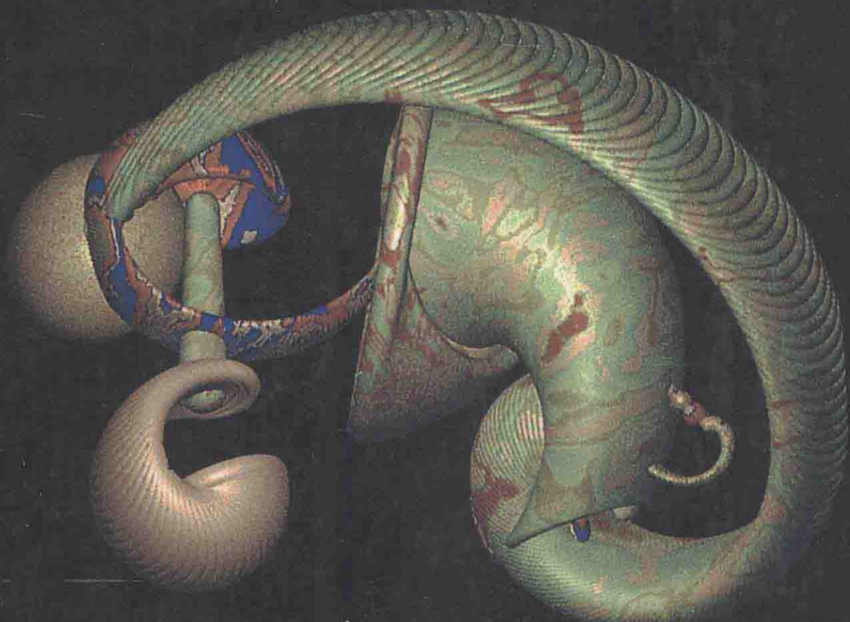
The Language of Computer Graphics



A dictionary of terms and concepts

John Vince

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Architecture Design and Technology Press
London

First published in 1990 by
Architecture Design and
Technology Press
128 Long Acre
London WC2E 9AN

British Library Cataloguing in Publication Data
A CIP catalogue record for this book is available from the British Library

ISBN 1 85454 147 1

Linotronic: Alphabet Set, London

Printed in Great Britain by The Bath Press

To Annie, Samantha and Anthony

preface

Twenty years ago – when computer graphics was starting to evolve – it seemed possible to understand the entire subject, as it was basically concerned with clipping, transformations and elementary shading. Today, this is no longer the case – one only has to open the latest SIGGRAPH proceedings to discover subjects such as radiosity, stochastic sampling, solid texture, global illumination models, parametric surfaces and inverse kinematics, to realize the enormous progress that has been made. However, as with all evolving subjects, computer graphics is having to introduce new words and terminology that are equally baffling for the newcomer.

My sole purpose in collecting these thousand or so words together was to provide the newcomer to this exciting subject with an introduction to the language of computer graphics using descriptions that are simple to understand and, where possible, without any supporting mathematics. The entries are not taken entirely from computer graphics, as I have wandered into various disciplines from optics to electronics, selecting terms that frequently surface within technical papers. I have considered each entry very carefully, anticipating the conceptual problems a reader will encounter in understanding the scope and significance of its meaning. Such descriptions have been limited by the total space available for this publication; consequently, I have had to balance the level of description with the perceived complexity of the entry. I only hope that I have succeeded in establishing this balance.

In the majority of entries, I have highlighted (using small capital letters) certain words that are explained elsewhere in the book, and might assist the reader in perfecting an understanding of the term – and to complete this cross-referencing I have also suggested other related entries that may be worth investigating.

Finally, a list of references has been provided which identifies doctoral theses, proceedings, scientific papers, patents and selected books that will take the reader into relevant areas of interest. I know that I wish such a resource had been available when I first became captivated by computer graphics; so perhaps you will randomly delve into the pages of this book and discover something new, or suddenly understand a concept for the first time. Hopefully, some of the entries will translate into 'mind pictures' and assist you in understanding some abstract terms, and enable you to comprehend this amazing world of synthetic imagery and, who knows, could stimulate you to explore an exciting avenue of research.

John Vince

acknowledgements

I am indebted to the colleagues I have pestered over recent months to clarify the meaning of certain terms and concepts, without whose help, this book would not have been possible. In particular, I wish to thank Gareth Edwards who read an early manuscript and revealed a wealth of extra terms I had overlooked or had not encountered, and sent me off investigating obtuse subject areas in SIGGRAPH proceedings. Similarly, I must thank Dr Tony Crilly at Middlesex Polytechnic, who innocently volunteered to read the manuscript, offered invaluable advice on many areas, and proposed alternative definitions and explanations. Paul Froggatt and Mark Schafer at Symbolics have also been of tremendous assistance in providing me with the terminology and explanations of terms used within the computer animation community. Alastair Horn actually volunteered to read the final draft and made some valuable suggestions, however, the extra terms he recommended will have to wait for a second edition. A special acknowledgement is due to Dietmar Saupe for providing me with the illustration on page 93 – and also an endless source of information from the book *The Science of Fractal Images*. William Latham of the IBM Scientific Research Centre generously provided the computer images on the cover. Finally, a global thank you to the authors of the books, articles and proceedings that provided the original source material for this book.

a

absolute coordinates

The term absolute coordinates is sometimes used in place of world coordinates, which form a basis for defining 3-D models and their positions, together with the positions of light sources and trajectory paths. (See also WORLD COORDINATE SPACE.)
[Gasson-83]

