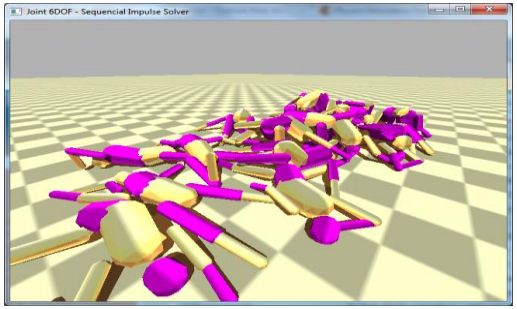
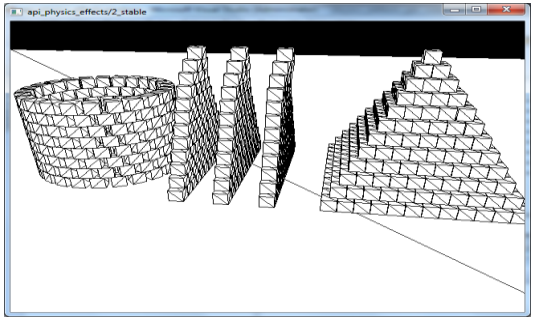
Destruction

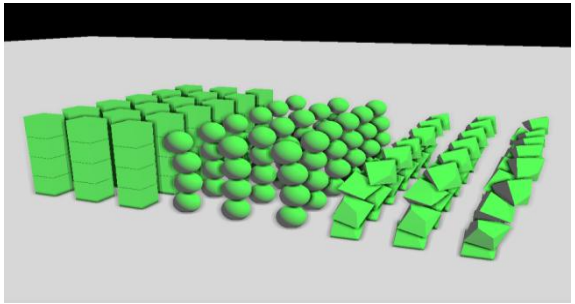
Erwin Coumans
Bullet Architect @ AMD

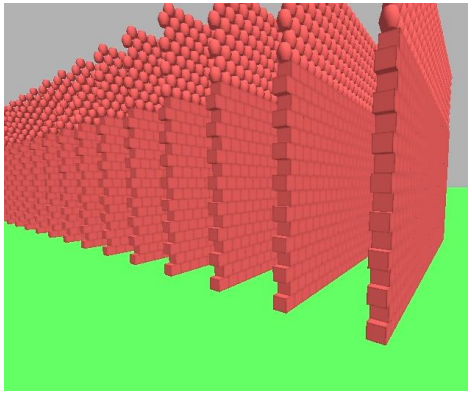
GAME DEVELOPERS CONFERENCE
SAN FRANCISCO, CA
MARCH 5-9, 2012
EXPO DATES: MARCH 7-9
2012

