Field deformation in an agent-based generalisation model: the GAEL model

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Abstract. Many research works in map generalisation concern building and road themes. Several generalisation models, such as an agent-based generalisation model on which this paper focuses, have been designed and applied for these themes and give promising results. Our purpose is to take into account field themes, such as the relief and the land use cover. Many relationships exist between these themes and other objects and should be preserved during the generalisation process.
The focus of this work is to design an hybrid generalisation system able to manage both discrete and continuous operations. Thus, we propose a model, called GAEL (for Generalisation based on Agents and ELasticity), which extends the existing agent-based model in order to make the triggering of continuous operations possible. The objects to deform are decomposed into small constrained objects and the points composing the geometry of these objects are modeled as agents. We apply this model to the deformation of fields.

1 INTRODUCTION

Map generalisation is "*the selection and simplified representation of detail appropriate to the scale and/or the purpose of a map*" [19]. Many research efforts have been made to make this process automatic. Pieces of research mainly concern the conception of new geometric algorithms to transform the shape of objects, spatial analysis methods to characterize the space in order to apply specific algorithms to specific configurations and learning methods to improve the generalisation rules. This paper focuses on generalisation models. A generalisation model is a generic framework, which allows to perform the generalisation of a whole dataset. In this paper, we focus on the agent-based model of [29]. This model is based on the works of [29] and [9]. It is used for building and road generalisation [21], [25]. Some production lines of several european national mapping agencies are based on this model [27], [22]. Figure 1 gives some outcomes.

The purpose is to go further in the generalisation automation by taking into account a new kind of themes: the fields. In the next section, we present the problem raised by taking into account these new themes. Then our proposition is presented.

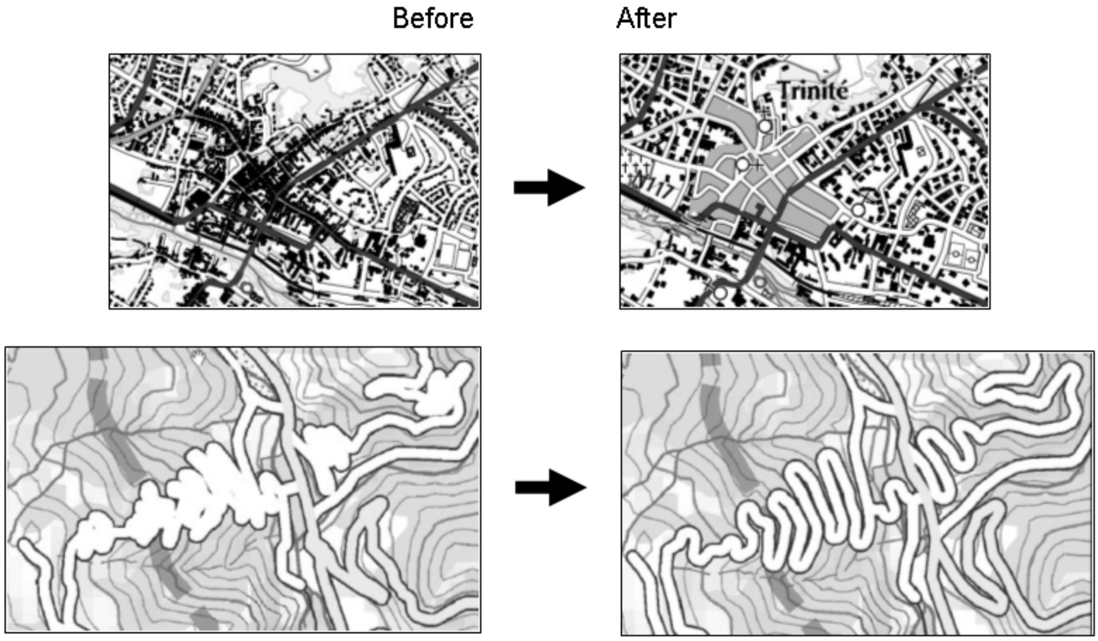

Figure 1: Agent-based generalisation model outcome examples for buildings and roads generalisation

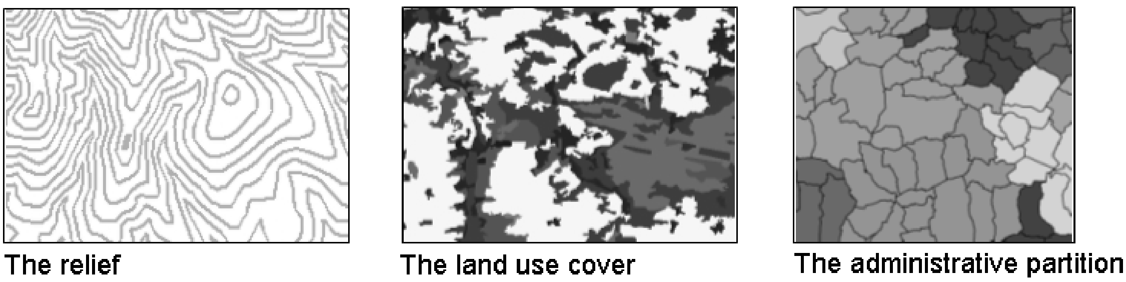

Figure 2: Examples of fields (data: IGN BDTopo©, Corine Land Cover©)

2 FIELDS IN MAP GENERALISATION

Field model provides a way to represent continuously defined variables. A field representation "*allows to assign a value to every location*" of the geographical space [7]. Many kind of fields can be used [15]. Field and object representations are complementary in geographic information sciences [7]. On a map, both kinds of representations are used. Objects such as buildings and roads are displayed upon fields such as the relief, the land use cover or the administrative partition (cf. figure 2)

On topographic maps, fields compose a map background on which other objects such as buildings and roads seem to be put. Many relation-

