

# A PROCEDURAL GEOMETRY MODELING API

Pedro Brandão Silva<sup>1</sup>, António Coelho<sup>1,2</sup>, Rui Rodrigues<sup>1</sup> and A. Augusto Sousa<sup>1,2</sup>

<sup>1</sup> INESC Porto, Departamento de Engenharia Informática, Faculdade de Engenharia, Universidade do Porto,  
Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

<sup>2</sup> 3Decide / Palcos da Realidade, Pólo de Industrias Criativas, Praça Coronel Pacheco, 2, 4050-453 Porto, Portugal

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**Abstract:** This paper presents a solution for geometric manipulation in procedural modeling as an Application Programming Interface (API). This approach intends to enable a more powerful control over the geometric entities by performing selections based on their attributes, similar to picking features in graphical interfaces. This is achieved through the definition of a topological structure, which features a set of properties, such as scope, spatial localization and semantic information. The applicable modeling operations allow a more customized control, as well as successive tracking, which induce a greater, faster and more intuitive approach for geometry generation. This approach still constitutes ongoing work, but has already been successfully applied for the generation of large virtual urban environments.

## 1 INTRODUCTION

An API - Application Programming Interface – provides an abstraction to a problem, specifying how to interact with the software components that implement that same problem. These are typically distributed through software code libraries, allowing its use by multiple applications. In short, APIs, define reusable code blocks that allow certain feature sets to be incorporated into final applications (Reddy, 2011).

In the area of geometric modeling, many APIs have already been conceived and are currently employed in some of the most popular tridimensional authoring tools, such as AutoCAD or Solid Works, used in various areas of engineering, architecture and media production, among others. Using visual interfaces for interaction, users are able to perceive the whole extent of their work while, at the same time, being able to navigate deep into the details of the created geometries for custom manipulation. When an operation is meant to be applied to a specific group of geometric elements (vertex, edge, face...), the user just needs to select them with its pointing device (an action commonly known as “picking”). While this sort of interaction is ideal and possible for individual and manual creation of tridimensional models, it is not compatible with the procedural paradigm of content generation.

The use of procedural methods for generating three-dimensional content is becoming more frequent and has been delivering very interesting results at a lesser effort cost, by generating three-dimensional models with much less human interaction.

Procedural methods require that the user, capturing the knowledge about the modeling process, introduces some guidelines and rules. It is also possible to start from existing shapes or general information from existing data sources. In this sense, some methods have already been conceived, but as far as control is concerned, procedural ways still lack powerful picking and manipulation facilities to apply geometric operations. This motivates the development of more advanced methodologies for such control.

The paper presents the PGCAD API, a solution for geometric manipulation in procedural modeling tools. It enables a more powerful control over geometric entities based on their properties and sequential application of modeling operations, therefore allowing a greater, faster and more intuitive approach for geometry generation.

This paper is structured as follows: first, some related work will be presented, followed by the description of PGCAD API, where its architecture and features will be detailed, but not without explaining some important concepts first. Some information regarding the implementation will come

next, followed by the results section, which includes its discussion. Lastly, the conclusions and some future work will be described.

## 2 RELATED WORK

This subject fits into the area of Geometry Modeling Kernels on the one hand, as well as Procedural Modeling on the other hand, and both already possess an average number of interesting solutions by various researchers and companies.

The 3D ACIS Modeler (Spatial Corporation, 2011) is a commercial modeling component developed by Spatial Corporation. Among other features, the creators highlight their advanced surface and solid modeling capabilities, as well as their simple, flexible and interactive interface.

Parasolid is a commercially licensed geometric modeling kernel now proprietary of Siemens PLM Software (Siemens PLM Software, 2010). It advertises many surface manipulation tools, Boolean operators, extrusion, embossing, patterning, lofting, sweeping, thickening, hollowing and many other modeling operations.

