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# ADAPTIVE SYSTEMS AND GEOGRAPHIC INFORMATION SYSTEMS IN ARCHAEOLOGY: RETROSPECTIVE AND PRACTICAL APPROACHES IN SPATIAL ARCHAEOLOGY

## 1. Introduction

Spatial analyses could be usually performed by using pencil and paper, nevertheless nowadays it is not even thinkable to do them in that way since the use of computer helped us accomplishing these tasks in a faster way, also keeping a higher level of accuracy. Moreover, in certain cases the procedures can be so long and the amount of data so huge that it is almost impossible to perform them in a reasonable time frame. Even if the information revolution has pushed the processing capability, and the processing power is not more an issue, there are tasks that a computer is not yet able to perform and the human intervention is needed. The dream of a machine doing part of the archaeologist's job (Barceló 1993, 2009) continues on a different path and the real deal has become the existence of a "thinking machine", able to reproduce human thoughts and/or decisions.

In archaeology this could be a great opportunity not only in order to save time and to analyse huge quantities of data, but also to suggest us processes and aspects not yet discovered or formalised. The first attempts of Artificial Intelligence (AI) in archaeology followed the destiny of New Archaeology (Barceló 2009), a failure dictated by the initial enthusiasm based on something new but not yet mature. Actually, looking it from nowadays perspective, we can say that archaeology, not AI systems, was not prepared for this evolution (Lake 2010). AI systems, in fact, have now being used for several years, with thousands of successful examples in the world of research and industry. The gap between archaeological methodology and the use of adaptive systems should be filled with solid and tested methods: if a computer is able to perform a certain task it is like to say that that procedure can be formalised (Doran, Hodson 1975), but especially in social sciences this is always a very difficult and complex task (Clarke 1972). So what if a model/procedure is not yet formalised? And what if the process is not even focused? Is there a way the computer could help the archaeologist in these operations? The world of adaptive systems, along with the concept of Machine Learning, seems to offer a support for the archaeologist in different areas of interest. Since there is a huge bibliography on AI methods and techniques, we will present here only few examples and their applications in the archaeological field, dividing their use into three main groups: 1) classification/data mining; 2) shape recognition; 3) spatial analysis.

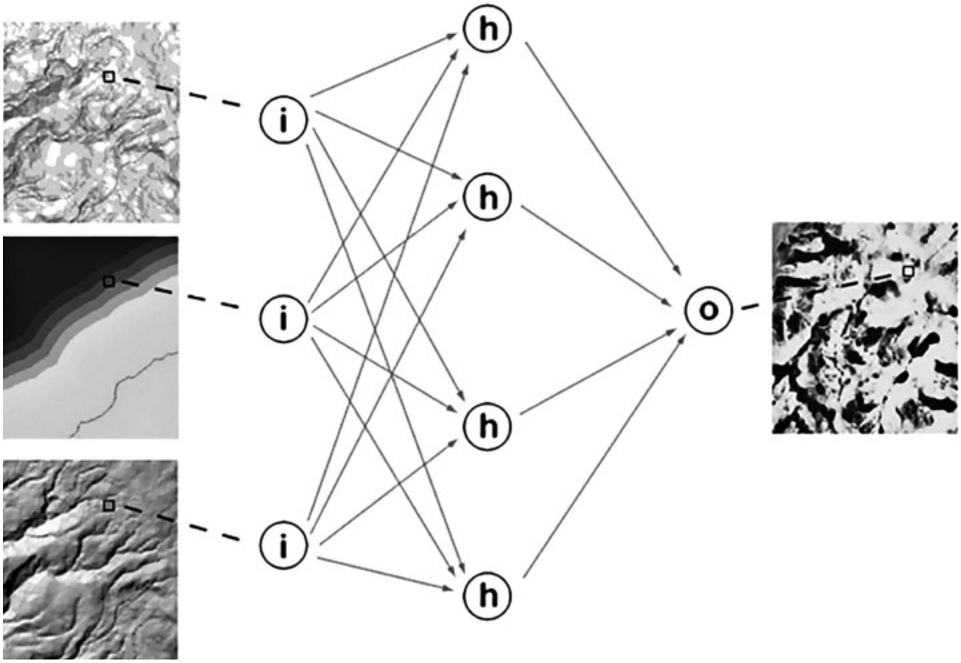


Fig. 1 – Example of ANN with three input raster layers and one output map.

