GIS and time

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Since maps present a snapshot of all the real world phenomena they are concerned with at the time of publication, they are not designed to show change through time. As GIS have typically evolved from digital mapping systems, so they have inherited this limitation. This section will briefly explain the different situations that challenge GIS representation, and then outline an example solution to one of these challenges.

A static vector GIS with layers each containing geometry representing the state of real world phenomena can be extended to handle changes in the phenomena. So, if you have a property GIS storing land parcels it is possible to store multiple 'states' for each land parcel, for example, to deal with the subdivision of a land plot into two or more parts. Hornsby and Egenhofer (2000) presented a formal scheme for spatio-temporal knowledge representation, based on possible changes to phenomena, modelled as discrete objects at a high level of abstraction. In their scheme objects representing phenomena can be in the following states: existing; not existing with no history of a previous existence; or, not existing but with a history of previous existence. Changes from one state to another are defined as 'transitions', which in total allows nine combinations: continue existence without history; create; recall; destroy; continue existence; eliminate; forget; reincarnate; and continue non-existence with history.

Keeping track of this change involves some extensions to the static GIS data model known as temporal GIS (Langran 1992). Essentially, this involves keeping track of all the 'states' of each object in a database, as the creation of a new layer each time an object changes leads to an unacceptable expansion of layers. By creating two sets of tables to handle firstly, object identity (with rows corresponding to objects known to the system) and secondly, all the change (with rows corresponding to change in objects that actually change) it is possible to store this kind of discrete change in well defined phenomena. Systems like this have been implemented in commercial GIS such as the ESRI Arcview Tracking Analyst, in which rows in a table store different states of an object and allow them to be visualised as they change through time.

These temporal GIS approaches are not suitable for other applications such as the representation of highly dynamic environmental phenomena change at a fine temporal resolution (minutes to weeks) in a continuous way, for example, in the migration patterns of animals or the continuous change of the tides in the coastal zone. In these application areas new GIS designs have been proposed, largely based on object-oriented designs. The key design issues in object-oriented approaches to handling spatio-temporal behaviour are firstly what approach should be used to define the spatio-temporal phenomena such as the moving herd of animals? For example, you can use events to bound spatial objects in temporal duration so as to create spatio-temporally extended objects. Events in time are stored, which define different objects either side of an event, e.g. the location of the herd each week. Or, you can make time a property of the objects so that objects have a spatial and temporal extent e.g. the line followed by the herd of animals as they move around during a year, Neither of these approaches has been implemented in a mainstream commercial GIS as they need designing specifically for the application envisaged, although there are lots of implemented research systems (Raper 2000).

Processes such as tidal flow or rainfall movement are however, more or less impossible to represent in this design as there are no 'objects' to represent as part of the phenomena. In this case it is conventional to use a raster rather than vector approach, making each cell a size suitable for the application being modelled. This kind of dynamic multidimensional process modelling aims to develop functional models of behaviour for these systems. Despite the fact that such processes surround us in society and the environment there are few representations of this kind. It is likely that this shortfall derives both from computational limitations and from the lack of knowledge of the dynamic systems concerned.

An example of a representational problem faced by a real GIS application can be seen in an example of a project to monitor coastal change on the east coast of England. Scolt Head is a barrier island consisting of a line of sand dunes backed by salt marshes, which forms part of the low-lying North Norfolk coast. It experiences a westerly longshore drift of sediment into a spit (sandy bar) at the western end (Far Point) reflecting the tidal circulation and the dominant north east wave energy in this area. The dynamic form of these spits reflects a balance between wave and tide energy in the short term and relative sea level change in the medium and long term. Hence, spits and bars marginal to tidal channels may be both sensitive indicators of coastal

