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Analyzing an Agrarian Territory: a Vectorial GIS for the Detection of Ancient Cadastral Divisions

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Abstract: This paper describes the use of a specific algorithm to perform semi-automatic analyses of vectorial photogrammetric maps for the purpose of detecting regularly aligned landscape features possibly corresponding to ancient cadastral boundaries. In some historical phases, ancient landscapes were organized in regular geometric patterns, and this organization can be detected by spatial analyses highlighting regularities in orientation. The authors' GIS, called "L_Orient", is based on the implementation of a routine, developed in the MapInfo environment, which decomposes complex landscape features into single lines, and then determines their orientation, which is expressed in three different formats. One of these formats is used to highlight lines orthogonal to a given alignment to the purpose of verifying the recurrence of regular modules in a given territory. However, only direct field observation can provide definitive proof that these modules actually correspond to ancient land boundaries.

Keywords. GIS; spatial analysis; planned landscape; rural cadastres.

1 Introduction

This paper presents the results of a research carried out in the framework of a joint program of the Archaeological Superintendency of Naples and the Oriental Institute in Naples. The purpose of the program is the study of two important archaeological locations in Campania, viz., the Greek colony of Cumae (d'Agostino and D'Andrea 2002) and the site of Acerra (Giampaola, Ronga and Sica 1997).

In 1999, thanks to funds granted by the Regional Government of Campania, we were able to plan and develop computational instruments to record, manage and analyze a vast corpus of information gathered by systematically exploring these two sites.

Here we deal especially with the preliminary results of a sub-project aimed at developing a specific algorithm to perform automatic analyses of linear traces in vectorial photogrammetric maps of these two ancient sites. This algorithm, based on a routine written in MapBasic, the programming language of MapInfo, determines the orientation of each line in a vectorial map.

The premise for our research is the consideration that, in some historical phases, ancient landscapes were organized on the basis of regular geometric criteria, and this organization can be detected by spatial analyses highlighting regularities in orientation.

Before illustrating the functioning and field of application of this algorithm, we will briefly discuss historical and archaeological contexts featuring advanced forms of spatial organization and subdivision.

2 Landscape planning in Greek and Roman times

In the course of time, man has modified his environment, adapting the natural landscape to the requirements of his productive activities. Agriculture, in particular, has called for major landscape alterations such as terracing, canalization, irrigation, etc. Man's conversion of the natural environment into rural land has been systematic and deliberate.

In the Greek and Roman periods, this conversion took the form of a planning of the agrarian and urban space according to regular modules. The older open-field system gave way to a stable separation of agrarian land from uncultivated land, pasture, and common land used for activities such as firewood gathering. The appropriation of cultivable plots and their delimitation by means of hedges, walls, drains, trails and roads, favored the creation of plots with regular and linear plans, at least in the plain. After the Roman conquest, this model of regular apportioning of agrarian land became generalized, eventually giving rise to centuriation.

The Romans measured and delimited agrarian land following patterns similar to those employed by modern cadastre maps. They organized the rural landscape geometrically by superimposing upon it two intersecting reference lines – the *decumanus* (usually oriented approximately east-west) and the *cardo* (approximately north-south) – and other lines parallel to them placed at regular intervals. The resulting gridiron was composed of square plots of 710 meters on a side and with a surface of about 50 hectares. The setting up of a rural cadastre – partly for taxation purposes – called for a redefinition of the agrarian landscape allowing for morphological variability and the potential of the soil.

Throughout the Italian peninsula, Roman centuriation lines have determined the later orientation of fields, property boundaries, canals, and country roads. Even today, land reclaiming and irrigation works have to take account of these regular alignments, which often determine the orientation of modern canals. No other land parceling system has left such widespread and durable marks on the Italian landscape.

This persistence of Roman land planning in the present landscape has stimulated many studies in ancient topography. Since the first half of the twentieth century, topographers, who previously based their investigations exclusively on cartography, have been adding new research tools to their equipment. Numerous techniques are available today. Surveys and geophysical or direct prospecting provide valuable information on vestiges of ancient agrarian boundaries.

