A GENERAL SURVEY OF COMPUTER APPLICATIONS IN ARCHAEOLOGY

by
J.D.Wilcock
Dept.of Computing, North Staffordshire Polytechnic

ABSTRACT

This article ranges widely over all the applications of the computer in archaeology. Its purpose is to expand the scope of the conference from pure information retrieval topics covered by earlier gatherings.

Introduction

The majority of papers at this conference concern information retrieval applications in archaeology. Undoubtedly the main expansion in the use of computers in archaeology over the next few years will be in the setting up of data banks with associated information retrieval facilities operated from remote terminals, but it should be pointed out that perhaps 90% of the effort devoted by computer scientists and especially by mathematicians and statisticians to archaeological problems in the past decade has concerned quite different techniques. Since it is hoped that this annual conference will in future years cover all applications of the computer in archaeology, this presentation gives a general survey of these techniques. Some present-day archaeological computer systems embody ancillary program packages for statistical, classification and graphic purposes as part of a data bank. The information carried in the data bank may be analysed at will by any of these packages, and it is envisaged that most future systems will have these facilities as a matter of course.

Archaeologists are often able to supply large bodies of multivariate data and perhaps this has made them much sought after by mathematicians and statisticians who wish to test their new techniques. Some mathematicians get so engrossed in the rigorous theoretical proofs of validity of their techniques that the original archaeological problems get quite lost, while others develop elegantly rigorous methods which have little real use in archaeology. Of course, proofs of validity are necessary but the archaeologist is usually more concerned with whether the methods yield sensible and useful results. Fortunately there have been many fruitful partnerships between mathematicians and archaeologists.

The computer is a useful workhorse for such mundane yet essential tasks as the routine reduction of proton gradiometer and resistivity meter readings, and the production of site maps indicating the most profitable areas to dig.

All archaeologists need to produce site plans and sections, and drawings of artefacts for publication. The proliferation of computer output devices such as plotters, cathode ray tubes and microfilm printers means that the computer can produce these diagrams from the information stored in a data bank in a form which is ready for direct publication. Once this computerised production of routine diagrams is accepted, it is but a short step to the further production of histograms, piecharts, scalograms, dendrograms and other aids to the interpretation of the archaeological data. Distribution maps, which are very tedious to plot by hand can be quickly drawn by computer; both the map outline and grid references of the points are derived from the data bank. A variety of symbols may be used and such features as scale, north point, border and legends are added automatically to produce the finished map. These uses of computer graphics generally require artefact profile information to be stored in numerical form, and this is produced at present by the 'pencil follower' from original diagrams, but the use of a stylus to follow the surface of the actual artefact would be possible using equipment now available in some machine tool systems.

The computer has been used in a host of miscellaneous archaeological studies, among them the connection between astronomy and standing stones, the analysis of texts in known languages and the decipherment of unknown languages, Egyptology, the study of mosaics, pollen analysis and radiocarbon calendar construction.

The combined computer system for archaeology uses all the above techniques. Information retrieval files carry graphics data. Computer graphics produce plans, sections and statistical diagrams on paper or microfilm, and these may also be stored for future reference on magnetic tape. Outline maps of any desired area of the world may be stored on files, and called for the production of distribution maps whenever required. All diagrams are ready for direct publication. Instrument survey data may be reduced to maps to guide the excavator, and the finds from the excavation recorded in the information retrieval system. Objective classification and other statistical analyses may also be carried out on the data. Here we see statistics, upon which most of the effort has been lavished, in its true perspective as just one of several tools in the workshop of the computer archaeologist.

The place of the computer in archaeology

Upon first consideration a discipline such as archaeology might be thought to have little to do with computing. Indeed the popular image of the archaeologist as an academic, perhaps wealthy or titled, spending leisured summers excavating fabulous treasures, has not quite been dispelled. Lord Caernarvon, who paid Howard Carter to excavate the tomb of Tutankhamun, has recently been much in the public gaze. But today archaeology is largely the province of young people and the average excavation yields not treasure but perhaps just pottery sherds of little intrinsic value. Excavation frequently takes place at weekends all the year round, often hard physical work in bad weather conditions. Again, the construction of new motorways and, in towns, the construction of tower blocks requiring deep foundations means that archaeological sites are being destroyed at an unprecedented rate. Contractors often allow only a few weeks, more often days or even hours for the complete recording of irreplaceable deposits.

