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Information technology — Coding of audio-visual objects —

Part 16: Animation Framework eXtension (AFX)

Technologies de l'information — Codage des objets audiovisuels —

Partie 16: Extension du cadre d'animation (AFX)

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Foreword

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The main task of the joint technical committee is to prepare International Standards. 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.

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ISO/IEC 14496-16 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 29, *Coding of audio, picture, multimedia and hypermedia information*.

This fourth edition cancels and replaces the third edition (ISO/IEC 14496-16:2009) which has been technically revised.

ISO/IEC 14496 consists of the following parts, under the general title *Information technology — Coding of audio-visual objects*:

— *Part 1: Systems*

— *Part 2: Visual*

— *Part 3: Audio*

— *Part 4: Conformance testing*

— *Part 5: Reference software*

— *Part 6: Delivery Multimedia Integration Framework (DMIF)*

— *Part 7: Optimized reference software for coding of audio-visual objects* [Technical Report]

— *Part 8: Carriage of ISO/IEC 14496 contents over IP networks*

— *Part 9: Reference hardware description*

— *Part 10: Advanced Video Coding*

— *Part 11: Scene description and application engine*

— *Part 12: ISO base media file format*

— *Part 13: Intellectual Property Management and Protection (IPMP) extensions*

— *Part 14: MP4 file format*

— *Part 15: Advanced Video Coding (AVC) file format*

— *Part 16: Animation Framework eXtension (AFX)*

— *Part 17: Streaming text format*

— *Part 18: Font compression and streaming*

— *Part 19: Synthesized texture stream*

— *Part 20: Lightweight Application Scene Representation (LASeR) and Simple Aggregation Format (SAF)*

— *Part 21: MPEG-J Graphics Framework eXtensions (GFX)*

— *Part 22: Open Font Format*

— *Part 23: Symbolic Music Representation*

— *Part 24: Audio and systems interaction* [Technical Report]

— *Part 25: 3D Graphics Compression Model*

— *Part 26: Audio conformance*

— *Part 27: 3D Graphics conformance*

Information technology — Coding of audio-visual objects —

Part 16:
Animation Framework eXtension (AFX)

1 Scope

This part of ISO/IEC 14496 specifies MPEG-4 Animation Framework eXtension (AFX) model for representing and encoding 3D graphics assets to be used standalone or integrated in interactive multimedia presentations (the latter when combined with other parts of MPEG-4). Within this model, MPEG-4 is extended with higher-level synthetic objects for geometry, texture, and animation as well as dedicated compressed representations.

AFX also specifies a backchannel for progressive streaming of view-dependent information.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 14496-1, *Information technology — Coding of audio-visual objects — Part 1: Systems*

ISO/IEC 14496-2, *Information technology — Coding of audio-visual objects — Part 2: Visual*

ISO/IEC 14496-11, *Information technology — Coding of audio-visual objects — Part 11: Scene description and application engine*

3 Symbols and abbreviated terms

List of symbols and abbreviated terms.

AFX	Animation Framework eXtension
BIFS	BInary Format for Scene
DIBR	Depth-Image Based Representation
ES	Elementary Stream
IBR	Image-Based Rendering
NDT	Node Data Type
OD	Object Descriptor
VRML	Virtual Reality Modelling Language
4C	4-bits-based Coding
AC	Arithmetic Coding
BPC	Bit Precision Coding

SVA	Shared Vertex Analysis
TFAN	Triangle FAN
QBCR	Quantization Based Compact Representation

The mathematical operators used to describe this part of ISO/IEC 14496 are similar to those used in the C programming language. However, integer divisions with truncation and rounding are specifically defined. Numbering and counting loops generally begin from zero.

Arithmetic operators:

+	Addition.
-	Subtraction (as a binary operator) or negation (as a unary operator).
++	Increment, i.e. *x*++ is equivalent to *x* = *x* + 1.
- -	Decrement, i.e. *x*-- is equivalent to *x* = *x* - 1.
$\left.\begin{matrix}\times\\ *\end{matrix}\right\}$	Multiplication.
^	Power.
/	Integer division with truncation of the result toward zero. For example, 7/4 and -7/-4 are truncated to 1 and -7/4 and 7/-4 are truncated to -1.
÷	Used to denote division in mathematical equations where no truncation or rounding is intended.
%	Modulus operator. Defined only for positive numbers.
Abs( )	$\mathrm{Abs}(x) = \begin{cases} x & x >= 0 \\ -x & x < 0 \end{cases}$.

