

SOME PROBLEMS IN ARCHAEOLOGICAL EXCAVATION 3D MODELLING

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ABSTRACT

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Photogrammetry has been used in archaeology for the recording of complex structures. Therefore, the use of those techniques is more frequent in medieval and classic archaeologies. In those cases the presence of buildings and architectonics makes profitable going beyond the traditional paper and pencil approach. For prehistoric sites, traditional hand drawing is still the most profitable approach. Elements and structures to be drawn are geometrically quite simple, and the problems are more on the complexity of stratigraphic and sedimentary aspects, than in buildings, walls or floors. In this paper, we explain how to use digital photography in prehistoric excavations, how to modify those pictures to adequately represent the archaeological record, and how to build geometric models from photographs. Our final goal is to build a geometric and dynamic model of the site, in order to explain not its architectonic complexity, but taphonomy and the site formation process.

ARCHAEOLOGICAL EXCAVATION AND THE DEFINITION OF ARCHAEOLOGICAL SPACE

We can define archaeological space as a sequence of finite states of a temporal trajectory, where an entity (ground surface) is modified successively, by accumulating things on it, by deforming a previous accumulation (for instance, by spreading) or by direct physical modification (building, excavation). Archaeological sites should be considered as the result of successive and overlapping modification steps (Barceló et al. 2003).

Natural and human process modify physical space, and as a result we are able to distinguish phase or modification steps, which can be used as analytical units. A phase is a homogeneous region in space delimited by a well-defined discontinuity or boundary. A well defined boundary is an abrupt change in some spatial values. We may define an interfacial boundary or interface, when two phases are in mutual contact, that is, when two neighbouring regions in space have different probabilities for the same formation processes.

A wall, a pit, a garbage accumulation are phases or distinct regions of the archaeological space, which can be defined not only in terms of their own properties, but also in terms of the differences with neighbouring phases. We need to distinguish where observed discontinuities or boundaries begin and end, that is what are the proper borders of an occupation floor, or the original shape of a pit, where pottery sherds are accumulated, or where an animal carcass has been broken into bones. Therefore, archaeological excavation cannot be reduced to the mere unearthing of artefacts and ruins, but an exhaustive documentation of an archaeological space in terms of a finite set of spatial variables. The purpose is to characterize observed discontinuities in terms of distinct components or relevant units with uniform value of shape, size, texture, composition. However, a phase cannot be defined only in terms of their boundaries (Barceló et al. 2003). They should be analyzed as the presence/absence of some qualitative spatial vari-

able, that is a feature which has positive value if it is present, and negative value in case of absence. Observed discontinuities between phases can also be expressed in terms of quantitative variables. Quantitative variables exhibit a variation in value throughout spatial regions. Variables such as geo-mechanical properties, mineral grades, material accumulations, soil morphological features, or any other property of sedimentary/depositional units and archaeological contexts, can be sampled or measured in terms of real, numerical values.

ARCHAEOLOGICAL INFORMATION SOURCES: WORKING WITH VARIABLES AND COORDINATES

Archaeological information sources can be reduced to three basic data types: variables, characteristics and coordinates. They are properties of the subsurface that can be sampled and measured in terms of real, numerical values. In contrast, characteristics are observable qualities of the archaeological space that have a finite number of possible descriptive values, and uniform value within finite, irregular volumes. Characteristic values are associated with discrete archaeological areas with distinct boundaries (a wall, an occupation floor, a pit, etc.).

The common feature of the archaeological information sources is that every variable or characteristic value is associated with a location and an extent (point, line, area, surface, volume) which in turn are defined by an implicit data geometry.

The usual way to define dependent variables in an archaeological model is by using observable characteristics. For instance, consider a texture classification or material identifier, with the following values:

Limestone, quartz, granite, pottery, charcoal, clay,...

or

Wall, occupation floor, brown sediment, red sediment, black sediment,...

or

Wall1, wall 2, wall 3, Floor 1, Floor 2, Floor 3, Pit 1, Pit 2,...

Although archaeology deals necessary with 'time', this is one of the less tractable independent variables. Even in the case of C14 dates, we do not have scalar values, but irregular intervals, which constitute mathematically complex structures. The easy way to solve this problem is by using ordinal values:

Period 1, Period 2, Period 3

Note that we are not equating stratigraphic depth with 'time'. In some cases, the temporal evolution of the site can be correlated with stratigraphic ordination, but not necessary.