## 1.1 *From data to knowledge*

Data mining and classification with the use of AI are maybe the paths more often chosen by archaeologists. The inner nature of the archaeological record is to be always fragmented and the "whole" dataset must be conceived as a part of the original data. For this reason, finding relationships between records, from artefacts to sites distribution, is one of the archaeological main aims. Unfortunately these aspects are not always recognisable at a first look and there is the necessity to discover "hidden" relations into datasets, trying to find a model suitable to match records. It derives that datasets availability is a necessity for these kinds of exploration, but with the Internet era the amount of data has become easily reachable in a worldwide scale and operations of data mining allow researchers to gain data also for testing models (Wurzer *et al.* 2013).

By using sources like ethnoarchaeology, that studies living societies to help explain cultural patterns in the archaeological record, it is also possible to increment these datasets adding examples to create a database of real experiences of hunter-gatherer populations, useful for the study of certain time periods (Binford 2001). The need to classify this enormous amount of

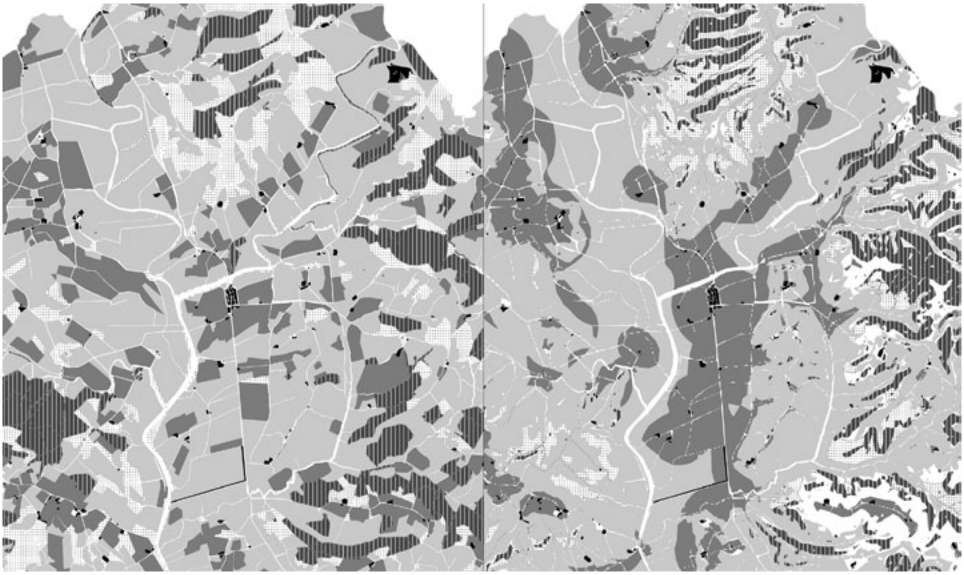

Fig. 2 – Comparison between the actual land use of Buonconvento area in XIX century (left) and the predicted one (right).

data, however, encounters the problem of how to do it in a critical way: even apparently simple tasks, like classifying and identifying pottery fragments, at a certain point become too complex and even if every new record adds more information, it also adds more complexity.

At the beginning of the 1980s some researchers tried to find solutions to these problems with the use of expert systems, based on different algorithms and applied on different case studies, like pottery (Bishop, Thomas 1984; Vitali, Lagrange 1988), other kind of artefacts (Ganascia *et al.* 1986; Grace 1989) or animal remains (Brough, Parfitt 1984; Baker 1987). The approaches varied a lot: from being based on artefacts shape similarity to chemical composition of the fabric, for example, obviously including also the time variable and all the problems related to ageing remains.

Beside expert systems or the so called "intelligent databases", with a limited applicability for computational problem solving, different methods based on Artificial Neural Networks or ANNs started to be applied in different archaeological contexts at the beginning of the 1990s (Gibson 1992, 1996) even if at the end of the decade they were not yet extensively explored (Van den Dries 1998). The use of these techniques, which in the last decade have been used more extensively in archaeology, especially due to their ability to use partial and incomplete datasets, can be divided in two groups based on their type of "learning" and their consequent different destination of use: supervised or unsupervised.

