A hierarchical graph matching method to assess accuracy of network extraction from DTM

Thommeret Nathalie
Laboratoire de Géographie Physique - UMR 8591
Université Paris 1 - CNRS
Meudon, France
nathaliethommeret@gmail.com

Bailly Jean-Stéphane
UMR LISAH - UMR TETIS
AgroParisTech
Montpellier, France
bailly@teledetection.fr

Puech Christian
UMR TETIS - Cemagref
Maison de la Télédétection
Montpellier, France
puech@teledetection.fr

Abstract— **More and more elevation data and methods are available to automatically map hydrographic or thalweg networks. However, there are few methods to assess the network quality. The most used method to compare an extracted network to a reference network gives global quality information on only geographic criterion. The method proposed in this paper allows a network assessment compared to a reference network whose results can be interpreted more easily and more related to networks morphologies. This method is based on a hierarchical node matching within a graph. Nodes are classified by hierarchical level according to their importance in the tree-structured network. Then, a matching process seeks for nodes pairs between the two networks based on the geographic distance. The hierarchy introduces a priority order in the matching. The relative location of nodes pairs is checked in order to ensure a topological consistency. Finally, similarity statistics based on nodes matching counts are computed. While the usual method only takes into account a geographic criterion, the presented method integrates geographic, geometric and topologic criteria. It is an interactive and object-by-object matching. Moreover, the hierarchical approach helps comparing networks represented at different scales. It provides global statistics but also step-by-step maps that helps characterizing the spatial distribution of network delineation errors.**

INTRODUCTION

The progresses in terrain modeling allow nowadays automatic and systematic mapping of morphological features as drainage or thalweg networks. Various methods make possible the automatic extraction of such networks from DTMs [1, 2, 3, 4, 5, 6, 7 and 8]. Consequently, for a given area, numerous representations of networks can be provided from several elevation data and/or from different extraction methods and sometimes from different softwares [9]. Usually, main branches of the different representation are similar but greater differences are pointed out for upstream branches. Each result should be compared to a ground-truth to determine which one is the most representative. In addition, another problem is that ground truth data are not always available with same scale which makes the usual accuracy assessments methods [10] inappropriate.

To assess the quality of a representation, we need a tool that permits to quantitatively and synthetically compare two networks (at different scales). A network assessment should respond to the following questions: how much of the network is over-detected and how much is under-detected [10]? But other questions seem to be important like: is the network topology correct? What proportion of errors occurred on the main branches of the network compared to those located upstream?

There is no standard method to assess the quality of an extracted network [6]. The automatic method the most used (known as the buffer method) allows for an estimate of the delineation error based on a geographic overlap of the networks [10]. It is a global comparison that focuses on the over and under-detection total lengths. It provides valuable information on the network's completeness and geometric accuracy [10]. However this method is based on a single criterion of linear geographic proximity while it seems interesting to take into account the networks'

morphology and thus integrate a topological criterion. In the other hand, strictly topological comparisons are possible [11] but not adapted to spatially referenced objects.

This paper deals with the issue of automatic and quantitative network comparison in order to assess extractions. We propose a method that integrates geometric, geographic and topologic criteria and perform accuracy assessment even when ground truth data are not at the same scale.

METHOD

The method presented is based on a hierarchical graph node matching when DTM extracted networks are transform in tree graph objects. It aims at seeking pairs of nodes between the extracted network to test (T) and a reference network (R).

Firstly, nodes are classified by hierarchical level from downstream to upstream for both networks. Then, an iterative matching is processed: first-classes nodes are matched then second-classes nodes up to the source-nodes. Matching can be based on a simple geographic criterion: the geographic distance of the two networks' nodes.

Node labeling

We chose the method to focus on the nodes rather than the edges of the network due to 1- nodes-edges duality and simple nodes geometry and 2- higher edges sensitivity to noise in geographic positioning: for instance, spatial resolution impacts reaches geometry and extent.

Labels that will be used to classify and match nodes are attributed to T and R nodes based on geometric and topologic attributes; simple geometric labels: x and y coordinates and topologic labels mainly based on Shreve magnitude [12]. We chose the shreve taxonomy rather than Strahler's one for a simple reason: for Shreve's, source-nodes have the same weight along the tree whereas for Strahler's they have not the same impact on the ordering increase. Each node magnitude (S) is normalized by the whole network magnitude (S_T) in order to allow comparison between R and T networks at different scales.

The hierarchical nodes classification

The second step consists in a hierarchical node classification for both networks based on the node importance in the tree. It aims to introduce a priority in the pairs' research.

Node importance is determined from the normalized Shreve magnitude that expresses a node relative upstream/downstream position in the tree. The first level of the hierarchy includes the greater junctions of the networks; at the opposite, the last level corresponds to source-nodes. Outlets are matched by definition so they are not taken into account in the classification.

