

Computer Animation:  
Past, Present, and Future

Adam Bargteil

University of Maryland, Baltimore County

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# Hunger (1974)

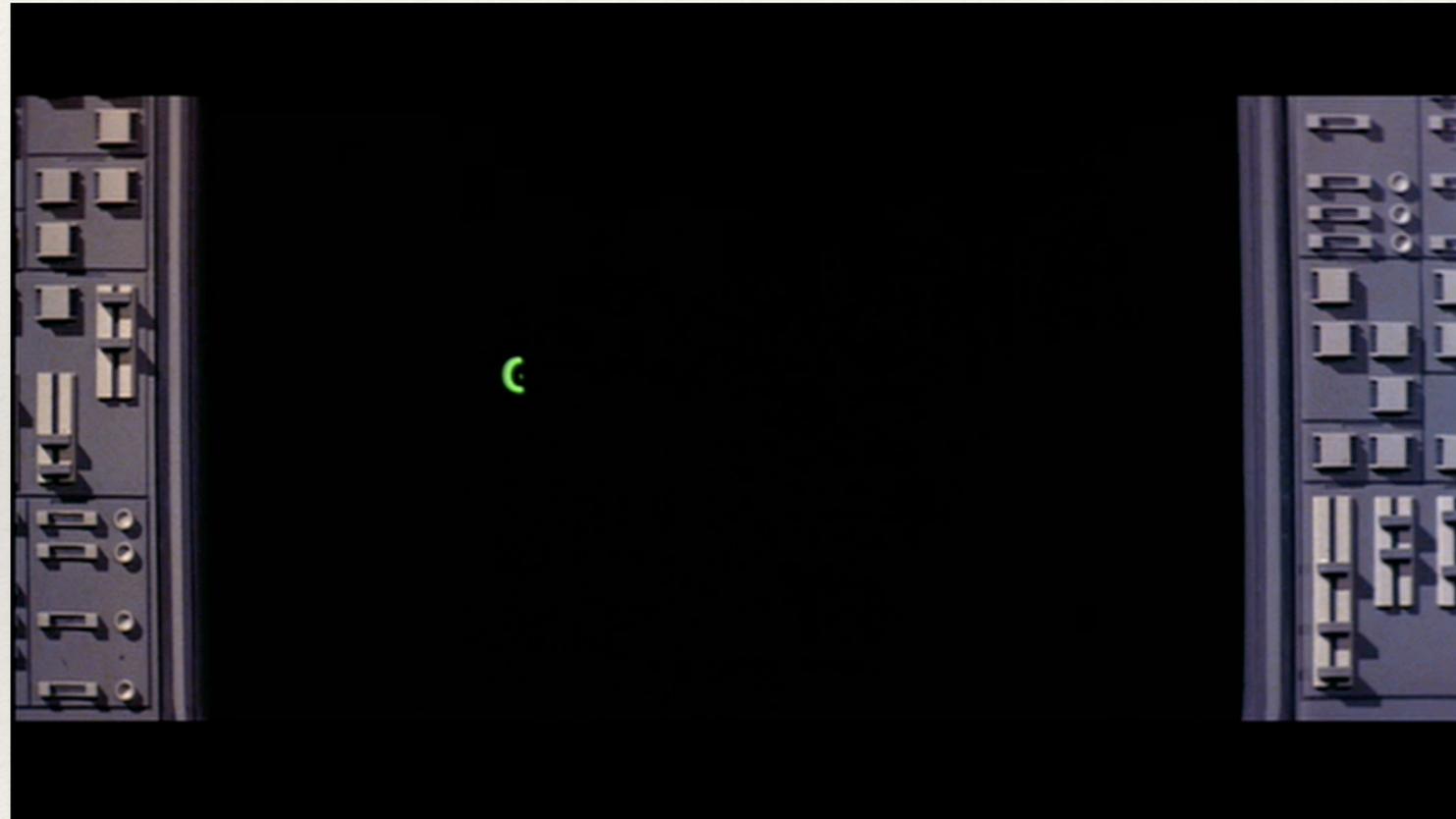
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# Star Trek: The Wrath of Khan (1982)

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# Particle Systems—A Technique for Modeling a Class of Fuzzy Objects

WILLIAM T. REEVES

Lucasfilm Ltd

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This paper introduces particle systems—a method for modeling fuzzy objects such as fire, clouds, and water. Particle systems model an object as a cloud of primitive particles that define its volume. Over a period of time, particles are generated into the system, move and change form within the system.

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Author's address: William T. Reeves, Lucasfilm Ltd, P.O. Box 2009, San Rafael, CA 94912.

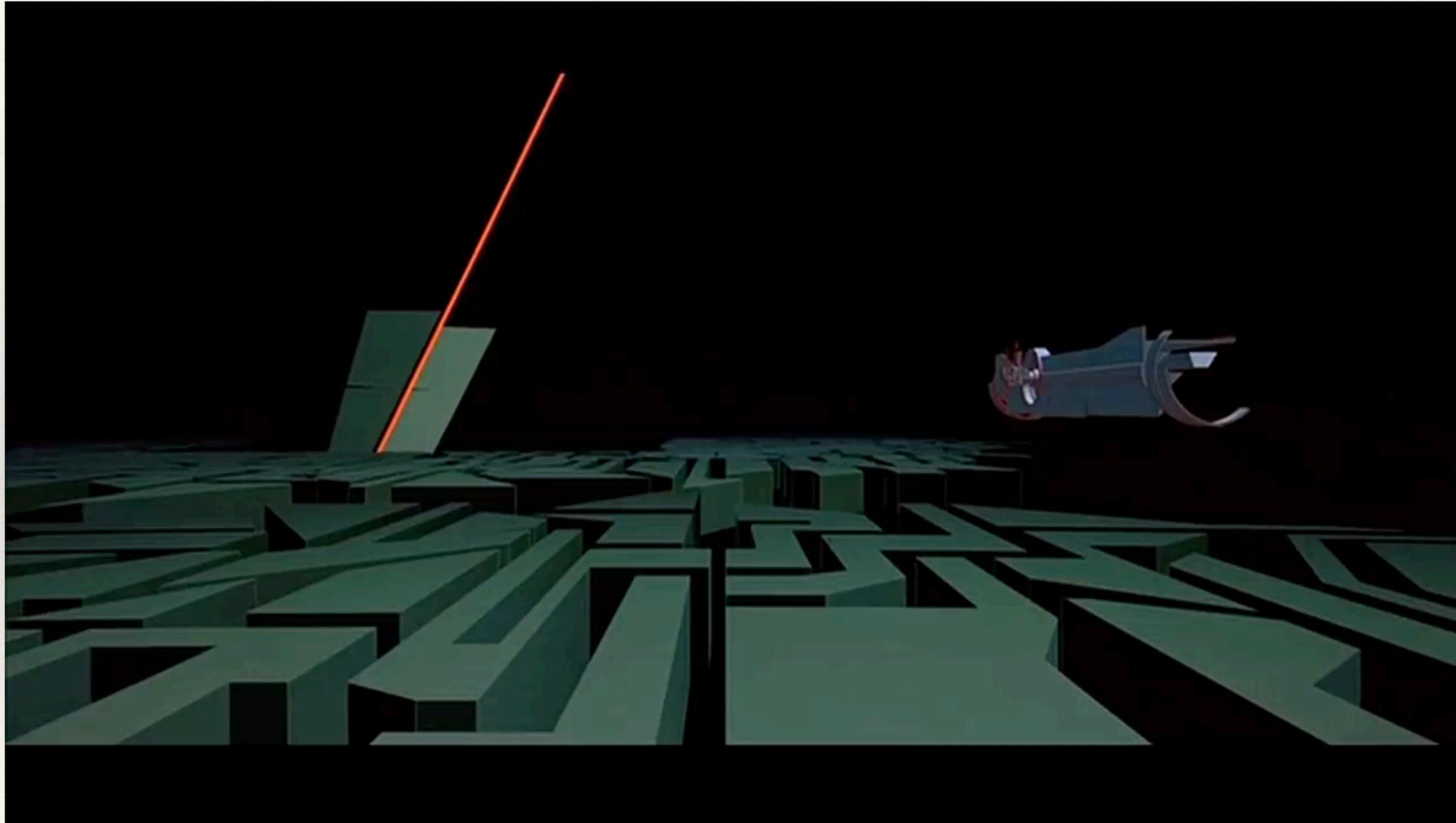
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# Tron (1982)

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# Principles of Traditional Animation (1987)



Computer Graphics, Volume 21, Number 4, July 1987

## PRINCIPLES OF TRADITIONAL ANIMATION APPLIED TO 3D COMPUTER ANIMATION

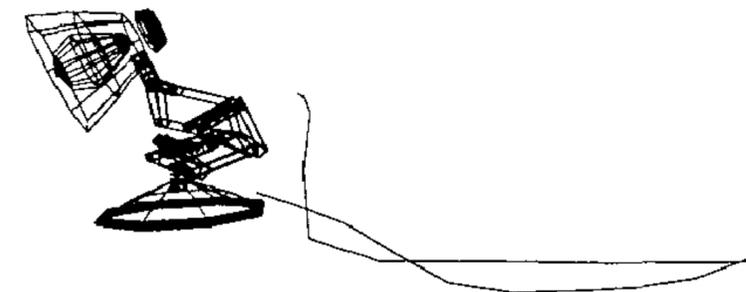
John Lasseter  
Pixar  
San Rafael  
California

*"There is no particular mystery in animation... it's really very simple, and like anything that is simple, it is about the hardest thing in the world to do."* Bill Tytla at the Walt Disney Studio, June 28, 1937. [14]

### ABSTRACT

This paper describes the basic principles of traditional 2D hand drawn animation and their application to 3D computer animation. After describing how these principles evolved, the individual principles are detailed,

FIGURE 1. Luxo Jr.'s hop with overlapping action on cord. Flip pages from last page of paper to front. The top figures are frames 1-5, the bottom are frames 6-10.



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# Principles of Traditional Animation (1987)

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- ❖ squash and stretch
- ❖ timing
- ❖ anticipation
- ❖ staging
- ❖ follow through & overlapping action
- ❖ straight ahead and pose-to-pose action
- ❖ slow in and out
- ❖ arcs
- ❖ exaggeration
- ❖ secondary action
- ❖ appeal

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# Jurassic Park (1993)

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“it was like one of those moments in history, like the invention of the light bulb or the first telephone call... A major gap had been crossed and things were never going to be the same.”

*–George Lucas*

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# Toy Story (1995)

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THE FOLLOWING **PREVIEW** HAS BEEN APPROVED FOR  
**ALL AUDIENCES**  
BY THE MOTION PICTURE ASSOCIATION OF AMERICA

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1995-2015

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The Golden Age of Computer Animation

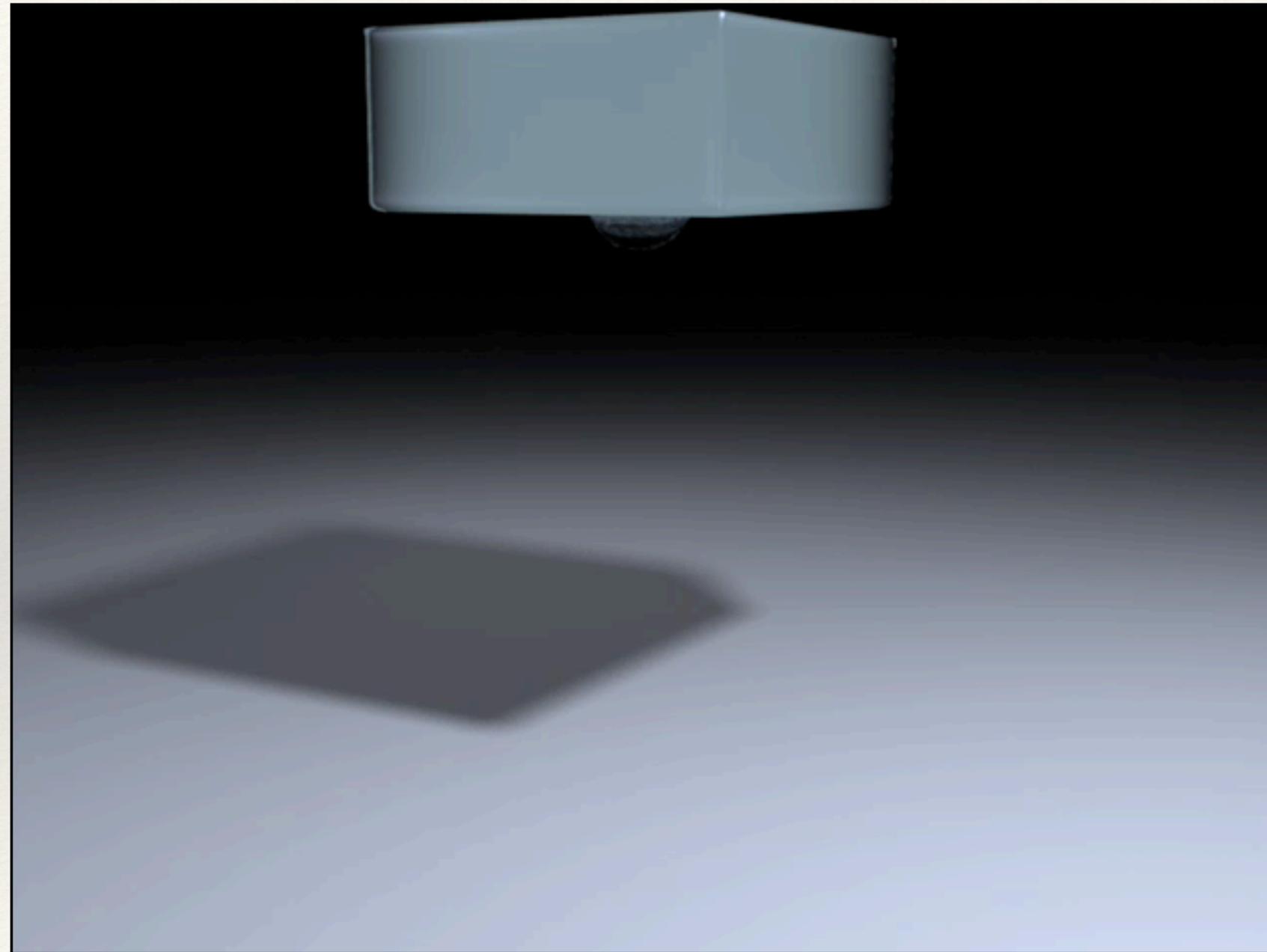
# The “Special Effects Problem”

explosions, tidal waves, city buildings destroyed by robots, aliens, supervillains, etc.

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# Eulerian Viscoelastic Fluids

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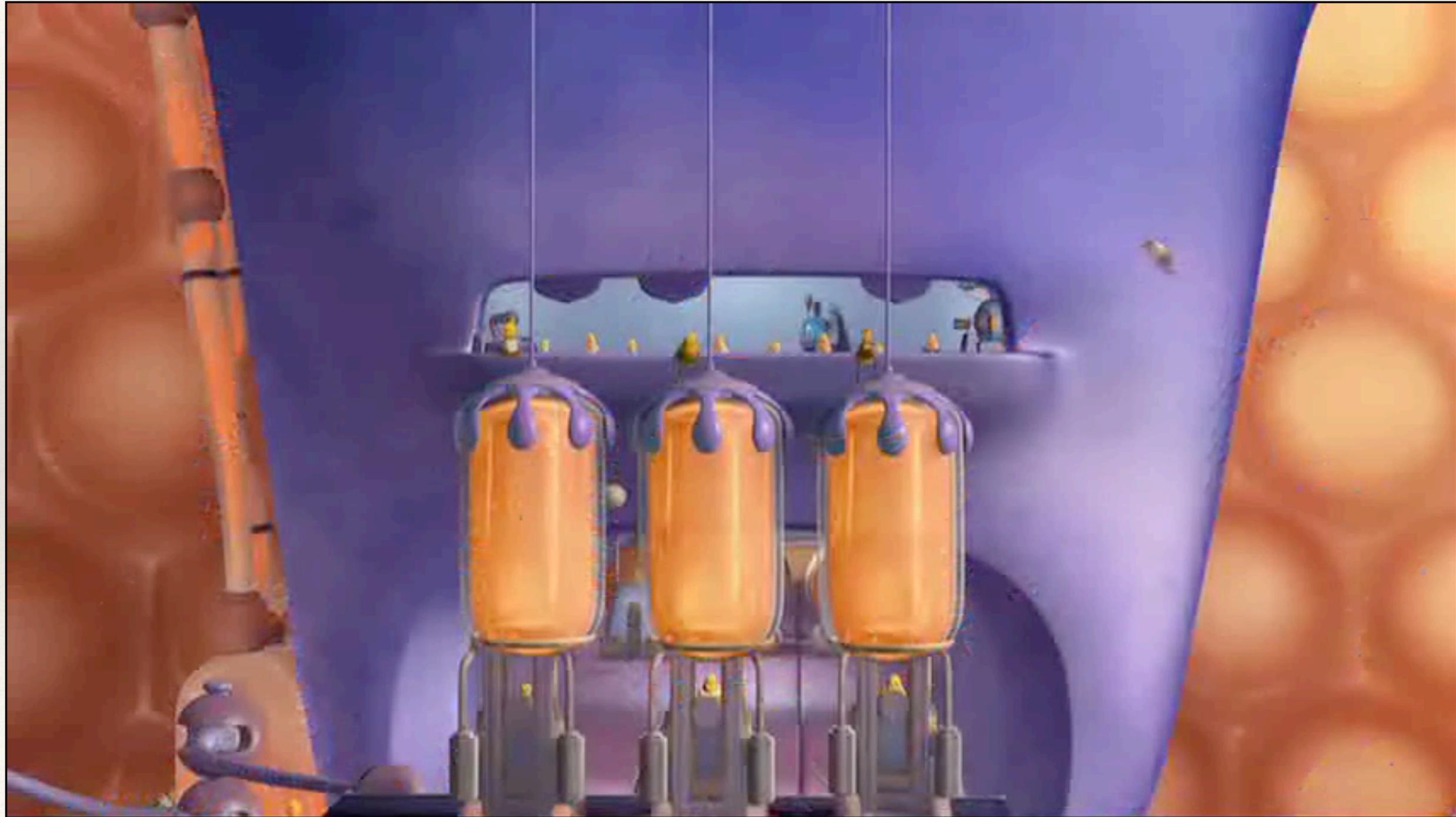


Goktekin, Bargteil, O'Brien [SIGGRAPH 2004]

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# DreamWorks Animation's *Bee Movie* (2007)

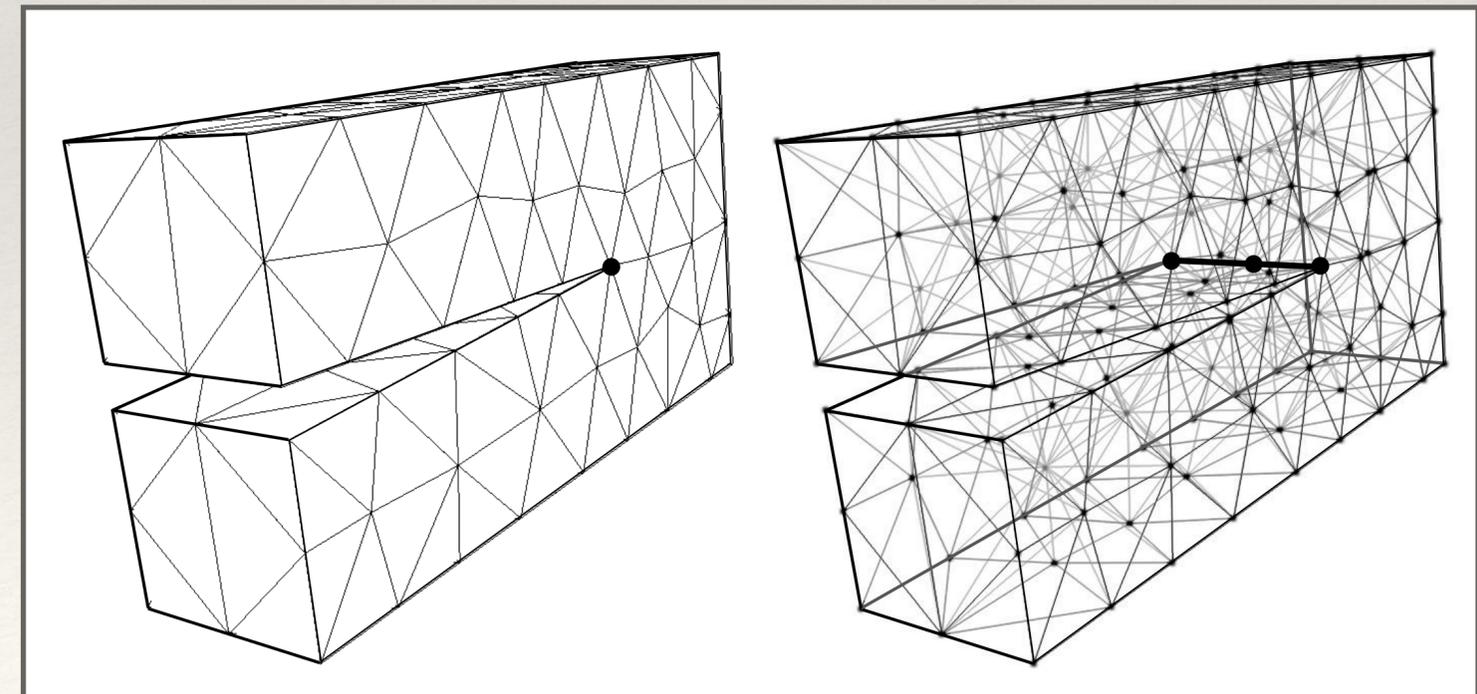
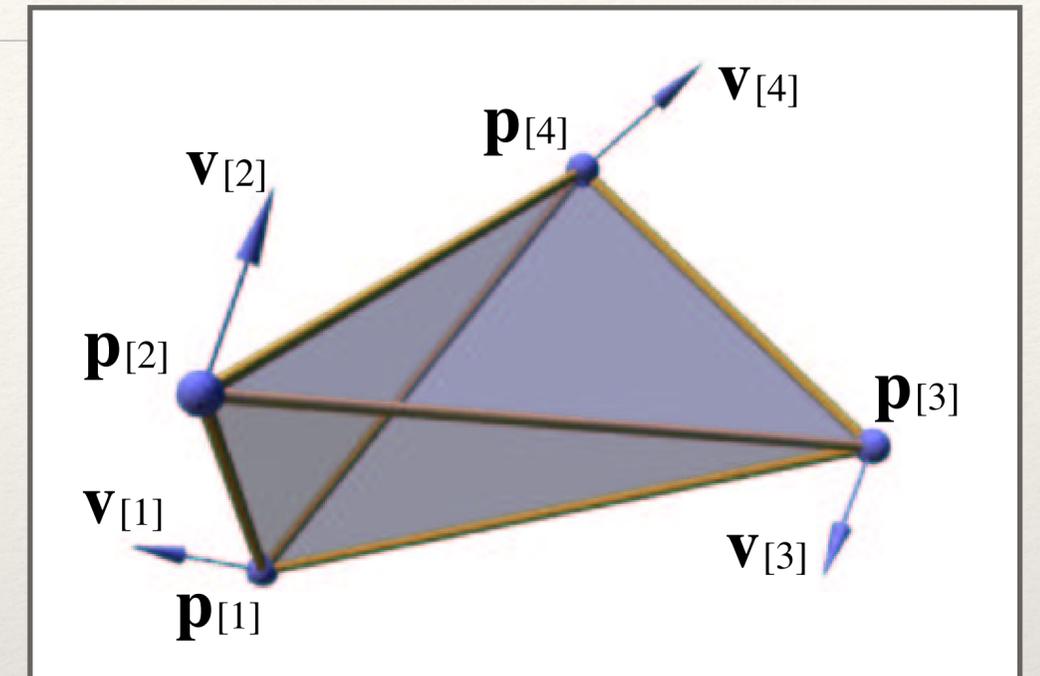
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# Finite Element Destruction: *A Success Story*

