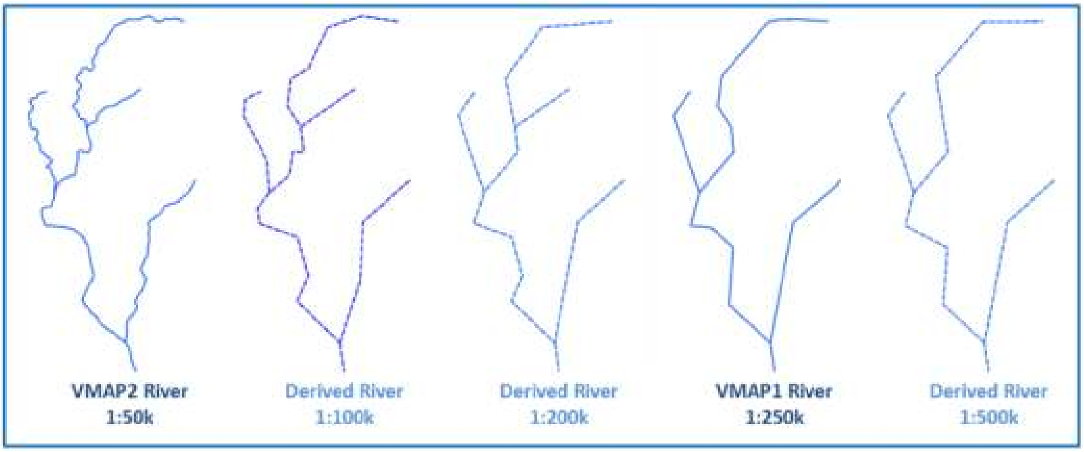

Figure 14. Derivation of rivers from VMAP MRDB.

The generalisation procedure of the river theme also integrates the possibility to collapse river areas from polygons to polylines, when their width is below a given threshold (Figure 15). A skeletonization algorithm is provided in the ScaleMaster2.0 implementation to allow this task.

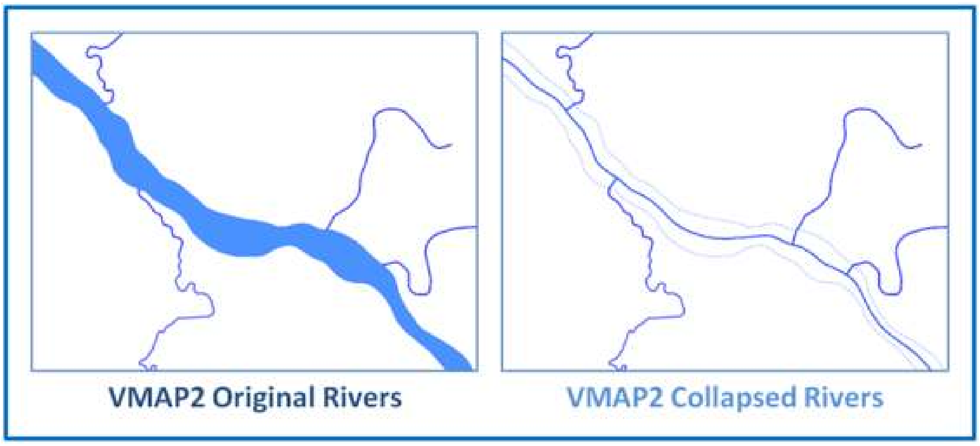

Figure 15. Collapse of the hydrographical surfaces from polygons to polylines.

The generalisation of urban areas illustrates the possibility given by the ScaleMaster2.0 model to order processes in a generalisation procedure. As exposed in Figure 16, the derivation of urban areas at the 1:100k scale involves: 1- the merging of neighbouring polygons, 2- the filtering with appropriate parameters.

