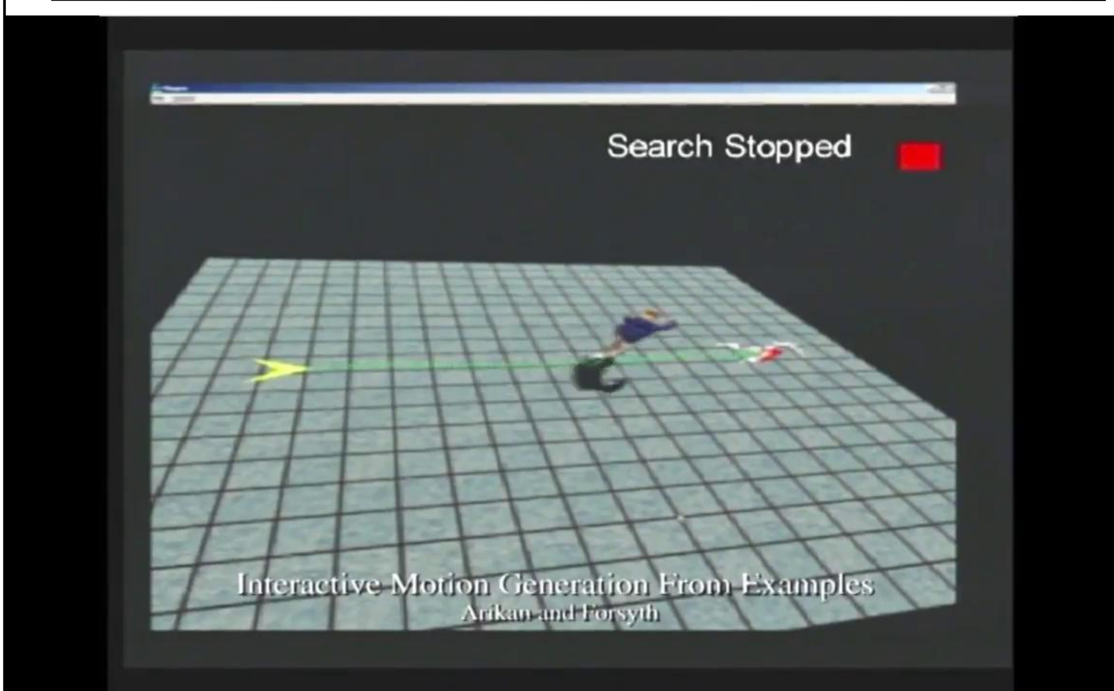
Animation, Motion Capture, & Inverse Kinematics

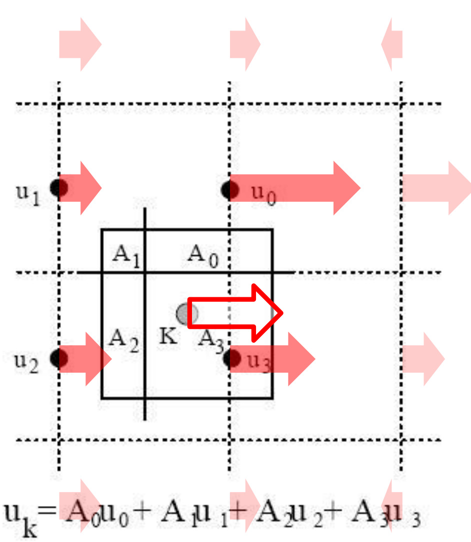
SIGGRAPH 2002 Mocap Papers

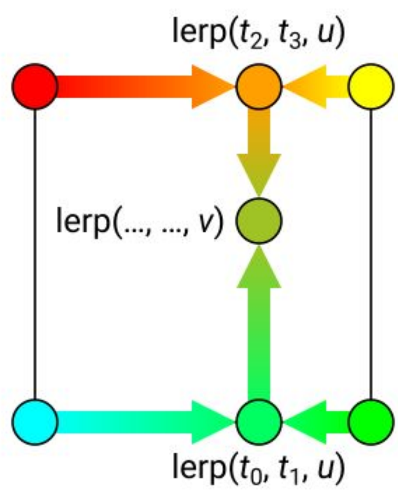


Spacetime Swing - Siggraph 1998

Velocity Interpolation

- In 2D: For each axis, find the 4 closest face velocity samples:
- (In 3D… Find 8 closest face velocities in each dimension)

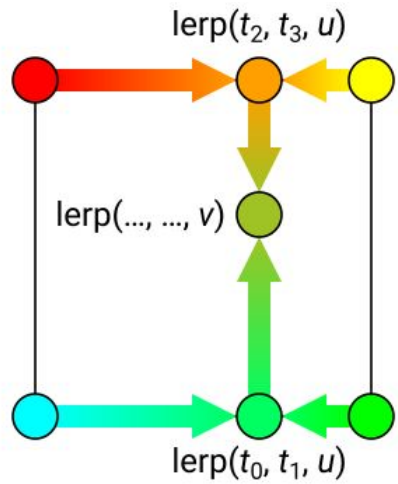




http://reedbeta.com/blog/quadrilateral-interpolation-part-2/

Bilinear Interpolation

- It might be simplest to think about one axis at a time
- It doesn't matter which axis you start with!