A-buffer

Loren Carpenter developed the A-buffer HIDDEN-SURFACE REMOVAL algorithm at Lucasfilm Ltd as part of the REYES renderer. It is a descendant of the Z-BUFFER and addresses the problems of ANTI-ALIASING, TRANSPARENCY and interpenetrating objects by maintaining lists of pixel bit masks, which records a polygon's impact upon a pixel. These bit masks, together with colour, Z-DEPTH, OPACITY and AREA PROPERTIES, enable a pixel's intensity to be computed. The algorithm's name is due to the Anti-aliasing being achieved through Area-Averaged Accumulation of intensities. (See also HIDDEN-SURFACE REMOVAL, PAINTER'S ALGORITHM, RADIOSITY, SCAN-LINE ALGORITHM, Z-BUFFER, and ZZ-BUFFER.)
[Carpenter-89]

achromatic light

Achromatic light is without colour and describes light consisting of varying degrees of grey from black to white, as found on monochrome CRT displays. (See also CHROMATIC LIGHT.)
[Gregory-86]

active list

In SCAN-LINE ALGORITHMS the active list maintains references to those facets that intersect the current scan-line. By exploiting EDGE COHERENCE, this active list can be updated for the following raster by dropping those facets no longer intersecting the raster and including new facets that do intersect. (See also EDGE COHERENCE, OBJECT SPACE ALGORITHM, and SCAN-LINE ALGORITHM.)
[Burger-89, Foley-90, Hearn-86, Rogers-85]

acuity

See VISUAL ACUITY.

acute angle

An acute angle is less than 90°. (See also OBTUSE ANGLE.)

adaptive clipping

Where many clipping algorithms operate upon single lines or polygons, adaptive clipping is sensitive to, or 'adapts' to, the existence of rotation/shear INSTANCE TRANSFORMS in a hierarchical DISPLAY FILE. (See also CLIPPING and CLIPPING DIVIDER.)
[Newman-79]

adaptive forward differences (AFD)

As a POLYNOMIAL can be evaluated using FORWARD DIFFERENCES, PARAMETRIC CURVES and surfaces can be rendered with the aid of this technique. But where conventional FORWARD DIFFERENCES uses fixed increments, adaptive forward differences dynamically adjusts the controlling parameter so that the PARAMETRIC CURVE or surface is evaluated at pixel sized steps. (See also ADAPTIVE SUBDIVISION, CRACKS, FORWARD DIFFERENCES, PARAMETRIC CURVE, PARAMETRIC SURFACE PATCH, and RENDERER.)
[Chang-89, Lien-87, Rockwood-87, Shantz-87, Shantz-88]

adaptive progressive refinement

Adaptive progressive refinement refers to the way an image is progressively refined until certain visual goals are obtained. (See also ADAPTIVE SAMPLING, ANTI-ALIASING, and STOCHASTIC SAMPLING.)
[Bergman-86, Cohen-88, Painter-89]

adaptive sampling

Adaptive sampling is an ANTI-ALIASING strategy in which additional samples are introduced between previous samples to improve the SAMPLING. (See also ALIASING, OVERSAMPLING, RAY TRACING, and STOCHASTIC SAMPLING.)
[Cook-86, Glassner-89, Whitted-79]

adaptive subdivision

One way of rendering a SURFACE PATCH is to repeatedly subdivide it into smaller subpatches – adaptive subdivision halts the process when some flatness criterion is achieved. Because the subdivision occurs in PARAMETER SPACE – rather than OBJECT SPACE – linear edges in PARAMETER SPACE are assumed to create linear polygon edges, which is not always the case. This assumption can create small visual artifacts between the rendered polygons in the form of missing detail called 'CRACKS'. (See also ADAPTIVE FORWARD DIFFERENCING, AREA SUBDIVISION ALGORITHMS, CRACKS, DIVIDE AND CONQUER, IMAGE SPACE ALGORITHM, PARAMETER SPACE, PARAMETRIC SURFACE PATCH, and WARNOCK ALGORITHM.)
[Catmull-74a, Clark-79, Dippe-84, Lane-80]

adaptive tree-depth control

In RAY TRACING, adaptive tree-depth control refers to the process of dynamically adjusting the depth of the RAY INTERSECTION TREE traversed by ignoring rays whose intensity falls below some threshold. (See also RAY INTERSECTION TREE and RAY TRACING.)
[Glassner-89]

additive colour mixing

Additive colour mixing is the technique of creating colours by superimposing two or three light sources from the red, green and blue portions of the visible spectrum. The idea is attributed to Thomas Young (1723–1829) who proposed additive colour mixing as the key to human colour vision. See Figure A-1. (See also ADDITIVE PRIMARY COLOURS, SUBTRACTIVE COLOUR MIXING, SUBTRACTIVE PRIMARY COLOURS, TRICHROMATIC COLOUR SYSTEM, and TRI-STIMULOUS THEORY.)
[Boynton-79, Burger-89, Gregory-86, Hunt-75]

additive primary colours

The additive primary colours are red, green and blue, because the human retina contains three types of cone photopigments with peak sensitivities in the red (650 nm), green (530 nm) and blue (425 nm) portions of the visible spectrum. Thus a model of colour matching – the TRICHROMATIC SYSTEM – can be used to describe colours as the additive combination of three primary components. This is the basis of most television and computer graphics display technology. See Figure A-1. (See also ADDITIVE COLOUR MIXING, SUBTRACTIVE COLOUR MIXING, SUBTRACTIVE PRIMARY COLOURS, TRICHROMATIC COLOUR SYSTEM, and TRI-STIMULOUS THEORY.)
[Boynton-79, Burger-89, Gregory-86, Hunt-75]

