

METHOD AND APPARATUS FOR OPTIMIZED DEPTH CUEING USING SHORT VECTORS.BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

This invention relates to computer graphics systems and, more particularly, to arrangements for varying the intensity of lines presented on computer displays in order to indicate a third dimension.

2. HISTORY OF THE PRIOR ART:

In presenting three dimensional representations of figures or shapes on two dimensional output displays, some means must be used for indicating the third dimension. Various methods of accomplishing this result have evolved from standard drafting techniques. An example of this is perspective drawing.

Certain other techniques have developed because of the peculiarities of the computer display. For example, in bit-mapped and vector computer output displays which are presented on a cathode ray tube (CRT), a method used to indicate or cue the viewer to the different depths of portions of a line is to vary the intensity of the bits of a line as the depth of the line increases. Thus, for a line running from the viewer's position to infinity, the closest location of the line is given its fullest intensity and the farthest location its zero intensity.

The fading of the line from view provides the same effect as that given by images as they extend progressively further from the viewer. This technique enhances the feeling of depth of the line on the output display.

The method of accomplishing the effect requires that each pixel have a different intensity value from a maximum to zero. In actual systems of the prior art, any individual line having a depth dimension is drawn by dividing the line length by the number of pixels and calculating an intensity value for each pixel. Thereafter, each individual pixel is written to the output display, a single pixel at a time. In color systems, if the line also varies in color along its length, the circuitry of such systems must calculate intensities for each of the colors red,

green, and blue separately, each from zero to one hundred percent intensity. The prior art arrangements for accomplishing this form of depth cueing require a separate calculation engine for the colors for each pixel.

5 In improving computer systems, the emphasis has been on improving the speed of operation of such systems. This is especially true of systems using bit-mapped displays where the graphics output is the point of the system which limits its speed.

10 Consequently, providing depth cueing in three dimensional bit-mapped graphics output systems has been speed limiting for the system.

 It is, therefore, an object of the present invention to improve the speed of computer graphics systems.

15 It is another object of the present invention to provide an extremely rapid means of providing depth cueing in a computer graphics system.

 An additional object of this invention is to provide a new technique
20 for providing depth cueing in a three dimensional computer graphics system.

SUMMARY OF THE INVENTION

These and other objects of the invention are realized in a computer graphics system which is based on the assumption that most lines rendered on a computer display are comprised of a series of short line segments. Based on this assumption, the system determines the intensities of the beginning and end points of a line to be drawn having a depth dimension, determines the value of the intensity of the line at its midpoint, and describes the entire line at the midpoint intensity which has been computed. Using this system, the intensities of most of the pixels rendered on the output display may be ignored, for only the endpoints of a line segment need be dealt with. Consequently, the system removes the bottleneck normal to depth cueing in a bit-mapped display.

These and other objects and features of the invention will become apparent to those skilled in the art by reference to the following detailed description taken together with the several figures of the drawing in which like elements have been referred to by like designations throughout the several views.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side view illustrating a viewer's perspective of a three dimensional line;

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Figure 2 is a view indicating the manner in which the prior art describes a three dimensional line on a bit-mapped computer display;

Figure 3 is a view indicating the manner in which the present invention describes a three dimensional line on a bit-mapped computer display;

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Figure 4 is a block diagram illustrating a computer graphics system in accordance with the present invention;

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Figure 5 is a block diagram illustrating a second computer graphics system in accordance with the present invention;

Figure 6 is a block diagram illustrating a specific circuit arrangement for the computer graphics system of Figure 5; and

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Figure 7 is a diagram useful in explaining the transform used in the system.

NOTATION AND NOMENCLATURE

Some portions of the detailed descriptions which follow are presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art.

An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities.

Further, the manipulations performed are often referred to in terms, such as adding or comparing, which are commonly associated with mental operations performed by a human operator. No such capability of a human operator is necessary or desirable in most cases in any of the operations described herein which form part of the present invention; the operations are machine operations. Useful machines for performing the operations of the present invention include general purpose digital computers or other similar devices. In all cases the distinction between the method operations in operating a computer and the method of computation itself should be borne in mind. The present invention relates to method steps for operating a computer in processing electrical or other (e.g. mechanical, chemical) physical signals to generate other desired physical signals.

