Air Meshes

for Robust Collision Handling

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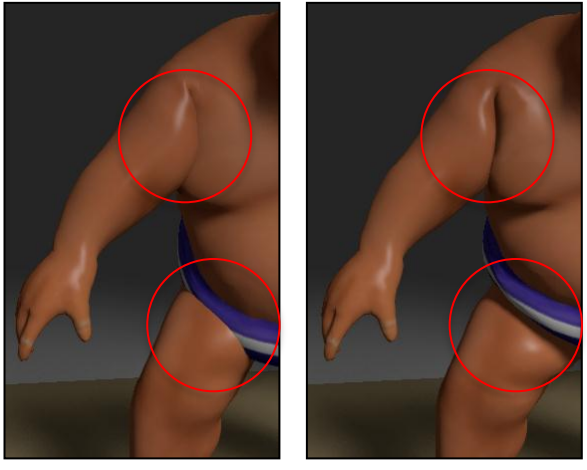
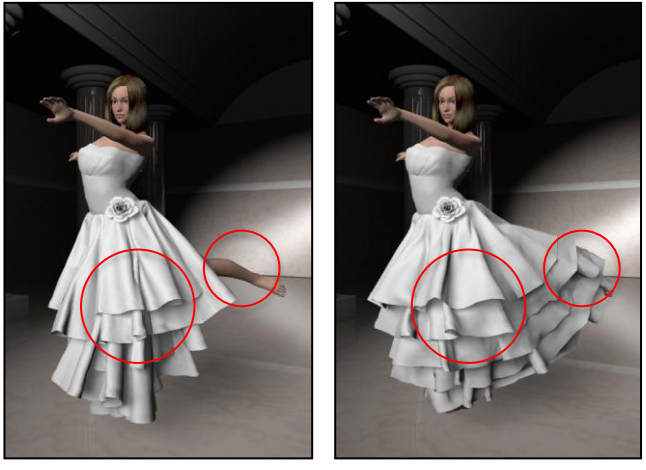
Motivation

Handling Collisions on Characters



Tissue Simulation

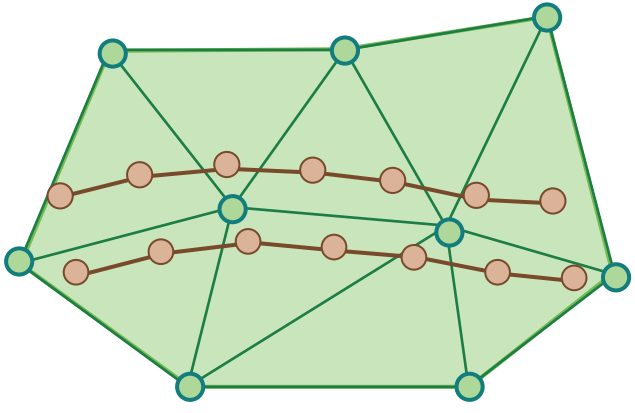


Clothing Simulation

Game Requirements

- Fast and simple
- Cannot guarantee a collision free state
  - Kinematic objects
  - Time limitation
- → Smooth recovery from any entangled state
- Suitable for GPU acceleration

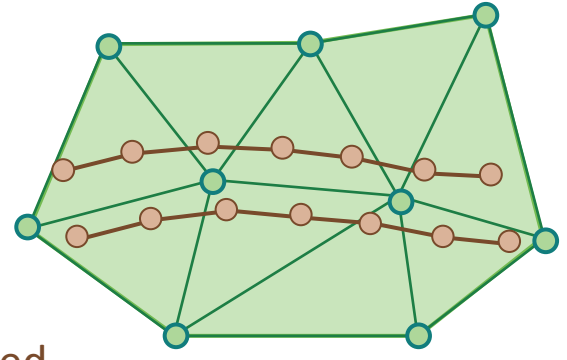
Embedding e.g. [Müller et al. 2004]



- Create enclosing tetrahedral simulation mesh
- Move cloth with the surrounding tetras

