Looking at Change, Continuity and Time in GIS: an example from the Sangro Valley, Italy

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Introduction

In a companion paper to this one (Daly and Lock, not submitted for publication), we detail the current situation in archaeological applications of temporal GIS, within a general background, of incorporating time and change through time, with GIS technology. This paper is a case-study, within that wider framework, presenting a pragmatic attempt at spatio-temporal modelling, based on the analytical requirements of a single field-work project and the functionality of readily available, low-cost GIS software. The work has resulted in a useful methodology, based on the quantified comparison of snapshot images, for identifying and quantifying change and continuity, along the axis of time, within surface survey data. It may have wider applications although, perhaps not surprisingly, it does raise some important archaeological questions, concerning theory, methodology and assumptions.

The Sangro Valley Project

The principal objectives of the Project are to improve the understanding of ancient settlement, culture and economy, in a relatively unexplored part of Abruzzo, central Italy. This is within the area of ancient Samnium, and the River Sangro is one of the region's major river systems, rising in the Apennines and flowing for 120km to the Adriatic coast. The temporal focus of the work is on the Samnite, Roman and early medieval periods, c. 500 BC-AD 1000. Fieldwork, since 1994, in conjunction with the Soprintendenza Archeologica Dell'Abruzzo, has concentrated on three study areas, within the Sangro valley, selected to provide varying environmental conditions; and, it is the middle valley area, which forms the case-study of this paper. Exploration has been based mainly on intensive surface survey, combined with a wider, landscape sampling strategy and small-scale excavation (Lloyd, *et. al.*, 1997). This is an integrated landscape approach, similar to that which has been successful in the nearby Biferno Valley (Barker, 1995), although the Sangro Project has been designed, with GIS analysis in mind. This has greatly influenced data structuring and data collection strategies (Lock, *et. al.*, Forthcoming).

The middle valley study area is centred on the 35 hectare, fortified hilltop site of Monte Pallano. Over 80 such *oppida* are known, from the territory of the Samnites (Oakley, 1995), although very few have been studied in detail, and their origins, function and integration, within the wider landscape, are poorly understood. However, fieldwalking of transects, within the hinterland of Monte Pallano, is establishing a picture of intensive and changing land use, through the Samnite and Roman periods. It is one such transect, measuring 3km by 1 km, which is the focus of this paper (shown in Figure 1).

The methodology used in fieldwalking, and recording of the material, mainly pottery and tile, is detailed elsewhere (Lock, *et. al.* Forthcoming), and summarised here. Fields (i.e., recording units) are systematically walked at a 10 meter spacing, with a 2 meter collection zone, per person, so that a 20% surface sample is taken. Concentrations of material, identified in the field, are recorded in more detail, including the size and shape of the scatter. The background field data, which this paper discusses, are recorded in a database as sherd counts and weights, and are then converted to densities, for each field, and displayed within the GIS, as colour coded fields. Field boundaries and other spatial data have been digitised, from maps and aerial photographs, so that composite displays, draped onto a DEM, can be used to visualise concentrations of material within the landscape (an example is shown in Figure 2).

Inherent, in this sort of analysis is the need to identify temporal change, and of equal importance, areas of non-change, which are, by implication, continuity. Traditionally, this is usually attempted visually, by the comparison of two pottery distributions, representing two different periods, and it incorporates the assumption, that any emerging patterns represent past social use of the landscape. The problem is that traditional, visual analysis is unable to make explicit, the complexities and subtleties of fieldwalking data. To be able to identify many small areas of gradual change, over a large study area, some kind of quantified approach is needed. Rigorous quantification is implicit, in the recording of sherds as continuous variables (counts and weights), although for spatio-temporal modelling, as used here, the quantification is of a different type.

Comparison depends on the establishment of temporal categories and spatial categories, which, by definition, as categorical variables, are subjective and negotiable. Temporal categories are those of pottery typologies, notoriously variable, with some fine wares being precisely dated, while other areas and periods may depend on coarse wares, with fuzzy ranges, spanning centuries. Considerable discussion has centred on the establishment of spatial categories, especially the concept of 'sites', and its implications for fieldwalking data. Foley (1981) introduced the idea of 'off-site' archaeology, while Gaffney and Tingle (1985) emphasised the importance of the artefact, as the unit of analysis, rather than the site, within micro-regional analysis. The idea of the landscape as a continuum is an attractive one, and it is useful to see concentrations of material as nodes of social action, whatever their size and density. It is often the more subtle 'background' patterning, which poses greater problems for interpretation, rather than the large and obvious concentrations (or 'sites'). Such background may be a spatially widespread, low density of material, perhaps representing scattering, by manuring, or a very localised low density concentration, a possible regular resting place of a shepherd.