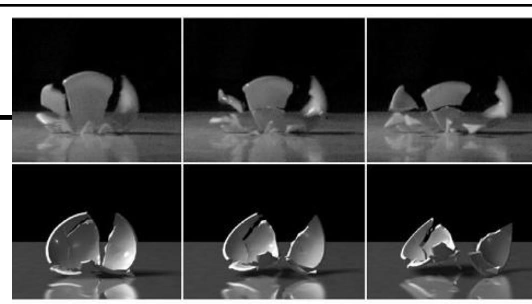
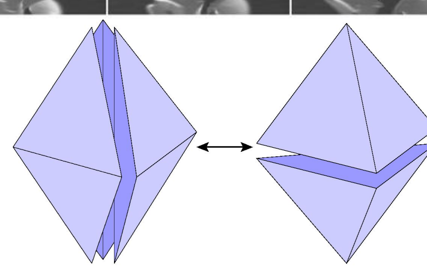
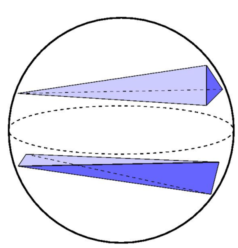


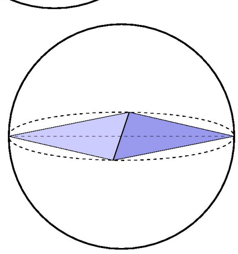
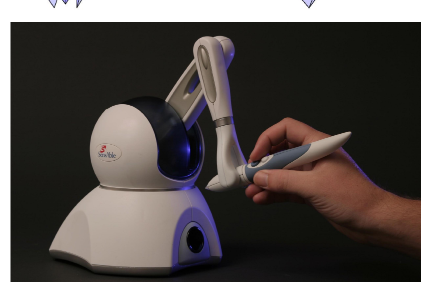
- Calculate *u*, the fraction of the distance along the horizontal axis, ***e.g., u=0.65***
- Then calculate the top & bottom averages:
  *orange = (1-u)*red + u*yellow*
  *bluegreen = (1-u)*cyan + u*green*
- Calculate *v*, the fraction of the distance along the vertical axis, ***e.g., v=0.6***
- Then calculate the final average:
  *pukegreen = (1-v)*bluegreen + v*orange*

http://reedbeta.com/blog/quadrilateral-interpolation-part-2/

Last Time?

- Tetrahedral Meshing
- Haptics
- Anisotropic Materials
- Fracture

Today: How do we Animate?

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  – Keyframing
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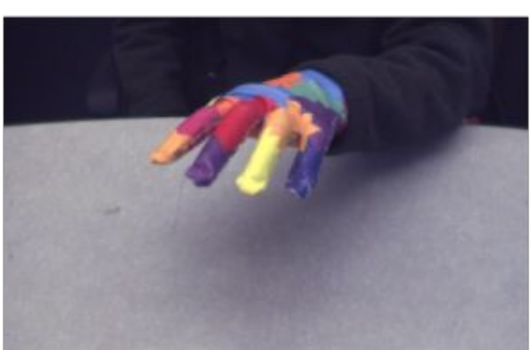
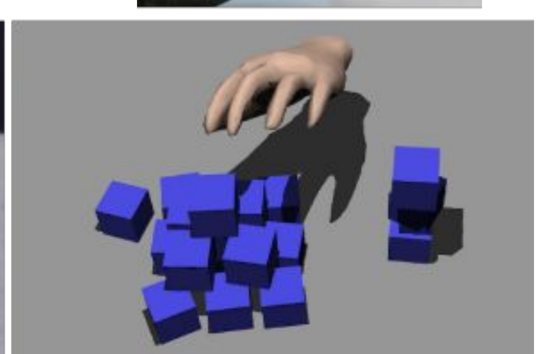
Reading for Today

