Dictionary of Computer Graphics

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Introduction

In the not-too-distant future, our current technology will manifest a class of machinery that will challenge our ideas concerning creativity, art and intelligence. Today, when we use computer graphic systems we confidently employ expressions such as 'Oh, it's only as good as the user. If you can't design, neither can the computer.' But this will change. Just imagine a computer of the future furnished with sight, speech and hearing, having a conversation with a child about painting. The child, perhaps, is drawing a picture whilst the computer responds with comment, criticism and suggestions concerning form, balance, colour, style and content. Consider, also, the development of machines capable of graphic invention. Impossible, you might think (or even hope), but I believe that we are currently witnessing the embryonic stages of this new race of systems.

Today, computer graphics has captured the imagination of computer users, as they are able to output results in a form easily assimilated by the brain, and often pleasing to the eye. Business systems employ the familiar histograms and graphs; CAD systems output meticulously detailed drawings, and science-fiction films exploit super computer animated images of imaginary worlds and impossible journeys. The artist/designer has now become seduced by the computer, and is generally extremely inquisitive to understand how it performs its tasks, and more importantly, how they can personally influence the development of future machines.

Unfortunately, in spite of computers being inherently simple, they are electronically tedious devices and, moreover, the science of computer graphics is woven in the convenient (for some) language of mathematics, embroidered with programing. This high-tech exterior does not always appear very friendly to someone of an artistic disposition, but I must insist that if one pulls back these mathematical veils, one discovers a magical collection of simple ideas.

To keep abreast of the latest techniques, it is essential to read books and papers published by researchers, but the major drawback with technical papers is the author's assumption that the reader understands the notation, language and ideas employed to communicate some new procedure. Naturally, the author has no other option, and it is the responsibility of the reader to widen the research until a reasonable understanding can be achieved.

The primary reason for writing the *Dictionary of Computer Graphics* was to describe in layman's terms, some of the words and concepts often employed in technical literature. But, even at this level, semantic assumptions have to be made when describing an outrageously complex topic in two paragraphs.

Even though the book has been organized in a convenient alphabetical order, for quick random reference, there is nothing to stop the adventurous reader from reading through from 'A' to 'Z', but if you do so don't expect to discover a theme!

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A

ACHROMATIC COLOUR

The monochromatic grey scale describes the transition from black to white, and any intermediate grey level is called an achromatic colour.

ADDITIVE PRIMARY COLOURS

Electromagnetic radiation is a fundamental element of the universe as it provides the mechanism for the transfer of energy across space at the speed of light. Part of this energy spectrum is called visible light, as our brain registers the response of colour when our eyes are exposed to this radiation.

Isaac Newton discovered that when a white light is passed through a prism the resultant light is divided into the spectrum of colours and, furthermore, that when the separate colours are recombined, white light is once more created. This basic principle of colour mixing gave rise to the idea that colours could be formed by mixing together other colours in varying quantities, which happens to be the case. The construction of the eye's retina is such that, when it is illuminated with different amounts of red, green and blue light, it integrates the combined radiation to create a singular colour sensation. Thus, almost any colour can be formed by different amounts of red, green and blue, which are called the primary colours. This characteristic of the eye is exploited within computer graphics, as it permits colour values to be stored as three numbers for describing any required colour.

When the colours are pigments—rather than radiant light—a subtractive primary colour mechanism functions, namely: yellow, magenta and cyan.

ALGORITHM

The word algorithm has found its way into computer jargon and simply means a procedure of rules for achieving a goal or objective

For example, one could write a BASIC program to sort a set of numbers into ascending sequence by repeatedly exchanging neighbouring pairs of numbers. Naturally, computer graphics has demanded the development of totally new algorithms to solve its range of problems, such as: hidden-line removal, colour shading, fractal surfaces and ray tracing.

