Research Statement

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Over the past few decades, simulating physically accurate natural phenomena has become an integral part of motion pictures, visual effects (VFX) and the game industry. Outside computer graphics, physics-based modelling is essential for numerous engineering applications such as the structural evaluation of water dams and aircraft bodies. During PhD, I investigated various aspects of physics-based realistic fracture simulation.

The existing fracture simulation algorithms [1] [4] incur additional computational costs for each new crack discontinuity in terms of additional degrees of freedom (DOF) or remeshing. The goal of my research is to develop a novel technique that should run independently of the number of cracks. To that end, I proposed a graph-based Finite Element Method (FEM) for remeshing-free fracture simulation [2]. When a fracture occurs, instead of remeshing or introducing extra DOFs in the system matrix, Graph-based FEM reformulates the internal elastic energy of a mesh to simulate the independent movements of disjoint segments produced due to material disintegration. Correspondingly, the system matrix size of graph-based FEM remains constant throughout the simulation making it much faster than state-of-the-art fracture techniques. Thus, on one hand, graph-based FEM adds negligible computational overhead compared to regular FEM and on the other, is capable of rendering fracture for a wide range of materials — brittle & ductile, isotropic & anisotropic.

Using a random graph technique, I extended graph-based FEM to demonstrate how material impurity affects crack propagation in object mesh [3]. Our probabilistic damage mechanics can capture the variation in material strength and corresponding fracture pattern inside an object. Finally, random graph-based impurity modelling inspired us to develop a framework that enables an artist to embed any kind of fracture pattern on a volumetric mesh.

To evaluate the effectiveness of our proposed algorithms, I built an interactive virtual sculpting framework by combining our graph-based FEM with Galerkin multigrid method [5]. Our framework can simulate complex cutting and fracture of high-resolution meshes ($\sim$ 300k tetrahedron elements) at an interactive rate ($\sim$ 30 frames/sec). To augment the user experience, our sculpting framework renders faithful haptic feedback also and provides multiple tools to perform various mesh manipulation operations e.g., deforming, cutting, grooving etc.

In the course of my PhD, I acquired theoretical knowledge in multiple diverse disciplines. I am also trained to program in different languages like C, C++, Python and am comfortable handling various APIs such as OpenGL, CUDA.

I have rudimentary exposure to various rendering software like Houdini and Blender.

I have multiple interesting ideas in my mind for potential future work. I am actively exploring different machine/deep learning-based frameworks to model our graph-based FEM fracture. I wish to work on the rich theoretical model of graph-based FEM and develop a better mathematical paradigm for reformulating internal strain energy due to fracture. However, I am open to work on any intriguing research problem in the field of graphics, mechanics and geometry.

References

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