Example-based geometric texture synthesis: a survey

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Abstract

3D object modelling is a key step in computer animation industry. How to generate models rich in high quality geometric details is still a challenging task and affects the final visual effects of animation. Example-based geometric texture synthesis (EGTS) is a powerful tool to automatically build models with rich geometric details. Given a small patch of geometric texture as an example and an arbitrary model as a target model, using EGTS, we can change the surface of the target model to the new geometric texture style. EGTS has been studied a lot by the literature and many papers have been published. In this paper, we will summarize the influential papers and present our thoughts on this topic.

Keywords: example-based, geometric texture synthesis, survey

1 Introduction

In the real world the majority of three-dimensional objects, especially those found in nature exhibit some form of texture. Plant surfaces like veins, thorns or needles, and animal surfaces like feathers or fur are the examples. There are two ways to add texture to an object, with colour texture or geometry texture. Adding colour texture means setting an object's surface colours. And by altering an object's surface geometry, geometry texture can be added.

In order to minimize the geometric complexity while creating visual complexity, texture mapping is developed by the early computer graphics researchers to balance the gap between the hardware limit of polygon processing and the need forever richer computer-generated scenes. To reduce the artefacts of image texturing, more general forms of textures are introduced, such as volumetric textures and bump mapping while modelling and rendering the 3D details of a surface is still excluded. But with the fast development of hardware, nowadays, commodity video cards are equipped with extremely flexible and powerful graphics processor. Displaying tens of millions of triangles and texture mapping in real-time have been both achieved. So the image-based textures' well-documented visual artefact's such as inaccurate shadows, smoothed contours and lack of parallax can be all overcome by enabling exquisite details to be directly rendered and purely geometrically modelled. As it does not suffer from most of the traditional limitations of animation, editing and modelling, this purely geometric detail representation offers an unrestrictive and versatile tool for artistic creation and turns out to be very desirable.

However, compared to image texture synthesis, it is still tedious to model complex geometric details such as weaves, ivies, chain mails or veins. So the problem of synthesizing 3D geometric textures remains challenging, while the basic techniques for image texture synthesis are mostly worked out. One way is to apply image texture synthesis ideas to geometric texture synthesis. Firstly, an example geometry is provided. Then, similarity matching can be used by a synthesis algorithm to generate more geometry. This is the basic idea of EGTS.

A number of approaches have been proposed for EGTS, but only some of them are mentioned by [1, 2]. Here we will give a more overall description on the topic covering all the influential papers published. A different interpretation of this idea is come up with as each research group looks at this problem.

And as the choice of geometric representation often guides the algorithm's style, we classify the papers into three categories according to the representation used: volumetric model [3-5], polygon mesh [6-12] and height field [13]. The section that follows gives a brief description of these approaches, and the interested readers are referred to the original papers for details.

2 Example-based geometric texture synthesis methods

The idea of texture synthesis is extended by some researchers to the creation of geometric texture from example geometry. For performing geometry synthesis from example, a number of different approaches have been invented. In this section the papers are firstly sorted into three categories (as shown in Table 1). Then we will introduce the representative works in detail by category.

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TABLE 1 Taxonomy of EGTS approaches

Geometric representation	Representative works
Volumetric model	Volumetric Grids [3], Search Tree [4], Model Pieces [5]
Polygon mesh	Geometry Images [6], Trivariate Mapping [7],Shell Maps [8], Cellular Texture [9], Mesh Quilting [10], Laplacian Texture [11], Discrete Element [12]
Height field	Terrain Synthesis [13]

2.1 VOLUMETRIC MODEL METHODS

Bhat et al. [3] generalize image texture synthesis to geometry by drawing an analogy between 2D pixels and 3D voxels. Begin with fine volumetric details such as holes, grooves, pits and spikes, their approach can place these detailed features on the surface of a model. The main idea of the approach is to extend Image Analogies [14] to the volumetric domain. Firstly, an object is provided, onto which additional geometric details are to be added. Then a pair of similar volumetric geometric objects input to the algorithm, one with and one without geometric features, as geometric example. For example, a cylinder with and without grooves. An example of the three input models and the synthesis result are shown in Figure 1. Besides the three input models, a vector field for orienting 3D voxel neighbourhoods needs to be built on the model to be modified.