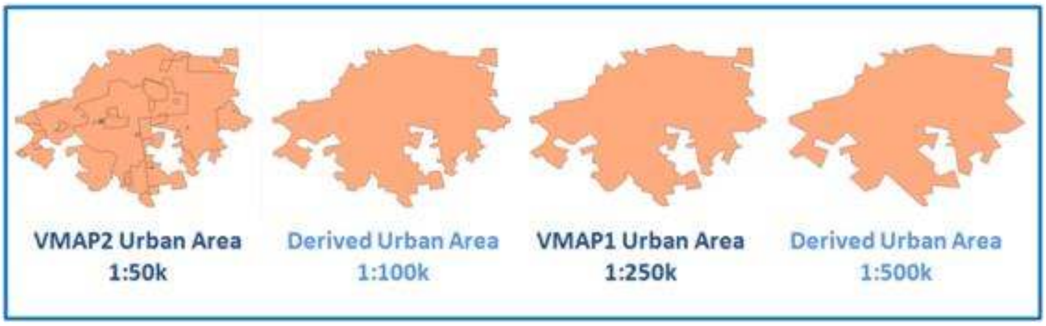

Figure 16. Derivation of urban areas from VMAP MRDB.

The derivation of contour lines (Figure 17) also involves two processes : the selection of contour lines (1 out of 3 at the 1:100k scale, and 1 out of 4 at the 1:200k scale), and a light filtering of the preserved contours.

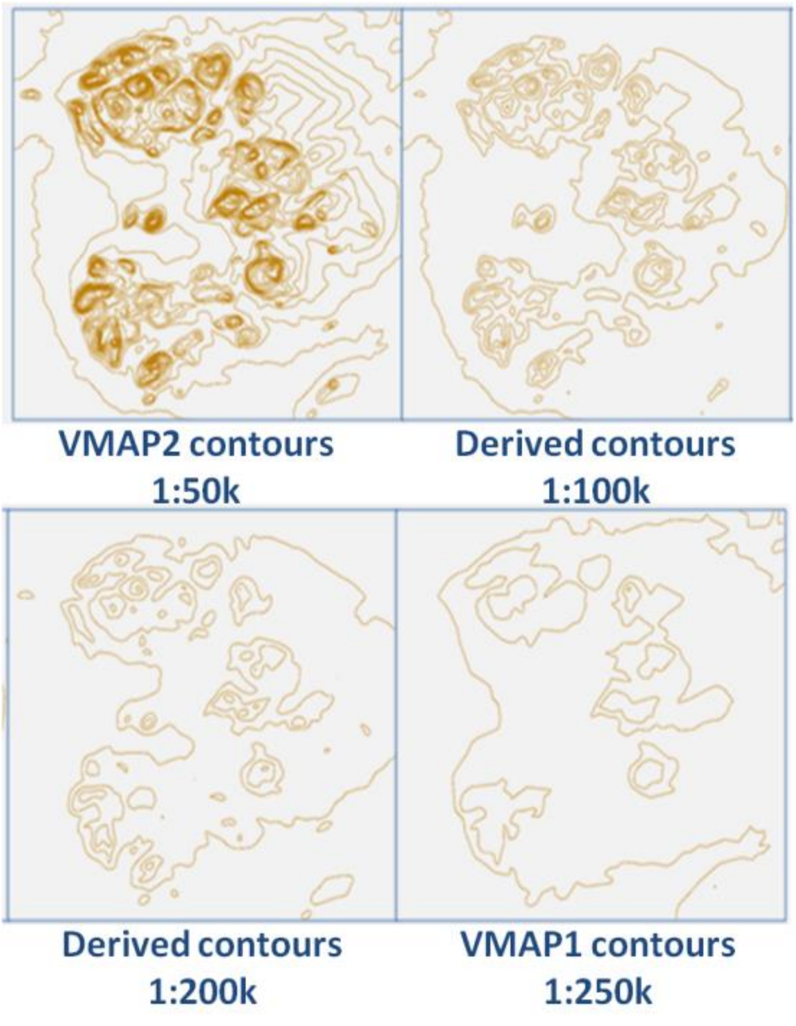

Figure 17. Derivation of contours from VMAP MRDB.