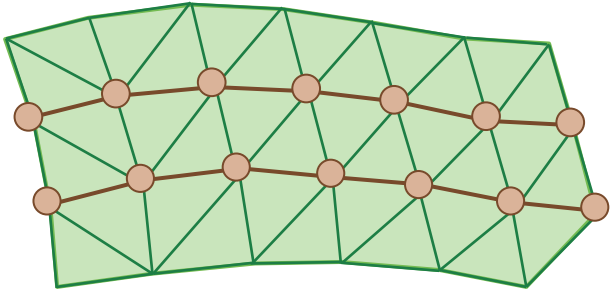
Embedding

- Pros:
  - Simple and fast
  - Untangling =
    handling inverted elements
  - No dynamic data structure for
    accelerating collision detection needed
- Cons:
  - Reduced flexibility (dof)
  - Influences cloth in collision free state



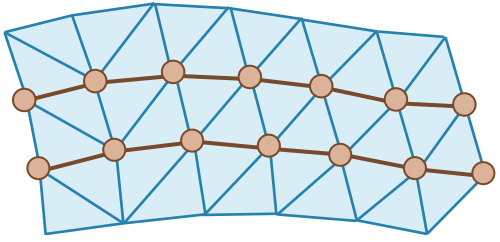
Fix Reduced Flexibility

- Let tetra vertices coincide with cloth vertices



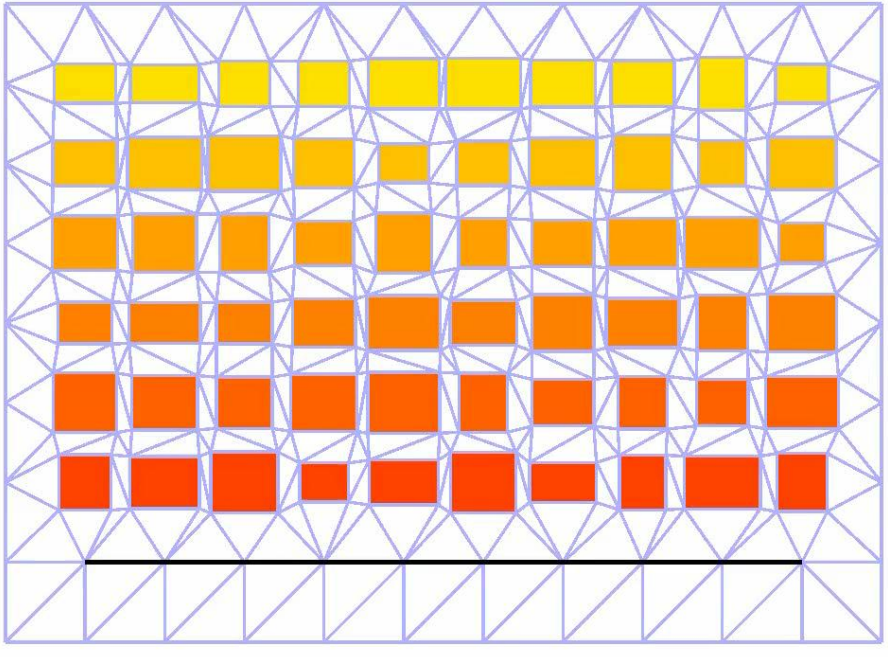
Remove Influence in Collision Free State

- Instead of elastic forces
- Use a constraint
  - Keeping the volume positive
  - Unilateral: Only active when the volume is negative!
- → Air mesh

