Sorcery to Science:
how Hollywood Physics impacts the Sciences

Eitan Grinspun

Columbia University

these images are frozen in time

animation: a brief history

3rd millenium B.C.

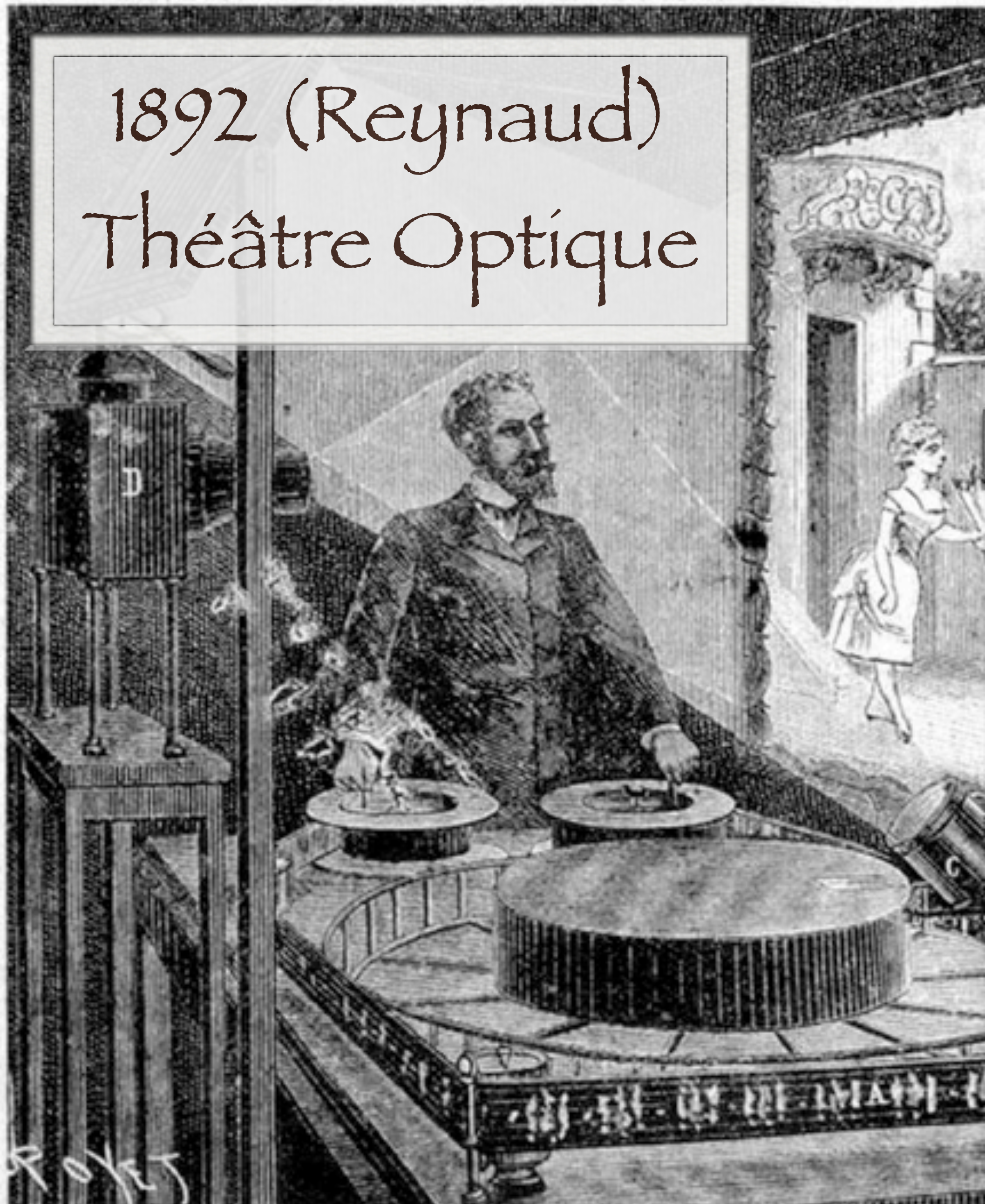
Persian vase depicts motion of goat

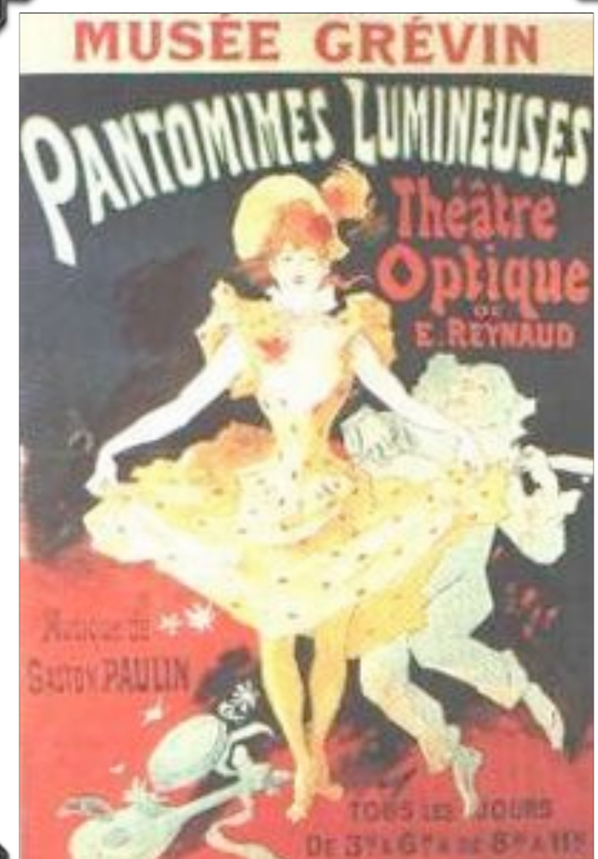
4000 years ago

Egyptian mural depicts wrestlers

1877 Praxinoscope (C.E. Reynaud)

1892 (Reynaud)
Théâtre Optique

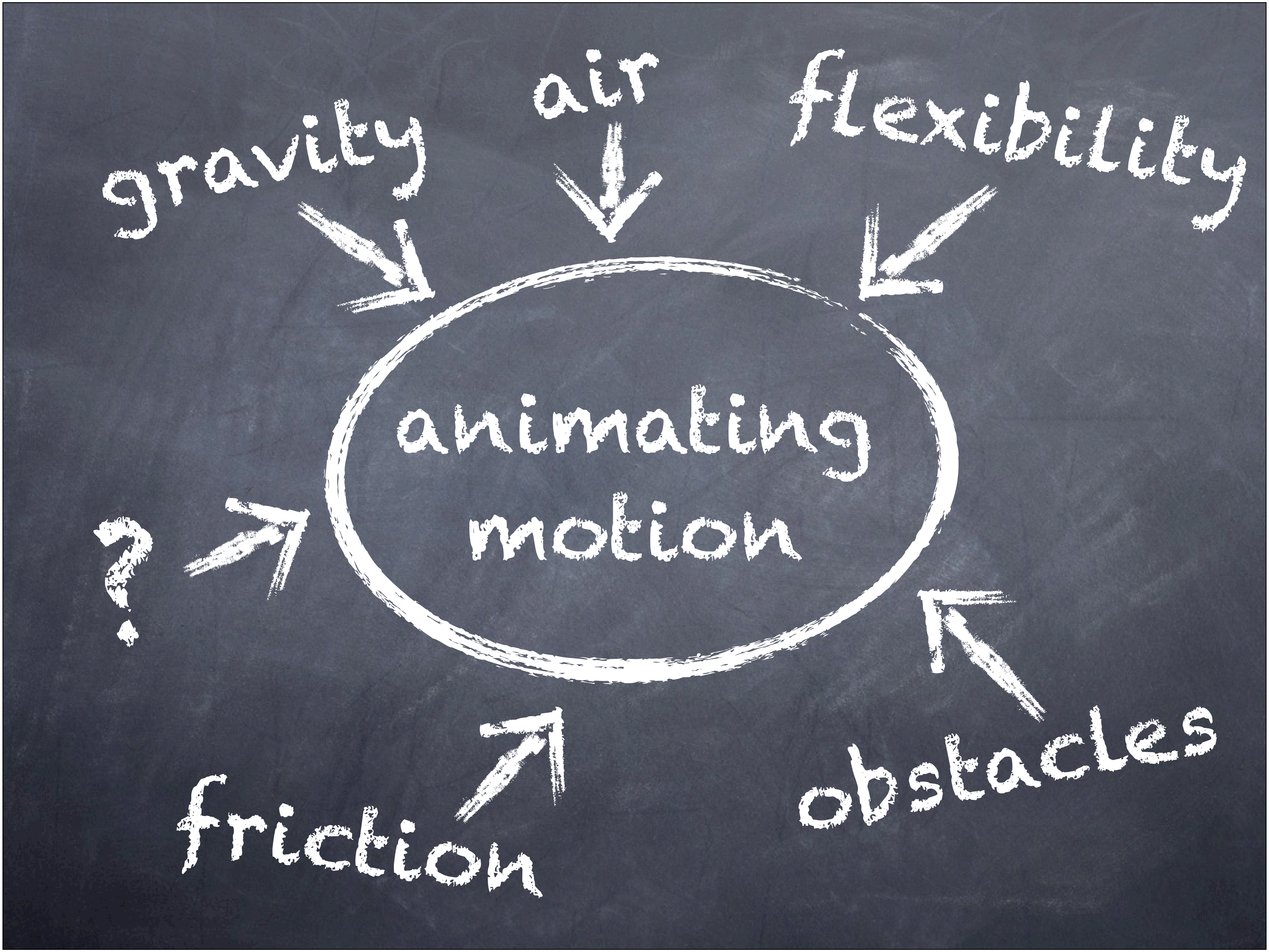




1937 Snow White (W. Disney)


WALT DISNEY
PRODUCTIONS

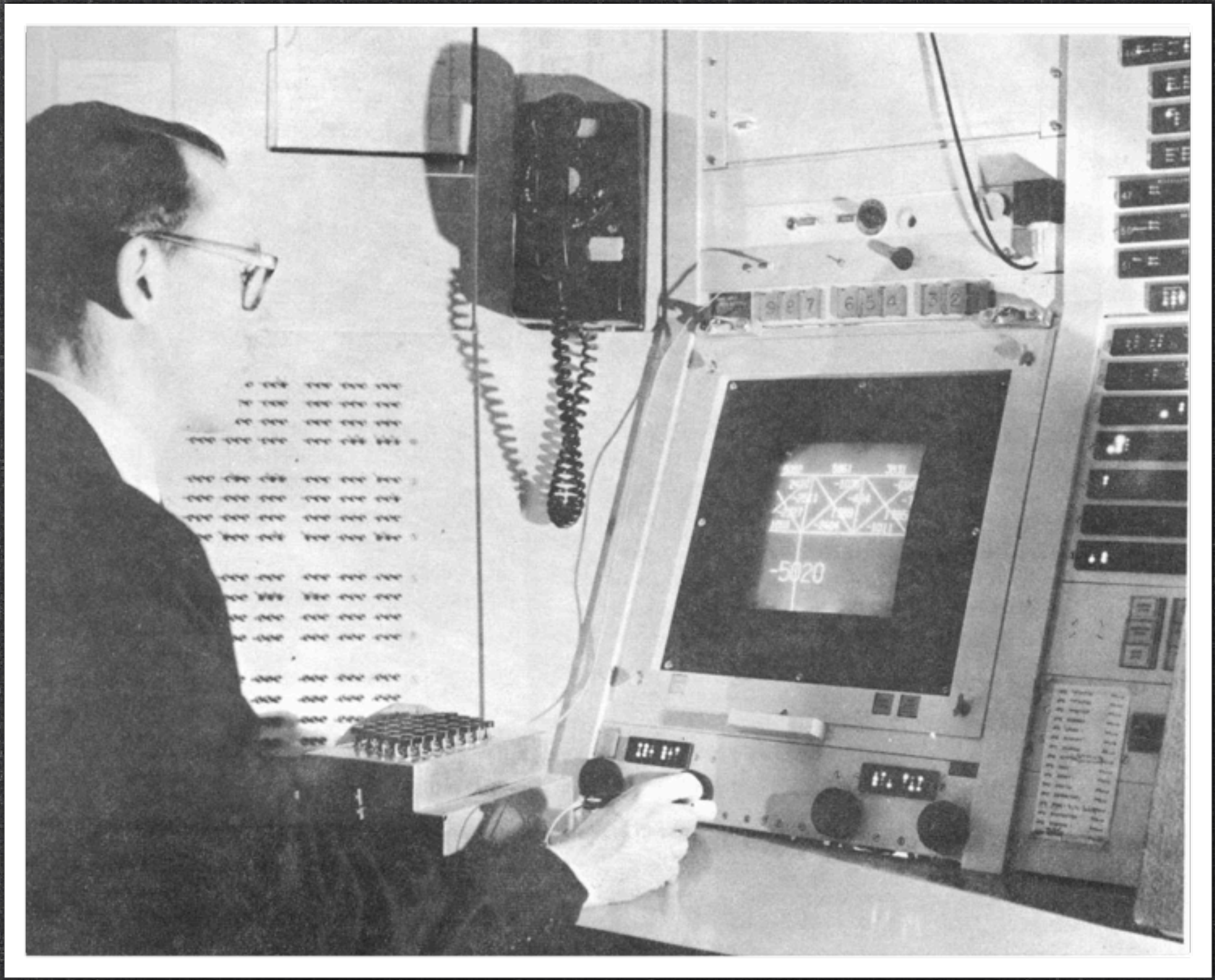
TWISTS
NEUTRAL
SLIGHT STRETCH
SLIGHT SQUASH
SQUASH
SQUASH2
PULL
EMOTIONS
CURIOUS
LAUGHTER
The famous half-filled flour sack, guide to maintaining


gravity
air
flexibility
animating motion
?
obstacles
friction

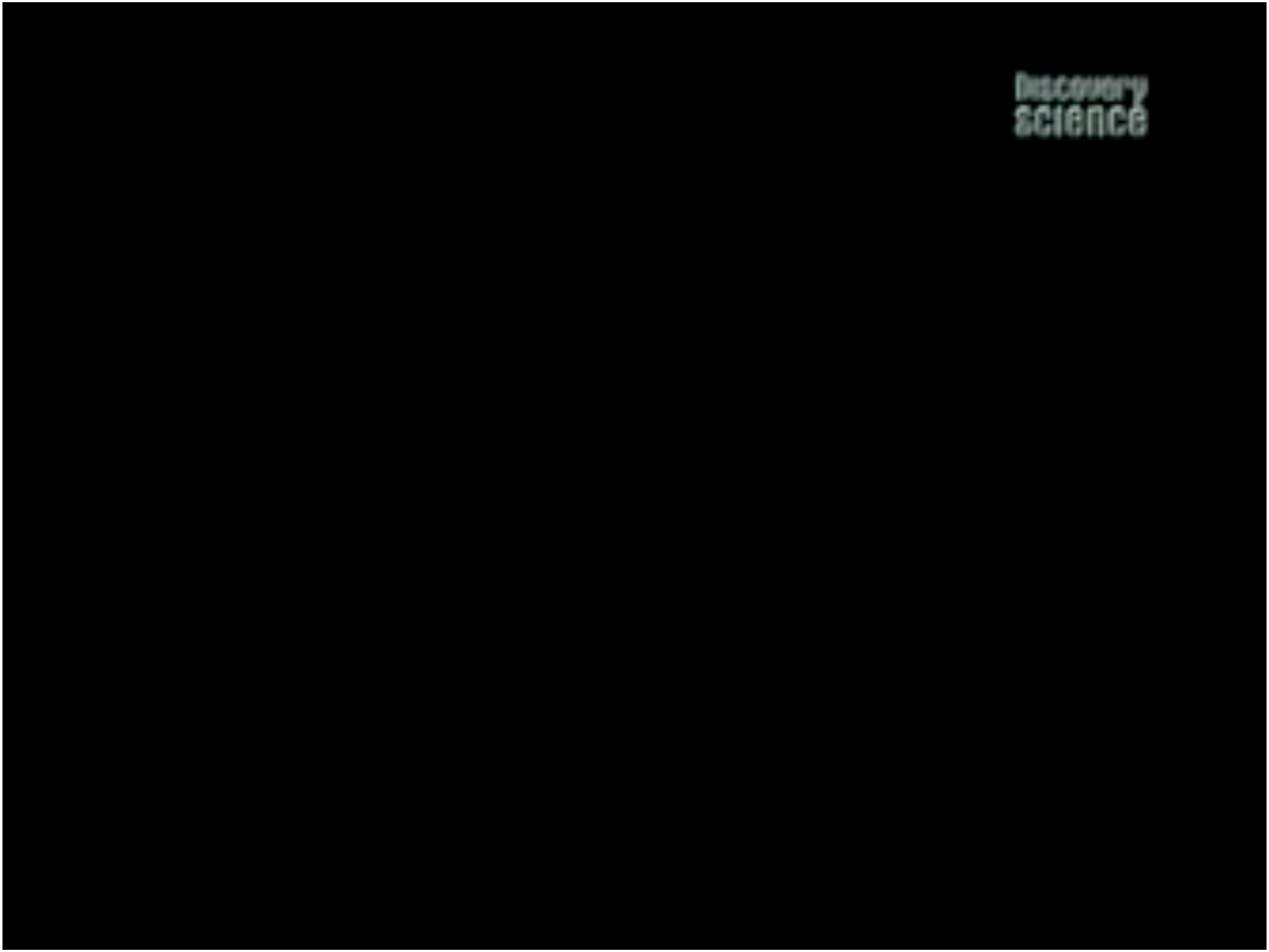
all was well...

until computers came
and broke everything

birth of
computer animation

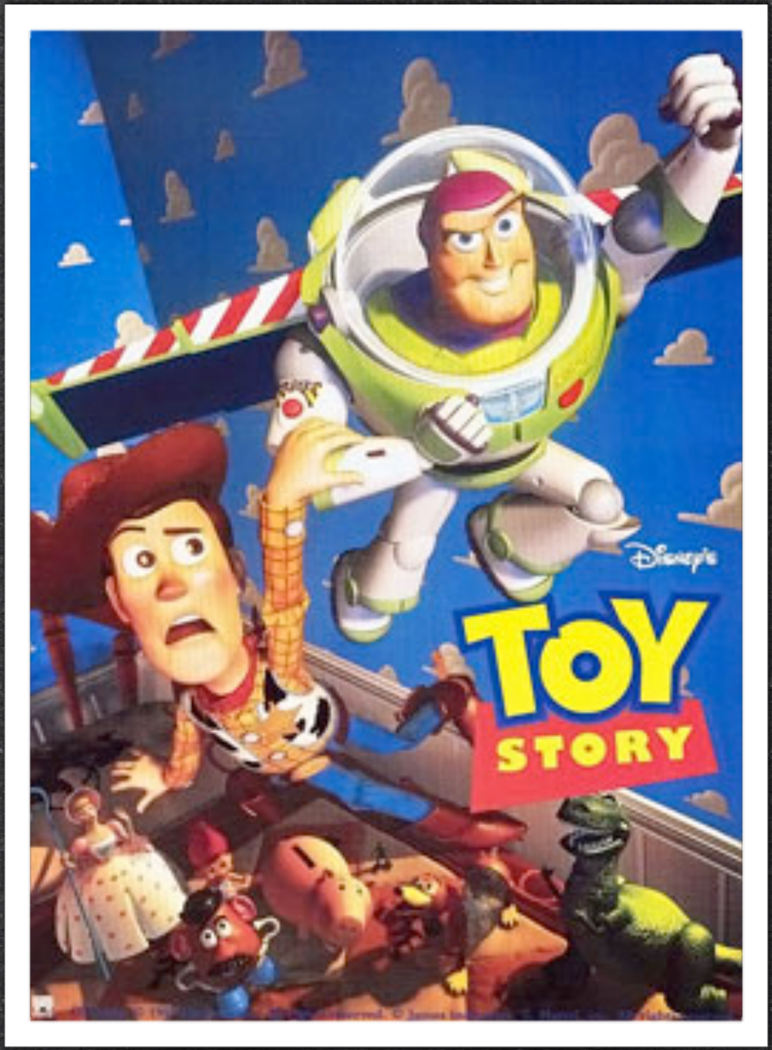


TX-2 Operating area, Sketchpad in use


Discovery
SCIENCE


Discovery
SCIENCE


Discovery
SCIENCE



1995 Toy Story (Disney/Pixar)

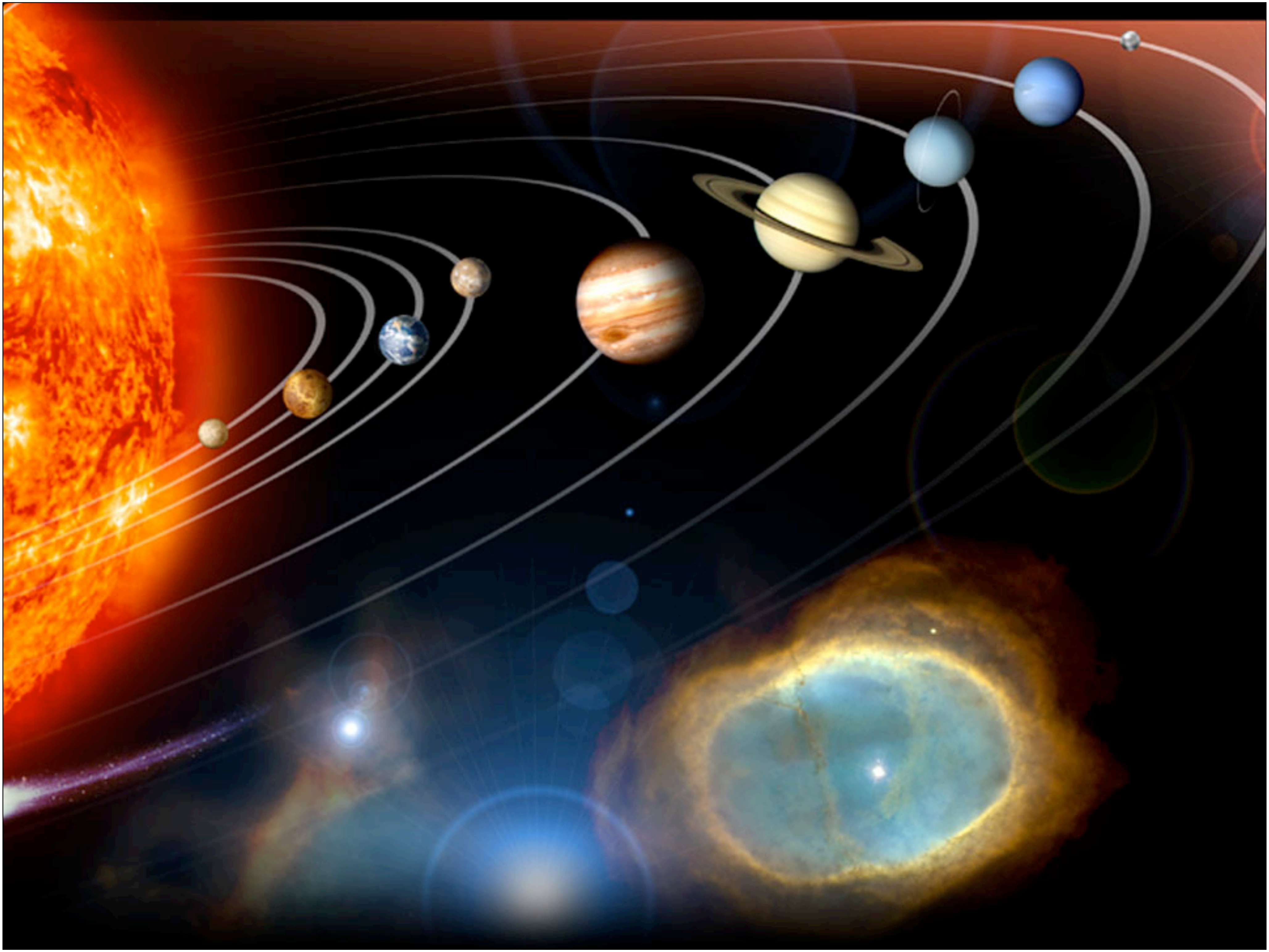
THE FOLLOWING **PREVIEW** HAS BEEN APPROVED FOR

