Outflow Preservation of the Hydrographic Network on the Relief in Map Generalisation

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Introduction

In most GIS softwares, geographical data are often stored and managed using a set of independent layers. Many important relationships existing between objects of these layers are not explicit and can therefore be broken by some treatments on the data (such as generalisation) and create inconsistencies.

In this paper, we focus on the relationship existing between relief and hydrographic network. This relationship is particularly important: in the real world, the hydrographic network flows down on the relief. Many rivers are located inside deep thalwegs, which have been hollowed out by the rivers themselves. The geographic data representing the relief and the hydrographic network should therefore respect this outflow relationship. This relationship is sometimes not respected in geographic datasets. A cause of this inconstancy is that the elevation and hydrographic data are often collected separately (with different acquisition processes and levels of detail) without taking into account this relationship. An other cause is the use of some treatments on either the relief or the hydrographic network or even both, which can alter the outflow relationship. For example, in map generalisation, hydrographic sections are often displaced in order to avoid an overlapping with other objects, such as a road parallel to a river. As a consequence, the outflow relationship between hydrographic sections and the relief can be broken. Our goal is to give a method to correct these inconsistencies.

Many works are related to the inconsistency between networks and relief. (Rousseaux and Bonin 2003) propose a method to correct the inconsistency between roads and a DTM by deforming locally the DTM according to the road 3D geometry. In (Kremeike, 2004) the same approach is proposed for the integration of a generalized road network: the generalised roads (which have become wider because of the symbol size) are used to deform the DTM, using a Voronoï diagram. (Koch and Heipke, 2006) propose a method to consistently integrate roads and lake surfaces and a DTM: a deformation of the objects and the DTM is performed using an optimisation method. More specifically for the hydrographic network, (Wanzeng at al. 2005) propose a method to detect the conflicts between contours and hydrographic sections based on the analysis of intersections between them.

In this paper, we present an application of an automatic generalisation model called GAEL (for Generalisation based on Agents and Elasticity, (Gaffuri, 2007)) to correct inconsistencies between the relief and the hydrographic network. This model provides a way to deform the relief and the hydrographic network in order to preserve this outflow relationship. This model aims at dealing with the general case of relationships between objects (which are usually represented by a point, line or surface, such as buildings, roads, rivers…) and fields (objects such as the relief which allows assigning a value to every location of the geographic space, as defined in (Cova and Goodchild 2002)). In a previous work (Gaffuri, 2006b), we proposed an application of the GAEL model for the preservation of the building elevation value. In this paper, we focus on the relationship between a network and the relief.

This paper is organised into two main parts. First and foremost, we present a method to measure the outflow of the hydrographic network on the relief. The purpose of this measure is to determine where the network does not flow down. In a second part, we present an application of our deformation model in order to correct the inconsistency. Finally, we discuss some outcomes of this work.

1- Outflow quality measure

In order to correct the inconsistencies between the hydrographic network and the relief, we need a measure to assess these inconsistencies. Our purpose is to measure how the hydrographic network flows down, in order to detect where the outflow is bad.

A first proposition would be to use the profile curve of each hydrographic section. The shape of the profile curve gives much information about the relationship between the hydrographic section and the relief, but is not really adapted to the outflow. The outflow is the result of a relationship between the slope values of the line and the surface, and not the elevation value. In the general case of an oriented line lying on a surface, the outflow relationship can be mathematically translated by using the slope vectors (the gradient) of the line and the surface: *a line perfectly flows down on a surface when, for each point of the line, the slope vector of the surface is equal to the slope vector of the line*.

Then, in order to measure the outflow in a point P(s) of a line (cf. figure 1a), we propose to use the values of the angles α and φ (cf. figure 1b) to define an outflow quality indicator Q. α is the difference between the direction of the tangent vector of the line and the direction of the slope in the horizontal plan. Its value is within the interval [-π, π]. φ is the value of the angle between the slope vector of the surface and the horizontal plan. Its value is within the interval [0, π/2]. When α is null, the line perfectly flows down. When φ is null, the surface is flat, and the outflow can be considered as correct. The higher the values of |α| and φ are, the worst the outflow is. If |α| is greater than π/2, it means that the line flows up, which is a case to strongly avoid.

