Archeologia e Calcolatori
13, 2002, 171-178

LINKING LOCATION AND SPACE TO PROCESS USING PRECISION MAPPING

1. Introduction

The contents of the current volume attest to a surge in adoption and innovation in GIS by archaeologists. This is particularly apparent when the program of the 2001 UISPP is compared to the proceedings of the 1996 UISPP meeting. Five years ago GIS was a novel technology, and archeologists were just starting to explore its potential (Bampton 1997; Johnson, North 1997). It is now a well established tool for data management and analysis and is rapidly changing approaches to CRM, and is driving the development of a new school of agent-based speculative modeling (Davidson, Ridge 2001; Lake 2001; Mehrer, this volume; Moscati, this volume). However the task of populating GIS with high quality purpose-built data sets remains challenging. Publically accessible digital data sets lack sufficient precision for all but the coarsest scale analytical work and transferring the results of traditional optical surveying from paper copy to digital data media requires significant investments of time and skill. These are significant problems as mapping is one of the most important data gathering techniques in archaeology. Site location, excavation records, and landscape characterization must all be mapped: several key analytical tasks such as dating, definition of activity areas, and identification of occupation areas rest on the quality of mapping.

In recent years there have been significant advances in mapping technologies; emerging from these advances is a cluster of techniques which combined can be called precision digital mapping. Precision digital mapping is based on the combination of two tools – global positioning systems (GPS), and electronic total stations (ETS). GPS gathers geographically specific points either with great precision very slowly, or with less precision very rapidly. ETS gathers very precise points fairly rapidly, but they float in free coordinate space. By using a GPS unit to create a set of datums within which to georegister an ETS it is possible to create a very precise and high-density georeferenced survey. This level of precision and data density offers to resolve the problem of populating GIS with archeological data, and simultaneously opens new prospects for archeological analysis, based on much richer spatial data sets than were previously available.

2. Overview of the technique

GPS uses signals from a network of 24 orbiting satellites to establish the ground position of a specified point. In optimal conditions the position is accurate to less than a centimeter globally, though yielding results of this quality can be a rather finicky process. GPS has been available in its present form since 1990. However it has only now being used as a field mapping tool following the advent of cheaper hand-held units, and the US government's decision in May 2000 to turn off the "selective availability" signal scrambling that diminished the real time output accuracy of most units to less than 10m. ETS employs the travel time of a broadcast light signal to establish distance and elevation between the instrument and a pole mounted reflecting prism. ETS units have been available to archaeologists, and other environmental scientists for almost a decade (Bodin, Flyg personal communication 1997; Amadesi, Mora 1998). However daunting cost, and even more daunting learning curves have discouraged many potential users from adopting them until quite recently.

At present operating systems and data formats for GPS and ETS are converging rapidly. At the same time instrument design is improving, with units becoming more robust and a lot lighter. Finally, many manufacturers are now employing human beings to write the instrument manuals. Consequently the tools are becoming far more accessible. Although (despite some extravagant claims by manufacturers), there is no single instrument capable of performing both GPS and ETS functions simultaneously. Rather these are two distinct instruments that perform complimentary tasks.

Each device measures point locations in space within an x,y,z coordinate system, recording the results in digital form. Each instrument allows the user to attach one or more additional attribute fields to the measured coordinate location. These attribute fields are essentially extra z axes built in non-geometric data space, that can be used to construct intricate multi-dimensional data terrains. As all data are rendered in Cartesian coordinates they can readily be translated into a vector-based graphical system, such as CAD or vector GIS by the simple expedient of exporting them as Ascii text files. Precision ranges from +/- 1cm to +/- 10m globally, depending on which instrument is employed, and how it is used.

Despite their comparatively high cost, and the complexity of their operation, these new tools are employed by a growing number of field archaeologists, who use GPS for low resolution site location, and ETS to generate CAD images of excavations. Very little work has so far been done connecting the output of the two technologies into a single integrated data product: this technique has so far only been employed by surveyors.