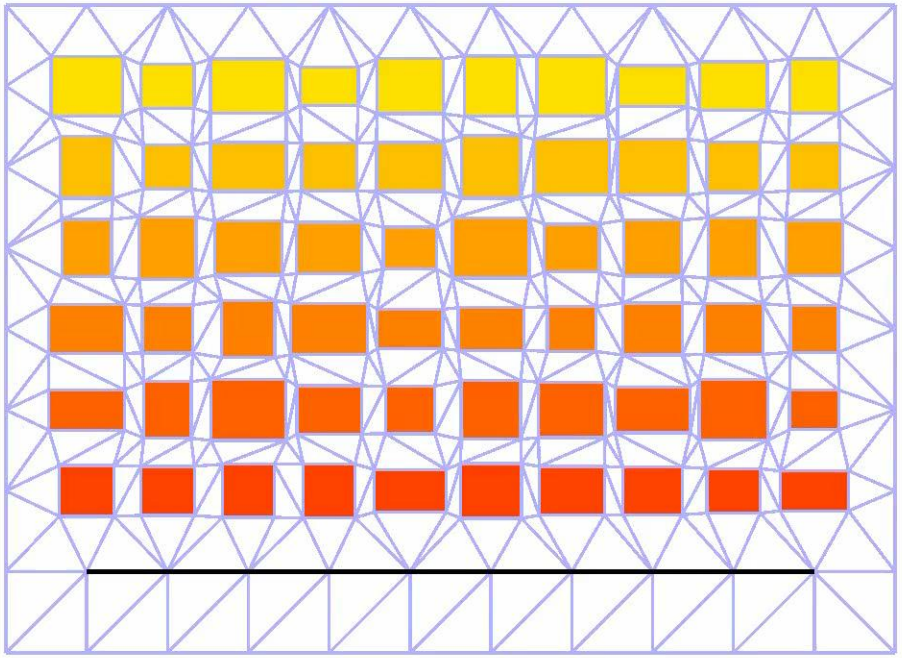


- Handles collision detection and response

2D Example

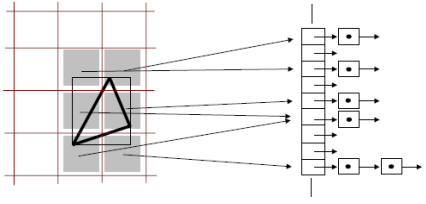


Recovery

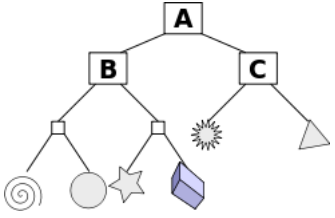


Related Work

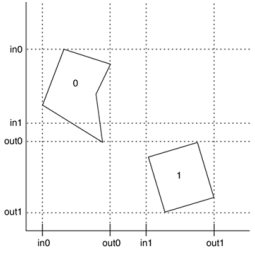
Collision Detection



Spatial Hashing
[Teschner et al. 2003]



Hierarchical
BVHs, BSPs, R-Trees



Sweep And Prune
[Baraff 1992]

- We: persistent triangle / tetrahedral mesh

Collision Response

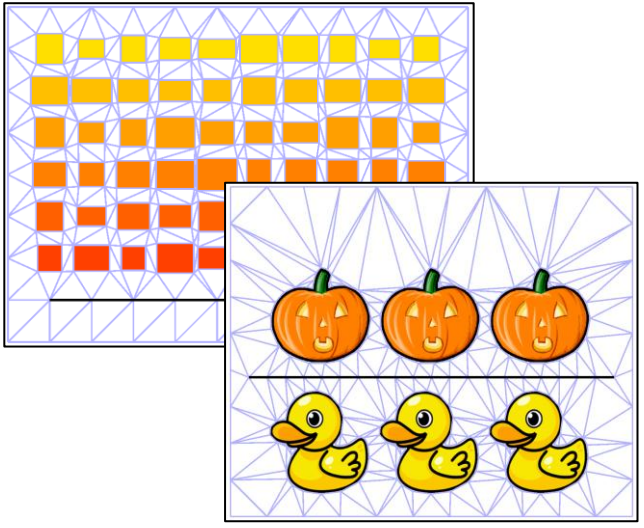
- Elastic repulsion based on proximity [Bridson et al. 2002]
- Stop motion at time of collision (CCD) by
  - Application of impulses [Bridson et al. 2002]
  - Application of position corrections [Müller et al. 2006]

- Air meshes
  - Flip inverted air elements at the end of the time step
  - No proximity measure or CCD necessary

Method

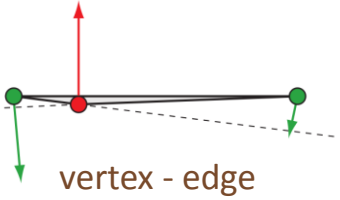
Initial Mesh Creation

- Conforming mesh needed
  - Element boundaries line up with object boundaries
- Procedural for simple scenes
- Compute a constrained Delaunay Mesh
- *TetGen* [Si 2015]

