REAL-TIME FEM AND TRESSFX 4

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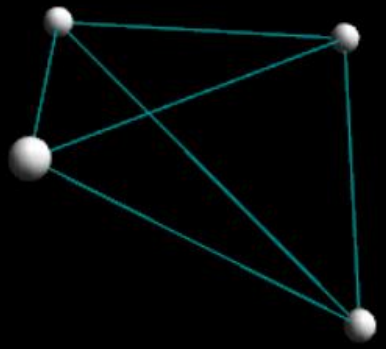
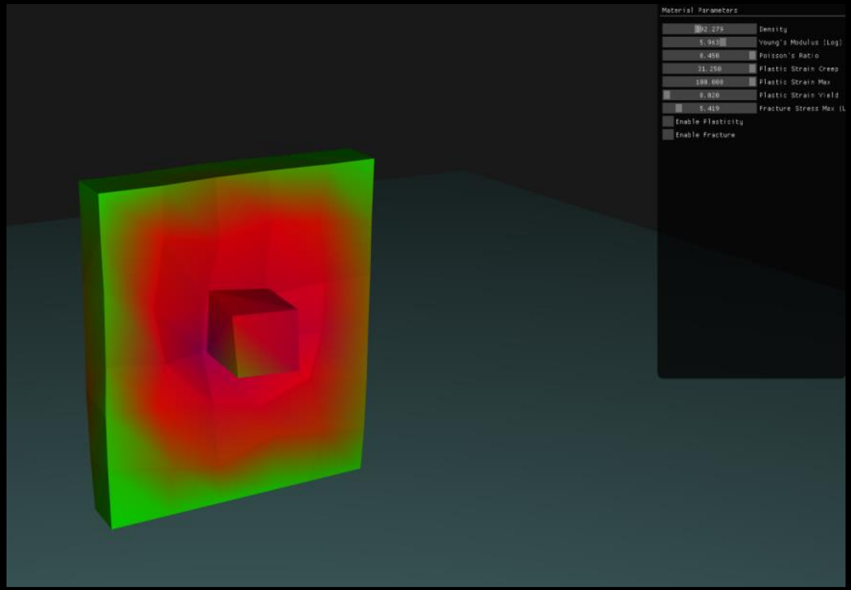
FINITE ELEMENT METHOD (FEM) SIMULATION

- Simulates soft to nearly-rigid objects, with fracture
- Models object as mesh of tetrahedral elements
- Each element has material parameters:
  - Young's Modulus: How stiff the material is
  - Poisson's ratio: Effect of deformation on volume
  - Yield strength: Deformation limit before permanent shape change
  - Fracture strength: Stress limit before the material breaks





MOTIVATIONS FOR THIS METHOD

- Parameters give a lot of design control
- Can model many real-world materials
  - –Rubber, metal, glass, wood, animal tissue
- Commonly used now for film effects
  - –High-quality destruction
- Successful real-time use in Star Wars: The Force Unleashed 1 & 2
  - –DMM middleware [Parker and O’Brien]

OUR PROJECT

- New implementation of real-time FEM for games
- Planned CPU library release
  - Heavy use of multithreading
  - Open-source with GPUOpen license
- Some highlights
  - Practical method for continuous collision detection (CCD)
  - Mix of CCD and intersection contact constraints
  - Efficient integrals for intersection constraint

STATUS

- Proof-of-concept prototype
- First pass at optimization
- Offering an early look for feedback
- Several generic components

CCD

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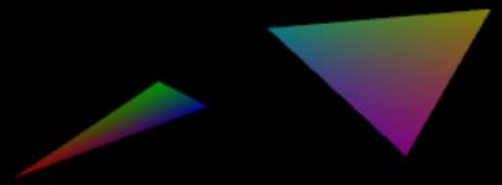
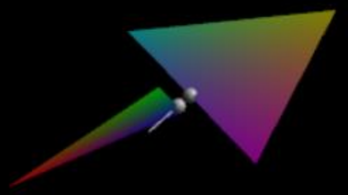
- Find time of impact between moving objects
  - –Impulses can prevent intersections [Otaduy et al.]
  - –Catches collisions with fast-moving objects
- Our approach
  - –Conservative-advancement based
  - –Geometric solution for degeneracies
  - –Allows gap between primitives
  - –Can limit steps or accuracy





