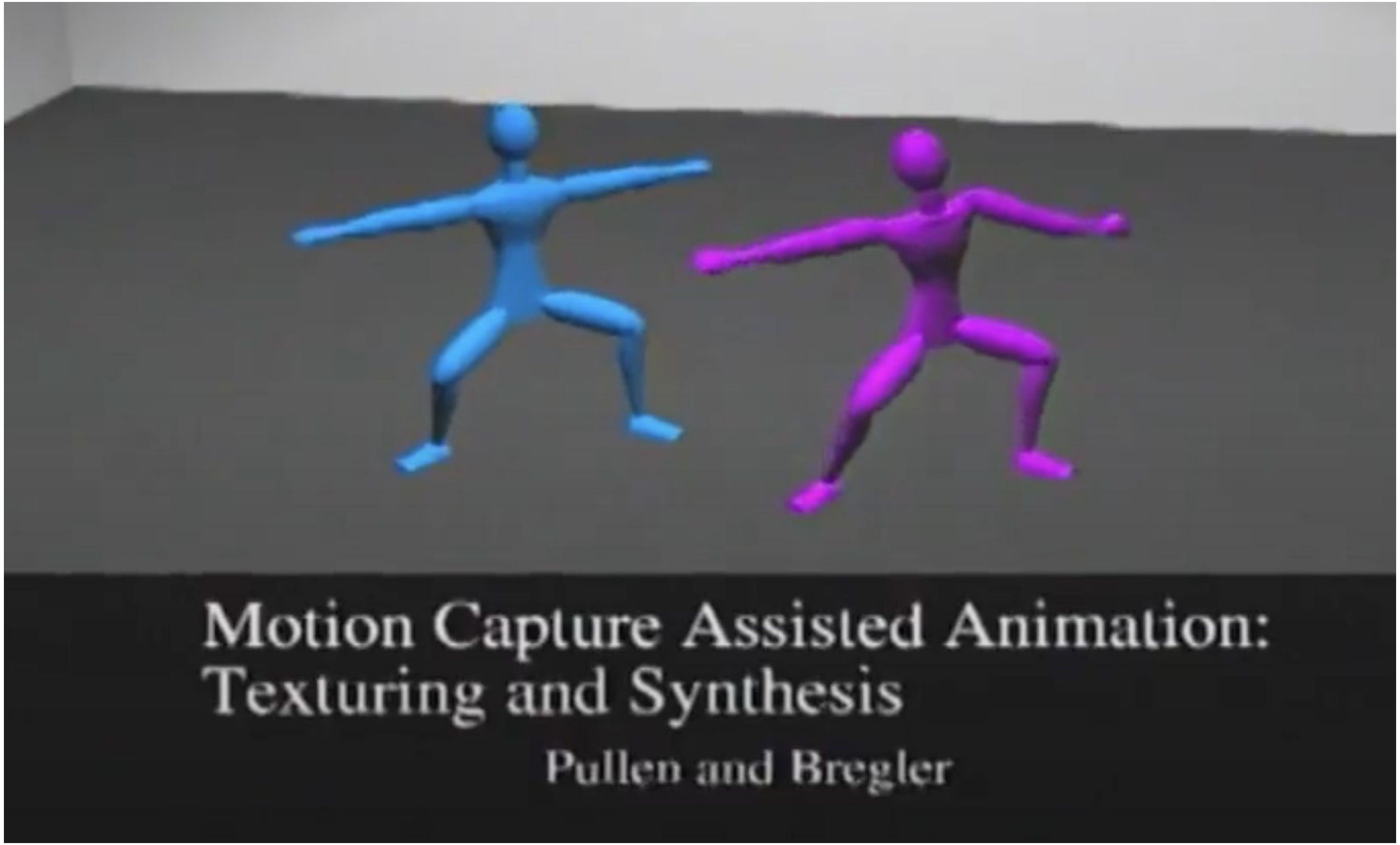
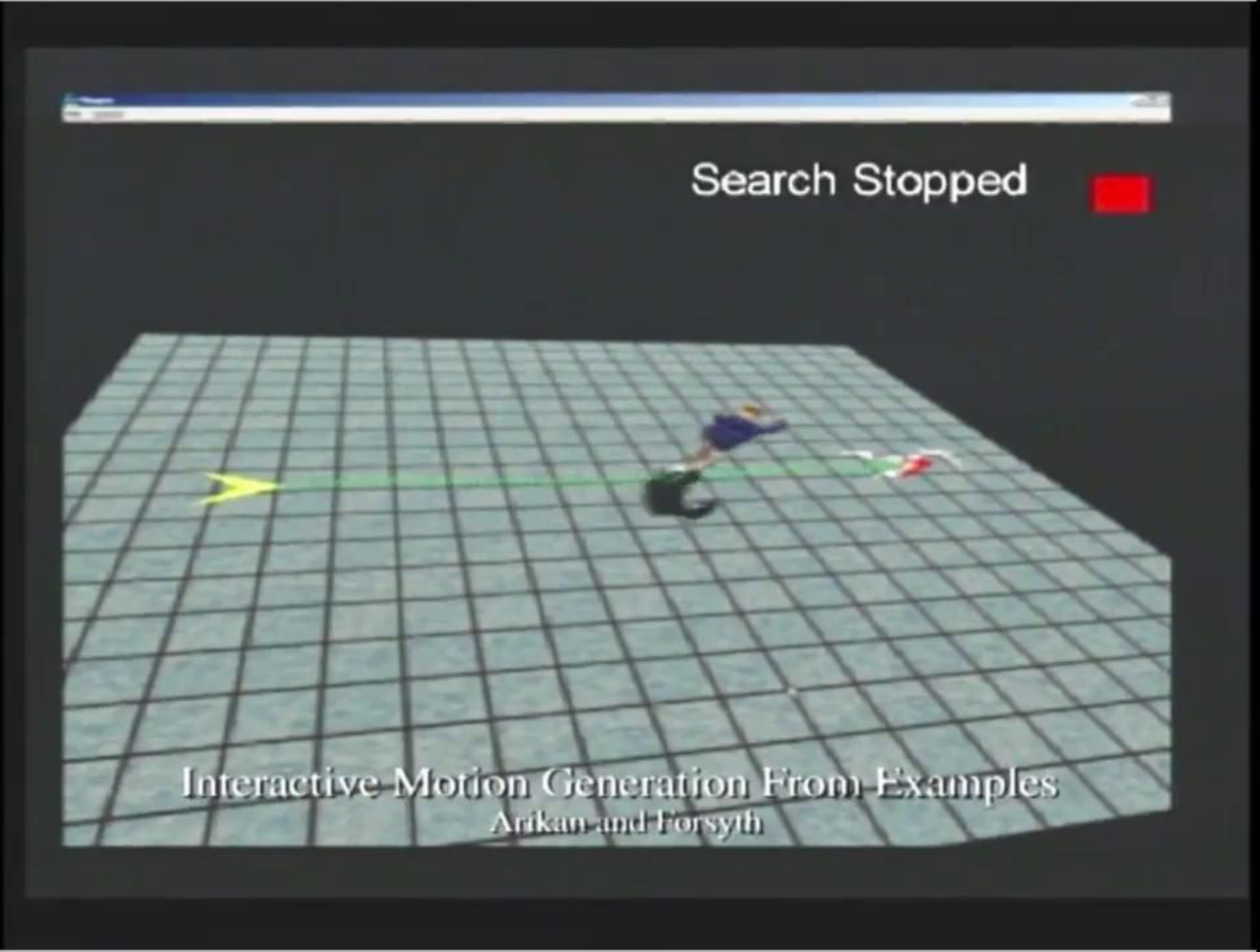
CSCI 4530/6530 Advanced Computer Graphics

https://www.cs.rpi.edu/~cutler/classes/advancedgraphics/S25/

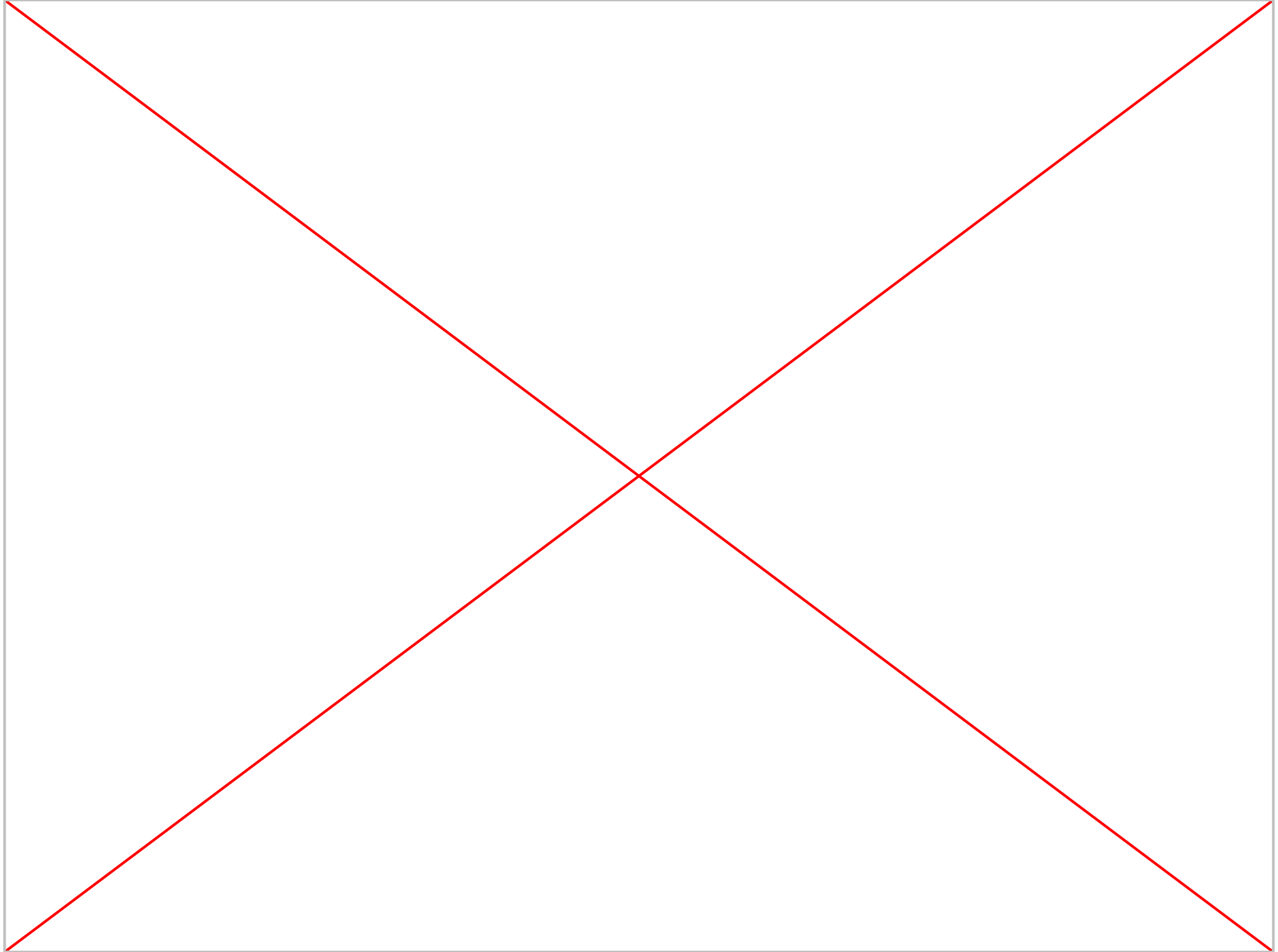
Lecture 10: Animation, Motion Capture, & Inverse Kinematics

SIGGRAPH 2002 Mocap Papers



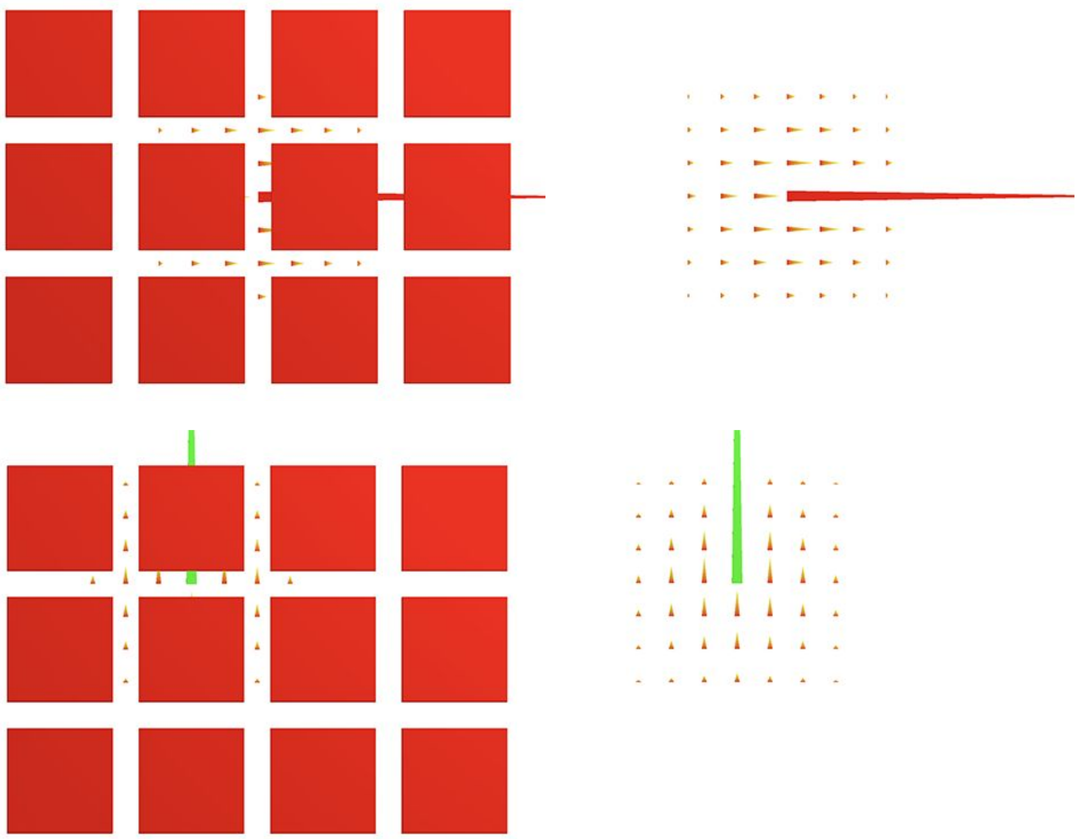

Search Stopped
Interactive Motion Generation From Examples
Arikan and Forsyth

Spacetime Swing - Siggraph 1998



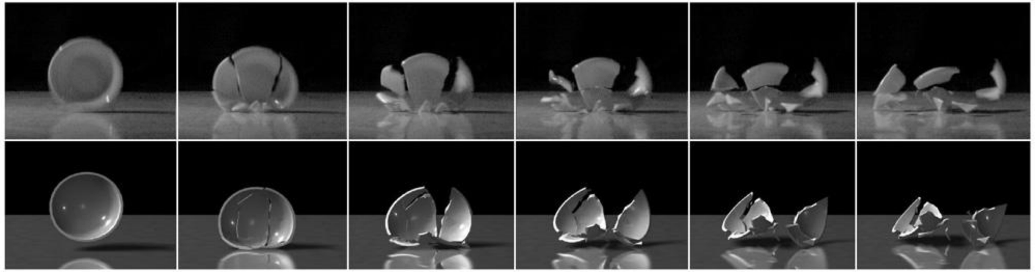
HW2 Velocity Interpolation Debugging

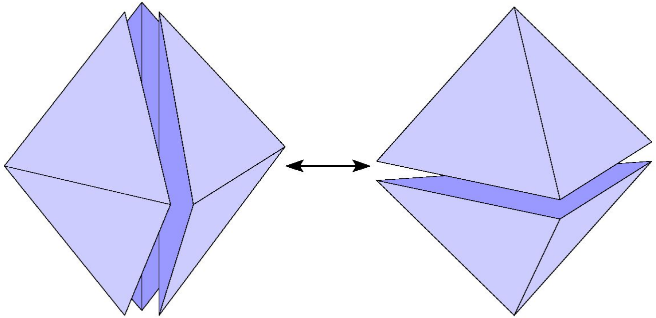
```
grid 6 4 1
cell_dimensions 1 1 1
timestep 0.01

flow compressible
xy_boundary free_slip
yz_boundary free_slip
zx_boundary free_slip
viscosity 0.1
gravity 0

initial_particles everywhere random
density 64

initial_velocity zero

u 1 2 0 10
```

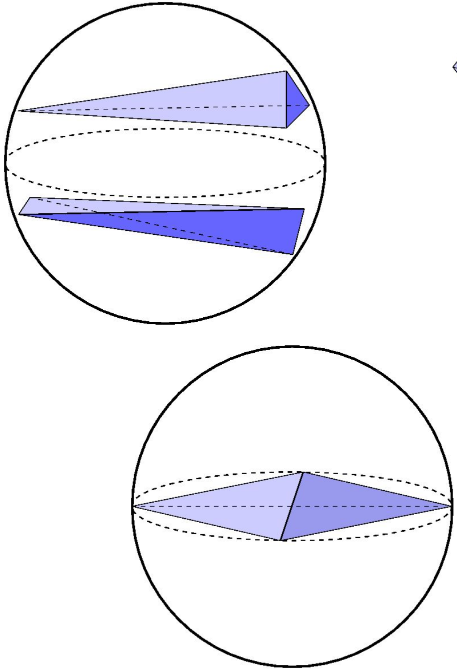


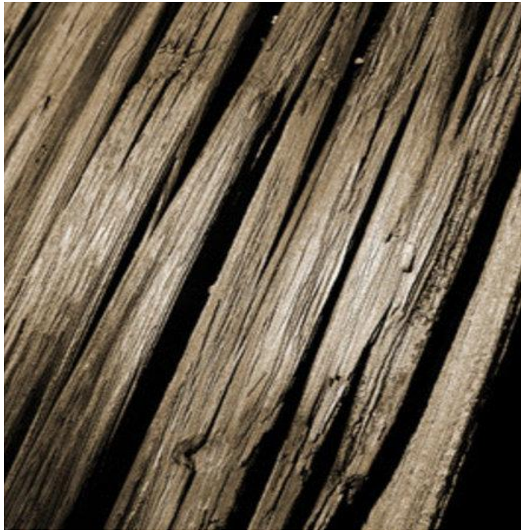
Last Time?

