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Information processing systems — Computer graphics — Programmer's Hierarchical Interactive Graphics System (PHIGS) —

Part 4:

Plus Lumière und Surfaces, PHIGS PLUS

*Systèmes de traitement de l'information — Infographie — Interface de
programmation du système graphique hiérarchisé (PHIGS) —*

Partie 4: Plus Lumière und Surfaces, PHIGS PLUS



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AVA Documents
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Contents	Page
1 Scope	1
2 Normative references	2
3 Definitions	3
4 The PHIGS PLUS system	7
4.1 About this part of ISO/IEC 9592	7
4.1.1 Specification and conformance	7
4.1.2 Registration	7
4.1.3 Notational conventions	7
4.2 Overview and concepts	8
4.2.1 Overview	8
4.2.2 Concepts	8
4.3 PHIGS PLUS structure elements	10
4.3.1 Output primitive structure elements	10
4.3.2 Attribute specification structure elements	10
4.3.3 Structure element archive	11
4.4 Output primitives	12
4.4.1 General	12
4.4.2 Polyline set with colour	12
4.4.3 Fill area set with data	12
4.4.4 Cell array PLUS	13
4.4.5 Set of fill area set with data	13
4.4.6 Triangle set with data	13
4.4.7 Triangle strip with data	13
4.4.8 Quadrilateral mesh with data	14
4.4.9 Non-uniform B-spline curve	14
4.4.10 Non-uniform B-spline curve with colour	16
4.4.11 Non-uniform B-spline surface	16
4.4.12 Surface trimming	17
4.4.13 Non-uniform B-spline surface with data	18
4.4.14 Area primitives and facets	20
4.4.15 Modelling clip	20
4.5 Output primitive attributes	21
4.5.1 General colour specification	21
4.5.2 Extended workstation state and description tables	22
4.5.3 PHIGS PLUS attributes applied to PHIGS output primitives	23
4.5.3.1 General.....	23
4.5.3.2 Polyline attributes.....	25
4.5.3.3 Polymarker attributes.....	25
4.5.3.4 Text attributes.....	25
4.5.3.5 Annotation text attributes.....	25
4.5.3.6 Fill area attributes.....	26
4.5.3.7 Fill area set attributes.....	26

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4.5.3.8 Cell array attributes.....	26
4.5.3.9 Generalized drawing primitive attributes.....	26
4.5.4 Attributes applied to PHIGS PLUS output primitives	27
4.5.4.1 General.....	27
4.5.4.2 Polyline set with colour attributes.....	27
4.5.4.3 Fill area set with data attributes.....	27
4.5.4.4 Cell array PLUS attributes.....	27
4.5.4.5 Set of fill area set with data attributes.....	27
4.5.4.6 Triangle set with data attributes.....	27
4.5.4.7 Triangle strip with data attributes.....	27
4.5.4.8 Quadrilateral mesh with data attributes.....	27
4.5.4.9 Non-uniform B-spline curve attributes.....	31
4.5.4.10 Non-uniform B-spline curve with colour attributes.....	32
4.5.4.11 Non-uniform B-spline surface attributes.....	33
4.5.4.12 Non-uniform B-spline surface with data attributes.....	36
4.5.4.13 Individual edge control for PHIGS PLUS area primitives.....	36
4.5.4.14 Reflectance properties.....	36
4.5.5 Implicitly specified attributes	37
4.5.5.1 General.....	37
4.5.5.2 Facet normal.....	37
4.5.5.3 Facet orientation.....	38
4.5.5.4 Reflectance normal.....	38
4.5.5.5 Intrinsic colour.....	39
4.5.6 Facet culling	40
4.5.7 Distinguishing facets by orientation	40
4.5.8 Hidden line and hidden surface removal	40
4.5.9 Stability	40
4.6 The PHIGS PLUS rendering pipeline	41
4.6.1 General	41
4.6.1.1 Primitives affected by the rendering pipeline.....	41
4.6.1.2 The effect of the interior style on lighting and shading.....	41
4.6.1.3 Aspects and attributes used in the rendering pipeline.....	42
4.6.2 Data mapping	42
4.6.3 Lighting	47
4.6.3.1 Reflectance calculation.....	47
4.6.3.2 Light sources.....	48
4.6.3.3 Workstation light sources.....	48
4.6.4 Shading	49
4.6.4.1 General.....	49
4.6.4.2 Interpolation.....	49
4.6.4.3 Colour interpolation.....	49
4.6.4.4 Data interpolation.....	50
4.6.4.5 Normal-vector interpolation.....	50
4.6.4.6 Polyline shading.....	50
4.6.4.7 Interior shading.....	50
4.6.5 The rendering colour model	53
4.6.6 Depth cueing	54
4.6.7 Colour mapping	55
4.7 Workstations	57

4.8 Graphical input	58
4.9 Limitations	59
4.9.1 General	59
4.9.2 Non-planar geometry and data	59
4.9.3 Relationship of shading method to geometry	59
4.9.4 Normal-vector interpolation	59
4.9.5 Effects of transformations	59
4.9.6 Approximation criteria and data splines	60
4.10 Minimum support criteria	61
5 PHIGS PLUS Functional Specification	65
5.1 Notational Conventions	65
5.2 Output primitive functions	65
5.3 Attribute specification functions	82
5.3.1 Bundled attribute selection	82
5.3.2 Individual attribute selection	84
5.3.3 Aspect source flag setting	99
5.3.4 Workstation attribute table definition	100
5.4 Inquiry functions	112
5.4.1 Introduction	112
5.4.2 Inquiry functions for workstation state list	113
5.4.3 Inquiry functions for workstation description table	123
5.4.4 Inquiry functions for structure content	138
6 PHIGS PLUS data structures	143
6.1 General	143
6.2 Notation and Data Types	143
6.3 PHIGS PLUS additions and replacements to the PHIGS description table	144
6.4 PHIGS PLUS additions and replacements to the PHIGS traversal state list	146
6.5 PHIGS PLUS additions and replacements to the PHIGS workstation state list	148
6.6 PHIGS PLUS additions and replacements to the PHIGS workstation description table	151
Annex A Function lists.....	155
A.1 Alphabetic	155
A.2 Order of appearance	157
Annex B Error list.....	161
B.1 Implementation dependent	161
B.2 Output attributes	161
B.3 Output primitives	161
Annex C Suggested reflectance formulae.....	163
C.1 Variable definitions and their sources	163
C.2 Reflectance formulae	164
Annex D Allowable differences in PHIGS PLUS implementations.....	167
D.1 Introduction	167
D.2 Workstation dependent differences	167
Annex E Suggested depth cueing formulae.....	169
E.1 Linear colour interpolation	169
E.2 Definitions	169
E.3 Formulae	169
Annex F Attribute table.....	171

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work.

In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

International Standard ISO/IEC 9592-4 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*.

ISO/IEC 9592 consists of the following parts, under the general title *Information processing systems — Computer graphics — Programmer's Hierarchical Interactive Graphics System (PHIGS)*:

- Part 1: *Functional description*
- Part 2: *Archive file format*
- Part 3: *Clear-text encoding of archive file*
- Part 4: *Plus Lumière und Surfaces, PHIGS PLUS*

Annex D forms an integral part of this part of ISO/IEC 9592. Annexes A, B, C, E and F are for information only.

Introduction

ISO/IEC 9592-1 provides a set of functions for the definition, display and modification of 2D or 3D graphical data. It does not provide support for simulating the effects of lighting, shading, and other properties that are important for the display of multi-dimensional data. This part of ISO/IEC 9592 specifies a basic set of such functionality for use in conjunction with the functionality defined in ISO/IEC 9592-1 and its amendment 1.

To provide this support, PHIGS PLUS defines

- a) output primitives specified by rational and non-rational B-spline curves and surfaces;
- b) output primitives containing both geometric and non-geometric data in their definition;
- c) attributes that control the application of lighting and shading to both the new primitives and the primitives specified in ISO/IEC 9592-1;
- d) a generalized mechanism for colour specification to allow non-indexed colour specification.

Information processing systems— Computer graphics— Programmer's Hierarchical Interactive Graphics System (PHIGS)— Part 4—Plus Lumière und Surfaces, PHIGS PLUS

1 Scope

This part of ISO/IEC 9592 specifies an additional set of functionality of the Programmer's Hierarchical Interactive Graphics System. This additional functionality is intended to satisfy basic application requirements in the areas of lighting and shading and defines additional primitives and functionality for controlling the rendering of 3D objects. It relies on the coexistence of the functions and functionality specified in ISO/IEC 9592-1, and is meant to extend that functionality in the above areas.

It is the intent of this part of ISO/IEC 9592 to be compatible with ISO/IEC 9592-1 and its Amendment 1. That is, in a standard conforming PHIGS PLUS implementation all functions defined in ISO/IEC 9592-1 and not altered by ISO/IEC 9592-4 shall perform as specified in ISO/IEC 9592-1, and all functions defined in ISO/IEC 9592-1 but altered in ISO/IEC 9592-4 shall perform as specified in ISO/IEC 9592-1 and ISO/IEC 9592-4, and, an application functionally conforming to ISO/IEC 9592-1 produces the same effect running on a standard conforming PHIGS PLUS implementation as it would produce running on a standard conforming PHIGS ISO/IEC 9592-1 implementation, excepting such differences among implementations as are allowed in ISO/IEC 9592-1. If PHIGS PLUS functions are used, they should only cause the extended effects specified in this part of ISO/IEC 9592.

This part of ISO/IEC 9592 defines a language independent extension to a graphics system for integration into a programming language. PHIGS PLUS is embedded in a language layer obeying the particular conventions of the language. Such language bindings are specified for ISO or ISO/IEC languages in ISO/IEC 9593.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO/IEC 9592. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO/IEC 9592 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO/IEC 646:1991, *Information technology – ISO 7-bit coded character set for information exchange*.

ISO/IEC 7942:1985, *Information processing systems – Computer graphics – Graphical Kernel System (GKS) functional description*.

ISO/IEC 8632:1987, *Information processing systems – Computer graphics – Metafile for storage and transfer of picture description information*.

ISO/IEC 8805:1988, *Information processing systems – Computer graphics – Graphical Kernel System for Three Dimensions (GKS-3D) functional description*.

ISO/IEC 9592-1:1989, *Information processing systems – Computer graphics – Programmer's Hierarchical Interactive Graphics System (PHIGS) – Part 1: Functional description*.

ISO/IEC 9592-1:1989/Amd.1:1992, *Information processing systems – Computer graphics – Programmer's Hierarchical Interactive Graphics System (PHIGS) – Part 1: Functional description – Amendment 1*.

ISO/IEC 9592-2:1989, *Information processing systems – Computer graphics – Programmer's Hierarchical Interactive Graphics System (PHIGS) – Part 2: Archive file format*.

ISO/IEC 9592-2:1989/Amd.1:1992, *Information processing systems – Computer graphics – Programmer's Hierarchical Interactive Graphics System (PHIGS) – Part 2: Archive file format – Amendment 1*.

ISO/IEC 9592-3:1989, *Information processing systems – Computer graphics – Programmer's Hierarchical Interactive Graphics System (PHIGS) – Part 3: Clear text encoding of archive file*.

ISO/IEC 9592-3:1989/Amd.1:1992, *Information processing systems – Computer graphics – Programmer's Hierarchical Interactive Graphics System (PHIGS) – Part 3: Clear text encoding of archive file – Amendment 1*.

ISO/IEC 9593:1990, *Information processing systems – Computer graphics – Programmer's Hierarchical Interactive Graphics System (PHIGS) language bindings*.

3 Definitions

For the purpose of this part of ISO/IEC 9592 the following definitions apply. This part of ISO/IEC 9592 also makes use of the definitions in ISO/IEC 9592-1. (Terms used within definitions in this clause that are themselves defined in this clause are italicized.)

3.1 ambient light source: A *light source* that contributes to the *reflectance calculation* independently of the orientation or position of the area being illuminated or the location of the viewer's eye.

3.2 ambient reflection coefficient: The fraction of *ambient light* reflected from an area.

3.3 area primitive: Any of the output primitives: fill area, fill area set, cell array, *fill area set with data*, cell array PLUS, *set of fill area sets with data*, *triangle set with data*, *triangle strip with data*, *quadrilateral mesh with data*, non-uniform B-spline surface and non-uniform B-spline surface with data. In addition, some generalized drawing primitives may have this classification.

3.4 attenuation coefficient: A coefficient that determines the decrease in intensity of light as a function of the distance between a *light source* and an illuminated object.

3.5 back facing: A back-facing facet has a *facet normal* that, when transformed to NPC, has a negative Z component. See also *front facing*.

3.6 colour mapping: The conversion of direct colours in the *rendering pipeline* to other colours before they are displayed on the workstation.

3.7 colour spline: The parametric curve or surface in colour space (or homogeneous colour space) defining the colour distribution over an output primitive.

3.8 concentration exponent: A parameter of a *spot light* source that specifies the relative decrease of light as the angle of the light diverges from the centreline of the light source's *cone of influence*.

3.9 cone of influence: A conceptual cone that represents the influence of light from a *spot light* source. The cone of influence is defined by the light source's position, direction and *spread angle*.

3.10 data mapping: The conversion of application-specific data or colour to *intrinsic colour*.

3.11 depth cueing: An effect in which the colours of points on an output primitive are combined with a specified depth cue colour. The degree of combination is dependent on the depth (Z in normalized projection coordinates) of the points.

3.12 depth cue mode: A field in each entry of the *depth cue table* of the workstation state list that indicates whether or not *depth cueing* should be performed.

3.13 depth cue table: A table in the workstation state list that contains information used to control *depth cueing*.

3.14 diffuse reflection: An approximation of the light reflected equally in all directions from an area.

3.15 diffuse reflection coefficient: The fraction of light from non-*ambient light* sources that is diffusely reflecting from an area.

3.16 direct colour specification: A non-indexed method of specifying colour where the components of the colour, i.e., coordinates in colour space, are specified together with the colour model in which those components are expressed.

3.17 directional light source: A *light source* that contributes to the *reflectance calculation* dependent on the orientation of the area being illuminated but independent of the area's position.

3.18 edge visibility flag: An indicator that is part of the specification of some output primitives, such as *fill area set with data*, that controls whether an individual edge is visible.

3.19 eye point: A point in world coordinates that transforms to infinite positive Z in normalized projection coordinates. This point is used in the *reflectance calculation* for determining viewing-position-dependent effects of lighting.

3.20 facet: An interior segment of an *area primitive*. Each facet of an output primitive is defined by a subset of the primitive's set of vertices. The subset is dependent on the individual primitive type, and in the case of parametric surfaces, on the approximation of the surface. Facets have an orientation in NPC described as *back-facing* or *front-facing*.

ISO/IEC 9592-4:1992(E)

3.21 facet culling: The process of removing *front-facing* or *back-facing facets* of area primitives.

3.22 facet data: *Intrinsic colour* data or a *normal vector* specified with an *area primitive*.

3.23 facet normal: A *normal vector* associated with a *facet* of an *area primitive*. Facet normals are used to determine the orientation of a facet and in some cases for determining the *reflectance normal*.

3.24 fill area set with data: An output primitive consisting of a set of coplanar polygons. It is similar to the fill area set output primitive defined in ISO/IEC 9592-1. The corresponding structure element may include other information such as colours or normals that are conditionally used to colour, light and shade the output primitive.

3.25 front facing: A front-facing facet has a *facet normal* that, when transformed to NPC, has a positive or zero Z component. See also *back facing*.

3.26 general colour: A data type that allows both the direct and indirect specification of colour. General colour specifies a colour type together with a type-dependent colour value. The colour type can either indicate a colour model, in which case the colour values are coordinates in the colour space corresponding to that model, or it can indicate that the colour is being specified indirectly, in which case the single colour value is an index into the workstation-dependent colour table.

3.27 geometry spline: The parametric curve or surface defining the geometry of a *parametric output primitive*.

3.28 indirect colour specification: A method of specifying colour via an index into a workstation dependent colour table.

3.29 intrinsic colour: The colour or colours of an output primitive that are independent of *lighting*, *depth cueing* and *colour mapping*.

3.30 intrinsic colour data: Colour or application-specific data associated with output primitives and specified in the output primitive's structure element. Intrinsic colour data, when specified, is conditionally used to determine the *intrinsic colour* of an output primitive.

3.31 isoparametric curve: A curve on a parametric surface produced by evaluating the surface over the range of one of its independent variables while holding its other independent variable constant.

3.32 knot vector: A non-decreasing sequence of real numbers that is part of the definition of non-uniform B-splines. This vector consists of values of the independent variables and is used in computing the B-spline basis polynomials.