Another important tool, used ever since the beginning of the last century, is aerial photography. Its diffusion has allowed the history of the rural landscape in Greek and Roman times to be reconstructed through the fossil remains of land parceling systems.

Traces of ancient human activities in aerial photographs fall into at least five categories. The most significant one for our purposes includes archaeological features whose function persists today, or which, at any rate, have had an enduring influence on the later history of the landscape, either because an analogous modern feature took up their function, or because they somehow conditioned the shape or size of later features.

3 Automatic Recognition of Ancient Landscape

3.1 A Short Introduction

The study of regular landscape features which may be referable to vestiges of earlier plot boundaries has long held an important place in archaeological and topographical research. The problem of determining orientation, on the other hand, is still a new one in computer-guided research. The first attempt in this direction was made by J.W.M. Peterson (1988), who used a computer-based simulation to calculate the orientation and location of two hypothetical Roman cadastre gridirons in East England. However, only in the late Nineties has automatic recognition of regularly aligned features by means of GISs gained an important role in landscape archaeology.

A study of the territory of West Belgium during Roman occupation by means of a GIS employed digital filters to examine oblique aerial photographs and old historical documents such as cadastre maps to highlight the boundaries of centurial plots (Vermeulen, Antrop, Hageman and Wiederman 2001). The idea of drawing up thematic maps of oriented features in an urban landscape found an application in a research on the city of Tours in France (Rodier 2000). The 17th-century Napoleonic cadastre map was scanned and vectorialized to reconstruct the city’s structure in the 10th century. Lines corresponding to cadastral boundaries were vectorialized using MapInfo. The data set was then exported as a TXT file to calculate orientations by means of a specific trigonometric function included in the Excel program.

3.2 A GIS Tool for Landscape Analysis

To perform a spatial analysis of data in a photogrammetric map, it is not sufficient to reproduce them in a traditional map drawn with tools such as vectorial drawing programs (e.g., AutoCAD): it is necessary to import the vectorial base into a GIS. GISs are especially well suited to landscape studies, since the position of geo-referenced lines is expressed by the geographic coordinates of their nodes.

The *x* and *y* data form a numerical matrix which can be analyzed by means of statistic or, as in our case, trigonometric calculations. By applying a simple trigonometric function to each pair of nodes, i.e., to each alignment of two nodes, it is possible to calculate their orientation (fig.1).

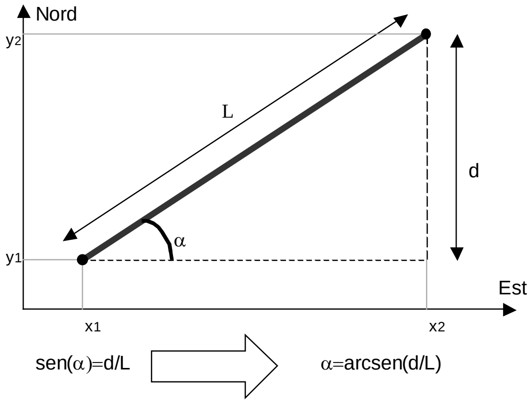


Fig. 1. *Use of a trigonometric function to determine line orientation.*

This simple method has a great potential. Vectorial lines read from a CAD environment into a geo-referenced map, or vectorialized directly within the GIS environment by tracing a raster map, automatically acquire spatial attributes by which their orientation can be determined.

Several tools for different platforms and environments, although not specifically designed for archaeology, are available on the Web today. A utility called Arc-SDM (Spatial Data Modeller) has been developed for ArcView (http://ntserv.gis.nrcan.gc.ca/sdm). Embedded in its code are functions for various GIS operations, such as selecting specific map contacts, multiple buffering, and several different systems of classification. According to its authors, it labels lines by orientation, a function which could be useful for line analysis.