- Tetrahedral Meshing
- Haptics
- Anisotropic Materials
- Fracture









Today

- Finish Slides from Last Time:
    - Level of Detail
    - Useful & Related Term Definitions
    - Tetrahedral Element Quality
- How do we Animate?
    - Keyframing & Procedural Animation
    - Physically-Based Animation
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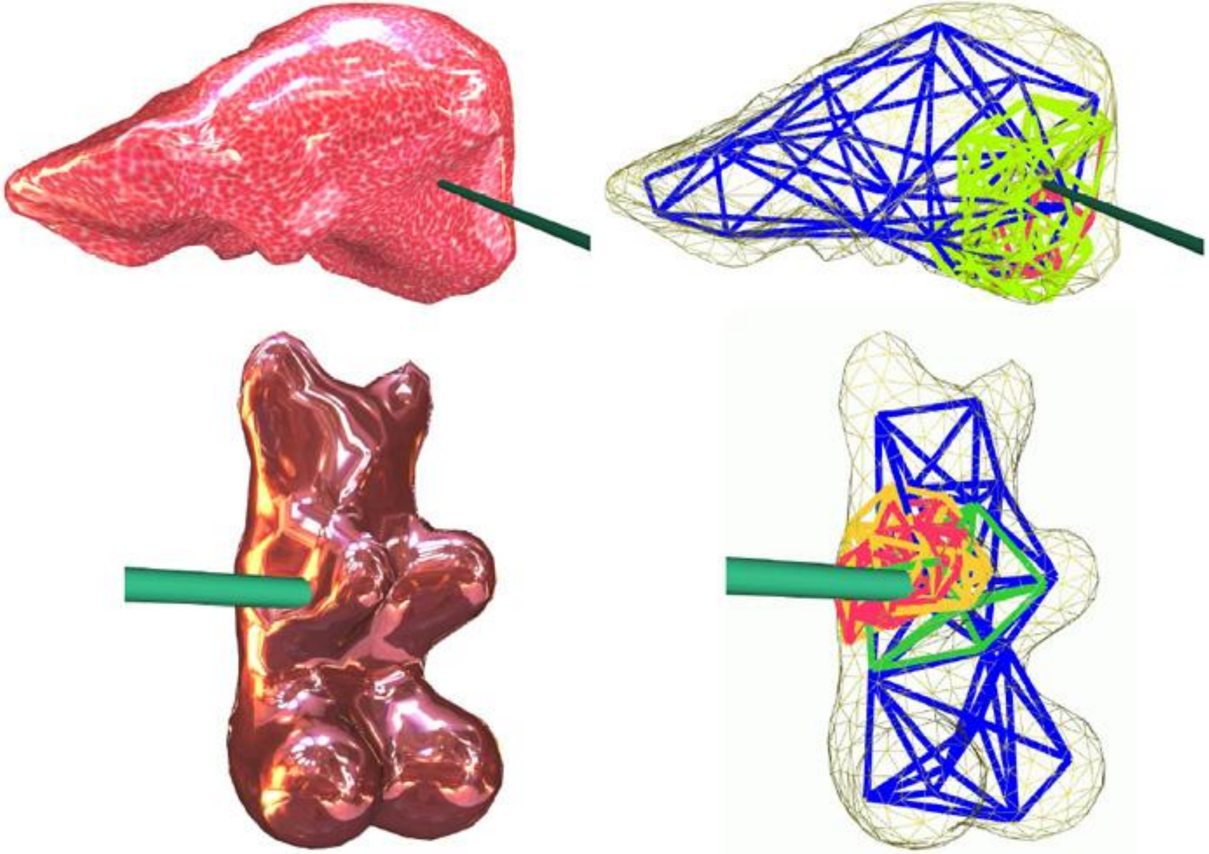
“Dynamic Real-Time Deformations using Space & Time Adaptive Sampling” Debunne, Desbrun, Cani, & Barr, SIGGRAPH 2001

- Level of Detail
- Interactive shape deformation

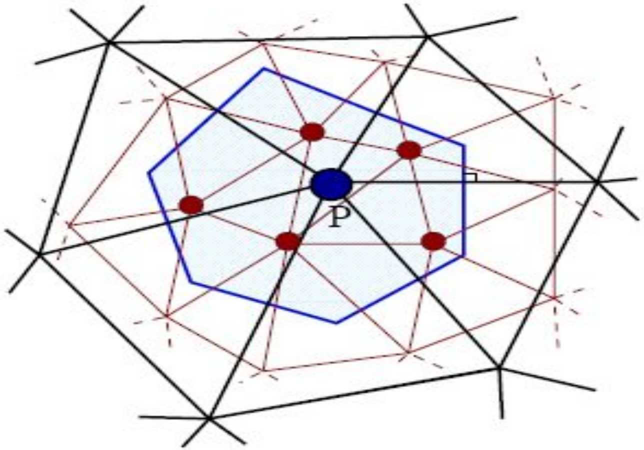
- Use high-resolution model only in areas of extreme deformation

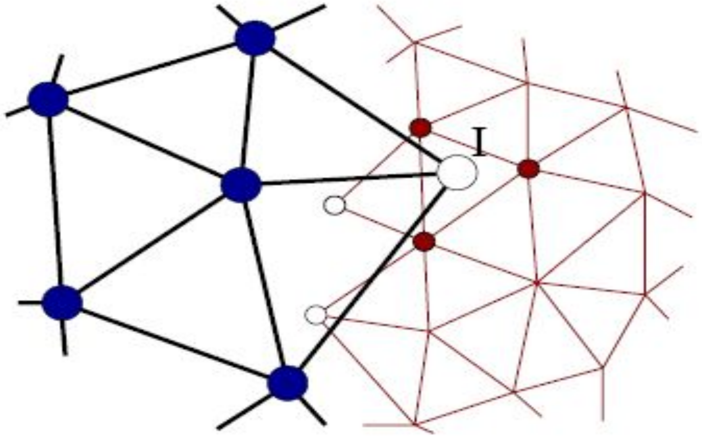


Multi-Resolution Deformation

Debunne, Desbrun, Cani, & Barr, SIGGRAPH 2001

- Use Voronoi diagrams to match parent & child vertices.
- Interpolate values for inactive interface vertices from active parent/child vertices



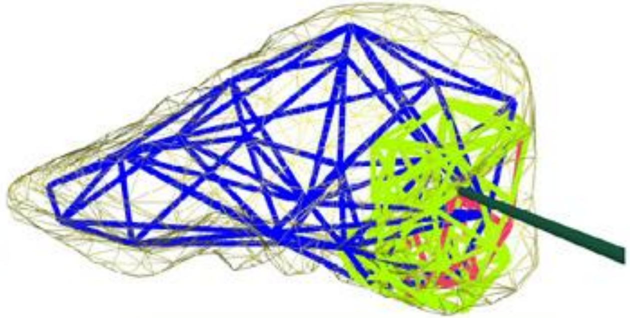


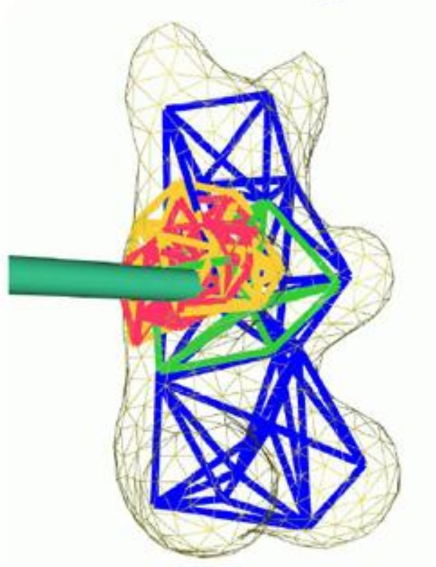
- *Need to avoid interference of vibrations between simulations at different resolutions*

Pre-Computation & Simulation

- FEM matrix pre-computed
- Level of detail coupling
  pre-computed
  for rest topology

- *Limitation: Not appropriate for applications that need to change connectivity of elements*
  E.g.:
  - *Cloth that is cut or torn*
  - *Surgery simulation*





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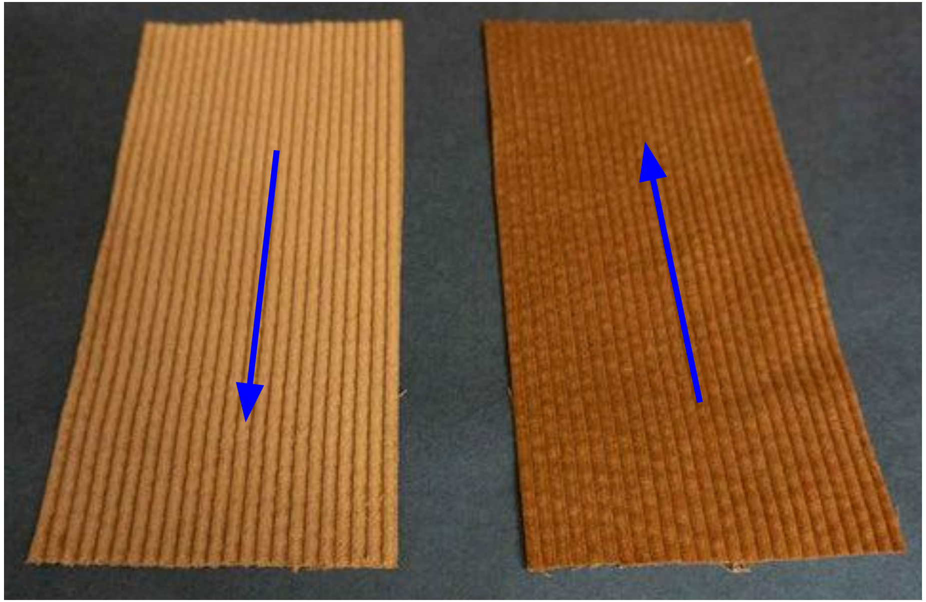
Miscellaneous Definitions

- *Isotropic*: is a property which does not depend on the direction.
- *Anisotropic*: is a property which is directionally dependent.

wood grain will impact strength & appearance

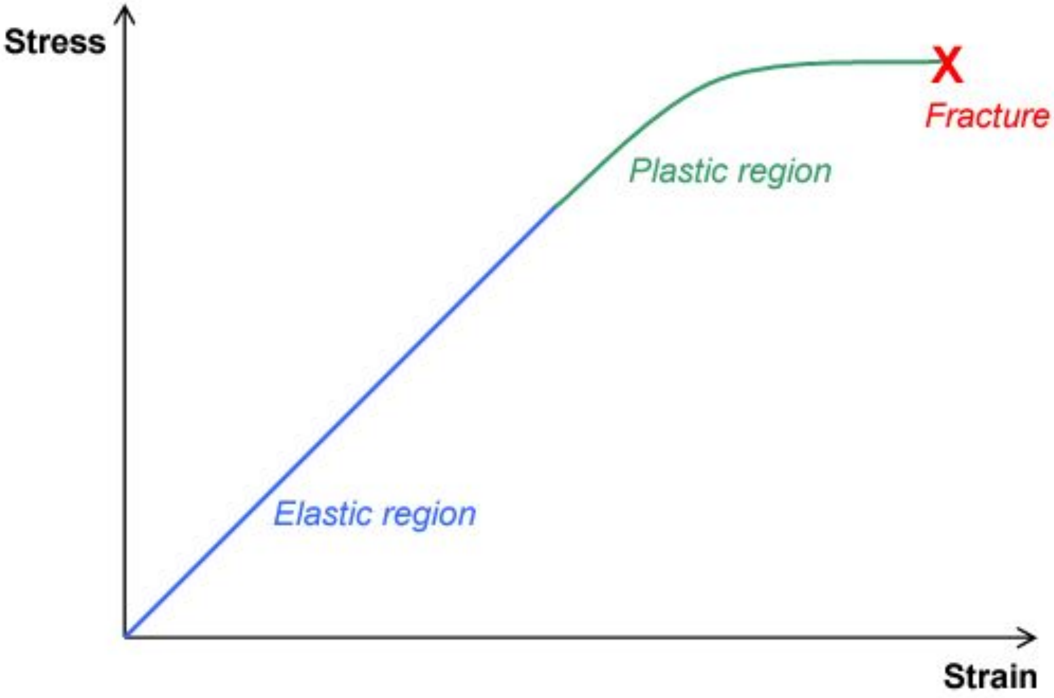


Same corduroy fabric!
Just oriented with nap rotated 180°!

https://missmaudesewing.co.nz/blogs/miss-maude-musings-1/sewing-with-corduroy-fabrics

Miscellaneous Definitions

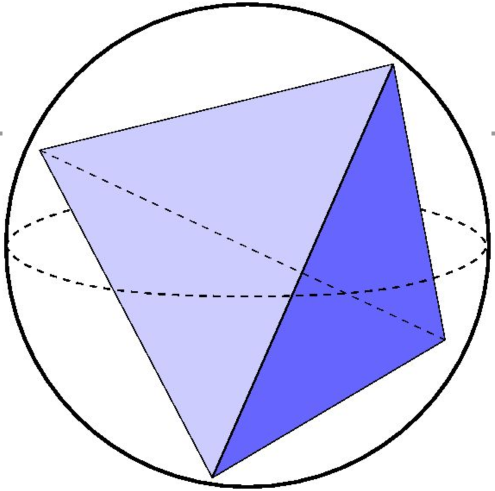
- *Elastic Deformation*: Once the forces are no longer applied, the object returns to its original shape.
- *Plastic Deformation*: An object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.

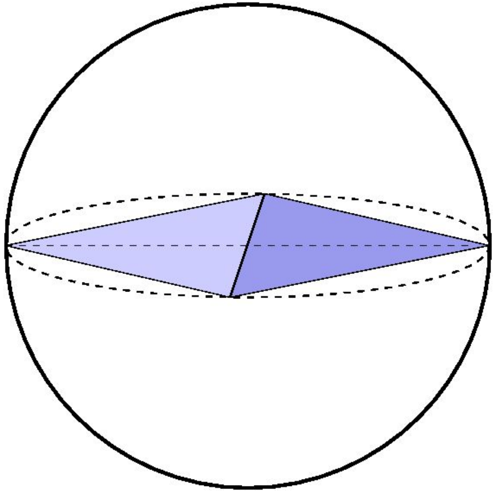


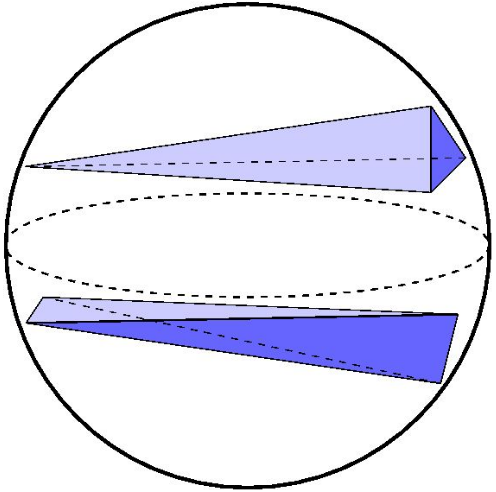
http://en.wikipedia.org/wiki/Image:Stress-strain1.png

Miscellaneous Definitions

- *Degenerate/Ill-conditioned Element*:
  a.k.a. how “equilateral” are the elements?
  - Ratio of volume^2 to surface area^3
  - Smallest *solid* angle
  - Ratio of volume to volume of smallest circumscribed sphere

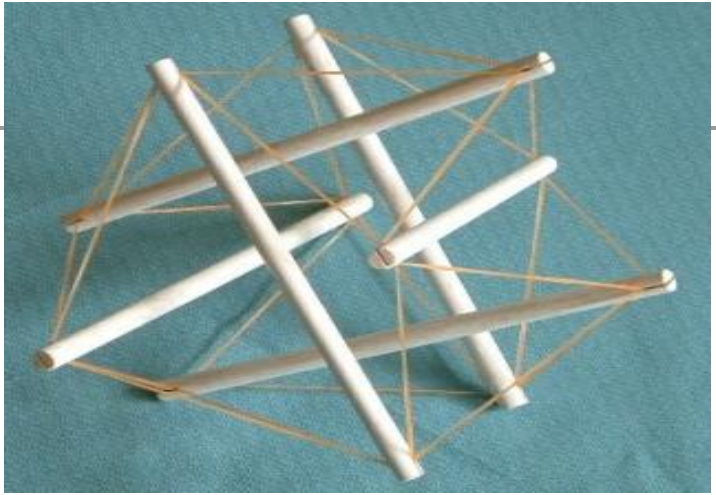






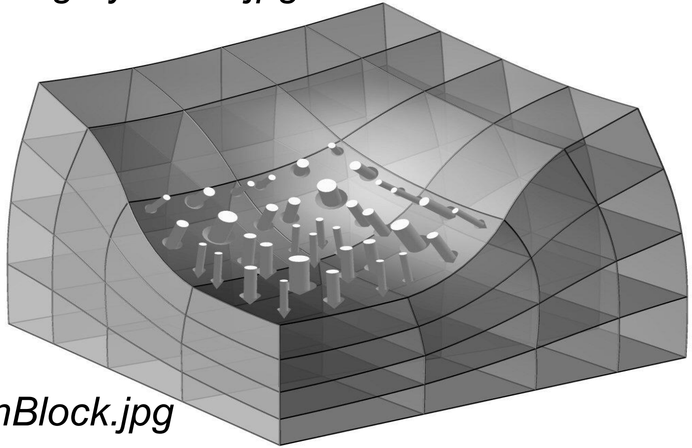
Miscellaneous Definitions

- *Tension*: The direction of the force of tension is parallel to the string, away from the object exerting the stretching force.



