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Time Series and Neural Networks in Archaeological Seriation. An example on early pottery from the Near East

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Abstract

Archaeological Seriation has been a current topic in Quantitative Archaeology. Nowadays, most scholars use Multidimensional Methods (Correspondence Analysis) in order to reduce the dimensionality in a set of data and obtain a uni-dimensional view that is related to chronological ordering. This paper criticizes this view, and proposes a new model based on bi-dimensional statistics (a generalization of hypothesis testing), using Neural Networks to calculate non-linear fittings among a series of observations. A case study on the first pottery evidence from the Near Eastern Late Neolithic (the Tell Halula sequence) will be presented.

1 Defining the problem: early pottery in the Near East

The First Pottery in the Near East appears, once production economy has been consolidated, in totally sedentary societies. Chronologically, the earliest pottery remains should be dated to the period ranging from the 9th. Millennium BP to the beginning of the 8th. They have been identified in sites in Anatolia (Mellaart 1975), the Syrian-Cilician region (Garstang 1953, Braidwood 1960, Contenson 1992), the Balikh Valley (Cauvin 1974, Le Mière 1979, Akkermans 1990, Le Mière & Nieuwenhuisse 1996), Northern Mesopotamia (Le Mière 1986, Campbell 1992) and the Zagros Region (Mortensen 1963). Along the Euphrates valley, however, there are only a very few sites with early pottery production.

Early pottery is a scarce material in all those sites, with little typological diversity, and of coarse manufacture. There are small to middle sized vases, made with non-purified fabrics and great quantity of vegetal inclusions. They are of simple shape such as bowls or hole-mouth jars. The finish is also very simple, mainly coarse pottery but including a few burnished items. Nevertheless in a very short period of time pottery manufacture develops and typological diversity increases, producing regional differences such as the *dark-faced burnished wares* in the Syrian-Cilician Region (Braidwood 1960) or the *Archaic Painted Ware* in the Zagros Region (Mortensen 1963).

In most cases, Early Pottery is analysed as a chronological indicator, and not as a consequence of historical processes. Many archaeologists seem only interested in describing the change in quantities of different kinds of pottery as an indication of time. Sentences like "If there are less than 5 fragments of Type A in this archaeological layer, then the chronology is *XX* " appear in many publications.

Our approach is completely different. We think that the frequencies of different kinds of pottery may or may not be correlated with time. The abundance of pottery is a consequence of some social and economic processes, and some of these processes are positively correlated with time. For instance: the total amount of pottery, the amount of "luxury" (well manufactured) pottery and the degree of typological diversity increases through time. Nevertheless, this correlation is not obvious, because the archaeological record is disturbed. Early pottery remains in the Near East have not been discovered in primary contexts, but as apparently random spreads of discarded material . The archaeological record of early pottery in the Near East consists mainly of sherds. They are not the result of *in situ* fragmentation, that is, we do not have broken vessels, but accumulations of unconnected sherds. The most obvious explanation for the formation process of those accumulations of sherds is cleaning and rubbish. Consequently, we cannot propose a correlation about pottery production/consumption and time, but we should limit ourselves to correlate time with rubbish formation. Rubbish is the result of some social actions, which are indirectly linked with production and consumption. Therefore we can assume that any change in the nature of rubbish is related with changes in consumption (there is an increase of refuse material from most commonly used pottery), which are also related with changes in productive systems (technology) and social demand.

As a result, any inference about correlation between frequency and time should take into account the influence of depositional, post-depositional and archaeological sampling.

We have developed some methods, although not entirely new, to deal with this problem. Our objective is not to offer an explanation of how pottery was invented, but to discover the *degree* of correlation between time and frequency, and inconsistencies derived from the nature of the archaeological data and the sampling procedure used. We do not pretend to obtain "definitive" solutions, but to consider some of the factors that may prevent archaeologists from making "simple" correlations between time and the archaeological record.

In this paper we offer a methodological approach to the reliability of correlations between time and the quantity of pottery. The data analysed come from the Tell Halula Site.

This archaeological site, located at the middle Euphrates valley, is being excavated by the Syrian Spanish Archaeological Expedition (Molist et al., 1996). This site provides continuous occupation from the Middle Pre-Pottery Neolithic B Phase (PPNB) until the end of historical phases on the first half of 7th. Millennium BP (8700 BP and 7400 BP). Detailed analyses of each archaeological and historical phase have been carried out. They allow the observation of a continuous cultural evolution, and of the origins of significant transformations, like animal domestication, the first pottery production, changes in raw material exploitation and distribution, and the even more complex structuring and use of space and the associated architectural structures.

In this site early pottery appears from Late Neolithic levels. Chronologically, those pottery remains are among the oldest in the Euphrates valley. We have only processed information from the layers with pottery.

There is not a General Typological Framework to describe Near Eastern early pottery production. Consequently, we have adapted the descriptive-morphological features used by other archaeologists (Braidwood 1960, Akkermans & Le Mière 1992, Campbell 1992) to describe the same type of early pottery in the sites excavated by them:

T1: THICK COARSE SIMPLE WARE (with vegetal inclusions)

T3: BURNISHED THICK COARSE WARE (with vegetal inclusions)

T5: PATTERN BURNISHED COARSE WARE (with vegetal inclusions)

T6: SLIPPED COARSE WARE (with vegetal inclusions)

T7: SLIPPED BURNISHED COARSE WARE (with vegetal inclusions)

T8: COARSE IMPRESSED AND INCISED WARE (with vegetal inclusions)

T9: EARLY COARSE PAINTED WARE (with vegetal inclusions)

T11: UNBURNISHED FINE WARE (with mineral inclusions)

T12: BURNISHED FINE WARE (with mineral inclusions)

T13: PATTERN BURNISHED FINE WARE (with mineral inclusions)

T14: SLIPPED FINE WARE (with mineral inclusions)

T15: SLIPPED BURNISHED FINE WARE (with mineral inclusions)

T16: DARK-FACED BURNISHED WARE (with mineral inclusions)

T19: GREY BLACK WARE (with mineral inclusions)

T20: BLACK WARE (with thick mineral inclusions)

T23: FINE PAINTED WARE (with mineral inclusions)

T24: UNBURNISHED FINE-COARSE WARE (with mineral inclusions)

T27: FINE IMPRESSED AND INCISED WARE (with mineral inclusions)

2 A seriation analysis of depositional units with pottery.

We have begun our analysis by ordering the quantity of different kinds of pottery in stratigraphical order. The main goal is to study whether changes in the quantity of different kinds of pottery are correlated with changes in the stratigraphic order. There were 161 depositional units and more than 7000 pottery sherds in all these units. A depositional unit is exactly the same as an occupation floor. In Tell Halula pottery *always* appears outside occupation floors. We do not have information about primary deposition, but accumulations of rubbish material (sherds) as a result of cleaning practices carried out in the neolithic houses. The materials do not appear concentrated in rubbish pits, but as random spread in areas without walls or architectural structures.

