Algorithms for Data Representation Graphics

Course Organizer

Tom Wright
Computer Associates

Course Lecturers

Lofton Henderson
Henderson Software

Tom Wright
Computer Associates

Course #18

LECTURERS

Lofton Henderson
Henderson Software
1225B Bear Mt. Rd.
Boulder, CO 80303
(303) 494-5241

Thomas Wright
Computer Associates/ISSCO
10505 Sorrento Valley Rd.
San Diego, CA 92121
(619) 452-0170

ABSTRACT

Data Representation Graphics is used for portraying existing scientific and engineering data. It is distinct for CAD/CAM style graphics in that the data comes from outside the system rather than being generated within the system. Here, the data is usually generated by computer models or gathered in the field. Data Representation Graphics is distinct from Business Graphics in there is generally much more data to be portrayed, and it is often two and three dimensional, which is rare in Business Graphics.

Engineers and scientists need Data Representation Graphics because they have prodigious amounts of data they wish to understand. Examples of the types of data to be portrayed are physical variables from two and three dimensional hydrodynamic simulations such as weather models and oil reservoir models, field data gather by measurement devices such as those used by oceanographers, and laboratory data gathered in the process of running experiments. The quantities of data are so vast that understanding them without computer graphics is almost impossible.

Algorithms for portraying these kinds of data are generally considered applications by most graphics experts and they are lightly covered in the much of the graphics literature. On the other hand, end users of this kind of graphics generally consider these algorithms to be part of the graphics system. A geologist knows how to interpret a contour map, but not how to generate one from raw data.

This course, then, helps fill the gap between the needs of a common set of end users, scientists and engineers, and the facilities provided by low level graphics systems such as GKS, Core based systems, and the forthcoming PHIGS standard. Areas to be covered include:

- System architectures
- Nonlinear scaling
- Interpolation and smoothing
- Contouring
- Mesh diagrams and hidden lines
- Mapping
- Flow and force diagrams
- Presentation graphics
- Scientific animation

COURSE OUTLINE

1. Introduction

The course is an overview of the portrayal methods and underlying algorithms for Data Representation Graphics intended for those who support such activities for scientists and engineers. Existing systems can be evaluated for functionality through the analysis of the algorithms. Algorithmic limits can be understood. Implementors will be shown algorithm overviews for common applications and pointed to sources for implementation details. Pitfalls and important functions needed will be highlighted. These discussions will also aid those selecting commercial support systems.

2. System Architectures

2.1 Relations to Standards

A conceptual model for graphics software systems has been presented in the standards arena. This model will be related to the typical model for a Data Representation Graphics software system.

2.2 Sample Architectures

Architectures of the NCAR Graphics System and DISSPLA will be reviewed.

3. Nonlinear Scaling

3.1 Motivation

Conventional scaling is only one method of the several needed in Data Representation Graphics. The data need to be displayed in a manner appropriate to each data type and the conventions of the discipline of the user.

3.2 Problem Statement

Polar, Log, Date, and other scaling systems are needed for transforming application data into displayable vectors and areas. Matching axis systems are needed for each of these.

3.3 Algorithms

Straightforward geometry and trigonometry are used. Traditional matrix multiplies with fixed coefficients can not be used.

3.4 Issues

- o Total robustness is mandatory, such as handling negative numbers in log scaling.
- o There are applications for user defined scaling.

4. Interpolation & Smoothing

4.1 Motivation

Curves are used to portray linear data. In almost all cases, data must be added between the data values to make a continuous curve from the discreet data values. The curves can be restricted to passing through the data values and interpolation used to construct the curve, or the curve can be given the freedom to merely pass near the data and smoothing be used to construct the curve.

4.2 Problem Statement

There are two classes of input, non-parametric data, where X (or Y) is monotone and there is one Y (or X) for each X (or Y), or parametric data, where the data can cross itself and make loops.

4.3 Algorithms

Polynomial, Spline, Rational Spline (under tension) methods have different costs and visual and mathematical benefits (e.g., continuous slopes).

4.4 Issues

- o Specialty techniques have applications, such as step interpolation for displaying histograms.