# Finite Elements

- ❖ Fundamental physics simulation
  - ❖ Rigid movement
  - ❖ Bending, twisting, stretching
- ❖ Dynamic tearing, cracking, ripping
- ❖ Wide range of materials

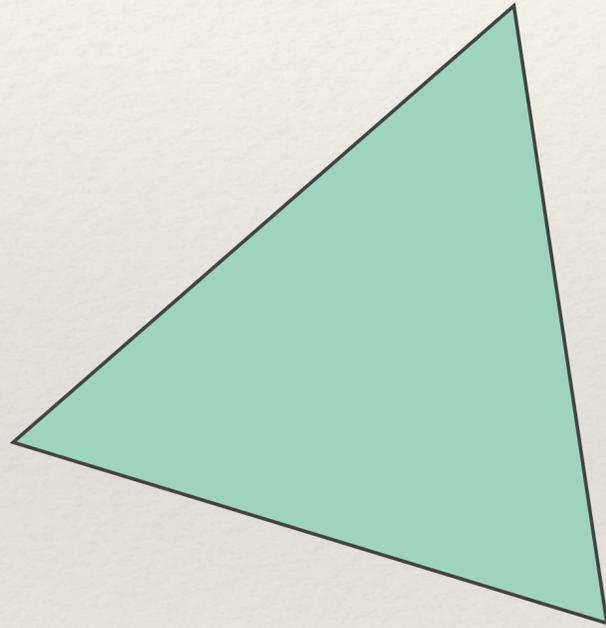


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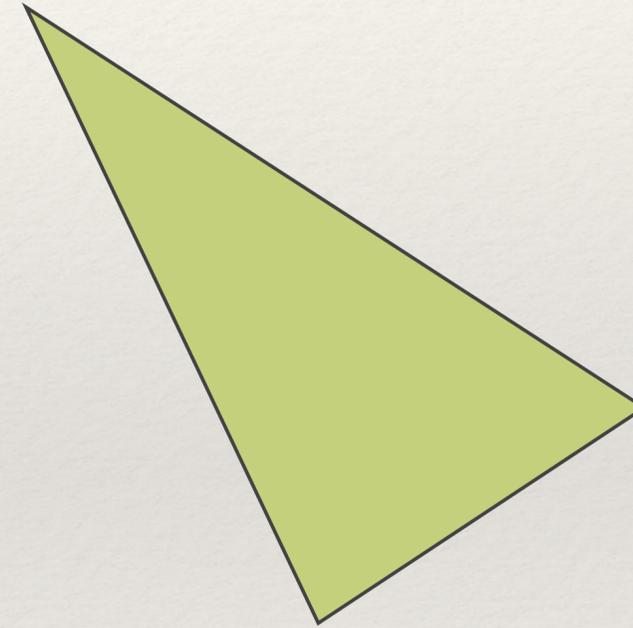
# Finite Elements

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Rest



Deformed

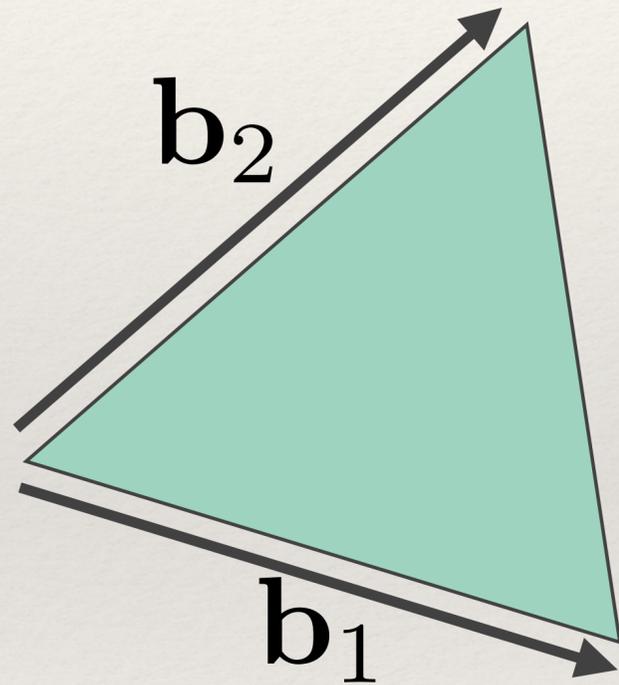


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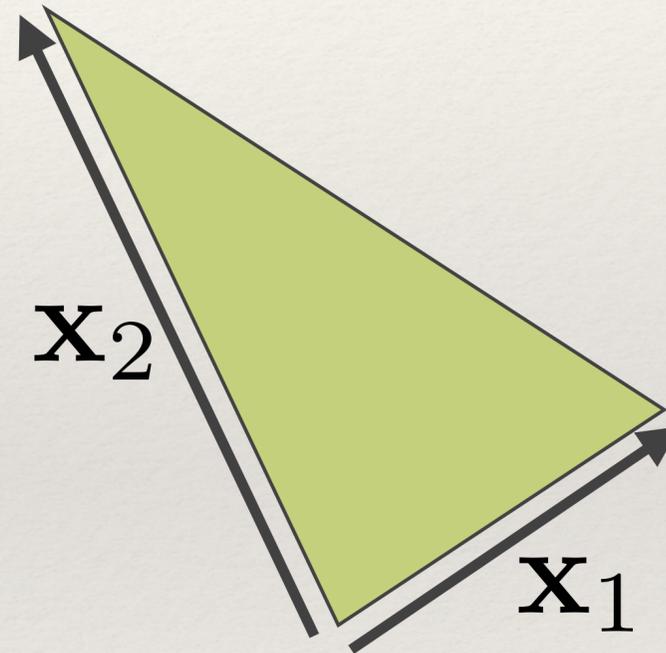
# Finite Elements

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Rest



Deformed

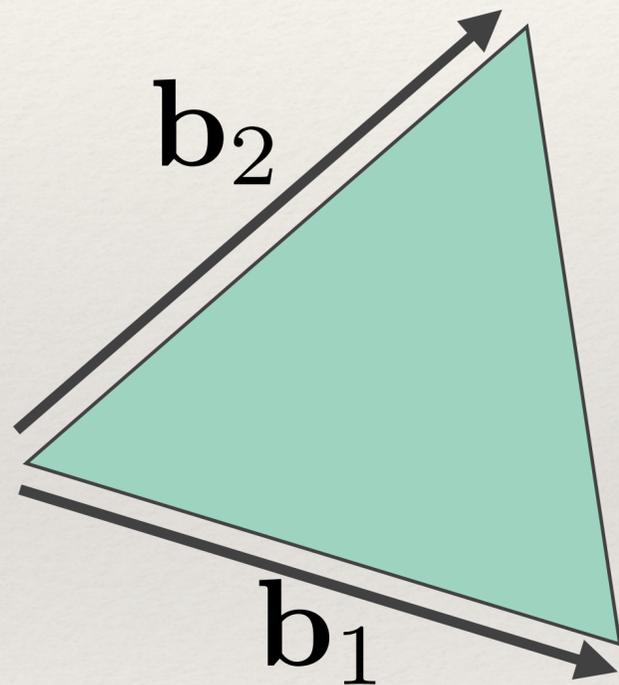


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# Finite Elements

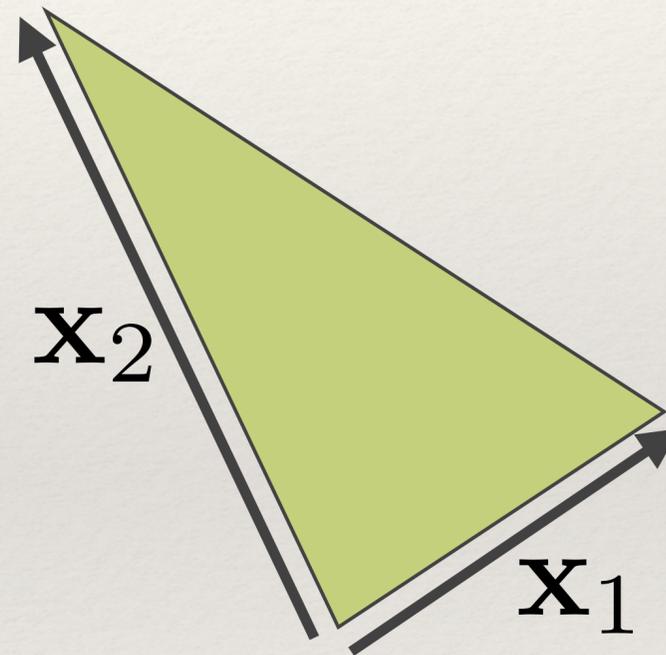
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Rest



$$\beta = (\mathbf{b}_1 \mathbf{b}_2)^{-1}$$

Deformed



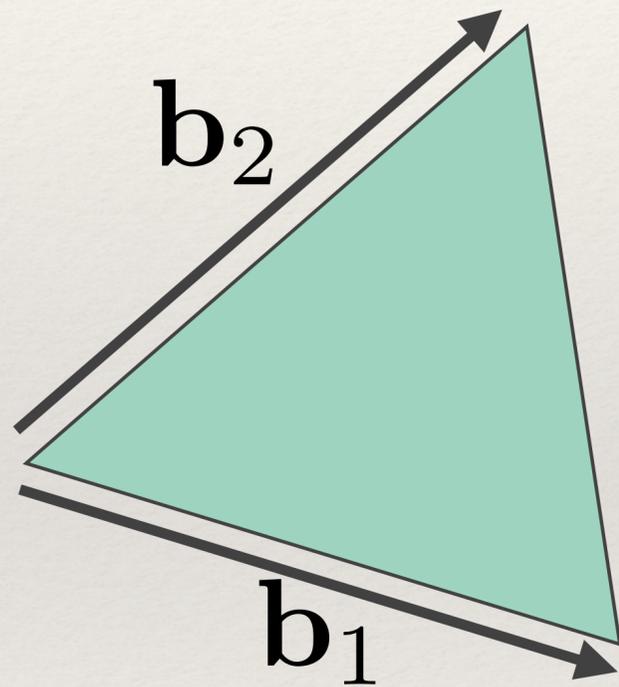
$$\mathbf{X} = (\mathbf{x}_1 \mathbf{x}_2)$$

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# Finite Elements

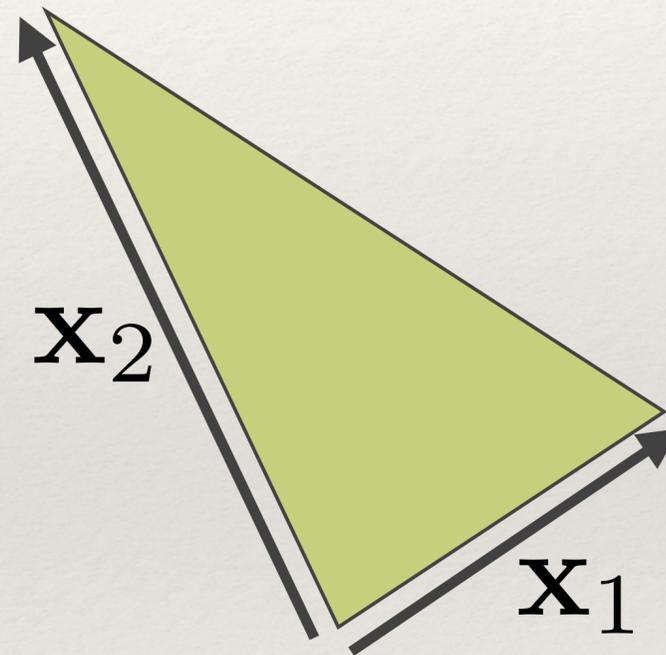
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Rest



$$\beta = (\mathbf{b}_1 \mathbf{b}_2)^{-1}$$

Deformed



$$\mathbf{X} = (\mathbf{x}_1 \mathbf{x}_2)$$

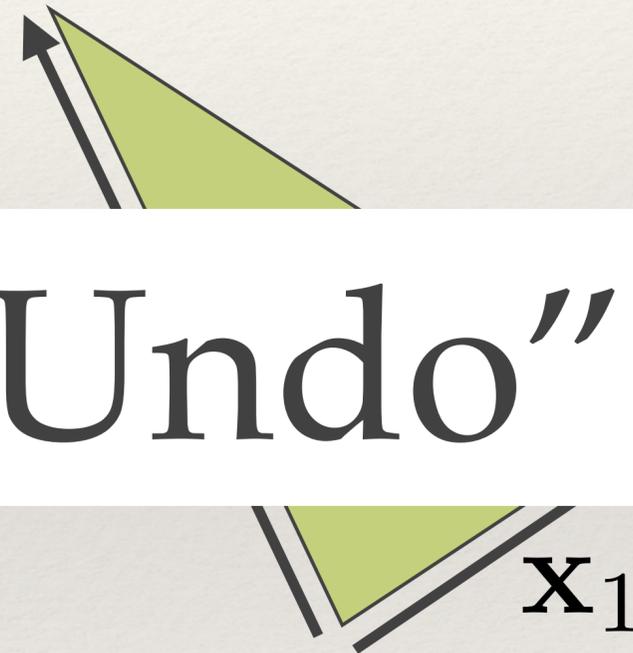
$$\mathbf{F} = \mathbf{X} \beta$$

# Finite Elements

Rest



Deformed



Elastic Forces “Undo”  $\mathbf{F}$

$$\beta = (\mathbf{b}_1 \mathbf{b}_2)^{-1}$$

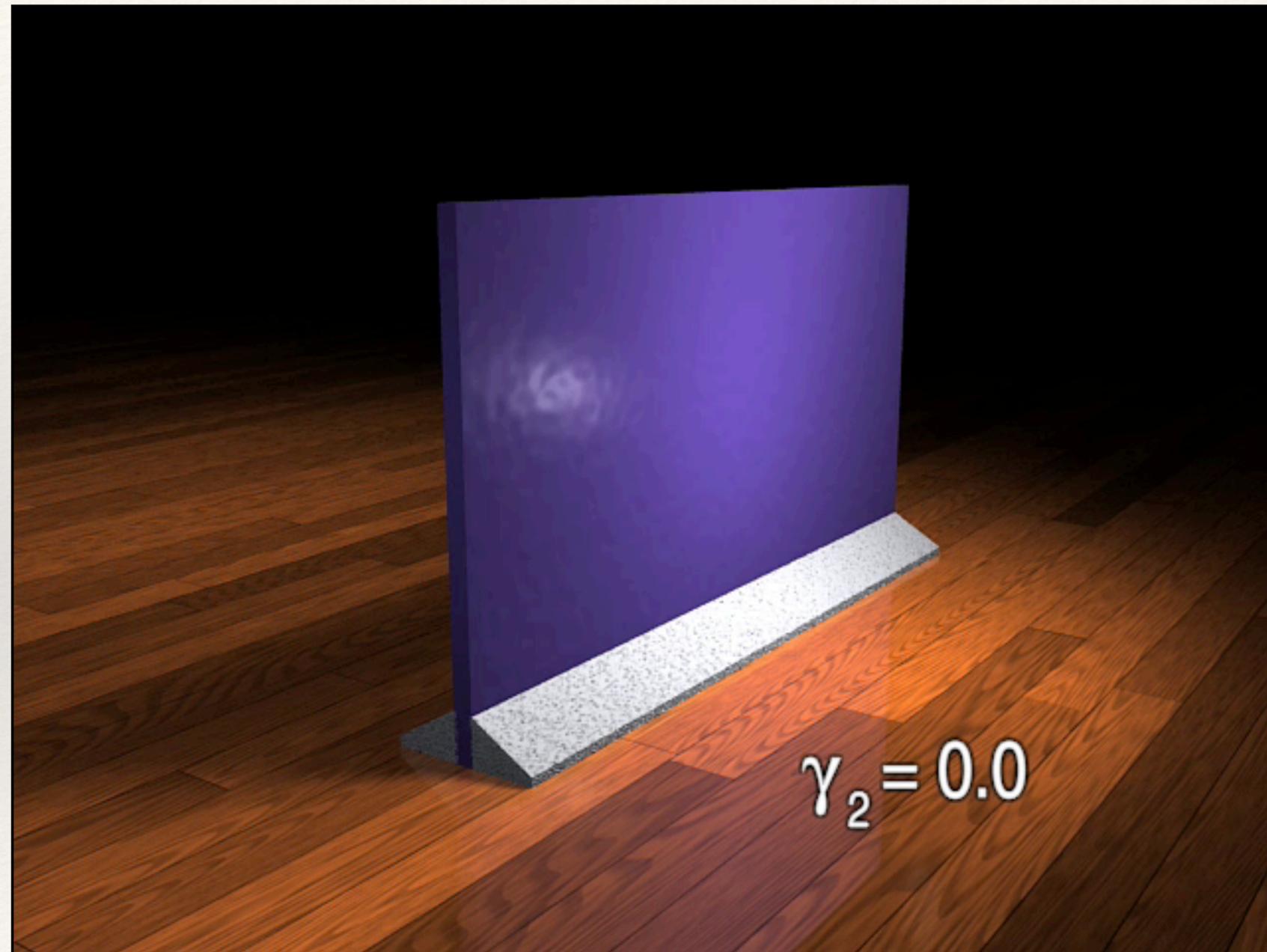
$$\mathbf{X} = (\mathbf{x}_1 \mathbf{x}_2)$$

$$\mathbf{F} = \mathbf{X} \beta$$

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# Graphical Modeling and Animation of Ductile Fracture

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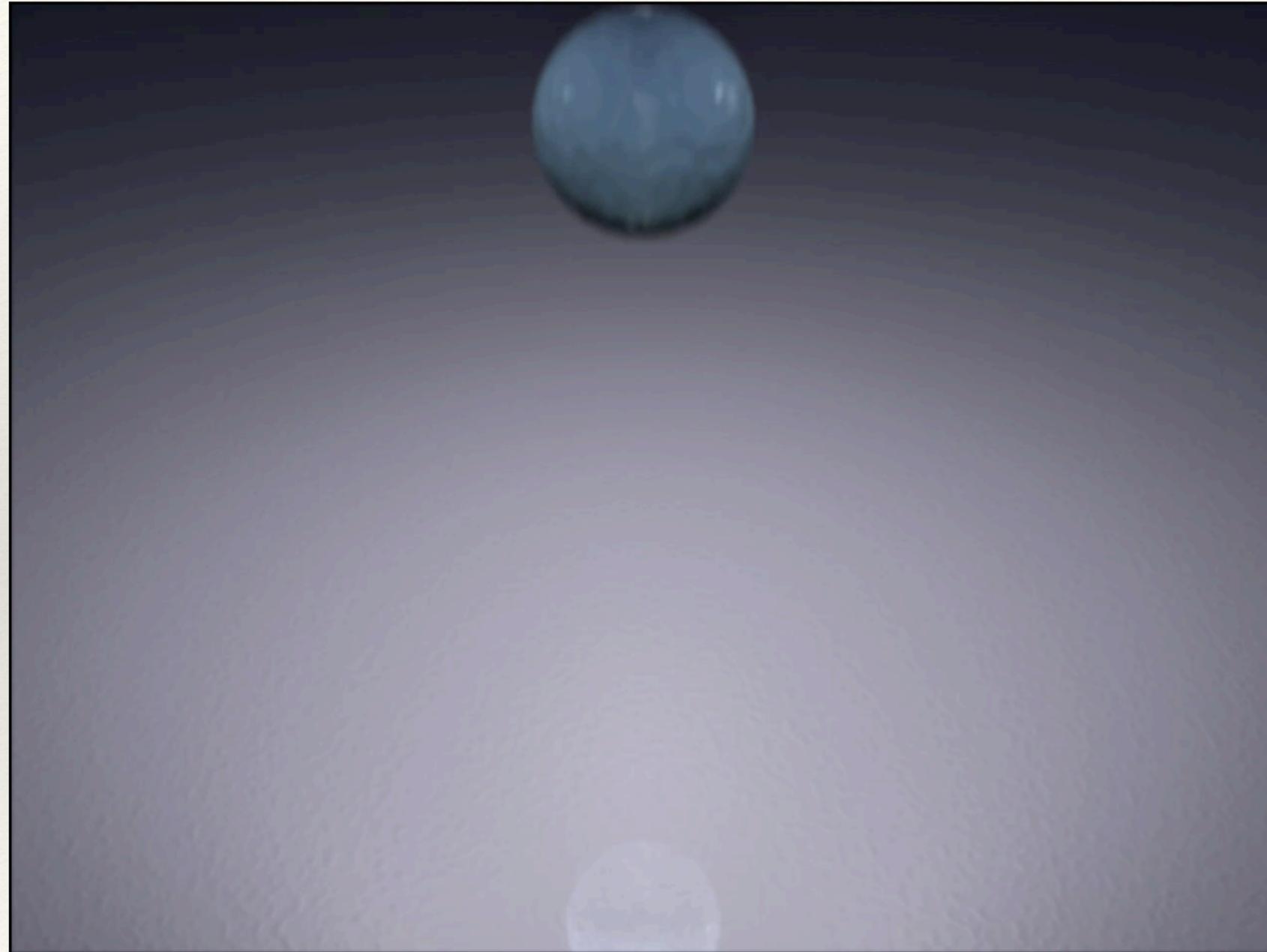


O'Brien, Bargteil & Hodgins [SIGGRAPH 2002]

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# Graphical Modeling and Animation of Ductile Fracture

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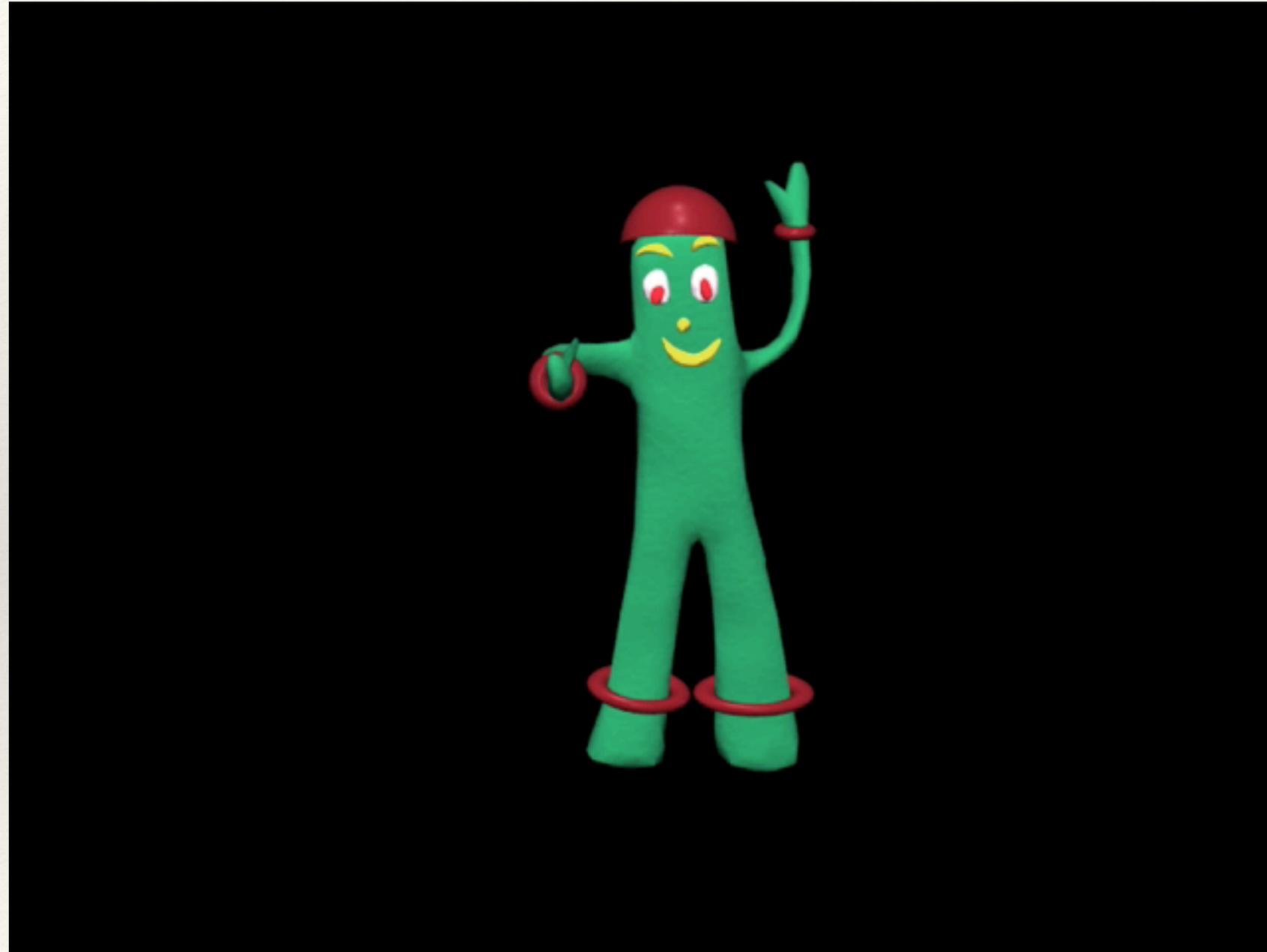


