GROUND SCULPTURE ON CADD:
FORMING AND COLORING THE LANDFORM IN A GRAPHIC DATA BASE.

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ABSTRACT

A graphic data base of our campus is being developed to record physical inventory and to provide a three-dimensional development tool for the University. The campus has many changes in elevation. Computer terrain modeling is planned to provide traditional contour information as well as to furnish a base for perspective views of the campus. Selecting an appropriate geometry to record the landform, and determining criteria for coloration of the ground surface is critical to the success of the project.

Methods of modeling a three-dimensional surface are discussed; color principles which articulate landform are explored. A methodology is illustrated which achieves a flexible model of the campus landform.

1. INTRODUCTION

Our University is concerned with keeping track of its physical self, counting and recording everything from its pipelines to its footpaths. The rapid expansion of this sort of information is not exclusively ours, but a problem that universities share with institutions all over the land. A computerized three-dimensional (3-D) data base has been conceived as our solution -- one giant repository of information that will serve the University for planning, promoting, research and education.

This presentation is concerned with a small but critical part of the data base: recording and displaying the land upon which the University is located.

Like many schools we have a large parcel of land. Furthermore the landscape is not flat, but undulates in a series of hills and valleys; and it must be seen in various ways in order to be fully understood. At times the landform must map in detail the physical facilities of the University, at other times it is only a platform for the display of buildings. Clearly, then, the method of recording the shape of this land must be carefully considered, in order for many and diverse needs to be accommodated.

2. CONTOUR POLYGON FORMATION

Polygons are the basic means of shading surfaces in computer imaging. A polygon is defined by a minimum of 3 nodes (points) and can be solid (FILL ON - transparent or opaque) or outlined (FILL OFF). Given the constraints of our current 3-D CADD modeling software, we were charged with the task of creating, organizing, and maintaining a 3-D computer model of our university campus. With no prior exposure to computer "mapping" and no mapping software compatible with our CADD software, we were forced to discover how to manipulate and display irregular landform in a regular way.

The process of creating a 3-D data base did not begin with three dimensions at all, but rather with a 2-D (plan) representation of existing landform and site elements. This was due to the availability of existing 2-D drawings, which are the designer's normal springboard for 3-D design.

Initially, land area limits were established. Given that our main campus consists of over 2 square miles of undulating hills, the campus was divided into small, regular, and easily comprehendible portions of the whole (34 acre quadrants). Also, a 10-foot contour interval was selected because of a restricted time frame for phase one completion. As the project progresses this contour interval will be reduced. Understandably, the smaller the contour interval the more accurate the contour model.

Then, the level of image development was determined. Questions were asked, "Is a 2-D computer plan sufficient?", "Is time savings of greater importance than a particular graphic quality?", "Is true polygon coloration critical?", "Will lighting, shadow, and reflection be a factor?" The answer to these and other questions determined the use of our current CADD software.

Several methods of polygon formation have been studied for developing a 3-D contour model in our graphic data base. These methods indicate levels of data base development which vary in speed of creation, flexibility of use, and effectiveness of desired results.

2.1. Stepped contours.

This method of polygon formation is illustrated in Figure 1 and in the slide presentation. This method is a computer simulation of what many scale model builders use to illustrate changes in landform and elevation. Each contour is shown by an irregular shaped "stair tread" seeming to indicate that the landform is a series of terraced or "stepped" flat planes. Each contour begins and ends at the limits of its lower and upper counterparts.

Figure 1. Landform model by the stepped contours method.

This type of 3-D contour model can be generated from a 2-D plan by simply adding the "Z" elevation to all points along a particular contour. Where the contour intersects the limits of a view or the limits of the land mass with which one is working, lines can be added to complete the polygon. Once a polygon is formed in this manner it can be extruded to illustrate a change in height according to the contour interval.

With our particular software, elements are re-drawn on the screen in the order they were input in the drawing. With this in mind, lower contours must be "introduced" into the drawing before higher contours. This will assure that lower elevation contours will be overdrawn by higher elevation contours. Also, a REDRAW SORT command can be issued which re-draws elements generally from "back" to "front". The order in which they are re-drawn is determined by the distance from their centroid to the current eye (viewpoint) location. For this command to work correctly on our software, polygons must be small in size and fairly regular in shape.