The initial assumption was that quantity of unconnected sherds in a depositional unit was a consequence of the number, and the nature and diversity of cleaning practices performed at this occupation floor. We are not interested in studying each deposition isolated, but in determining the general tendency of rubbish accumulation spread over the site. That is, to determine whether there were changes in the quantity of accumulated material through time, and if those changes were related with transformation in social practices and economy

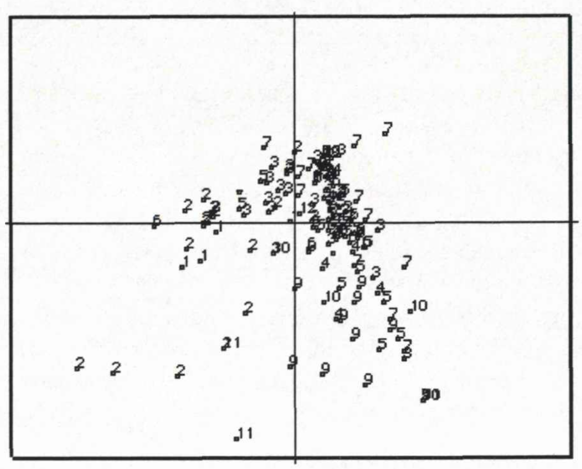

Figure 1. Correspondence Analysis of occupation floors in Tell Halula

Correspondence Analysis (fig. 1) showed that there was no Seriation Structure in the data. This seemed at first sight a contradictory result in view of the archaeologists' assumptions that the most recent depositional units had more sherds than the oldest ones. Global inertia is low (0.2778 the first component, 0.1382 the second one, 0.0961 the third, 0.0837 the fourth, etc.).However this result was expected. In standard seriation studies, the assumption is made that the total number of objects found is assumed to be a function of the total number of people who used them at any given time.

However, the frequency of the observed objects reflects the frequency of production, *only if enough objects have been found.*

It is evident that the main assumption of seriation analysis does not apply in this case, for two reasons:

1. depositional units have very different sizes and shapes, and most of them have not been recorded in the same way. The excavation of some of them was incomplete.
2. frequencies have been estimated using sherd count, and not vessel count. The number of sherds is hardly an adequate estimation of the original quantities. However, we are not interested in estimating the quantity of whole vessels in each occupation floor, but the quantity of rubbish, and it may be estimated using the number of sherds.

These problems in the nature of the data do not prevent the existence of a correlation between time and quantity of pottery, only the interpretation of Correspondence Analysis. The difficulty is that there are many sources of variation in the data series (not only "time"). *Sampling* may be one source, but the social and economic process that caused the accumulation of rubbish are another. There are differences among deposition units, but these differences are not related with the amount of pottery they originally had. They are a consequence of the process that broke pottery and created a variable accumulation of sherds. It is important to realize that the socio-economic process of rubbish formation is temporally very slow. Rubbish accumulations are not formed in a single moment as a consequence of a single action, but they grow with time, as a result of an accumulation of depositional actions.

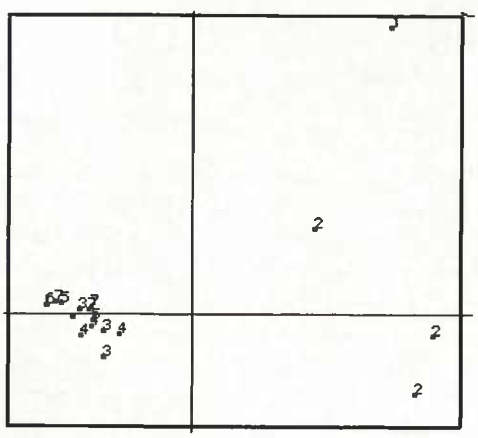

Figure 2. Correspondence Analysis of occupation floors with more than 30 sherds of pottery (numbers in the figure represent the stratigraphic order of each deposition unit in the sequence)

The effects of sampling in the seriation are clearly seen if we select from the original 161 depositional units with pottery, those with more than 30 sherds. The original distribution of 161 depositional units is significantly non normal, but if we reduce the data to units with more than 30 sherds and select the most frequent type of pottery *-Thick Coarse Simple Ware-* the resulting distribution is significantly normal (Lilliefors probability = 0.247). Selections of units with more than 15 sherds produced non-normal distributions, too. A Correspondence Analysis of those 18 deposition units with more than 30 sherds (Fig. 2) shows more sound results.

Global inertia is higher than in the other case (0.54 for the first component, 0.13 for the second one, 0.12 for the third,...). It is easy to see that there is a strong correlation (although characteristically non linear) between the seriation of frequencies and the stratigraphic order.

In other words, there is some kind of regularity in the changing pattern of rubbish accumulation along the period.

This "regularity" or serial structure was hidden when we considered all depositional units, that is, the pattern cannot be seen when we include occupation floors in which sherds have been accumulated randomly. A few sherds may have been spread by an enormous quantity of processes. "Random" means here "indeterminate". Nevertheless, when more than 30 sherds appear in an occupation floor, the "indeterminacy" decreases, and it is easier to determine which socio-economic process produced that accumulation. A comparison of those socio-economic processes is only possible in cases with a low degree of indeterminacy.

3 Statistical analysis of stratigraphic sequence

3.1. Finding order in the stratigraphic sequence of depositional units

Our data are a typical example of *longitudinal investigation,* that is a repeated measurement of a given phenomenon ("the quantity and diversity of pottery rubbish") over time (Frederiksen and Rotondo 1979, Mccleary and Welsh 1992, Mcdowell et al.1980). In our case *time* is represented by *stratigraphic order.* We will deal further with problems derived from this fact.

If we consider that the system we are studying is the formation of pottery accumulations (the social formation of rubbish), it is obvious that this process is not completely static or unchanging. The possible kinds of change can range from cyclical or periodic change in which the quantity and diversity of rubbish accumulations return to prior states of accumulation, or formation processes that develop, grow, decline, or in other ways exhibit changes that permanently alter the characteristics of the accumulation. Consequently, an important problem in our study is to demonstrate that there is some correlation between the quantity of pottery and time (or stratigraphic order in this case); the quantity of different kinds of pottery should exhibit a periodic pattern of change, growth and development. This problem involves investigating the *stationarity* of the stratigraphic series, that is, the existence of linear or non-linear trends in the sequence.