O'Brien, Bargteil & Hodgins [SIGGRAPH 2002]

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# Graphical Modeling and Animation of Ductile Fracture

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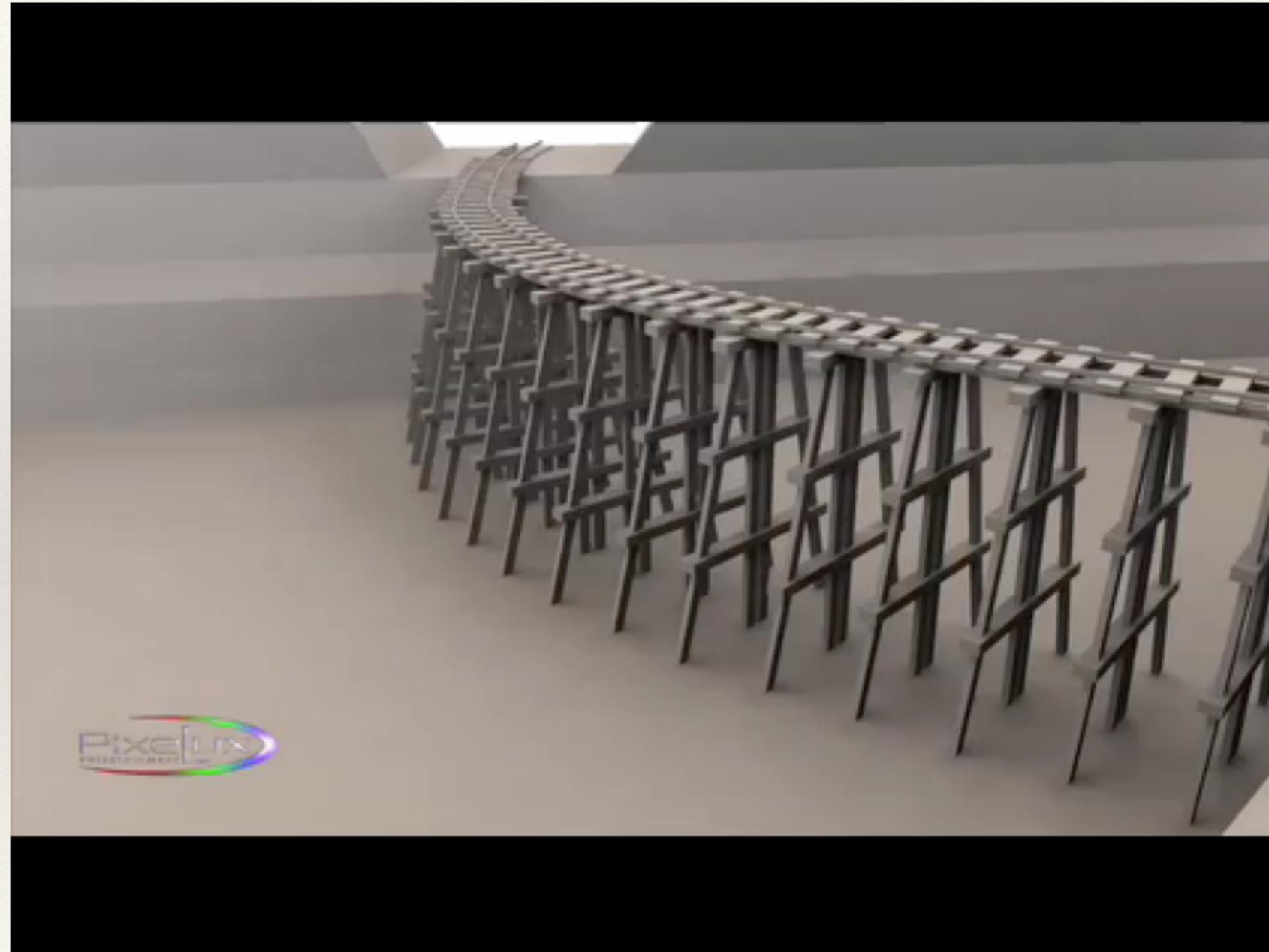


O'Brien, Bargteil & Hodgins [SIGGRAPH 2002]

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# Digital Molecular Matter

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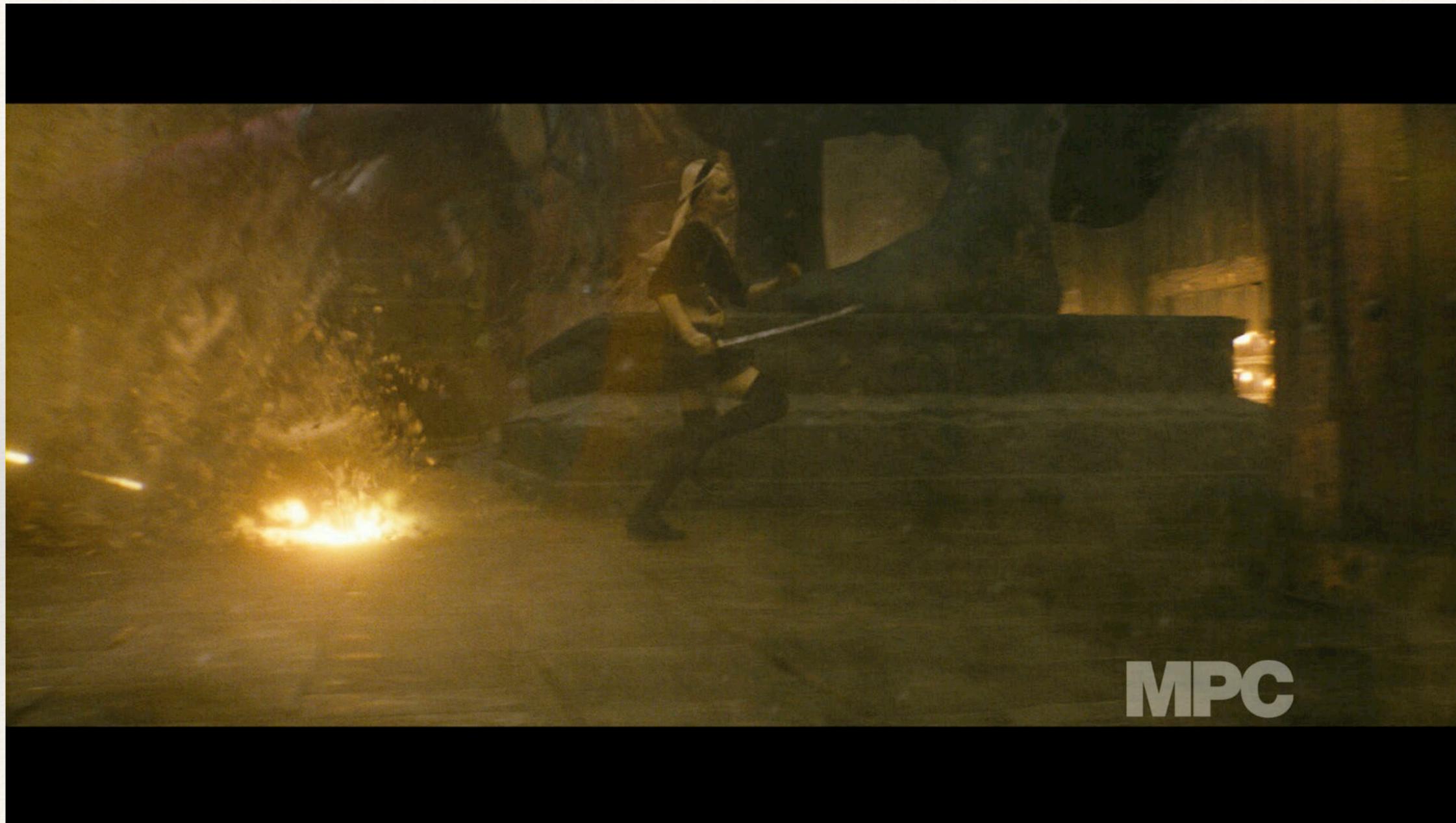


Parker & O'Brien [SCA 2009]

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# Moving Picture Company's *Kali*

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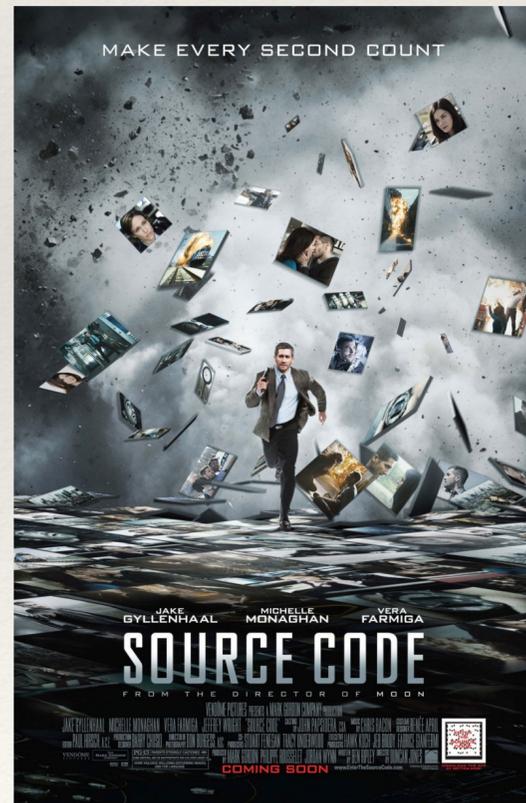
Cole [SIGGRAPH 2011 Talk]

2010

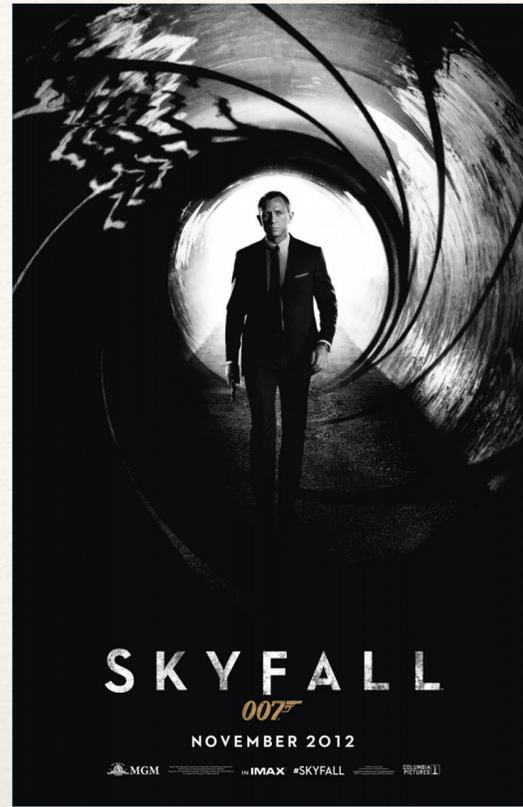
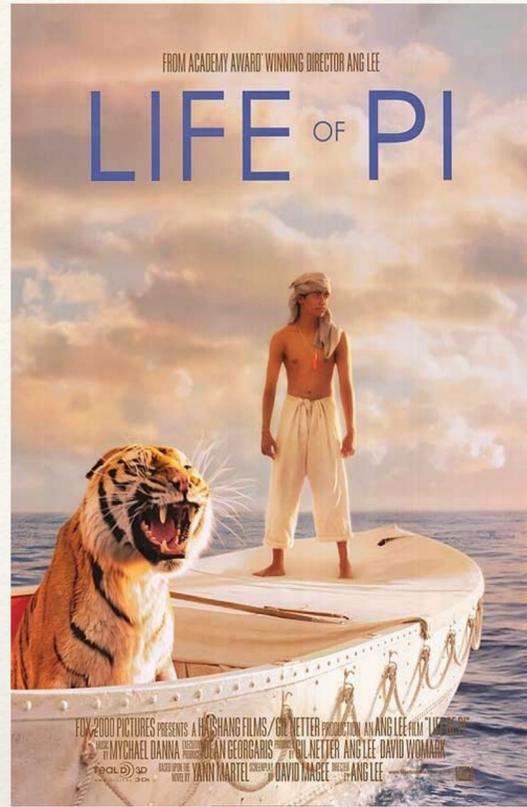


# MPC Films using Kali / DMM

2011



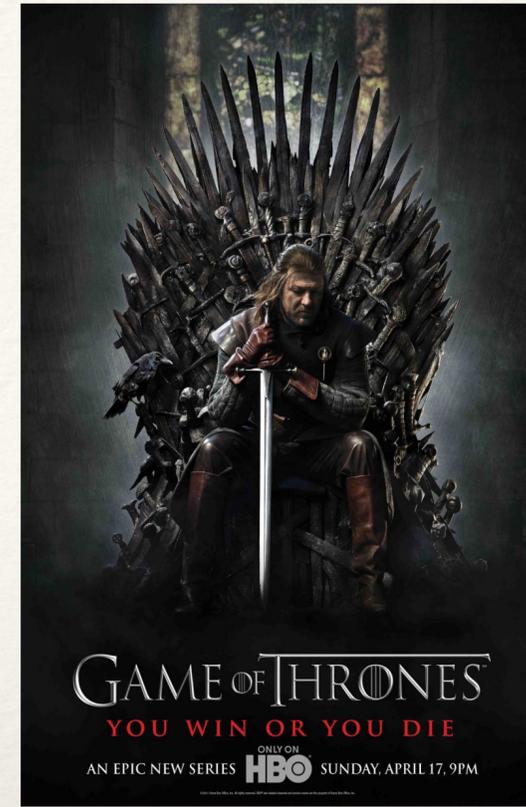
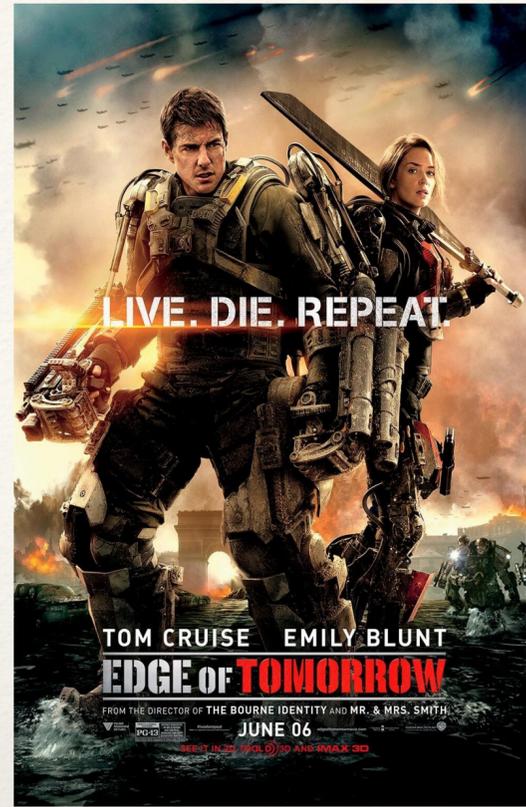
2012



2013



2014



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# 2015 Technical Achievement Award

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# The State of the Art

- ❖ special effects are almost universally achieved through computer graphics
- ❖ almost all films contain some computer animation
- ❖ an artist can create almost any effect they can imagine

Groundhog Day (1993)



Edge of Tomorrow (2014)



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# The Future

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more, better tools

interactive animation

virtual / augmented / mixed reality

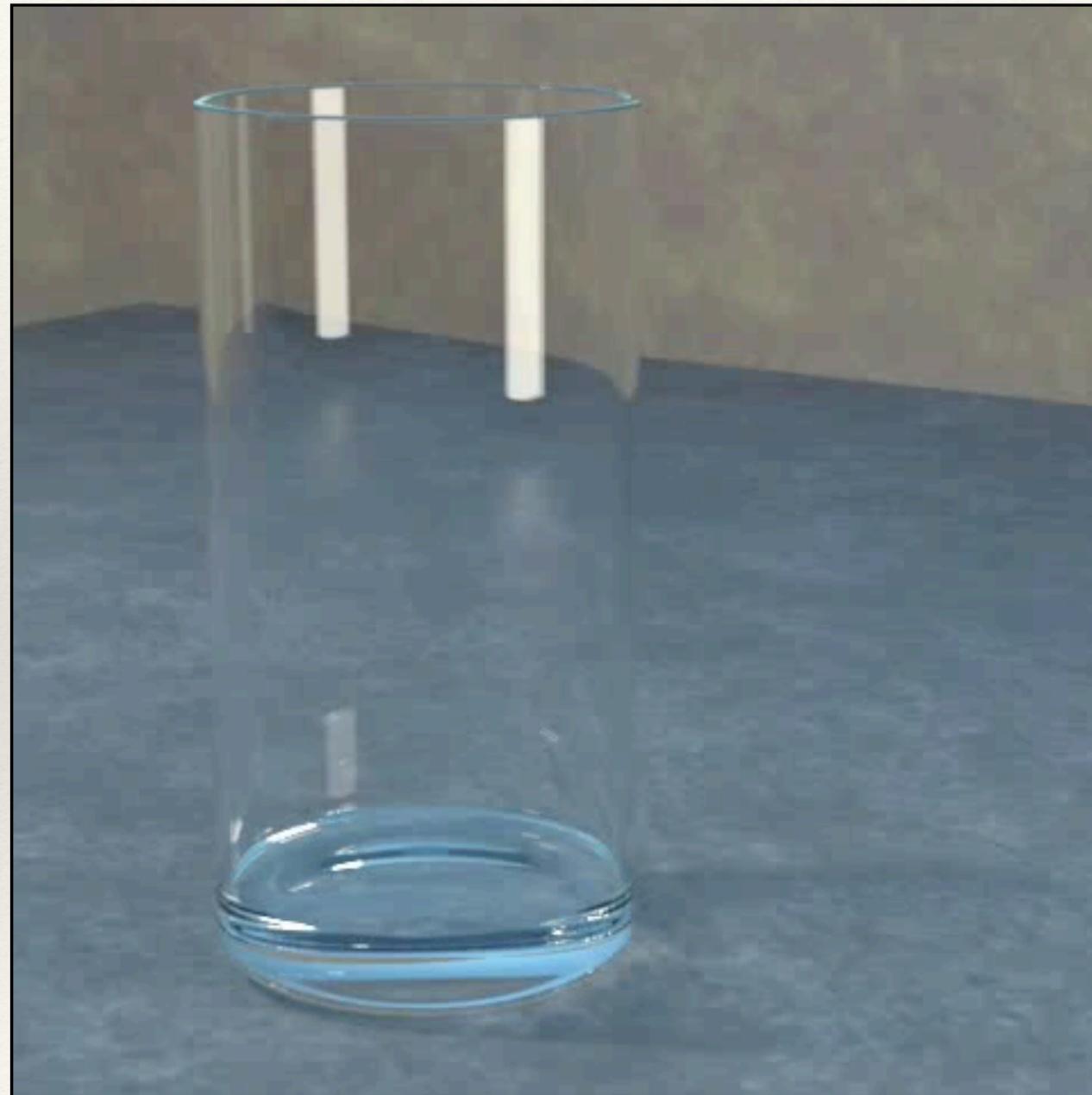
content creation

*A Specialized Tool for  
Large-scale Splashing Liquids*

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# Small Scale Liquids

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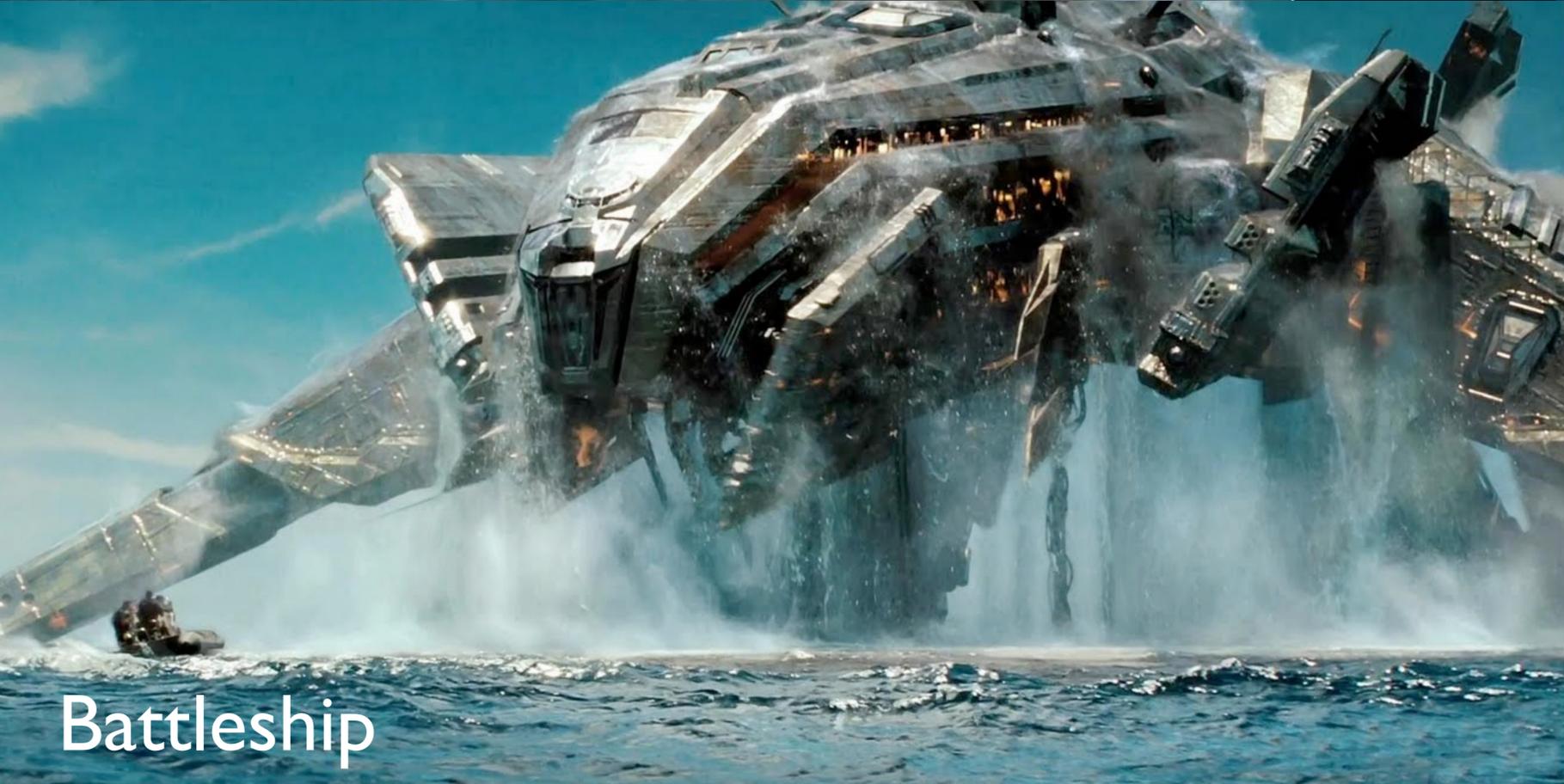
Enright, Marschner & Fedkiw [SIGGRAPH 2002]



Deep Impact



2012



Battleship



The Day After Tomorrow

like a good physicist we observe the  
phenomena we wish to model





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# An Observation About Splashes

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surface tension causes liquids to pinch  
off into droplets, which then mix freely  
with air and...

