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10 | MODELLING MOVEMENT AND PERCEPTION

Klemen Zakšek – Elise Fovet – Laure Nuninger – Tomaž Podobnikar

Path Modelling and Settlement Pattern

Abstract: This paper describes the contribution of path modelling to the ancient settlement pattern study over the long term. The path modelling methodology is a stimulating tool, which is complementary to the hierarchical approaches in the landscape archaeology since it contributes to the understanding of the spatial relation between archaeological sites. The existing methodology was enhanced by enlarging the set of path reconstitution parameters (visibility) and by modelling in two scales. The proposed model is based on parameters derived merely from the relief because its changes should be insignificant even over a long period time.

Introduction

Nearly 1000 sites (from the Iron Age to Middle Age) have been recorded in Languedoc, an area in south-eastern France. Most of them have been detected by systematic field walking. This kind of survey enables a good overview of the ancient settlement distribution. The road network is quite well preserved in the landscape of this region and the archaeological sites are very often still connected to the present paths. This fact was used by some archaeologists as a criterion in the classification of settlements (Favory / Fiches / Girardot 1988; Van der Leeuw / Favory / Fiches 2003) since it indicates the ability of a settlement to durably mark the road network. However, there is almost no recent study of ancient road networks, and our knowledge about them is too poor to handle the connection between all the archaeological settlements. Spatial relations between archaeological sites are very important to understand the evolution of the territory. The reconstruction of an ancient road network is usually based on regressive methodology, starting from present elements of the landscape and eliminating recent tracks. The problem with this method is that one cannot know if settlements made the network or if the network provided a suitable environment to settle down. Therefore, a constructive approach has been adopted by simulating the connections between contemporary sites in order to get an overview of the evolution of the micro-regional network. This study aims to reconstruct the skeletons of the settlement patterns taking into account the hierarchical relationships between settlements.

Theoretical movements resulting from settlement pattern were mapped by the optimal paths method in order to model the development of the network. Paths used for labour were considered, since this path type can explain establishment or abandonment of settlements. These paths should be efficient; they should be fast for movement and energy consumption over them should be low. In the present study, the visibility was used next to the energy consumption because a path providing a good field of view is important for orientation and safety reason. Moreover, in the case of a planned network (by community or owners), it is important that roads are visible; some agronomical Latin texts show the importance of visual control to supervise people, holding, and villae or storage buildings (Clerget 2004: Caton, De agri cultura; Columelle, De agri cultura I). The proposed model is based on parameters derived merely from the relief because its changes should be insignificant at the micro-regional scale for the historical times. Land cover and the hydrological network are also important aspects of movement because of their impact on visibility and energy consumption. However, the vegetation and

hydrological network may have changed significantly, especially in plains due to karstic phenomena on the hills. Unfortunately, our knowledge about the paleo-environment is limited and it is still not possible to produce reliable maps, thus this data was not used. The following section describes the implementation of the additional relief parameter (visibility) and improvement of the least cost energy model (taking into account the aspect of the slope). The modelling is done in two scales in order to make the procedure more robust – first a coarse path is determined in the regional scale (coarse grid) model and then an additional modelling in the micro-regional scale (fine grid) refines it.

Methodology

Research Background

A raster based path model is easier to implement than a vector model (Stefanakis / Kavouras 2002; Shirabe 2005), which explains why it has become a standard tool in GIS software. Many algorithms that are integrated in the existing commercial GIS software, are based on the algorithm of Dijkstra (1959). The algorithm has its origin in graph theory: it aims to find the shortest path between two vertices in a directed graph over edges with nonnegative weights. A similar algorithm can be applied to raster that can be thought of as a graph, where vertices can be connected with up to eight edges. However, within the raster modelling, the algorithm is applied to all the cells in the raster. Therefore, the raster modelling procedure starts with choosing a target point (a sink) in a friction layer. Then, a cost surface is computed and it can be considered as a kind of cone turned upside down with the sink at its bottom. There is only one optimal path after a start point (a source) is chosen on the surface of this cone. One can think of water that runs from the source to the sink over the path with the least impedance: this "riverbed" represents the least cost. In most raster based algorithms, the only way to manipulate least cost path modelling within this procedure is to customize the friction layer: combination of different layers, layer reclassification, etc. (Clark Labs 2002; Esri 2005).

