Adaptive Tearing and Cracking of Thin Sheets

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This is an *easy-read* summary of a **SIGGRAPH**2014

Technical Paper

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While the simulation of fracture dynamics has a long history in computer graphics, reproducing the variety and detail of fracture patterns observed in real-world materials remains a difficult problem. Many of the objects exhibiting interesting breaking behavior can be well approximated using thin-shell models represented as triangle meshes…

The distinctive crack patterns observed in many materials arise due to small-scale interactions between elastic strain, plastic yielding, and material failure. Stress gradients can be very large near the crack tip where the stress field often approaches singularity… Subsequent coarsening … avoids continually increasing computational cost and keeps overall simulation times reasonable. Adaptive mesh refinement also permits nearly arbitrary crack paths by removing… the triangles…

The use of aggressive adaptive remeshing in conjunction with fracture simulation introduces some challenges:… spurious crack initiation, unrealistic crack boundaries, and loss of shape…

Overview

> Simulation Loop
> We perform our simulation on a triangulated mesh. Each vertex has a position in undeformed reference space **u** and in world space **x**, and a velocity **v**. Each face stores a thickness **h**, and the plasticity tensors $\mathbf{F}_p$ and $\mathbf{S}_p$ … stretching and bending plasticity. … At each timestep … to obtain an updated velocity and position for each vertex, and collisions are handled. Next, we account for plastic yielding by updating … plasticity tensors… Based on the updated configuration, we can now evaluate the fracture criterion, and split the mesh where the material fails… To ensure good resolution during the fracture process, the mesh is also remeshed locally around the opened cracks in each substep. After the fracture substepping is complete, a global remeshing step is performed for the whole mesh. This step coarsens around newly formed cracks once the local stress is relieved, and regulates triangle size in regions of the mesh where no fracture is active...

Elasticity Model

Our elasticity model… embeds the reference shape in three dimensions so that we can represent … shapes, such as spheres… The deformation gradient $\mathbf{F} = \nabla_{\mathbf{u}}\mathbf{x}$ is thus a 3 × 3 matrix…

Fracture and Plasticity

Fracture Model

… Fracture occurs due to concentrations of stress, so at each timestep we evaluate stress at each node of the mesh… we first need to find the optimal splitting plane which would maximally relieve the stress around that vertex… By formulating a computable measure of that relief, we can solve a small optimization problem to find the appropriate splitting plane… Given a potential splitting plane, we can calculate the traction across the plane using the path integral along the disc boundary...

Plasticity

To be able to simulate materials such as sheet metal, we need to represent plasticity of both tensile and bending stress… The measured total deformation gradient $\mathbf{F}$ of a triangle is multiplied with a per-triangle plasticity matrix, yielding the elastic deformation gradient $\mathbf{F}_{\mathbf{el}}$… To represent the thinning of plastically stretched material, the per-triangle thickness is updated in… the area toughness $\boldsymbol{\tau}$ from the volume toughness, and similarly the bending stiffness (thinned parts of the mesh … therefore bend and break more easily.)

Remeshing

… Through remeshing, we increase mesh resolution around the crack tip, maintain well-shaped elements as the fracture propagates, and coarsen the mesh in regions where stress is relieved. This allows complex crack patterns to be realistically produced without excessive computation elsewhere…

However, for a system that includes fracture modeling, artificial stresses can disturb the process of crack propagation and introduce spurious initiation sites. For stable results, therefore, it is essential to minimize artificial stresses caused by remeshing…

… An animator often may require a specific fracture behavior, such as cracks running in a particular direction or avoiding certain regions… An easy way to adjust crack paths is anisotropy. To make cracks in direction a more or less likely, the traction vectors… can be multiplied by a weakening matrix… Another way to influence crack behavior is to locally modulate the material's toughness…(material defects)... However, without a very high mesh resolution… as small features vanish within big triangles…

Get the complete paper:
http://bit.ly/s2014-paper-tearing
Catch the SIGGRAPH 2014 presentation:
Wednesday, 13 August; 2-330 pm
[ballroom A, East Building; VCC]

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