The most versatile tool for the MapInfo environment is “Orientation”. This routine, developed by Russel Lawley in 1999 (http://www.directionsmag.com/tools), is not conceived for a very specific target and has some intrinsic limitations, the main one being that the program processes each polygon as a totality, whereas the lines are often assembled into a single object only for practical reasons, viz., to simplify their vectorialization, and not with regard to topological, spatial or descriptive homogeneity. Besides these intrinsic limits, the application cannot process maps with more than 4,000 objects. Finally, its query function allows any orientation to be chosen (with a certain degree of approximation), but when values are close to 0 (corresponding to the north) it ignores measurements lying opposite the north.

Using this preexisting algorithm, we set out to develop a tool capable of processing individual lines, unlimited objects, and even non-packed tables and graphs (without modifying the original map). We designed our program for a specific field of application, namely, landscape analysis performed on vectorial photogrammetric maps, as well as other types of maps. Today, maps are available easily and at low cost, mainly because town administrations produce them for town-planning purposes.

To show the possible field of application of our algorithm, we chose the archaeological sites of Acerra and Cumae as case studies. Several photogrammetric maps of both sites exist, but they are at different scales and were created for different purposes. While the map of Cumae is on a 1:500 scale and was drawn specifically for the use of archaeologists, only a 1:5,000 map was available for the town of Acerra. The oriented lines and modules we detected are based exclusively on vectorial photogrammetric data not verified in the field, and our results are hence purely theoretical. This simulation, however, is an important test for our method, which could prove especially useful for exploring the areas of Cumae and Acerra, where the Archaeological Superintendency of Naples has been conducting systematic investigations for several years. Computer utilities applicable to the study of vast territories could not only contribute to a historical understanding of the evolution of Cumae's and Acerra's ancient landscape, but also play a role in the development of new methods for the management and preservation of their territory.

4 "L_Orient"

The utility "L_Orient" associates each line in a vectorial map with a record in tabular form specifying: a) the length of the line; b) its orientation, expressed in three different formats: 360°, 180°, and 90°.

The user can choose any orientation from the database or the map itself and highlight all lines parallel or orthogonal to the said orientation. It is thus possible to detect recurrent regular modules possibly referable to early land apportioning systems. Of course, only direct field observation can provide definitive proof that the highlighted modules actually reflect an ancient subdivision of the agricultural space into plots. No method of archaeological investigation, however sophisticated, can dispense with direct examination. As we have already observed above, only single lines between pairs of nodes are significant for our purpose. Hence, it is necessary to decompose complex vectorial elements – polylines and polygons – into single lines. The following figure summarizes the different phases of the application of this "L Orient" routine (fig. 2).

To preserve the data of the original map, the first operation that "L Orient" carries out is the creation of a new table (with a user-assigned name) into which all the features of the original map are copied. In order to avoid processing certainly modern data, some layers – e.g., those corresponding to railroad lines, the electric grid, or rooftops – can be deleted.

The decomposed lines are then redrawn in a new map. To each line are attached four types of attributes in tabular form (fig. 3).

Field two contains the line's *length* expressed in meters. Fields three, four and five contain the line's *orientation* in degrees relative to the north, expressed in three different formats to allow different kinds of search.

In field three, orientation is expressed as a fraction of 360 degrees. As illustrated in fig. 4, the same orientation can be expressed as "332" or "152" degrees (fields four and five), depending on the order in which the two nodes marking the beginning and end of the line have been drawn.

