First Thoughts for the Orchestration of Generalisation Methods on Heterogeneous Landscapes

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1. Introduction

Cartographic generalisation is a process that seeks to summarise and characterise geographical information from a geo-database in order to produce a less detailed and readable map. First, research on generalisation dealt with algorithms and measures that are small bricks necessary to build an automatic generalisation process. Then, research in generalisation focused on generalisation models that aim at knowing when, where and how [McMaster & Shea 1988] to automatically trigger the generalisation algorithms. Such models are able to produce correct automatic results on given relevance domains i.e. on particular data, target scales or landscapes. Nevertheless, the existing models all have limitations that prevent them from being the solution to provide complete automatic cartographic generalisation. No model has been able yet to automatically generalise all themes of a map jointly, particularly with heterogeneous landscapes. It seems unlikely that a new generalisation model may be developed in order to solve this problem. However, the existing generalisation models and processes seem sufficient to locally solve the different issues raised by generalisation. Hence, we believe that it is interesting to find a way to automatically orchestrate some of the existing models in order to apply them on the relevant situations. The core issue of our work is the design of a generic model that would orchestrate generalisation models on relevant geographic spaces. It should be able to integrate any model in its orchestration process.

The aim of the paper is to present first thoughts about the issue of orchestrating different generalisation models. The next part briefly describes different examples of generalisation models in order to highlight our premise: models exist with relevance domains and we should orchestrate them rather than designing a new one. Then, the third section deals with the frame of this work and the first hypotheses. The fourth section details our first thoughts about generalisation models orchestration and space partitioning. Finally, the last part draws some conclusions and announces further work.

2. Examples of generalisation models

Years of research in generalisation have yielded many different generalisation models or processes. The following section describes some of the available generalisation models along with the ideal use configurations and the limitations or difficulty of use of each model, in relation to the problem of generalisation models orchestration.

2.1 The AGENT Model

The AGENT project that originates in [Ruas 1999], is a European project that aimed at developing on a commercial GIS (LAMPS2 by 1Spatial) a generalisation platform based on constraints, a step-by-step approach and multi-agent technologies [Barrault *et al* 2001]. The principle is the modelling of geographical objects as agents that can be defined as autonomous

entities able to perceive their environment and willing to achieve their personal goals. In the AGENT model, agents are able to perceive their cartographic context and choose and apply on themselves generalisation algorithms with the appropriate parameters.

The agents are guided by their own cartographic constraints: for instance, a building agent is guided by a granularity constraint (its parts should be bigger than a given threshold) and a shape conservation constraint (the building shape should be similar to initial). The agent's goal is to satisfy as much as possible its constraints by applying algorithms (enlargement and simplification in this case).
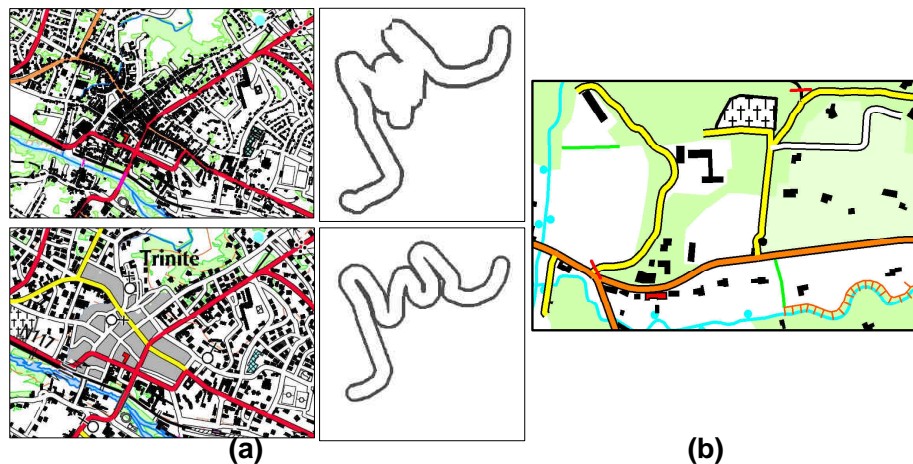

Figure 1. *(a): Results of the AGENT model: above, initial data symbolised (an urban area and a sinuous road) for 1:50 k and below the corresponding generalised data. (b): A rural area without clear hierarchical organisation: the AGENT model is not adapted to deal with the situation [Duchêne 2004a].*

The AGENT model appears to be a relevant method with roads, in zones with well defined hierarchies like urban areas (Figure 1a) as it is used in production in some NMAs or for polygonal maps [Galanda 2003]. Nonetheless, in situations without clear hierarchical organisation like rural areas (Figure 1b), no meaningful and efficient meso agent (group of agents) can be created and the AGENT model is not able to produce optimal results.

2.2 The CartACom Model

The CartACom model designed by Cécile Duchêne [Duchêne 2004a] follows the step by step approach to generalisation [Brassel & Weibel 1988], [McMaster & Shea 1988] such as the AGENT model. Moreover, it fits to the multi-agent paradigm in a constraint-based modelling. CartACom means "cartography with communicating agents" as the model relies on transversal interactions between agents.