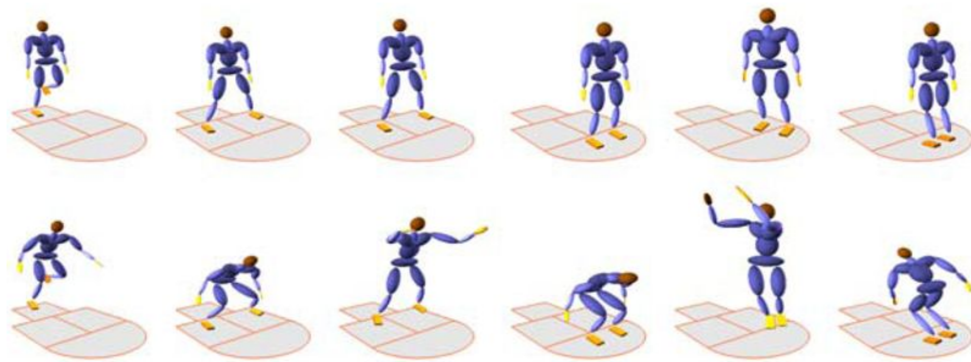
- “Real-Time Hand-Tracking with a Color Glove” SIGGRAPH 2009, Wang & Popović





Reading for Today

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



- Rapid prototyping of realistic character motion *from rough low-quality animations*
- Obey the laws of physics & stay within space of naturally-occurring movements

Reading for Today

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

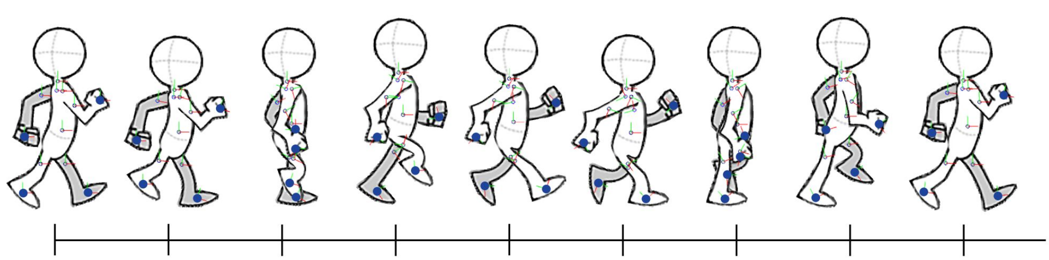


Figure 6: ***Keyframes used in the articulated character walk example.*** *The artist only specifies keyframes for a subset of handles (handles at hands and feet) which are shown as blue dots. Nine keyframes are used to create a walking cycle. Their timing is visualized by the black lines at the bottom.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

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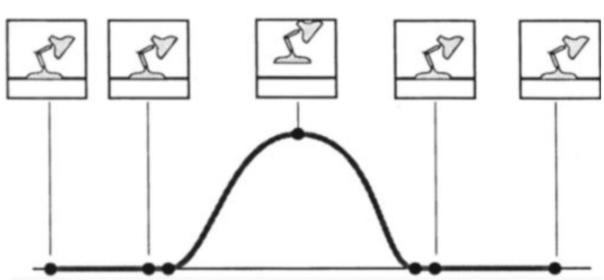
Keyframing

- Use spline curves to automate the in betweening
  - 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

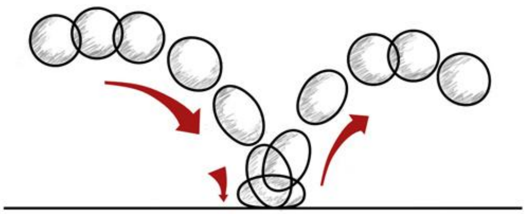


ACM © 1987 "Principles of traditional animation applied to 3D computer animation"

Disney's 12 Principles of Animation

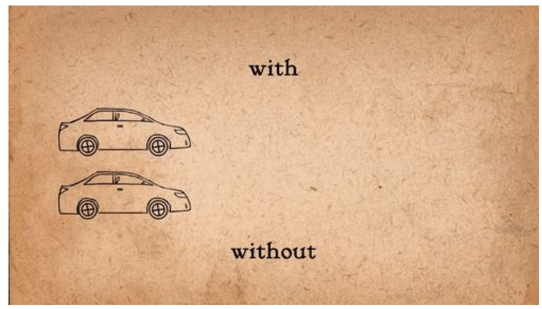
"The Illusion of Life: Disney Animation",
Ollie Johnston & Frank Thomas, 1981

