

# Deformation using Agents for Map Generalization - Application to the Preservation of Relationships between Fields and Objects

**Gaffuri Julien**

COGIT laboratory, Institut Géographique National  
2/4 avenue Louis Pasteur – F-94165 Saint-Mandé CEDEX – France  
Phone : +33 1 43 98 80 00 – 7584 Fax : +33 1 43 98 85 81  
[Julien.Gaffuri@ign.fr](mailto:Julien.Gaffuri@ign.fr)

## Abstract

Some research in map generalization techniques using the agent paradigm have allowed to progress significantly toward automation. These models allow the computation of discrete transformations of the objects but are not adapted for continuous transformations such as deformations. Our challenge is to allow these models to manage such continuous transformations.

As an application, we aim to introduce field data such as the relief in agent-based generalization models. Many relationships exist between fields and objects (especially buildings, roads and rivers). Our concern is to preserve these relationships. We propose to allow the geographic agents to deform a field during the generalization process.

To attain this objective, we propose a model:

- To measure and interpret relationships between fields and objects (this allows to define new constraints),
- To compute fields deformations under objects stretching,
- To manage the automatic trigger of these measurements and deformations in the existing agent based generalization models.

We propose to model the field as a triangulation, and to explicit some shape preservation constraints on the points, segments, angles and triangles composing the field. When a point is stretched, its displacement propagates to its neighbors using a multi-agent convergence method we have built.

## I. Introduction and context

Cartographic generalization is the process of transformation of map objects to make them legible for a specific scale. Operations such as dilation, displacement, elimination, etc, are applied on the objects, to make them satisfy their legibility constraints. Generalization is an information synthesis process: some important details must be preserved or emphasized, while other must be erased. Map generalization automation attempts to produce a map for a target scale from vectorial geographic databases. The issue of the automation is to improve map production from geographic databases: updating propagation from geographic databases to map would be faster, and on-demand maps for specific customers needs could be easier produced.

Works in generalization automation mainly focus on the conception of algorithms for geometric transformations, measures for characterisation, generalization models (triggering processes) and assessment of generalization. Our work concerns generalization models. Several approaches have been studied.

Optimization based models adopt an holistic approach. A balance position between all the constraints of the map is found using a global resolution method (finite elements method or least square adjustment). This methods allows to compute a continuous transformation of all the objects of the map to make them satisfy their constraints. As applications of this approach, we could

mention the use of flexible triangles modelisation (Hojholt 2000), least square adjustement (Harrie and Sarjakoski 2002; Sester 2005), snakes (Burghardt and Meier 1997; Galanda 2003; Guilbert et al. 2006) or elastic beams (Bader 2001).

Other models use a discrete transformations approach. The principle of these models is to proceed step by step to solve specific cartographic conflicts: a generalization engine detects the conflict to solve, chooses the right algorithm and triggers it. The principles of this approach are presented in (McMaster and Shea 1988; Shea and McMaster 1989; Brassel and Weibel 1988). Some agent based generalization models such as the AGENT (Ruas 1999; Barrault et al. 2001) and the CartACom model (Duchêne 2004 a) follow this approach. Our work is based on these models. An agent is defined as *“a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives”* (Weiss 1999, 29). The principle of these models is to consider the map objects (such as buildings, roads...) as agents: the purpose of each agent is to satisfy its constraints (following the approach of (Beard 1991)). To reach this purpose, each agent is able to analyse himself its own state: it measures its characteristics and checks if the level of satisfaction of its constraints is good. Then, depending on its unsatisfied constraints, the agent chooses a suitable generalization algorithm to apply to himself, in order to progress toward the global satisfaction of its set of constraints. During its generalisation process, the agent controls the evolution of its state and is able to backtrack to a previous state if a treatment failed to improve its state. These models consider several levels of objects: the so-called “micro” and “meso” levels. The “micro level” is the level of the individual objects (such as the buildings, the roads...). The “meso level” is the level of groups of objects (building alignments, buildings of a urban block...). Constraints can be carried by micro objects (for example, the size of a building) and by meso objects (for example, the alignment of a building set). In this paper, we call “micro objects” the object considered individually, such as a building, a road, according to (Ruas 1999).

Most of the generalization models proposed have been applied mainly to the generalisation of roads and buildings. We propose in this paper to take into account fields in the agent-based generalization models previously presented. A field could be defined as a phenomenon which allows assigning a value to every location of the geographic space (Cova and Goodchild 2002). In this paper, we consider the relief and the land use cover as fields. A specificity of these objects in the generalization process is that they should be subjected to continuous transformations, rather than discrete. Both transformations are useful in map generalization. The limit of agent-based models is their non-adaptation to compute such continuous transformations.