ALIASING

Aliasing has its origins in a branch of mathematics called Sampling Theory, and describes a form of error introduced by systems which manipulate data in discrete units. In the area of computer graphics, visual aliasing occurs when display devices attempt to handle detail which exceeds the basic resolving power of the system. The effect is most obvious in pixel-based frame stores and manifests itself as jagged edges (staircase effects) when edges that are almost vertical or horizontal are displayed. Plate 1 shows an image held in a frame store and is magnified to illustrate the aliased edges. Plate 2 shows the complete image. It is only obvious to the eye on low resolution systems and can be reduced by anti-aliasing procedures. (See ANTI-ALIASING.)

ANIMATION

When we perceive the world, objects move and colours change in a continuous fashion, but it is possible to achieve similar movement by artificial means using animation techniques. This involves the projection of a continuous sequence of related images at a speed which matches the human eye's inherent persistence to create a flicker-free image. An 8 mm cine projector might display 18 or 24 frames per second, whilst 16 mm and 35 mm systems operate at 24 fps, a speed which was chosen when soundtracks were first incorporated, and has remained the same ever since.

In the case of video equipment as American electricity is generated at 60 Hertz, a transmission rate of 30 fps was chosen because of problems with cross-talk encountered in early electronic transmission equipment. Although these problems no longer exist, the 30 fps rate is still maintained. On the other hand, European electricity is generated at 50 Hertz, with a transmission rate of 25 fps.

Certain problems arise when film is transmitted, as there is a conflict between the 24 film images and the 25 or 30 frames broadcast. American television overcomes the problem by scanning alternate frames three times, and the intervening ones twice; this requires a device called a limping intermittent. British television simply transmits the film at 25 fps, giving rise to a speed increase of approximately 4 per cent, and the sound pitch is raised by about a third of a whole tone. More recently, film intended for television has been taken at 25 fps.

ANTI-ALIASING

Anti-aliasing is a technique for disguising the aliasing errors introduced by discrete systems. Aliasing errors found in pixel-based frame stores manifest themselves as jagged edges, but these can be 'softened' or anti-aliased, by filtering the shading intensities around the offending pixels to create a smoother transition of colour changes.

An anti-aliased image will appear slightly blurred or softer to the eye. It should also be appreciated that anti-aliasing is unnecessary on high-resolution systems (in excess of 1500 lines). It is normally a software procedure but can be implemented in hardware, as in the QUANTEL paint box and some colour display devices which provide anti-aliased vectors.

AREA INFILL

Area infill is associated with pixel-based systems and describes the process of flooding a defined area of the screen with a specified colour. Some systems incorporate the facility in hardware and achieve extremely rapid results on complex shapes, typically $\frac{1}{25}$ second to 2 seconds. Painting systems will normally include this feature and so do many microcomputers.

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ASPECT RATIO

Aspect ratio in computer graphics relates the height of an image to its width, and for images created for television this ratio is 3 : 4. Film aspect ratios vary considerably, depending on the format used. For example, the aspect ratio for 35 mm film employed in a single-lens reflex camera is 2 : 3.

B

BACK FACE

When objects are modelled within computer graphic programs they are often assembled as a collection of facets. For example, a rectangular box would be created from six faces touching one another. However, natural physical laws prevent us from seeing all six sides at once; in fact normally we can only see between one and three, with the remaining sides presenting their backs to us. Consequently, if we can identify these back-facing sides there is no need to draw them or include them in hidden-line removal procedures (see HIDDEN-LINE REMOVAL). One way of detecting them is

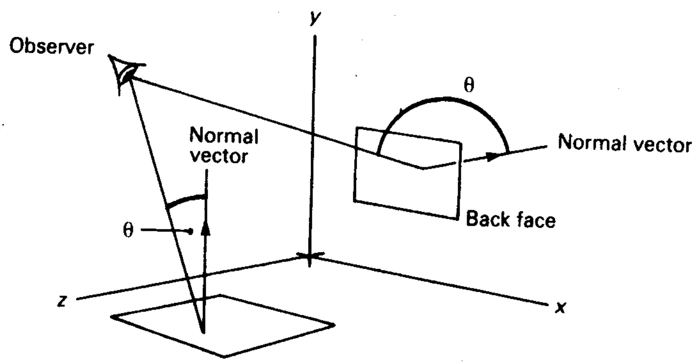

Figure 1. The magnitude of θ determines back-facing facets

to examine the plane equation describing the facet, as this also defines a vector (the normal vector) intersecting the plane at right angles. (See NORMAL VECTOR.)