The present invention also relates to apparatus for performing these operations. This apparatus may be specially constructed for the required purposes or it may comprise a general purpose computer as selectively activated or reconfigured by a computer program stored in the computer. The

5 algorithms presented herein are not inherently related to any particular computer or other apparatus. In particular, various general purpose machines may be used with programs written in accordance with the teachings herein, or it may prove more convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these machines will

10 appear from the description given below.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In presenting three dimensional representations on two dimensional output displays of computer systems, some means must be used for indicating the third dimension to the viewer. One method of accomplishing this result in a bit mapped computer output display which is usually presented on a cathode ray tube (CRT), is to indicate or cue the viewer to the different depths of portions of a line by varying the intensity of the bits of a line as the depth of the line increases. The fading of the line from view on the screen enhances the feeling of depth because it conveys the same effect as do real images as they recede progressively further from the viewer.

The way this is done by the prior art is to give the closest location of a line its fullest intensity, the farthest location zero intensity, and intervening locations intensities varying with the distance from the eye. Figure 1 illustrates a line 10 lying in a three dimensional cube 12 of space. The cube 12 is provided with a Y axis, an X axis, and a Z axis to indicate the three dimensions of space in a conventional manner. The eye 14 of a viewer is also shown.

In Figure 1, an endpoint A of the line 10 nearest the eye 14 of the viewer is indicated to be bright and an endpoint B farthest from the viewer is indicated to be dark. In fact, the endpoint B is given a color to blend with the background color of the display in most prior art arrangements. In this manner, the line 10 appears to disappear into the background.

The method of accomplishing the effect in a system using a bit-mapped output display requires that each pixel defining the line have a different intensity value varying from a maximum to zero. In actual systems, the line is drawn by dividing the line length by the number of pixels and calculating an intensity value for each pixel. Figure 2 illustrates the actual bits of the line 10 shown in Figure 1 with percentage values applied to the bit positions from the brightest point at A (100%) to the least bright point B (0%).

In general, most individual lines are displayed with but a single color; however, many graphics displays may well present a line which changes in color from one end to the other. For a system to handle such a situation, the circuitry of the system must include separate calculation engines which
5 calculate intensities for each pixel of each of the colors red, green, and blue separately, each from zero to one hundred percent intensity. Such an operation is extremely time consuming and is one of the reasons computer graphics displays are so slow.

10 As computer systems have improved, the emphasis at each step has been on improving the speed of operation of such systems. This is especially true of computer systems using bit-mapped displays where the graphics output is slowest and thus becomes the limiting point of the system. Consequently, providing depth cueing in three dimensional bit-mapped graphics
15 output systems has been speed limiting for the system.

In designing computer systems, it has become apparent that the display of graphic images substantially slows the operation of most computers. This occurs because the amount of information that the computer must deal with
20 for each frame to be presented on the output display is very large and because the manipulation of that information to present the graphics image requires inordinate use of the central processing unit (CPU).

The system of which the invention is a part reduces the delay
25 inherent in the normal systems used for displaying computer graphics by handling most of the operations in hardware so that the information is available instantaneously. In order to allow the use of hardware to implement the presentation of graphics, it has been found that the information presented to the hardware must, as viewed by that hardware, appear to be of essentially the same
30 nature no matter what the shape to be presented on the display. In this manner, decisional steps need not be taken to determine what type of information is involved, slowing the processing time. This invention is part of a system which is based on breaking the graphics images to be presented into quadrilaterals all of

which may be handled in the same manner by the graphics presentation hardware and recombined on the display to present the desired shape. The system decomposes these quadrilaterals into pairs of line segments each of which subtend the same output display scan lines. Thus, each quadrilateral is decomposed into a series of line segment pairs which define the minimum set of trapezoids required to properly reconstruct the quadrilateral in the display memory. The X and Y coordinates of the two ends of each scan line between the line segments are then determined. Using only these two points, each scan line may be defined without the necessity of determining intermediate pixels.

The endpoints of each scan line may be stored in a frame buffer and displayed on an output display. This is accomplished in hardware so that an insignificant delay occurs in the translation and the output to the display is not delayed.

