Confidence maps: a tool to evaluate data's relevance in spatial analysis.

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CONFIDENCE MAPS:
A TOOL TO EVALUATE DATA'S RELEVANCE IN SPATIAL ANALYSIS

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Summary: Inventory data used in archaeology are often incomplete and heterogeneous. In the framework of the ArchaeDyn program, a method has been proposed to evaluate heterogeneity in archaeological inventories. The purpose of this work is to create a validation tool to interpret the results. This tool is called a "confidence map" and is produced by combining representation and reliability maps. The first step consists in generating representation maps to describe the clustering of archaeological items. The second step is based on reliability maps. Data providers are asked to define and outline the level of reliability of their data. Finally, representation and reliability layers are combined using map algebra. The resulting maps allow for the comparison and analysis of data confidence.

Keywords: confidence maps, spatial analysis, modelling.

Confidence Maps: a Tool to Evaluate Data's Relevance in Spatial Analysis

Spatial data in is getting more and more important in social and human sciences. However, it is often incomplete and heterogeneous, making its interpretation a difficult task. The collected data represents in fact a (limited) sample of a more complex reality. The application of spatial data analysis tools to social studies data therefore requires great caution in the interpretation. The issue is to avoid the identification of spatial trends that are just a consequence of sampling and reliability problems.

1. INTRODUCTION

Inventory data used in archaeology are often incomplete and heterogeneous, making their interpretation, dating and localization a difficult task. They represent in fact a sample of a more complex reality. The analysis of archaeological data using spatial analysis tools therefore requires great caution in the interpretation that is drawn from them. The issue is to avoid the identification of spatial trends that are just a consequence of the degree of archaeological investigation.

In the framework of the ArchaeDyn program, a method has been proposed to evaluate and give a spatial insight on the heterogeneity in archaeological inventories. ArchaeDyn is combining the efforts of several archaeologists working on various topics, ranging from the diffusion of manufactured objects in pre- and protohistorical times, to the use of land through the study of settlements, parcels and manuring during the antiquity (Nuninger and Favory 2008). A great diversity in analysis scales and studied objects led to different inventory protocols such as systematic field walking, bibliography studies, museum researches, etc. The variety of available data raised questions on the validity of spatial results based on archaeological material of different nature, temporality and spatial extent. The purpose of this preliminary study is to create a control tool that will be used for the interpretation of results in trying to extract the most valuable information to the archaeological interpretation. This tool is expressed spatially through what was called "confidence maps", a data layer produced by combining reliability and representation of the data.

2. REPRESENTATION MAPS

Evidence for data dispersion/location over separate study areas is symbolized with representation maps. They were designed with the aim of being standardised in respect to the theoretical mean of the individual study area (i.e. variations to the average). Therefore they allow the quantification and visualization of spatial heterogeneity in the sampling and the inventory of the different datasets. The number of archaeological items in each pre-defined grid cell is computed and this value is compared to the expected (usually mean) value in the study area, which gives an idea of the over- or under-representation of data.

First the analysis grid size has to be defined for each individual study area. The proposed optimal cell size calculation is based on the assumption that archaeological data is approximately evenly distributed, which means that each data object is assigned the same area, defined by the cell. The cell size is therefore "unique" for each study area because it is directly related to the area of investigation and the number of observations – in effect it is an average distance among observations (Sánchez 2006). In our case we have computed the optimal cell size as cell_size = sqrt(total_area/$N_{observations}$). This empirical method is based on the assumption that if the objects are normally distibuted, then a similar area should approximately belong to every object. Therefore, the average area of an object can be computed by dividing the whole area of interest by the number of objects. This average area is square shaped when working with a regular grid, thus the cell size of the grid can be computed by square rooting the average area. This number is then rounded and represents the optimal resolution. A similar approach is mentioned by Shary *et al.* (2002). However, data is rarely evenly distributed. In order to improve the statistical significance we have chosen the first larger grid size, fitting the "standard" resolution system used in ArchaeDyn, i.e. 1, 2.5, 5, 10, 25, 50, 100, 250 km … This produces grids that are both optimal and well populated that is containing a significant number of points. In order to simplify the process of data transformations and comparison of different datasets further, the common point of origin has been defined for all the grids, meaning the cell boundaries of different resolutions and study areas overlap at the same coordinates. This means that even different scale phenomena can be processed as imagery in order to combine their information over the same or different areas when it is relevant.