The proposed procedure induces computing the friction layer from visibility and energy consumption parameters. Visibility was already implemented into least cost path modelling in the past, using intervisibility based on viewshed analysis (Lee / Stucky 1998; Llobera 2003). The active visibility can be defined with the average vertical angle of horizon. Areas with the average vertical angle of horizon values close to zero do not have many obstacles in their horizon, and areas with a high average vertical angle of horizon provide a low field of view.

The energy consumption can be considered as the force that an object has to produce to move over a surface. The gravity force of the object and the roughness of the surface can be considered as constant values by walking, thus the energy consumption depends only on the slope. The slope is often used as an important friction of a movement because energy consumption is larger on steep slopes than in the flat areas (Hernandez 2001; Podobnikar / Hvala / Dular 2004). The slope within the path modelling modules in the commercial GIS software is usually considered as an absolute value (isotropic model), which means that the friction is always independent from the direction of the movement: there is no difference when walking up, down or along the slope, which is not true *(Fig. 1)*.

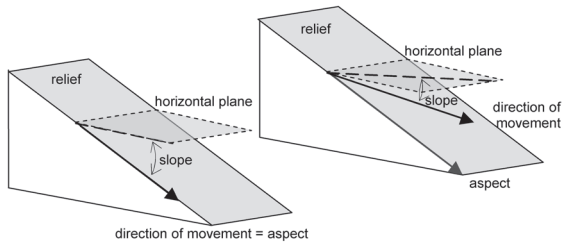

Fig. 1. The slope differentiates when a traveller moves in the direction of aspect or in other directions (if the traveller moves perpendicular to the aspect, the slope equals zero).

Some studies already attempted to deal with the difference when walking up or down a slope (anisotropic model; Podobnikar / Hvala / Dular 2004; De Silva / Pizziolo 2001); but not along the slope. Therefore, it is necessary to recalculate the slope in at least approximate direction of movement, which enables one to differentiate the energy consumption going up or down the slope:

$$slope_{recalc} = \cos (aspect_{relief} - direction) \cdot slope$$

The recalculated slope value is changed from 0 (if the difference between the aspects is equal to 90°) to the previous slope value (multiplied by 1) or to a

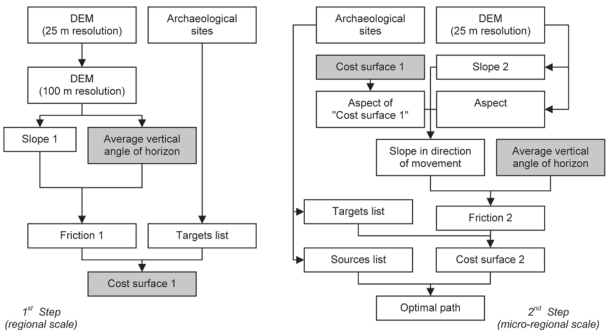

Fig. 2. Procedure of ancient path modelling.

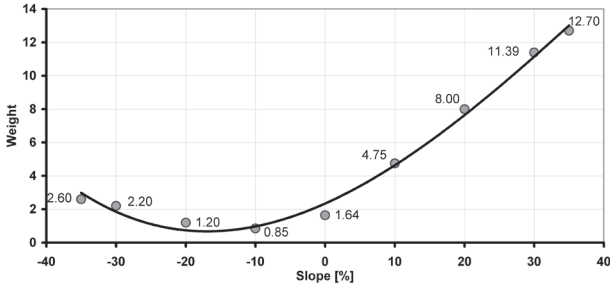

Fig. 3. Slope reclassification weights (Minetti et al. 2002) and a fitted weight line (weights only present the relative energy consumption and not the actual energy; negative slope values stand for walking down the slope).

negative value (if the difference is more than 90°).

The proposed procedure induces a modelling procedure in two steps at two scales (at the regional and the micro-regional scale). Modelling with data at two or more scales has many advantages. First of all, a path modelled at micro-regional scale can be based on a path modelled at regional scale – a low resolution data at the regional scale model makes it possible to predict the approximate direction of movement that can be then used within the micro-regional scale model (the energy consumption cannot be effectively estimated if the approximate direction of movement is unknown). Secondly, the model is robust because the DEM is first resampled to the regional scale resolution, which means that local anomalies and gross errors in the relief data do not have large influence on the final path. At last, the uncertainty of the start point can be neglected in the regional scale model (a different start point can significantly change the path at micro-regional scale).

