It's about Time: Temporality and Intra-Site GIS

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Abstract

Archaeology is fundamentally temporal: GIS approaches that ignore time are therefore limiting. Further, archaeological time is complex. This paper focuses on the complexities of the constructed temporality of chronology and, in particular, its inherent uncertainties; uncertainties that render existing temporally-precise temporal-GIS (TGIS) unable to adequately (and appropriately) conceptualise and analyse archaeological data. This research seeks to bring TGIS functionality to existing GIS (ArcGIS), but based upon explicitly archaeological data and questions. The software handles the fundamental uncertainty of archaeological dates, by using several different methods to compare the internal probability intrinsic to each date to a selected date range. The output can normalise any spatial analysis, taking it forward into the time dimension. As such, it forms a foundation for introducing further temporal models into analyses, whilst remaining within the "software horizons" of archaeologists.

Keywords

TGIS, GIS, temporality, uncertainty, radiocarbon dating, chronology, intra-site GIS

1. Introduction

Fundamentally, archaeology is concerned with time. Change, chronology, and the elucidation of past events are intrinsic concerns of the discipline. Of course, archaeology also takes place within space and, as a result, the use of GIS to explore archaeological questions has become widespread. However, conventional GIS are temporally frozen: they are only able to deal with aggregated period data. This situation elides the complexity of many of our models of the past.

This temporal inadequacy of conventional GIS has been long discussed. Many archaeologists have written about the problem (e.g. Castleford 1992; Daly and Lock 1999; Johnson 1999), but few published attempts have been made to solve it in practice. Those that have, have tended towards case specificity with only limited applicability beyond their intended project (e.g. Ceccarelli and Niccolucci 2003). Furthermore, work of wider applicability has tended to focus on issues somewhat tangential to the core issues of archaeological TGIS (temporal GIS) that will be outlined below (e.g. Johnson 2005; Johnson 2004b). Perhaps most importantly, these earlier works were unable to fully engage with recent critical thinking on the nature of archaeological time.

2. Archaeological temporality

To simplify somewhat, archaeological time takes two forms. Firstly, there is the temporality constructed by archaeologists when establishing their chronologies (discussed at length in Lucas 2005). Secondly, there is the perceived temporality of persons in the past (see Bradley 2002). The latter is arguably more difficult to characterise and I would argue depends upon careful analysis and interpretation carried out within the first of these frameworks. I would argue that to attempt to consider these concepts using TGIS, the ability to handle chronological time must be incepted first: this forms the focus of the present paper.

Chronological time is itself complex. It is multi-linear and topological, as illustrated by the Harris matrix and its variants (Harris 1989, 33–34; Wheatley and Gillings 2002, 41). It is also fundamentally uncertain. For example, radiocarbon dates carry a complex internal probability illustrated in their familiar "battleship" curves (Aitken 1990, 76–77, 84, 92–93), thermoluminescence and other scientific dates carry probabilities that obey a normal distribution (Aitken 1990, 164–165; Aitken 1997, 211), and even an otherwise accurately dated numismatic or dendrochronological date may only act as a terminus post quem for its context of discovery (Barker 1993, 205).

Beyond these theoretical fundamentals, chronological time has also been developing fast in practice. In particular, this may be seen in the increasing popularity of Bayesian modelling (e.g. Bayliss *et al.* 2007), and also in the use-life approach suggested by Gavin Lucas and others (Lucas 2005, Chapter 4). TGIS that already exist on the commercial market (e.g. Discovery Software's STEMgis[1]) are built around a framework of precisely recorded chronological "instants" placed within modern calendrical and clock time and, as such, fall far short of the needs of archaeology: put simply, the temporal needs of public utilities, urban planners, environmental scientists and others at whom such TGIS are primarily marketed do not accord well with archaeological temporal needs (Daly and Lock 1999, 288–289). As a result, a TGIS is needed that is truly sensitive to the characteristics of archaeological data.