Various portions of the system above described are more particularly described in the following patent applications, all of which are assigned to the assignee hereof: GB 2227147A, HARDWARE IMPLEMENTATION OF CLIPPING AND INTER-COORDINATE COMPARISON LOGIC, Malachowsky and Priem; GB 2229069A, APPARATUS AND METHOD FOR PROCESSING GRAPHICAL INFORMATION TO MINIMIZE PAGE CROSSINGS AND ELIMINATE PROCESSING OF INFORMATION OUTSIDE A PREDETERMINED CLIP, Malachowsky and Priem, GB 2227146A, APPARATUS AND METHOD FOR LOADING COORDINATE REGISTERS FOR USE WITH A GRAPHICS SUBSYSTEM UTILIZING AN INDEX REGISTER, Malachowsky and Priem; GB 2227148A, APPARATUS AND METHOD FOR USING A TEST WINDOW IN A GRAPHICS SUBSYSTEM WHICH INCORPORATE HARDWARE TO PERFORM CLIPPING OF IMAGES, Malachowsky and Priem; GB2226482A, METHOD AND

APPARATUS FOR SORTING LINE SEGMENTS FOR DISPLAY AND MANIPULATION BY A COMPUTER SYSTEM, Malachowsky and Priem; GB2226480A METHOD AND APPARATUS FOR DETERMINING LINE POSITIONS FOR DISPLAY AND MANIPULATION BY A COMPUTER SYSTEM, Malachowsky and Priem; GB 2226478A, METHOD AND APPARATUS FOR TRANSLATING RECTILINEAR INFORMATION INTO SCAN LINE INFORMATION FOR DISPLAY BY A COMPUTER SYSTEM, Malachowsky and Priem; and GB2226481A, METHOD AND APPARATUS FOR DECOMPOSING A QUADRILATERAL FIGURE FOR DISPLAY AND MANIPULATION BY A COMPUTER SYSTEM, C. Malachowsky.

If the system described were to utilize the conventional manner of providing depth cueing in which each of the individual pixels would have to be computed, the entire system would be slowed to approximately one-tenth of its actual speed.

The present invention eliminates the need to determine the number of pixels which are used to describe a line having depth, the need to assign different intensities to each pixel, and the need to describe each of the pixels, one at a time. The invention relies on one basic assumption. The first of these is that most lines described on an output display are short. This is especially true in molecular modelling, one of the more advanced uses of a graphics display, where all of the vectors displayed are exceedingly short. In other uses such as describing the wing of an airplane where one might assume that a number of very long vectors are used the actual lines are often found to be composed of a large number of very short line segments.

The system of the present invention accomplishes depth cueing without the time consuming operations of the prior art arrangement by computing the intensity of the

two end points of each line segment to be described on the output display, averaging the intensity of the two end points, and using this average intensity to describe all of the points connecting the two end points of the line, Consequently, the system operates at a rate approximately ten times the rate it would otherwise operate.

Figure 3 is a diagram illustrating a line 20 drawn according to the present invention. The line 20 is comprised of a number of line segments joining the points B, C, D, and F. Also shown are mid-points E and G of the line segments CD and DF, respectively. In order to provide depth cueing, the system
5 determines for each of the individual line segments shown the intensity of the end points of that line segment. It then averages these two intensities and draws the entire line segment at that intensity. For example, to render the line segment CD, the intensities of the points C and D are determined and averaged; and the line segment CD is drawn at the average intensity of the mid-point E. In like manner,
10 to render the line segment DF, the intensities of the points D and F are determined and averaged; and the line segment DF is drawn at the average intensity of the mid-point G. As may be seen, since the point C has a higher intensity than the point D and, likewise, the point D has a higher intensity than the point F, the average value of intensity at point E used for rendering the line
15 segment CD is greater than the average value of intensity at point G used for rendering the line segment DF. Thus the intensities of the line segments vary decreasingly as the line recedes from the viewer. With short line segments, the effect of this rendering of intensities is to provide depth cueing to the viewer.

20 Systems utilizing the present invention demonstrate the effectiveness of the depth cueing provided by the invention without the slowing effect of depth cueing arrangements of the prior art methods of accomplishing the effect. As pointed out, the speed accrues because the invention draws the whole line at a single intensity no matter how many pixels are involved in the line.
25 The removal of the requirement to compute and describe the individual pixels eliminates a substantial portion of the bottleneck to speed of the prior art systems. Examples of systems using the invention have demonstrated that the invention does, in fact, provide depth cueing without any of the detrimental effects which might be expected such as color banding in which the colors of the system
30 appear to change in jumps. Again, this is because most line segments described by computer graphics systems are very short line segments.