Open Cascade (OPEN CASCADE S.A.S., 2011) is a powerful CAD component developed by Open CASCADE S.A.S., and consists in free open source C++ libraries. Among other features, their topological structure is stressed, along with the various modeling operations, primitive instantiation and rendering capabilities.

SMLib (Solid Modeling Solutions Inc., 2011) is another geometry modeling kernel, developed by Solid Modeling Solution Inc., based in NURBS curves and surfaces combined with a topological non-manifold structure. The company emphasizes the choice over a Boundary representation which induced the possibility to model any tridimensional model, and with high efficiency.

IRIT (Elber, 2009) is a solid geometry modeling environment that allows 3D modeling based on primitives and Boolean operations to connect them (CSG – Constructive Solid Geometry). Its original creator, Gershon Elber, stresses also its simultaneous potential for freeform curve and surface manipulation tools.

Although the mentioned list of tools is not, by any means, extensive, it contains an overview on the most popular geometry modeling tools, enumerating some of the its most interesting and powerful features any modeler should possess. However, as said, the paradigm is not procedurally-oriented.

On the other hand, concerning the area of

procedural modeling, there is also a considerable amount of work.

L-Systems (an acronym for Lindenmayer Systems) are amongst the most popular approach for procedural generation in computer graphics, having been initially employed, by Aristid Lindenmayer in the simulation of plant and organism growth (Prusinkiewicz & Lindenmayer, 1996). The behavior of the development sequence of an L-System can be parameterized and configured, allowing the control over the modeling processes. Parish and Müller employed the same methodology to generate extensive street networks (Parish & Müller, 2001). Geospatial L-Systems (Coelho, Bessa, Sousa, & Ferreira, 2007) are an extension of parametric L-Systems which incorporates spatial awareness. This approach combines the ability of data amplification provided by the L-Systems with the geospatial awareness of geospatial systems.

Wonka et al. introduced the split grammars (Wonka, Wimmer, Sillion, & Ribarsky, 2003), a new type of parametric set grammar based on the concept of shape brought up by Stiny and Gips (Stiny, 1980; Stiny & Gips, 1972), also with applications in the field of modeling architectural buildings. He also presented an attribute matching system oriented by a control grammar, offering the flexibility required to model buildings with many different styles and designs. Based on this work, Müller et al. developed the CGA Shape (Müller, Wonka, Haegler, Ulmer, & Gool, 2006), a shape grammar capable of producing extensive architectural models with high detail. The CGA Shape is a sequential grammar (such as the Chomsky Grammar (Chomsky, 1956)), therefore all the production rules are applied in sequence, in order to allow the characterization of the structure. The implementation of the CGA Shape is integrated in the CityEngine framework (Procedural Inc., 2009). Considering that text-based shape definitions were impractical to use by most artists, Lipp presented in (Lipp, Wonka, & Wimmer, 2008) a visual editing system which introduced traditional modeling techniques, allowing a more intuitive and powerful control over each grammar aspect.

## 3 THE PGCAD API

PGCAD is a geometric modeling kernel oriented for procedural modeling. Its name stands for Procedural Generation Computer-Aided Design and aims at providing a more powerful control over the development of procedural modeling processes, by

allowing actions and operations to be executed based on each element properties and previously applied operations. This is only possible due to the object-oriented nature of all PGCAD-involved elements.

Before the overall features can be explained, it is necessary for some architecture basics to be presented.

### 3.1 Topology

PGCAD topological structure is based on a polygon mesh representation, having been inspired by Open CASCADE (OPEN CASCADE S.A.S., 2011) and OGC's *Simple Features* (Open Geospatial Consortium Inc., 2006) specification. The conceived modeling kernel has therefore the following basic geometric elements:

**Shape:** The basic, not instantiable, abstract element, from which all the remaining ones inherit from, sharing therefore some common attributes.