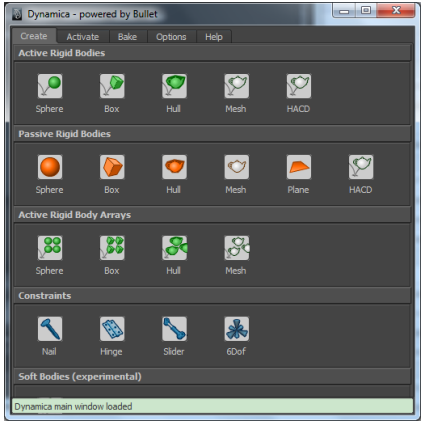
Our open source work

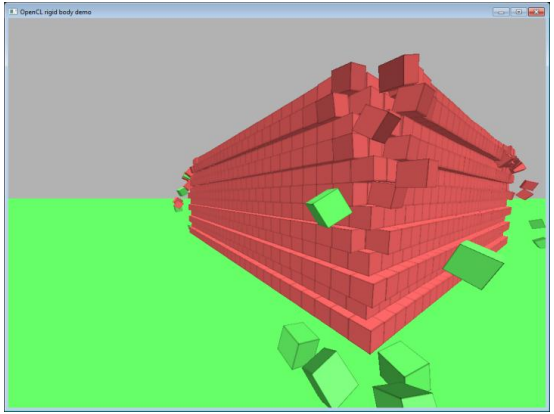


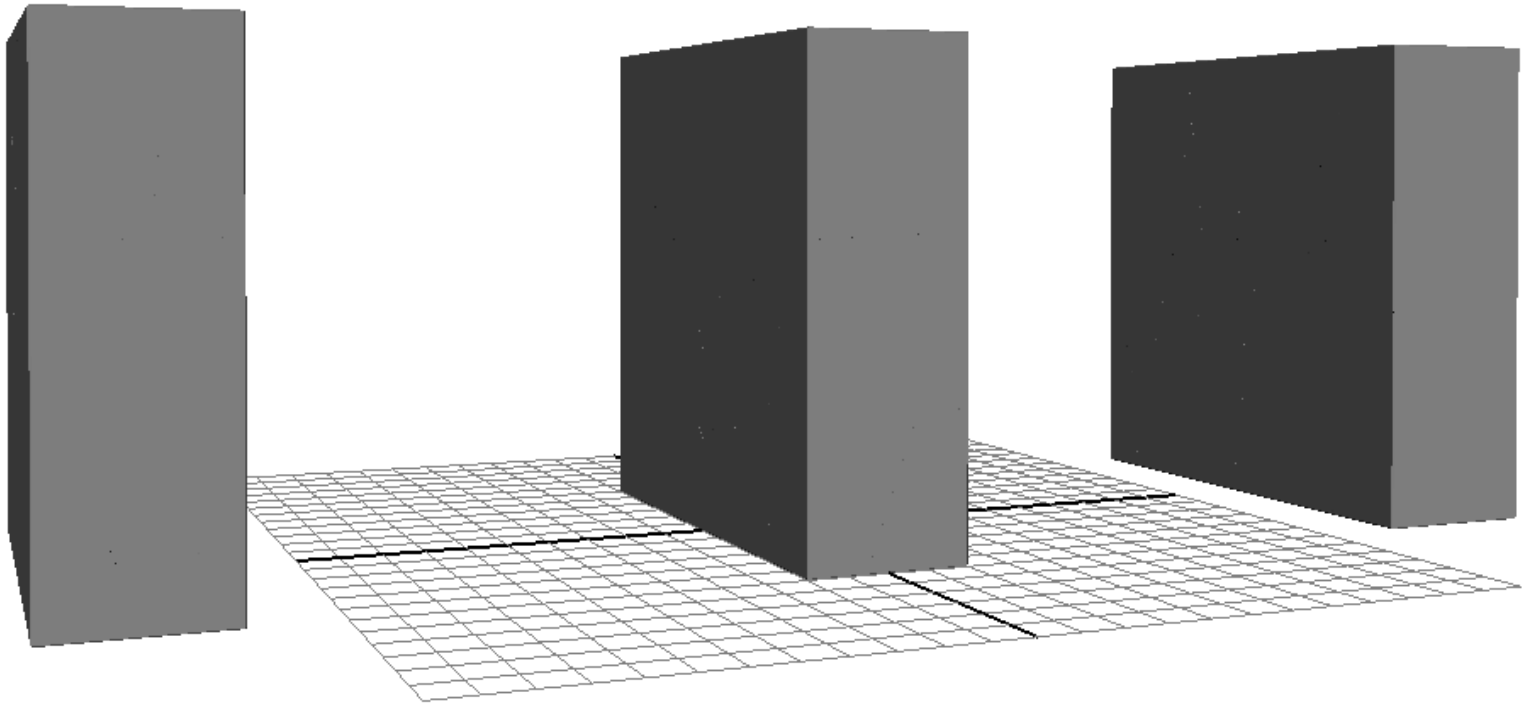


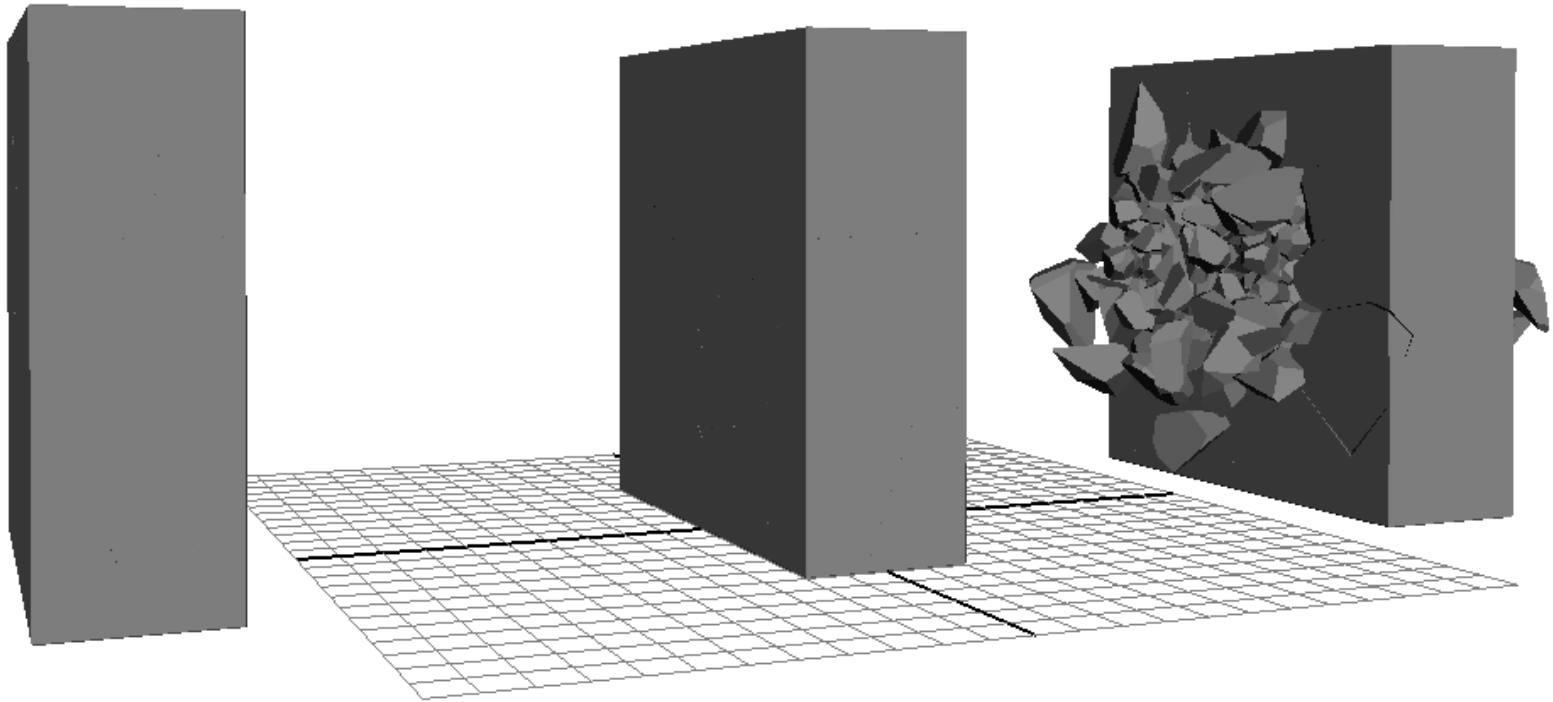


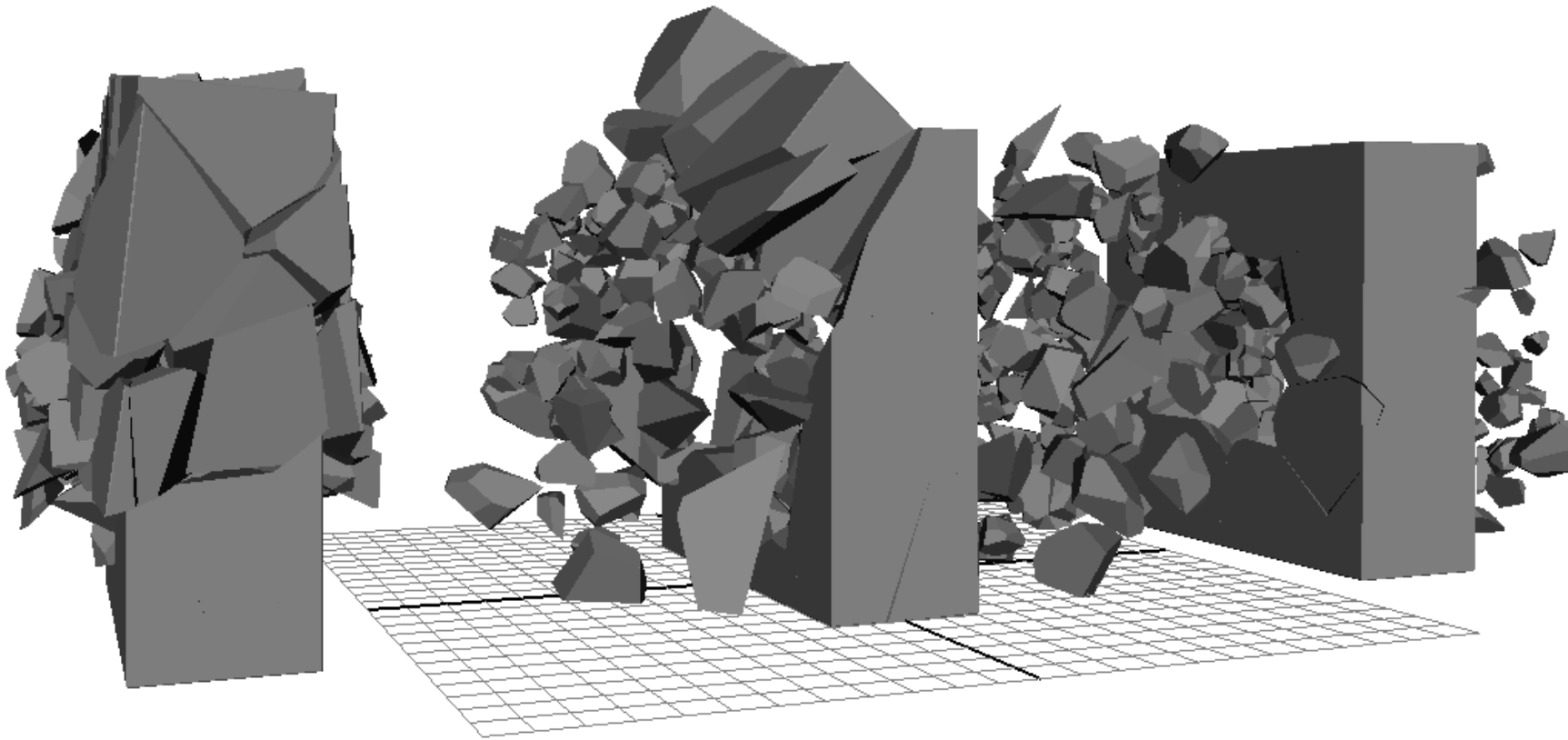


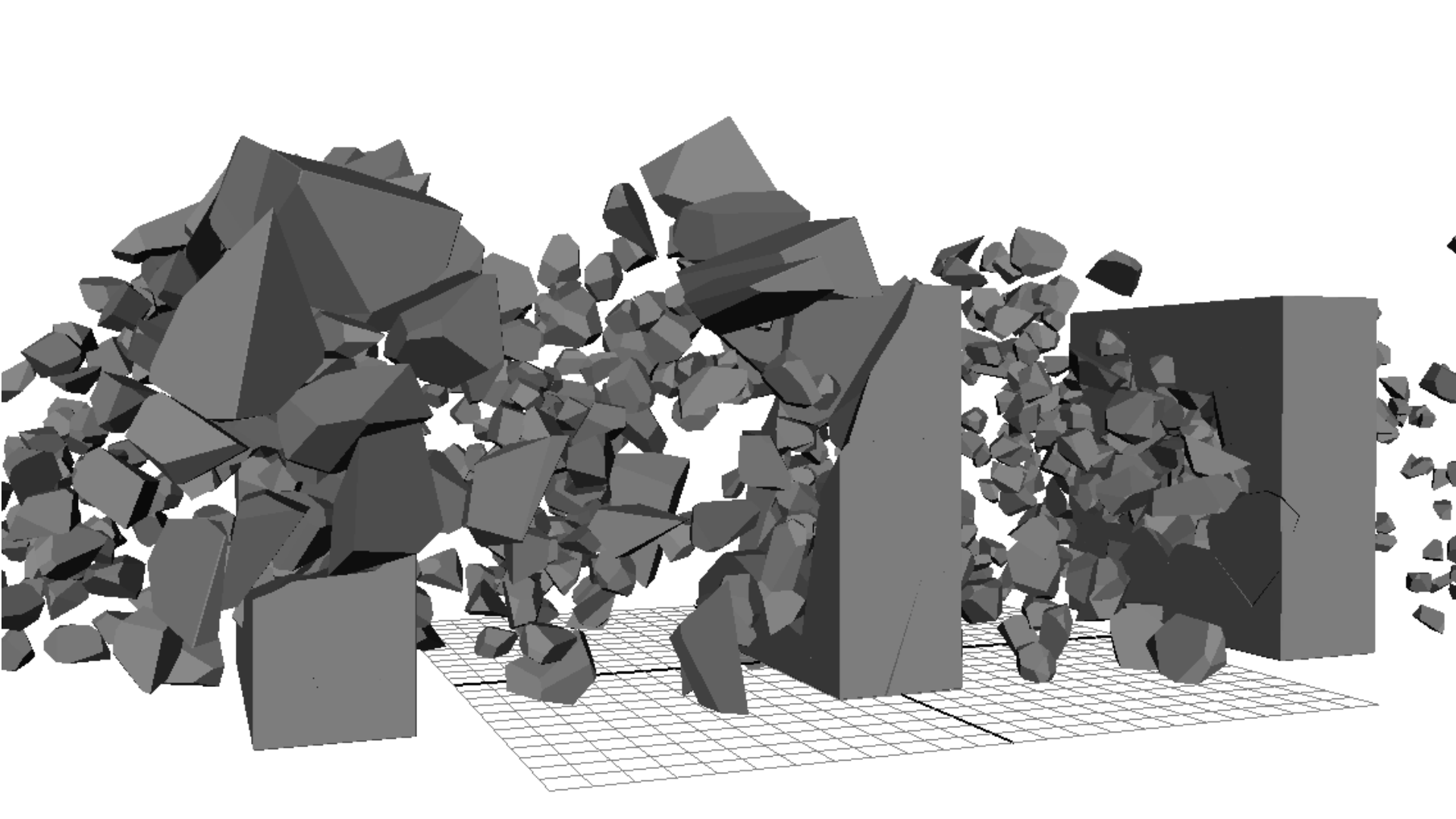


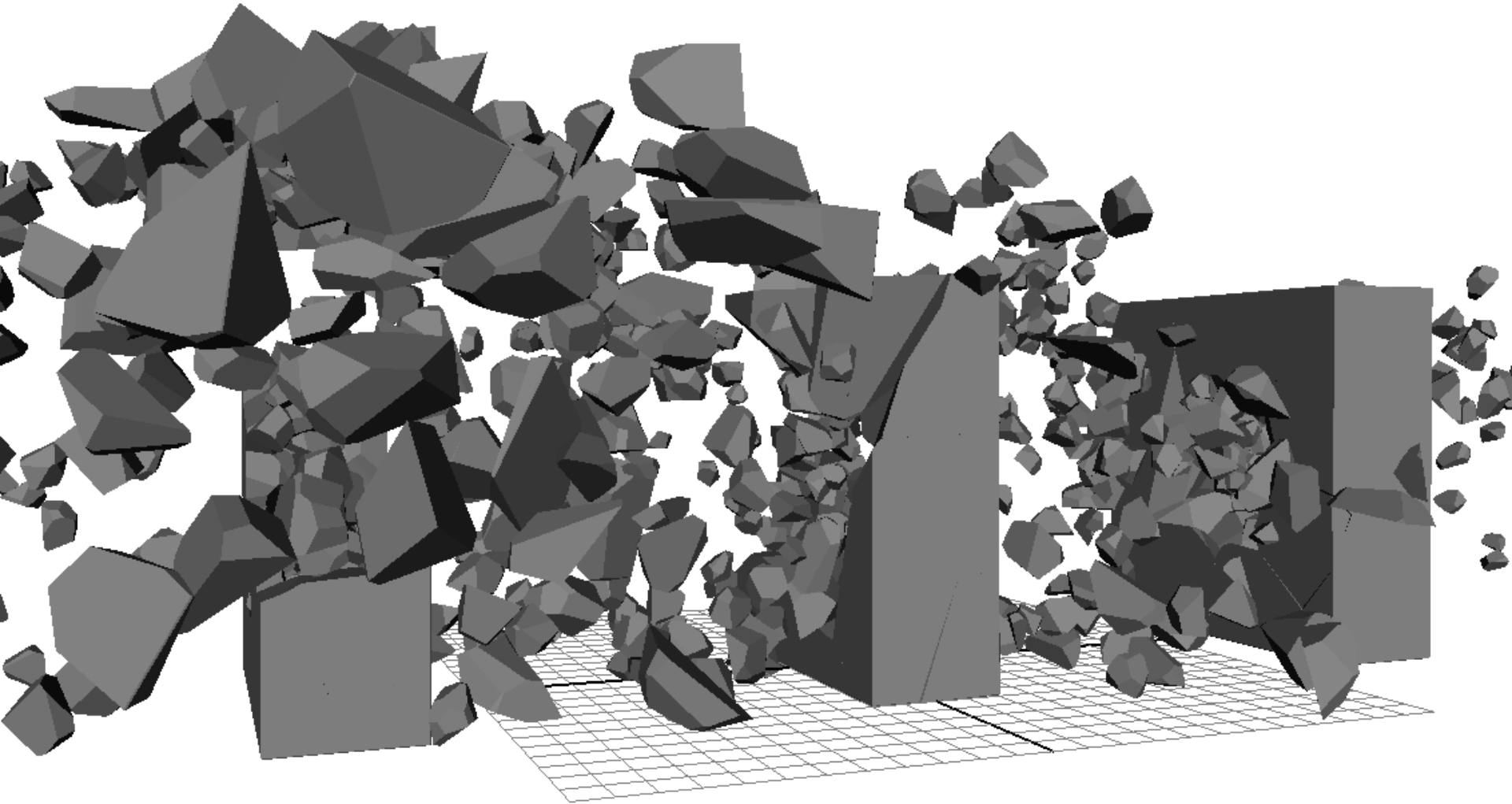


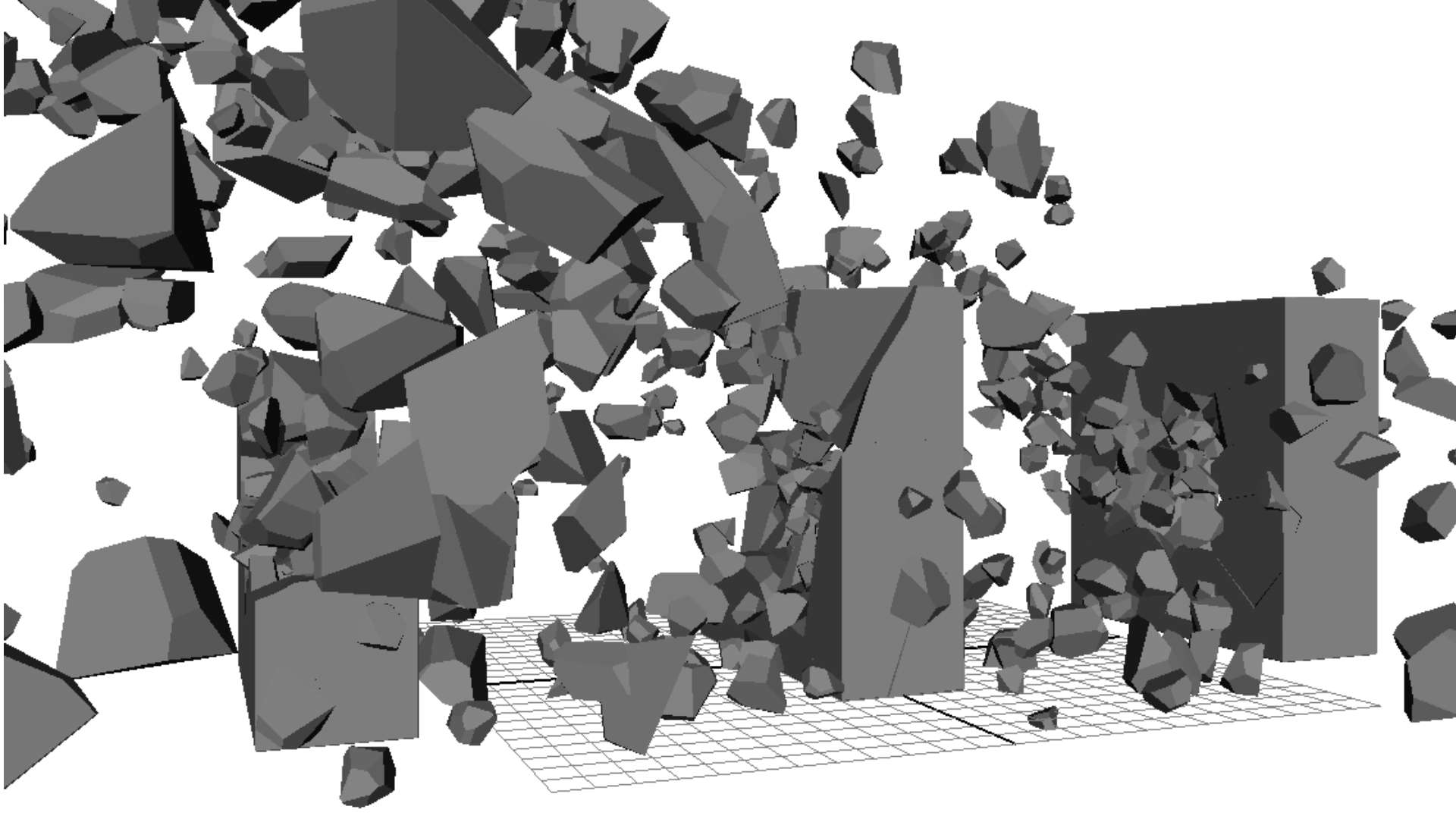


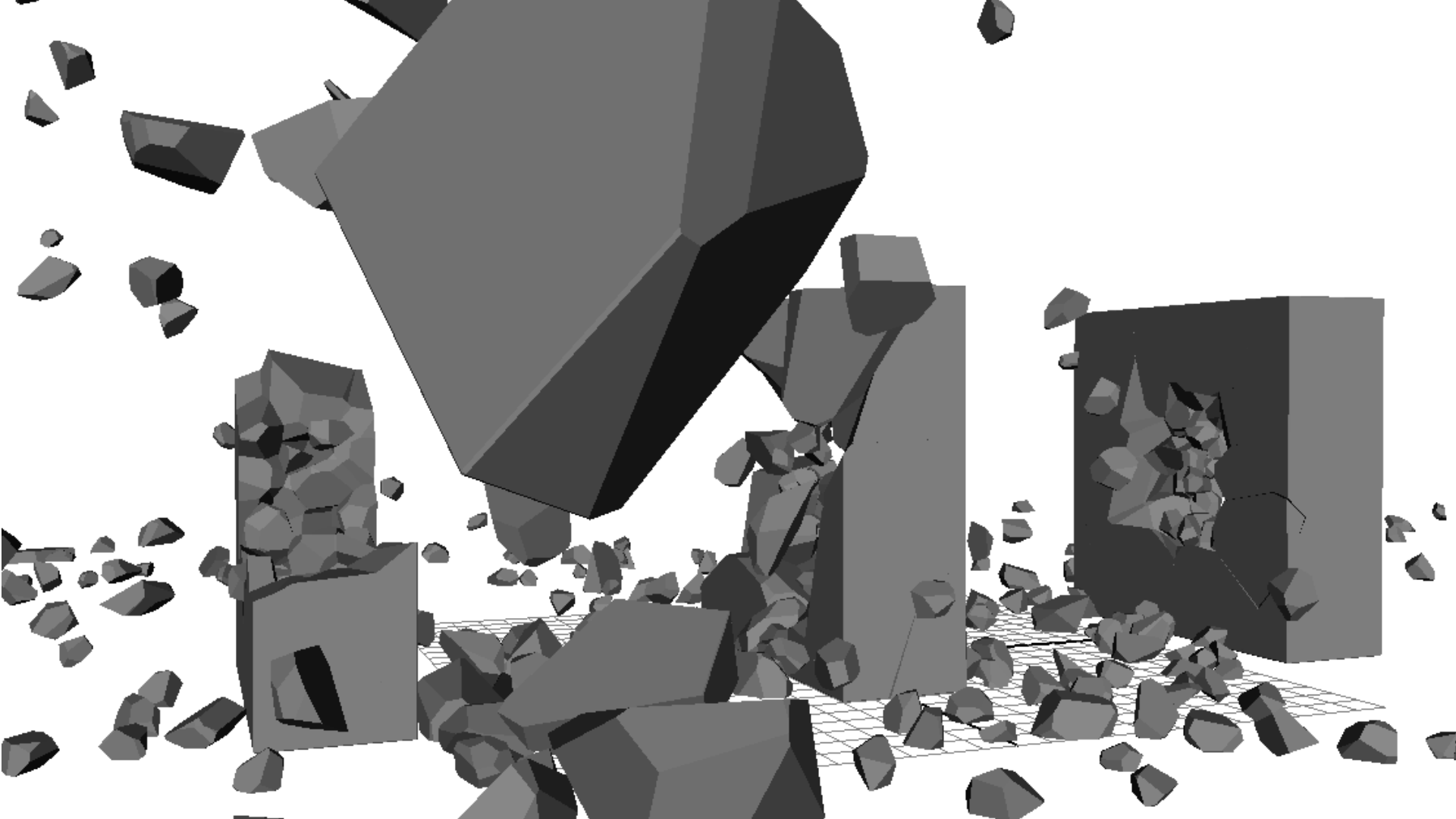


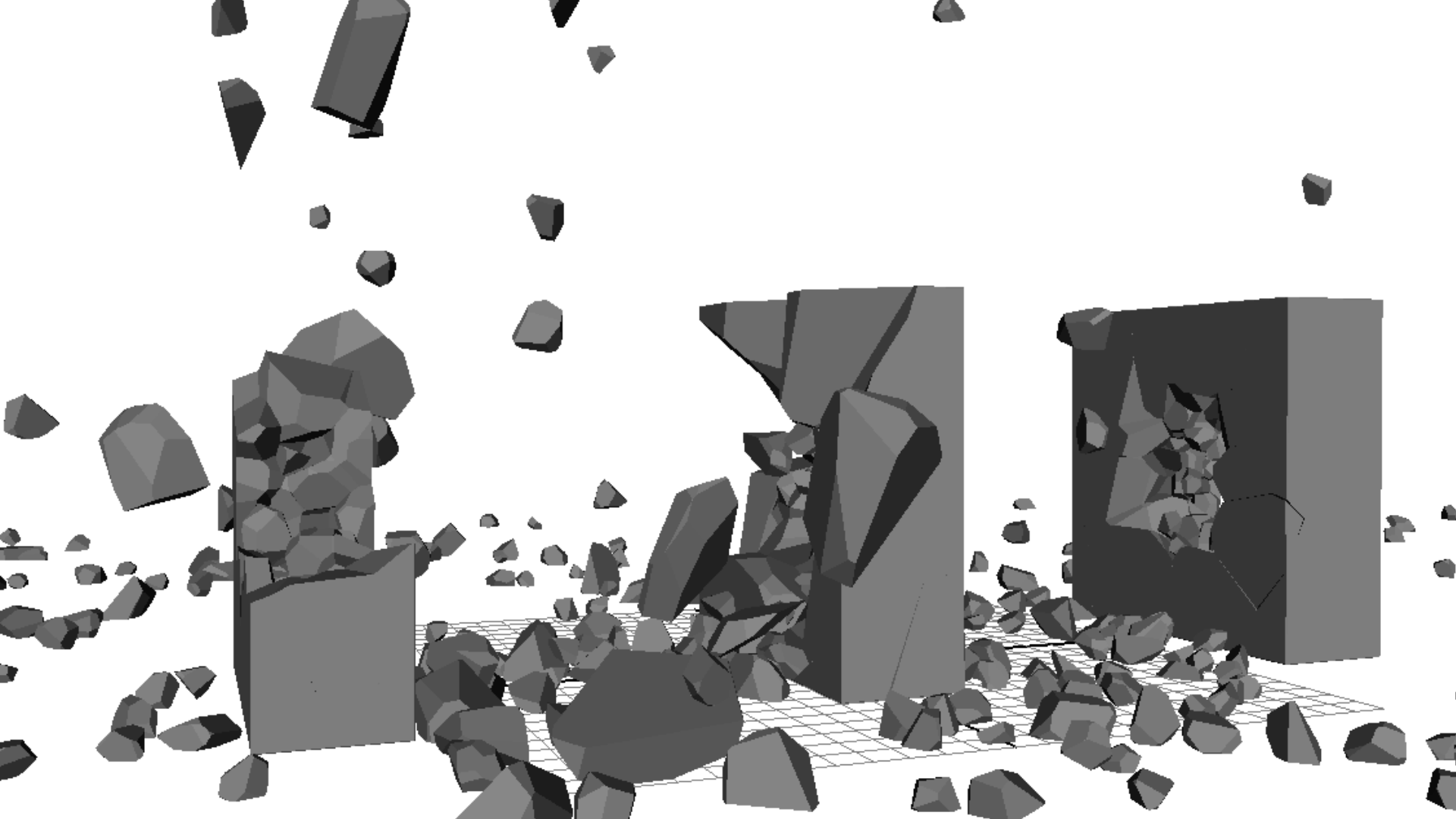