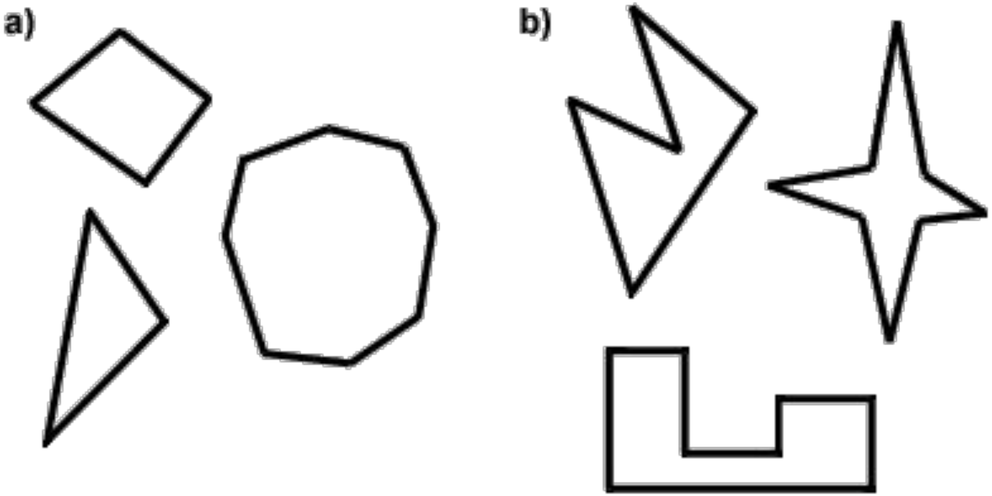
http://fig.cox.miami.edu/~cmallery/
255/255chem/tensegrity.sticks.jpg

- *Compression*: resulting in reduction of volume

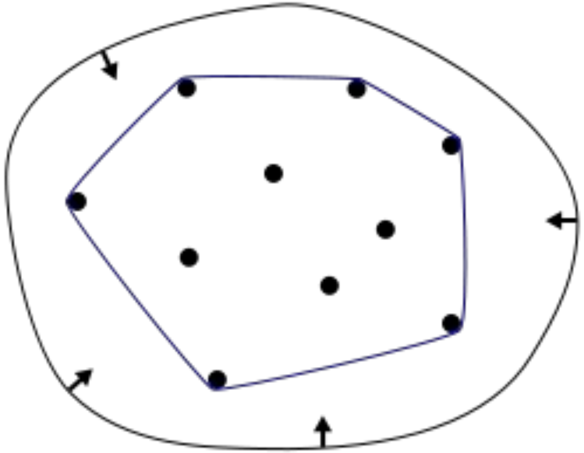


http://www.aero.polimi.it/~merlini/
SolidMechanics-FiniteElasticity/CompressionBlock.jpg

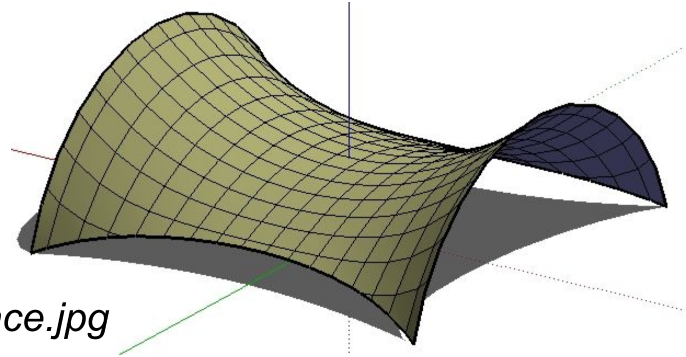
Miscellaneous Definitions: Convex vs. Non-Convex



http://img.sparknotes.com/figures/B/b333d91dc e2882b2db48b8ad670cd15a/convexconcave.gif



http://en.wikipedia.org/wiki/File:ConvexHull.svg



http://www.tensile-structures.de/Bilder/SaddleSurface.jpg

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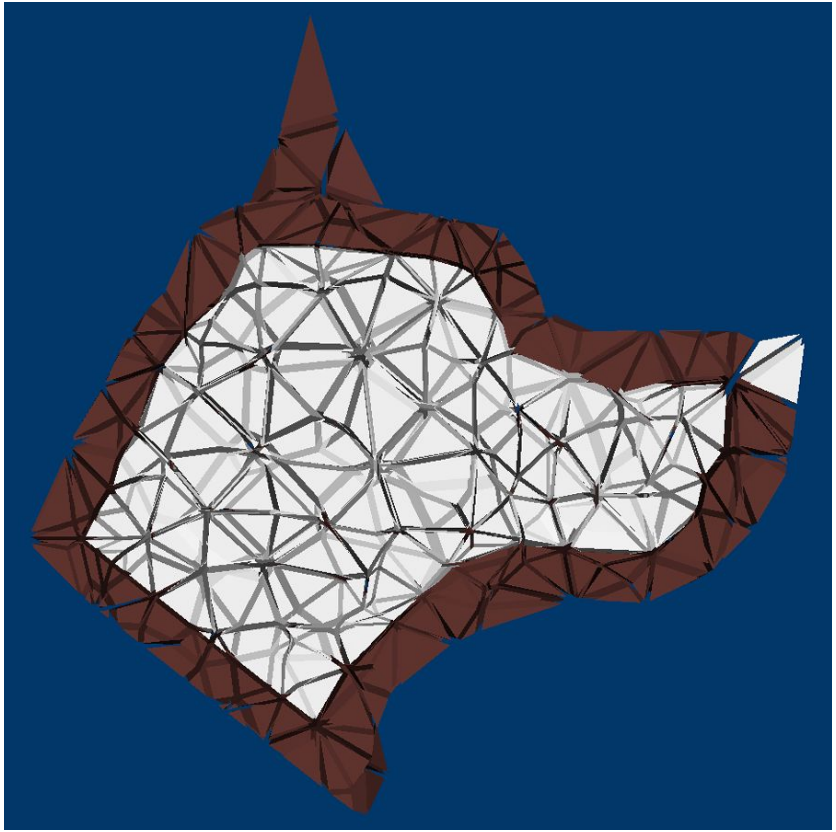
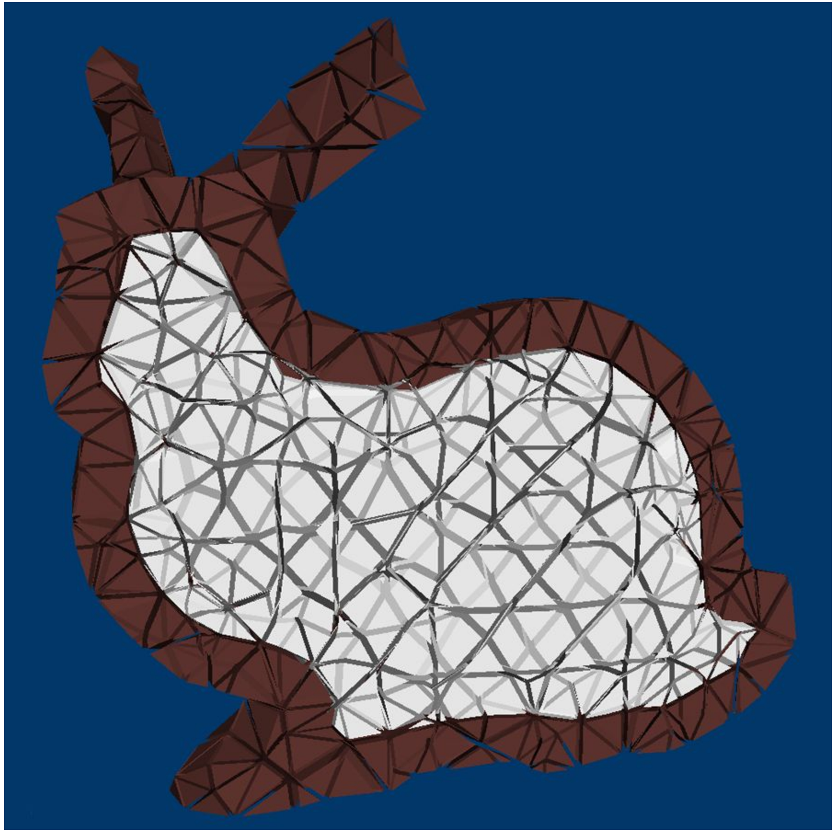
Multiple Materials

Mueller, Dorsey, McMillan, Jagnow, & Cutler
Stable Real-Time Deformations
Symposium on Computer Animation 2002





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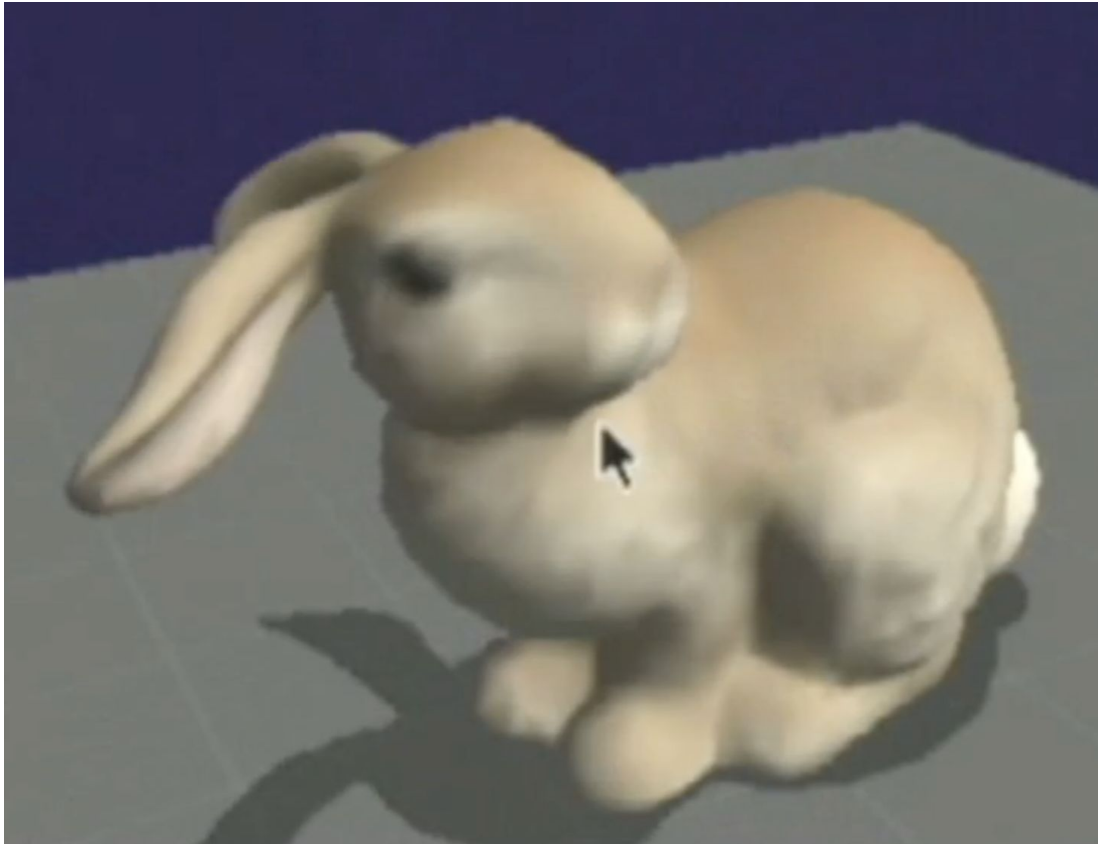


Multiple Materials

Images from Cutler et al. 2002

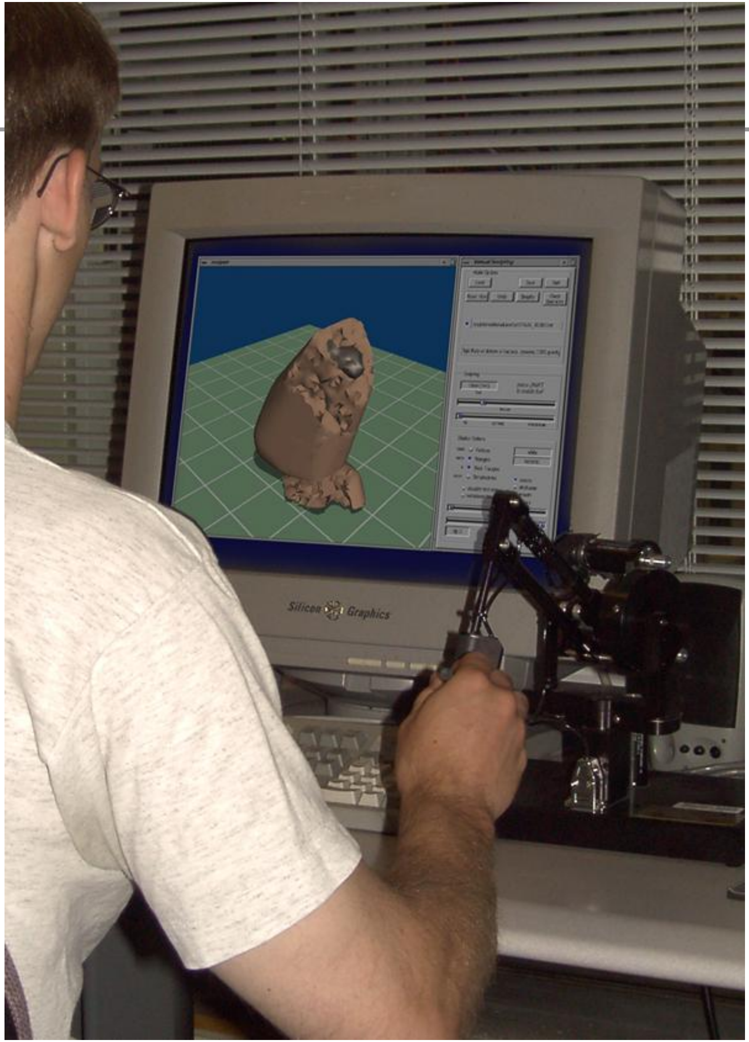

Image from Cutler et al. 2002

Image from Cutler et al. 2002

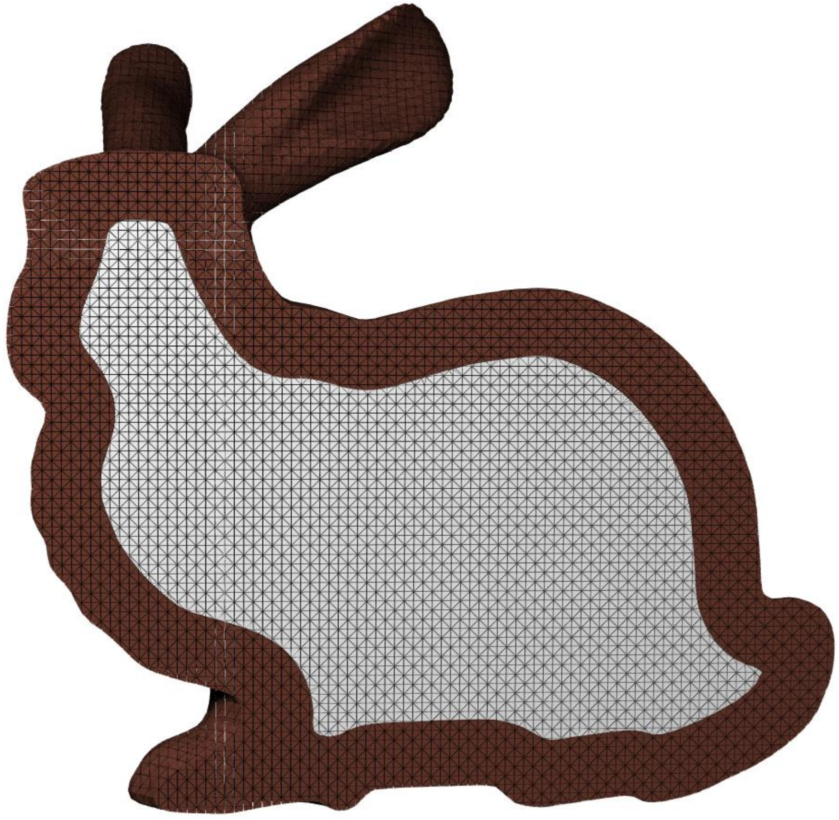
Haptic Device

- "3D mouse" + force feedback
- 6 DOF (position & orientation)
- *requires 1000 Hz refresh*
  (*visual only requires ~30 Hz*)

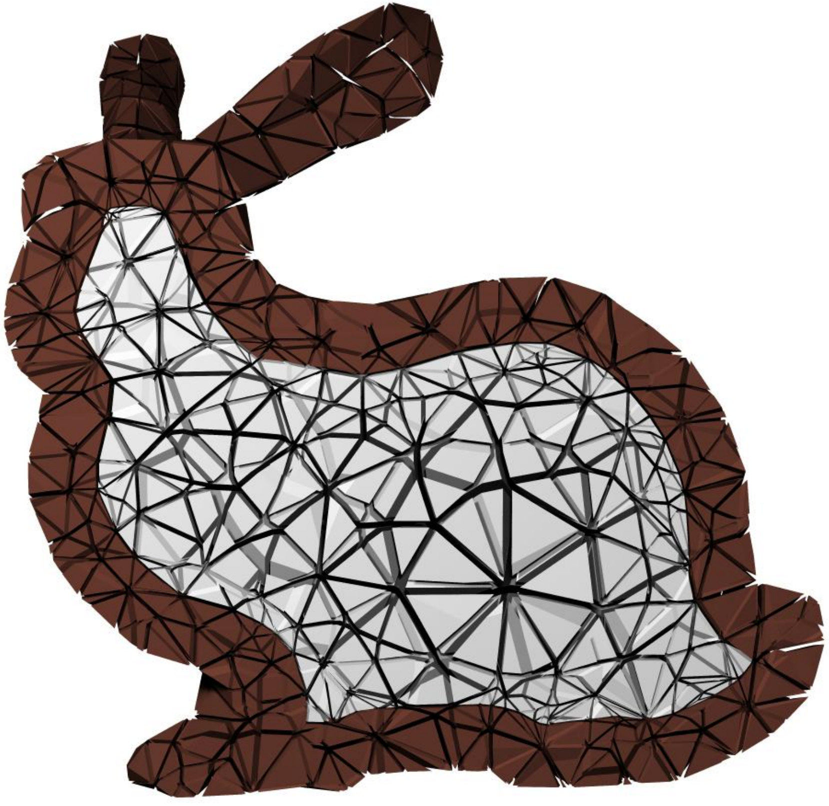
Sensable's Phantom
http://www.sensable.com/



3D Mesh Simplification



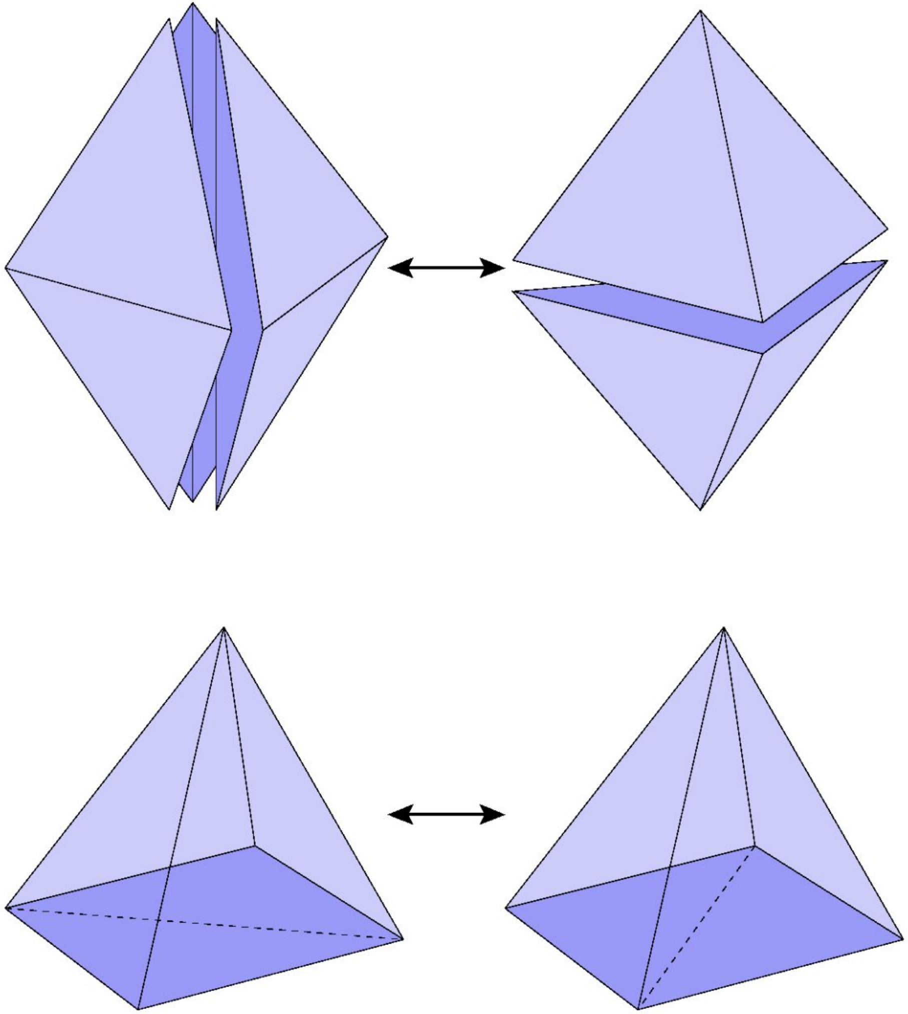
1,050K tetras (133K faces)



10K tetras (3K faces)