APPROPRIATE AUDIENCES

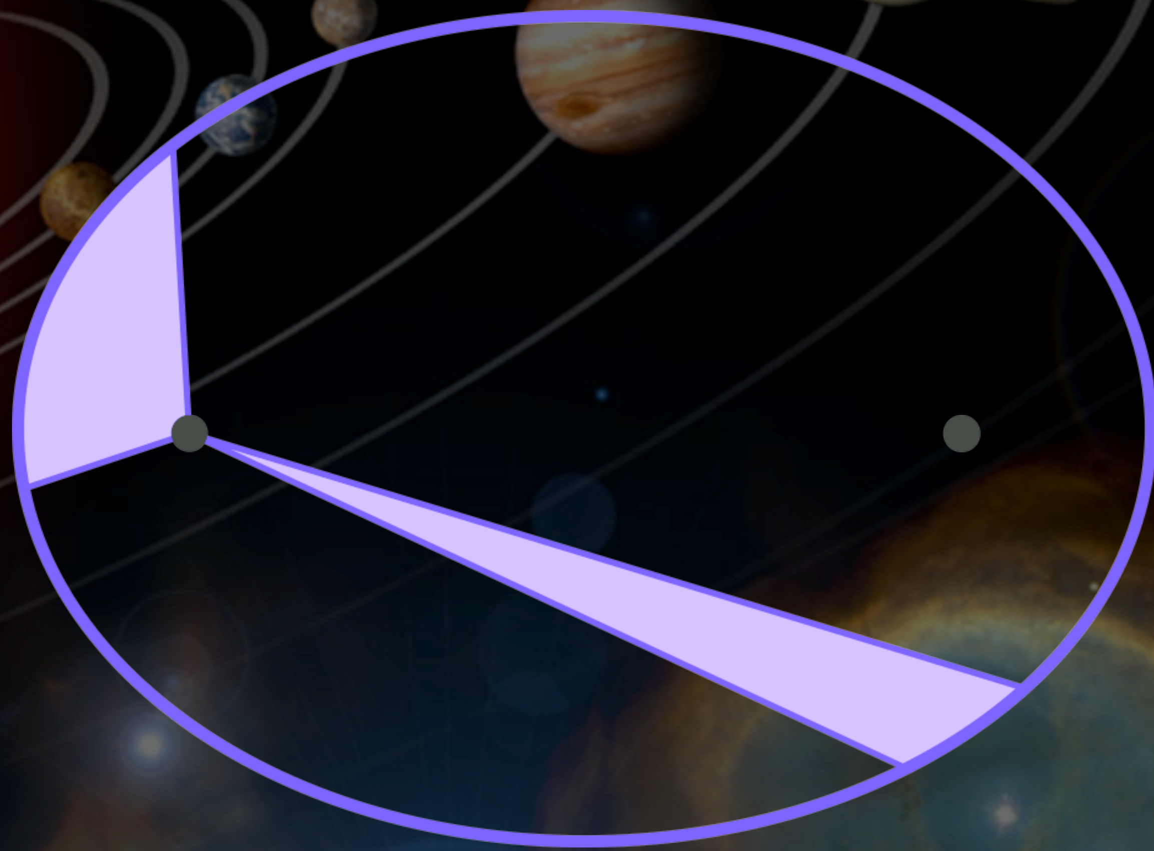
BY THE MOTION PICTURE ASSOCIATION OF AMERICA, INC.

www.filmratings.com

www.mpaa.org



Kepler’s Second Law



Newton's Proof

Principia

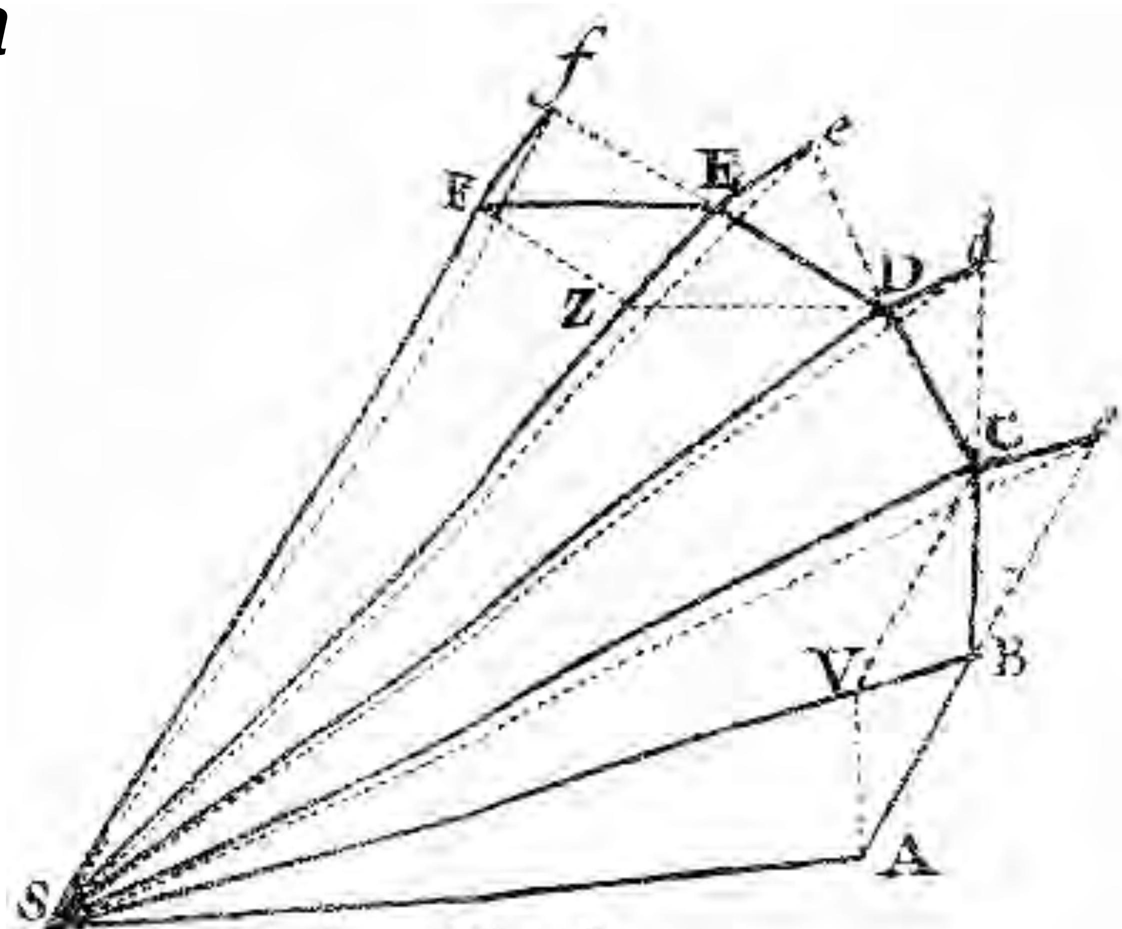
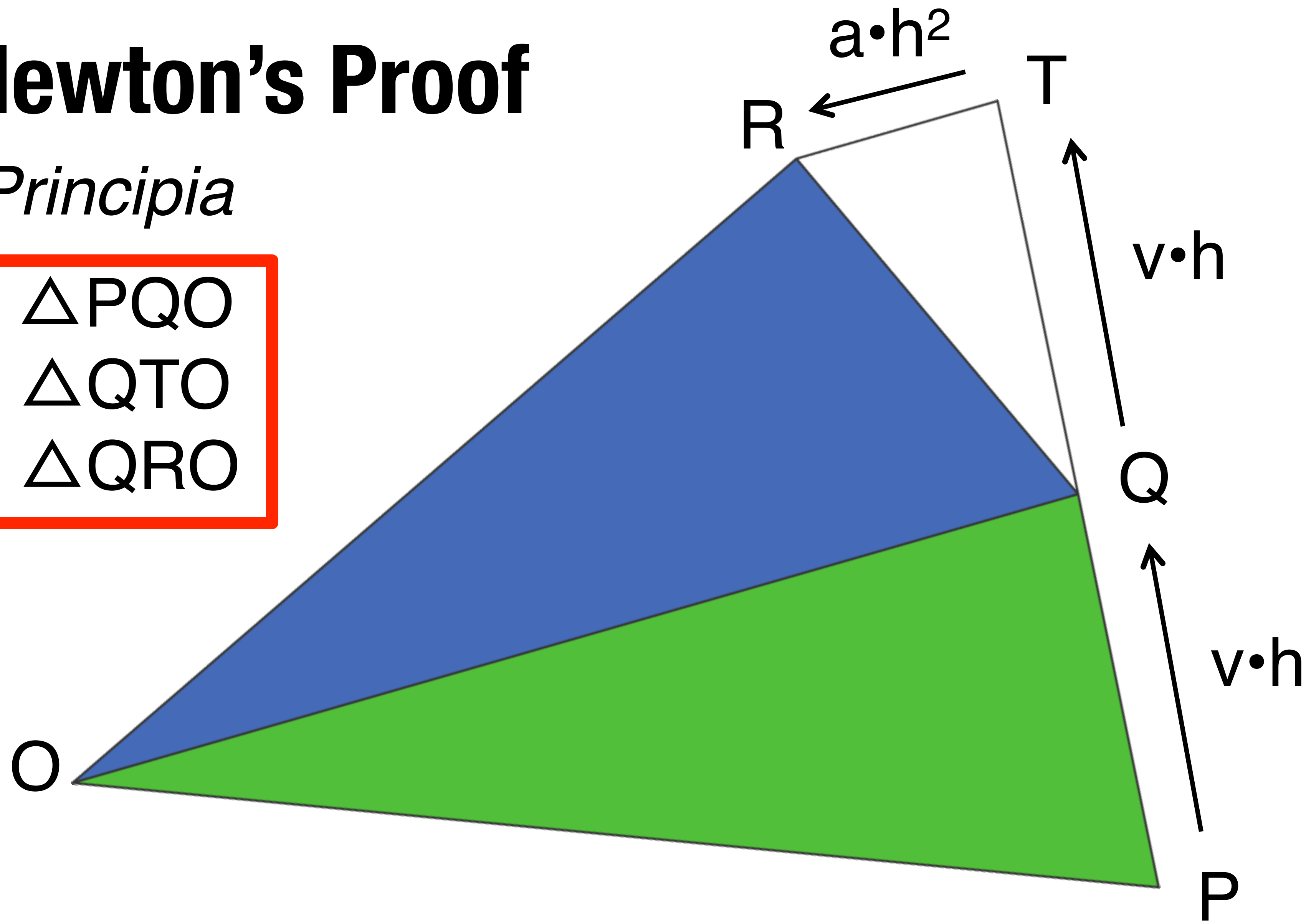


Fig. 13.

Newton's Proof

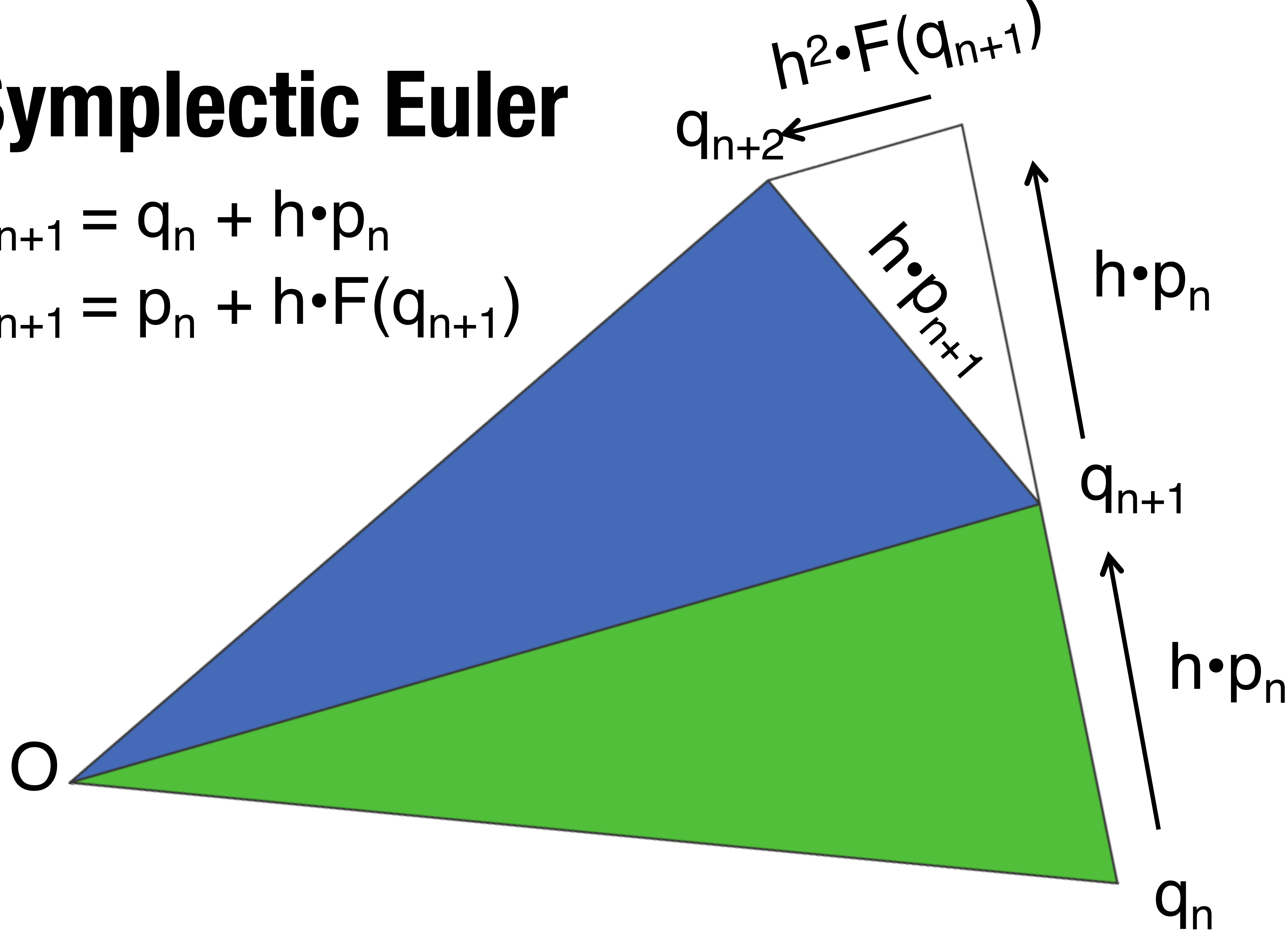
Principia

$$\triangle PQO = \triangle QTO = \triangle QRO$$



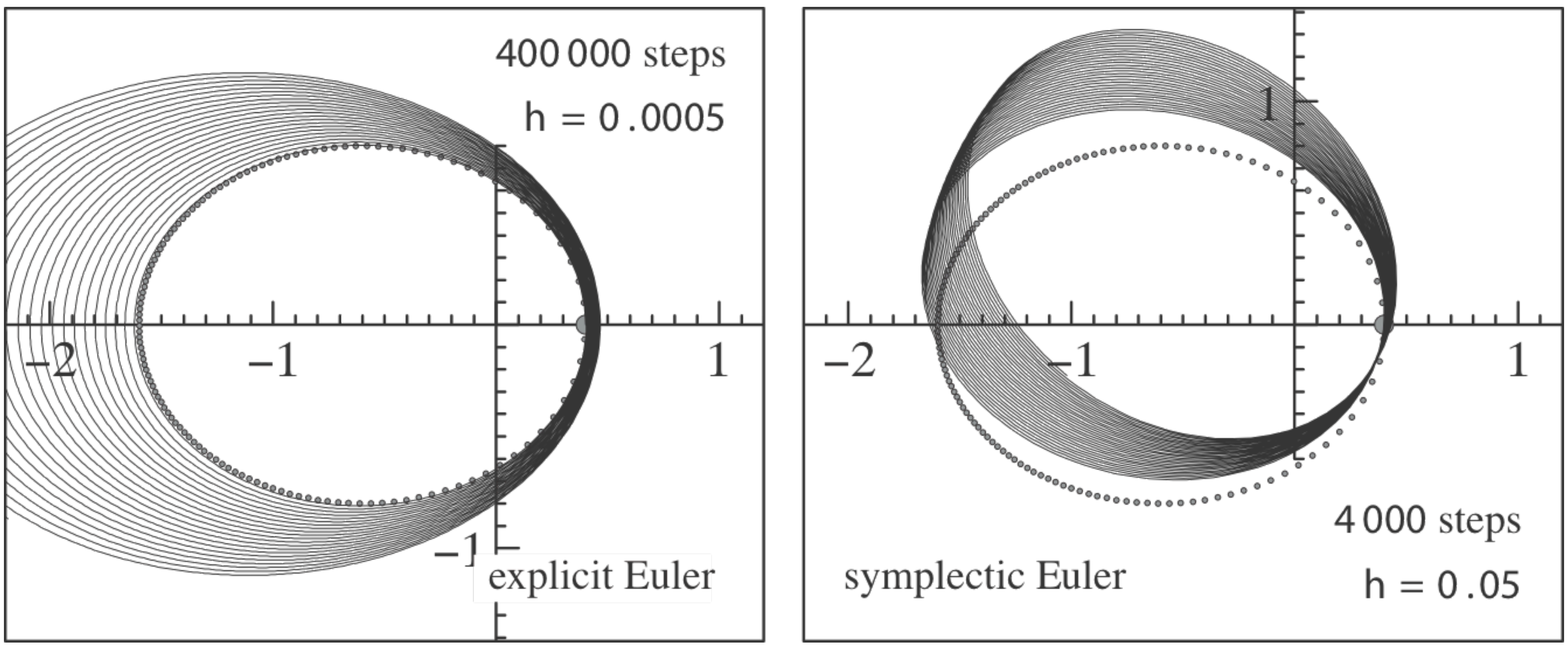
Symplectic Euler

$$q_{n+1} = q_n + h \cdot p_n$$
$$p_{n+1} = p_n + h \cdot F(q_{n+1})$$



Symplectic Euler

Source: Hairer, Lubich, Wanner



$$q_{n+1} = q_n + h \cdot p_n$$
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$$q_{n+1} = q_n + h \cdot p_n$$
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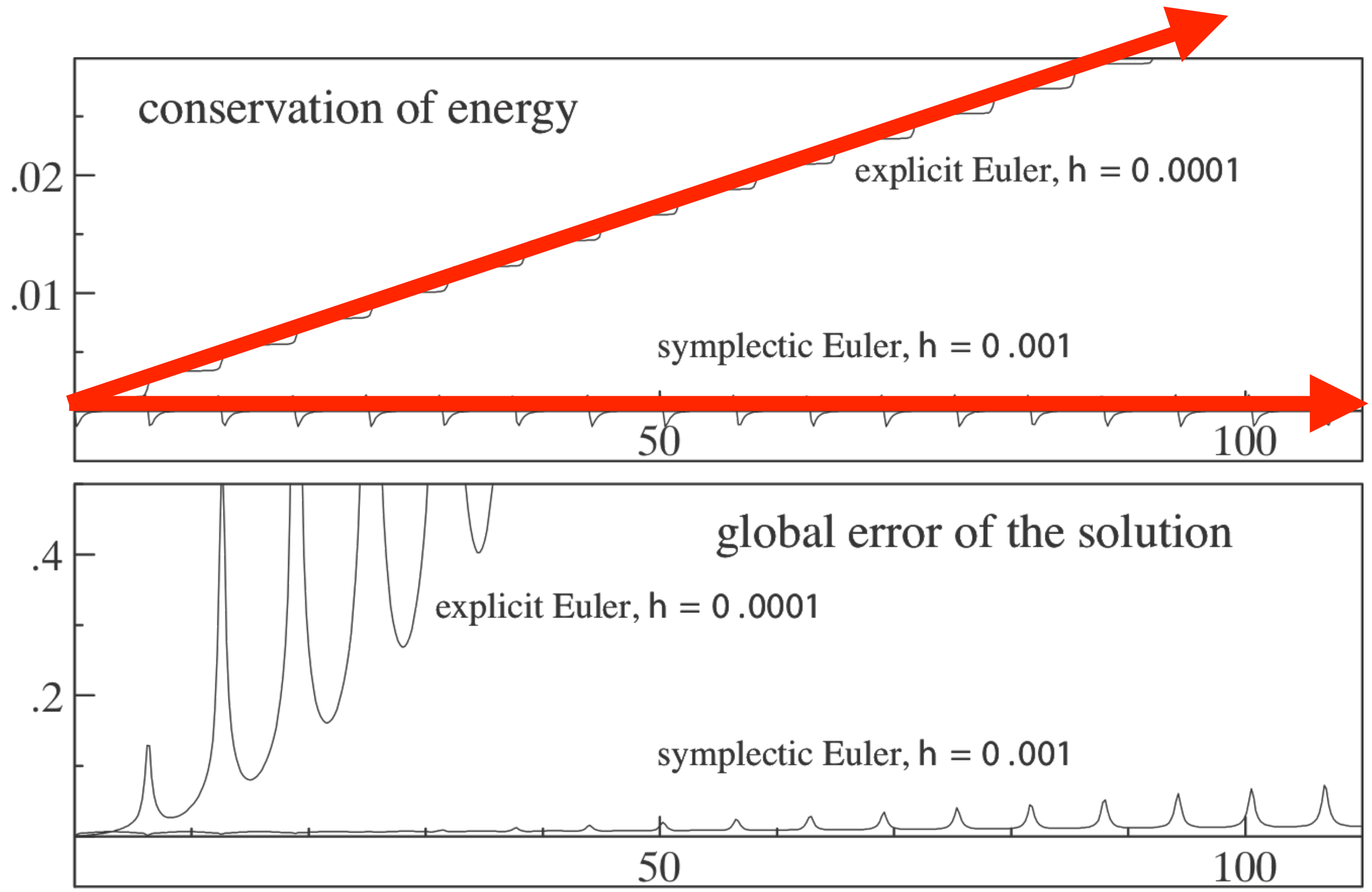
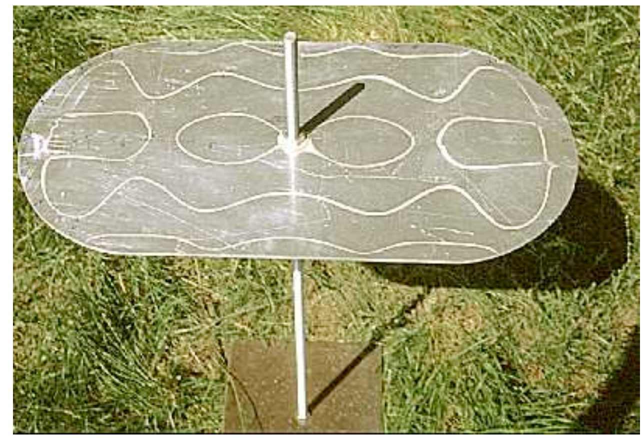
Symplectic Euler