As well as classical constraints on an object, the model takes into account constraints on a relationship between two geographical objects (Figure 2) namely relational constraints [Duchêne 2004b]. In order to satisfy both the internal (micro) and relational constraints, the agents communicate by dialog with their neighbours and choose the appropriate generalisation algorithms like displacement or rotation.
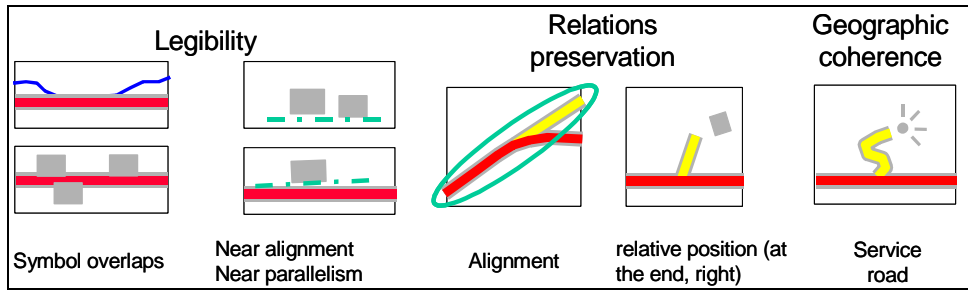
Figure 2. *Examples of the different types of relational constraints [Duchêne 2004a].*

CartACom is relevant for the generalisation of topographic rural data (Figure 3). The highlighted situations 1, 2 and 3 in the figure show how the model allows the satisfaction of relational constraints by a dialog communication of agents. The situation 4 of the figure shows the main limitation of the CartACom model when used alone: in some over-constrained situations, it is not able to solve the conflict properly.
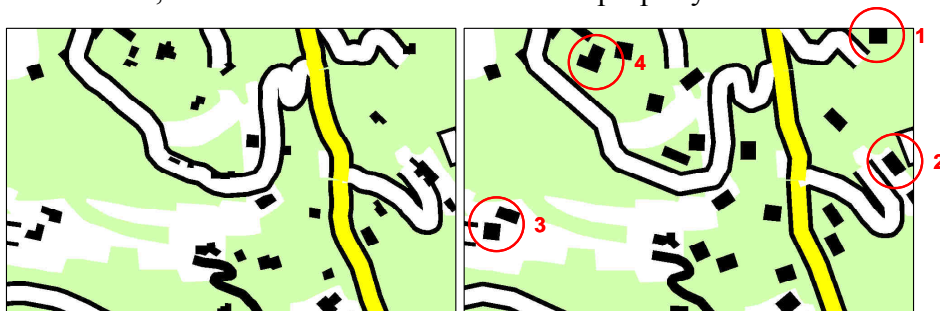

Figure 3. *Results of CartACom at 1:50k scale [Duchêne 2004a]. (1) shows a preservation of relative position. (2) shows a corrected near parallelism. (3) shows a case where a dialog was necessary to generalise the two buildings. (4) shows a situation where the model did not find a correct solution.*

2.3 Collaborative filtering in a workflow

[Burghardt & Neun 2006] address the constraint based approach in a slightly different way: generalisation is seen as a workflow of (possibly web) services [Petzold *et al* 2006] that can analyse the situation, apply an operator or evaluate the situation. In this particular workflow, the sequencing of generalisation operations is guided by the machine learning technique of collaborative filtering. This technique allows for instance some website to propose services according to one's tastes that were learnt by previous navigation. Applied to generalisation, the system learns knowledge during the process on what service succeeded in a particular situation. The relevance domain of the approach is a geographic space where many situations are to be generalised the same way.

2.4 Global generalisation methods

The global generalisation methods do not follow the step-by-step approach but try to solve all generalisation at one stroke. Inspired from physical models, such method consists in expressing the cartographic constraints with simultaneous equations on geographical object coordinates. Then, a mathematical method is used to solve the simultaneous equations. Different resolution methods have been tried in generalisation research: least square adjustment [Sester 2000; Harrie & Sarjakoski 2002] or the finite elements method [Burghardt & Meier 1997; Højholt 2000]. The global methods are very effective for generalisation that mainly need small displacements and deformations of objects (Figure 4). The major limitations of such methods are the impossibility to take into account during the process the discrete transformations like typification or elimination operators that are required in most generalisations.
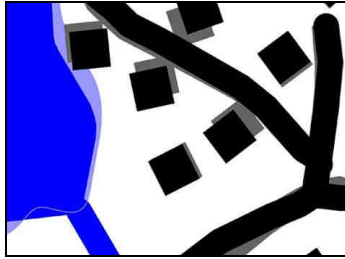
Figure 4. *Example of results coming from a least square adjustment [Harrie & Sarjakoski 2002]. The original shapes are displayed in grey and pale blue.*