Representation classes were defined to stand for no data, normal, over and extreme representation (see fig. 1). It was found that these types of classes correspond to the nature of archaeological data, whose frequency is typically exponentially distributed and hardly ever normal. In case of being so, the classes would be under, normal, and over representation. The approach is different from the previous work done by the group (Nuninger

and Favory 2008). Some not completely resolved issues remaining are the automatic or semiautomatic selection of thresholds for classes and the no-data phenomenon.
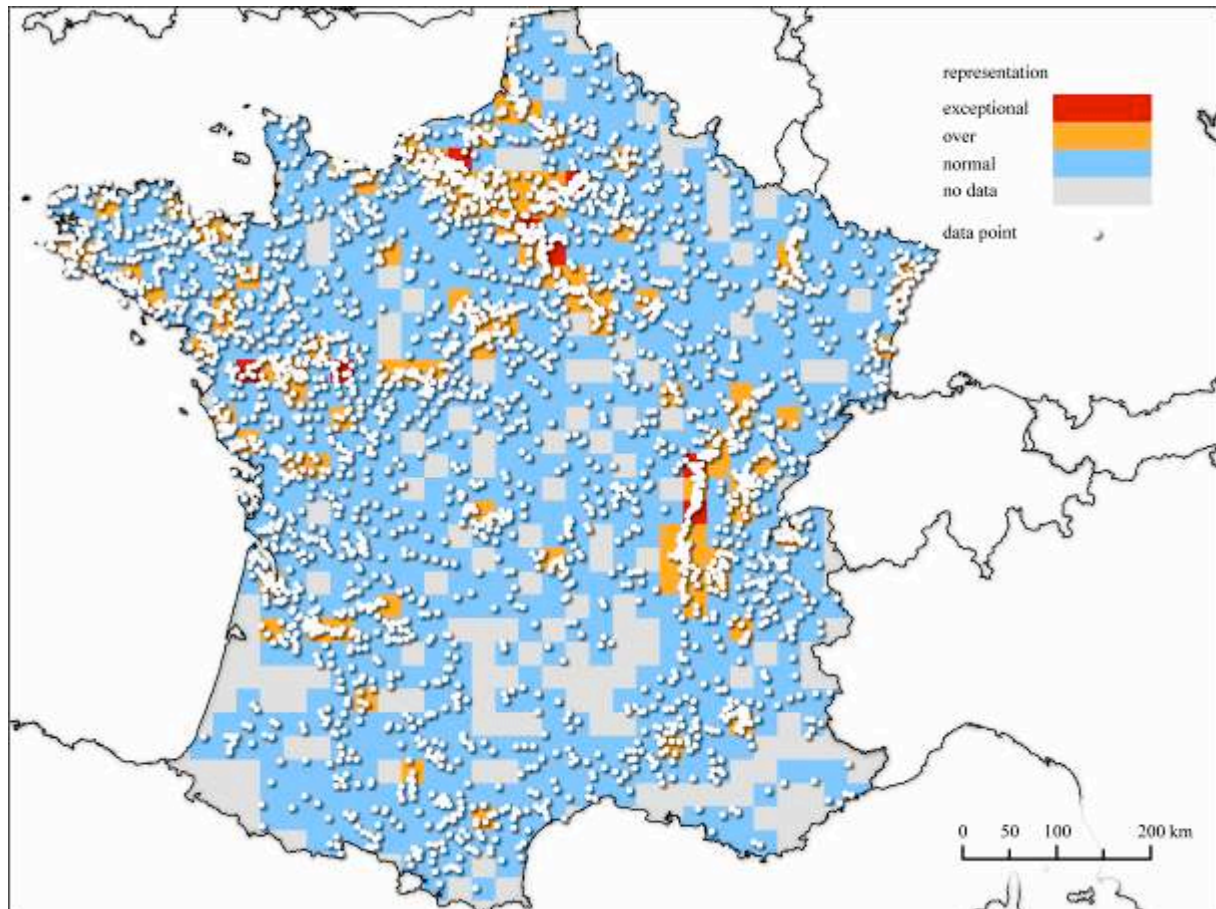

Fig. 1: *A representation map of dated archaeological bronze objects in France* (map: Z. Kokalj, data: F. Pennors).

