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3D modelling functions and algorithms

ABSTRACT
3D modelling is process of creation of three dimensional object mathematical representations. Every 3D model represents information and data collection about points in 3D space which computer interpret like virtual object displayed on screen. This article present analyse of 3D modelling program tools. Based on 3D modelling tools comparation some functions that are usually used can be identified. Function can be seen from two aspects: customer and programmer/designer aspects. For each aspect there are some basic function groups. From customer aspect function groups are identified based on method for 3D model creation. Programmer/designer aspect describes algorithms that are used to perform specific function group. These algorithms are used in various program tools to practice identical or similar functions.
Keywords: 3D modelling; 3D program tools; 3D modelling methods, functions and algorithms

1. INTRODUCTION

The process of designing real or imaginary three-dimensional (3D) objects is referred to as 3D modelling. The development of information technology enables the user to select from among various methods and techniques in order to achieve optimal efficiency. Selection options include classical 3D modelling, procedural 3D modelling and 3D modelling aided by specialized hardware and software solutions. Using 3D modelling techniques a user can create a 3D model by using polygons or NURBS curves. Yet another possibility is a hybrid solution between the two techniques, known as subdivision modelling. Although the technique itself does not determine the quality of the final product, it can considerably affect the time needed to create a 3D model. Each of the aforementioned techniques includes a great number of algorithms that range from those enabling the user to design and manipulate basic primitives to the ones used for creating complex geometric bodies. The number of algorithms and functions per single modelling technique exceeds twenty options that users can select from during their work. This is enabled by 3D tools complexity and variety of their capabilities.

By comparing some of the most widely used 3D modelling programmes it can be revealed that there is a certain group of functions and algorithms that come under different names, but represent the same logic behind the user level. Each function of a certain modelling technique has its user and programming part. The user part describes and shows the current result of modelling on the display. In this part the user does not think about the underlying processes and is focused on the modelling skill itself in order to design an elaborate 3D model. The programming part of each function is the one carried out beneath the user level and comprises mathematical laws and principles. It consists of an array of algorithms which enable real time manipulation of 3D models. It is not possible to access or modify algorithms outside of the predefined basic parameters through the user interface. In general, each specialized 3D modelling tool supports a programming language (or a specialized language) that can be used to develop an original procedure or algorithm.

A comparative overview of some of the most widely used 3D tools shows the functions and algorithms that the user most often encounters. Variations in their names arise from a lack of standardized approach to 3D modelling. The programming part of these functions is based on the same foundations, which allows for their comparison, analysis and description. A few selected functions are described in detail from the perspective of both levels of usage to enable insight into the creative and programming aspects executed during every instance of 3D model manipulation.

2. RESEARCH METHODOLOGY AND FINDINGS

The research described in this paper concerning the knowledge and usage of 3D programming tools was conducted in tertiary level educational institutions in the Varaždin County. An anonymous survey was conducted among 200 students enrolled in the second and third year of undergraduate studies. The questionnaire consisted of the following questions:

1. Have you used a 3G programming tool over the last two years? If so, which one?
2. How would you describe your knowledge of the 3D tools mentioned above?
   1- very poor, 5 – very good
   1 2 3 4 5
3. Do you consider yourself to be a person who would relatively quickly master the basics of a new 3D programme?
   1- I hardly agree, 5 – I completely agree
   1 2 3 4 5
4. How good is your perception of 3D space?
   1- very poor, 5 – very good
   1 2 3 4 5
5. Did you have an opportunity to analyze objects in terms of the object’s drawing, ground plan and body plan?
6. Would you be able to show a simple 3D object in 2D space (on paper) as a UV map?
7. Do you consider yourself a creative person?
   1- I hardly agree, 5 – I completely agree
   1 2 3 4 5
8. Are you capable of transforming your idea into a 2D image?
9. Are you capable of transforming your idea into a 3D model?
10. Which 3D modelling tools do you use?
11. Explain the term 'polygon' using your own words.
12. Explain the term 'particle' using your own words.
13. Explain the term 'rendering' using your own words.
14. Explain the term 'NURBS' using your own words.
15. What level of knowledge would you like to achieve?
   1- basic, 5 – advanced
   1 2 3 4 5