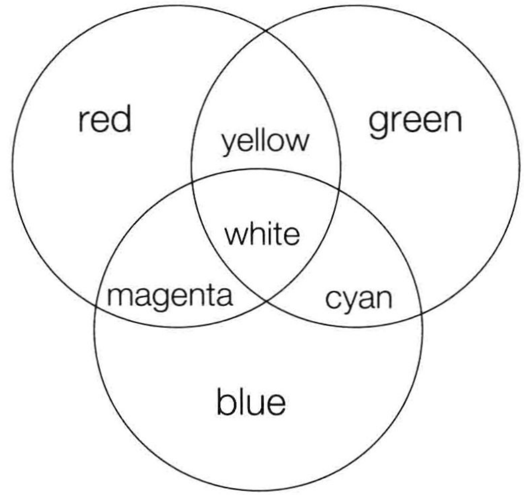

Figure A-1 *When the additive primary colours red, green and blue are combined together, they produce the secondary colours cyan, magenta and yellow. Furthermore, if equal amounts of red, green and blue are mixed together different intensities of grey result.*

AFD

See ADAPTIVE FORWARD DIFFERENCES.

affine transformation

Affine geometry and its associated transformations preserves the concept of parallelism, with the implication that any lines parallel before an affine transformation will

still be parallel after the operation. Examples of affine transformations are scale, reflection, rotation and shear. An affine transformation can consist of any number of linear transformations followed by a translation. A PERSPECTIVE TRANSFORMATION, for example, is not affine, as it does not preserve parallelism. (See also LINEAR TRANSFORMATION, MATRIX OPERATION, NON-LINEAR TRANSFORMATION, PERSPECTIVE TRANSFORMATION, and TRANSFORMATION.)
[Gasson-83, Rogers-89, Stevenson-74]

aim point

The orientation of the OBSERVER in WORLD COORDINATES can be effected by the EYE POINT and the aim point; the latter is the point at which the gaze of the OBSERVER is directed, and in general coincides with the centre of the VIEWPORT. See Figure E-2. (See also EYE COORDINATE SYSTEM, EYE POINT, LINE OF SIGHT, OBSERVER, VIEWPORT, and VIEW VECTOR.)

airbrush

(1) An airbrush is an air-driven paint gun which may be used to spray paint over a surface to achieve photo-realistic images.
(2) Airbrush is a paint mode in computer paint systems to imitate physical airbrushing. (See also PAINT SYSTEM.)

algebraic surface

An algebraic surface is a geometric representation of an equation describing in 3-D space the relationship between three variables. For example, the equation

$$z = 3x + y^2$$

relates together x, y and z, and by substituting values fo and y, one could identify the IMPLICIT SURFACE represented by the algebraic equation. Such surfaces are the basis of CONSTRUCTIVE SOLID GEOMETRY and RAY TRACING strategies. (See also EXPLICIT SURFACE.)
[Gasson-83, Glassner-89]

algorithm

A rigorous definition of an algorithm is: a mathematical or logical procedure for solving a problem composed from an indefinite number of steps, each step applying to the result of the one preceding it. Informally, it means a procedure used to solve a problem. The word algorithm is a corruption of Al Kworesmi, a ninth century Arabian mathematician. (See also DETERMINISTIC, HEURISTIC, and STOCHASTIC.)
[Earnshaw-85]

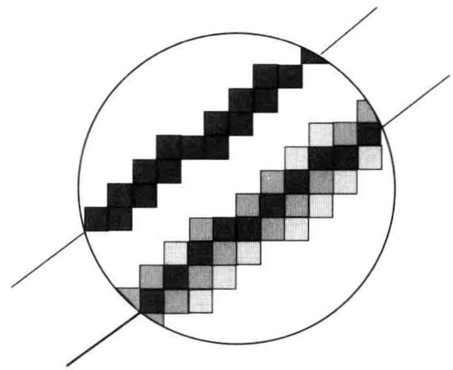

Figure A-2 *The magnified top jagged line can be improved by an anti-aliasing procedure which introduces neighbouring pixels of different intensities as shown in the bottom line.*

aliasing

(1) **Analytic**: When a complex signal is discretely sampled and a reconstruction is made from the samples, any frequency components in the original signal that exceed the NYQUIST LIMIT will appear as a low-frequency 'alias' in the reconstruction. The introduction of these extraneous artifacts is called aliasing.
(2) **Spatial**: In pixel-based display systems, visual artifacts such as jagged edges and MOIRÉ PATTERNS caused by insufficient spatial sampling are referred to as SPATIAL ALIASING. See Figure A-2.
(3) **Temporal**: Animation artifacts such as 'wagon wheels' apparently rotating backwards caused by the insufficient temporal sampling of moving objects is referred to as TEMPORAL ALIASING. (See also ADAPTIVE SAM-

