THE DESIGN OF SPATIAL DATA WAREHOUSE

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Abstract

This paper states that it is necessary to develop the spatial data warehouse for the digital earth development, the spatial data integration and the spatial DSS. The frameworks of the spatial data warehouse are designed, which are the organizational content, the functional flow chart, the network structure and the hardware & software environment.

1. Introduction

To meet the demands of the global change and the continual development, it is necessary to integrate, generalize and save data sets, which come from different units and departments, according to unification view of information and main subjects. These data sets are combined with a kind of specialty models by different directions in order to develop DSS.

1.1 The needs of digital earth development

The aim of digital earth is to integrate the spatial data and the thematic data, which comes from nature source, environment, society, economy, military etc., to form the framework of spatial information from local to whole parts, region to globe. The framework in digital earth is established on the distributing network and is based on the common geographic coordinate system. Besides to support the integration, aggregation and mutual operation of the spatial data sets, the main function of framework is to overlay the thematic data sets on the spatial data sets to support DSS and the scientific research for some organizations and departments. These thematic data sets which contain temporal data are consist of the data sets of natural source, environment, society, economy, military etc. These data sets are saved in different nodes on the spatial information network. It is a key technology for digital earth to how to obtain the spatial data sets and thematic data sets from different spatial databases and thematic databases in different organizations and departments and how to integrate, generalize and save these data sets according to the principle of unification view of information and main subjects.

1.2 The needs of integration for the spatial data sets

Because of the development and application of GIS, it results in the multi-source spatial data sets that make some difficult for the application and share of the spatial data sets. The characters of the multi-source spatial data sets are concluded below:

- Multi-semantic character
- Multi-spatiotemporal character
- Multi-scale character
- Multi-mode character to obtain spatial data sets
- Multi-format character to save spatial data sets

With development and popularization of Internet in computer, it is necessary for different organizations and departments to share information. Also, geographic spatial information is asked to share. With development of information technology and GIS, GIS has divorced from pure geographic system of science and technology and is combining with IT. People demand more and more geographic spatial information. Owing to multi-semantic character, the multi-spatiotemporal character, multi-scale character, multi-mode character, multi-format character for spatial data sets and isolation development of GIS, it becomes difficult to share GIS information. Because of emergence of digital earth concept, it is an important foundation to share GIS information for the application of geographic spatial information in all kinds of unit. It is a key step for sharing GIS information to integrate Multi-semantic, Multi-spatiotemporal, Multi-scale, Multi-mode and Multi-format GIS data sets.

1.3 The needs of the spatial DSS

1.3.1 The main elements to determine spatial DSS

The main elements to determine spatial DSS include the spatial information, the thematic information and the temporal...
information which make up of the environment information. The content of the spatial information contains Geodetic control database, Orthoimage database, Elevation model database and digital map database. The content of the thematic information contains politics factor: economic condition, society environment, nationality and culture nature, weather condition, communication equipment, troop information, traffic status, science and education, medical treatment etc. The content of the temporal information contains time information that is combined with the spatial information and the thematic information.

1.3.2 the data characters to determine spatial DSS

Spatial DSS is based on the spatial information, the thematic information and the temporal information. It is impossible to determine spatial DSS with traditional databases. In condition of high technology, there are five abilities for spatial DSS. They are described below:

1. Data integration

The data sets to be integrated are needed for spatial DSS. Not only the spatial DSS needs the spatial data sets, but also the spatial DSS should own to the thematic data sets and the temporal data sets. The traditional databases are not provided with the capability of data integration for the spatial data sets, the thematic data sets and the temporal data sets.

2. Data generalization

Spatial DSS needs a lot of data sets to be generalized. Before spatial DSS is operated, a number of detail data sets must be generalized into outline data sets. It is impossible for the traditional databases to generalize the spatial data sets and the thematic data sets.

3. Data dynamic integration

After data integration, if the data sets that happen to change cannot connect with people, spatial DSS shall be based on old data sets in order to make an error determination for spatial DSS. It is impossible for the traditional databases to dynamically integrate the spatial data sets and the thematic data sets.

4. Temporal data

It is an important for spatial DSS to own a lot of the temporal spatial data sets and thematic data sets. In traditional databases, a lot of the temporal data sets cannot be saved.