3.33 light source: A simulated source of light.

3.34 light source direction: A unit vector that defines the orientation of oriented *light sources*.

3.35 light source state: A field in the traversal state list that selects which *light sources* in a workstation light source table are active.

3.36 lighting: See *reflectance calculation*.

3.37 normal vector: A unit length vector, typically indicating the orientation of a *facet* or object.

3.38 parameter range: The *parameter space* over which a parametric curve or surface is defined.

3.39 parameter range limits: Minimum and maximum parameter values, specified separately from any knot values, that limit the parameter range over which parametric curves are generated.

3.40 parametric output primitive: Output primitives defined as a mapping from a parameter space to modelling coordinates. Parametric output primitives defined in PHIGS PLUS are non-uniform B-spline curve, non-uniform B-spline curve with colour, non-uniform B-spline surface and non-uniform B-spline surface with data.

3.41 parameter space: The coordinate system of the independent variable(s) of parametric curves and surfaces. The parameter space is one-dimensional for curves and two-dimensional for surfaces.

3.42 polyline set with colour: An output primitive consisting of an unconnected set of polylines. The corresponding structure element may include colour information that is conditionally used to shade the primitive.

3.43 portion: A portion of an area primitive refers to one or more *facets* of the primitive that are distinguished as a group from its other facets by some property such as orientation or position relative to a *trimming loop*. The term can be applied to groups of explicitly defined facets as well as the facets conceptually used to approximate a non-uniform B-spline surface.

3.44 positional light source: A *light source* that contributes to the *reflectance calculation* dependent on the orientation and position of an area being illuminated relative to the light source.

3.45 quadrilateral mesh: An output primitive in which an array of quadrilaterals is specified by a two-dimensional array of vertices.

3.46 reflectance calculation: The computation of the effect of *light sources* on the colour of an area primitive's facets.

3.47 reflectance model: An aspect that selects the *reflectance calculation* and thereby specifies which lighting effects are to be displayed.

3.48 reflectance formulae: Formulae that model the light reflected by an *area primitive*.

3.49 reflectance normal: A vector used in the *reflectance calculation* and indicating the orientation of a primitive at a point on the primitive. The vector is conceptually perpendicular to the surface of an object being represented by an *area primitive*. It is derived from the *vertex normals* of the primitive, if specified, or the *facet normal*.

3.50 reflectance properties: An aspect of *area primitives* that indicates how a primitive reflects light.

3.51 rendering colour model: The colour model used for performing colour interpolation during *shading* and *depth cueing*.

3.52 rendering pipeline: A sequence of operations that performs *data mapping*, *lighting*, *shading*, *depth cueing*, and *colour mapping* of output primitives. Each of these operations is considered a stage in the rendering pipeline.

3.53 rigid-body transformation: A modeling transformation composed of at most translation, rotation, and scaling transformations, where translation transformations move every point of an object an equal distance in the same direction, the rotation transformations maintain relative angles, and the scaling transformations apply equal scaling in all coordinate dimensions.

3.54 set of fill area sets with data: An output primitive in which a number of possibly non-coplanar fill area sets are defined by indices into a single list of vertex data. The fill area sets are not required to form a closed or connected surface.

3.55 shading: The interpolation stage of the *rendering pipeline*.

3.56 specular colour: A *reflectance property* indicating the effect of a primitive on the colour of *specular reflections* from that primitive.

3.57 specular exponent: A non-negative number indicating the shininess of an area. The higher the specular exponent, the shinier the area. A specular exponent of 0 indicates a minimum relative degree of shininess.

3.58 specular reflection: An approximation of the unequal reflection of light in different directions from an *area primitive*, dependent on the relationship of the viewer to the primitive and the *light source*.

3.59 specular reflection coefficient: The fraction of non-ambient light contributing to *specular reflection*.

3.60 spot light source: A *light source* that contributes to the *reflectance calculation* dependent on the orientation and relative position of the area being illuminated. Light from such a source is restricted to a semi-infinite cone of influence and its intensity may decrease as it deviates from the centreline of this cone. (See *concentration exponent* and *spread angle*.)

3.61 spread angle: An angle that determines the shape of the *cone of influence* of a *spot light source*. Spread angle is the angle between the center of the cone of influence and the limit of the cone of influence measured at the position of the spot light source.

3.62 triangle set: An output primitive in which a number of possibly unrelated triangular facets are defined by indices into a single list of vertex data.

ISO/IEC 9592-4:1992(E)

3.63 triangle strip: An output primitive comprised of a group of adjacent triangles formed by connecting a list of vertices such that the second and third vertices of each triangle are used as the first and second vertices of the next triangle.

3.64 trimming curve: A parametric curve in the parameter space of the surface to which it applies. Trimming curves are combined to form *trimming loops* which limit the *parameter range* over which a parametric surface is evaluated.

3.65 trimming loop: A sequence of connected and similarly oriented *trimming curves* that form a closed path. Trimming loops are used to limit the *parameter range* over which a parametric surface is evaluated.

3.66 vertex colour: A *general colour* associated with each vertex of some output primitives. This colour is conditionally used within the *rendering pipeline* to colour and shade the primitive.

3.67 vertex data: Geometric, *intrinsic colour data*, or *vertex normal* data specified at vertices of certain output primitives.

3.68 vertex normal: A *normal vector* optionally supplied with the *vertex data* of some area primitives.

3.69 with-data primitives: Any of the output primitives: *fill area set with data*, *set of fill area sets with data*, *triangle set with data*, *triangle strip with data*, *quadrilateral mesh with data* and non-uniform B-spline surface with data. In addition, some generalized drawing primitives may have this classification.

3.70 workstation light source. A *light source* entry in a workstation light source table.

4 The PHIGS PLUS system

4.1 About this part of ISO/IEC 9592

4.1.1 Specification and conformance

The set of functions known as PHIGS PLUS shall be as described in clauses 4, 5, and 6 of this part of ISO/IEC 9592 in addition to the functions described in clauses 4, 5, and 6 of ISO/IEC 9592-1. A conforming implementation of PHIGS PLUS shall be a conforming implementation of ISO/IEC 9592-1, as amended by amendments to that part, and in addition correctly implement all the functions described in clauses 4, 5, and 6 of this part of ISO/IEC 9592. Minimum support criteria for the additional functionality are specified in 4.10. A conforming implementation of PHIGS PLUS shall provide the additional information described in annex D as well as annex D of ISO/IEC 9592-1, and the minimum support specified in 4.10 as well as 4.14 of ISO/IEC 9592-1. In a conforming implementation all graphical capabilities that can be addressed by PHIGS PLUS shall be used only via PHIGS PLUS.

4.1.2 Registration

For certain parameters of the functions, PHIGS PLUS defines value ranges as being reserved for registration.¹ The meanings of such values and ranges will be defined in the Register. These procedures do not apply to values and value ranges defined as being workstation or implementation dependent; such values and ranges are not standardized.

4.1.3 Notational conventions

This part of ISO/IEC 9592 uses the following typographical conventions.

- a) The names of primitive attributes appear in upper case.
- b) Geometric aspects of primitives appear in upper case. Non-geometric aspects appear in lower case except when the corresponding individually specified attributes are being used, in which case they appear in upper case.
- c) The names of entries in the PHIGS data structures, including those defined by PHIGS PLUS, appear in lower case surrounded by single quotation marks.
- d) The names of structure elements appear in lower case surrounded by double quotation marks.
- e) The names of PHIGS PLUS functions appear in upper case.
- f) The values of an enumeration data type appear in upper case.
- g) The names of data types appear in upper case.

1) For the purpose of this part of ISO/IEC 9592 and according to the rules for the designation and operation of registration authorities in the ISO/IEC Directives, the ISO and IEC Councils have designated the following as the registration authority: National Institute of Standards and Technology (National Computer Systems Laboratory), The Registration Authority for Graphical Items, A-266 Technology Building, Gaithersburg, MD 20899, USA

4.2 Overview and concepts

4.2.1 Overview

The Programmer's Hierarchical Interactive System (PHIGS) Plus Lumière Und Surfaces (PHIGS PLUS) provides a functional interface between an application program and a configuration of graphical input and output devices. The functional interface contains all of PHIGS, the basic functions for interactive graphics on a wide range of graphics equipment, and adds new facilities for the specification of curved lines and curved and faceted surfaces. Lighting and other effects such as depth modulation can be specified to allow realistic presentation of the geometry. There is direct support for the visualization of data that can be associated with the geometry.

The interface is at such a level of abstraction that hardware peculiarities are shielded from the application program. As a result, a simplified interface presenting the additional primitives is obtained.

Some PHIGS PLUS concepts are described as being workstation dependent. This means the implementation is allowed to specify the characteristics of these concepts on a workstation by workstation basis. All workstation dependent concepts are explicit in the standard. Other PHIGS concepts are described as being implementation dependent. This means that an implementation is allowed to determine the effect (rather than having the effect mandated by the standard). However such effects shall be the same on all workstations in a single implementation.

Annex D (taken with annex D of ISO/IEC 9592-1) describes the permitted differences between PHIGS PLUS implementations.

4.2.2 Concepts

PHIGS PLUS defines a set of output primitives whose definitions contain, in addition to the geometry of the primitive, information that further specifies certain characteristics of the primitive and influences its appearance on the display surface. These output primitives are called *with-data primitives*.² The data defined for these with-data primitives is used to colour and shade the primitive, and in the case of *area primitives*, to indicate the primitive's apparent orientation and control the visibility of its edges. Depending on the output primitive, the information that can be specified in addition to geometry is *intrinsic colour data* that indicates a colour distribution across the primitive, *normal vectors* that indicate the primitive's apparent orientation, and *edge visibility flags* that control the visibility of an area primitive's edges. This data is optionally specified and conditionally used when rendering the primitive. Some of the with-data primitives are the output primitive types defined in ISO/IEC 9592-1 extended to include the additional information. Some other with-data primitives offer data compaction and other advantages.

A colour is specified in PHIGS PLUS as a *general colour*, which consists of a colour type and a type-dependent colour value. The colour type can indicate any one of a number of colour models, in which case the corresponding colour value is interpreted as a value in that colour space. Alternatively, the colour type can indicate an indirect colour, in which case the colour value is an index into the workstation colour table. PHIGS PLUS thus supports the indirect colour specification of ISO/IEC 9592-1 as a subset of a more general colour specification mechanism. PHIGS PLUS defines general colour extensions to most areas of ISO/IEC 9592-1 where colours are specified.

PHIGS PLUS has the concept of a *rendering pipeline*. Conceptually, all output primitives pass through this pipeline as they are displayed. Operations are performed in the pipeline that affect the colour and appearance of each facet of a primitive. These operations include, for most primitives, the mapping of application-specific data to colour (*data mapping*), the calculation of reflectance effects (*lighting*), data interpolation (*shading*), and *depth cueing*. Output primitive attributes and any data attached to the primitives are conditionally used in these operations. The last stage of the rendering pipeline is a *colour mapping* that maps the resultant colours from the earlier stages into workstation dependent colours. The application may have control over which of these stages are active and what methods are used within each stage.

²) In this subclause, terms in the glossary are italicized when first used.

Data mapping in PHIGS PLUS provides a mechanism to convert application-specific data to colour within the rendering pipeline. Data such as temperature, pressure or other scalar or multi-dimensional information can be specified for most area primitives. Selected portions of this data may then be used during traversal to determine the *intrinsic colour* of the primitive, which is the colour or set of colours associated with a primitive before the effects of lighting are applied. The method to use to convert the data to intrinsic colour is under application control. More data can be specified than is used during any single rendering of a primitive.

Explicitly specified and implicitly specified aspects control the operations of the rendering pipeline. Explicitly specified aspects are *facet normals*, used to determine facet orientation, and *vertex normals* used to determine *reflectance normals* in *reflectance calculations*. When not supplied, facet normals are implicitly determined from the geometry of the facet.

PHIGS PLUS defines the *light sources* and suggests their interaction with output primitives. Several types of light sources are defined: *ambient*, *directional*, *positional* and *spot*. *Workstation light sources* are associated with workstations and are defined as entries in the 'light source table' in the workstation state list.³ Active light sources are selected from this table by the 'current light source state' in the traversal state list.

Each *facet* of an area primitive has an orientation, either *front facing* or *back facing* as determined in normalized projection coordinates from the facet normal. PHIGS PLUS defines separate attributes for front and back facing facets of area primitives and provides controls for determining when they should be applied. PHIGS PLUS also defines an attribute to control whether individual facets are removed prior to viewing based on their orientation.

PHIGS PLUS defines non-uniform B-spline curve and surface output primitives. These output primitives are specified by a series of control points and parameter values that define non-uniform B-spline curves and surfaces in terms of the B-spline representation. This interface allows the exact specification of commonly required shapes including conics, conic sections such as circles, ellipses, parabolas, spheres, and spheroids without resorting to special cases. The curves and surfaces are represented by non-rational and rational splines using the mathematically robust B-spline representation. Variants of these primitives are defined that allow specification of an intrinsic colour data distribution over the primitive.

PHIGS PLUS replaces some fields of some of the data structures defined in ISO/IEC 9592-1 and adds a number of fields to these data structures. Replacements and additions have been made to the PHIGS description table, traversal state list, workstation state list and workstation description table, and are listed in clause 6.

³) Light sources with their specification included directly in the CSS are not defined by this part of ISO/IEC 9592, but their inclusion as GSEs or GDPs is not prohibited.

ISO/IEC 9592-4:1992(E)

4.3 PHIGS PLUS structure elements

4.3.1 Output primitive structure elements

The output primitive structure elements defined by this part of ISO/IEC 9592 are listed in table 1.

Table 1 — Output primitive structure elements

polyline set 3 with colour	triangle strip 3 with data
fill area set 3 with data	triangle strip with data
fill area set with data	quadrilateral mesh 3 with data
cell array 3 PLUS	quadrilateral mesh with data
set of fill area sets 3 with data	non-uniform B-spline curve 3
set of fill area sets with data	non-uniform B-spline curve 3 with colour
triangle set 3 with data	non-uniform B-spline surface 3
triangle set with data	non-uniform B-spline surface 3 with data

4.3.2 Attribute specification structure elements

The attribute specification structure elements defined by this part of PHIGS are listed in table 2.

Table 2 — Attribute specification structure elements

set polyline colour	set back reflectance properties
set polyline shading method	set interior shading method
set polymarker colour	set back interior shading method
set text colour	set reflectance model
set edge colour	set back reflectance model
set back interior style	set reflectance index
set back interior style index	set back reflectance index
set interior colour	set light source state
set back interior colour	set depth cue index
set back interior index	set rendering colour model
set facet distinguishing mode	set colour mapping index
set facet culling mode	set curve approximation criteria
set data mapping method	set surface approximation criteria
set back data mapping method	set parametric surface characteristics
set data mapping index	set parametric surface index
set back data mapping index	set individual ASF (additions)
set reflectance properties	

4.3.3 Structure element archive

This part of ISO/IEC 9592 defines output primitive and attribute specification structure elements. The archive file format for these structure elements is defined in ISO/IEC 9592-2 and its amendment 1. The clear text encoding of that format is defined in ISO/IEC 9592-3 and its amendment 1.

4.4 Output primitives

4.4.1 General

PHIGS PLUS augments the set of output primitives defined in ISO/IEC 9592-1 by defining additional output primitives and output primitive structure elements. Some of these new output primitives can have optional data associated with them. The optional data can be some combination of vertex normals, facet normals, edge visibility flags, and intrinsic colour data, as shown in figure 1. Depending on various attribute settings, PHIGS PLUS uses this information at various points in the rendering pipeline to light, shade and otherwise determine the appearance of the output primitive. If the application does not provide the optional information, PHIGS PLUS, under some conditions, computes portions of it and uses the computed information in the rendering pipeline.

