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Multiple Material Meshes for Erosion Simulation

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Abstract

Triangle meshes have a very strong position in the computer graphics. They are getting more popular even in the field of erosion simulation, where the volumetric representation used to prevail. The real-life erosion scenes are usually formed of multiple materials and so a reliable means of material definition is needed. This paper proposes several easy-to-use approaches for multiple material definition, based on the space subdivision. Binary space partitions are used to simulate complex multi-material scenes. The approach allows the definition of a nontrivial scene composed of several materials, including the definition of gradually changing material.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Boundary representations

1. Introduction

Surface triangle meshes are becoming more and more popular in various fields of research, such as medical applications, architectural design or gaming industry. Material properties usually have to be assigned to the mesh to describe its visual appearance or to define its structure, which is necessary for applications working with the haptic feedback.

A multi-material scene is commonly represented as a set of non-intersecting 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.

We propose a material description approach suitable for the use in dynamic simulations. Our method uses binary space partitions (BSP) to define the different materials in the scene, with an optional definition of a distance function to represent a continuous change of the material. We simulate the erosion forces by the smoothed particle hydrodynamics (SPH) [GM77] particles in a way similar to the approach used by Krištof et al. [KBKS09], but any other erosion simulation could be easily used as well.

2. Related Work

Most of the work on domains with multiple materials focus on extracting a correct and consistent mesh for each of the materials present in the volumetric data obtained, e.g., from a medical scan. Wu and Sullivan [WS03] enhanced the marching cubes algorithm to reconstruct multiple material meshes. Zhang et al. [ZHB10] generate the mesh using an octree-based isocontouring method. Wang [Wan11] generates the mesh surfaces using a ray representation of a solid as an intermediate structure. These approaches are suitable for static scenes, where the domains 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 size mix up to form a river bank, that is being eroded by the flowing water. We could describe such a scene using a volumetric approach similar to the one used by Benes et al. in [BTHB06]. The volumetric representation is very memory consuming, a layered data representation introduced by Benes and Forsbach [BF01] 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 gradually changing material, it converges back to the volumetric representation.

A different approach is used by Tychonievich and Jones in [TJ10], where a Delaunay deformable model is used to represent the eroded terrain and the material is defined for each cell of the Delaunay triangulation. A new mesh is generated every iteration of the method and the material properties have to be reconstructed using the resemblance of the two meshes.

The proposed solution represents the scene with a surface mesh for each individual object in the scene, regardless of the object material. The material is then assigned through a separate BSP structure, defining the material volume throughout the scene.

3. Multiple Material Meshes

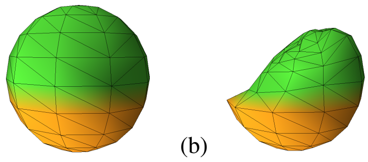
A real-life scene is composed of objects made of different materials. Objects made of different materials are eroded in a different way; hard and resistant materials are eroded slowly, while the erosion of soft materials is happening much faster. To be able to simulate such phenomena, we need means to 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 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 ways 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 partitions (BSP). We describe the methods in the following text.

3.1. Material in a Vertex

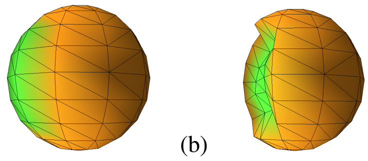
The most simple way to define multiple materials for a single mesh is to assign material properties to each individual vertex. This approach is very easy to implement, however, it brings many disadvantages as well. Storing material properties for each vertex takes up a lot of memory. Furthermore, this kind of material definition applies only to the surface of the object, not to the volume. Using this approach, the result of the 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. Figure 1 shows an object made of two different materials. The orange material is hard and sturdy, while the green material is soft and easily erosible. Figure 1b captures the result of the erosion simulation.

The disadvantage of the approach is insinuated in Figure 2. This time the boundary between the materials is perpendicular to the erosion direction. Figure 2b shows that the soft green vertices have been eroded past the boundary between the materials; assuming that the boundary was supposed to be straight. This is the main downside of the method, the fact, that we have no information about the volume of the material, we operate only with the surface.



(a) (b)

Figure 1: *Material properties assigned to each vertex (a), erosion applied from the left gives correct results (b).*

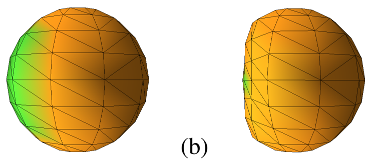


(a) (b)

Figure 2: *Material properties assigned to each vertex (a), erosion applied from the left gives incorrect results (b).*

3.2. Division by a Plane

The problem of the previous approach can be reduced, if we define the material properties for the whole volume of the scene, using a plane to separate different materials. Figure 3 shows the situation from Figure 2, but the material definition is done by the dividing plane. Material is then assigned not to each vertex, but is dynamically determined based on the eroded vertex location during the simulation. The simulation gives the expected result, as shown in Figure 3b.