Logical operators

||	Logical OR.
&&	Logical AND.
!	Logical NOT.

Relational operators

>	Greater than.
>=	Greater than or equal to.
≥	Greater than or equal to.
<	Less than.
<=	Less than or equal to.
≤	Less than or equal to.
==	Equal to.

!= Not equal to.

max [, … ,] the maximum value in the argument list.

min [, … ,] the minimum value in the argument list.

Bitwise operators

& AND.

| OR.

>> Shift right with sign extension.

<< Shift left with zero fill.

Assignment

= Assignment operator.

4 3D Graphics Primitives

4.1 Introduction

MPEG-4, ISO/IEC 14496, is a multimedia standard that enables composition of multiple audio-visual objects on a terminal. Audio and visual objects can come from *natural* sources (e.g. a microphone, a camera) or from *synthetic* ones (i.e. made by a computer); each source is called a *media* or a *stream*. On their terminals, users can display, play, and interact with MPEG-4 audio-visual contents, which can be downloaded previously or streamed from remote servers. Moreover, each object may be protected to ensure a user has the right credentials before downloading and displaying it.

Unlike natural audio and video objects, computer graphics objects are purely synthetic. Mixing computer graphics objects with traditional audio and video enables augmented reality applications, i.e. applications mixing natural and synthetic objects. Examples of such contents range from DVD menus, and TV's Electronic Programming Guides to medical and training applications, games, and so on.

Like other computer graphics specifications, MPEG-4 synthetic objects are organized in a *scene graph* based on VRML97 [1], which is a direct acyclic tree where *nodes* represent objects and branches their properties, called *fields*. As each object can receive and emit events, two branches can be connected by the means of a *route*, which propagates events from one field of one node to another field of another node. As any other MPEG-4 media, scenes may receive updates from a server that modify the topology of the scene graph.

The main objective of Animation Framework eXtension (AFX) is to propose compression scheme for static and animated 3D assets. This encoded version is encapsulated in an Elementary Stream, a similar approach as the one used by audio or video in MPEG-4. The AFX compression is closely connected to the definition of the graphics primitives in the scene graph. For such reason, AFX second objective is to update the scene graph when necessary and define new BIFS nodes for graphics primitives. However, AFX compression can also operate on other scene graph formalisms (as indicated in ISO/IEC 14496-25 a.k.a. MPEG-4 Part 25).

The place of AFX within the MPEG-4 terminal architecture is illustrated in Figure 1.

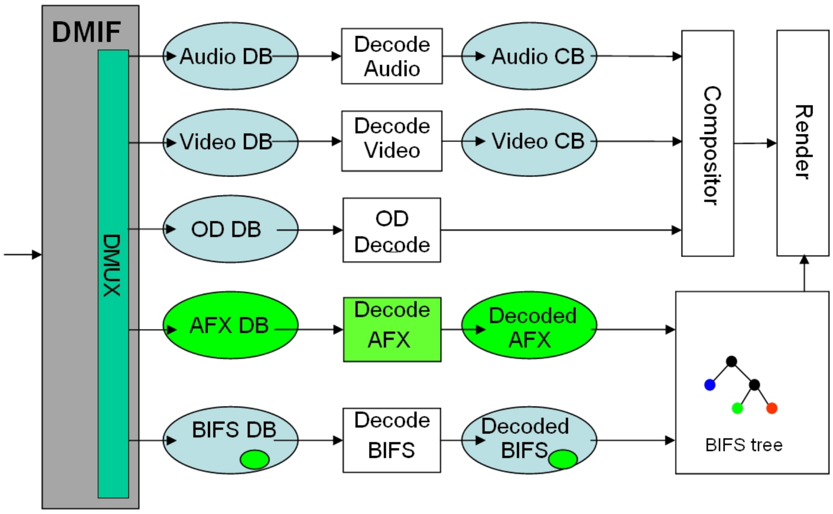

Figure 1 — Animation Framework eXtension (in green) and MPEG-4 Systems.

Figure 1 shows the position of AFX within MPEG-4 Terminal architecture. It extends the existing BIFS tree with new nodes and define the AFX streams that carry dedicated compressed object representations and a backchannel for view-dependent features.