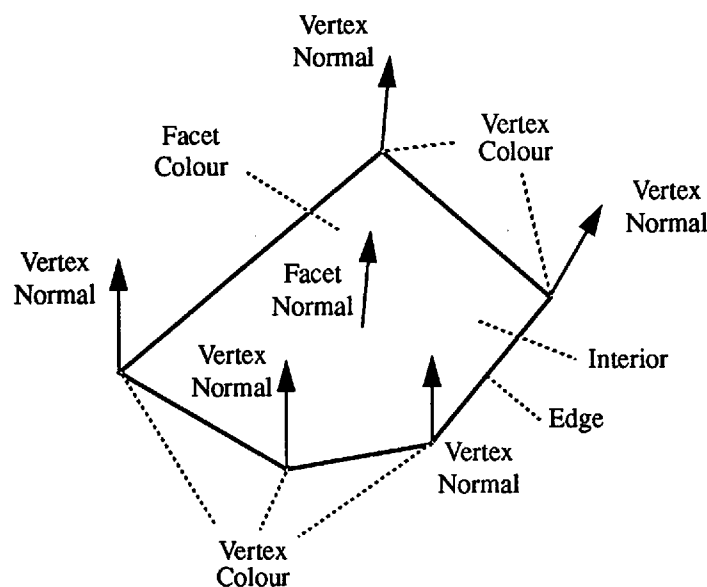


Figure 1 — Data that may be associated with a facet

When present, normal vectors should be of unit length. The specification of a non-unit length normal vector does not produce an error when the element is created. When primitives containing non-unit length normal vectors are interpreted during traversal, the effect of the non-unit length normals is workstation dependent.

4.4.2 Polyline set with colour

PHIGS PLUS generates a set of unconnected polylines. Each polyline is defined by vertex sequences. Colour information can be specified with each vertex as part of the primitive definition.

4.4.3 Fill area set with data

PHIGS PLUS generates a fill area set that can be empty, hollow, hatched, or filled with a colour distribution or pattern. The edges of a fill area set consist of the line segments comprising its defining polygons. The primitive specification may contain any combination of facet or vertex intrinsic colour data, vertex normals, a facet normal, and edge visibility flags. The interior of a fill area set with data primitive is the same as that defined in ISO/IEC 9592-1 for a fill area set primitive.

Ensuring that all the points of the fill area set are coplanar is the responsibility of the application. While slightly non-coplanar points (e.g. owing to numerical roundoff errors) should be mapped to a plane by the implementation, the effect of larger divergences is workstation dependent.

4.4.4 Cell array PLUS

PHIGS PLUS generates a cell array. The cell colours are specified with general colours.

4.4.5 Set of fill area set with data

PHIGS PLUS generates a group of fill area sets. The vertices of each fill area set are specified by lists of indices into a single list of vertices. This allows vertices and their associated data to be shared among the fill area sets. The specification may contain any combination of facet or vertex intrinsic colour data, vertex normals, facet normals, and edge visibility flags.

The fill area sets are not required to be coplanar. Each individual fill area set in the set of fill area sets, however, is expected to be planar. Ensuring that each fill area set is planar is the responsibility of the application. The effect produced by non-planar fill area sets is workstation dependent.

4.4.6 Triangle set with data

PHIGS PLUS generates a set of triangles (see figure 2). The vertices of each triangle are specified by three indices into a list of vertices. The set of triangles need not be coplanar. The primitive definition allows specification of any combination of facet or vertex intrinsic colour data, vertex normals, facet normals, and edge visibility flags.

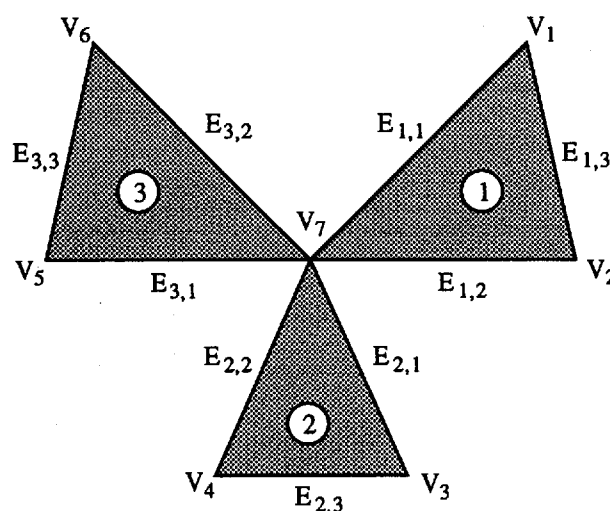


Figure 2 — A triangle set primitive (The vertex list is $\{V_1, V_2, V_3, V_4, V_5, V_6, V_7\}$. The list of vertex indices is $\{(1, 7, 2), (3, 7, 4), (5, 7, 6)\}$. The list of edge visibility flags is $\{E_{1,1}, E_{1,2}, E_{1,3}, E_{2,1}, E_{2,2}, E_{2,3}, E_{3,1}, E_{3,2}, E_{3,3}\}$)

4.4.7 Triangle strip with data

PHIGS PLUS generates a set of $N-2$ triangles from a list of N vertices (see figure 3). Each triangle of the strip has as its vertices three successive vertices from the vertex list. The set of triangles need not be coplanar. The triangles are implicitly numbered by the ordering of the defining list of vertices. The first triangle in the strip is numbered 1. The edges of a triangle strip are the line segments forming the boundaries of all triangles in the strip. There is only one edge between any two adjacent triangles, hence there are $2(N-2) + 1$ edges. The primitive definition allows specification of any combination of facet or vertex intrinsic colour data, vertex normals, facet normals, and edge visibility flags.

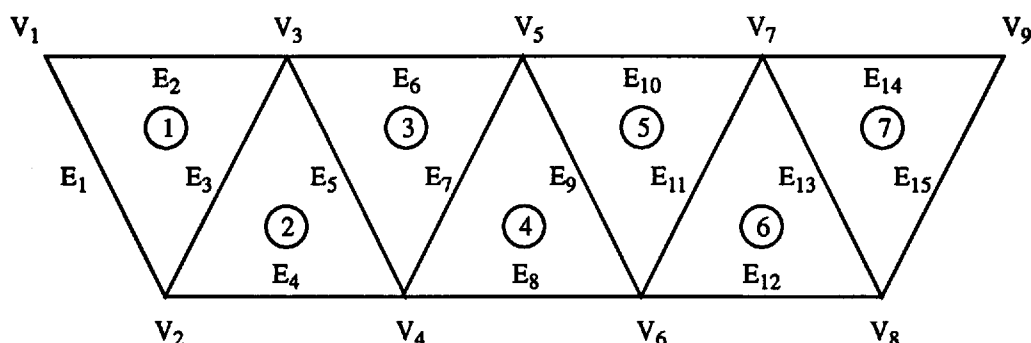


Figure 3 — A triangle strip primitive (Vertices, V_i , are identified by their position in the vertex list. Edges, E_i , are identified by their position in the optional list of edge visibility flags)

4.4.8 Quadrilateral mesh with data

PHIGS PLUS generates a set of $(M-1) \times (N-1)$ quadrilaterals from a two dimensional array of $M \times N$ vertices (see figure 4). The set of quadrilaterals need not be coplanar. The edges of a quadrilateral mesh are the line segments forming the boundaries of the individual quadrilaterals in the mesh. There is only one edge between any two adjacent quadrilaterals, hence there are $M(N-1) + N(M-1)$ edges. The primitive definition allows specification of any combination of facet or vertex intrinsic colour data, vertex normals, facet normals, and edge visibility flags. Quadrilaterals in the mesh can be non-planar. Non-planar quadrilaterals are rendered in a workstation dependent way.

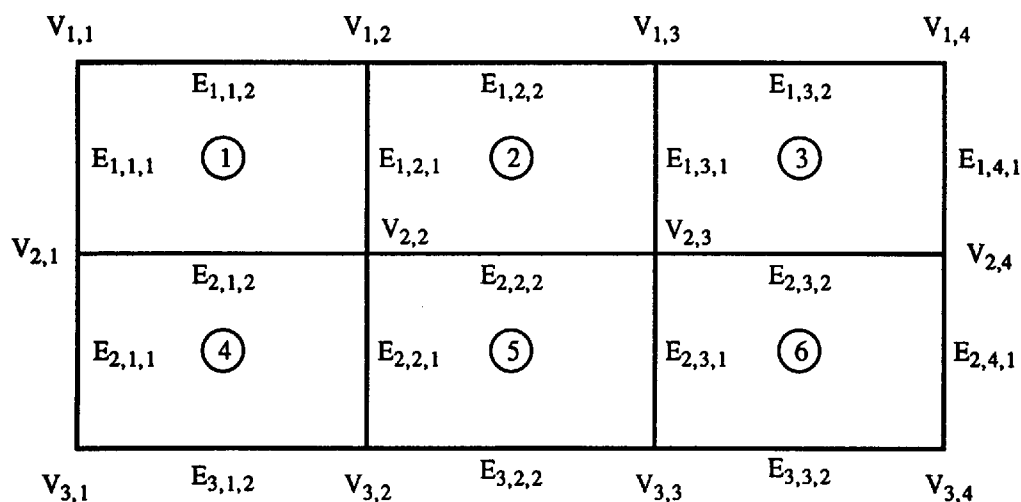


Figure 4 — A quadrilateral mesh primitive, $M = 3$, $N = 4$ (Vertices $V_{i,j}$ are identified by their position in the vertex array. Edges $E_{i,j,k}$ are identified by their position in the optional edge flag array)

4.4.9 Non-uniform B-spline curve

PHIGS PLUS generates a non-uniform B-spline curve of a specified order over a specified range of a single independent parameter. The curve is specified by its order, its rationality, a list of control points in modelling coordinates, a list of knots in the one-dimensional parameter space, and two parameter range limits. Either a rational or a non-rational B-spline curve can be specified. The extreme values of the knots specify the curve's parameter range. Parameter range

limits can be specified that limit the range over which the independent variable is evaluated and the B-spline curve is generated.

A B-spline curve is defined in PHIGS PLUS as a mapping from a bounded one-dimensional parameter space into a set of points that compose the curve:

$$C(t) = \sum_{i=1}^n B_{i,k}(t) P_i \quad (1)$$

where

$C(t)$ is the curve;

P_i are the n control points;

$B_{i,k}(t)$ is the i -th B-spline basis function of order k ;

t is the parameter, $t_k \leq t \leq t_{n+1}$.

The B-spline basis functions are determined by the order k and a knot vector, $\{t_j\}$, $j = 1$ to $n+k$, where the sequence t_j is non-decreasing; thus the number of knots is equal to the number of control points plus the curve order. The parameter range is defined by the knot values t_k and t_{n+1} , and defines the bounds of the parameter space domain over which the curve is defined. The B-spline basis functions are defined by the recursion formula:

$$B_{i,1}(t) = \begin{cases} 1, & t_i \leq t \leq t_{i+1} \\ 0, & \text{elsewhere} \end{cases} \quad (2a)$$

$$B_{i,k}(t) = \begin{cases} 0, & t < t_i \text{ or } t < t_{i+k} \\ \frac{(t-t_i)B_{i,k-1}(t)}{t_{i+k-1}-t_i} + \frac{(t_{i+k}-t)B_{i+1,k-1}(t)}{t_{i+k}-t_{i+1}}, & t_i \leq t \leq t_{i+k} \end{cases} \quad (2b)$$

The terms $\frac{(t-t_i)B_{i,k-1}(t)}{t_{i+k-1}-t_i}$ and $\frac{(t_{i+k}-t)B_{i+1,k-1}(t)}{t_{i+k}-t_{i+1}}$ may produce the indeterminate quantity $\frac{0}{0}$ when multiple identical knot values are specified. In these cases the terms are defined to be 0.

The curve is said to be uniform if there exists a real number, δ , such that $t_{j+1} - t_j = \delta$ for all j such that $k \leq j \leq n$; otherwise the curve is said to be non-uniform.

A non-rational non-uniform B-spline curve output primitive is generated by applying equation 1 to a set of modelling coordinate points, $P_i = (x_i, y_i, z_i)$.

A rational B-spline curve is defined in PHIGS PLUS as a mapping from a bounded one-dimensional parameter space into a set of homogeneous points:

$$C^h(t) = \sum_{i=1}^n B_{i,k}(t) P_i^h \quad (3)$$

where $P_i^h = (w_i q_i, w_i r_i, \dots, w_i)$.

The projection of $C^h(t)$ into non-homogeneous coordinates is achieved by dividing all the curve's coordinates by the last coordinate, w . This definition of a B-spline curve applies to the non-uniform B-spline curve output primitive, any colour spline associated with that output primitive, and trimming curves associated with non-uniform B-spline surfaces.

A rational non-uniform B-spline curve output primitive is generated by applying equation (3) to a set of homogeneous modelling coordinate points, $P_i^h = (w_i x_i, w_i y_i, w_i z_i, w_i)$, and projecting the resulting points to three-dimensional modelling coordinates.

In both the rational and non-rational cases the curve generated by PHIGS PLUS is the result of mapping a portion of the curve's parameter range to modelling coordinates. The portion to map is indicated by parameter range limits specified with the structure element. The curve is mapped only within and at the parameter range limits, and this portion constitutes the geometry of the curve for the purposes of display, picking and incremental spatial search. The parameter range limits shall be within the specified parameter range of the curve.

Conceptually, a non-uniform B-spline curve is rendered by evaluating a number of sample points on or near the curve. The density of the sample points is controlled by the curve approximation criteria. If the sampling is higher than the density of points on the display surface, displaying the sample points themselves produces a complete rendering of the curve. Alternatively, adjacent sample points may be joined by straight lines that are then displayed.

4.4.10 Non-uniform B-spline curve with colour

PHIGS PLUS generates a non-uniform B-spline curve. The curve's definition contains an optional non-uniform B-spline curve that describes the colour distribution over the curve's geometry. The control points of this colour spline are colour coordinates in one of the available directly-specifiable colour models.

The control points of the colour spline are colour values of the appropriate dimension for the specified colour model. The parameter range of the colour spline shall wholly include the parameter range limits of the geometry spline, thus the colour for any point on the mapped portion of the curve can be determined by evaluating the colour spline at the corresponding parameter value.

The colour spline need not have the same order, rationality nor knot sequence as the geometry spline. The values of the colour spline control point coordinates can be outside the range normally associated with the colour value. (This is necessary to allow colour specification with rational B-splines, and to allow B-splines that interpolate a set of colours.) If the colour spline is rational, the dimension of the control points is one more than the dimension of the corresponding colour model coordinates. The colour spline is defined by equations (1) and (3).

The curve's colour is determined from the colour spline at the sample points used for the geometry spline. These colours are then considered to be vertex colours. The polyline shading method aspect indicates how these vertex colours are applied to the rendering of the curve.

4.4.11 Non-uniform B-spline surface

PHIGS PLUS generates a non-uniform B-spline surface of two specified orders over a specified range of two independent parameters. The surface is specified by its order, its rationality, an array of control points in modelling coordinates, and a list of knots for each of the independent parameters. Either a rational or a non-rational B-spline surface can be specified. The extreme values of the knots specify the parameter range of the surface. An optional set of trimming curves (defined by non-uniform B-spline curves) can be specified to limit the parameter range over which the independent variables are evaluated and the B-spline surface is generated. If trimming curves are specified the edges of this primitive consist of the points on the displayed surface corresponding to the trimming curves. If no trimming curves are specified the edges consist of curves of constant parameter value at the parameter range boundaries of the surface.

A B-spline surface is defined in PHIGS PLUS as a mapping from a bounded two-dimensional parameter space into a set of points that compose the surface:

$$S(u, v) = \sum_{i=1}^n \sum_{j=1}^m B_{i,k}(u) B_{j,l}(v) P_{i,j} \quad (4)$$

where

$S(u, v)$ is the surface;

$P_{i,j}$ are an $n \times m$ array of control points;

$B_{i,k}(u)$ is the i -th B-spline basis function of order k , defined by the knot vector $\{u_p\}$, $p = 1$ to $n+k$;

$B_{j,l}(v)$ is the j -th B-spline basis function of order l , defined by the knot vector $\{v_q\}$, $q = 1$ to $m+l$;

u and v are the two parameters, $u_k \leq u \leq u_{n+1}$, $v_l \leq v \leq v_{m+1}$.

The B-spline basis functions are determined by the orders k and l and the respective knot vectors, each of which is a non-decreasing parameter sequence. The B-spline basis functions are defined by equation (2) in 4.4.9. The parameter range is defined by the knot values u_k , u_{n+1} , and v_l , v_{m+1} , which define the bounds of the parameter space domains over which the surface is defined. The surface is said to be uniform in the u parameter if there exists a real number, δ , such that $u_{p+1} - u_p = \delta$ for all p such that $k \leq p \leq n$; otherwise the surface is said to be non-uniform in that parameter. The surface is said to be uniform in the v parameter if a similar test holds for that parameter. The surface is said to be non-uniform if it is non-uniform in either parameter.