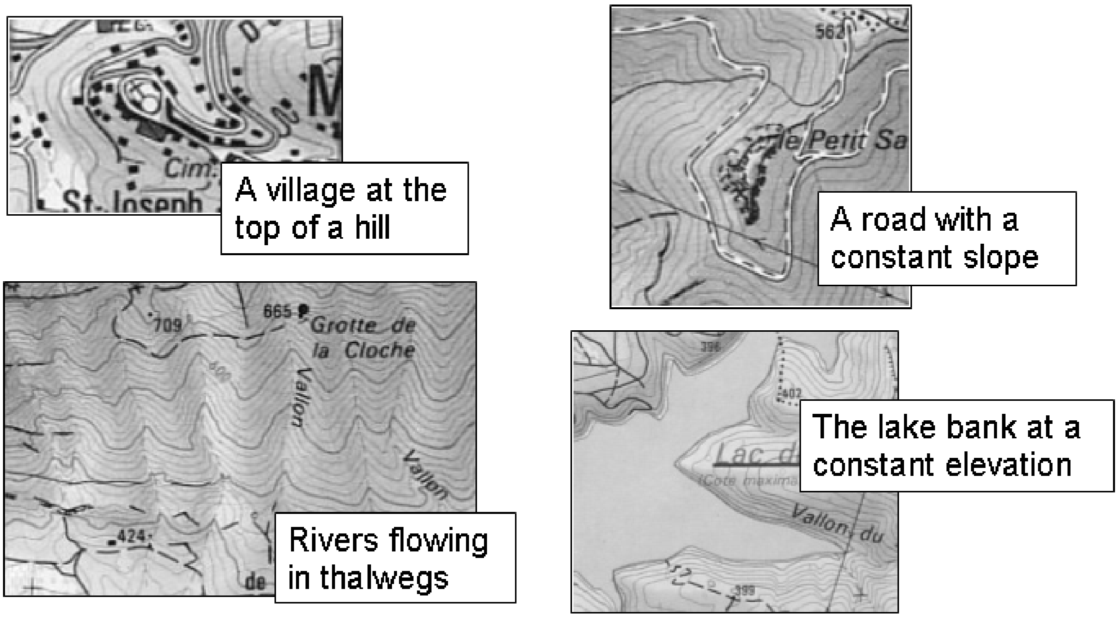

Figure 3: Examples of relationships between a field (the relief) and objects. (Maps: IGN©, 1:25k)

ships exist between fields and objects. Figure 3 gives some examples of relationships between buildings, roads, hydrography and the relief. Many other relationships may exist.

When generalising buildings and roads, some of the relationships can be broken. The problem we propose to tackle is the preservation of such relationships during the automatic agent-based generalisation process.

We can wonder how fields could be taken into account in an automatic generalisation process. When generalising manually, cartographers often use deformation operations on fields. Figure 4 presents an example of such a manual operation. Contours representing the relief are deformed in order to enlarge a valley and get enough space for the enlargement of network symbols.

Figure 5 presents how we propose to manage the interactions existing between fields and objects during the generalisation process. Objects are displayed upon fields. Fields compose the map background. Both kinds of objects share relationships. Because of these relationships, two kinds of interactions between fields and objects can occur when generalising:

- **Objects deform fields:** when objects are generalised, fields can be deformed in order to preserve some relationships with objects (as shown on figure 4). The final state is the result of a balance between

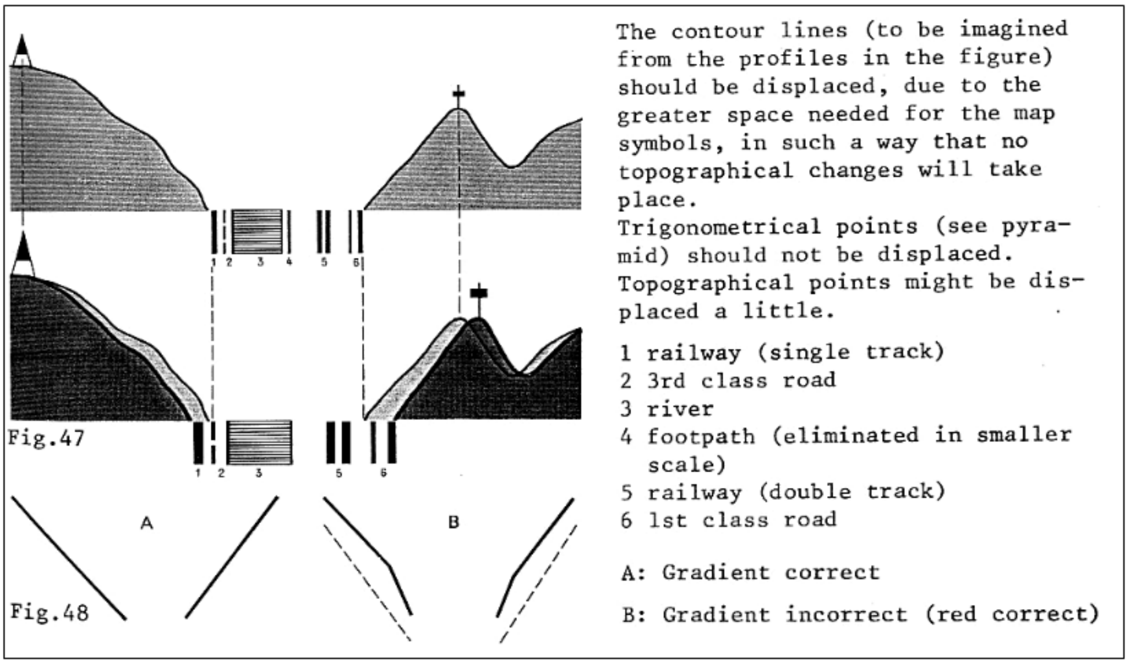

Figure 4: Enlargement of a valley during the generalisation process [32]

relationships preservation with the objects and shape properties of fields, which have to be preserved too. Such a deformation can be considered as a side effect of the transformation of objects on fields: transformations on objects should be propagated to the fields for the objects fields relationships preservation.

- **Fields constrain objects:** when objects are generalised, fields are taken into account to preserve the relationships between objects and fields. For example, a road, that has to be displaced in order to avoid overlapping an other object, should stay in its valley (as shown on figure 4). The fields constrain the generalisation of the objects in order to preserve their relationships.

3 Agent-based generalisation automation

In this section, we first present the generalisation model on which our model lies [29]. After a presentation of the main principles of this model, we explain why the model need to be extended in order to manage fields objects relationships preservation.