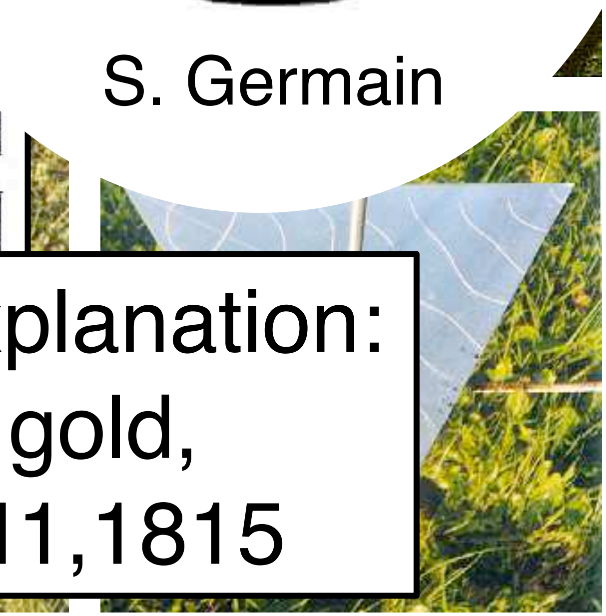
Source: Hairer, Lubich, Wanner



Chladni’s vibrating plates



Chladni's vibrating plates



S. Germain

Prize for explanation:
1kg of gold,
1808,1811,1815

Bending Energy

Fn. of principal curvatures

- even ← orientation invariance
- symmetric ← isotropy
- extrinsic ← bending as change of embedding

S. Germain

$$E_b(S) = \frac{1}{2}\int_S H^2 \mathrm{d}A$$

Symmetries ⇔ Conservation Laws

Invariant under Möbius group

- rigid motion
- uniform scaling

E. Noether

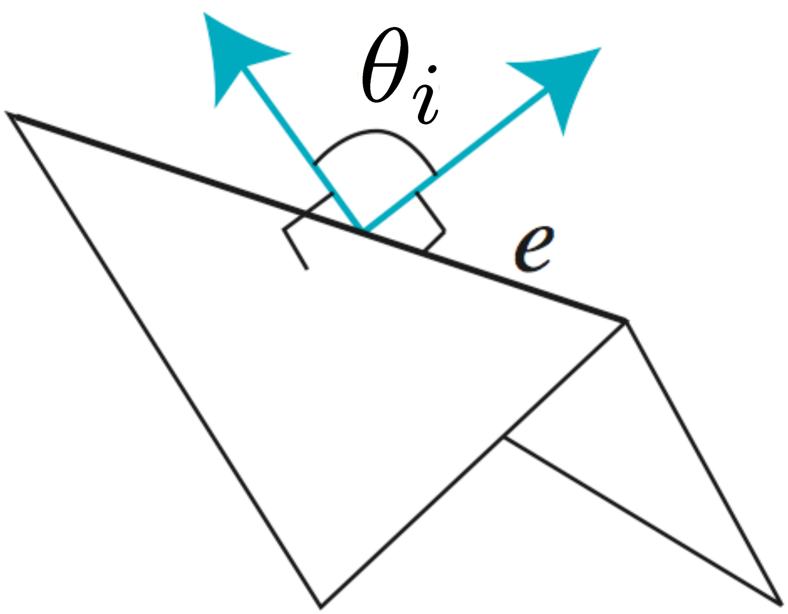
Conservation laws (Noether's Thm)

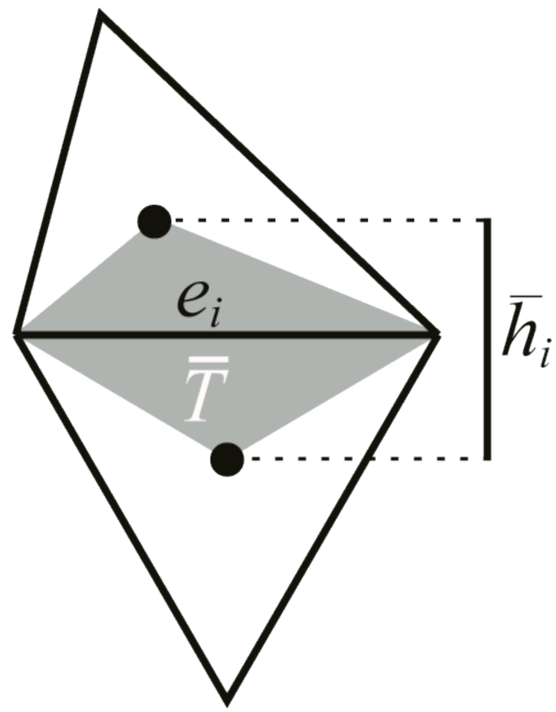
- linear & angular momentum

$$E_b(S) = \frac{1}{2}\int_S H^2 \mathrm{d}A$$

Computing discrete shells

Elastic energy = $$\frac{K_B}{2}\sum_i(\theta_i-\bar{\theta}_i)^2\frac{\|\bar{e}_i\|}{\bar{h}_i}$$