These results underline the possibility offered by the ScaleMaster2.0 model (and its implementation) to automatically derive DCMs from a MRDB, involving the use of several generalisation processes. In terms of computing performance, the ScaleMaster2.0 is also efficient, but its efficiency greatly depends on processes efficiency. For instance, the generalisation procedure of the five VMAP2 themes at the 1:100k scale needs almost 10 seconds, including data loading and exporting.

Finally, the enrichment of the model with other algorithms available in the CartAGen library will give the opportunity to provide better generalisation results, especially for themes that require contextual algorithms like roads, rivers or land use.

4.4. Discussion

Although the ScaleMaster2.0 model has the genericity to allow a large variety of generalisations, it still has limitations to discuss. First, there is a loss compared to the previous ScaleMaster model in relation to symbol design. We still do not have symbol information in our research project, so we did not focus on modelling symbol choices. We plan to extend the model to allow symbol design at the ScaleMasterElement level, using the SLD standard.

Up to now, the generalisation processes triggered by the ScaleMaster2.0 only concern one of the themes of the map (e.g. not roads and rivers at the same time). But such operations are frequently required, for instance to remove symbol overlaps between network features like parallel roads and rivers. Such operations cannot be included in one of the ScaleLines due to processing order issues, so the model has to be extended to manage the specification of multi-themes processes in additional ScaleLines.

Moreover, many of the existing generalisation processes are based on trial/error mechanisms (Harrie & Weibel 2007), but the ScaleMaster2.0 runs sequentially. When such mechanisms are required, the simple way to handle the problem is to encapsulate a trial/error process as a single process that can be parameterised and triggered by the ScaleMaster, like in CollaGen model (Touya & Duchêne 2011): the process is triggered as a black box, the same way a simple algorithm is triggered, with eventually more complex parameters as the process is more complex.

CollaGen also differentiates the processes to be used according to landscapes (e.g. different processes are used in urban and rural areas), and such an extension is necessary to improve the results that can be provided by a ScaleMaster2.0 generalisation system. Indeed, it is rare that a single set of parameters for a process, or even a single process, is suitable for the generalisation of all landscapes: for instance, the generalisation of river networks requires different parameters in humid and arid landscapes (Buttenfield et al. 2010). A way to overcome this problem would be to specify in the ScaleMaster the kind of landscape suitable for a process.

Added to that, our experience on the use case illustrated the well-known difficulty to specify the parameters of generalisation processes in order to obtain the expected map result. Testing is required to correctly tune the parameters of the processes for each of the scale intervals. Past research demonstrated that it easier to define generalisation constraints (Beard 1991), from which the parameters could be automatically extracted like in (Touya & Duchêne 2011).

Finally, we believe that the ScaleMaster2.0 model is a good opportunity to work on generalisation processes aware of the multiple representations they are working on. For instance, multi-scale generalisations would benefit from processes that take into account the other representations of a feature in scales further in the ScaleLine to decide which operation to apply to the feature (Figure 18).

