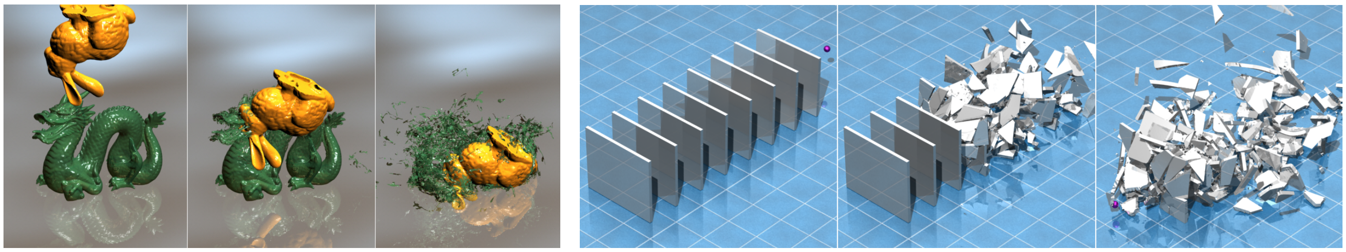
FASTCD: Fracturing-Aware Stable Collision Detection

Jae-Pil Heo[1], Duksu Kim[1], Joon-Kyung Seong[1], Jeong-Mo Hong[2], Min Tang[3], and Sung-Eui Yoon[1]
[1] KAIST [2] Dongguk University [3] Zhejiang University



(a) Exploding Dragon Benchmark (b) Breaking-Wall Benchmark

Figure 1: *These figures show two complex and large-scale fracturing benchmarks that have topological changes. (a) Three frames of a breaking dragon benchmark that consists of 252 K triangles throughout the simulation. (b) Three frames of a breaking-wall benchmark that starts with 42 K triangles and ends with 140 K triangles. Our method spends 252 ms and 97 ms for discrete collision detection including self-collision detections of these dragon and wall benchmarks respectively by using a single CPU-thread. Moreover, we show a more stable performance by achieving up to two orders of magnitude performance improvement at fracturing events where deforming meshes change their topologies.*

1 Introduction

Simulating complex phenomena such as fracture requires collision detection (CD) methods to avoid any inter-collisions among deforming models and self-collisions (i.e. intra-collisions) within each deforming model. CD is typically the main computational bottleneck of simulating such complex phenomena.

CD methods are commonly accelerated by using bounding volume hierarchies (BVHs) constructed from deforming models. BVHs of deforming meshes should be updated as deforming meshes change their geometry and topology. At fracturing events, the geometry and topology undergo more drastically changes. Therefore, BVHs at fracturing events become to have lower culling efficiencies, degrading the performance of CD more significantly. As a result, users may experience noticeable performance degradations at such fracturing events. Therefore, large-scale fracturing simulations have not been widely employed in various interactive applications, because of their unstable performances, which are critical problems for interactive applications.

2 Our Method

In this work, we propose a **F**racturing-**A**ware **ST**able **CD** (FASTCD) method for complex and large-scale fracturing models that have geometric and topological changes, in order to achieve a stable and fast performance for CD including self-collision detection. Our FASTCD method relies on three main contributions: 1) a novel culling method to improve the performance of self-collision detection, 2) a selective BVH restructuring method based on a novel cost metric, and 3) fast BVH construction method.

We present a novel culling method, *Dual-Cone* method, for self-collision detection. Our dual-cone method is inspired by two sufficient conditions for self-colliding surface proposed by Volino and Thalmann [Volino and Thalmann 1994]. The time complexity for checking these conditions was $O(n^2)$ at worst case, where n is the number of triangles of given surface. We use two cones to reduce the overhead to examine whether the surface can have self-collisions or not. Our dual-cone method has $O(1)$ time complexity and is efficient even when deforming models have drastic geometric and topological changes.

At fracturing events, the geometry and topology undergo drastically changes. Therefore, culling efficiencies of BVHs of fracturing models can be significantly lowered. In order to maintain high-quality BVHs, we restructure sub-BVHs which have low culling efficiency. In order to detect such sub-BVH, we define a novel cost metric that measures expected number of BV overlap tests performed recursively identify self-collisions and inter-collisions. We also consider the potential benefit and the potential performance loss due to restructuring. We do restructuring only when the benefit is expected to be larger than the overhead.

Even though we perform selective restructuring for fracturing models, it may take a huge amount of time to reconstruct sub-BVHs

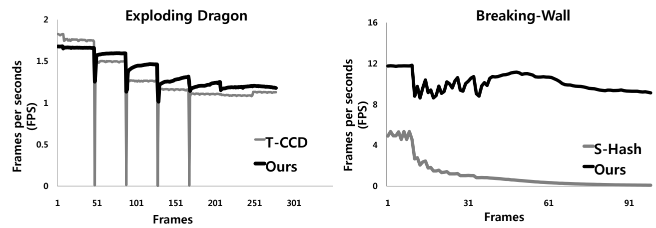


Figure 2: *Left figure shows frame rate graphs of continuous CD for the exploding dragon benchmark with Tang et al.'s method (***T-CCD***), and our method (***Ours***). Right figure shows frame rate graphs of discrete CD for the breaking-wall benchmark with Teschner et al.'s method (***S-Hash***), and our method (***Ours***).*

for complex fracturing models as shown in Fig. 1. This can cause the overall CD method to be unstable, because the performance degradations from the reconstruction can be very high. In order to overcome this problem, we propose a fast BVH construction method based on grid and hashing, instead of heavily relying on expensive sorting techniques, which are commonly used in most $O(nlogn)$ construction methods.

3 Result

As can be seen in the left graph of Fig. 2, our method (**Ours**) shows a more stable performance even when deforming models change their topology. On the other hand, **T-CCD** [Tang et al. 2008], one of the-state-of-the-art techniques for deforming models, shows drastic performance degradations at such cases. More specifically, our method improves the continuous CD performance by a factor of 260 times over **T-CCD** method at frames where deforming models change their topologies. The more graceful performance degradation of our method is due to our selective restructuring method that also uses our fast BVH construction method.

We also compare the discrete CD performance of our method with that of **S-Hash** [Teschner et al. 2003], one of most widely used techniques for volumetric fracturing simulations. Our method (**Ours**) runs 20 times faster in the breaking-wall models (right graph of Fig. 2). The inferior performance of **S-Hash** is mainly because many parts of fracturing models come in a close proximity, causing many grid cells to have multiple triangles.

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