SIMULATING AND DISPLAYING SURFACE NETWORKS

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ABSTRACT

This paper deals with surface structures using valleys (channels) and ridges of fluvially eroded terrain. The basic proposition is that they are topological duals. Both channel and ridge networks are binary trees, with the ocean the root of channel trees and high mountaintops the root of ridge trees.Given the topological relationship between the two networks, it is straight-forward to estimate the approximate geometric position of one network from the other.

To estimate one network from the other, we have to have a notion of the surface between the two networks which we will call "slope behavior" here. The fall-line or slope-line will be used here as representative for the slope behavior. A crude approximation to the fall-line could be a straight line. But that is usually not enough. A more general approximation would be an s-curve or concavo-convex profile. Of course, in some cases, components of the s-curve could degenerate to zero.

The approach has many applications: 1. It can serve as a testbed for physical geographers to visualize different assumption about erosion and slope shape. 2. It can speed up digitizing efforts by encoding less than the full terrain and estimating the missing components. 3. It can provide more natural terrain for animation sequences.

INTRODUCTION

This paper is a combination of two efforts:

- Representing terrain
- Using a novel structure of terrain

The attempt to give relief the impression of depth is an old cartographic undertaking. Wiechel (1878) developed the first method for relief shading. The idea was used extensively by cartographic artists but the analytical method had to wait until computers made the many calculations feasible (Yoeli, 1965; Horn, 1982; Peucker and Cochrane, 1974). Their approximations through linework (Tanaka 1930; Tanaka 1950; Peucker, Tichenor, and Rase 1974) were successful while line plotters dominated graphic production but have not been used for the last twenty years. The belief that different colors appear at different distances to the viewer let Karl Peucker (Peucker, 1908) develop a system of altitudinal tints that were supposed to give a plastic impression.

All these were orthographic representations of terrain which in cartography were considered superior because of the ability to measure horizontal position and distance. But with the rapid evolution of computer graphics and its emphasis on camera-like graphics, cartography went along with this field's push for an increasing use of perspective views. For the last decade, this issue has been in the hands of the computer graphics community.

What is left for the GIS community is to develop realistic or at least believable models of terrain.

MODELLING TERRAIN

There are many ways a computer can be used to generate terrain. The challenge is to allow control over the general look of the terrain. How much control is needed depends on the wishes of the user. For GIS purposes, where the graphical representation must match real terrain as closely as possible, as much of the terrain's features as possible has to be controllable.

In computer graphics, where the user does not need to represent an existing terrain, landscapes are often generated using fractal brownian methods (Mandelbrot, 1982; Fournier et all, 1982). The entire landscape is random. While fractal methods are commonly used, they give no control to the terrain creator with respect to the locations of the mountains or valleys.

The Ridge-Channel Concept

Digital Terrain Models as a subject within GIS has seen a passage through four levels of structures. This passage shows the evolution of structures from highly machine-oriented ones to those that attempt to integrate expert knowledge of terrain.

The first level, lasting for a fairly short period, was the attempt to duplicate some manual methods of data gathering. Terrain profiles across street-lines to compute cut-and-fill values are the most frequently mentioned. (Miller and Laflamme, 1958)

The second level, that of the regular grid, was initially used because of its simple geometry and the ease with which it could be adapted to loop-oriented early programming languages, its main drawbacks being the large data volumes and the distortion of terrain that all but the finest grid created. These problems have recently been eliminated by the development of very efficient compression algorithms which have given this approach a new license.

As an alternative to the regular grid, different types of surface approximations were developed. The one that has survived the period and is still in use is the Triangulated Irregular Network (TIN) (Peucker, et al. 1976), which divides surfaces into triangular facets. The edges often follow breaks in the surface, thus eliminating one of the major weaknesses of the regular grid.

The fourth and so far final level creates meta-structures of terrain. Typically, this is by describing terrain by networks, either of contours or of valley- and ridge-lines (Mark, 1977). This can be a very powerful structure because it incorporates much of our knowledge about surfaces.