2.5 The Elastic Beams model

The "Elastic Beams" model is a specialised global generalisation method (§ 2.4) with a finite elements method resolution [Bader 2001]. The method consists in defining internal and external forces on each vertex of the lines in conflict and in finding the minimum energy by the finite element technique. The line segments, modelled as beams, are assigned values of stiffness and modulus [Bader & Barrault 2001]. Stiffness represents the rigidity of the beam: a rigid beam will be rather stretched than twisted by the deformation. Modulus corresponds to the resistance of beams to stretching or compression. Both parameters allow a major road to remain straight after deformation while a river will be more distorted. Figure 5 shows the results obtained on a symbolised road network with many overlap conflicts. The difficulty is to know exactly on which objects it is necessary to use the elastic beams [Lemarié 2003].
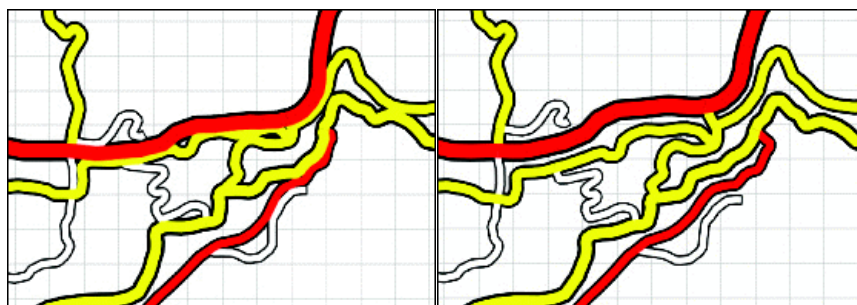

Figure 5. *On the left, a road network with many symbol overlaps. On the right, the overlaps are solved by the elastic beams [Bader & Barrault 2001].*

2.6 The GAEL Model

The GAEL model deals with the particular relations that the major themes (roads , buildings) share with the background themes (relief or land use) which are very important in a map and help its understanding. The relations between a river and its talweg represented by contour lines or the one between a building and a summit or a glade should all be preserved by generalisation (Figure 6a). In order to preserve the relations between micro objects (using the AGENT terminology) and the fields, the GAEL model [Gaffuri 2006] translates constraints on such relations into elastic constraints that concern the geometric atomic parts of the field (points, segments, angles or triangles, Figure 6b) and cause deformations of the field to be satisfied.
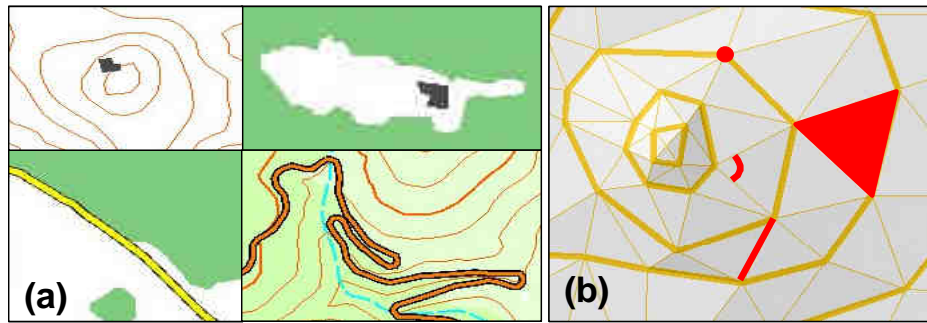
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Figure 6. *(a) Different kind of relations between fields and micro objects : a building on a summit or in a glade, a road along a forest or in mountain, a river flows in a talweg. (b) The parts of a field (here triangulated) that are constrained by elastic constraints.[Gaffuri 2006]*

The dynamic deformation of the GAEL model is based once again on a multi-agent system. The agents have to find a balance position between the elastic constraints violated by a generalisation operation and the field shape conservation constraints (a point should keep its initial position, an angle should keep its initial value etc...). The GAEL model is relevant to maintain the relations between objects and fields like a river and its talweg represented by contour lines [Gaffuri 2007]. (Figure 7) shows some results of the application. One difficulty to use the model is to know exactly when to launch the deformation to maintain the relations in order to limit the time-consuming calls during a generalisation process.
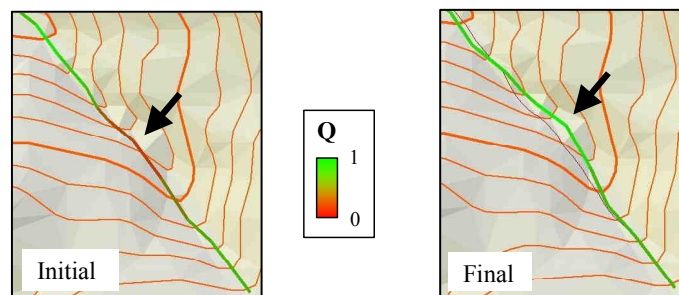

Figure 7. *A generalisation makes the river not flow correctly (the part in red highlighted by the arrow). After GAEL deformation, the relation is re-established [Gaffuri 2007].*

2.7 Ad-hoc generalisation processes

There are likewise generalisation processes designed for particular generalisation application that are not generic enough to be considered as models. However, the effectiveness of such ad-hoc processes on their relevance spaces makes us consider them as generic models. For instance, network selection processes (Figure 8) [Touya 2007] can be noticed as well as land use generalisation methods [Haunert 2007]. In this case, the relevant space is often thematic and the processes can simply not be applied on other spaces.
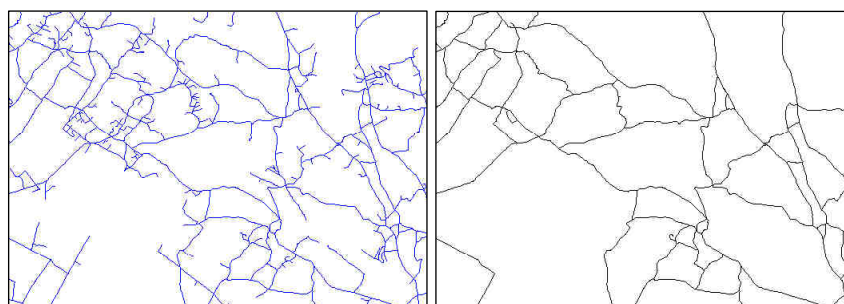