Even though the process was designed with the aim of being non subjective and based solemnly on statistics, a uniform automatic statistical division of classes based on average proved to be unreasonable because of the extreme data heterogeneity, including different distributions, differences in absolute values, no data phenomenon, and the use of integer values. According to our tests, the classification process has to be done (semi)manually and individually for every dataset with the help of statistical and mathematical tools. The usual procedure is based on histogram analysis and its modification using a logarithmic function, and defining the natural breaks in the data. The latter are especially difficult to define if absolute frequencies (representations) are low. This implies the importance of selecting the optimal grid size.

The problem of handling no data values has not been solved satisfactory, but rather bypassed. The statistics can be significantly altered with the inclusion of cells with no data values in the calculation. The argument for including such values is the fact that the space is continuous and areas cannot be left out, however in cases where data is highly concentrated this can lead to dramatic decrease of the average and as a result even the areas with only one object can be classified as over represented. Increasing the cell size by one "standard" step and manual delimitation of classes evaded this problem as with the latter the interpreter can manually classify such areas as normally represented and with the first the number of no data cells is effectively decreased anyhow. A problem which arises is further concentration of extreme values and resulting reduction of "contrast", but if this is not the primary concern it is well supplemented with improved overall legibility and accuracy of the final map.

3. RELIABILITY MAPS

Reliability maps express the settings (and limitations) of inventory exploration (i.e. how the archaeological sources were explored) in terms of common indicators such as survey level – sampling, visibility level, the quality of references etc., about a specific dataset. A reliability map gives information on the intensity of research and exploration (reliability of the inventory), and is not primarily concerned with the quality of data's

location. It can therefore also be interpreted as a correlation between intensity of research and actually identified sites or archaeological evidence. In our case a reliability map covers the entire study area and distinguishes three reliability levels: reliable, fairly reliable and not reliable. It has been defined by the providers of individual datasets and has been mostly drawn by hand according to a predefined set of rules. The rules were defined by each workgroup or even by each archaeological team. Indeed, such rules are depending on the kind of investigation. Nonetheless, each set of rules is written with respect to the three predefined degrees allowing comparison. The definition of reliability levels is adjusted according to the nature of data. For example, instead of field walking, data availability in museums or publications can be considered (Tab.1). The identification of individual levels is based on an empirical method because its foundation is the knowledge on data, and is therefore inherently biased. It is also highly dependent on the phase of studies and of course directly connected to the state of the studied database. The ArchaeDyn's databases are, from now on, fixed at the present state of the investigation in order to provide analysis. New discoveries or new development of the database will be used by the end of the project during the step of validation and for final interpretations.

	Level 1 (reliable)	Level 2 (fairly reliable)	Level 3 (not reliable)
WG2 and WG1 Manuring	1) areas where systematic field walking with spacing of 10 m maximum has been completed, and 2) where there are optimal visibility conditions (ploughing or vineyard or lavender).	1) areas where systematic field walking with spacing of more than 10 m has been completed, or 2) where systematic field walking has been carried out but there is only partial visibility of the ground (wildland, fallow, meadow, woods)	1) areas where only partial or no field walking has been performed and/or 2) there is very poor visibility due to land use and/or areas where significant taphonomic problems are assumed (sedimentary covering or erosion).
WG1 Field systems	1) areas where systematic field walking (under forest condition) has been completed and 2) where there are optimal visibility conditions, 3) with a good precision in recording features < or = 10 meters	1) areas where punctual field walking has been completed or 2) where there is poor visibility (high density of vegetation...) and/or 3) imprecise records of features (error > 10 meters)	1) areas where very punctual or ancient field walking has been completed
WG3 Bronze objects	1) areas where the author of the database paid a special attention. 2) where field walking and excavation have been completed with a relatively high density of research/field walking (due to preventive archaeology, dredging) on the study area. 3) where data are easily accessible (straight access to raw data, no access limitation to the stored data - archaeological services, museum, private collection -) and with many publications.	1) areas where the author of the database paid a special attention and/or 2) where field walking and excavation have been completed with a relatively medium to high density of research/field walking on the study areas but with less sufficiency and/or 3) where data are easily accessible (straight access to raw data, no access limitation to the stored data -archaeological services, museum, private collection-) but with few publications only.	1) areas where the author of the database paid a good to fairly attention and/or 2) where only partial or no field walking/ excavations have been performed with almost no archaeologists working on the study area or without sufficiency and/or 3) where data are less accessible (no or partial access to raw data, limited access to the stored data -archaeological services, museum, private collection-) and with few publications only.

