SPATIAL AND TEMPORAL VISUALISATION OF THREE-DIMENSIONAL SURFACES FOR ENVIRONMENTAL MANAGEMENT

Malcolm J. Herbert and David B. Kidner

Department of Computer Studies
University of Glamorgan
Pontypridd, Mid Glamorgan
United Kingdom CF37 1DL

ABSTRACT

In geographical modelling, various triangulation techniques are used to model three-dimensional data, to provide computer-based visualisation. This now forms an important component of many geographical information and three-dimensional modelling systems.

There are an increasing number of data sets that now provide information about a particular model with a temporal element, with a repeated number of measurements made at a particular site. The resultant images make up a series of snapshots of the model, but may not represent the significant points in the life of the model. We propose two methods that use serial section reconstruction techniques, which can be used to construct three-dimensional models and to interpolate new models at other moments in time.

A prototype system has been developed and is illustrated with data provided by the Countryside Council for Wales of a sand-shingle spit. This has been surveyed at regular intervals since 1981, to examine the effects of coastal management and climatic conditions on the spit.

INTRODUCTION

A three-dimensional object can be commonly represented by a set of serial sections, where contours define the intersection with a plane (or section), and the surface of the object. On a conventional map, contours of varying heights (or depths) appear together on a two-dimensional drawing to give an indication of the shape and form of the surface. Other disciplines, such as medical imaging (Rhodes 1990), geology, and palaeontology (Ager 1956), use serial sectioning to produce a set of two-dimensional images of an object. This allows the observer to view otherwise hidden features.

Various techniques have been developed to create computer-based three-dimensional models from these sections (Ekoule, Peyrin and Odet 1991, Meyers, Skinner and Sloan 1992).

This paper illustrates how two surface reconstruction techniques can be used to display three-dimensional geographical data. It also discusses how these methods can be adapted to carry out temporal interpolation between existing three-dimensional models.

SERIAL SECTION RECONSTRUCTION.

Introduction.

The problem of reconstructing three-dimensional surfaces from two-dimensional sections can be broken down into a number of sub-problems (Meyers, Skinner and Sloan 1992), (see Figure 1). The *correspondence problem* is concerned with specifying the underlying topology of the object and the correct connectivity between contours in adjacent sections. The *tiling problem* is that of finding the best set of triangulated facets to define the surface between a pair of connected contours. The *branching problem* occurs when the connectivity between contours is not a simple one-to-one scenario and the *surface fitting problem* fits a smooth surface to the resultant triangulation, to facilitate visual inspection of the reconstructed object.

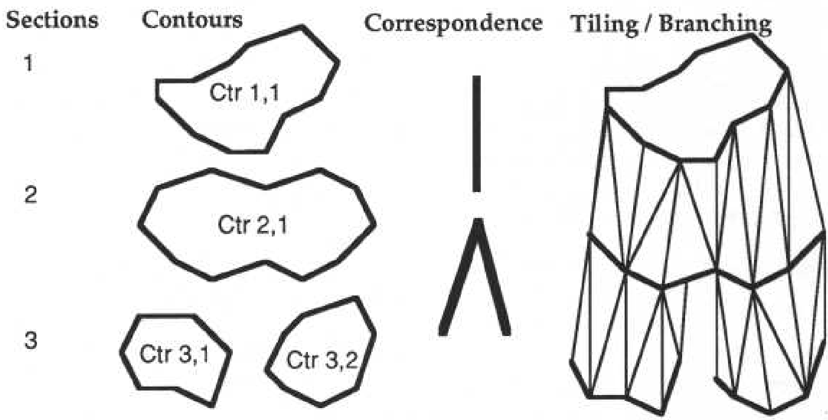


Figure 1. Serial Section Reconstruction Sub-Problems.

Tiling and Branching Problems.

The tiling problem was the first sub-problem to be addressed in detail by researchers. There are a number of solutions, which decompose the problem from the section level to the contour level and then 'stitch' together a triangulated surface between a pair of contours (Keppel 1975, Fuchs, Kedem and Uselton 1977, Christiansen and Sederberg 1978). Refinements have been made to these original methods to enable the handling of more complex scenarios (Sloan and Painter 1988, Ekoule, Peyrin and Odet 1991), and to resolve the branching problem (Meyers, Skinner and Sloan 1992). A solution based on three-dimensional Delaunay triangulation (Boissonnat 1988), tackles the problem at the higher, section level and therefore has the advantage of not requiring the prior resolution of the correspondence problem or the need to treat branching as a special case. This method has been used successfully for complex objects in medical imaging (Lozanoff and Deptuch 1991), but it has not received the same attention as the contour-level methods.

Correspondence Problem.

The correspondence problem has received less attention from researchers than the tiling problem. This is because it's importance is not as great when dealing with well sampled data sets, as are encountered in medical imaging. Reconstruction algorithms usually rely on user input (Giertsen, Halvorsen and Flood 1990), or simple metrics (Ekoule, Peyrin and Odet 1991) to resolve the problem. More complex data sets have been solved automatically (Shinagawa and Kunii 1991, Meyers, Skinner and Sloan 1992) using graph based approaches, whilst information about the relationships between contours in the same section have been used to help deduce a solution (Haig, Attikiouzel and Alder 1991).