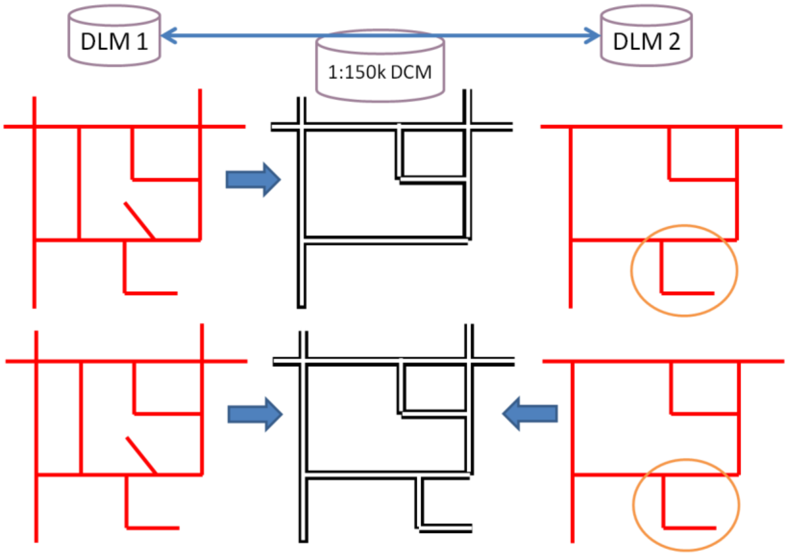

Figure 18. Multi-representation aware road selection process.

5. Conclusion

To conclude, we proposed an extension of the ScaleMaster framework, the ScaleMaster2.0, which allows automatic multi-scale generalisation. This generic model can be filled by any generalisation process and provides maps at any scale derived from MRDB source data. The model was implemented in CartAGen Open Source platform and it can be specified with XML files. The model was tested on real data with good results considering the low number of processes that have been integrated yet.

The ScaleMaster2.0 is a generic tool that now needs experiments with a large number of processes. However, some limitations have already been identified and the model needs to be improved to manage symbol design, multi-themes processes, landscape differentiation or constraints. Moreover, we plan to work on what we call multi-representation aware generalisation to make good use of the ScaleMaster2.0 possibilities.

References

Abadie N (2009) Schema matching based on attribute values and background ontology. Proceedings of 12th International Conference on Geographic Information Science (AGILE'09), Hannover, Germany

Baella B, Lleopart A, Pla M (2012) ICC topographic databases: Design of a MRDB for data management optimization. Proceedings of 15th ICA Workshop on Generalisation and Multiple Representation, Istanbul, Turkey

Barrault M, Regnauld N, Duchêne C, Haire K, Baeijs C, Demazeau Y, Hardy P, Mackaness WA, Ruas A, Weibel R (2001) Integrating multi-agent, object-oriented, and algorithmic techniques for improved automated map generalisation. Proceedings of 20th International Cartographic Conference. Vol. 3. ICA, pp. 2110-2116

Beard, KM (1991) Constraints on rule formation. Buttenfield B, McMaster R (Eds.), Map Generalization, pp. 121-135. Longman Pages

Brewer CA, Buttenfield B (2007) Framing guidelines for Multi-Scale map DesignUsing databases at multiple resolutions. Cartography and Geographic Information Science 34(1):3-15

Brewer CA, Buttenfield B (2009) Mastering map scale: balancing workloads using display and geometry change in multi-scale mapping. GeoInformatica 14(2):221-239

Brewer CA, Thatcher JE, Butzler SJ (2011) Combining varied federal data sources for multiscale map labeling of populated places and airports for the national map of the united states. Proceedings of 14th ICA/ISPRS Workshop on Generalisation and Multiple Representation, Paris, France

Bucher B, Brasebin M, Buard E, Grosso E, Mustière, S, Perret J (2012) GeOxygene: Built on top of theexpertness of the french NMA to host and share advanced GI science research results. In Bocher E, Neteler M (Eds.), Geospatial free and open source software in the 21st century, pp. 21-33. Springer, Berlin Heidelberg

Buttenfield B, Stanislawski LV, Brewer CA (2010) Multiscale representations of water: Tailoring generalization sequences to specific physiographic regimes. Proceedings of GIScience 2010, Zurich, Switzerland

Buttenfield BP, Stanislawski LV, Brewer CA (2011) A comparison of star and ladder generalization strategies for intermediate scale processing of USGS national hydrography dataset. Proceedings of 14th ICA/ISPRS Workshop on Generalisation and Multiple Representation, Paris, France