Tab. 1: *Reliability rules (examples) define by the workgroups of the Archaedyn's project* (Nuninger and Favory 2008)
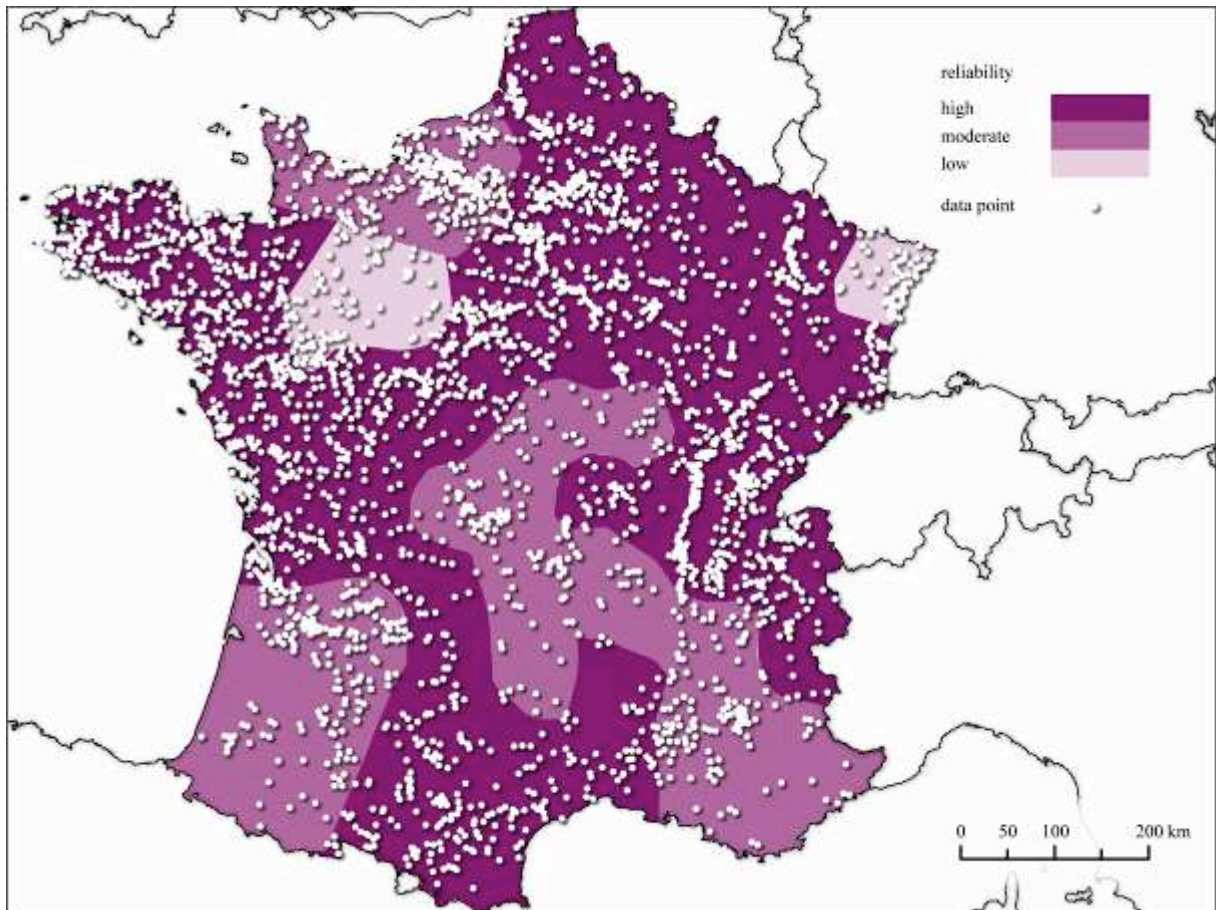
Fig. 2: *A reliability map of dated archaeological bronze objects in France* (map: Ž. Kokalj, reliability zones and data: F. Pennors).