This paper presents a way to compute such continuous transformations to the fields in an agent context. We present an application to the preservation of relations between fields and objects. We propose to constrain the generalization process to allow a preservation of these relationships by deforming the fields.

The part II presents an example of object-field relationship preservation constraint. We show that a deformation of the field is necessary. Then, we present our general approach to manage field objects, and then we show the limits of the agent-based models to manage deformations.

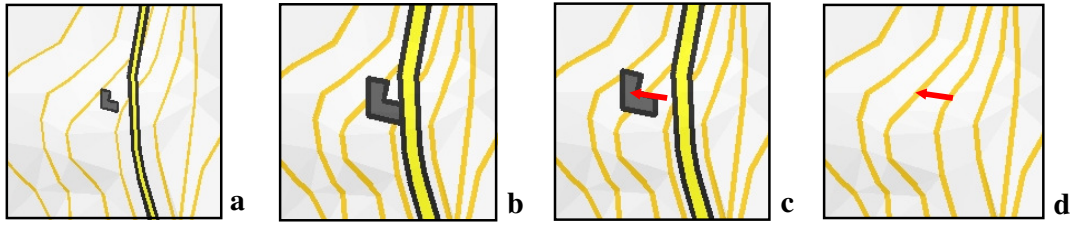
The part III presents our proposition to compute continuous transformations of fields using the so-called “sub-field objects”. We give a way to trigger such continuous transformations from the existing agent-based generalization models.

## **II. The issue**

### ***II.a. An example case***

We introduce the issue with a simple example: a building and a road (Figure 1a). When generalizing this situation, the building dilates itself to satisfy its size constraint (Figure 1b) and must therefore be displaced to satisfy its proximity relation with the road (Figure 1c). Because of this

displacement, its altitude seems to have changed. We propose to constrain the preservation of the altitude of this building.



**Figure 1.** *An example case: the altitude of the building changes when it generalizes.*

This constraint concerns the relationship between an object (the building) and a field (the relief). The altitude of the building is not a static attribute: it is given by its localisation on the relief.

How to preserve this relationship? The building can't be changed because of its own constraints (size and proximity to the road). An other solution would be to act on the field.

How to change the field? The relationship could be preserved by stretching a point of the field to get the altitude of the building as near of its initial value as possible (Figure 1d). The field has some shape characteristics to preserve (for example, structure lines of the relief). This displacement must be diffused to respect the relief's own shape preservation constraints.

This situation is overconstrained: it is not possible to preserve totally both the shape of the relief and the relationship with the building. A balance between the inner shape constraints of the field and the object-field constraint must be found. The deformation can be seen as a result of this balance position research.

We present now a proposition of a general framework allowing to consider object-field relationships preservation constraints in the generalization process.

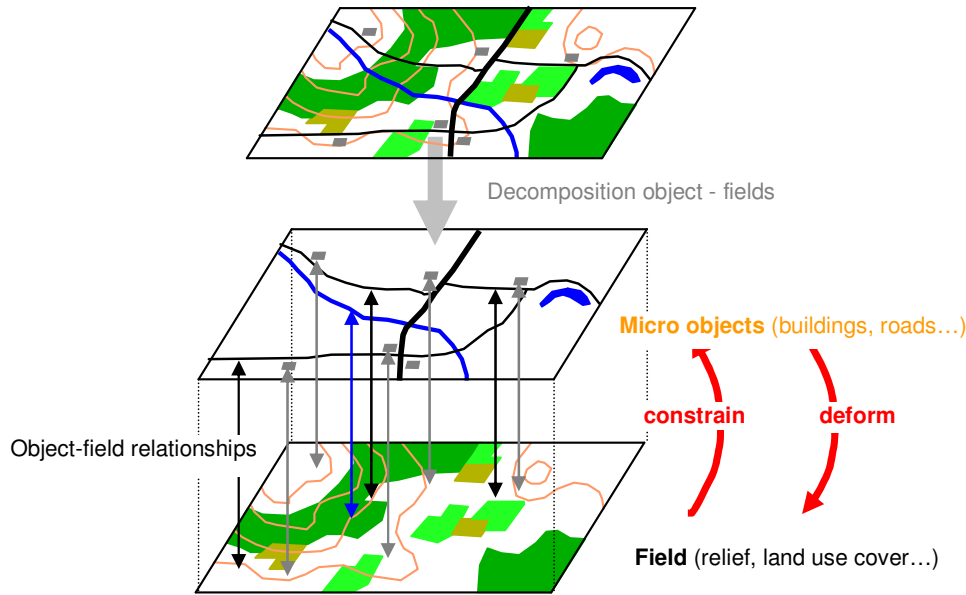
## ***II.b. Object-field relationship preservation constraints***

The previous part gave an exemple of object-field relationship. We could generalize this case to other object-field relationships.