The study of rivers as networks (or rather trees) is a branch of Geomorphology that is relatively old. Arthur Strahler suggested a hierarchy of rivers (Strahler, 1956). Werner showed that besides river networks, there are also ridge networks and they are topological duals (Werner, 1977; Pfaltz, 1976). In other words, for every pair of rivers that meet at a confluent, there is a ridge that originates in such a confluent or at least nearby and between the two rivers Maxwell (1870) and later Warntz (1966) developed a different structure that did not have confluents.

To give the above statement more precision, we should elaborate. First, river and ridge systems only develop on "fluvially eroded surfaces". Even though these types of surfaces cover the largest part of the earth's land, there are areas where the statements do not hold. We will disregard these areas. It is appropriate to exchange the term "river" with the term "channel" as the more general term. A channel does not have to carry water all the time, yet it has the valley shape that is so important for this consideration. As one follows a channel from the source to the end, the run-off becomes shallower, relating the logarithm of the height to the channel's length. Both channel and ridge networks are binary trees, with the ocean the root of channel trees and mountain tops the roots of the ridge trees. Incidentally, channels and ridges are often called "surface-specific lines" (Peucker et al., 1976).

Given the topological relationship between the two networks, it is straightforward to deduce the approximate geometric position of one network from the other. In practice, the estimation of the ridge network from the channel network is the more likely one to happen since the latter is more recognizable from maps and other materials and easier to digitize.

To deduce one network from the other, we have to have a notion of the surface between the two networks which we will call "slope behavior" here. The fall-line or slope-line will be used as representative for the slope behavior. A crude approximation to the fall-line could be a straight line. But that is usually not enough. A more general approximation would be an s-curve which would be defined by three lines of certain lengths and angles (the upper, middle and lower arms) plus, if desired, some smoothness factors at the junctions. Of course, in some cases, components of the s-curve could degenerate to zero.

In the early stages of a river, material is eroded by water and ice and transported away. A V-shaped valley (only the middle arm non-zero) is the result. Toward the river mouths, the water slows and deposits some of the debris that was carried down. The river plane which is being built is the lower arm of the s-curve. When a glacier moves through a valley, it cuts into the valley, leaving the upper parts of the old valley intact and building a usually wide, u-shaped valley: all three arms are well developed. In the case of canyons, the upper arm is totally flat and so is the lower, with the middle arm being nearly vertical.

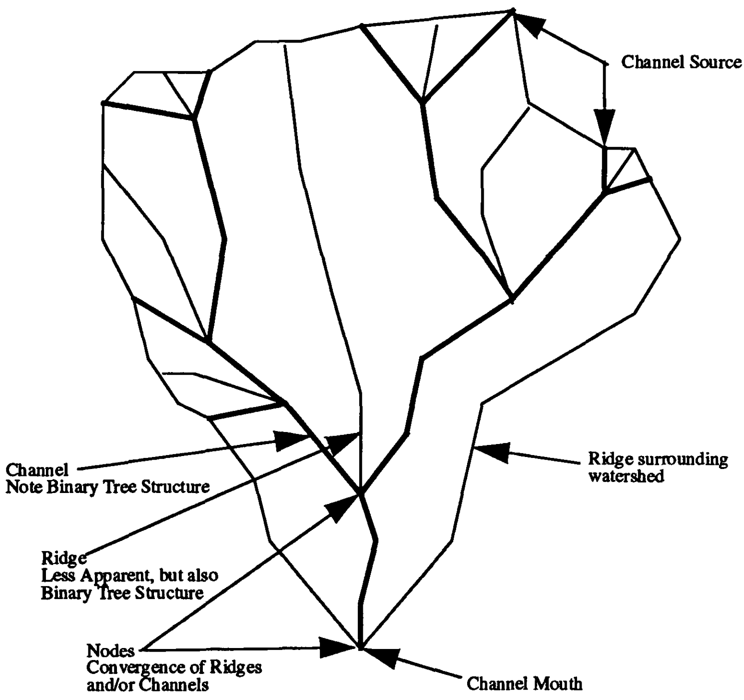

FIGURE 1. Example of a Ridge Channel Network

THE RIDGE-CHANNEL STRUCTURE

Neither the Maxwell/Warntz nor the Werner approach specified the Ridge Channel properties sufficiently for our work. we therefore had to put forward some of our own properties:

1. Ridges bisect the angle formed by two Channels emanating from a Channel confluent.
2. Channels end at Ridges, and the root of the binary tree of Channels starts at a meeting point of two Ridges.
3. If one follows a Channel from a node to its end (at a Ridge) and then follows the Ridge back to the node, one will make one loop of what we call a Face. A Face is a polygon that has as its edges Ridges on one side and Channels on the other. Encircling a Face involves one change from Ridge to Channel. A Face has no Ridges or Channels inside. This is true for any Face defined in a Ridge Channel network.
4. A node will consist of one of the following: 3 Channels and 1 Ridge; 1 Channel and 2 Ridges (at the outside of a watershed), 2 Channels and 2 Ridges (at the inside of a watershed), 0 Channels and 3 Ridges, 1 Channel and 3 Ridges.

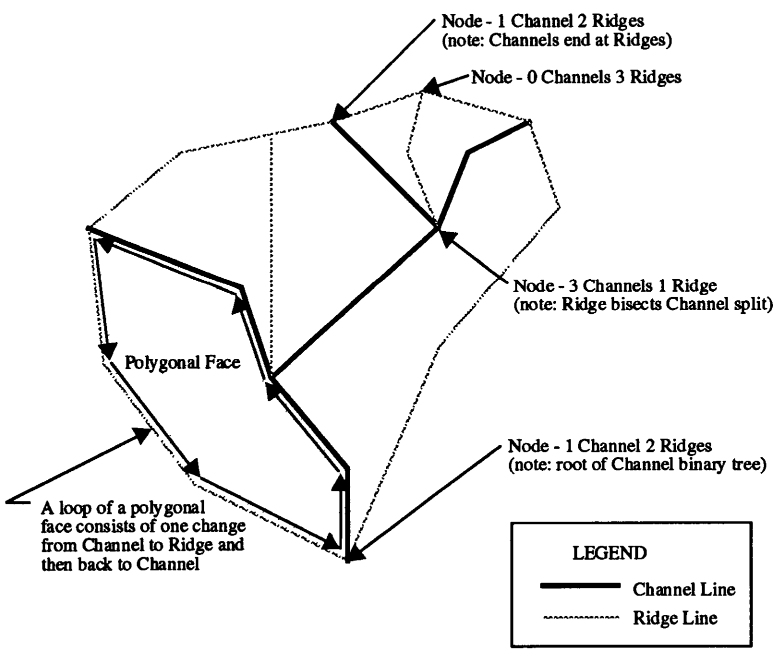

FIGURE 2. Ridge Channel Properties

The most important property mentioned above is that of the Face. By using well known polygon data structures, the algorithm can take advantage of the power of these data structures in building the surface representation. Since a Face always consists of 1 Channel (or rather, a series of Channel lines linked together) and 1 Ridge (or rather a series of Ridge lines linked together), the Face becomes a good starting point for calculating the resulting surface.

The algorithm begins by reading in the Ridge Channel data in line segments. At the same time, it builds up a winged edge data structure (Baumgart, 1972), a structure very similar to POLYVRT (Peucker and Chrisman, 1975) and other topological polygon structures. A winged edge data structure is a polygon data structure which uses pointers to link edges of one polygonal face together. The edge structure contains pointers to the two polygons it partially defines, pointers to the two end coordinates that define it, and pointers to the next and previous edges on each polygon. The pointers are the "wings" of the winged edge data structure. Using a winged edge structure ensures several things:

1. The validity or completeness of the data can be verified by checking (among other things) the nodes,
2. Ridges and Channels can easily be moved within the structure, due to the same properties of the winged edge data structure.
3. Faces can be encircled easily
4. The structure can easily be defined recursively --with greater detail, one face can become another Ridge Channel network. This ensuing network can be linked to the lesser detailed Faces by using a few extra pointers (or "wings").