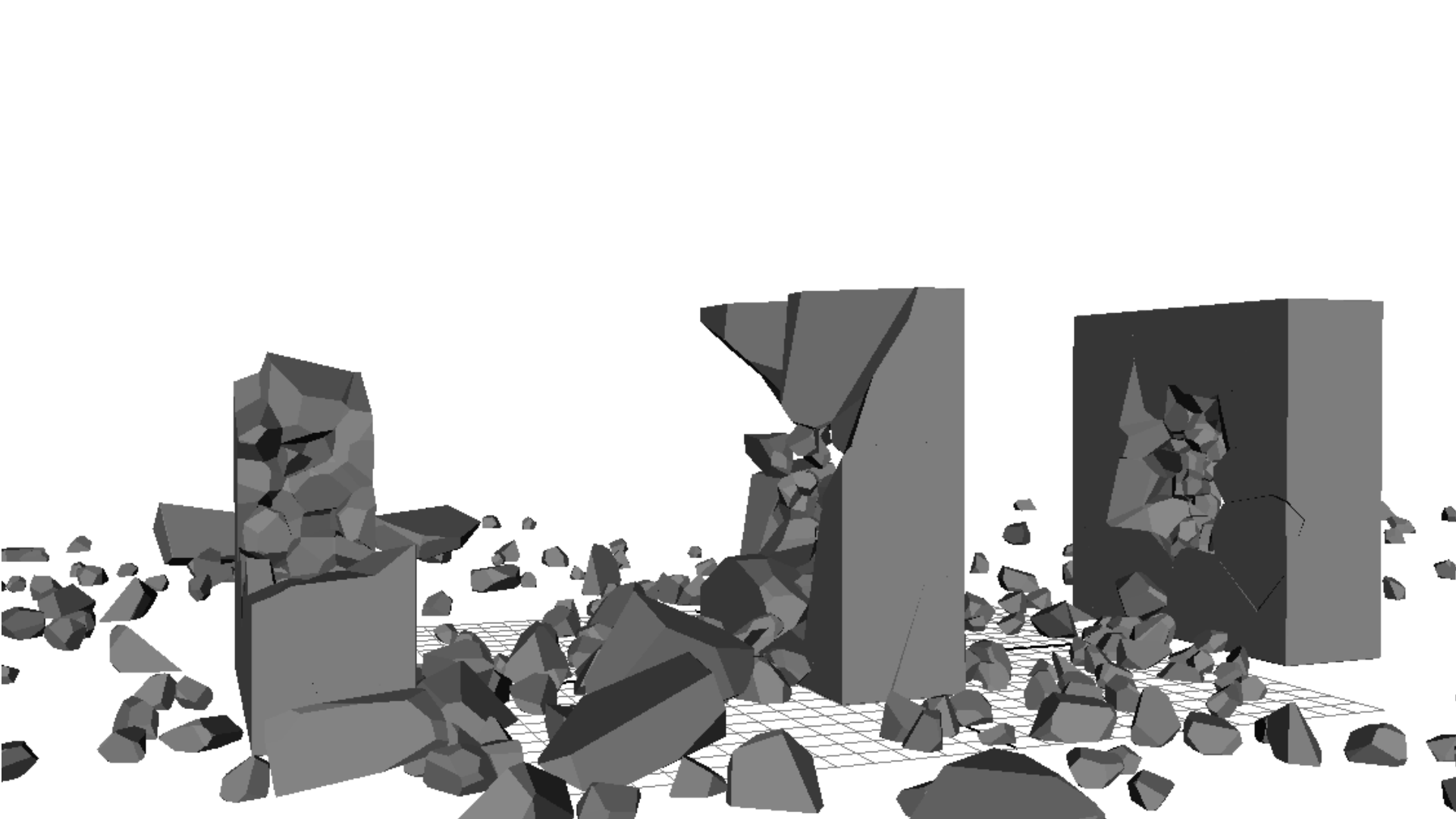








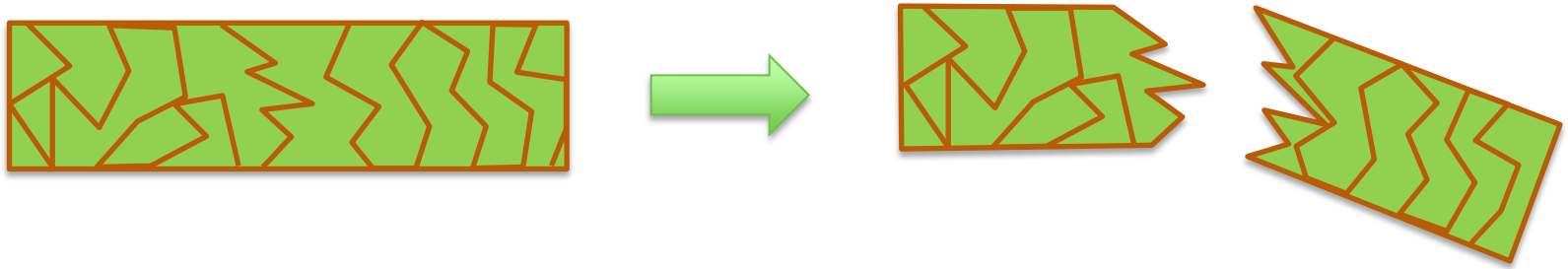




Offline versus runtime

- Geometry preparation and artist tools

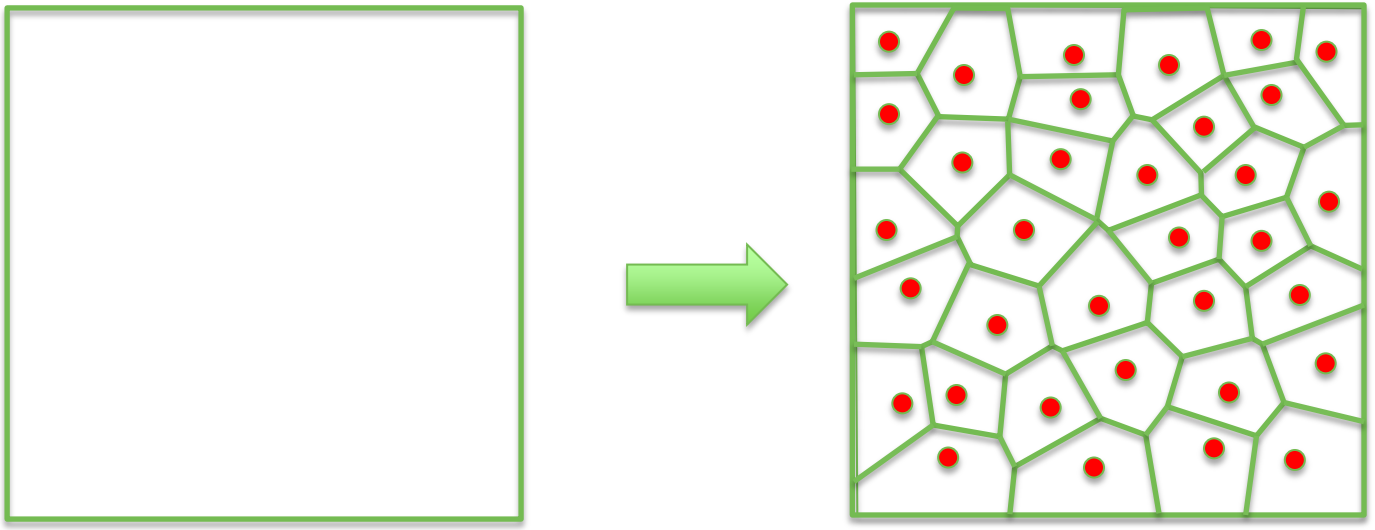
- Runtime destruction methods



Geometry Preparation

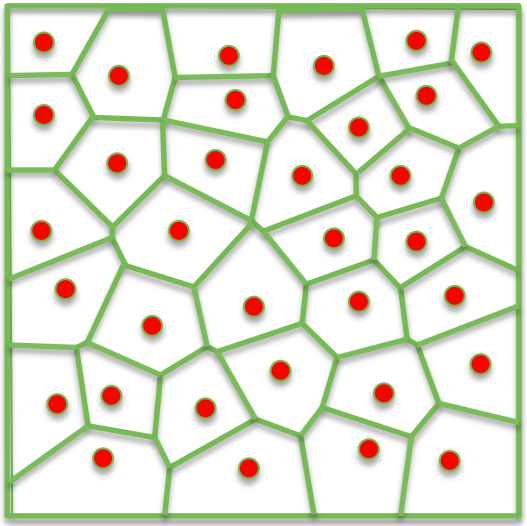
Voronoi shatter, slicing	**Runtime Destruction**
Boolean operations	Canned animation
Convex decomposition	Real-time Booleans
Tetrahedralization	FEM, particle based
Simplification	Rigid body & Hybrid