PLING, ANTI-ALIASING, ARTIFACT, CONVOLUTION, FILTER, FILTERING, JAGGIES, NYQUIST LIMIT, POINT SAMPLING, SAMPLING, SPATIAL ALIASING, STOCHASTIC SAMPLING, and TEMPORAL ALIASING.)
[Blinn-89a, Burger-89, Foley-90, Gupta-81, Rogers-85]

alpha channel
The alpha channel is a video channel derived from a value called the ALPHA VALUE associated with each pixel in a video FRAME STORE. It is often used for storing MATTES when COMPOSITING images – and as each pixel may have a number of bits of KEY SIGNAL, the MATTE boundary can create an interpolated blend of intensities. (See also COMPOSITING and MATTE.)

alpha value
See ALPHA CHANNEL.

ambient light
ILLUMINATION MODELS employ a constant term to represent a background light level assumed to be caused by multiple DIFFUSE REFLECTIONS. This ambient light component allows surfaces not directly illuminated by light sources to receive some level of illumination. The ambient light level must be carefully adjusted in relation to the intensities of the other light sources, to ensure that surfaces are not saturated with light – a typical level might be around 25% of the total illumination level. (See also DIFFUSE REFLECTION, GLOBAL ILLUMINATION MODEL, ILLUMINATION MODEL, LIGHT SOURCE, and SPECULAR REFLECTION.)
[Burger-89, Foley-90, Glassner-89, Hearn-86, Rogers-85]

ambient reflection coefficient
The ambient reflection coefficient is a fractional value associated with a reflective surface that determines the level of ambient light it reflects. It is common to have a coefficient for each of the red, green and blue components. (See also DIFFUSE REFLECTION COEFFICIENT and SPECULAR REFLECTION COEFFICIENT.)
[Burger-89, Foley-90, Glassner-89, Hearn-86, Rogers-85]

analogue signals
Analogue signals vary continuously in time. Such signals are found in moving-coil microphones, gramophone pickups and loudspeakers. (See also ANALOGUE-TO-DIGITAL CONVERTER, DIGITAL SIGNAL, and DIGITAL-TO-ANALOGUE CONVERTER.)

analogue-to-digital converter
Analogue-to-digital converters translate an ANALOGUE SIGNAL into a DIGITAL SIGNAL by SAMPLING the waveform's amplitude at intervals and converting it to a binary number with a specified bit resolution. For example, the rotary controls on a FUNCTION BOX will employ an analogue-to-digital converter to translate rotational positions into DIGITAL SIGNALS for processing by a computer. (See also ANALOGUE SIGNAL, DIGITAL SIGNAL, and DIGITAL-TO-ANALOGUE CONVERTER.)

angle of incidence
The orientation of a source of illumination relative to a surface is measured by the angle of incidence, which is the ACUTE ANGLE formed by the SURFACE NORMAL and the incident ray illuminating the surface. For reflecting surfaces, the ANGLE OF REFLECTION equals the angle of incidence. See Figure A-3. (See also ANGLE OF REFLECTION and ANGLE OF REFRACTION.)
[Glassner-89, Jenkins-76]

angle of reflection
For a perfect reflecting surface, the angle of reflection is the ACUTE ANGLE formed by the SURFACE NORMAL and the reflected ray away from the surface. For such surfaces, the angle of reflection equals the ANGLE OF INCIDENCE. See Figure A-3. (See also ANGLE OF INCIDENCE and ANGLE OF REFRACTION.)
[Glassner-89, Jenkins-76]

angle of refraction
When light moves from one medium to another and undergoes a speed change, the direction of the transmitted light is also disturbed (refracted); this angle of refraction is the ACUTE ANGLE formed by the refracted ray

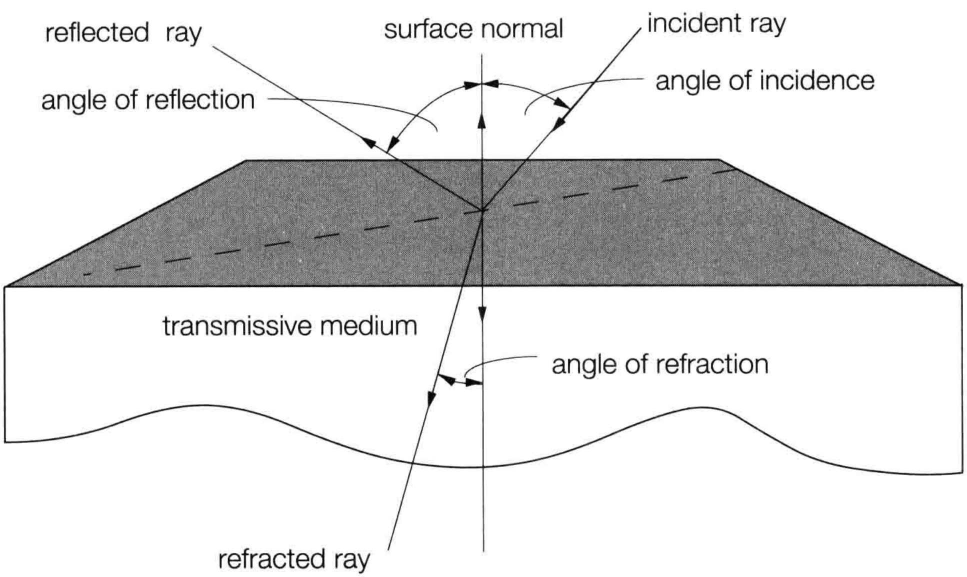

Figure A-3 *The first law of reflection states that the incident ray, the reflected ray and the surface normal at the point of incidence lie in the same plane; whilst the second law states that the angle of reflection equals the angle of incidence.*

and the reflected SURFACE NORMAL for a transmissive medium. The relationship between the ANGLE OF INCIDENCE and the ANGLE OF REFRACTION is defined by SNELL'S LAW. See Figure A-3. (See also ANGLE OF INCIDENCE, ANGLE OF REFLECTION, REFRACTION OF LIGHT, REFRACTIVE INDEX, and SNELL'S LAW.)