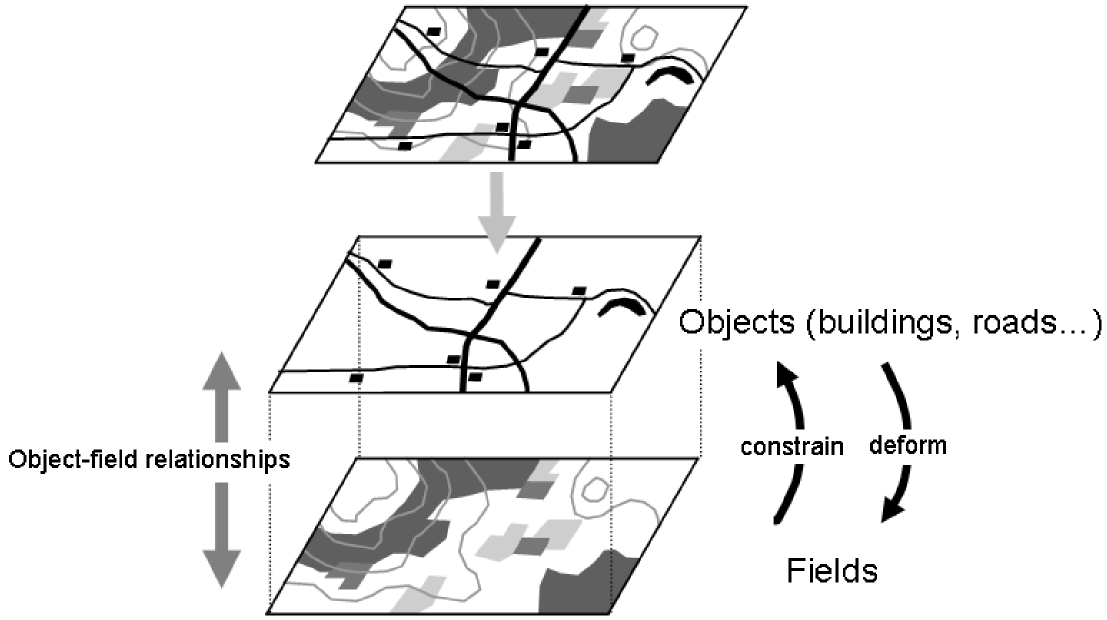

Figure 5: Interaction between fields and objects during the generalisation process

3.1 The agent-based generalisation model of [29]

The model originally bases on the approach of [4]. The principle is to use methods to identify the cartographic conflicts (for example, when two objects overlap, or when an object is too small), and then to apply locally a specific transformation to the object(s) involved in each cartographic conflict. The generalisation process is a sequence of transformations applied to some parts of the map.

The agent-based model is based on this approach. Their 3 main principles are the following:

- **Each geographic agent is modeled as an agent.** (cf. figure 6a)
  An agent is "*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*" [34], p.29. An agent can be compared to an alive object, which has a goal, capabilities to reach this goal autonomously by interacting possibly with other agents. An agent can have some capabilities to perceive its environment and to communicate with other agents. In the agent-based generalisation model, each geographic object that need to be generalised (buildings, roads...) is a geographic agent (cf. figure 6a): it is autonomous

and has a goal.

- The goal of each geographic agent is to generalise itself, that is **to satisfy its cartographic constraints.** (cf. figure 6b)
  The map specifications are translated into a set of constraints according to [3]. Each constraint is carried by an agent (for example, an object which should be big enough will have a constraint on its size). The goal of each agent is to try to satisfy its constraints. To achieve this goal, an agent is able to measure its satisfaction level (which is the result of an aggregation of the satisfaction of all its constraints), and then to choose an algorithm to apply to itself in order to improve its satisfaction state. This algorithm depends on its violated constraints. For example, an object whose size constraint is violated will try to enlarge itself. Every time an agent applies an algorithm to itself, it checks afterward if its state has been improved by this algorithm, and can possibly backtrack and try another algorithm. This process allows geographic agents to improve their constraints satisfaction autonomously step by step and tend toward a satisfying generalised state.

- The use of several levels: **the micro and meso levels.** (cf. figure 6c)
  The objects does not generalise themselves independently, but depending on their own context. The generalisation process must take into account relationships between objects: some constraints are relative to groups of objects (for example, the density of an urban block). In order to take into account these constraints, the agent-based model is based on the use of several levels of organisation. The *micro level* concerns the levels of the objects taken independently. The so-called *meso level* concerns the level of the groups of object [28]. Each meso agent is composed by other agents, meso or micro. For example, a town agent is composed by urban block agents, and a urban block agent is composed by building agents (cf. figure 6c). A meso agent manages the generalisation of its components. Micro agents also have the capability to communicate in order to satisfy relational constraints shared by both, such as a proximity constraint between two buildings [9].

This agent-based model gives a generic framework to perform generalisation of several kind of data. This model is quite open, because it is possible to tune the system depending on the need of the map. It is possible to add new agents, algorithms, constraints and spatial analysis measures

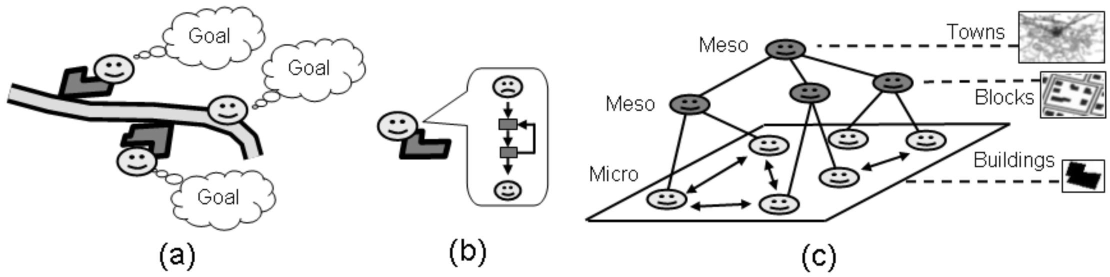

Figure 6: The principles of the agent-based generalisation model

easily. Some results of this model on building and road generalisation are shown figure 1.

3.2 Limits of the model

Taking into account the fields in the previously presented agent-based model raises problems that are presented in this section.

3.2.1 A new kind of relationship

The first problem is the new kind of relationships we have to deal with. The existing agent-based generalisation model has been designed to take into account relationships between groups of objects (the meso objects) and binary relationships between two micro agents. The relationships we have to deal with are different: a field-object relationship involves an object and a part of a field under this object.

3.2.2 Necessity of deformation

We have presented section 2 page 4 the necessity to compute deformations on fields during the generalisation process. A second problem concerns the use of such a transformation in the agent-based model: the agents improve their satisfaction step by step by applying a sequence of discrete operations. The model is not yet adapted to compute continuous transformations such as the deformation of a field.

The root of this problem lies on the fact that in map generalisation two kinds of operations are needed [24]:

- **Discrete operations:** These operations cause sudden changes on the map objects. For example, enlargement or displacement of buildings, typification of groups of buildings, removal of road bends are discrete operations. The result of a discrete operation on an object gives a different representation of the object.

- **Continuous operations:** These operations cause smooth changes. These changes seem to be reversible. For example, the diffusion of the displacement of a road part, the deformation of the relief layer are continuous operations. A continuous operation does not change the object shape much. The result is close to the initial representation.

