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Complex multi-material approach for dynamic simulations

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ABSTRACT

Triangle meshes are the most common representation of an object in the field of computer graphics. Recently, they have found their way into the field of erosion simulation, where volumetric representation used to prevail. Real-life erosion scenes are usually formed of multiple materials and so a reliable means of material definition is needed. Unfortunately, coupling the material information with a triangle mesh is not as straightforward as in the volumetric case. This paper proposes an approach for multiple material definition based on space subdivision. Binary space partitioning (BSP) is used to simulate complex multi-material scenes. The approach allows the definition of a nontrivial scene composed of several materials, including the definition of a gradually changing material. A method for an automated creation of the BSP tree from input volumetric data is proposed. The construction algorithm extracts a triangle mesh as an intermediate product and uses its faces as the splitting planes of the BSP tree.

1. Introduction

When representing a heterogeneous object or scene in 3D graphics simulations, multiple materials can be assigned to it to achieve better results or visual quality. Material properties can describe its visual appearance or define its structure, which is necessary, e.g., for applications working with haptic feedback. The way the material properties can be assigned depends greatly on the data structure used for the representation of the object.

A heterogeneous scene is commonly represented as a set of non-intersecting triangle meshes, one for each material present in the scene. This representation is efficient for static scenes with several separated materials; however, it may not be sufficient to describe a dynamic scene containing several materials blending into each other, e.g., during an erosion simulation. During such a dynamic simulation, the surface mesh evolves and a more sophisticated way to describe the material properties is necessary. A volumetric approach is another common method of addressing the problem. This approach gives satisfactory results in many situations, but the memory requirements grow very fast with the increasing size of the scene.

As triangle meshes are the most commonly used data structure in 3D graphics, a multiple-material mesh-based approach for dynamic simulations is needed. In this paper, a material description approach suitable for such purposes is proposed. The method is an extension of the approach by Skorkovská and Kolingerová [1]. In [1], the scene is represented with a surface mesh for each individual object in the scene, regardless of the material of the object. The material is then assigned through a separate binary space partitioning (BSP) structure. As the BSP tree is independent of the triangle meshes, it can be constructed once in the pre-processing step and used throughout the simulation. The method also allows an optional definition of a distance function as a simulation of a continuous change of the material.

The main contributions of this paper are

- An extension of the BSP method [1] to allow general implicit surfaces as splitting functions in the BSP tree;
- An automated method for the construction of the BSP tree from an input volumetric data to eliminate the need for the manual definition of the BSP tree.

These extensions of the original method allow much wider range of uses in the field of dynamic simulations.

The structure of the paper is as follows. Section 2 summarizes the related work. In Section 3, several simple multiple-material definition approaches are proposed. Section 4 describes a more complex approach using BSP. In Section 5, an automated method for the generation of a BSP tree is proposed. Results are presented in Section 6 and Section 7 concludes the paper.

2. Related work

Most of the research on multiple-material scenes focuses on extracting a correct and consistent mesh for each of the materials

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present in the volumetric data obtained, e.g., from a medical scan. Wu and Sullivan [2] enhanced the marching cubes algorithm to reconstruct multiple material meshes. Zhang et al. [3] generate the mesh using an octree-based isocontouring method. Wang [4] generates the mesh surfaces using a ray representation of a solid as an intermediate structure. These approaches are suitable for static scenes, where the materials are strictly separated.

For dynamic scenes or scenes where the individual domains are blending into each other, the aforementioned approaches are inappropriate. An example of such a scene could be an erosion scenario, where sand and pebbles of various sizes mix up to form a river bank that is being eroded by the flowing water. Such a scene could be described using a volumetric approach similar to the one used by Benes et al. in [5]. However, the volumetric representation is very memory-consuming. A layered data representation introduced by Benes and Forsbach [6] can be used instead to alleviate the problem. The layered data structure is a sufficient description of a terrain scene consisting of several layers of material, but for a general scene with a gradually changing material, it converges back to the volumetric representation.

A different approach is used by Tychonievich and Jones in [7], where a Delaunay deformable model is used to represent an eroded terrain and material properties are defined for each cell of the Delaunay triangulation. A new mesh is generated at every iteration of the method. Material properties for the new mesh have to be reconstructed using the data from the preceding iteration, which can be time-consuming.

Function representation [8] defines an object as a real-valued continuous function of point coordinates. The points with positive functional value belong to the object, the points with negative functional value lie outside of the object and the points with zero functional value form the boundary. Attributes can be associated with the representation, such as the material properties.