We propose to define an outflow quality indicator Q as:

$$Q = 1 - |\alpha| * \varphi * 2/\pi^2$$

Q is defined within the interval [0,1]. High values of Q are found where the outflow is good. Q varies along the line, depending on the value of the curvilinear abscissa s. The outflow quality of the line can be represented using the variation of Q (cf. figure 1c).

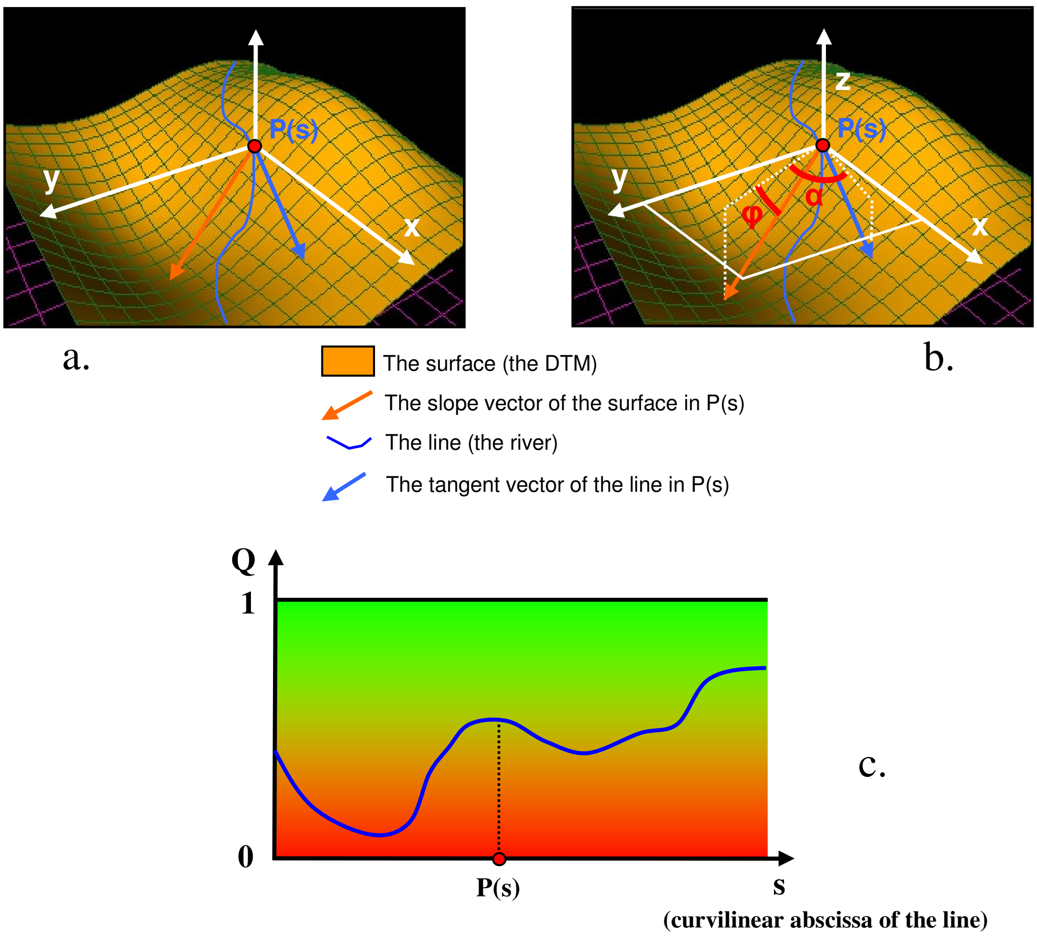
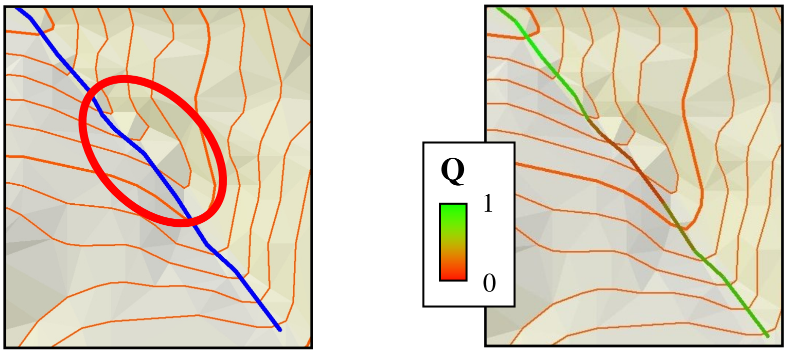


Figure 1: the principle outflow quality measure.