5. Multi-scale spatial data

The topographical environment of spatial DSS is based on multi-scale spatial information so that leader acquaints him with information of topographical environment in area from macroscopic state to microcosmic state. The paper map provides the spatial information of region by some scale map. It is too difficult to select multi-scale spatial information in paper map for spatial DSS. It is possible for leader to obtain multi-scale spatial information for spatial DSS by establishing some scale map database and using multi-scale selection technology of spatial information.

With development of computer technology and new demands to be provided by users, some spatial databases cannot meet the needs of the digital earth development. The spatial data integration and the spatial DSS. People try to process data in the spatial database in order to form an environment of subject-oriented, integration-oriented, generalization-oriented, dynamic integration-oriented, temporal-oriented, multi-scale-oriented, analysis-oriented. Until meta-phase of ninety ages, the theory and technology of the spatial data warehouse begins to come into being. Based on the spatial database, the thematic database and other data files which come from different units, different mediums and different structure, the main aim in this paper is to provide an structure environment of subject-oriented, integration-oriented, generalization-oriented, dynamic integration-oriented, temporal-oriented, multi-scale-oriented, analysis-oriented for the digital earth development, the spatial data integration and the spatial DSS by the theory and technology of the spatial data warehouse and the network technology of Internet/Intranet.

2 Description of the framework

2.1 the organizational content

The spatial data warehouse is divided into five parts that are described below:

- the framework of spatial data
- the aggregation of spatial data
- the management of spatial data warehouse
- the selection of multi-scale spatial data
- the analysis of spatial data

2.1.1 Research and establishment for the framework of spatial data

The framework of spatial data consists of the spatial data and the thematic data and provides an interface keyword to query the spatial data and the thematic data. The research contents in the framework of spatial data are to obtain and manage the spatial data and to obtain and manage the thematic data.

2.1.2 Research and establishment for the aggregation of...
spatial data

The main aim of the aggregation of spatial data is to study how to apply the technology of the mutual operation, transformation, integration and generalization for supporting the integration of multi-source data sets which have multi-semantic character, the multi-spatiotemporal character, multi-scale character, multi-mode character, multi-format character. Its research fields contain the mutual operation, transformation, integration and generalization.

2.1.3 Research and establishment for the management of spatial data warehouse

According to Digital Earth calling for the sharing of spatial information, the main subject of the spatial data warehouse is research how to manage multi-source data sets, that are the spatial data, the thematic data and the temporal data. Its main contents are to how to design the conceptual mode, physical mode, logic mode and systematic structure for the management of spatial data warehouse.

2.1.4 Research for the analysis of spatial data

According to Digital Earth calling for the analysis of spatial information, it is main suppose for the analysis of spatial data to analyze the integration data sets of the spatial data and the thematic data. Its main research contents are the conformation analysis, the overlay analysis, the buffer analysis, the connection analysis, the network analysis, the statistic analysis, the Cube analysis.

2.1.5 Research for the selection of multi-scale spatial data

Its aim is to build up some scale spatial databases, to select data according to geographic feature grade, to code geographic feature, to construct generalization model of geographic feature and to design the multi-scale map symbolic base.

2.2 the functional structure

The functional structure of the spatial data warehouse is composed of the functional flow chart, the network structure and the hardware & software environment that are drawn below (refer with Fig.1, Fig.2, Fig. 3).

3 Conclusion

The theory and technology of data warehouse is created in ninety. In metaphor of ninety ages, data warehouse is developed very well. In USA, data warehouse is a hot technology after Internet. So far, the theory and technology of spatial data warehouse is begun to study. Its purpose is to support the development for the digital earth development, the spatial data integration and the spatial DSS. Hence, we should catch hold of this opportunity of development of data warehouse to study and establish the spatial data warehouse for supporting our country NSDI.

CONFERENCES

HTTP://www.esri.com/base/company/openGIS
http://nli.nist.gov/niiinfo.html
Fig. 2: The chart of network structure
Fig 3 the chart of hardware & software environment
Terrain Modelling from Contours

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ABSTRACT

Good quality terrain models are becoming more and more important, as applications such as runoff modelling are being developed that demand better surface orientation information than is available from traditional interpolation techniques. A consequence is that poor-quality elevation grids must be massaged before they provide usable runoff models.

Rather than using direct data acquisition, this project concentrated on using available contour data, for two reasons. Firstly, despite modern techniques, contour maps are still the most available form of elevation information. Secondly, manual contour tracing has imposed a subjective interpretation of the form of the landscape that is lost with automation, yet which is of considerable value.