angle of view

The angle of view of a lens is the SOLID ANGLE of incident light transmitted by the lens. This may vary between 8° for a telephoto lens, through 50° for a normal lens, to 100° for a wide-angle lens. This optical phenomenon can be simulated in computer graphics. (See also APERTURE, DEPTH OF FIELD, F-NUMBER, and FOCAL LENGTH.)
[Glassner-89, Potmesil-81, Potmesil-82]

animation

Animation is the technique of creating continuously moving scenes by projecting a sequence of gradually changing discrete images in rapid succession to an observer. In computer animation, the computer is sometimes able to generate images in REAL-TIME, but frequently several minutes are required to create just one frame – and usually only when a sequence is complete can they be observed in an animated form. (See also BEHAVIOURAL ANIMATION, CELL ANIMATION, CHARACTER ANIMATION, COMPUTER ANIMATION, FLICKER, FUSION FREQUENCY, KEY-FRAME ANIMATION, and REAL-TIME.)
[Lasseter-87, White-86]

anisotropic

Anisotropic means varying as a function of direction. For example, SPECULAR REFLECTIONS are anisotropic as they can only occur over a limited angular range. (See also ISOTROPIC.)
[Kajiya-85]

anti-aliasing

In general, anti-aliasing encompasses strategies concerned with the removal or reduction of ALIASING ARTIFACTS arising from the insufficient SAMPLING of complex signals. In RASTER COMPUTER GRAPHICS this might be achieved by increased SAMPLING and averaging the result: this reduces aliasing by effectively raising the NYQUIST LIMIT. Unfortunately, no matter how many samples are taken, there will always be higher frequencies that will alias, so research effort has been expended in achieving better SAMPLING. See Figure A-2. (See also ADAPTIVE SAMPLING, ALIASING, ARTIFACT, BASIS FUNCTION, CONVOLUTION, FILTER, FILTERING, FOURIER WAVEFORM ANALYSIS, JAGGIES, NYQUIST LIMIT, OVERSAMPLING, PIXEL AVERAGING, POINT SAMPLING, POINT-SPREAD FUNCTION, SPATIAL ALIASING, STOCHASTIC SAMPLING, and TEMPORAL ALIASING)

[Abram-85, Blinn-89a, Blinn-89b, Crow-81, Crow-86, Dippe-85, Forrest-85, Glassner-89, Grant-85, Max-90a]

anticlockwise polygon

Polygons are an essential building block in modelling – and are constructed with an inherent 'sense', in that their boundary follows a clockwise or anticlockwise path: an anticlockwise polygon is defined as one whose interior is to the left and whose exterior is to the right when its boundary is traversed in the direction of its edges. The 'sense' of polygons can be critical to some algorithms, as they might assume that clockwise polygons represent solids and anticlockwise polygons represent holes. Similarly, a modelling scheme might require that all surfaces are constructed with a clockwise sense, to create outward-facing SURFACE NORMALS. A mistake in this scheme would produce an inward-facing surface normal, possibly creating problems in rendering and HIDDEN-SURFACE REMOVAL. (See also BACK FACE REMOVAL and CLOCKWISE POLYGON.)

aperture

Aperture is a measure of the physical area associated with a lens through which light can pass – and a conventional method of expressing this is by the F-NUMBER. Because lens systems are not 100% accurate, especially at large apertures, the DEPTH OF FIELD depends upon the F-NUMBER; this phenomenon can be simulated in RAY TRACING. (See also CIRCLE OF CONFUSION, DEPTH OF FIELD, F-NUMBER, and RAY TRACING.)

[Burger-89, Glassner-89, Jenkins-76, Potmesil-81, Potmesil-82]

approximating spline

Spline curves can be categorized into two simple types: those that intersect their CONTROL POINTS, and those that only approach them. Approximating splines are of the latter type, whilst the former are known as INTERPOLATING SPLINES. B-SPLINE CURVES are approximating splines. (See also BÉZIER CURVE, B-SPLINE CURVE, CATMULL–ROM SPLINE, CONTROL POINTS, INTERPOLATING SPLINE, NURBS, and SPLINE.)

[Bohm-84, Farin-88, Smith-83, Woodwark-86]

area coherence

Some algorithms are able to exploit area coherence by recognizing features that are consistent over ranges of area. For example, DIVIDE AND CONQUER algorithms or even the use of SPACE FILLING CURVES in IMAGE COMPRESSION exploit area coherence. (See also AREA SUBDIVISION ALGORITHMS, COHERENCE, DEPTH COHERENCE, DIVIDE AND CONQUER, EDGE COHERENCE, and QUADTREE.)