Both kinds of operation are used during the generalisation process. The use of these types of operation mainly depends on two factors:

- **The object nature:** depending on their nature, the objects will be rather subjected to one type of operation. [16] underlines that some objects have a "*rigid*" behavior while other are much more "*elastic*". For example, buildings are mainly subjected to discrete operations (enlargement, suppression, typification of a group...) while fields are rather subjected to continuous transformations (deformations). Some objects such as the networks are subjected to both kinds of operation depending on the situation (for example, a continuous deformation or a discrete bend removal).

- **The scale change range:** As presented in [24], the higher the scale change range is, the more discrete operations will be needed during the generalisation process. For small scale changes (for example from 1:10k to 1:20k), only light deformations of objects could be sufficient to get a satisfying generalised result. As illustrated in [33], when this scale change increases, discrete operations have to be performed on some objects.

Continuous operations are often used after discrete operations in order to manage the side effects that discrete changes can cause on other objects. The main part of the change toward a satisfying generalisation is obtained with discrete operations. The use of continuous operation can improve the outcome of the generalisation process, but it is not the most important part of the process. Continuous operations can therefore be considered as "*second order operations*", compared to discrete operations.

Today, our agent-based model is adapted to discrete operations. The focus of our work is to complement it to compute jointly discrete and continuous operations. We present hereafter our proposition to get such a hybrid generalisation model. Then an application to the deformation of the fields for the preservation of field-object relationships is presented.

4 THE GAEL MODEL

This section describes our proposition, called GAEL model (Generalisation based on Agents and Elasticity). This model aims at extending the capabilities of the agent-based model presented in part 3.1 to compute continuous transformations.

The first part of the section presents the principle of this deformation model, and then an application to the deformation of the field for the preservation of field-objects relationships is described.

4.1 Toward an agent-based deformation method

Many research works have proposed some deformation methods applied to map generalisation. Most of them are based on the adaptation of mechanic of solids principles. In [17], the map is globally deformed by the use of flexible triangles. [1] proposes an adaptation of the beams structure to road network deformation and buildings displacement. [6] adapts the snakes model for the deformation of linear objects. [16] and [31] propose a deformation method based on least square adjustment. These methods give satisfying result to compute continuous operations.

Many authors mention the utility to use both continuous and discrete transformations during the automatic generalisation process. In [31], the presented continuous generalisation model is designed to be used after some discrete operations: "*Least square adjustment as such can only model continuous changes of objects during generalisation (...). In order to also apply it for discrete changes (...), an underlying model for these changes has to be available that can be introduced in the adjustment process*" ([31], p.872). [22] present a road network generalisation process using both the agent-based model of [29] and, afterward, the beams algorithm of [1]. It appears that continuous and discrete generalisation are not completely merged: discrete operations are applied first and then, a global deformation is performed. Our conviction is that the generalisation process would be improved by merging the deformation methods with the agent-based model to get a system able to compute continuous and discrete operation [12].

Several improvement of the agent-based model of [29] have been designed in order to progress toward this goal. [14] proposes an adaptation of this model to the generalisation of categorical maps (like geological maps): the snakes model of [6] is used during the discrete generalisation process to deform limits of areas. In [23], a propagation algorithm used during the agent-based generalisation process is presented. These works represent progress toward our purpose but have been designed for specific cases of deformation. Our purpose would be to provide a generic way to perform a wide set of continuous operations.

The main issue raised by the merge of continuous and discrete generalisation model is that the deformation methods previously presented are based on closed and global resolution methods (finite elements method, energy minimisation, least square adjustment). And so, it is not possible to include discrete operation in these processes. The whole dataset is deformed in a single step process. Our purpose is to build of a generic deformation model allowing to trigger some local deformations on some parts of objects (such as a part of field) during a process composed of a succession of discrete operations.

Our choice is to extend the agent-based model capabilities to compute continuous transformations. Many works in the multi agent systems domain have designed methods to solve problems, which have a continuous nature. [30] proposes an agent approach for outflow dynamics simulation. The continuous outflow equations provided by mechanic of liquids are translated at the level of some water particles modeled as agents interacting in a continuous environment. [5] presents a simulation model of sand piles, with the modeling of each sand grain as an agent interacting with its neighbors. [8] presents a simulation of coastal erosion based on an agent modeling of both the water and sediment particles.

These works show the capability of the agent paradigm to solve continuous problems. By adopting the same approach, we propose a method to perform continuous operations using the agent paradigm.

4.2 The principles of the agent-based deformation model

4.2.1 The need for a new level: the *submicro level*

The agent-based model refers to two organisation levels, micro and meso (cf. part 3.1). The micro level concerns the individual objects while the meso level concerns groups of objects. The use of deformations requires a new level because deformations involve parts of the objects.

Indeed, to define a deformation on an object, several elements are needed:

- **External constraints:** Such constraints cause the deformation. The effect of these constraints is to stretch or compress the object. The constraints are applied to some parts of the object.

- **Internal constraints:** Such constraints represent the shape preservation constraint of the object, depending on its composition and inner organisation. The effect of internal constraints is to react to external constraints.

- **A balance between internal and external constraints:** The deformation is the result of the balance. The balance is obtained by the displacement of some parts of the object.

Therefore, external constraints, internal constraints and balance concern parts of the object to deform. In order to allow to add some constraints on parts of objects and therefore to make them deformable, we propose to add a new level, called *submicro level* (cf. figure 7). This level concerns the parts of objects. It complements the existing levels of the generalisation model. An object to deform, such as a field, will be decomposed into small parts of the submicro level called submicro objects (for example, points, segments, angles, triangles...). The submicro objects will carry both internal and external constraints needed to compute deformations.

In the next part, we present internal constraints of submicro objects. External constraints applied for the field-object relationship preservation will be presented in part 4.3.