A lot of relationships exist between the micro objects (buildings, roads) and the fields (relief, land use) as presented in (Gaffuri 2005): the repartition of micro objects on the map is constrained by the fields. For example, the road sections in a mountainous area are built to have a specific slope, road sections are often limits of land use parcels, buildings have a specific altitude, and are located in a specific type of land use parcel... These relationships between micro objects and fields can be broken when generalizing the micro objects.

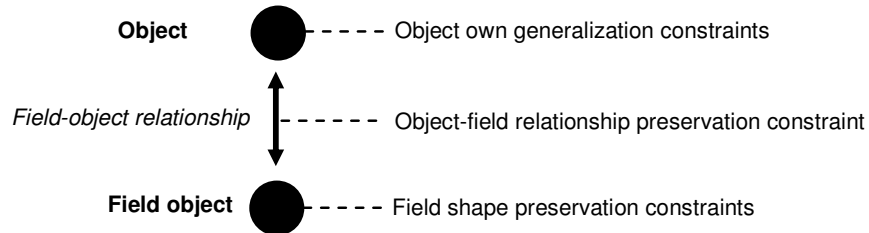
Figure 2 gives our proposition to take into account the field objects in a generalization process. We propose:

- to differentiate, among the map objects, the micro objects (roads, buildings...) and the fields (relief, land use cover...),
- to characterize the relationships between the objects and fields,
- to allow the objects to deform the fields and the fields to constrain the objects, in order to preserve the relationships between fields and objects.



**Figure 2.** *Our framework proposition for the preservation of object-field relationships*

The deformation of the field should not be a simple isotropic diffusion caused by the displacement of a point of the field. It should take into account shape specificities of the field. From the field point of view, the relationship constraint appears like an external constraint that stretches one of its points, and the shape preservation constraints are inner preservation constraints. The deformation of the field is the result of the research of a balance position between the external and the inner constraints of the field (Figure 3).



**Figure 3.** *The constraints to consider*

To make these constraints preservation possible, we have to allow the management of continuous and discrete transformations jointly, in a the same process. We present the problem in detail in the following part.

### ***II.c. Discrete and continuous changes in map generalization***

During the generalization process, two kinds of transformation are considered.

- Continuous transformations: these transformation correspond to a smooth change of the objects. The objects are deformed to satisfy progressively their constraints.
- Discrete transformations: these transformations correspond to a violent change of the objects. Operations such as elimination, big displacements, aggregation, collapse, typification... are discrete transformations.

The kind of transformation useful for a given generalization process mainly depends on two factors:

- The level of detail change: when the level of detail change is little, continuous operations can be sufficient to satisfy the cartographic constraints. The bigger the level of detail change

is, the more discrete transformations are needed, as illustrated by (Van Kreveld 2001).

- The nature of the objects: depending on their nature, geographic objects do not behave the same way during the generalization process. Some of them are much more deformed (fields, networks...) while other are rather curtly treated (buildings, clusters...). (Harrie & Sarjakoski 2002) make a distinction between “rigid” and “plastic” objects. Continuous transformations are much more adapted to plastic objects (fields) while discrete transformations are suitable for rigid objects (buildings).

It seems impossible to determine a priori which kind of transformations will be needed for a generalization process. Often, both discrete and continuous transformations are needed for some objects. For example, a road section can be subjected to continuous transformations such as deformation, and to discrete transformations, such as the bend removal operation. For a field object such as the relief, transformations could be continuous (for example, the smoothing algorithm presented in (Gold & Thibault 2001)), or discrete (like the thalweg elimination algorithm of (Ai 2004)). These examples show that a complete generalization system should be able to manage both types of transformation.

As presented in the introduction, optimization techniques allow continuous transformations while agent-based allow discrete ones. The reason of this is inherent to the way these models have to satisfy a set of constraints. In optimization based models, a balance position between constraints is searched; constraints are considered as “elastic constraints”. In agent-based models, the constraints are satisfied step by step. Some of them are considered as much more important than others and are therefore completely satisfied while the others are relaxed: there is no balance position. As seen previously, a deformation is the result of a balance position between external stretching constraints and inner shape preservation constraints. So we should use a method to get a balance between constraints, such as the ones used in optimization (finite elements methods and least-square adjustment). The problem is that these resolution methods are too closed and can not manage discrete transformation.