Figure 8. *A road network selection: the initial network on the left and the selected one on the right.*

3. Frame of research

3.1 The issue of heterogeneity of spaces

In most generalisation applications such as [Lemarié 2003; Lecordix *et al* 2007], there is a significant heterogeneity of situations or spaces i.e. different themes (relief, roads, buildings...) and different landscapes (urban, rural, coastal areas). This work focuses on the derivation of topographic Digital Cartographic Models (DCMs) i.e. geographic data symbolised for cartographic output [Brassel & Weibel 1988], wherein roads and buildings are essential information but that also contain hydrographical, land use, relief or tourism data that require specific concern during generalisation. The goal is to tackle some of the problems raised by the issue of heterogeneity of geographic spaces, caused by thematic diversity and landscape heterogeneity. In order to face thematic diversity, our process should be able to manage the geographic relations between objects of different themes, for instance by maintaining a building on a summit, an embankment along a road or to aggregate land use areas taking roads and buildings into account.

The heterogeneity of the landscapes to derive is a key issue as some geographic landscapes raise specific generalisation problems. For instance, mountainous landscapes require specific focus on road generalisation, as roads contain large series of bends causing major coalescence conflicts (Figure 9a). Mountainous landscapes also require a model to deal with relief issues. Urban areas require methods to contextually optimise space between streets and buildings (Figure 9b) while rural areas require to solve relational conflicts between geographic objects (roads and buildings or roads and rivers in Figure 9c).
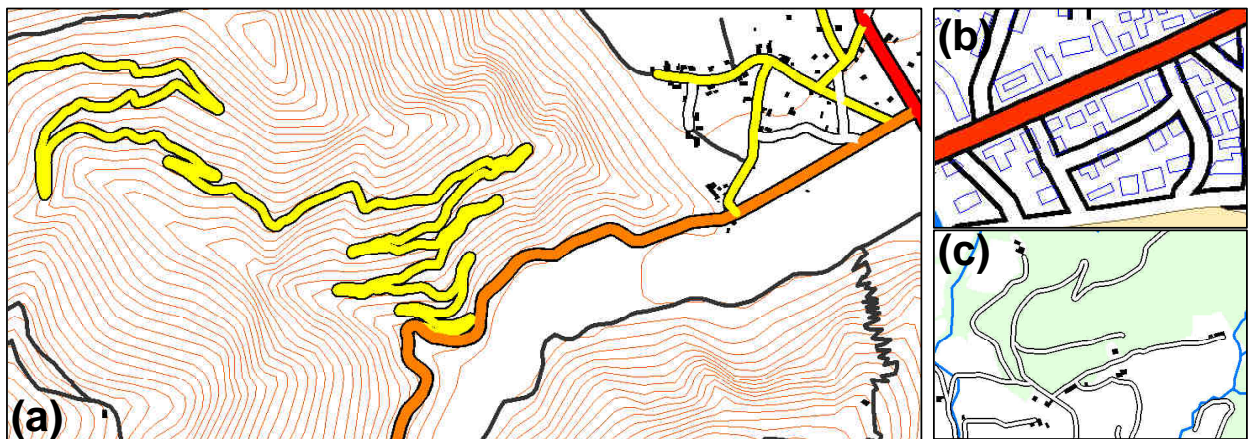

Figure 9. *Examples of generalisation problems in different geographic landscapes: mountainous, urban and rural areas.*

3.2 A constraint-based approach

The first working choice is the use of a constraint-based approach to model the generalisation output specifications. Indeed, [Beard 1991] showed that it was more interesting and efficient for cartographic conflicts to be described by cartographic constraints. For instance, a cartographic constraint can be: "a building should be bigger than 0.16 map mm2". The cartographic output and its specifications will be described by a set of constraints that follow the guidelines defined during the EuroSDR Generalisation State-of-the-art project [Burghardt *et al* 2007]. The defined constraints belong to four different categories:
- single object constraints (a granularity constraint on buildings).

- group constraints: constraint on a structure and its components (a constraint to maintain the building alignments).
- relational constraints (a distance legibility constraint between roads and rivers or a constraint to maintain relationship between rivers and relief) [Duchêne 2004b].
- macro constraints on populations [Ruas 1999] (a constraint to reduce the total length of the road network).