One of the drawbacks of the winged edge structure is that the algorithm does not make clear to which polygon the next and previous edges belong. This was solved by using a structure which is similar to the split edge data structure which defines two records for each edge - one for one polygon (and the corresponding next and previous edges) and one for the other polygon (and the corresponding next and previous edges). The structure still has only one record, but sorts the pointers so that the first next edge, previous edge and polygon pointers correspond to each other, and the second next edge, previous edge and polygon pointers correspond to each other. The structure looks as follows:

```
typedef struct w_edge
{
    coordinate   *end[2];    // array of two coordinates define the ends of
                             // the edge.
    polygon      *poly[2];   // array of two polygon pointers - polygon[0]
                             // and polygon[1].
    w_edge       *next[2];   // next[0] corresponds to polygon[0], next[1]
                             // corresponds to polygon[1].
    w_edge       *prev[2];   // prev[0] corresponds to polygon[0], prev[1]
                             // corresponds to polygon[1].
} winged_edge;
```

Figure 3 is a diagram of the modified winged edge data structure:

Once the structure is complete, the terrain is generated on a face by face basis. For each face, the nodes which defines the transition between the Ridge of the Face and the Channel of the Face are identified. The Ridge and the Channel are divided into equal segments depending on the resolution needed for the picture and, at each subdivision interval, a strip is generated from the Channel to the Ridge using the slope behavior as a guide.

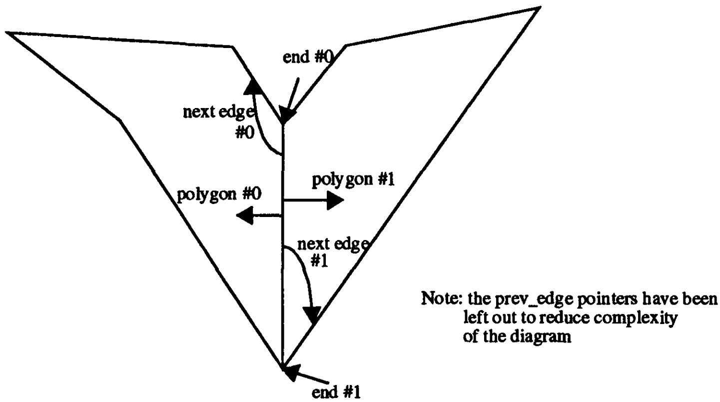

FIGURE 3. Pointer sorting in Winged Edge data structure

The new algorithm:

```
ridge_channel()
{
    /* read in from a file in the form: (x,y,z) (x,y,z)... */
    read_in_ridges_and_channels();

    /* nodes stored in a linked list with pointers to the winged edge data structure */
    store_node_locations();

    /* for each edge, find it's left and right adjacent edge at both ends and set the
       edge pointers accordingly. Node pointers are also resorted for easier traversal */
    set_winged_edge_pointers();

    /* each node is checked for validity, */
    check_node_validity();

    /* setup the polygon data structure - polygons have a pointer to one of its edges and
       are stored in a linked list of polygons */
    build_polygons();
```

```
    /* the polygons are now each traversed and drawn */
    draw_polygons();
}
```

Slope Behavior

Werner(1988) argues that Channels(C) and Ridges (R) are related through the valley side slope (V, our slope behavior), so that C + V = R and R + V = C, where "the plus sign represents the combination of two bodies of information" (p 253). The combination C + R = V is not possible because the same ridges and channels can be linked by different slopes.

Without giving justice to the finer points of slope geomorphology but following the advice of some knowledgeable geomorphologists, we postulate that all slopes between ridges and channels can be approximated by an S-curve. The S-curve is defined by three lines of varying lengths and angles (the upper, middle and lower arms) plus, if desired, some smoothness factors at the junctions. As described above, some of the arms can be reduced to zero.

At this stage of the research, we have restricted ourselves to three types of slope behavior: 1. Young erosion or the V-shaped valley, 2. The glacial or U-shaped valley, and 3. The canyon shape with the upper and lower arms being horizontal and the middle arm being vertical. These slope types are hard coded in the program. Later, a slope generation layer will be inserted, allowing the user the choice of form or deducing the behavior from digitized fall-lines.

CONCLUSION

This model obviously needs refinement. Certain results of such a simple structure don't look right. For refinement, we need the input of the geomorphologist and at present, they are not very interested in this type of landscape treatment. But such a framework has the advantage of providing visualizations that can be readily compared. It allows experimentation with different parameters. It also delivers landscape views for animation that are clearly better than the present fractal models supply.

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