To give to the agent-based generalization models the capability to manage continuous transformations, we aim to give them the ability to find a balance between elastic constraints. We propose an enrichment of agent based models for continuous deformations using the approach of (Kocmoud and House 1998) for cartogram construction. We present now our model and an application for the field deformation.

### **III. Proposition of deformation model**

#### ***III.a. Principles***

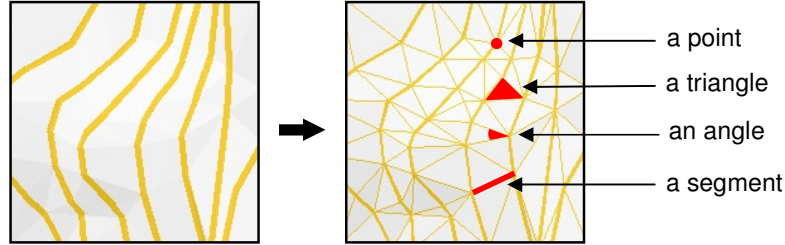
The principles of our model are the three following points:

- The field is decomposed into parts (points, segments, angles and triangles) carrying elastic shape preservation constraints (Figure 4). The association of these inner constraints of the field allows constraining the general shape of the field. Because they are parts of the field, we propose to call these objects “sub-field objects”.
- Ability of the micro objects to stretch points of the field to satisfy its field relationship preservation constraint. This stretching of the field is done through an elastic constraint between the micro and points of the field. We propose to call this external constraint of the field “stretching constraint”.
- Points are agents: to compute a deformation by finding a balance position of between the inner and external constraints of the field, we propose to consider the points of the field as agents.

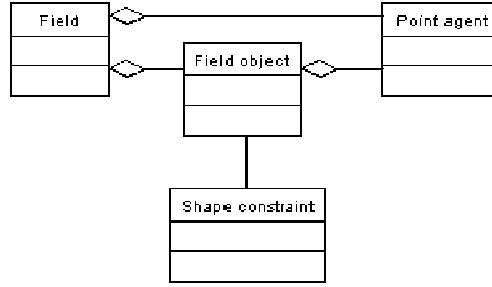
The deformations are triggered during the generalisation of the micro objects. The micro objects act

on the field by stretching points. When a point is stretched, it is not in a balance position anymore. Our method allows displacing this point and its neighbours until a balance position between the stretching and the shape constraints is attained. The displacement of the point is diffused; the field is deformed.

The example shown in this article concerns the relief. For the triangulation of this field, we have chosen to merge the contour lines in the triangulation (Figure 4). This could allow constraining the shape of the contours, as explained later.



**Figure 4.** *Decomposition of the field into sub-field objects.*



**Figure 5.** *UML class diagram of the field decomposition objects.*

We detail now how a point behave, how is its displacements toward its balance position are computed, and finally how the micro manage the stretching of the field.

### **III.b. Points as agents**

To find a balance position of the points, we propose to consider the points as agents: each point is “alive”. It is able to analyse itself and moves in order to reach a balance position between its constraints. Its constraints are all the constraints of the sub-field objects it belongs to. Each constraint forces its points to do a displacement to progress toward its satisfaction (as an elastic constraint). We give some details about the way to calculate these displacements in III.c.

A point as the following methods:

**checkBalance():** the point computes the displacement of its constraints to be satisfied integrally. If the length of the displacement is less than a little threshold (equal to the resolution of the data for example), it is considered as null. Then the point is in a balance position. Figure 7 page 8 gives a representation of a point in its balance position.

**computeDisplacement():** the point computes a displacement for each constraint. This is not the displacement to do in order to satisfy integrally the constraint, but only a certain part of this displacement, in order to progress toward the satisfaction of this constraint. The sum of these displacements allows to progress toward the balance position of the point.

**progressTowardBalance():** displace the point toward the displacement given by the method computeDisplacement().

To find its balance position, the point progress until it reaches its balance position. All the points try to progress toward their balance position together.

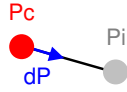
We give now further details on the computation of the displacement of each shape preservation constraint.