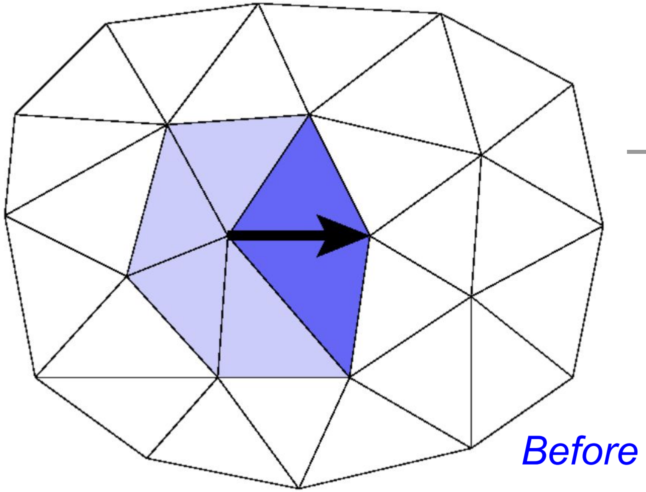
3D Mesh Operations

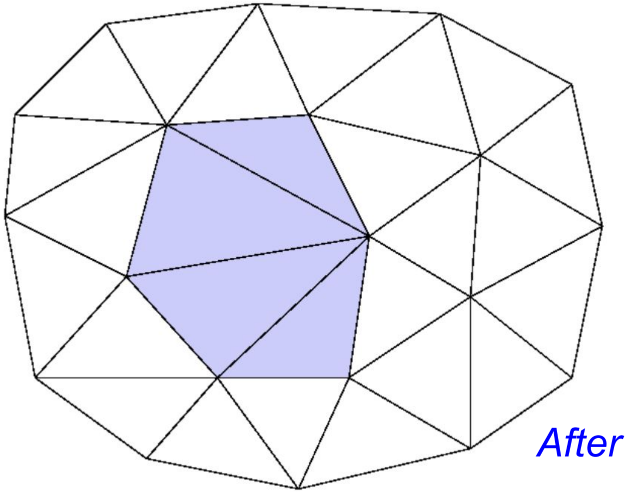
- Tetrahedral Swaps
  - Choose the configuration with the best local element shape
- Edge Collapse
- Vertex Smoothing
- Vertex Addition



3D Mesh Operations

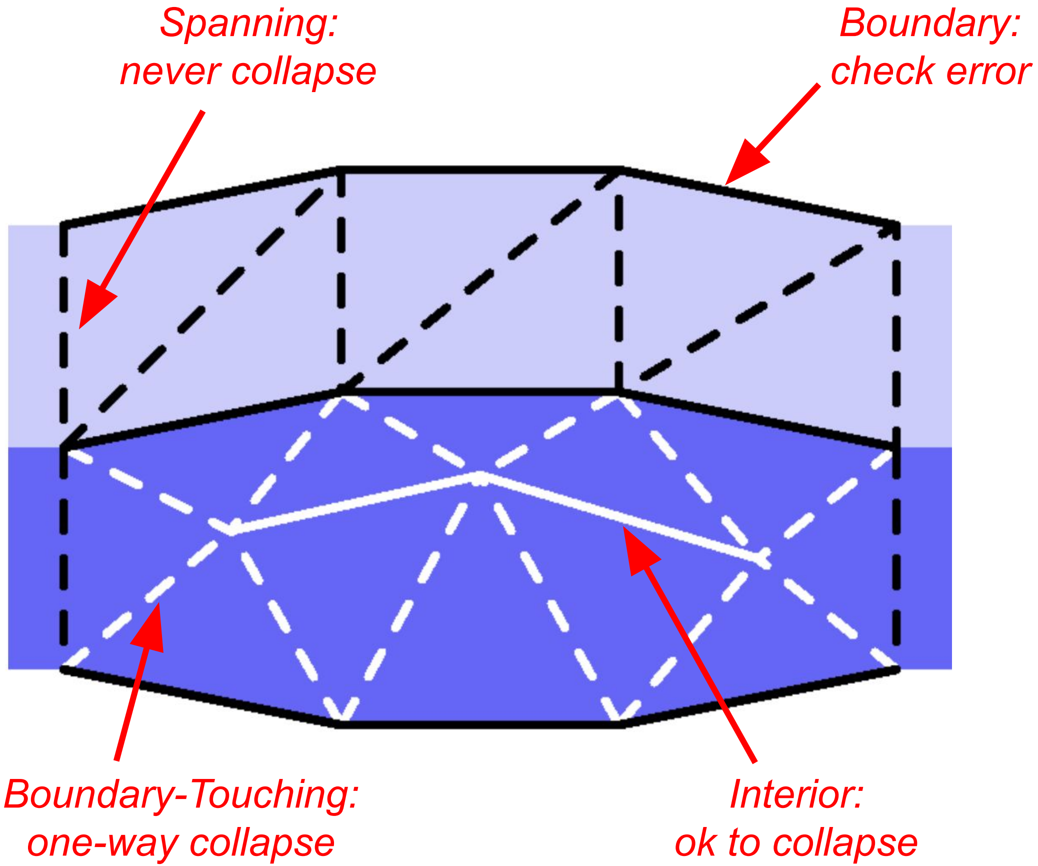
- Tetrahedral Swaps
- Edge Collapse
    - Delete a vertex & the elements around the edge
- Vertex Smoothing
- Vertex Addition





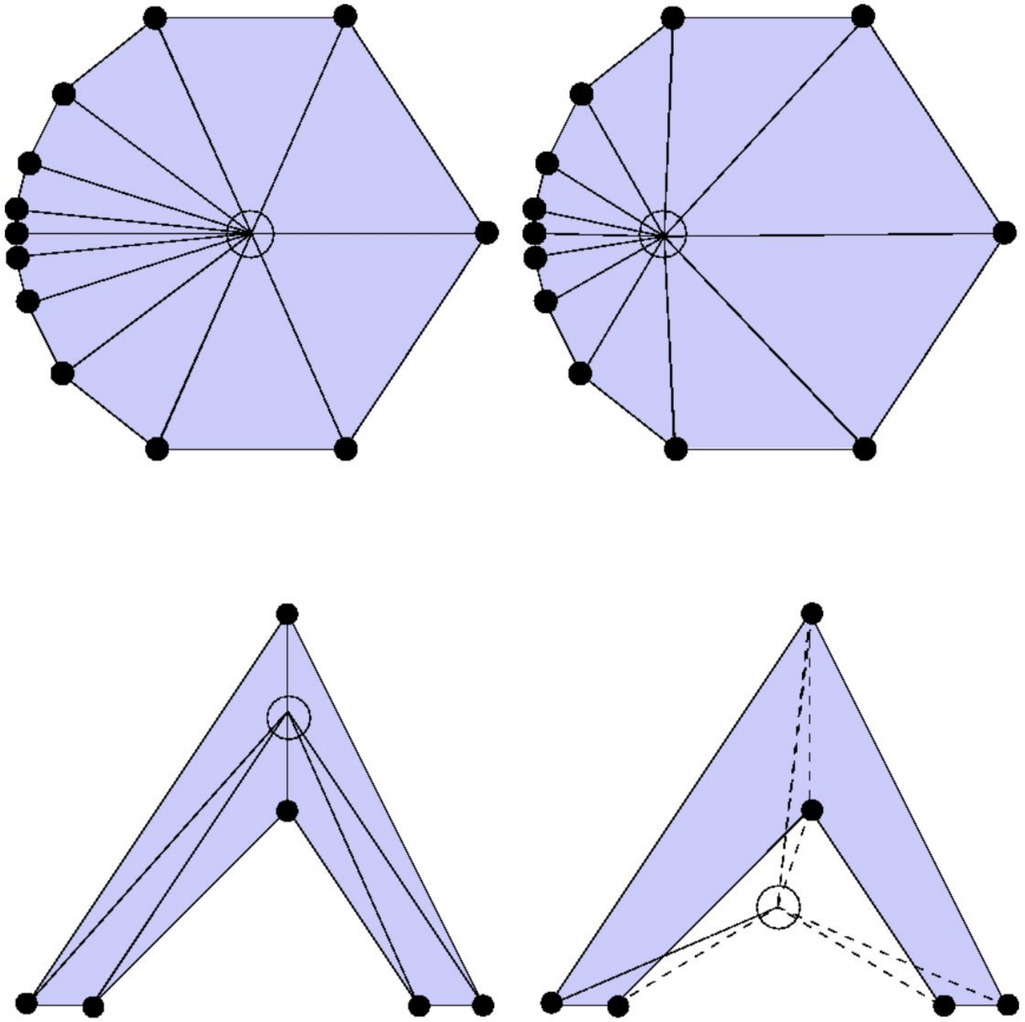
Prioritizing Edge Collapses

- Preserve topology
  - *Thin layers should not pinch together*
- Collapse weight
  - *Edge length + boundary error*
- No negative volumes
- Local element quality does not significantly worsen



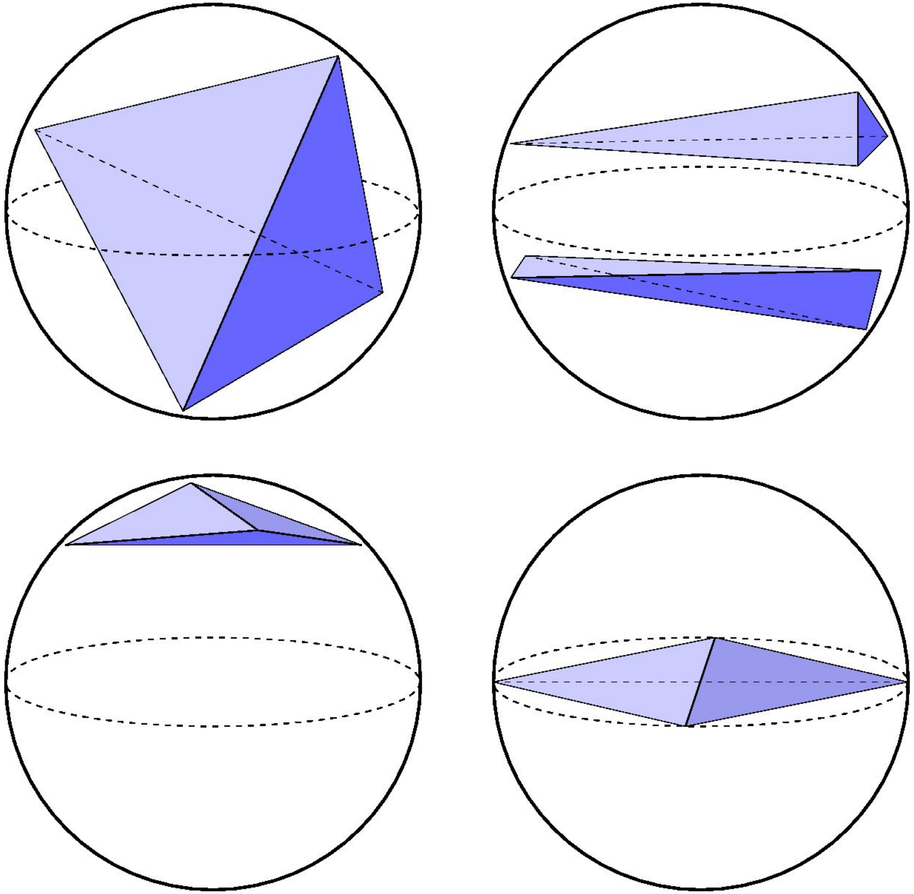
3D Mesh Operations

- Tetrahedral Swaps
- Edge Collapse
- Vertex Smoothing
  - Move a vertex to the centroid of its neighbors
  - Convex or concave, but avoid negative-volume elements
- Vertex Addition

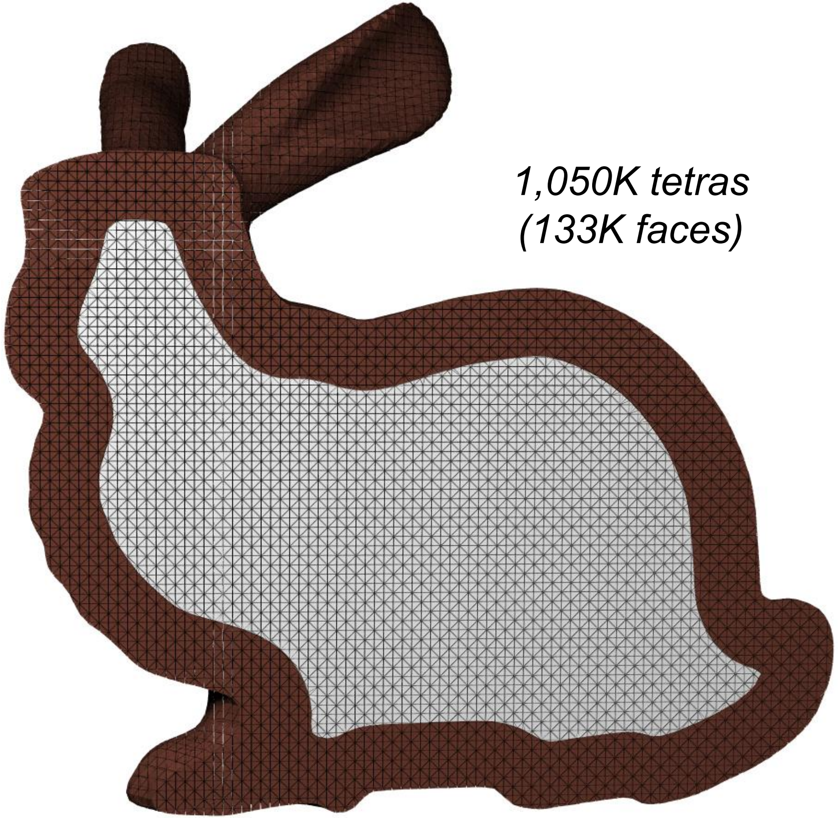


3D Mesh Operations

- Tetrahedral Swaps
- Edge Collapse
- Vertex Smoothing
- Vertex Addition
  - At the center of a tetra, face, or edge
  - Useful when mesh is simplified, but usually needs further element shape improvement



Visualization of Tetrahedra Quality



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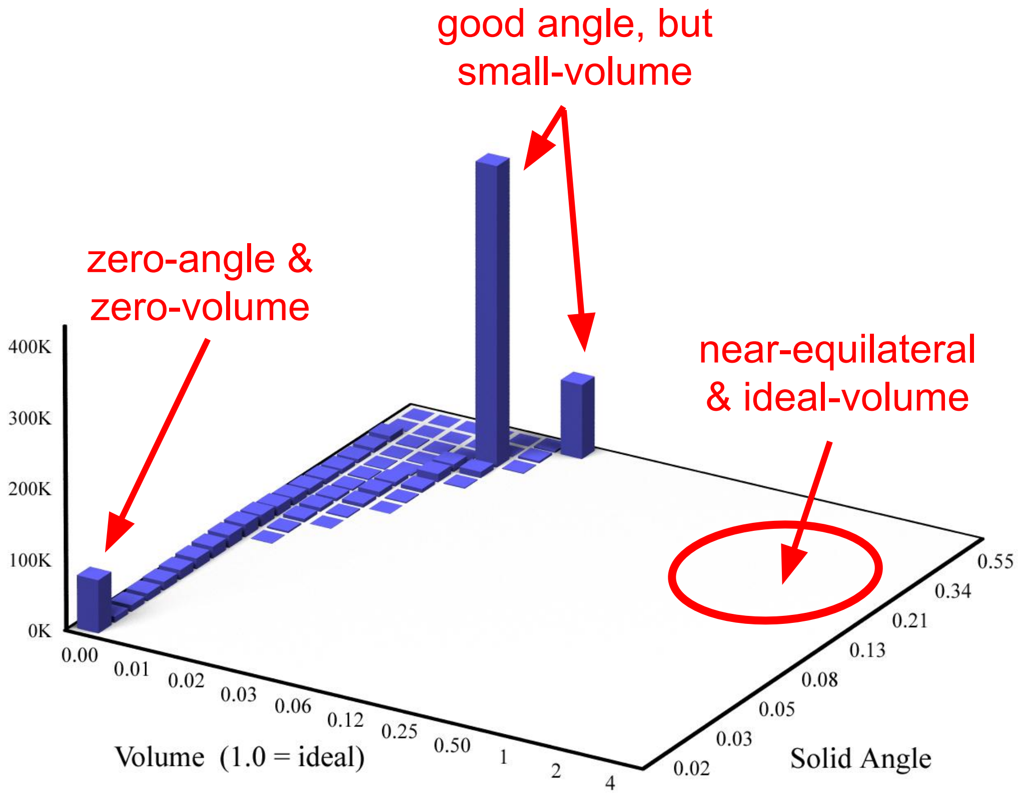

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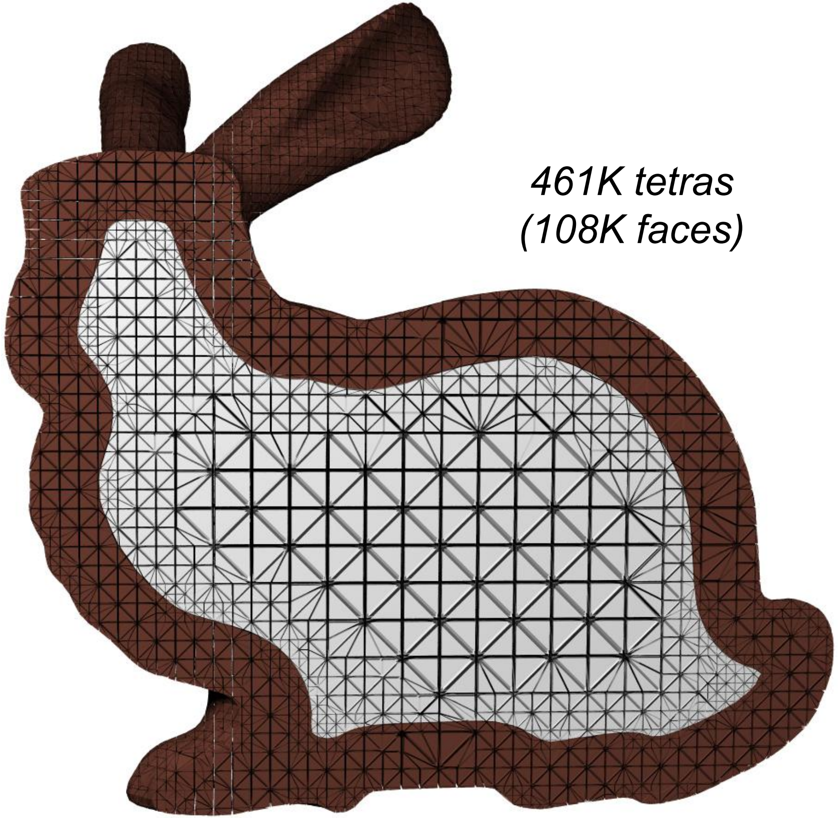
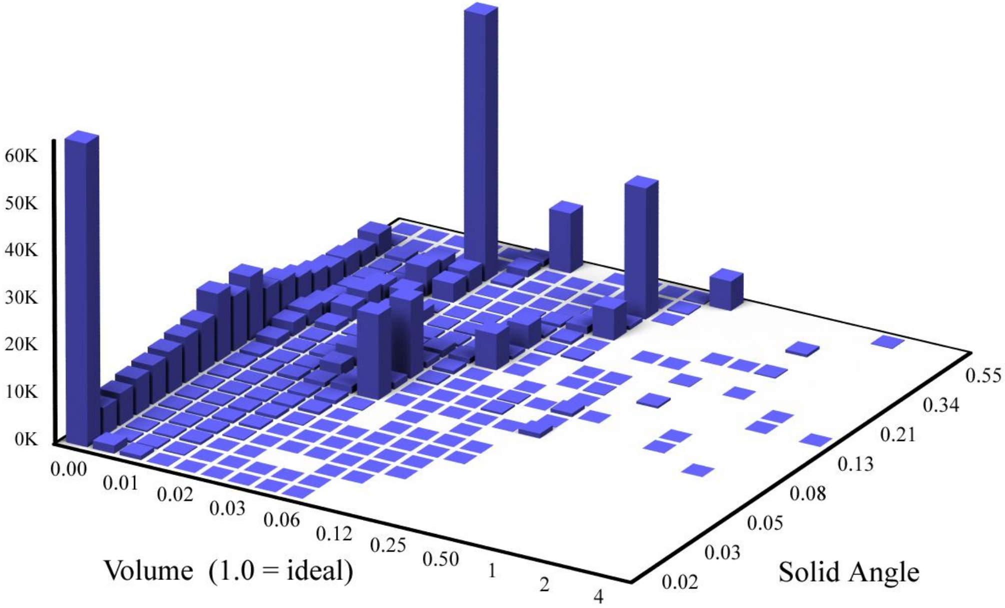