The second initial choice concerns the modelling of constraints in the process. We choose to represent the constraints by database classes and objects (Figure 10). We follow the same approach as in AGENT, CartaCom and GAEL models and enunciated in [Ruas 1999]. Indeed, orchestrating different generalisation models on relevant spaces is a distributed approach and representing constraints as objects is often a convenient and effective way to represent and localise the cartographic conflicts.
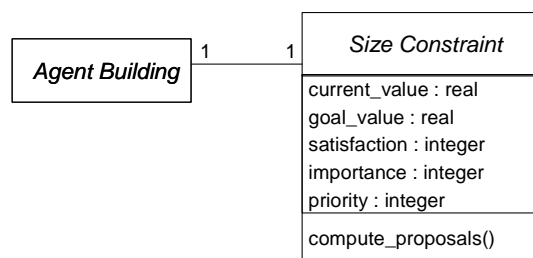
Figure 10. *UML data schema of building agents associated with a size constraint in the AGENT model [Ruas 1999].*

4. Orchestration of the multi-model generalisation: first thoughts

Answering to the issue of heterogeneity of spaces by the orchestration of generalisation models raises different questions:
- Where to apply which model ?
- What are the relevant boundaries ?
- What happens at the boundaries ?
- How to ensure homogeneity of treatment in final map ?
- What is the relevant sequence to apply ?

To clarify what is meant by orchestration, Figure 11 shows of data schema of the results (excluding generalised data) of a generalisation by model orchestration. A *generalisation* is an ordered sequence of *generalisation items* that can be *side effects sessions* or *generalisation applications*. A *generalisation application* is the relevant association of a *geographic space* and a *sequence of generalisation models*. For instance, it can be the application of the AGENT model on urban spaces.
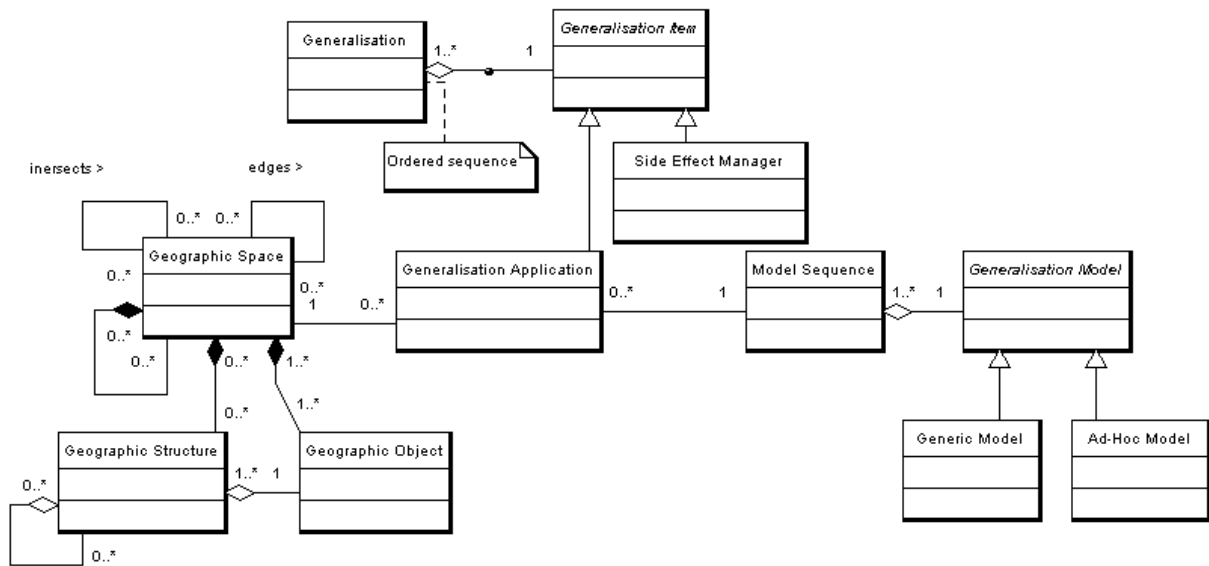
Figure 11. *Data schema of the output of one orchestration of generalisation models.*

This section deals with the first propositions to answer to these questions. The first part addresses the search for relevant spaces upon which generalisation models are applied (first question, where...?). The second part introduces first thoughts about the orchestration techniques. Then, the third part deals with homogeneity and interoperability issues. The fourth part outlines the management of side effects between spaces. Finally, the last part summarises these points describing a first version of our orchestration model.

4.1 The relevant spaces for generalisation

The proposed approach that aims at orchestrating the existing generalisation models and processes by using them on their relevant geographic space (both thematic and spatial), needs to partition space into the different relevant spaces. Partitioning is not only a way to find relevant spaces for each model but also a technique to manage the generalisation of large amounts of data. The first step is to better determine the relevant spaces for each existing generalisation model that could be used. Another issue is to characterise the discovered relevant spaces to optimise the chosen generalisation model results and performances. Indeed, [Steiniger 2007] claims that a precise characterisation of groups of geographic objects makes the choice of generalisation operations easier. We think it would be interesting to adapt the approach to generalisation models and their relevant spaces. Then, a final step is the development of spatial analysis algorithms to build the chosen relevant spaces. The steps 1 and 3 are discussed more in detail in the following paragraphs.