However, the stationarity, lack of stationarity or discontinuities associated with this pattern of change are not only a consequence of a social process correlated with time, but the result of sampling or the specificity of some depositional units. For instance, a discontinuity in any point, may be explained as a "temporal" change in the social process that produced rubbish, or as an individual property of that depositional unit, where rubbish was accumulated differentially due to a different function, a different post-depositional process (preservation) or a different sampling procedure.

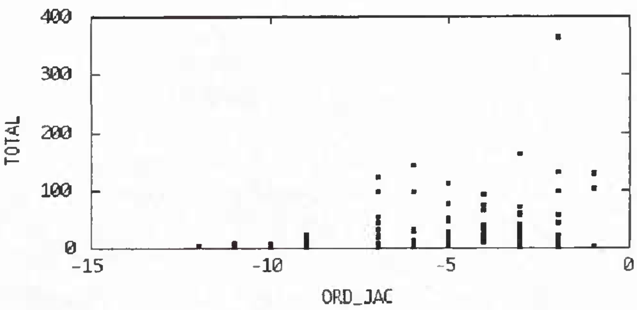

Figure 3. A dot plot of stratigraphic sequence quantity of pottery

These plots allow the study of a social action (deposition of rubbish) whose behaviour at any point in the stratigraphic sequence is governed by possibly non-deterministic rules. However, archaeological data are not homogeneous. In each time phase there are a number of different occupation floors with pottery, and it appears that the quantity of pottery in contemporaneous occupation floors is different. In spite of the these differences, it may be possible to calculate a general tendency (pattern) in the data: it seems that the quantity of pottery grows through time. This tendency is not linear, however. Although at the beginning of the series all occupational floors have very few sherds of pottery or nothing at all, at the end of the series (late phases), there are occupation floors with pottery and others without pottery. The better explanation for this fact is that the nature of accumulation (and not only *quantity*) changes with time. Not only frequency increases, but also the variability of depositional process. At the beginning (the origins of pottery), pottery is scarce and rubbish is spread randomly; at the end of the sequence (once pottery manufacture and use is consolidated), there are a lot of vessels in circulation; rubbish is not produced by a series of random actions of discard, but as a result of specific processes that are different in different occupational floors. Rubbish accumulation becomes specialised and spatialized.

If we need to analyse the correlation between quantity of pottery and time, then we should take into account, that the process of rubbish accumulation is not homogeneous during the whole period, and that rubbish formation processes at the beginning of the sequence are not comparable to formation processes at the end of the series. Nevertheless, we may interpolate a line that *resumes* only that part of the variability that is correlated with time. This line is what we call its *path* or *trajectory*.

Using the classical distinction between population and sample, each point in the plot (the frequency of pottery *X* in depositional unit *Y*) represents a statistical population, and each depositional unit is a sample produced by a stochastic process. The analysis pretends to build a model of the stochastic process that produced the observed series. Following Wold's theorem, this process may be represented by the following expression:

DATA = DETERMINISTIC COMP. + STOCHASTIC COMP. + RANDOM COMP.

The theorem states that a temporal process may be modelled as the sum of two independent processes: the first is totally *deterministic* and the other is characteristically *non deterministic* (also called *stochastic* or *probabilistic*). The objective of the analysis will be to decompose the series variance in deterministic components and stochastic ones. The deterministic component reflects consistent effects through time, and it includes other kinds of systematic variation:

1. SECULAR VARIATION or *trend*, which represents the general orientation followed by the series of samples through time
2. SEASONAL VARIATION *or cycles*, which represents fluctuations of trend at periodic intervals

The stochastic component reflects the effects of *serial dependency*. In a time series it is not evident that the value of a variable in a specific time point is independent of the values this variable has had before or will have thereafter. We call *serial dependency* this property of temporal series: the degree of dependence between contiguous points in a sequence (Mcdowall et al., 1980, Uriel 1985).

In our case, the *deterministic* component is the part of total variance explained only by time; the *stochastic* component is the part of total variance explained by sampling and individual properties (depositional, post-depositional) of depositional units.

Trend (the deterministic component) may be detected investigating non-stationarity of mean and variance in the series, that is, whether both indexes increase (or decrease) through time. In our case it is easy to see that the mean and variance of pottery in different occupation floors is not constant, but changes are not uniform. We may be forced to think that there is no *linear trend* in the series, but stochastic or random variation among the quantity of pottery rubbish accumulated in different places through time.

In order to eliminate the disturbing effects of sampling differences, we have added all depositional units belonging to a same archaeological layer. A layer has been defined by the Tell Halula archaeologists as a relevant change in architecture, a new building or a modification in a former building. Depositional units (pits, occupation floors, activity areas, hearth, outside courts, etc.) are always related with houses, consequently, the rebuilding of the house, or the construction of a new one constitutes a significant change in the temporal sequence. Addition of depositional units in archaeological layers allows the elimination of effects due to the different nature of the depositional process - rubbish accumulated in a hearth is not the same as the material dispersed on an outside court.

The period in which pottery appears has been divided in Tell Halula into 19 building/rebuilding levels; therefore, the 161 depositional units have been grouped into 19 occupation phases. This transformation of data changes slightly our working hypothesis. We are not comparing rubbish accumulated in occupation floors, but the total amount of rubbish accumulated in a time period of undetermined duration (stratigraphic layer). We want to discover whether the quantity and diversity of pottery rubbish is correlated with time. The spatialisation of rubbish formation process during the later phases prevents a deeper correlation. We know already that rubbish is accumulated differently in early phases than in later ones, and that difference is based on spatial differences. But, are there other differences to add to this one? Is the *quantity* and *diversity* of pottery different in early phases than in later ones? When did this difference begin ?

3.2 A seriation analysis of archaeological layers

As in previous cases, a Correspondence Analysis of archaeological layers (Fig. 4) shows no serial structure, although inertia is relatively high (0.52 the first component, 0.15 the second one, 0.12 the third,...). The only thing we may say is that the last period (No. 12) is significantly different from the rest.

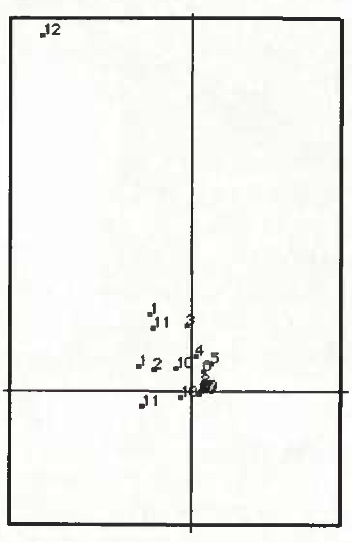

Figure 4. Correspondence Analysis of Archaeological layers. Numbers represent the stratigraphic order of each layer. Although there are 19 layers, they come from 3 different sectors, and there are temporal simultenities between them. Two contemporaneous layers from different excavation sectors have been represented using the same order number.