Surface Fitting Problem.

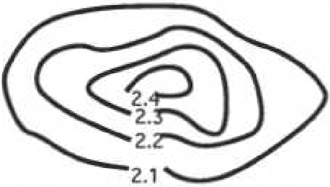
Surface fitting is used to improve the quality of the final three-dimensional image. Usually the triangulated facets will not provide an adequate result, as the contours do not necessarily sample the original object too well. A common method is to fit parametric surface patches based on the vertices of triangulation (Farin 1990).

THREE-DIMENSIONAL RECONSTRUCTION.

A set of programs has been developed, primarily to reconstruct palaeontological specimens from serial sections (Herbert 1993). These have also been applied to a number of other geoscientific areas. These include contour data from land surveys as well as geological data. The paper concentrates on the tiling and branching algorithms and their potential for temporal interpolation, but notes that the successful resolution of the correspondence problem plays an important part in producing complex images. This can be attributed to the nature of the data and lack of sampling in many geoscientific data sets. Two different approaches to the tiling and branching modules have been implemented and are described below.

Contour-Level Method.

The first is a contour-level algorithm based on the heuristic proposed by Christiansen and Sederberg (1978). It produces a series of triangular facets between adjacent contours, which have been matched after the resolution of the correspondence problem (see Figure 2) . Changes to the original algorithm allow the tiling of extremely concave contours and the detection and resolution of complex branching scenarios (Herbert 1993).



Contours - with Heigth(Depth).

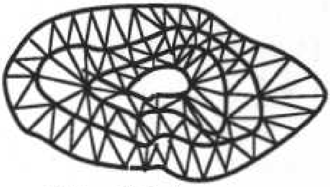

Tiling Solution.

Figure 2. Sample Contours, with a tiling solution.

Section-Level Method.

The second method, a section-level routine based on that of Boissonnat (1988), has been developed, both to compare it with the contour-level routine and also to evaluate it's potential with complex branching scenarios. Here surfaces are constructed between all the contours that appear in an adjacent section pair simultaneously. The method consists of two stages. The first stage constructs a two-dimensional constrained Delaunay triangulation (CDT), based on the contour vertices and edges, in both of the sections. The second stage uses these triangulations and their Voronoi duals to construct a set of tetrahedra that lie between the two sections. The final surfaces are obtained by stripping away unwanted tetrahedra from the three-dimensional object, and extracting the external triangular facets. A number of improvements to the Boissonnat method have been made, including using an iterative method to calculate the two-dimensional CDT (De Floriani and Puppo 1988) . Other enhancements allow the reconstruction of objects with holes and the ability to restrict certain surfaces between contours, allowing an object to be made up of separate components.

By adapting the routines for three-dimensional reconstruction, it is possible to build another model at any time throughout the history of measurement of the site. The methods can be used to interpolate the framework of a new model, by deducing new contour sets, based on two existing models. For a pair of three-dimensional models, one at time t1 and the other at time t2, a number of new contour sets can be interpolated, whose times lie between those of t1 and t2 (see Figure 3).

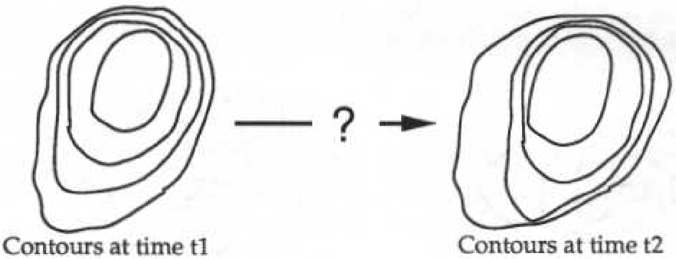


Figure 3. Changes in Contours through time.

Certain features must be present in a set of data, to make temporal interpolation possible, using the methods described below.

1. The contours are recorded at the same heights and intervals throughout the sequence of surveying.
2. The surveys are recorded in some form of standard coordinates and contain reference points that appear in all of them. This enables the models to be aligned.

This situation which allows temporal interpolations to be made can be defined as follows. There exists a number of surveys or measurements, taken at time $t_1 \dots t_n$. For each survey, there are a set of sections $s_1 \dots s_n$, which contain a set of contours $c_1 \dots c_n$. Only one section will exist at a certain height (depth) and there will be one or more contours in each of the sections. A contour vertex is defined as a four-dimensional coordinate (x,y,z,t), where x and y are longitude and latitude, z is the height (depth) value of the section and t is the time.

Contour Level Method.