A non-rational non-uniform B-spline surface output primitive is generated by applying equation (4) to a set of modelling coordinate points, $P_{i,j} = (x_{i,j}, y_{i,j}, z_{i,j})$. A rational non-uniform B-spline surface output primitive is generated by applying equation 4 to a set of homogeneous modelling coordinate points, $P_{i,j}^h = (w_{i,j}x_{i,j}, w_{i,j}y_{i,j}, w_{i,j}z_{i,j}, w_{i,j})$, and projecting the resulting points to three-dimensional modelling coordinates by dividing the first three coordinates of each point by the point's homogeneous coordinate, w .

In both the rational and non-rational cases the surface generated by PHIGS PLUS is the result of mapping either all or portions of the surface's parameter range to modelling coordinates. If only portions are to be mapped then they are identified with a set of trimming loops (4.4.12). For the purposes of display, picking and incremental spatial search, only the portions of the surface actually mapped to modelling coordinates constitute the geometry of the primitive.

4.4.12 Surface trimming

The B-spline surface mapping is defined on a two-dimensional parameter space rectangle defined by the surface's parameter range. The mapping of the surface can be restricted to portions of that parameter range by specifying a set of trimming loops that define those portions. Trimming loops are composed of one or more trimming curves. Trimming curves are B-spline curves, as defined by equation 1 or 3, that map a one-dimensional parameter range to the two-dimensional parameter range of the surface. In the non-rational case, the P_i of equation 1 are two-dimensional control points in the parameter space of the surface, $P_i = (u_i, v_i)$. The trimming curve is the result of applying equation 1 to these points. In the rational case the P_i are homogeneous control points $P_i^h = (w_i u_i, w_i v_i, w_i)$. The trimming curve is the result of applying equation 3 to these points and projecting the computed points to two-dimensional parameter space.

Each trimming loop is composed of one or more trimming curves of order greater than or equal to two, connected to each other in a head to tail fashion. The head of a curve is the point corresponding to its minimum parameter range limit, the tail is the point corresponding to its maximum parameter range limit. A correctly specified trimming loop is explicitly closed; that is, the tail of each curve touches the head of the subsequent curve, and the tail of the last curve touches the head of the first curve. Correctly specified trimming loops do not intersect themselves or other trimming loops of the surface. Trimming curves only touch other trimming curves of the surface or themselves when they are adjacent in a trimming loop, and then only at their endpoints. Each trimming curve should be continuous. The implementation may assume continuity, non-intersection, head-to-tail connectivity, and closure of trimming loops. During traversal, trimming loops that violate these assumptions are treated in a workstation dependent manner.

Two rules are used to define the portion of the surface's parameter range to map (see figure 5):

- a) **Odd Winding Rule:** A point is in the mapped portion of the surface's parameter range if any ray projected from that point to infinity has an odd number of intersections with the set of trimming loops.

- b) **Curve Orientation Rule:** For any given trimming loop, the mapped portion of the surface is “to the left” of the directed loop and the unmapped portion is “to the right”. The term “to the right” is defined as follows: Let $f(t) = (u, v)$ denote the trimming curve, and (du, dv) the tangent to the curve at point t oriented in the direction of increasing t ; then the vector $(-dv, du)$ is said to point to the left at point t , and the vector $(dv, -du)$ is said to point to the right.

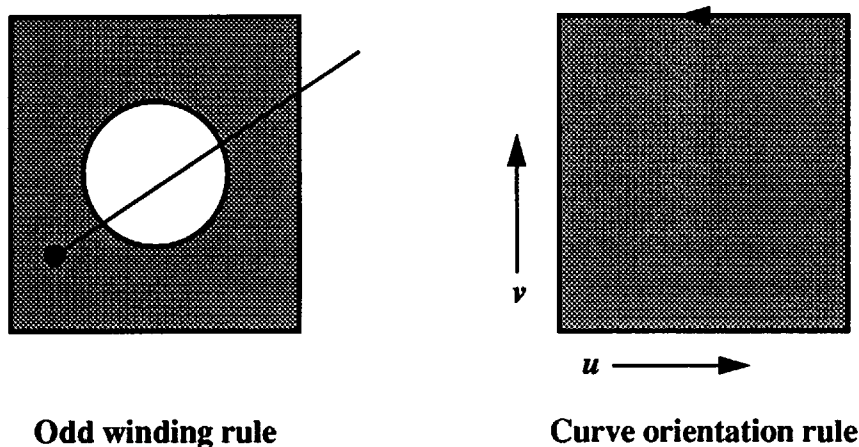


Figure 5 — Parameter space mapping rules for trimming curves (The mapped region is shaded)

The curve orientation rule requires that the curves be directed appropriately to define the mapped region. To be valid, the set of trimming loops shall satisfy both the above rules. If a set of trimming curves is specified that violate these rules, the resulting image is undefined and workstation dependent. See figure 6 for examples of valid trimming loop specifications. See figure 7 for examples of invalid trimming loop specifications.

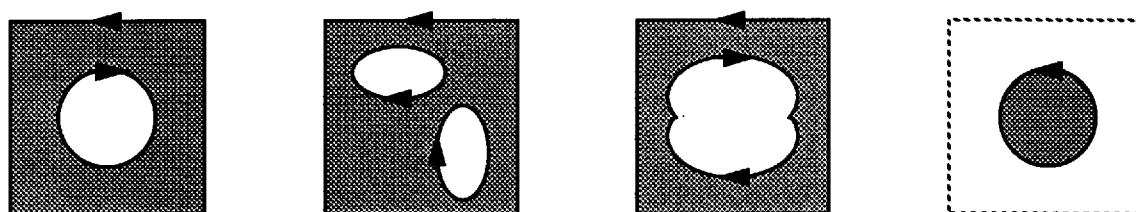


Figure 6 — Examples of valid trimming loops (Solid lines represent trimming loops, dashed lines represent the parameter range of the surface. Shading denotes the mapped region of the surface. Each arrowhead corresponds to a single trimming curve)

4.4.13 Non-uniform B-spline surface with data

PHIGS PLUS generates a non-uniform B-spline surface. The surface's definition may contain a number of associated non-uniform B-spline surfaces that, subject to data mapping, indicate the intrinsic colour of the surface. The control points of these associated surfaces are data or colour coordinates that describe the data or colour distribution over the primitive's geometry.

There may be a single color spline associated with the surface. The control points of the colour spline are colour values of the appropriate dimension for the specified colour type. When the colour spline is the source of intrinsic colour, the

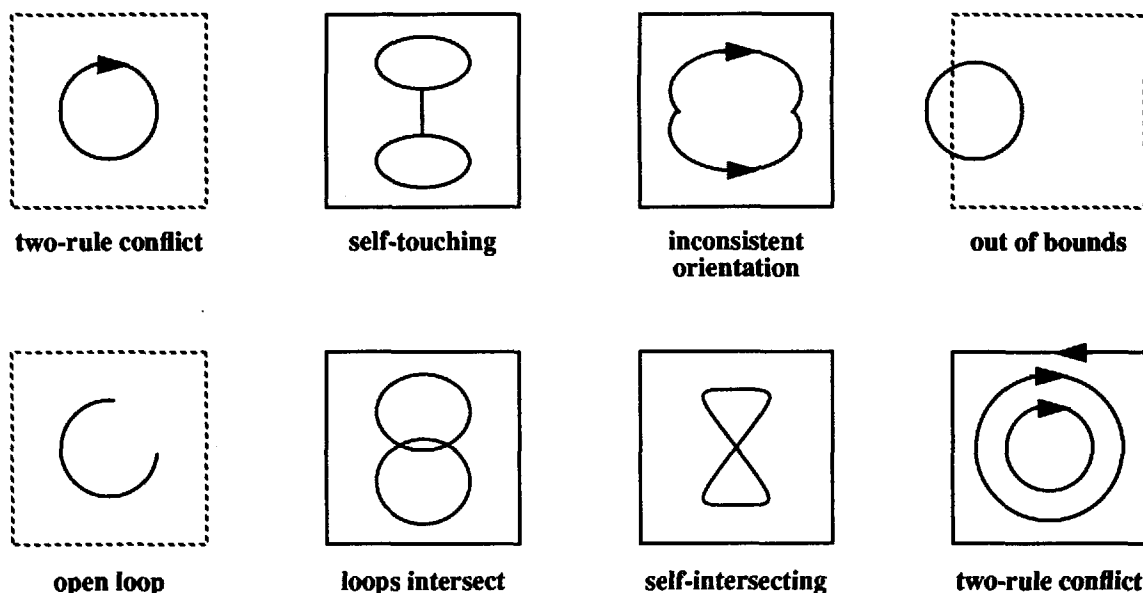


Figure 7 — Examples of invalid trimming loops (Solid lines represent trimming loops, dashed lines represent the parameter range of the surface. Each arrowhead corresponds to a single trimming curve.)

colour is determined from the colour spline at the sample points used for the geometry spline. These colours are then considered to be vertex colours of the corresponding facets.

The colour spline is a B-spline surface as defined by equation (4) in 4.4.11. It can be rational or non-rational. The colour spline need not have the same order, rationality or knot sequence as the geometry spline. The values of the control point coordinates can be outside the range normally associated with the colour type. (This is necessary to allow colour specification with rational B-splines, and to allow B-splines that interpolate a set of colours.) If the colour spline is rational the dimension of the control points is one more than the dimension of the corresponding colour model coordinates.

The parameter range of the colour spline shall wholly contain the parameter range of the geometry spline, or, if trimming loops are specified, the parameter range of the colour spline shall wholly contain the parameter range defined by the collection of trimming loops. Thus the colour for any point on the mapped geometry of the surface can be determined by evaluating the colour spline at the corresponding parameter value.

Application-specific data for data mapping can be associated with a non-uniform B-spline surface with data primitive by specifying an optional list of B-spline surfaces that define the data distribution over the surface geometry. The list of data splines corresponds to the list of real values associated with the other with-data area primitives, but there is only one list per primitive for non-uniform B-spline surfaces (as opposed to one list per facet or vertex for the other primitives). The data splines to use when mapping the data are indicated by the data selector in the data mapping method data record. When data mapping is the source of intrinsic colour, the data is determined from the data splines at the sample points used for the geometry spline. This data is then considered to be vertex data for the corresponding facets. Intrinsic colour is determined from this data according to the data mapping method and interior shading method aspects.

Data splines can have more than one dimension. Each data mapping method indicates how it uses the data values in multi-dimensional data splines. (The defined data mapping methods use only the first dimension.)

The data splines are B-spline surfaces as defined by equation (4) in 4.4.11. They can be rational or non-rational. The data splines need not have the same order, rationality nor knot sequence as the geometry spline. The parameter range of the data splines shall wholly contain the parameter range of the geometry spline, or, if trimming loops are specified, the parameter range of the data splines shall wholly contain the parameter range defined by the collection of trimming loops.

ISO/IEC 9592-4:1992(E)

Thus the data values for any point on the mapped geometry of the surface can be determined by evaluating the data splines at the corresponding parameter value. Data splines can be specified in addition to an optional colour spline.

4.4.14 Area primitives and facets

Area primitives are fill area, fill area set, cell array, fill area set with data, cell array PLUS, set of fill area set with data, triangle set with data, triangle strip with data, quadrilateral mesh with data, non-uniform B-spline surface and non-uniform B-spline surface with data. For the purposes of specifying data and applying attributes area primitives are conceptually composed of facets. While B-spline surfaces are not inherently faceted, they are treated here as if faceted to describe their display and the application of interior attributes.

The definition of each primitive's facets are as follows:

- a) the whole of a fill area or fill area set constitutes one facet;
- b) each cell of a cell array or cell array PLUS constitutes one facet;
- c) each fill area set of a set of fill area sets constitutes one facet;
- d) each triangle of a triangle set or triangle strip constitutes one facet;
- e) each quadrilateral of a quadrilateral mesh constitutes one facet;
- f) Conceptually, a non-uniform B-spline surface is rendered by computing a number of sample points on or near the surface. The density of the sample points is controlled by the surface approximation criteria. If the sampling is higher than the density of points on the display surface, displaying the sample points themselves will produce a complete rendering of the surface. Alternatively, adjacent sample points can be joined to form polygons (usually triangles or quadrilaterals) that are then displayed as fill areas. The facets of the B-spline surface are the polygons or the sample points themselves (taken as areas). Depending on the approximation criteria, these facets can be smaller than the smallest displayable region on the workstation or as large as the surface itself.

Vertex normals of facets are the normals to the surface at the corresponding sample points. The facet normal can be either a workstation dependent combination of the vertex normals, or the normal to the surface at some point on the facet. The point chosen in the latter case is workstation dependent.

4.4.15 Modelling clip

Modelling clip conceptually generates new vertices of output primitives at the intersection of the clipping planes and the primitive's boundary. If colour, data, or vertex normals are associated with the original vertices, then new colour, data, or vertex normals shall be interpolated at the new vertices. The interpolation method shall be such that if the geometry plus colour, geometry plus data, or geometry plus normal vectors are planar as defined by 4.6.4.2, then the interpolated values lie on the corresponding plane. If the set of vertices and associated data defining a facet are non-planar, then the results are workstation dependent.

4.5 Output primitive attributes

4.5.1 General colour specification

ISO/IEC 9592-1 defines only indirect colour specification. PHIGS PLUS defines direct colour specification and requires that both direct and indirect colour specification be supported.

Colour in PHIGS PLUS is specified through the concept of a general colour, which is capable of specifying colours both directly and indirectly. A general colour specifies a colour type and corresponding colour value. The colour type indicates either the colour model of the corresponding n-tuple of colour coordinates, or that the colour is being specified indirectly, in which case the single integer colour value is an index into the colour table of the workstation state list (see figure 8).

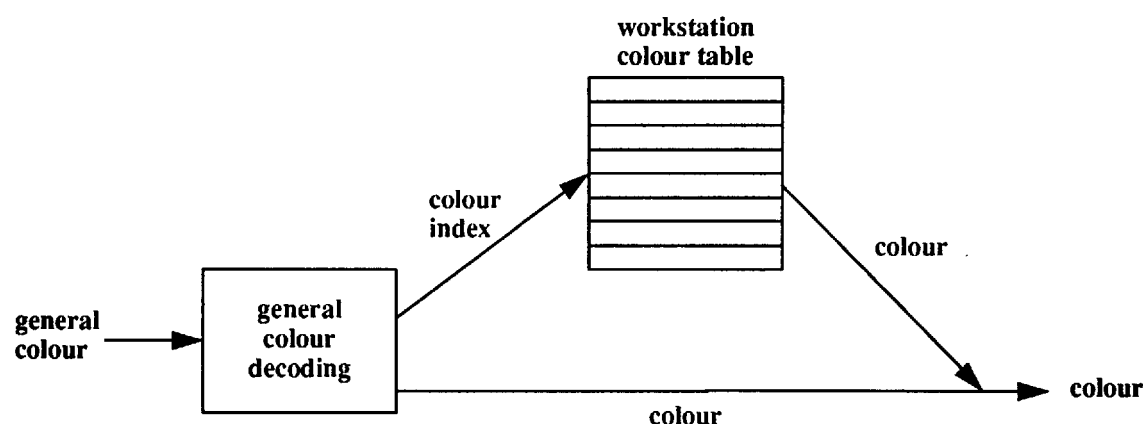


Figure 8 — A general colour holds either the index of an entry in the workstation colour table or a colour in a particular colour model

The defined colour types are listed in table 3. The result of resolving a general colour is a colour consisting (conceptually) of a colour model and the associated colour value.

Table 3 — Colour types

Value	Meaning
< 0	Implementation dependent.
0	INDIRECT (Indirectly specified colour)
1	RGB (Directly specified colour)
2	CIELUV (Directly specified colour)
3	HSV (Directly specified colour)
4	HLS (Directly specified colour)
≥ 5	Reserved for registration or future standardisation. ¹

1) Registered colour type values are drawn from the same set of values as colour model values.

As in ISO/IEC 9592-1, four colour models are defined: RGB, CIELUV, HSV, and HLS. See ISO/IEC 9592-1, annex I for a description of these colour models. The defined coordinate ranges are [0, 1] for all coordinates of the RGB and CIELUV

ISO/IEC 9592-4:1992(E)

colour models, $[0, 1]$ for the radius and height coordinates of the HSV and HLS colour models, and $(-\infty, +\infty)$ for the angle coordinate of the HSV, and HLS colour models. Structure elements may contain colour coordinates that are not within the defined range for the specified colour model. During traversal out of range colour coordinates are treated in a workstation dependent way.

If a non-supported colour type is encountered during traversal, colour type INDIRECT and a colour value of 1 is used. This is equivalent to the default colour behaviour specified in ISO/IEC 9592-1. If an undefined colour index is encountered during traversal a colour index of 1 is used.