The analysis of survey results shows that 43 respondents are not capable of analyzing objects in terms of the object's drawing, ground plan and body plan. Furthermore, 35 respondents do not consider themselves to be creative and are not capable of representing their idea as a 3D model or an image. The remaining 122 students have demonstrated a considerably higher motivation for learning and understanding of the logic of 3D expression. Substantial knowledge of 3D modelling and animation was the requirement in the second part of the research, so 49 students provided their answers to all the questions.

The research has shown that students are familiar with six 3D modelling tools: Maya, Solidworks, AutoCad, 3DsMax, Blender and SketchUp. Whereas 12 respondents had independently examined a 3D tool in their free time, only 3 respondents had participated in competitions or projects related to 3D modelling. Based on the research results a table has been designed in which a comparative overview of 3D modelling tools is provided at the programming functions level (Table 1). The key criteria used are availability of tools, their capabilities and the demand for such tools in practice.

Autodesk Maya	**Autodesk 3D Studio Max**	**NewTek LightWave**	**Autodesk AutoCAD**
Combine / Separate	Combine / Separate	Combine / Separate	Combine / Explode
Booleans	**Booleans**	**Booleans**	**Booleans**
Extrude	**Extrude**	**Extrude**	**Extrude**
Create polygon	**Make polygon**	**Make polygon**	**Polyline**
Split polygon	**Slice tool**	**BandSaw / Knife tool**	**Split Face**
Cut Face	**Cutting**	**Drill tool**	**Split Face**
Edge loop	**Edge loop**	**Edge loop**	**Flow Connect**
Attach / Detach curve	**Attach / Detach curve**	**Attach / Detach curve**	**Fit Curve tool**
Open / Close curve	**Open / Close curve**	**Open / Close curve**	**Open / Close polylines**
Revolve	**Lathe**	**Rotate (Master Pitch – Null)**	**Revolve**
Loft	**Loft**	Rail Extrude	**Loft**
Planar	**Make Planar**	**–**	**Planar Surface**
Convert	Convert To	Convert	Conversion
Bevel	Bevel	Edge / Surface Bevel	Bevel
Soft Modification	Soft Selection	Modify tool	Modification tool
Smooth	Turbo Smooth	Smooth Shift	Smooth tool
Edit Mesh / Normals / Polygon	Edit Mesh / Normals / Polygon	Sketch	Edit Polyline
Make / Fill Holes	Cap Holes	SubPatches	Vector tool (HPattern util.)
Cleanup	**Cleanup tool**	**Mesh Cleanup**	**Drawing Cleanup**
Wedge face	Wedge	**–**	Wedge
Sculpt Geometry	Skin Morph / Wrap	Spline Guide tool	Sculpt
Merge	Shape Merge	Merge	Merge
Bridge	Bridge	Bridge tool	Bridge
Extend	HSDS Modifier	Extend	Extend
Mirror	Mirror	Mirror tool	Mirror
Trim tool	Trim Modifier	**–**	Trim Edges / Convert

Table 1. Comparative overview of functions of the most widely used CAD programmes

3. ANALYSIS OF SELECTED FUNCTIONS

3.1. Polygonal modelling displays models by means of an array of polygonal surfaces. The key component is the vertex of 3D space. Two connected vertices constitute an edge, while three vertices generate a triangle, which is also the simplest polygon. Each polygon has a direction vector, or a normal, which determines the orientation of a polygon face. Three- and four-sided polygons, i.e. tris and quads, are the most common elements of polygonal modelling. A group of polygons linked by common vertices is called a mesh. Apart from the basic constituents, a mesh contains its own geometry which can easily identify errors occurring during modelling. The 3D modelling process can be approached through several sets of general-purpose or specialized algorithms or functions. The advantages and disadvantages of polygonal modelling are related to the ease of model creation, computer resources needed, and the appearance of the final model.