Squash & Stretch



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

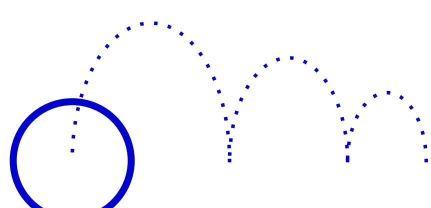
Slow In & Slow Out



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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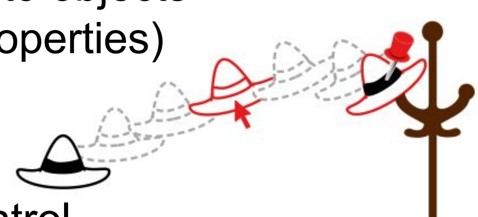
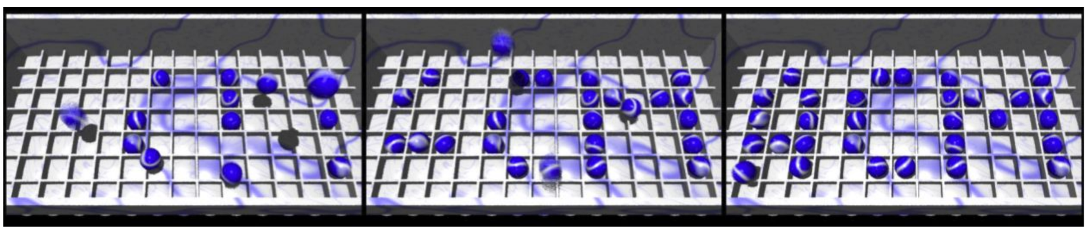
Physically-Based Animation

- 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 at high-resolution
- You must observe someone do something
- Difficult (or impossible?) to *edit* mo-cap data

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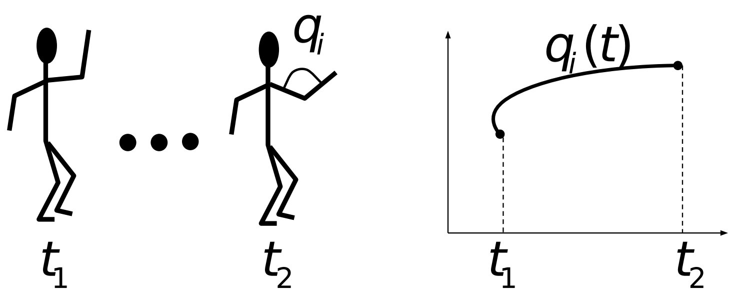
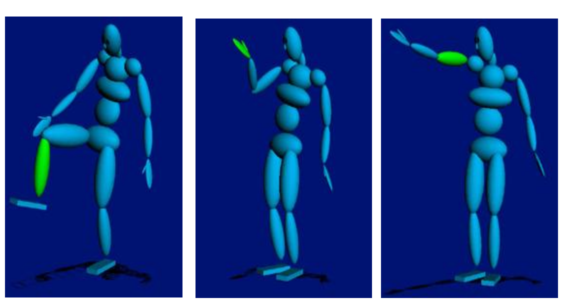
Articulated Models

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

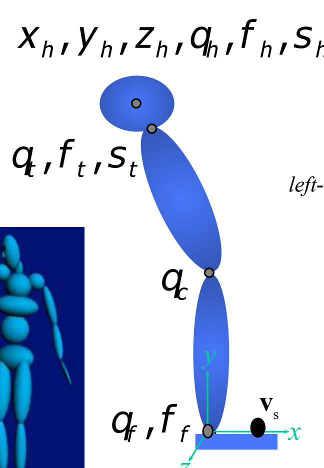


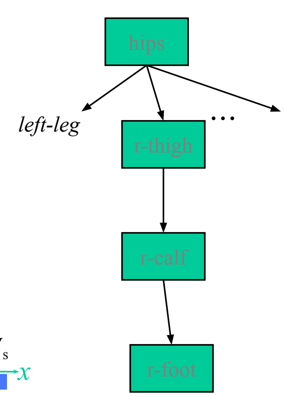
Skeleton Hierarchy

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



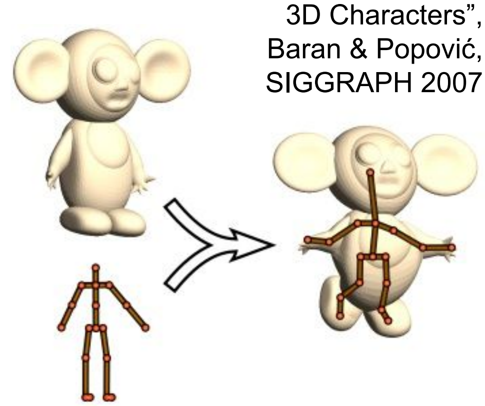
1 DOF: knee 2 DOF: wrist 3 DOF: arm





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

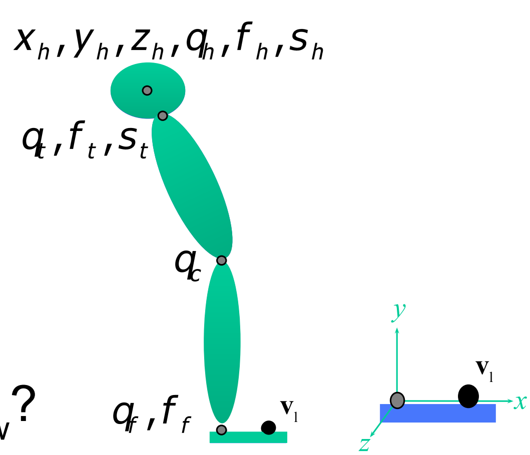


"Automatic Rigging and Animation of 3D Characters", Baran & Popović, SIGGRAPH 2007