Why does the archaeological layer seriation lack any serial structure? The frequency of different pottery types in each layer is a result of the quantity of pottery accumulated in all contemporaneous occupation floors, and probably not all depositional units belonging to a single layer have been recovered. *Sampling* is again a source of variation. Another source of irregular variation may be the inclusion of three different, non-contiguous, sectors of the site: Sector 1, Sector 7 and Sector 14, separated by approximately 350 meters. The formation process of rubbish accumulation and spread may have been different in each one.

According to the theory of Serial Analysis, what we call in archaeology *seriation* is in fact a *deterministic trend.* And there is nearly always some degree of deterministic trend. Our case is not an exception, but we cannot observe it, because it is hidden by sampling differences in the data. Our purpose will be, then to *extract* this deterministic component, as if *sampling* differences and error introduced by spatial differences among sectors were the source of random noise.

Furthermore, if the trend shows an increase through time, and the most recent layers have been excavated with more detail and extension that the oldest, then this trend would be the result of differential excavation. But this is not the case. A previous study on the extension of depositional units (Saña 1997) has demonstrated that their size is not correlated with stratigraphic order. Therefore, we are sure that the quantity of pottery is not related to the size of depositional units or the excavated area.

3.3 Discovering "trend" in the stratigraphic sequence.

The analysis of trends and cycles is a descriptive enterprise at its best. The problem with many such analysis, however, is that even basic questions about trend are assumed rather than proven, and that such interpretations seem too readily accepted as a fact. We cannot assume trends by visually examining peaks and valleys in the data. Only statistical analysis can answer whether observed trends are significant or not (Mccleary and Welsh 1992), and the presence of outliers in these data make any visual interpretation questionable.

Smoothing techniques are a simple approach to uncover patterns in data with a minimum of preconceptions and assumptions as to what hidden patterns may be (Goodall 1990, Freixa et al., 1992. Without any assumption at all, the possibilities are too broad. The user of smoothing techniques assumes that the most useful relationships between the variables are smooth: an almost continuous curve or surface that does not jiggle too rapidly and may include a small number of steps or transitions.

The goal of smoothing is to separate the data into a smooth component and a rough component:

DATA = SMOOTH + ROUGH

The *Rough* should contain as little structure as possible. In our case, the percentage of total variance explained by the rough component is greater that the percentage explained by the smooth component, but the latter is a real model of deterministic temporal variation in the stratigraphic order. Its relevance as a source of variation was originally greater, but it has been reduced because we are not analysing primary data, but samples ordered stratigraphically.

This is not the proper place to elaborate a theory of smoothing in statistics (See Goodall 1990, Cleveland 1993, among others, or the more technical works by Kitagawa and Gersch 1996, Györfi et al., 1989, Müller 1988). There are many different techniques for smoothing a data series, and each one has its advantages and disadvantages. Fig. 5a,b,c compares some different smoothing functions on different types of pottery from Sector 7.

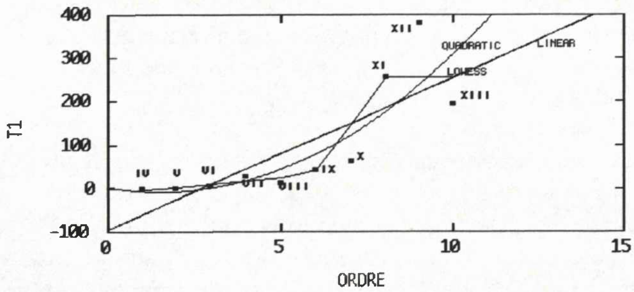

Figure 5a. Thick Coarse Simple Ware. Roman numerals represent stratigraphic order. Lines represent three different smoothing techniques (linear, non-linear quadratic, non-linear Loess coefficient).

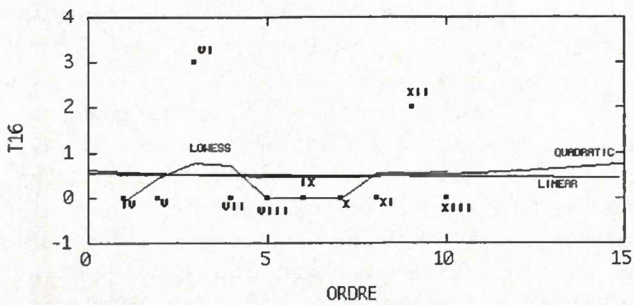

Figure 5b. Dark-faced Burnished Ware. Roman numerals represent stratigraphic order. Lines represent three different smoothing techniques (linear, non-linear quadratic, non-linear Loess coefficient).

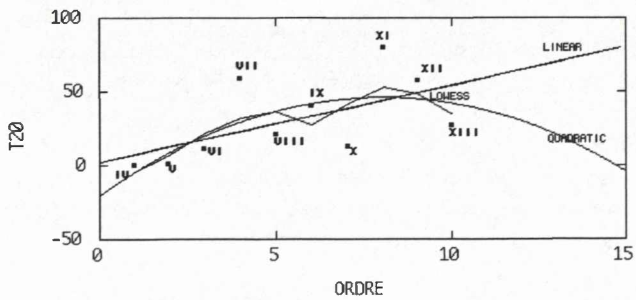

Figure 5c. Black series with thick mineral inclusions. Roman numerals represent stratigraphic order. Lines represent three different smoothing techniques (linear, non-linear quadratic, non-linear Loess coefficient).

The main distinction is between non-linear smoothing and linear interpolation. Smoothing is also a technique of curve fitting, but whereas linear interpolation calculates a *global* trend, *smoothing* makes a revision at each point, based on observations in the neighbourhood of this point. As a result, we obtain a calculation of *local* trends.

Cleveland and McGill (Cleveland & Mcgill 1984) advocated the smoothing of scatterplots to assist in detecting the shape of the point cloud in situations where the error in the data is substantial, or where the density of points changes along the abscissa. However, other authors have stressed doubts on the benefits of the technique (Spence and Lewandowsky 1990), because it is unclear what is being estimated when these smoothing functions are fitted. No well-defined parametric function is employed, and the use of different, arbitrary fitting procedures could easily yield markedly dissimilar functions. This criticism is especially relevant in our case. If we determine the existence of a trend in our data, should we conclude that we have discovered a *source of variation related to time*? First of all, smoothing does not *always* discover a trend. In some cases, we have obtained a horizontal line as the smoothing result (Fig. 5b), showing an absence of correlation between the variable under question and time.