Douglas DH, Peucker TK (1973) Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. Cartographica: The International Journal for Geographic Information and Geovisualization 10(2):112-122

Duchêne C (2003) Automated map generalisation using communicating agents. Proceedings of the 21st International Cartographic Conference, pp. 160-169. ICA

Foerster T, Stöter JE, Köbben B (2007) Towards a formal classification of generalization operators. Proceedings of 23rd International Cartographic Conference. ICA, Moscow, Russia

Gould N, Chaudhry O (2012) An ontological approach to on-demand mapping. Proceedings of 15th ICA Generalisation Workshop, Istanbul, Turkey

Harrie LE, Sarjakoski T (2002) Simultaneous graphic generalization of vector data sets. Geoinformatica 6(3):233-261

Harrie LE, Weibel R (2007) Modelling the overall process of generalisation. In Ruas A, Mackaness WA, Sarjakoski LT (Eds.), Generalisation of Geographic Information: Cartographic Modelling and Applications, pp. 67-87. Elsevier, Amsterdam

Harrie L, Sarjakoski LT, Lehto L (2002) A variable-scale map for small-display cartography. International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences 34(4):237-242

Mackaness WA, Edwards G (2002) The importance of modelling pattern and structure in automated map generalisation. Proceedings of the Joint ISPRS/ICA Workshop on Multi-Scale Representations of Spatial Data, pp. 7-8

McMaster RB, Shea KS (1988) Cartographic generalization in digital environment: A framework for implementation in a GIS. Proceedings of GIS/LIS'88, pp. 240-249

Meijers M (2011) Simultaneous & topologically-safe line simplification for a variable-scale planar partition. Geertman S, Reinhardt W, Toppen F (Eds.), Advancing Geoinformation Science for a Changing World, Chapter 17, pp. 337-358. Springer, Berlin, Heidelberg

Meyer U (1986) Software developments for computer-assisted generalization. Proceedings of Auto-Carto London, pp. 247-256

Mustière S (2001) Apprentissage supervisé pour la généralisation cartographique. Ph. D. thesis, Université Pierre et Marie Curie

Regnauld N, Plews M, Martin P (2012) An enterprise system for generalisation. Proceedings of 15th ICA Workshop on Generalisation and Multiple Representation, Istanbul, Turkey

Renard J, Gaffuri J, Duchêne C (2010) Capitalisation problem in research - example of a new platform for generalisation: CartAGen. Proceedings of 12th ICA Workshop on Generalisation and Multiple Representation, Zürich, Switzerland

Roth RE, Brewer CA, Stryker MS (2011) A typology of operators for maintaining legible map designs at multiple scales. Cartographic Perspectives 68

Ruas A, Plazanet C (1996) Strategies for automated generalization. Proceedings of 7th International Symposium on Spatial Data Handling. Delft, Netherlands, pp. 319-336

Sester, M., 2005. Optimization approaches for generalization and data abstraction. International Journal of Geographical Information Science 19(8):871-897

Stöter JE (2005) Generalisation: The gap between research and practice. Proceedings of 8th ICA Workshop on Generalisation and Multiple Representation, La Coruña, Spain

Thomson RC, Richardson D (1999) The "good continuation" principle of perceptual organization applied to the generalization of road networks. Proceedings of 19th International Cartographic Conference

Touya G, Duchêne C (2011) CollaGen: Collaboration between automatic cartographic generalisation processes. Ruas A (Ed.), Advances in Cartography and GIScience, pp. 541-558. Springer, Berlin, Heidelberg

Trévisan J (2004) From DLM to multi representation DCM - modelling an application on buildings. Proceedings of 7th ICA Workshop on Generalisation and Multiple Representation, Leicester, UK

van Oosterom P (2005) Variable-scale topological data structures suitable for progressive data transfer: The GAP-face tree and GAP-edge forest. Cartography and Geographic Information Science 32(4):331-346

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