To support the specification of general colour, the PHIGS traversal state list fields 'current XXX colour index', (where XXX is polyline, polymarker, text, interior, or edge) are replaced by the corresponding 'current XXX colour' fields in the traversal state list. For each of the "set XXX colour index" structure elements defined in ISO/IEC 9592-1, PHIGS PLUS defines a corresponding structure element, "set XXX colour". The ISO/IEC 9592-1 "set XXX colour index" structure elements are defined by PHIGS PLUS to set the 'current XXX colour' field in the traversal state list to colour type INDIRECT and the colour value to the specified colour index.

Each of the 'current XXX colour index ASF' fields in the traversal state list defined in ISO/IEC 9592-1 are replaced in PHIGS PLUS with the fields 'current XXX colour ASF'. The 'current XXX colour ASF' selects between bundled and individual colour values. If the 'current XXX colour ASF' is INDIVIDUAL the 'current XXX colour' is used. If the 'current XXX colour ASF' is BUNDLED the colour is taken from the entry in the extended XXX bundle table indicated by the 'current XXX index' (see figure 9). The ISO/IEC 9592-1 "set XXX colour index ASF" structure elements are defined by PHIGS PLUS to set the 'current XXX colour ASF' field in the traversal state list to the value specified in the structure element.

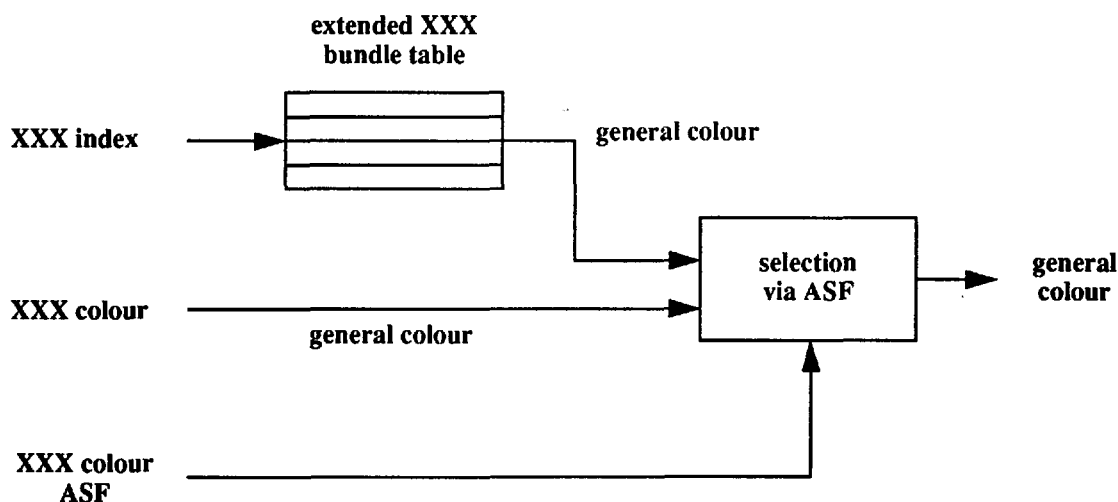


Figure 9 — Selection of the XXX COLOUR attribute

4.5.2 Extended workstation state and description tables

The 'colour index' field in the polyline, polymarker, text, interior, and edge bundles is replaced with a 'colour' field that enables these bundles to support general colour specification. The functions SET POLYLINE REPRESENTATION PLUS, SET POLYMARKER REPRESENTATION PLUS, SET TEXT REPRESENTATION PLUS, SET INTERIOR REPRESENTATION PLUS, and SET EDGE REPRESENTATION PLUS set these modified bundles. The functions, INQUIRE <bundle type> REPRESENTATION PLUS and INQUIRE PREDEFINED <bundle type> REPRESENTATION PLUS are the corresponding inquiry functions for these modified bundles. The ISO/IEC 9592-1 functions SET <POLYLINE | POLYMARKER | TEXT | INTERIOR | EDGE> REPRESENTATION are here defined to set the colour type of the bundle's 'colour' to INDIRECT and the value to the specified colour index.

The polyline bundle is extended to support bundled specification of the PHIGS PLUS polyline aspects. With the exception of the 'colour index' field, the extended polyline bundle contains both the fields specified in ISO/IEC 9592-1 and the additional fields specified in this part of ISO/IEC 9592. The ISO/IEC 9592-1 function SET POLYLINE REPRESENTATION sets only those fields specified in ISO/IEC 9592-1 and the 'colour' field. The additional fields are left unchanged.

The interior bundle is extended to support bundled specification of the PHIGS PLUS interior aspects. With the exception of the 'colour index' field, the extended interior bundle contains both the fields specified in ISO/IEC 9592-1 and the interior shading method field specified in this part of ISO/IEC 9592. The ISO/IEC 9592-1 function, SET INTERIOR REPRESENTATION, sets only those fields specified in ISO/IEC 9592-1 and the 'colour' field. The interior shading method field is left unchanged.

Pattern table entries are extended to support general specification of colour. The functions SET PATTERN REPRESENTATION PLUS, INQUIRE PATTERN REPRESENTATION PLUS, and INQUIRE PREDEFINED PATTERN REPRESENTATION PLUS are defined. The extended pattern table entry contains a 'colour type' field and an array of colour values. These replace the array of colour indices specified in ISO/IEC 9592-1. The ISO/IEC 9592-1 function SET PATTERN REPRESENTATION sets the 'colour type' to INDIRECT and the colour values to the specified colour indices.

Since the ISO/IEC 9592-1 inquiry functions cannot return a general colour specification a new error is defined to be returned from INQUIRE POLYLINE REPRESENTATION, INQUIRE POLYMARKER REPRESENTATION, INQUIRE TEXT REPRESENTATION, INQUIRE INTERIOR REPRESENTATION, INQUIRE EDGE REPRESENTATION, and INQUIRE PATTERN REPRESENTATION when the requested entry contains a general colour specification and the colour type is not INDIRECT. The error is:

134 Ignoring function, the requested entry contains a general colour specification with colour type other than INDIRECT

Predefined entries shall contain colours of type INDIRECT.

Two bundle tables are defined to support bundled specification of reflectance aspects and parametric surface aspects. These tables are the reflectance bundle table and the parametric surface bundle table. The REFLECTANCE INDEX and BACK REFLECTANCE INDEX attributes indicate the entries in the reflectance bundle table to use when resolving bundled reflectance aspects for front and back facing facets, respectively, of area primitives. The PARAMETRIC SURFACE INDEX attribute indicates the bundle entry in the parametric surface bundle table to use when resolving bundled parametric surface attributes. Aspect source flags are defined for the aspects in these bundles.

The 'dynamic modification accepted for' entries in the workstation description table for the polyline bundle table, poly-marker bundle table, text bundle table, interior bundle table, edge bundle table and pattern table apply to the tables as extended. Additional 'dynamic modification accepted for' entries in the workstation description table are defined for the reflectance bundle table, the parametric surface bundle table, and the data mapping, light source, depth cueing, and colour mapping tables. These entries are returned by the function INQUIRE DYNAMICS OF WORKSTATION ATTRIBUTES PLUS.

The enumeration values for the list of attributes used by generalized drawing primitives are extended to include the parametric surface and reflectance tables.

4.5.3 PHIGS PLUS attributes applied to PHIGS output primitives

4.5.3.1 General

Output primitive attributes defined in this part of PHIGS apply to the output primitives defined in ISO/IEC 9592-1 as listed in table 4.

Table 4 — PHIGS PLUS attributes applied to ISO/IEC 9592-1 primitives

POLYLINE	
POLYLINE COLOUR RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	POLYLINE COLOUR ASF
POLYMARKER	
POLYMARKER COLOUR RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	POLYMARKER COLOUR ASF
TEXT	
TEXT COLOUR RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	TEXT COLOUR ASF
ANNOTATION TEXT RELATIVE	
TEXT COLOUR RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	TEXT COLOUR ASF
FILL AREA and FILL AREA SET	
REFLECTANCE INDEX BACK INTERIOR INDEX BACK REFLECTANCE INDEX FACET DISTINGUISHING MODE FACET CULLING MODE INTERIOR COLOUR INTERIOR SHADING METHOD REFLECTANCE PROPERTIES REFLECTANCE MODEL BACK INTERIOR STYLE BACK INTERIOR STYLE INDEX BACK INTERIOR COLOUR BACK INTERIOR SHADING METHOD BACK REFLECTANCE PROPERTIES BACK REFLECTANCE MODEL LIGHT SOURCE STATE RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	INTERIOR COLOUR ASF INTERIOR SHADING METHOD ASF REFLECTANCE PROPERTIES ASF REFLECTANCE MODEL ASF BACK INTERIOR STYLE ASF BACK INTERIOR STYLE INDEX ASF BACK INTERIOR COLOUR ASF BACK INTERIOR SHADING METHOD ASF BACK REFLECTANCE PROPERTIES ASF BACK REFLECTANCE MODEL ASF

Table 4 — PHIGS PLUS attributes applied to ISO/IEC 9592-1 primitives (Continued)

CELL ARRAY	
REFLECTANCE INDEX	
BACK REFLECTANCE INDEX	
FACET DISTINGUISHING MODE	
FACET CULLING MODE	
REFLECTANCE PROPERTIES	REFLECTANCE PROPERTIES ASF
REFLECTANCE MODEL	REFLECTANCE MODEL ASF
BACK REFLECTANCE PROPERTIES	BACK REFLECTANCE PROPERTIES ASF
BACK REFLECTANCE MODEL	BACK REFLECTANCE MODEL ASF
LIGHT SOURCE STATE	
RENDERING COLOUR MODEL	
DEPTH CUE INDEX	
COLOUR MAPPING INDEX	
GENERALIZED DRAWING PRIMITIVE	
Zero or more of the attribute sets listed above.	

4.5.3.2 Polyline attributes

PHIGS PLUS defines the following additional aspects and attributes for polylines: the non-geometric aspect polyline colour, which is controlled by the POLYLINE INDEX or the individually specified attribute POLYLINE COLOUR; the individually specified attributes DEPTH CUE INDEX and COLOUR MAPPING INDEX. The source of the polyline colour is selected by the POLYLINE COLOUR ASF.

4.5.3.3 Polymarker attributes

PHIGS PLUS defines the following additional aspects and attributes for polymarkers: the non-geometric aspect polymarker colour; the individually specified attributes DEPTH CUE INDEX and COLOUR MAPPING INDEX. The polymarker colour aspect is controlled by the POLYMARKER INDEX or the individually specified attribute POLYMARKER COLOUR. The source of the polymarker colour is selected by the POLYMARKER COLOUR ASF.

4.5.3.4 Text attributes

PHIGS PLUS defines the following additional aspects and attributes for text: the non-geometric aspect text colour; the individually specified attributes DEPTH CUE INDEX and COLOUR MAPPING INDEX. The text colour aspect is controlled by the TEXT INDEX or the individually specified attribute TEXT COLOUR. The source of the text colour is selected by the TEXT COLOUR ASF.

4.5.3.5 Annotation text attributes

PHIGS PLUS defines the following additional aspects and attributes for annotation text: the non-geometric aspect text colour; the individually specified attributes DEPTH CUE INDEX and COLOUR MAPPING INDEX. The text colour aspect is controlled by the TEXT INDEX or the individually specified attribute TEXT COLOUR. The source of the text colour is selected by the TEXT COLOUR ASF.

4.5.3.6 Fill area attributes

PHIGS PLUS defines the following additional aspects and attributes for fill areas: the non-geometric aspects interior colour, interior shading method, reflectance properties, reflectance model, back interior style, back interior style index, back interior colour, back interior shading method, back reflectance properties, and back reflectance model; the individually specified attributes LIGHT SOURCE STATE, FACET DISTINGUISHING MODE, FACET CULLING MODE, RENDERING COLOUR MODEL, DEPTH CUE INDEX and COLOUR MAPPING INDEX. Aspects in the first group are controlled by the INTERIOR INDEX, REFLECTANCE INDEX, BACK INTERIOR INDEX, BACK REFLECTANCE INDEX, or the individually specified attributes INTERIOR COLOUR, INTERIOR SHADING METHOD, REFLECTANCE PROPERTIES, REFLECTANCE MODEL, BACK INTERIOR STYLE, BACK INTERIOR STYLE INDEX, BACK INTERIOR COLOUR, BACK INTERIOR SHADING METHOD, BACK REFLECTANCE PROPERTIES, and BACK REFLECTANCE MODEL. The source of the attributes for these aspects is selected by the corresponding aspect source flag attribute listed in table 4.

4.5.3.7 Fill area set attributes

Fill area sets are affected by the same PHIGS PLUS attributes that affect fill areas, plus the non-geometric aspects edge flag, edgetype, edgewidth scale factor, and edge colour, which are controlled by the EDGE INDEX or by the individually specified attributes EDGE FLAG, EDGETYPE, EDGEWIDTH SCALE FACTOR, and EDGE COLOUR. The source of these aspects is selected by the corresponding aspect source flag attribute. Fill area set edges are not affected by lighting or shading.

4.5.3.8 Cell array attributes

PHIGS PLUS defines the following additional aspects and attributes for cell arrays: the non-geometric aspects reflectance properties, reflectance model, back reflectance properties and back reflectance model; the individually specified attributes LIGHT SOURCE STATE, FACET DISTINGUISHING MODE, FACET CULLING MODE, RENDERING COLOUR MODEL, DEPTH CUE INDEX and COLOUR MAPPING INDEX. Aspects in the first group are controlled by the REFLECTANCE INDEX, BACK REFLECTANCE INDEX, or the individually specified attributes REFLECTANCE PROPERTIES, REFLECTANCE MODEL, BACK REFLECTANCE PROPERTIES and BACK REFLECTANCE MODEL. The source of the attributes for these aspects is selected by the corresponding aspect source flag attribute listed above. The interior colour, interior style, interior shading method, back interior style, back interior colour, and back interior shading method aspects and their corresponding aspect source flags do not apply to cell arrays.

4.5.3.9 Generalized drawing primitive attributes

Any of the PHIGS PLUS attributes listed in 4.5.4 may also apply to Generalized Drawing Primitives (GDPs). Whether bundle indices or associated individually specified attributes are used depends upon the values of the appropriate aspect source flags. The sets of attributes most appropriate for the specified GDP structure element are selected for the GDP as part of the definition of the GDP and are recorded in the workstation description table.

4.5.4 Attributes applied to PHIGS PLUS output primitives

4.5.4.1 General

The attributes defined in ISO/IEC 9592-1 and the attributes defined in this part of ISO/IEC 9592 that apply to each PHIGS PLUS output primitive are listed in table 5.

4.5.4.2 Polyline set with colour attributes

Polyline set with colour output primitives are affected by the same attributes as polylines. They are also affected by the RENDERING COLOUR MODEL and the polyline shading method aspect, which is controlled by the POLYLINE INDEX or the individually specified attribute POLYLINE SHADING METHOD. The source of the polyline shading method is selected by the POLYLINE COLOUR ASF. Each polyline of a set is treated as an individual polyline when applying the attributes.

4.5.4.3 Fill area set with data attributes

Fill area set with data output primitives are affected by the same attributes as fill area sets. Their display is also affected by the data mapping method and back data mapping method aspects.

4.5.4.4 Cell array PLUS attributes

Cell array PLUS output primitives are affected by the same attributes that affect cell arrays.

4.5.4.5 Set of fill area set with data attributes

Set of fill area set with data output primitives are affected by the same attributes that affect fill area set with data output primitives. Each fill area set of the set is rendered as a single fill area set with data. Interior styles HATCH and PATTERN apply to each fill area set in the set as if it were an individual fill area set.

4.5.4.6 Triangle set with data attributes

Triangle sets are affected by the same attributes that affect fill area set with data output primitives. Interior styles HATCH and PATTERN apply to the triangle set in a workstation dependent manner. For interior style HOLLOW the bounding polyline is drawn along boundaries created by clipping.

4.5.4.7 Triangle strip with data attributes

Triangle strips are affected by the same attributes that affect fill area set with data output primitives. Interior styles HATCH and PATTERN apply to the triangle strip in a workstation dependent manner. For interior style HOLLOW the bounding polyline is drawn along boundaries created by clipping.

4.5.4.8 Quadrilateral mesh with data attributes

Quadrilateral meshes are affected by the same attributes that affect fill area set with data output primitives. Interior styles HATCH and PATTERN apply to the quadrilateral mesh in a workstation dependent manner. For interior style HOLLOW the bounding polyline is drawn along boundaries created by clipping.