Booleans

Booelan functions are used in polygonal objects with intersecting surfaces. The result of performing Boolean functions is a polygonal object with a new geometry based on the geometry of its constituent objects. Boolean functions represent an intuitive modelling procedure by using 3D models of various shapes for creating a new one. As a rule, the following three Boolean functions are used: Union, Difference and Intersection.

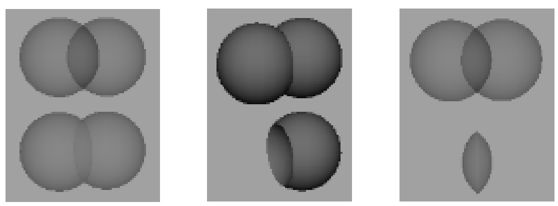

Figure 1. Union, Difference and Intersection operations

The Union operation connects polygonal objects into a new one by erasing overlapping surfaces. The Difference function creates a new geometry by subtracting the overlapping surface of one object from another. The Intersection function creates a new geometry exclusively by using intersecting surfaces between objects.

Extrude

The Extrude function enables the creation of new polygonal components using the existing ones. By executing the Extrude function on the elements of a polygon (e.g. face, edge or vertex), it is possible to create additional elements and thus design a new geometry in the process of modelling. During the translation of polygonal components the user changes the position of polygons in space. By executing the Extrude function on a polygon and its translation in space new polygons (or polygonal components) are created that surround the initial polygon.

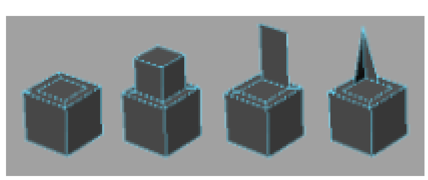

Figure 2. Extrude function executed on the face, edge and vertex of a polygon

Polygonal extrusion can be described by a display of inputs and outputs. The input is represented by a polygon and the path along which the polygon is translated in space. The output represents a set of polygons that define the volume created by translating the original polygon in space. One of possible implementations of the Polygonal extrusion function is by means of Voronoi diagrams. This assumption is based on the existence of a polygonal chain that represents the path of the translated polygon under the implemented Extrusion function. In Figure 3 the Voronoi diagram of a polygonal chain divides the space of the chain into separate regions.

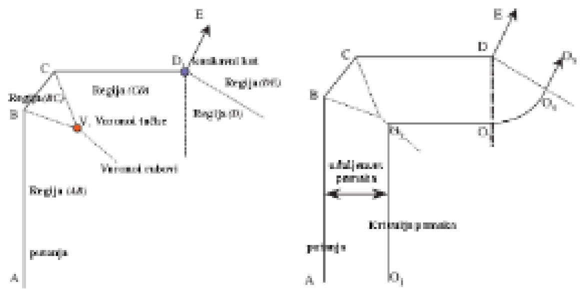

Figure 3. Programming level of the Extrude function

Each region is the closest to the element of the chain that defines it. For instance, the element closest to region vertices (*A*, *B*) is the line segment *AB*. The concave angle *D* has its own region *D*, since concave angles of the chain are interpreted as circular arches with a null radius. As a rule, a common boundary between two regions is called a Voronoi edge or a bisector. A vertex on a Voronoi edge exists if, and only if, the defining elements of regions are equidistant from the vertex.

Create polygon

The Create polygon function enables the user to create a polygon by manually placing constituent vertices in space. Create polygon most commonly represents the first step in the process of modelling an object based on a two-dimensional image. As a rule, this function is performed in the orthographic view of the scene and results in creating filled polygons consisting of an arbitrary number of vertices.