This method of 3-D contour modeling gives a quick illustration of general site layout but lackes the flexibility which is desired for our computer model. Since each contour "tread" is a single polygon, only one color (hue) can be represented by it. Shadows are cast at each "rise" in the contour "stair".

2.2. Shaped contours.

This method of polygon formation is illustrated in Figure 2 and in the slide presentation. It simulates more closely the true look of a natural landform. The enhancement of this method over the stepped contour method is in its smooth transition from one contour to the next. No contour "faces" are detectable though they are used to create this type of 3-D contour model.

Figure 2. Landform model by the shaped contours method.

This "shaped" surface can be formed from a 2-D contour map or from the above described stepped contour model. If this were generated from a 2-D plan one must first give the proper "Z" elevation to all points along a contour line. Where the stepped contour method requires a single contour extended to the limits of the land mass, the shaped contour requires a minimum of 2 such contours. The polygon formed from this method contains the same contour points as a stepped contour model except that it is inclined rather than flat, and its perimeter depends upon the "nosing" of two adjacent contours for its definition.

If generated from a 3-D stepped contour model, simply connect the "tread nosing" of two adjacent contour "steps" to form polygons. This process has been automated using our software by the creation of a COMMAND file which "traces" the contour around its perimeter and draws the contour polygon.

A drawback of this method is that it produces a "warped" polygon surface. Some software applications will not allow this.

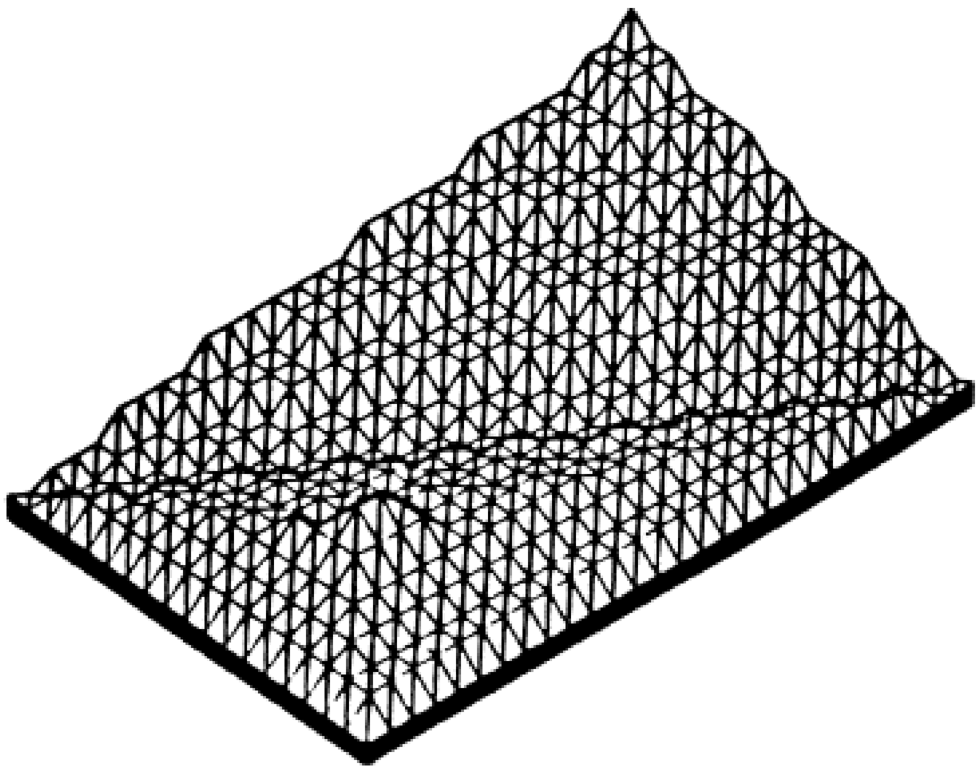

Figure 3. Landform model by the multi-polygon contour method.