4. CONFIDENCE MAPS

Confidence maps offer a tool to evaluate the relevance of archaeological data in spatial analysis. They give an impression about the confidence a user can have on the final results that is based on input data. The representation and reliability layers are combined using map algebra in order to obtain confidence maps. The logic behind lies in joining two spaces: location-based density (representation) and intensity on inventory (reliability). Results allow for the comparison and analysis of data confidence and thus the evaluation of the trustworthiness of the interpretation and spatial modelling, but also give information on the correlation between data representation and reliability. The map can be used to eliminate "spurious" zones for space-time analysis over long-term (according to the comparison of each study area with their chronology and the interpretation key of the representation map).
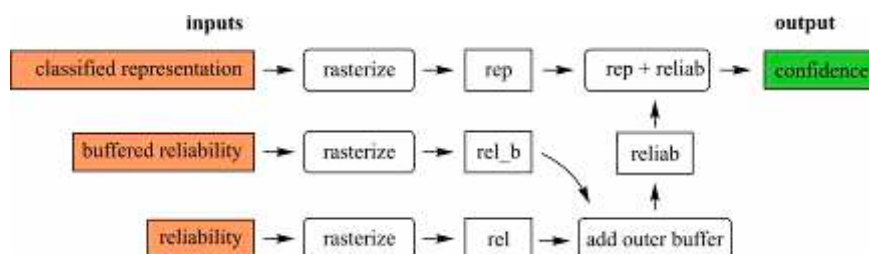

Fig. 3: *Confidence map processing model*.

The proposed process is essentially based on simple algebraic operations and "binary" logic. The confidence was coded into two digit numbers, with one digit reserved for representation and the other for reliability. To technically enable the addition, the representation map has to have "denary" classes, 10, 20, 30, and 40, being extreme representation, over representation, normal representation and no data, respectively, and the reliability map was used with values of 1, 2, and 3, ranging from highly, moderate to low reliability. Another technical

issue is an accurate rasterization of the reliability map. Normal rasterization omits border areas with less than half cell occupancy. Consequently a 3/4 cell size buffered layer with preserved attributes has to be created and rasterized. Its outer buffer is then added to the rasterized reliability and the result combined with the representation map. An ArcGIS tool was designed to speed up and enable batch processing.

The ensuing confidence map is in effect an overlay of both maps (see fig. 3). By inspecting the map one can immediately find areas of different representation but also areas with low data reliability. The strongly coloured areas are more reliable than the light coloured areas but both can and should be included in the analyses with a different level of caution. The proposed process can also be applied to analyse and compare other spatial phenomena, and tests are underway to evaluate it for the effectiveness in representing temporal changes.