[Crocker-87b, Warnock-68, Warnock-69]

area coordinates

If the vertices P_1, P_2 and P_3 of a 2-D triangle have Cartesian coordinates $[x_1, y_1]$, $[x_2, y_2]$ and $[x_3, y_3]$ respectively, then any point P with coordinates $[x, y]$ which is inside the triangle can create three areas from the vertex sequences: (P, P_2, P_3), (P, P_3, P_1) and (P, P_1, P_2). If these areas are normalized so that they represent fractional values of the triangle's area and are labelled A_1, A_2 and A_3 respectively, then these area coordinates of P are related to its Cartesian coordinates as follows:

$$\begin{bmatrix} 1 \\ x \\ y \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ A_3 \end{bmatrix}$$

As one can also define the areas A_1, A_2 and A_3 in terms of the triangle's vertices and *P*, it is possible to tell whether *P* is inside or outside the triangle, or whether it is located on an edge or a vertex. (See also BARYCENTRIC COORDINATES, CARTESIAN COORDINATES, and HOMOGENEOUS COORDINATES.)
[Jassen-83]

area filling curves
See SPACE FILLING CURVES.

area filling primitives
Area filling primitives refer to polygon filling modes allowed within GKS; this is normally in the form of a pattern and colour. (See also GKS.)
[Burger-89]

area infill
Area infill is the process of filling in regions of connected pixels on a display system with a colour or pattern. (See also BLEED, FLOOD FILL, and PAINT SYSTEM.)
[Burger-89, Dunlavey-83, Smith-79]

area properties
Modern RENDERERS include sophisticated illumination and reflectance models, which are central to PHOTOREALISM, but one consequence of these advances is the need to define parameters that provide control over the final synthetic image. Area properties are used to describe the physical attributes associated with an area such as AMBIENT REFLECTION COEFFICIENT, DIFFUSE REFLECTION COEFFICIENT, TRANSLUCENCY, TEXTURE MAPS, and TRANSPARENCY. (See also AMBIENT REFLECTION COEFFICIENT, ATTRIBUTES, BUMP MAP, COLOUR ATTRIBUTES, DIFFUSE REFLECTION COEFFICIENT, GLOSS COEFFICIENT, MATERIAL EDITING, OPAQUE SURFACE, TEXTURE MAP, TRANSLUCENT SURFACE, and TRANSPARENT SURFACE.)

area subdivision algorithms
Area subdivision algorithms follow the DIVIDE AND CONQUER strategy whereby an area is repeatedly divided into smaller elements until a condition is obtained capable of easy classification and analysis. The WARNOCK ALGORITHM is a typical example of this technique, as this repeatedly divides an area into four equal smaller squares until one of four possible conditions halts the process. See Figure A-4. (See also DIVIDE AND CONQUER, IMAGE SPACE ALGORITHM, QUADTREE, RECURSIVE ALGORITHM, and WARNOCK ALGORITHM.)
[Burger-89, Foley-90, Hearn-86, Rogers-85, Warnock-68, Warnock-69]

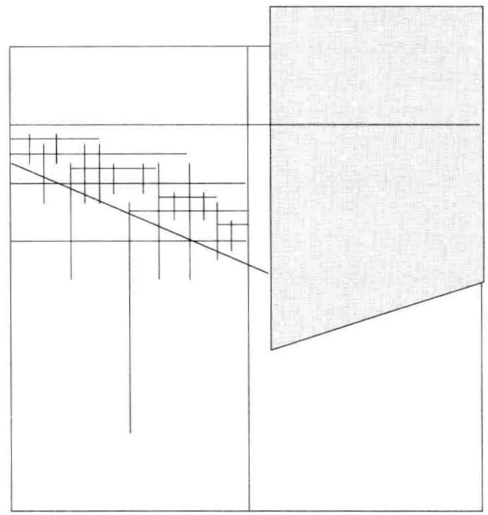

Figure A-4 *The lower left-hand corner of this image has been partially divided using an area subdivision algorithm. The process halts when a condition is reached that can be analyzed without the problems caused by the original complexity.*

arithmetic mean
See AVERAGE.

artifact
Artifacts refer to unwanted visual features introduced by a type of technology or an inaccurate algorithm. In raster displays, the discrete nature of the pixels causes ALIASING

artifacts in the form of jagged edges and flickering texture. See Figure A-2. (See also ALIASING, ANTI-ALIASING, FILTERING, FOURIER WAVEFORM ANALYSIS, JAGGIES, NOISE, NYQUIST LIMIT, POINT SAMPLING, QUANTIZING, SAMPLING, SPATIAL ALIASING, STOCHASTIC SAMPLING, TEMPORAL ALIASING, and UNIFORM SAMPLING.)
[Blinn-89a, Glassner-89]

ASCII
ASCII is an acronym for the American Standard Code for Information Interchange, and defines the bit patterns used to represent characters within a computer system. Seven bits are allocated to data and one bit for a parity check. (See also BINARY and BYTE.)

ASIC
ASIC is an acronym for Application-Specific Integrated Circuit, and relates to VLSI technology and the design of electronic circuits that undertake a specific operation such as LINEAR INTERPOLATION, square-root extraction or MATRIX OPERATIONS. (See also GEOMETRY ENGINE and VLSI.)

aspect ratio
The aspect ratio relates the vertical to the horizontal dimensions of an image or shape; in television this ratio is 3:4, but the recommendation for HDTV is 9:16.

asynchronous
An asynchronous process is not in step with another process: for example, the input signals from a keyboard are asynchronous events. (See also SYNCHRONOUS.)