Thus archaeology has had to move with the times. Techniques have been borrowed from most of the natural sciences. Sites are usually surveyed nowadays before excavation by instruments such as the *proton gradiometer* and *resistivity meter* which provide a picture of the remains to be found below ground. The archaeologist then knows the most profitable places to dig, and does not waste time on barren areas. Finds may be dated by a variety of scientific techniques. The dating of bone by its fluorine content exposed the Piltdown hoax.

Radiocarbon dating may be applied to samples of carbon, a constituent of all plants and animals, both living and dead. *Potassium-argon dating* is of use for much older deposits. *Thermoluminescent dating* is used to date pottery, and *magnetic dating* to date kilns. Archaeological finds are often analysed by techniques borrowed from Physics and Chemistry with four aims in mind:

(a) the place of manufacture of an object may be deduced by comparison with samples of raw materials;

(b) the method of manufacture may be deduced, or perhaps the economic stature of a people may be indicated by the proportion of base metal in their coinage;

(c) evidence for the existence of trade routes may be found; and

(d) fakes may be identified.

Today archaeology is a 'bridge subject' between the two cultures of arts and sciences.

The computer has been seized as yet another tool to be borrowed and used to the advantage of archaeology. But the computer is a power-tool compared with the other techniques. Its main uses in archaeology are as follows:

1 Data banks and Information Retrieval

2 Statistical analyses, including classification

3 Routine reduction of instrument survey readings

and 4 Graphics, *i.e.* the production of diagrams.

1 *Data banks and Information Retrieval*

It is becoming very common for large files of information to be stored by computer for subsequent analysis. A file of data covering a well-defined topic is called a *data base*, which may then be used for an *information retrieval* exercise; information relevant to a particular query is located. For example, an archaeological record retrieval request might be for those sites which are Iron Age or Roman in date, not associated with military equipment, containing a bronze brooch, at least two types of pottery, and situated less than 10km from a main Roman road. Much more complex requests than this can be handled. The result of an information retrieval exercise is usually a list of items printed by computer and then directly available for reference or publication by offset-litho printing process.

Three main types of archaeological data file may be distinguished:

A The large amount of specialist data

B The museum collection

and C The excavation record.

A. *Specialist Data*

A file may contain all known information on a well-defined topic, *e.g.* Roman inscriptions, prehistoric carvings, cave deposits, clay pipes, pottery types, and so on.

B. *Museum Records*

The centralisation of museum catalogues is just becoming a practical possibility. Up to now it has been necessary for an archaeologist interested in, say, Anglo-Saxon brooches to first of all write to the curators of all museums in the country asking if they have suitable specimens, and then to travel long distances at much cost to see all the located specimens. If museum records were to be stored in computer files linked by communications network then the archaeologist could quickly be informed of the location of all suitable specimens. Not only that, but full descriptions of the items could be furnished, as well as names, addresses and telephone numbers of the experts concerned in the identification, and photographs of the items. In many cases it would not be necessary for the archaeologist to visit the relevant museums himself. Pilot computer systems are now working for this facility. In Britain a single interdisciplinary system is being set up by the *Information Retrieval Group of the Museums Association* (IRGMA) and the format has also been accepted by the international body UNESCO-ICOM. The committee coordinating similar work in North America may also accept the format, in which case the system will at last be truly international, an event which will have immense implications for museum studies.

C. *Excavation Records*

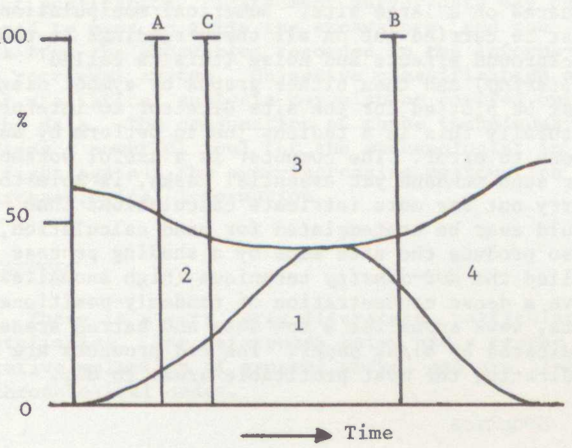
The computer is just beginning to be applied to the field recording of excavations. A *remote terminal*, consisting of a *teletype*, transmitter/receiver (*MODEM*) and *acoustic coupler* can be operated in a site office near the excavation and connected by normal telephone line to a computer which may be hundreds of miles away. The operator telephones the computer bureau in the usual way, awaits the connection of the transmission carrier wave, then places the telephone handset in the acoustic coupler. The remote terminal then effectively becomes part of the computer and may be used to insert new records, amend old records and perform analyses. A plotter may also be used at a remote site to produce computer-drawn maps and diagrams to aid the site director.