3. Archaeological TGIS: an agenda

The main aim of the project out of which this paper has arisen has been to construct a TGIS for explicitly archaeological requirements. In particular, this TGIS was envisaged as having an analytical emphasis to aid archaeologists in their day-to-day work, in contrast to the current emphasis on visualisation and public dissemination, typified by for example the TimeMap project[2]. The agenda of requirements for development of this everyday archaeological TGIS may be set out as follows:

1. The ability to handle uncertain dates of multiple different forms of uncertainty;
2. The ability to consider the temporal topological relationships inherent in archaeological stratigraphy;
3. The possibility to then model alternative versions of past perceptions of time.

For the present project, it has only been possible to approach a resolution to the first item. Moving the agenda further forward will, ironically, require more time.

Furthermore, if it is accepted that temporally-frozen GIS is inadequate, then it is clearly desirable for TGIS to one day become widely used in archaeology. As such, it is necessary for us to persuade other archaeological users of GIS of these current limitations and to build up desire and demand in the archaeological community for temporally-enabled GIS. To facilitate this process, the decision was taken in this project to implement the software within ESRI's ArcGIS[3] environment, as that software is widely used amongst archaeologists. A bespoke solution in turn demands that users move to new and unfamiliar software which may in turn elide the TGIS evangelism integral to the project. Further, little advantage would be gained in scripting for any alternative software package that was thoroughly embedded in modern clock time. As they are based upon Visual Basic, it is hoped that many GIS-aware archaeologists might experiment with the tools created and, in that sense, the agenda for archaeological TGIS can be moved onward.

4. Dealing with uncertainty

The data loaded into the TGIS must be a shapefile containing two fields: one to carry the minimum possible date for each item and one to carry the maximum. These dates should be entered as an integer year, with negative numbers being used for BCE and positive for CE. The user then selects their time period of interest and launches the calculation procedure (*Fig 1*). The probabilities are written to the layer's table for each item, expressed as a probability of between 0.0 (0% probability) and 1.0 (100%). Some users might be unused to fractional weightings

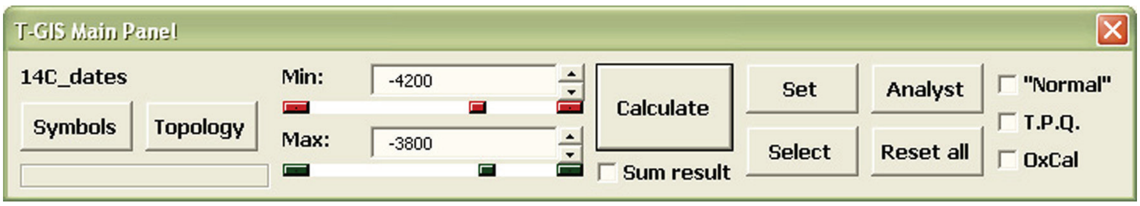

Fig. 1. The main user interface of the T-GIS.

[1] http://www.discoverysoftware.co.uk/STEMgis.htm

[2] http://www.timemap.net/

[3] http://www.esri.com/software/arcgis/index.html

(Ratcliffe 2000, 678), but archaeologists accustomed to working with radiocarbon dates ought to grasp these intuitively. The TGIS models the internal probability within each date using several different methods. Different dating techniques should ideally be separated out onto individual layers, so that their different probability models may be applied. The probability models incepted are as follows:

4.1. Standard probability:

This is calculated by the TGIS as a simple percentage overlap between the time period currently selected in the TGIS and the time period of each date. As such, it is adapted from aoristic analysis (see Johnson 2004a), but without the associated compromises caused by that methodology's division of time into time-slices of specific resolution. For example, an aoristic evaluation at 100 year resolution of the date range AD340–520 would be divided into thirds according to a binary decision of presence or not in each snapshot, and given the following aoristic weights: AD301–400 – 0.33 (present in one of three snapshots); AD401–500 – 0.33 (as previous); AD501–600 – 0.33 (as previous). In truth, however, the probabilities for each snapshot should in fact be: AD301–400 – 0.33 (61 years [AD340 to 400] out of the 180 year span for the date); AD401–500 – 0.56 (100 years out of 180); AD501–600 – 0.11 (19 years out of 180). This is the result that the standard probability calculation in the TGIS would produce.