The number of classes (N) is directly related to the scale representation of the network: the more the network is detailed (great values of S_T, the more N is high. A theoretical hierarchical level number (N_T) can be obtained by reasoning on a perfect binary tree (Eq. 1). However, studied networks are not perfect binary trees, this number is a maximum. Thus, we introduce an arbitrary correction factor of 2 (related to the two first obvious classes: sources and outlet) in order to obtain a less restricting number of classes given by Eq. 2.

$$S_T = 2^{N_T} \tag{1}$$

$$N = floor\left(\frac{\log(S_T)}{\log(2)}\right) - 2 \tag{2}$$

At the end of this step, the two set of nodes (extracted and reference) are classified by comparable hierarchical level.

Matching the nodes class by class

In the third step, we seek for nodes pairs for the different hierarchical levels. The matching is an iterative process starting with the first class of nodes up to the source class.

Geographic proximity rules the matching: a distance matrix is performed from the two node subsets for each hierarchical level. Then each node of the extracted network is related to the closest node of the reference. A distance threshold determines if the pair is acceptable or not. We set the threshold considering the base DTM's resolution, the network extraction accuracy and the length of the shortest distances between nodes in the network.

Unmatched nodes are put back into play at the next step. It permits to soften strict class limits.

Topological consistency checking

Once the matching is done, we check their topological consistency of the pairs. Each pair is assumed to be related to the same physical node, but in the two networks, i.e. in T and R trees: so these two representations must have the same topological location (upstream-downstream positions) in their respective tree. If not, the pair is inconsistent and rejected. The number of inconsistent pairs provides a quality criterion of the matching process: if all pairs are topologically correct then the matching completely succeeded. In the algorithm implemented, only the topological consistency with the nearest neighbor was tested.

Global similarity statistics

Finally, simple global statistics are computed from the matching. By analogy to [10], we count ratios of matched nodes

in T, and ratio of unmatched nodes for both the extracted and the reference networks.

RESULTS

Material

The method is applied to compare two extracted networks (T1 and T2) to a detailed reference network R (Fig. 1) on a test-area of the Draix experimental basins in French Prealps. The study area corresponds to badlands area meaning that terrains are highly dissected. Networks are extracted from a one-meter-resolution airborne LiDAR DTM. The reference is a field-mapped network.

The extracted networks result from different extraction method: T1 was extracted using Thommeret et al. (2010) method that combines a morphological index and a drainage algorithm (CI based network); T2 was obtained using the classical D8 algorithm [1].
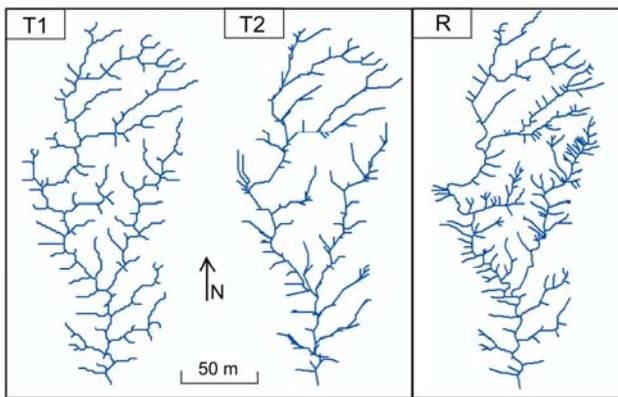

Figure 1. Comparing extracted networks (T1 and T2) to the ground-truth network (R)

Hierarchical matching results

In this particular case study, the distance threshold chosen is 0.5 m. It is small because of the particular terrain, DTM's high resolution and the shortness of the distance between nodes of the networks. The number of classes (N) is the same for the extracted networks. At the end of the process, every node pairs of both networks appears to be topologically consistent.

Global ratios coming from the matching are presented TABLE 1. For the T1, the matched nodes represent 87% of the total number of nodes. For T2, they represent 76%. Thus, the D8 network (T2) shows more over-detected nodes than the other network (T1). The more compliant network selection is based on a compromise between the number of pairs, over and under-detection.

TABLE I.   QUANTITATIVE MATCHING RESULTS

Networks	Total node number	Pairs	Unmatched nodes	
			Extracted	Reference
CI based network	200	174	26	170
D8 network	238	181	56	162

The hierarchical matching process also provides step-by-step results. Thus the results are sharper than with the global buffer approach. The matching progression for T1 and T2 is shown figure 2. We can distinguish for each step of the matching the extracted nodes that find a reasonable pair (in red) and those that are not matched (in green). These results show different extraction quality. For the T1, unmatched nodes are localized in specific areas where the DTM is less accurate. While unmatched nodes of T2 are dispersed in the space. Thank to theses maps, the spatial distribution of extraction errors can be interpreted significantly.

DISCUSSION AND CONCLUSION

In this paper, we propose an interactive method to quantitatively and automatically compare two networks of a same area. The method aims to help assessing networks extracted from DTM to a reference since more and more elevation data and methods are available to automatically extract thalweg networks.

This method relies on hierarchical node matching. It is based on an object-by-object approach which provides more controlled results. The hierarchical approach helps comparing networks represented at different scales. It helps distinguishing extraction artifacts from unmatched nodes resulting from a scale difference between the networks.