What are the results we have obtained so far? First of all it is clear that parametric interpolation (linear and non linear - quadratic) do not produce reliable information, that is to say, the regression line does not properly *represent* the data points. The *loess* function produces far better results. If the underlying pattern in the seriation of archaeological layers with pottery were simple, parametric fitting would be enough (in terms of fitting to raw data). But this is not the case, because of sampling differences and the use of an incorrect frequency estimator. There is a pattern underlying the data, but it is too complex to be represented by a parametric function. The *loess* function follows the original data more precisely.

The name *loess* is short for *local regression* (see a more detailed presentation of this method in Cleveland 1993). Two parameters need to be chosen to fit a loess curve. the first parameter, a, is a smoothing parameter; it can be any positive number (in our case it is 0.5). As a increases, the curve becomes smoother. The second parameter, l, is the degree of certain polynomials that are fitted by the method. In our case, l = 2.

The observations are assigned *neighbourhood weights* using a weight function, calculated as the normal distribution around a centroid (number of observations multiplied by the parameter a). The weight function has a maximum at the centroid, decreases (normally) as we move away from this value, and becomes zero. The observations whose x_i lie closest to the centroid receive the largest weight, and observations further away receive less. A line is fitted to the data using weighted least-squares with weight $w_i(x)$ at (x_i, y_i). The $w_i(x)$ determine the influence that each (x_i, y_i) has on the fitting of the line. The influence decreases as x_i increases in distance from x, and finally becomes zero. The loess fit is the value of the line at x. A loess fit is displayed by evaluating it a grid of equally spaced values from the minimum value of the x_i to the maximum, and then connecting these evaluated points by line segments.

Of course, loess fitting does not explain all the variation in the data, but only the proportion of variance correlated with stratigraphic order, and this proportion is very low. Fig. 6a,b shows the residuals of some fittings, that is, the difference between original data and smoothed data (loess function).

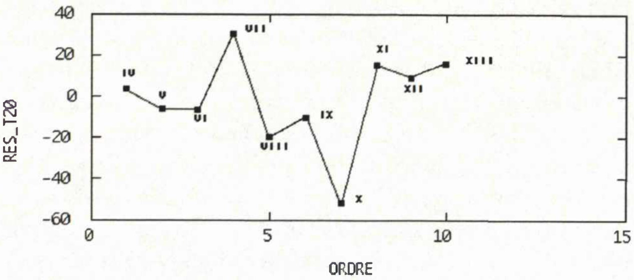

Figure 6b. Residuals for variable: Black Series with Thick Mineral Inclusions

These two plots show that there is a considerable amount of regularity in the residuals, meaning that smoothing has not deleted all existing trend. What is worst, there is already some regularity correlated with stratigraphic order. The difference between original and smoothed data increases until the 10th layer, which coincides with the increasing of quantity in original data. In other words, residuals grow as the quantity in pottery in each layer grows. This fact may be explained in historical terms, since as pottery becomes more frequent, rubbish accumulation becomes more spatialised, and variability in a single archaeological layer increases. Given that the smoothing function is an estimation of the central tendency of the series, any increase in variability or any reduction in serial dependence causes an increase in the residuals.

In other words, the smoothed function does not provide a good fit to the data, except in some parts of the series. Fig. 6a shows a linear ordering of residuals around zero for the first 6 phases. This fact coincides with the archaeological interpretation (Faura 1996) that during the first centuries early pottery is accumulated in very low quantities, and this is specially the case for the "Thick Coarse Simple Wares" Series. However, in other cases ("Black Wares with Thick Mineral Inclusions" Series) non-random irregularities in residual distributions occur, even for the first (ancient) part of the series. According to the archaeological analysis (Faura 1996) this is produced because the Black series is a chronologically fixed production, that begins production very early in the historical sequence, reaches a climax during phase 7th., and decreases in popularity thereafter, disappearing at the end of the sequence.

An analysis of Sector 7 is not enough to discover trend, because later occupation floors do not appear there, but in Sector 14 and Sector 1. Fig. 7 shows the existence of a general linear trend for the three layers from S14, and a great heterogeneity for layers from Sector 1.

In this case we have a good example of bad fitting, or lack of correlation between the quantity of pottery and the stratigraphic sequence. The smoothed function is very well fitted to Sector 7 data (points without label in the plot), and relatively well to data from sector 1; but the function is not able to integrate information from sector 14. But even when the function does not fit, there is a lot of archaeological information that allows a partial testing of the archaeological hypothesis (cf. Faura 1996). We are not saying that there was more pottery in certain phases of Tell Halula site than in the others, but that rubbish was accumulated differentially in time and space. There is an increase in rubbish accumulation of Thick Coarse Simple Wares at the end of Sector 7 sequence, and this increase coincides with the linear increase of sherds accumulated in Sector 14. The quantities are different, but the trend is the same

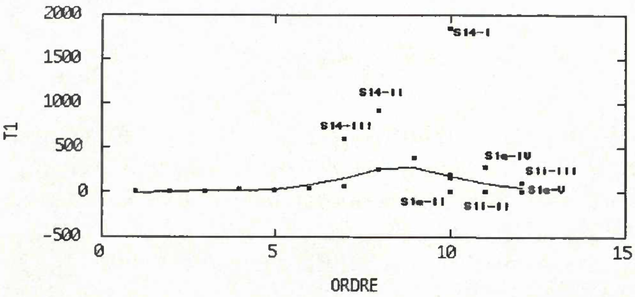

Figure 7. Thick Coarse Simple Ware Series. Smoothed function of all layers from Sector 1, Sector 7 (see the number of layers in previous figures), and Sector 14. Ordering of layers follow archaeological information about simultaneities among different sectors

Burnished Thick Coarse wares evolve in a different way. There is not a bell-shaped smoothed function, but an asymmetric increase, showing that there is more rubbish accumulated at the end of the sequence that at the beginning. (Fig. 8).