2.3. Multi-polygon contours.

This method of polygon formation is illustrated in Figure 3 and in the slide presentation. As with most design decisions "tradeoffs" are a fact of life. This is true in 3-D contour modeling as well. This method of 3-D contour modeling is the most definitive of the modeling techniques discussed, but also more difficult to construct. This method uses a multitude of polygons within a single contour interval. Each polygon can then be individually manipulated to reflect subtle height or color changes. This flexibility allows the approximation of true landform colors. In some CADD applications, rendering and surface reflectance of individual polygons becomes significant.

This method is excellent for wire frame generation or 3-D contour modeling. It allows more realism in views and is generally a better descriptive tool in the designer's box.

2.4. Adding a working mesh.

If polygons are to remain planar, each three points will determine a plane. If a mesh is not used, irregular polygonal shapes can be created. With a defined mesh two triangular polygons can be constructed within each square of the defined mesh.

Each of the above contour formation methods can also be "tied" to a working mesh (grid). If this is done, points (nodes) along a contour line correspond to X, Y, and Z mesh intersections. This mesh brings to the 3-D contour model a predetermined increment from which to work. "Snapping" contour lines to mesh points is useful when editing is necessary. If every line segment begins and ends on a mesh intersection editing is simplified.

With this mesh a 3-D coordinate interval is established for each nodal element. Every node can be located at a different "Z" elevation thereby allowing the model to be shaped and molded as a natural landform. Minor height variations then become evident.

3. COLORING THE LANDMASS

In a diagram or a planning document it is adequate to represent landform as a line drawing. But if a data base is to provide visual information, to communicate the physical image of "place", then line drawings are no longer adequate. Instead we must see the landform as it might be observed in nature -- as the setting for both existing and proposed built forms.

Introducing color to represent the ground plane is not a simple matter, nor is it a new problem. Painters have been wrestling with this issue as long as they have been painting. It is said that the mystery of the Mona Lisa's smile is due to the differences in rendering the landscape to her left and to her right.

3.1. A search for principles.

In an architectural plan the ground is traditionally colored a grass green; but the flat and totally uniform green of a computer palette does not easily suggest the form of the landscape that we observe in nature. The subtleties of color that suggest land mass and distance are evasive and complex, though in the hands of a painter these problems have been mastered in many styles and in many situations. The landscape paintings of the nineteenth century achieved a carefully articulated landscape, one filled with drama that conveyed images of the American landscape around the world.

An architectural data base requires a more systematic approach to landform. The land mass of a data base will be viewed from many perspectives, its color composition cannot be simply an assemblage of color designed to be seen from one point. In selecting the colors a systematic approach to color is appropriate. The rules of vision should be carefully explored--what is the perceptual basis of articulating landform, of suggesting distance and space?

Several techniques for providing a more realistic color base on the computer are provided in commercial paint systems. Flat color areas can be "sprayed" with contrasting colors, varying pixel color to relieve the flatness of the colored surface. Brush strokes can be applied in a variety of ways that add a richness to the color surface. While these are useful techniques to the painter. They offer very little suggestion as to how the geometry of the land can be communicated as a system.

Josef Albers, in his ***Interaction of Color*** suggests that mass is articulated by equal visual gradations of color, where as spatial separation is visually caused by strong color boundary contrasts. This information offers some clues as to how hues, values, and saturations may be selected to model the landform in a data base.

3.2. Coloring polygons.

Varying the flat color of a computer usually involves determining a ramp of color - a progression of color in equal steps from one color to another. When such steps are selected in fine gradations they are perceived as a "ramp" of color rather than as steps.

Ramp colors can be applied selectively to the landform, with the assumption that one color will appear near, another far. Because the steps are formed of equal color gradients, following Albers' theory, they visually unite to express "surface". The eye is thus led from "hither" to "yon", from near to far, by this change of color. If a break in the ground surface appears from a particular point of view, such as a small hill in the foreground, then - if the system of coloring has been wisely chosen - a boundary contrast will be created at the edge of the hill, breaking the continuity of the ramp and suggesting distance.

Several possibilities exist for using color ramps to color polygons. First, as a simple background to a perspective view one could opt to assign a ramp color depending on the height of the polygon above a reference plane. If the polygonal divisions are sufficiently small, the overall effect will be of a continuous color change.