To implement this measure, we propose to use a constrained TIN based on the contour lines triangulation. The slope vector is constant on each triangle. Each hydrographic section is decomposed into a set of connected segments. The angles α and φ are computed on each segment (the slope of the DTM under each segment is an average value).

Figure 2 shows a result of this measure on a hydrographic section. On figure 2a, we can see that the hydrographic section does not perfectly flow down in its thalweg. On figure 2b, the part of the hydrographic section which does not perfectly flows down seems to be well detected by the presented quality measure.



a. b.

Figure 2: result of the outflow measure.

We have presented a measure to detect the inconsistencies between the hydrographic network and the relief. In the next section, we present an application of the GAEL model using this measure. Our purpose is to correct this inconstancy by deforming the hydrographic network and/or the relief.

2- Application of the GAEL model to the outflow preservation

In this part, we present an application of the GAEL model to the presented problem. In a first part, we give the principles of this model, then we present its application for our case using the quality measure presented previously.

The principles of the GAEL model

GAEL (for Generalisation based on Agents and Elasticity, (Gaffuri, 2007)) is a model designed to compute deformations in map generalisation. The principle of this model is to give to some geographic objects an elastic behaviour by decomposing them into small parts (points, segments, angles, triangles…) and to constraint some characteristics of these parts (cf. figure 3) according to the work of (Kocmoud and House, 1998). These constraints depend on the specific shape properties of the object to deform. The deformation is computed using an agent-based optimisation method: the points composing the geometry of the object to deform are modelled as agents. An agent can be 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, p29). The purpose of each agent-point is to reach a balance position between all the constraints it is subjected to. Each point can be considered as an "alive object", which moves autonomously to reach a balance position. The deformation is the result of the progressive displacement of the agent-points.

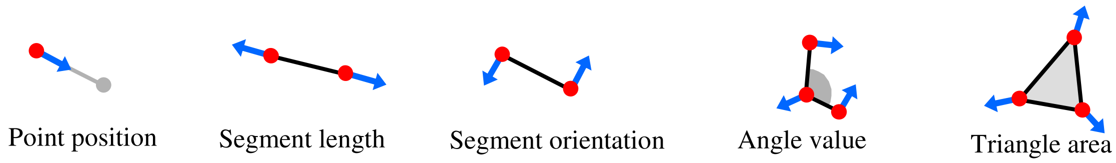


Figure 3: shape preservation constraints of the deformable objects.

Agent-based models are used in map generalisation (Ruas and Duchêne 2007). The GAEL model is an extension of these models, whose purpose is to compute continuous deformation. The aim is to mix rigid and elastic behaviours together during a generalisation process in order to obtain as efficient results as possible (Gaffuri 2006a).

Application to the outflow preservation

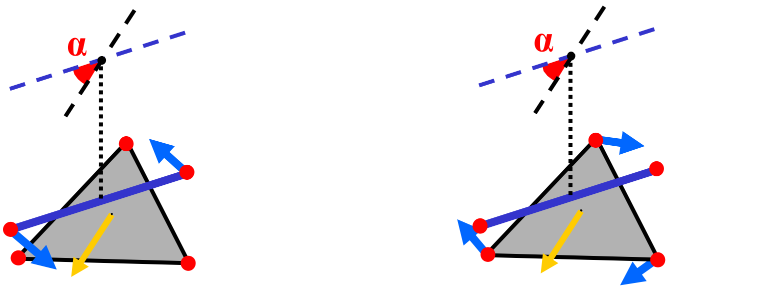
For the outflow preservation constraint, we have to deal with 3 kinds of constraints:

- the inner shape preservation constraints of the hydrographic network,
- the inner shape preservation constraints of the relief,
- and the outflow preservation constraint.