Archaeological visualization is the graphical expression of relationships between observed and sampled values distributed in space. To adequately visualize these complex data structures we must consider a semi-infinite continuum made up of discrete, irregular, discontinuous volumes which in turn control the spatial variation of archaeological features. Therefore, an archaeological site should be described in terms of a volumetric information, that is, a group of data that describe a solid object from a three-dimensional space. Volumetric data occupies a volume of space. For example, when data is collected by excavation, there are data points spanning the height, width, and thickness of the archaeological element and a data value representing the type of material, sediment, structure, bone accumulation, etc. at each point.

VOLUMETRIC DATA ACQUISITION

The usual way is to acquire separately coordinates, and after excavation, characteristic regions are built by joining characteristic points with lines, areas or surfaces. The archaeologist has an external database with a qualitative description of information related to each point, and then is able to create geometric shapes and structure by linking already existing points. By using polygons connecting points, by interpolating parametric surfaces or volumetric primitives. For instance, an occupation floor is acquired by calculating the 3D coordinates of some characteristic points along the contour, and then fitting a polygon to those coordinates.

The problem with this approach is that it is a modellization process, and not a real sampling procedure. Archaeologist is projecting what he/she things to know about the nature of a finite and very reduced series of coordinates, and focusing only on specific characteristics. Walls, and built structures can be easily built using standard geometric fitting tools, but then we are forgetting all information about interfacial boundaries. A wall is a characteristic of the archaeological space, but the sediment covering the wall, or the accumulation of stones around it, are also important characteristics which should be sampled.

We suggest to use a different approach to sample archaeological data. We need coordinates and characteristics to be acquired simultaneously, and we need a huge quantity of data points to approximate to scalar fields. The only way is through photographs.

A photograph is a spatial pattern of different luminance values. It is not a surrogate for reality, but a device for capturing some initial input (luminance perception) which should be translated into observed data. Given that spatial discontinuities are the building blocks of archaeological discontinuities, and they can be analysed in terms of texture variation, photographs can be used as a model of texture discontinuities.

Of course, we need more than a single photograph. 3D data sampling presupposes that a series of cross-sectional images, representing some volume which was regularly sampled at some constant interval, exists in digital form. An 'image stack' is a display of multiple spatially or temporally related images in a single window. The images that make up a stack are called slices. Stacks can be viewed from different perspectives, treating the layers of the stack as another spatial dimension.

This works only if certain conditions are satisfied. First, the individual files must be in the same format and bit depth. Second, they must have similar structure, i.e., same numeric type, number and sizes of dimensions, etc (Fig.1).

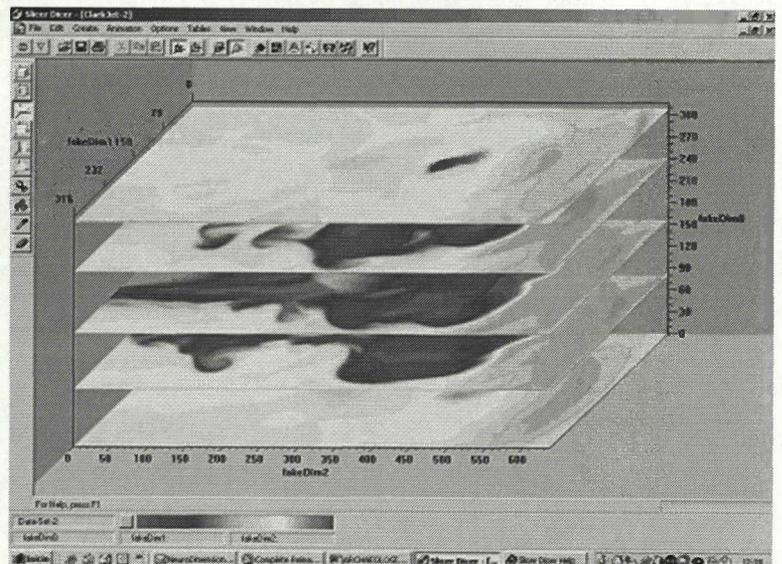


Figure 1 a stack of images sampled at different intervals. Simulated data using the SlicerDicer software from Pixotec, Inc.

Each image or 'slice' in a given dataset is made up of a number of picture elements or pixels. The distance between any two consecutive pixel centres in any slice within a dataset represents a real world distance referred to as the interpixel distance. Similarly, the distance between any two consecutive slices represents some constant real world depth with which the volume was sampled. This constant depth is referred to as the interpixel distance.