The methodologies related to the first group, in particular the Self-Organizing Maps or SOMs (Kohonen 1984), due to their characteristics, have been mostly used for clustering, classification and taxonomy. For simplicity we can say that these methods are mostly based on the concept of similarity, on different parameters, that lay in between the records of a certain dataset. On the other hand, supervised systems focus their strength on the process of "learning" by examples. In this group we can include techniques like Feed Forward/Back Propagation, Bayesian, Perceptron and many other types of networks. It is clear that, in this case, the necessity of a consistent sample to train the network is fundamental: the more the records are, the more the result will be accurate.

Some typical examples of ANNs in archaeology, mostly based on unsupervised training methods, can be found in the study of different kinds of ceramics (Lopez-Molinero *et al.* 2000; Fermo *et al.* 2004), in which, coupled with the use of Gas chromatography/Mass spectrometry or similar archaeometric techniques able to recognise the elements present in the fabric, the association is made by the similarity of the materials that compose the pottery (clay, glaze) in order to identify, for example, the place of provenience. One last aspect that should be at least mentioned is the Fuzzy Logic theory implementation (Zadeh 1965), another important part of the AI that has been involved in several archaeological case studies on classification, allowing to overtake the "classical" true/false, 1/0 approach (Barceló 1996) by allowing an element to be "partially" part of a certain group.

### 1.2 *Toward a territorial approach*

The applications presented in the above paragraph do not take in account the location or the territorial aspects of the records, and also in the case of archaeological sites studies they were considered only as entities characterised by certain variables, but not by their position in the space. Spatial analyses can cover a huge quantity of aspects of the investigation, going from intra-site analyses, i.e. the location of an artefact in the site, to the organisation of the site itself, its relationships to the surrounding sites and so on. Moreover, we have to consider that not only the coordinates are fundamental, but also the chronological aspects that are deeply related with the location. We must remember that the archaeologist, for example studying archaeological sites location patterns in a certain area, can investigate them in a synchronic way, analysing sites of the same period, but also in a diachronic way, by looking for relationships between sites of different periods, adding a time variable. In this case, the use of GIS is an aspect that characterises, for their inner nature, almost all of the applications presented in this section.

One of the major applications of adaptive systems in this field is the one related to shape and pattern recognition (Bishop 1995), usually in combination with remote sensing, satellite images and aerial photogrammetry, in order to find ancient evidences on the earth surface that can help us in the reconstruction of the past. The analysed evidences are mostly artificial (De Guio 1996; Davino *et al.* 1999; Alexakis, Sarris 2010; Cavalli *et al.* 2012), like buildings, roads and human settlements/sites in general, but also natural, like paleochannels, ancient land assessments and so on; of course in this case the type of evidence is related also to the level of detail of the used data. One of the most fascinating fields, however, is maybe the one of predictive modelling and simulations in a spatial context. Trying to individuate and/or to recreate the processes that led to a certain settlement pattern means, in a certain way, to understand some aspects of how humans thought in the past, which were their priorities and how they conceived life. A real territorial approach in archaeology, with the use of AI in combination with GIS, is quite recent and not yet explored extensively, while adaptive systems were often used as a support to territorial analyses (Ramazzotti 1999, 2013).

Some examples that take in account the space aspect, even if not in a GIS environment but mostly in a pseudo-real space characterised by some variables like presence of resources and provisions or communication channels, are based on simulations. Several examples in this field were attempted (Doran 1990) with different methodologies, like multi-agents systems, that can simulate actions/reactions in relationship with the variables that characterize, for example, the environment. This characteristic has been used, even if some see a limited potential for agent-based modelling in archaeology for the tendency to make human societies too static, especially in prehistoric field for the study of sociological and cultural changes in a multi-actor environment (Zubrow 2003, 173-180) or for replicating hunter-gatherer decision-making strategies, resource-sharing strategies, and the impact on population dynamics (Costopoulos, Lake 2010).

At one point researchers started to consider the possibility to couple adaptive systems to the use of GIS (Reeler 1999). The field that maybe has been more affected by this tendency is the one of predictive modelling that in the last years has grown extensively in archaeology, making an intense use of the adaptive systems, in particular ANNs (Ducke 2003; Van Leusen *et al.* 2005). Even if these approaches are mainly focused on predictive purposes, we think that they can also be used for the study of ancient settlements, involving spatial analyses in a more extended form. The training process in fact, even considering all the problems related to the "black box", could be a way to compare, and so understand, settlements patterns.

