Efficient and Seamless Volumetric Fracturing

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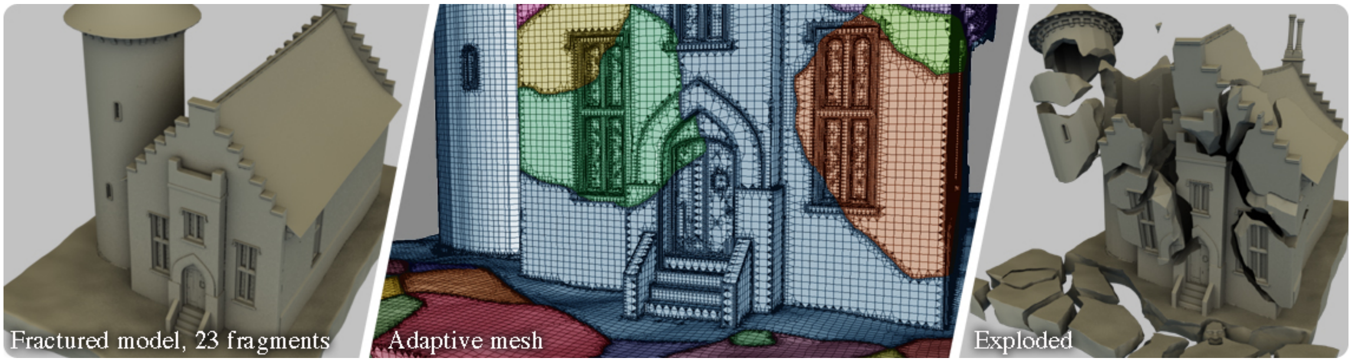
DreamWorks Animation *



Introduction

We present a novel framework for seamless volumetric fracturing that offers significant advantages over existing methods. Our approach is based on new memory-efficient data structures and fast parallel algorithms that, for the first time, make seamless volumetric fracturing practical for large-scale destruction in a VFX production pipeline. Production tests comparing our new framework to [Garg and Maxwell 2010] using grids of equal resolution show that our approach is $40\times$ faster, delivering higher quality and adaptive meshing at a fraction of the memory footprint.

Overview

Fracturing is an integral part of most VFX pipelines today. The desire for larger-scale destruction is constantly pushing the development of these fracture tools. As such there is a large body of previous work on fracturing, the simplest employing Voronoi diagrams to define clipping planes for polygonal models. While these methods are fast and robust, they often suffer from limited artistic control and produce a recognizable faceted look. Alternatively, many have tried to develop fracture tools based on polygonal constructive solid geometry (CSG) algorithms, but these have proven to be rather sensitive to the quality of the input mesh and generally complex to implement. This has led some to explore implicit surface representations, which support robust CSG. This also forms the foundation for our work.

Conceptually our approach combines the best features from two previous volumetric fracture systems: [Museth and Clive 2008], which introduced fast and compact level set based fracturing, and [Garg and Maxwell 2010] which offered seamless (but slow) fracturing by means of the so-called Hermite data representation proposed in [Ju et al. 2002]. In addition, our approach exploits the acceleration features of a new hierarchical volumetric data structure, and it is heavily multithreaded.

In CrackTastic [Museth and Clive 2008], narrow-band level sets are used to implement an efficient and robust fracturing tool, but it often fails to preserve sharp surface features. The conversion of polygonal models to level set representations results in a low-pass filtering of surface details, which can lead to visible seams between fragments and loss of sharp detail. To address this issue, [Garg and Maxwell 2010] used higher-order Hermite information for CSG, an idea originating from [Ju et al. 2002]. This approach enabled high fidelity surface reconstruction with seamless cuts, but introduced significant computational and memory costs.

Our Approach

A compact and efficient volumetric data representation is achieved through the use of our in-house sparse volume data structure, VDB [Museth 2013] which offers extreme resolution, low memory footprint, fast random access and hierarchical acceleration of CSG. The memory footprint is further reduced by bit-compressing the high-order Hermite data by about $5:1$ with almost no time overhead. This compact representation is used to derive a toolset of new efficient parallel algorithms for mesh-to-Hermite scan-conversion, Hermite CSG, and Hermite-to-mesh reconstruction. Our algorithms are robust with respect to non-manifold surfaces with self-intersections and inconsistent surface normals and can extract adaptive meshes directly from the Hermite data without the need for any post-processing steps as in [Museth and Clive 2008] and [Garg and Maxwell 2010]. Additionally, the CSG operations take full advantage of VDB's hierarchical tree structure to perform interactive boolean operations directly on the compressed data.

Our fracture toolkit is integrated into Houdini[1] and takes full advantage of that package's procedural paradigm to offer a flexible work flow and artistic control over the final fracture look. The toolkit consists of a small set of nodes that each perform a specific task, e.g. scattering cutter objects or CSG operations, and can be chained together in different ways to produce complex fracturing effects.

	Our approach	[Garg and Maxwell 2010]
Mesh-to-Hermite	5.6s	1m 17s
Hermite CSG	11.65s	3m 16s
Hermite-to-mesh	2.39s	8m 38s
Reconstructed mesh	296583 faces	408841 faces
Volume size	48 MB	462 MB

Table 1: *Performance comparison. A polygonal model consisting of* 173734 *primitives is represented with high-order Hermite data on a* $600\times 56\times 283$ *voxel grid. The model is fractured into* 30 *fragments using CSG operations.*

References

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JU, T., LOSASSO, F., SCHAEFER, S., AND WARREN, J. 2002. Dual contouring of Hermite data. *ACM Trans. Graph. 21* (July), 339–346.

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[1]Procedural 3D animation package from Side-Effects Software.