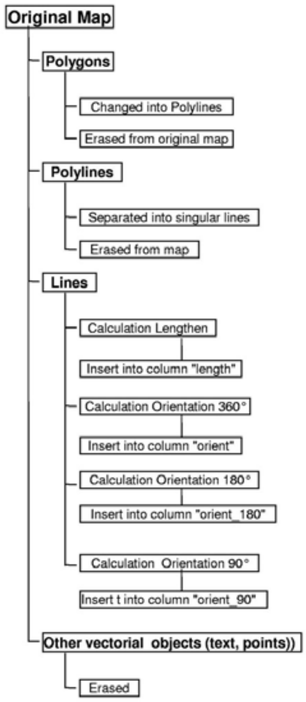
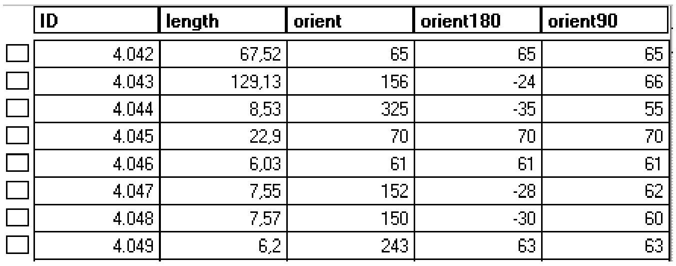


Fig. 2. *Flow diagram of the L_Orient" routine.*



	ID	length	orient	orient180	orient90
☐	4.042	67,52	65	65	65
☐	4.043	129,13	156	-24	66
☐	4.044	8,53	325	-35	55
☐	4.045	22,9	70	70	70
☐	4.046	6,03	61	61	61
☐	4.047	7,55	152	-28	62
☐	4.048	7,57	150	-30	60
☐	4.049	6,2	243	63	63

Fig. 3. *New table resulting from the decomposition of the original map.*

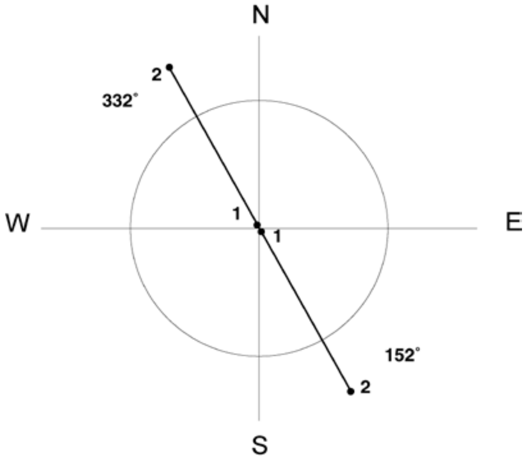


Fig. 4. *The choice of start and end nodes determines whether an orientation is expressed as "NW" or "SE", "332°" or "152°" (values range from 0° to 359°).*

Although theoretically there are 360 possible orientations, *where* a line in the vectorial map begins is irrelevant for our purposes. It follows that two of the four quadrants actually contain a duplicate. Therefore, we have created another column where all orientations are transposed to the two north quadrants (fig. 5).

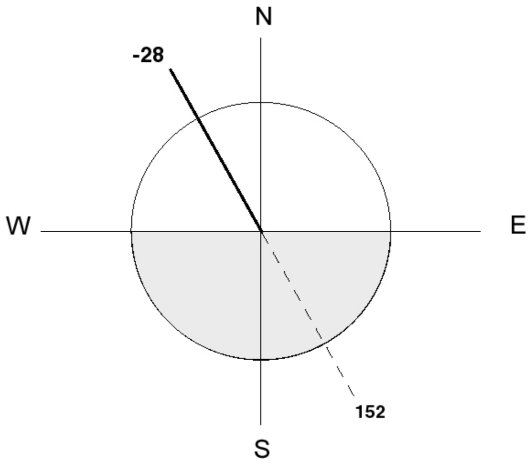


Fig. 5. *The orientation of a line (152°) transposed to the two north quadrants (field "orient180"). Values between –90° and 89°. The orientation is now expressed as "–28°".*

Orientations lying in the west quadrant are expressed as negative values. In the example illustrated on fig. 4, the orientation in the southeast quadrant (152°) is transposed to the northwest quadrant and expressed as "-28°" (although it remains possible to search for it as "332°").

Since one of our principal objectives was to highlight orthogonality between lines, we created another column where all orientations are transposed to a single quadrant, the northeast one (fig. 6).