Voronoi shatter



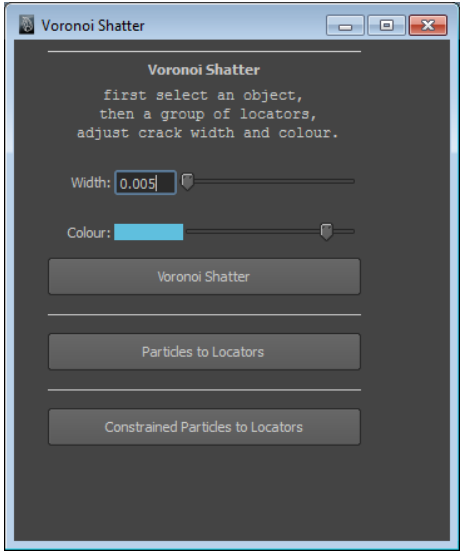
Voronoi generation


```
Distribute point set S within the 3D model
For each point A in S
{
   Create cube around the point
   For each point B in {S-A}
        Create a plane between point A and B
        Slice the cube by this plane
   Boolean Intersect cube with model
}
```

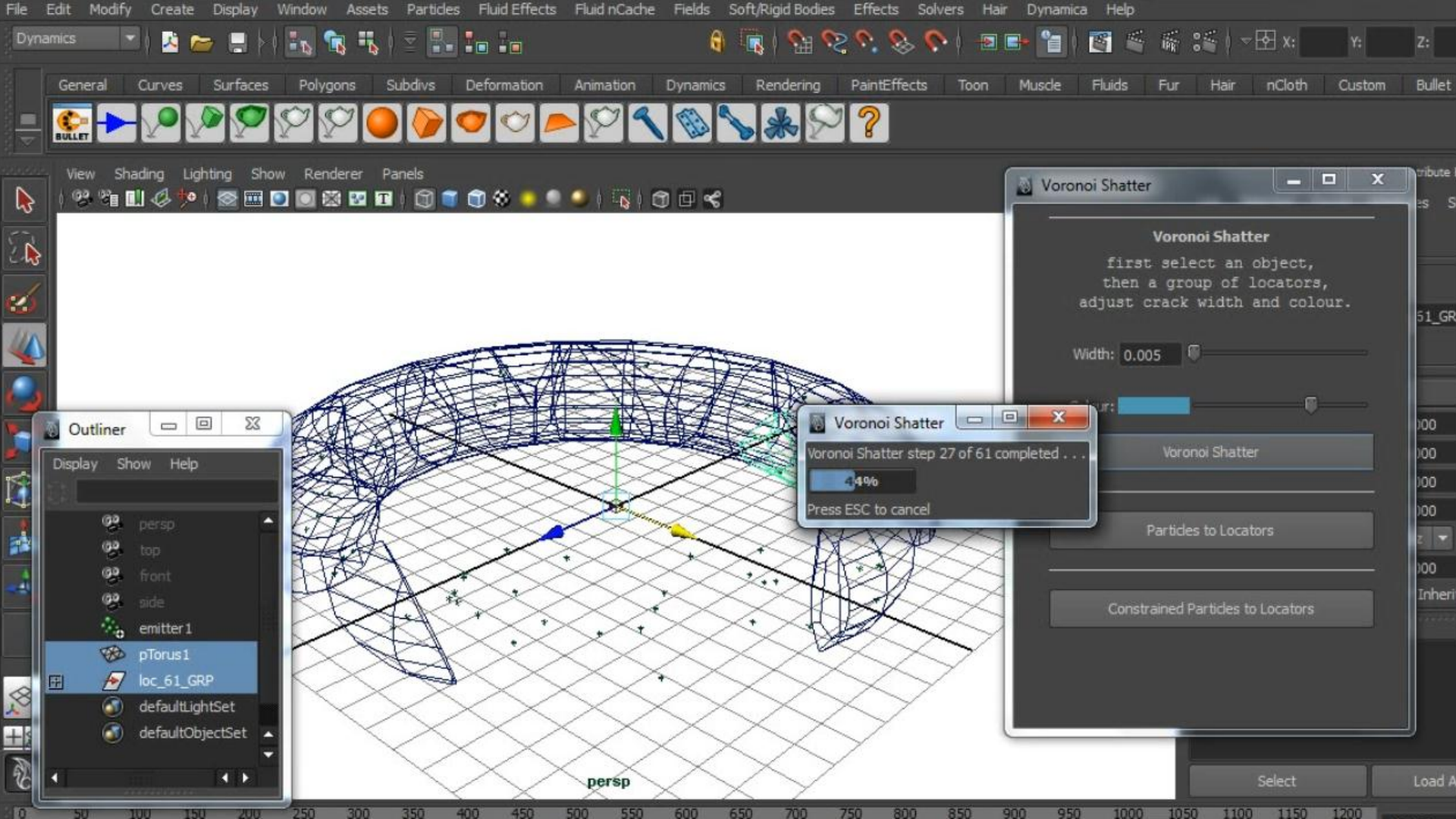


Maya Voronoi Shatter

- MEL/Python script by Dave Greenwood



http://www.creativecrash.com/maya/downloads/scripts-plugins/modeling/poly-tools/c/dg_voro_py--2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Voronoi Shatter
Voronoi Shatter
first select an object,
then a group of locators,
adjust crack width and colour.
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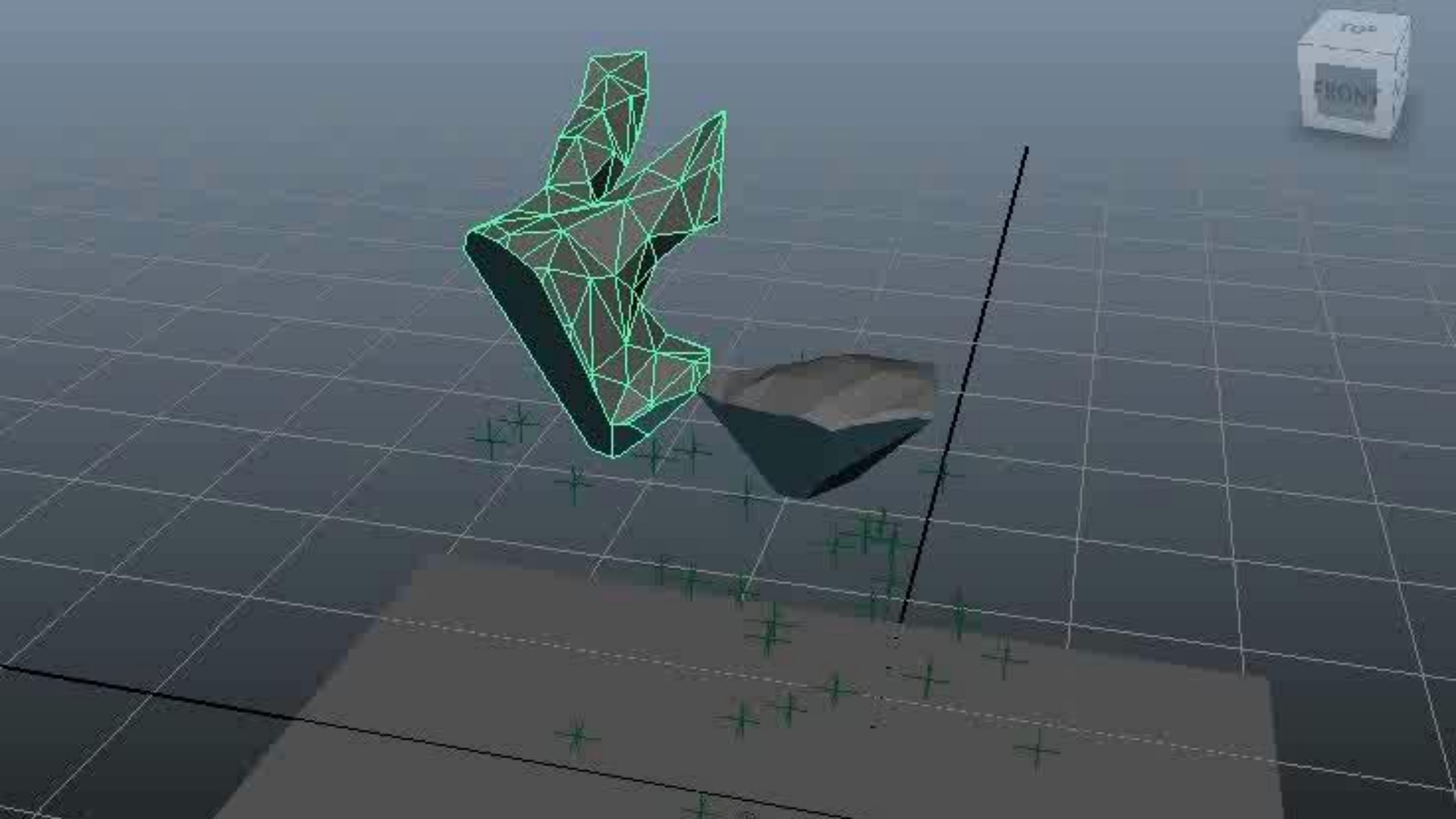
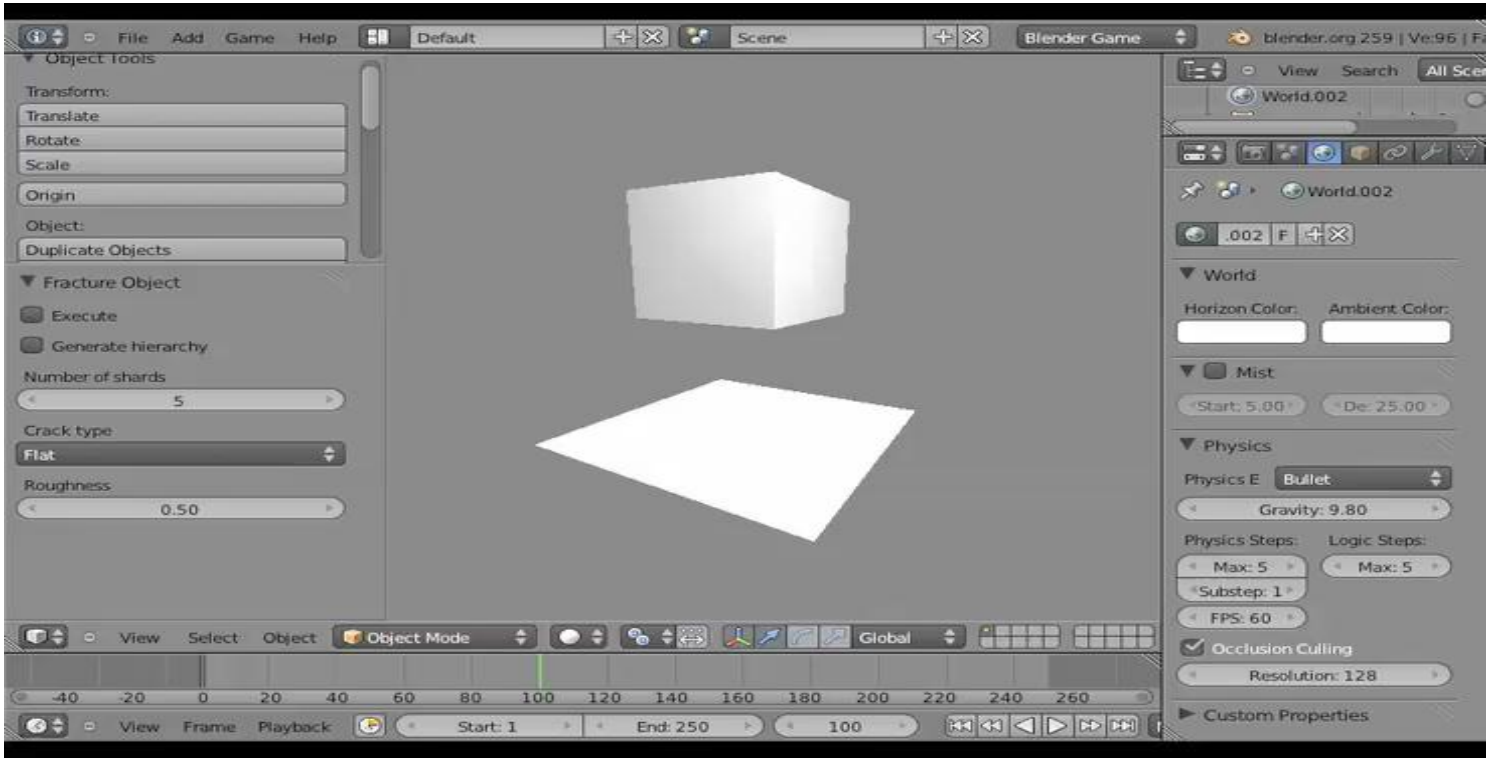