3.3. Selecting ramp colors.

Most computer systems contain a built-in color model. This can be accessed by specifying three properties of color: hue, lightness and saturation. By identifying these three factors, any point in the color space can be located.

A color ramp, being formed of equal visual gradations, is a linear series of colors between any two identified points in the model. It is true that the gradation does not always appear equal, but then that is a fault of the particular model, rather than the definition of a ramp. If one defines the hue, the lightness, and the saturation of each endpoint, then the ramp can be created mathematically between these points.

Once a method has been defined for dividing the landmass into polygons, various color ramps can be explored to determine which is most effective. The selection of appropriate color draws from the many several that are known about color behavior:

1. ***Light values advance - dark values recede:***
   This is easily demonstrable on the color computer, and is the obvious first choice for sculpting landform. The one obvious problem is the limits between which the colors are unbelievable as a representation of natural vegetation.

2. ***Warm hues advance - cool hues recede:***
   While this is an effective method of forming color differences, the range of green hues which suggest a natural landform is rather limited.

3. ***Color saturation recedes in the distance:***
   While saturation changes do not suggest themselves as a logical first choice, experimentation has proven them to be effective.

Variations of each of these methods have been tested to identify color ramps that will show the sculptural form of the landmass.

When an architect colors the ground for a project a green hue is usually selected as best representing the natural world; at least we like to think of the world as a beautiful, green place to live. If a particular green hue can be agreed upon, then only lightness and saturation remain as variables with which to fashion a color ramp. A simple look at the choices available indicates four options:

1. ***Constant lightness / constant saturation***

2. ***Constant lightness / decrementing saturation***

3. ***Decrementing lightness / constant saturation***

4. ***Decrementing lightness / decrementing saturation.***

If the hue is permitted to vary within a ramp, then many more combinations exist.

4. RESEARCH PROCESS

The process of coloring a 3-D contour model is new for even the most experienced CADD users. Selection of colors which accurately represent landform is critical to the success of an architectural data base. Therefore, preliminary research into color and its manipulation was initiated.

Hue, lightness (value), and saturation all combine to form what we know as color. Through the manipulation of these 3 variables different colors are created. Mathematically there are 27 possible combinations of hue, lightness, and saturation. Each of these combinations describe a *color ramp.* Initial research has been confined to four or these ramps.

To compare the effects of these color ramps, various object groupings were selected for study.

1. ***Isolated objects:***
   This object grouping was used to study color as an isolated spatial element.

2. ***Adjoining objects:***
   This object grouping was used to study color as a spatial element based upon its environment. One's perception of color changes when its environment changes, though the color remains constant.

3. ***Single campus quadrant:***
   This object grouping was used to study the effects of a particular color ramp on a small site area. The ramp was constructed with a constant hue, decrementing lightness, and decrementing saturation.

4. ***Multiple campus quadrants:***
   This object grouping was used to demonstrate the effect of a particular color ramp on a 3-D contour model. The purpose was to verify research conclusions on a large scale with many color variations.

5. CONCLUSIONS

The shaped contour has been selected as the method of defining polygons for the University Data Base. By using this technique of recording the land form we are able to develop information that will draw traditional contour maps when needed, and still provide a platform of polygons when seen in full color perspective.

When printed as maps the matrix of contour information forms contour lines and is indistinguishable from the standard quadrant contour maps that have been in use by the University for years. This mapping continues to be good documentation for many uses, it is used for plotting utilities, for counting parking spaces and for locating buildings; the list is endless. But the same digital information, when connected to form polygons becomes a three-dimensional representation of University land. It becomes a part of the promotional material for the University, serving to illustrate University facilities in detail or as a whole.

In selecting appropriate colors for rendering the landform a standard green hue has been selected to indicate the mass of the ground. It has been found that color ramps that indicate a variation of both lightness and saturation give a maximum definition of landform. Using these ramps it is possible to make the shape of the land understandable from most of the perspective points that have been generated.

There is a time dimension to this landform also, for it can be used to illustrate the history of the University, or conversely it can be altered as a planning tool for future growth. The overall effect of this effort has been the development of a rendering of University landholdings as a piece of ground sculpture that can be seen in many ways -- a truly dynamic picture of the site.

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