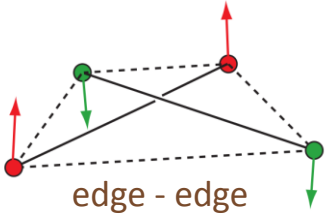


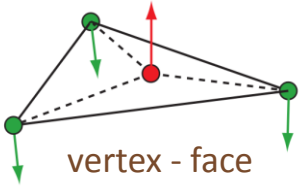
Per Element Constraint

- In a Position Based Dynamics Framework [Müller et al. 2008]
- 2D: $C_{air} = |(\mathbf{p}_2 - \mathbf{p}_1) \times (\mathbf{p}_3 - \mathbf{p}_1)| \geq 0$

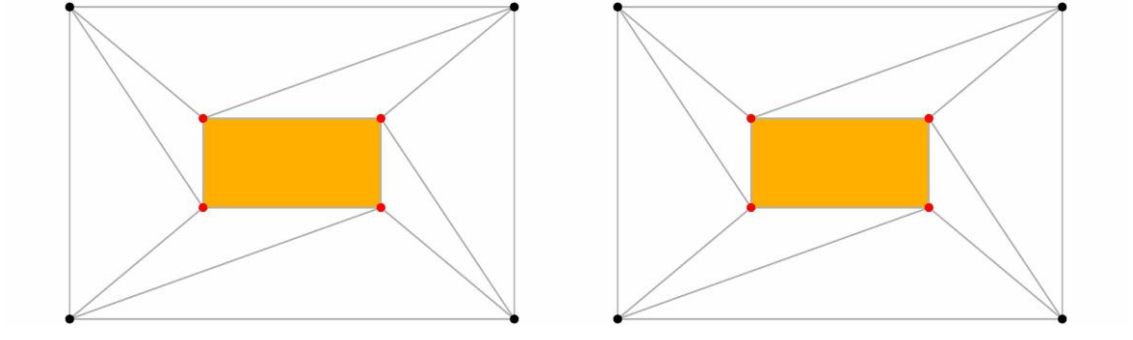


- 3D: $C_{air} = det[\mathbf{p}_2 - \mathbf{p}_1, \mathbf{p}_3 - \mathbf{p}_1, \mathbf{p}_4 - \mathbf{p}_1] \geq 0$





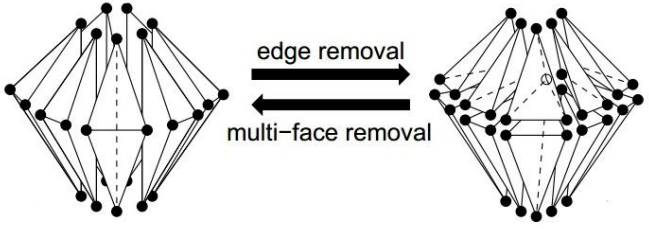
Locking Problem



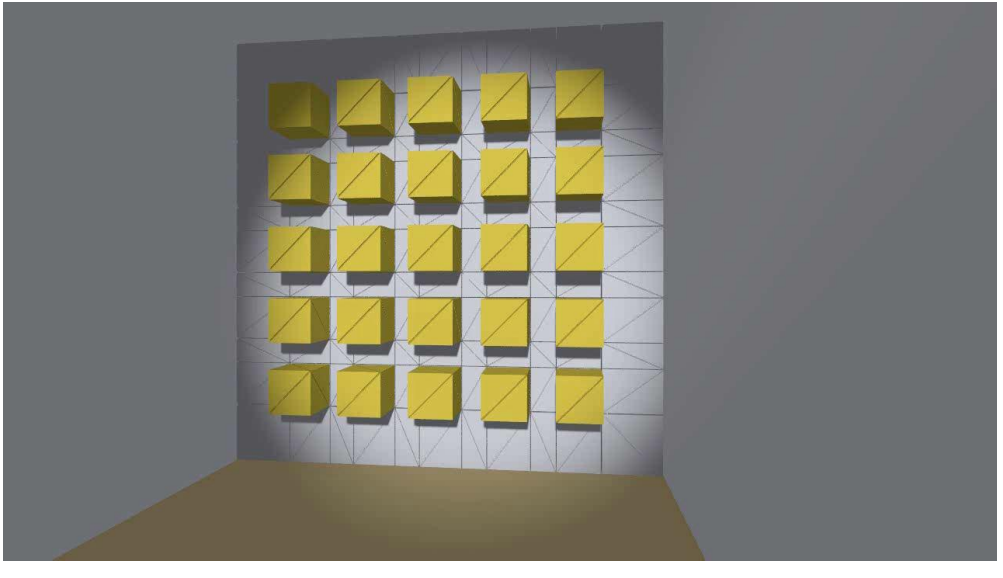
- Use kinetic pseudo triangulation Agarwal et al. [2000]
  - Provably avoids the locking problem, expensive, only in 2D
- Perform all edge flips that improve triangle quality
  - Simple, effective in practice