Primarily, the standard probability is intended for forms of date with no known internal probability model, or models not integral to the TGIS. This would include, in particular, ceramic and other typological dates, and calibrated radiocarbon dates where the full internal probabilities are unknown. In addition, if the user wishes to examine different types of date as part of the same layer, then this would be the recommended probability model for that scenario.

4.2. Normal probability:

The next probability calculation method incepted was designed to capture an internal probability that obeys a normal (or Gaussian) distribution. The normal probability is intended to cater for scientific dates expressed as a date with an error margin, such as thermoluminescence dates and uncalibrated radiocarbon dates. The TGIS assumes that the minimum and maximum given for each date in the layer's data table are expressed at ±2 standard deviations – containing 95% of all possible solutions (Orton 1980, 90–91), as this is conventionally the case when quoting such a date. The TGIS works out the mean and standard deviation, then calculates the probabilities for a series of slices through the date's normal curve where the normal curve overlaps the selected period. These slices are of 1/20 of a standard deviation, resulting in an output precision of better than 1%. When using the normal method, the TGIS works out the probabilities between ±3 standard deviations, to incorporate 99.5% of all possible answers. Archaeologists should always bear in mind, however, that there will always be a tiny percentage chance of the true date falling outside of this bracket - or indeed a bracket of any size (Orton 1980, 91–92).

4.3. Terminus post quem probability:

The terminus post quem probability is intended to cater for dates which may be very accurate in themselves, but where the event of archaeological interest falls after that date. Erring on the side of simplicity, it is modelled as a triangle of constantly decreasing probability, and is particularly intended for numismatic, dendrochronological, and other similar dates. When defining dates of this nature, the user must make an assessment of the likely period during which the item could have been deposited. This date should be given as the maximum and the date of the object itself as the minimum, and the calculation is made using elementary trigonometry.

4.4. Radiocarbon probability:

The final probability model works with the output of the radiocarbon calibration software OxCal[4], and is designed to handle the internal probabilities of calibrated radiocarbon dates and Bayesian modelled dates. Mapping the normal distribution of an uncalibrated date against the vacillations of the tree-ring curve results in a calibrated probability that can oscillate up and down, like the decks, guns and smokestacks of a battleship. Fortunately, OxCal is able to output these internal probabilities in a series of slices, by default five years thick (the TGIS is able to discover this thickness on calculation). To utilise

4 http://c14.arch.ox.ac.uk/oxcal.html

this output in the TGIS, these probabilities should be copied into a table for the entire series of radiocarbon dates in the layer, along with an identifying code for each sample's series of probabilities. This identifying code, conventionally the laboratory code, should also be in the data table for the layer shapefile in the GIS. The user then has to add this probability table to their map and link the date layer to it using a one-to-many relate based upon the identifier common to both tables. Then the TGIS simply has to query the probability table linked to the layer table, and sum the probabilities of any time-slices that fall within the currently selected period for each item.

These four probability calculation methods incepted in the TGIS provide the functionality to handle the vast majority of conventional archaeological dates. Furthermore, the standard probability stands in as a useful approximating catch-all for any dating methods that behave differently. This system for probability calculation is an important step forward beyond the limits of pre-existing TGIS methodologies designed to handle temporal uncertainty, insofar as it gives greater account to the internal probabilities of dates and escapes from some of the limitations of snapshot timeline methodologies.

5. Topology, spatial analysis and cartography

The TGIS also writes a second piece of useful information to the layer's data table when calculating the probabilities: that is, the temporal topological relationship between each date and the selected period. The results are expressed with regard to the date's relationship to the selected time period. As such, they may be:

- Date falls before the time period (i.e. 0.0 probability);
- Date overlaps the maximum of the time period;
- Date overlaps all of the time period;
- Date falls within the time period (i.e. 1.0 probability);
- Date overlaps the minimum of the time period;
- Date falls after the time period (i.e. 0.0 probability).