**Vertex:** A single point in 3D space owning, in its simplest form, a reference to its position.

**Edge:** A line connecting two vertices. By definition, an edge does not possess an orientation.

**Wire:** A set of connected and sequential edges, joined by common vertices.

**Face:** A planar polygon, having its external boundary defined by a closed, non self-intersecting wire, and a set of internal holes, also defined as by wires with the same requirements.

**Shell:** A set of faces connected by their edges or wires.

**Solid:** A closed shell of planar faces, therefore a polyhedron.

**Compound:** An element which groups sets of shapes, including other compounds.

### 3.2 Shape Properties

Besides the geometrical component, the concept of shape in PGCAD relies on four fundamental aspects: scoping, materials, spatial localization and semantics.

The purpose of scope is to store information concerning the orientation and size of the shape, a concept similar to the one found in the CGA Shape (Müller, et al., 2006). In short, each shape has a reference for its coordinate system, in order to facilitate operations internal to the structure of the shape (for example, texture mapping). According to the type of shape, the scope format may vary, but is in most cases defined by a point of origin and 3 sized axes, which can indicate also the dimension of a line, bounding rectangle or bounding box,

depending on the type of shape (see Figure 1).

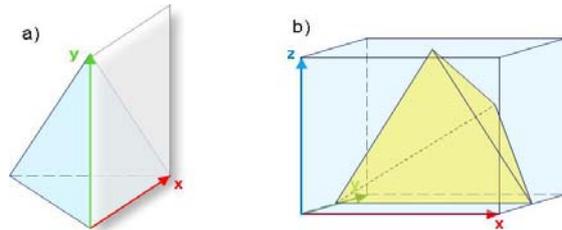


Figure 1: Shape scoping in PGCAD, exemplified for faces (a) and solids (b). Note that on (a) the z-axis vector is not displayed, since it is of zero size.

Spatial localization in PGCAD is essential in order to achieve spatial awareness features. This concept consists in allowing shapes to be aware of their surrounding elements, a fact that might be important when operating on the shape. Supposing that one's goal is to connect a vertex with all its neighboring ones within a certain distance, such operation could use spatial awareness to avoid the need to indicate each one of the items to connect to.

Another, not exactly related, property of shapes is its material. Each can possess certain lighting and rendering options, such as color, light reflectance (ambient, diffuse, specular), shininess, texture, etc., which can be afterwards be interpreted by the renderer to visualize the shapes.

Finally, and perhaps the most important characteristic of shapes is the possibility to continuously store semantic information. Each shape has a container of "Labels", each being able to hold a set of key-value pairs related to its meaning, location, applied operations or any other fact. Labeling can be done at any time, being especially useful to keep track of a model's evolution process. In the end, by having additional semantics, the integration of the generated geometry with more interactive applications could be done more easily.

### 3.3 Shape Properties

The development of shapes can be done in two ways. One strategy is to manually create complex shapes by joining more basic shapes through their direct references. For instance, starting with a list of vertices:

$$L1 = [\text{Vertex}(0,0,0), \text{Vertex}(0,5,0), \text{Vertex}(5,0,0)] \quad (1)$$

One can transform it into a wire:

$$W1 = \text{Wire}(L1) \quad (2)$$

And afterwards into a face:

$$F1 = \text{Face}(W1) \quad (3)$$

and so on, always using direct references to the shapes. In theory, it is possible to build very complex models using this approach. However, although this is essential for the first steps and usable as long as there are a reduced number of shapes, it is not effective when masses of shapes are considered.

A second methodology, supported by PGCAD, is to use modeling operations, similar to what can be found in any geometry modeling API. PGCAD, however, features two major differences in how operations can be applied:

1. Operations can be applied to entire sets of shapes, which follow a specific condition;
2. Operations can be applied to entire sets of shapes, where the parameters can be based on each shape's properties.

Modeling operations are objects, which can be instantiated as such. This allows a greater set of parameters to be added, without the need to define multiple object constructors.