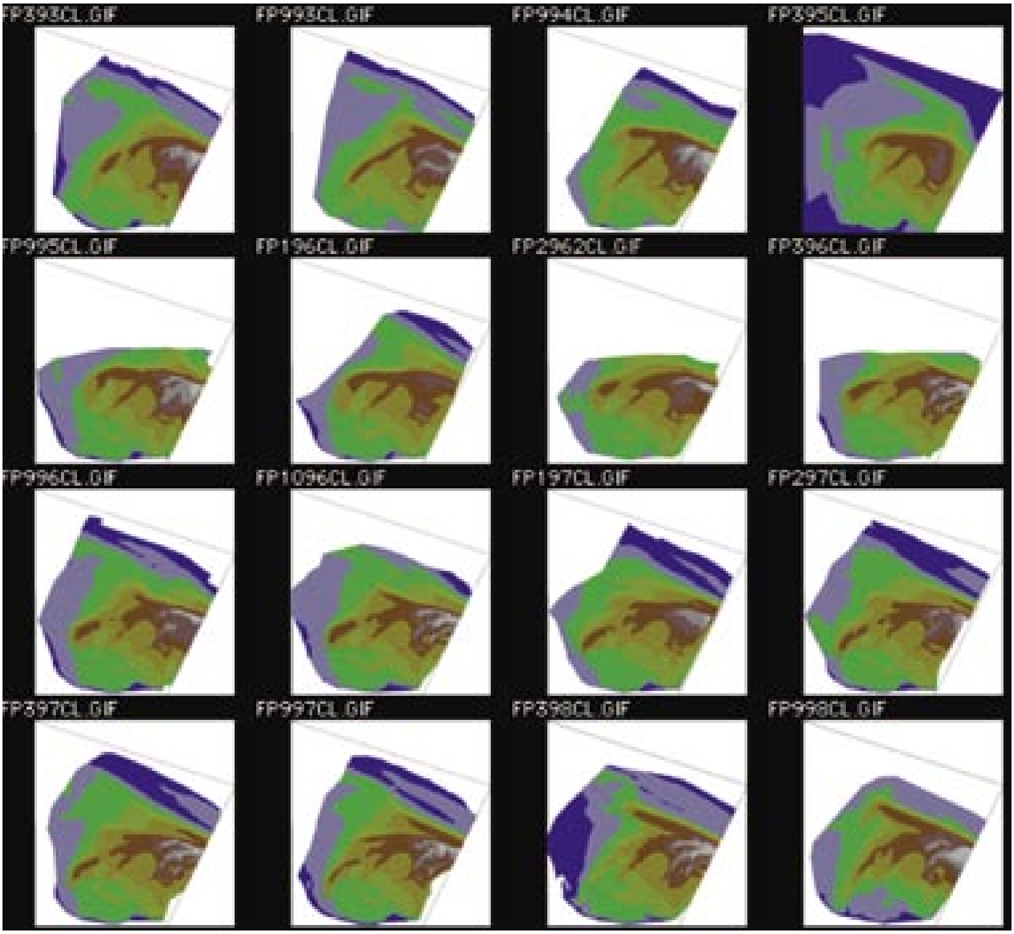

Figure 1 Far Point, Scolt Head Island, Norfolk (Eastern England) Snapshot contour maps (1m colour interval) of coastal spit landforms and their change through time (FPmonth/yearCL notation in labelling). Modelled area is 1km across.

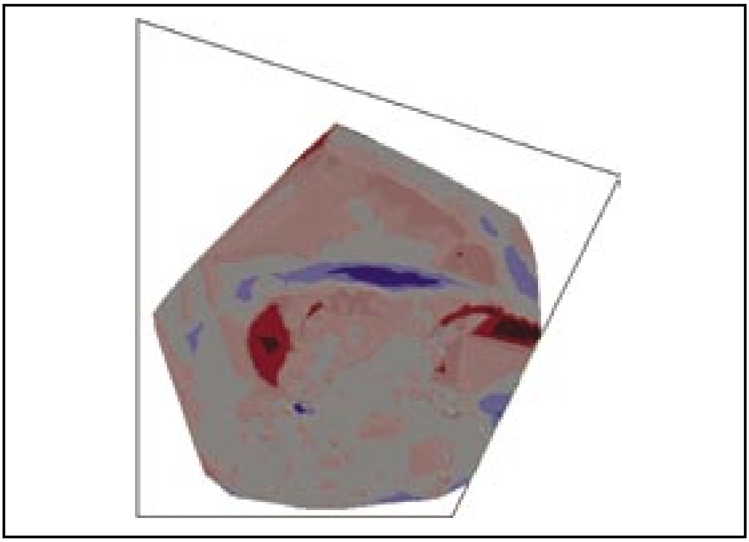

Figure 2 Far Point, Scolt Head Island, Norfolk (Eastern England). Difference map between intertidal terrain surface in March and September 1995 (blue is terrain lowering [erosion] and red is terrain elevation [deposition]). Modelled area is 1km across.

change *and* reservoirs of sediment whose budgets may be of considerable importance to the management of the adjacent coastline on an annual and decadal scale.

Representing these landforms and their change is complex. Surveys using a total station surveying instrument with sampling points at approximately 10m horizontal resolution over 13 years of the rapidly changing spits on Scolt Head Island have produced over 20 separate maps of the terrain (Figure1) at Far Point (Raper *et al.* 1999) and over 20,000 data points describing terrain elevation and surface sedimentary composition. Change has been explored by comparing the surface elevation models at different times to see if the amounts lost and gained from the surface can be correlated with wave energy inputs and sea level rise (Figure 2). Looking at the areas of erosion and deposition and comparing their magnitude allows estimation of the changes produced by storms of particularg magnitude.
The Scolt Head example shows both how GIS can be used to model temporal change but also what still needs to be done. There is no way to automatically compare these surfaces in a GIS as they are based on (inevitably) different sample data points collected at different times as the landform itself is moving and changing through time. The GIS has no way to define spatio-temporal objects or events, and so contains no toolset to allow spatio-temporal analysis.

References

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Jonathan Raper, joined the Department of Information Science in 1999 as Professor of Geographic Information Science and became Head of Department in 2003. Jonathan founded the Geographic Information Science Group at City University in 1999 and has led a series of research projects since then including: Hypergeo (Mobile tourist systems), WebPark (Virtual Guides for the outdoors), LBS4all (location-based services for visually-impaired and older people) and Locus (Augmented reality tools for mobiles) projects. Before he came to , Jonathan was at Birkbeck College, University of London for 11 years. Jonathan is a graduate of Cambridge University in Geography, and gained his PhD in Geomorphology in 1988.