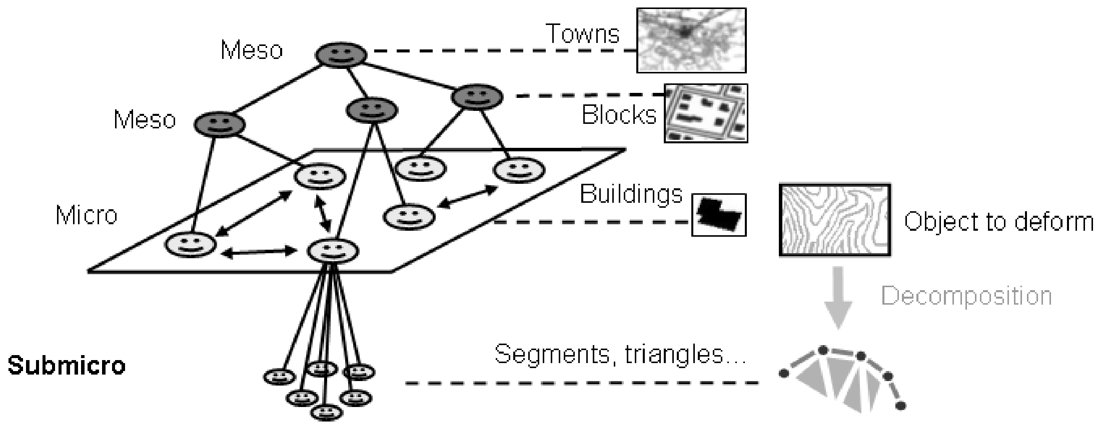

Figure 7: The submicro level

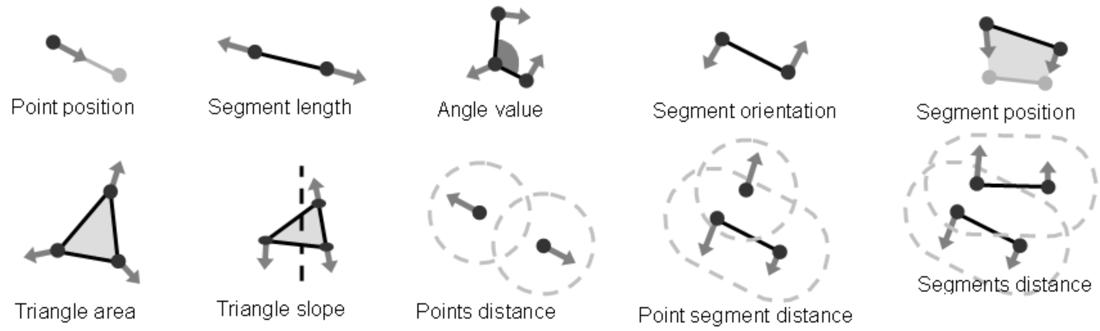

Figure 8: Examples of submicro constraints

4.2.2 Submicro internal constraints

Figure 8 presents some constraints carried by submicro objects. Some of these constraints are comparable to the ones proposed by [20] and [18]. Each submicro constraint concerns a characteristics of a submicro object, which has to be preserved. A submicro constraint acts on the submicro object as a force. The effect of a violated submicro constraint is translated to the points composing the constrained submicro object (represented by arrows in figure 8) [11].

The submicro constraints compose the shape preservation constraints of an object to deform. Depending on the nature of the object and on the specifications, some of these constraints can be added or not to the submicro objects composing the object. It is possible to tune the relative weight of these constraints in order to preserve some specific shape properties.

The combination of the internal constraints gives to the object elastic

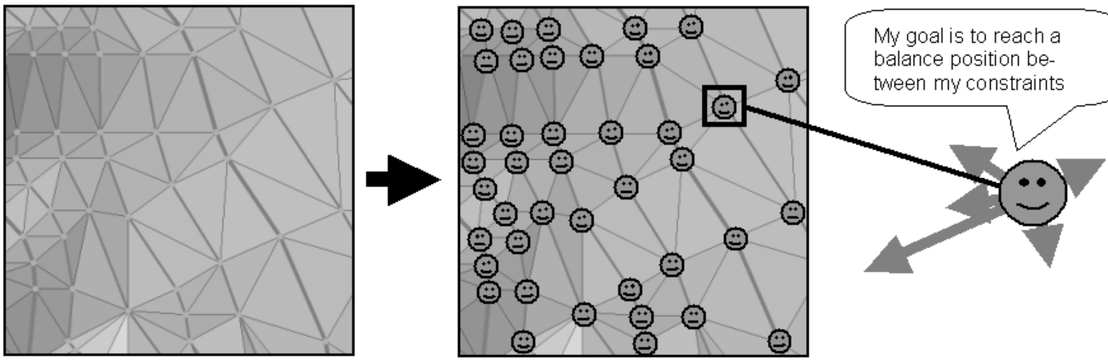

Figure 9: The points as agents

properties with appropriate shape preservation characteristics. When external constraints are applied on parts of the object, the stretching or compression caused by the external constraints are diffused inside the object in order to get a balance between the internal and external constraints. We describe in the next part how this balance is obtained.

4.2.3 Agent points

In order to make the object deformable, we propose to model the points composing the object geometry as agents as proposed for example in [10] and [2]. The points are considered as autonomous entities, that can move according to a specific goal. The goal of each point is to reach a balance position between all its constraints (cf. figure 9). The constraints of a point are all the constraints of the submicro objects it belongs to.

The agent point interactions allow to give to the object an elastic behavior. Figure 10 presents an example of such behavior. Figure 10a shows the relief field used representation. We use a TIN based on the contour line segments. The elements composing the TIN have some specific internal constraints: preservation of triangles area, of contours segments orientation and length, of points position. The effect of an external constraint is simulated by stretching one of the points (the gray arrow figure 10a). The figure 10b shows the progressive deformation of the field obtained by the displacement of the points around the stretched point. The figure 10c shows the final result. All the points are balanced, and the field is deformed. The global shape of the field seems to be preserved for the best.

The activation of the agent points is managed by a scheduler presented in figure 11. This scheduler uses a queue structure containing all the agent points to activate. At the beginning of the deformation process, the queue