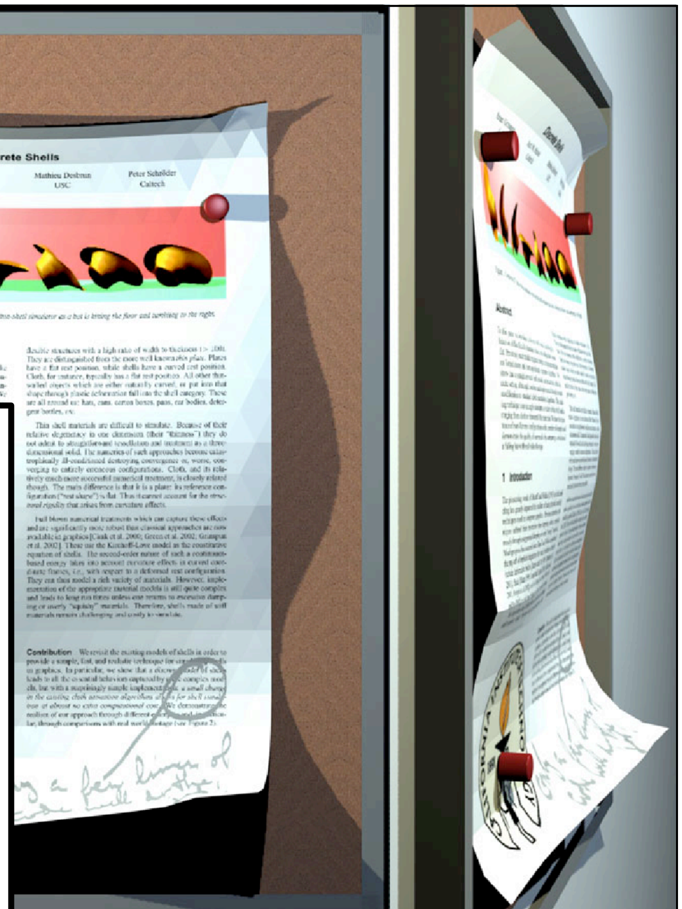


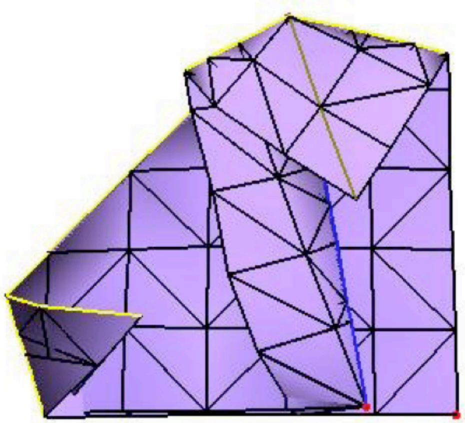


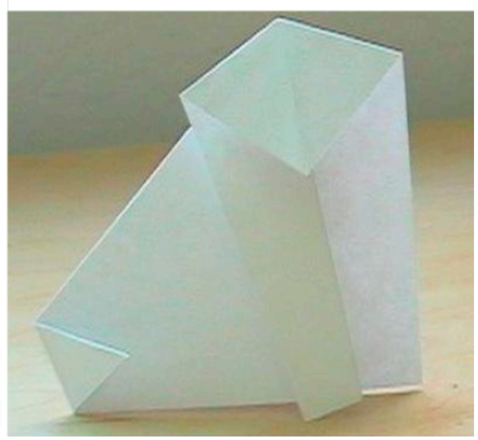
Discrete Shells: Modeling Paper

Paper sheet

- curled
- creased
- pinned

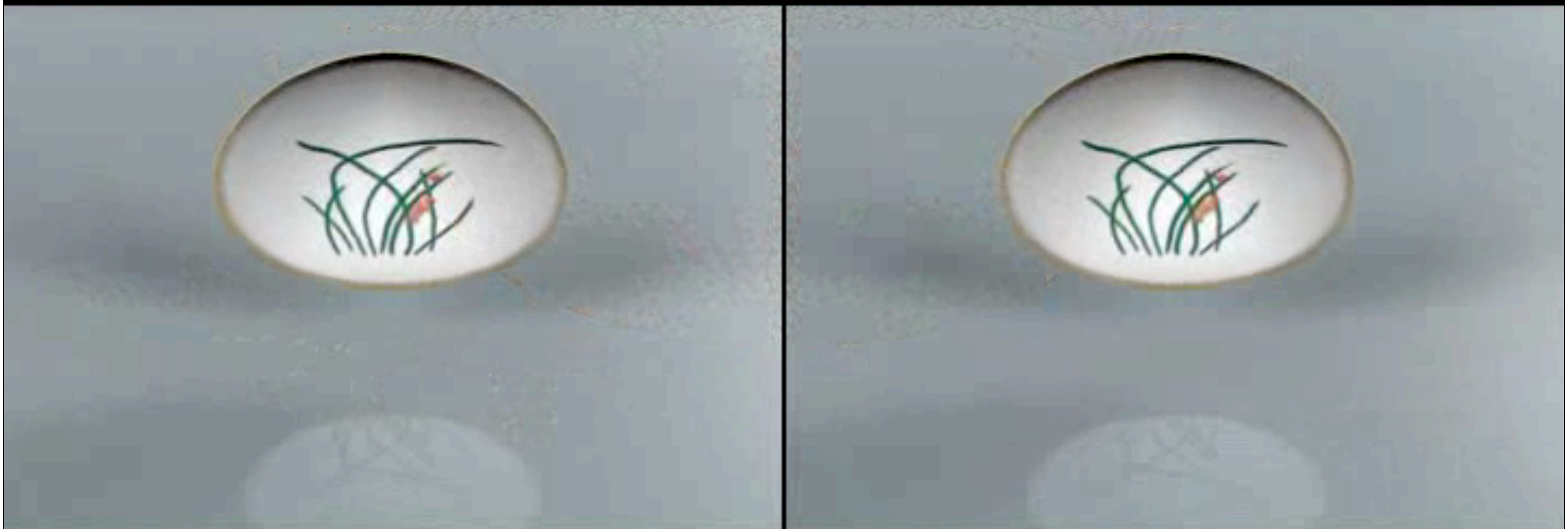






with R. Burgoon, Z. Wood

esbrun, A. Hirani, P. Schröder



Isotropic

$Y = 40$

Vertical

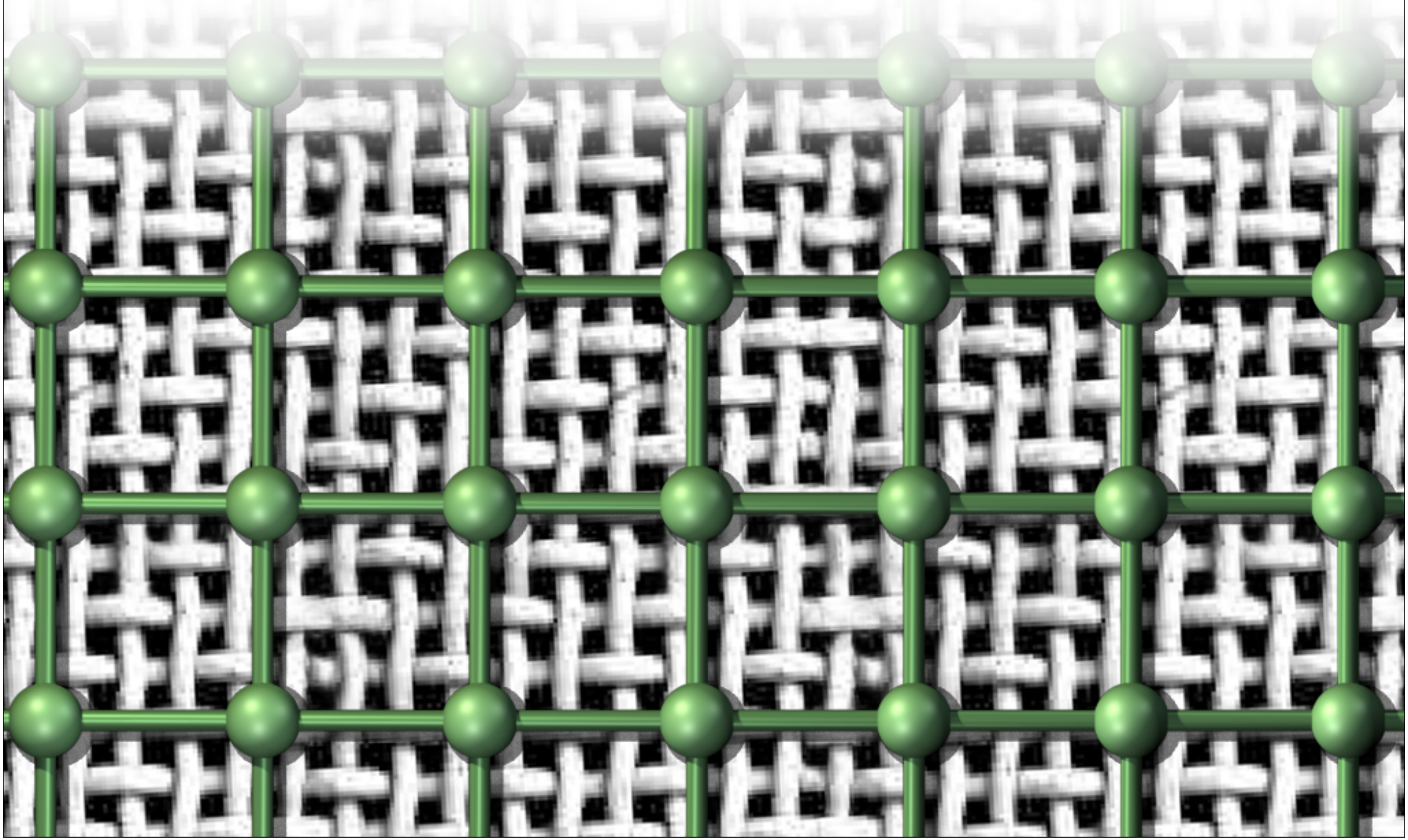
$Y0 = 1.e\text{-}4$, $Y1 = 10$, $G = 5$

with Akash Garg, Max Wardetzky, Denis Zorin

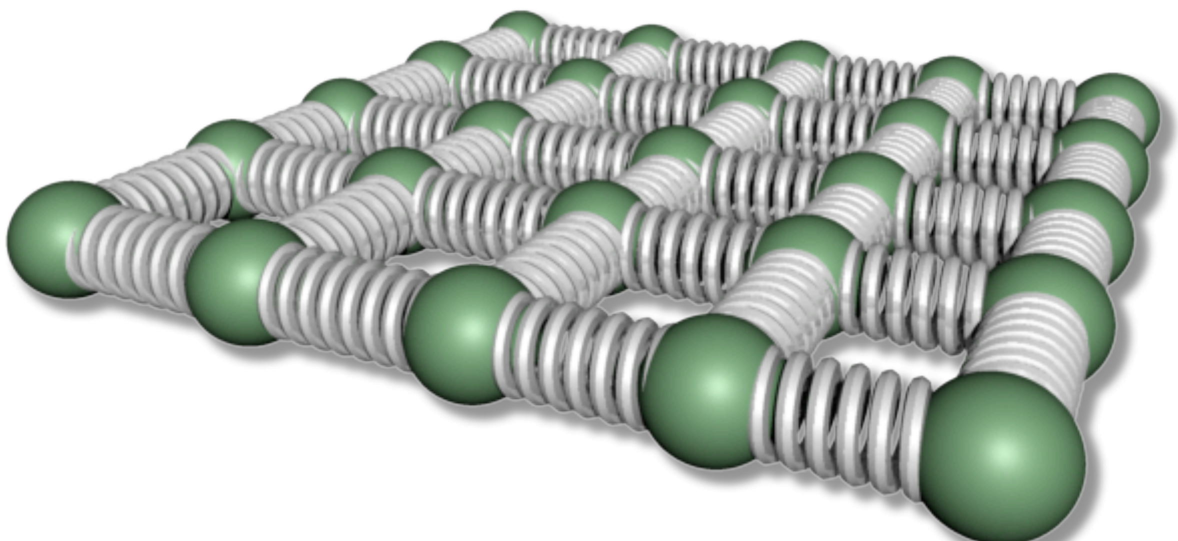
Enforcing Inextensibility

with Rony Goldenthal, David Harmon, Rannan Fattal, Michiel Bercovier

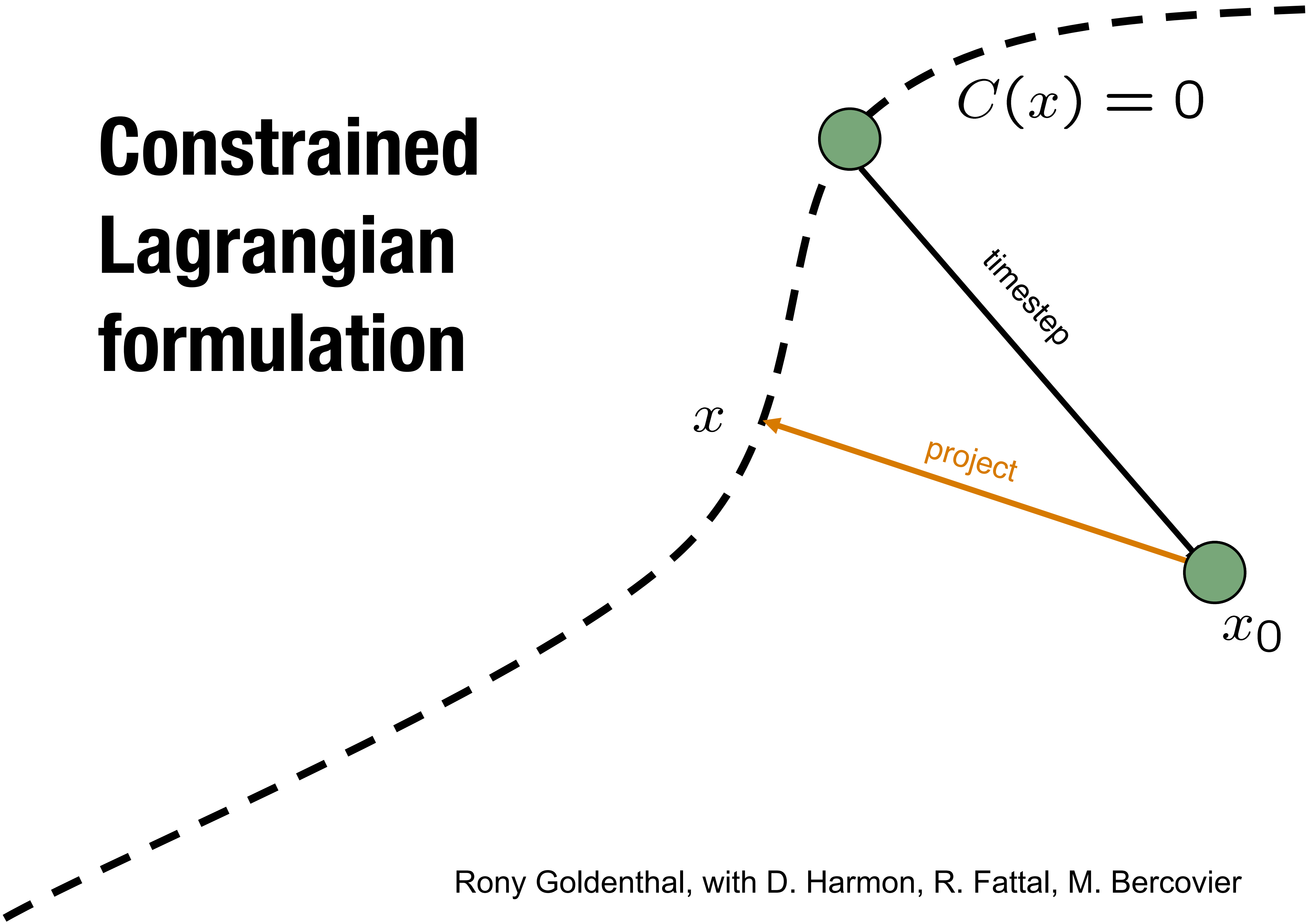
Cloth Model



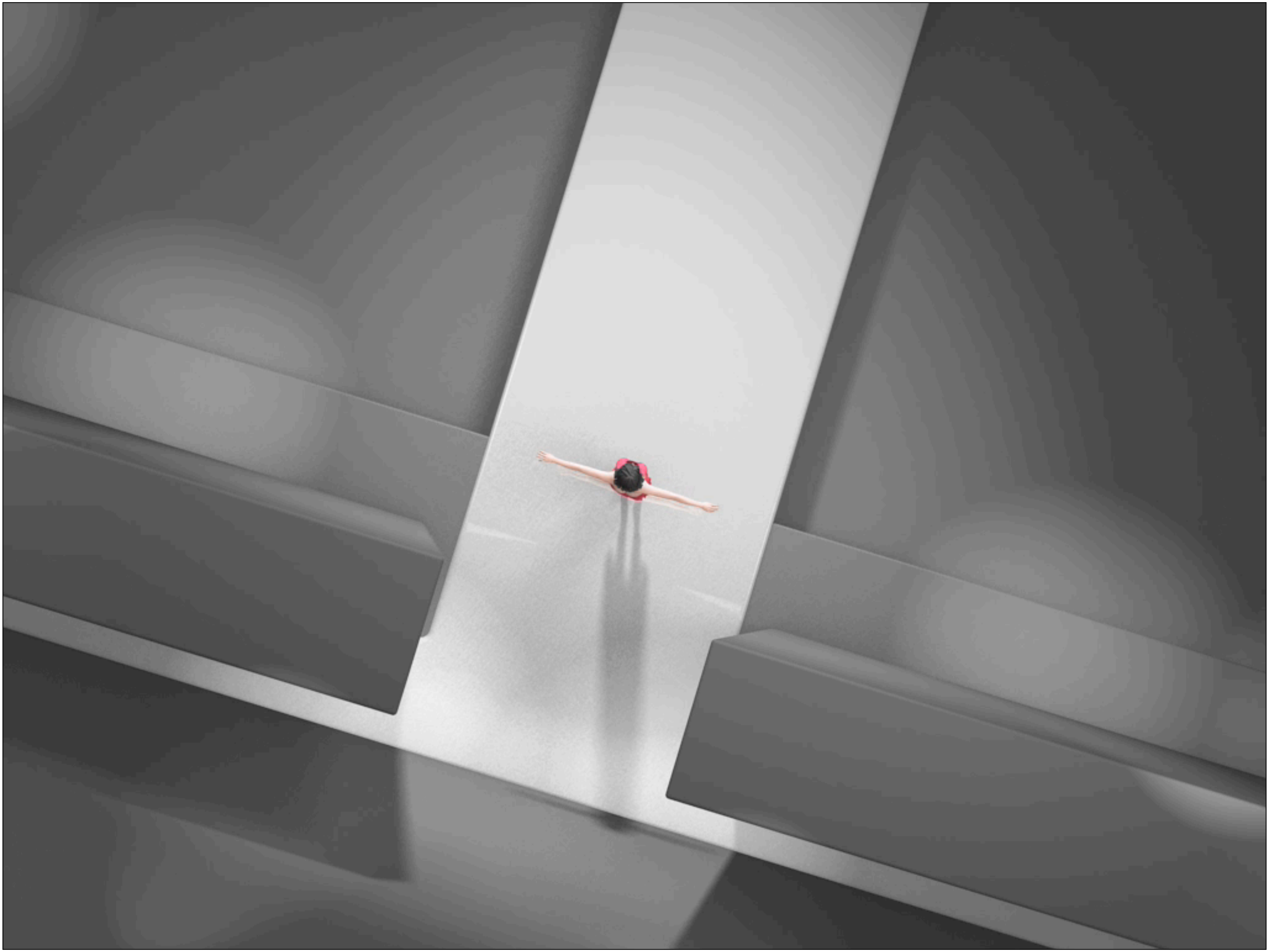
Stiff Springs



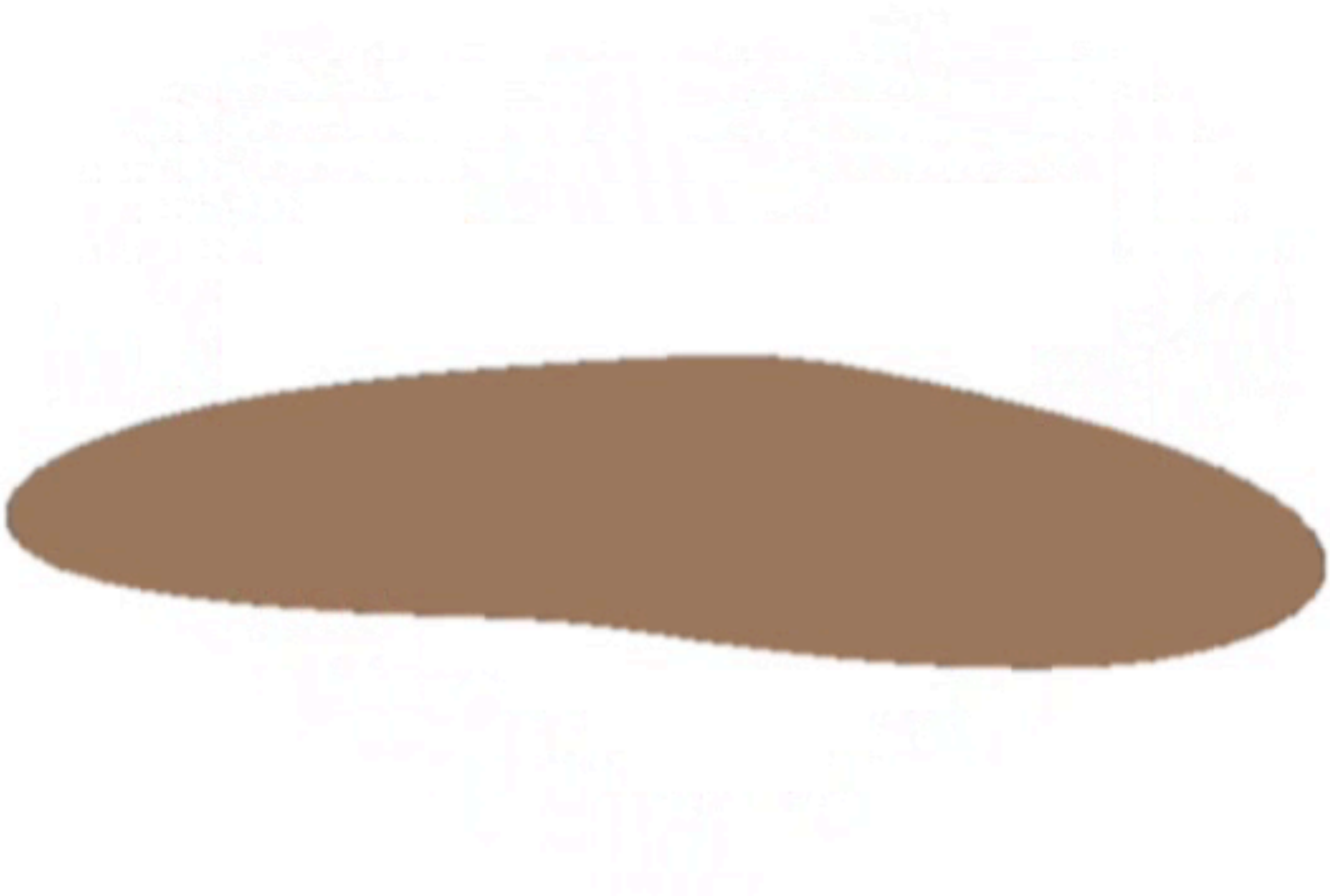
Constrained Lagrangian formulation



Rony Goldenthal, with D. Harmon, R. Fattal, M. Bercovier

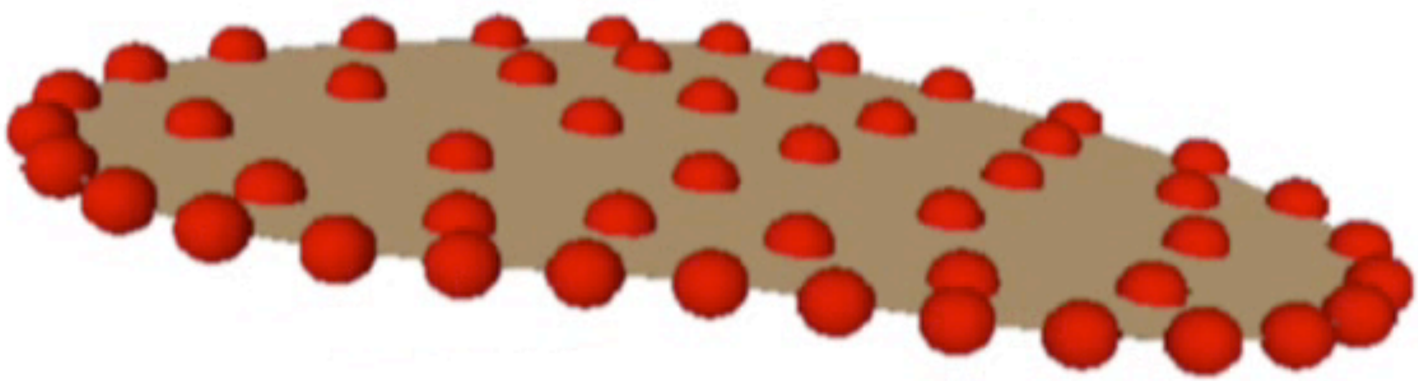


“CHARMS adaptive simulation” (with Petr Krysl and Peter Schröder)



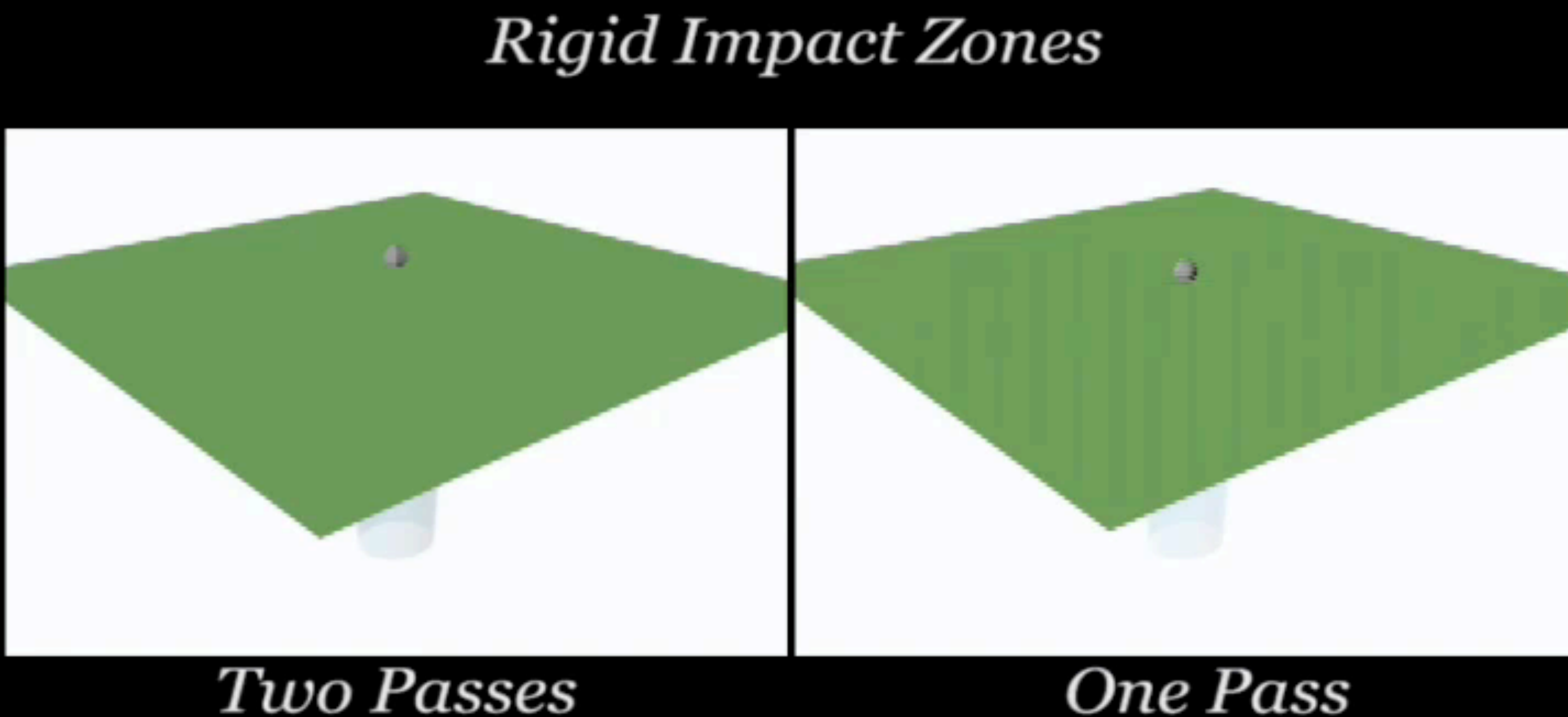
focus on the wrinkles & folds

“CHARMS adaptive simulation” (with Petr Krysl and Peter Schröder)



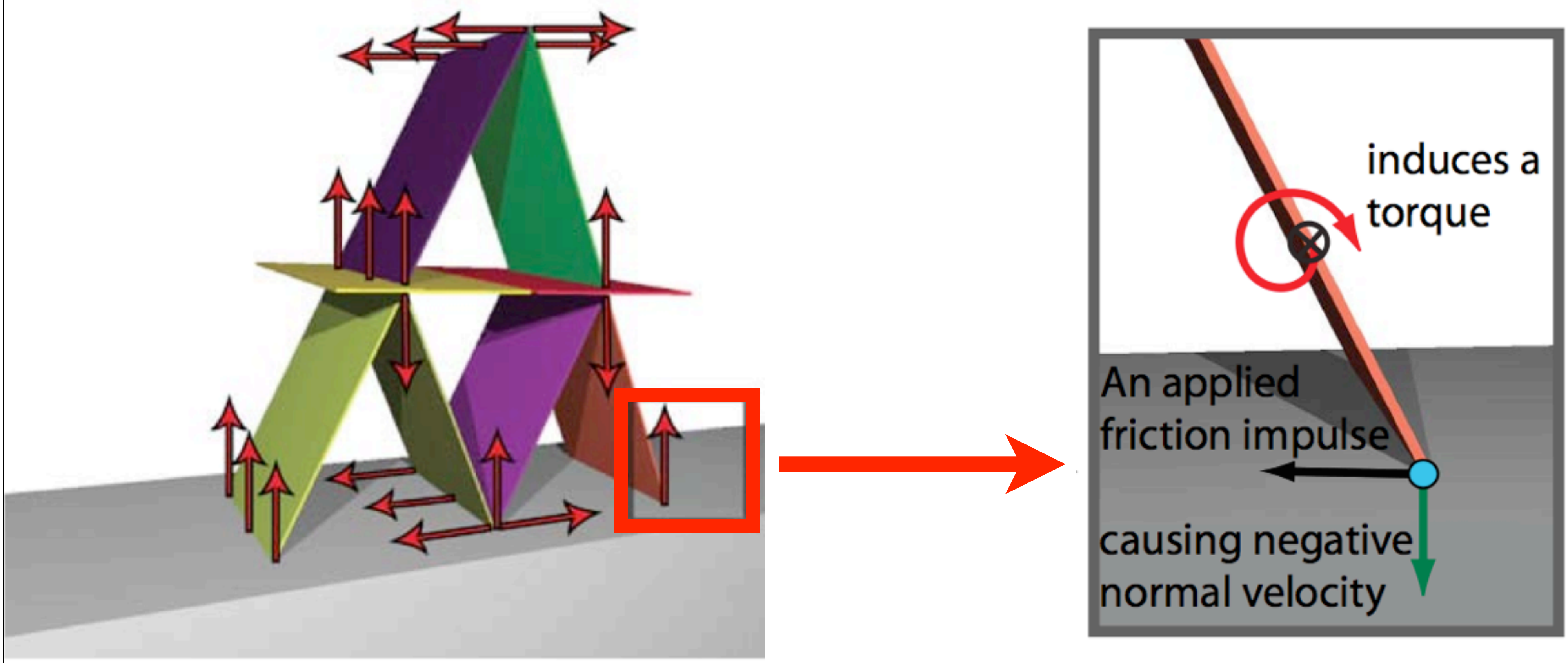
computation focuses on wrinkles

“Robust Treatment of Simultaneous Collisions”



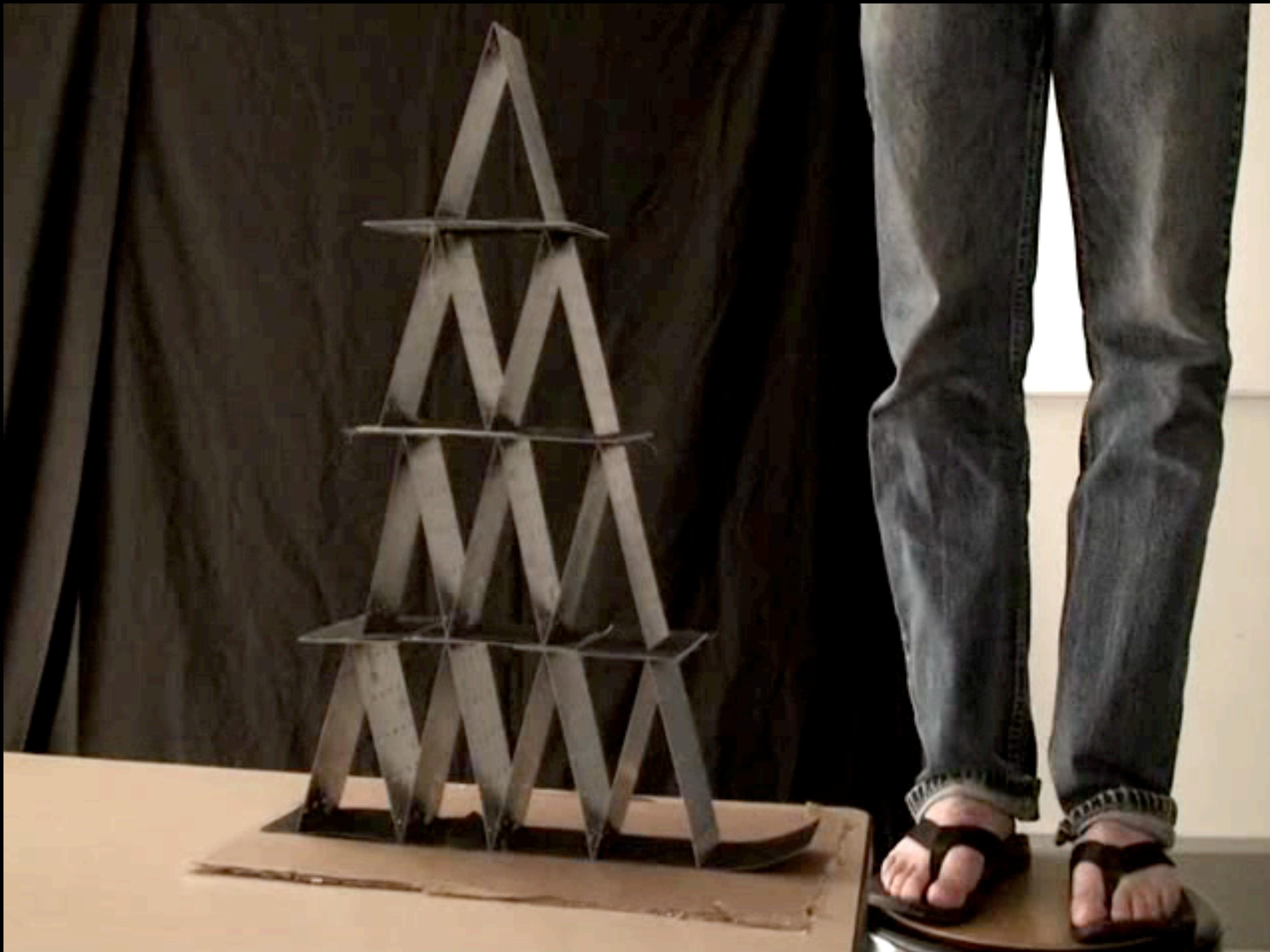
with David Harmon, Etienne Vouga, Rasmus Tamstorf

"Staggered Projections for Frictional Contact in Multibody Systems"



Danny Kaufman, Shinjiro Sueda, Doug James, Dinesh Pai

"Staggered Projections for Frictional Contact in Multibody Systems"