461K tetras
(108K faces)

Octree or Adaptive
Distance Field (ADF)



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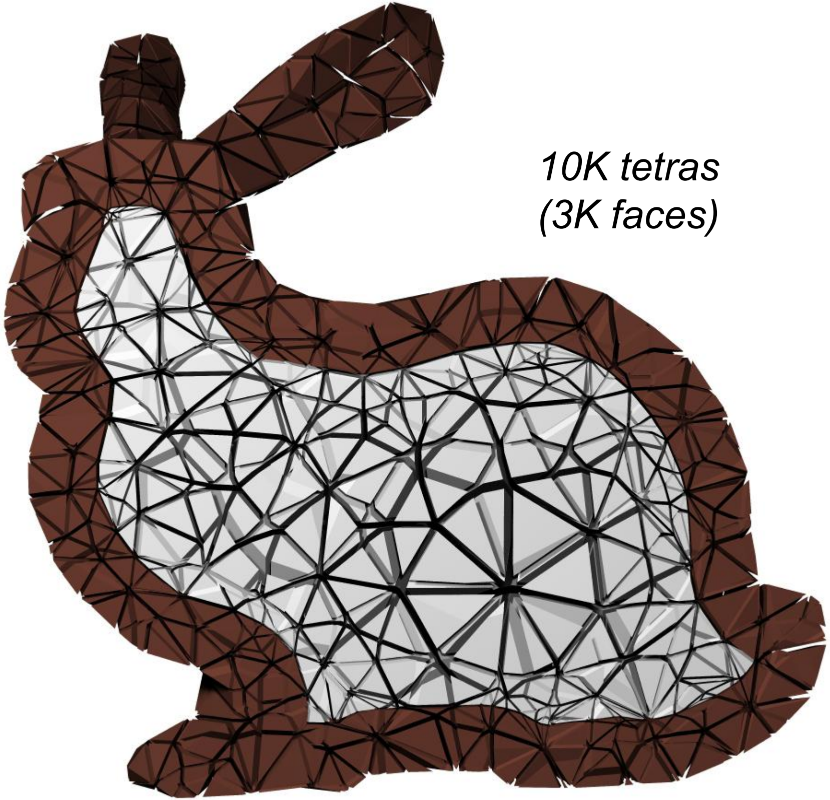
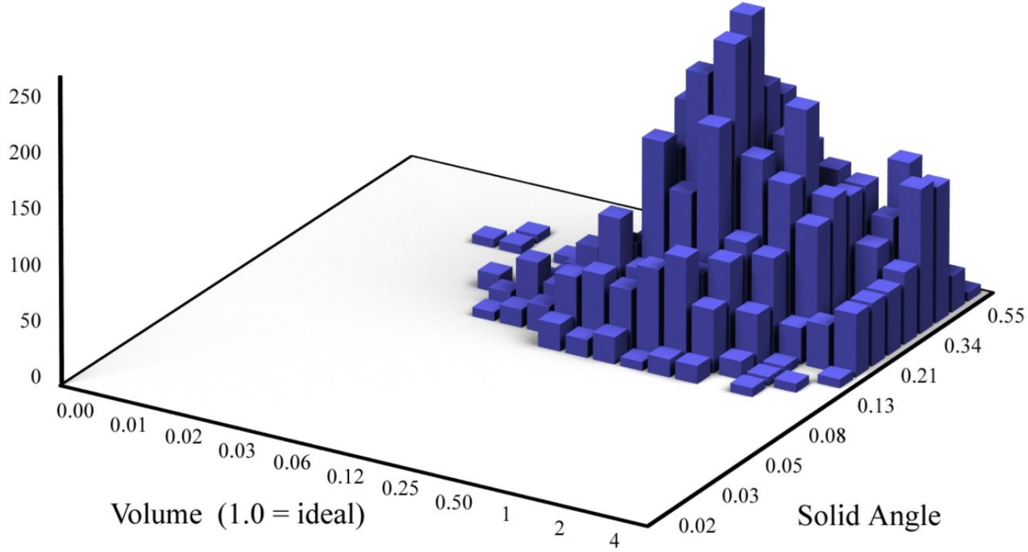
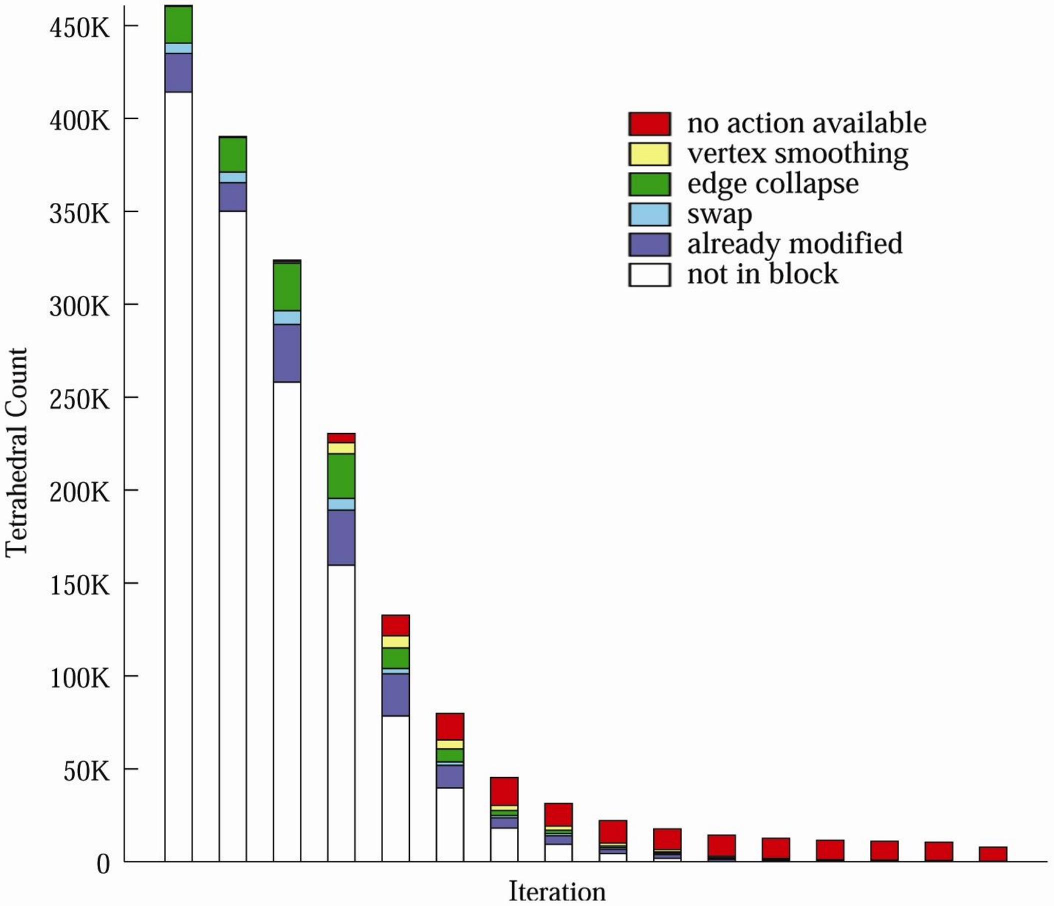


10K tetras
(3K faces)

After Simplification
& Mesh Improvement



Visualization of Simplification Algorithm



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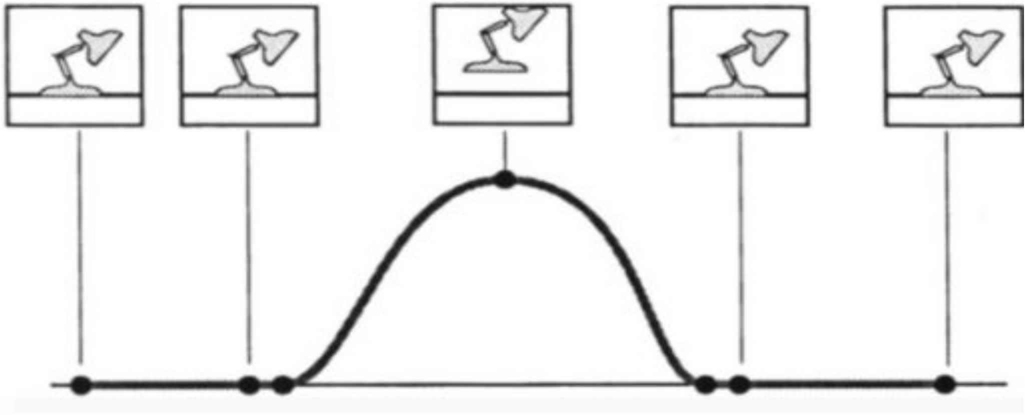
Keyframing

- Use spline curves to automate the inbetweening
  - Good control
  - Less tedious than drawing *every* frame
- Creating a good animation still requires considerable skill and talent and learning from observing the real world

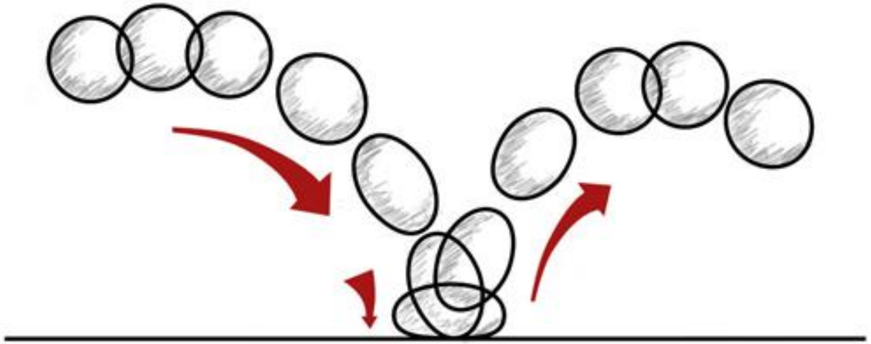


ACM © 1987 "Principles of traditional animation applied to 3D computer animation"

Disney's 12 Principles of Animation

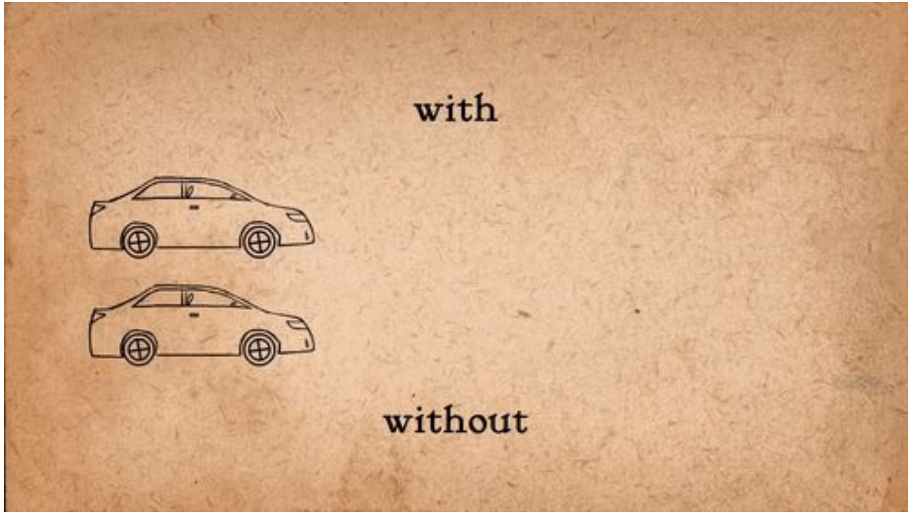
"The Illusion of Life: Disney Animation", Ollie Johnston & Frank Thomas, 1981

Squash & Stretch



https://www.animdesk.com/the-principles-of-animation-squash-and-stretch

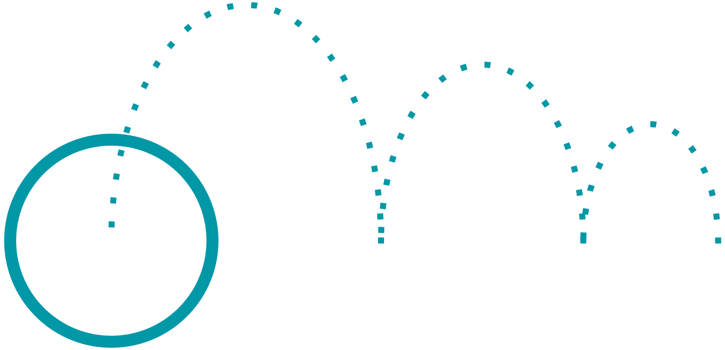
Slow In & Slow Out



https://characteranimationlara.home.blog/2018/10/21/the-12-principles-of-animation

Procedural Animation

- Describes the motion algorithmically, as a function of small number of parameters
- Example: a clock with second, minute and hour hands
  - express the clock motions in terms of a "seconds" variable
  - the clock is animated by varying the seconds parameter
- Example: A bouncing ball
  - $Abs(\sin(\omega t+\theta_0))*e^{-kt}$



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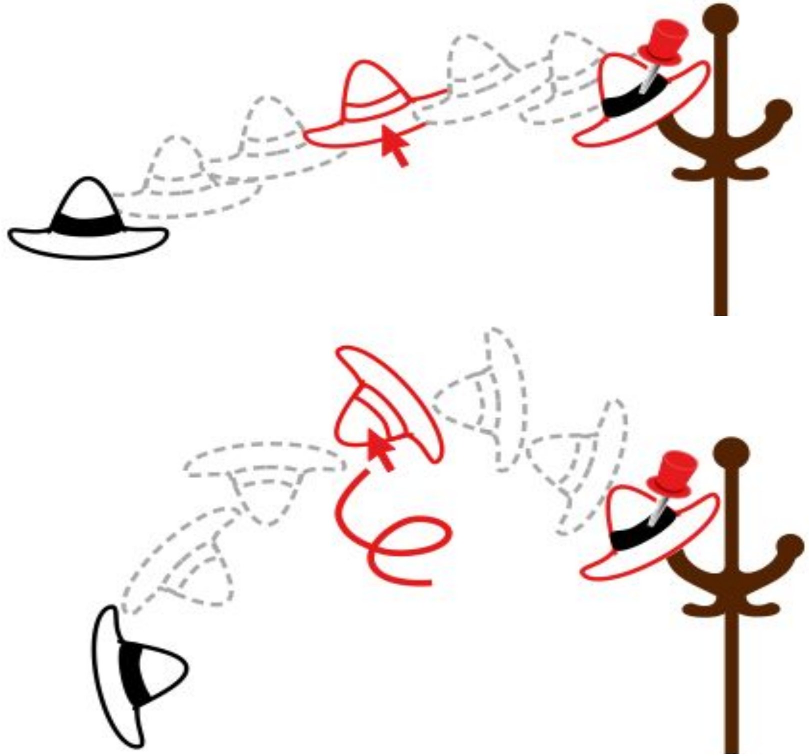
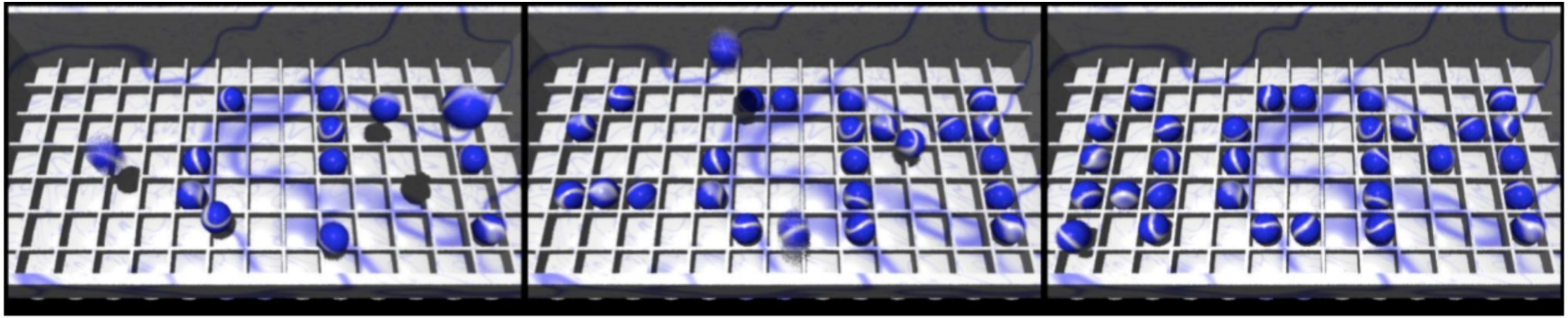
Physically-Based Animation

- Assign physical properties to objects (masses, forces, inertial properties)
- Simulate physics by solving equations
- Realistic, but difficult to control
- Used for *secondary motions* (hair, cloth, scattering, splashes, breaking, smoke, etc.) that respond to primary *user controlled* animation



"Interactive Manipulation of Rigid Body Simulations"
SIGGRAPH 2000, Popović, Seitz, Erdmann, Popović & Witkin

“Sampling Plausible Solutions to Multi-body Constraint Problems”
Chenney & Forsyth,
SIGGRAPH 2000



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Motion Capture

- Optical markers & high-speed cameras: Triangulation → 3D position
- Captures style, subtle nuances and realism
- You must observe someone do something
- Difficult (or impossible?) to *edit* mo-cap data

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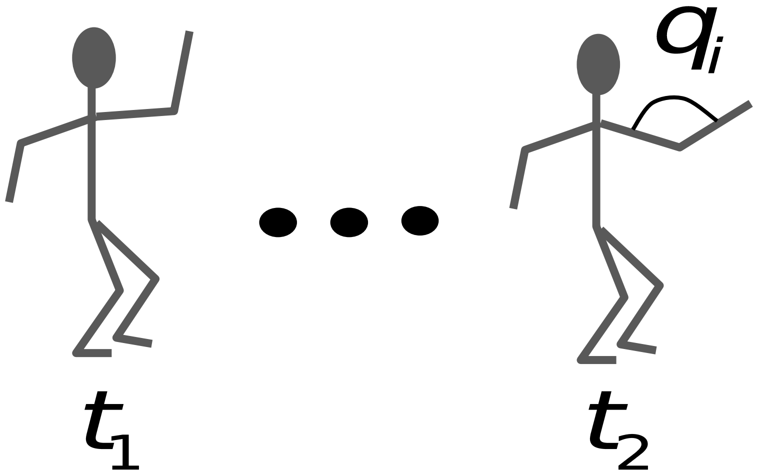
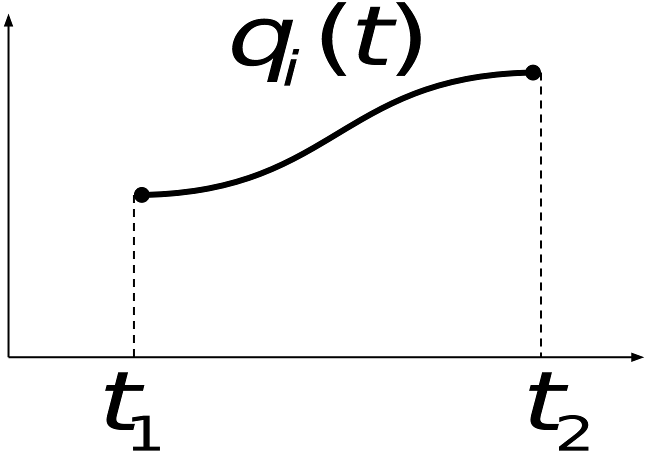
Articulated Models

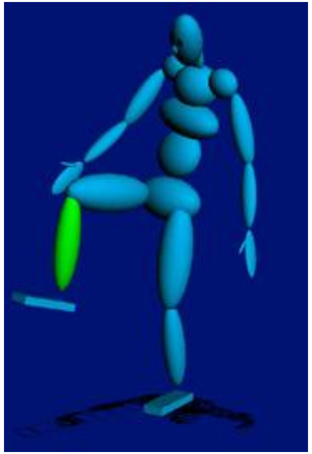
- Articulated models:
  - rigid parts
  - connected by joints
- They can be animated by specifying the joint angles as functions of time.