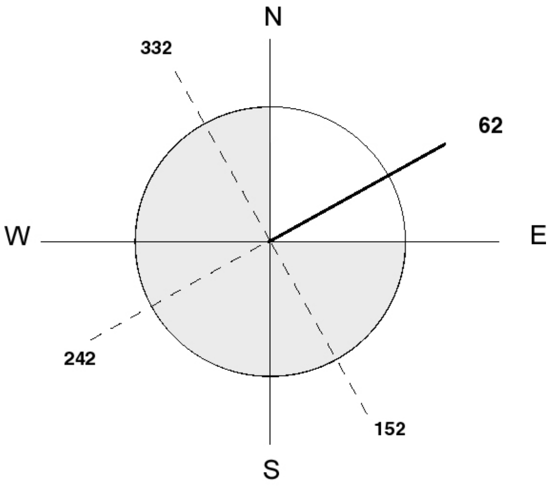
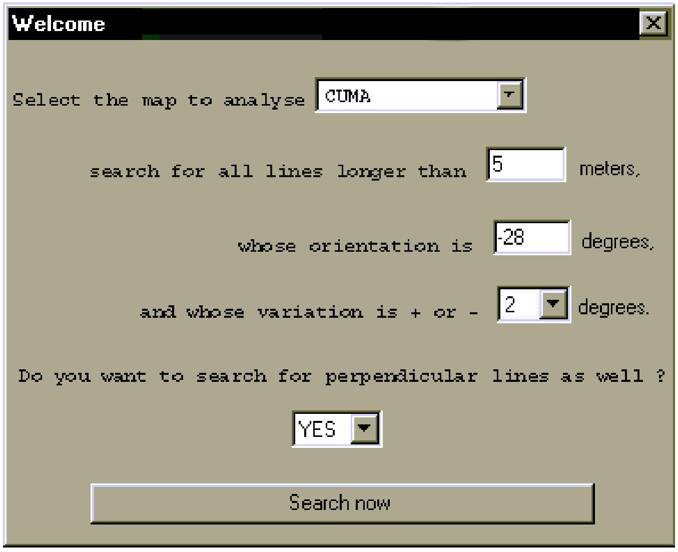


Fig. 6. *Orientations transposed to the N-E quadrant (field "orient90"). Values from 0° to 89°.*

In the example illustrated in fig. 5, all orientations not in the northeast quadrant (152°, 332°, and 242°) are transposed to the northeast quadrant (62°).

The transposition of all orientations to the two northern quadrants, or just to the northeast quadrant, is necessary to search for a given orientation for the purpose of generating thematic maps based on user-defined value ranges or predefined statistic methods (Natural Break, Standard Deviation, etc.).

"L_Orient" automatically recognizes a map which has been already processed following the above-described steps. In this case, the program skips the first phase (the creation of a new map), and takes us directly to the following "selection" window (fig. 7).



Select the map to analyse CUMA

search for all lines longer than 5 meters,

whose orientation is -28 degrees,

and whose variation is + or - 2 degrees.

Do you want to search for perpendicular lines as well ?

YES

Fig. 7. *The tool's interface.*

Through this user-friendly interface it is possible to search for any orientation in any of the three formats mentioned above (as we have seen in the previous example, where "332°" = "-28°"). Lines shorter than a specified length can be ignored. The user can search for the requested orientation with an approximation ranging from 0 to + / - 10°. We have solved the problem of dealing with ranges of selected values within the limits of a chosen approximation: if, for example, we select the degree 89° with an approximation of 5 degrees in the "orient_180" column, the utility carries out two searches, one between 84° and 89°, the other between –90° and –86°.

On a PC of average power, "L Orient" required only a few minutes to decompose polylines and analyze orientations in a map of Cumae with over 46,000 records.

At the end of the process, the map window is automatically maximized in the screen, and zooms out until all layers are visible. Detected orientations are stored in a query table (whose name appears in a message), where they are highlighted in red. In the final active window, "L Orient" superimposes this query, the processed map, and the original map, in this order. The original data is still stored in the initial map, which remains unmodified.