Table 5 — Attributes applied to PHIGS PLUS output primitives

POLYLINE SET WITH COLOUR	
POLYLINE INDEX LINETYPE LINEWIDTH SCALE FACTOR POLYLINE COLOUR INDEX VIEW INDEX HLHSR IDENTIFIER PICK IDENTIFIER NAME SET POLYLINE COLOUR POLYLINE SHADING METHOD RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	LINETYPE ASF LINEWIDTH SCALE FACTOR ASF POLYLINE COLOUR INDEX ASF POLYLINE COLOUR ASF POLYLINE SHADING METHOD ASF
FILL AREA SET WITH DATA SET OF FILL AREA SETS WITH DATA TRIANGLE SET WITH DATA TRIANGLE STRIP WITH DATA QUADRILATERAL MESH WITH DATA	
INTERIOR INDEX INTERIOR STYLE INTERIOR STYLE INDEX INTERIOR COLOUR INDEX EDGE INDEX EDGE FLAG EDGETYPE EDGEWIDTH SCALE FACTOR PATTERN SIZE PATTERN REFERENCE POINT PATTERN VECTORS VIEW INDEX HLHSR IDENTIFIER PICK IDENTIFIER NAME SET DATA MAPPING INDEX REFLECTANCE INDEX BACK INTERIOR INDEX BACK DATA MAPPING INDEX	INTERIOR STYLE ASF INTERIOR STYLE INDEX ASF INTERIOR COLOUR INDEX ASF EDGE FLAG ASF EDGETYPE ASF EDGEWIDTH SCALE FACTOR ASF

Table 5 — Attributes applied to PHIGS PLUS output primitives (Continued)

BACK REFLECTANCE INDEX FACET DISTINGUISHING MODE FACET CULLING MODE INTERIOR COLOUR INTERIOR SHADING METHOD DATA MAPPING METHOD REFLECTANCE PROPERTIES REFLECTANCE MODEL BACK INTERIOR STYLE BACK INTERIOR STYLE INDEX BACK INTERIOR COLOUR BACK INTERIOR SHADING METHOD BACK DATA MAPPING METHOD BACK REFLECTANCE PROPERTIES BACK REFLECTANCE MODEL EDGE COLOUR LIGHT SOURCE STATE RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	INTERIOR COLOUR ASF INTERIOR SHADING METHOD ASF DATA MAPPING METHOD ASF REFLECTANCE PROPERTIES ASF REFLECTANCE MODEL ASF BACK INTERIOR STYLE ASF BACK INTERIOR STYLE INDEX ASF BACK INTERIOR COLOUR ASF BACK INTERIOR SHADING METHOD ASF BACK DATA MAPPING METHOD ASF BACK REFLECTANCE PROPERTIES ASF BACK REFLECTANCE MODEL ASF EDGE COLOUR ASF
CELL ARRAY PLUS	
VIEW INDEX HLHSR IDENTIFIER PICK IDENTIFIER NAME SET REFLECTANCE INDEX BACK REFLECTANCE INDEX FACET DISTINGUISHING MODE FACET CULLING MODE REFLECTANCE PROPERTIES REFLECTANCE MODEL BACK REFLECTANCE PROPERTIES BACK REFLECTANCE MODEL LIGHT SOURCE STATE RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	REFLECTANCE PROPERTIES ASF REFLECTANCE MODEL ASF BACK REFLECTANCE PROPERTIES ASF BACK REFLECTANCE MODEL ASF
NON-UNIFORM B-SPLINE CURVE	
POLYLINE INDEX	

Table 5 — Attributes applied to PHIGS PLUS output primitives (Continued)

LINETYPE LINEWIDTH SCALE FACTOR POLYLINE COLOUR INDEX VIEW INDEX HLHSR IDENTIFIER PICK IDENTIFIER NAME SET POLYLINE COLOUR CURVE APPROXIMATION CRITERIA DEPTH CUE INDEX COLOUR MAPPING INDEX	LINETYPE ASF LINEWIDTH SCALE FACTOR ASF POLYLINE COLOUR INDEX ASF POLYLINE COLOUR ASF CURVE APPROXIMATION CRITERIA ASF
NON-UNIFORM B-SPLINE CURVE WITH COLOUR	
All those for Non-uniform B-spline curve, plus: POLYLINE SHADING METHOD RENDERING COLOUR MODEL	POLYLINE SHADING METHOD ASF
NON-UNIFORM B-SPLINE SURFACE	
INTERIOR INDEX INTERIOR STYLE INTERIOR STYLE INDEX INTERIOR COLOUR INDEX EDGE INDEX EDGE FLAG EDGETYPE EDGEWIDTH SCALE FACTOR PATTERN SIZE PATTERN REFERENCE POINT PATTERN VECTORS VIEW INDEX HLHSR IDENTIFIER PICK IDENTIFIER NAME SET REFLECTANCE INDEX PARAMETRIC SURFACE INDEX FACET DISTINGUISHING MODE FACET CULLING MODE INTERIOR COLOUR INTERIOR SHADING METHOD REFLECTANCE PROPERTIES REFLECTANCE MODEL	INTERIOR STYLE ASF INTERIOR STYLE INDEX ASF INTERIOR COLOUR INDEX ASF EDGE FLAG ASF EDGETYPE ASF EDGEWIDTH SCALE FACTOR ASF INTERIOR COLOUR ASF INTERIOR SHADING METHOD ASF REFLECTANCE PROPERTIES ASF REFLECTANCE MODEL ASF

Table 5 — Attributes applied to PHIGS PLUS output primitives (Continued)

BACK INTERIOR INDEX BACK REFLECTANCE INDEX BACK INTERIOR STYLE BACK INTERIOR STYLE INDEX BACK INTERIOR COLOUR BACK INTERIOR SHADING METHOD BACK REFLECTANCE PROPERTIES BACK REFLECTANCE MODEL EDGE COLOUR LIGHT SOURCE STATE SURFACE APPROXIMATION CRITERIA PARAMETRIC SURFACE CHARACTERISTICS RENDERING COLOUR MODEL DEPTH CUE INDEX COLOUR MAPPING INDEX	BACK INTERIOR STYLE ASF BACK INTERIOR STYLE INDEX ASF BACK INTERIOR COLOUR ASF BACK INTERIOR SHADING METHOD ASF BACK REFLECTANCE PROPERTIES ASF BACK REFLECTANCE MODEL ASF EDGE COLOUR ASF SURFACE APPROXIMATION CRITERIA ASF PARAMETRIC SURFACE CHARACTERISTICS ASF
NON-UNIFORM B-SPLINE SURFACE WITH DATA	
All those for NON-UNIFORM B-SPLINE SURFACE, plus: DATA MAPPING INDEX DATA MAPPING METHOD BACK DATA MAPPING INDEX BACK DATA MAPPING METHOD	DATA MAPPING METHOD ASF BACK DATA MAPPING METHOD ASF

4.5.4.9 Non-uniform B-spline curve attributes

Non-uniform B-spline curve output primitives are affected by the same attributes as polylines. They are also affected by the curve approximation criteria aspect. The curve approximation criteria aspect is controlled by the POLYLINE INDEX or the individually specified attribute CURVE APPROXIMATION CRITERIA. The source of the curve approximation criteria is selected by the CURVE APPROXIMATION CRITERIA ASF.

The curve approximation criteria indicates the minimum quality desired for the approximation of the curve's geometry. It provides an indication of the degree of approximation tolerable and the relative importance of image quality versus rendering speed. Specification of lower relative approximation quality is intended to produce relatively lower quality approximations at relatively higher speeds. Specification of higher relative approximation quality is intended to produce higher quality approximations at possibly lower speeds. Implementations may produce a higher quality approximation than that requested. Approximation of the curve shall not introduce any gaps, holes or other visible spatial discontinuities.

An approximation criteria consists of a type and a data record. The data record contains information specific to the type and is generally unique for each type. The defined curve approximation criteria types are

≤ 0 Implementation dependent.

1 WORKSTATION DEPENDENT: A workstation dependent approximation criteria is used. There are no data record contents for this type.

ISO/IEC 9592-4:1992(E)

- 2 **CONSTANT PARAMETRIC SUBDIVISION BETWEEN KNOTS:** Sample points are at equal parameter increments between each pair of the curve's knots. The data record contains a single integer value that indicates the minimum number of sample points between each pair of knots. The value is interpreted as follows:
 - ≤ 0 : Sample points are at the parameter range limits and at the knots within the parameter range limits.
 - > 0 : Sample points are at the parameter range limits and at the knots within the parameter range limits. In addition, sample points are at this number of positions between each pair of knots, but only if the position is within the parameter range limits.
- 3 **CHORDAL SIZE in WC:** Generate at least sufficient sample points such that the length in world coordinates of every line segment (chord) between the sample points is less than a specified real approximation value. The data record contains the single approximation value.
- 4 **CHORDAL SIZE in NPC:** Generate at least sufficient sample points such that the length in normalized projection coordinates of every line segment (chord) between the sample points is less than a specified real approximation value. The data record contains the single approximation value.
- 5 **CHORDAL SIZE in DC:** Generate at least sufficient sample points such that the length in device coordinates of every line segment (chord) between the sample points is less than a specified real approximation value. The data record contains the single approximation value.
- 6 **CHORDAL DEVIATION in WC:** Generate at least sufficient sample points such that the absolute value of the maximum deviation measured in world coordinates between the curve and line segments (chord) between sample points is less than a specified real approximation value. The data record contains the single approximation value.
- 7 **CHORDAL DEVIATION in NPC:** Generate at least sufficient sample points such that the absolute value of the maximum deviation measured in normalized projection coordinates between the curve and line segments (chord) between sample points is less than a specified real approximation value. The data record contains the single approximation value.
- 8 **CHORDAL DEVIATION in DC:** Generate at least sufficient sample points such that the absolute value of the maximum deviation measured in device coordinates between the curve and line segments (chord) between sample points is less than a specified real approximation value. The data record contains the single approximation value.
- 9 **RELATIVE in WC:** A single real approximation value between 0 and 1 indicates a relative quality of rendering to be maintained independent of scaling in world coordinates. Higher values specify a better relative quality. The data record contains the approximation value.
- 10 **RELATIVE in NPC:** A single real approximation value between 0 and 1 indicates a relative quality of rendering to be maintained independent of scaling in normalized projection coordinates. Higher values specify a better relative quality. The data record contains the approximation value.
- 11 **RELATIVE in DC:** A single real approximation value between 0 and 1 indicates a relative quality of rendering to be maintained independent of scaling in device coordinates. Higher values specify a better relative quality. The data record contains the approximation value.
- ≥ 12 Reserved for registration or future standardisation.

It is not intended that there be any correspondence between the approximations produced by different approximation criteria types. For example, the set of all possible approximations achievable by CHORDAL SIZE in WC can be disjoint from the set of all possible approximations achievable by RELATIVE in WC.

4.5.4.10 Non-uniform B-spline curve with colour attributes

Non-uniform B-spline curve with colour primitives are affected by the same attributes that affect non-uniform B-spline curve primitives. In addition, they are affected by the RENDERING COLOUR MODEL and the polyline shading method

aspect, which is controlled by the POLYLINE INDEX or the individually specified attribute POLYLINE SHADING METHOD. The source of the polyline shading method is selected by the POLYLINE COLOUR ASF.

4.5.4.11 Non-uniform B-spline surface attributes

With the exception of the data mapping method and back data mapping method aspects, non-uniform B-spline surfaces are affected by the same attributes that affect fill area set with data output primitives. In addition, they have the non-geometric aspects surface approximation criteria and parametric surface characteristics. These aspects are controlled by the PARAMETRIC SURFACE INDEX or the individually specified attributes SURFACE APPROXIMATION CRITERIA and PARAMETRIC SURFACE CHARACTERISTICS. The source of the surface approximation criteria is selected by the SURFACE APPROXIMATION CRITERIA ASF. The source of the parametric surface characteristics is selected by the PARAMETRIC SURFACE CHARACTERISTICS ASF.

Non-uniform B-spline surfaces can be approximated when displayed. Conceptually, the result of this approximation is a collection of facets. The surface approximation criteria indicates the minimum quality desired for the approximation of the surface's geometry. It provides an indication of the degree of approximation tolerable and the relative importance of image quality versus rendering speed. Specification of lower relative approximation quality is intended to produce relatively lower quality approximations at relatively higher speeds. Specification of higher relative approximation quality is intended to produce higher quality approximations at possibly lower speeds. Implementations may produce a higher quality approximation than that requested. Approximation of the surface shall not introduce any gaps, holes or other visible spatial discontinuities.

A surface approximation criteria consists of a type and a data record. The data record contains information specific to the type and is generally unique for each type. The defined surface approximation criteria types are

≤ 0 Implementation dependent.

- 1 WORKSTATION DEPENDENT: A workstation dependent approximation criteria is used. There are no data record contents for this type.
- 2 CONSTANT PARAMETRIC SUBDIVISION BETWEEN KNOTS: Sample points are at equal parameter increments between each pair of u knots and v knots. The data record contains two integer values that indicate the minimum number of sample points in the u and v parameter dimensions. Both values have the following interpretation:
 - ≤ 0: Sample points are at the u and v knot values, and where lines of constant parameter across the surface at these knot values would intersect the approximated trimming loops.
 - > 0: Sample points are at the u and v knot values, at this number of positions between each pair of knot values in each parameter dimension, and where lines of constant parameter across the surface at these parameter values would intersect the approximated trimming loops.
- 3 CHORDAL SIZE in WC: Generate at least sufficient sample points such that the length in world coordinates of every line segment (chord) between the sample points for both the u and v parameter directions is less than the corresponding specified real approximation value. The data record contains two approximation values, one for each parameter direction.
- 4 CHORDAL SIZE in NPC: Generate at least sufficient sample points such that the length in normalized projection coordinates of every line segment (chord) between the sample points for both the u and v parameter directions is less than the corresponding specified real approximation value. The data record contains two approximation values, one for each parameter direction.
- 5 CHORDAL SIZE in DC: Generate at least sufficient sample points such that the length in device coordinates of every line segment (chord) between the sample points for both the u and v parameter directions is less than the corresponding specified real approximation value. The data record contains two approximation values, one for each parameter direction.

ISO/IEC 9592-4:1992(E)

- 6 PLANAR DEVIATION in WC: Generate at least sufficient sample points such that the absolute value of the maximum deviation measured in world coordinates between the surface and the approximating facet is less than a specified real approximation value. The data record contains the approximation value.
- 7 PLANAR DEVIATION in NPC: Generate at least sufficient sample points such that the absolute value of the maximum deviation measured in normalized projection coordinates between the surface and the approximating facet is less than a specified real approximation value. The data record contains the approximation value.
- 8 PLANAR DEVIATION in DC: Generate at least sufficient sample points such that the absolute value of the maximum deviation measured in device coordinates between the surface and the approximating facet is less than a specified real approximation value. The data record contains the approximation value.
- 9 RELATIVE in WC: A single real approximation value between 0 and 1 indicates a relative quality of rendering to be maintained independent of scaling in world coordinates. Higher values specify a better relative quality. The data record contains the approximation value.
- 10 RELATIVE in NPC: A single real approximation value between 0 and 1 indicates a relative quality of rendering to be maintained independent of scaling in normalized projection coordinates. Higher values specify a better relative quality. The data record contains the approximation value.
- 11 RELATIVE in DC: A single real approximation value between 0 and 1 indicates a relative quality of rendering to be maintained independent of scaling in device coordinates. Higher values specify a better relative quality. The data record contains the approximation value.
- ≥ 12 Reserved for registration or future standardisation.

It is not intended that there be any correspondence between the approximations produced by different approximation criteria types. For example, the set of all possible approximations achievable by CHORDAL SIZE in WC can be disjoint from the set of all possible approximations achievable by RELATIVE in WC.

The parametric surface characteristics aspect further specifies the appearance of parametric surfaces beyond those aspects also associated with fill area sets. The aspect consists of a type and a data record. The data record contains information specific to the type and is generally unique for each type. The definition of each type indicates whether or not the application of that type to the surface distinguishes between front and back facing portions when the 'current facet distinguishing mode' is ON. If it does then the associated data record contains separate parameters for front and back facing portions. If it does not then only one set of parameters is defined and they apply to the surface as though the 'current facet distinguishing mode' were OFF.

The defined parametric surface characteristics types are

≤ 0 Implementation dependent.