### III.c. Shape preservation constraints

Our model does not use a “force” model to determine the displacement caused by each constraint of the point: the displacement is directly computed. For each constraint, the point is able to determine the displacement to do in order to satisfy completely the constraint. Because the point has several constraints and aims to find a balance position between them, the displacement is only a part to progress toward the constraint satisfaction. This part depends on the number of constraints the point has. If a point has  $N$  constraints, the displacement of each constraint will be  $1/N$  of the displacement needed to satisfy completely the constraint. We give the computation detail for the constraints used. (Some of them are an adaptation of the springs used in (Kocmoud and House 1998)).

Notation:  $P_i$  is a point in its initial position,  $P_c$  in its current position,  $dP(dx,dy)$  is the part of the displacement to do to progress toward the constraint satisfaction.

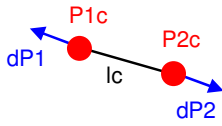
Initial position point constraint :



$$dx = 1/N * (P_i.x - P_c.x)$$

$$dy = 1/N * (P_i.y - P_c.y)$$

Segment length constraint:



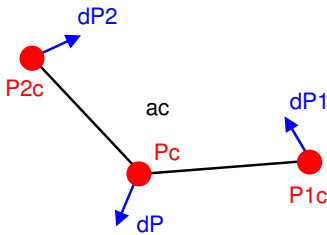
$$dx1 = 1/2N * (li/lc - 1) * (P1c.x - P2c.x)$$

$$dy1 = 1/2N * (li/lc - 1) * (P1c.y - P2c.y)$$

$$dP2 = -dP1$$

$li$ =initial length of the segment;  $lc$ =current length of the segment.

Angle value constraint:



$$dx1 = p.x - p1.x + \cos(da) * (p1.x - p.x) - \sin(da) * (p1.y - p.y)$$

$$dy1 = p.y - p1.y + \sin(da) * (p1.x - p.x) + \cos(da) * (p1.y - p.y)$$

$$dx2 = p.x - p2.x + \cos(da) * (p2.x - p.x) + \sin(da) * (p2.y - p.y)$$

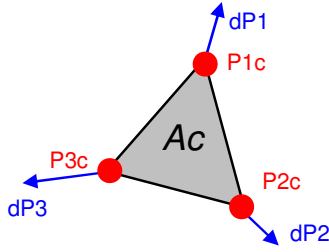
$$dy2 = p.y - p2.y - \sin(da) * (p2.x - p.x) + \cos(da) * (p2.y - p.y)$$

$$dx = -dx1 - dx2 \quad ; \quad dy = -dy1 - dy2$$

With  $da = 1/2N * (ac - ai)$

$ai$ = initial value of the angle;  $ac$ = current value of the angle.

### Triangle area constraint:



$$dx1 = 2/3N * (Ai - Ac) / P2cP1c^2 * (P2c.x - P1c.x)$$

$$dy1 = 2/3N * (Ai - Ac) / P2cP1c^2 * (P2c.y - P1c.y)$$

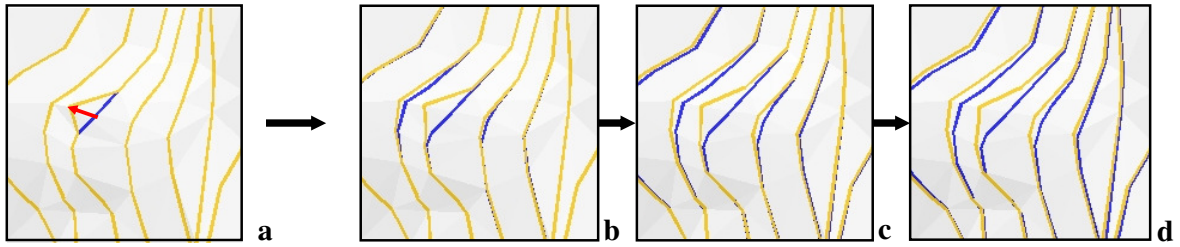
Analog calculus for dP2 and dP3.

$A_i$  = initial area of the triangle.

$A_c$  = current area of the triangle.

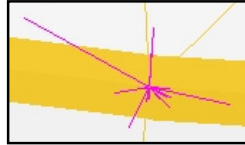
The displacement of each point influences the balance of its neighbours. Then, this displacement propagates until each point has its balance. The result is a deformation of the field.

We present an example of such a deformation Figure 6. We force a displacement of a point (the red arrow figure a). This displacement is progressively diffused to its neighbours (figures b,c). The result is a deformed field (d), where each point has reached its balance position.