The subtlety of these data requires intuitive decisions to be made, about what is background and what is of interest, thus introducing the concept of 'threshholding'. Thresholding is difficult to define, because it is used intuitively in many different ways and different situations, although, at a very simple level, it is concerned with establishing the boundaries, to units of analysis, as part of a wider analytical framework. It is normal in archaeology for such units, or categories, to be decided within an inherently subjective process, based on perception. We need to categorise things before we can count, compare and contrast them. Once a threshold has been established, however, it can be applied objectively, and it is the application, that can give the misleading appearance of overall objectivity. In Image Processing, for example, thresholding is a technique, that is well established, as an apparently objective method of enhancing certain chosen characteristics of an image, as compared to 'background noise', within the image (Pratt, 1978).

The act of establishing and applying thresholds is in much wider use, than just Image Processing. In GIS applications, similar decisions are involved in the selection of class intervals, or thresholds, for the analysis and display of continuously varying data values. Chοropleth maps from a continuous variable, altitude bands from a DEM, for example, or the size of distance buffers around a river or site, involve intuitive decisions, often determined implicitly, rather than objectively. Martin (1996; 149) has described four basic ways of establishing class intervals, which can also be applied to thresholding: *exogenous*, where meaningful thresholds, external to the dataset, are applied, *idiographic*, where thresholds are derived from the data themselves, such as percentiles or standard deviations, as used below, *serial*, regular intervals, not necessarily derived from the data, and *arbitrary*, where thresholds are unrelated to the data, or any external rationale.

The methodology described below involves a flexible, sensitive and exploratory approach to thresholding, which accepts the role of the analyst as interpreter, within a hermeneutic circle of negotiation and re-negotiation with the data (Shanks and Tilley, 1987, 104). Interpretation involves the acceptance or rejection of connections, made between the data and existing preconceptions, and the corresponding plurality of meanings, that can be attached to any data. While this is carried out, within a quantified framework, it is quite different in intent, to the hard quantification of positivist hypothesis testing, which is often based on the notion of objective data with inherent meaning.

Quantifying change and continuity

Thresholding and its application to fieldwalking data is a useful concept, within a wider structured, methodological approach to identifying change and continuity, and that adopted here, is based on Eastman, *et. al.*, (1995). Several of the more complex methods, described therein, have not been applied here, specifically multiple image comparisons, such as Time Series Analysis and Vector Change Analysis. This paper is limited to pairwise comparison, i.e., two images which represent Time 1 and Time 2 (T_1 and T_2), although the same techniques could be applied to a series of images (T_1 to T_n), in steps of two at a time.

The following discussion differentiates between change in quantitative data and qualitative data, with the former being further subdivided, into absolute change and relative change. During the process of this work, the methods were applied to two simulated data sets of different complexity, to gain familiarity in situations, where the expected outcomes were known in advance. For the sake of brevity, these are not presented here, and the applications below are on real data, from the Monte Pallano transect. This uses a simplified sequence, whereby T_1 consists of the combined prehistoric wares of Black Gloss (approx. 300-30BC) and Impasto (approx. 1000-300BC), and T_2, of the Roman Italian Terra Sigillata (approx. 30BC-AD150) and African Red Slip ware (approx. AD150-500).

Counts and weights, for each type of pottery, are converted to densities, per field, and the same value is assigned to each pixel, within a field. The resulting raster images are manipulated, in Idrisi (a cell-based GIS package), and field boundaries are then overlain as vector data.

Absolute change

Because T_1 and T_2 are geo-referenced, the simplest method of identifying change, between the two, is a technique known as Image Differencing, which subtracts the corresponding cells from the two input images, and produces an output image of the differences. Subtracting T_1 from T_2 ($T_2 - T_1$), results in each cell (and, in this application, each field) having either a value of zero, if there is no change, a positive value for positive change (a higher density in T_2 than in T_1) or a negative value for negative change (a lower density in T_2 than in T_1). The simplest way, to display this absolute change, is to re-classify the output image into three categories and colour code accordingly, as shown in Figure 3. The small areas of positive change (higher densities of Roman than Prehistoric pottery), can be seen and compared spatially, with the larger areas of negative change (higher densities of Prehistoric than Roman pottery).

Images of simple absolute change, such as in Figure 3, are acceptable at a level of generalisation, although it is possible to characterise change in more detail. The act of re-classification, as above, involves a sacrifice of information, to facilitate display, so that the quantitative data of individual density values are lumped together, into simple categories. A refinement of this process can be combined, with the notion of thresholding, to produce a more sensitive result. When applied to change, as here, this carries the implication that a certain level of change is significant, and a lower level of change is not, although, of course, no change equals continuity, which is also of interest. It is deciding on these break points, between change and no change, that is not only the definition of thresholding, but also is at the heart of debates, about the analysis of fieldwalking data, 'sites', and off-site interpretations.