## 2. ANNs for the study of ancient settlements patterns

While the previous papers on this research were mostly based on the methodological side, here the focus will be more on results analysis. A first version of the presented methodology can be found in Deravignone, Macchi (2006), after which several technical aspects were improved and the case studies and fields of applications extended. A very brief explanation of the methodology is reported here in order to better understand the rest of the present contribute. The main idea was to train a feed forward ANN in order to "understand" the dynamics that lead to a certain settlement pattern by training the network with some variables that characterise the single features (archaeological sites) of the pattern itself, like geo-morphological aspects, proximity to other kinds of settlements or resources and so on.

The first attempts were made with medieval hilltop settlements (castles), of southern Tuscany (Italy), thanks to the huge database available made by the University of Siena since the beginning of the 1990s. The training pattern was constituted by real castles (identified by the value 1), and a set of null or "negative" points (identified by 0): in this way the net learns all the characteristics of the "real" sites and it is able to recognise the areas more suitable for them (Fig. 1).

All the values are originated from raster datasets, counting not only the site itself but also the surrounding areas, using different distance radiuses, for more than 60 total input variables. Raster files were also used during the final phase where they are processed with the trained network, and an output probability map, with values from 0 to 1, is produced.

### 2.1 *Methodology improvements and new case studies*

On the technical aspect one of the major improvements to the previously explained methodology was the creation of the SNNSraster Manager software (freely downloadable from http://sourceforge.net/projects/snnsraster/) that allows everyone to easily perform the final part of the process. Once again the Open Source approach was followed and the multi-platform aim was respected since the whole procedure is achievable under Windows and Linux operating systems. The total replicability of the analysis process has been preserved, making the procedure even easier than before and with no particular needs regarding the GIS software, since the standard and open ASCII file format is still used. In this way the whole process has became faster, reducing also the number of steps in order to simplify the method, from data creation to analysis results.

On the data side, the list of variables has been increased with new values, including Landsat satellite images, and an important decision was to couple the laboratory testing, made with castles excluded during the learning procedure and used as a test set, with field surveys. In order to accomplish this, the analysis area was extended to the total area of the ancient Volterra diocese, focusing on areas with a scarce presence of sites on the archaeological map. The reason is mostly imputable to the extreme difficulty of surveying those areas with a standard method, especially due to the strong forestation that characterises them. Surface surveys in high probability areas lead us to the discovery of several new sites of the same period used for training (1150-1300 AD), basing especially on built up evidences and on the numerous pottery findings. After all these tries, there was inevitably the need to test the method on a completely different context, in order to see if our results were so significant to spread the method also to other case studies. The opportunity was offered from a study on northern Norway pit dwellings in collaboration with Prof. Blankholm, University of Tromso.

The choice was perfect thanks to the different context, different type of site (only present on the seaside) and historical period (Neolithic and Early Metal Age). That was also a good occasion to formalise the procedure named "Grosseto predictive method" (Deravignone *et al.* 2014). The first step was to perform new ANN analyses with a small sample of already known sites, covering the total area of Senja Island, Troms County, in northern Norway. After that, two survey sessions were performed in 2010 and 2012, focusing on high probability areas along the coastline. Due to the different type of sites, different variables were used.

### 2.2 *ANNs and historical sources for land use studies*

A different attempt has been done applying the same methodology to land use (Deravignone 2011a, 2011b) where, instead of point pattern analysis, the input was constituted by the single cells of land use; moreover, while the previous approach was based on only one output (castle/not castle), in this case an output for every single land use was necessary. In order to accomplish this, the land use was simplified to five main categories: built up, agriculture areas, specialised cultivations, pastures and woods. The built up was used only in training process while the rest were used both in training and back-casting phase. Also in this case, in fact, an important aspect was the distance from inhabited areas, towns, villages or even single farms. The idea was to train the net on a certain area and to apply the trained network on another similar context. For testing the results the use of "Leopoldino" cadastre, from the first decades of 1800, was fundamental. In this cadastre the land use of the various parcels is reported in detail allowing to see if and how the results were, with the real XIX century land use. After converting all the parcels in raster format, a net was trained with data from S. Quirico d'Orcia area, while the test was done on Buonconvento area, both located in Siena province in southern Tuscany (Fig. 2)