Danny Kaufman, Shinjiro Sueda, Doug James, Dinesh Pai

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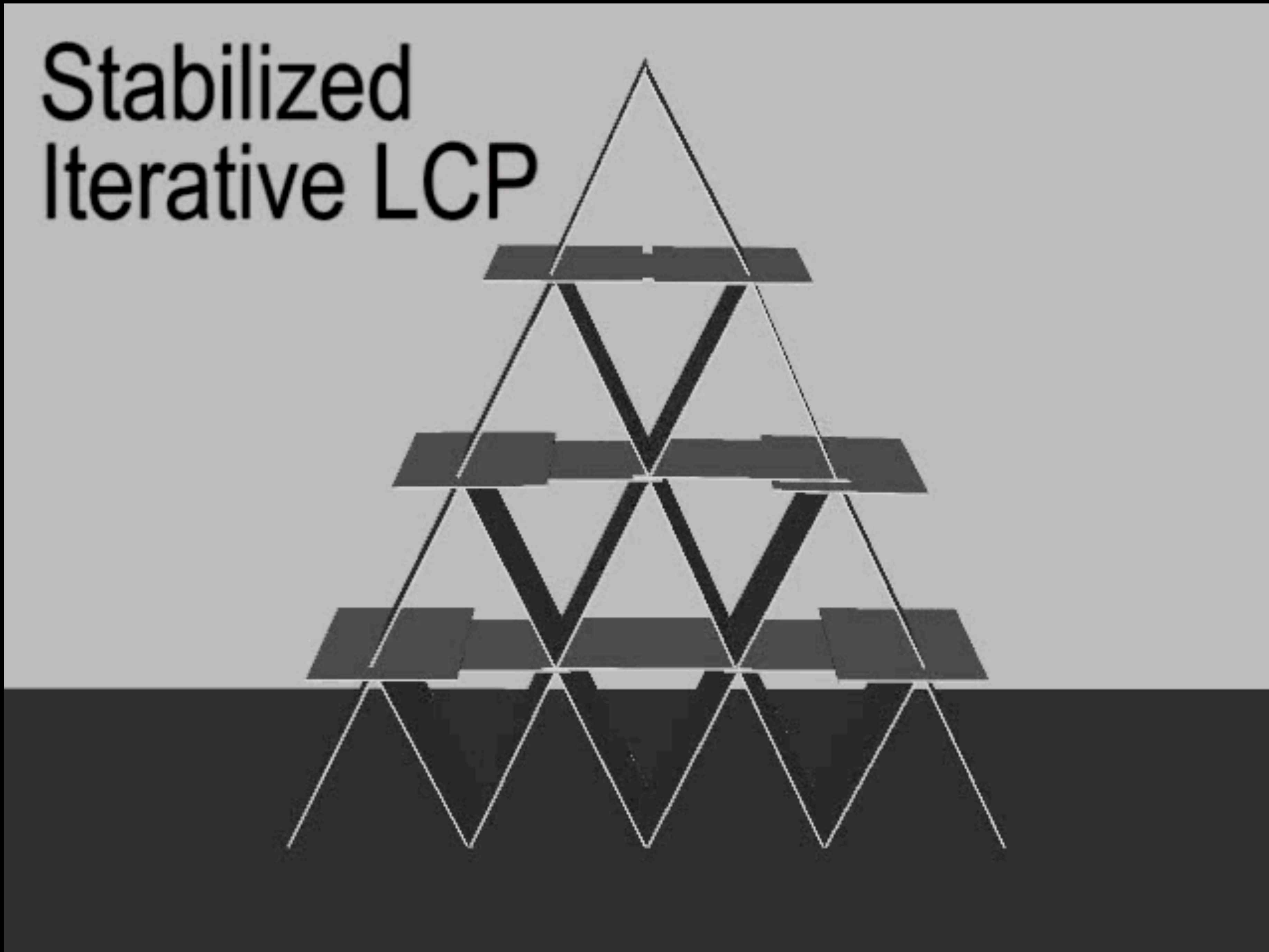
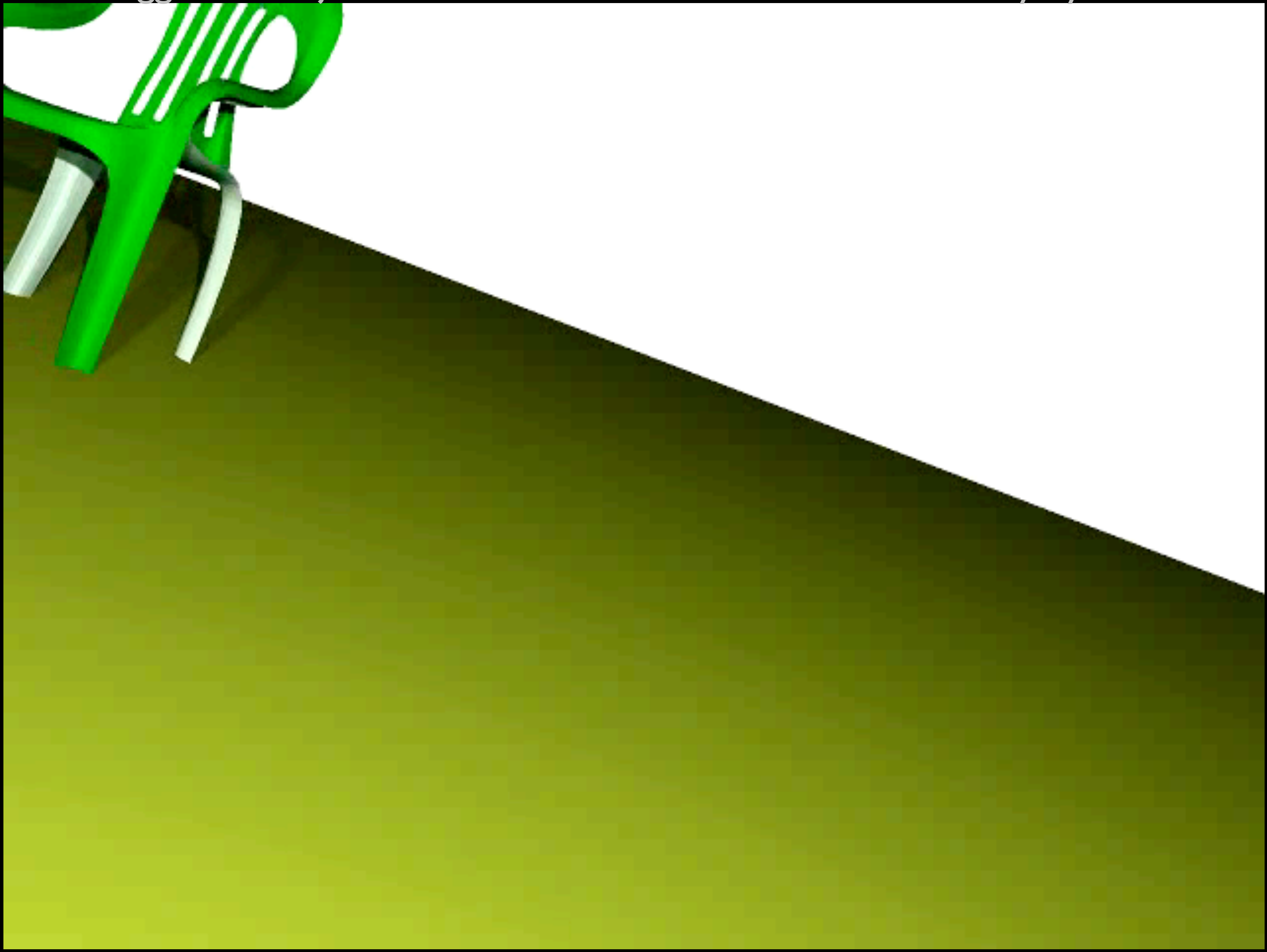


Danny Kaufman, Shinjiro Sueda, Doug James, Dinesh Pai

“Staggered Projections for Frictional Contact in Multibody Systems”

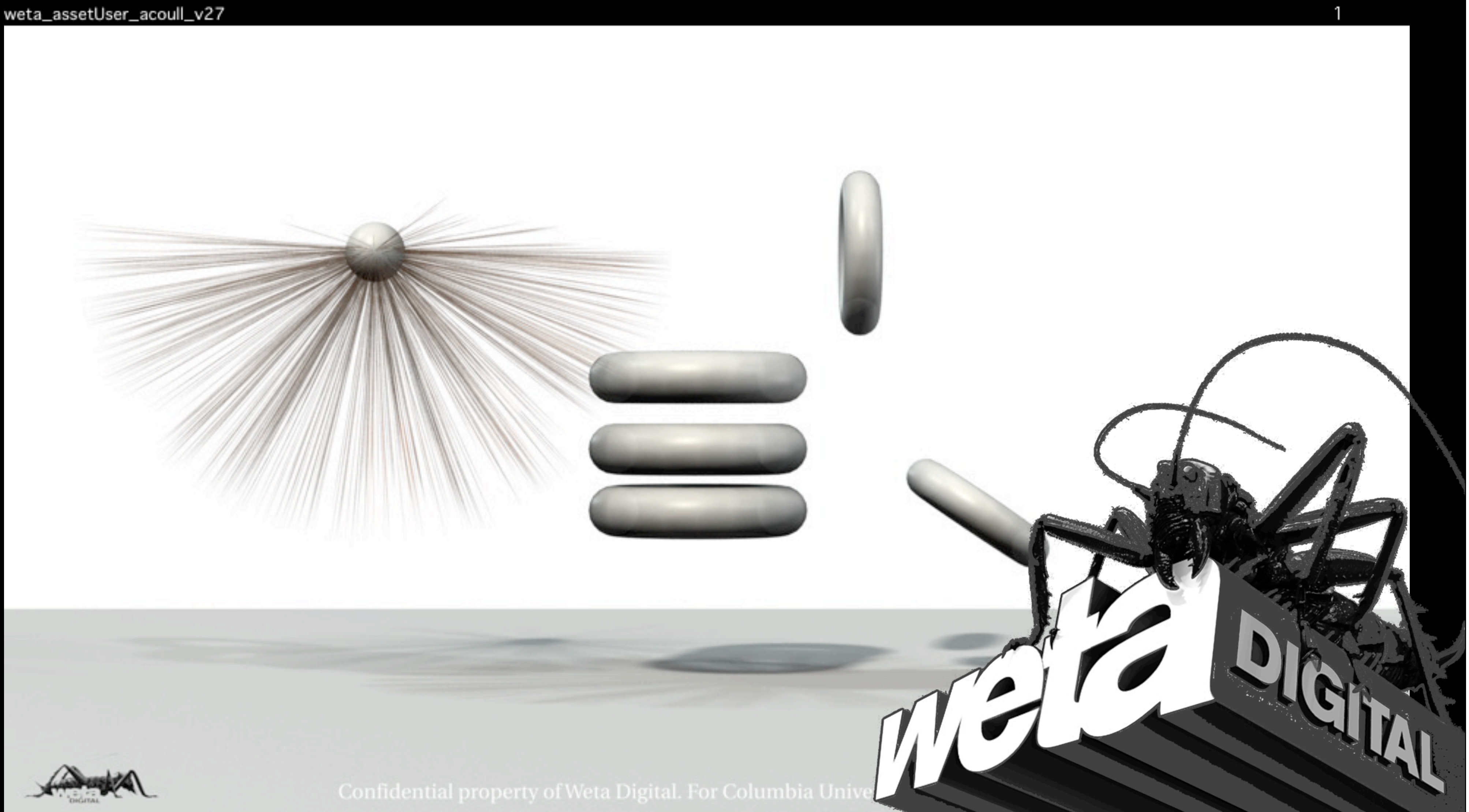


Danny Kaufman, Shinjiro Sueda, Doug James, Dinesh Pai

“Discrete Elastic Rods,” Miklós Bergou, Basile Audoly, Max Wardetzky

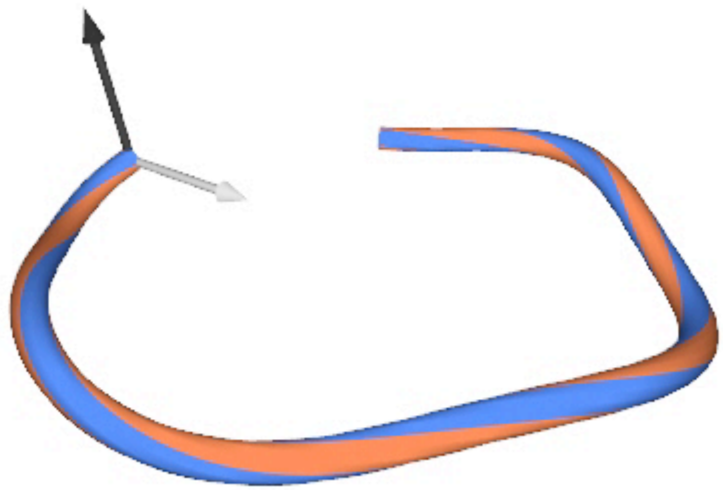
computing motion of elastic rods

credits: Weta Digital (New Zealand)