Some hard to manage issues still remain in this approach. Questions, such as how to discretize representation maps and how to interpret areas with no data will have to be addressed in the future.
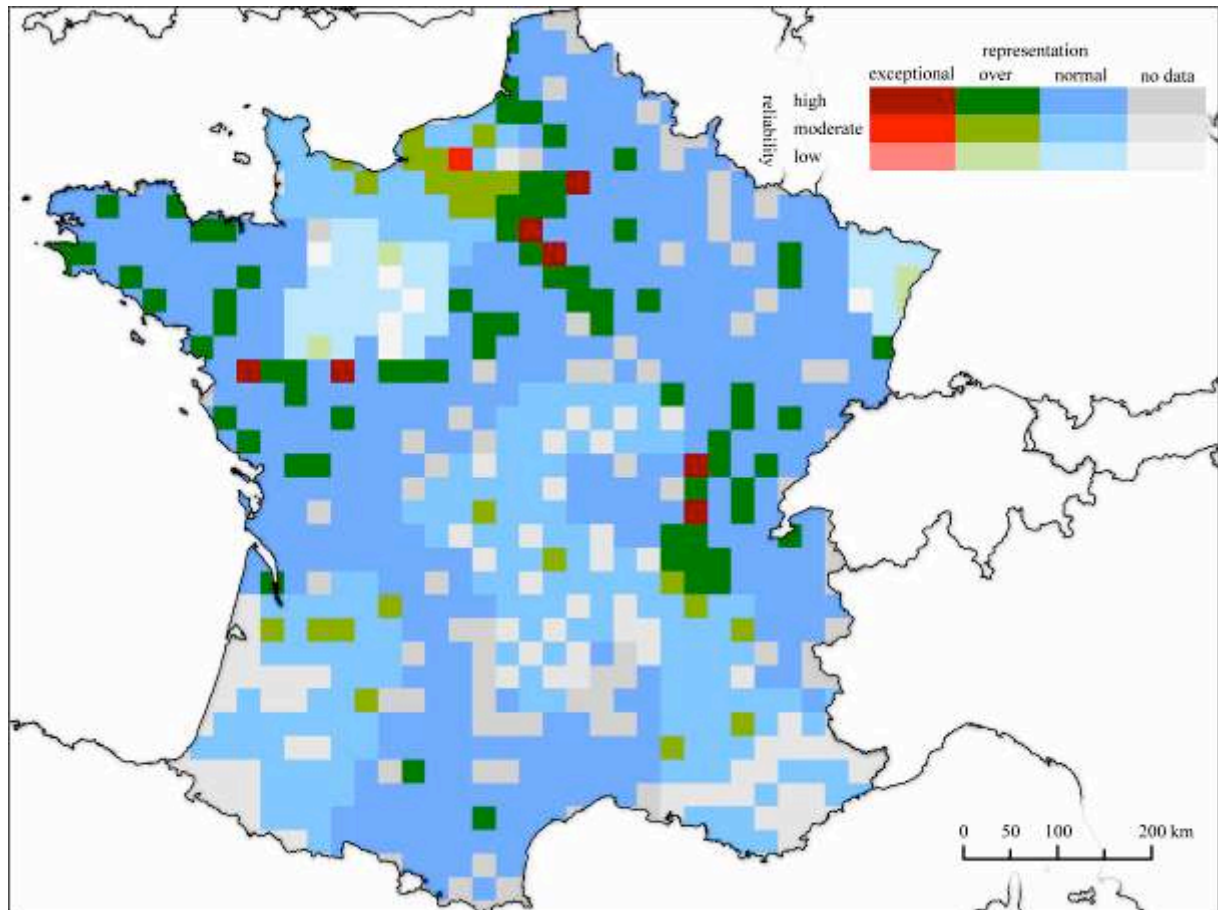

Fig. 4: *A Confidence map of dated archaeological bronze objects in France* (map: Z. Kokalj, data: F. Pennors).

5. CONCLUSIONS

To represent the level of trust of the spatial analysis and modelling results we have defined a tool called confidence maps. Confidence maps provide the user a spatial impression about the representation and the reliability of the input data in the same time, giving him the opportunity to detect "artefacts" in the data. The same methodology has been defined for different scales and for different observed phenomena. Despite the fact that the data used can be very dissimilar the interpretation of confidence maps is the same. This is an innovation especially considering the extent of the ArchaeDyn project.

There are still some problems that have to be solved though. Confidence maps are not suitable for all databases. They suit better databases containing "noise" – they perform better with large amount of statistically well represented data. We have also found a rather strong scale dependence of the results. Different tests have shown that the tool does perform better with small scale (big area), large quantity of points (often it will be studies of objects and not sites or settlements), and a low positional accuracy (studies about the diffusion of material, circulation of artefacts).

The method was developed and successfully applied to various archaeological dataset (Oštir et al. 2007, Nuninger, Favory dir. 2008, Saligny et al. 2008). In the presented paper, our purpose is to show a first example

of the methodology applied to data obtained and used in human and social studies in the framework of the Caenti project. While the methodology is still under development, it can be used effectively to map the reliability of the spatial modelling results.

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