In order to constrain the hydrographic network shape, we propose to constrain the position of the points, the length and the orientation of the segments. To constrain the relief shape, we propose to constrain the position of the points, the length and the orientation of the contour segments, and the area of the triangles (as presented figure 3).

Concerning the outflow preservation, we propose to constrain the value of the angle α defined in the previous part to be null. This constrain can be shared into two constraints we present now: one for the hydrographic segments, and the other for the relief triangles (cf. figure 4).

- Hydrographic segments outflow constraint (cf. figure 4a): the orientation of each segment of the hydrographic network is constrained to be as close as possible to the orientation of the slope. Each segment behaves like a compass needle in a magnetic field. The effect of this constraint is to rotate and move the segment.
- Relief triangle outflow constraint (cf. figure 4b): the orientation of each triangle of the relief is constrained in order to be closest of the orientation of the potentially present hydrographic segments upon it. Each triangle is able to measure the average orientation of the hydrographic network. The effect of this constraint is to rotate and displace the triangle.



Hydrographic segment outflow constaint
a.

Relief triangle outflow constraint
b.

Figure 4: the outflow preservation constraints.

After their activation, agent-points move gradually in order to find an average position between their constraints. As a result, the relief and the hydrographical network can be deformed and the outflow improved. Both constraints figure 4 can be combined. They have the same effect on the value of the angle α: it decreases. This evolution can be seen on the curve figure 1c: the curve progressively goes up close to the value 1, which means that the outflow quality increase. Depending on the relative planimetric precision of the hydrographic data and the DTM, it is possible to tune the relative effect of both constraints (a.) and (b.). For example, if the planimetric precision of the hydrographic network is higher than the DTM (which is usually the case), it is possible to make the relief more malleable than the hydrographic network, and to favour (b.) upon (a.).

The outflow constraints are weighted depending on the value of the slope angle φ (defined figure 1b). Indeed, in an almost flat area, the non-respect of the outflow constraint is less important than in a steep area. That is why the effect of the outflow constraints is more important in a case of a high value of the slope angle φ. The constraints have almost no effect when the value of φ is closed to 0.

In the next part, we present some outcomes and discuss them.

3- Results and discussion

Results

The presented work was implemented on the GIS Radius Clarity/Gothic©. Tests were computed on data of the hydrographic layer of BDTopo© and BDAlti© from IGN France.

Figure 5 presents a first result. In this case, we apply only a deformation to the hydrographic network using the hydrographic network segment outflow constraint presented figure 4a. In the initial case (figure 5a.), our outflow measure shows a part of the section with a bad outflow part (shown by the black arrow). Figure 5b. presents the result of the deformation of the network (the initial network is still visible). The river seems to have fallen down in its thalweg. The result is controlled by the outflow measure: the green colour reveal that the outflow has been improved.

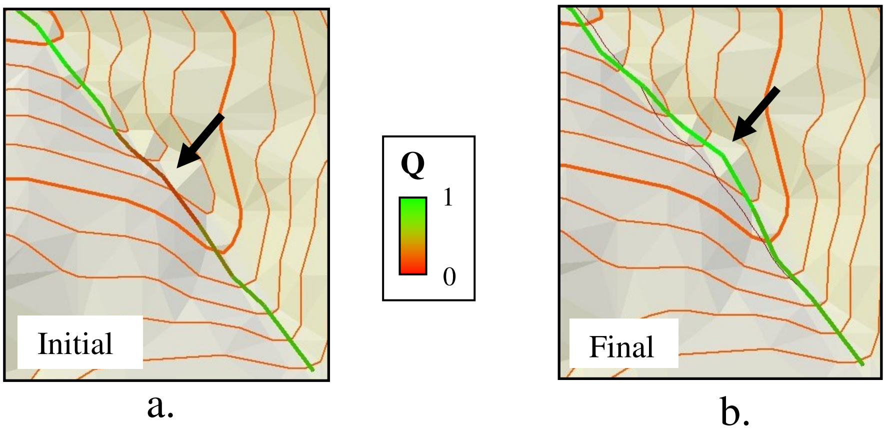


Figure 5: deformation of the hydrographic network for outflow preservation.