2 *Statistics*

Mathematicians, statisticians and computer scientists have been interested in archaeological problems for more than 20 years. Archaeologists are often able to supply large bodies of data with many variables, and perhaps this has made them popular with mathematicians. Whatever the reason, perhaps 90% of the work has taken place in this area. Some of the more successful techniques will be described.

A. *Seriation*

Suppose we have collections of finds from three archaeological sites, A, B and C. Referring to the figure, if for site A 10% of the total amount of pottery found is of type 1, 40% is of type 2, and 50% of type 3; site B has 30% type 1, 55% type 3 and 15% type 4; whilst site C has 20% type 1, 25% type 2 and 55% type 3, it is evident that C is more like A than it is like B.



If the three sites are to be placed in the most likely chronological order, we must make some assumptions about the trends in the use of pottery types. It seems fair to assume that a type of pottery will in general be invented, grow to popularity, then become outmoded and superseded by other types. Thus some types will be seen to perform this whole cycle during an archaeological sequence (*e.g.* type 1 in the figure), for others only the dying away (type 2) or only the growth to popularity (type 4) will be seen, while yet others will be present both at the beginning and end of the sequence, growing to a popularity peak in the middle of the sequence (type 3). Purely on these assumptions it is possible to place site C between sites A and B in chronology, rather nearer A and B. This method is known as *seriation*. A large number of collections of finds may be placed by the computer in the most likely chronological order on the basis of trends in the percentages of finds. There is, of course, no absolute determination of age, the sites only being placed in relative order, and the sequence may be found to be inverted, *i.e.* the oldest site may sometimes be positioned first in the sequence, sometimes last. This ambiguity may be resolved by absolute dating methods not involving the use of the computer, *e.g.* radiocarbon dating, and the result is a powerful chronological ordering technique.

B. *Multidimensional Scaling*

Seriation is essentially a linear ordering which assumes that the variables are one-dimensional, showing variations with respect to time alone. In archaeological studies, however, it is frequently found that the variables depend not only on time but also on geographical and other features. Thus we must consider at least 3 dimensions (2 geographical, say latitude and longitude, and one time); in some situations the variables may require more than 3 dimensions if their true relationships are to be portrayed. In *multidimensional scaling* the position of the archaeological object along one axis in a single-dimensional series as derived by seriation is replaced by a spatial position in however many dimensions are necessary, the distances apart of pairs of points in this distribution representing the *degrees of dissimilarity* of the pairs of archaeological entities which they represent (similar entities appear close together and unlike entities far apart from each other). Starting from an unbiased initial configuration, the aim is to move the points around in space until the distances between the points reflect as far as possible the degrees of dissimilarity between the entities which they represent.

For the unbiased starting position, we know that three points can be placed equal distances apart in two dimensions at the vertices of an equilateral triangle. For four points it is necessary to position the points in three dimensions at the corners of a regular tetrahedron. In general, n points can be positioned equal distances apart in (n-1) dimensions. Humans, of course, cannot perceive more than 3 dimensions, but there is no similar restriction on the computer.

During each iteration of the program each point is moved under the action of 'forces' moving it towards those objects which are most similar to it and away from those to which it is unlike, this polygon of forces in hyperspace being resolved into a single resultant (most profitable) direction for the point to move. The process continues until the configuration cannot be improved. A fully correct result is frequently not possible because of conflicting requirements, but the computer produces the solution which is most nearly correct, which may be in many more than the 3 dimensions readily understood by humans. The computer is, therefore, instructed to try the effect of reducing the number of dimensions, squashing the points into strained positions, until the strain is no longer acceptable. Often the computer is able to portray an archaeological point relationship in 3 or even 2 dimensions without too much inaccuracy, and a graphic picture may then be produced showing the relationship of the archaeological entities for the archaeologist to review and interpret. Multidimensional scaling has had some significant successes in archaeology.