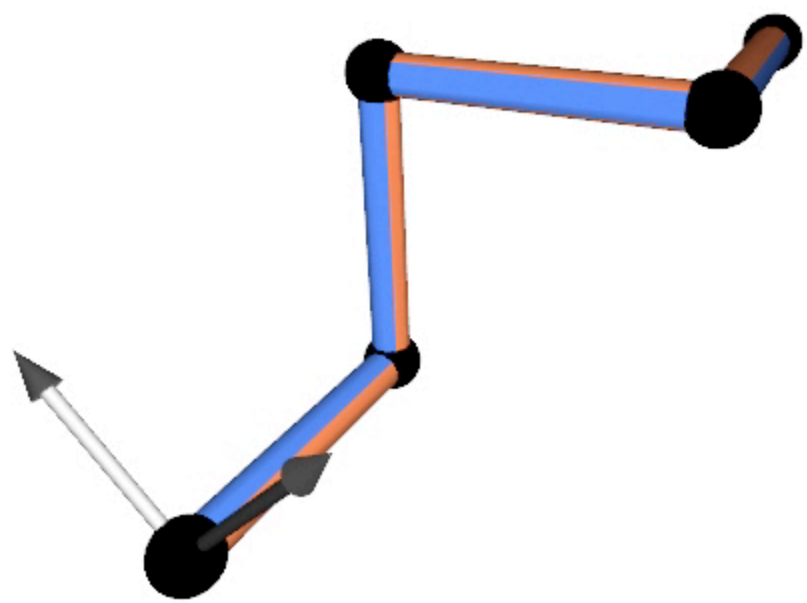


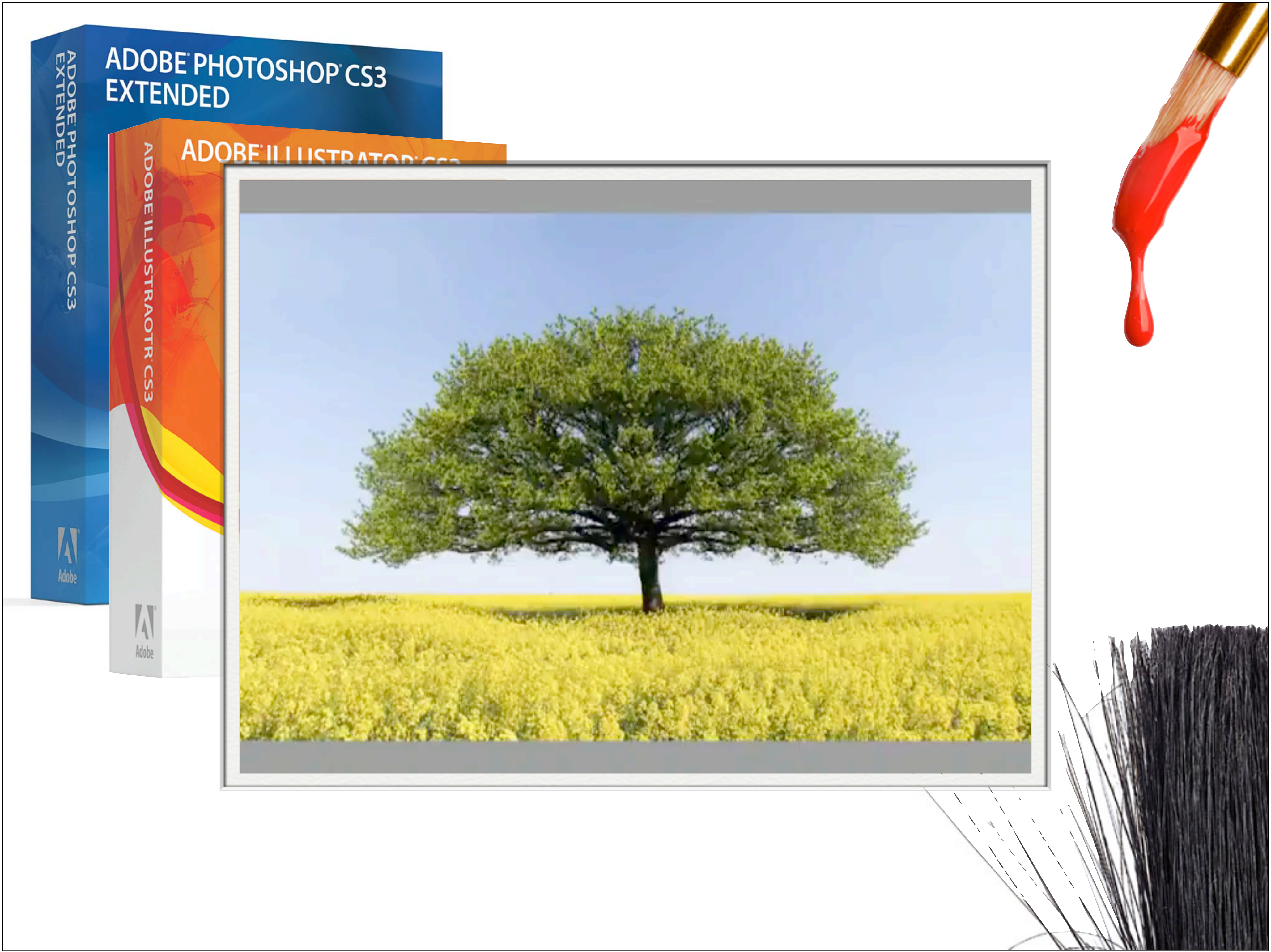
...behind-the-scenes: hair workout

Twist-Free Frame

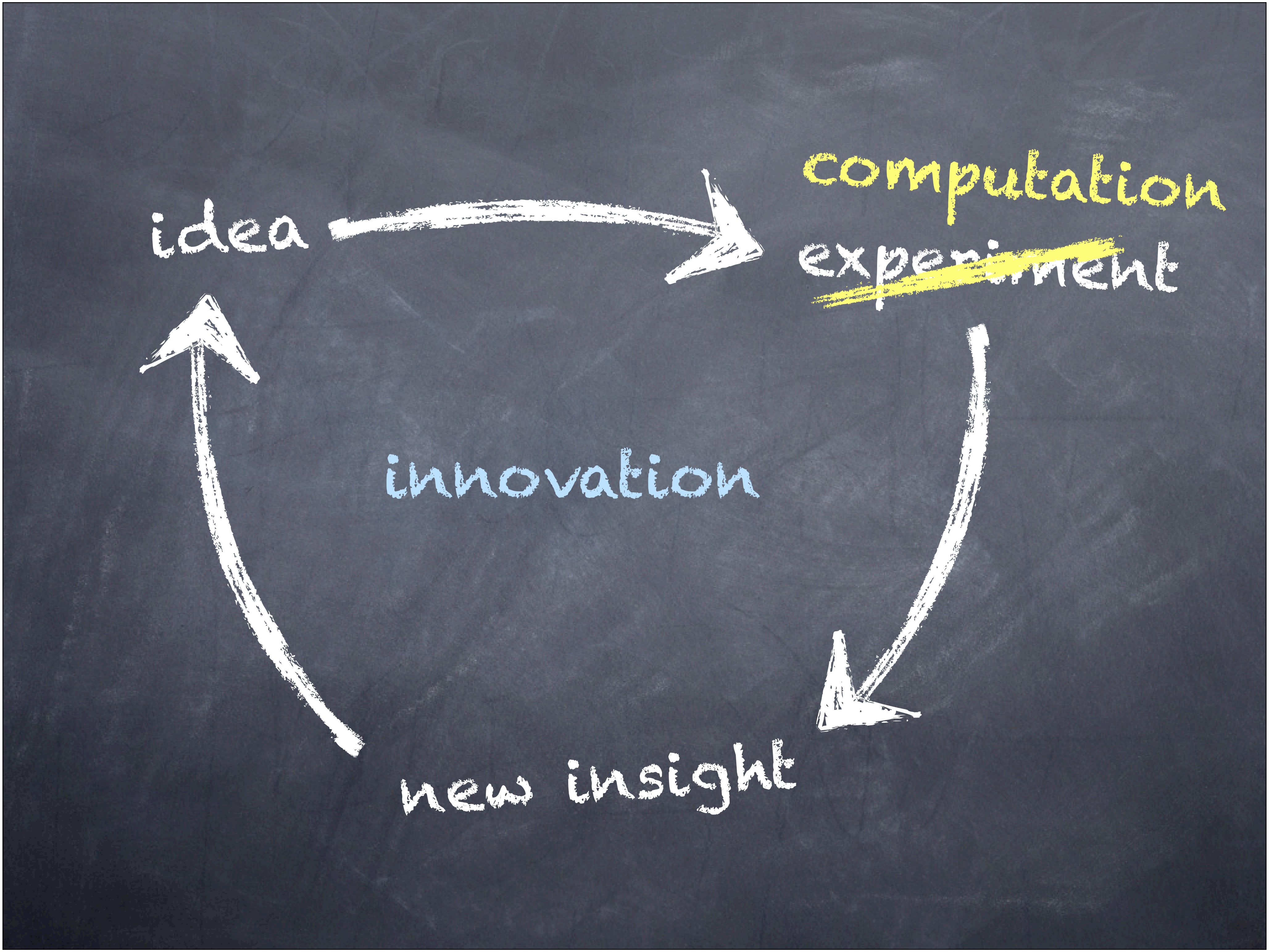


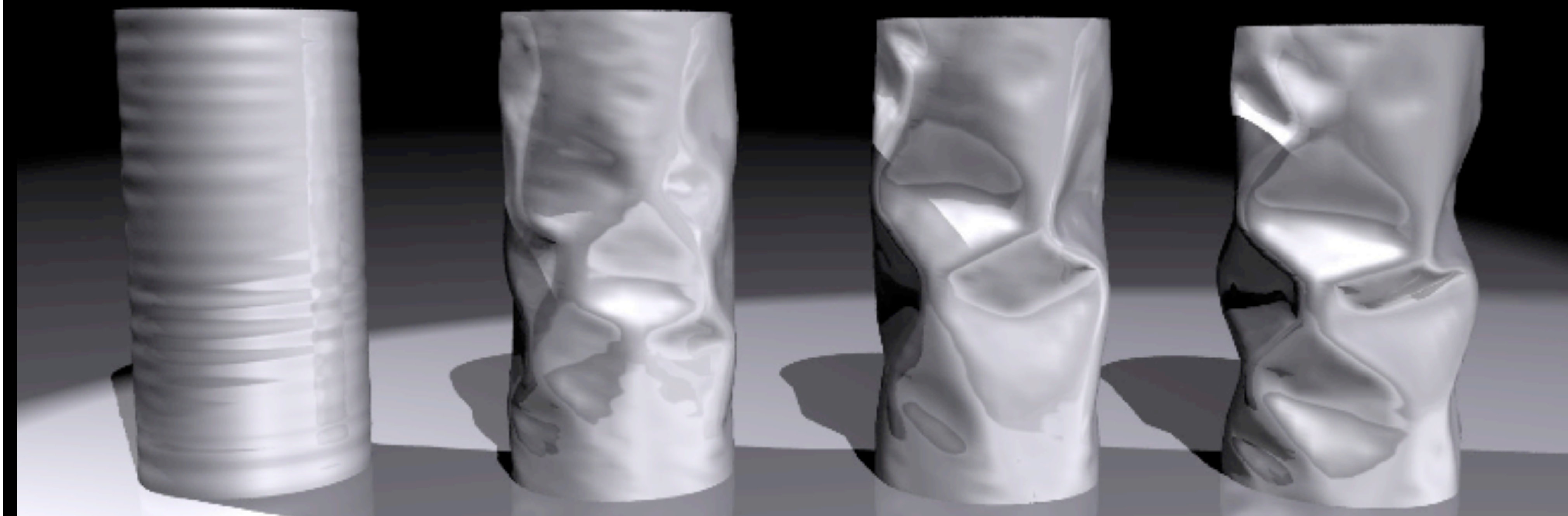
Twist-Free Frame

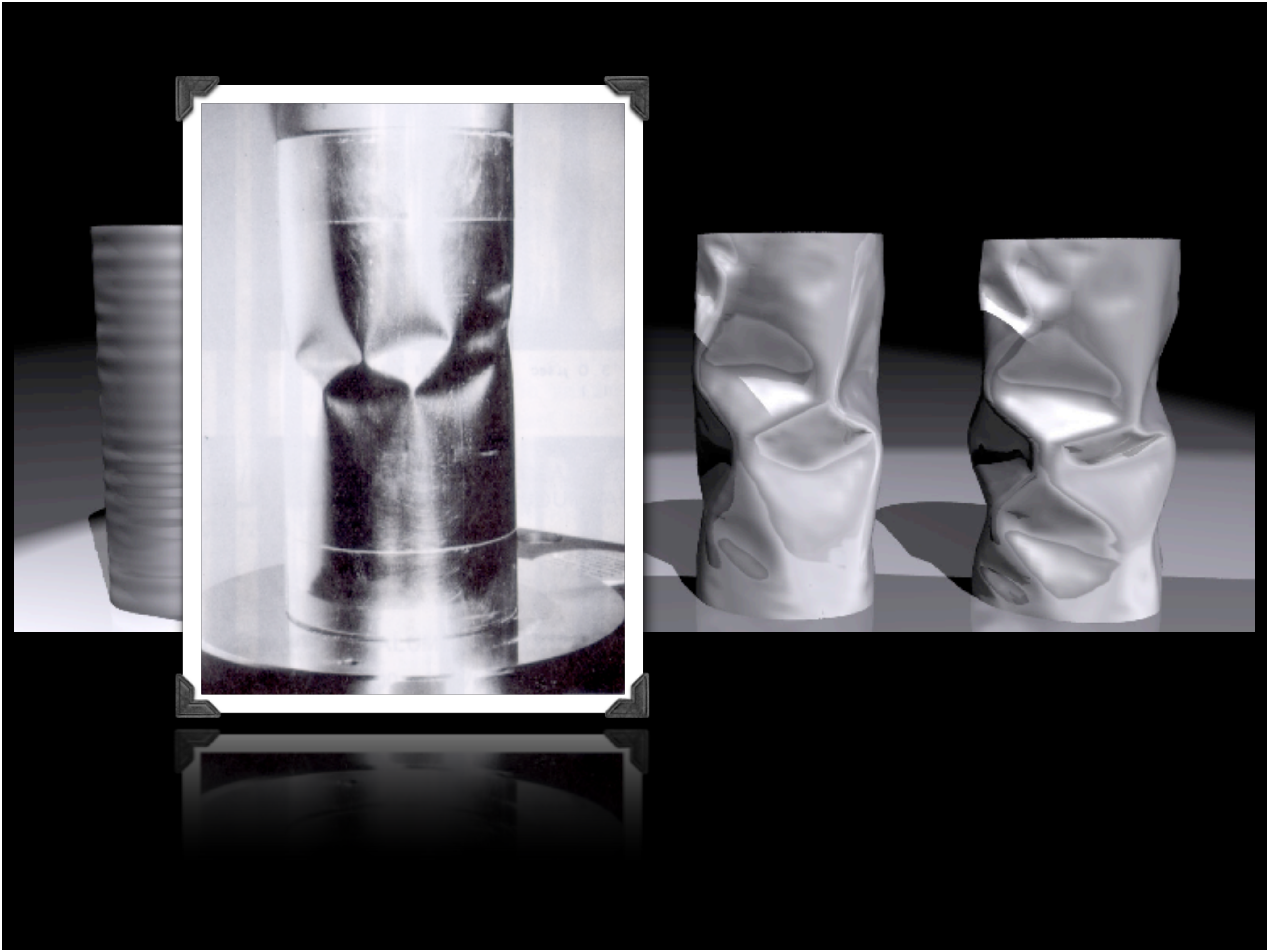



ADOBE PHOTOSHOP CS3 EXTENDED
ADOBE PHOTOSHOP CS3 EXTENDED
Adobe
ADOBE
ADOBE ILLUSTRAOTR CS3
Adobe

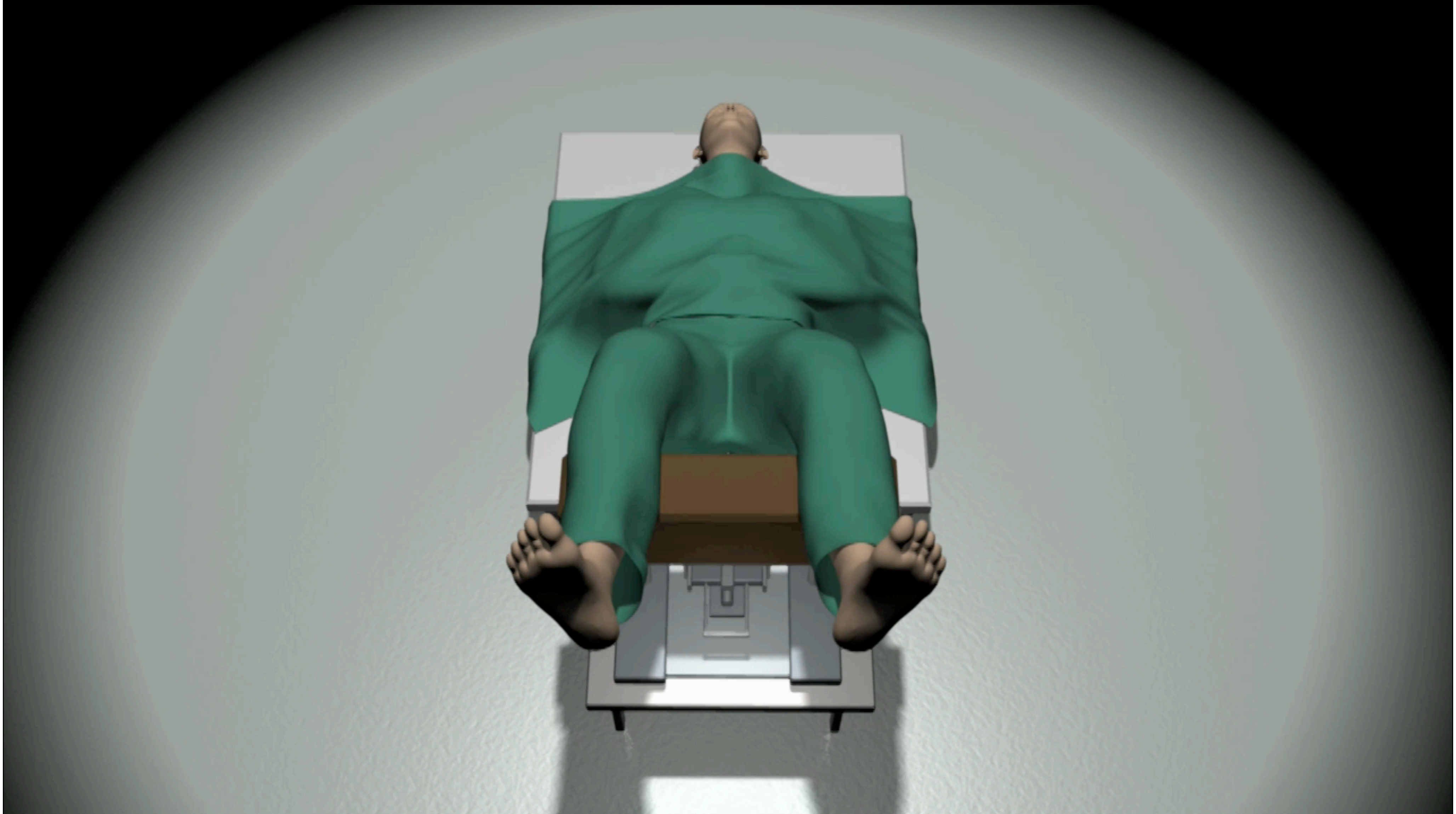
is there life beyond hollywood?

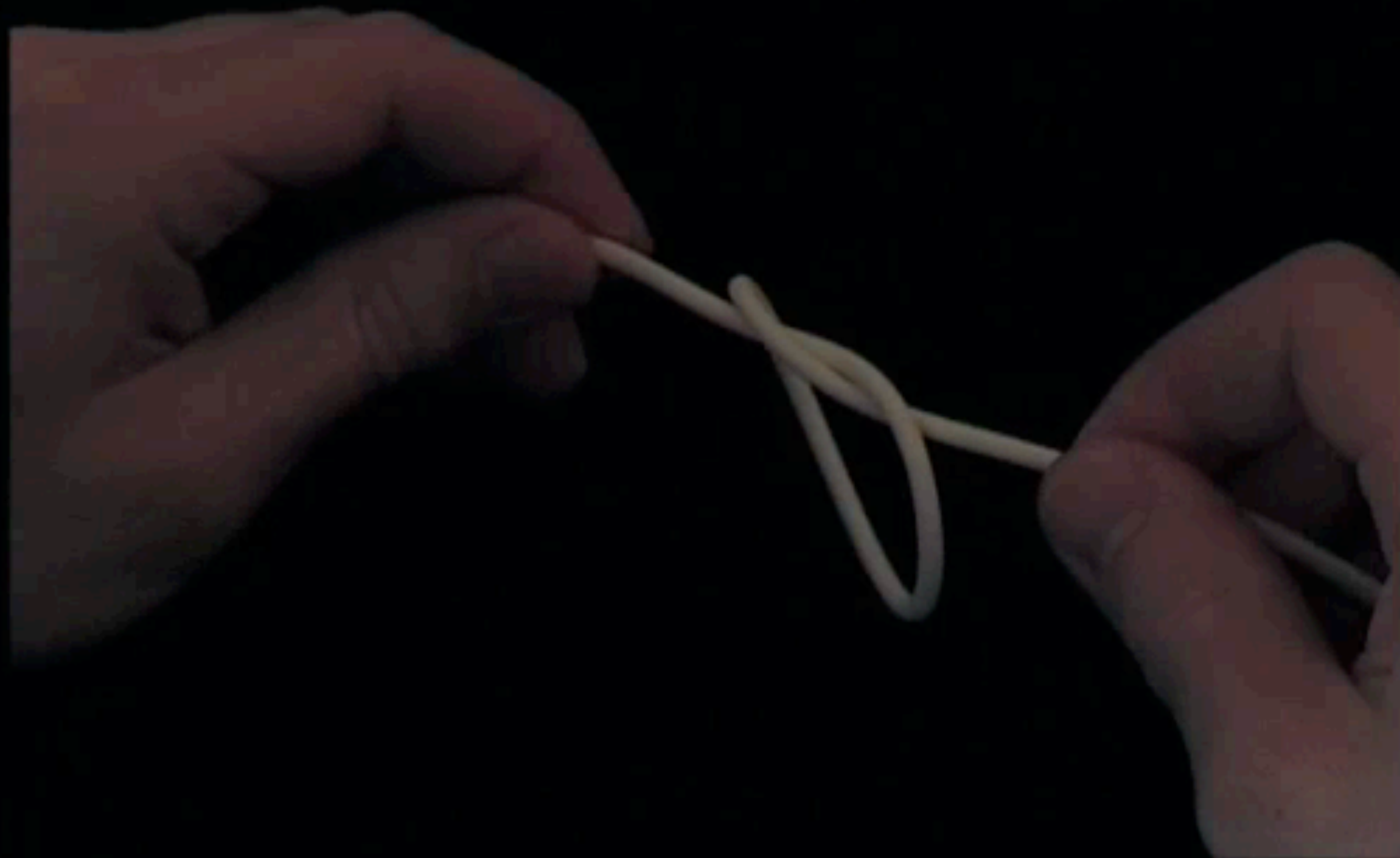

idea
computation
experiment
innovation
new insight





U. C. Berkeley, U. N. C. Chapel Hill, & Johns Hopkins University
using "Discrete Elastic Rods"

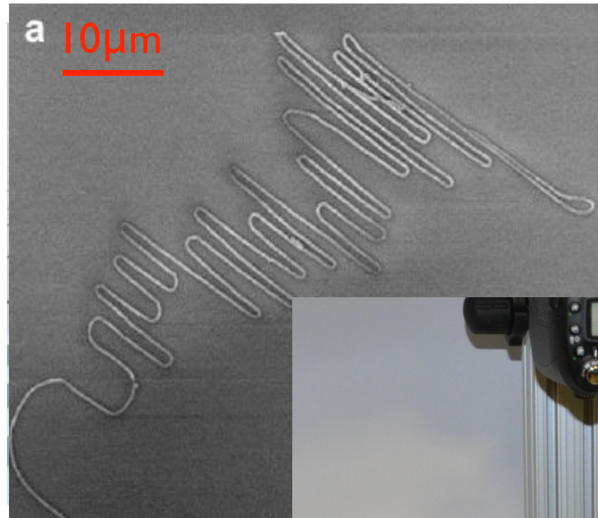




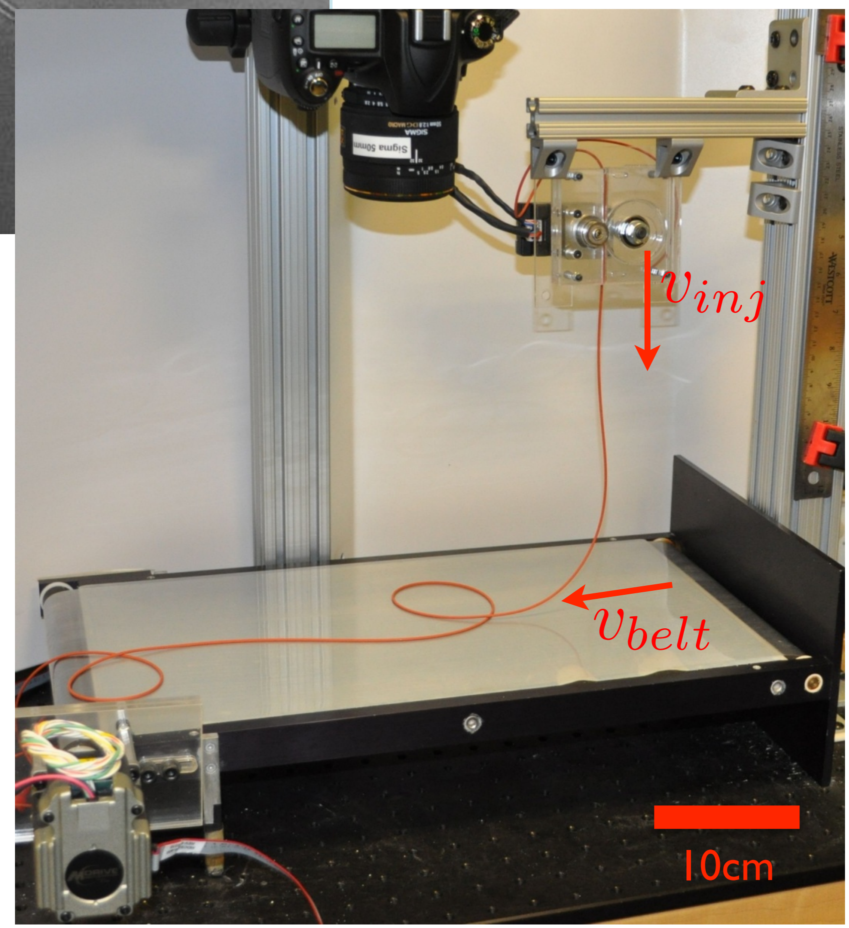
Basile Audoly, University Paris Marie et Pierre Curie

Coiling Spaghetti: thin elastic rods on a moving substrate

Laying down of cable/pipeline in the ocean bed



Coiling of nanotubes
[Geblinger *Nature Nanotech* 2008]

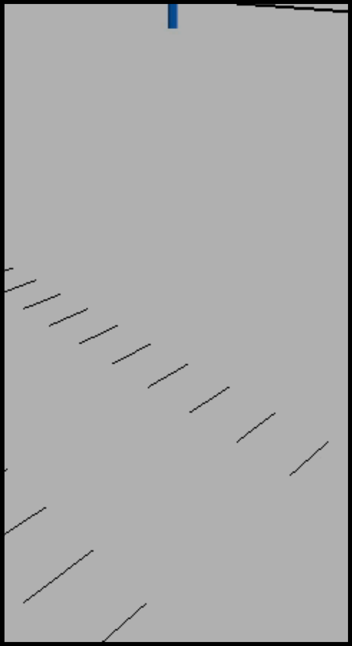


macroscopic experiments
Pedro Reis (MIT)

Coiling onto a Static Substrate

with Pedro Reis
(MIT)

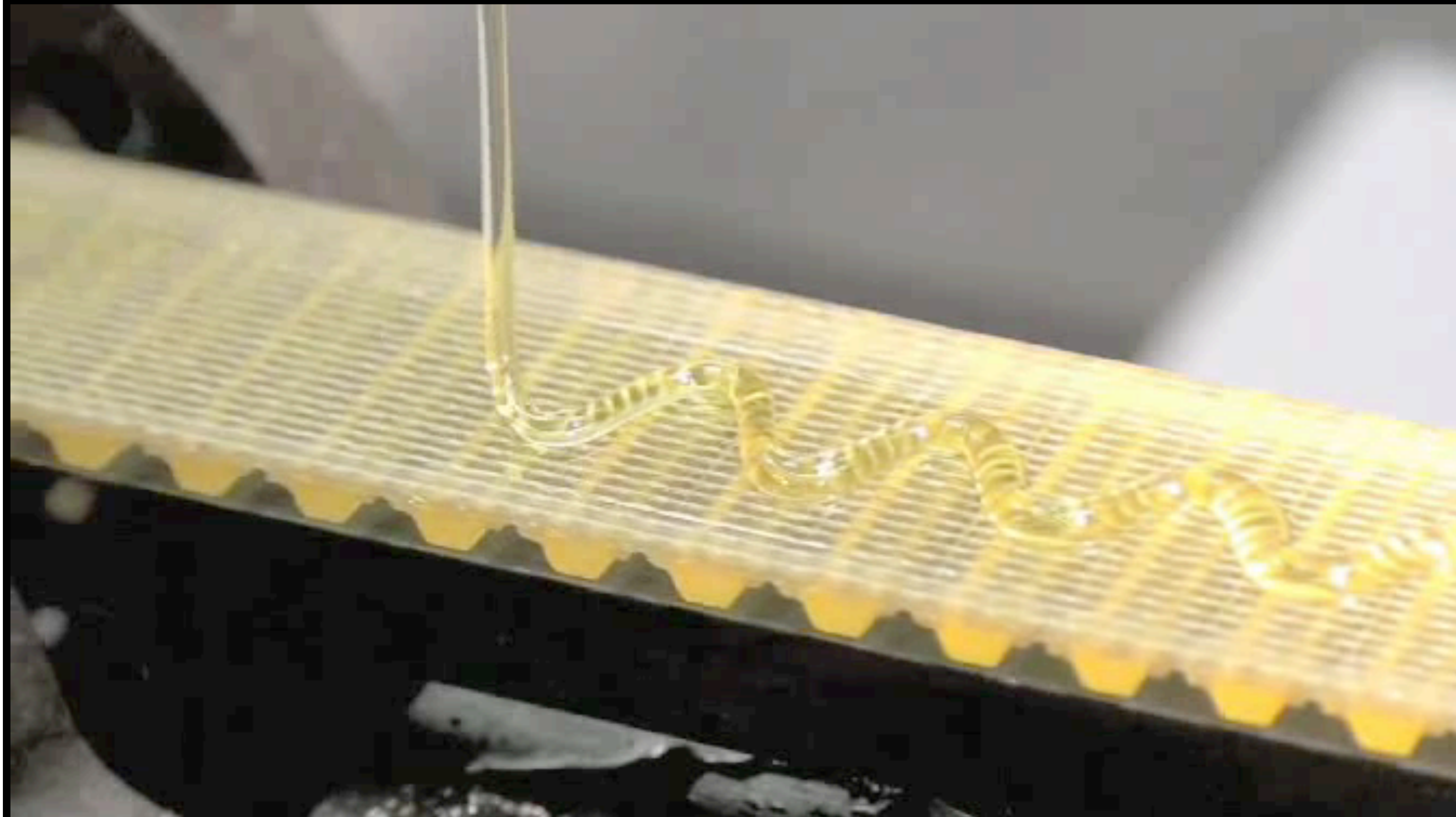
$V_{inj} = 5cm/s$
$H = 30cm$
$2mm$ silicon