These six states capture all of the six important temporal topological relationships that may exist between any date and the time period of interest. The recording of this topology enables the user to be aware of how any particular date relates to the selected time period and also gives a strong clue as to temporal change across the dataset.

The probabilities and these topological relationships are written to the data table of the shapefile with which the user is working. This means that users are easily able to perform any analyses that they wish to carry out on the probabilities of the dates relating to the current period of interest. Spatial analyses may use the probabilities to normalise any output (analogous to interpolation of a terrain model from spot heights) extending spatial analysis into the temporal dimension. As an aid to this, the "Set"

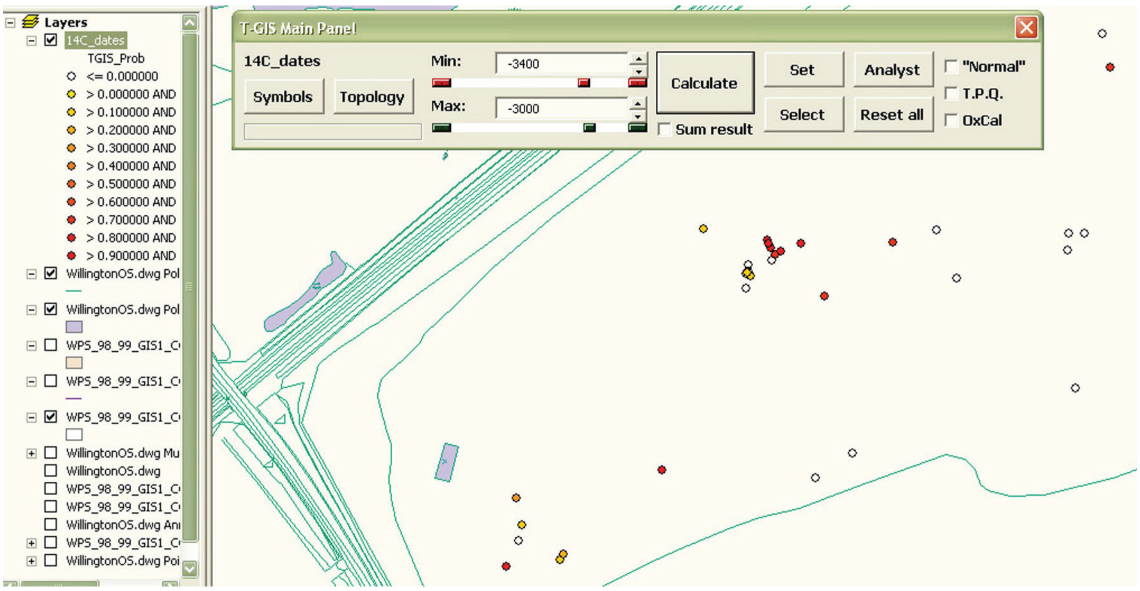

Fig. 2. The display of dates coloured according to probability. No colour is zero probability, ramping up through yellow to red as probability rises to 100%.