INTERSECTION-BASED CONTACT

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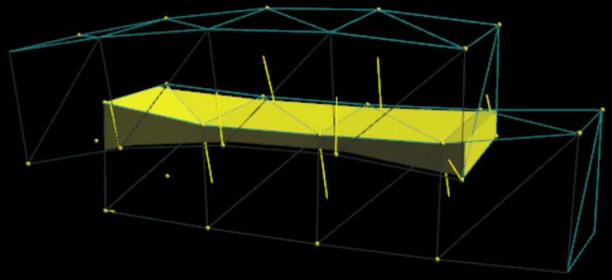
- Preventing all intersection is expensive
  - High solver accuracy
  - Multiple iterations of CCD, solving
- Can handle intersection with volume constraint [Allard et al.]
  - Need integrals over intersection surface faces
- Our approach
  - Sum over edges and vertices of intersection
    - Found during BVH traversal
    - No explicit intersection surface
  - Dependent on topologically robust polyhedral intersection [Smith and Dodgson]



SIMULATION PIPELINE

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Update Tet State:
- Rotation
- Stiffness
- Plasticity state
- Stress

Fracture Mesh:
- Split at tetrahedron faces
- Update mesh topology

Integration Solve:
- Implicit integration
- Assemble system matrix
- Solve with PCG

Build BVHs:
- Based on Radeon Rays
- Axis-aligned boxes with velocity bounds for CCD

Contact Solve:
- Create Jacobian matrix from contacts
- Nested Gauss-Seidel solves
- Correct velocity and step

Find contact islands:
- Group contacting bodies

Mesh Collision Detection:
- Compare mesh pair BVHs
- Sum integrals for intersection contacts
- CCD for distance contacts

Broad Phase:
- Find potentially colliding meshes
- Uses scene BVH

OPTIMIZATIONS

- Multithreading optimizations
  - Across meshes for tet state update, fracture, integration solve, BVH build
  - Across mesh pairs for CCD and intersection contact generation
  - Across contact island solves
  - Some parallelism within contact island
- Memory optimization
  - Pre-allocated memory using bounds on maximum meshes, vertices, etc.
  - Subdivision of memory for sub-meshes created by fracture