4.2 The AFX place within computer animation framework

To understand the place of AFX within computer animation framework [35], let's take an example. Suppose one wants to build an avatar. The avatar consists of geometry elements that describe its legs, arms, head and so on. Simple geometric elements can be used and deformed to produce more physically realistic geometry. Then, skin, hair, cloths are added. These may be physic-based models attached to the geometry. Whenever the geometry is deformed, these models deform and thanks to their physics, they may produce wrinkles. Biomechanical models are used for motion, collision response, and so on. Finally, the avatar may exhibit special behaviors when it encounters objects in its world. It might also learn from experiences: for example, if it touches a hot surface and gets hurt, next time, it will avoid touching it. This hierarchy also works in a top to bottom manner: if it touches a hot surface, its behavior may be to retract its hand. Retracting its hand follows a biomechanical pattern. The speed of the movement is based on the physical property of its hand linked to the rest of its body, which in turn modify geometric properties that define the hand.

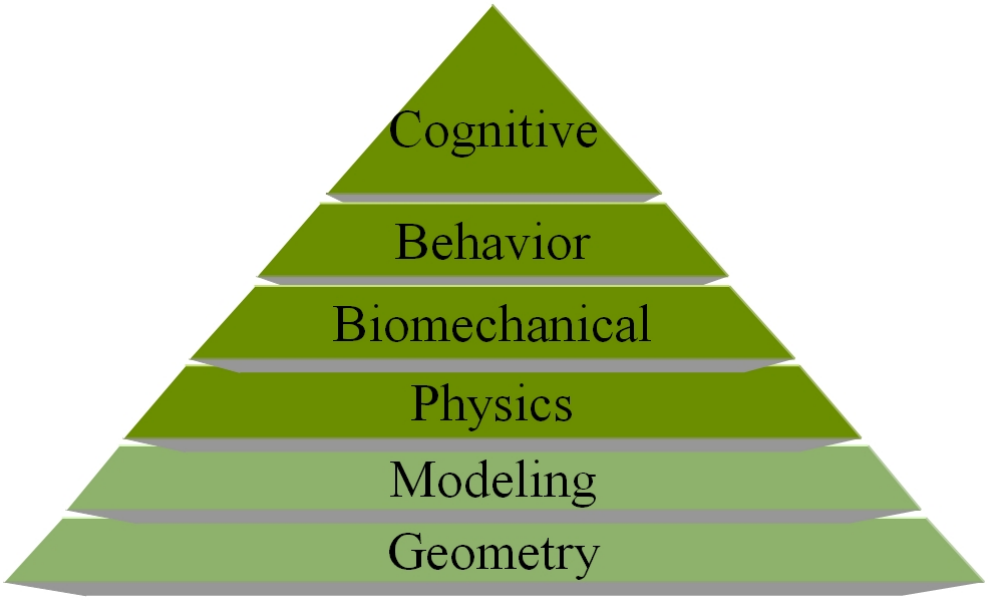

Figure 2 — Models in computer games and animation [35].

1) Geometric component. These models capture the form and appearance of an object. Many characters in animations and games can be quite efficiently controlled at this low-level. Due to the predictable nature of motion, building higher-level models for characters that are controlled at the geometric level is generally much simpler.

2) Modeling component. These models are an extension of geometric models and add linear and non-linear deformations to them. They capture transformation of the models without changing its original shape. Animations can be made on changing the deformation parameters independently of the geometric models.

3) Physical component. These models capture additional aspects of the world such as an object's mass inertia, and how it responds to forces such as gravity. The use of physical models allows many motions to be created automatically and with unparallel realism.

4) Biomechanical component. Real animals have muscles that they use to exert forces and torques on their own bodies. If we already have built physical models of characters, they can use virtual muscles to move themselves around. These models have their roots in control theory.

5) Behavioral component. A character may expose a reactive behavior when its behavior is solely based on its perception of the current situation (i.e. no memory of previous situations). Goal-directed behaviors can be used to define a cognitive character's goals. They can also be used to model flocking behaviors.

6) Cognitive component. If the character is able to learn from stimuli from the world, it may be able to adapt its behavior. These models are related to artificial intelligence techniques.

AFX specification currently deals with the first two categories. Models of the last two categories are typically application-specific and often designed programmatically. While the first four categories can be animated using existing tools such as interpolators, the last two categories have their own logic and cannot be animated the same way.

In each category, one can find many models for any applications: from simple models that require little processing power (low-level models) to more complex models (high-level models) that require more computations by the terminal. VRML [1] and BIFS specifications provide low-level models that belong to the Geometry and Modeling components.

