Texture Pattern Generation Using Clonal Mosaic*

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Abstract In this paper, an effective system for synthesizing animal skin patterns on arbitrary polygonal surfaces is developed. To accomplish the task, a system inspired by the Clonal Mosaic (CM) model is proposed. The CM model simulates cells' reactions on arbitrary surface. By controlling the division, mutation and repulsion of cells, a regulated spatial arrangement of cells is formed. This arrangement of cells shows appealing result, which is comparable with those natural patterns observed from animal skin. However, a typical CM simulation process incurs high computational cost, where the distances among cells across a polygonal surface are measured and the movements of cells are constrained on the surface. In this framework, an approach is proposed to transform each of the original 3D geometrical planes of the surface into its Canonical Reference Plane Structure. This structure helps to simplify a 3D computational problem into a more manageable 2D problem. Furthermore, the concept of Local Relaxation is developed to optimally enhance the relaxation process for a typical CM simulation. The performances of the proposed solution methods have been verified with extensive experimental results.

Keywords procedural texture, clonal mosaic, pattern synthesis, geometry processing

1 Introduction

The aim of this project is to synthesize the fascinating color patterns of animals in the application domain of computer graphics. Several biological models for the pattern formation on animal skin are studied. Computational approaches for the synthesis task have also been examined. The existing models have successfully predicted the pigmentation processes of the seashells and the color pattern formation on several species of fishes. Besides, the previous work on simulating simple patterns on mammalian coats also achieved certain success. Despite this achievement, it is difficult to obtain acceptable computational performance and/or realistic results by using existing methods for synthesizing animal skin with complex patterns.

Our work is inspired by a procedural texture method, namely, Clonal Mosaic (CM) model, proposed by Walter[1]. This model works with a large number of points (cells), which are distributed over a piece of geometry. The movement and division of cells are controlled by some parameters, so that by grouping cells with similar properties and keeping away cells with different properties, a regulated spatial arrangement of cells can be formed. The resulting arrangement of cells, once associated with a Voronoi Diagram, represents a tessellation of cell regions, which are visually identical with color patches on animal skin. A CM model is able to create various animal skin patterns like spots on cheetah, patches on giraffe and rosettes on leopard. However, a typical CM texture requires an extensive simulation process.

Our goal is to improve the computational performance of the CM simulation on arbitrary polygonal surfaces, while maintaining the quality of a simulated texture pattern. Two techniques are successfully developed, in order to overcome the drawbacks and limitations of the existing CM model. First, an intermediate spatial configuration of polygonal object, which is called as the Canonical Reference Plane Structure (CRPS), is proposed. This geometrical structure aims at simplifying the computational cost incurred during a simulation process. Second, a Local Relaxation is introduced, so that the simulation process can be optimized by avoiding redundant computation of cell repulsions.

2 Related Work

Ball[2] conducted a comprehensive survey on biological skin pattern formation. One of the earliest discussions on pattern formation in biological discipline was initialized by Alan Turing[3]. He proposed a Reaction-Diffusion (RD) system, which explains how the anatomical structure of an organism is developed from its zygote. In Turing's chemical system, diffusion is acting in competition with an autocatalytic chemical reaction. A chemical compound $A$ undergoes an autocatalytic reaction to produce more of itself. While another compound $B$ acts as an inhibitor, which inhibits the production of more $A$. The key element for obtaining a spatial pattern is to diffuse $A$ and $B$ through the reaction medium at different rates.

Gierer and Meinhardt[4] described an Activator-Inhibitor and Activator-Substrate model, which are types of RD systems. These methods are proven true in generating remarkable seashell pigmentation[5,6]. The concepts were also used by Koch and Meinhardt[7] to simulate several types of mammalian coat pattern such

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as the cheetah, giraffe and leopard. However, the model did not give comparable realistic result with the real world patterns. Painter\textsuperscript{[8]} simulated an RD system on an irregular domain determined by tracing the boundary of a real fish.

Murray\textsuperscript{[9]} suggested that the formation of pattern on mammalian coat starts in the embryonic stage. Besides, the scale of body size has dramatic effect on pattern formation. Small animals with short gestation periods have less complex skin patterns than larger animals, as their smaller embryos support fewer modes. The size and shape of the region, where a chemical process occurs, also influence the pattern formation process. For example, the formation of either spots or stripes pattern on a cat’s tail is decided by the length and shape of the tail.