In situations in which the line segments are not short, it is possible to use the teachings of this invention by simply breaking the longer line segments into shorter line segments and describing the shorter line segments each at their average intensities. Figure 3 illustrates a second line segment 30 which is, in fact, a single straight line. In order to use the present invention, the line segment 30 is broken into the shorter line segments MN, NO, OP, PQ, QR, and RS and described by the intensities at the mid-points of each of these short line segments.

Figure 4 illustrates in block diagram form a computer graphics system 40 utilizing the present invention. The system 40 includes a transformation engine 42, a central processor 44, a line drawing engine 46, a frame buffer 48, and an output display 50 such as a cathode ray tube. The circuitry of all of these individual components may be of a type well known to the prior art although their association is distinct therefrom. For example, the transformation engine 42 receives as input the X, Y, and Z values of each individual point to be described on the output. The engine 42 utilizes circuitry well known to the prior art to transform the original coordinates of the point by rotation, translation, scaling or perspective to accomplish whatever is to be done to the particular point. Normally this provides an output having new X, Y, and Z values.

In the system 40 of the present invention the Z values may be directly utilized to provide intensity values for the points. That is, the input Z values is operated on by the transformation engine 42 so that the output gives a new X, Y, and an intensity value. The new intensity value is directly related to the Z value which would normally be produced but has a percentage intensity level from 100% at the display to 0% at the least point.

The method by which the transformation engine accomplishes the conversion of Z values to intensity values is an extension of the normal transformation operation. The normal transformation operation applies a four-by-four transform which is the result of applying matrices which individually

represent the translation, rotation about the desired axes, and scaling transforms to the X, Y, and Z values. In the present invention the four-by-four matrix may be realized by including a transform representing the cueing operation. Such a transform is represented by the concatenation of the standard transformation

5 matrices which may be found in Chapter 22, Principles of Interactive Computer Graphics, 2d. Edition, Newman and Sproull, McGraw-Hill Book Co., with a transform representing the cueing operation.

The cueing operation may be termed the Z-to-intensity conversion

10 transform. It is reached using Figure 7 of the drawing as follows:

$$I = (I_{\max} - I_{\min}) * (Z - Z_{\min}) / (Z_{\max} - Z_{\min}) + I_{\min},$$

where Z is the Z value of a point of interest, Zmin is the Z value of the object closest to the screen, and Zmax is the Z value of object farthest from the

15 screen,

I_{max} and I_{min} are the maximum and minimum values of grey scale levels available.

A particular transform which is a concatenation of equation 22-1 for

20 translation and equation 22-5 for scaling along with the Z-to-I conversion transform from Principles of Interactive Computer Graphics, and therefore accomplishes the conversion for translation, scaling, and Z-to-I conversion is:

$$\begin{bmatrix} X & Y & Z & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & Z_s & 0 \\ 0 & 0 & Z_t & 1 \end{bmatrix} = \begin{bmatrix} X' & Y' & I' & 1 \end{bmatrix}$$

25

$$\text{Where } Z_s = (I_{\max} - I_{\min}) / (Z_{\max} - Z_{\min})$$

$$Z_t = I_{\min} - Z_{\min} * (I_{\max} - I_{\min}) / (Z_{\max} - Z_{\min}).$$

In this transform, only the Z values are changed since these are the only

30 values of interest.

$$\text{Then } I' = Z * Z_s + Z_t.$$

The values for intensity of the two ends of a line segment to be rendered which are provided by the transformation engine 42 are added by the CPU 44 and divided by two to give an average intensity value. This average intensity value is handed to the drawing engine 46. In the preferred embodiment
5 of the invention, the drawing engine 46 describes a line segment by drawing a straight line between these two endpoints at the average intensity. A drawing engine such as that of the preferred embodiment is described in the above-mentioned patent applications describing various portions of the system. The drawing engine 46 provides the line values to the frame buffer 48 for presentation
10 on the output display 50.