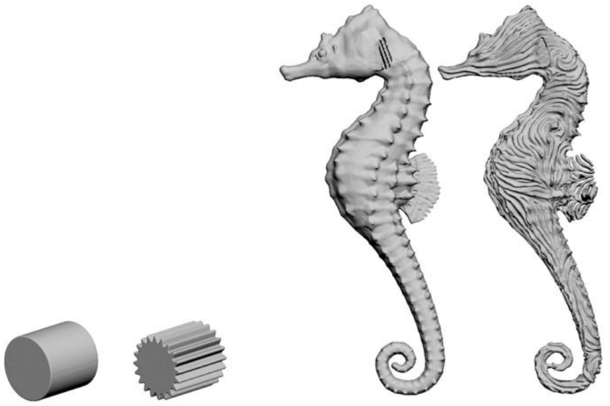

FIGURE 1 The grooved cylinder and the flat cylinder form the input geometric example (left). The seahorse model (middle right) is the input model to be modified. The last model is the resulting volumetric geometry (far right)

Lagae et al. [4] develop a similar approach using voxel matching to synthesis geometry. The input example geometry is assumed to satisfy the constraints of a Markov Random Field model. And a hierarchical distance field is used to represent the input geometry. Their method is a two-phase process. In the first analysis phase, on the input example geometry, the regularly sample distance field is computed, and its hierarchical representation is organized in a tree. In the second synthesis phase, on the distance field, for a partially synthesized neighbourhood, a tree search algorithm is used to find its best match. The un-synthesized samples are replaced with those of the best match. They construct the final synthesized geometry in parallel. A result of their approach is shown in Figure 2.

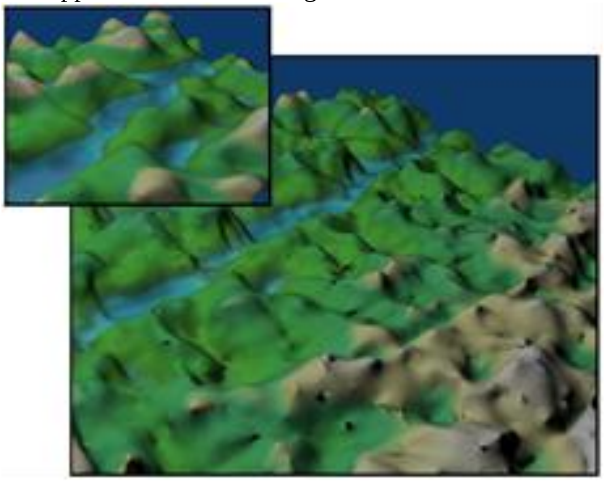

FIGURE 2 The example geometry in the upper left is used to synthesize the terrain geometry in the large image

Another way to synthesis 3D models based on example geometry is demonstrated by Merrell [5]. First, the model is partitioned into uniformly-sized blocks and then these blocks are reassembled in a consistent manner. Given the example geometry, the user specifies the block size, which is used to partition the geometry. After the size of the desired output model is given by the user, then a pattern of blocks is found by the system that is consistent block adjacency. The relative positions of adjacent blocks from the example model is defined as consistency. An iterative algorithm is used to assemble blocks in a consistent manner. First, a simple pattern of block ID's (such as all zeroes) is used to fill a 3D lattice. Then the sub-regions of the lattice are analysed and the block ID's is modified in a constrained random fashion to maintain correct block adjacency. Then the process is repeated several times for more sub-regions. A model of a pillar divided into four pieces is shown in Figure 3.

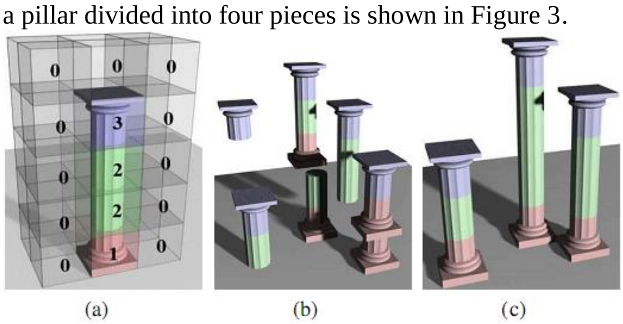

FIGURE 3 Four model pieces compose a model (a), An Inconsistent Model (b) and A Consistent Model (c)

2.2 POLYGON MESH METHODS

As polygon mesh is the most popular representation for 3D model, EGTS methods of this category is far ahead over the other two in quantity. And the generality of polygon mesh makes these methods more feasible in application.