- 1 NONE: No surface characteristics beyond those aspects defined for fill area sets are used. The data record is empty for this type.
- 2 WORKSTATION DEPENDENT: A workstation dependent representation that displays the shape of the surface is drawn. This method does not distinguish between front and back facing portions of the surface. The appearance of the representation is controlled by the appropriate set of output primitive attributes for the representation. It is workstation dependent how the representation interacts with any interior rendering indicated by the interior aspects. There are no data record contents for this type.
- 3 ISOPARAMETRIC CURVES: Isoparametric curves are drawn on the surface. The data record contains the number of curves to draw in each of the parameter dimensions and their placement. If the placement is UNIFORM OVER SURFACE the specified number of curves are evenly spaced within the parameter range of the surface; curves are also drawn at the limits of the parameter range. If the placement is UNIFORM BETWEEN KNOTS the specified number of curves are evenly spaced between each pair of knots; curves are also drawn at the knots. In both cases only the portions of isoparametric curves are drawn that are within the interior of the surface as defined by any trimming loops.

This method does not distinguish between front and back facing portions of the surface. The appearance of the isoparametric curves is controlled by the current polyline colour, linewidth scale factor, and linetype aspects. The approximation of the isoparametric curves is controlled by the surface approximation criteria. The isoparametric curves shall lie on the approximated surface. The isoparametric curves are drawn in addition to any interior rendering indicated by the interior style or back interior style. Isoparametric curves have higher visual priority than the primitive's filled or hollow interiors, but lower priority than the primitive's edges.

- 4 LEVEL CURVES in MC: Level curves are drawn on the surface. The curves correspond to the intersections of the surface and a finite set of planes perpendicular to a modelling coordinate direction vector. The positions of the planes are specified by a sequence of intersection points along an infinite line defined by a modelling coordinate origin point, P_0 , and a direction vector, $\vec{V}$, as follows:

$$P_i = P_0 + t_i \vec{V}$$

The t_i are a sequence of parameters specifying the intersection points. They are in the range $-\infty < t_i < +\infty$. The P_i are the intersection points of the perpendicular planes with the infinite line. P_0 is a specified origin point in modelling coordinates, and $\vec{V}$ is the specified direction vector in modelling coordinates. The i -th plane is perpendicular to the direction vector, $\vec{V}$, and intersects the infinite line at point P_i . The data record consists of the origin point, P_0 ; the direction vector, $\vec{V}$; and the ordered list of parameters, t_i . Only the portions of the level curves are drawn that are within the interior of the surface as defined by any trimming loops.

This method does not distinguish between front and back facing portions of the surface. The appearance of the level curves is controlled by the current polyline colour, linewidth scale factor, and linetype aspects. The approximation of the level curves is controlled by the surface approximation criteria. The level curves shall lie on the approximated surface. The curves are drawn in addition to any interior rendering indicated by the interior style or back interior style. Level curves have higher visual priority than the primitive's filled or hollow interiors, but lower priority than the primitive's edges.

- 5 LEVEL CURVES in WC: Level curves are drawn on the surface. The curves correspond to the intersections of the surface and a finite set of planes perpendicular to a world coordinate direction vector. The positions of the planes are specified by a sequence of intersection points along an infinite line defined by a world coordinate origin point, P_0 , and a direction vector, $\vec{V}$, as follows:

The t_i are a sequence of parameters specifying the intersection points. They are in the range $-\infty < t_i < +\infty$. The P_i are the intersection points of the perpendicular planes with the infinite line. P_0 is a specified origin point in world coordinates, and $\vec{V}$ is the specified direction vector in world coordinates. The i -th plane is perpendicular to the direction vector, $\vec{V}$, and intersects the infinite line at point P_i . The data record consists of the origin point, P_0 ; the direction vector, $\vec{V}$; and the ordered list of parameters, t_i . Only the portions of the level curves are drawn that are within the interior of the surface as defined by any trimming loops.

This method does not distinguish between front and back facing portions of the surface. The appearance of the level curves is controlled by the current polyline colour, linewidth scale factor, and linetype aspects. The approximation of the level curves is controlled by the surface approximation criteria. The level curves shall lie on the approximated surface. The curves are drawn in addition to any interior rendering indicated by the interior style or back interior style. Level curves have higher visual priority than the primitive's filled or hollow interiors, but lower priority than the primitive's edges.

- ≥ 6 Reserved for registration or future standardisation.

The effect of PATTERN and HATCH interior styles on parametric surfaces is workstation dependent.

Lighting and shading shall be applied to parametric surfaces. The interior shading method shall be applied to each facet.

Trimming curves, when specified, define the edges of a surface. If no trimming curves are specified, the edges consist of curves of constant parameter value at the parameter range boundaries of the surface. The edges lie on the approximated surface and are displayed using the edge attributes. The approximation of trimming curves is controlled by the trimming curve approximation criteria specified with each trimming curve. The trimming curve approximation criteria are analo-

ISO/IEC 9592-4:1992(E)

gous to the curve approximation criteria, but the approximation types are restricted to the defined types 1 and 2 or appropriate implementation dependent types. The trimming curve definition contains an edge visibility flag. In conjunction with the EDGE FLAG the edge visibility flag controls the visibility of each trimming curve. When the EDGE FLAG is ON, the edge visibility flag determines whether the trimming curve is visible. When the EDGE FLAG is OFF, no trimming curves are displayed.

4.5.4.12 Non-uniform B-spline surface with data attributes

Non-uniform B-spline surface with data output primitives are affected by the same attributes as non-uniform B-spline surfaces. In addition, their display is affected by the data mapping method aspects.

4.5.4.13 Individual edge control for PHIGS PLUS area primitives

All area primitives defined in PHIGS PLUS except cell array PLUS can have edge visibility flags specified with them. If edge visibility flags are specified, each edge is displayed only if both the edge flag aspect and the corresponding edge visibility flag (or, where multiple facets share an edge, any of the corresponding edge visibility flags) in the output primitive structure element are set to ON. If the edge flag aspect is set to OFF, the edge visibility flags specified in the output primitive structure element are ignored. If edge visibility flags are not specified, then the edge flag aspect solely determines whether edges are displayed.

For all primitives that have edge visibility flags associated with them, the rendering of the edges in the presence of bounding polylines resulting from interior style HOLLOW has the same effect as for fill area set primitives.

4.5.4.14 Reflectance properties

Reflectance properties indicate how an area primitive models the reflection of light. All area primitives are affected by the reflectance properties aspect. Reflectance properties are specified by a type and a data record. The reflectance property types are as follows:

≤ 0 implementation dependent;

- 1 simple reflectance: The reflectance properties consist of an ambient reflection coefficient, diffuse reflection coefficient, specular reflection coefficient, specular colour and specular exponent. The ambient reflection coefficient controls the amount of ambient light reflected from the primitive. If the coefficient is zero, no ambient light is reflected. An increase in the coefficient increases the amount of ambient light reflected, up to a maximum of 1 for the coefficient. The diffuse reflection coefficient similarly controls the amount of non-ambient light reflected equally in all directions from a surface, resulting in a dull, matte appearance that is independent of the viewing direction. The specular reflection coefficient similarly controls the amount of non-ambient light contributing to reflections unequally from a surface, resulting in a shiny appearance.

In general there is a direction in which the specular reflected light is at a maximum, specified implicitly by a reflectance vector. The specular colour and specular exponent have significance if the specular reflection coefficient is non-zero. Whereas the intrinsic colour, which may vary across an output primitive, contributes to the ambient and diffuse reflections, the colour of the specular highlights is also contributed to by the specular colour aspect. The specular exponent controls the intensity of the specular reflection in directions other than the direction of the reflectance vector. Increasing the exponent decreases the intensity of the specular reflection away from the direction of the reflectance vector. The minimum value of the exponent is 0.

≥ 2 reserved for registration or future standardisation.

Reflectance properties is a non-geometric aspect and is both individually specified and bundled. Reflectance properties are in the entries in the reflectance bundle table in the workstation state list.

During structure traversal the 'current reflectance properties ASF' in the traversal state list determines the source of the reflectance properties. If it is BUNDLED then the reflectance properties specified in the reflectance bundle indicated by the 'current reflectance index' is used. If it is INDIVIDUAL then the 'current reflectance properties' in the traversal state

list is used. Similarly, the 'current back reflectance properties ASF' indicates the source of the back reflectance properties, either from the reflectance table bundle indicated by the 'current back reflectance properties index' or the 'current back reflectance properties' entry in the traversal state list.

During traversal, reflectance properties type 1 is used if the specified type is not available on the workstation. The data record values used in this case are the default values indicated in the PHIGS description table.

4.5.5 Implicitly specified attributes

4.5.5.1 General

Area primitives have aspects that are implicitly derived from output primitive structure element data, traversal state attributes, and workstation state tables. These implicit attributes are used in the PHIGS PLUS rendering pipeline.

4.5.5.2 Facet normal

The facet normal is used for determining the orientation of a facet of an area primitive. In some cases it is also used to determine reflectance normals. Facet normals can be supplied for the with-data area primitives. In the case of the other area primitives or where facet normals are not supplied for a with-data primitive, facet normals are computed for each facet using a method that depends on the output primitive type, as follows:

- a) For a fill area or fill area set primitive a normal is computed by selecting three points: A, B, and C. Point A is the first point in the first list of vertices. Point B is the next point in that list that is not coincident with A. Point C is the next point in that list that is not colinear with A and B. The normal is the normalized cross product of the vector extending from A to B with the vector extending from A to C.

If it is not possible to find three such points in the first list of vertices, then, in the case of fill area set, the rest of the lists are searched in order to select three appropriate points from a single list. If it is not possible to find three such points in any list, then the output primitive is degenerate, in which case the result is workstation dependent.

- b) All cells of a cell array have the same normal. The normal for the three dimensional form of the cell array is the normalized cross product of the vector, $\vec{V}_1$, extending from point P to point Q with the vector, $\vec{V}_2$, extending from point P to point R (refer to ISO/IEC 9592-1 for the definition of P , Q and R):

$$\vec{N} = \frac{\vec{V}_1 \times \vec{V}_2}{|\vec{V}_1 \times \vec{V}_2|}$$

The normal for the two dimensional form of the cell array is the normalized cross product of a vector along the side $(QX, PY) - (PX, PY)$ with the vector along the side $(PX, QY) - (PX, PY)$.

- c) For a set of fill area set primitive the normal for each fill area set of the primitive is computed separately, using the procedure specified above for fill area sets.
- d) For a triangle set primitive the normal for each triangle is computed as for a fill area.
- e) For a triangle strip primitive the normal for each triangle is the normalized cross product of vectors along two of its sides. The vectors used are different for even numbered and odd numbered triangles. (The triangles are implicitly numbered by the ordering of the defining list of vertices. The first triangle in the strip is numbered 1.) Referring to figure 3, the normal for odd numbered triangles is defined by

$$\vec{N}_{i_{odd}} = \frac{(\vec{V}_{i+1} - \vec{V}_i) \times (\vec{V}_{i+2} - \vec{V}_i)}{|(\vec{V}_{i+1} - \vec{V}_i) \times (\vec{V}_{i+2} - \vec{V}_i)|}$$

ISO/IEC 9592-4:1992(E)

where

$\vec{N}$ is the normal;

$\vec{P}_i$ are the vertex coordinates.

The normal for even numbered triangles is defined by

$$\vec{N}_{i_{even}} = \frac{(\vec{P}_{i+2} - \vec{P}_i) \times (\vec{P}_{i+1} - \vec{P}_i)}{|(\vec{P}_{i+2} - \vec{P}_i) \times (\vec{P}_{i+1} - \vec{P}_i)|}$$

- f) For a quadrilateral mesh primitive the normal for each quadrilateral is the normalized cross product of its diagonals. Referring to figure 4, the normal is defined by

$$\vec{N}_{i,j} = \frac{(\vec{P}_{i+1,j+1} - \vec{P}_{i,j}) \times (\vec{P}_{i,j+1} - \vec{P}_{i+1,j})}{|(\vec{P}_{i+1,j+1} - \vec{P}_{i,j}) \times (\vec{P}_{i,j+1} - \vec{P}_{i+1,j})|}$$

where

$1 \leq i \leq M - 1$;

$1 \leq j \leq N - 1$;

$\vec{N}_{i,j}$ is the normal;

$\vec{P}_{i,j}$ are the vertex coordinates;

M and N are the dimensions of the two-dimensional array of vertex data ($M \times N$).

- g) For a non-uniform B-spline surface primitive the normal is computed by normalizing the cross product of the tangent vector along the u direction, $\vec{T}_u$, (usually the partial derivative with respect to u), and the tangent vector along the v direction, $\vec{T}_v$, (usually the partial derivative with respect to v). The normal is computed as

$$\vec{N} = \frac{\vec{T}_u \times \vec{T}_v}{|\vec{T}_u \times \vec{T}_v|}$$

At positions on the surface where this cross product is not meaningful, such as where tangent vectors are colinear, the normal is computed in a workstation dependent way.

Notice that when the normal is computed, its sense is determined by the order of points in the lists that are part of the specification of the primitive. For fill area set, triangle set, triangle strip and quadrilateral mesh, the order of the primitive's vertices determines the sense of the computed normal. For the parametric surfaces, the sense is determined by the order of the surface's control points.

4.5.5.3 Facet orientation

PHIGS PLUS provides explicit controls to allow the appearance of an area primitive to be determined by the orientation of its facets. Individual facets can be culled from the primitive or be rendered with different attributes according to their orientation. The orientation of a facet is defined to be front facing if its facet normal has a positive or zero Z component when transformed to NPC, otherwise its orientation is back facing.

4.5.5.4 Reflectance normal

The reflectance normal vector defines the orientation of a facet at a certain point for the purpose of performing a reflectance calculation at that point. The determination of the reflectance normal is dependent on the presence of data optionally provided with an output primitive. If vertex normals are specified, then, depending on the interior shading

method, they are used or interpolated to define the reflectance normals at the reflectance calculation positions. If vertex normals are not specified then the facet normal is used.

If a facet is determined to be front facing, reflectance normals as described are used for subsequent reflectance calculations. If a facet is determined to be back facing, normals of the opposite sign are used for reflectance calculations.

4.5.5.5 Intrinsic colour

The intrinsic colour is the colour or colours associated with an output primitive prior to applying the reflectance calculation. The possible sources of intrinsic colour differ among different output primitives, and some output primitives have multiple possible sources. In the case of area primitives, the source of intrinsic colour is dependent on the interior style and the data mapping method. Table 6 lists the source of intrinsic colour for each output primitive. Where multiple sources are listed, they are listed in their decreasing order of default precedence.

Table 6 — Sources of intrinsic colour

Output Primitive	Sources of intrinsic colour
polyline	polyline colour aspect
polymarker	polymarker colour aspect
text	text colour aspect
annotation text	text colour aspect
fill area	pattern representation, interior colour aspect
fill area set	pattern representation, interior colour aspect
cell array	cell colours
generalized drawing primitive	any, according to the type of GDP
polyline set with colour	vertex colours, polyline colour aspect
fill area set with data	pattern representation, data mapping, interior colour aspect
cell array PLUS	cell colours
set of fill area sets with data	pattern representation, data mapping, interior colour aspect
triangle set with data	pattern representation, data mapping, interior colour aspect
triangle strip with data	pattern representation, data mapping, interior colour aspect
quadrilateral mesh with data	pattern representation, data mapping, interior colour aspect
non-uniform B-spline curve	polyline colour aspect
non-uniform B-spline curve with colour	colour spline, polyline colour aspect
non-uniform B-spline surface	pattern representation, interior colour aspect
non-uniform B-spline surface with data	pattern representation, data mapping, interior colour aspect

Where pattern representation is indicated in table 6, the pattern representation is the source of intrinsic colour only when the interior style is PATTERN. In this case the source of the intrinsic colour is the pattern representation indicated by the appropriate INTERIOR STYLE INDEX or BACK INTERIOR STYLE INDEX attribute. Intrinsic colour is derived from the pattern representation in a workstation dependent way.

Except in the case described in the preceding paragraph for interior style PATTERN, the source of intrinsic colour for the output primitives defined in ISO/IEC 9592-1 is the corresponding colour aspect for that primitive. For polyline set with colour primitives the source is the vertex colours, if specified, otherwise the source is the polyline colour aspect. For fill area set with data, set of fill area set with data, triangle set with data, triangle strip with data and quadrilateral mesh with data primitives the source of the intrinsic colour is determined by the data mapping method aspect. For cell array and cell

array PLUS primitives the intrinsic colour is the collection of the primitive's cell colours.⁴ For non-uniform B-spline curve primitives the source of intrinsic colour is the polyline colour aspect. For non-uniform B-spline curve with colour primitives the source of intrinsic colour is the colour spline specified with the primitive, or the polyline colour aspect if no colour spline is specified. For non-uniform B-spline surface primitives the source of intrinsic colour is the interior colour aspect. For non-uniform B-spline surface with data primitives the source of intrinsic colour is determined by the data mapping method aspect if colour or data splines are specified; the intrinsic colour is the interior colour aspect if no colour or data splines are specified. The source of intrinsic colour for generalized drawing primitives can be any of the defined sources.