C. *Trend Surface Analysis*

This is a statistical technique which attempts to discover the main relationships between different civilisations in the past. Suppose a number of sites have been excavated in the region between two main centres of population. Each will yield objects typical of both civilisations but in differing proportions, and we expect that the nearer the site to one civilisation (in the absence of natural barriers such as mountains or rivers) the larger will be the proportion of objects from that civilisation found at the site. Taking the numerical ratio of the two types at each site together with the geographical position of the site, and repeating this for all the sites, we may construct a mathematical surface which we may provide with 'contour lines' by analogy with a hill surface. The steepest part of the 'hill' indicates the *major trend* of cultural influence between the two peoples. We may then calculate an 'ideal' surface for the relationship and subtract it from the actual observations. The *residuals* may possibly be analysed for *subsidiary trends* perhaps due to the influence of a third civilisation.

D. *Clustering*

Clustering is an iterative process which aims to set up a classification scheme for a set of objects using the principles of *numerical taxonomy* for the derivation of similarity figures. A very large number of linkage criteria have been proposed by mathematicians and statisticians over the last 20 years. Archaeologists are able to supply large amounts of multivariate data and this has made them much sought after by mathematicians and statisticians wishing to test out their new techniques. There have been many fruitful partnerships between mathematicians and archaeologists. The aim is to set up an automatic classification scheme which will be useful in the allocation of newly-excavated objects to classes. Both *agglomerative* (starting with a set of distinct objects and grouping similar ones together) and *divisive* techniques (starting with one group of objects and splitting it into subgroups) have been used. These objective classification schemes are complementary to the subjective classification schemes derived by experienced archaeologists. The computer is capable of pointing out something 'new' about the objects, perhaps indicating similarities between objects which had not occurred to the archaeologists.

E. *Models*

A growing interest is being shown in computer simulation of archaeological cultures. Mathematical models are set up on the computer to simulate the life cycles and interactions of groups of people, and the predictions are tested for accuracy. There is a good chance that parallels between archaeological reasoning and machine reasoning will prove fruitful, and the computer may indicate what questions archaeologists should be asking about the past.

3 *Routine Reduction of Instrument Survey Readings*

Sites are often surveyed nowadays before excavation by geophysical instruments. The *proton gradiometer,* a very sensitive detector of magnetic fields actually detects minute changes in the earth's magnetic field caused by archaeological remains below ground. The features detected most easily by this instrument are filled-in pits, ditches and especially kilns. Pits have been used in antiquity for food storage, rubbish disposal and burial of the dead, and consequently most of the dating material for the site will befound there. The pits are detected because the contents have a markedly different *magnetic susceptibility* to the surrounding natural earth. Ditches have been used for fortifications and are important to the archaeologist. The detection of kilns and hearths depends on a property of the clay of which they are constructed called *thermoremanence.* When clay is fired above a certain temperature the particles of iron within it all line up along the current direction of the earth's magnetic field. When the kiln cools down, this direction is 'locked in' preserving as a weak permanent magnet the direction of the earth's magnetic field at the time the kiln was last fired. Since magnetic north is continually changing, the present-day magnetic field direction is quite different to the 'locked in' direction (this is the basis of a dating method called *magnetic dating*) and a large anomaly in magnetic field is detected over the kiln.

The second instrument commonly used to survey sites is the *resistivity meter.* This measures the electrical resistance of the soil. Such archaeological remains as buried wall foundations and road surfaces have a higher resistance than the surrounding earth and are consequently detected. The resistivity meter is not so good at detecting pits and ditches, and fails to detect kilns altogether, while the proton gradiometer is poor at detecting walls, so the two instruments are complementary.

The method of use for these instruments is to take a reading at the intersections of a rectangular grid superimposed on the site, often of 1m spacing. Thus a 100m square (hectare) produces 10,000 readings, and there may be several such hectare squares on a large site. Numerical manipulation must be carried out on all these readings to remove background effects and noise (this is called *filtering*) and then either graphs or symbol diagrams must be plotted for the site director to interpret. Naturally this is a tedious job to perform by hand, prone to error. The computer is a useful workhorse for such mundane yet essential tasks, is able to carry out far more intricate calculations than could ever be contemplated for hand calculation, and also produce the site maps by a shading process called the *dot-density* technique (high anomalies have a dense concentration of randomly-positioned dots, weak anomalies a few dots and barren areas are indicated by blank paper. The end products are maps indicating the most profitable areas to dig.