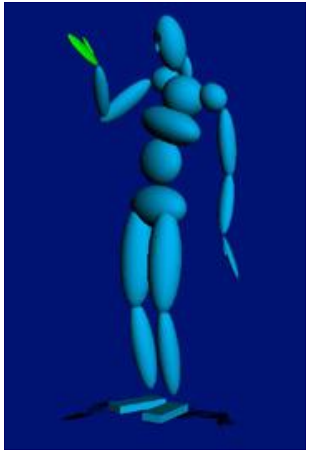


Skeleton Hierarchy

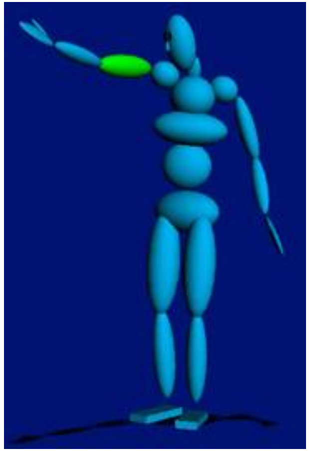
- Each bone transformation described relative to the parent in the hierarchy:



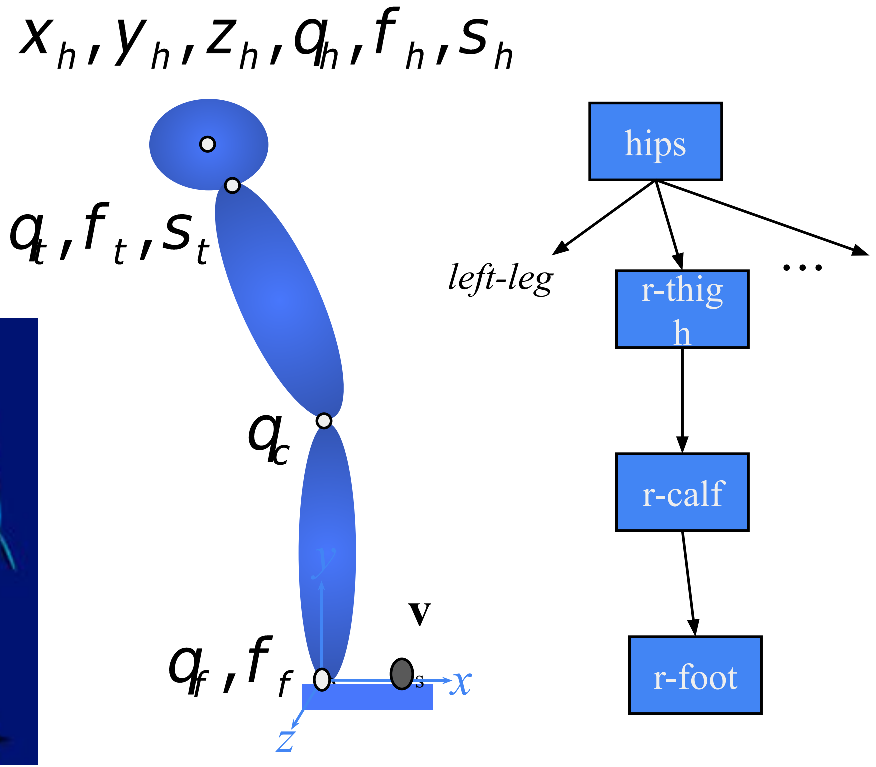
1 DOF: knee



2 DOF: wrist



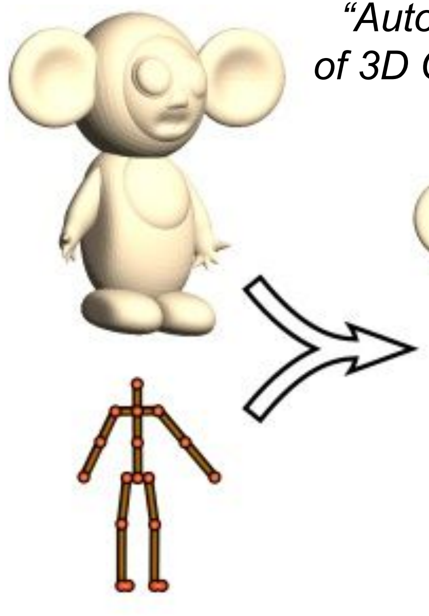
3 DOF: arm

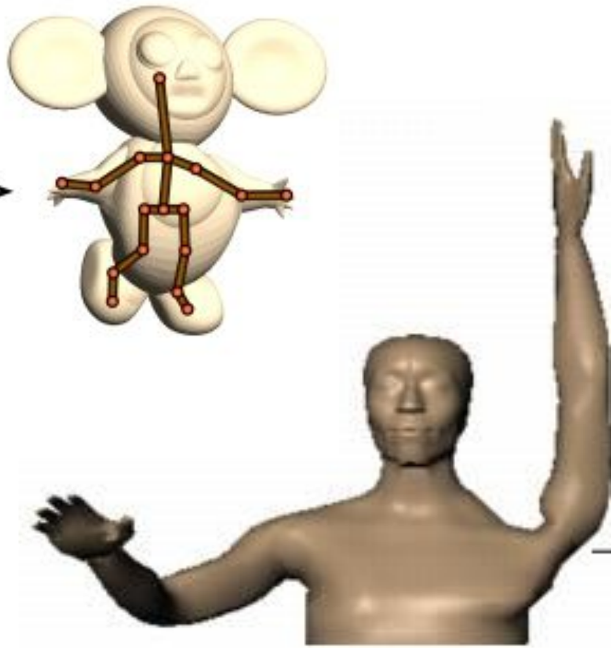


Skeletal Animation Challenges

- Skinning
  - Complex deformable skin, muscle, skin motion
- Hierarchical controls
  - Smile control, eye blinking, etc.
  - Keyframes for these higher-level controls
- A huge amount of time is spent building the 3D models, its skeleton, and its controls

"Automatic Rigging and Animation of 3D Characters", Baran & Popović, SIGGRAPH 2007

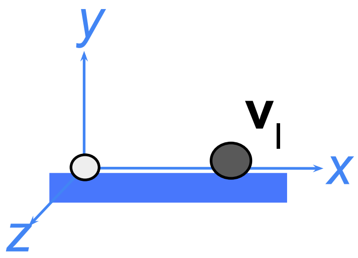


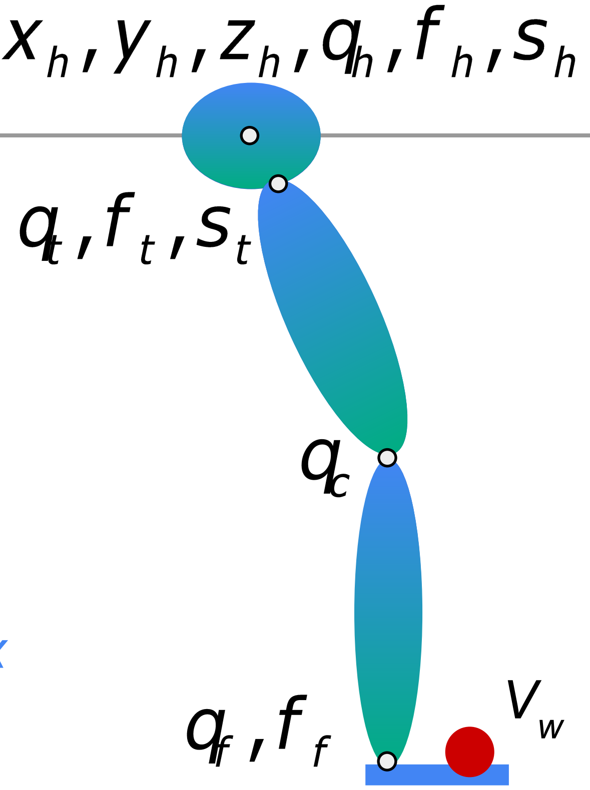


Maya tutorial

Forward Kinematics

- Given skeleton parameters p, and the position of the effector in local coordinates V_l, what is the position of the effector in the world coordinates V_w?





$$V_w = T(x_h,y_h,z_h)R(q_h,f_h,s_h)T_hR(q_t,f_t,s_t)T_tR(q_c)T_cR(q_f,f_f)V_l$$

$$V_w = S(p)V_l$$

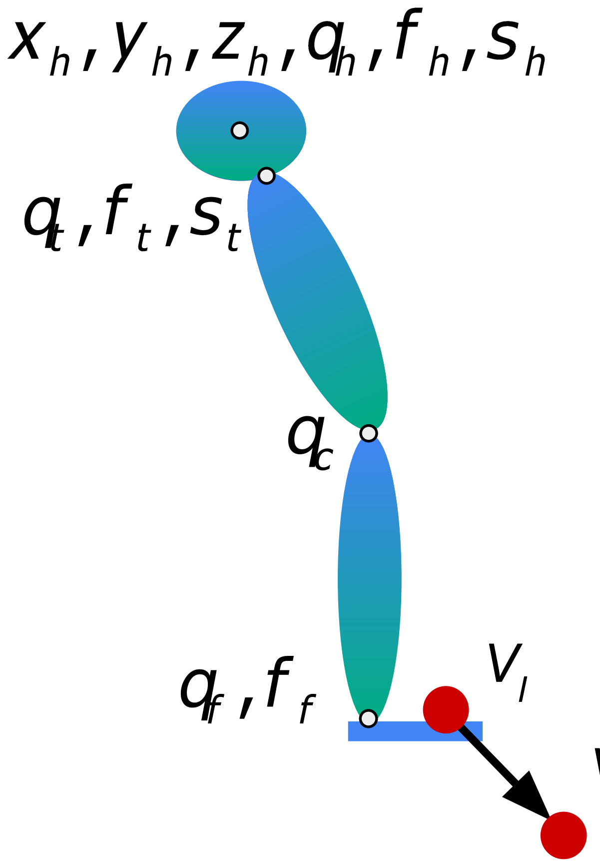
S(p) is "just" a 4x4 affine transformation matrix!

Inverse Kinematics (IK)

- Given the position of the effecter in local coordinates V_l and the *desired position* V_w in world coordinates, what are the skeleton parameters p?
- Much harder!! It requires solving the inverse of the nonlinear function:

find *p* *such that* $S(p)V_l = V_w$

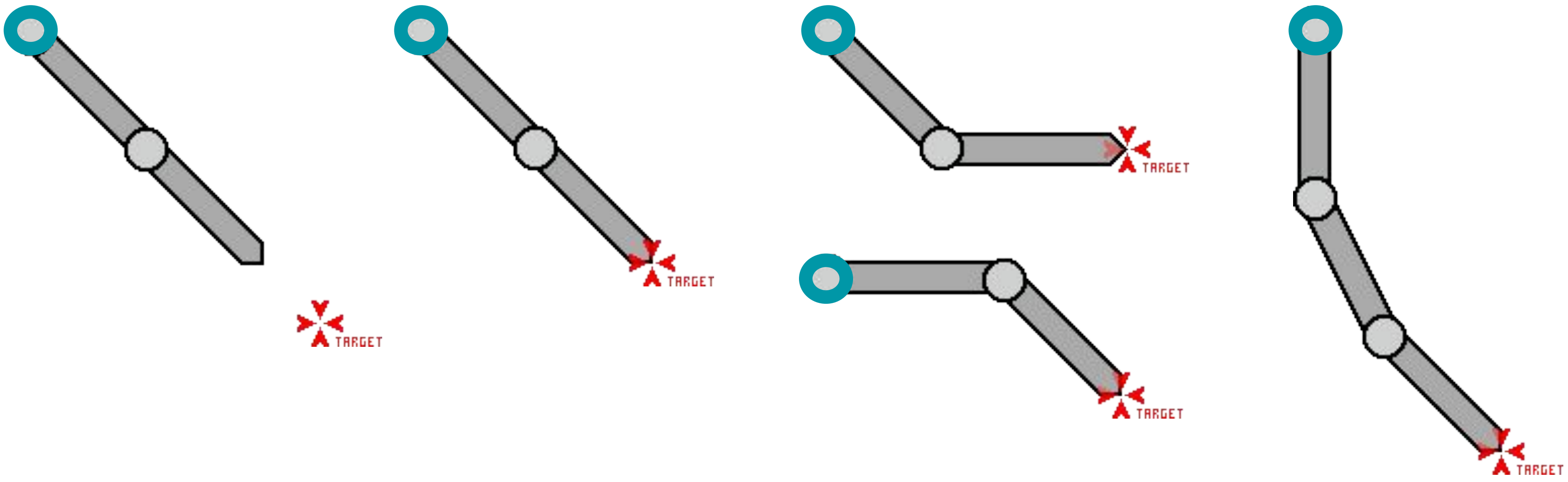
Why is this hard? Why is it non-linear?



Under-/Over- Constrained IK

- Application: Robot Motion Planning

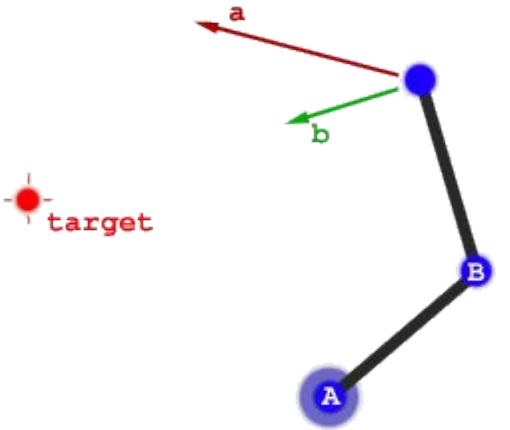
No solutions *One solution* *Two solutions (2D)* *Many solutions*



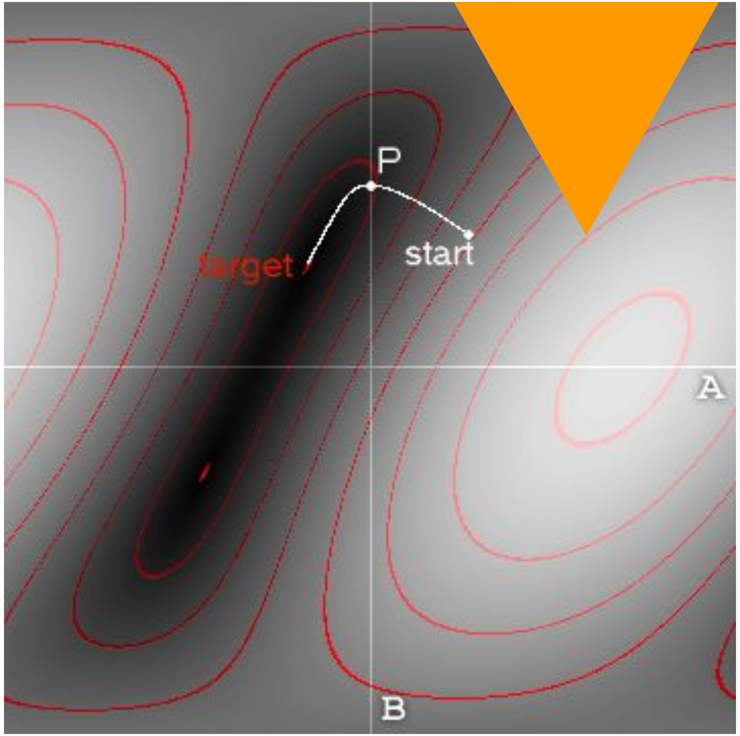
"The good-looking textured light-sourced bouncy fun smart and stretchy page"
*Hugo Elias, **http://freespace.virgin.net/hugo.elias/models/m_ik.htm***

Searching Configuration Space

- Use *gradient descent* to walk from starting configuration to target
- **Angle restrictions & collisions can introduce local minima**



pose space shaded by distance to target



"The good-looking textured light-sourced bouncy fun smart and stretchy page"
Hugo Elias, ***http://freespace.virgin.net/hugo.elias/models/m_ik2.htm***

IK Challenge

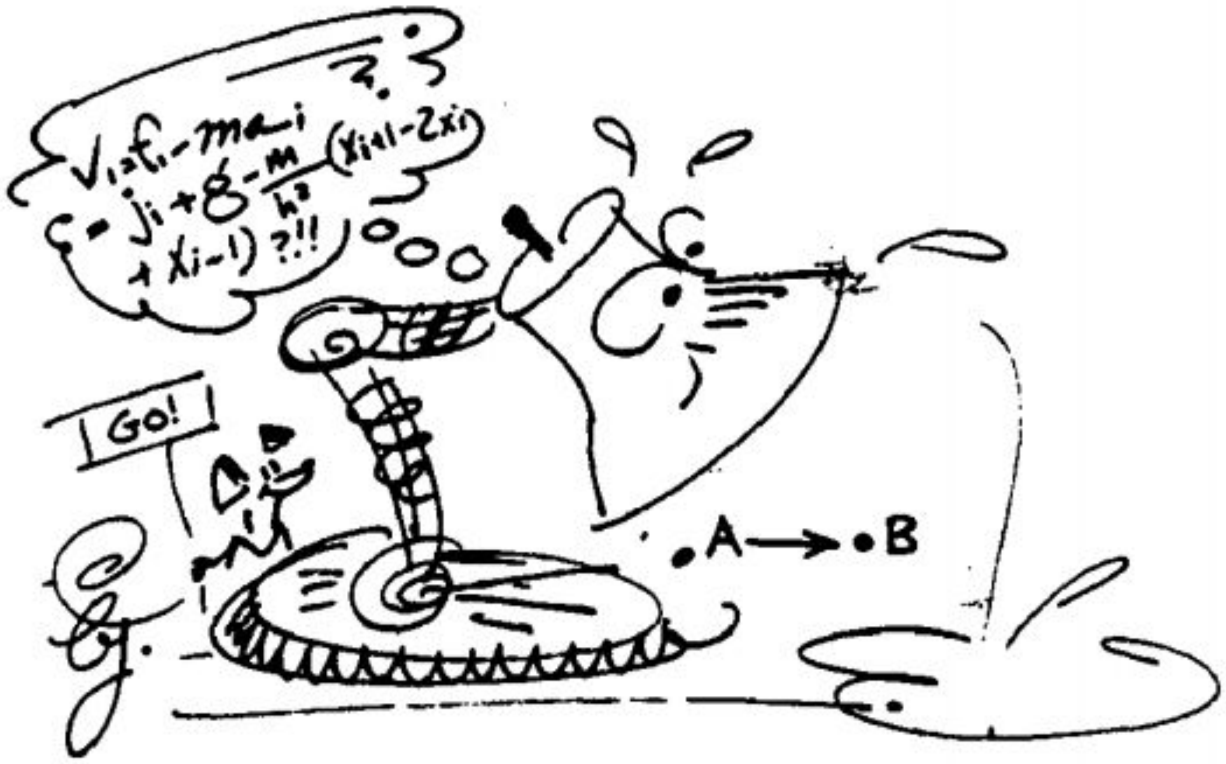
- Find a “natural” skeleton configuration for a collection of pose constraints
- A *vector constraint function $C(p) = 0$* collects all pose constraints
- A *scalar objective function* $g(p)$ measures the quality of a pose,
  $g(p)$ is minimum for most natural poses.