...the liquid *appears* to expand

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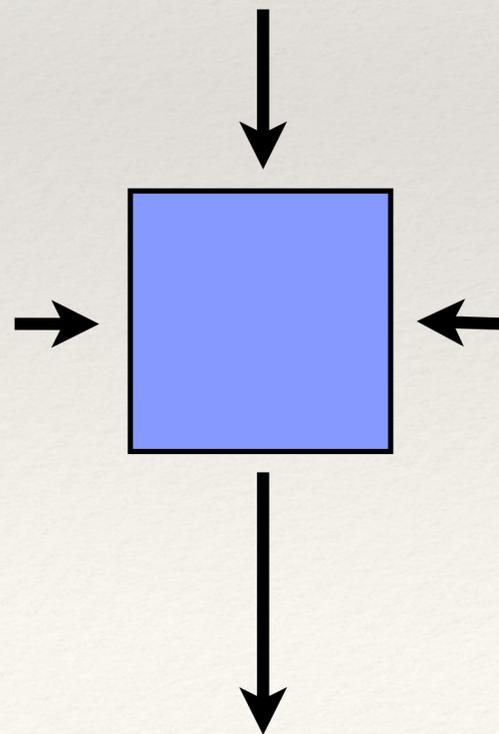
# A New Model

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Bilateral

Incompressibility

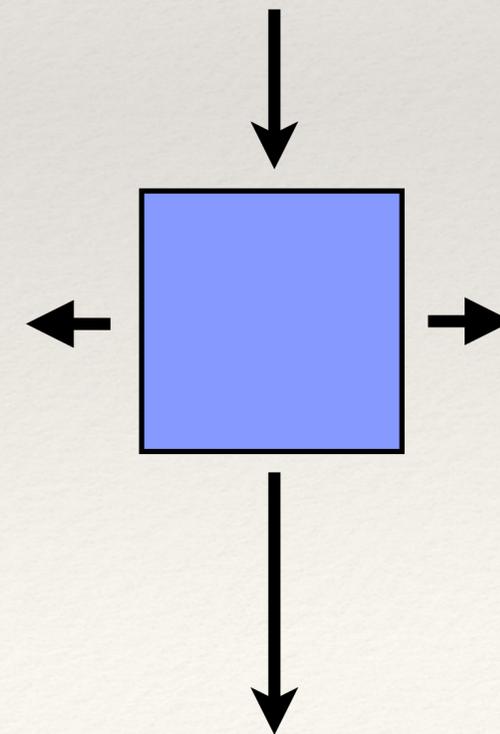
fluid in == fluid out



Unilateral

Incompressibility

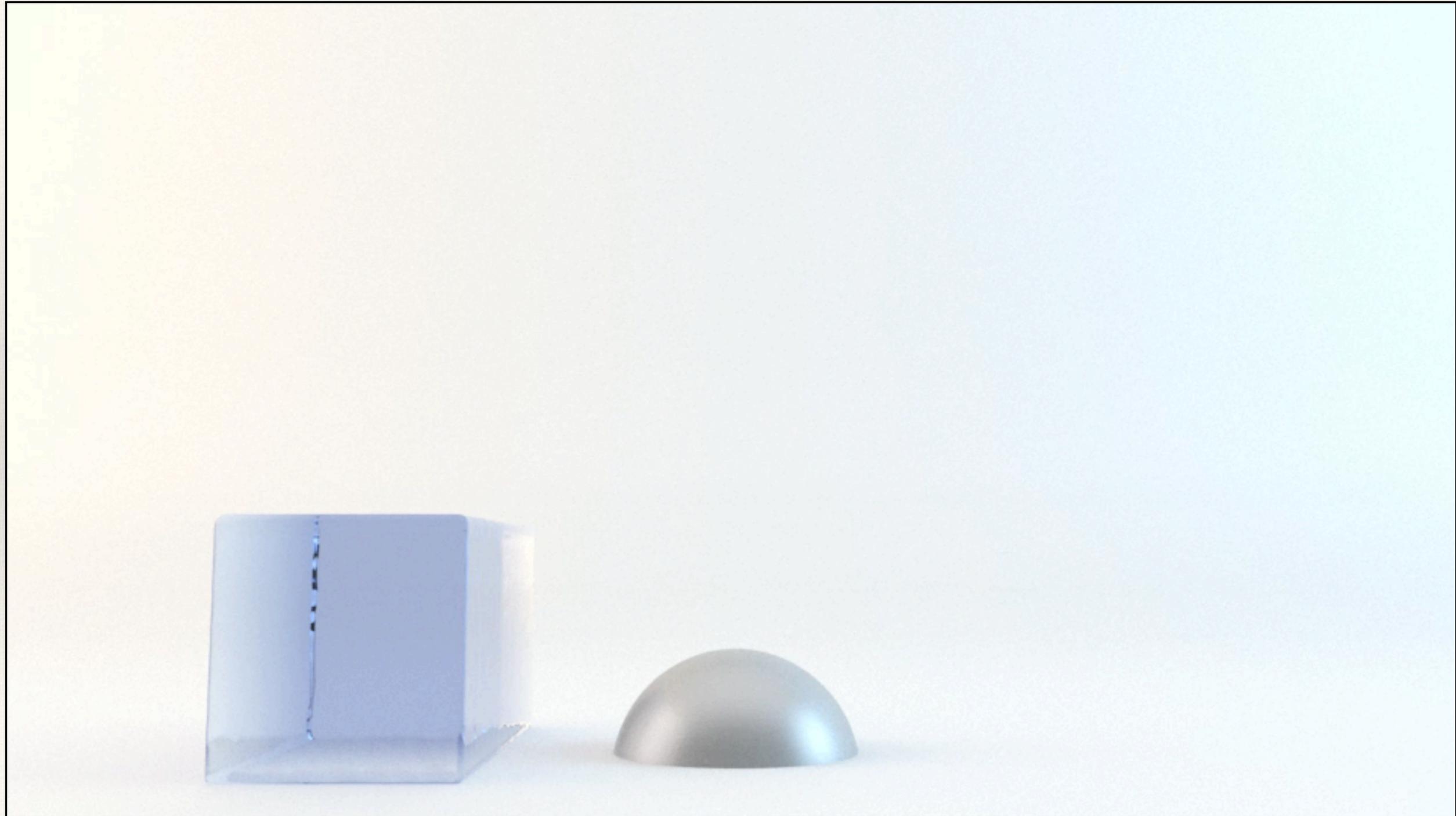
fluid in <= fluid out



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# Traditional Fluid Simulation: Incompressible

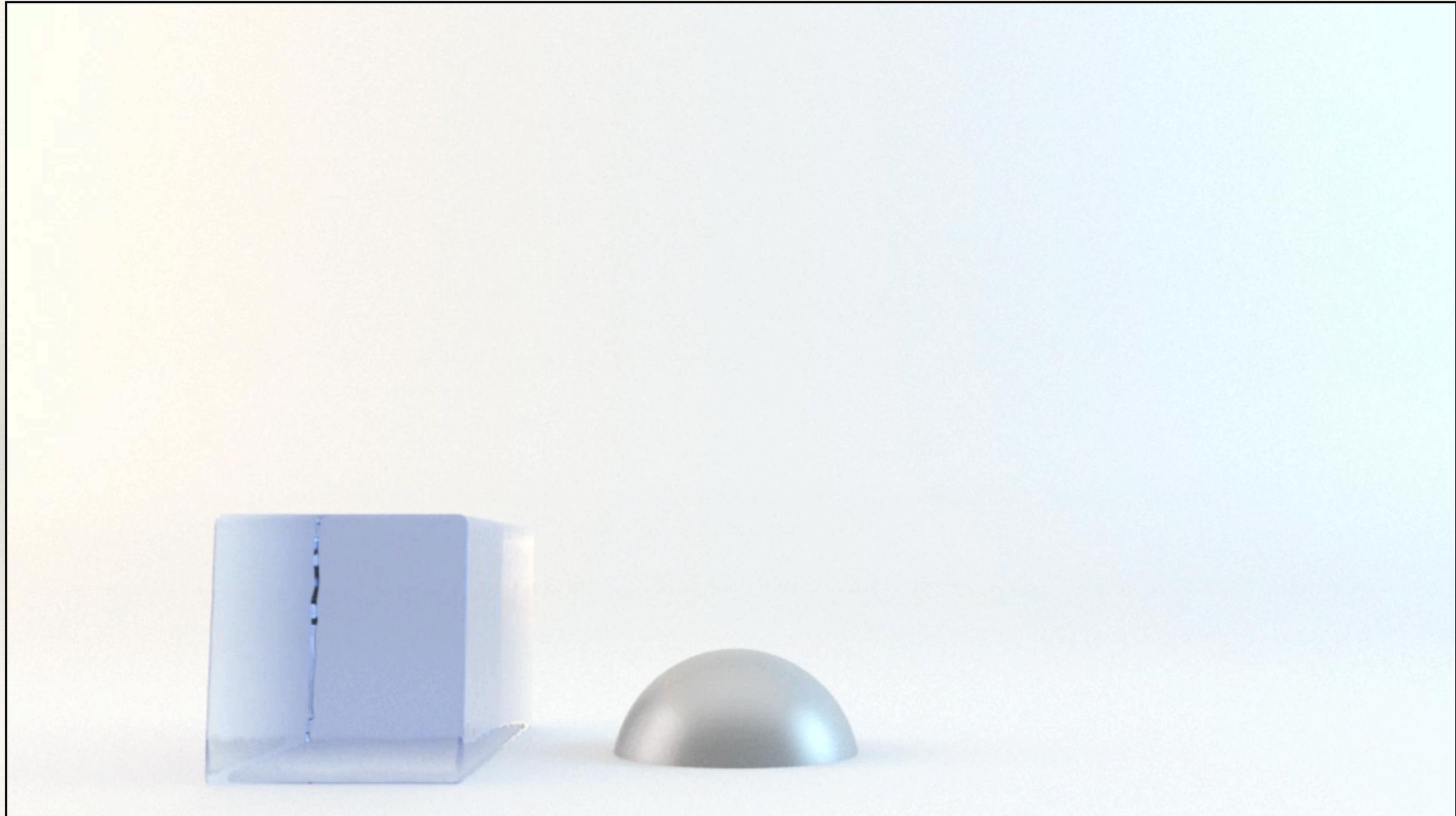
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# New Model: Unilateral Incompressibility

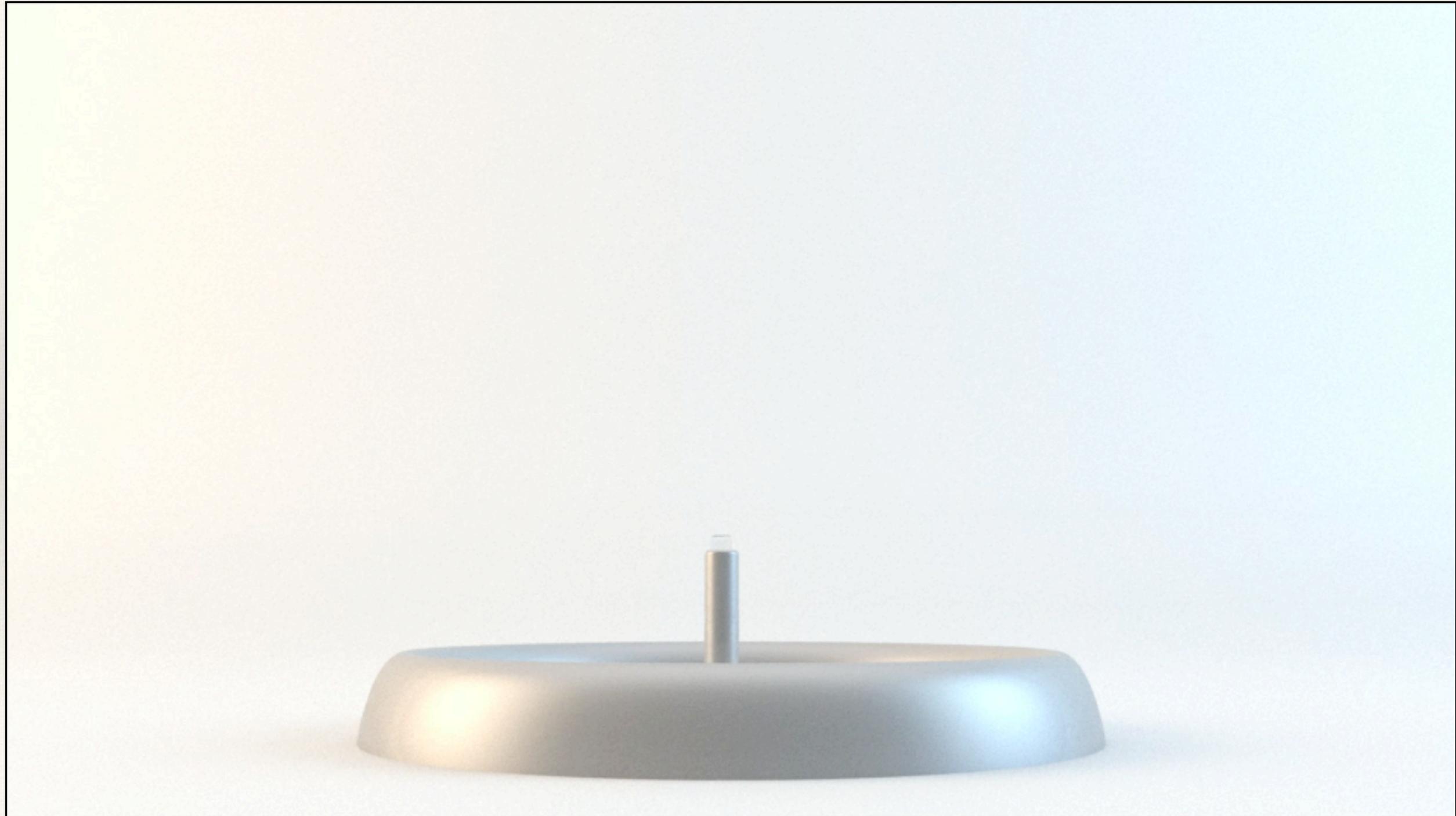
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# Incompressible Fountain

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# Unilaterally Incompressible Fountain

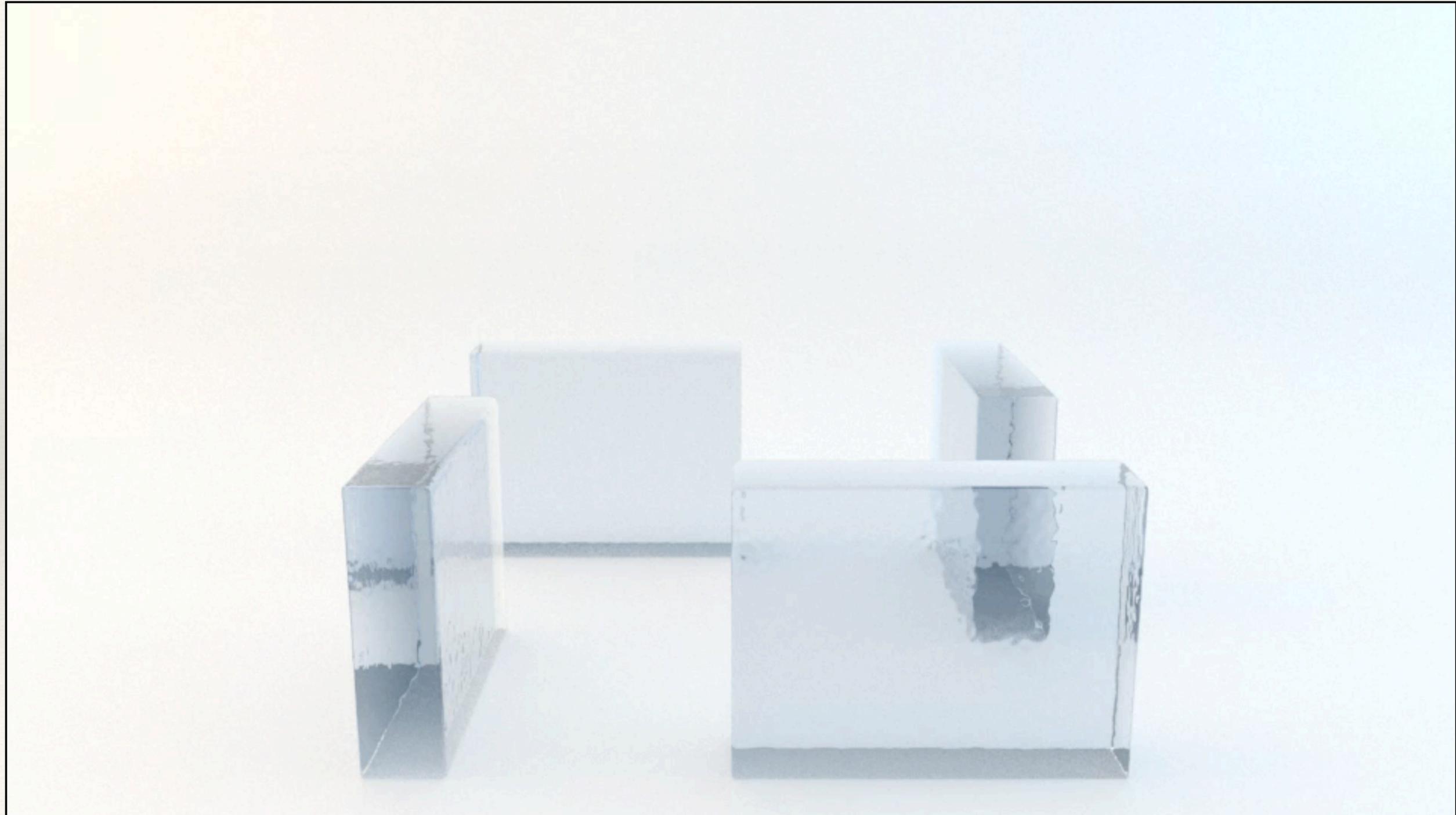
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# Four Dams

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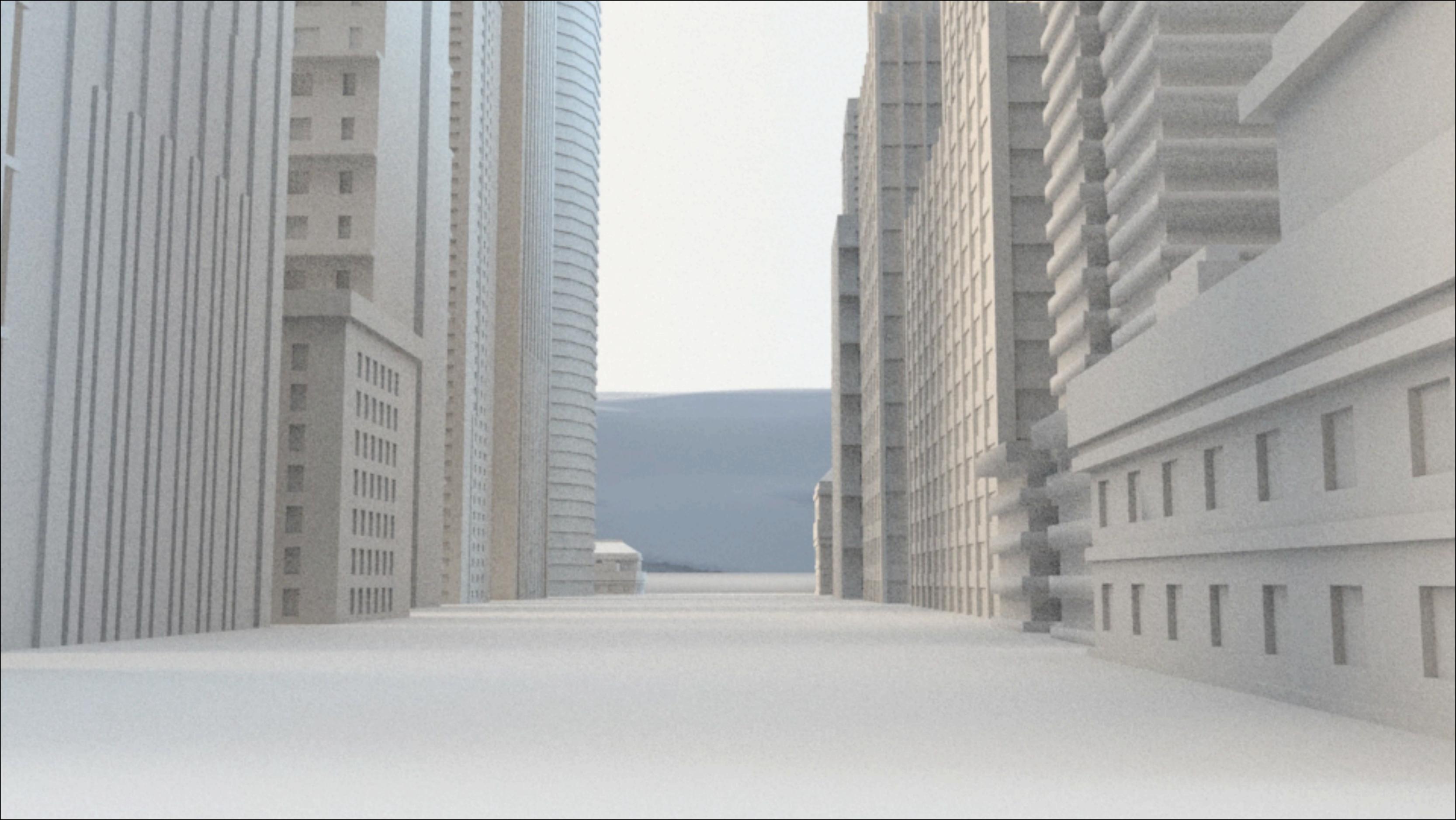