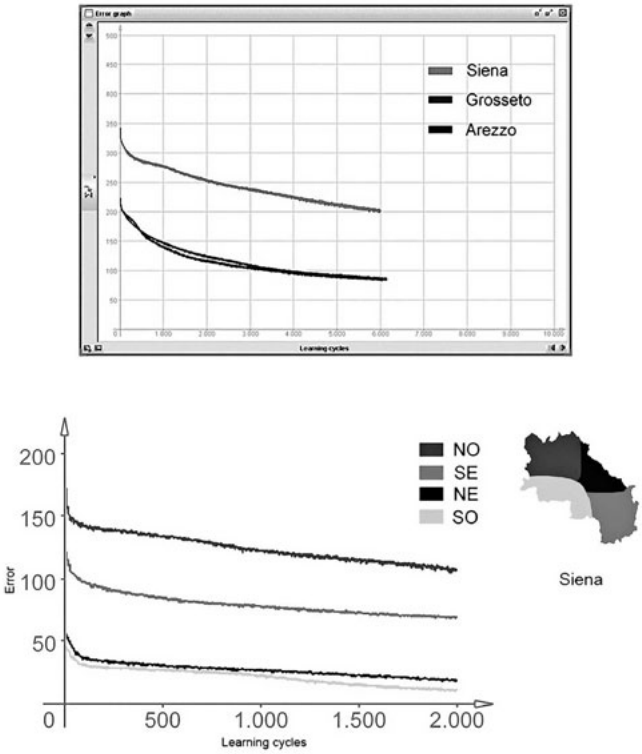


Fig. 3 – Error graphs relative to the ANN training in the Provinces of Siena, Grosseto and Arezzo, and the focus on the Province of Siena, divided in four sub-areas.

The results were extremely interesting and gave us the idea of a society where distances were more important than today, and the closeness of the house or community to the field was very important. Here we can immediately recognise a classical model of land organisation, where the best suitable land is cultivated, due to the type of soil or good slope and exposure, while the rest is left uncultivated as woods or pasturelands. We can easily see an example of Von Thunen model where also the role of distance is easily visible: starting from the city, where the closest areas are dedicated to specialised cultivations, we reach the more distant ones, where the situation tends to have more "natural" aspects that do not need human intervention. The use of historical sources was very useful in this first experiment in order to test the results using them as a litmus paper. Once that the methodology has been tested, in fact, the method can be applied to similar contexts where we do not have historical evidences, hopefully with the help of other methods like palynology or other archaeometric methodologies.

## 3. Conclusions and empirical evidences

The use of feed forward ANNs for the study of ancient landscapes and settlements patterns has been giving very interesting results; both the survey sessions results, for hilltop settlements in Italy and pit dwellings in Norway, were very encouraging, and after few years of testing we are now able to do some more in depth considerations. Besides the predictive approach we can also state something about the utility of these kinds of spatial analyses for the study of ancient settlements: while the diachronic analyses did not give significant results, the application of a trained net on a different context gave us some food for thought. An interesting aspect, for example, comes out looking at the differences between the training of the whole area, constituted by Grosseto, Siena and Arezzo provinces, and the training of the singles provinces. Analysing the error graph it is possible to notice a higher level of error related to the Siena area training, compared to the other two. For this reason it was decided to investigate more in depth the reason, dividing the area in four, partially overlapped, parts and analysing them singularly (Fig. 3).

The visible differences in the error graphs can be explained by a more complex situation that, even if determined also from variables not used in the training phase, is a sign of the complex social dynamics derived from the presence of an important city like Siena, also taking into account the proximity of Florence on that side. There are also many other interesting aspects that should be explored, like the presence of many high probability areas containing a high number of aerial photography anomalies not yet checked or surveyed, or the presence of numerous farms, mostly from the XIX century. The exploration of this field is far to be concluded, but the exigency of testing more case studies and analysing results, with the help of different analyses in order to look for social dynamics and along with the help of strong historical sources where available, is expected.

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ABSTRACT

For several years now archaeology has made use of methodologies based on Artificial Intelligence (AI) and Artificial Adaptive Systems (AAS). However, there are still only a few experiments that involve the spatial aspect, and in particular spatial analyses of the territory. Moreover, we are often faced with theoretical approaches, procedures that cannot be used or repeated by the scientific community because they are based on proprietary or undivulged algorithms. The first part of the paper is focused on a short historical retrospective of the applicative experiences of AI and GIS, from the "new archaeology" pioneers to the latest experiments in predictive approaches. Subsequently, we present an "open source" application, both from the software as well as the procedural point of view, oriented to the creation of predictive maps and focused in particular on the study of ancient settlements.