To better explain the concept of operation, an example of face extrusion will be presented. Considering a list of shapes  $Ls1$ , an operation instance (which must be given a tag), receiving this list as shape data input.

$$Extr1 = FaceExtrusion("Extr1", Ls1) \quad (4)$$

This operation will only consider faces, ignoring any other types of shape that the list may contain. If additional filters are intended, they must be specified:

$$Extr1.SetCondition(shape => ((Face)shape).area > 20 \parallel 2 > 5 \parallel myVariable == 15) \quad (5)$$

The definition of conditions can be achieved through lambda expressions, which allow the condition to be based on each shape property, a simple Boolean expression or by using external variables (5).

So far no extrusion value has been defined. That constitutes another interesting feature of PGCAD. While the value can be the same for all the selected faces (6), it can also be defined base on each face's properties (7):

$$Extr1.SetValue(Vector(0,0,10)) \quad (6)$$

$$Extr1.SetValue(shape => ((Face)shape).normal * 10) \quad (7)$$

Once the operations properties have been defined, the process may start.

$$Ls2 = Extr1.Apply() \quad (8)$$

The output is a list of shapes, which includes all shapes, including:

- The non-face shapes;
- The faces which did not match the conditions;
- The original faces which were operated on;
- The newly created faces.

Out of this list it would be now useful to select them apart. This is possible due to the automatic labeling, where labels are applied to all generated elements according to a specific mapping, which is different according to the modeling operation. In case of face extrusion, where shells, faces, rings, edges and vertices are created, labeling occurs as demonstrated in Figure 2.

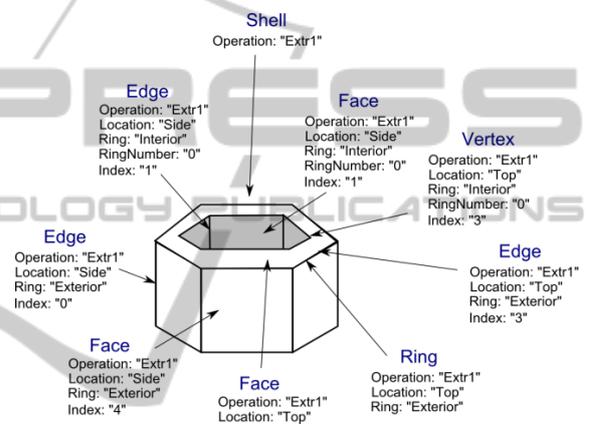


Figure 2: Automatic labeling of a holed face, after being extruded. Due to the high number of shapes and labels, only a demo subset is shown.

It is possible to query the list of shapes according to the applied labels. There is a common key-value combination that has been added to all the shapes that have been created in the process of face extrusion: "Operation" => "Extr1", based on the indicated parameter at the beginning of the action (See (4)). Filtering such shapes can be done in the following way, also using lambda expressions:

$$Ls3 = Ls2.Where(shape => shape.Labels.Exists(label => label["Operation"] == "Extr1")) \quad (9)$$

However, it is important to understand what kind of shapes was actually added in the process of the modeling operation. In the case of face extrusion, a shell shape is added, which means that  $Ls3$  contains now only the shells. They must now be unfolded to the intended type.

$$Ls4 = CreateShapeList(Ls3, ShapeType.Edges) \quad (10)$$

In (10) a list of edges was created, by unfolding the higher order shapes (shells into faces, faces into

rings, rings into edges), and discarding them. It is now possible to select, for instance, the vertical edges at the inner side of the model through the following statement (based on Figure 2):

```
Ls5 = Ls4.Where(shape => shape.Labels.Exists(
    label => label["Location"] == "Side" &&
    label["RingNumber"] == 0))
```

 (11)

## 4 IMPLEMENTATION

PGCAD has been implemented in Microsoft's .NET C# 4.0, whose managed, object-oriented nature facilitated its topological definition and integration. One of its most useful features, which made this API flexible query definition possible, is Microsoft-specific extensible, general-purpose language LINQ (language-Integrated Query), as well as the possibility to use Lambda Expressions. Both these features influenced also PGCAD's approach and syntax, due to their ease of use and effective application.