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# Flooded Terrain

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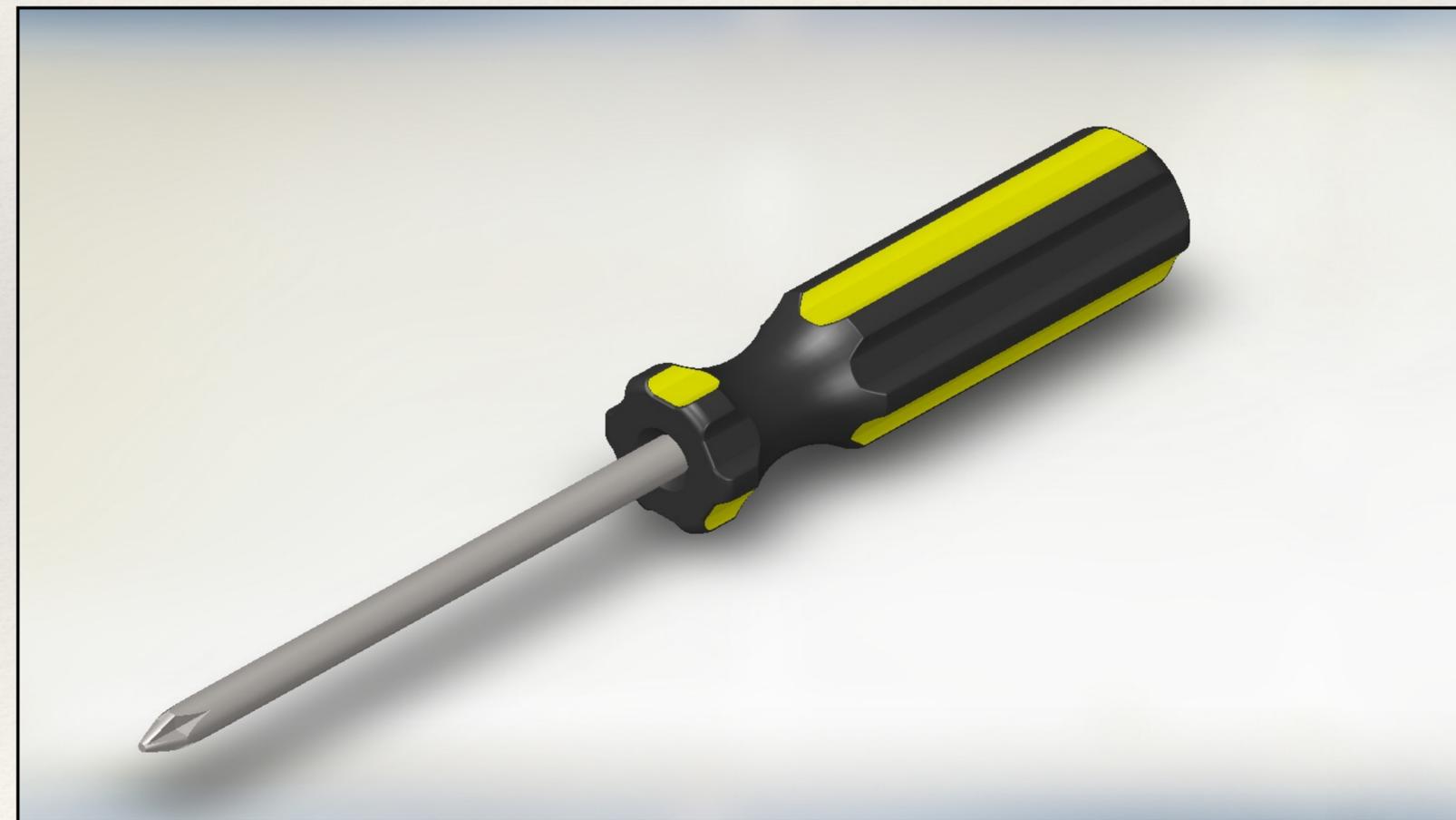
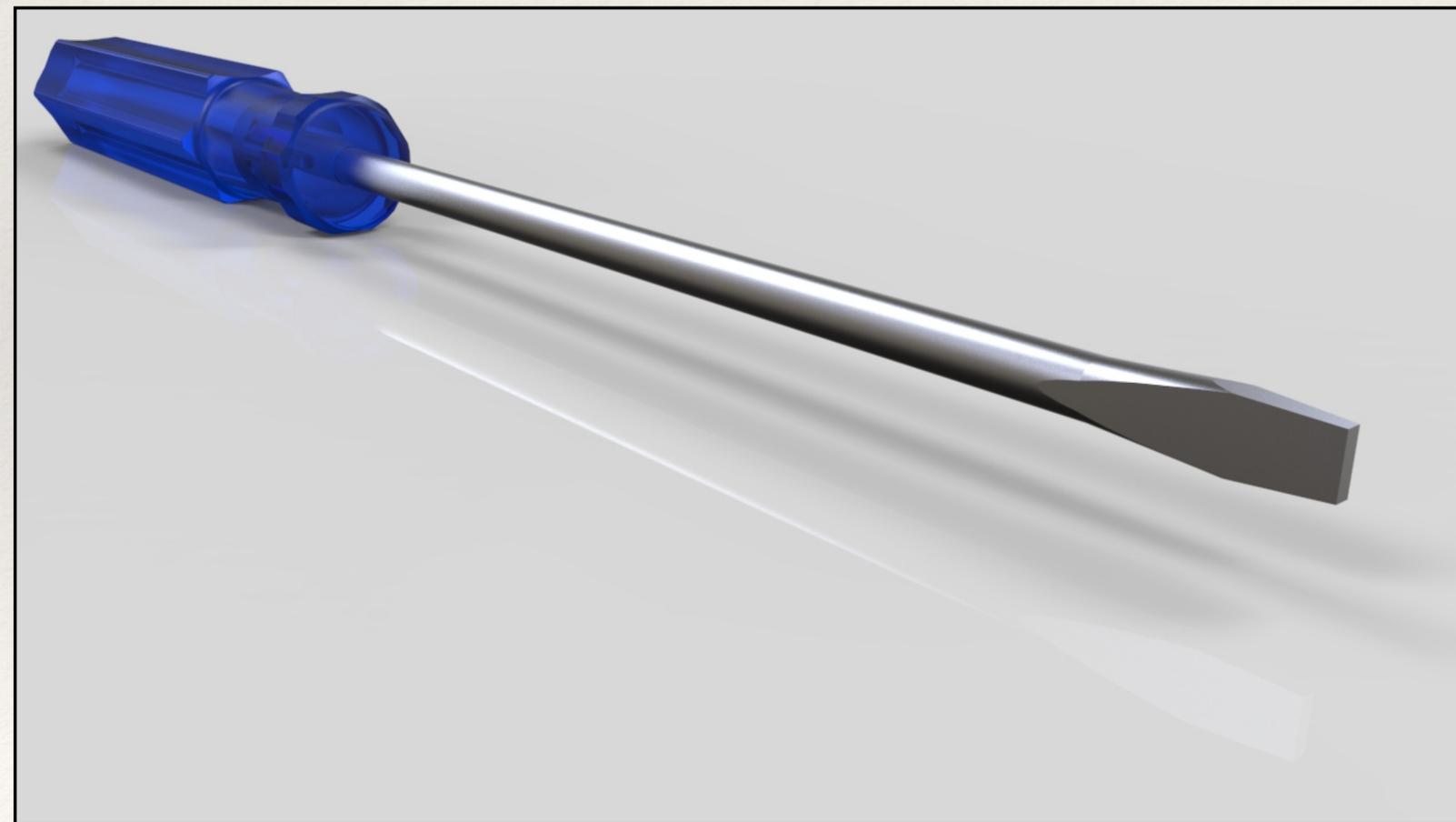
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# Flathead & Philips

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bilateral  
incompressibility

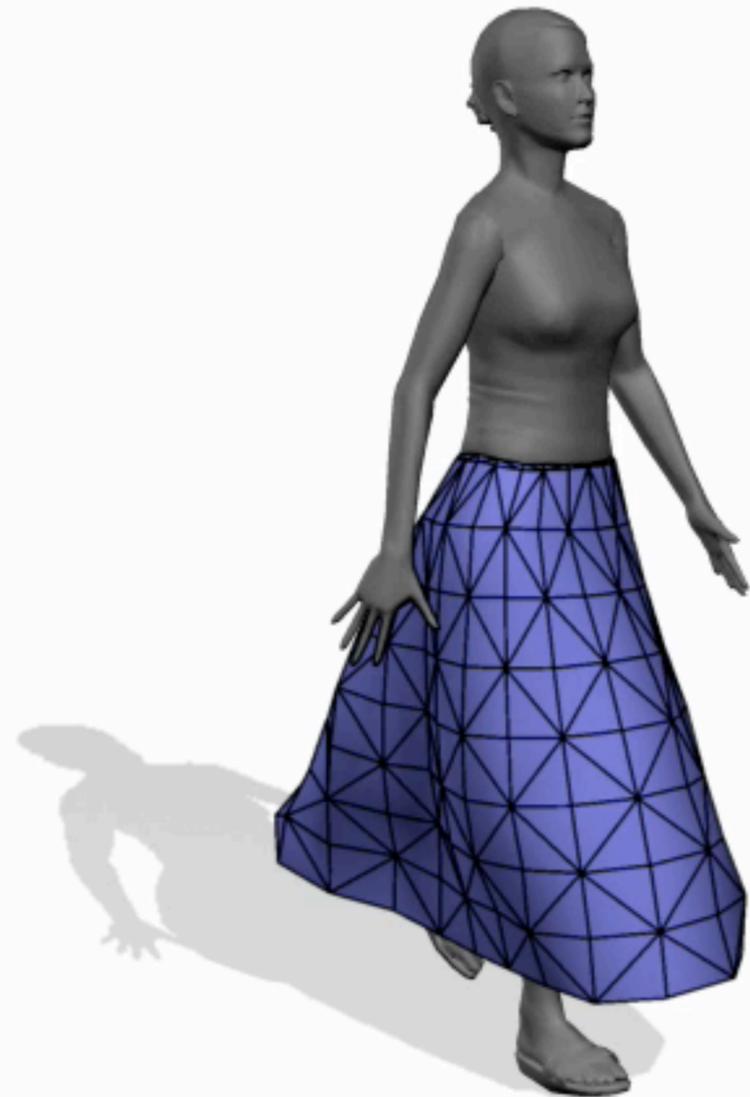
unilateral  
incompressibility



# Beyond Special Effects: Interactive Animation

# Learning an Upsampling Operator

Input  
(Coarse Simulation)



Output  
(Upsampled)



# Learning an Upsampling Operator

Regularization on Training Data



None



Just Right

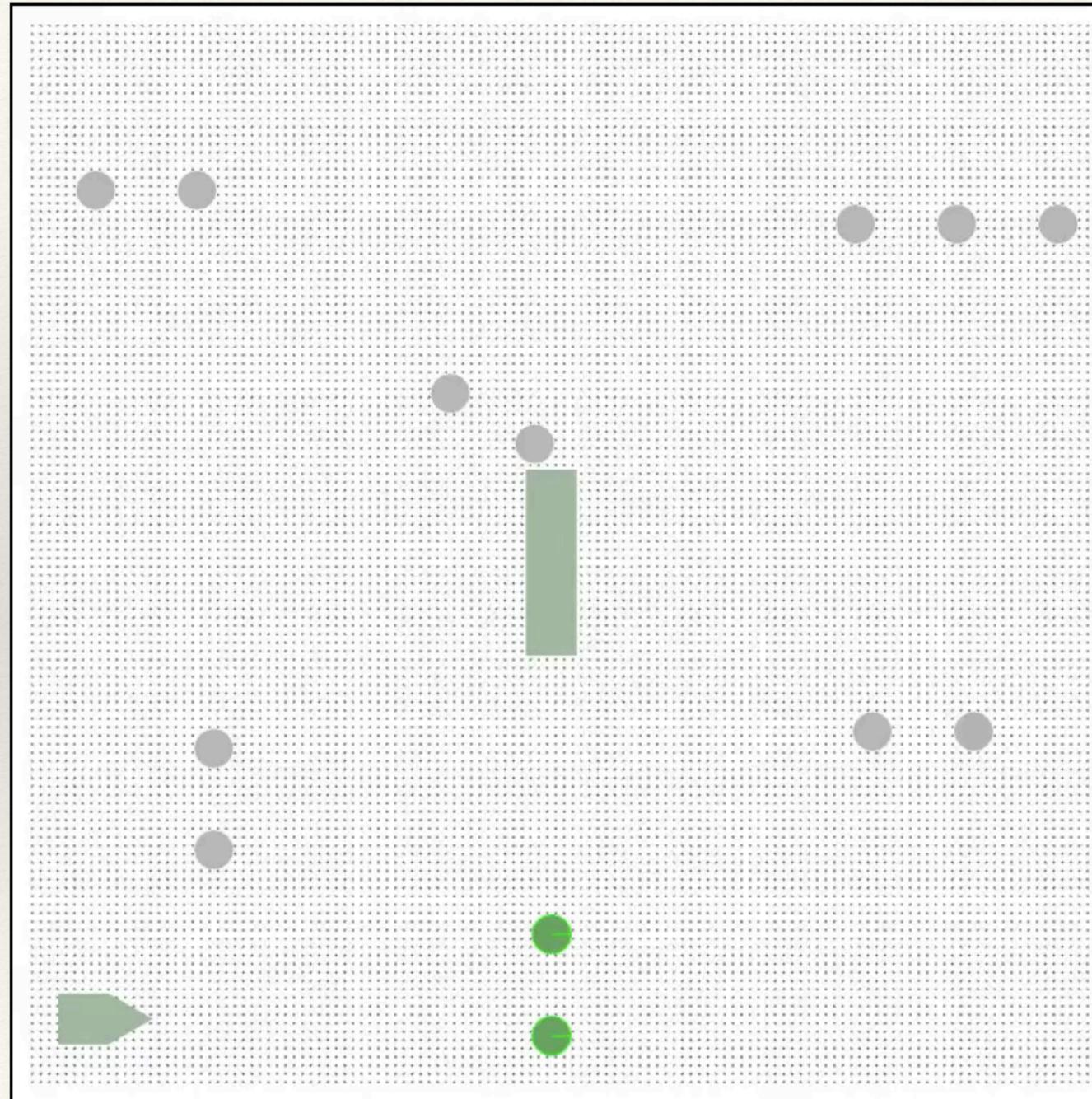


Too High

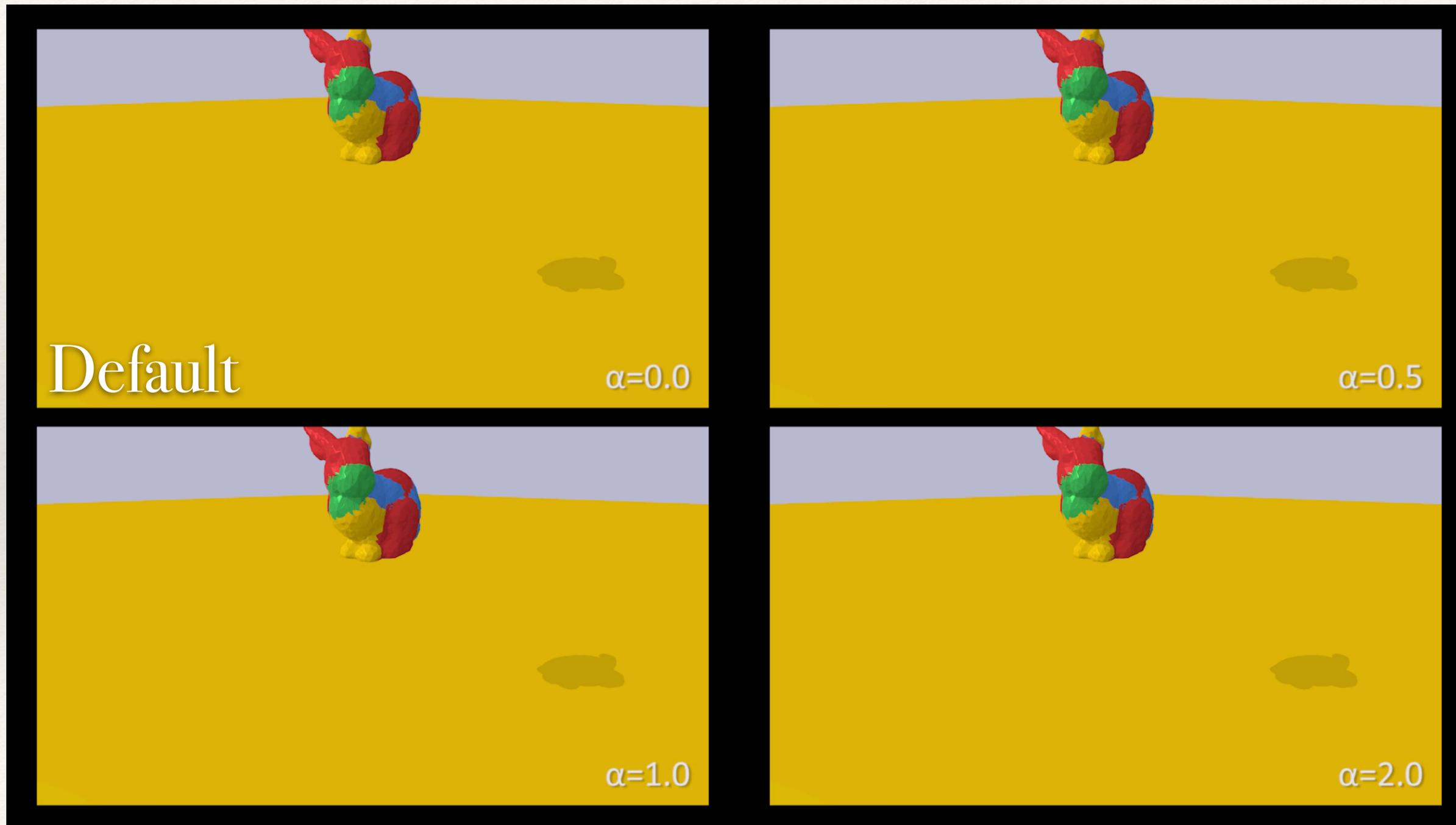
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# Model Reduced Fluids

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# Energizing Fracture



take away:

making offline methods faster is not enough,  
interactive animation requires new techniques



Virtual / Augmented / Mixed

Reality is Going to Drive

Computer Animation

# Content Creation

(the elephant in the room)

let's look at physics-based animation /  
simulation

- (1) simulation is a *tool* for artistic expression
- (2) good tools are easy to use

are physical simulations easy to use?

no.

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# Physics is like a cat...

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... it does what it wants

# Artists want dogs



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# Dynamic Sprites

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bring images to life by

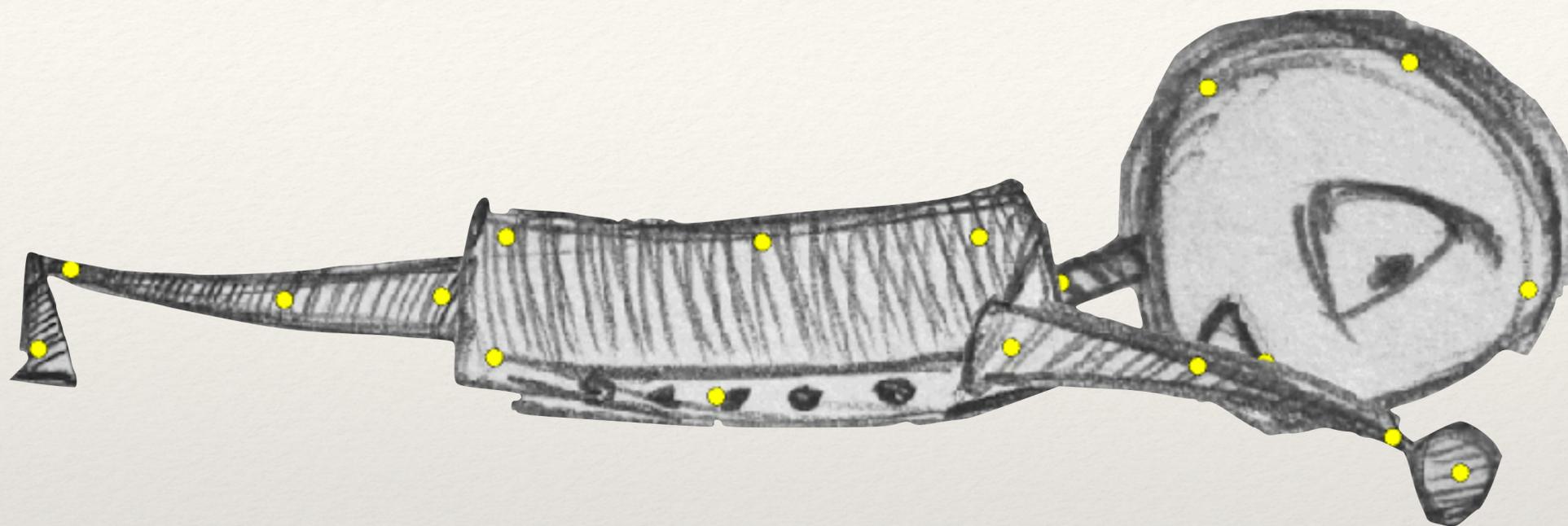
letting artists define the behavior and

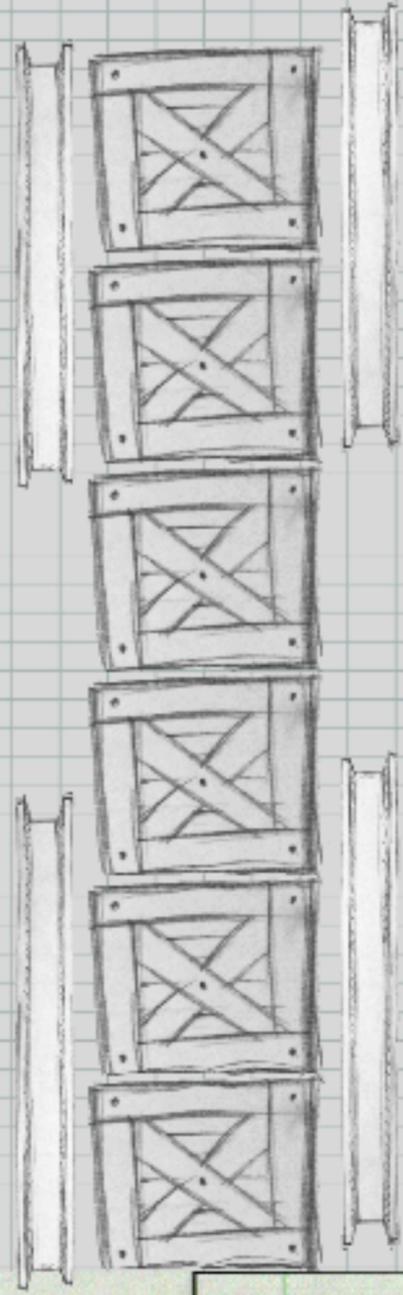
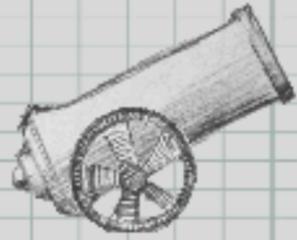
letting physics handle interaction & timing

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# Step 1: Draw a “Stuntman”

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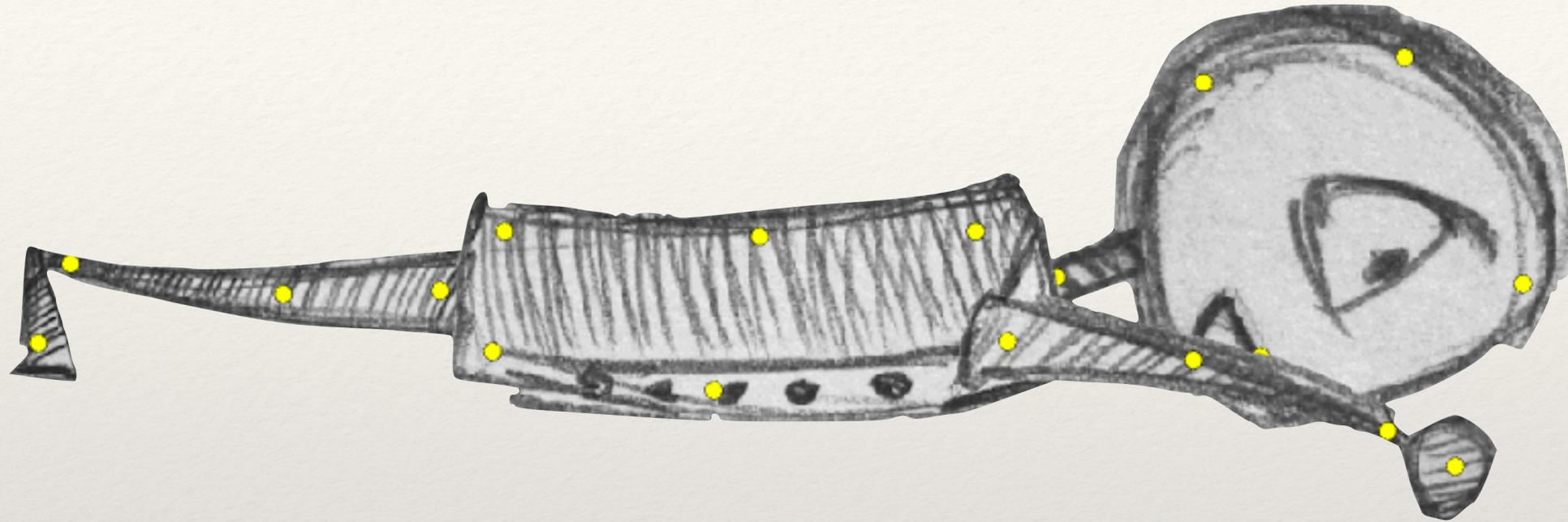