Photogrammetry

A series of cross-sectional digital images of this type is referred to as a 'volumetric dataset' or simply as a dataset. Such a data set is represented by a series of photographs, each containing a similar n-dimensional data array. Collectively, these files are interpreted as a single array of n+1 dimensions. For instance, we have 5 image files, each containing a 100 x 200 x 200 data array. By opening them all at once, a computer can read these data as if they come from a single 5 x 100 x 200 x 200 array, where 5 is the number of slices.

Processing a volumetric dataset begins by stacking the slices of a given dataset in computer memory according to the 'interpixel' and 'interslice' distances so that the data exists in a "virtual" coordinate space which accurately reflects the real world dimensions of the originally sampled volume. The next step is to create additional slices to be inserted between the dataset's actual slices so that the entire volume, as it exists in computer memory, is represented as 'one solid block of data'. The number of slices needed to fill in the blanks is based on the dataset's interpixel and interslice spacing and the slices needed are created through interpolation.

In this case, spatial values should be defined on regular, rectangular grids. Such data take the form of n-dimensional Cartesian arrays.

Once a dataset exists in computer memory as a solid block of data, the pixels in each slice take on an additional dimension. In effect, the pixels become volume pixels or 'voxels'. Once loaded into memory, a volume can be translated and rotated and a rendering of the dataset can be obtained (Fig.2).

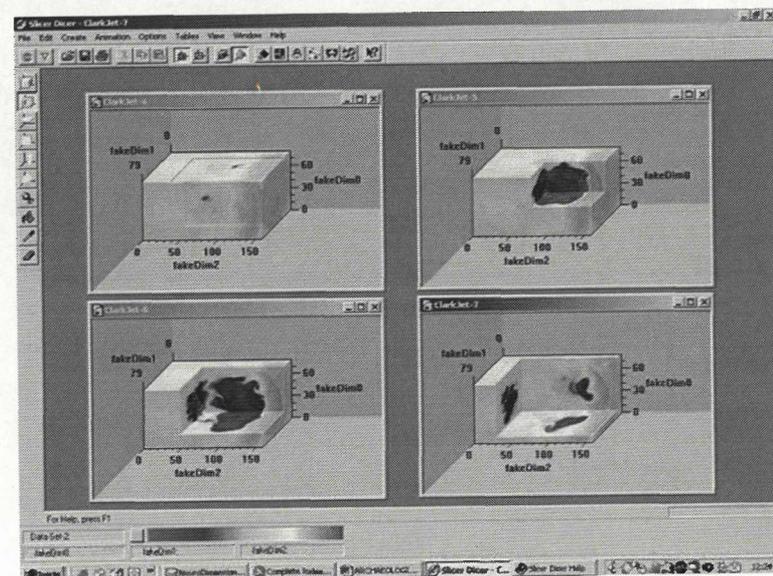


Figure 2 a rendered volumetric data set. Simulated data using the SlicerDicer software from Pixotec, Inc.

TECHNICAL CONSIDERATIONS BEFORE BUILDING AN IMAGE STACK

If we need to overly photographs to 'slice' a 3D reality (the archaeological site), it is necessary that all slices be spatially related. Of course, sharing attributes on sample points only works if all scalar fields were sampled at the same locations.

To make comparable all photographs in the stack, we have to geo-reference them. This step can be done with 'photogrammetrical' methods, where a image is modified introducing the real coordinates, and deforming it to be adjusted to a real scale.

Georeferenciation implies that discontinuities observed in the photographs should be positioned in space. The x, y and z axes of the representation are aligned with the east, north and azimuth axes of the projection being used. Each pixel in the photo and each geometric primitive in the vectorial representation is geo-coded with its associated coordinate in the map projection. We introduce in the model a new variable: location. Some control points should be measured independently and then transferred to a database with a reference to the photo. Those control points will be used to 'register' the image and substitute pixels using specific geo-registration algorithms.

Also, the georeferenciation implies the rectification of perceptual errors, focal angle or focal distortion produced by the position of the archaeologist. In the case of a photograph a preliminary rectification transforms the pixels of the photo by interpolation of luminance wave length according to x and y axes.

However, even after geo-rectification photographs are always a misleading representation of reality. Scale variations are caused by the natural point-to-point variations in the elevation of the terrain being photographed. Scale variations are also caused by the varying distances of objects out from the principle point of the camera, as it is a perspective projection. Photographs are a 2D contrast map of luminance reflections on a 3D real surface. In other words, a 2D photograph is a deformed representation of reality. If it is deformed, a sequence of images within a stack would not be a right volumetric data set, because the spatial distribution of variables and archaeological characteristics sampled at one layer has nothing to do with data sampled at other layers.