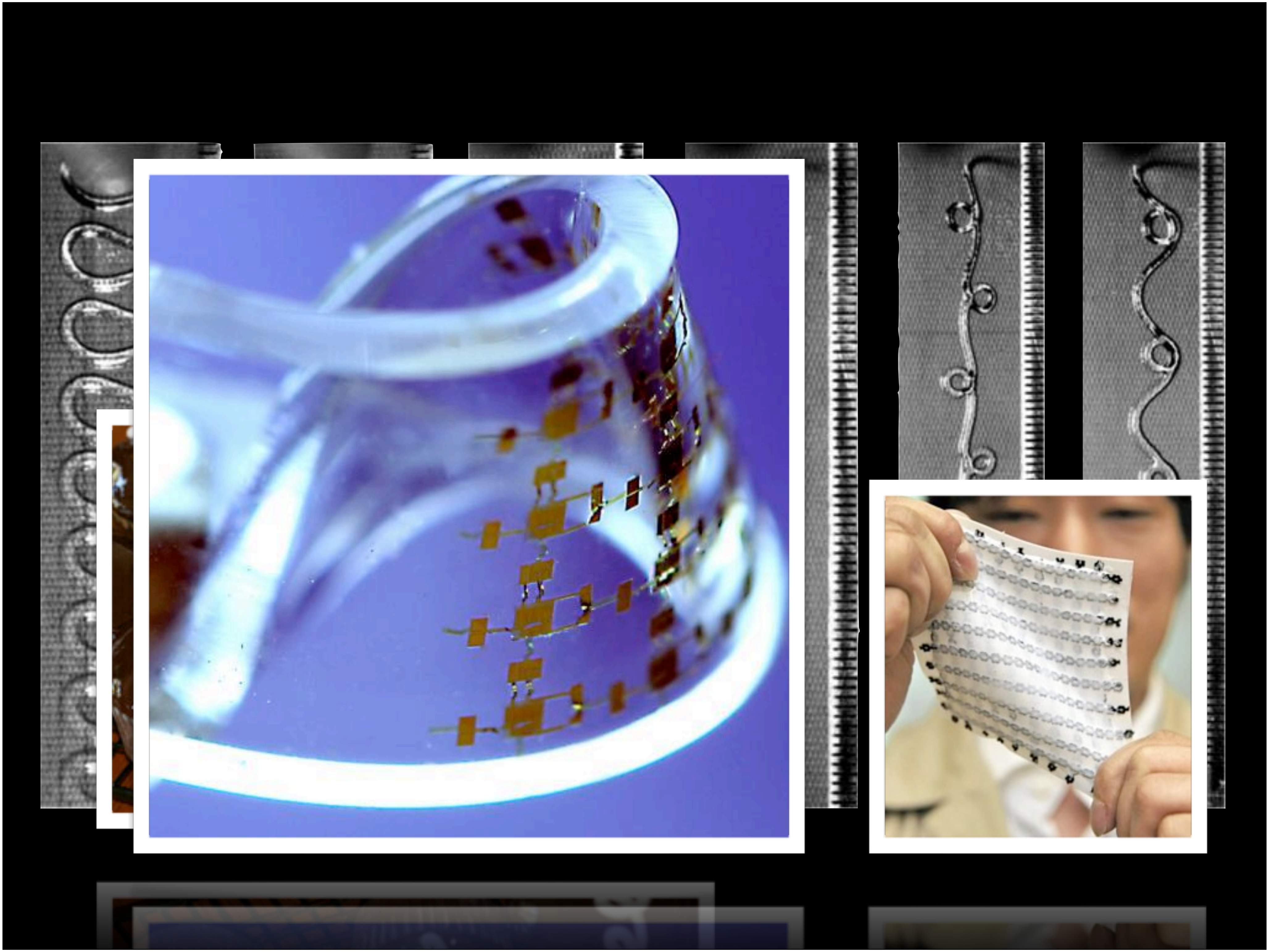
Numerical Simulations

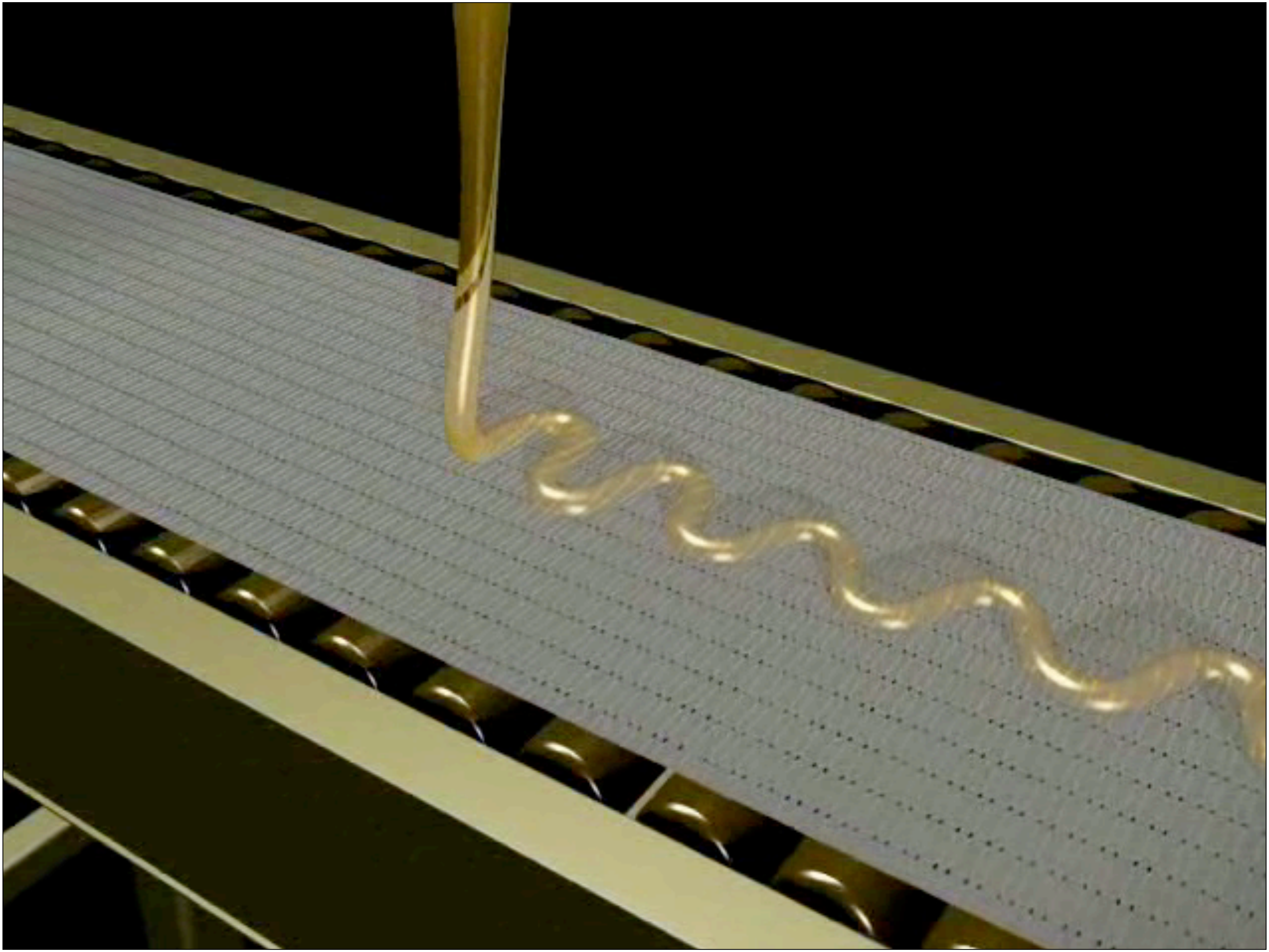

Breakout flowing into old skylight, Royal Gardens
USGS


gettyimages
.040kx
250µ

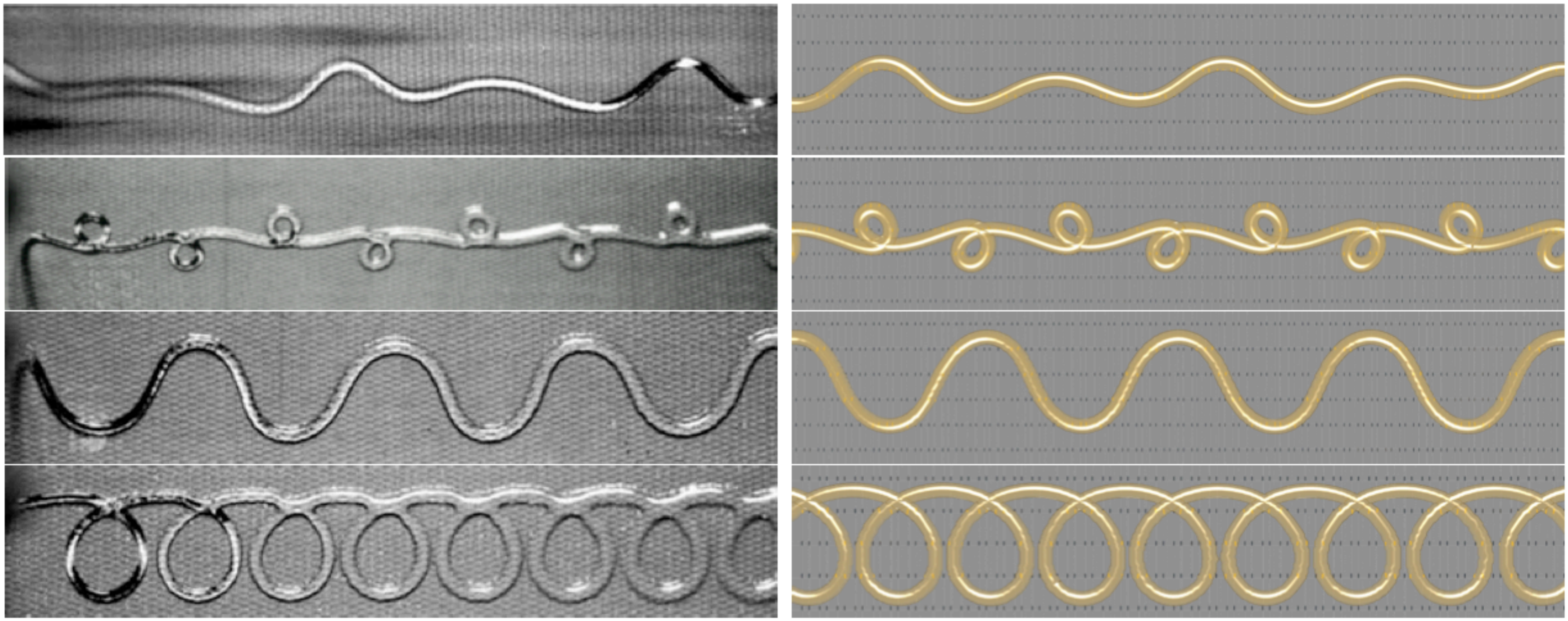


Stephen Morris (U. Toronto)

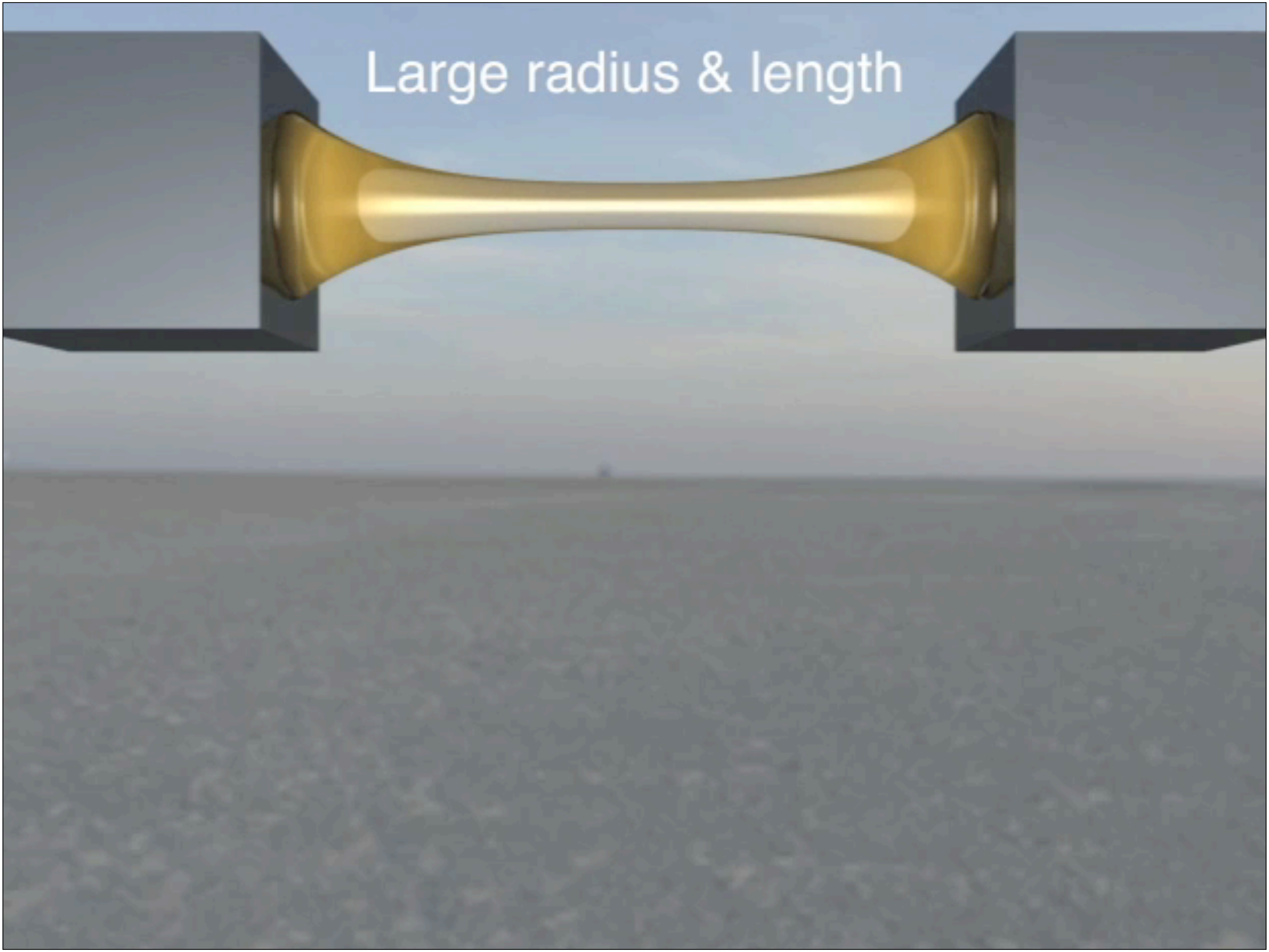




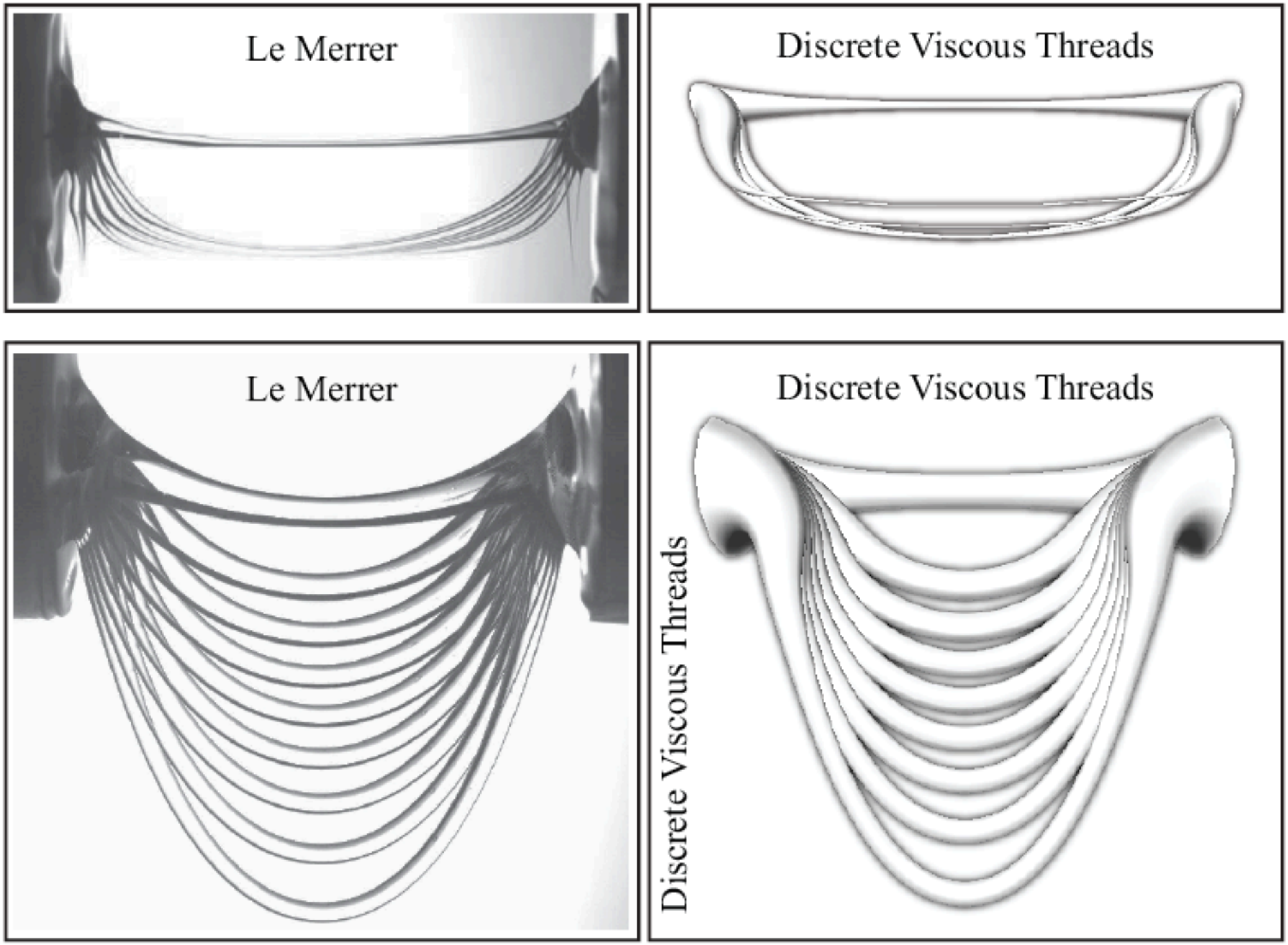
“Discrete Viscous Threads”