**Figure 6.** Progressive diffusion of a point displacement (a) to its neighbours by constraint balance of the sub-field objects (b)(c)(d). (in orange: the contour lines; in blue: the contour lines in their initial state)

Figure 7 represent a zooming on a point in its balance position at the end of the process. Each purple line represents a displacement proposed by each constraint. The sum of these displacements is considered as null.



**Figure 7.** A point in its balance position, and its displacements

For a point having  $N$  constraints, the position obtained position is a balance position between all the constraints of the point. It is possible to define a relative importance of the constraints by tuning a weight value for each constraint in order to obtain a weighted balance position. In the presented case, the weights of the constraints are all equal (the value of the weight is  $1/N$ ). It is possible to define an importance value for each constraint. The weight of a constraint is determined from its importance value and the importance values of the other constraints of the point by the following way:

$$weight = importance / \text{sum of the importances}$$

When the importance values of the constraints are all equals, the value of the weight is  $1/N$ .

With this way, it is possible to force some specific shape characteristics preservations. For example, we could choose to increase the importance of the contour line shape preservation constraints, because these shapes are cartographically important.

Eventually, to compute such a deformation, it is not necessary to activate all the agents of the field: when a point is stretched, only some of its neighbours will move to diffuse the stretching effect. For this reason, each point is in a passive state and become active as soon as it is “waken” by a

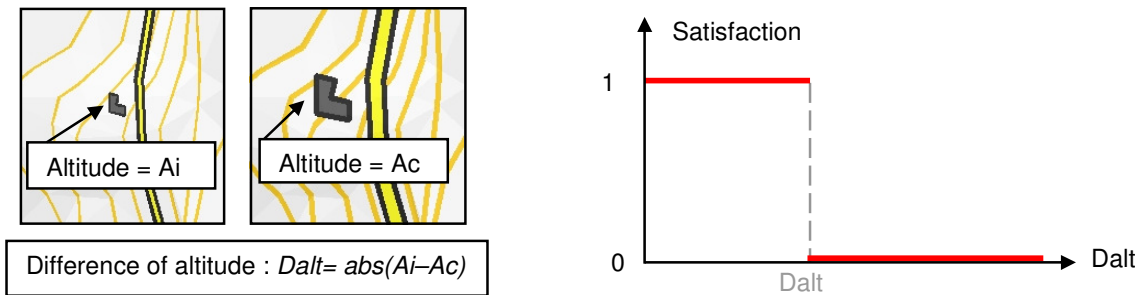


stretching from an object, or by one of its activated neighbours points. This way to activate the agents allows making local deformations during the generalization process. The deformation is not obtained with huge time-consuming global method on the whole field.

We present now how an object can stretch the field.

### III.d. Stretching constraint

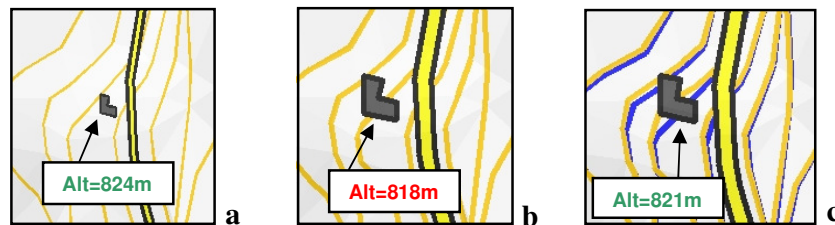
As shown previously Figure 1, when an object changes during the generalisation process, its relationship with a field can be broken. To constrain this relationship, we need to measure it, and tune how we want this relationship to be constrained. For that purpose, we need an interpretation of the difference between the current and the initial state of the relationship. Figure 8 shows an example for the building altitude preservation constraint presented previously. The altitude of the building is measured on the DTM represented the relief. The violation of this constraint is given by the value  $Dalt$  and interpreted with the satisfaction graph.



**Figure 8.** Satisfaction of the altitude constraint depending on the variation of altitude.

The satisfaction graph allows tuning how we want the relation to be constrained, depending on the map specifications. The satisfaction is given by a value between 1 (satisfied) and 0 (unsatisfied). For our example, we propose a stair-like graph (Figure 8, on the right). Under the value  $Dalt$ , the altitude change is considered as not significant: the satisfaction is 1. Then, the constraint is considered as unsatisfied. For example, the Figure 9a shows the building whose altitude is 824m. We suppose we want constraint the building to keep an altitude precision of 3m. On the Figure 9b the building has generalized itself: its altitude is 818m: the satisfaction value is 0; the constraint is considered as violated.