Precision mapping can be applied in situations where traditional optical surveying, field sketching, large format photography, and high-resolution grid mapping would be used. To the best of my knowledge the technique was first used in an archaeological application in a pilot project conducted in Rapa Nui (Easter Island) in 1998 for mapping artifact locations and distributions within individual $1m^2$ excavation units, for delimiting the excavation grid itself, and for mapping larger landscape features (BAMPTON, FLYG 1999). On the largest scale it was used to delimit the dimensions of ruined and extant structures, and to map the debris field of structures destroyed in battle. On an intermediate scale it was used to map underground burial chambers, and the positioning of human remains within the chambers. On the smallest scale it was used to trace the outlines of individual petroglyphs, some only a few centimeters across. GPS was used to coordinate the total station, to map the coastline surrounding the site, and to georegister ariel photographs.

3. PROCEDURE

There are three basic strategies for collecting GPS positions. First, it is possible to get results accurate to within about 10m using an uncorrected signal, simply by accepting the coordinates given by a hand-held unit. Secondly, it is possible to correct the position recorded for a point against a matching data set from a second known position – a technique commonly referred to as post-processing differential correction. With a data collection period ("occupation") of a couple of hours this technique can yield results accurate to within a centimeter or less. Thirdly, there are several techniques that employ radio links to broadcasting base stations allowing field survey GPS units ("rovers") to calculate differential correction in real time. These are collectively referred to as real time kinematic or RTK techniques, and yield results that are accurate to within 10cm or less. The ETS, if corrections are made for humidity, air pressure, and temperature, if the prism is tripod mounted, and if each measurement is averaged over a couple of minutes, yields results that are accurate to less than a centimeter. If the prism is held on a 1.5m range pole on a breezy day, and the instrument is used in "fast" mode results are more likely to be +/- 5cm.

At least two static points from a long occupation by the GPS are necessary to create a baseline with which to georeference the ETS. Precise points measured using the total station can be gathered fairly quickly, and are best suited for establishing excavation grids, for mapping artifact locations, and mapping other excavation features. RTK GPS can, if used in "stream" mode, gather huge quantities of data, and is ideal for mapping larger features such as shorelines and surface topography.

Downloaded to a laptop and processed in the field, all but those results requiring post-processing can be viewed and edited in the field in real time.

4. WHY MAKE BETTER MAPS?

Establishing location in space is pivotal in several key areas of archaeological analysis, hence the long and productive intellectual relationship between archaeologists and geographers. It defines stratigraphic sequences, activity areas within habitation spaces, and within larger landscapes, and it also defines a host of other landscape variables. The role of location can be considered in three analytical arenas.

Location is a process in its own right. Patterns of climate, micro-climate, flood risk, drainage, and ecosystem are heavily influenced by specific locational characteristics such as altitude, latitude, and orientation, and by the proximity and distribution of other elements of the environment. Likewise many human social processes are heavily influenced by locational variables. Phenomena as varied as kinship patterns and economic success can be attributed, at least in part, to the locations of the players.

Location is also a cipher for time. In stratigraphic sequences, in correlations between similar features such as river terraces, and in cases where an object in motion has a known velocity, the more precise the measurement of location, the more accurate the calculation of time.

Location is a cipher for other process in those instances where shape and position can be used to deduce change, as geologists have long been aware. Deformation of bedrock structures, and the position, orientation, and juxtaposition of fractures and intrusions yields a model of the kinematics of past tectonic process (Swanson 1999). Removal or accretion of a field's surface yields a model of soil erosion, or sub-surface geological dynamics (Formento-Trigilio, Pazzaglia 1998; Kurushin *et al.* 1997) – which has significant implications for geoarchaeology. Recently Julia Day and her colleagues have used precise mapping of orientation and spacing in fossilized tracks in Bathonian (163 my BP) sediments to deduce the biomechanics of dinosaur gait (Day *et al*. 2002). In a similar fashion, location can reveal the topology of social spaces: spatial patterning of stone flakes can indicate an activity area; the compressed earth of a pathway can indicate a trading relationship.

In sum: accurate measurements of location and subsidiary spatial variables such as distance, proximity, distribution, and terrain allow the researcher access to a series of otherwise inaccessible observations. Or to put it another way: the better your maps are, the better your analysis will be.