FRONT

Maya Shatter Recipe

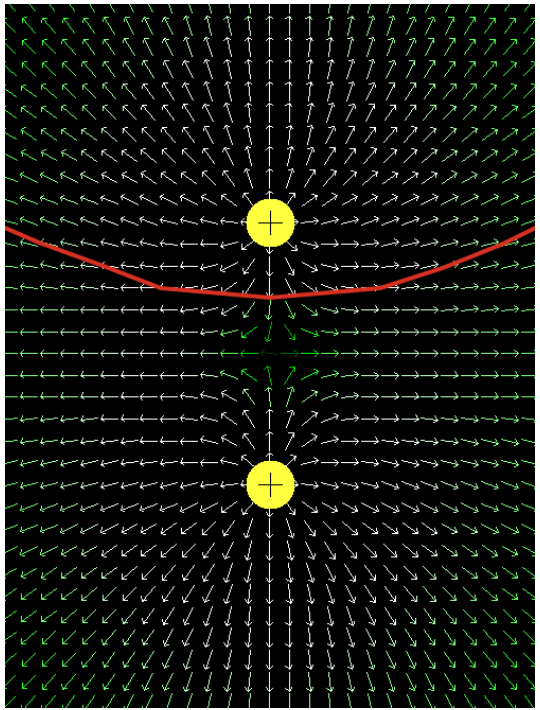
- Create a particle emitter
- Create a polyhedral mesh
- Convert the particles to locators
  - Select mesh and then particles
- Create a mesh from each locator
  - Select mesh then locators

Blender Fracture Tools

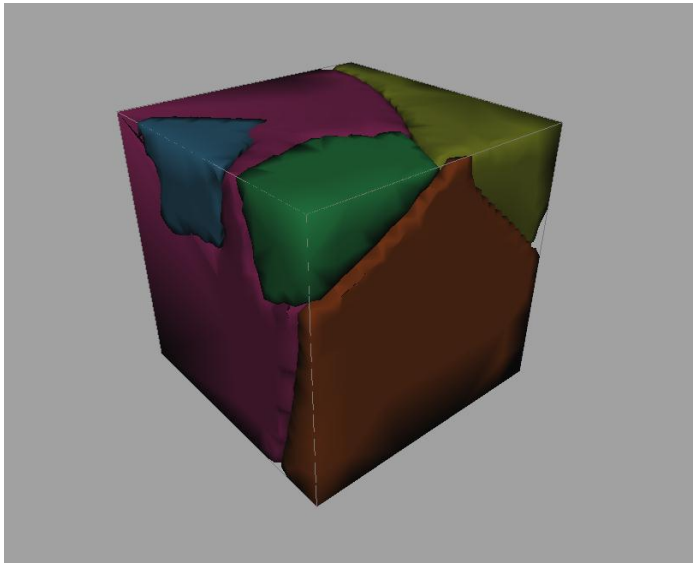


http://www.directcg.info/how-to-use-fracturetools-inside-blender.html

Electric Fields



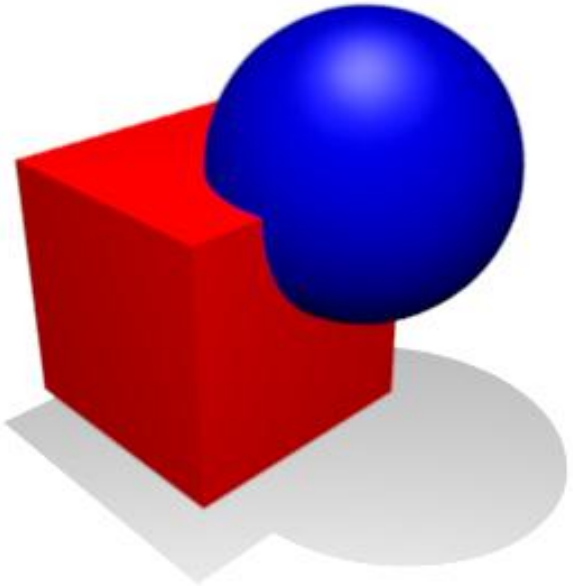
$$E = \sum_{i=1}^{n} \frac{q_i}{4\pi\varepsilon_0 r_i^2} \hat{r}_i$$



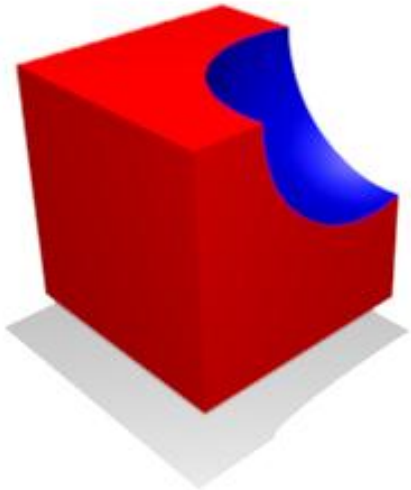
- See the 'Fragged' article in GDMag 2010, December

Boolean operations

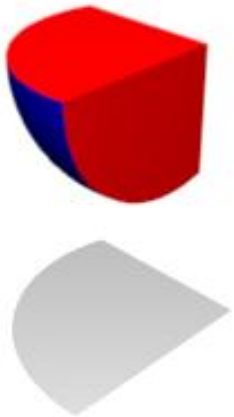
Union



Difference



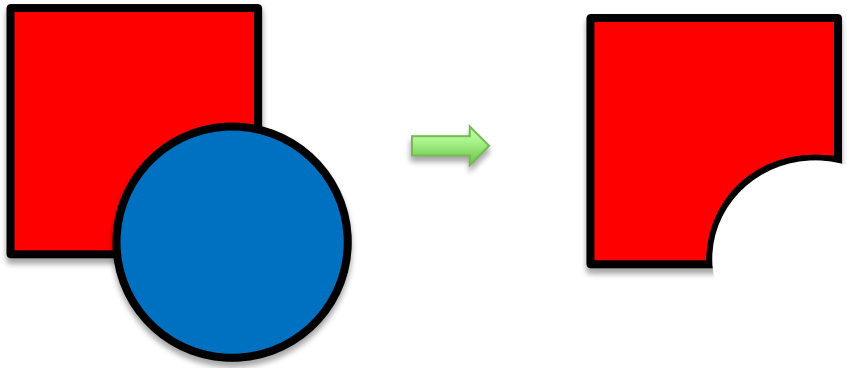
Intersection



Modeled and Rendered in **Blender**. Made by **Captain Sprite**

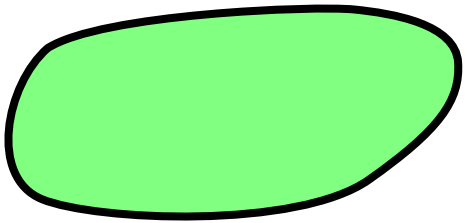
Polyhedral Booleans

- Merging BSP trees yields polyhedral set operations, Bruce Naylor, SIGGRAPH '90

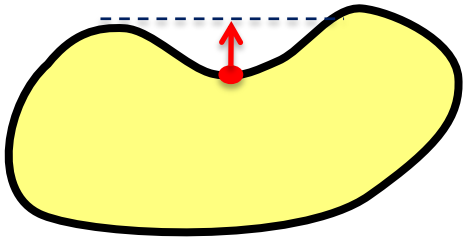


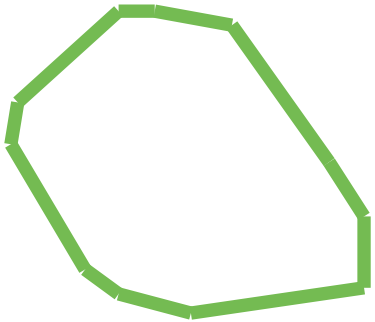
Collision shapes types

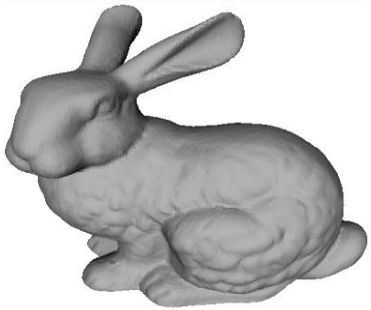
Convex

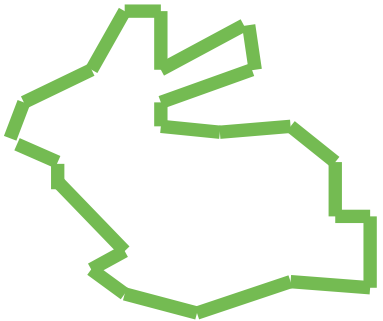


Concave



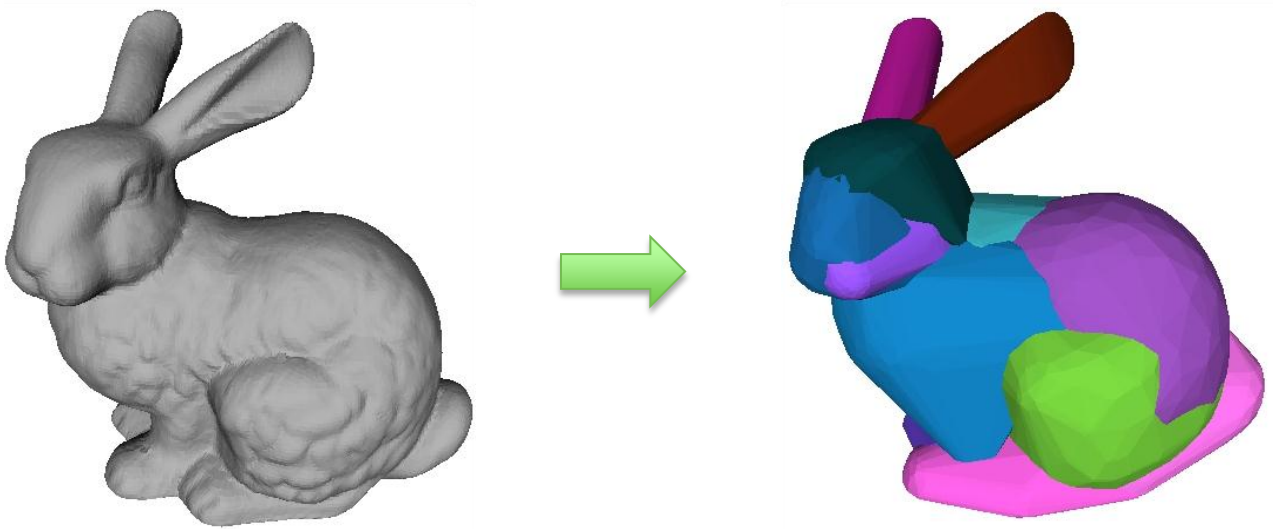






Convex Decomposition

- (Semi) Automatic physics shape generation

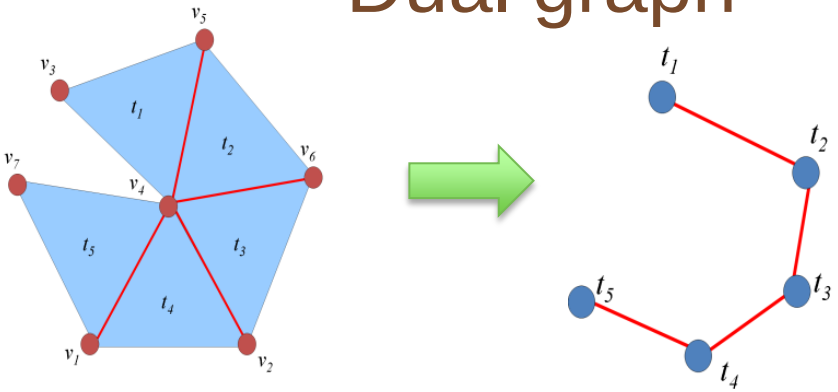


HACD

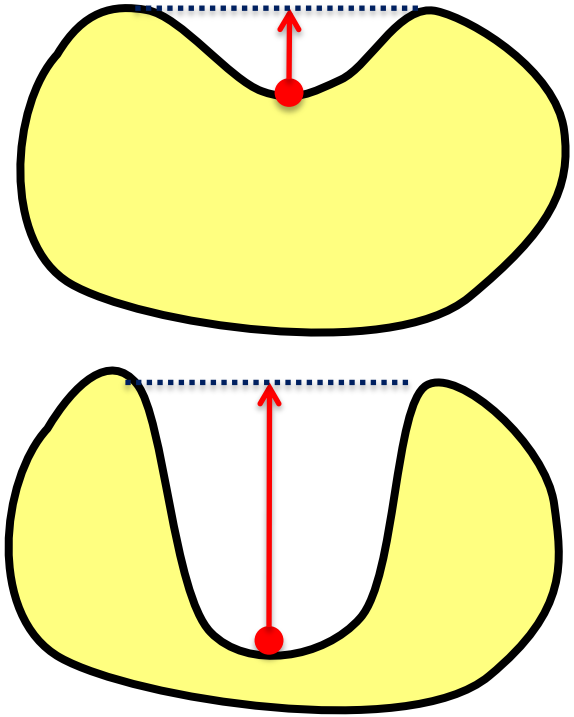
- Hierarchical Approximate Convex Decomposition
by Khaled Mammou, ICIP 09
- Bottom up, merging convex clusters
- http://sourceforge.net/projects/hacd