Path Modelling

First, a coarse path is determined in the regional scale model (cost surface 1 in *Fig. 2*; 100 m resolution) and then an additional modelling at micro-regional scale refines it (optimal path in *Fig. 2*; 25 m resolution). A "traveller" moves approximately along the path defined in the regional scale model (along a path where the surrounding area is visible for the greatest distance possible) and by choosing a path with the least energy consumption defined in the second step.

The relief data was obtained from a digital elevation model of 25 m resolution (Nuninger / Oštir 2005). The slope values were reclassified regarding relative energy consumption. Weights determined by biometrical observations of mountaineers were used (Minetti et al. 2002, *Fig. 3*). The visibility was defined with the average vertical angle of horizon. It was computed by searching the horizon at the maximum distance of 7 km in 100 directions in the resolution of 100 m.

The friction surface is then obtained by map algebra. The reclassified slope is multiplied with the average vertical angle of horizon. In the second step, the new friction layer (friction2) is obtained from a recalculated slope, which takes into account the direction of the movement. Since the direction of movement between two sites might differentiate significantly from a straight-line, the (approximate) direction is given by the aspect of a previous cost surface (cost surface 1).

Testing the Model

We tested the model on two archaeological sites occupied from the 5th century BC until now (Nîmes and Sommières). A path resulting from a two steps modelling and/or with implementation of visibility is quite different from a path computed with a "classical" method using only slope *(Fig. 4)*. The path made using only slope as friction (dotted line) is the shortest and has low altitude difference. However, the proposed model path (solid line) presents other advantages: the good visibility induces that paths are often situated on the ridges which provide gradual altitude changes, which can be more efficient when considering the accumulated weariness. One can notice that modleling merely at regional scale using visibility and isotropic slope makes the path too straight (dashed line) and modelling at two scales using only slope makes the path too long because of many turns

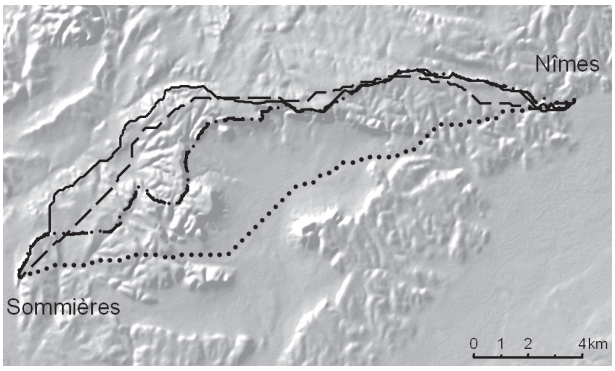

Fig. 4. Different results are obtained with different parameters. The solid line represents the path modelled with the final model, the dashed line is modelled with first step of the described model (isotropic slope and visibility), the dot-dashed line is modelled in two steps with only slope as the friction image (anisotropic slope), and the dotted line is modelled in one step and only with slope as the friction image (the classical approach).

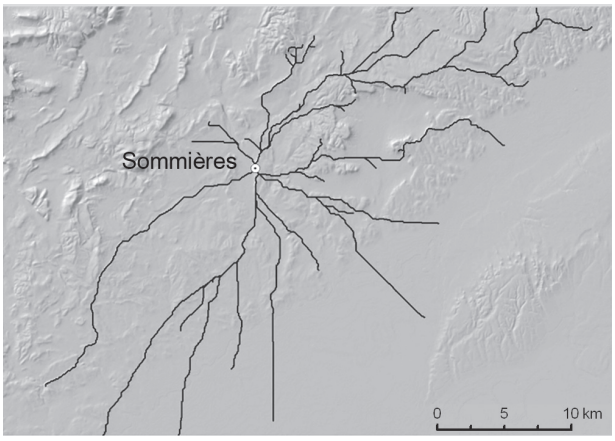

Fig. 5. Paths from a common start site (white circle) to other points (made with the final model).

(dot-dashed line). The best solution seems then to be modelling in two scales using anisotropic slope and visibility.

The example of the Sommières site, which is connected to all the other contemporaneous settlements (during the 1st century BC), shows that paths from the same direction pour into a single path *(Fig. 5)*. The same result is obtained when we simulate paths between several sites; some tracks are used by several paths – this fact is enhanced by the density of calculated paths per century *(see Fig. 6)*. Moreover, one can notice that optimal path corridors of the networks often pass through other contemporaneous settlements *(see Fig. 6 and infra)*, which indicates that the modelled paths are probably similar to the ancient paths.