atmospheric attenuation
The study of light transmission in the atmosphere is an extremely complex science and was an area of investigation long before the advent of computer graphics; however, models involving the sun and the atmosphere, and its associated attenuation, can only be approximated, as the attenuation is proportional to such things as slant angle, time of day, pollution and WAVELENGTH. The subject is treated at great length in the references below. (See also NATURAL PHENOMENA MODELLING, RADIOSITY, and RAY TRACING.)
[Glassner-89, Overington-76, Middleton-52, Willis-87]

attributes
Attributes are properties associated with various entities within a computer graphics system. They include parameters for intensity, colour, line style, text style, texture etc. (See also AREA PROPERTIES, MATERIAL EDITING, OPACITY, REFRACTIVE INDEX, TRANSLUCENCY, and TRANSPARENCY.)
[Burger-89]

auto-dimensioning
Auto-dimensioning is a feature of a CAD system which allows dimensions of a component to be derived from information already input. It also relates to the automatic calculation of dimensions when a scaling factor is introduced. (See also COMPUTER-AIDED DESIGN.)

average
The term average is the arithmetic mean of a set of variables and is expressed mathematically as

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{n}$$

or

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

average normal
If $\boldsymbol{V}_1$, $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$ are three different normal vectors

$$\boldsymbol{V}_1 = a\boldsymbol{i} + b\boldsymbol{j} + c\boldsymbol{k}$$
$$\boldsymbol{V}_2 = d\boldsymbol{i} + e\boldsymbol{j} + f\boldsymbol{k}$$
$$\boldsymbol{V}_3 = g\boldsymbol{i} + h\boldsymbol{j} + i\boldsymbol{k}$$

then the average normal $\boldsymbol{V}_n$ is given by

$$\boldsymbol{V}_n = r\boldsymbol{i} + s\boldsymbol{j} + t\boldsymbol{k}$$

where

$r = a + d + g$
$s = b + e + h$
$t = c + f +$

This may need normalizing to its unit form $\boldsymbol{V}_n$

$\boldsymbol{V}_n = (r/w)\,\boldsymbol{i} + (s/w)\,\boldsymbol{j} + (t/w)\,\boldsymbol{k}$

where $|w| = \sqrt{(r^2 + s^2 + t^2)}$

See Figure A-5. (See also GOURAUD SHADING, NORMAL VECTOR, SURFACE NORMAL, UNIT VECTOR, and VECTOR.)
[Burger-89, Foley-90, Rogers-89]

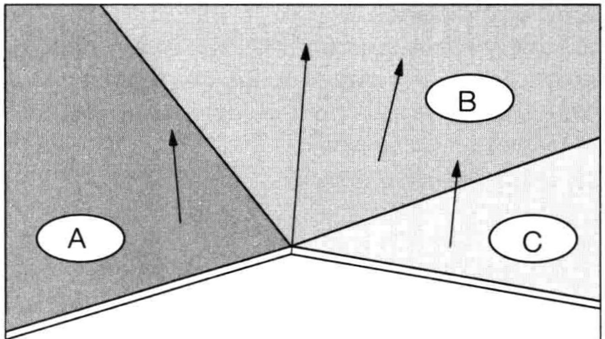

Figure A-5 *Facets A, B and C have separate facet normals, but at their common vertex an average normal vector can be computed, which is used in Gouraud shading.*

axis
(1) An axis is an arbitrary line in 2- or 3-D space about which operations such as reflection and rotation are performed.
(2) An axis is a line used to construct a system of axes as in Cartesian notation. (See also CARTESIAN COORDINATES, LEFT-HANDED AXES, and RIGHT-HANDED AXES.)

axonometric orthographic projection
The axonometric orthographic projection is a PARALLEL PROJECTION and shows more than one face of an object. Perhaps the most widely used example is the ISOMETRIC PROJECTION. (See also CAVALIER PROJECTION, ISOMETRIC PROJECTION, ORTHOGRAPHIC PROJECTION, PARALLEL PROJECTION, PERSPECTIVE PROJECTION, PROJECTION, and PROJECTION PLANE.)
[Foley-90, Gasson-83, Hearn-86, Rogers-89]

b

back clipping plane
The FAR PLANE, YON CLIPPING PLANE or the back clipping plane in the VIEWING PYRAMID controls the distance up to which objects are visible. See Figure C-5. (See also CLIPPING and FRONT CLIPPING PLANE.)
[Burger-89, Hearn-86, Foley-90, Rogers-85]

back face
The back face of a PLANAR polygon is defined as invisible when its SURFACE NORMAL is facing away from the observer, for when objects are constructed from polygons some display algorithms require to identify and reject back-facing polygons. However, with RADIOSITY and RAY TRACING, back-facing polygons are just as important as forward-facing polygons, because in RAY TRACING they could appear in a reflection and in RADIOSITY they receive and reflect light back into the environment. (See also BACK FACE REMOVAL, CLIPPING, FRONT FACE, HIDDEN-LINE REMOVAL, HIDDEN-SURFACE REMOVAL, and SURFACE NORMAL.)
[Burger-89, Hearn-86, Rogers-85]

back face culling
See BACK FACE REMOVAL.

back face removal
Back face removal, or BACK FACE CULLING, refers to the removal of all back-facing surfaces of a scene before it is rendered: this ensures that these invisible features do not impede the overall efficiency of a display algorithm. This can be accomplished by computing the angle between the SURFACE NORMAL and the observer's EYE VECTOR using the SCALAR PRODUCT rule; if this angle is equal to or greater than 90°, the surface is back facing. See Figure B-1. (See also BACK FACE, FRONT FACE, HIDDENLINE REMOVAL, HIDDEN-SURFACE REMOVAL, and SCALAR PRODUCT.)
[Hearn-86, Rogers-85]

backlight
A backlight is used to illuminate an object from behind to emphasize its SILHOUETTE EDGE. (See also AMBIENT LIGHT, DIRECTIONAL LIGHT SOURCE, INCIDENT LIGHT, LIGHT SOURCE, POINT LIGHT SOURCE, and SPOT LIGHT.)