HACD in one slide

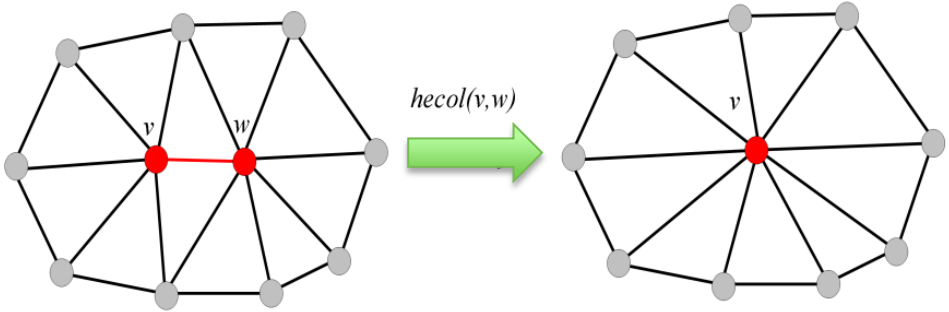
Dual graph



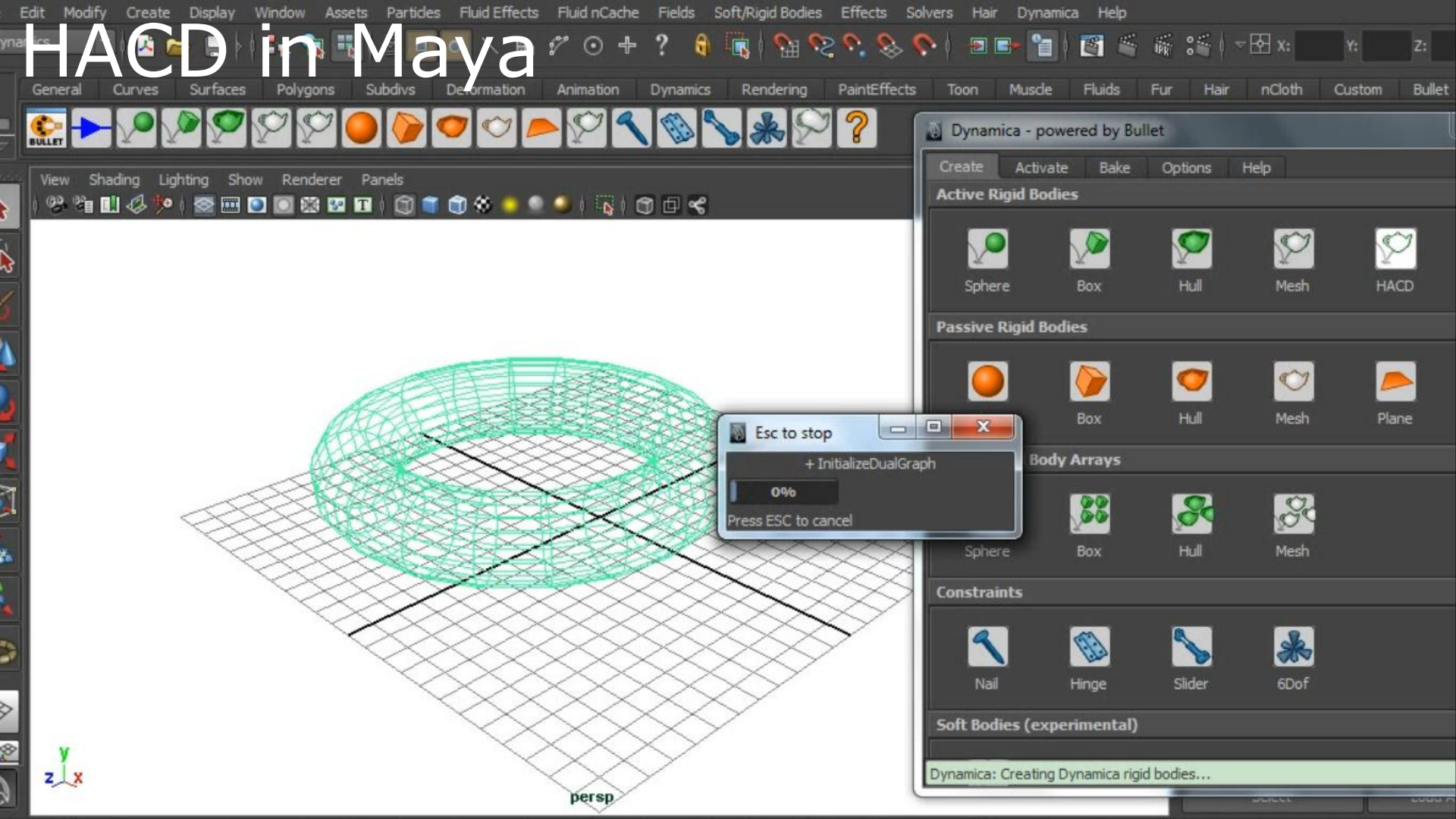
Measuring concavity



Decimation operator



HACD in Maya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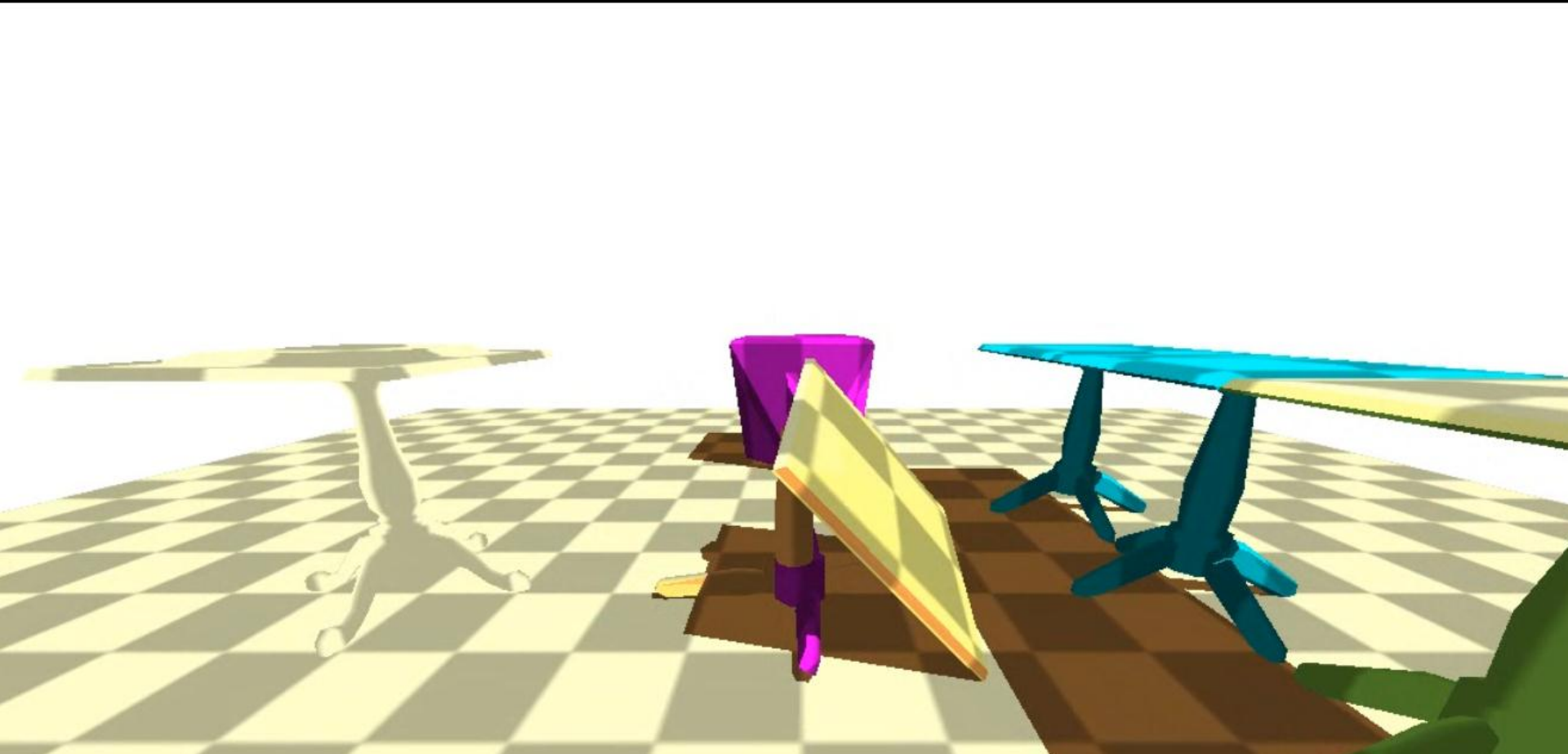
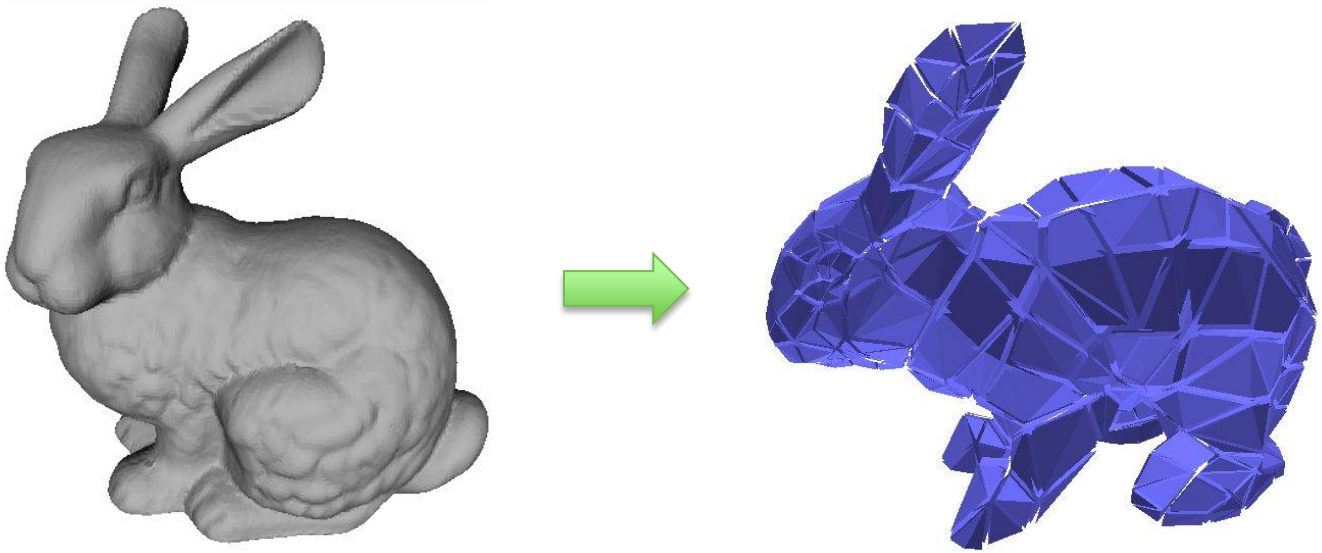
Press ESC to cancel
Dynamica - powered by Bullet
Create Activate Bake Options Help
Active Rigid Bodies
Sphere Box Hull Mesh HACD
Passive Rigid Bodies
Box Hull Mesh Plane
Body Arrays
Sphere Box Hull Mesh
Constraints
Nail Hinge Slider 6Dof
Soft Bodies (experimental)
Dynamica: Creating Dynamica rigid bodies...
persp

HACD in Bullet



Tetrahedra Creation



- Tetrahedralization by 3D Delaunay Triangulation, Boris Delaunay, 1934

Tetrahedralization

- Netgen, LGPL,
  http://sourceforge.net/projects/netgen-mesher
- Tetgen

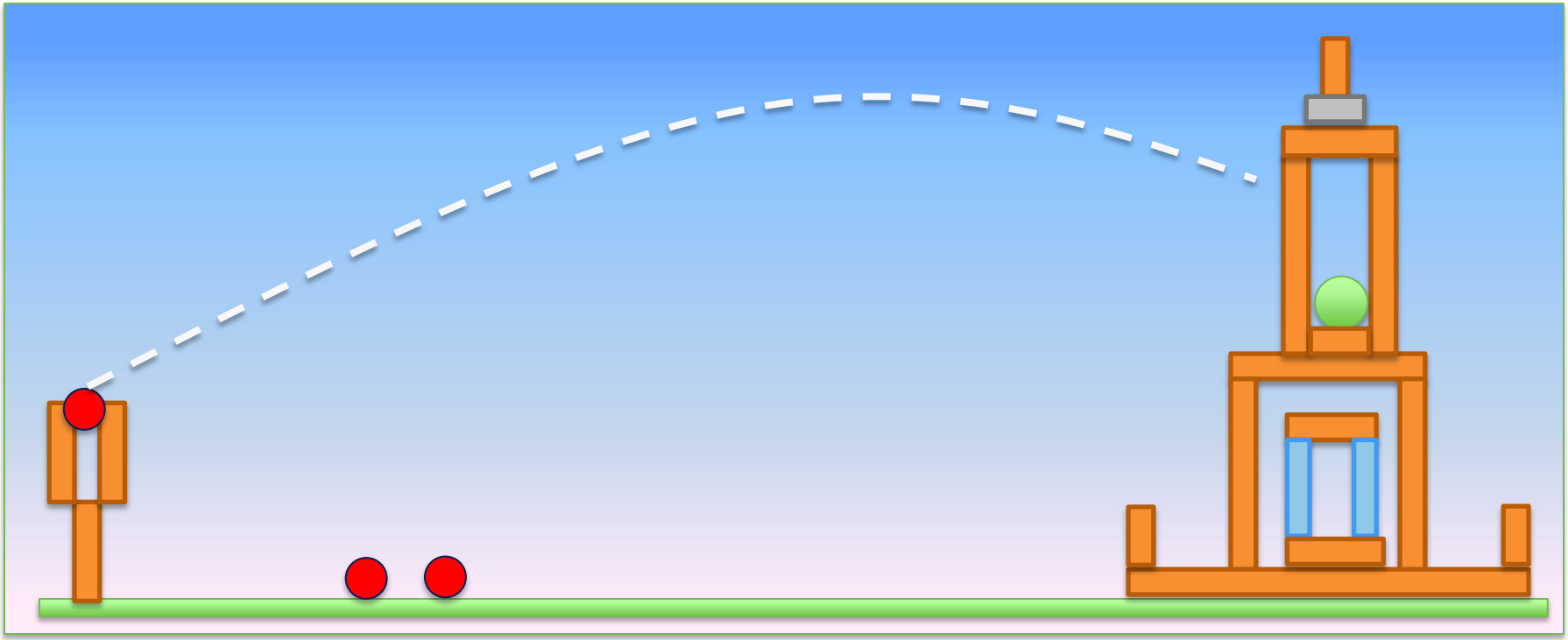
- Maya 2012 with DMM plugin
  Pixelux Digital Molecular Matter

