

# Avatar : Bending Rigid Bodies

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Figure 1: Figure: Avatar (c) Industrial Light & Magic. All rights reserved.

## 1 Introduction

Simulating bending and denting of rigid materials has become an increasingly important aspect for modeling the realistic destruction of objects. Historically, modeling these phenomena has been a tedious and time consuming process for the artists at Industrial Light & Magic. Typically the artists would manually shape the rigid bodies after the simulation to produce this realistic look. However, for the movie *Avatar*, we have developed a new system that seamlessly transitions between rigid and deformable simulations allowing the artists to achieve realistic destruction without the need to apply any post corrective shapes.

To solve this problem, we used a low resolution spring-mass simulation as a pre-processing step to the rigid body simulator. At the start of the simulation, a tetrahedral and thin shell representation of the rigid bodies was initialized as a spring cage to model the surface deformations during the rigid simulation. At the beginning of each relevant frame, the cages were advanced using a spring-mass simulator and their resulting deformations were transferred to the surface of the rigid bodies. After all the objects are processed, the rigid bodies were advanced using a rigid body simulator. The results allowed for a quick and realistic deformation of rigid bodies that could be used for complex scenes such as those shown in Figure 1.

## 2 Mesh Generation

During initialization of the simulation we automatically generated a tetrahedral mesh to represent the interior region of the rigid body. The tetrahedral mesh and the triangulated surface of rigid body were initialized as a set of deformable objects that were connected through a series of springs. The tetrahedral mesh defines a set of volumetric altitude springs that controlled the restorative properties of the rigid body volume, and the rigid body surface defined a set of surface tension springs that provided controls over surface bending and stretching properties. We also created a set of alignment springs to connect the volumetric and surface springs. For stability and robustness we used unconditionally stable springs allowing us to take rather large time steps.

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## 3 Simulation

At the beginning of each frame, each rigid body was analyzed to determine which objects might interact due to collisions or other interacting forces. The simulation system collects the potential impulses between objects and determined which rigid objects needed to be simulated as deformable objects. Any objects that are not interacting with other objects in a significant way remained rigid bodies during the deformable evolution.

Next the solver advanced the deformable objects and all non-deforming rigid bodies. If the deforming surfaces experienced a noticeable change, the rigid bodies were updated from the resulting deformations to reflect changes in the surface and mass distribution. We note that for this advancement, the frame length and time step size were set separately from the standard frame length of the final rigid body evolution. The length of the deformable evolution was adjustable so it could run slightly longer than a standard animation frame, allowing for more exaggerated deformations.

During the deformable evolution, all simulation objects needed to experience the same forces and constraints that effected their associated rigid bodies. This required the consideration of all our existing constraints currently used by the artists. The deformable cage could be effected by wind, pulled by stiction, frozen within the clustering system, and attached to the various other simulation controls. The addition of the external controls allowed the resulting deformations of rigid bodies to accurately reflect its simulation environment.

After the deformable evolution, the solver was rewound to the beginning of the frame with the modified rigid bodies. Finally, the rigid objects were simulated to process the collisions and constraints on the updated surface.

**Special thanks to : Ron Fedkiw, Michael DiComo, Karin Cooper**

## References

- BRIDSON, R., MARINO, S., AND FEDKIW, R. 2003. Simulation of clothing with folds and wrinkles. 28–36.
- GUENDELMAN, E., BRIDSON, R., AND FEDKIW, R. 2003. Nonconvex rigid bodies with stacking. *ACM Trans. Graph. (SIGGRAPH Proc.)* 22, 3, 871–878.