Figure 1 illustrates an eye observing two facets in space. One is *facing the eye, but the other is back-facing. It is possible to distinguish* one from the other by computing the angle θ, because if this exceeds 90°, the side is a back face. Back face removal is sometimes referred to as culling.

BASIC

BASIC (Beginner's All-purpose Symbolic Instruction Code) is a simple language for controlling computers—especially micro-based systems—and although it can be used for computer graphic applications its relatively slow execution speed is a major disadvantage. Many graphic packages implemented upon microcomputers are written in machine code to achieve maximum speed.

BÉZIER CURVES AND PATCHES

Dr P. Bézier of Régie Nationale des Usines Renault developed his UNISURF system which enabled car body panels to be modelled within a computer and formed by numerically controlled machines. To achieve this process, he developed a mathematical technique of specifying smooth continuous lines and surfaces (patches), which require a starting and finishing point with several intermediate points which influence (or control) the path of the linking curve. The 'secret' of the technique employed by Bézier lies in the blending functions used to control the local influence exerted by intermediate points. They are such that:

(a) at the starting and finishing points all other points have zero influence, but
(b) intermediate points attract and release the passing curve as if they had some gravitational influence.

To illustrate this process, imagine four points in space: *A, B, C* and *D*. It does not really matter how they are placed. Now suppose we have to make a journey from *A* to *D*, but must respect the attractive forces of *B* and *C*. As we move away from *A* we become influenced by *B, C* and *D*. The Bézier blending functions will allow *B* to dominate initially, followed by *C* and then *D*. As we pass by *B*, *C*'s influence takes over and *D* slowly becomes more noticeable. As time passes we become less and less attracted by *A, B* and *C* but now *D* drags us inevitably towards it. The blending functions shown in Figure 2 illustrate the attractive influence exerted by the four points as the above journey is made.

Bézier curves are extremely useful in computer programs as they enable very complex paths to be specified with the minimum of information, and apart from being used in three-dimensional modelling, they can be utilized as flight paths for the 'computer's eye' in animation sequences.

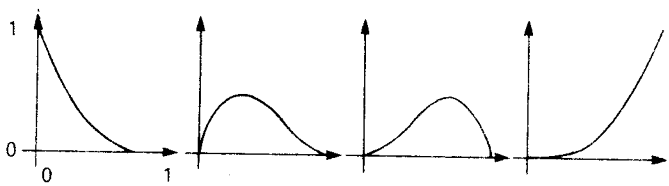

Figure 2. Four Bézier blending functions

BINARY

Early attempts to employ a decimal coding system in computers failed through the instability of valve equipment. So today a two-state code (binary) is employed to encode data and instructions that control computer processors.

To appreciate the combinations that are possible with a two-state code, consider a system having three bits (binary digits). The possible combinations are:

000	010	100	110
001	011	101	111

There are eight combinations for three bits. For eight bits there are 256 combinations, which permits the letters of the alphabet to be assigned separate codes (upper case and lower case), the ten decimal numbers (0 to 9), together with all the essential punctuation characters and other symbols. This group of eight bits is called a byte.

BIT

The binary code employed in computer processors is composed of a two-state signal, where each state represents a bit (binary digit) of information. This is often represented by 0 and 1.

BRIGHTNESS

Light is a word describing part of the natural electromagnetic spectrum to which our eyes are sensitive. The further we are from a light source the less intense it becomes, in fact, the relationship is an inverse-square function, which can be summarized by the equation:

$$\text{Intensity of illumination } \alpha\ J/D^2$$

where J represents the power of the light source, and D is the distance between the source and the point of detection. But the intensity of illumination does not indicate how bright an illuminated surface will appear to the human eye; this parameter demands a knowledge of the area and orientation of the surface. However, computer programs must make certain assumptions when attempting to model physical phenomena, and one common assumption is that conventional surfaces reflect light equally in all directions, i.e. they are diffuse reflectors.

