Adapted Laplacian Operator For Hybrid Quad/Triangle Meshes

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Dedication

Su uso es opcional y cada autor podrá determinar la distribución del texto en la página, se sugiere esta presentación. En ella el autor dedica su trabajo en forma especial a personas y/o entidades.

Por ejemplo:

A mis padres
o

La preocupación por el hombre y su destino siempre debe ser el interés primordial de todo esfuerzo técnico. Nunca olvides esto entre tus diagramas y ecuaciones.
Albert Einstein

Acknowledgement

Esta sección es opcional, en ella el autor agradece a las personas o instituciones que colaboraron en la realización de la tesis o trabajo de investigación. Si se incluye esta sección, deben aparecer los nombres completos, los cargos y su aporte al documento.

Abstract

This thesis proposes a novel modeling method for a hybrid quad/triangle mesh that allows to set a family of possible shapes by controlling a single parameter, the global curvature. The method uses an original extension of the Laplace Beltrami operator that efficiently estimates a curvature parameter which is used to define an inflated shape after a particular operation performed in certain mesh points. Along with the method, this work presents new applications in sculpting and modeling, with subdivision of surfaces and weight vertex groups. A series of graphics examples demonstrates the quality, predictability and flexibility of the method in a real production environment with software Blender.

Resumen

Es el mismo resumen pero traducido al ingl\'{e}s. Se debe usar una extensi\'{o}n m\'{a}xima de 12 renglones. Al final del Abstract se deben traducir las anteriores palabras claves tomadas del texto (m\'{\i}nimo 3 y m\'{a}ximo 7 palabras), llamadas keywords. Es posible incluir el resumen en otro idioma diferente al espa\~{n}ol o al ingl\'{e}s, si se considera como importante dentro del tema tratado en la investigaci\'{o}n, por ejemplo: un trabajo dedicado a problemas ling\"{u}\'{\i}sticos del mandar\'{\i}n seguramente estar\'{\i}a mejor con un resumen en mandar\'{\i}n.

Keywords: laplacian smooth; curvature; sculpting; subdivision surface

Contents

1 Introduction

Over the last years several, modeling techniques able to generate a variety of realistic shapes, have been developed [3]. Editing techniques have evolved from affine transformations to advanced tools like sculpting [6, 10, 19], editing, creation from sketches [12, 11], and complex interpolation techniques [17, 20]. Catmull-Clark based methods however require to interact with a minimun number of control points for any operation to be efficient, or in other words, a unicity condition is introduced by demanding a smooth surface after any of these shape operations. Hence, traditional modeling methods for subdividing surfaces from coarse geometry have become widely popular [4, 18]. These works have generalized a uniform B-cubic spline knot insertion to meshes, some of them adding some type of control, for instance with the use of creases to produce sharp edges [7], or the modification of some vertex weights to locally control the zone of influence [1]. Neverteless these methods are difficult to deal with since they require a large number of parameters and a very tedious customization. Instead, the presented method requires a single parameter that controls the global curvature, which is used to maintain realistic shapes, creating a family of different versions of the same object and therefore preserving the detail of the original model and a realistic appearance.

Interest in meshes composed of triangles and quads has lately increased because of the flexibility of modeling tools such as Blender 3D [2]. Nowadays, many artists use a manual connection of a couple of vertices to perform animation processes and interpolation [14]. It is then of paramount importance to develop operators that easily interact with such meshes, eliminating the need of preprocessing the mesh to convert it to triangles. The shape inflation and shape exaggeration can thus be used as such brush in the sculpting process, when inflating a shape since current brushes end up by losing detail when moving vertices [19]. In contrast, the presented method inflates a mesh by moving the vertices towards the reverse curvature direction, conserving the shape and sharp features of the model.

Contributions This work presents an extension of the Laplace Beltrami operator for hybrid quad/triangle meshes, representing a larger mesh spectrum from what has been presented so far. The method eliminates the need of preprocessing and allows preservation of the original topology. Likewise, along with this operator, it is proposed a method to generate a family of parameterized shapes, in a robust and predictable way. This method enables customization of the smoothness and curvature, obtained during the subdivision surfaces process. Finally, it is proposed a new brush for inflating the silhouette mesh features in modeling and sculpting.

This work is organized as follows: Section \ref{sub:1.1-Related-work} presents works related to the Laplacian mesh processing, digital sculpting, and offsetting methods for polygonal meshes; In section \ref{sec:Laplacian-Smooth} , it is described the theoretical framework of the Laplacian operator for polygon meshes; In section \ref{sec:Proposed-Method}, it is presented the method for shape inflation and applications of subdivision of surfaces and sculpting; finally some Laplacian operator results, to hybrid quad/triangle meshes are graphically shown as well as results of the shape inflation applications in sculpting, subdivision and modeling.