The proposed methodology to achieve the first step (determination of the relevant spaces) is a combination of an inductive reasoning and a deductive reasoning [Ruas 1999, p.153]: some spaces are deduced from the experience of the use of some generalisation models; some spaces are induced from map generalisation tests. For instance, by deductive reasoning, urban areas are deduced to be the relevant space for AGENT, rural areas are deduced to be the relevant space for CartACom, and mountainous areas are deduced to be the relevant space for GAEL. On the other hand, for instance, by inductive reasoning, forested regions will be tried as candidate to be a relevant space of some generalisation models. If it appears that a generalisation model or process suits for the forested regions of the tests, it will be induced that forested regions are in general a relevant space for the model. Generalisation experiments will be carried out on chosen test areas, using the different existing models. The experiments

will allow to validate the deduced relevant spaces and to induce some new relevant spaces among the tested ones.

For both ways of reasoning, some literature partitioning or clustering methods are implemented to test the recognition of the geographically meaningful spaces on which the generalisation tests are carried out. [Anders 2003] describes a proximity graph clustering method for set of points that takes local densities into account (Figure 12d). The clusters obtained by the method on building centroïds or on road junctions are interesting spaces to test maybe to induce relevant rural areas for CartACom model. Furthermore, in order to use the elastic beams on large amounts of data (§ 2.4), flexibility graphs were developed [Lemarié 2003]. Flexibility graphs are part of the networks grouping the conflicting sections (overlaps between network sections) and all the sections that make a good resolution by the elastic beams possible. [Ruas 1995] hierarchically partitions geographic space in order to ease the generalisation process. Major roads are used to create 1st level partition and then secondary roads and railways. It allows to partition space in order to manage the large amounts of data resulting from the completeness of the generalisation process. Furthermore, it would be necessary to test generalisation models on spaces that abstract geographic phenomena. For instance, cities created from buildings using [Boffet 2000] or [Chaudhry & Mackaness 2006] are ideal areas to test the AGENT model (Figure 12c). [Mackaness *et al* 2007] proposes a method to recognise forested regions at small scales (i.e. large forests). Such spaces (Figure 12a) that are poor in roads and buildings should be tested as particular areas to induce which model would be more relevant. Finally, determining the extent of hill ranges and mountain chains as [Chaudhry & Mackaness 2007] could be an interesting way to delimit the use of the GAEL model (Figure 12b).
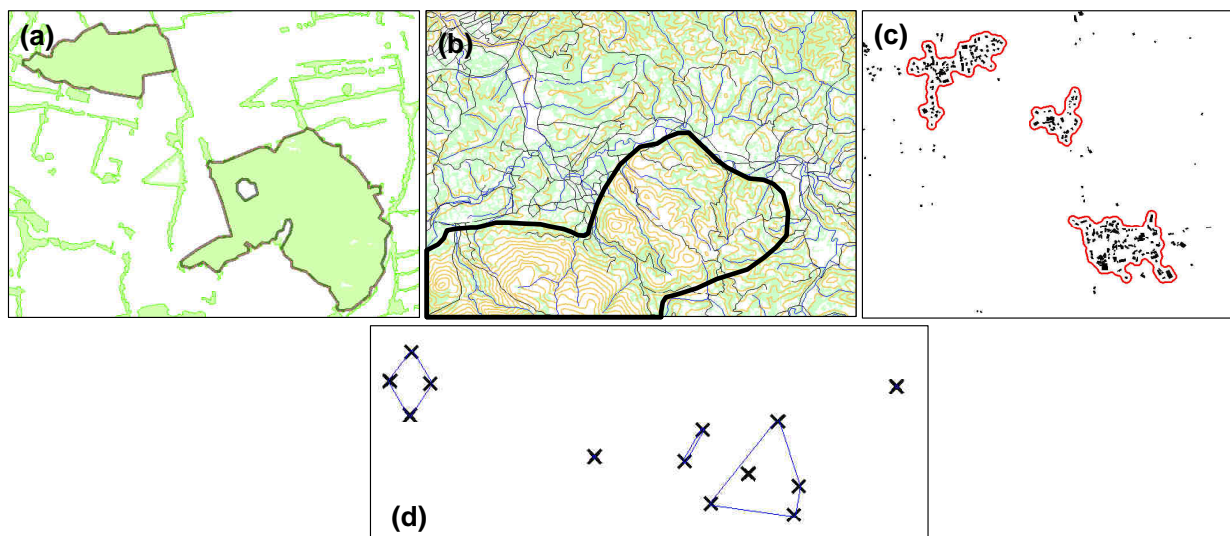

Figure 12. *(a) Forests derived from the vegetation coverage. (b) A mountainous area manually selected. (c) City extents obtained from buildings with [Boffet 2000] technique. (d) Implementation of [Anders 2003] on a random point set.*

Added to the deductive and inductive reasoning, a third way to discover spaces is based on conflicts detection, namely emerging spaces. Emerging spaces are situations that a priori do not require a particular application of a model. But during the generalisation process, it is possible that conflicts remain unsolved and the aggregation of unsolved conflicts should lead to the dynamic creation of an emerging space that will be treated with a different model or process. An analogy can be made with the concept of emergence in multi-agent systems. [Beni & Hackwood 1992] define emergence as the apparition of a global phenomenon that

was not explicitly coded in the behaviour of the agents. Such emergence can be caused by a particular configuration of constraint violation, highlighted by a machine learning technique like the case based reasoning or collaborative filtering [Burghardt & Neun 2006]. Or it can be caused by the impossibility to solve a conflict using the default model for the space the situation is part of. Such a situation refers to the third type of meso objects from [Ruas 1999, p.111].