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# Step 2: “Rig” Drawing

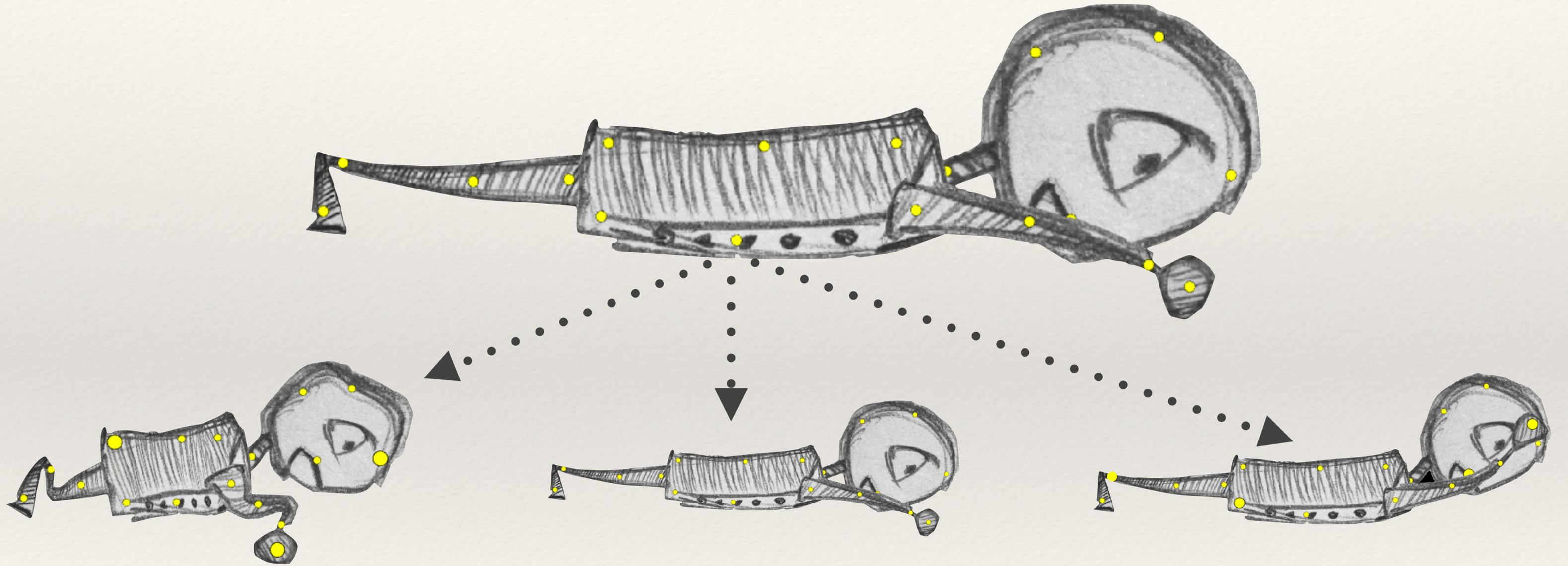
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# Step 3: Deform Drawing

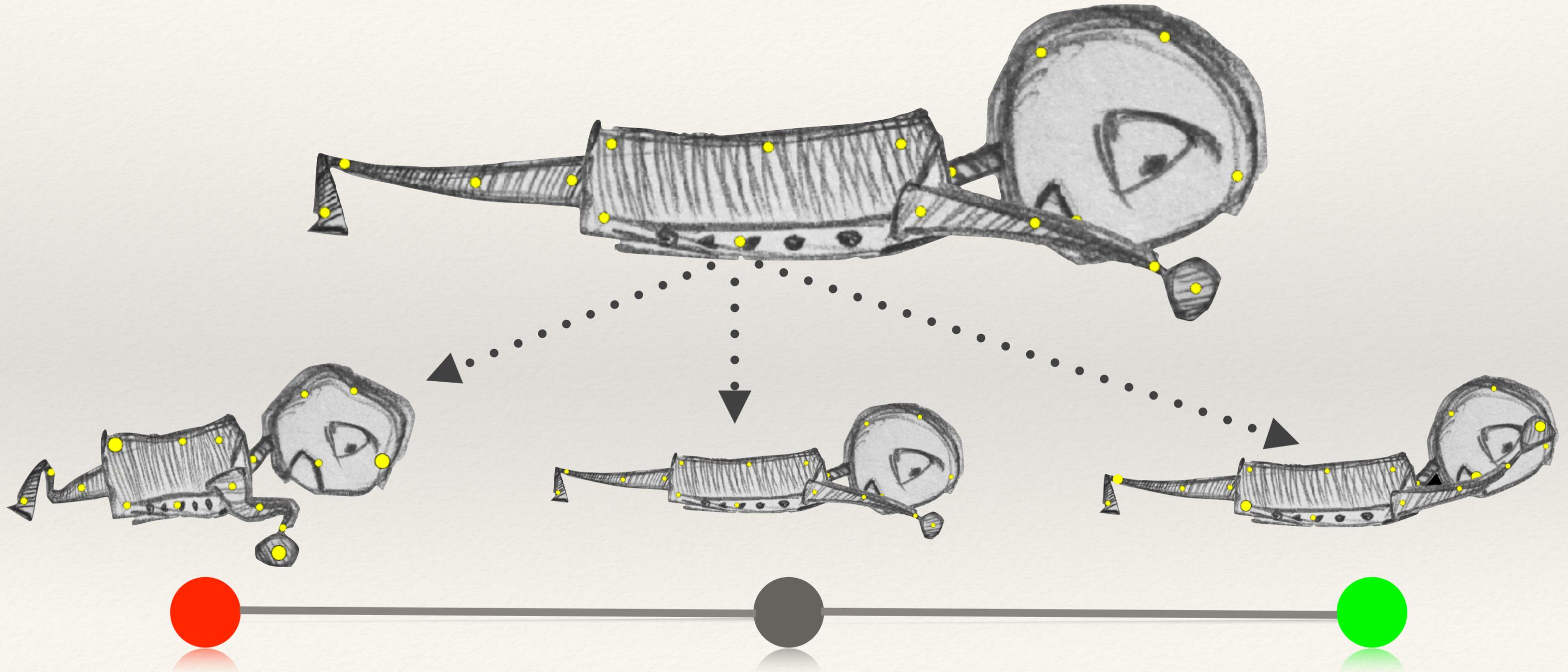
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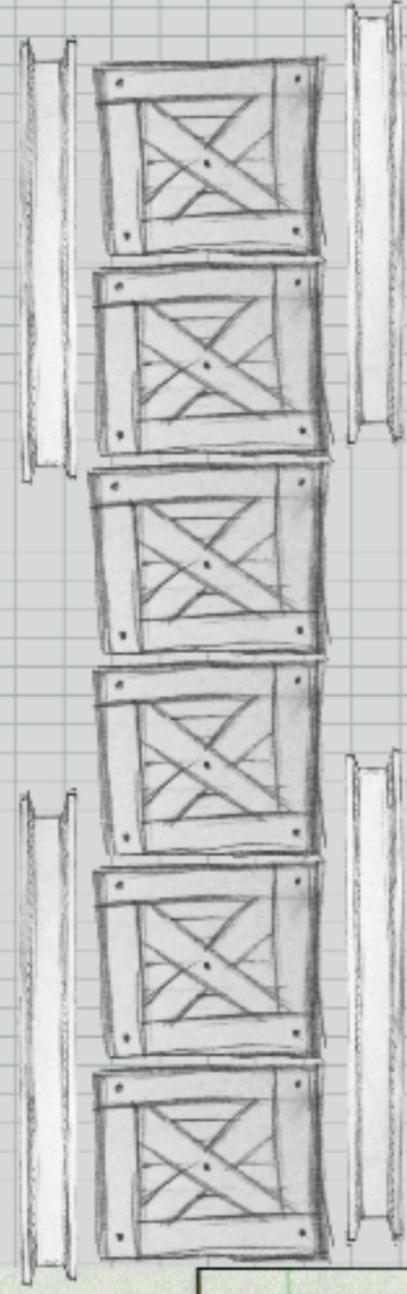
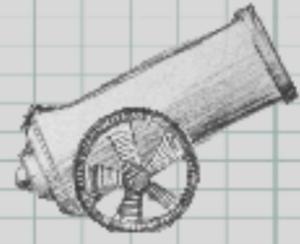


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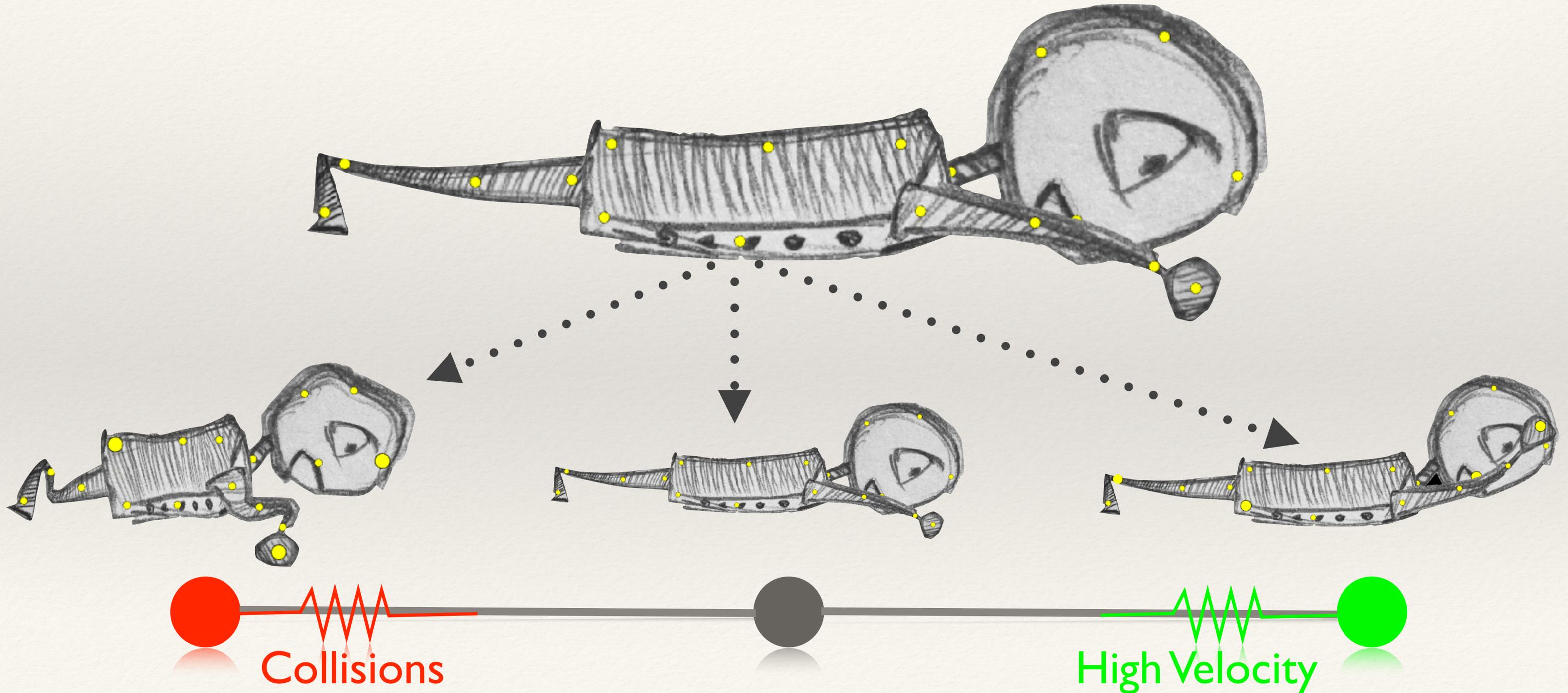
# Step 4: Create “Example Manifold”

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# Step 5: Define Navigation in the Manifold

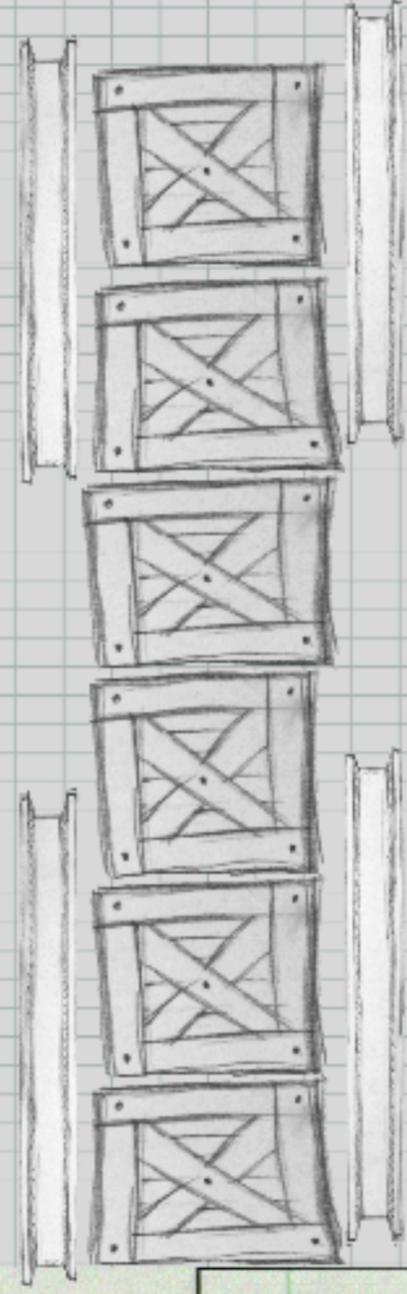
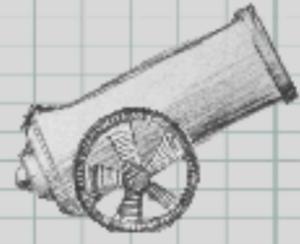


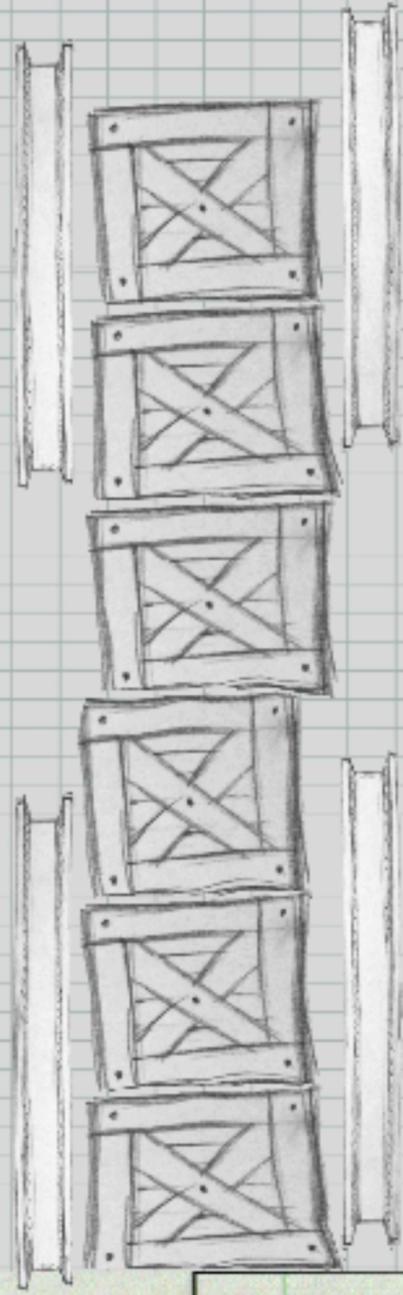
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# Other Controls

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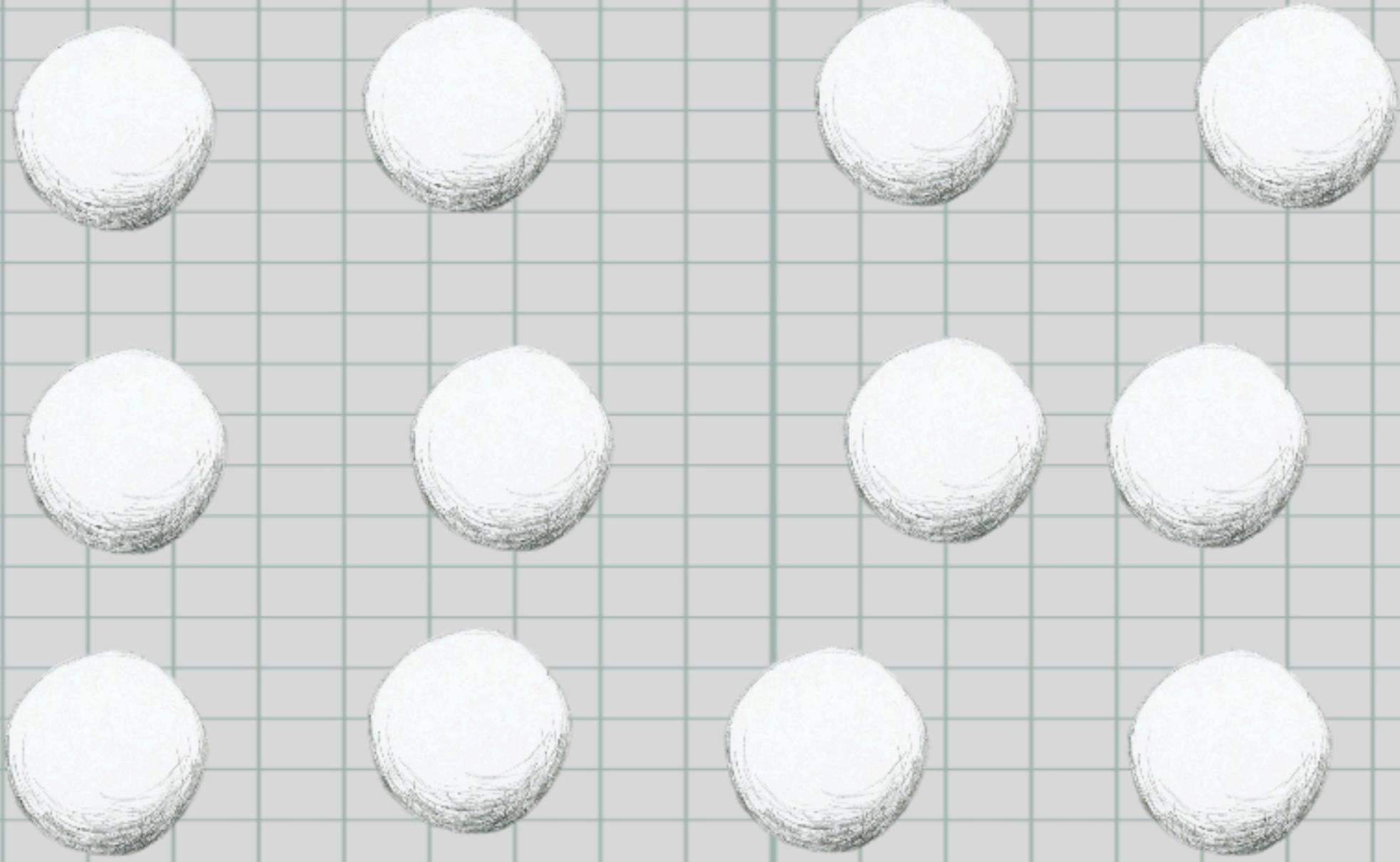
- ❖ Applying additional controls is simple in position based framework
- ❖ Controls can depend on arbitrary properties of the object
  - ❖ speed
  - ❖ orientation
  - ❖ angular momentum
  - ❖ ... etc









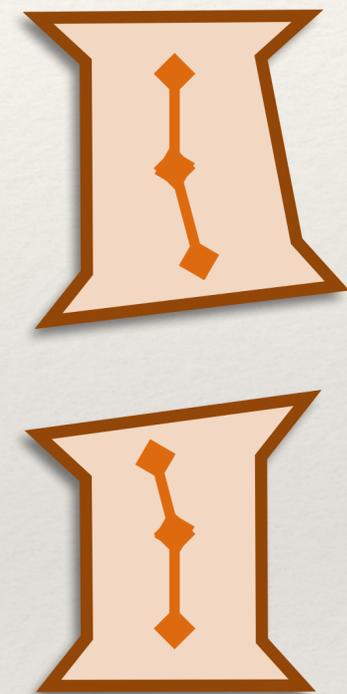
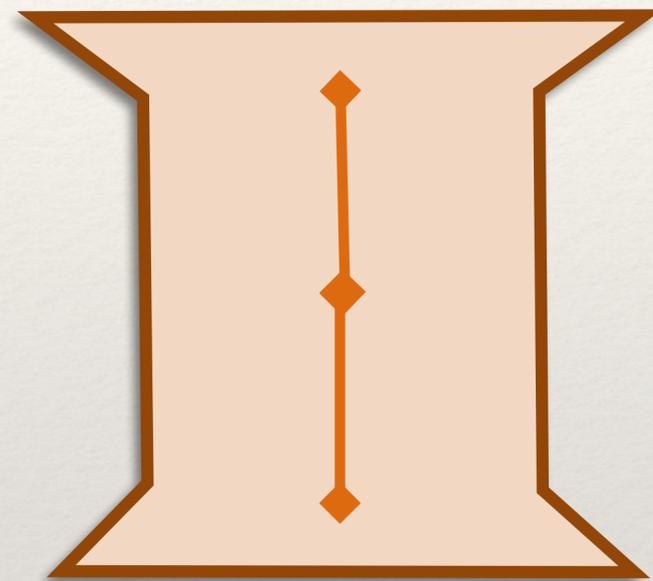
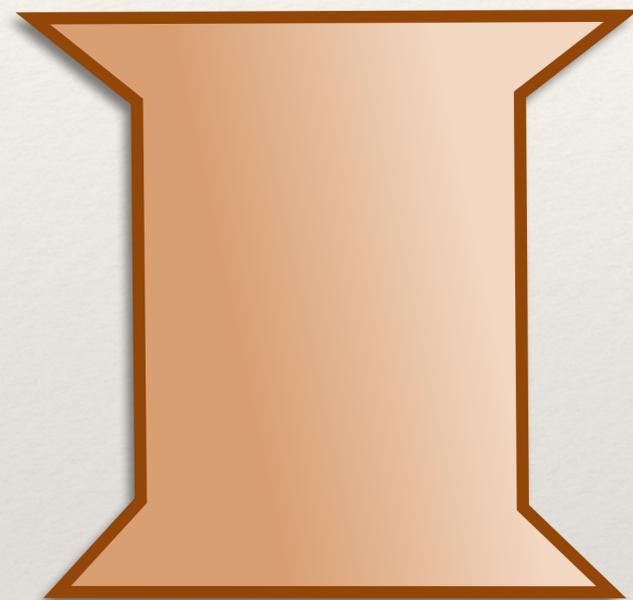