Figure 6 presents a second result. In this case, we apply a deformation to the relief using the relief triangle outflow constraint (cf. figure 4b). The hydrographic network is not changed. The initial situation is the same as the figure 3a. The result of the relief deformation is shown in figure 6c. Contours have moved (see the black arrows) and the river outflow has been improved. The relief behaves like an elastic layer which automatically adapts to the hydrographic network, taking into account its inner shape preservation constraints. Figure 6a and b give an assessment of the DTM triangles outflow using a new quality indicator comparable to the one defined in the first part of this paper: the more red a triangle is, the worth is the outflow of the hydrographic network upon it. Inversely, the greener a triangle is, the best is the outflow upon it. In the initial situation (cf. figure 6a.), many triangle under the hydrographic section are red. In the final situation (cf. figure 6b.), many red triangle have turned out to green.

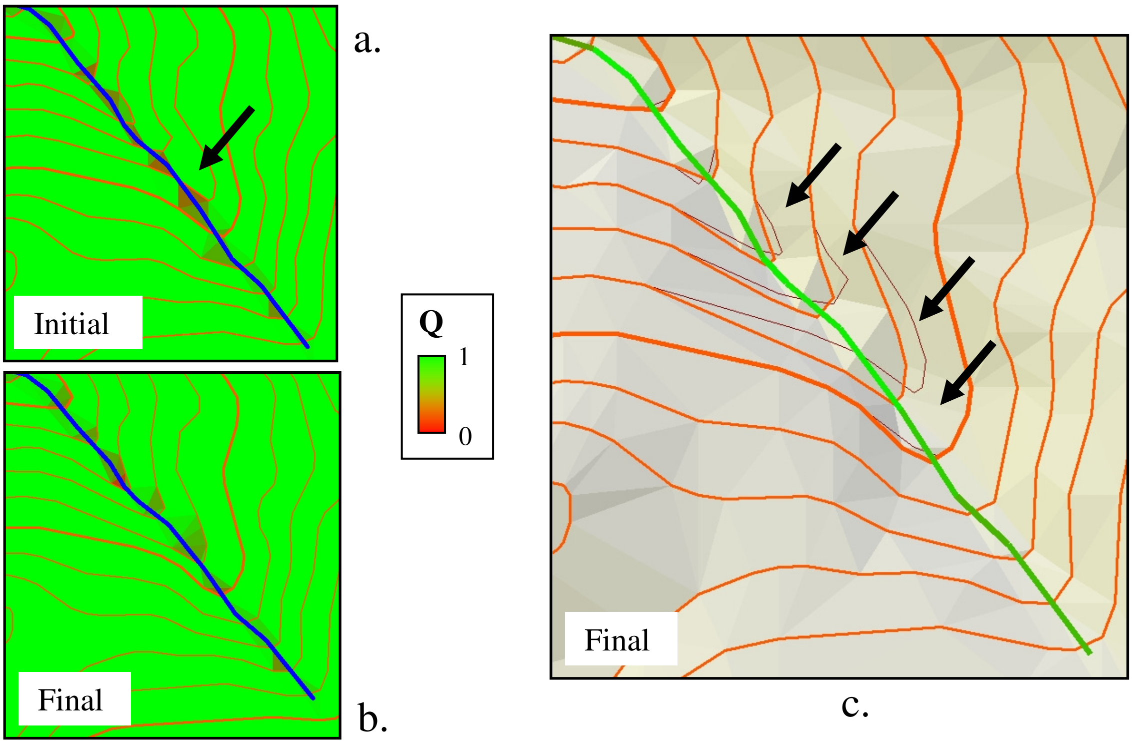


Figure 6: deformation of the relief for outflow preservation.