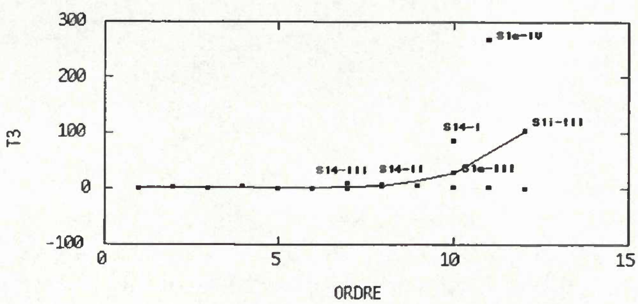

Figure 8. Burnished Thick Coarse Ware Series. Smoothed function of all layers from Sector 1, Sector 7 (see the number of layers in previous figures), and Sector 14. Ordering of layers follow archaeological information about simultaneities among different sectors

Fitting is better than in previous case, but it is not very good for data from sector 1. The smoothed function follows exactly the stratigraphic evolution for sector 1 and 14, and tests again the archaeological hypothesis (Faura 1996), but it neglects some layers from sector 1, those without pottery. This is a very good example of the ability of the method to find the best possible solution. The Smoothed function allows the discovery of an increase of rubbish of this kind of pottery accumulated at the end of the sequence, although this rubbish was concentrated spatially. The same fitting has been discovered for the Coarse Impressed, Incised and Painted Wares, and for the *Dark-faced Burnished Ware* (Fig. 9). In this latter case, the smoothed function has a lack of fit in a point at the beginning of the sequence (Sector 7th Phase VI). The function ignores the fact that during this phase a sudden increase in rubbish from this kind of pottery was produced.

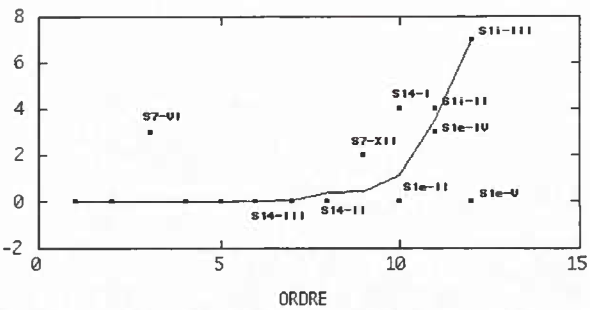

Figure 9. Dark-faced Burnished Ware. Smoothed function of all layers from Sector 1, Sector 7 (see the number of layers in previous figures), and Sector 14. Ordering of layers follow archaeological information about simultaneities among different sectors

In the following case (Fig. 10), the explanation is the same - an increase in rubbish accumulation at the end of the sequence, but the smoothed function makes a great mistake, calculating erroneously a decrease in quantity (belly-shaped curve). Spatialisation is here more accentuated than in the other case, and this fact produces the lack of fitting.

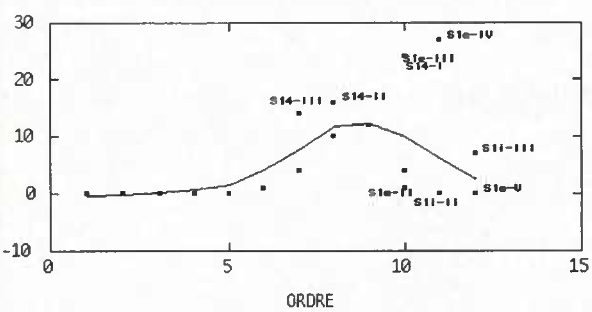

Figure 10. Slipped Coarse Ware. Smoothed function of all layers from Sector 1, Sector 7 (see the number of layers in previous figures), and Sector 14. Ordering of layers follow archaeological information about simultaneities among different sectors

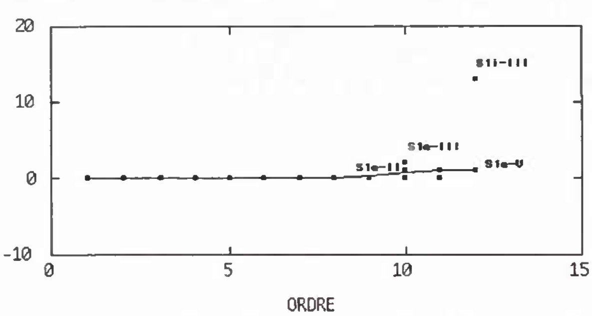

Figure 11. Grey Black Ware. Smoothed function of all layers from Sector 1, Sector 7 (see the number of layers in previous figures), and Sector 14. Ordering of layers follow archaeological information about simultaneities among different sectors

The Fine Impressed, Incised and Painted ware Series and the Grey Black Ware Series are another example of bad fitting (Fig. 11). Here smoothed function shows an absolute lack of correlation quantity/stratigraphic ordering, even when there is an statistically significant increase of quantity at the end of the sequence (Phase III at Sector 1i).The Series for Black Wares with Thick Mineral Inclusions is much more intriguing (Fig. 12). At first sight, it seems to show a typical lack of fit between the smoothed function and the raw data, as if the function was not able to calculate the degree of spatialisation at the end of the sequence. Nevertheless, a closer inspection of the plot, shows a better coincidence with the archaeological hypotheses (this ware is characteristic of the early part of the sequence, and its quantity decrease at the end, cf. Faura 1996). The function fits very well with the data from Sector 7 and Sector 1, showing that there is no change in the spatial accumulation of rubbish during late phases. The problem is the same as we saw with the Thick Coarse Simple Ware Series: the accumulation of this kind of rubbish is different in Sector 14. In this case, not only the quantity of sherds accumulated, but also the trend, because the linear cumulative trend in Sector 14 is completely different to the belly-shaped (and in this case it is not a bad fitting) curve fitted to Sector 7 and Sector 1.

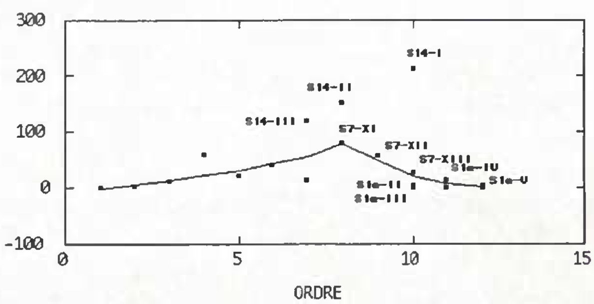

Figure 12. Black Wares with Thick Mineral Inclusions. Smoothed function of all layers from Sector 1, Sector 7 (see the number of layers in previous figures), and Sector 14. Ordering of layers follow archaeological information about simultaneities among different sectors

The series for Unburnished Fine-Coarse Ware (Fig. 13) shows a much better fit. In this type of pottery, rubbish accumulation in Sector 14 is not statistically different from that in the other Sectors of the site.