Lai et al. [6] present a method that can synthesis a geometric texture which is designed manually to a model, and can automatically transfer geometric texture between different objects. Their method is based on geometry images proposed by Gu et al. [15]. They first represent the geometric example and target model in geometry images. Then in the 2D geometry images domain, they use image synthesis method to modify the target model's geometry image. A vector field is built to guide sequence of the image texture synthesis. Finally, the result geometric model is reconstructed from the geometry image (as shown in Figure 4).

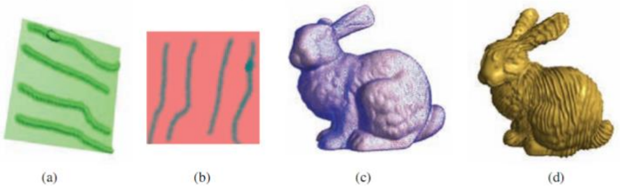

FIGURE 4 A result of Lai et al. [6]. A manually created texture (a) is the converted to a geometry image (b). The vector field (c) is built based on a given orientation. And (d) is the synthesized result

For geometric detail modelling, Elber et al. [7] and Porumbescu et al. [8] use mesh-based details as a versatile representation. In both the two methods, textures are simply tiled over the plane and then mapped to 3D surfaces. And the process is only suitable for periodic textures. Most importantly, as a global parameterization over the plane is not supported by arbitrary surfaces, texture discontinuity will be produced across chart boundaries. Fleischer et al. [9] propose a method to create geometric textures on arbitrary meshes based on mesh details. But they are restricted mostly to the synthesis of simple texture elements like scale or thorns over the surface, the design of complex textures is not allowed, for instance woven materials.

To create complex geometric details in the manner guided by a user-supplied base mesh such as vines, chain mail and weave, Zhou et al. [10] introduce Mesh Quilting, an algorithm depending on having a correspondence between patches in 2D and the base mesh. The algorithm repeatedly uses portions of the texture swatch proceeds to fill empty regions until geometric detail covers the base mesh. In detail, firstly, an empty region of the surface that already has texture detail surrounding it is identified. For filling the empty region, these adjacent parts of the texture work as start constraints. Then in order to fill the empty region with texture, they try portions of the texture swatch. For each part of the swatch, they test several offsets of the texture. Finally, with retaining of the best match, they find a correspondence between the existing pieces and the triangles of the new piece. Figure 5 shows their result.

Ran et al. [11] present a method to synthesize geometric texture details from a sample texture patch onto an arbitrary surface. Their key idea is to represent geometric texture details using Laplacian texture images, which enables flexible geometry texture editing and facilitates effective and simple geometry texture synthesis. First, a sample model and a target model are given. Then a patch from the sample model is selected to extract the geometric texture details.

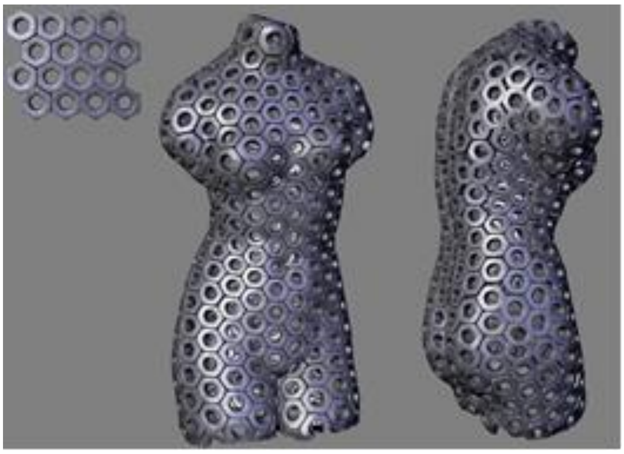

FIGURE 5 Mesh Quilting result by Zhou et al. [10]. The geometric example is shown in the upper left

Next, a Laplacian texture image of the extracted texture is constructed. An image texture synthesis technique is used to synthesize the Laplacian texture image to the target model. Finally, the textured target model is reconstructed based on adjusted Laplacian coordinates of the target model. Some of their results are shown in Figure 6.