Skorkovská and Kolingerová [1] use binary space partitioning (BSP) to subdivide the scene into convex regions of homogeneous material. A distance function is defined to mimic the behavior of gradually changing materials. However, the BSP tree is defined manually, which is inappropriate for large and complex scenes.

The method proposed by Skorkovská and Kolingerová [1] is suitable for the use in dynamic simulations while having lower memory requirements than the volumetric approach, but it also has its shortcomings; above all, the need to manually define the splitting planes. This paper addresses the problems by extending the method [1] to allow the definition of general splitting surfaces defined by implicit functions. It also introduces an automated method for the creation of the BSP tree.

3. Definition of multiple materials

A real-life scene is composed of objects made of different materials which are eroded in different ways; hard and resistant materials are eroded slowly, while the erosion of soft materials is happening much faster. To be able to simulate such phenomena, we need a means to consistently describe the material of an object. A common way of representation is to have a separate mesh for each material present in the scene. This approach is suitable for the simulation of static scenes, where the materials are strictly separated. If the scene contains objects with material gradually changing, a different approach is necessary.

We have tested several methods of material description that allow the definition of multiple materials for a single mesh, ranging from a material definition for each vertex of the mesh to a more sophisticated method of binary space partitioning (BSP). The methods are described in the following text.

3.1. Material in a vertex

The most simple way to define multiple materials for a single mesh is to assign material properties to each individual vertex. This approach is very easy to implement; however, it has disadvantages as well. This kind of material definition applies only to the surface of the object, not to the volume. Using this approach, the result of an erosion simulation will change according to the direction of the erosion. If the erosion direction is parallel with the boundary of the individual materials, the erosion will be simulated correctly. Fig. 1 shows an object made of two different materials. The dark brown material is hard and sturdy, while the light brown material is soft and easily erodible. Fig. 1(b) captures the result of the erosion simulation.

The disadvantage of the approach is illustrated in Fig. 2. The boundary between the materials is assumed to be straight and going through the middle of the object, perpendicular to the direction of the erosion. Fig. 2(b) shows that the soft vertices (light brown) have been incorrectly eroded beyond the boundary. However, if the boundary inside the object was curved, the result shown in Fig. 2(b) could be correct. This ambiguity is the main downside of the method.

3.2. Division by a plane

The problem of the previous approach can be reduced, if the material properties are defined for the whole volume of the scene, using a plane to separate different materials. Fig. 3 shows the situation from Fig. 2, but the material definition is done by a

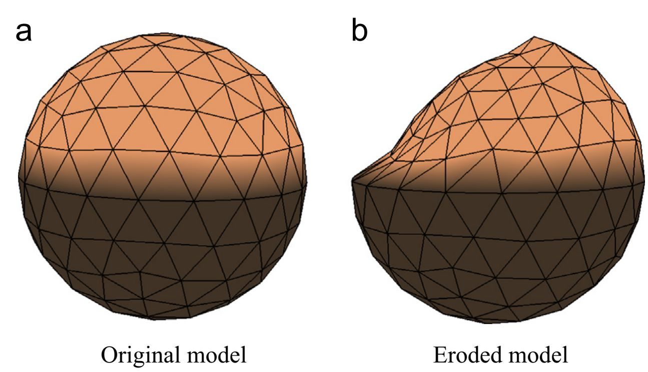

Fig. 1. Material properties assigned to each vertex, correct case. Erosion force is applied from the left. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

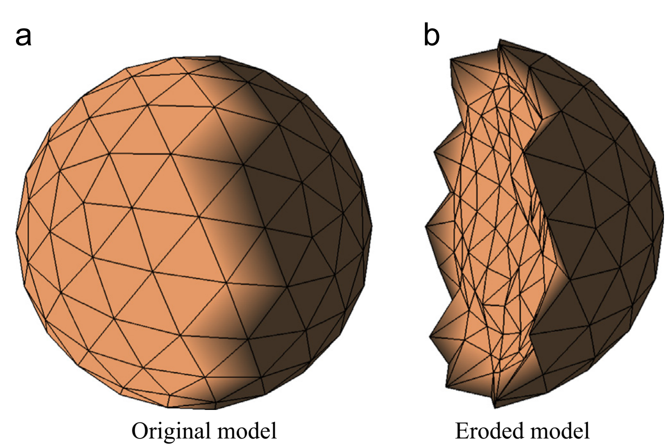

Fig. 2. Material properties assigned to each vertex, incorrect case. Erosion force is applied from the left. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)