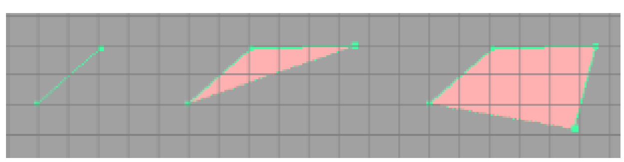

Figure 4. Create polygon function in the orthographic view of the scene

The aim of the Create polygon function is creating an array of user-defined vertices in space. Upon determining the array of vertices it is necessary to execute the procedure of filling the space between the vertices. The Create polygon function has thus been devised to include the following six steps ranging from determining initial vertices to filling the blank space between them: 1. Determining the existing connections between polygon peaks; 2. Initializing a global edges table; 3. Parity initializing; 4. Scan-line initializing; 5. Initializing an active edges table; 6. Polygon filling.

Split polygon/Cut faces

The Split polygon function enables the user to divide a polygon face into several parts. By arbitrarily placing vertices onto a face, the function creates edges by means of which the existing polygon is split. The Cut faces function also divides a polygon into several parts. In case of this function, however, a user-defined lined in space is used.

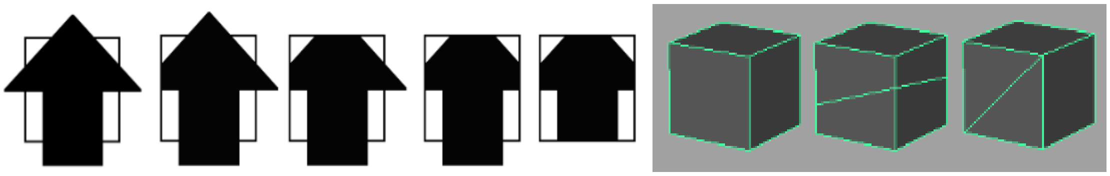

Figure5. Sutherland-Hodgman algorithm and procedure of performing Cut faces and Split polygon functions

The Sutherland-Hodgman algorithm is frequently executed in dividing or cutting polygons in 2D space. The algorithm is based on cutting polygons by using the edges of infinite length. It accepts a sorted array of vertices (v_1, v_2, v_3,...,v_n) as input and provides an array of vertices that define a cut-out polygon as output. Figure 5 shows the steps in the process of polygon cutting by executing the Sutherland-Hodgman algorithm.

Edge loop

The Edge loop function enables the insertion of an array of edges over the existing edge ring of a polygonal object. The edge ring represents a path of polygonal edges connected into an array through common polygon faces. The edge loop represents a path of polygonal edges connected into an array through common vertices. By performing the Edge loop function a division of polygon faces that share a common edge ring occurs. As a rule, this function is used for adding details to a great number of polygons simultaneously.

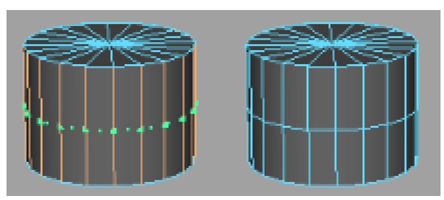

Figure 6. Performing the Edge loop function

Advantages and disadvantages of polygonal modelling

One of the major issues concerning polygons is their inability to faithfully display curved surfaces. The processing speed is slow, especially in case of the scan-line rendering method, where each polygon needs to be converted to a primitive. Furthermore, in absence of a hierarchy, large-scene manipulation is practically impossible owing to computer resource consumption. On the other hand, one of the advantages of polygons is the ability to merge several models into a single whole. The model thus created is not disintegrated during deformation. Moreover, in conventional rendering methods fewer resources are required. Finally, they enable simple modelling of orthogonal models, mechanical objects, etc.

3.2. NURBS (Non-Uniformal Rational Bézier Splines) is a mathematical expression that displays 3D models by means of curves and surfaces. The result of such a display is a smooth surface with smooth edges regardless of the display resolution. The NURBS geometry is based on the Bézier curve which is drawn by the programme between control vertices (CVs). Each curve has its beginning, ending and curvature. The curvature depends on the control vertices within the curve. A NURBS surface is defined by the curve and control vertices called isoparms. The surface created between isoparms consists of spans which follow surface curvature. The NURBS approach to modelling is possible by using basic curve-oriented functions, algorithms by means of which a surface is generated between curves or methods and techniques for manipulating the generated surfaces. The advantages and disadvantages of NURBS modelling are related to model appearance, the ease of modelling and transformation of NURBS into an alternative modelling method. The most common field of NURBS application is organic 3D modelling. Modelling by using NURBS function is determined by Bézier curves and the surfaces between them. The most commonly used functions in CAD tools are: Attach Curves, Open/Close Curves, Revolve, Loft and Planar.