4.2 Orchestration techniques

The orchestration of some generalisation models deals with the sequence of generalisation model applications and the communication between them. The experiments described in the previous section, that will be carried out on the existing models and the different spaces will also help to venture hypotheses about the correct orchestration of the models. The existence of a pre-defined sequence of models applied on defined spaces seems very unlikely and it would have to be changed each time a new model is introduced in the process. Thus, different orchestration scenarios have to be considered amongst which two are addressed here: the use of multi-agent systems or of a predefined workflow. The scenarios are not exclusive and could also be combined.

The first possible approach is to stay in the multi-agent paradigm. As in [Bonneaud *et al* 2007] space-agents and model-agents would be defined for each space and generalisation model. A model-agent would be an autonomous entity that guides a particular generalisation model by registering it in "Yellow Pages". The registration would concern the functionality of the model and a list of relevant spaces for the model. Then, a space-agent would be a kind of meso-agent [Ruas 1999] that would seek to generalise its components as a *Legislator* and a *Controller* by consulting the Yellow Pages and applying the appropriate model.

Another possible approach is to call upon a predefined workflow of actions. Workflows are sequencing graphs that allow conditional jumps, loops and concurrent processes. Such as workflow application in generalisation [Petzold *et al* 2006; Burghardt & Neun 2006], it could be possible to produce complex sequences of generalisation model calls with this approach like the *Global Master Plan* of [Ruas & Plazanet 1996] or the *Strategies* of [Weibel & Dutton 1998].

4.3 Homogeneity and interoperability issues

Homogeneity of treatment and interoperability are different obstacles to orchestration grouped in this paragraph as they can both be overcome the same way. On the one hand, a relative homogeneity of treatment between the different geographic spaces, which is a criterion for cartographic generalisation evaluation, has to be maintained. On the other hand, the different existing generalisation models have different inputs and outputs but they have to be chained in an orchestration sequence. For instance, sequencing a multi-agent system based model like AGENT with a simultaneous equations based system like the least square adjustment requires a common language to translate the inputs and outputs.

Both issues can be solved using an *ontological base of generalisation constraints*. Thus, by analogy with the research domain of data heterogeneity, making different processes interoperable often relies on ontologies [Lemmens 2006] and/or a common standard language. Concerning homogeneity of treatment, if all generalisation models calls are driven by the satisfaction of such base of constraints, a relative homogeneity of generalisation is guaranteed although the way of generalising is not the same. As a consequence, we will have to model

this ontological base of constraints according to different taxonomies of the literature [Beard 1991; Weibel & Dutton 1998; Ruas 1999; Burghardt *et al* 2007].

4.4 Side effects and networks

Whether the different relevant spaces are adjacent (they form a partition) or intersect, applying a generalisation model on a particular space can lead to side effects on the neighbouring or intersecting spaces. Such a problem has to be a key issue of the proposed orchestration model. The side effects could be corrected afterwards and/or foreseen using data matching techniques as for the integration of heterogeneous data (data coming from different countries at a frontier). Another interesting approach is to adapt an incremental update method like rubber sheeting [Anders *et al* 2007] to propagate the modifications caused by a model.

The management of networks all along the process is also a challenging task as networks have the particularity to cross over or delimit the different chosen spaces (Figure 13). Thus, the networks will have to be assigned a specific behaviour to avoid multiple and useless modifications and checking.
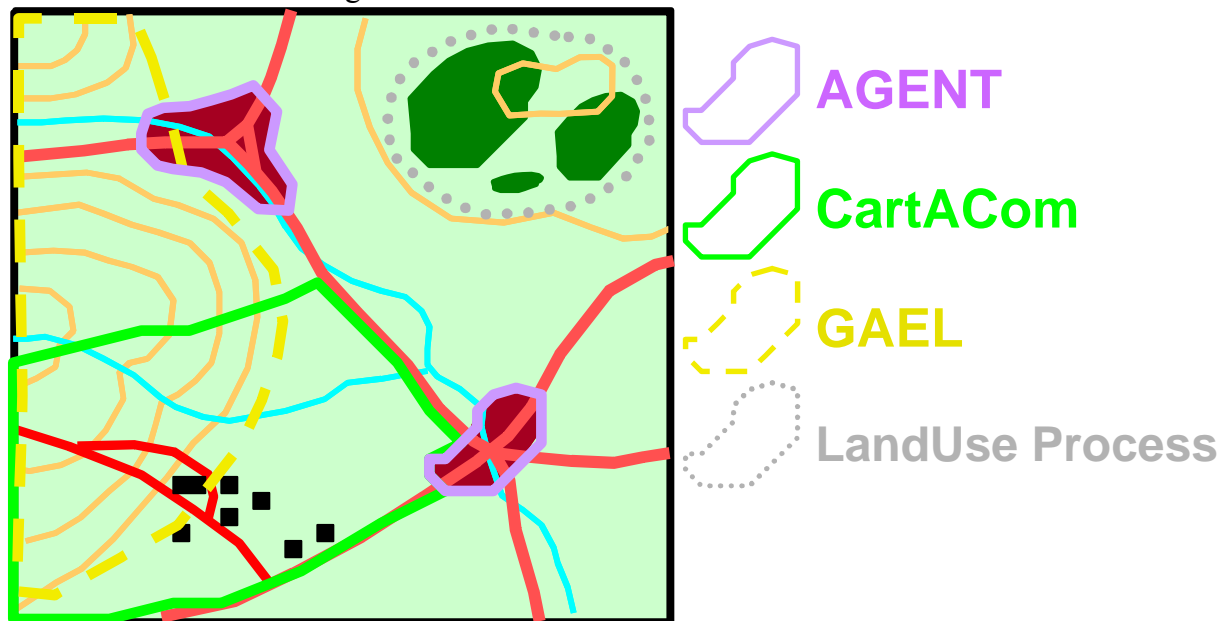