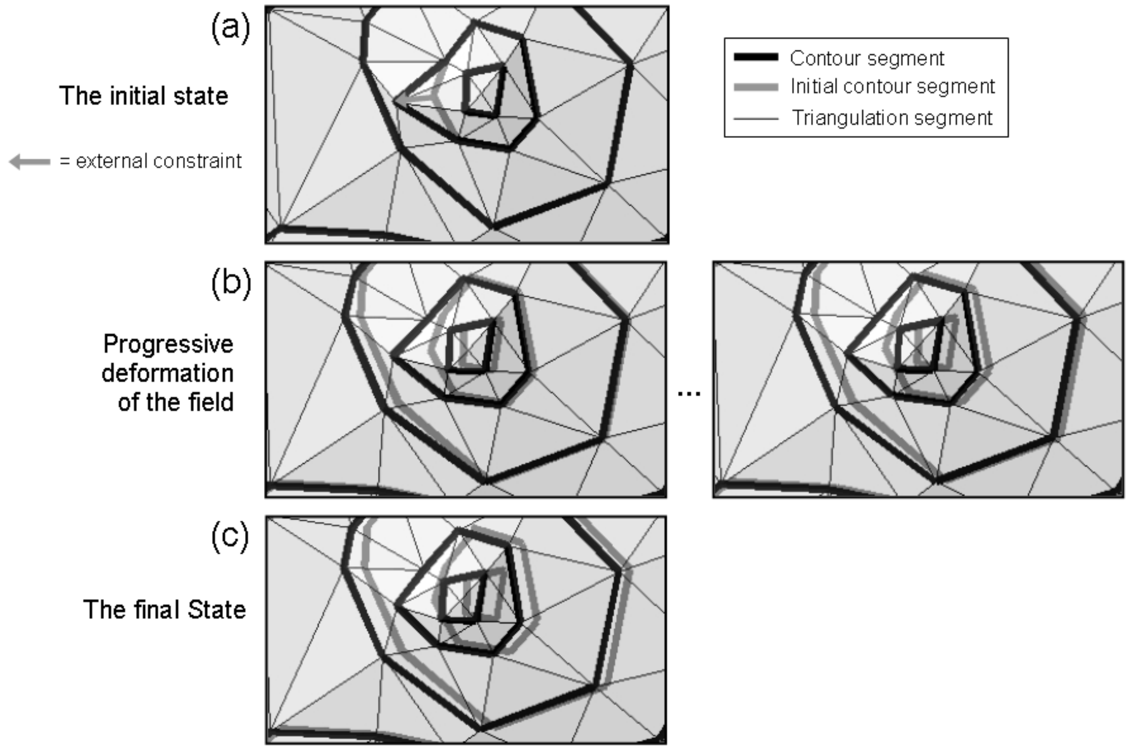

Figure 10: Example of a deformation on a field

is initialized with the points on which the external constraint is applied. All the points of this queue will be activated until the queue is empty. During its activation, an agent point can add some other agent points in the scheduler as shown in the life cycle of the agent point (cf. figure 11 on the right). When a point is activated, it checks if it is in a balance position. If it is, it leaves the queue, so it is deactivated. If it is not balanced, it moves toward its balance position and then, because this movement can have affected the balance of its neighbors, it wakes up its neighbors by putting them into the queue of the scheduler. The neighbors of a point are all the points whose balance can be affected by a move of this point, that is, all the points belonging to the same submicro objects as the point.

All the points of the scheduler progressively move toward their balance position. At the end of the process, the points around the initial points have moved depending on the internal constraints of the objects.

Agent point have several behavior, which give them some capabilities:

- **The capability to progress toward a balance position:** Each agent point can compute a right displacement allowing him to improve its balance state. This displacement is the sum of several displacements

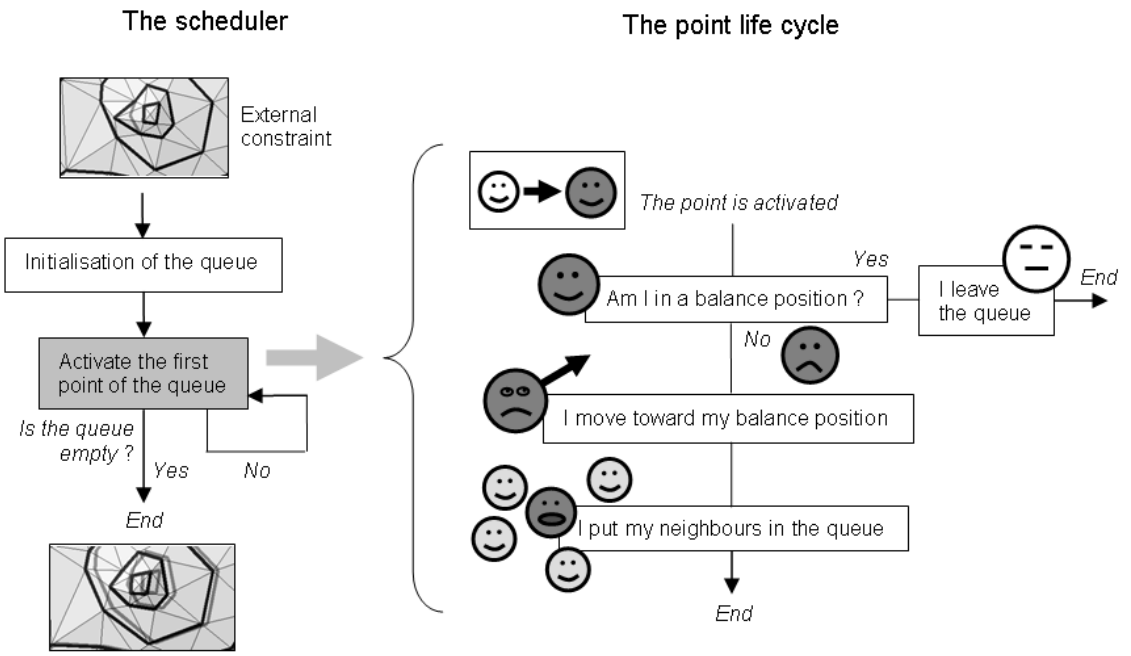

Figure 11: The scheduler and the agent point life cycle

computed for each constraint of the point. For each constraint, a displacement is computed using a steepest gradient method. The more a constraint is violated, the higher the weight of its displacement in the total displacement of the point is. The role of each constraint can be compared to a spring applied to the agent point [12].

- **The capability to check if it is nearly in a balance position:** It is not possible to get the exact balance position of a point: the point always moves toward its balance position, making always smaller displacements during the process. This situation is comparable to the famous arrow paradox of Zeno [26]. To avoid an infinite movement, the point is considered as in a balance position when the computed displacement becomes insignificant (less than the resolution of the data for example).

- **The capability to wake up its neighbors:** Because of the object structure, each point is able to retrieve its neighbors. As soon as an agent point moves itself, it activates its neighbors by putting them into the scheduler queue. Because of this mechanism, only a few points are activated during the deformation process (cf. figure 12). The deformation is considered as a local transformation: the object is not globally deformed in a single step process (as it is in the deformation methods based on finite elements method or least square adjustment presented part 4.1).

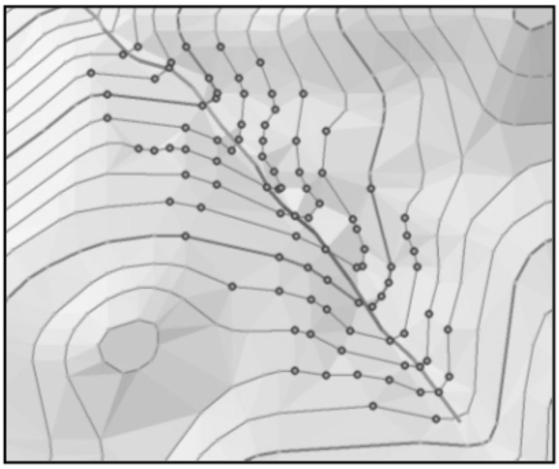

Figure 12: A local deformation (only the black points have been involved in the deformation of the field)

4.3 Field-object relationships constraints

In the previous part, we presented how to make objects deformable by the use of internal constraints of submicro objects and agent points. In this part, we present how to apply deformations to fields to preserve relationships between fields and objects. Fields deformations are caused by external constraints linked to object relationships.