Maya tutorial

Forward Kinematics

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



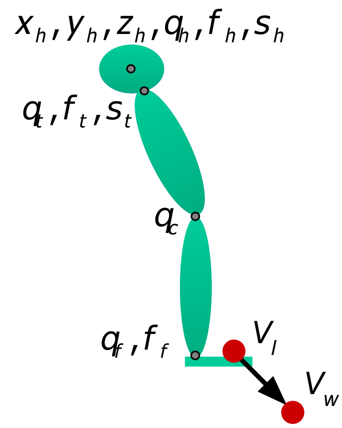
$V_w = T(x_h,y_h,z_h)R(q_h,f_h,s_h)T_hR(q_t,f_t,s_t)T_tR(q_c)T_cR(q_f,f_f)V_l$

$V_w = S(p)V_l$

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

Inverse Kinematics (IK)

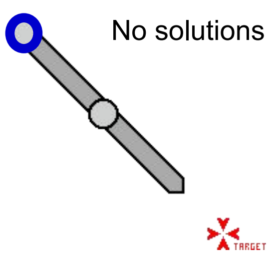
- Given the position of the effecter in local coordinates V_l and the *desired position* V_w in world coordinates, what are the skeleton parameters p?
- Much harder requires solving the inverse of the non-linear function:



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

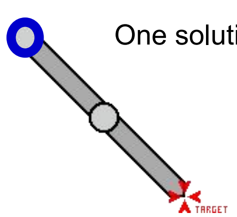
Why is this hard? Why is it non-linear?

Under-/Over- Constrained IK

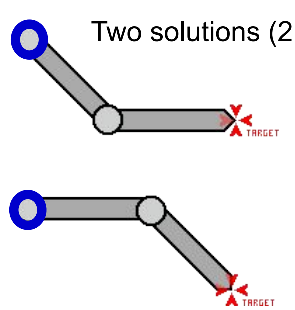


No solutions

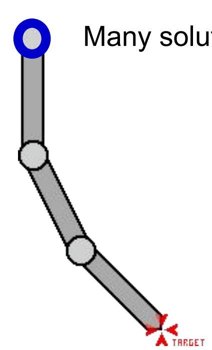
- Application: Robot Motion Planning



One solution



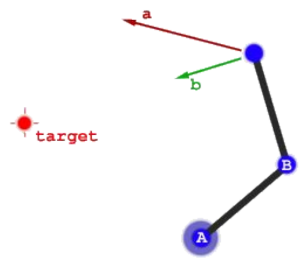
Two solutions (2D)



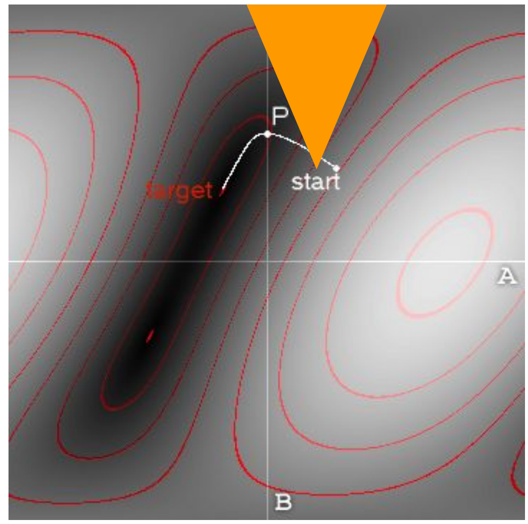
Many solutions

“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



pose space shaded by distance to target



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

"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 given 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?

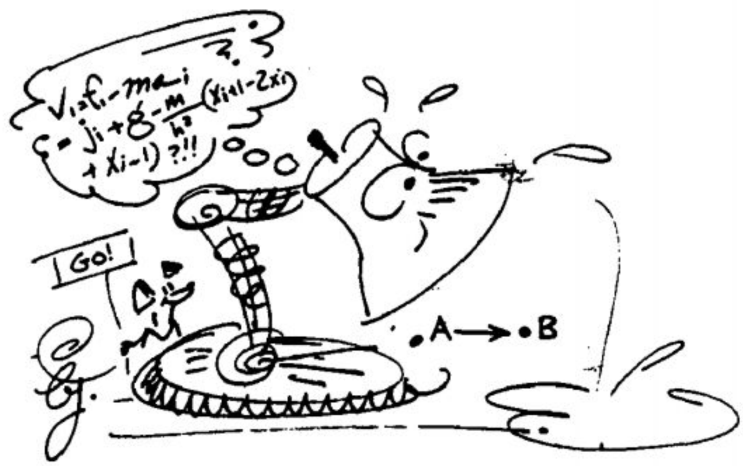


Figure 8: Spacetime constraints: a cartoonist's view. (c) 1988 by Laura Green, used by permission.