To preserve the altitude constraint, the building has the capability to measure itself the satisfaction of its altitude preservation constraint after its own generalization, and then to stretch the relief field to make its constraint satisfied again. We propose to compute this stretching of the field from the initial position of the center of the building (Figure 9a) in the field. To stretch this point, we propose to us a segment with a length preservation constraint (as presented in IIIc). This segment links a point of the DTM and the center of the generalized building; and allow the building to stretch the field. Because it is not possible to determine a priori which weight value to choose for this stretching constraint, the building tries several values until the constraint is satisfied again. The result is shown Figure 9c. The relief has been deformed by the building (the initial contours are drawn in blue) in order to correct the buildings altitude (according to the satisfaction graph).



**Figure 9.** The building altitude preservation constraint

In this process, the field is passive. A further objective is to allow the field to control its state after the stretching of the object, in order to avoid some possible too important field deformations. If the field consider it is too much deformed, it should refuse this deformation and constraint the objects to change.

## IV. Conclusion and further work

In this article we have proposed an agent-based method to compute continuous deformations. This method can be computed with discrete transformations, as we showed for the object-field relationship preservation. This work is an example of a way to manage discrete and continuous transformations in the same process. Because we need both transformations in the generalization process, the association between the generalization models seems so important than the models themselves. The agent paradigm is an opened resolution method, which is useful for this purpose. Further works could be done to progress toward a merging between continuous and discrete transformation models as we propose in (gaffuri 2006).

We could propose to apply our method to other deformable objects. For example, for the generalization of networks, we could define specific road section and crossroad shape preservation to improve the diffusion of discrete transformations. The need to compute both continuous and discrete transformation for networks generalization is high.

Concerning the object-field relationship conservation, further works could be developed. We gave one proposition for the building altitude preservation. In our example, the building is considered as a point. Some other constraints between other objects, especially network sections, would be much trickier, because these objects are deformable too, and should deform the field through several points. Some works proposed a way to merge roads section in a DTM for map generalization (Kremeike 2004). The use of characterisation measures on the section of the section as proposed in (Plazanet and spagnuolo 1998) could be used.

We observed too that some constraints between fields and objects are sometimes hard (for example, the topologic relationship between a road section and a land use parcel, or the position of a river flowing in a thalweg). The stretching constraints should not be elastic for these cases.

Finally, we could improve the proposed field deformation process by adding other sub-field objects and other shape preservation constraints. An other method could be proposed to determine which point of the field to stretch to deform it for a specific purpose. As we proposed, we could use a characterisation method to determine when a field is too much deformed. In this case, the field could constrain the stretching object to change. For the choice of relative importance of the shape preservation constraints, we choose the same value for each constrain. We could imagine allowing the field to tune itself these importance values depending on its state: if the field measure a too high deformation of some of its sub-field objects, it could constrain some specific shape preservation constraints to be much more important.

## References

- Ai, T. 2004. A generalisation of contour line based on the extraction and analysis of drainage system, ISPRS, Istanbul, Turkey, July 2004.
- Bader, M. 2001. Energy minimization methods for feature displacement in map generalisation, PhD thesis, university of Zurich, 2001.
- Barraut, M., N. Regnauld, C. Duchêne, K. Haire, C. Baeijs, Y. Demazeau, P. Hardy, W. Mackaness, A. Ruas, R. Weibel, Integrating multi-agent, object-oriented, and algorithmic techniques for improved automated map generalisation, In: *Proceedings of the 20th international conference of cartography*, International Cartographic Association, Beijing, Vol. 3, 2001, pp 2110-2116.
- Beard, K. 1991. Constraints on rule formation, In: *Map generalization: Making rules for knowledge representation*, B. Buttenfield, and R. B. McMaster (ed.), Longman, 1991, pp 121-135.