The maximum slope of the terrain is perpendicular to the contour, and this permits us to visualize the relationships between pairs of contours. With care this may be modelled by triangulation methods, as the spatial relationships can be preserved, although standard grid interpolation methods based on "n nearest neighbours" often have problems. However, whenever we have relationships between portions of the same elevation contour, such as in peaks, pits or valley heads, our interpretation based on triangle slope is insufficient - we get "flat triangles". In this case we need to re-examine our spatial model.

The usual triangulation approach, the Delaunay triangulation, is effective because it is locally stable - a property based on its dual, the Voronoi diagram. These two spatial structures have been much studied by workers in the field of computational geometry - largely in terms of efficient calculation, but also in terms of their properties. In particular, recent work on the automatic reconstruction of curves from point samples, and the generation of medial axis transforms (skeletons) has greatly helped in the visualization of the relationships between sets of boundaries, and families of curves. This provides us with tools to enrich our original contour data for "flat triangles". The insertion of skeleton points in these cases guarantees the elimination of all flat triangles. Additional assumptions about the local uniformity of slopes, either along or across valleys and other features, give us enough information to assign elevation values to these skeleton points. If required, appropriate interpolation techniques may generate an elevation grid for visualization purposes that preserves reasonable slopes at all points on the model - even at the data points themselves - and that are faithful to the input data. In addition, the algorithms used are only moderately more complex than the underlying Voronoi diagram or Delaunay triangulation. The result provides us with a surprisingly realistic model of the surface - that is, one that conforms well to our subjective interpretation of what a real landscape should look like.

INTRODUCTION

This paper concerns the generation of interpolated surfaces from contours. While this topic has been studied by many people (including the first author) for over 20 years, this work is interesting for a variety of reasons. Firstly, contour data remains the most readily available data source. Secondly, valid theorems for the sampling density along the contour lines have only just been discovered.

In addition, comparisons of the methods used in a variety of weighted-average techniques throw a lot of light on the key components of a good interpolation method, using three-dimensional visualization tools to identify what should be "good" results - with particular emphasis being placed on reasonable slope values, and slope continuity. This last is often of more importance than the elevation itself, as many issues of runoff, slope stability and vegetation are dependent on slope and aspect - but unfortunately most interpolation methods cannot claim satisfactory results for these parameters.

GEOMETRIC PRELIMINARIES

The methods discussed here depend on a few fundamental geometrical constructs that are now fairly well-known - the Voronoi diagram and its dual, the Delaunay triangulation, as shown in Fig. 1. The first is often used to partition a map into regions closest to each generating point, the second is usually used as the basis for triangulating a set of data points, as it is guaranteed to be locally stable. It may easily be constructed using its "empty circumcircle" property - this circle is circumscribed at the Voronoi node associated with each triangle. As will be seen later, these nodes, and circles, are associated with the skeleton, or "medial axis transform".

GENERATION OF RIDGE AND VALLEY LINES

Amenta, Bern and Eppstein (1998) examined the case where a set of points sampled from a curve, or polygon boundary, were triangulated, and then attempted to reconstruct the curve. They showed that this "crust" was formed from the triangle edges that did not cross the skeleton, and that if the sampling of the curve was less than 0.25 of the distance to the skeleton the crust was guaranteed to be correct. Their algorithm consisted of inserting all the Voronoi vertices into the diagram. Gold (1999) and Gold and Snoeyink (2001) simplified the approach, showing that, in each Voronoi/Delaunay edge pair, one edge could be assigned
to the crust and the other to the skeleton. Fig. 2 shows the results for a simple contour. Thus skeleton points may be inserted into the original diagram, or not, as needed.

Figure 1: Crust and skeleton of a simple polygon

In our particular case, the data is in the form of contour lines, that we assume are sufficiently well sampled—perhaps derived from scanned maps. Despite modern satellite imagery, much of the world's data is still in this form. An additional property that is not sufficiently appreciated—they are subjective, the result of human judgement at the time they were drawn. Thus they are clearly intended to convey information about the form of the surface—and it would be desirable to preserve this, as derived ridges and valleys.

Fig. 3 shows our raw data set, and Fig. 4 shows the resulting crust and skeleton. Fig. 5 shows only those skeleton points that provide unique information—ridge and valley lines that separate points on the same contour, rather than merely those points that separate adjacent contours. Aumann et al. (1981) produced somewhat similar results by raster processing.