Consequently, slices within an image stack cannot be considered a true input of volumetric data if we do not remove scale variations from any image. Once these variations in scale are removed from a photo, the photo becomes a true image map of the ground, where "map" is defined as a constant scale representation of a portion of the Earth's surface.

LIMITATIONS OF THIS APPROACH

However, in most archaeological cases we cannot use this procedure.

There is a temptation to consider the process of building an image stack as a suggestion for excavating imposing artificial layers. Nevertheless, modern archaeology abhors the use of artificial layer slicing, because it makes impossible the

correct reconstruction of stratigraphic sequence. We always follow observable discontinuities, that is, what we often call 'natural layers'. As a result, slices in an archaeological volumetric data set are not planes, but complex data arrays.

We should remember that archaeological characteristics and all variables describing the archaeological space are intrinsically four dimensional. Stratigraphic sequence is, in fact, a measure of temporal modification, which should be always taken into account.

Only when considering a stack of 4D data arrays we can represent properly archaeological or interfacial phases (contact surfaces between spatial discontinuities) at different time steps. For instance, Figure 3 is a 5D representation of an archaeological time step. Here colour (grey level) is used to represent different W values at different x,y,z coordinates. Let W be the value at a position in the array defined by $t = t'$, $x = x'$, $y = y'$, and $z = z'$. This datum will be rendered in the data view as a coloured pixel. The colour is defined by a data-to-colour mapping, or colour table, and the position of the pixel in the window is defined by a data-to-view coordinate mapping. If we had 3 files, each containing, for instance a $10 \times 100 \times 200 \times 200$ data array, we can integrate all data into a single volumetric set with $3 \times 10 \times 100 \times 200 \times 200$ array, where 3 is the number of temporal steps (slices), 10 the num-

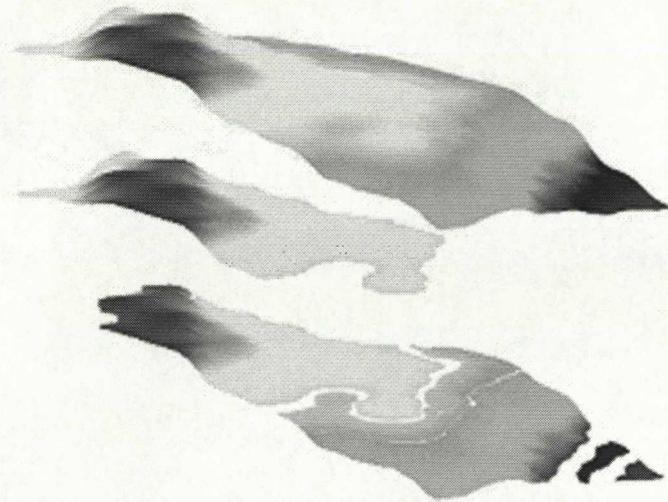


Figure 3 a 5Dimensional representation of an archaeological site

ber of values of the W characteristic, and $100 \times 200 \times 300$ the dimensionality of the 3D grid where spatial values vary.

If we use z to represent height of ground level, then image rectification as explained previously does not work. We have here scale variations far greater than when considering only camera placement and focal angle. The only solution is to create a 3D model with textures, were textures can be used to build discontinuities, and then to locate characteristic values according to real topography. In this case, we can excavate following natural layers, and building 4D models (spatial coordinates plus textures) for each time step, identified also in terms of texture or qualitative discontinuity.

CONCLUSIONS

When visualizing archaeological spatial data, the exact values of the data are not as important as the relationship between values. Data visualization is used to gain insight into the data set, and expose relationships between values that might not be apparent in the raw data. As a result, intuitive, but less exact, representations of data values are often used.

Regularly gridded data are not very easy to take during field work (see an alternative method in Barceló et al. 2003). The problem is that spatial values defined on unstructured grids, which often take the form of tables with X-Y-Z-Value columns, cannot be directly visualized with common volumetric data visualizing software. It is often necessary to resample them onto a regular grid. One way of obtaining this rectangular grid is by creating images stacks.

However many real-world data sets are irregularly sampled. There may be a strong temptation to resample the data into a regular grid. This approach can be problematic in many cases, since the data may not change linearly between grid points. False relationships can be created in the resampled data.

This is the case in archaeological site modelling.

FINAL NOTE: A much more technical explanation of this procedure, and a suggestion for archaeological multidimensional field data format appears in the CD-ROM

REFERENCES

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