5. Contouring

5.1 Motivation

Functions of two variables or their approximations through two dimensional arrays are difficult to understand using only raw data. Contouring offers a good compromise between a qualitative display showing trends and smoothness and a quantitative display where the actual values are easy to read. Contour lines draw the viewers attention to areas of change. Shading between contours can draw attention to highs and lows through appropriate color selections.

5.2 Problem Statement

Given a two dimensional array of real numbers and a set of contour levels, for each level, draw the curves that separate values in the array larger than the level from those values less than the level.

5.3 Algorithms

There are two algorithms commonly used: producing all the contour lines within each cell so that contour lines are produced in a piecemeal fashion, or following each line to its conclusion. The cell-at-a-time algorithm is simplest and fastest to execute, but the level-at-a-time minimizes graphics I/O, can be more easily integrated to labeling algorithms, and shaded areas can be more efficiently defined. The level-at-a-time algorithm involves remembering where lines have been draw so they will not be mistakenly redrawn when the array is searched for possible contour starting locations.

5.4 Issues

- o Two dimensional arrays can be used for polar and other data forms.
- o Data can be randomly located.
- o There are traditions in contouring that must be observed.

6. Mesh Diagrams & Hidden Lines

6.1 Motivation

The data sets displayed by contouring can be displayed as a mesh diagram, a form that stresses qualitative form over quantitative content. This form of display may model the actual appearance of the data, such as topography.

6.2 Problem Statement

Given a two dimensional array of real numbers, treat the values as heights with the positions of the heights determined by the position of the value in the array. Connect each data value with its four neighbors. All the lines for all the values taken together form a mesh. For a given observer view point, if the four sided polygon generated by four neighboring values were opaque, it could hide some of the edges of other polygons in the mesh. Eliminating these lines is called hidden line removal. (There are other hidden line removal algorithms for other types of data.)

6.3 Algorithms

The most commonly used algorithm involves drawing the lines nearer the observer first and remembering a horizon representing the highest (and another representing the lowest) vertical screen coordinates achieved so far for each horizontal position. As each line is drawn, it is first tested to see it is above the horizon line (or below the lower horizon line). Parts of each line passing the test are drawn and used to update the horizon information.

6.4 Issues

- o Extreme discontinuities create visibility errors unless the three space to two space transformation is distorted.
- o There are several forms of data storage such as two dimensional arrays representing polar coordinate data awaiting someone to do the work on the ordering needed and to publish the results.
- o There is a solution to the three dimensional analogy to this problem.

7. Mapping

7.1 Motivation

Latitude-Longitude data representing coastlines, locations, political boundaries, paths, or areas need to be displayed on maps drawn with different projections.

7.2 Problem Statement

Given a latitude-longitude position, project it from its position on the globe on to a two dimensional display surface.

7.3 Algorithms

Different map projections have different useful properties including preserving area, preserving directions measured in different ways, or preserving the appearance of a globe. The mathematics varies from trivial to fairly complex, but each projection can be described in geometric term so its advantages and disadvantages can be understood.

7.4 Issues

- Data filling is needed when linking points on most projections. Inverse transformations for input can be quite tricky.

8. Flow & Force Diagrams

8.1 Motivation

Flow field models are used to study the behavior of various liquids and gasses inside containers and around obstructions. Force field models are used in gravitational and electromagnetic research. Vector diagrams are used when a compromise between quantitative and qualitative displays is needed. Stream lines are used for more qualitative displays.

8.2 Problem Statement

Force fields and flow fields are often modeled by a pair of two dimensional arrays of real numbers representing the two components of the force or flow or the direction and magnitude of the force or flow. For vector diagrams, for each data location, draw a vector with an arrow head with the direction indicating the direction of the force or flow field at the location and the length indication the magnitude of the force or flow.

8.3 Algorithms

Vector displays are based on simple trigonometry. Stream lines are based on simulating the flow of a particle within the field.

8.4 Issues

- Two dimensional arrays can be used for polar and other data forms.

9. Presentation Graphics

9.1 Motivation

Data Representation Graphics can be used for individual analysis or for conveying ideas to others. The individual is familiar with the problem and is most concerned with performance so the maximum amount of data can be viewed in the fastest amount of time with the least consumption of resources. When the data is to be shared, emphasis shifts to the ease with which a graph can be duplicated, its clarity, and publication standards.