3D Mesh Optimization

- Tetra mesh optimization is expensive
- Edge flips correspond to two complex operations

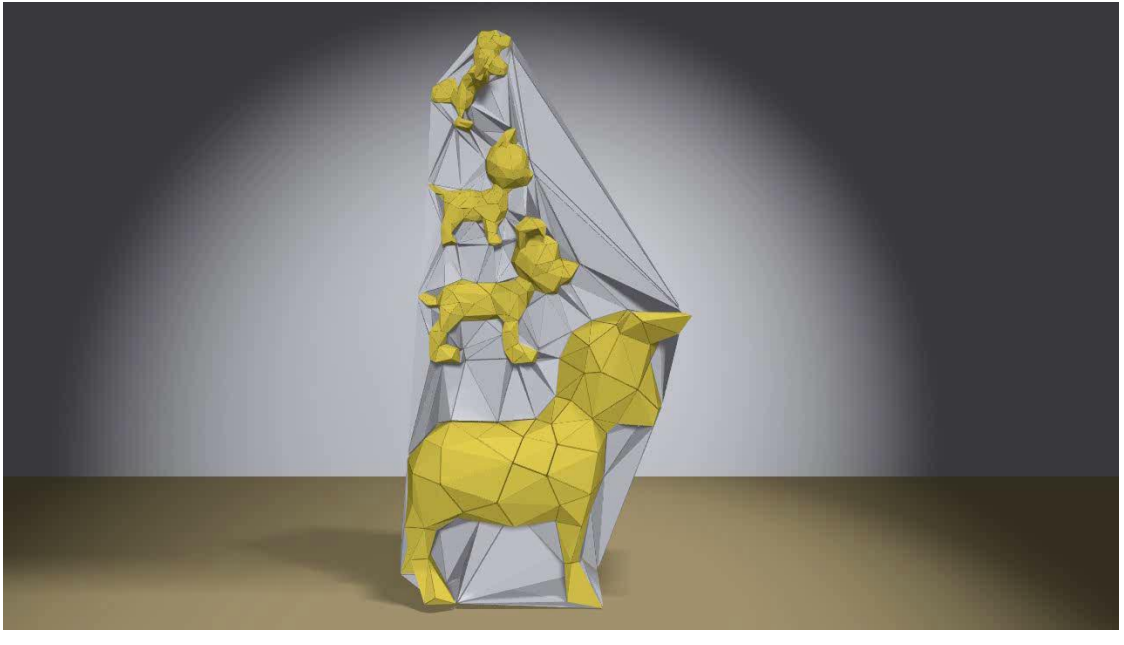


3D Mesh Optimization

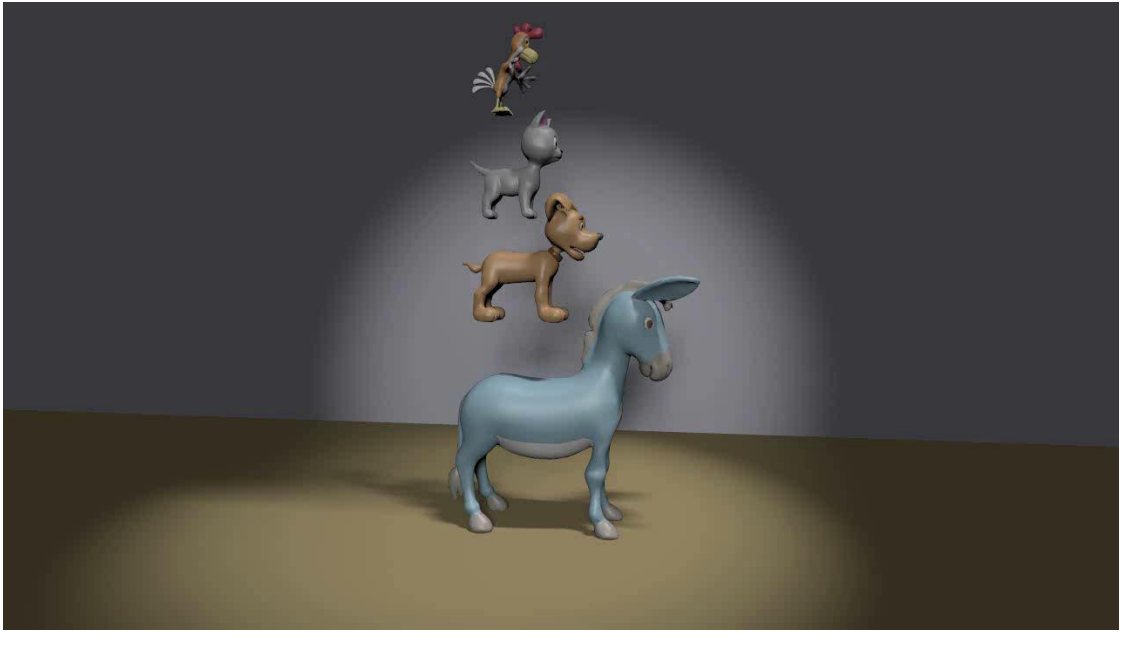


- Single thread on CPU
- 250 object elements
- 3k air elements
- Simulation: 2 ms
- Optimization: 80 ms

Irregular Mesh



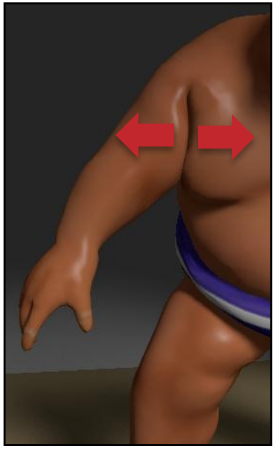
With Surface Meshes



Omitting Mesh Optimization

- Locking is not a severe problem if
  - Motion mostly perpendicular to character surface
  - Minimal relative rotation and sliding

tissue



clothing

Results

Sumo Fighter

- Single thread on CPU
- 32k tissue elements
- 1.7k air elements
- 20 fps

Sumo Fighter

Dancer

- Single thread on CPU
- 47k cloth elements
- 165k air elements
- 2 fps