(a) (b)

Figure 3: *Material defined by a dividing plane (a), correctly eroded model (b).*

This approach allows us to simulate a simple terrain composed of several materials, imitating the layering nature of the terrain. Figure 4 captures a simple terrain composed of two materials. The hydraulic erosion is simulated using the SPH particles, which erode the upper layer of soft material, exposing the underlying hard one (Figure 4b).

A similar approach is used in the work of Tychonievich and Jones [TJ10], where the authors define the toughness of the material as a function of the z-coordinate. They demonstrate the results on an example of water flowing through a rock canyon, eroding its soft sides and the bottom made of tougher material (Figure 5). We modeled a similar scene, the results are shown in Figure 6.

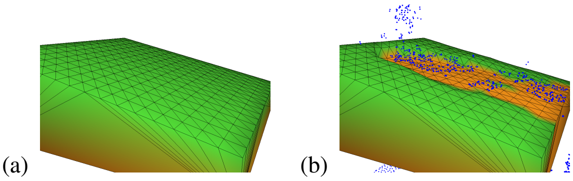


Figure 4: *Material defined by a dividing plane (a). Hydraulic erosion is simulated by the SPH particles (b).*

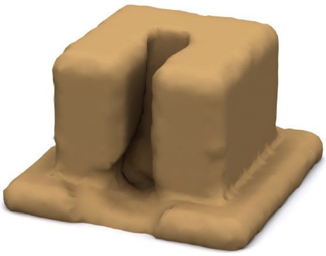


Figure 5: *Water erodes the sides of the canyon [TJ10]*

3.3. Division by a Function

The division by a plane can imitate the material distribution of a simple small-scale scene, however, in bigger scale, the boundary between materials will usually not be linear. To simulate a more complex boundary, a division function may be used. This approach allows us to describe a non-linear boundary analytically, without the use of a memory demanding data structure such as the volumetric approach. Figure 7 shows a demonstrative example of the function division approach. The terrain starts as a plane and is eroded by the water particles. The boundary between materials is defined by Equation 1 for Figure 7a and by Equation 2 for Figure 7b. The downside of this approach is the need to enumerate the function for each eroded vertex to determine the material. Also, it may be very difficult to describe a complicated boundary with a single division function.

$$z = \cos\left(\frac{x}{2} + \frac{y}{3}\right) - \sin\left(\frac{y}{3}\right) - \frac{x}{3} + 9; x, y, z \in \mathbb{R} \quad (1)$$

$$z = \sin\left(\sqrt{x^2 + y^2}\right) - \frac{x}{3} + 9; x, y, z \in \mathbb{R} \quad (2)$$

3.4. Binary Space Partitions

To simulate more complex distribution of the material, we are using binary space partitions (BSP). This approach extends the method described in Section 3.2 and allows us to split the scene up into more parts, using multiple division planes. The division planes are stored in a binary tree, each

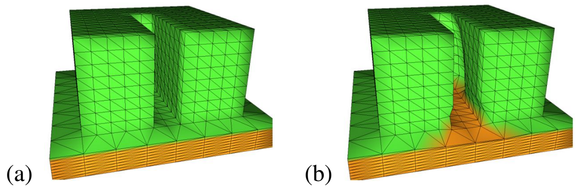


Figure 6: *Canyon erosion. Original (a) and eroded mesh (b)*

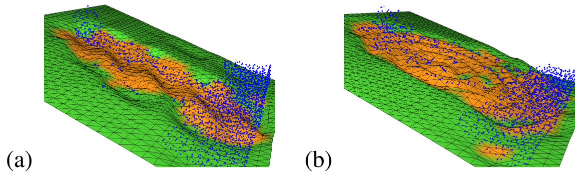


Figure 7: *Division defined as Eq. 1 (a) and Eq. 2 (b)*

leaf of the tree containing the information about the material of the subspace delimited by the corresponding planes. To decide which material should be assigned to a vertex, we need to search the BSP tree and determine for each level of the tree, on which side of the division plane the vertex lies. When we reach the leaf of the tree, we have found the subspace the vertex belongs to. The BSP approach is much more memory efficient than the commonly used volumetric representation, as the memory consumption depends on the number of blocks of different materials, not on the size or complexity of the mesh itself.

Figure 8 shows an example of BSP material definition. The scene has been divided into 16 spatial cells, each one has been assigned a random unique material. Darker color of the mesh marks the regions made of a tougher material; the lighter the color, the less durable the material is. As can be seen in Figure 8, the parts of the mesh made of less durable material are being eroded much faster than the the regions made of a tougher one.