5. The value of precision

There are four areas of benefit to using precision mapping techniques in archaeology: precision, scale, data volume and reproducibility.

5.1 *Precision as an end in itself*

The overall quality and reliability of any analysis which depends upon the measurement of location will be improved in direct proportion to the extent to which the measurement of location is improved.

5.2 *Scale*

Preliminary work in structural geology suggests strongly that there is a class of phenomena visible at scales hitherto impossible to map. Any extended feature which can only be seen at resolutions <10 cm, and in which spatial trends and patterning emerge over hundreds of meters "falls through the cracks" of traditional mapping techniques. As, in the first half of the twentieth century, ariel photographic survey revealed previously invisible field boundaries, routeways, and foundation lines, so precision mapping offers access to new classes of landscape features. Our most successful work in this area to date has been mapping kinematic indicators of tectonic processes in the Norumbega Fault Zone, of coastal Maine (Swanson, Bampton, in preparation).

5.3 *Volume of data*

Both of the tools used in precision mapping allow for the collection of a volume of data several orders of magnitude greater than has been possible using conventional mapping techniques. This is not merely a quantitative increase in the data set, but rather represents a qualitative change in what can be mapped. For example terrain mapping has previously been based on contours interpolated from measured high points, low points, and breaks of slope. Three operators walking a parallel path arm's length apart with RTK GPS units gathering a data point every two meters can rapidly create a high-density data grid with a vertical resolution of <10cm. Standard functions in many GIS packages will allow this digital elevation model to be rendered as a raster coverage, a TIN, or a contour map. This offers an image of micro-topography unobtainable with any other technique, and could reveal features as diverse as relict cultivation mounds, and solifluction ripples.

5.4 *Reproducibility and comparability*

Much of the work of compiling archaeological data sets balances delicately between science and qualitative interpretation. There are a set of observations that clearly fall into the realm of science, as they require absolute measurements and definitive interpretations, for example physical dimensions of artifacts, raw counts of finds, and C14 dates. There is also a set of observations that falls clearly into the realm of qualitative interpretation. The function of an object, particularly a ceremonial object, is famously qualitative, as are interpretations of some of the more nebulous landscape variable such as "ecological quality" and "functional area". Between these two extremes is a large set of what might be termed "semi-qualitative" variables. This class comprises those things which have some measurable qualities, but are in some fashion qualitative and non-reproducible. Because excavation destroys the archeological record as it documents it, many variables such as pre-excavation surface topography, stratigraphic relationships, and the position and spatial relationships of finds, are non-reproducible. By mapping into a single common global coordinate system these variables become reproducible within sites, and comparable over space within an objective framework.

6. Conclusions

Umberto Eco (1994) in his essay «On the impossibility of drawing a map of the Empire at a scale of 1:1» argues that making a map at a scale of 1:1 would create a number of inescapable paradoxes - for example, unfolded the map would necessarily cover the terrain it depicted, rendering itself inaccurate unless it depicted the Empire covered by a map. In which case the map would be inaccurate when it was folded up, because it could not show the Empire containing a large folded map. A data-rich GIS populated using precision digital mapping techniques does not offer a resolution to the problematics posed by the wily Italian linguist. However it does create an interesting and rather different relationship between the map-maker and the object being mapped. The data record, created in an absolute coordinate space is (at least mathematically) generated at a scale of 1:1, and every measured point is reproducible, and could be returned to in the field. This removes a whole layer of abstraction separating the GIS record from the field environment.

In more prosaic terms, the growing use of GPS and ETS in conjunction with GIS for field mapping constitutes an instrumental development comparable to that experienced in the bench and medical sciences towards the middle of the nineteenth century, when reliable optical microscopes became widely available (Jones 1997). Although in both cases the techniques employed in instrument design are well-established, it is only when readily available, reliable, and fairly affordable mass produced instruments are available to working scientists that their full potential can be realized. In both cases the transformation of the tools of the trade serve to transform the trade. Better tools improve the quality of high quality data; as the data improve new analytical perspective are opened.