Applied to Destruction

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# Authoring

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Input  
geometry

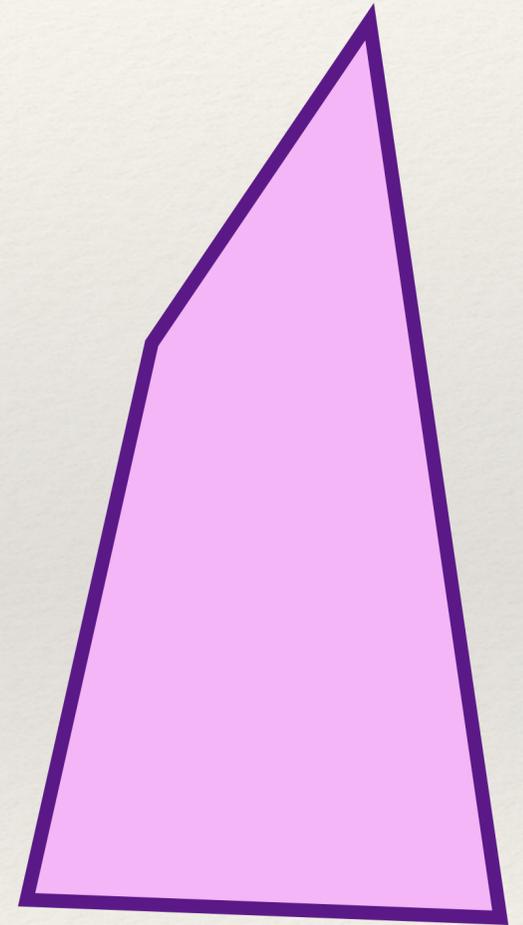
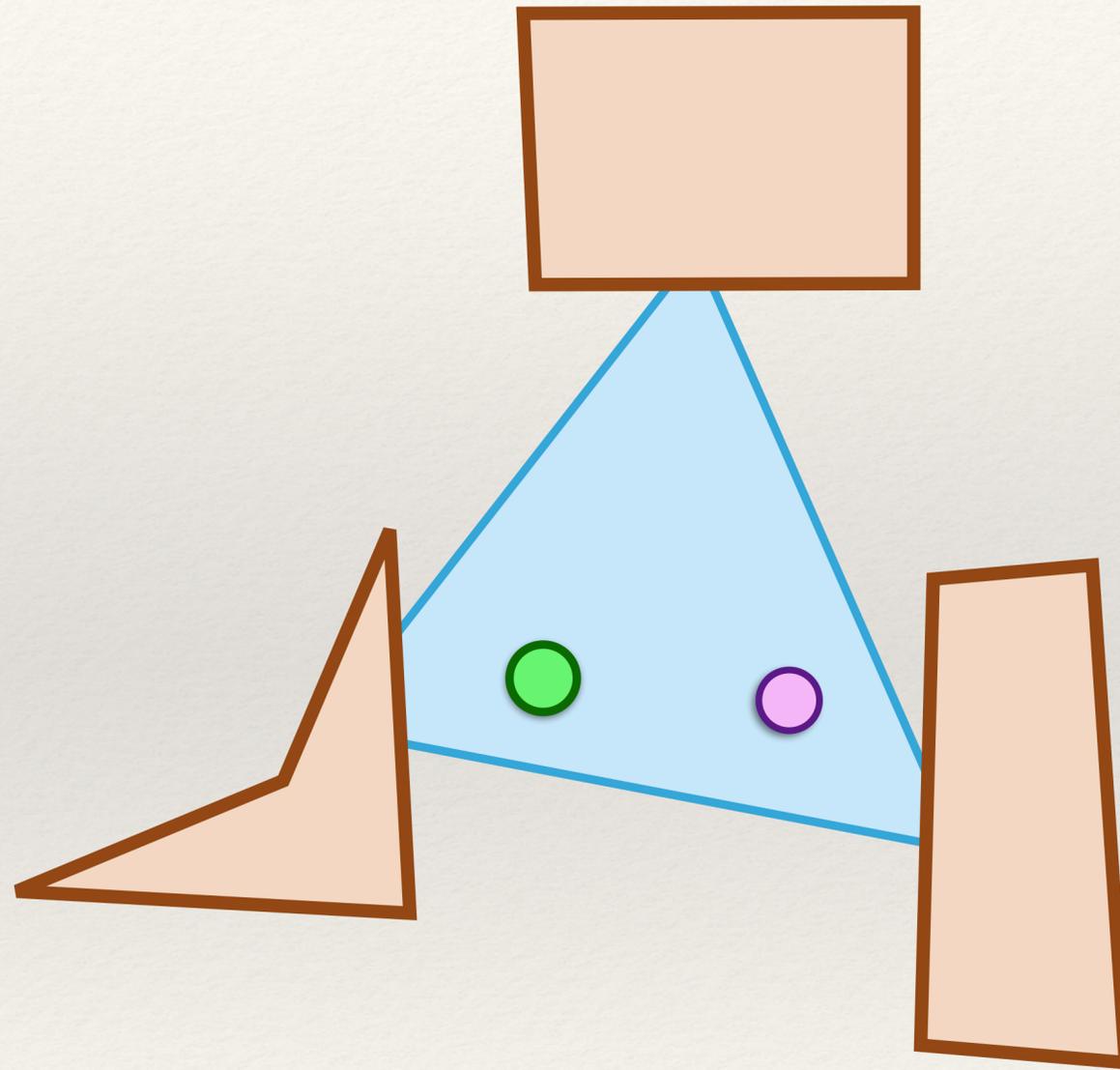
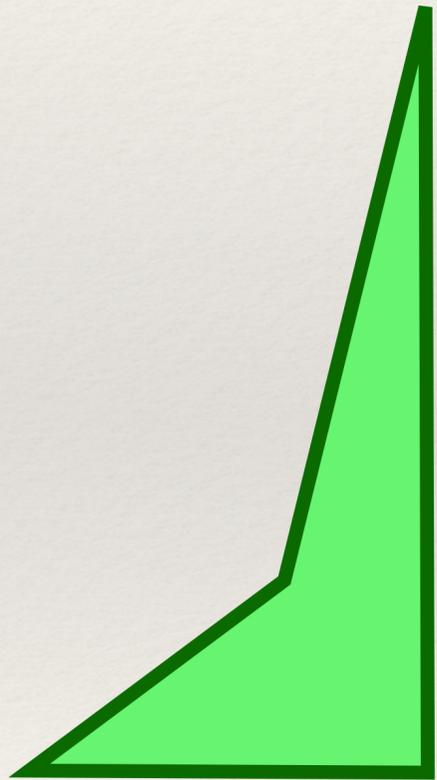
Rig

Characteristic  
Deformations

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# Example Manifold

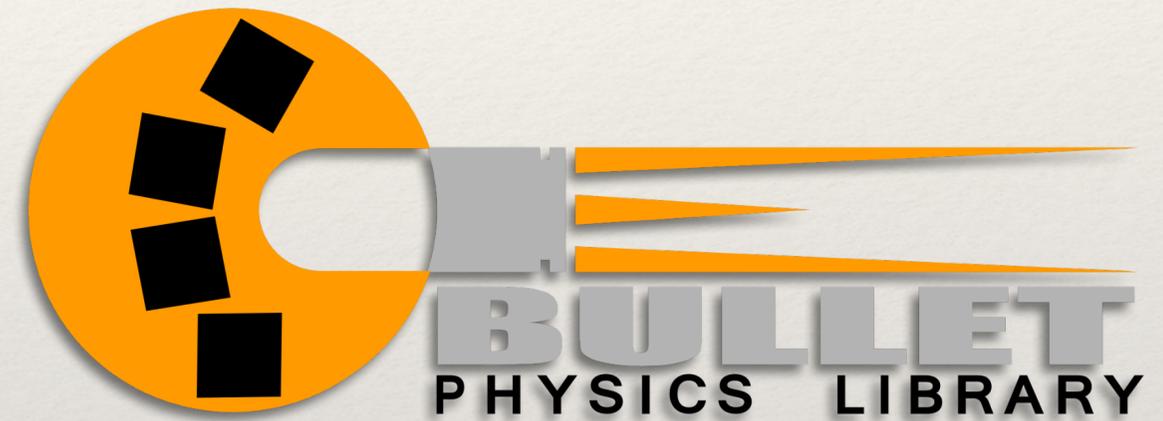
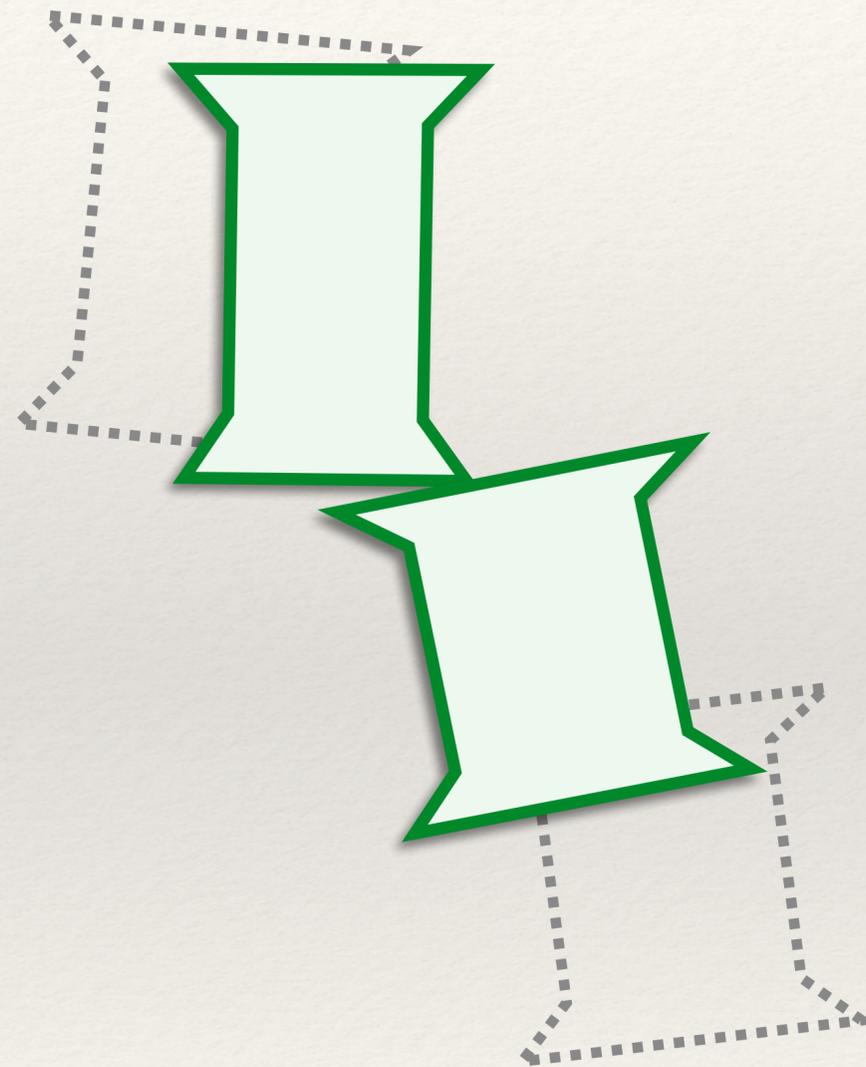
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# Simulation

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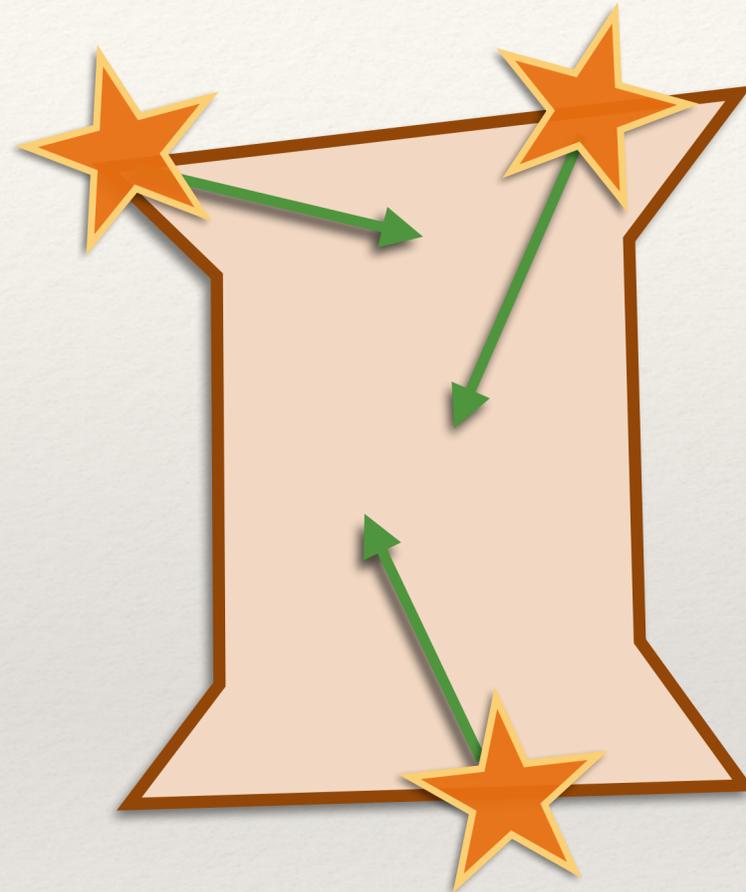


Unmodified Rigid Body Simulation

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# Simulation

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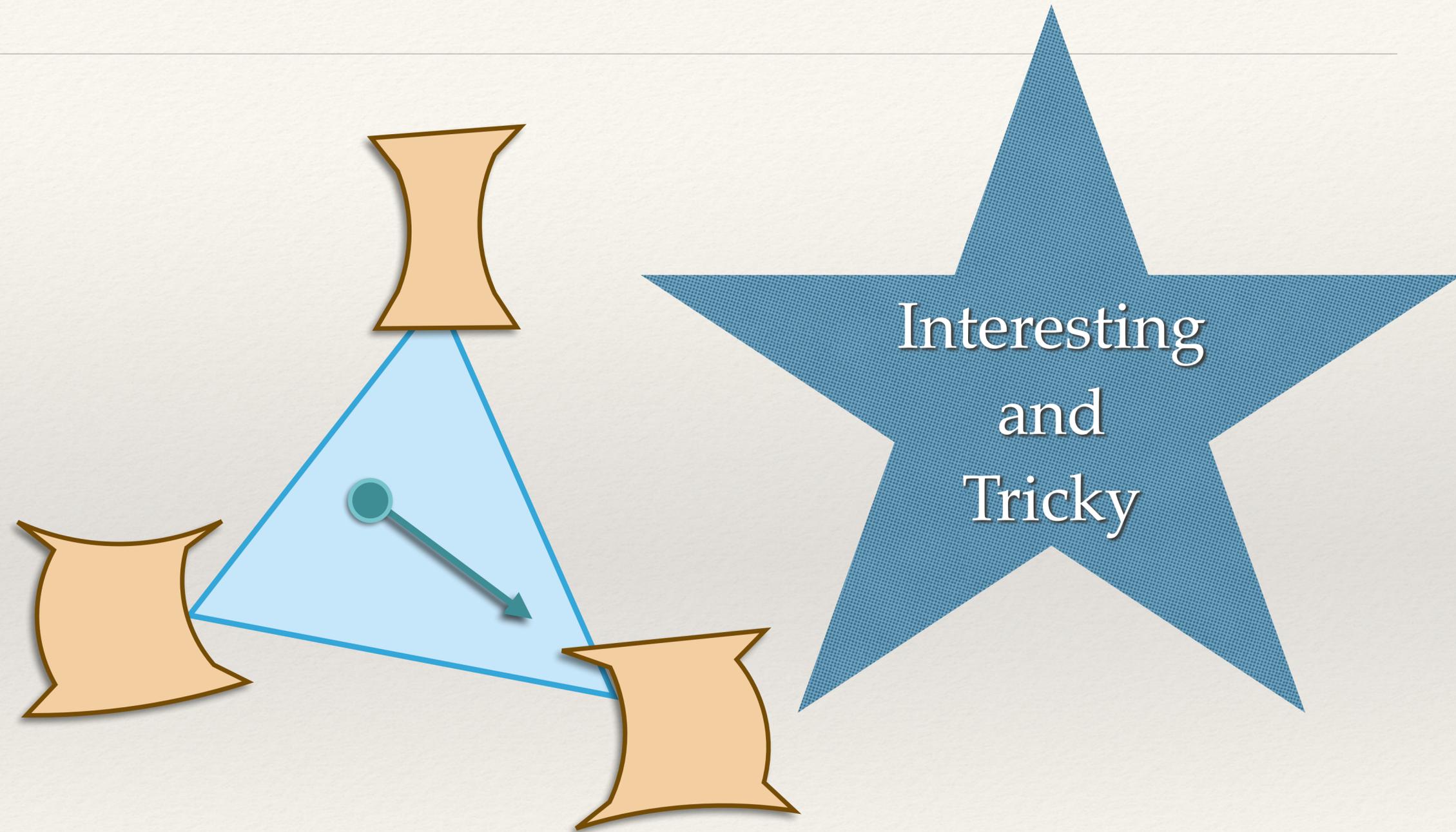


Collect Impulses

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# Simulation

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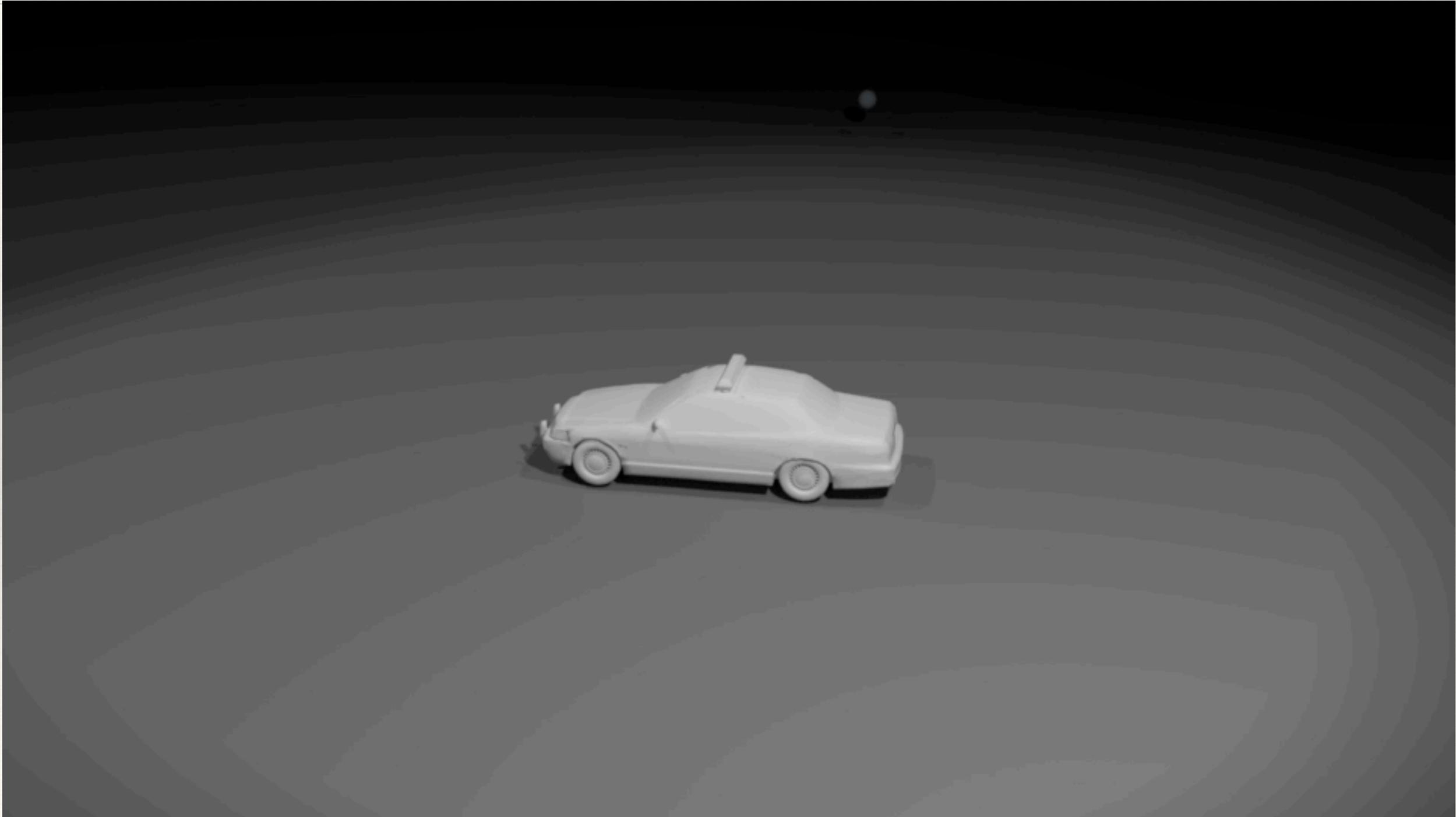


Update Example Interpolation Weights

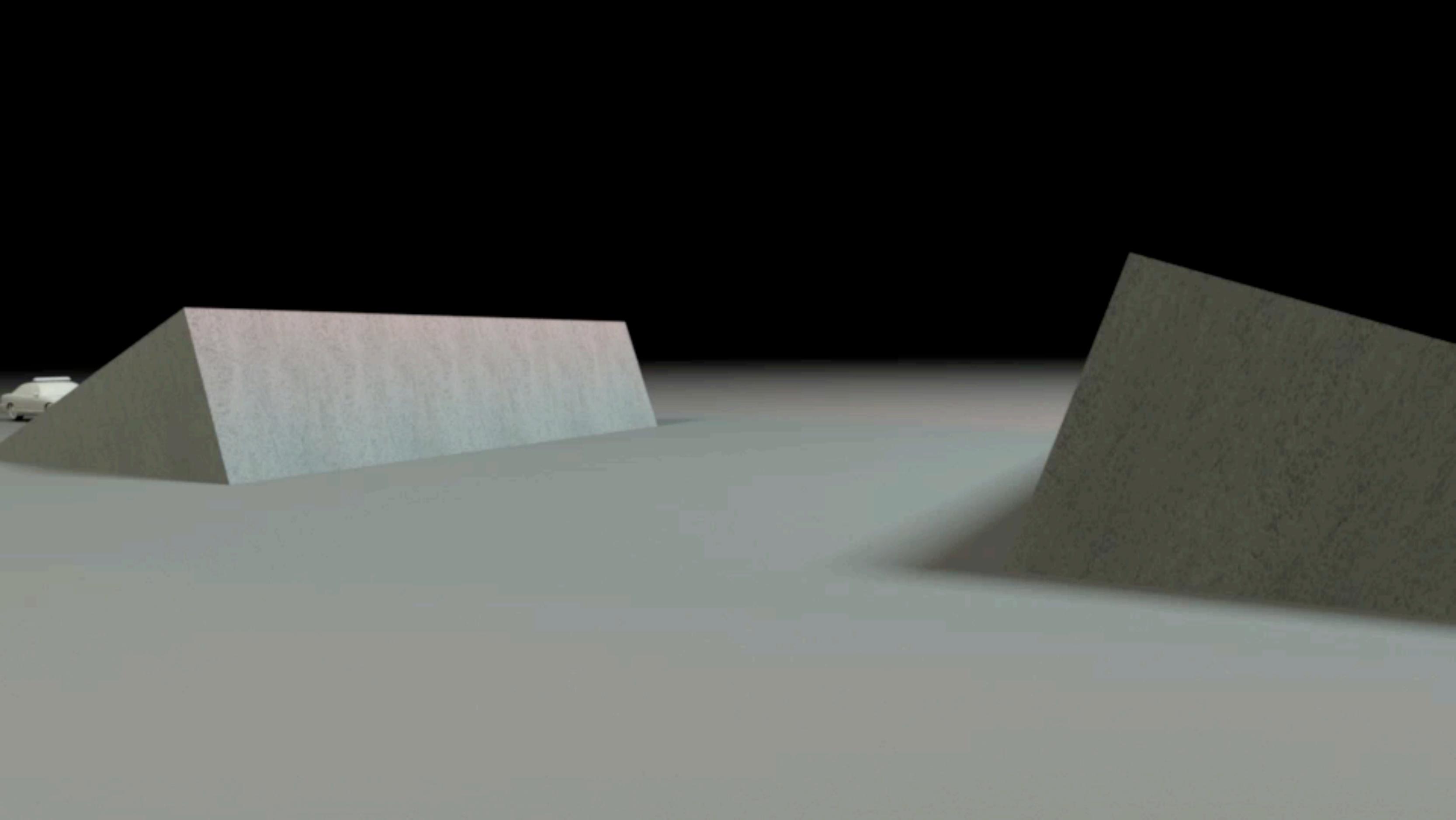
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# Sample Result