Results are satisfying and compliant to visual comparison. This method supplies results detailed, with clear signification that can be directly interpreted: even small differences in similarity statistics are significant; while the buffer method is based on an estimate of consistent extracted lengths that informs in a global way. Moreover, step-by-step matching maps observation helps qualifying the spatial distribution of extraction errors. The matching progression through the steps can be used to better characterize the networks adequacy along the network hierarchy. It provides another key to the assessment and the interpretation of the differences between the networks.

REFERENCES

[1]   O'Callaghan, J. and D. Mark, 1984. "The extraction of drainage networks from digital elevation data", Computer vision, graphics and image processing, 28: 323-344.

[2]   Quinn, P.F., K.J Beven, P. Chevallier and O. Planchon,, 1991. "The prediction of hillslope flow paths for distributed hydrological modeling using digital terrain model", Hydrological Processes, 5: 59–79.

[3]   Lea, N. J., 1992. "An aspect-driven kinematic algorithm", In, Overland flow: hydraulics and erosion mechanics, Edited by: Parson, A. J. and Abrahams, A. D., UCL Press, London, 393-407.

[4]   Tarboton, D. G., 1997. "A new method for the determination of flow directions and contributing areas in grid digital elevation models", Water Resources Research, 33(2): 309-319.

[5]   Tarboton, D. G. and D. P. Ames, 2001. "Advances in the mapping of flow networks from digital elevation data", In: Proceedings of World Water and Environmental Resources Congress, Orlando, Florida, May 20-24.

[6]   Molloy, I. and T.F. Stepinski, 2007. "Automatic mapping of valley networks on Mars", Computers & Geosciences, 33:728–738.

[7]   Thommeret N., J.S. Bailly and C. Puech, 2010. "Extraction of thalweg networks from DTMs: application to badlands", Hydrology and Earth System Sciences, 14: 1527-1536.

[8]   Pirotti, F. and Tarolli, P., 2010. "Suitability of LiDAR point density and derived landform curvature maps for channel network extraction", *Hydrological Processes*, 24, 1187-1197.

[9]   Hengl T., C.H. Grohmann, R.S. Bivand, O. Conrad and A. Lobo, 2009. "SAGA vs GRASS: A Comparative Analysis of the Two Open Source Desktop GIS for Automated Analysis of Elevation Data", In: Proceedings of Geomorphometry 2009, Zurich, August 31- September 3.

[10]   Heipke, C., H. Mayer, C. Wiedemann and O. Jamet., 1997. "Evaluation of Automatic Road Extraction" *International Archives of Photogrammetry and Remote Sensing*, 23: 151–160.

[11]   Ferraro, P. and C. Godin, 2003. "An edit distance between quotient graphs, Algoritmica, 36: 1-39.

[12]   Shreve, R.L., 1966. "Statistical law of stream number", Journal of Geology, 74: 17-37.
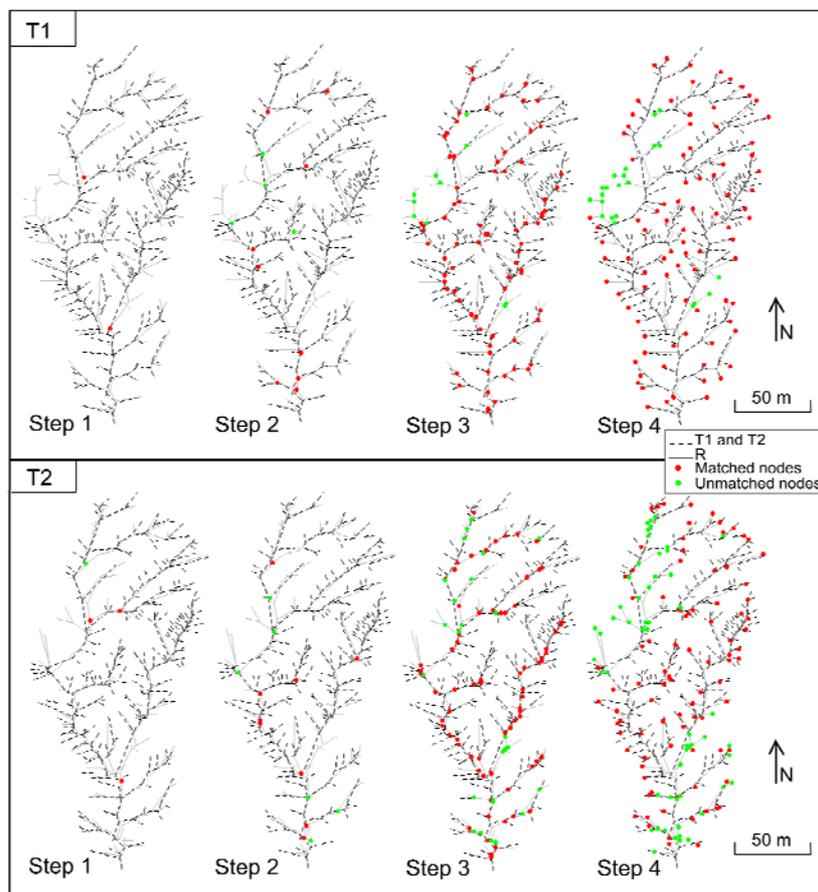
Figure 2. Matching progression through the different steps for the two extracted networks (T1 and T2)