Millett (1991) has recognised this problem and suggested an approach, based on ADABS (Abnormal Densities Above Background Scatter). This involves converting absolute counts to a relative scale, so that deviations, from the normally expected quantity, can be identified. Comparing absolute counts for pottery types may be problematic, because the statistical distributions of types can vary greatly, T_1 and T_2 above, for example, have very different ranges (the difference between the lowest and highest count), means, and standard deviations. By adopting a relative measure for comparison, similarities and differences are more obvious and accessible. Millett (*ibid.*) experimented with using the octiles, so that 'sites' were equated with the top eighth of the distribution. The approach, used here, is based on standard deviations.

The same difference image, used in the re-classification above ($T_2 - T_1$), can be re-classified, according to any threshold levels chosen. Assuming that the distribution of the difference values (amount of change) is normal, around a mean of 0.0, then re-classifying the values, that fall within one standard deviation of the mean implies the decision that significant change is restricted to the top and bottom 16% of the values, and the rest is continuity. Choosing a threshold, of two standard deviations, isolates the two, 2.5% extremes as change, accepting a wider definition of continuity. Figures 4 and 5 show the results for one and two standard deviations, respectively highlighting the high levels of continuity, lack of positive change, and concentration of negative change in one area. The actual Sangro results are not the main point here, however, but rather, the flexibility of the method and the inherently interpretative nature of thresholding. There are no strict guidelines to thresholding, although examination of the distribution of pixel values, for the difference image, may suggest sharp breaks that could be equated with change. Re-classifying, at different percentage levels, enables different models of continuity and change to be explored, within a hermeneutic circle of analysis, integrating fieldwalking data with other bodies of evidence.

Relative change

So far, change has been defined by an absolute difference, between counts of two pottery types, or combinations of types, that equate with temporal periods. In certain circumstances, this approach is too crude for the complexities of the data. A very common pottery type may occur in large numbers, while a relatively rare type may carry more interpretative significance, in much smaller numbers. If, for example, there is a widespread absence of a particular type, then any presence of that type, and certainly changes between small counts, may be very significant. In an attempt to be sensitive to the comparison of high counts with low counts, the methodology outlined, so far, can be refined, by working with image ratios, rather than differences, so that the difference image is calculated, by dividing T_2 by T_1 (T_2/T_1). It can be seen below that the ratio differences give weighting to lower counts, as compared to similar, absolute differences:

Count at T_1	Count at T_2	Absolute difference	Ratio difference
5	10	5	2
95	100	5	1.05
495	500	5	1.01

The difference image produced by ratioing, in this way, produces a distribution of values, that is neither symmetric nor linear (Eastman, *et. al.*, 1995, 11). To enable the thresholding techniques, based on standard deviations described above, the difference image needs to be subjected to a logarithmic transformation, to produce an approximated normal distribution. Figure 6 shows the transformed, ratio difference image re-classified into no change, positive, and negative change. Compared to the equivalent, absolute image of Figure 3, there is little difference, although, when thresholding at a single standard deviation is applied, the difference between ratioed and absolute is considerable. Partly due to the characteristics of the normalised distribution, the sensitivity of the ratioing method identifies many more fields with negative change, and also retains some of the positive change (compare Figures 7 and 4).

Qualitative change

The methods described, so far, have been based on quantitative data, in the form of count or weight densities, per field. A different, although complimentary, approach is to reclassify the quantitative data into categories, and then use methods, based on contingency table analysis and cross-tabulation. The data become qualitative, through the process of categorisation, so that a classification into 'low', 'medium', and 'high' density areas carries with it, interpretative implications for suggested pottery use in the past, and formation processes since. Change between the different combinations of categories, for T_1 and T_2, can be identified and compared, through contingency table associations, represented as a crosstabulated, output image.

Starting simply, as with the quantitative methods above, for each of the images T_1 and T_2, a corresponding binary image can be produced, containing only two values for the presence or absence of pottery. Crosstabulation of the binary images gives a spatial representation of change, between T_1 and T_2, utilising the four categories of 'pottery absent in both periods', 'prehistoric pottery present, but not Roman', 'prehistoric pottery absent, but Roman pottery present' and 'pottery present in both periods' (Figure 9). This is very different information on change and continuity, compared to that provided by Figure 3, and shows the complimentary nature of the two methods. Not only are four categories more sensitive than three, but the identification of the absence of pottery is important. A change to or from no pottery, or the continuity of no pottery, can lead to very different interpretations, to those based on the ideas of simple negative or positive change, shown in Figure 3. In extensive areas, devoid of pottery, the smallest amounts can be of significance.