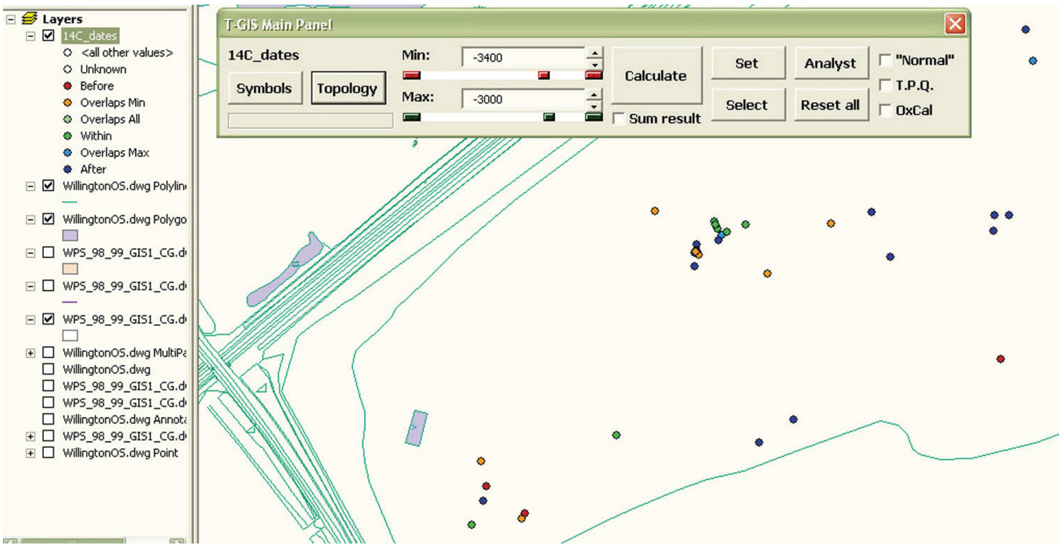

Fig. 3. The display of dates according to temporal topology. The colour coding is according to the temporal topological relationship between each date and the currently selected time period.

button enables the user to set the period of interest to the minimum and maximum of a currently selected date: this is a form of temporal buffering. Further, the "Select" button enables the selection of dates above a certain probability. Finally, the user is able to apply whatever symbologies they wish to the dates, but two specific systems are built into the TGIS (*Figs. 2* and *3*). Between them, they provide quick visual assessment of temporal probability "hotspots" and broad temporal change across the site in relation to the currently selected period. Some dates may hide behind one another in the display, but this greater complexity should come out in any spatial analysis undertaken.

6. Regional TGIS: an aside

Naturally, the TGIS is also applicable to inter-site, regional datasets. Specific to that usage is the ability to sum the results of any output. Summing radiocarbon dates is not necessarily worthwhile (Bayliss *et al.* 2007, 8–11), but summing dates can be more useful for regional data. For example, field-walked pottery datasets for a region may comprise many thousands of records from only tens or hundreds of sites. In this instance, summing the results of any probability outputs is essential to avoid confusion. This summed output may be normalised by another field in the layer table, such as sherd count or weight, and is output to a new shapefile by the TGIS. It is then possible to produce trend surfaces or perform other spatial analyses, based upon outputs that are temporally weighted according to the probability of their membership of a period of interest. This is in clear contrast to the conventional methodology, where it is only possible to work with relatively closely dated pottery and where time periods may overlap according to the specific dating of the pottery types concerned.

Further, the analyst tool built into the TGIS can sum probabilities across a whole layer or groups of layers, or a selected subset of a layer. This output can be copied into a spreadsheet and graphs produced. Through this methodology, weighted timelines may be built, which could be considered a step along the road towards calibration of pottery dates (as advocated in Going 1992). The analyst tool may be run using different period widths to consider different scales of rates of change, and the period widths may be grouped back into larger periods according to the percentage rate of change for analysis back in the main user interface.

7. Conclusions

The TGIS script produced for this project will hopefully help to develop the agenda for future archaeological TGIS, through enabling the possibility of undertaking spatial analysis with a more powerful connection to the temporalities and uncertainties of archaeological data. Yet it remains within the "software horizons" of most archaeological users of GIS. The next stage in its development would be to integrate a system for dealing with the topological relationships between archaeological dates, i.e. stratigraphy. How this will be accomplished is, as of yet, uncertain. Doing so falls outside of the remit of this project and would probably require a more bespoke solution, outside of ArcGIS. Such a move would elide the democratic aims of this project and may have to wait for the next generation of GIS.

Finally, over time the vast majority of GIS will come to incorporate temporality. Unless we as archaeologists can demonstrate to GIS developers how their current temporalities are insufficient for our needs, this step forward for mainstream GIS will likely leave us behind. Furthermore, it may come to pass that alternative models of time become important to other disciplines outside of archaeology: this is an area where we can perhaps lay the groundwork now that will serve many non-archaeological TGIS users, as TimeMap can claim for animation and web delivery (Johnson 2004b, 29). Hopefully, through projects such as this one, and TimeMap, we can begin to make that demonstration to GIS developers. In the end, only time will tell.

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