Superformula solutions for 3D Graphic Arts and CAD/CAM

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1 Introduction

Implicit functions based on one single equation can provide different solutions for problems in computer graphics and CAD. This particularly interesting and entirely unique equation called the Superformula, a generalization of superellipses and supercircles, with a stunning representation of natural geometries in plants and living things [1] and with potential for computer graphics [2] (see also www.genicap.com). Here we describe our current research, to show how the Superformula can be used advantageously for CAD. Description of a wide variety of shapes using a single formula allows for extremely compact file sizes. This will allow CAD applications and cooperative work on all platforms, including wireless application.

2 3D shapes

There are a variety of ways to extend the SF into 3-D, for example in spherical coordinates as implicit function [2]. Another approach is based on the parametric formulation of a sphere, defining two supershapes perpendicular to each other, one as f(□), the other as f(□). Superformula distances are applied directly on two perpendicular sections:

x = SF1(□) cos □ SF2(□) cos (□)

y = SF1(□) sin □ SF2(□) cos (□)

z = SF2(□) sin (□) Equation 1

In comparison with the sphere, superquadrics and superellipsoids various symmetries are possible in different dimensions. In three dimensions non-integer symmetries generate self-intersecting shapes that do not close in one rotation. Eq. 1 can define a variety of 3-D shapes, many of which are well-known primitives, including the well-known extrusions and revolve operations. In addition, knots, helices and spirals can easily be made as well within the same equation. Because of their very nature, not only the outer boundaries of the shapes are defined, but any point on, inside and outside the shape is defined as well.

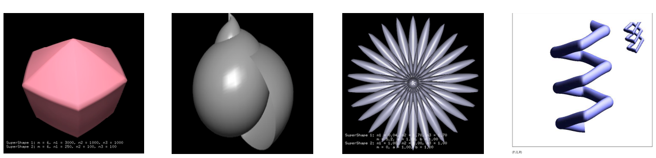

Figure 1: Supershapes in 3-D Shells, spirals and helices with path and cross section defined by the Superformula

Equation 1 can be formulated alternatively as operation SF1 SF2, the product of object and path. This operation can for example be square square = cube, circle circle = sphere, circle rectangle = cylinder, or circle big circle = torus, ensuring simple transformations among any of these shapes. This provides a straightforward expression for 3D shapes. This allows one to develop a simple interface to draw 3D shapes, based on two perpendicular sections. These shapes can be combined in a meaningful way, as is common in high end CAD/CAM modelers. With Boolean operations and an intelligent objects-parts-assembly structure a lot of functionality can be implemented.

3. Results: Extremely compact files

Based on the 3D Superformula objects [2], a Supergraphx Shape Explorer was developed in which the two perpendicular sections can be modified, with Z-axis movements (www.genicap.com). By changing the mathematical parameters of the Superformula, the 3D artist and designer can explore the universe of mathematical objects defined by Superformula equations (Figure 1). This shape explorer was integrated in a modeler with full parts-assembly structure with definition of Boolean structure.

Using the shape generator, very complex shapes can be constructed (see Figure 1 and body and wings of race car in Figure 2). Nevertheless, all shapes derive from one Equation and differ in less than 20 bytes at most. Therefore it is possible to fully encode complex shapes in extremely small files.

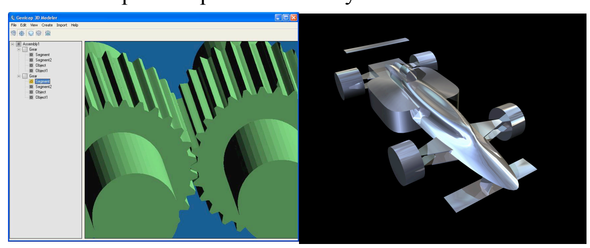

Figure 2: CAD/CAM modeler with shape, positional, parts-assembly and Boolean information for gear (195 bytes) and a racecar (0,9 kb). See http://users.skynet.be/bert.beirinckx.

4. Future research and applications

The current modeler is in a prototype stage, but its potential has been proven. It is an easy-to-use modeler and even complex surfaces and objects can be made. File sizes of a toy racecar is less than the file size of an icon on a desktop.

We plan to introduce this technology into existing CAD packages, and also to introduce full 3+D functionality directly onto widely used platforms such as Microsoft Office. The variety of shapes can satisfy both engineer and designer. In addition, Supergraphx technology with fully asymmetrical and controllable deformation will be built in as well and further enhanced with parametric information.

Research also exploits the advantages of the analytical expression, since any numerical calculation can be made on the shape directly. In cooperation with Prof. V. Shapiro (Spatial Automation Lab, U. Wisconsin) we are further exploiting mesh-free modeling to calculate any differential equation directly on the shape.

[1] Gielis J. (2003) *American Journal of Botany* 90(3) 333-338.

[2] Gielis, Bastiaens, Beirinckx (2003) Proc. of 8th ACM Solid Modeling and Applications 03, Seattle, June 16-20, 262-265.