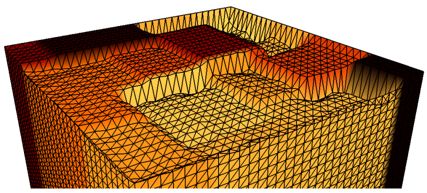


Figure 8: *Material defined via BSP. Softer material gets eroded faster than the tougher one.*

We can also extend this method to support the definition of a gradually changing material to be able to represent materials blending into each other, such as sand and pebbles at a river bank. This is achieved by the addition of a distance function. The material properties are computed based on the distance of the eroded vertex from the division plane. An example can be seen in Figure 9. In this instance, the toughest material is assigned to the vertices on the division planes, as we move farther from the planes, the material gets softer.

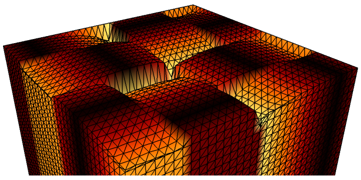


Figure 9: *Material defined via BSP and a distance function.*

The two aforementioned approaches can be combined as seen in Figure 10. Each spatial cell has been assigned a random unique material. With growing distance from the division plane, the material grows weaker. The division planes do not need to be axis-aligned, any plane can be used. An example of BSP using general planes and a distance function is shown in Figure 11.

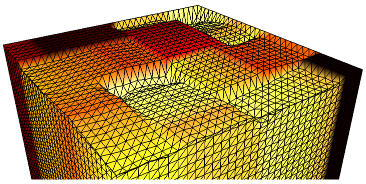


Figure 10: *Material defined via BSP and a distance function with unique properties for each spatial cell.*

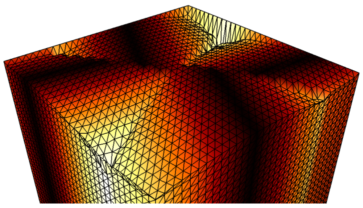


Figure 11: *BSP material definition using general planes.*

4. Results and Discussion

We have implemented and tested the discussed methods of multiple material definition for triangle meshes. We have confirmed the applicability of the methods for the use in simple erosion simulation scenarios, while having very low memory requirements. However, for big and complex scenes, the use of the proposed methods may be troublesome as the definition of the division planes by hand would be complicated and time-consuming.

5. Conclusion

The erosion simulation is a very important topic of computer graphics. More and more often, triangle meshes are used to represent the eroded terrain. Means to simulate the erosion of scenes composed of various materials are needed, but the commonly used approach of integrating the material properties with the vertices of the mesh may not be appropriate.

We have proposed a multiple material definition method based on the use of binary space partitions (BSP). The BSP tree subdivides the scene into cells and we define the material for each of them separately. The approach also supports the definition of gradually changing material through the use of a distance function.

Our solution is suitable for the use in scenarios composed of several types of material, where it is possible to define the splitting planes by hand. For very complex scenes, the BSP definition by hand would be tiresome. For future work, we would like to design an automatic function for the detection of the splitting planes.

Acknowledgements

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References

[BF01] BENES B., FORSBACH R.: Layered data representation for visual simulation of terrain erosion. In *Computer Graphics, Spring Conference on, 2001.* (2001), IEEE, pp. 80–86. 1

[BTHB06] BENEŠ B., TĚŠÍNSKÝ V., HORNYŠ J., BHATIA S. K.: Hydraulic erosion. *Computer Animation and Virtual Worlds 17*, 2 (2006), 99–108. 1

[GM77] GINGOLD R. A., MONAGHAN J. J.: Smoothed particle hydrodynamics - Theory and application to non-spherical stars. *Monthly Notices of the Royal Astronomical Society 181* (Nov. 1977), 375–389. 1

[KBKS09] KRIŠTOF P., BENEŠ B., KŘIVÁNEK J., ŠŤAVA O.: Hydraulic erosion using smoothed particle hydrodynamics. *Computer Graphics Forum (Proceedings of Eurographics 2009) 28*, 2 (2009), 219–228. 1

[TJ10] TYCHONIEVICH L. A., JONES M.: Delaunay deformable mesh for the weathering and erosion of 3d terrain. *The Visual Computer 26*, 12 (2010), 1485–1495. 1, 2, 3

[Wan11] WANG C. C.: Computing on rays: A parallel approach for surface mesh modeling from multi-material volumetric data. *Computers in Industry 62*, 7 (2011), 660–671. 1

[WS03] WU Z., SULLIVAN J. M.: Multiple material marching cubes algorithm. *International Journal for Numerical Methods in Engineering 58*, 2 (2003), 189–207. 1

[ZHB10] ZHANG Y., HUGHES T. J., BAJAJ C. L.: An automatic 3d mesh generation method for domains with multiple materials. *Computer methods in applied mechanics and engineering 199*, 5 (2010), 405–415. 1