2 Related work

Many tools have been developed for modeling, based on the Laplacian mesh processing. Thanks to the advantages of the Laplacian operator, these different tools preserve the surface geometric details when using them for different processes such as free-form deformation, fusion, morphing and other applications [17].

Offset methods for polygon meshing, based on the curvature defined by the Laplace Beltrami operator, have been developed. These methods adjust the shape offset by a constant distance, with enough precision. Nevertheless, these methods fail to conserve sufficient detail because of the smoothing, a crucial issue which depends on the offset size [21]. In volumetric approaches, in case of point-based representations, the offset boundary computation is based on the distance field and therefore when calculating such offset, the topology of the model may be different to the original [5].

[9] propose automatic feature detection and shape edition with feature inter-relationship preservation. They define salient surface features like ridges and valleys, characerized by their first and second order curvature derivatives, see [15], and angle-based threshold. Likewise, curves have been also classified as planar or non-planar, approximated by lines, circles, ellipses and other complex shapes. In such case, the user defines an initial change over several features which is propagated towards other features, based on the classified shapes and the inter-relationships between them. This method works well with objects that have sharp edges, composed of basic geometric shapes such as lines, circles or ellipses. However, the method is very limited when models are smooth since it cannot find the proper features to edit.

Digital sculpting have been traditionally approached either under a polygonal representation or a voxel grid-based method. Brushes for inflation operations only depend on the vertex normal [19]. In grid-based sculpting, some other operations have allowed to add or remove voxels since production of polygonal meshes require a processing of isosurfaces from a volume [10]. The drawback comes from the difficulty of maintaining the surface details during larger scale deformations.

3 Laplacian Smooth

Computer objects, reconstructed from the real world, are usually noisy. Laplacian Smooth techniques allow a proper noise reduction on the mesh surface with minimal shape changes, while still preserving a desirable geometry as well as the original shape.

Many smoothing Laplacian functionals regularize the surface energy by controling the total surface curvature S.

$$E\left(S\right)=\int_{S}\kappa_1^2+\kappa_2^2dS \tag{3-1}$$

Where κ_1 and κ_2 are the two principal curvatures of the surface S.

3.1 Gradient of Voronoi Area

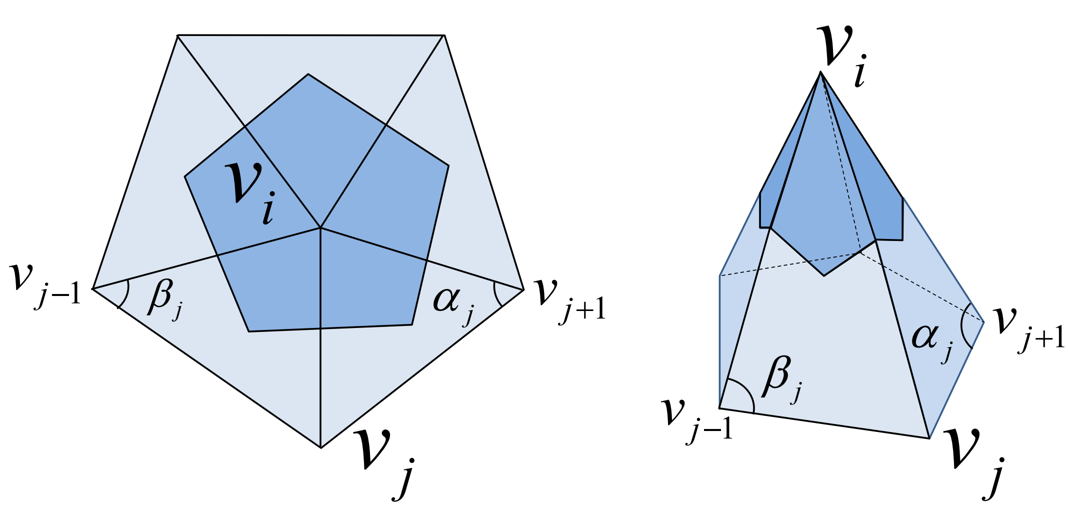

Figure **3-1**: Area of the Voronoi region around v_i in dark blue.v_j belong to the first neighborhood around v_i. α_j and β_j opposite angles to edge $\overrightarrow{v_j - v_i}$.

Consider a surface S composed of a set of triangles around vertex v_i. Let us define the *Voronoi Region* of v_i as show in figure **3-1**, The area change produced by the movement of v_i is called the gradient of *Voronoi region* [16, 8, 13].

Bibliography

[1] Henning Biermann, Adi Levin, and Denis Zorin. Piecewise smooth subdivision surfaces with normal control. In *Proceedings of the 27th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '00, pages 113–120, New York, NY, USA, 2000. ACM Press/Addison-Wesley Publishing Co.