Since the interior shading method potentially influences the interpolation of colour and data, the intrinsic colour at each point of the output primitive is also dependent on the interior shading method.

4.5.6 Facet culling

Individual facets can be removed from an area primitive according to their orientation and the value of the FACET CULLING MODE attribute. A value of BACKFACING indicates that back-facing facets are removed from the primitive. A value of FRONTFACING indicates that front-facing facets are removed from the primitive. A value of NONE indicates that no facets are removed from the primitive. When a facet is removed, no portion of it is displayed, e.g., its interior, edges, or parametric surface characteristics.

4.5.7 Distinguishing facets by orientation

Different attributes can be applied to individual facets of an area primitive according to whether their orientation is front facing or back facing. The attribute FACET DISTINGUISHING MODE controls whether PHIGS PLUS uses the orientation of a facet to select which attributes to apply. When FACET DISTINGUISHING MODE has the value OFF, the same aspects are applied to both front-facing and back-facing facets. Many attributes have counterparts that are applied to back-facing facets when FACET DISTINGUISHING MODE has the value ON. The aspects, attributes, and ASFs that apply to back-facing facets are prefixed with BACK.

4.5.8 Hidden line and hidden surface removal

As in ISO/IEC 9592-1, implementation of any HLHSR capabilities is optional. If HLHSR capabilities are provided, however, an implementation shall not make methods available that interfere or conflict with PHIGS PLUS functionality.

4.5.9 Stability

The aspects of output primitives composed of planar convex facets (where planarity is in all of the geometry, colour, data, and vertex normals used—4.6.4.2—and convexity is in the geometry only) and undergoing only rigid transformations shall not appear to vary based only on the primitive's orientation in any coordinate space. Similarly, the aspects of parametric curve and parametric surface output primitives when those primitives undergo rigid transformations shall not appear to vary based only on the primitive's orientation in any coordinate space.

4) Colours of cell array and cell arrays PLUS primitives are, unlike other area primitives, substantial properties of the primitives themselves. Therefore, their intrinsic colour is taken solely from the cell array values, never being derived from any other aspects or attributes.

4.6 The PHIGS PLUS rendering pipeline

4.6.1 General

In PHIGS PLUS, colour values to be displayed on the display surface of a workstation are computed by the rendering pipeline (see figure 10). The conceptual rendering pipeline consists of a data mapping stage, a shading (interpolation) stage, a lighting stage, a depth cueing stage, and a colour mapping stage. The input to this pipeline includes the output primitive facets that remain after facet culling, and the primitive attributes as determined by the orientation of the primitive and the FACET DISTINGUISHING MODE attribute.

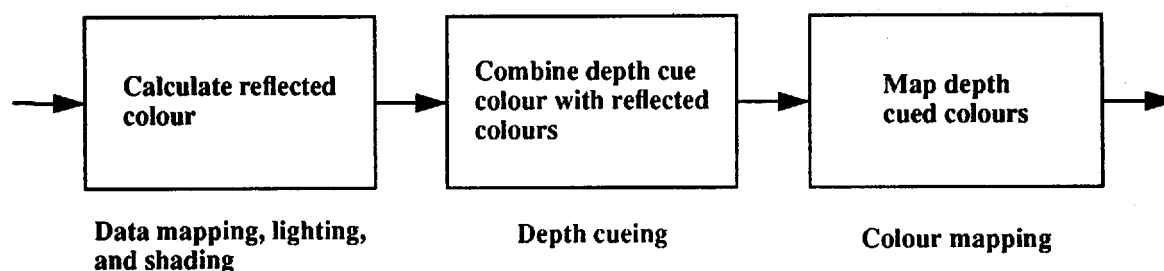


Figure 10 — The conceptual rendering pipeline

The rendering pipeline uses a primitive's attributes, orientation and position in world coordinates to determine the displayed colours for that primitive. The data mapping stage computes a primitive's intrinsic colour from data specified with the primitive. The lighting stage computes the effect of light sources on a primitive's appearance. Lighting in PHIGS PLUS is applied on a primitive by primitive basis; no interactions between objects such as shadows or reflections are defined. The shading stage interpolates data across a primitive. The depth cueing stage conditionally modifies the colours of the lit and shaded primitive by combining them with the depth cue colour on the basis of the primitive's Z component in NPC. The colour mapping stage maps the colours produced by the previous stages into other, possibly workstation dependent, colours before they are displayed.

4.6.1.1 Primitives affected by the rendering pipeline

Lighting and shading are applicable to only area primitives, with the exceptions that polyline primitives utilize shading for interpolation of colours, and cell arrays may be affected by lighting. It is acceptable not to apply lighting to cell array and cell array PLUS primitives, and shading does not apply to them. Markers, text and annotation text, as well as fill area set edges and edges of other area primitives are not processed by the lighting and shading stage. Data mapping applies to all with-data primitives. Depth cueing and colour mapping are applicable to all primitives.

The effect of lighting and shading self-coincident or self-intersecting facets of area primitives is workstation dependent.

4.6.1.2 The effect of the interior style on lighting and shading

Conceptually, lighting applies to HOLLOW, SOLID, and PATTERN interior styles; shading applies to HOLLOW, SOLID, PATTERN, and HATCH interior styles. It is acceptable for an implementation not to light and shade an area primitive when the interior style is PATTERN or HATCH. Lighting and shading are not applied when the interior style is EMPTY.

The effect of lighting and shading when the interior style is HOLLOW is the same as for SOLID, but only primitive boundaries are displayed. Points on the boundaries, including points in boundary segments created by clipping, have the same colour as they would if the interior style were SOLID. For interior style PATTERN the pattern is conceptually applied prior to lighting and shading, and the colours used in the reflectance calculation are taken from the pattern definition.

4.6.1.3 Aspects and attributes used in the rendering pipeline

The rendering pipeline makes use of the following aspects and attributes: polyline shading method, interior colour, interior style, interior style index, data mapping method, DATA MAPPING INDEX, reflectance properties, reflectance model, interior shading method, back interior colour, back interior style, back interior style index, back data mapping method, BACK DATA MAPPING INDEX, back reflectance properties, back reflectance model, back interior shading method, LIGHT SOURCE STATE, RENDERING COLOUR MODEL, DEPTH CUE INDEX, and COLOUR MAPPING INDEX. The rendering pipeline also makes use of the implicit eye point and any geometric and colour information specified with an output primitive.

The eye point is a physical parameter that is implicit in the PHIGS viewing matrices. The eye point is that point in WC that transforms to infinite positive Z in NPC (the homogeneous point (0, 0, 1, 0)). The eye information needed for the reflectance calculations can therefore be determined by transforming the NPC point (0,0,1,0) through the inverses of the view mapping and view orientation matrices, in that order. For perspective projections this operation will result in a location in world coordinates that corresponds to the projection reference point of the PHIGS view mapping utility function (if the PHIGS utility functions or comparable methods were used to derive the view mapping). For parallel projections this inverse transformation results in a direction vector on which the eye point lies at infinity. In the case of singular matrices there is either no determinate eye point or an infinite number of them. The implementation will choose an arbitrary location in the former case and one of the possible locations in the latter case.

4.6.2 Data mapping

Data mapping is a means of computing intrinsic colour from colour or other application-specific data associated with the following output primitives: fill area set with data, set of fill area sets with data, triangle set with data, triangle strip with data, quadrilateral mesh with data and non-uniform B-spline surface with data. The data mapping process converts one or more fields of data to a single colour at points on the output primitive where an intrinsic colour is needed. This colour is used as input to the reflectance calculation and subsequent stages of the rendering pipeline.

For all the output primitives listed in the previous paragraph except non-uniform B-spline surface with data, the data is specified as either a colour at each facet or vertex or a list of real values at each facet or vertex. If a list of real values is specified, more entries in the list can be specified than are used in any single traversal of the output primitive structure element. The values to use in a particular execution are specified separately in the data mapping method data record.

For non-uniform B-spline surface with data output primitives the data is in the form of a colour spline or a list of data splines. Each spline specifies the distribution of colour or data over the surface's geometry. If a list of data splines are specified, more entries in the list can be specified than are used in any single execution of the output primitive structure element. Which data splines to use in a particular execution are specified separately in the data mapping method data record. These data splines may have a greater dimensionality than that needed by a particular data mapping method (perhaps because the full dimensionality is used by some other data mapping method), in which case the description of the data mapping method shall describe the dimensions used. (The defined data mapping methods use only the first dimension of the data splines.)

The data mapping method aspect controls the mapping of data values to intrinsic colour. It specifies which data values are used and how they select the intrinsic colour. There are separate data mapping method aspects for front- and back-facing facets. The data mapping method aspect consists of a method indicator and a data record, the contents of which are method dependent.

Output primitives subject to data mapping may have more information specified with them than is used during any single execution of their structure element. For all but non-uniform B-spline surface with data output primitives this information can be a combination of vertex colours, vertex data, facet colours or facet data. For non-uniform B-spline surface output primitives both a colour spline and a list of data splines can be specified. Which of this information to use for a particular data mapping is indicated in the source selector list in the data mapping method data record. The source selector list is a list of flags indicating the precedence of the possible intrinsic colour sources. Each selector in the list may have one of the values listed in table 7.

Table 7 — Intrinsic colour source selectors

Selector value	Selector meaning
COLOUR_ASPECT	Use the appropriate colour aspect, e.g., interior colour, as the source of intrinsic colour.
FACET_COLOUR	Use facet colour as the source of intrinsic colour.
FACET_DATA	Use facet data as the source of intrinsic colour.
VERTEX_COLOUR	Use vertex colour as the source of intrinsic colour.
VERTEX_DATA	Use vertex data as the source of intrinsic colour.

The order of the flags in the selector list indicates the precedence of the corresponding data relative to the other sources. The first entry in the list has the highest precedence, the last entry has the lowest. When an output primitive subject to data mapping is encountered during traversal, the selector list is searched from first entry to last until a selector is found that corresponds to a source of intrinsic colour specified with the output primitive and applicable to the current data mapping method. If such a match occurs then the indicated source is used to determine the intrinsic colour of the primitive. If no match is found or the selector list is empty the interior colour aspect is used as the source of intrinsic colour. For non-uniform B-spline surface with data output primitives source selector flag values of FACET_COLOUR and VERTEX_COLOUR indicate that the surface colour spline is the source of intrinsic colour. Source selector flag values of FACET_DATA and VERTEX_DATA indicate that the data splines are the source of intrinsic colour.

Not all data mapping methods support all the above sources of intrinsic colour. Data mapping method COLOUR, for instance, uses only the appropriate colour aspect, vertex, or facet colour, so only those three source selector values are meaningful for that data mapping method. The description of each data mapping method indicates which sources are supported by that method. Intrinsic colour sources not meaningful to a particular data mapping method are ignored when that data mapping method is in effect.

The data mapping method is a non-geometric aspect and is both individually specified and bundled. Data mapping bundles are entries in the data mapping table in the workstation state list. They are set with the function SET DATA MAPPING REPRESENTATION. The front and back data mapping methods are set individually with the structure elements "set data mapping method" and "set back data mapping method", and are selected from the data mapping bundle table with the structure elements "set data mapping index" and "set back data mapping index". Each index indicates a bundle in the data mapping bundle table.

During traversal the 'current data mapping method ASF' in the traversal state list determines the source of the data mapping method. If it is BUNDLED then the data mapping method specified in the data mapping bundle indicated by the 'current data mapping index' is used. If it is INDIVIDUAL then the 'current data mapping method' in the traversal state list is used. Similarly, the 'current back data mapping method ASF' indicates the source of the back data mapping method, either from the data mapping bundle indicated by the 'current back data mapping index' or the 'current back data mapping method' entry in the traversal state list.

Data mapping method 1 is used during traversal if the specified data mapping method is not available on the workstation, or if the data mapping method or the data record contents are inconsistent with the data specified with a primitive. The data record values used in these cases are the default values indicated in the PHIGS description table. (Examples of inconsistencies include fewer data values specified than are needed and a data value index specifying a data item that does not exist in a list of data associated with the primitive.) The effect of this fallback behaviour shall be only on the display of the primitive associated with the inconsistency.

The defined data mapping methods are

≤ 0 Implementation dependent.

1 COLOUR: Any colours specified with the output primitive are used directly as the source of intrinsic colour. Only source selector values of COLOUR_ASPECT, FACET_COLOUR, and VERTEX_COLOUR are meaningful for this data mapping method. Other values can be specified but will be ignored. For non-uniform B-spline surface with

ISO/IEC 9592-4:1992(E)

data output primitives, both FACET_COLOUR and VERTEX_COLOUR indicate that the surface's colour spline, if specified, is used as the source of intrinsic colour.

- 2 SINGLE VALUE, UNIFORM: A single data value is mapped to a colour selected from a specified list of N colours (see figure 11). The colour selected from this list is based on the relationship of the data value to a specified data range. Data values below the data range are assigned the first colour in the colour list. Data values above the data range are assigned the last colour in the colour list. Data values within the data range are assigned a colour by associating, uniformly, a portion of the range with each of the colours from the second to the penultimate colour in the colour list and selecting the colour associated with the portion of the range containing the data value. The colour-to-range association is defined in figure 11.

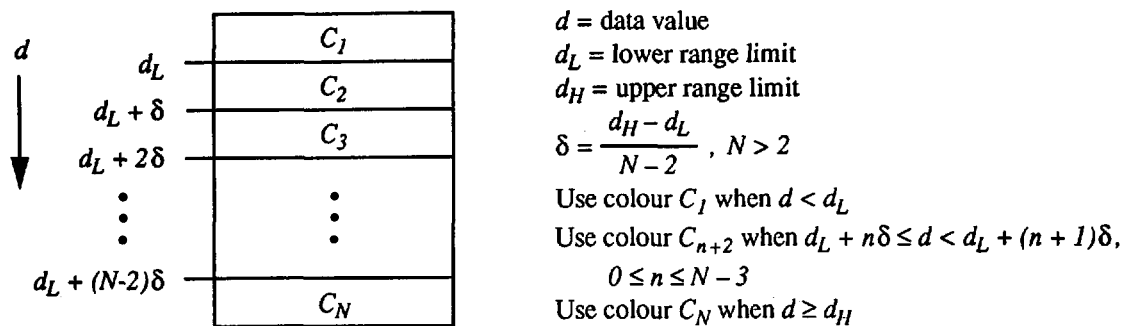


Figure 11 — UNIFORM data mapping of data values to colours

The data value to map, subject to any interpolation indicated by the shading method aspect, is indicated by an index into the data lists. This index is specified in the data mapping method's data record. For non-uniform B-spline surface with data output primitives, the index indicates the single data spline in the list of data splines, if specified, that is used to determine the data values to map. If that data spline is multi-dimensional only the first coordinate value is used.

The data record for this method contains the intrinsic colour source selector list, the data value index, the two data range limits, and the list of colours. The list of colours must contain at least three colours, unless the lower range limit is equal to the upper range limit, in which case the list must contain at least two colours.

Only source selector values of FACET_DATA and VERTEX_DATA are meaningful for this data mapping method. Other values can be specified but will be ignored. For non-uniform B-spline surface with data output primitives both FACET_DATA and VERTEX_DATA indicate that the surface's data splines, if specified, are used as the source of intrinsic colour.

- 3 SINGLE VALUE, NON-UNIFORM: A single data value is mapped to a colour selected from a specified list of N colours (see figure 12). The colour selected is based on the relationship of the data value to a specified set of data ranges. The ranges are specified as a list of $N-1$ range boundaries in increasing order; N shall be ≥ 2 . Each range boundary specifies the lower limit of the range above it, inclusive, and the upper limit of the range below it, non-inclusive, that is, range $i = [d_i, d_{i+1})$; thus the ranges are adjacent. The first range extends to negative infinity, the last range extends to positive infinity. Each range is associated with a colour in the colour list. Data values are assigned the colour associated with the range that contains them. Data values below the first range boundary are assigned the first colour in the colour list. Data values above the last range boundary are assigned the last colour in the colour list. The colour-to-range association is defined in figure 12. The number of colours in the list shall be one more than the number of boundaries.

The data value to map, subject to any interpolation indicated by the shading method aspect, is indicated by an index into the data lists. This index is specified in the data mapping method's data record. For non-uniform B-