9.2 Problem Statement

There are many well known criteria by which presentation graphics are judged from a graphics arts standpoint. A number of Data Representation Graphics Systems can produce suitable presentation graphics if the right techniques are used.

9.3 Algorithms

Preparing presentable graphics involves using a combination of appropriate techniques including shaded fonts, thickened lines, graphics arts symbols, symbol blanking, drop shadows, more shaded areas, more interpolation, and right-of-way paths for curves.

9.4 Issues

- There are various graphics arts conventions that must be followed.

10. Scientific Animation

10.1 Motivation

In the physical sciences the time variant behaviour of phenomena is often of key importance. Whereas looking carefully at a time series of pictures can help detect trends, animation is the tool of choice to illustrate data patterns that exist in time, and perturbations in patterns. It is useful both as a research tool and a teaching or demonstration aid.

10.2 Problem Statement

Given a set of data that has time trends, the problem is to isolate the trend of interest from the rest of the data, choose appropriate display techniques to illustrate the phenomenon of interest, to choose the information content for effective highlighting of the key time-variant data, to chose cost-effective computation and graphical techniques, and finally the data to an animated series of images on tape or film.

10.3 Techniques

All of the graphical display algorithms of the rest of this course are candidates for the basic display technique to animate. Use of segmentation is critical for efficiency. Freeze frames and replicated frames are useful for slowing the pace of the presentation and giving the viewer time to comprehend, as well as saving computational expense. Scrolled titles are a natural way to present textual information, and clocks help calibrate the activity with real world time. Leaders and trailers are usually necessary for titling, credits, introductory explanation, etc.

10.4 Issues

- Is your data really suitable for animation?
- The phenomenon of interest must be carefully isolated.
- Information overload (too fast, or too much information per frame) is common.
- If color is appropriate, the colors used must be chosen carefully to avoid overload and distraction.

REPRINTED ARTICLES
by course topic area

1. System Architectures

2. Nonlinear Scaling

3. Interpolation & Smoothing

Cline, A.K., "Curve Fitting Using splines Under Tension," Atmospheric Technology, Vol. 1, No. 3 (September, 1973), pp 60-65.

Brodlie, K.W., "Methods for Drawing Curves," Fundamental Algorithms for Computer Graphics, Springer-Verlag, Berlin, 1985, pp 303-323.

4. Contouring

Akima, H., "A Method of Bivariate Interpolation and Smooth Surface Fitting for Irregularly Distributed Data Points," ACM Transactions on Mathematical Software, Vol. 4, No. 2, June, 1978, pp 148-159.

Sabin, M.A., "A Survey of Contouring Methods," Computer Graphics Forum, Vol. 5, 1986, pp 325-340.

Sutcliffe, D.C., "Contouring Over Rectangular and Skewed Rectangular Grids," Mathematical Methods in Computer Graphics and Design, Academic Press, Orlando, 1980, pp 39-62.

5. Mesh Diagrams & Hidden Lines

Wright, T., "A Two-Space Solution to the Hidden Line Problem for Plotting Functions of Two Variables," IEEE Transactions on Computers, Vol. 22, No. 1 (January 1973), pp 28-33.

Wright, T., Humbrecht, J., "ISOSRF - an Algorithm for plotting Iso-Valued Surfaces of a Function of Three Variables," Computer Graphics, Vol 13, No. 2 (August 1979), pp 183-189.

6. Mapping

DISSPLA Users Manual, Part D, Sections 3-4, pp D.3.1-D.4.10.

NCAR Graphics Software, Fifth Preliminary Edition (October, 1978), pp 12.SUPMAP.9-26.

7. Flow & Force Diagrams

8. Presentation Graphics

9. Scientific Animation

Wright, T., Mungall, J.C.H., Vastano, A.C., Whitaker, R.E., "The Production of Scientific Films Using a Digital Computer and Optical Output Device," NCAR Graphics Software, Fifth Preliminary Edition (October, 1978), pp 1-39.