Figure 2: Contour data points

Figure 3: Crust and skeleton of Fig. 3 data

Figure 4: Skeleton branches from Fig. 4

Figure 5: Skeleton and "flat triangles"

Figure 6 shows a close-up of the test data set, illustrating a key point of Amenta, Bern and Eppstein's work. If crust edges (forming the contour boundary) may not cross the skeleton, then inserting the skeleton points will break up non-crust triangle edges. In particular, if the skeletons between different contours are ignored, then the remaining branch skeleton points will eliminate all "flat" triangles formed by triangles connecting points at the same elevation. Thus ridge and valley lines are readily generated automatically. The challenge is to assign them meaningful elevation values. The same is true in the case of closed summits.
This is illustrated in Figs. 7 and 8, where points on a simple closed curve are used to generate the crust and skeleton. In Fig. 7, the circumcentres of the skeleton points are given an elevation equal to the circumradius. The resulting interpolated model is shown in Fig. 8. This model is based on the idea that all slopes are identical, and thus the radius is proportional to the height of the skeleton point. Of course, in the case of a real summit as in Fig. 9, the slope would initially be unknown, and would be estimated from the circumradius of the next contour level down.

Figure 1: Skeleton and circumcentres

Two techniques have been developed, each with its own physical interpretation: The first, following Thibault and Gold (2000), uses Blum’s (1987) concept of height as a function of distance from the curve or polygon boundary, with the highest elevations forming the crust at the skeleton line.

Figure 2: Elevation model of Fig. 7

Figure 3: Skeleton of a summit

Figure 4: Estimating skeleton heights from circumradii

In the case of a ridge or valley, the circumradius may also be used, as in Fig. 10, to estimate skeleton heights based on the hypothesis of equal slopes. The larger circle, at the junction of the skeleton branches, has a known elevation – half way between the contours – and may be used to generate the local slope. The elevation of the center of the smaller circle is thus based on the ratio of the two radii. For more details see Thibault and Gold (2000).

Figure 5: Estimating skeleton heights from ridge or valley lengths

While this method is always available, it is not always the preferred solution where constant slope down the drainage valley, rather than constant valley-side slope, is more appropriate. In a second approach, illustrated in Fig. 11, the line of the valley is determined by searching along the skeleton, and heights are assigned based on their relative distance along this line. This may be complicated where there are several valley branches — in which case the longest branch is used as the reference line. This involves careful programming of the search routines, although the concept is simple. In practice, an automated procedure has been developed, which uses the valley length approach where possible, and the side-slope method when no valley head can be detected, such as at summits and passes.
COMPONENTS OF AN INTERPOLATION MODEL.

On the basis of a sufficient set of data points, we now wanted to generate a terrain model with satisfactory elevations and slopes, as the basis of a valid rainfall runoff model. Our approach was to interpolate a height grid over the test area, and to view this with an appropriate terrain visualization tool—in this case Genesis II, available from www.geospat.com. We feel that 3D visualization has been under-utilized as a tool for testing terrain modeling algorithms, and the results are often more useful than a purely mathematical, or even statistical, approach.

We have restricted ourselves to an evaluation of several weighted-average techniques, as there are a variety of techniques in common that can be compared. All of the methods were programmed by ourselves—which left out the very popular Kriging approach, as too complicated. Nevertheless, many aspects of this study apply to this method as well, since it is a weighted-average method, with the same problems of neighbour selection, etc., as the methods we attempted.

Figure 1: Interpolation from nearest point
In general, we may ask about three components of a weighted-average interpolation method. Firstly: what is the weighting process used? Secondly: what is the set of neighbours used to obtain the average? Thirdly: what is the elevation function being averaged? (Often it is the data point elevation alone, but sometimes it is a plane through the data point incorporating slope information as well.)

Figure 2: Interpolation from Delaunay triangulation
The simplest possible technique, useful on occasion, is merely to give each grid node (if a grid is being created) the height of the nearest data point. While trivial, it is valuable for a variety of applications, such as image rectification, rainfall estimation, and others. All grid cells falling within the Voronoi cell of a particular data point are assigned its elevation. Fig. 12 shows the result for our contour data set: the skeleton can be seen to separate each plateau around a contour.