"Spacetime Constraints", Witkin & Kass, SIGGRAPH 1988

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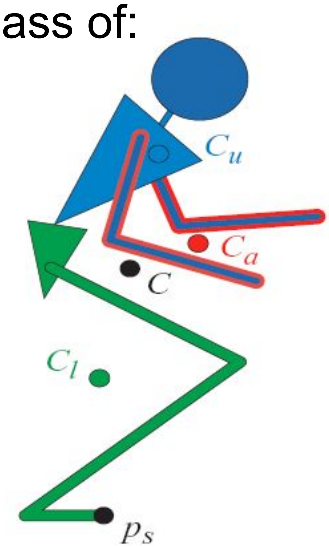
"Synthesis of Complex Dynamic Character Motion from Simple Animation", Liu & Popović, 2002

- Rapid prototyping of realistic character motion *from rough low-quality animations*
- Obey the laws of physics & stay within space of naturally-occurring movements

What's a Natural Pose?

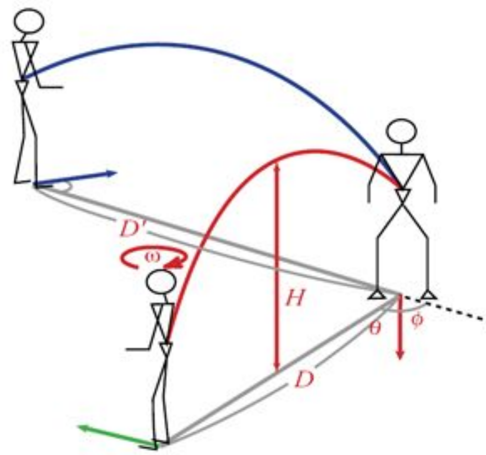
- Training database of ~50 "natural poses"
- For each, compute center of mass of:
  - Upper body
  - Arms
  - Lower body
- The relative COM of each generated pose is matched to most the most similar database example



Liu & Popović

Linear and Angular Momentum

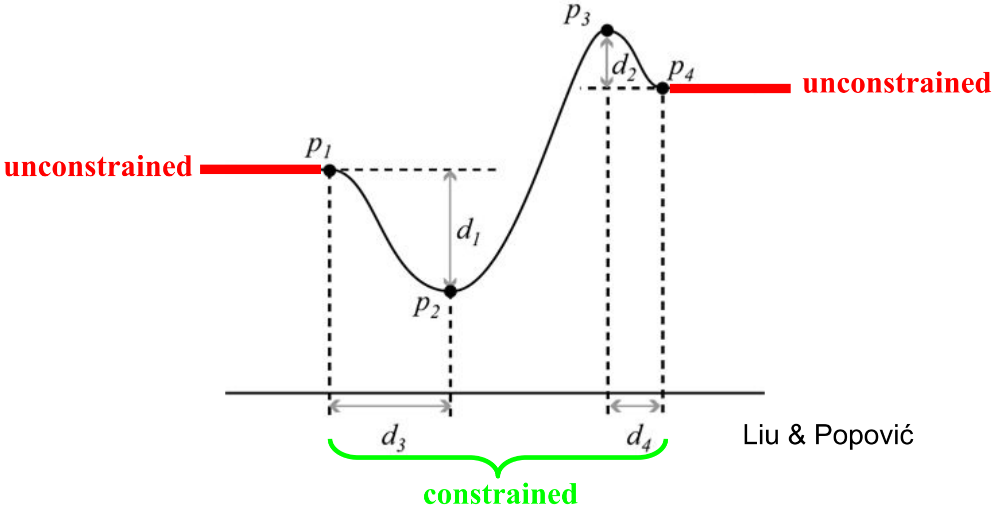
- In unconstrained animation (no contacts), both linear & angular momentum should be conserved
- The center of mass should follow a parabolic trajectory according to gravity
- The joints should move such that the angular momentum of the whole body remains constant