Volume Conservation Constraint

Volume Inversion Constraint

Untangling

Cat Walk

- GPU implementation
- 110k triangles
- 320k air elements
- 60 fps (Titan Z)

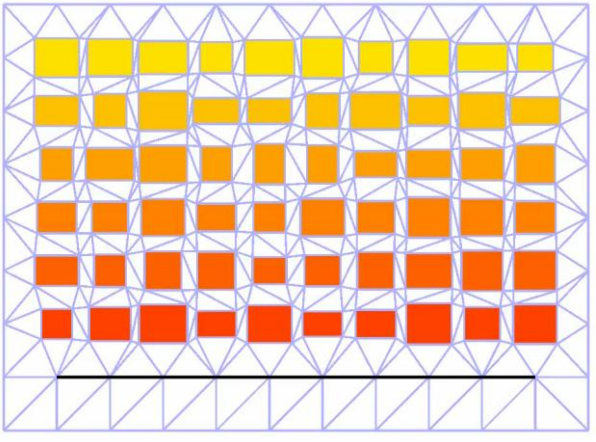
Cat Walk

Conclusion

- New method for combined collision detection and response
  - Triangulate air, make sure elements do not invert
  - Solves the difficult untangling problem
- Mesh optimization is needed to prevent locking
- Simple in 2D
  - Suitable for arbitrary scenes, mobile phone games
- Complex in 3D
  - Two important applications allow omission of optimization
  - Tissue simulation and multi-layered clothing

Future Work

- Air mesh does not need to be consistent tetra mesh
  → simpler and faster way to optimize mesh?
- Dynamic creation and deletion of air elements



Questions?