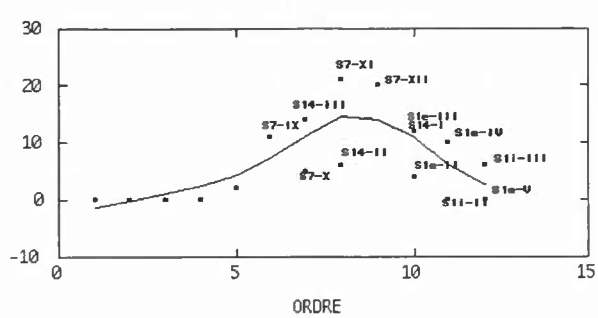

Figure 13. Unburnished Fine-Coarse Ware. Smoothed

function of all layers from Sector 1, Sector 7 (see the number of layers in previous figures), and Sector 14. Ordering of layers follow archaeological information about simultaneities among different sectors

To sum up, what appears as a result is an increasing of variability in rubbish spread at the end of the sequence. For the majority of pottery types we may infer three different "historical" stages: a *formation* period, where pottery is scarce and rubbish spread seems random (until S7-IX/S7-X); a second period (S7-XI, S7-XII, S7-XIII, S14-IIII, S14-II) where the quantity of pottery increases, but rubbish formation do not change (linear increase of frequencies), and finally, a third period (S14-I, S1 all layers) where frequencies increase and rubbish formation changes from a random to a non-random pattern, beginning a spatialisation of the social actions producing rubbish. These statistical results coincide with archaeological hypotheses (Faura 1996).

Nevertheless if this is the general trend for the *majority* of pottery types, it is not the trend for *all* types. *Thick Coarse, Unburnished Fine and Coarse, and Black Wares* have a distinctive trend, characterised by a decline in frequency during the third period, and reaching a peak during the second one. Variability of rubbish spread maintains the same tendency throughout the sequence; there are two peaks at S7-VI and S7-VII that are ignored by the smoothing function, because there is no serial dependency with values in neighbouring time-points.

An historical explanation would be that during the third period, the moment of consolidation of pottery manufacture and use, new types appear that substitute the older ones. Old vessels are being broken due to their use, and they become slowly part of rubbish. As the old types are substituted by new types, better manufactured or more suitable for their new uses, their circulation decreases and their proportion in rubbish accumulations (directly related with the quantity of vessels in use) decreases too, until they disappear.

4 The reliability of the chrono-stratigraphic sequence

Up to now we have been analysing stratigraphic order *as if* it were an analogue of temporal order. However, this assumption is mostly wrong. Although seriation order is the same, stratigraphic order assumes the same longitude for all time intervals; for instance, archaeological layer 1 should have the same duration than archaeological layer 2. Sometimes archaeologists introduce correction factors, such as the depth of the archaeological layer, assuming that deeper layers take more time to accumulate.

Fig. 14 shows a seriation by Correspondence Analysis of smoothed values for S7 layers. Here, the distance between contiguous layers is not homogeneous. Some authors have used this pattern to infer the existence of temporal intervals of different duration between archaeological layers. Using this assumption, the period of time from S7-IV to S7-VII would be much longer than the period of time between S7-VII and S7-XII, or the period between S7-XII and S7-XIII.

These results are exactly compatible with those obtained through chronological analysis (Faura 1996). The distance between S7-IV and S7-V should be of ca. 300 years, between S7-V and S7-VI 200, between S7-VI and S7-VII 200, between S7-VII and S7-XII 200. There is no statistically significant difference between S7-VII, S7-VIII, S7-IX, S7-X, S7-XI, S7-XII, because differences less than 100 years are hardly noticeable in the archaeological record, and they cannot be measured using calibrated C14. The distance between S7-XII and S7-XIII is, again, ca. 200 years. What does it mean in historical terms? That the few rubbish sherds accumulated in earlier phases take more time to accumulate than the greater quantities of rubbish of later phases. At the end of the sequence (from 6250 BC and later) more quantities of pottery were broken, and their sherds accumulated in less time than in earlier times.

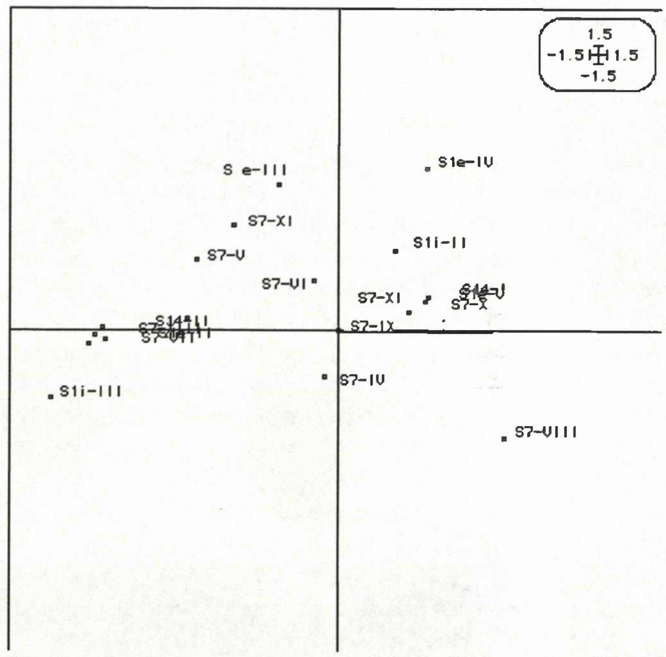

Figure 14. Correspondence Analysis of Smoothed Values for all types of pottery in Sector 7

In other words, seriation analysis of stratigraphic order provides consistent results with temporal scale (as far as we know it). It is important to realise that this correlation quantity of accumulated pottery/temporal order exists only for the Sector 7 sequence and with smoothed values. Remember that the loess function fitted Sector 7 data better than Sector 1 and Sector 14 data. Seriation analysis has also proved that rubbish was accumulated in Sector 14 in a different way, because occupation floors in the sectors were different, and different social actions were performed on them. The same is true for Sector 1 (1e and 1i), where *spatialisation* is more evident as a source of variation, and where the time of layer formation was much shorter than in other sectors (depositional history is also different).

We have tried to test this chronological and historical hypothesis using radiocarbon dates. Six radiocarbon dates are available for the early pottery series in Tell Halula (see Faura 1996, Molist et al. 1996, Saña 1997) (Fig. 15).