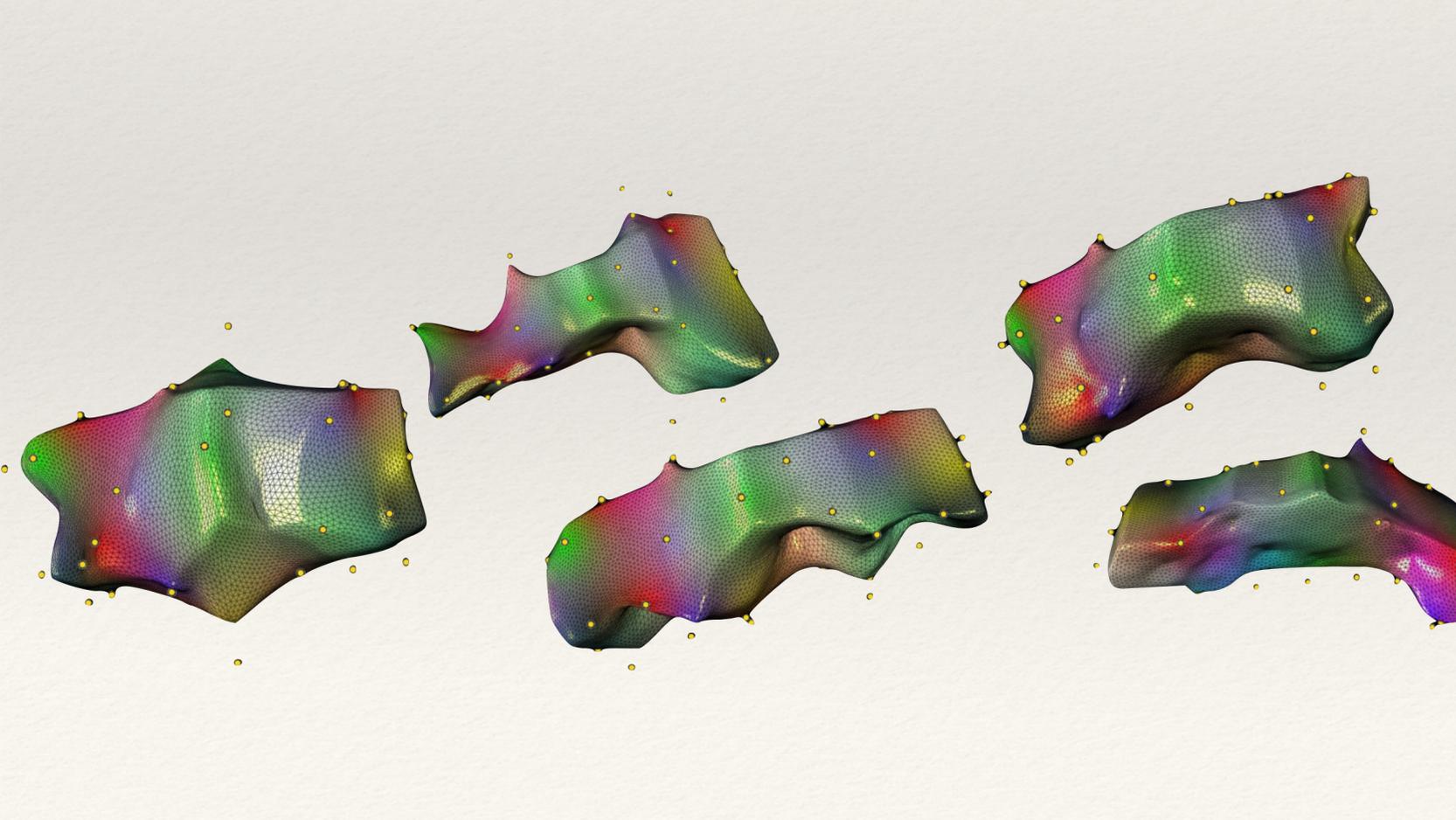
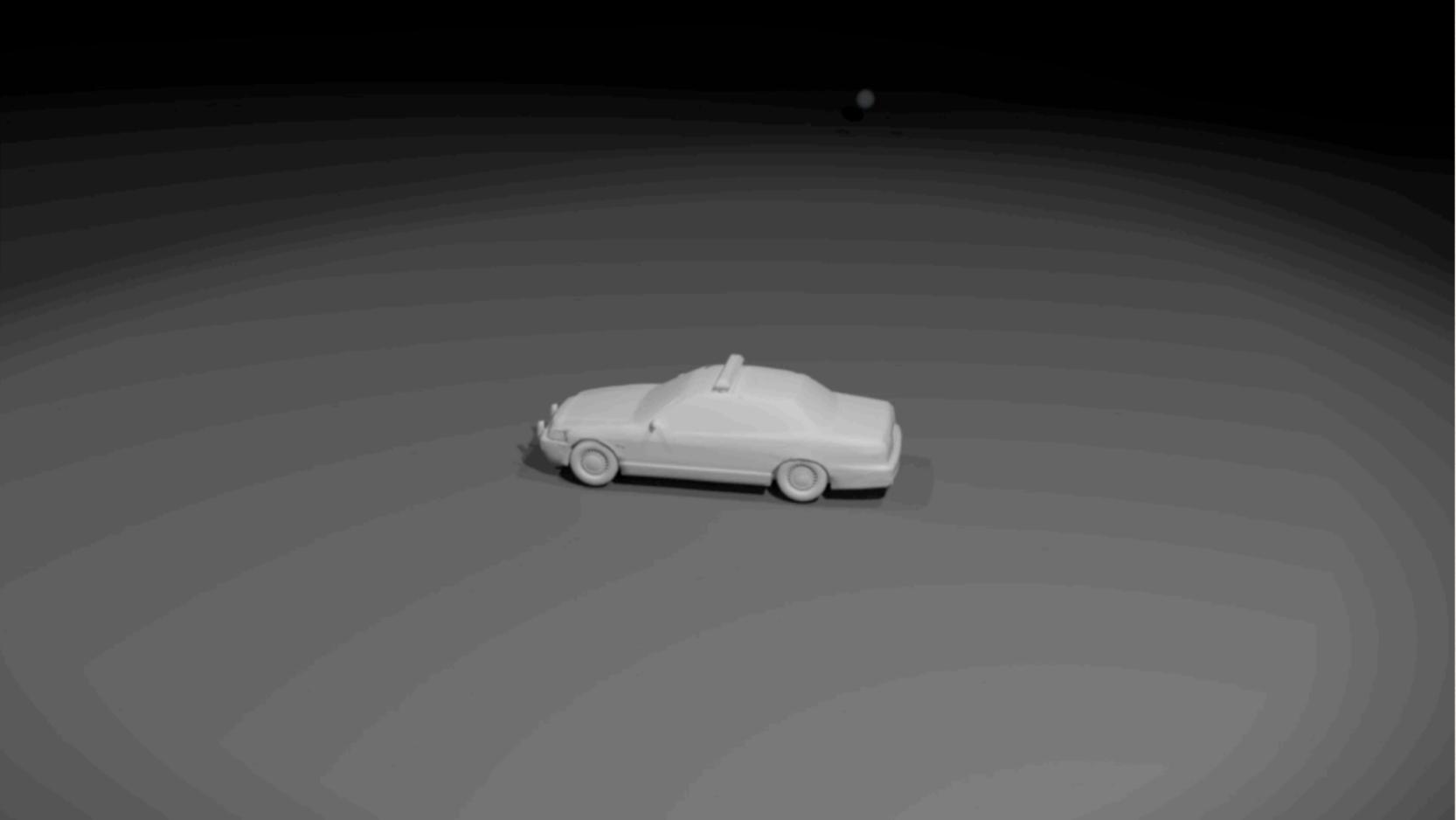
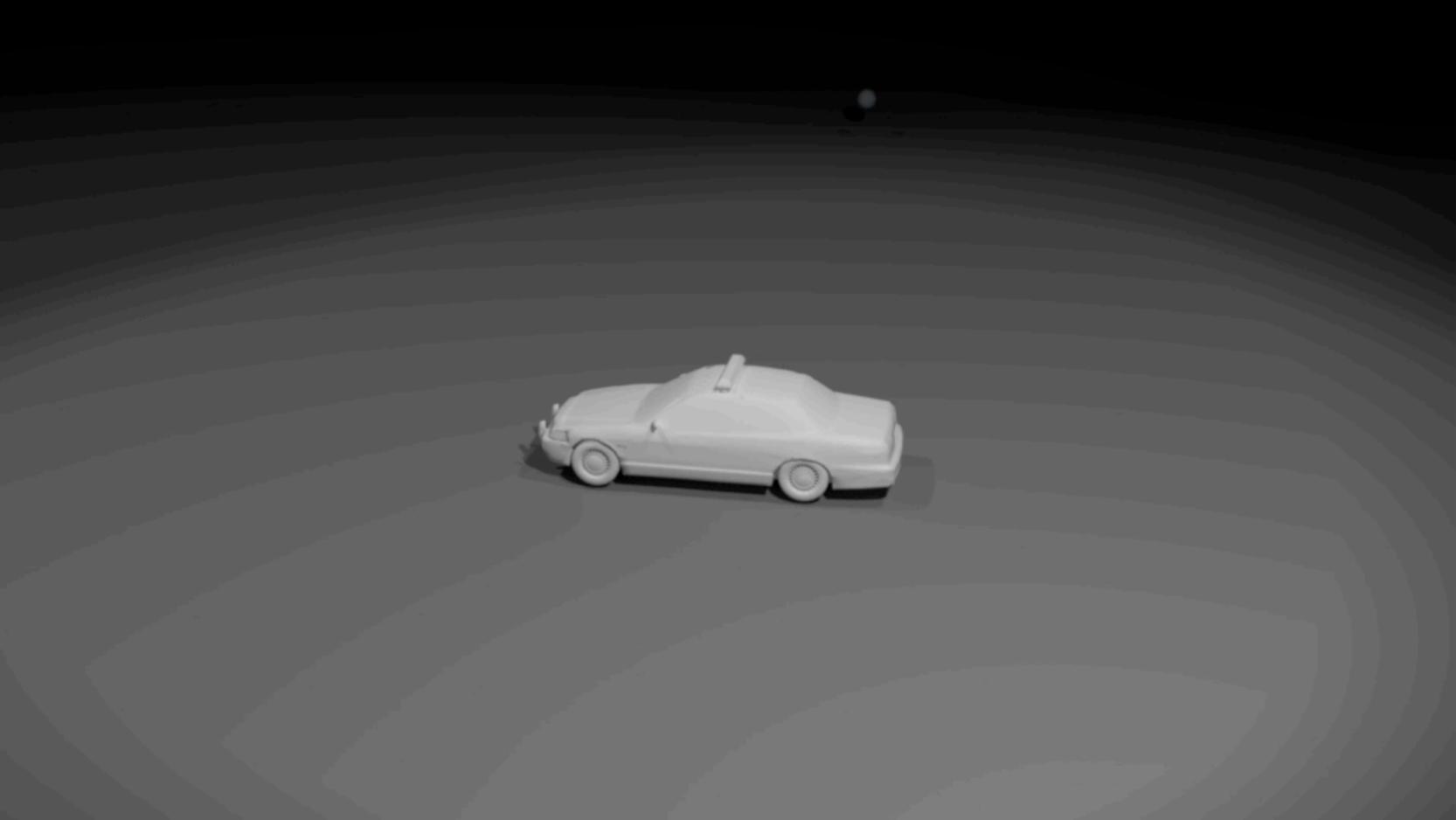
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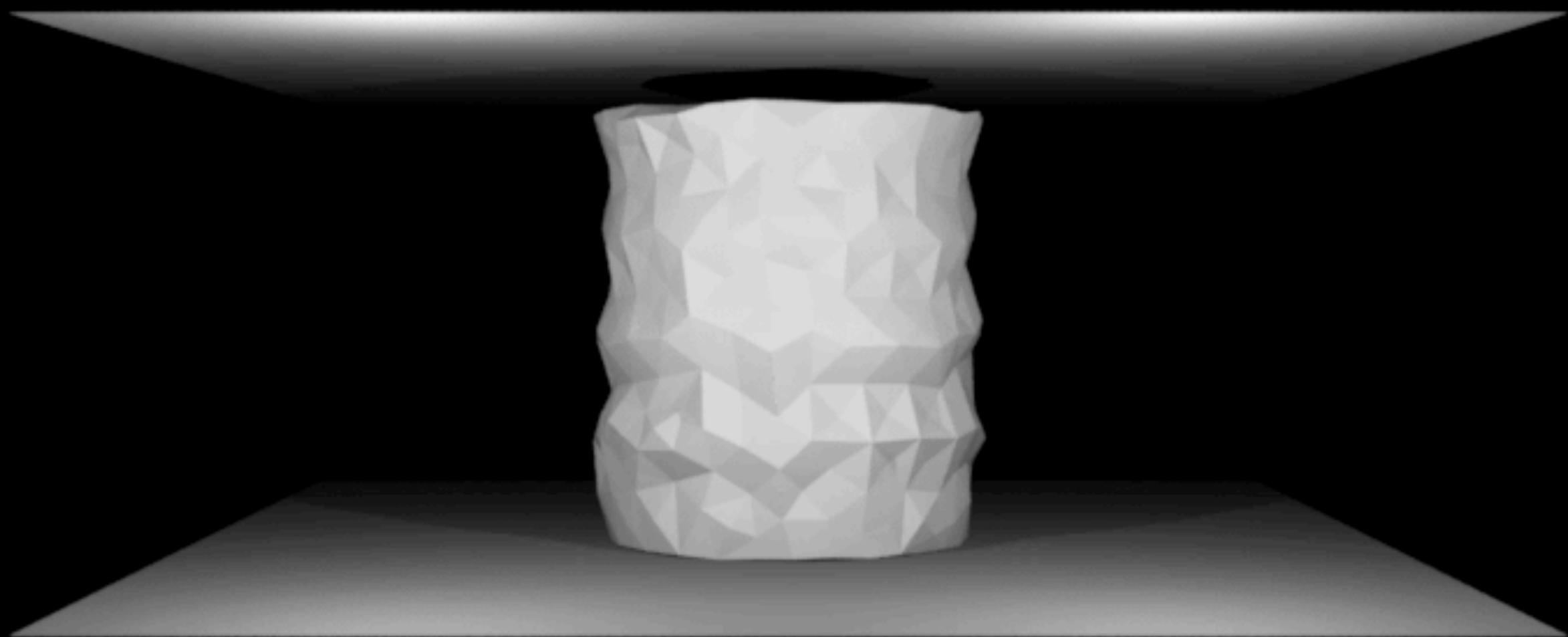
# Car Launch

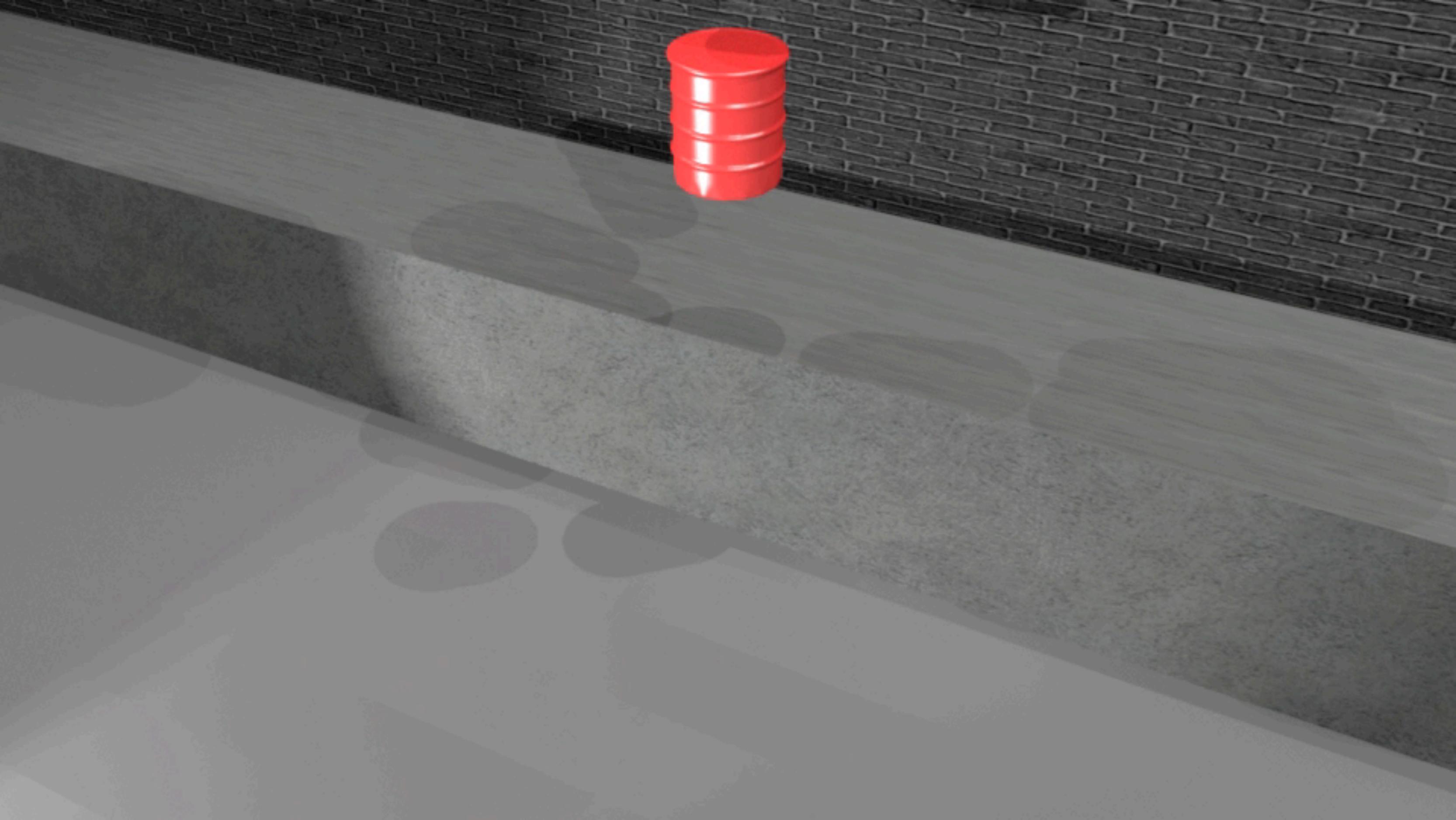


# Example Iteration

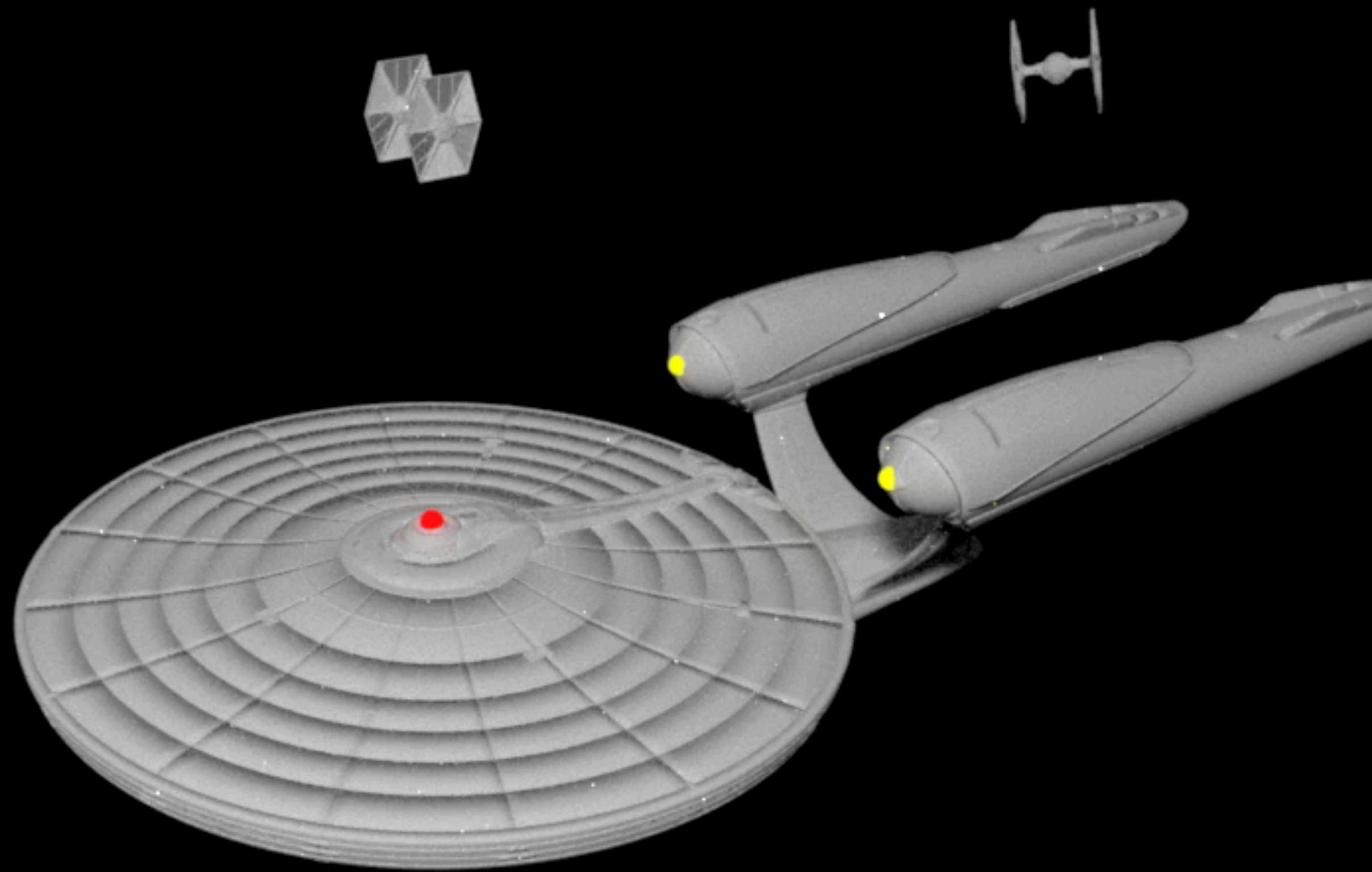


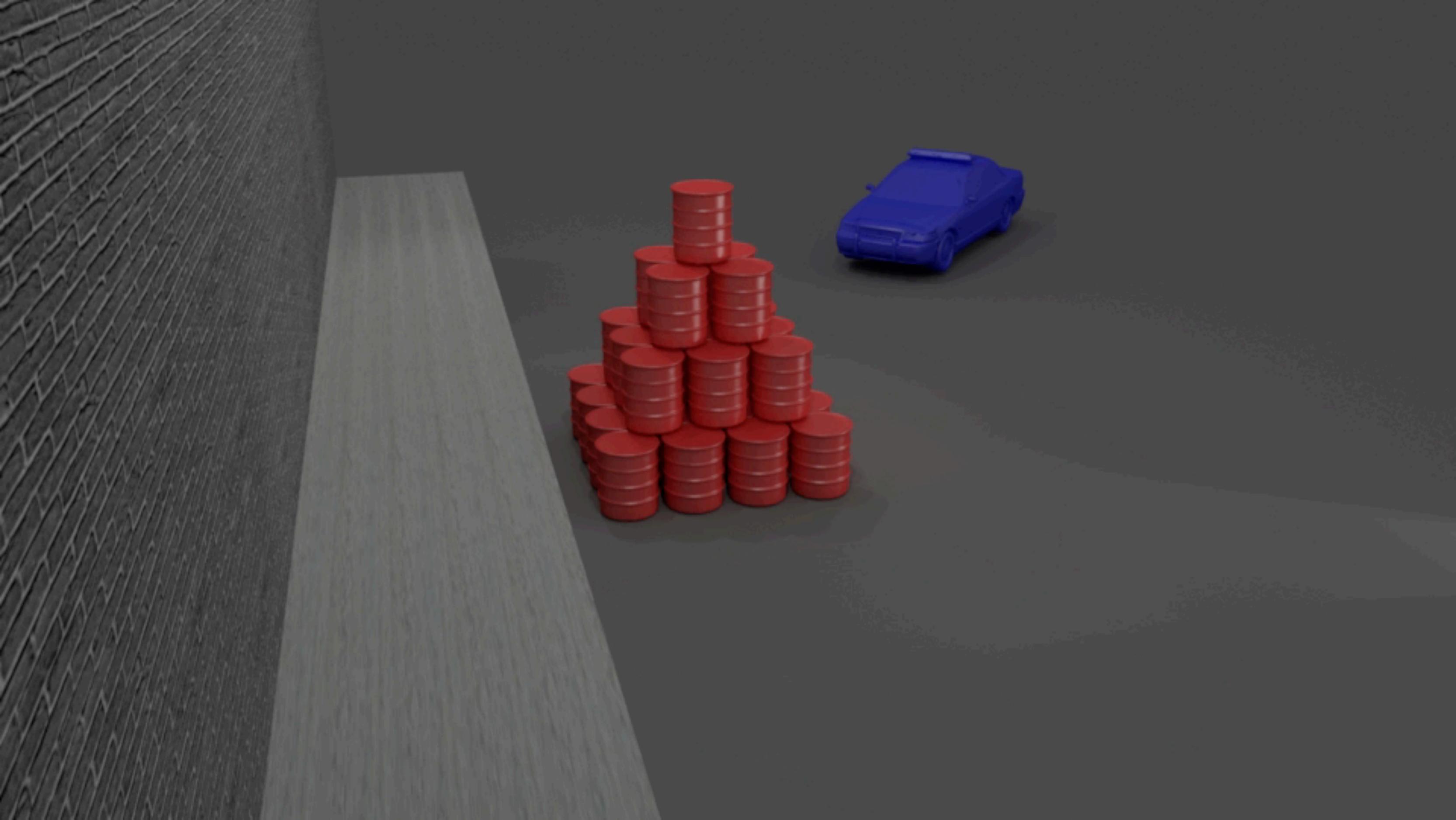
Physics imitating art imitating physics





JJ Abrams Fanfic





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