4.3.1 Fields as deformable layers

In order to take into account fields in the generalisation process, we propose to make them deformable using the GAEL model. A field becomes a kind of alive layer adapting to the transformation of other objects (cf. figure 13). Each agent point of the field will be able to perceive what happens upon him during the generalisation process and to move depending on the constrained relationships with these objects.

In the next parts, we present some field-object relationships constraints. According to figure 5 page 5, the effects of these constraints are:

- to deform the fields (they act on the field as external constraints). Agent points composing fields have to find a balance between internal constraints of the submicro objects they belong to and external constraints of the field-object relationship.
- to constrain the objects. Objects can be displaced and/or deformed by fields.

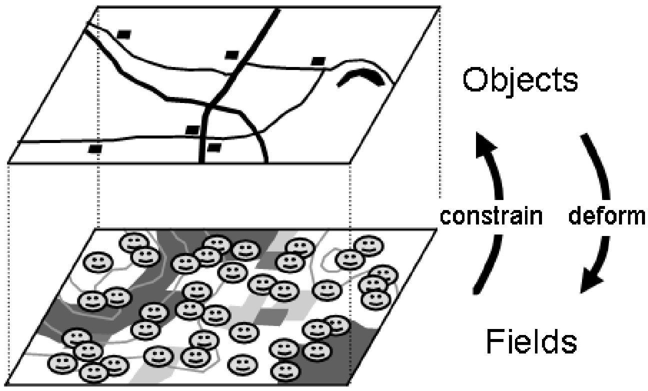

Figure 13: Fields as elastic layers

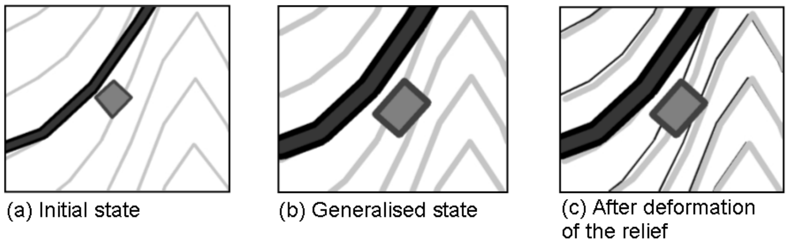

Figure 14: Building elevation constraint

For each constraint, we show how it is possible for the objects to deform the field, and for the field to constrain the objects.

4.3.2 Building elevation preservation constraint

The first proposed constraint concerns the elevation value of a building. Figure 14a presents a building and a road. These objects are generalised figure 14b. Because of the displacement of the building, its elevation value has changed (the elevation value of the building is linked to its relationship with the relief). In order to preserve this value, the relief has to be deformed. The result is shown in figure 14c (the initial contour lines are drawn in dark gray). The relief has been deformed, and the elevation value of the building is closer to its initial value.

The deformation is obtained by using an external constraint on points composing the triangles on which buildings are located (cf. figure 15a). The displacement of the building on the relief causes an external constraint on the triangle under the building. Reversely, the building could be constrained too in order to keep its elevation value (cf. figure 15b). In this case, the relief would not be changed, but the building would move to retrieve a

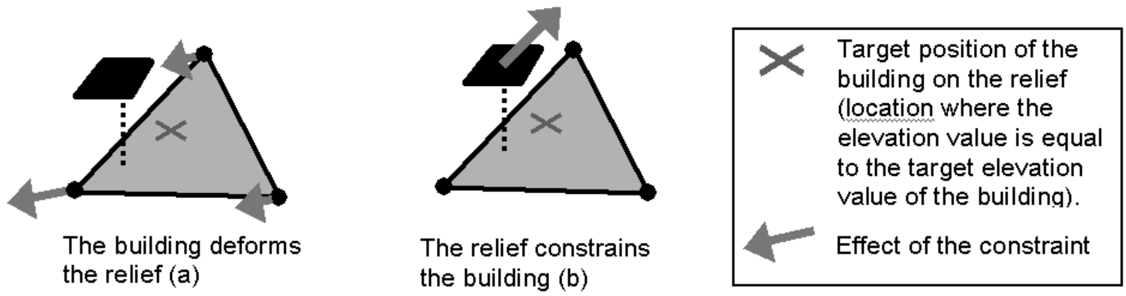

Figure 15: Building elevation constraint

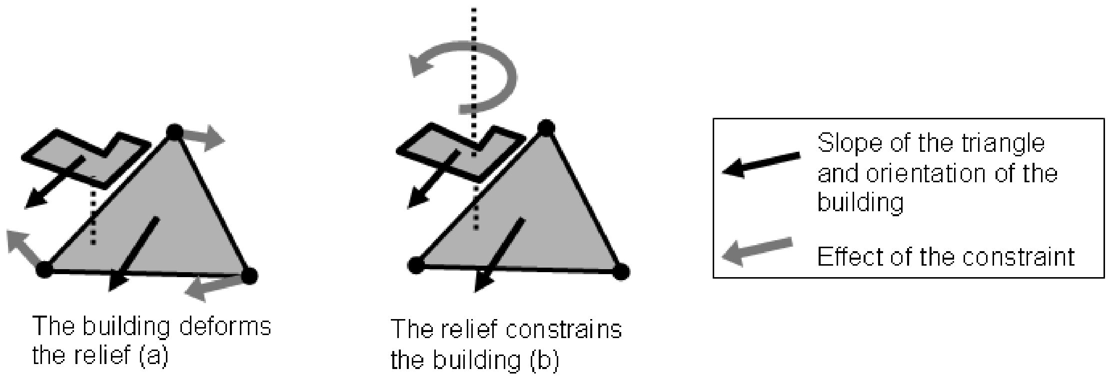

Figure 16: Building slope orientation preservation constraint

right elevation value.

4.3.3 Building slope orientation preservation constraint

In the same way the elevation value of a building can be constrained to be preserved, it is possible to preserve the difference between the orientation of a building and the orientation of the slope under the building. This constraint can be useful to preserve when buildings are oriented toward the slope.

This constraint is presented figure 16. Figure 16a shows how the constraint can deform the relief by applying a rotation to the triangle under the building. Figure 16b shows how the relief constrain the building by applying a rotation to it.