with Bergou, Audoly, Vouga, Wardetzky


Large radius & length

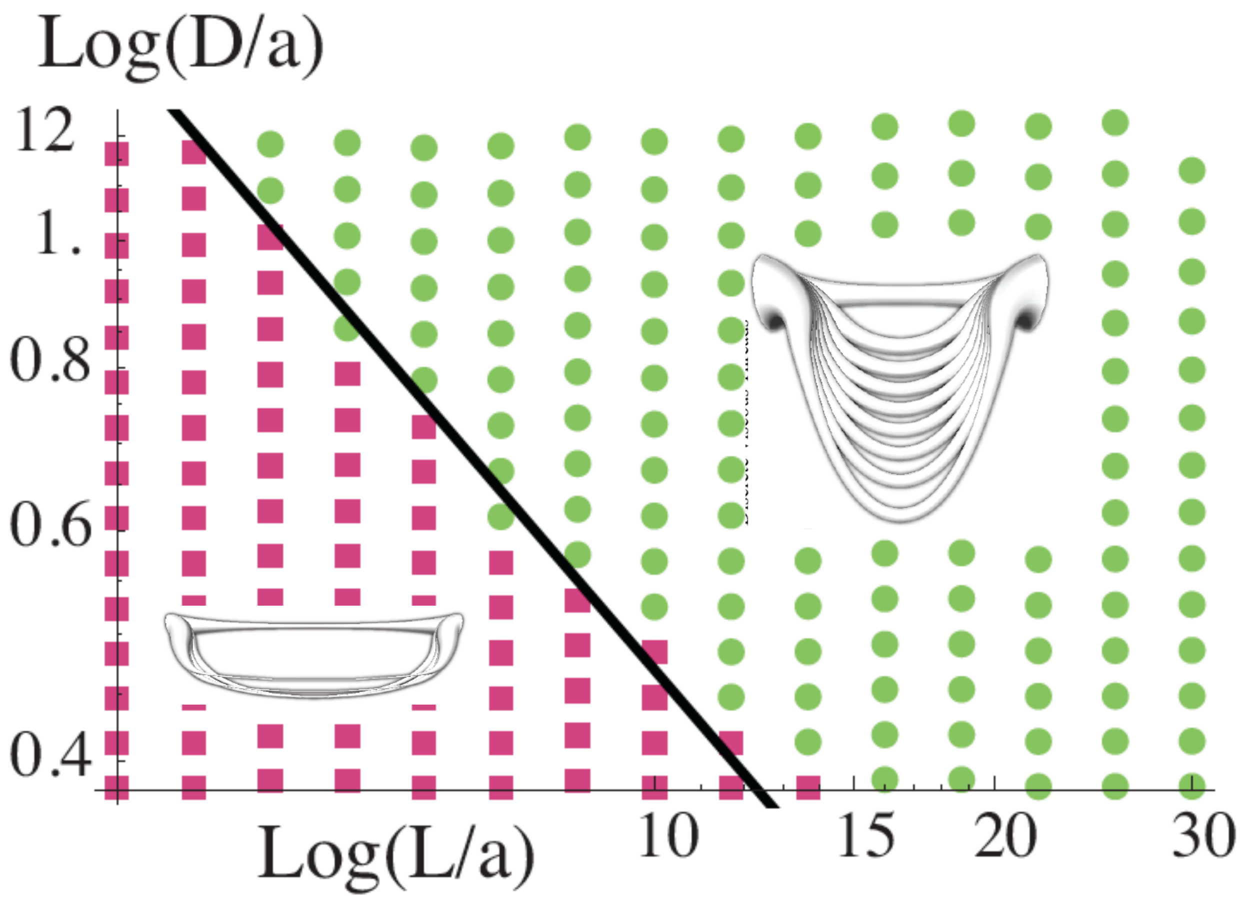
surface tension



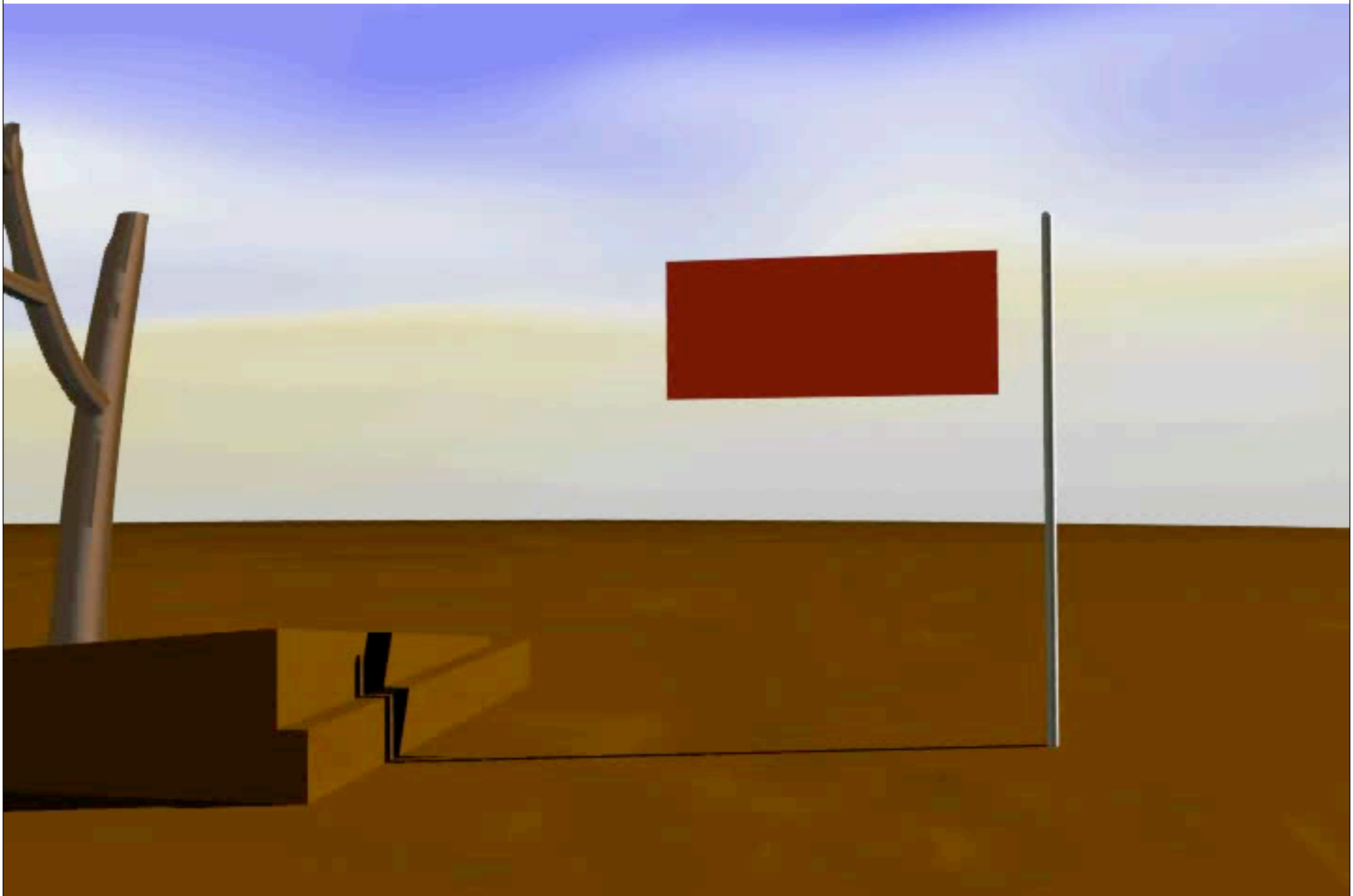
gravity

Gravity vs. Surface Tension

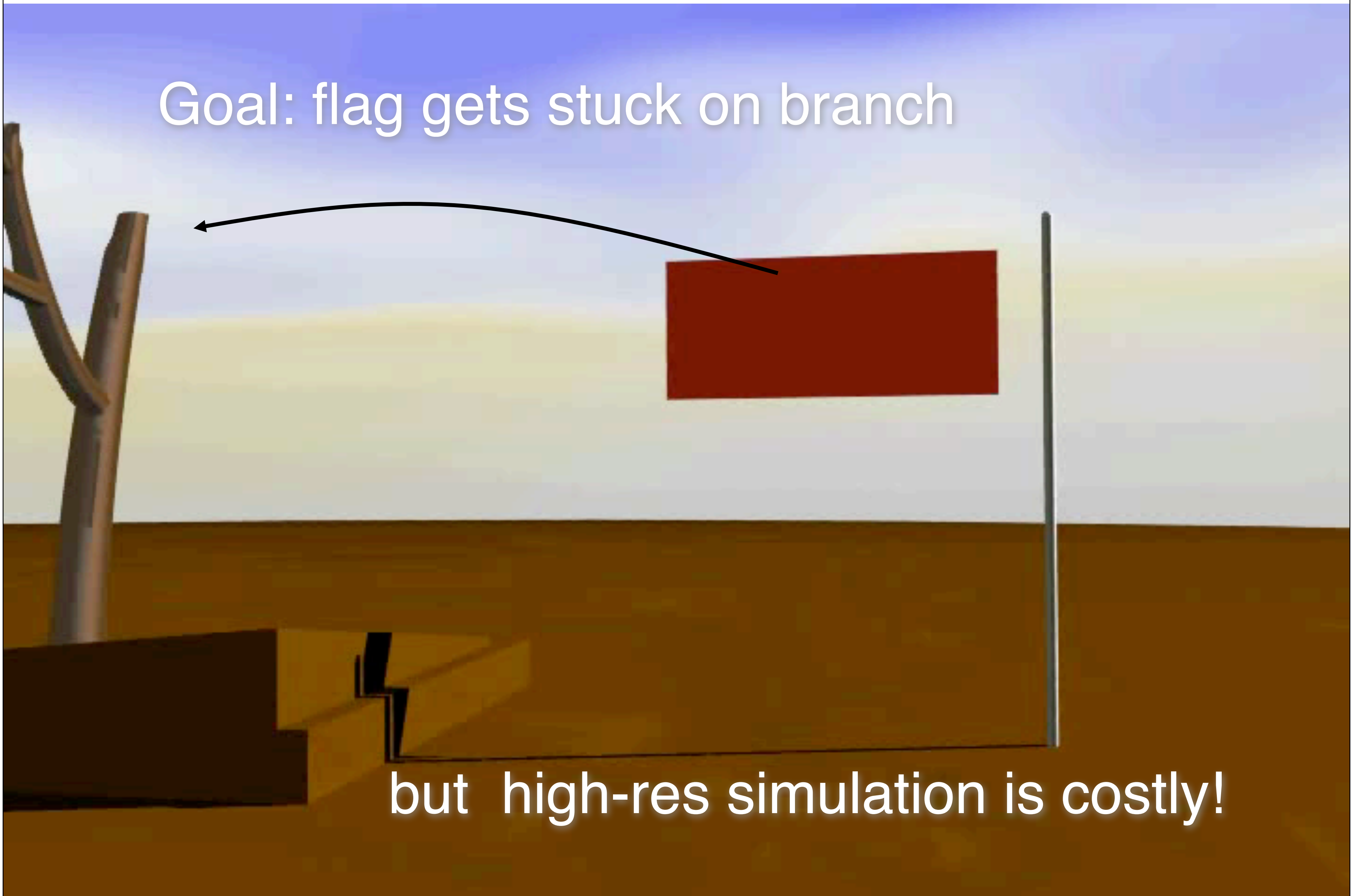
A thread forms either a catenary (green circle) or U (purple square) as it falls, depending on its length L and diameter D. The boundary fits the law LD = 4.7 a², where a is the capillary length (determined by fitting to the data), in accordance with theory of Le Merrer et al. [2008].



with Bergou, Audoly, Vouga, Wardetzky



“TRACKS,” Miklos Bergou, with S. Mathur and M. Wardetzky



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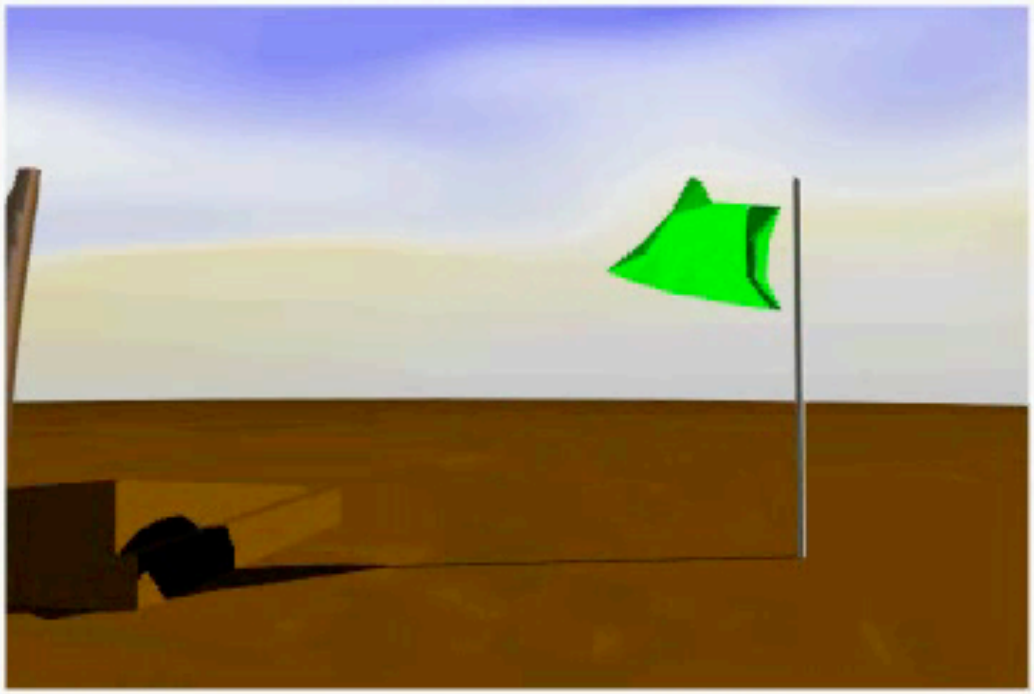
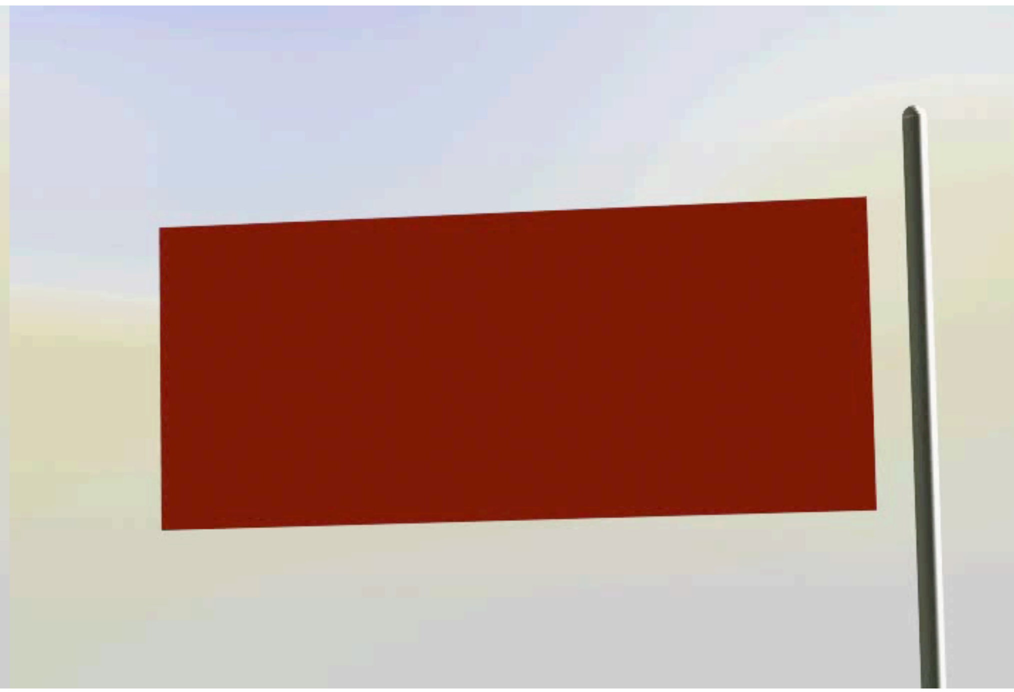


“TRACKS,” Miklos Bergou, with S. Mathur and M. Wardetzky

TRACKS

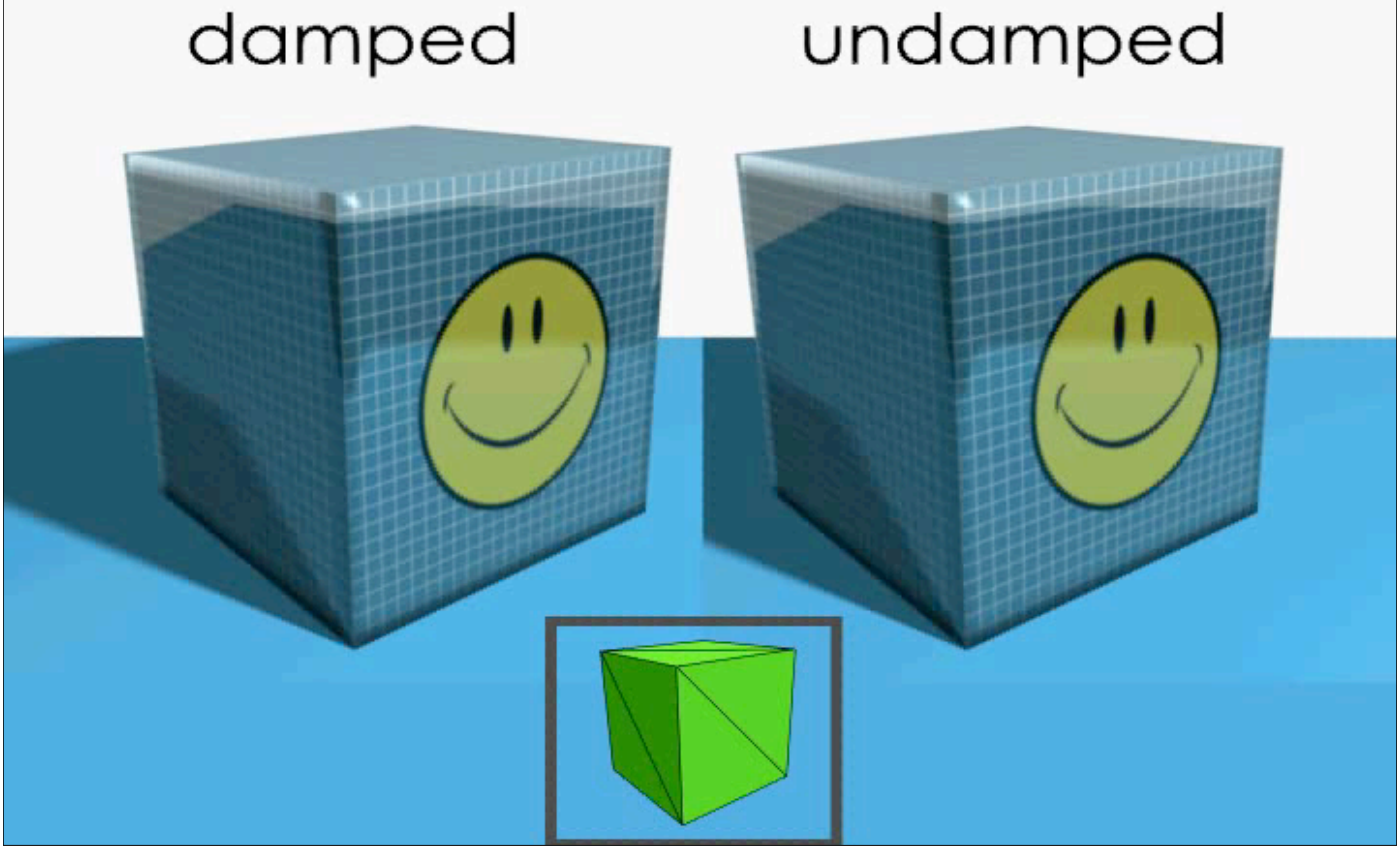
- Guarantee output matches the input

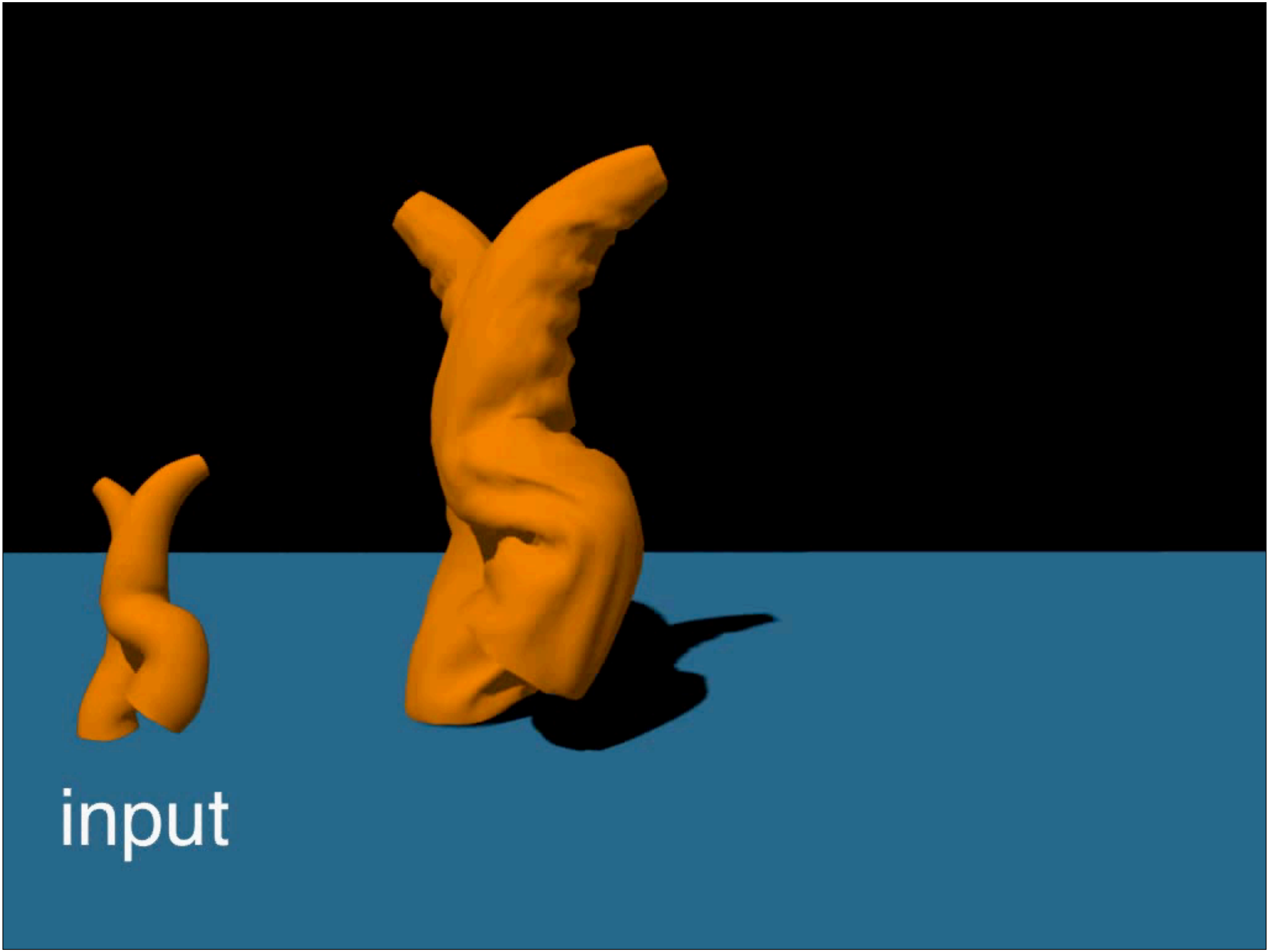
input



output

Expressive materials




input

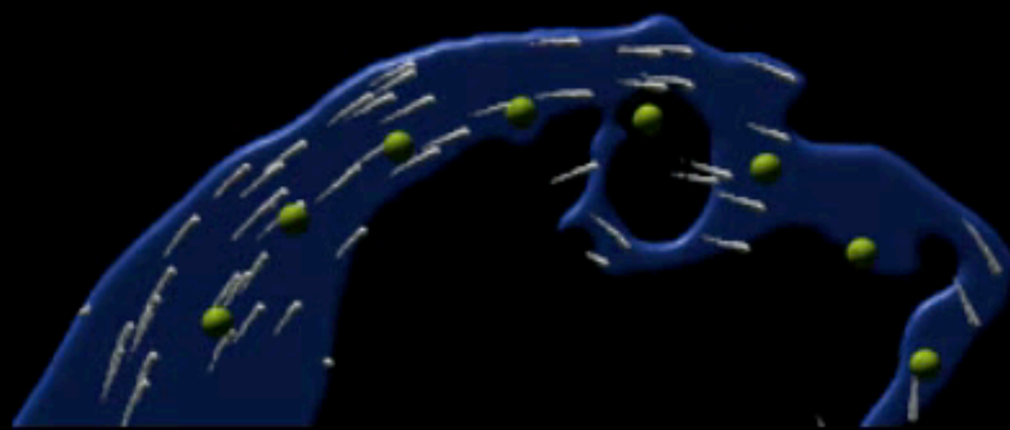
“Stable Fluids,” Jos Stam, Autodesk

“Stable Fluids,” Jos Stam, Autodesk

Control of Smoke

Adrien Treuille, Antoine McNamara, Zoran Popović, Jos Stam

Detail-Preserving Fluid Control



Instructional 2D-Example:

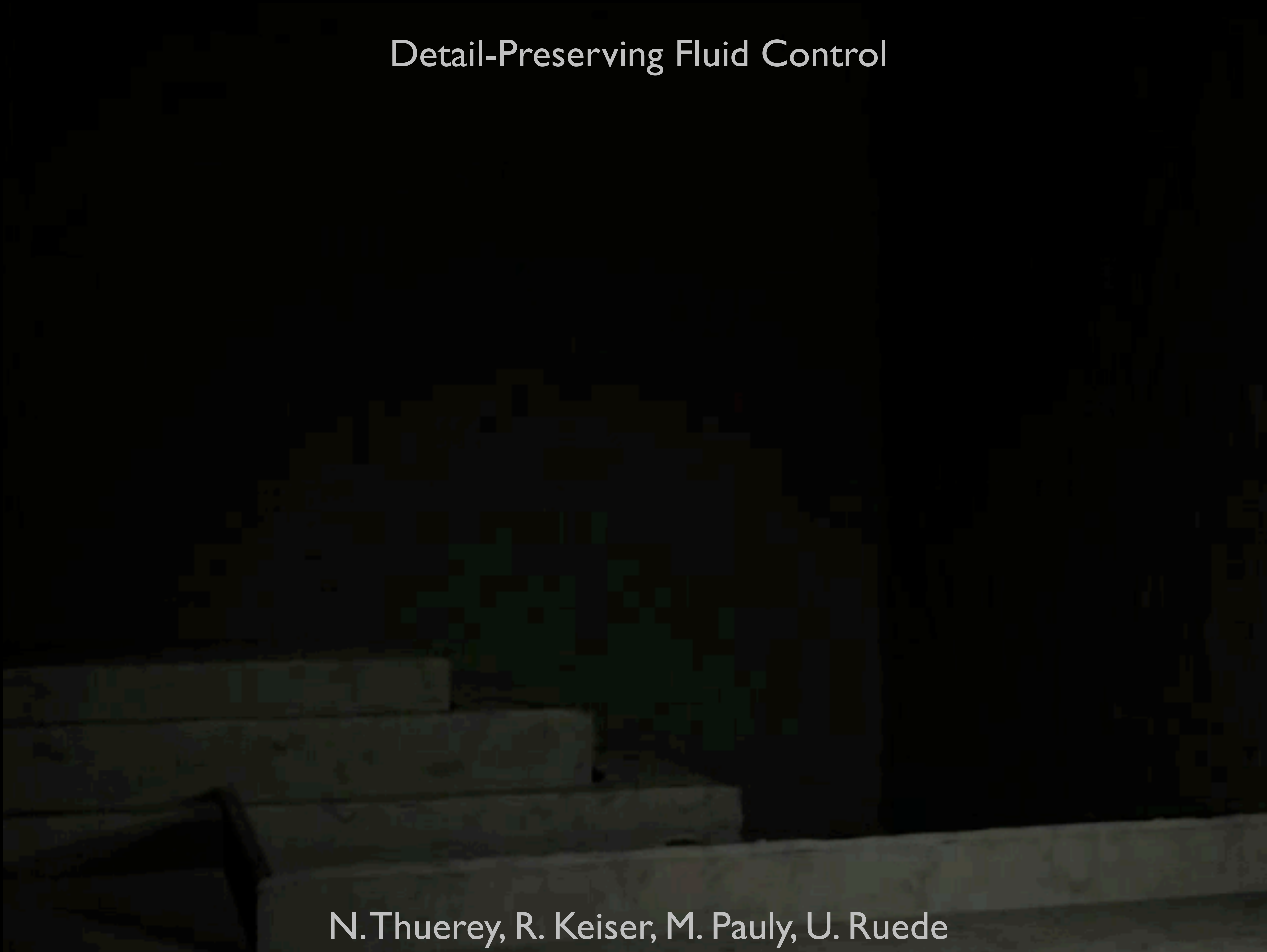
Comparison of Velocity Influence

Resolution: 128^2

Controlparticles: 10

N. Thuerey, R. Keiser, M. Pauly, U. Ruede

Detail-Preserving Fluid Control



N. Thuerey, R. Keiser, M. Pauly, U. Ruede


to
allowed
Inspect
via this entrance)


Discrete Shells
Abstract
1 Introduction
CALIFORNIA INSTITUTE OF TECHNOLOGY
1891
THANK YOU