Ancient Path Corridors Network Analysis

Main path networks were determined between the settlements of the highest rank for each period in order to observe their evolution and to evaluate the position of each main settlement in the general network. The highest rank settlements were previously determined by a hierarchical classification based on a factorial analysis elaborated during the Archaeomedes program (Favory et al. 1999). Optimal paths were computed for four different periods, which illustrate different states of the evolution of the settlement pattern in the studied region (the 5th century BC, the 2nd century BC, the 2nd century AD and the 5th century AD; *Fig. 6*). We obtained 12, 56, 552 and 650 paths respectively. The density of optimal paths was computed in order to interpret the results more easily. *Fig. 6* shows tracks that were used by several settlements, and represents basic trends and general itineraries.

Between the 5th century BC and the end of the 2nd century BC, two main settlements (Ambrussum and Virunes) were built aside of the previous network and changed the configuration of the gathered paths whereas Nages was built relatively near to the old potential itinerary from Nîmes to Lattes (around 1.5 km on the same plateau). The situation in the 2nd century AD shows two different cases. Many important settlements were built on previous potential paths (Clarensac, Bizac, Solorgues, Pataran, St-Cirice, Sorriech) and/or near previous potential paths (from 400 to 800 m: Caveirac, Meyrargues, St-Julian; and l'Estelle at 1 km). We can also notice that LunelViel was built only 1.5 km from an important potential crossroad of the 5th century BC which joined Substantion to Ambrussum and Virunes, and Lattes to Ambrussum. However some other important settlements (Obilion, Miech-Camp and Psalmodi) were built aside the previous potential network (at a distance of 3 km and more). This fact suggests that these settlements had to create their own network to connect to other important places. Between the 2nd century AD and the end of the 5th century AD, four main settlements were built and two were abandoned; these small changes in the pattern do not really affect the configuration of the gathered paths. Apart from Ramaux, the new settlements are situated on or near previous potential paths and also near preferable itineraries with a high density of paths (Fournieux, Minteau and Missargues). Also, gathered paths of the 5th century AD pass through the position of two sites which