4 *Graphics*

All archaeologists need to produce site plans and sections, and drawings of objects for publication. Such devices as *digital incremental plotters, cathode ray tubes* and *microfilm printers* can be used to produce these diagrams from the information stored in a data bank. The diagrams are produced complete with border, lettering, etc. and are ready in all respects for publication. Statistical information can also be presented in the form of *histograms, piecharts* (where the total content of a site is illustrated by a circle, and the relative importance of each type of object is indicated by a segment or 'slice of the pie'), *scalograms* (the end product of multidimensional scaling) and *dendrograms* ('tree' diagrams which illustrate the formation of clusters). Distribution maps, which are very tedious to plot by hand can be quickly drawn by computer; both the map outline and the grid references of the points are derived from the data bank. A variety of symbols may be used and such features as scale, north point, border and lettering are added automatically to produce the finished map. These uses of computer graphics generally require profile information to be stored in numerical form, and this is produced at present by the *'pencil follower'* (a device which tracks a lens and crosswire system as it moves across the surface of a diagram), but the use of a stylus to follow the surface of an actual archaeological object is under development.

Miscellaneous applications

The computer has been used in a host of miscellaneous archaeological studies, among them the connection between astronomy and Stonehenge, the analysis of texts in known languages and the decipherment of unknown languages, the reconstruction of the Akhenaten temple at Karnak and the cosmic ray detection of unknown chambers in pyramids, the study of Greek and Roman mosaics, the study of climate in antiquity by analysis of pollen samples, and the construction of a calendar for radiocarbon dating stretching back 8000 years.

The Combined System

The combined computer system for archaeology uses all the above techniques. Information retrieval files carry graphics data. Computer graphics produce plans, sections and statistical diagrams on paper or microfilm, and these may also be stored for future reference on magnetic tape. Outline areas of any desired area of the world may be stored on files, and called for the production of distribution maps whenever required. All diagrams are ready for direct publication. Instrument survey data may be reduced to maps to guide the excavators, and the finds from the excavation recorded in the information retrieval system. Objective classification and other statistical analysis may also be carried out on the data. The conjunction of these techniques provides a powerful tool for the archaeologist in his fight against the ever-increasing destruction of archaeological information.

REFERENCES

There is a very large literature, particularly in statistics. The references below are a representative selection of general works, and are listed in chronological order.

Heizer, R.F. and Cook, S.F.(eds), 1960

The application of quantitative methods in archaeology
Viking Fund Publications in archaeology No.28
Quadrangle Books, Chicago

Chenhall, R.G., 1965 onwards

Newsletter of computer archaeology
Department of Anthropology, Arizona State University, Tempe, Arizona 85281

Cowgill, G.L., 1967

Computer applications in archaeology
Computers and the Humanities 2(1) 17-23

Doran, J.E., 1967

Computers in archaeology
72nd ordinary meeting of the British Region of the Biometric Society, 7 December, 1967, London

Binford, S.R. and Binford, L.R. (eds), 1968

New perspectives in archeology
Aldine publishing Co., Chicago

Clarke, D.L., 1968

Analytical Archaeology
Methuen, London

Wilcock, J.D., 1969

Computer applications in archaeology
Datafair 69
Abstracts of the British Computer Society Symposium Papers

Burton, V. et al., 1970

The computer and archaeology
American Journal of Archaeology 74, 221-223

Gardin, J-C(ed.), 1970

Archéologie et Calculateurs
Editions du CNRS, Paris
(Some papers are written in English)

Wilcock, J.D., 1971

Non-statistical applications of the computer in archaeology
in Hodson, F.R., Kendall, D.G. and Tautu, P. (eds)
Mathematics in the archaeological and historical Sciences 470-481
Edinburgh University Press, Edinburgh

Chenhall, R.G., 1971

Computers in anthropology and archeology
IBM GE20-0384-0

Gardin, J-C., 1971

Archaeology and computers: new perspectives
Int. Soc. Sci. J. 23(2), 189-203

Whallon, R. Jr., 1972

The computer in archaeology: a critical survey
Computers and the Humanities 7(1), 29-45

The journal *Science and Archaeology* (George Street Press, Fancy Walk, Stafford) covers general scientific and computing topics in archaeology, while *Computers and the Humanities* carries frequent details of scholars active in the field of computer archaeology with details of their projects.

J.D.Wilcock
Dept. of Computing
North Staffordshire Polytechnic,
Blackheath Lane,
STAFFORD