In order to be able to visualize the produced results, the Microsoft XNA Framework (Microsoft Corporation, 2011), a popular game development framework, was used. An intermediate layer between PGCAD and XNA has been conceived, in order to integrate the geometric kernel's topological elements to the rendering engine data structures.

Such approach makes it directly possible for the API to be used in digital games.

## 5 RESULTS AND DISCUSSION

As a starting example to test PGCAD's methodology and specification, an application focused on the popular research area of virtual urban area generation has been conceived (Coelho, et al., 2007; Müller, et al., 2006; Procedural Inc., 2009; Wonka, et al., 2003).

By starting with some real-world GIS Data, the geometries were imported and converted using PGCAD's import and conversion capabilities. The used information concerned building, block and road information, which had to be correctly integrated using PGCAD's spatial localization abilities.

At this point, PGCAD only supports a limited number of modeling operations, such as extrusion, texture mapping, geometric transformations, roof construction and material application. Still, they are enough to produce quality models, as it can be seen in Figure 3.

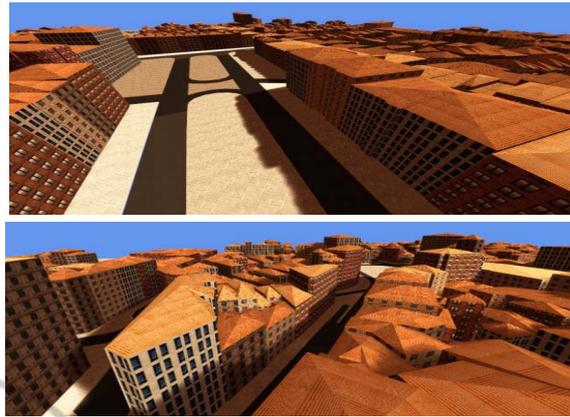


Figure 3: Application of the PGCAD geometry kernel to the procedural modeling of the downtown of the city of Porto, Portugal.

Concerning the efficiency of the modeler, PGCAD appears to perform very well. Although the number of applied operations per object (building, block or street) was reduced, it is important to consider the total number of objects. Table 1 indicates the measured times for different-sized city areas. It is important to note that, since information is loaded from a GIS data source, disk access must also take place, and is included in the measured times. Also, many optimizations can still be done.

Table 1: Performance test of PGCAD on a Intel Core 2 Duo 2,53Ghz, 3GB RAM, Windows 7 32-bit Laptop.

Area	Time	Loading Time	Generation Time	Base Entities	Faces	Vertices
1 ha	636ms	323ms	313ms	74	1053	2299
5ha	838ms	400ms	438ms	242	3764	7906
10ha	1000ms	493ms	507ms	478	7355	15165
100ha	2985ms	1345ms	1640ms	2198	32413	67890

Its speed suggests that it could be employed for real-time generation in virtual reality applications, such as games, where the virtual environment is created on-the-fly.

## 6 CONCLUSIONS AND FUTURE WORK

In this paper, the PGCAD API has been presented as a new geometric modeling solution for procedural tools whose main characteristic lies on the powerful control given over the manipulated geometric entities. This is achieved through its intuitive

topological structure, which features a set of properties, such as scope, spatial awareness and semantic information. The modeling processes can be massively applied to sets of shapes, yet act according to each individual shape's properties. This allows a more customized control, as well as successive tracking, which induce a greater, faster and more intuitive approach for geometry generation.

PGCAD is still undergoing development, but has already been applied in the field of virtual urban environment generation, with promising results in reduced time, proving its usability in real-time applications such as games. Its concept of spatial awareness and semantic control constitute PGCAD's most novel features, which will continue to be explored, as well as its mass modeling process, which can operate based on each shape's properties. Other current limitations, such as the scarce number of higher-level modeling operations, will also be subject of future attention, so that richer and more detailed objects can be created.

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