FUTURE WORK

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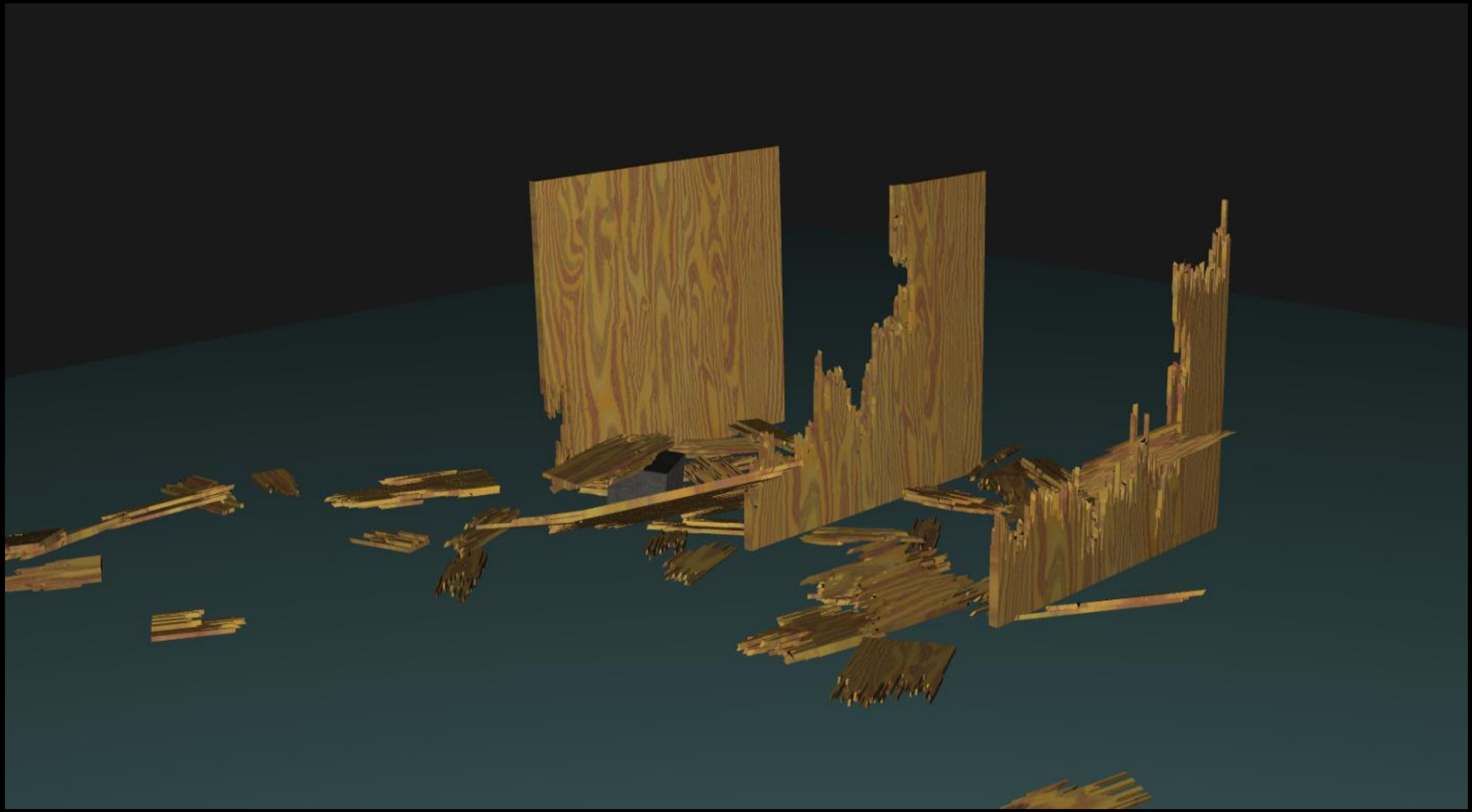
- Optimization
  - Parallelism on large islands and meshes
  - SIMD
- Improvements to solver
- Integrating FEM with rigid-bodies or cloth
  - Solver can support other dynamics models
  - Transition between FEM and rigid
- Content pipeline
- Rendering

WOOD FRACTURE EXAMPLE



REFERENCES

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- Baraff and Witkin, “Large Steps in Cloth Simulation” 1998
- Müller and Gross, “Interactive Virtual Materials” 2004
- Otaduy et al., “Implicit Contact Handling for Deformable Objects” 2009
- Miguel and Otaduy, “Efficient Simulation of Contact Between Rigid and Deformable Objects” 2011
- Allard et al., “Volume Contact Constraints at Arbitrary Resolution” 2012
- Ascher and Boxerman, “On the modified conjugate gradient method in cloth simulation” 2003
- Smith and Dodgson, “A topologically robust algorithm for Boolean operations on polyhedral shapes using approximate arithmetic” 2006
- Curtis et al., “Fast Collision Detection for Deformable Models using Representative-Triangles” 2008
- McAdams et al., “Computing the Singular Value Decomposition of 3x3 Matrices with Minimal Branching and Elementary Floating Point Operations” 2011
- Parker and O’Brien, “Real-Time Deformation and Fracture in a Game Environment” 2009