Lambert's Law, which states that 'the effective candlepower per unit area of a perfectly diffusing surface is proportional to the cosine of the angle between the normal to the surface and the direction from which it is viewed' is generally employed to make brightness computations in shading models.

Another simplification made by illumination models is to assume that the original light source is sufficiently distant that the change in distance between the source and different parts of the object is so slight as to be insignificant. Thus, to calculate the brightness of a point on a surface one only needs to know the angle θ and the intensity of the light source as shown in Figure 3. For example, if we make the source intensity unity, the brightness levels will vary between zero and one, depending upon the angle θ, which can be used to control primary colour levels in a frame store.

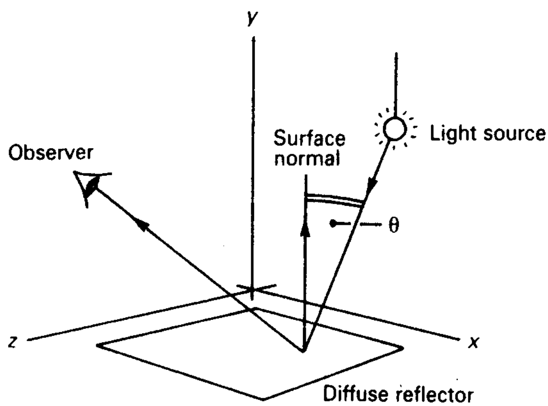

Figure 3. Light reaching the observer is proportional to cos(θ)

B-SPLINE CURVES

The word 'spline' is derived from hull design in shipbuilding and is a long thin strip of wood used by a loftsman to produce smooth continuous curves. The mathematical equations describing a stressed thin lamina touching several guide or control points can be obtained by examining segments of the curve between pairs of control points. These segments can be described by using cubic equations of the form:

$$F(t) = B_1 + B_2t + B_3t^2 + B_4t^3$$

Where B_1, B_2, B_3 and B_4 are coefficients chosen to satisfy the boundary condition of the segment. The latter are such that the curve touches the end points and the slope of the curve matches the following segment.

Once coefficients have been assigned, it is possible to compute intermediate points along the segment in two or three dimensions using a simple parametric technique.

B-Splines (as originally introduced by Curry and Schoenberg (1947)) are closely related to Bézier curves, and enable two or three-dimensional curves to be formed by control points which 'guide' the curve through space. However, unlike Bézier curves the guide points of B-Splines have local span control, which means that when a guide point is adjusted its influence is local and not global. Figure 4 illustrates a family of curves created by a B-spline algorithm.

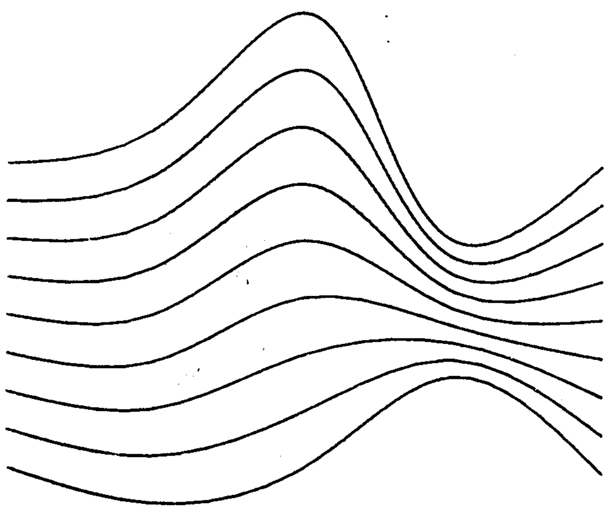

Figure 4. A family of B-spline curves

BUSINESS GRAPHICS

Computer graphics is increasingly employed in business applications to communicate to management visual interpretations of numeric data in the form of: histograms, pie-charts, maps,

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