[2] Blender-Foundation. Blender open source 3d application for modeling, animation, rendering, compositing, video editing and game creation. http://www.blender.org/, 2012.

[3] Mario Botsch, Mark Pauly, Christian Rossl, Stephan Bischoff, and Leif Kobbelt. Geometric modeling based on triangle meshes. In *ACM SIGGRAPH 2006 Courses*, SIGGRAPH '06, New York, NY, USA, 2006. ACM.

[4] E. Catmull and J. Clark. Recursively generated b-spline surfaces on arbitrary topological meshes. *Computer-Aided Design*, 10(6):350–355, November 1978.

[5] Yong Chen and Charlie C. L. Wang. Uniform offsetting of polygonal model based on layered depth-normal images. *Comput. Aided Des.*, 43(1):31–46, January 2011.

[6] Sabine Coquillart. Extended free-form deformation: a sculpturing tool for 3d geometric modeling. *SIGGRAPH Comput. Graph.*, 24(4):187–196, September 1990.

[7] Tony DeRose, Michael Kass, and Tien Truong. Subdivision surfaces in character animation. In *Proceedings of the 25th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '98, pages 85–94, New York, NY, USA, 1998. ACM.

[8] Mathieu Desbrun, Mark Meyer, Peter Schröder, and Alan H. Barr. Implicit fairing of irregular meshes using diffusion and curvature flow. In *SIGGRAPH '99: Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, pages 317–324, New York, NY, USA, 1999. ACM Press/Addison-Wesley Publishing Co. Skeleton Extraction.

[9] Ran Gal, Olga Sorkine, Niloy J. Mitra, and Daniel Cohen-Or. iwires: An analyze-and-edit approach to shape manipulation. *ACM Transactions on Graphics (Siggraph)*, 28(3):#33, 1–10, 2009.

[10] Tinsley A. Galyean and John F. Hughes. Sculpting: an interactive volumetric modeling technique. *SIGGRAPH Comput. Graph.*, 25(4):267–274, July 1991.

[11] Ozgur Gonen and Ergun Akleman. Smi 2012: Short paper: Sketch based 3d modeling with curvature classification. *Comput. Graph.*, 36(5):521–525, August 2012.

[12] Takeo Igarashi, Satoshi Matsuoka, and Hidehiko Tanaka. Teddy: a sketching interface for 3d freeform design. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '99, pages 409–416, New York, NY, USA, 1999. ACM Press/Addison-Wesley Publishing Co.

[13] Mark Meyer, Mathieu Desbrun, Peter Schröder, and Alan H. Barr. Discrete differential-geometry operators for triangulated 2-manifolds. In Hans-Christian Hege and Konrad Polthier, editors, *Visualization and Mathematics III*, pages 35–57. Springer-Verlag, Heidelberg, 2003.

[14] Tony Mullen. *Introducing character animation with Blender*. Indianapolis, Ind. Wiley Pub. cop., 2007.

[15] Yutaka Ohtake, Alexander Belyaev, and Hans-Peter Seidel. Ridge-valley lines on meshes via implicit surface fitting. *ACM Trans. Graph.*, 23(3):609–612, August 2004.

[16] Ulrich Pinkall, Strasse Des Juni, and Konrad Polthier. Computing discrete minimal surfaces and their conjugates. *Experimental Mathematics*, 2:15–36, 1993.

[17] O. Sorkine, D. Cohen-Or, Y. Lipman, M. Alexa, C. Rössl, and H.-P. Seidel. Laplacian surface editing. In *Proceedings of the 2004 Eurographics/ACM SIGGRAPH symposium on Geometry processing*, SGP '04, pages 175–184, New York, NY, USA, 2004. ACM.

[18] Jos Stam. Exact evaluation of catmull-clark subdivision surfaces at arbitrary parameter values. In *Proceedings of the 25th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '98, pages 395–404, New York, NY, USA, 1998. ACM.

[19] Lucian Stanculescu, Raphalle Chaine, and Marie-Paule Cani. Freestyle: Sculpting meshes with self-adaptive topology. *Computers & Graphics*, 35(3):614 – 622, 2011. Shape Modeling International (SMI) Conference 2011.

[20] Kun Zhou, Jin Huang, John Snyder, Xinguo Liu, Hujun Bao, Baining Guo, and Heung-Yeung Shum. Large mesh deformation using the volumetric graph laplacian. *ACM Trans. Graph.*, 24(3):496–503, July 2005.

[21] Wei Zhuo and Jarek Rossignac. Curvature-based offset distance: Implementations and applications. *Computers & Graphics*, 36(5):445 – 454, 2012.