Discussion

The presented method has been tested on many other cases. A weak point of this method is its dependence to the computation of the slope, which value deeply depends on the level of detail of the DTM and on the interpolation method. Two DTMs of the same area with different precisions that have neighbours values of their elevation in a same point might have significantly different values of the slope. As a consequence, some unsatisfying results can be obtained in some areas where the slope is not well determined. For example, the consequence of the presence of flat triangles (cf. figure 7a.) especially in steep thalwegs can have wrong consequences on the outflow. The presented method could be improved with the correction of these artefacts such as flat triangles, or with the choice of an other interpolation method.

The method is affected too in the case of the presence of some local high variations of the slope, such as the presence of an embankment (cf. figure 7b.). The outflow direction of a river can be affected by such variations of the slope, which are not visible on a DTM. On figure 7b, the river outflow is detected as bad, in despite of the presence of the embankment. A possible solution would be to enrich the DTM with such objects in order to insert an area with an appropriate slope closed to the river. An other solution would be to enrich the capability of the agent-points of the network: the agent-points could be able to "see" the presence of the embankment and then to move appropriately.

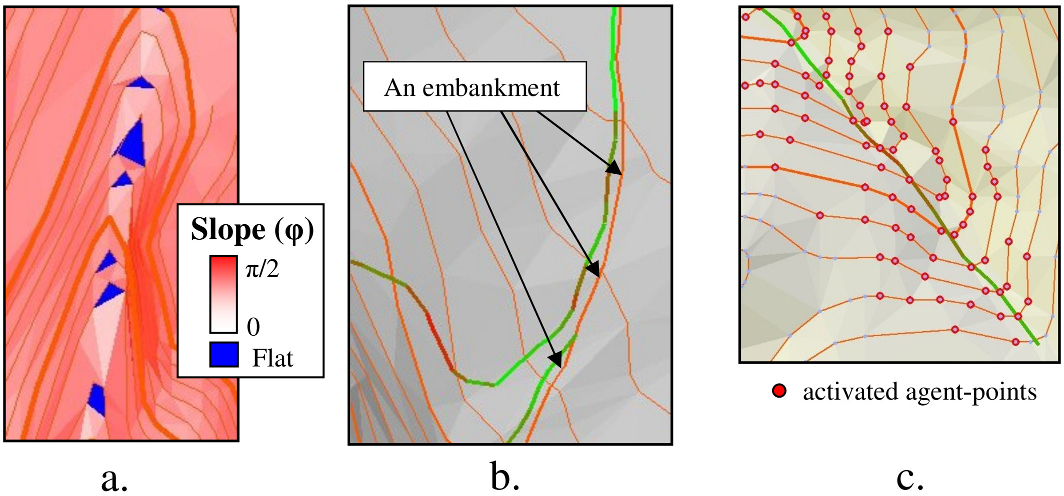


Figure 7

Concerning the computation time of the process, the deformation processes takes around 2s for the hydrographic deformation (figure 5) and around 6s for the relief deformation (figure 6). During these processes, only a few agent-points are activated (cf. figure 7c for the relief deformation). Moving agents-points have the capability to activate themselves their neighbours (Gaffuri, 2006a). The deformation propagates depending on its amplitude and the shape preservation constraints of the relief. Many other improvements of the deformation method could be considered.

In this paper, we presented an application of the GAEL model for the specific case of the outflow preservation. The method presented here could be generalised to many other relationships existing between other networks (especially the road network) and other fields. For the road network, we can see that many mountain roads have a constant slope when climbing a mountainside. We could provide a constraint to preserve this slope value constancy. (Gaffuri, 2007) presents an other constraint concerning channel sections which have to be flat. The principle is the same as the one presented in this paper, except that the value of α is constrained to be $\pi/2$.

Conclusion and perspectives

In this paper, we presented an application of the GAEL model to the outflow preservation of the hydrographic network on the relief. The principle is to make the hydrographic network and the relief deformable by decomposing them into constrained segments and triangles, and then to constrain the angles values between the segments of the hydrographic network and the slope to be null. This paper also proposes a robust quality measure of the outflow which could be used independently of the presented deformation method.

This work illustrates the high genericity of the agent based models. Such models have indeed the capability to be very open and can always be improved by adding new components. Using the agent paradigm, we could consider geographic features as “aware” objects, able to detect and correct themselves their inconsistencies.

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