Higher-level components can be defined as providing a compact representation of functionality in a more abstract manner. Typically, this abstraction leads to mathematical models that need few parameters. These models cannot be rendered directly by a graphic card: internally, they are converted to low-level primitives a graphic card can render.

Besides a more compact representation, this abstraction often provides other functionalities such as view-dependent subdivision, automatic level-of-details, smoother graphical representation, scalability across terminals, and progressive local refinements. For example, a subdivision surface can be subdivided based on the area viewed by the user. For animations, piecewise-linear interpolators require few computations but require lots of data in order to represent a curved path. Higher-level animation models represent animation using piecewise-spline interpolators with less values and provide more control over the animation path and timeline.

In the remaining of this document, this conceptual organization of tools is followed in the same spirit an author will create content: the geometry is first defined with or without solid modeling tools, then texture is added to it. Objects can be deformed and animated using modeling and animation tools. Behavioral and Cognitive models can be programmatically implemented using JavaScript or MPEG-J as defined in ISO/IEC 14496-11.

NOTE Some generic tools developed originally within the Animation Framework eXtension have been relocated in ISO/IEC 14496-11 along with other generic tools. This includes:

- Spline-based generic animation tools, called Animator nodes;
- Optimized interpolator compression tools;
- BitWrapper node that enables compressed representation of exisiting nodes;
- Procedural textures based on fractal plasma.

4.3 Geometry tools

4.3.1 Non-Uniform Rational B-Spline (NURBS)

4.3.1.1 Introduction

A Non-Uniform Rational B-Spline (NURBS) curve of degree $p > 0$ (and hence of order $p+1$) and control points $\{\mathbf{P}_i\}$ ($0 \le i \le n-1$; $n \ge p+1$) is mathematically defined as [34], [60], [85]:

$$\mathbf{C}(u) = \sum_{i=0}^{n-1} R_{i,p}(u)\mathbf{P}_i = \frac{\sum_{i=0}^{n-1} N_{i,p}(u) w_i \mathbf{P}_i}{\sum_{i=0}^{n-1} N_{i,p}(u) w_i}$$

The parameter $u \in [0, 1]$ allows to travel along the curve and $\{R_{i,p}\}$ are its rational basis functions. The latter can in turn be expressed in terms of some positive (and not all null) weights $\{w_i\}$, and $\{N_{i,p}\}$, the p^{th}-degree B-Spline basis functions defined on the possibly non-uniform, but always non-decreasing knot sequence/vector of length $m = n + p+1$: $U = \{u_0, u_1, \ldots, u_{m-1}\}$, where $0 \le u_i \le u_{i+1} \le 1 \ \forall \ 0 \le i \le m - 2$.

The B-Spline basis functions are defined recursively using the Cox de Boor formula:

$$N_{i,0}(u) = \begin{cases} 1 & \text{if } u_i \le u < u_{i+1}; \\ 0 & \text{otherwise;} \end{cases}$$

$$N_{i,p}(u) = \frac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1,p-1}(u).$$

If $u_i = u_{i+1} = \ldots = u_{i+k-1}$, it is said that u_i has multiplicity k. $\mathbf{C}(u)$ is infinitely differentiable inside knot spans, *i.e.*, for $u_i < u < u_{i+1}$, but only $p–k$ times differentiable at the parameter value corresponding to a knot of multiplicity k, so setting several consecutive knots to the same value u_j decreases the smoothness of the curve at u_j. In general, knots cannot have multiplicity greater than p, but the first and/or last knot of U can have multiplicity $p+1$, *i.e.*, $u_0 = \ldots = u_p = 0$ and/or $u_{m-p-1} = \ldots = u_{m-1} = 1$, which causes **C** to interpolate the corresponding endpoint(s) of the control polygon defined by $\{\mathbf{P}_i\}$, *i.e.*, $\mathbf{C}(0) = \mathbf{P}_0$ and/or $\mathbf{C}(1) = \mathbf{P}_{n-1}$. Therefore, a knot vector of the kind $U = \left\{ \underbrace{u_0 = 0, \ldots, 0}_{p+1}, u_{p+1}, \ldots, u_{m-p-2}, \underbrace{1, \ldots, 1 = u_{m-1}}_{p+1} \right\}$ causes the curve to be endpoint interpolating, *i.e.*, to interpolate both endpoints of its control polygon. Extreme knots, multiple or not, may enclose any non-decreasing subsequence of interior knots: $0 < u_i \leq u_{i+1} < 1$. An endpoint interpolating curve with no interior knots, *i.e.*, one with U consisting of $p+1$ zeroes followed by $p+1$ ones, with no other values in between, is a p^{th}-degree Bézier curve: *e.g.*, a cubic Bézier curve can be described with four control points (of which the first and last will lie on the curve) and a knot vector $U = \{0, 0, 0, 0, 1, 1, 1, 1\}$.