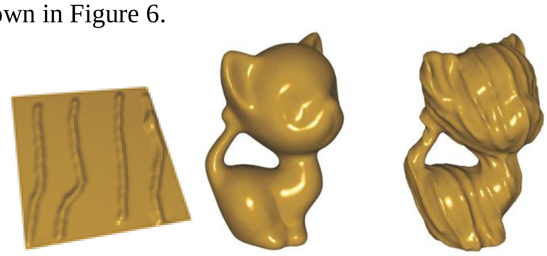

FIGURE 6 Laplacian texture method by Ran et al. [11]. From left to right: example texture, target model and the synthesis result

For synthesizing repetitive elements from a small input exemplar to a large output domain, Ma et al. [12] present a data-driven method, discrete element textures (as shown in Figure 7). Individual element aggregate distributions and their properties can be both preserved by the method. Due to the generality, it can be applied to different effects including both physically realistic and artistic ones, and a variety of phenomena, including different distributions, different element properties and dimensionalities. Each element is represented by one or multiple samples. Relevant element attributes are encoded by samples positions including orientation, shape, size, and position. An energy optimization solver and a sample-based neighbourhood similarity metric are proposed to synthesize desired outputs. Both the input exemplars and output domains are observed. Optional constraints such as boundary conditions, orientation fields and physics are all solved. Existing element distributions can also be edited using their method.

FIGURE 7 Synthesis results of Ma et al. [12]. The smaller images are the example textures. The larger ones are the synthesis results

2.3 HEIGHT FIELD METHOD

With land forms guided by a user's sketch, Zhou et al. [13] assemble real terrain data represented by height field to create terrain geometry. First, the user's sketch is segmented into small curvilinear features including branch points, curves and straight segments. Then matching features are found from patches of the input height field data. A combination of 2D warping, graph cut merging and Poisson blending is used to blend together these height field patches. The patches are typically 80×80 height samples in size. They reduce the terrain features such as valleys, mountains and rivers into simplified curvilinear features to speedup this method. Figure 8 shows a result from this approach.

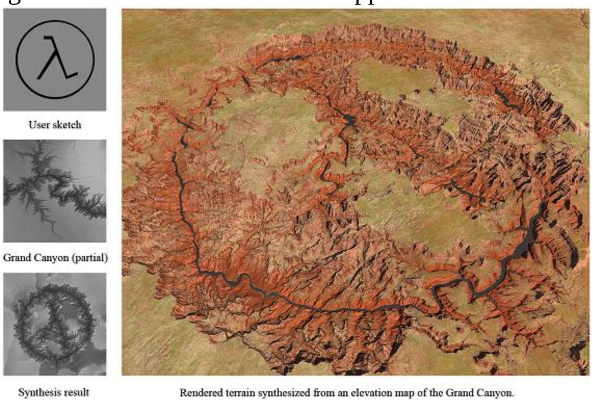

FIGURE 8 Terrain synthesis (right) by Zhou et al. [13] based on example texture (middle left) a user input sketch (upper left).

3 Conclusions

For providing end-users with powerful modelling tools, EGTS is one of the most promising ideas. By combining examples, almost anyone can learn to create results with rich geometric texture. Also, this intuitive approach requires minimal technical skills and experience. We believe that EGTS provides insights and key tools towards efficient rich-detail modelling.

In this paper, we make the first comprehensive survey of the EGTS method, which is a powerful tool to synthesis geometric texture on arbitrary model given an example texture. Since 2004, many influential papers have been published on the topic. Depending on the type of geometric representation (volumetric model, polygon mesh and height field), we classify the previous works into three categories. Of all the three types, with the wide application of mesh model, the literature also mainly focus on EGTS algorithm for polygon mesh, and reaches convincing results.

Though great achievements have been made in the last decade, there are still challenges left for us to solve. For example, the synthesized geometric texture are too uniformly distributed, but sometimes we need a more flexible arrangement of the texture's density. And after the successfully automatic synthesis of geometric texture on an arbitrary model, there are still room for improvement on the complexity of the example texture. We hope this survey will help and encourage researchers to direct towards these challenges.

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