back mapping
See INVERSE MAPPING.

back projection
In resolving HIDDEN-LINE and HIDDEN-SURFACE REMOVAL problems it is necessary to perform MAPPINGS between the IMAGE SPACE and the OBJECT SPACE. The back projection is used to relate points for a line on the PICTURE PLANE back to the original line in OBJECT SPACE. (See also PERSPECTIVE PROJECTION.)
[Burger-89]

backward ray tracing
Backward ray tracing is the strategy employed in RAY TRACING where, for every pixel, a light ray is traced backwards into OBJECT SPACE to determine its origins and its

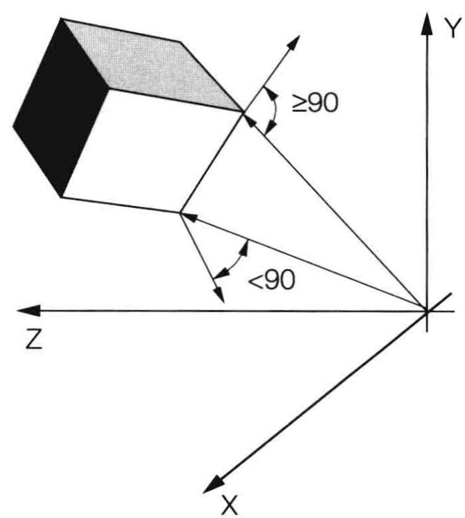

Figure B-1 *If the observer is located at the origin, then a surface is visible if the angle between the eye vector and the surface normal is less than 90 degrees, otherwise it is invisible.*

object intersections. (See also FORWARD RAY TRACING, OBJECT SPACE, and RAY TRACING.)
[Arvo-86, Burger-89, Glassner-89]

bandwidth

The maximum frequency range that a system is capable of transmitting without errors is specified by its bandwidth: in relation to display systems, this influences the highest level of detail that can be handled. In television, the PAL video bandwidth is 5.5 MHz, whilst NTSC is 4.2 MHz, with PAL providing a resolution of 625 lines at 25 Hz and NTSC 525 lines at 29.97 Hz. (See also HORIZONTAL SCAN FREQUENCY, RESOLUTION, and VIDEO FREQUENCY.)
[Hunt-75]

bar sheets

Bar sheets are used in animation projects as a reference document controlling dialogue, music and movements with frame numbers. (See also ANIMATION, COMPUTER ANIMATION, MODEL SHEETS, and STORYBOARD.)
[White-86]

Bartlett filter

A Bartlett filter can be approximated by a matrix of weights and convolved with an image to remove NOISE. It can also be used for reducing the resolution of an image; for example, an image computed to 1024 x 1024 can be filtered to 512 x 512 by using the weightings

1 2 1
2 4 2
1 2 1

where the central weight 4 is placed over an appropriate high-resolution pixel and the low-resolution pixel is formed by summing the weighted pixel intensities, and dividing the result by 16. The filter is then located along the same raster such that it shares one pixel horizontally; for the next raster the filter shares a common row. Similar weightings can be computed for (5 x 5), (7 x 7) etc., which incur a greater computational overhead. (See also ALIASING, ANTI-ALIASING, BASIS FUNCTION, BED-OF-NAILS, BOX FILTER, CONVOLUTION, CONVOLUTION FILTER, FILTER, FILTERING, FOURIER WAVEFORM ANALYSIS, GAUSSIAN FILTER, IMAGE PROCESSING, NYQUIST LIMIT, PIXEL AVERAGING, POINT SAMPLING, POINT-SPREAD FUNCTION, SAMPLING, SINC FILTER, STOCHASTIC SAMPLING, TENT FILTER, and UNIFORM SAMPLING)
[Crow-81, Gonzalez-87, Oppenheim-75, Pratt-78]

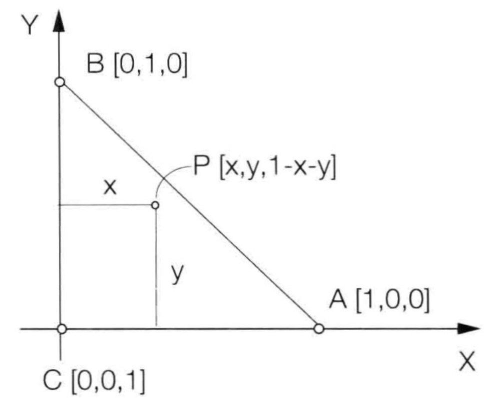

Figure B-2 *For any point P[x,y] the barycentric coordinates are the original Cartesian coordinates followed by 1-x-y.*

barycentric coordinates

Unlike CARTESIAN COORDINATES where two measurements are needed to locate a point on a 2-D plane, barycentric coordinates can relate a point with the three vertices of a triangle; this generates three measurements. For example, given three points **A**, **B** and **C** with Cartesian coordinates [1, 0], [0, 1] and [0, 0] respectively, then a point **P** with Cartesian coordinates [*x, y*] has barycentric coordinates [*x*, *y*, 1 – *x* – *y*], and the barycentric coordinates of **A, B** and **C** are [1, 0, 0], [0, 1, 0] and [0, 0, 1] respectively. They are of particular interest in INTERPOLATION schemes