At this point it is possible to create a "thematic map" from the map processed with "L Orient" in order to highlight a chosen orientation or specific features in a given territory. Thus, the algorithm can be used to test different hypotheses about the persistence of ancient traces in a modern territory.

5 Archaeological case studies

5.1 Cumae

Cumae, regarded by ancient sources as the oldest and northernmost of the colonies of Great Greece, was founded by Euboic colonists in the second half of the 8th century BC. Few vestiges of the ancient town are preserved, notably the acropolis with its temples, renovated in the Oscan-

Campanian and Augustan periods; the Roman forum with some earlier structures of the Oscan-Campanian main square and, probably, of the still earlier Greek *agorá*; and the remains of a few roads dating from the Roman period (d'Agostino and D'Andrea 2002). The relationship between the plan of the ancient town and the organization of its rural territory has never been systematically examined (D'Onofrio 2002).

Starting from the two main alignments observable in the area of the forum - 105°, probably earlier, and 115°, referable to the Roman period - we processed the vectorialized cadastre map of the site to determine whether the orientation of urban monuments or features located by means of geo-electrical prospecting (Mauriello 2002) reappears elsewhere within the territory under examination (fig. 8). The results are illustrated in fig. 9. Three different axes (highlighted in blue) show the earlier orientation. The southernmost one is a street of the Archaic period leading up to the acropolis. South of this street one can observe that modern plot boundaries also conform to this ancient alignment. The terracing of Monte Grillo, the hill on the east side of the city, probably had the same orientation. The more recent orientation (in red) seems to have been less influential. It is found again only in a small group of plots north of the ancient town.

These data, although partial, show the potentialities of the "L Orient" algorithm, which allows alternative hypotheses for the reconstruction of town plans to be formulated by comparing different systems of spatial organization presumably corresponding to different historical phases.