Matthew Bampton
Geography Anthropology Department
University of Southern Maine

Acknowledgements

My thanks are due to my colleague Dr. Mark T. Swanson of the Department of Geosciences at the University of Southern Maine, who has been my collaborator throughout the development of this project. This project, and continuing work on precision digital mapping, is supported by the National Science Foundation (NSF DUE – 9950822, NSF DUE – 013902).

REFERENCES

Amadesi E., Mora P. 1998, *Discovery of a lucina layer and its reckoning by means of an integrated GPS survey*, «Mensura », 3, 14-15.

Bampton M. 1997, *Archeology and GIS: The view from outside*, «Archeologia e Calcalatori», 8, 9-26.

Bampton M., Flyg P. 1999, *Field mapping the Ahu Ra'ai, La Pérouse Area, Rapa Nui (Easter Island)*, in J.A. Barceló, I. Briz, A. Vila (eds.), *New Techniques for Old Times: Computer Applications and Quantitative Methods in Archaeology*, *Proceedings of the 26th CAA Conference (Barcelona 1988)*, BAR International Series 757, Oxford, 149-152.

Bodin U., Flyg P. 1997, *Personal communication, Riksantikvarieämbetet, Avd för Arkeologiska Underskökningar*, Stockholm, Sweden, May 11, 1997.

Davidson I., Ridges M. 2001, *Modeling the Analysis of Stone Artefact Variation in Cultural Resource Management Projects: Australian Case Studies Using GIS*, *XIVth Congress of the International Union of Prehistoric and Protohistoric Sciences (Liège 2001)*.

Day J.J., Norman D.B., Upchurch P., Powell H.P. 2002, *Dinosaur locomotion from a new trackway*, «Nature», 415, 494-495.

Eco U. 1994, *On the Impossibility of Drawing a Map of the Empire at a Scale of 1:1. How to Travel with a Salmon and Other Essays*, Orlando, FL., Harcourt Brace.

Formento-Trigilio G., Pazzaglia F.J. 1998, *Tectonic geomorphology of the Sierra Nacimiento: Traditional and new techniques in assessing long-term landscape evolution in the southern Rocky Mountains*, «Journal of Geology», 106, 433-453.

Johnson I., North M. 1997, *Archaeological Applications of GIS*, Sydney University Archeological Methods Series 5, Sydney.

Jones T.E. 1997, *History of the Light Microscope* (http:/www.utmem.edu/~thjones/hist/hist_mic.htm).

Kurushin R.A., Bayasgalan A., Olziybat M., Enhtuushin B., Molnat P., Bayarsayhan C., Hudnut K.W., Lin J. 1997, *The Surface Rupture of the 1957 Gobi-Altay, Mongolia Earthquake*, Geological Society of America, Special Paper 320.

Lake M. 2001, *A Multi-Agent Computer Simulation of Mesolithic and Early Hominid Land-Use Patterns*. *XIVth Congress of the International Union of Prehistoric and Protohistoric Sciences (Liège 2001)*.

Philpotts A.R., Gray N.H., Carroll M., Steinen R.P., Reid J.B. 1997, *The electronic total station - a versatile, revolutionary new geological mapping tool*, «Journal of Geoscience Education», 45, 38-45.

Swanson M.T. 1999, *Kinematic indicators for regional dextral shear along the Norumbega fault system in the Casco Bay area, coastal Maine*, in A. Ludman, D.P. Jr. West, *Norumbega Fault System of the Northern Appalachians*, Geological Society of America, Special Paper 331, 1-24.

Swanson M.T., Bampton M. (in preparation), *Precision Digital Mapping of Kinematic Indicators in the Norumbega Fault Zone*, Casco Bay, Maine.

ABSTRACT

Over the last five years global positioning systems (GPS) and electronic total stations (ETS) have become viable tools for use in archaeological field mapping. When used in conjunction GPS and ETS can generate precise, accurate, and georeferenced three-dimensional digital data sets in real time. As survey work proceeds associated attribute tables, incorporating field measurements and commentary can also be created, and the

entire data set can be imported directly into a geographic information system (GIS). This technique may be called precision digital mapping, and produces accurate, high density data sets of unprecedented richness. The revolutions in data management, visualization, and analysis made possible by GIS are now being mirrored by a revolution in field mapping technique.