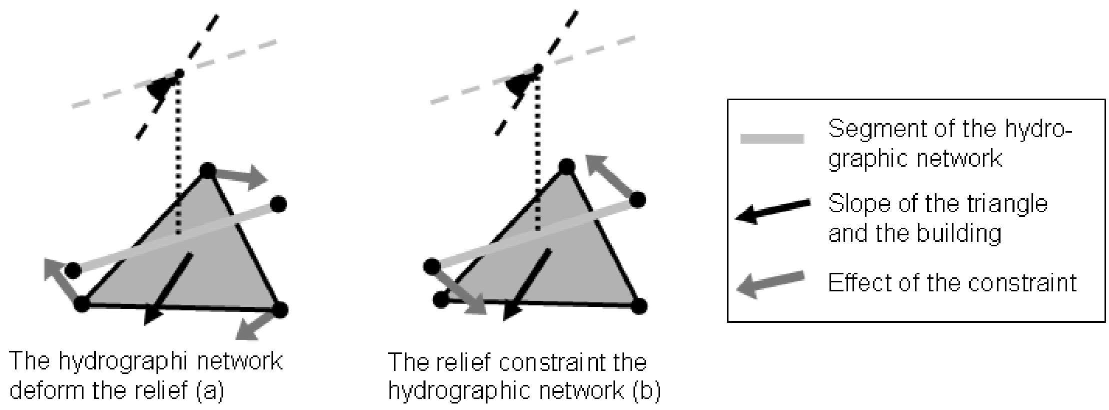

Figure 17: Outflow preservation constraint

4.3.4 Outflow preservation constraint [13]

The constraint between the hydrographic network and the relief is strong: the hydrographic network flows down on the relief. A river section must therefore not be displaced away from the valley it flows in. Reversely, the relief must follow the hydrographic network when it is generalised.

Figure 17 presents a constraint, which allows to preserve the outflow of the hydrographic network on the relief. The principle is to constrain the difference value between the orientation of each segment of the hydrographic network and the orientation of the slope under each segment. This difference value represented as a black angle on figure 17 a and b is null when the segment perfectly flows down on the relief. The hydrographic network can deform the relief by applying a displacement and a rotation to the triangle it is on (cf. figure 17a). The relief can constrain the hydrographic network by constraining the orientation of the segments composing the network (cf. figure 17b). Further details on this constraint are available in [13].

Figure 18 and figure 19 give some results of this constraint.

On figure 18a, a hydrographic section (in black) does not flow in its thalweg. After a deformation of the hydrographic network using the presented constraint, the outflow has been improved (cf. figure 18b).

On figure 19, the relief has been deformed. The segments of the hydrographic network constrain the relief triangle to flow. The result after deformation of the relief field allows to preserve the outflow relationship.

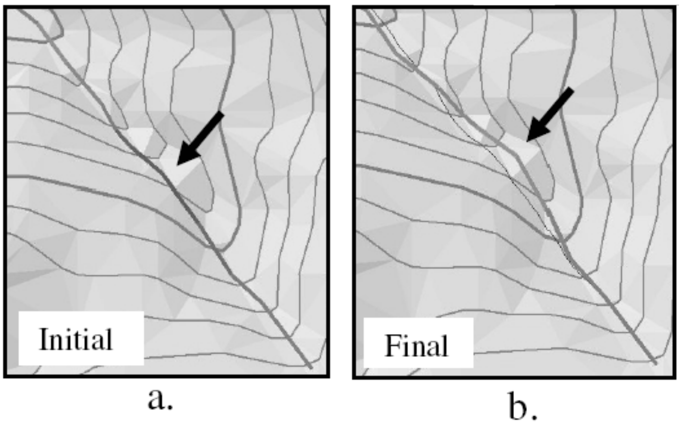

Figure 18: Deformation of the hydrographic network by the relief (data: RGE IGN©)

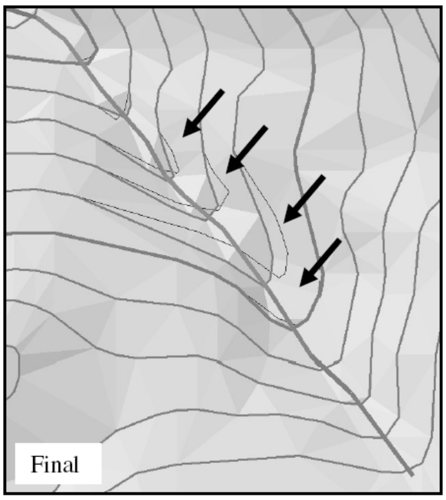

Figure 19: Deformation of the relief by the hydrographic network

4.3.5 Other constraints

Many other constraints could be designed depending on the specifications of the generalisation process. They could be adapted from the given ones. For example, some specific hydrographic sections, such as the channel section have the specific property to have a slope close to zero: a channel section is horizontal. The previous constraint can be adapted to this type of section. Each segment of a channel must be constrained to be flat. The difference between the orientation of a segment and the slope of the relief must be constrained to be Pi/2.

The presented field object relationships preservation constraints concern the relief, buildings and hydrographic sections. Some other constraints involving other themes such as the road network and the land use partition field could be designed. The genericity of the model make this improvement conceivable.

5 CONCLUSION AND FUTURE WORK

In this paper, we presented the issue of taking into account fields in an agent-based generalisation model. The main problem was the necessity to get a hybrid system able to manage discrete and continuous operation together. The GAEL model was proposed to progress toward this goal. This deformation model is based on the use of the so-called submicro level and the use of agent points. We have proposed an application of this deformation model to the preservation of some field-object relationships preservation.

The presented work has been implemented on the COGIT laboratory generalisation platform based on the GIS software Radius Clarity©of 1spatial. A future work concerns the strategies the object can adopt when they try to deform the same field together. The presented model could be applied to field object relationships involving other objects (the road network...) and other fields (the land use field). A long term purpose would be to merge both *elastic* and *rigid* generalisation. Geographic agents should be able to become sometimes rigid (to apply discrete transformation to themselves) sometimes elastic in order to improve their generalisation.

This work emphasizes the advantages of the agent approach in geographical information science. Agent-based models, not only in generalisation, have the characteristics to be very flexible and easily improvable. New functionalities can be added to a multi agent system by adding new kinds of agents, new capabilities to existing agents (perception, action, communication...), or new levels of organisation. Using an agent approach in geographic database managing would allow to get geographic databases composed of *alive* objects, able to adapt their state to a specific purpose. Objects of such a database would not only be characterized by their geometry and attribute values, but also by capabilities to perceive their context, to analyse this context and act in order to achieve a predefined goal.

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