Geometry Preparation	Runtime Destruction
Voronoi shatter, slicing	Canned animation
Boolean operations	Real-time Booleans
Convex decomposition	FEM, particle based
Tetrahedralization	Rigid body & Hybrid

Real-time booleans

- Stan Melax, http://melax.googlecode.com

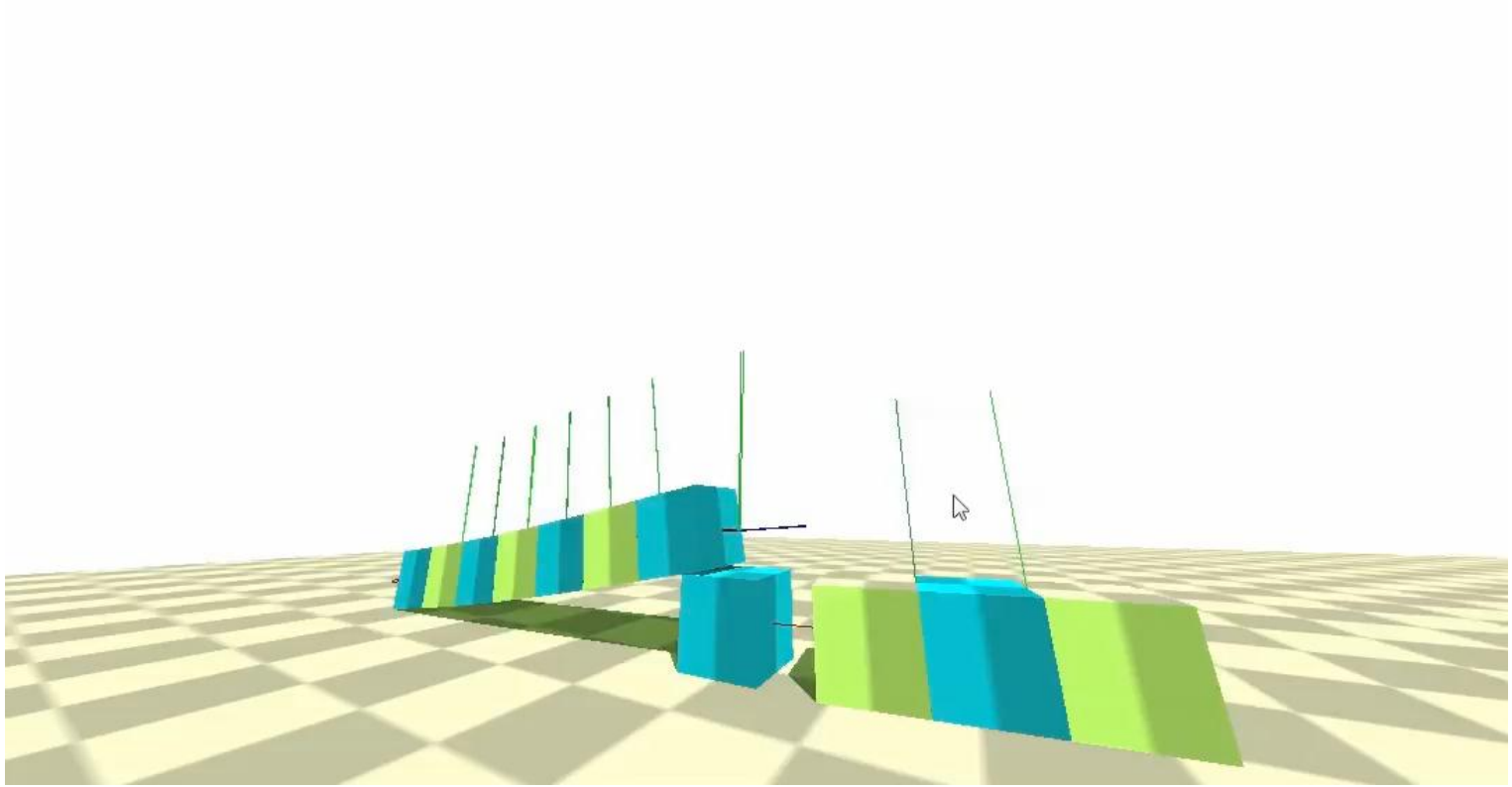
Rigid bodies



Breakable Rigid bodies

- Breakable constraints
- Composite single rigid body

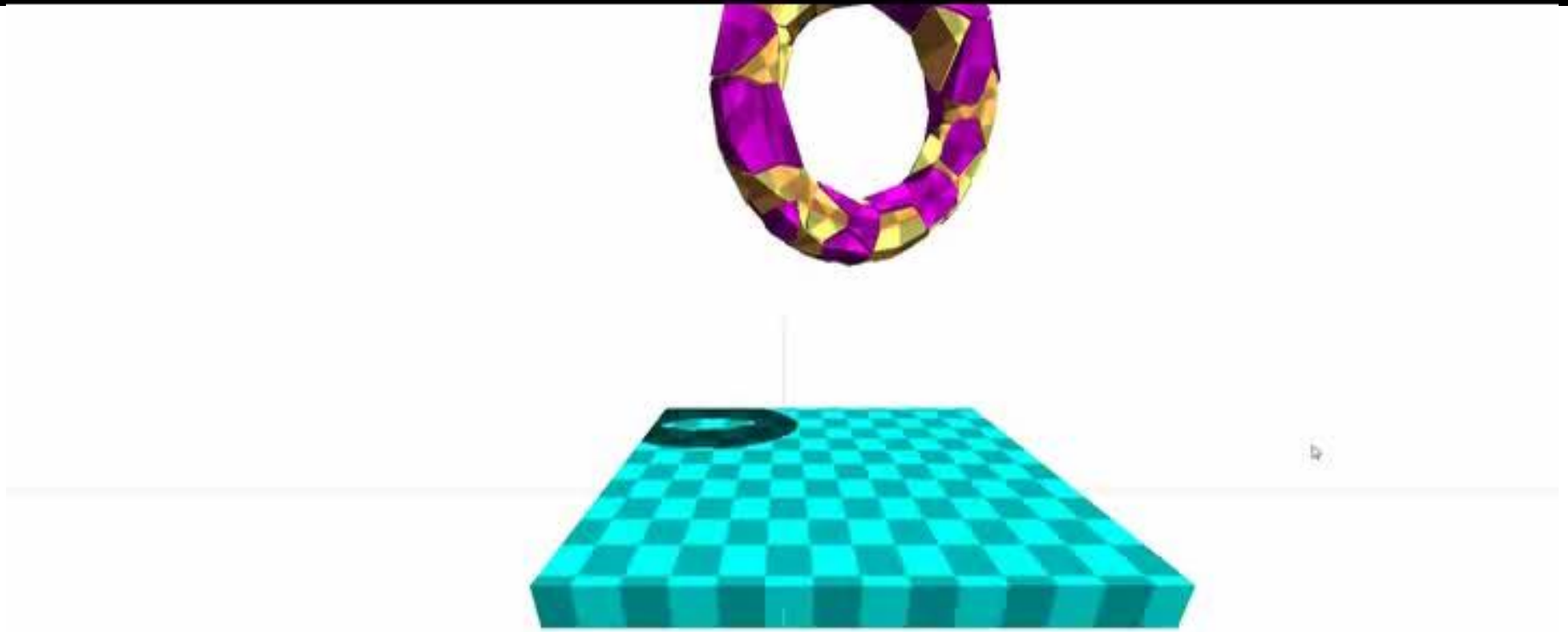
Breakable constraints



Breakable constraints

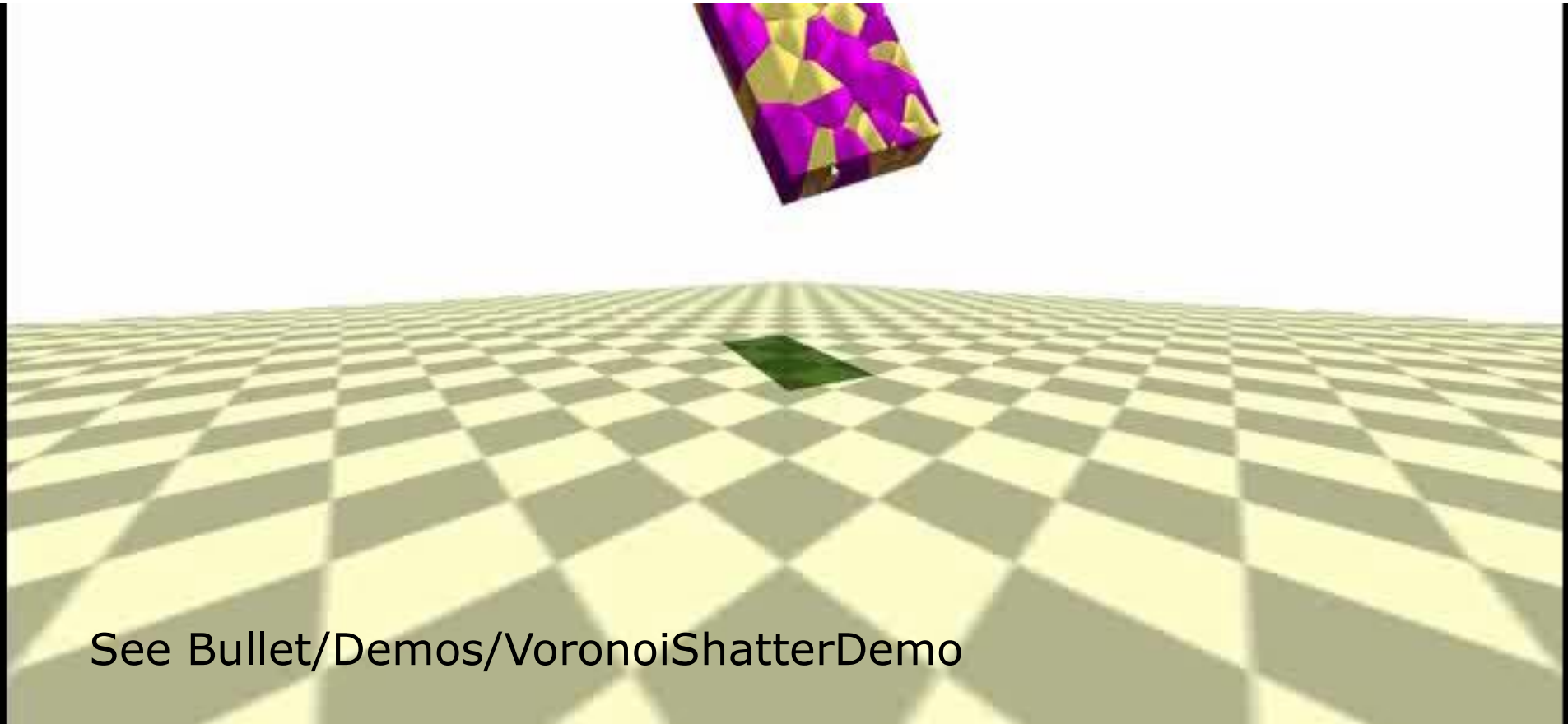
- Break an object into parts
- Automatically create constraints
  - based on contact points (collision detecion)
  - assign a breaking threshold to constraints
- At run-time propagate a collision impulse
  - break connections if the impulse > threshold

Stiffer constraints



Increase number of constraint solver iterations for the fixed constraints

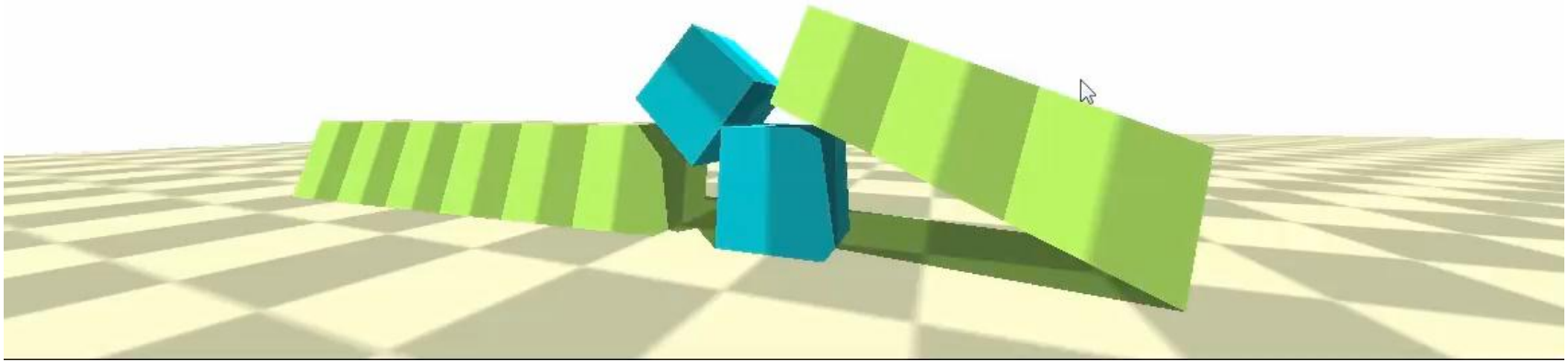
On-line voronoi shatter



See Bullet/Demos/VoronoiShatterDemo

Composite single body

See Bullet/Demos/FractureDemo



Composite method

- Break an object into parts
- Automatically create connections
  - based on contact points (collision detecion)
  - assign a breaking threshold to connections
- At run-time propagate a collision impulse
  - break connections if the impulse > threshold
  - determine disconnected parts using union find
  - create new rigid bodies for each disconnected part
  - update inertia tensor and velocity