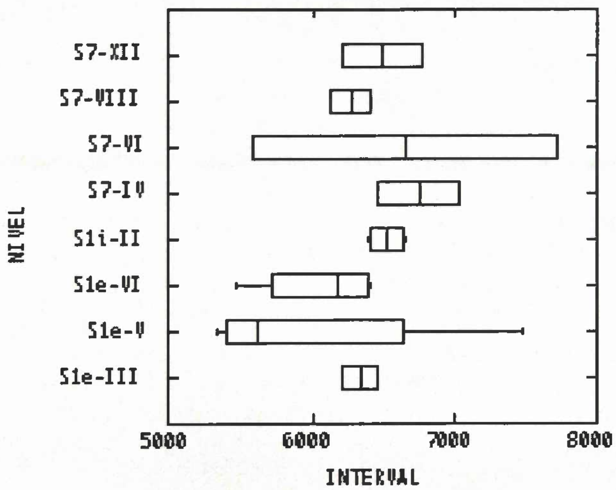

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Figure 15. Calibration intervals for C14 dates from Tell-Halula (using CALIB 3.0)

Radiocarbon dates are bad candidates for temporal seriation, because they cannot be represented as fixed points, but as intervals. We have used CALIB 3.0 to compute the 2sigma intervals. These dates produce some inconsistencies with archaeological results, especially in S1, whose radiocarbon chronology seems much older than the date expected by archaeologists. Even in the simpler S7 seriation, there are some problems, as the uncertainty of S7-VI (a layer that produced more than a surprise in the frequencies of pottery), and the inverse values for S7-VIII (stratigraphically older) and S7-XII (stratigraphically one of the most recent in this sector).

We have tried to extract some pattern from these overlappings, trying to eliminate intervals that are statistically two long or with less relevance. These calculations have been carried out using a neural network with the following data:

LEVEL	DATE	Total Quantity of Pottery
S7-iv	7034	5
S7-iv	6465	5
S7-vi	7727	25
S7-vi	5596	25
S7-viii	6415	35
S7-viii	6119	35
S7-xii	6779	539
S7-xii	6200	539

This table has been processed through the Neural Network, following this input-output schema:

INPUT VECTOR	MIDDLE LAYER	OUTPUT VECTOR

Year	Hidden Unit 1	Quantity of Pottery
	Hidden Unit 2	

The input unit contains "time" values (transformed into a 0/1 scale, that is, 6200 is represented as 0.6200) and the output unit contains frequencies (also transformed). We have used back-propagation to learn this network (cf. Barcelo 1993, Caudill and Butler 1992, Rogers and Vemuri 1994, Zirili 1997, Masters 1995).

Seriation results for the total quantity of pottery, after 15000 iterations, are very bad. The Neural Network has learnt correctly the negative correlation between time (negative values because we are in BC years) and quantity of pottery, but it has not been able to learn the correct values. The beginning of the series (5 sherds at -7034) is totally different according to the model generalised by the network. It is obviously wrong to place a quantity of 140 sherds of pottery at the 9000 BC!

Although the method is sound, and it has been used with success in other domains (see Rogers and Vemuri 1994, Zirili 1997, Masters 1995), in our case, predicted values are too bad, and contradictions too important. The neural network can never learn correct values if the input contains contradictory information like: in the year 6200 BC there can be 25, 35 or 539 sherds. There is nothing wrong in using neural networks with C14 intervals, but not in this case, because we do not have enough data to eliminate contradictions. If we had more than 30 calibrated dates, calculations would be more significant.

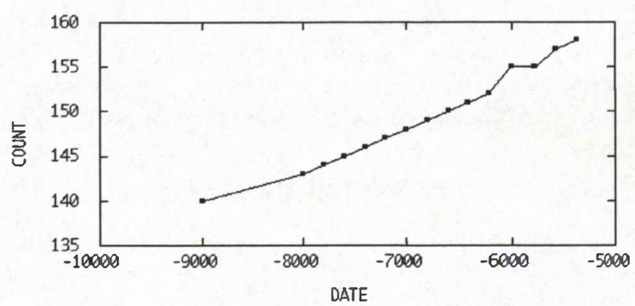

Figure 16. Function fitted to neural network estimates. Inputs are total quantity pottery per layer in Sector 7.

Even in those circumstances (too few data, overlapping intervals), a Neural Network algorithm has been proved to be suitable for this kind of analysis. In our example, it has not calculated a well fitted curve to the quantity/chronology correlation because we have not enough data. Some essays using simulated data (30 radiocarbon intervals, that is around 60 inputs) show that a neural network is the best method to calculate a trend not affected by the overlapping intervals. In the Tell Halula case, the neural network has been able to delete the influence of S7-VI interval (7727-5596). Although estimations are wrong, the general trend (there is more rubbish accumulated at 5596 BC, than at 7727 BC) has been correctly calculated.

If neural network estimates were correct, then we could compare the stratigraphic seriation (each layer has the same duration) with the c-14 calibrated intervals seriation. A better chronology of archaeological layers would be possible, and a better interpretation of the correlation between *quantity* and *time*.

5 Conclusions.

In this paper we have introduced some techniques to extract the maximum quantity of information from stratigraphic order. This has not been a classical example of *seriation*, as developed by other authors (Marquardt 1978, Herzog & Scollar 1988, Laxton 1987, 1990, Laxton & Restorick 1989, Andresen 1993, Wilcock 1995), because we were not interested in obtaining a *serial order* from "similarity" among archaeological units, but in describing and analysing the correlation between *quantity* and *time* as represented by stratigraphic order.

The methodology we have introduced is not new, but we think it is the most appropriate when data are intrinsically noisy and unequally sampled. We have applied some techniques in the worst imaginable scene. Of course our research continues and we are now analysing *diversity* between archaeological units, as represented by differences in pottery percentages.

The low frequencies are also a cause of noise in the data. We have processed archaeological layers and not depositional units because we have tried to increase the original frequencies. Nevertheless, earliest layers have too few sherds to be considered significant samples. Of course we cannot do without, because historically when pottery appears there were only a few items. Once the critical analysis of post-depositional disturbance is finished we will process depositional units instead of adding then in archaeological layers.

Even in these "bad" but "real" circumstances, non-parametric smoothing is able to produce some results. Unequal samples and the use of bad estimators of quantity do not prevent the existence of a hidden trend in the data: a non-linear increase in the quantity of pottery, associated with changes in the ways rubbish is produced and accumulated. At the moment of consolidation of pottery manufacture and use, new types appear that substitute for the older ones. Old vessels are being broken due to their use, and they become slowly part of rubbish. As far as these old types are substituted by new types, better manufactured or more apt to new uses, their circulation decreases and their proportion in rubbish accumulations (directly related with the quantity of vessels in use) decreases too, until their disappearance.

A Neural Network has been programmed to deal with this problem. Although this technique seems very useful in this context, the scarce quantity of radiocarbon dates has prevent a more correct model of the correlation between quantity (of pottery) and (absolute) time. More work in this domain is needed.

Acknowledgments.

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