  Example $g(p)$:

  - deviation from natural pose
  - joint stiffness
  - power consumption

Force: Newton (N) = kg * m / s^2
Work: Joule (J) = N*m = kg * m^2 / s^2
Power: Watt (W) = J/s = kg * m^2 / s^3

Questions?



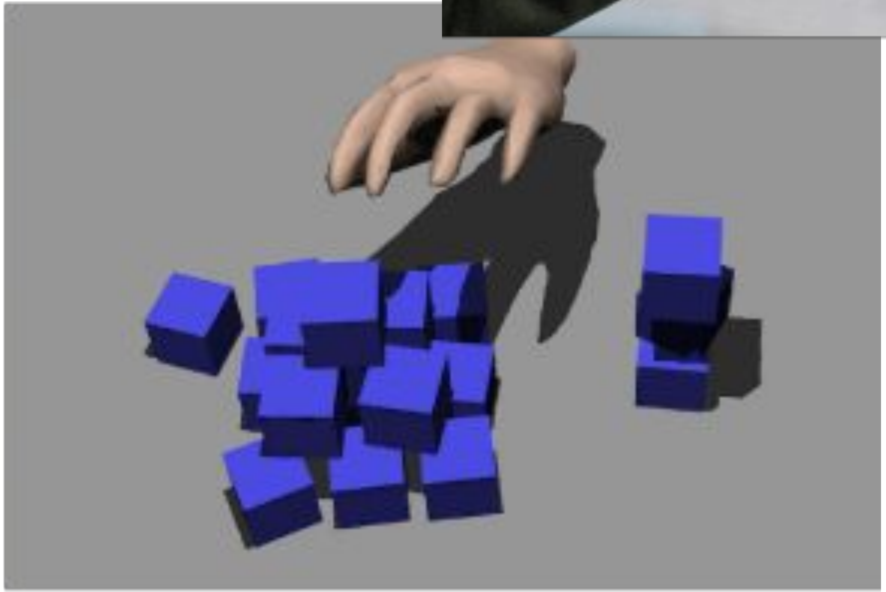
“Spacetime Constraints”, Witkin & Kass, SIGGRAPH 1988

Today

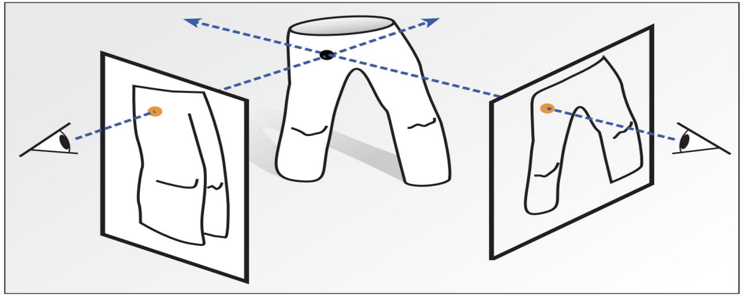
- Finish Slides from Last Time:
  - Level of Detail
  - Useful & Related Term Definitions
  - Tetrahedral Element Quality
- How do we Animate?
  - Keyframing & Procedural Animation
  - Physically-Based Animation
  - Motion Capture
  - Skeletal Animation & Forward and Inverse Kinematics
- Readings for Today
- Figure Skating Lesson
- Readings for Next Time

Reading for Today: *(pick one)*

- “Real-Time Hand-Tracking with a Color Glove”
  SIGGRAPH 2009, Wang & Popović



Capturing and Animating Occluded Cloth, White, Crane, & Forsyth, SIGGRAPH 2007



Reading for Today: *(pick one)*

- "Artist-Directed Dynamics for 2D Animation",
  Bai, Kaufman, Liu, & Popović, SIGGRAPH 2016

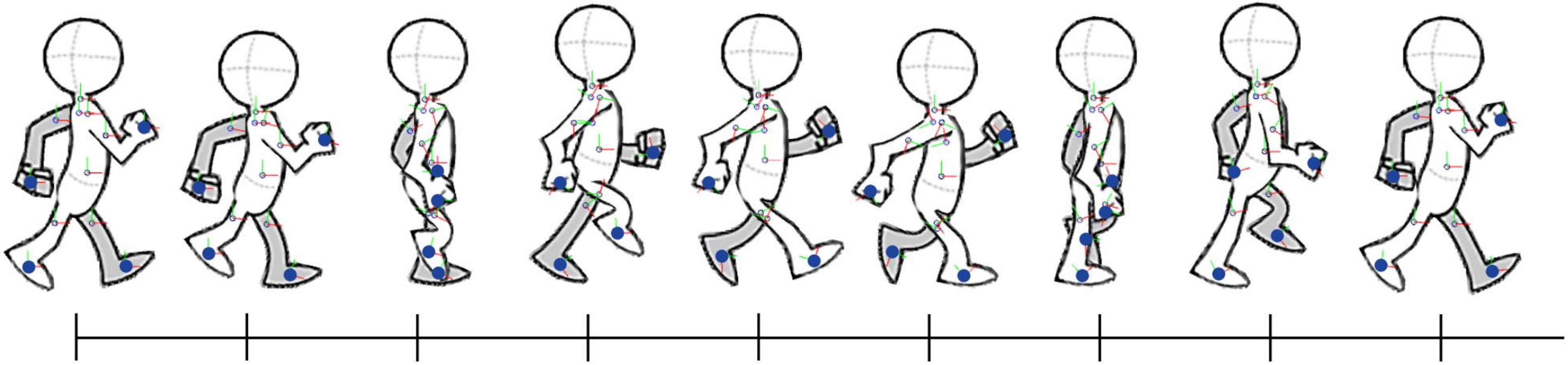


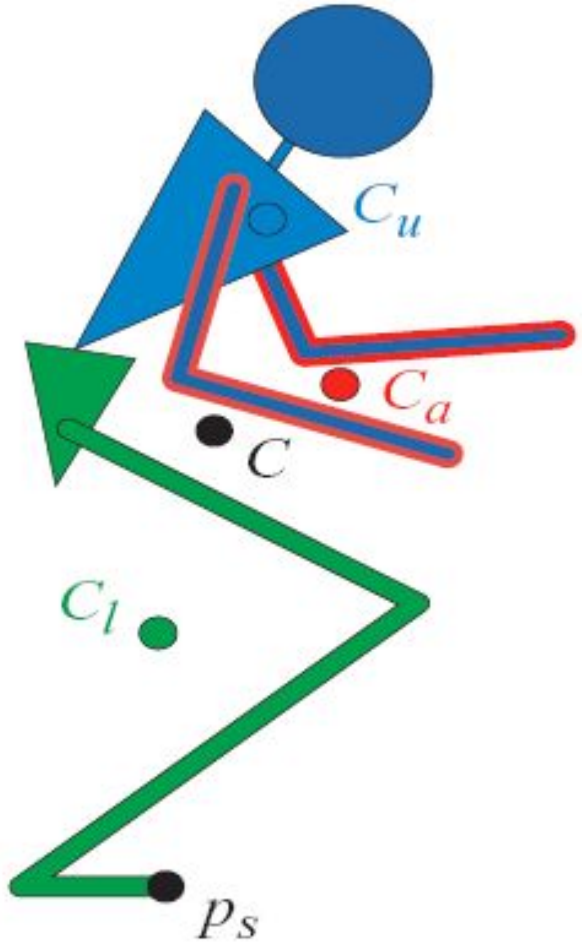
Figure 6: ***Keyframes used in the articulated character walk example.*** *The artist only specifies keyframes for a subset of handles (handles at hands and feet) which are shown as blue dots. Nine keyframes are used to create a walking cycle. Their timing is visualized by the black lines at the bottom. The artworks are adapted from Angryanimator.com (http://www.angryanimator.com/)*

Reading for Today: *(pick one)*

- “Synthesis of Complex Dynamic Character Motion from Simple Animation”, Liu & Popović, 2002

What's a Natural Pose?

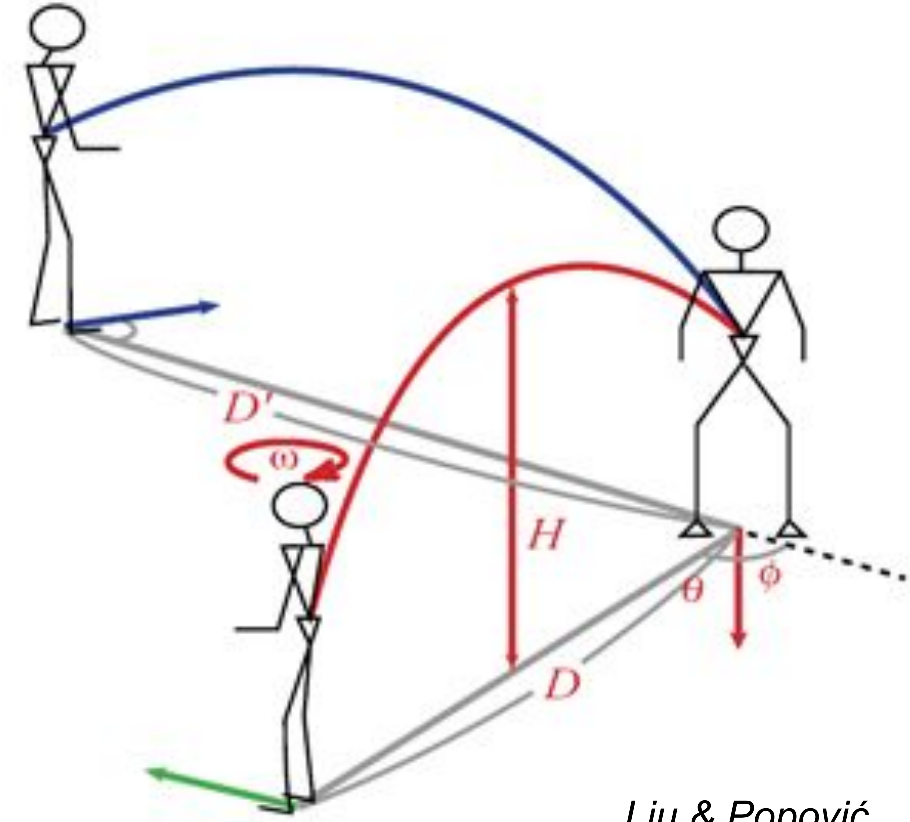
- Training database of ~50 “natural poses”
- For each, compute center of mass of:
  - Upper body
  - Arms
  - Lower body
- The relative COM of each generated pose is matched to most the most similar database example



Liu & Popović

Linear and Angular Momentum

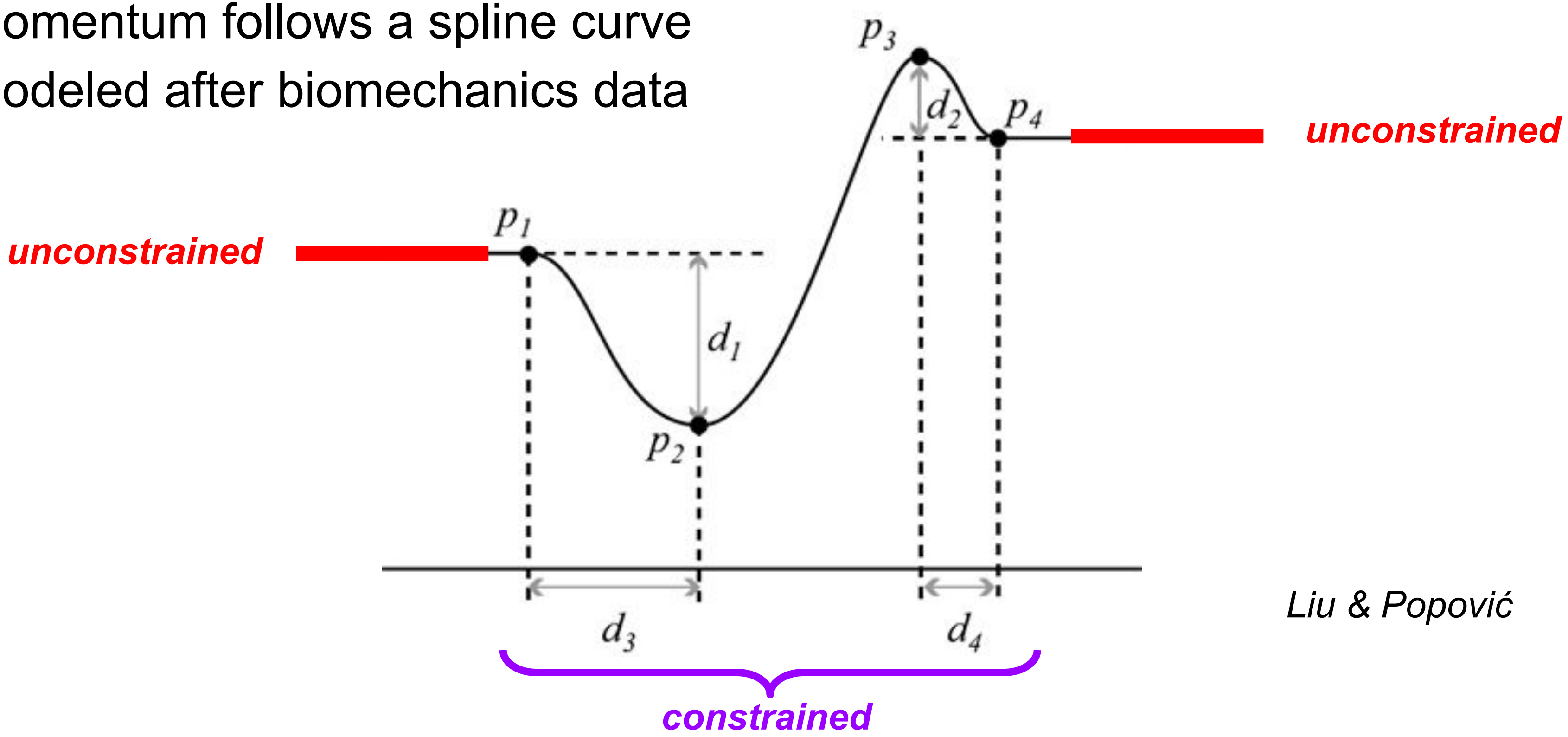
- In unconstrained animation (no contacts), both linear & angular momentum should be conserved
- The center of mass should follow a parabolic trajectory according to gravity
- The joints should move such that the angular momentum of the whole body remains constant



Liu & Popović

During Constrained Motion

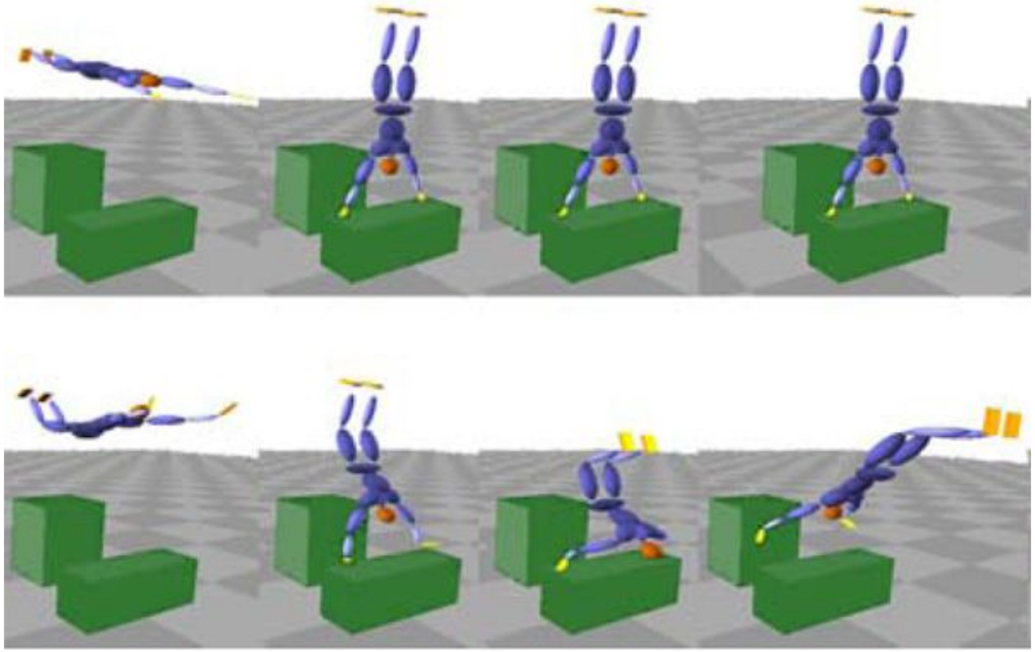
- During *constrained* motion (when in contact with the ground), the angular momentum follows a spline curve modeled after biomechanics data