Attach Curves is the function by which two separate curves are merged into a single new curve. In the process, the beginning of the second curve is connected to the ending of the first. The angle between them is approximated depending on their position and distance. The original position of the curves is recorded. As long as the information on previous states of the new curves is available, the original curves can affect the shape and appearance of the newly created curves. By erasing the information on states it is possible to eliminate two separate curves, so that only one connected curve is left on which work can be continued.

Open/Close Curves is the function by which one curve is closed into a certain shape. In the process, the initial and the final vertex of the curve are connected into a single vertex. In this way anomalies that can arise during NURBS geometry manipulation owing to the openness of the curve are avoided. Opening the curve refers to a reverse process implemented when new elements need to be added to the existing curve. Owing to the request for further manipulation, the closing of the curve definitely occurs as the final step.

Revolve is the function that generates the surface around the barycentre of a curve. The surface shape is determined by the curve itself, whereas the surface direction is defined by one of the three-dimensional axes X, Y or Z. The surface is connected to the curve as long as the information on past states has not been deleted, which means that any modification of the curve directly affects the surface appearance. Once the information has been removed, the curve can be deformed or erased without any effect upon the newly created surface.

Loft is the function which requires two closed curves for surface creation. The surface direction and appearance are determined by the shape and size of curves in space. The result of this function is not necessarily only a surface, but also a polygonal model created in any modelling technique (*Tris*, *Quad*).

The **Planar** function generates a surface within a single curve, which does not have to be closed. The key requirement is that the curves lie in the same plane. The result is the filling of curve space. The newly generated surface disappears if any curve or vertex of a curve is removed outside the defined plane. Manipulation and continuation of work on the surface is possible only after the information connecting the curves and the surface has been removed.

Advantages and disadvantages of NURBS modelling

NURBS modelling is based on interpolation of curves, which enables it to much more easily obtain smooth surfaces and deformations by using only a few control vertices. Their behaviour resembles that of vectors in 2D computer graphics, which do not depend only on the surface detail level. They make texturing easier owing to their two-dimensional UV coordinate system. NURBS can easily be converted into any other modelling method. However, work and manipulation in this type of modelling is based on vertices and curves, which can complicate the perception of a 3D model. One of its major disadvantages is the inability to easily connect several NURBS models into a single whole. As a result, geometry disintegration can occur during animation. Problems can also arise during work on large textured scenes.

4. CONCLUSION

The computer graphics development trend has been faturing an increasingly more frequent application of 3D models of real or imaginary objects. Due to a dynamic informatics and computer graphics market lots of alternative 3D modelling tools are developed. As a result, users can select an optimal tool that meets the required criteria.

The recognizability of this field is implied in a fact concerning some of the world's major industries, including film and computer games industries. Namely, almost any product created by them contains a 3D model, thus reducing the costs and expanding the capabilities of displaying new yet unseen features. Considering the situation in the global market, it is essential to ensure quality education for creative young individuals. In that respect, promoting 3D modelling tools and introducing users to relevant current literature represent the foundations that education rests upon. The survey conducted among 200 students reveals that the Varaždin region has acknowledged the future direction of computer graphics development. Students are familiar with several 3D modelling tools and have demonstrated great interest for expanding their knowledge and skills in that area. Considering the large number of 3D modelling programmes, the research focuses on the features present in the most frequently used 3D tools. The table provided in this paper comprises the functions of particular tools that are further explained through the user and programming level. Although an average user does not necessarily require the knowledge of the programming level, in order to grasp the complexity of the issue, basic methods and algorithms are described that are implemented within some of the most commonly used 3D modelling functions.

5. LITERATURE:

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