It is possible to represent all types of curves with NURBS and, in particular, all conic curves (including parabolas, hyperbolas, ellipses, etc.) can be represented using rational functions, unlike when using merely polynomial functions.

Other interesting properties of NURBS curves are the following:

- Affine invariance: rotations, translations, scalings, and shears can be applied to the curve by applying them to $\{\mathbf{P}_i\}$.
- Convex hull property: the curve lies within the convex hull defined by $\{\mathbf{P}_i\}$. The control polygon defined by $\{\mathbf{P}_i\}$ represents a piecewise approximation to the curve. As a general rule, the lower the degree, the closer the NURBS curve follows its control polygon.
- Local control: if the control point $\mathbf{P}_i$ is moved or the weight $\mathbf{w}_i$ is changed, only the portion of the curve swept when $u_i < u < u_{i+p+1}$ is affected by the change.
- NURBS surfaces are defined as tensor products of two NURBS curves, of possibly different degrees and/or numbers of control points:

$$\mathbf{C}(u,v) = \frac{\sum_{i=0}^{n-1}\sum_{j=0}^{l-1} N_{i,p}(u) N_{j,q}(v) w_{i,j} \mathbf{P}_{i,j}}{\sum_{i=0}^{n-1}\sum_{j=0}^{l-1} N_{i,p}(u) N_{j,q}(v) w_{i,j}}$$

The two independent parameters $u, v \in [0, 1]$ allow to travel across the surface. The B-Spline basis functions are defined as previously, and the resulting surface has the same interesting properties that NURBS curves have. Multiplicity of knots may be used to introduce sharp features (corners, creases, etc.) in an otherwise smooth surface, or to have it interpolate the perimeter of its control polyhedron.

4.3.1.2 NurbsCurve

4.3.1.2.1 Node interface

NurbsCurve { #%NDT=SFGeometryNode

eventIn	MFInt32	set_colorIndex		
exposedField	SFColorNode	color	NULL	
exposedField	MFVec4f	controlPoint	[ ]	
exposedField	SFInt32	tessellation	0	# [0, ∞)
field	MFInt32	colorIndex	[ ]	# [-1, ∞)
field	SFBool	colorPerVertex	TRUE	
field	MFFloat	knot	[ ]	
field	SFInt32	order	4	# [3, 34]

}

4.3.1.2.2 Functionality and semantics

The **NurbsCurve** node describes a 3D NURBS curve, which is displayed as a curved line, similarly to what is done with the **IndexedLineSet** primitive.

The **order** field defines the order of the NURBS curve, which is its degree plus one.

The **controlPoint** field defines a set of control points in a coordinate system where the weight is the last component. The number of control points must be greater than or equal to the order of the curve. All weight values must be greater than or equal to 0, and at least one weight must be strictly greater than 0. If the weight of a control point is increased above 1, that point is more closely approximated by the surface. However the surface is not changed if all weights are multiplied by a common factor.

The **knot** field defines the knot vector. The number of knots must be equal to the number of control points plus the order of the curve, and they must be ordered non-decreasingly. By setting consecutive knots to the same value, the degree of continuity of the curve at that parameter value is decreased. If *o* is the value of the field **order**, *o* consecutive knots with the same value at the beginning (resp. end) of the knot vector cause the curve to interpolate the first (resp. last) control point. Other than at its extremes, there may not be more than $o-1$ consecutive knots of equal value within the knot vector. If the length of the knot vector is 0, a default knot vector consisting of *o* 0's followed by *o* 1's, with no other values in between, will be used, and a Bézier curve of degree $o-1$ will be obtained. A closed curve may be specified by repeating the starting control point at the end and specifying a periodic knot vector.

The **tessellation** field gives hints to the curve tessellator as to the number of subdivision steps that must be used to approximate the curve with linear segments: for instance, if the value *t* of this field is greater than or equal to that of the **order** field, *t* can be interpreted as the absolute number of tesselation steps, whereas $t = 0$ lets the browser choose a suitable tessellation.