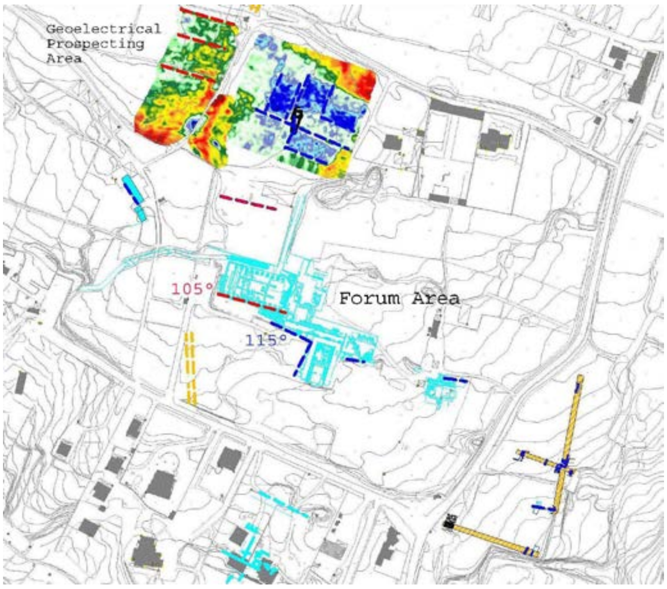


Fig. 8. *Cumae. The two main alignments observable in the area of the forum.*

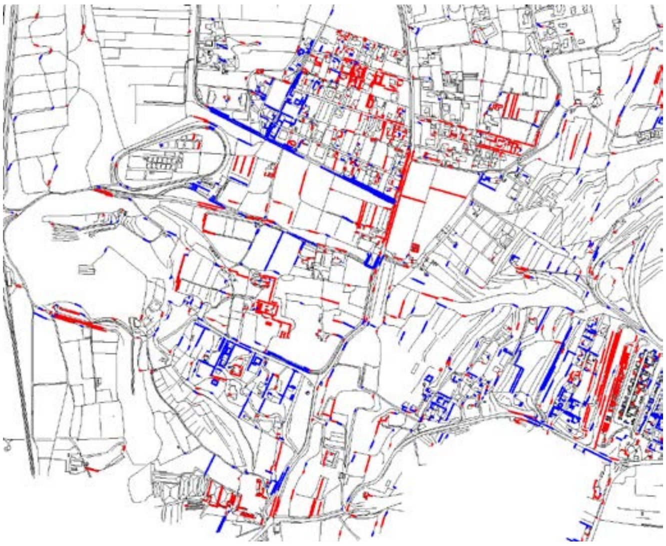


Fig. 9. *Cumae. The orientations (red: 105°; blue: 115°) found in cadastre map by processing vectorial data with L_Orient.*

5.2 Acerra

In the late fourth century BC, the town of Acerra, in the Campanian plain, was surrounded by a double wall of tuff blocks. The two main orthogonal streets of the modern town probably correspond to the *cardo* and *decumanus* of the ancient town (fig. 10).

By processing a photogrammetric map of Acerra with "L Orient" (fig. 11), we were able to detect a fine-meshed grid reflecting the earlier organization of agrarian space. Furthermore, in the area northwest of the town, the present boundaries of agricultural land appeared to be aligned with the street grid of the ancient town.

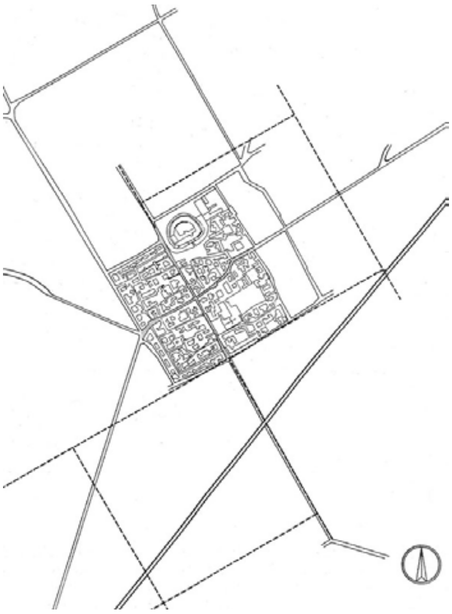


Fig. 10. *Historical center of Acerra (Giampaola, Ronga, Sica 1997).*

Fig. 11. *Acerra. The orientation (red) of probably ancient roman streets found in photogrammetric map by processing vectorial data with L_Orient.*

6 The future

Further applications of “L Orient” are already foreseeable, and we plan to implement them in the future. The program could be used to detect recurrent geometric features in traditional and digital air or satellite photographs. Geo-referenced and geometrically correct raster images can be vectorialized directly in Mapinfo; thus, traces would acquire sufficient spatial coordinates to be processed like photogrammetric surveys. In this case, however, we would have to restrict our analysis to manually selected regular geometric features possibly referable to ancient vestiges.

Another possible field of application is the analysis of the spatial distribution of objects on paleo-surfaces. The orientation of individual objects in areas frequented by prehistoric humans can be an important indicator of taphonomic phenomena such as depositional processes and post-depositional noise. When examining “complex”, two or three-dimensional archaeological objects, it is possible to weigh the evidence to obtain homogeneous results. Correction is needed, however, to allow for distortions induced by the representation of three-dimensional archaeological objects – such as pottery sherds, faunal remains, and stone artifacts - in two-dimensional plans. This mode of representation can be misleading, since it does not render the object’s full volume, and hence its global orientation. Furthermore, in this case, “complex objects” (i.e., polylines and polygons) are significant, and hence should not be decomposed, as “L_Orient” currently does.

The results we have obtained so far are encouraging, and we intend to go on with our research. We would like to conclude by stressing, once again, that spatial analysis tools such as the one we have developed can provide a valid support to landscape archaeology as long as their role remains auxiliary: a one-sided reliance upon them could lead to simplistic results. They can never be a substitute for direct field observation.

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