- Brassel, K., and R. Weibel. 1988. A review and conceptual framework of automated map generalisation, In: *International Journal of Geographical Information Systems*, Vol. 2, No 3, 1988, pp 229-244.
- Buckley, A., C. Frye, B. Buttenfield, and T. Hultgren. 2005. An information model for maps: toward cartographic production from maps, In: *Proceedings of AutoCarto 2005*, Las Vegas, USA, 2005.
- Burghardt, D., and S. Meier, 1997. Cartographic displacement using the snakes concept, In: *Semantic modelling for the acquisition of topographic information from images and maps*, Foerstner W., Pluemer L. (ed.), Birkhaeuser verlag, Basel, 1997.
- Cova, T. J., and M. F. Goodchild. 2002. Extending geographical representation to include fields of spatial objects, In: *International Journal of Geographical Information Sciences*, Vol. 16, No. 6, 2002, pp 509-532.
- Duchêne, C. 2004a. Généralisation cartographique par agents communicants: le modèle CartACom, PhD thesis, University Pierre et Marie Curie Paris VI, COGIT laboratory, juin 2004. <ftp://ftp.ign.fr/ign/COGIT/THESES/>
- Duchêne, C. 2004b. The CartACom model: a generalisation model for taking relational constraints into account, *ICA/EuroSDR workshop on generalisation and multiple representation*, International Cartographic Association, commission on map generalisation and multiple representation, Leicester, England, august 2004. <http://aci.ign.fr/Leicester/paper/Duchene-v2-ICAWorkshop.pdf>
- Gaffuri, J. 2005. Toward a taken into account of the “background themes” in a multi-agent generalisation process, *workshop in generalisation and multiple representation*, International Cartographic Association, commission on map generalisation and multiple representation, a Corona, Spain, 2005.
- Gaffuri, J. 2006. How to merge optimization and agent based techniques in a single generalization model?, *workshop on generalisation*, International Cartographic Association, commission on map generalisation and multiple representation, Vancouver, Washington, june 2006. (to be published)
- Galanda, M. 2003. Modelling constraints for polygon generalisation, *Fifth workshop on progress in automated map generalisation*, International Cartographic Association, commission on map generalisation and multiple representation, Paris, France, april 2003.
- Guilbert, E., E. Saux, and M. Daniel. 2006. Conflict removal between B-spline curves for isobathymetric line generalization using a snake model, In: *Cartography and Geographic Information Science*, Vol. 33, No. 1, 2006, pp 37-52.
- Gold, C., and D. Thibault. 2001. Map generalisation by skeleton retraction, In: *Proceedings of the 20th International Cartographic Conference*, International Cartographic Association, 2001, pp 2072-2081. [http://www.voronoi.com/pdfs/2000-2003/Map\\_generalisation\\_by\\_Skeleton\\_Retraction.pdf](http://www.voronoi.com/pdfs/2000-2003/Map_generalisation_by_Skeleton_Retraction.pdf)
- Harrie, L., and T. Sarjakoski. 2002 Simultaneous graphic generalization of vector data sets, IN: *GeoInformatica 6:3*, 233-261, Kluwer Academic Publishers, 2002.
- Hojholt, P. 2000. Solving space conflicts in map generalisation: using a finite element method, In: *Cartography and Geographic Information Sciences*, Vol. 27, No.1, 2000, pp 65-74.
- Kocmoud, C. J., and D. H. House. 1998. A constraint-based approach to constructing continuous cartograms, In: *Proceedings of SDH'98*, 1998. Available at <http://www-viz.tamu.edu/faculty/house/cartograms/>
- Kremeike, K. 2004. Generalization of dense digital terrain models while enhancing important objects, In: *International Archive of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 35, ISPRS, Istanbul, Turkey, 2004.
- McMaster, R. B., and K. S. Shea. 1988. Cartographic Generalization in a Digital Environment: a Framework for implementation in a GIS, In: *Proceedings of GIS/LIS'88*, San Antonio, Texas, USA, 1988, pp.240-249.
- Plazanet, C., and M. Spagnuolo. 1998. Seafloor valley shape modeling, In: *Proceedings of SDH'98*, 1998.
- Ruas, A. 1999. Modèle de généralisation de données géographiques a base de contraintes et d'autonomie, PhD thesis, Marne la Vallée University, COGIT laboratory, 1999. <ftp://ftp.ign.fr/ign/COGIT/THESES/RUAS/>
- Ruas, A. 2000. The roles of meso objects for generalisation, In: *Proceedings of SDH'00*, Vol. 3b, 2000, pp 50-63.
- Sester, M. 2005. Optimization approaches for generalization and data abstraction, In: *International Journal of Geographical Information Science*, P. Fisher, M. Gahegan, and B. Lees (ed.), Vol. 19, No 8-9, September - October 2005.
- Van Kreveld, M. 2001. Smooth generalization for continuous zooming, *Fourth workshop on progress in automated map generalization*, International Cartographic Association, commission on map generalisation and multiple representation, Beijing, 2001.
- Shea, K. S., and R. B. McMaster, 1989. Cartographic generalisation in a digital environment: When and how to generalize, In *Proceedings of AutoCarto 9*, Baltimore, USA, 1989, pp 56-67.
- Weiss, G. 1999. Multiagent systems. A modern approach to distributed artificial intelligence, The MIT Press, 1999.