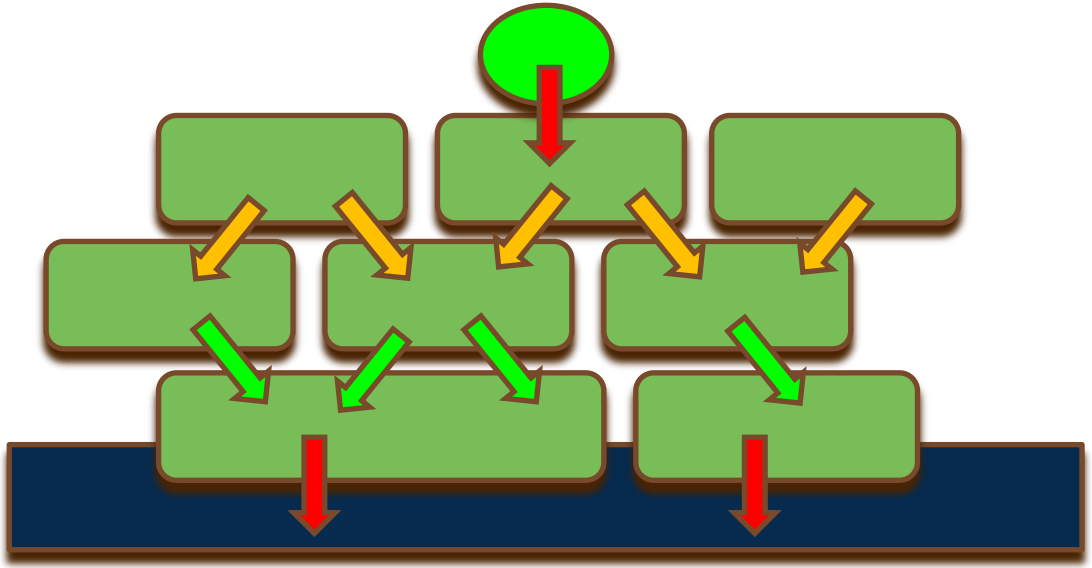
Structural Analysis

Layer 3

Layer 2

Layer 1

Ground



Red Faction: Spread calculations over multiple frames

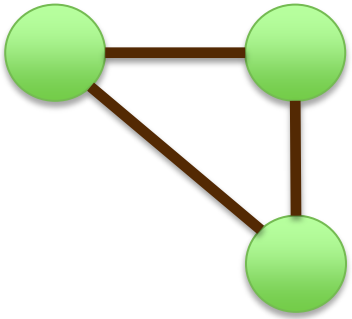
Other methods

- Position based dynamics
- Finite element method
- Hybrid

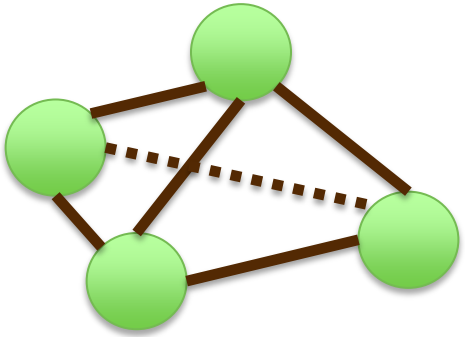
Connected particles

1D Rope

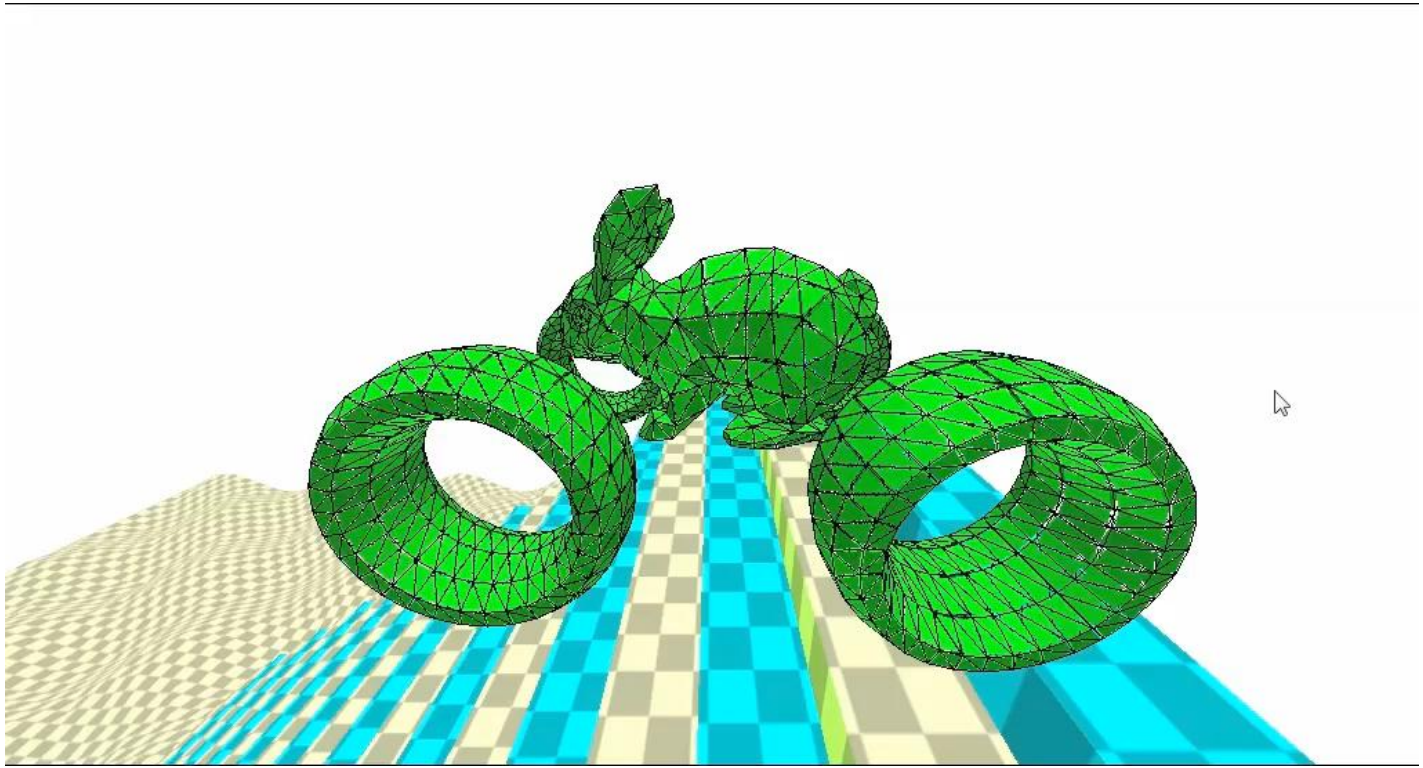
2D Triangle



3D Tetrahedron

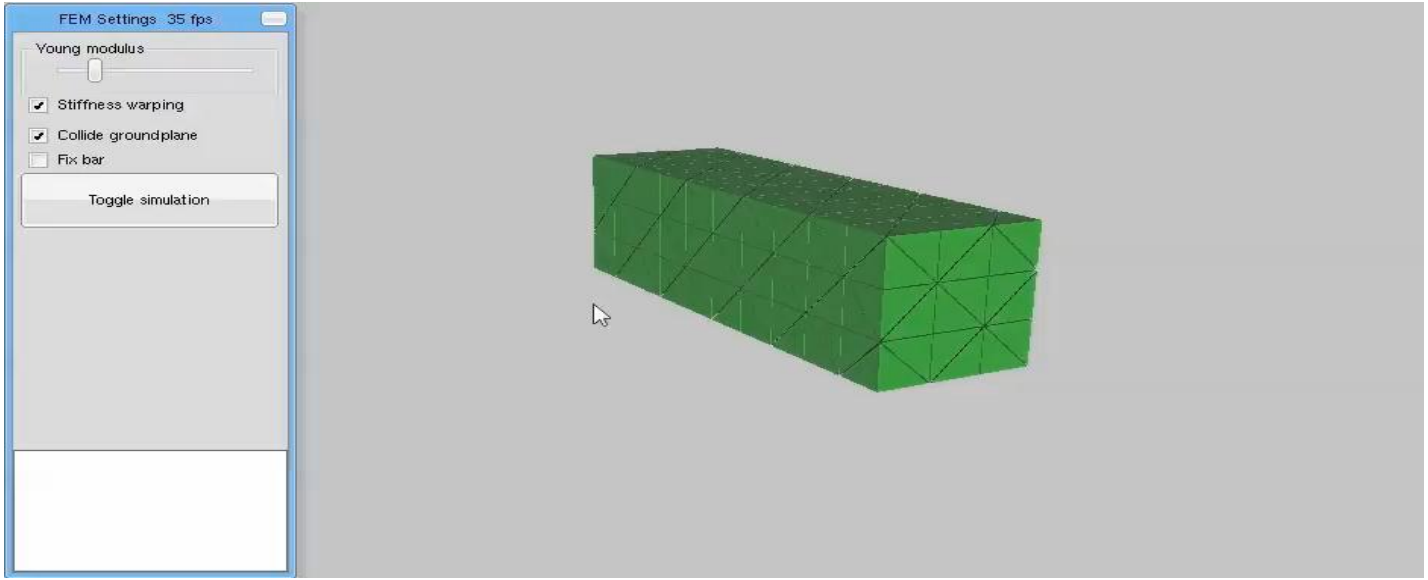


Position based dynamics



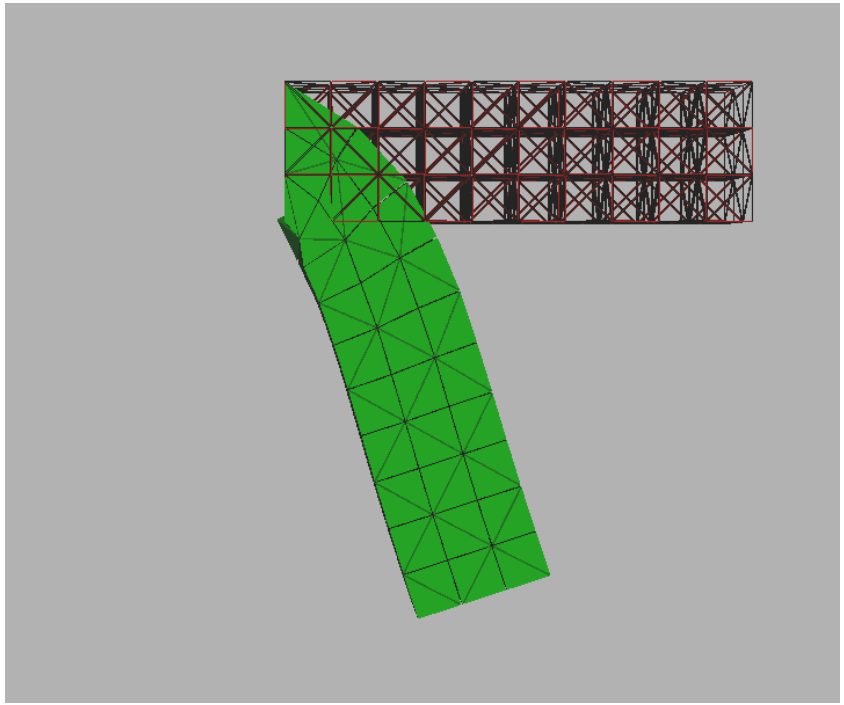
- Bullet, http://bulletphysics.org

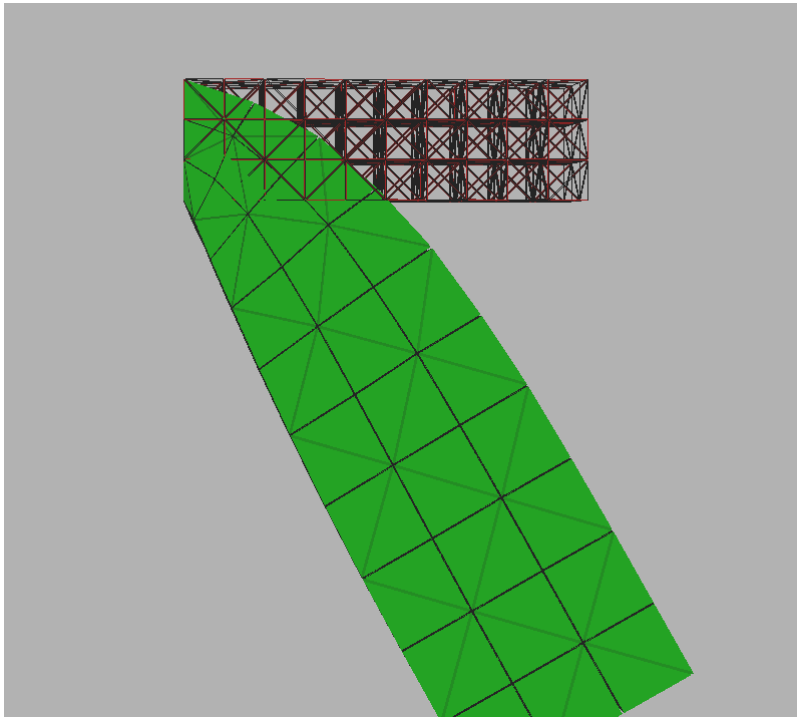
Finite element method



- Original from OpenTissue, Kenny Erleben et. al.
- https://github.com/erwincoumans/experiments/tree/master/dynamics/corotational_fem

Stiffness warping





FEM on GPU

- SOFA, http://sofa-framework.org
- Chapter 21 of GPU Computing Gems Jade Edition
- https://github.com/erwincoumans/experiments/tree/master/dynamics/ivi-sofa-tp1

Hybrid method

- Composite rigid body with static FEM analysis
  - Matthias Müller et al. Eurographics CAS 2001

Thanks!

- http://bulletphysics.org
- http://github.com/erwincoumans
- http://youtube.com/erwincoumans