Fields **color**, **colorIndex**, **colorPerVertex**, and **set_colorIndex** have the same semantic as for **IndexedLineSet** applied to the control points.

4.3.1.3 NurbsCurve2D

4.3.1.3.1 Node interface

NurbsCurve2D { #%NDT=SFGeometryNode

eventIn	MFInt32	set_colorIndex		
exposedField	SFColorNode	color	NULL	
exposedField	MFVec3f	controlPoint	[ ]	
exposedField	SFInt32	tessellation	0	# [0, ∞)
field	MFInt32	colorIndex	[ ]	# [-1, ∞)
field	SFBool	colorPerVertex	TRUE	
field	MFFloat	knot	[ ]	# (-∞, ∞)
field	SFInt32	order	4	# [3, 34]

}

4.3.1.3.2 Functionality and semantics

The **NurbsCurve2D** is the 2D version of **NurbsCurve**; it follows the same semantic as **NurbsCurve** with 2D control points.

4.3.1.4 NurbsSurface

4.3.1.4.1 Node interface

NurbsSurface { #%NDT=SFGeometryNode

eventIn	MFInt32	set_colorIndex		
eventIn	MFInt32	set_texCoordIndex		
exposedField	SFColorNode	color	NULL	
exposedField	MFVec4f	controlPoint	[]	
exposedField	SFTextureCoordinateNode	texCoord	NULL	
exposedField	SFInt32	uTessellation	0	# [0, ∞)
exposedField	SFInt32	vTessellation	0	# [0 ,∞)
field	MFInt32	colorIndex	[] # [-1, ∞)	
field	SFBool	colorPerVertex	TRUE	
field	SFBool	solid	TRUE	
field	MFInt32	texCoordIndex	[]	# [-1 ,∞)
field	SFInt32	uDimension	4	# [3, 258]
field	MFFloat	uKnot	[]	# (-∞,∞)
field	SFInt32	uOrder	4	# [3, 34]
field	SFInt32	vDimension	4	# [3, 258]
field	MFFloat	vKnot	[]	# (-∞,∞)
field	SFInt32	vOrder	4	# [3, 34]

}

4.3.1.4.2 Functionality and semantics

The **NurbsSurface** Node describes a 3D NURBS surface. Similar 3D surface nodes are **ElevationGrid** and **IndexedFaceSet**. In particular, **NurbsSurface** extends the definition of **IndexedFaceSet**. If an implementation does not support **NurbsSurface**, it should still be able to display its control polygon as a set of (triangulated) quadrilaterals, which is the coarsest approximation of the NURBS surface.

The **uOrder** field defines the order of the surface in the *u* dimension, which is its degree in the *u* dimension plus one. Similarly, the **vOrder** field define the order of the surface in the *v* dimension.

The **uDimension** and **vDimension** fields define respectively the number of control points in the *u* and *v* dimensions, which must be greater than or equal to the respective orders of the curve.

The **controlPoint** field defines a set of control points in a coordinate system where the weight is the last component. These control points form an array of dimension **uDimension** x **vDimension**, in a similar way to the regular grid formed by the control points of an **ElevationGrid**, the difference being that, in the case of a **NurbsSurface**, the points need not be regularly spaced. The number of control points in each dimension must be greater than or equal to the corresponding order of the curve. Specifically, the three spatial coordinates (*x*, *y*, *z*) and weight (*w*) of control point $\mathbf{P}_{i,j}$ (NB: $0 \le i <$ **uDimension** $\ge$ **uOrder** and $0 \le j <$ **vDimension** $\ge$ **vOrder**) are obtained as follows:

```
P[i,j].x = controlPoint[i + j*uDimension].x
P[i,j].y = controlPoint[i + j*uDimension].y
P[i,j].z = controlPoint[i + j*uDimension].z
P[i,j].w = controlPoint[i + j*uDimension].w
```

All **weight** values must be greater than or equal to 0, and at least one weight must be strictly greater than 0. If the weight of a control point is increased above 1, that point is more closely approximated by the surface. However the surface is not changed if all weights are multiplied by a common factor.

The **uKnot** and **vKnot** fields define the knot vectors in the *u* and *v* dimensions respectively, and their semantics are analogous to that of the **knot** field of the **NurbsCurve** node.