As with the quantitative methods, the qualitative approach can be refined, by the introduction of thresholding. Again, this is subjective and flexible, embedded in the creation of categories, being meaningful within a particular analysis. The example, shown in Figure 10, is based on a 3 by 3 contingency table, giving nine possible categories of change or continuity. The distributions for T_1 and T_2 have been divided, into the three categories of 'no pottery', '1 to 75% of the remaining distribution (the middle)', and 'the top 25% of the distribution'. The amount of detail, in the crosstabulation image, is immediately apparent, with individual fields identified, for each of the nine combinations of categories. Because the categories are ordinal, i.e., there is an inherent ordering from less to more, gradual change is suggested by movement of a single category, whereas more sudden change is implied by movement across two categories; for example, from none to middle is less of a change, than from none to top. Continuity is also defined in more detail, by containing three categories, so that although from none to none is the same, as in Figure 9, the identification of persistent areas of high density, between the two periods, is highlighted, rather than just continuity of any density of pottery.

Because this procedure is based on contingency tables, it is possible to use formal statistical tests of significance, if these are thought to be appropriate for the analysis being performed. Within a cell-based data structure, tests of association, such as Chi-Squared and Cramer's V, will be based on cell counts for each data category. Eastman, *et al.*, (1995, 22) suggest particular importance for the Kappa Index of Agreement, which varies from -1.0 (complete disagreement between T_1 and T_2, i.e., every cell is different) through 0.0 (difference accountable by chance) to $+1.0$ (complete agreement between T_1 and T_2, i.e., every cell is the same), with an overall Kappa value and individual category values being produced. In our view, this introduces an unnecessary formality, and the strength of the procedures, outlined here, lie in the visualisation of spatial patterns of change, through time. These statistical tests involve underlying assumptions about the data, which the complex relationship between field size (number of cells), quantification of sherds, and density may not justify.

Conclusion

The methodology, described above, has been developed within the Sangro Valley Project, as part of a GIS-based structuring, for the collection and analysis of surface, survey data. It may be of wide interest and applicability, because it uses readily available, low cost software, and is based on simple procedures, for identifying and characterising continuity and change, within the data, which are the major concerns of any surface, survey project. It must be emphasised, however, that this is a methodology and not a theoretical framework, within which to explain continuity and change. Moving from patterns in the data to explanation, based on pottery distributions, introduces major questions, which are similar, regardless of how the patterns are identified. The concerns of Millett (1991), regarding how the supply rates of different types of pottery to different geographical areas, and the equality of access to different pottery types, impact on the archaeological record and, hence on the data of fieldwalking, are just as relevant here. The importance of this offering is seen to be in the flexibility and sensitivity of the methodology, in identifying patterns, based on the complimentary approaches of quantitative and qualitative data, and the notion of thresholding, to focus on possible areas of interest.

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Figure 1. A rendered surface model of the Monte Pallano study area, showing the position of the case-study transect (lighter shade). Monte Pallano is the flattened summit of the

hill, and the lake, on the River Sangro, is artificial. The model is produced from contour data, supplied by the Soprintendenza Archeologica Dell'Abruzzo.

Figure 2. The fieldwalked transect, showing changing densities of pottery within field collection units, draped onto a DEM. Note that the regular grid of 'fields' (towards the top right of the image) is an artificial grid, used during the first season of work, before the real field boundaries were digitised.

Figure 3. Simple change between later prehistoric and Roman pottery ($T_2 - T_1$). The differences between absolute counts have been re-classified into 'no change' (i.e., continuity), 'positive change' (more Roman than prehistoric pottery) and 'negative change' (more prehistoric than Roman pottery).

Figure 4. Absolute differences, with thresholding at one standard deviation, thus widening the definition of continuity and isolating greater levels of change.

Figure 5. Absolute differences, with thresholding at two standard deviations.

Figure 6. Ratioed simple change, between later prehistoric and Roman pottery (T_2 / T_1), re-classified into 'no change' (i.e., continuity), 'positive change' (more Roman than prehistoric pottery) or 'negative change' (more prehistoric than Roman pottery). Compare with Figure 3.

Figure 7. Ratioed differences, with thresholding at one standard deviation, thus widening the definition of continuity and isolating greater levels of change. Compare with Figure 4.

Figure 8. Ratioed differences, with thresholding at two standard deviations. Compare with Figure 5.

Figure 9. Using qualitative data. A crosstabulated image, based on presence/absence of pottery in T_1 and T_2, giving four categories of change and continuity.

Figure 10. A crosstabulated image, based on three categories of pottery for T_1 and T_2 giving nine categories of change and continuity (combinations of 'no pottery', '1 to 75% of the remaining distribution', and 'the top 25% of the remaining distribution').