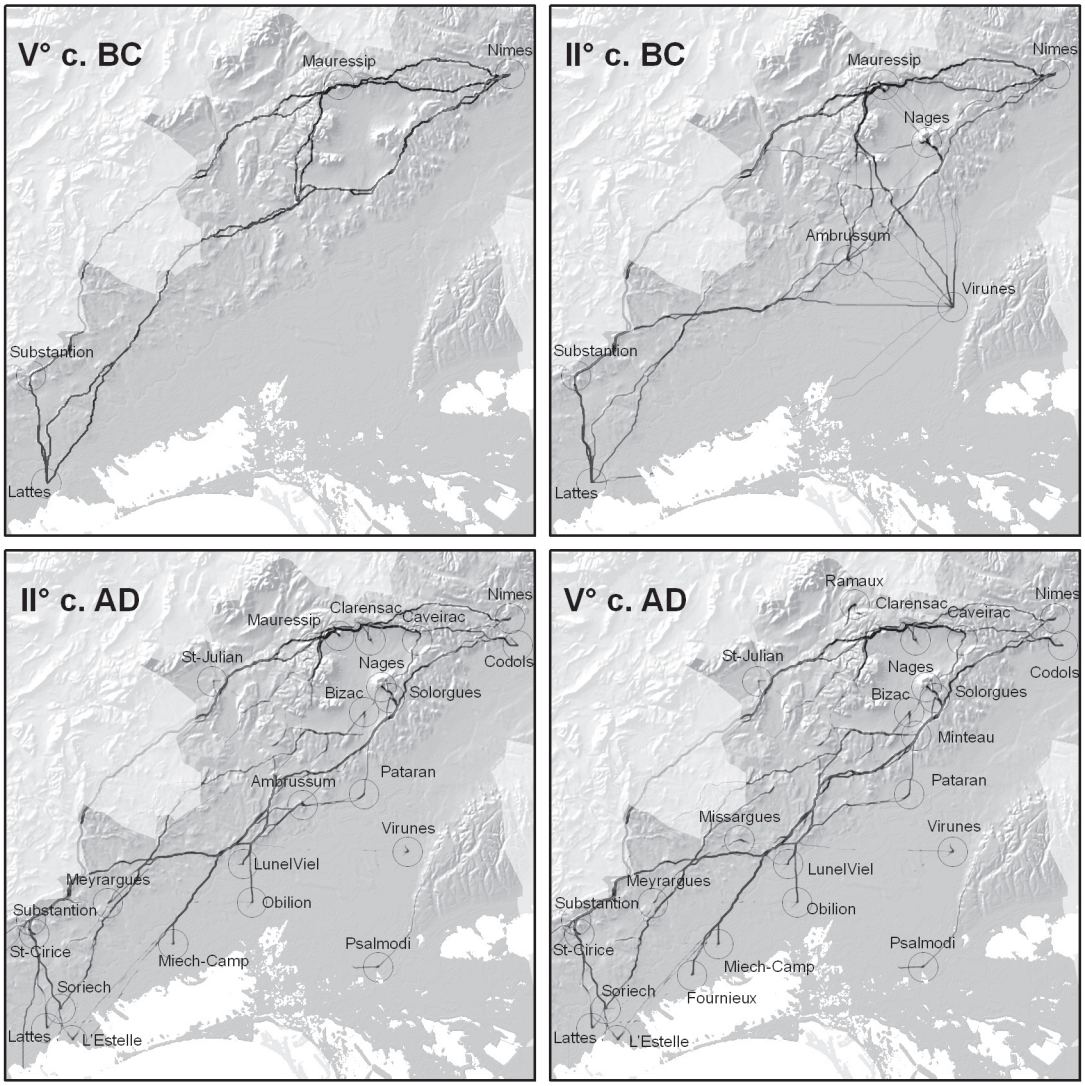

Fig. 6. Density of main paths for each period (darker colour presents higher density; the lightened zone is the study area, and the circles mark the archaeological settlements).

no longer exist during this period (Mauressip and Ambrussum). This means that the configuration of the general settlement pattern would have induced movements through these sites anyway (despite this, these sites were not used to compute the 5th century AD paths).

This overview shows the long evolution of the main path network into the settlement pattern and point out "key settlements" which had the most influence on the configuration of gathered paths. These "key settlements" were mainly built before the end of the 2nd century AD. The modelled path networks (especially of the 2nd and the 5th century AD) enable us to determine, which main settlements were "actors" in the evolution of the network (creating their own network), and which were more "opportunists" (settling along the previous network). The location of the categorized settlements has also to be taken into account; one cannot assume any connections with another settlement(s) out of the case study area or the possibility of some connections to another network at a smaller scale (especially during Protohistory).

One can also assume that the road network was persistent in spite of the evolution of the settlement pattern (i.e. Mauressip and Ambrussum in the 5th century AD). The example of Ambrussum is particularly interesting; in the 2nd century AD, new settlements were established around it (Pataran, Lunel Viel and Obilion), and the optimal paths joining these new settlements to other places pass through Ambrussum. After the abandonment of Ambrussum in the 3rd century AD the road network stayed unchanged. This process explains how an archaeological settlement can be connected to

a present path. Moreover, path modelling helps one to make assumptions about the associated sites that would maintain the path.

Conclusion

This article shows that path modelling is a valuable way to understand the evolution of the settlement pattern. We tested whether new settlements were generally established along paths among already existing settlements or if they enriched the existing road network providing new connections. It has been shown within the article that visibility can be efficiently integrated into the model. It was also demonstrated that an anisotropic model can be used even with basic GIS tools when the direction of movement is approximated, which is possible if the modelling procedure is made at two steps. Furthermore, modelling at two scales makes the modelling procedure more robust. The proposed procedure is still developing, and we envisage additional testing, in order to find out the appropriate relation between energy consumption and visibility. Additional tests will enable us to develop further the analysis of the ancient path corridors network in order to compare them to the general distribution of archaeological settlements. One will be able to consider the reasons to settle down aside the networks of the previous periods, which would imply important efforts made to connect these particular settlements to other places. These locations could be related to the environmental quality (for agrarian activities for instance). In the same way, the positions of small settlements will be analysed regarding the evolution of main path pattern in order to evaluate the impact of the micro-regional network on settlement pattern at a local scale and if the abandonment of an important settlement can be a factor for the desertification of a small area.

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