Liu & Popović

During Constrained Motion

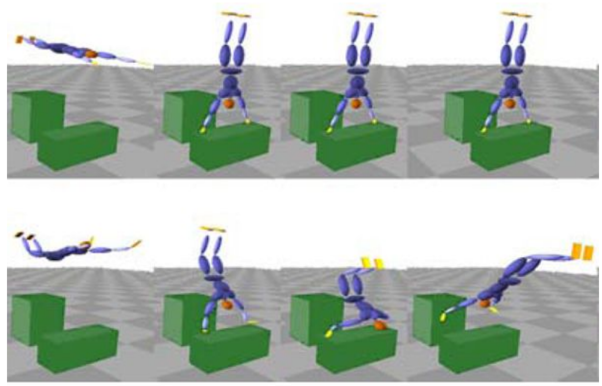
- During *constrained* motion (when in contact with the ground), the angular momentum follows a spline curve modeled after biomechanics data



Liu & Popović

System Features

- Automatically detect point/line/plane constraints
- Divide animation into constrained portions (e.g., feet in contact with ground) and unconstrained portions (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)



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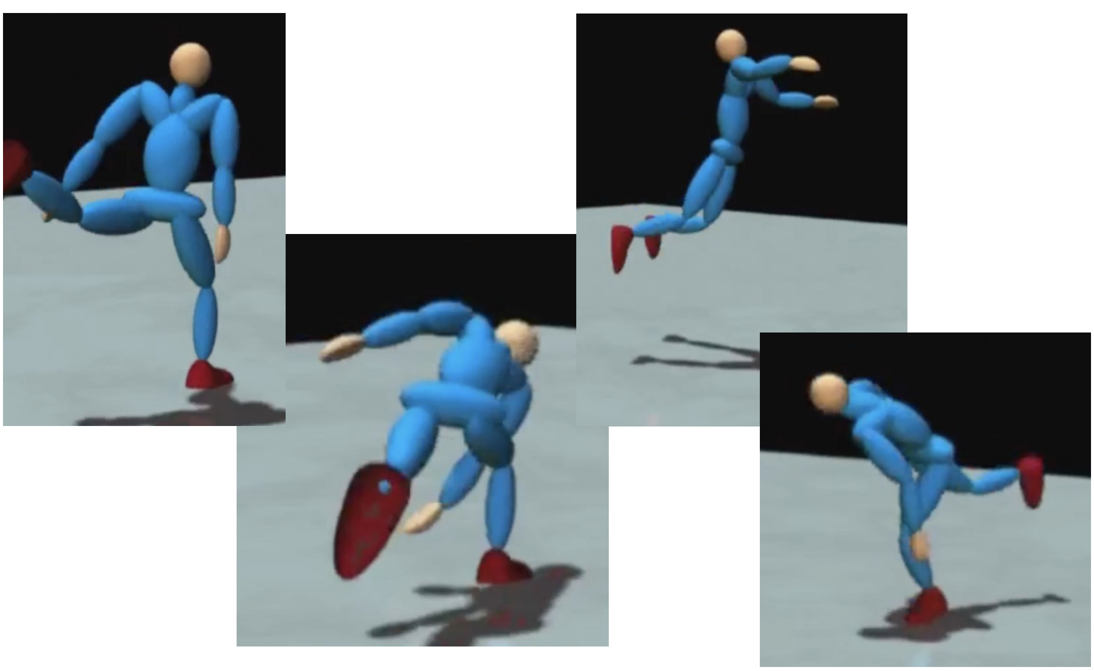

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Coach Mary Figure Skating

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

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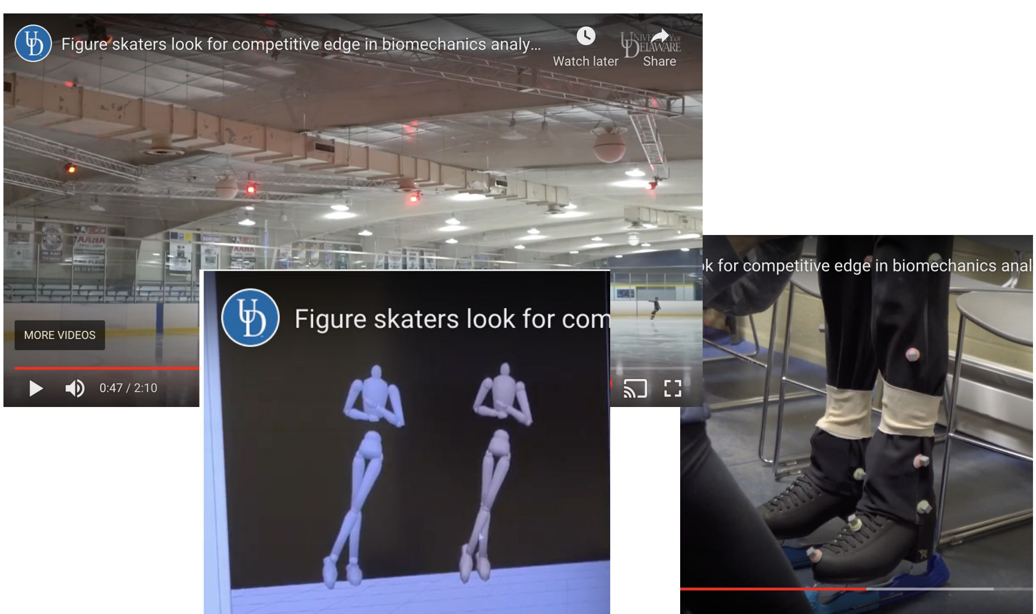
Figure Skating Motion Capture, Richards Biomechanics Lab, University of Delaware, 2017