Figure 3: Adding skeleton points to Fig. 14
The next most simple weighted-average model is the triangulation, using the Delaunay triangulation described previously. Fig. 13 shows the result, including the skeleton draped over the flat triangles. Fig. 14 shows the improvement when estimated skeleton points are added.

Figure 4: Selecting neighbours using a counting circle
The other weighted average models that were tested were the traditional gravity model, and the more recent “area-stealing” or “natural neighbour” or perhaps more properly “Sibson” interpolation methods (Sibson 1980, Watson and Philip 1987, Gold 1989). Here the number of neighbours used may vary. In the case of the gravity model the weighting of each data point used is inversely proportional to the square of the distance from the data point to the grid node being estimated, although other exponents have been used. There is no obvious set of data points to use, so one of a variety of forms of ‘counting circle’ is used, as in Fig. 15. When the data distribution is highly anisotropic there is considerable difficulty in finding a valid counting circle radius.

Figure 16 shows the resulting surface for a radius of 5 (about a quarter of the map). Data points form bumps or hollows. If the radius is reduced there may be holes in the surface where no data is found within the circle. If the radius is increased the surface becomes somewhat fattened, but the bumps remain. The result depends on the radius, and other selection properties, being used. Clearly, in addition, estimates of slope would be very poor, and very variable.
The Sibson method, illustrated in Fig. 17, is based on the idea of inserting each grid point temporarily into the Voronoi diagram of the data points, and measuring the area stolen from each of a well-defined set of neighbours. These stolen areas are the weights used for the weighted average. The method is particularly appropriate for poor data distributions, as illustrated in Fig. 18, as the number of neighbours used is well defined, but dependent on the data distribution.

Fig. 19 shows the results. It behaves well, but is angular at ridges and valleys. Indeed, slopes are discontinuous at all data points (Sibson, 1980). One solution is to re-weight the weights, so that the contribution of any one data point not only becomes zero as the grid point approaches it, but the slope of the weighting function approaches zero also (Gold, 1989).

This brings us to a subject often ignored in selecting a method for terrain modelling – the slope of the generated surface. In real applications, however, accuracy of slope is often more important than accuracy of elevation – for example in runoff modeling, erosion, sedimentation, etc. Clearly an assumption of zero slope, as above, is inappropriate. However, in our weighted average operation we can replace the height of a neighbouring data point by the value of a function defined at that data point – probably a planar function involving the data point height and local slopes. Thus at any grid node location we find the neighbouring points...
and evaluate their planar functions for the (x, y) of the grid node. These z estimates are then weighted and averaged as before.

Fig. 21 shows the result of using Sibson interpolation with data point slopes. It gives an apparently excellent result — and looks even better than when the smoothing function is added to it.

While it is impossible to show the results of all our experiments in this paper, in order to see what was happening we used the method of (Burnough and Mctonnell, 1988) to calculate slopes and profile curvature for grids created from various combinations of our available weighted-average methods. Somewhat surprisingly, the version without smoothing gives more consistent regions of coherent slopes, indicating that the smoothing function adds unwarranted undulations to the surface. However, examination of the profile curvature map shows that without smoothing there are folds in the surface at all contour lines — as would be expected — although the effects are minor. Adding slopes to the simple TIN model (i.e. using the position in the triangle to provide the weights) produced results that were almost as good as the Sibson method where the sample points were closely spaced along the contours, but the Sibson method is much superior for sparser data, or where the points do not form contour lines. The gravity model does not provide particularly good slope estimates, but even here including the data point slope function produces a significant improvement.

CONCLUSIONS.

From our work, several broad generalizations may be made. To produce good surface models, with reasonable slopes, from contour maps the single most valuable contribution is the addition of skeleton points along the ridges, valleys, pits, summits and passes. These are guaranteed to eliminate flat triangles. Height estimates at these points may be based either on longitudinal or lateral slope consistency, depending on the physical model desired, or the detection of valley-head information.

Figure 2: Sibson interpolation with slopes

We conclude with another imaginary example. Fig. 22 shows four small hills defined by their contours, modeled by a simple triangulation. Fig. 23 shows the result using Sibson interpolation, slopes and skeletonators. Skeleton heights were obtained using circumcircle ratios, as no valley-heads were detected. While our evaluation was deliberately subjective, we consider that our results in this case, as with the previous imaginary valley, closely follow the perceptual model of the original interpolation. Thus, for the reconstruction of surfaces from contours, we believe that our methods is a significant improvement on previous work.

REFERENCES