In computer graphics, textures are attached onto a piece of geometry in order to increase its realistic appearance. There exist two major ways to texture a piece of geometry, namely image-based texturing and procedural texturing.

An image-based texturing technique employs a piece of 2D image, which is either painted by an artist, captured with image scanner or digital camera. A texture mapping process is needed to create a correspondence between 3D surface point and a pixel on the image. There are several problems for this approach. First, a given image might not be large enough to cover the entire surface. Methods have been proposed to solve this problem by repeatedly tiling the texture image\textsuperscript{[10,11]}. However, it is difficult to blend the patterns at the sides of the texture images (texture seam problem). Secondly, a 2D image does not always fit well to an arbitrary surface manifold. Hence, stretching and distortion are common. Next, it is normally difficult to create variation and transition of texture elements in this approach.

A texture synthesis method attempts to solve some of these potential problems. One or more smaller texture images are used as input to the system for generating a larger and richer image. Praun\textsuperscript{[12]} gives an approach to cover an arbitrary surface with overlapped texture patches from an input image. Tong\textsuperscript{[13]} describes a bi-directional texture function, which creates seamless texture from an input image. Soler\textsuperscript{[14]} proposed a hierarchical pattern mapping technique, which iteratively fills geometry with small patches of an input image in different sizes and shapes. Zhang\textsuperscript{[15]} shows a progressively variant synthesis on arbitrary surface.

For procedural texture, mathematical models are used to generate texture directly on a surface. The most widely used procedural texture is \textit{Perlin Noise}, which can be used to generate a variety of 2D and 3D textures (including marble, water, fire and other kinds of natural phenomena).

Turk\textsuperscript{[16]} used the biological pattern formation technique, RD model, to generate mammalian coat pattern on arbitrary surfaces. The system simulates the interaction of chemical pigments as they diffuse over the surface. Turk adopted a suggestion from Bard\textsuperscript{[17]}, where a complex pattern can be generated by a cascade process. The process combines the results of several RD systems by freezing one of the processes while running the other process. This cascading process successfully simulated the typical large and small spots on cheetahs and rosette patterns on leopard.

Witkin and Kass\textsuperscript{[18]} introduced the anisotropy concept into the RD system. The concept allows different diffusion rates for horizontal and vertical directions. The anisotropy information is given by a diffusion-map, which is defined by the user.

Walter\textsuperscript{[19]} proposed the CM model, where attractive patterns are formed by simulating cell reactions. Cell division, mutation and repulsion are the key elements to obtain these patterns.

### 3 Overview

CM model is a method, which simulates mammalian coat patterns on arbitrary 3D surfaces. The model proposes that the typical spot, rosette and strip patterns, which occur in several species of mammals, reflect a spatial arrangement of epithelial cells. These cells are derived from a single progenitor. The color of furs and hairs are hence affected by these underlying cells. The generation of CM patterns includes the simulation of three cell actions, which are the cell division, cell mutation and cell repulsion.

A CM cell is represented as a point in a given domain. Several types of cells, where each type is responsible for the synthesis of a single color appearance of the entire texture pattern, are introduced into the system. Typical properties of a given type of cell are cell color, division rate, mutation rate and repulsive value. Division rate controls the frequency of a cell to divide itself. Mutation rate controls the probability of a cell to mutate itself into another type of cell. Repulsive value defines repulsiveness between any two types of cells.

All the cells in the system divide themselves into two according to their division rate. The progenies inherit all attributes of their parent if no cell mutation happens. Whenever a division event happens, a newly produced cell repels its neighboring cells. Repulsion computation is needed to displace the cells accordingly.

The process to compute repulsion among cells and displace the cells according to the repulsive forces is named as a relaxation process. The total repulsive force received by a single cell $P_c$ is computed by summing all repulsive forces from its neighboring cells $P_i$. For a total area $A$ and $m$ number of cells, the neighbor cells are those who reside within a given repulsive radius $r$ from $P_c$, where $r = w_r \sqrt{A/m}$. The repulsive weight $w_r$ acts as the scaling factor of the repulsive radius. Fig. 1 shows a cell $P_c$ with two neighbor cells $P_1$ and $P_2$, which are located within the repulsive radius $r$. $P_1$ and $P_2$ each apply an acting force $f_{1c}$ and $f_{2c}$ onto $P_c$. $P_c$ is hence receiving a total acting force of $F = f_{1c} + f_{2c}$, which...