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

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

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"Articulated Swimming Creatures" Jie Tan, Yuting Gu, Greg Turk, and C. Karen Liu, SIGGRAPH 2011

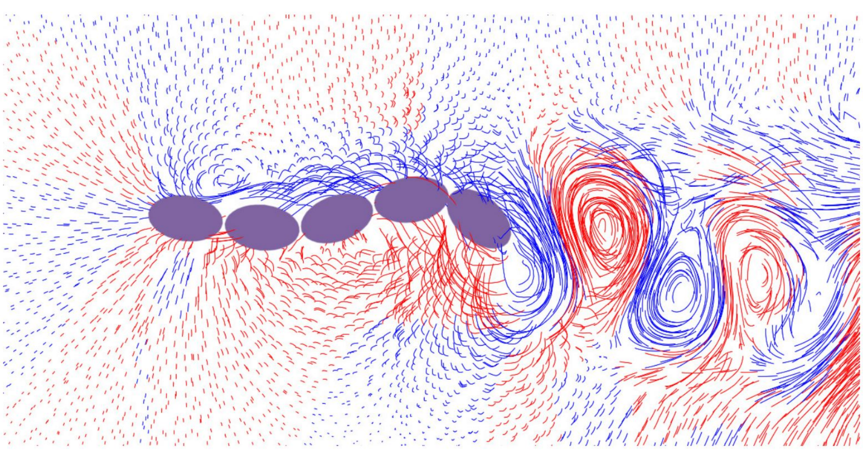

Figure 8: *A five-link eel swims in a 2D fluid environment. In contrast to the simulation in 3D, an eel swimming in 2D fluid sheds only one single vortex street. Red traces show the counter-clockwise vortices while blue traces show the clockwise vortices.*

http://www.cc.gatech.edu/~jtan34/project/articulatedSwimmingCreatures.html

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

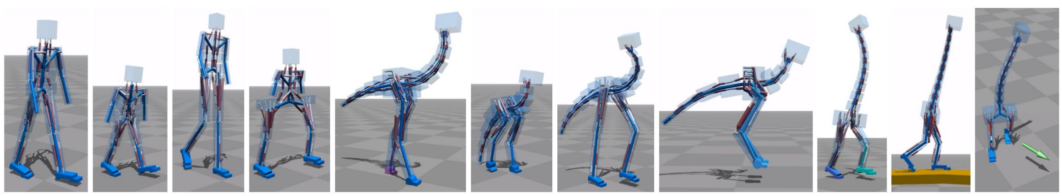

Figure 1: *Physics-based simulation of locomotion for a variety of creatures driven by 3D muscle-based control. The synthesized controllers can locomote in real time at a range of speeds, be steered to a target heading, and can traverse variable terrain.*

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Reading for Tuesday

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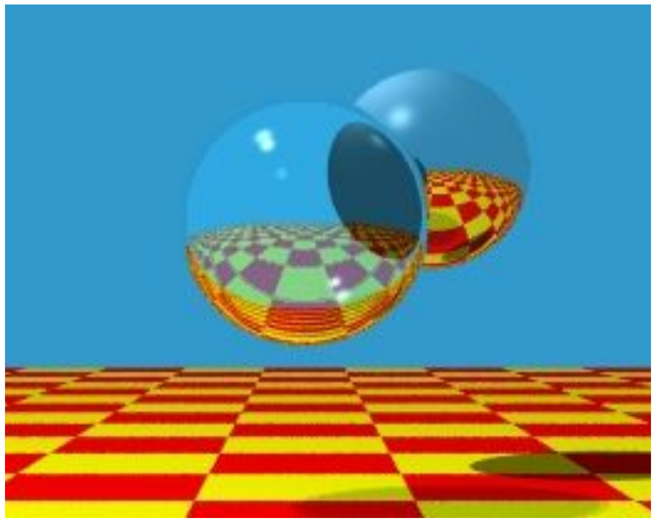

Optional Makeup/Extra Credit Reading

Also pick any paper you didn't read originally and read & post about it before Tuesday's class