This method requires the correspondence between pairs of contours in the adjacent models, which have the same height (ie in the same section), to be deduced first. The tiling and branching algorithm can then follow this to produce a triangulation between the contour pair. The height values for the contour are ignored during this process and this is replaced with the time value. From this triangulation, a new contour, with a time value lying between the times of the two original contours can be extracted (see Figure 4). This contour will be at the same height (depth) value as the original contours.

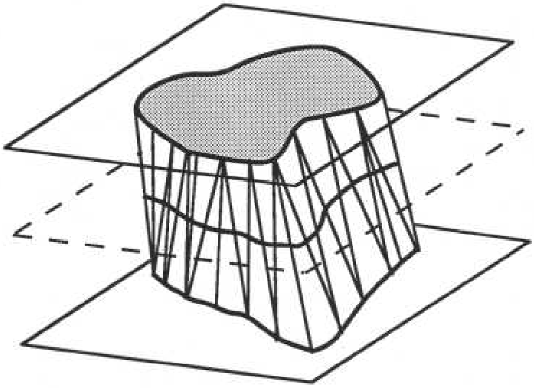


Figure 4. New Interpolated Contour.

Hence, a set of contours at the new time, can be extracted from sets of contour pairs, which are at various height levels in the original models. A three-dimensional model can then be built from these contours at this new time. Whilst this process is relatively simple for straightforward sets of data, as with the three-dimensional process, there is a need for an automatic correspondence solution when reconstructing more complex data sets.

Section-Level Method.

This method also requires the matching of sections of the same height value in a time adjacent pair of three-dimensional models, but does not require the correspondence to be resolved. As with the three-dimensional reconstruction section-level method, branching situations (see Figure 5) are handled by the routine automatically. Again the height (depth) level is replaced with the two time values, and a new cross section is calculated at the new interpolation time.

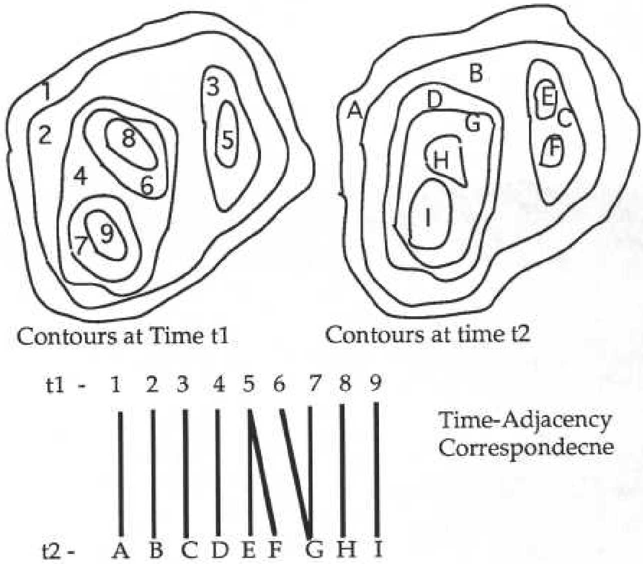


Figure 5. Time Adjacency Correspondence, with Branching.

This method may be more suitable for modelling complex situations, as it does not require the correspondence to be resolved beforehand and since it is polyhedra-based it can handle objects with more complex topology (Lozanoff and Deptuch 1991).

MODELLING FOR ENVIRONMENTAL MANAGEMENT

An area of the Gronant Dunes, near Prestatyn, North Wales, United Kingdom, a designated Site of Special Scientific Interest (SSSI), has been surveyed regularly by the Countryside Council for Wales (CCW) since 1981. This is in order to monitor topographic changes to the site and to assess how the nesting birds are being affected, especially since groynes have been installed further along the coast. The prime motivation for the computer-based modelling was visualisation and the opportunity to experiment with the extension to serial section reconstruction to enable some form of temporal interpolation. The contours from the maps produced each year were digitised and three-dimensional surfaces reconstructed using both of the contour and section-level models. The three-dimensional images benefitted from the use of false height values for the contours to help visualisation, as well as the use of surface fitting in the form of Gouraud shading.

The interpolation and creation of new models at intermediate points in time can show the rate of change to the site and also the way in which it changes. This data when used in conjunction with other information, such as climatic conditions, can be used to predict effects on the site and plan for future management. It provides additional ways in which the data can be analysed and presented.

CONCLUSION.

With both the three-dimensional reconstruction and the temporal interpolation, the section-level or Boissonnat method is capable of handling more varied data sets, without the need to solve complex correspondence situations. However, the contour-level method is more flexible, in that by defining the correspondence solution prior to tiling , the underlying topology of the final three-dimensional object can be determined.

The data set that has been presented is fairly straightforward and there is no doubt further work is required to model more complex geoscientfic data sets. Firstly there is potential for the section-level or Boissonnat method to interpolate between two complete three-dimensional model pairs without decomposition to the section level. The surface facets could be used to build a set tetrahedra directly, with new intermediate surfaces being extracted from them. Another area involves the development of more accurate solutions to the correspondence problem, so enabling the contour-level method to be more effective with highly complex data sets, both in three-dimensional reconstruction and temporal interpolation.

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