WHAT'S NEW IN TRESSFX 4.0 SIMULATION

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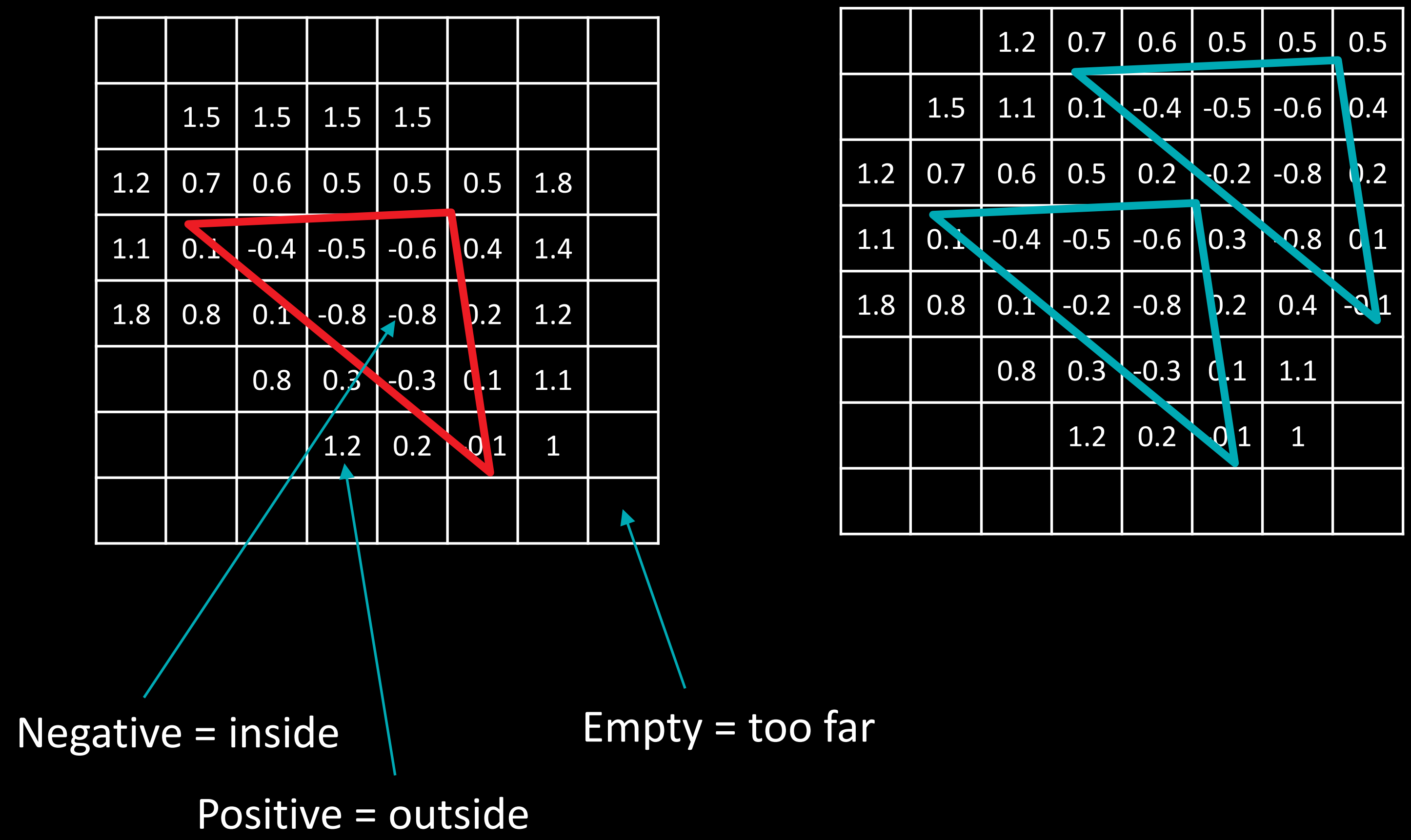
- SDF (Signed Distance Field)
- SSH (Sudden Shock Handler)
- Bone-based skinning
- Improved art tool
- Code Improvements