Figure 13. *A simplistic view of a heterogeneous geographical area with different relevant spaces. The networks cross or delimit the spaces instead of being contained.*

4.5 The generalisation models orchestration model

In order to summarise the first ideas advanced in the previous parts, the Figure 14 shows a schema of the proposed generalisation models orchestration model with its main components (in ellipses), resources (in rectangles) required and produced and the relations between them. The different components and particularly the *sequencing component* will have to be specified in further work so as the *model description* and *constraints ontological base* resources.
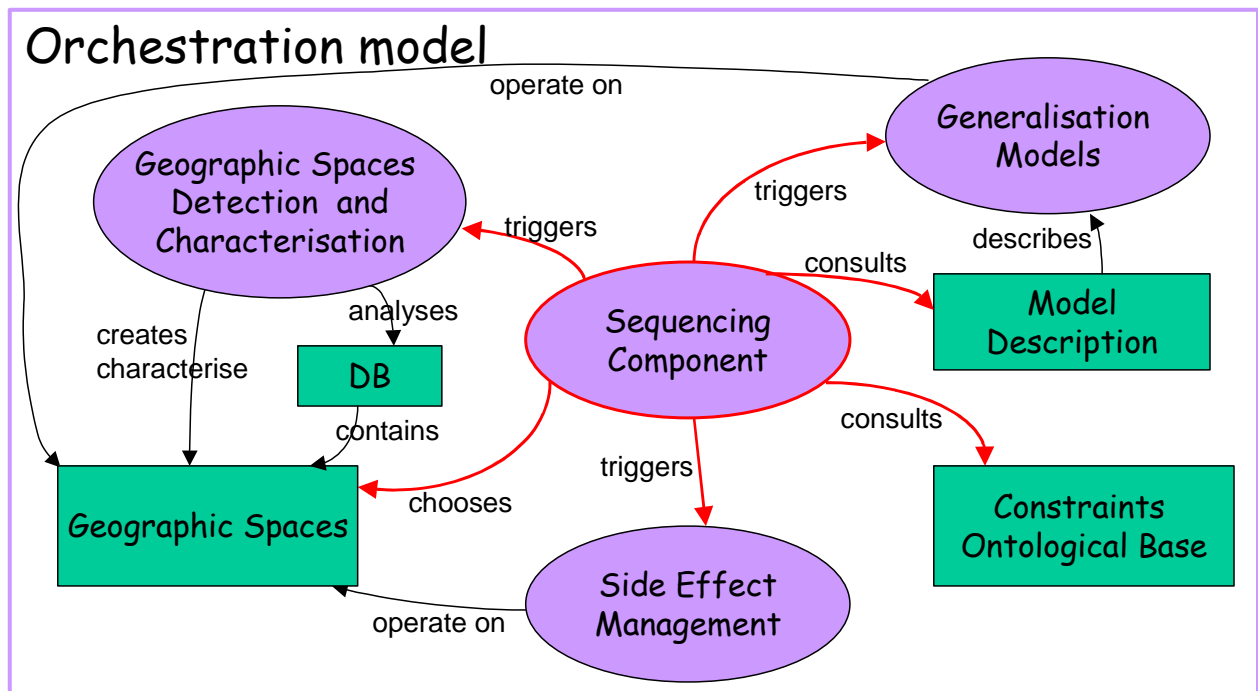
Orchestration model

Geographic Spaces Detection and Characterisation

operate on

Generalisation Models

triggers

triggers

Sequencing Component

consults

describes

Model Description

analyses

creates

characterise

DB

contains

chooses

consults

Constraints Ontological Base

Geographic Spaces

triggers

Side Effect Management

operate on

Figure 14. *The components (in ellipses) and resources (in rectangles) of the proposed orchestration model.*

5. Conclusion and further work

To conclude, this paper has presented the issue of a beginning PhD about the orchestration of a multi-model generalisation process on heterogeneous landscapes. The a priori application relevance domain for different existing generalisation models has been detailed to justify the relevance of our approach. Some of the problems raised by the design of a complete generalisation process have been exposed, particularly the management of the heterogeneity of thematic data and landscapes. First thoughts about the methodology to propose have been discussed with four research key issues: find out the relevant geographic spaces, find out an orchestration technique, tackle homogeneity of treatment and interoperability and manage the side effect.

Different tasks will now be undertaken to tackle the key issues: carry out tests with some existing models to acquire knowledge on the relevant spaces, on the sequencing of generalisation models and on side effects; model the ontological base of constraints; design a generic model for orchestrating generalisation models on geographic spaces; apply this model with different available generalisation models.

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