A second system 60 constructed in accordance with the invention is shown in Figure 5. Such a system may be utilized in situations in which the system CPU does not have direct access to the component elements of the
15 graphics systems. This is the more usual arrangement. In the system 60, the transformation engine 42 provides transformed X, Y, and I values derived from the X, Y, and Z values furnished to it for both ends of each line segment in a manner well known to the prior art. These output values are transferred to an intensity calculator 62 which provides output values of the X, Y, and average
20 intensity values for each line segment. These values are transferred to the line drawing engine 46 described above for transfer to the frame buffer 48 and later rendering on the output display 50.

An intensity calculator 62 is illustrated in Figure 6. The converter
25 62 comprises an adder circuit 64 constructed in a manner well known to the prior art. The adder 64 receives the two transformed I values from the transform engine 42, and adds those two values to give a result. This result is transferred to a shift register 66 which shifts the result by one bit, dropping the lowest order bit to accomplish a division by two. This result is furnished to the drawing engine 46 of
30 Figure 5 to represent the average intensity of the line segment.

The speed of the operation of the system of the invention might be further enhanced by simply using the intensity of the beginning or end point of an

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individual line segment to render the entire line segment. In such a case, the system need not average the two intensities to compute a midpoint intensity, so even greater speeds are attained. It is also possible to utilize the invention to draw lines which vary in color from one end to the other. Such an arrangement
5 requires that each color be individually described but the intensity of such color may be averaged over the individual line segments just as described for one color line segments above.

Although the present invention has been described in terms of a
10 preferred embodiment, it will be appreciated that various modifications and alterations might be made by those skilled in the art without departing from the spirit and scope of the invention. The invention should therefore be measured in terms of the claims which follow.



17.

CLAIMS

1. A computer graphics system which determines intensities of points representing line segments to be displayed on a computer output display which intensities vary in general in accordance with the depth of each point to be represented, comprising means for determining the intensities of each end point of such a line segment to be displayed, means for averaging the intensities of the two endpoints, and means for providing a value for rendering all points describing the line segment at an intensity equal to the average value of the intensities of the two end points.

2. A computer graphics system as claimed in Claim 1 in which the means for determining the intensities of each endpoint of a line segment comprise means for converting the Z value of each such point to an intensity value.

3. A computer graphics system as claimed in Claim 2 in which the means for converting the Z value of each such point to an intensity value comprises means for applying a transform to such values.

4. A computer graphics system as claimed in Claim 1 in which the means for averaging the intensities of the two endpoints comprises an adder for summing the intensity values of the two endpoints of a line segment, and means for dividing the result by two.

5. A computer graphics system as claimed in Claim 4 in which the means for dividing the result by two comprises a shift register.

6. A computer graphics system as claimed in Claim 1 in which the means for providing a value for rendering all points describing the line segment at an intensity equal to the average value of the intensities of the two end points comprises a drawing engine for writing to a frame buffer.



18.

7. A method for determining the intensities of points representing line segments to be displayed on a computer output display which intensities vary in general in accordance with the depth of each point to be represented, comprising the steps of determining the intensities of each end point of such a line segment to be displayed, averaging the intensities of the two endpoints, and providing a value for rendering all points describing the line segment at an intensity equal to the average value of the intensities of the two end points.

8. A method as claimed in Claim 7 in which the step of determining the intensities of each endpoint of a line segment comprises converting the Z value of each such point to an intensity value.

9. A method as claimed in Claim 8 in which the step of converting the Z value of each such point to an intensity value comprises applying a transform to such values.

10. A method as claimed in Claim 7 in which the step of averaging the intensities of the two endpoints comprises summing the intensity values of the two endpoints of a line segment, and dividing the result by two.

11. A method as claimed in Claim 10 in which the step of dividing the result by two comprises shifting the result in a shift register.

12. A method as claimed in Claim 7 in which the step of providing a value for rendering all points describing the line segment at an intensity equal to the average value of the intensities of the two end points comprises furnishing the value to a drawing engine for writing to a frame buffer.



19.

13. A computer graphics system substantially as hereinbefore described with reference to the accompanying drawings.

14. A method for determining the intensities of points representing line segments to be displayed on a computer output display which intensities vary in general in accordance with the depth of each point to be represented substantially as hereinbefore described.