SIGNED DISTANCE FIELD

Input: Triangles

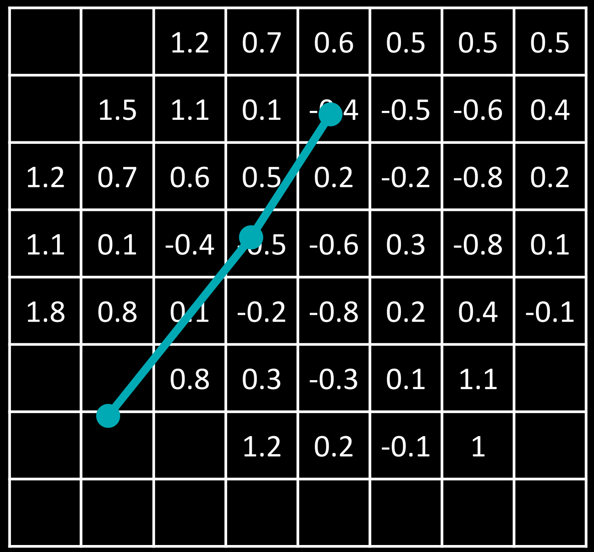
Output: 3D Grid of values

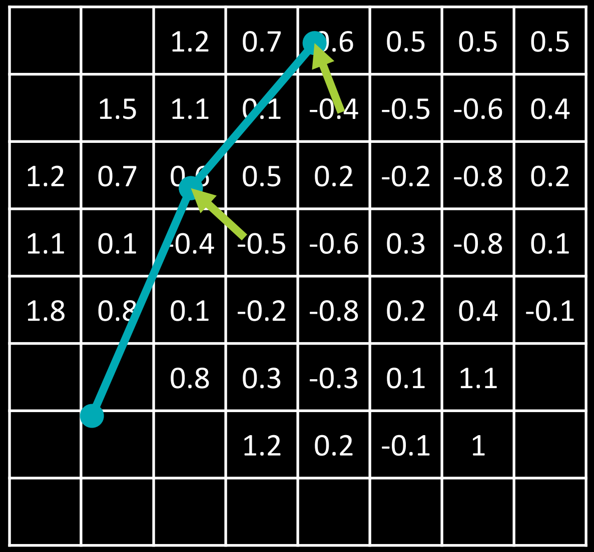


COLLIDE WITH HAIR

Input: Hairs + Grid

Output: Moved Hairs





- Check distance vs margin
- Compute gradient
- Project

```
// Compute SDF Gradient using forward differencing


//Project hair vertex out of SDF
float3 normal = normalize(sdfGradient);


if(distanceAtVertex < g_CollisionMargin)
{
 float3 projectedVertex =
      hairVertex.xyz + normal * (g_CollisionMargin - distanceAtVertex);
 g_HairVertices[hairVertexIndex].xyz = projectedVertex;
 g_PrevHairVertices[hairVertexIndex].xyz = projectedVertex;
}
```

SDF CHARACTERISTICS

- SDFs Independent of hair objects
  - Separate according to resolutions
  - Separate according to updates
- Cost proportional to
  - SDFs / hair
  - Number of hairs
- Cost of applying independent of mesh density

SDF IN THE DEMO

- Three SDFs (body-130x162x120, hands-46x45x36)
- Per frame generation from the skinned mesh (red) for moving character. ~2.0ms in our demo.
- Collision checking and response takes ~0.5ms

SIGNED DISTANCE FIELD EXTRAS

- For static objects, no cost for generation.
- Can be used for other purposes such as cloth.
- Can be visualized using Marching Cubes (yellow) for debugging.

SIMULATION

- Update collision mesh
- Update bone matrices
- Simulate
- Update with SDFs

FAST MOTION PROBLEM

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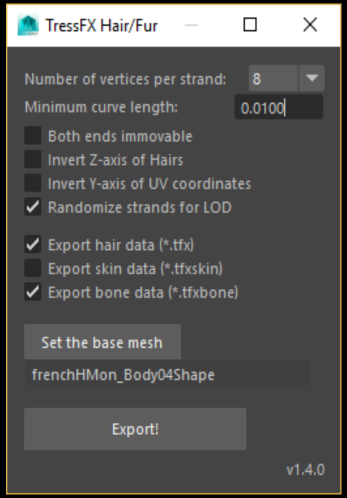
- Teleportation
- User Movements
- “Fixed” using
  - Increased iterations
  - Parameter tweaks
  - Hair “reset”

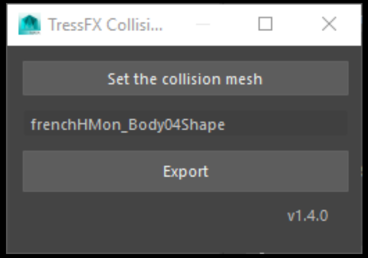
SSH (SUDDEN SHOCK HANDLER)

- Propagate acceleration
- Linear and Rotational
- Weight and Threshold
- Weight = 1
  - –Skinning only
  - –LOD

SKINNING CHANGES

- Maya® Exporter
  - –Computes weights from mesh
  - –Exports bone names
  - –Exports weights
- Can remap bone indices to match engine
  - –Optional (if Maya indices = bone indices, you’re done)
  - –Runtime or preprocess
- Hair roots skinned directly
  - –No intermediate mesh
- Bonus: Export skinned mesh (for SDF generation)





CODE IMPROVEMENTS

- Graphics through callbacks
  - GPU resource allocation, etc
  - “layouts” and “bindsets”
  - Transitions
- Shader code encapsulated in functions
- DX12 support
  - Async example

THANK YOU

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