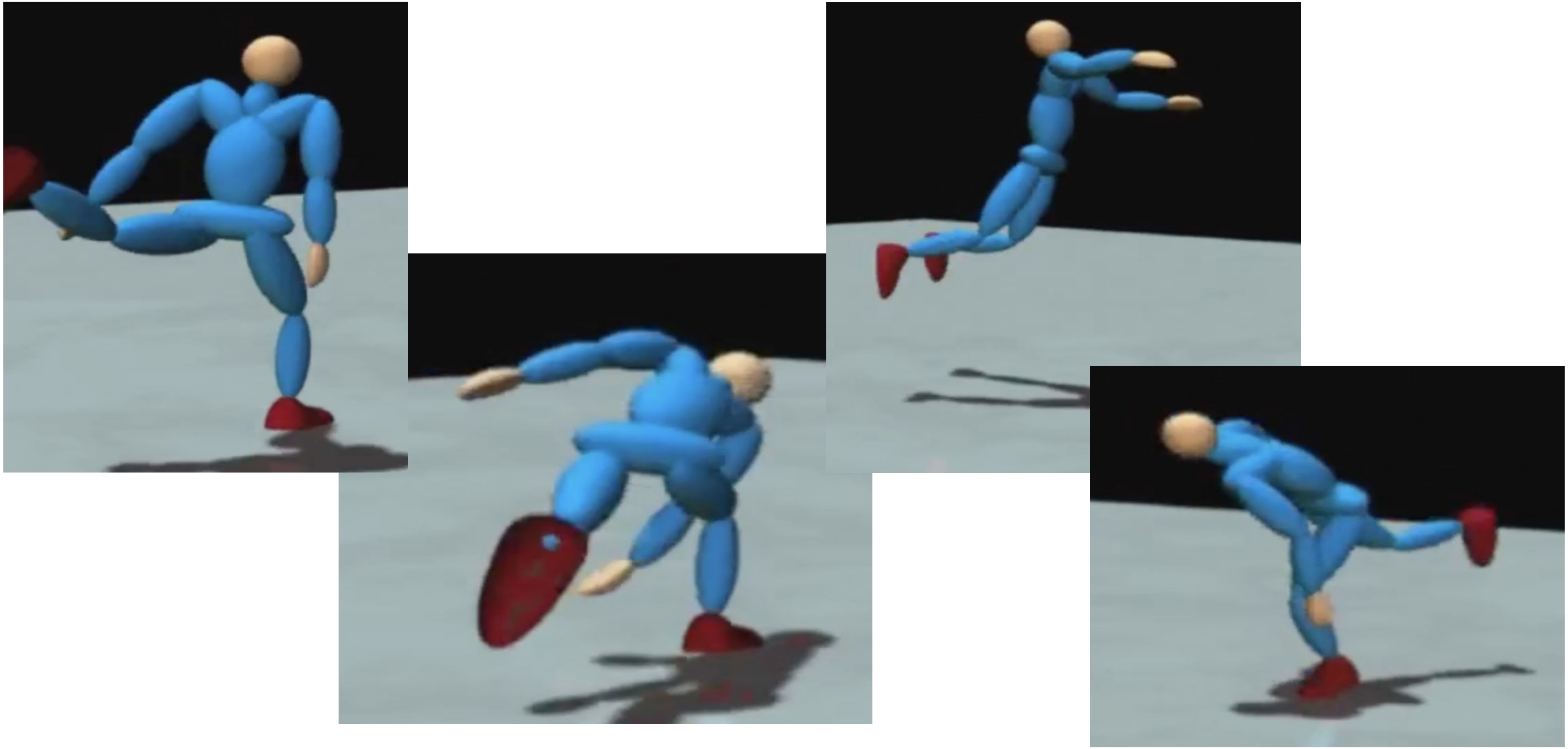
Liu & Popović

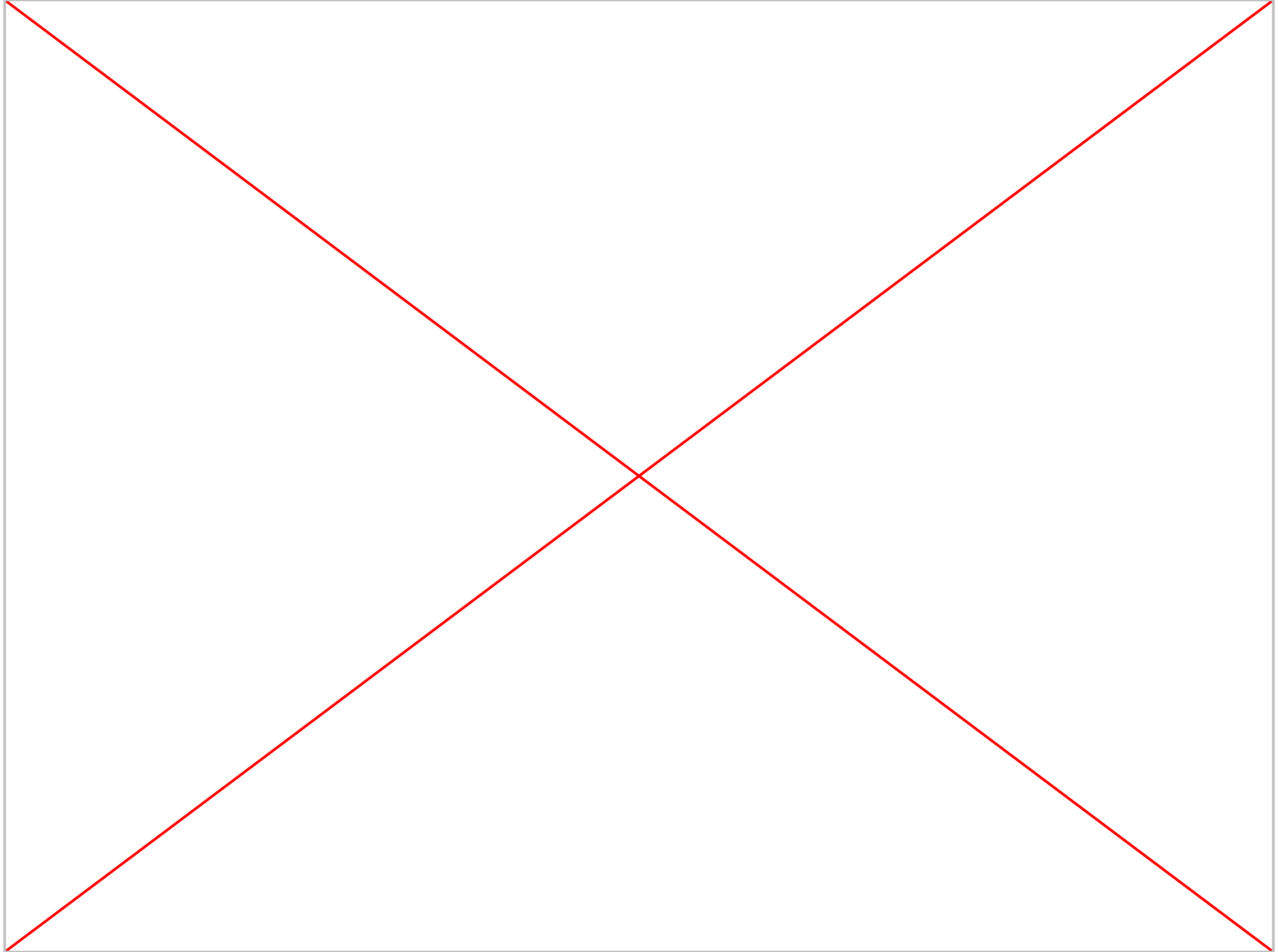
System Features

- Automatically detect point/line/plane constraints (e.g., feet in contact with ground) and unconstrained portions of animation (e.g., free flight)
- Linear and angular momentum constraints *without having to compute muscle forces*
- Minimize:
  - Mass displacement
  - Velocity of the degrees of freedom (DOF)
  - “Unbalance” (distance the COM is outside of ground constraints)



"Synthesis of Complex Dynamic Character Motion from Simple Animation", Liu & Popović, 2002





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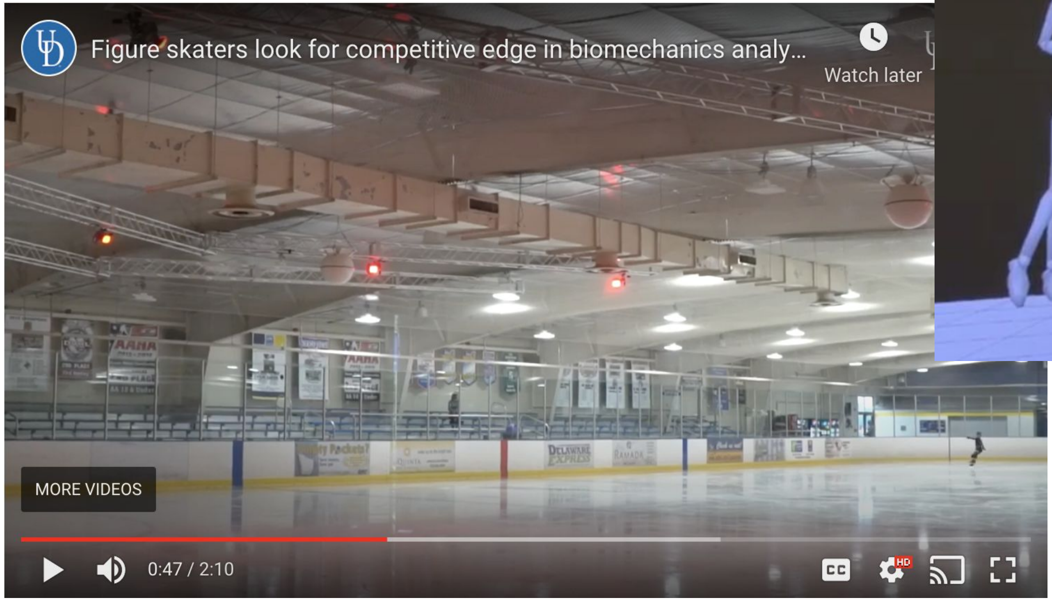
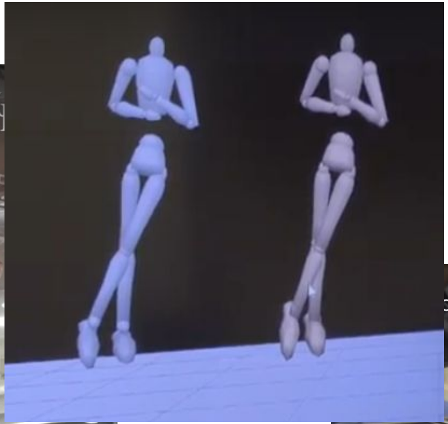
Coach Mary Figure Skating

https://www.youtube.com/channel/UCUqodbdTE3hIjfloPDn6amw
https://www.youtube.com/watch?v=eVP8r-ubbp8

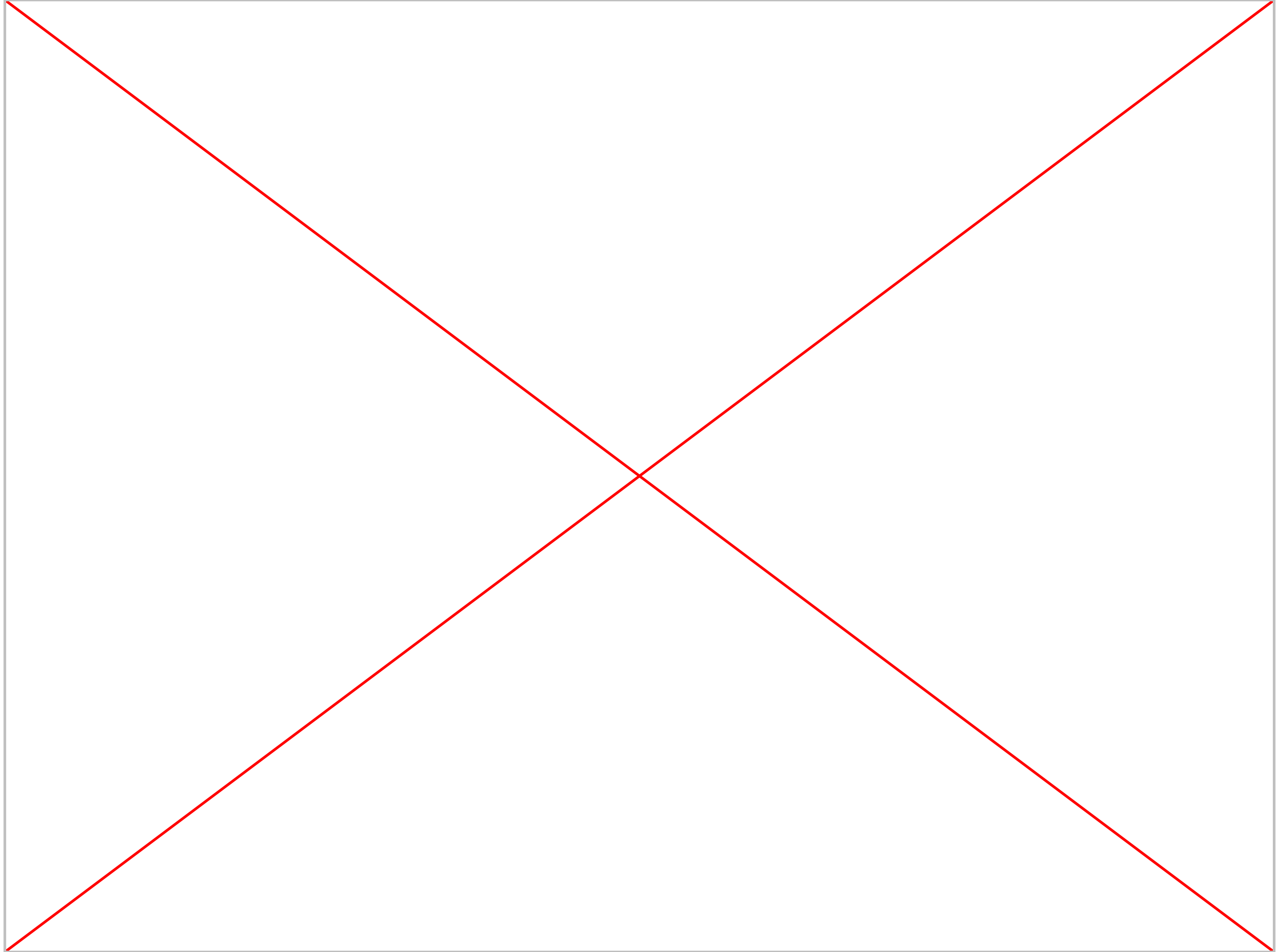

RINK
2
12:23
forward outside edge arms back knees
back shoulders and chest up right a

Figure Skating Motion Capture,
Richards Biomechanics Lab, University of Delaware, 2017





https://www.udel.edu/udaily/2017/december/figure-skating-biomechanics-olympics/



"Articulated Swimming Creatures"

Jie Tan, Yuting Gu, Greg Turk, and C. Karen Liu, SIGGRAPH 2011

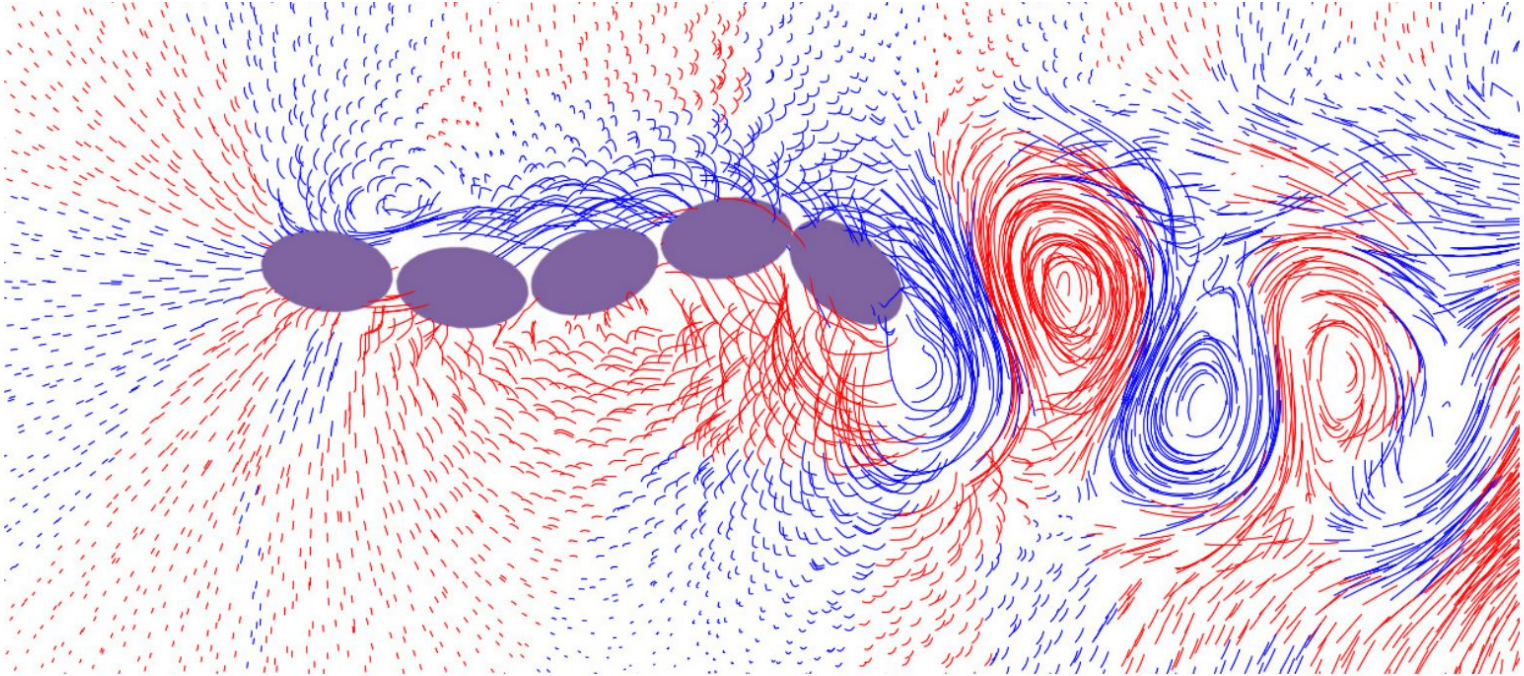


Figure 8: *A five-link eel swims in a 2D fluid environment. In contrast to the simulation in 3D, an eel swimming in 2D fluid sheds only one single vortex street. Red traces show the counter-clockwise vortices while blue traces show the clockwise vortices.*

“Flexible Muscle-Based Locomotion for Bipedal Creatures”, Geijtenbeek, van de Panne, van der Stappen, SIGGRAPH Asia 2013

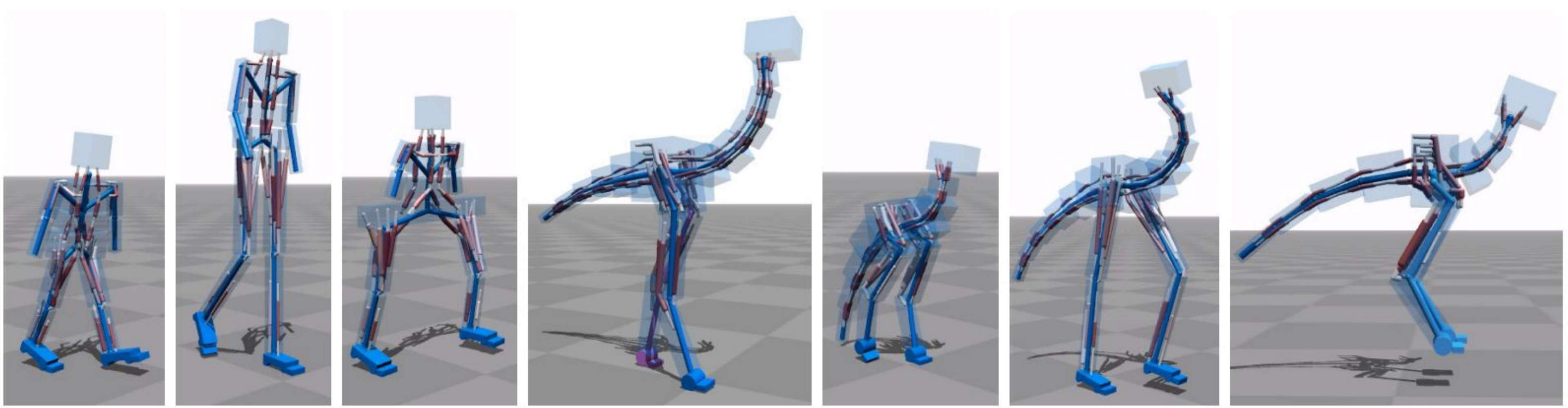


Figure 1: *Physics-based simulation of locomotion for a variety of creatures driven by 3D muscle-based control. The synthesized controllers can locomote in real time at a range of speeds, be steered to a target heading, and can traverse variable terrain.*

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Reading for Tuesday

- "An improved illumination model for shaded display" Turner Whitted, Communications of the ACM, 1980.