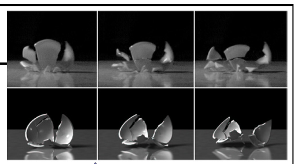
Animation, Motion Capture,
& Inverse Kinematics

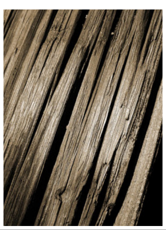
Announcements: Quiz

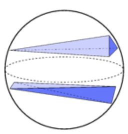
- On Friday (3/2), in class
- One 8.5x11 sheet of notes allowed
- Sample quiz (from previous year) on website
- Focus on “reading comprehension” and material for Homeworks 0, 1, & 2

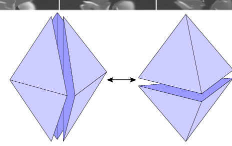
Last Time?

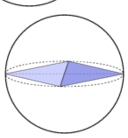
- Tetrahedral Meshing
- Haptics
- Anisotropic Materials
- Fracture

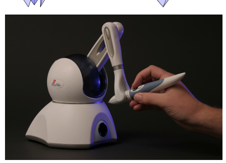






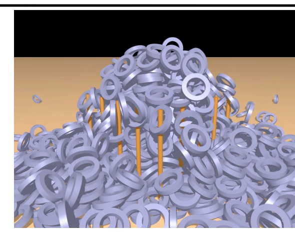


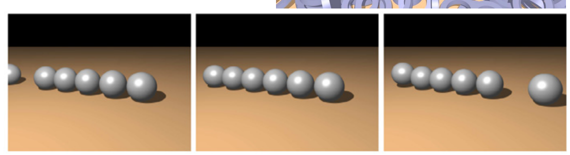




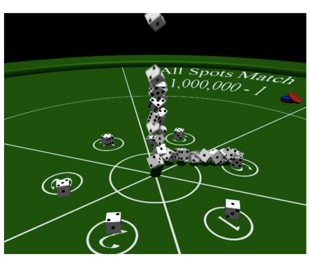
Reading from Last Time:

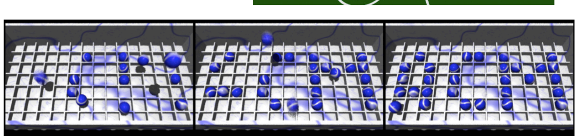
Guendelman, Bridson, & Fedkiw
“Nonconvex Rigid Bodies with Stacking”
SIGGRAPH 2003





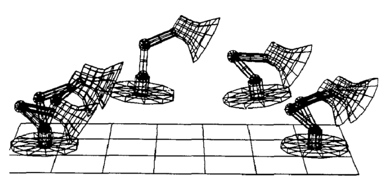
“Sampling Plausible Solutions to Multi-body Constraint Problems”
Chenney & Forsyth, SIGGRAPH 2000





Today: How do we Animate?

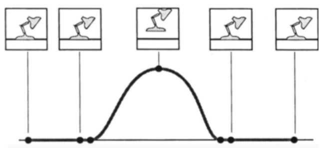
- Keyframing
- Procedural Animation
- Physically-Based Animation
- Motion Capture
- Skeletal Animation
- Forward and Inverse Kinematics



“Spacetime Constraints”, Witkin & Kass, SIGGRAPH 1988

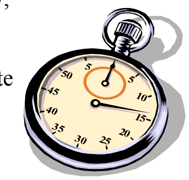
Keyframing

- 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

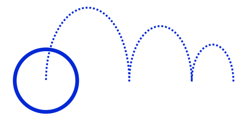


ACM © 1987 "Principles of traditional animation applied to 3D computer animation"

Procedural Animation

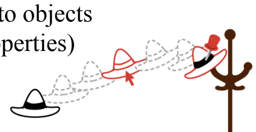


- Describes the motion algorithmically, as a function of small number of parameters
- Example: a clock with second, minute and hour hands
  - express the clock motions in terms of a "seconds" variable
  - the clock is animated by varying the seconds parameter
- Example: A bouncing ball
  - $Abs(sin(\omega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



Physically-Based Animation

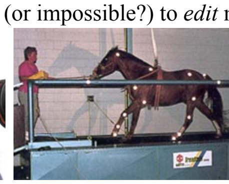
- Assign physical properties to objects (masses, forces, inertial properties)
- Simulate physics by solving equations
- Realistic, but difficult to control
- Used for *secondary motions* (hair, cloth, scattering, splashes, breaking, smoke, etc.) that respond to primary *user controlled* animation



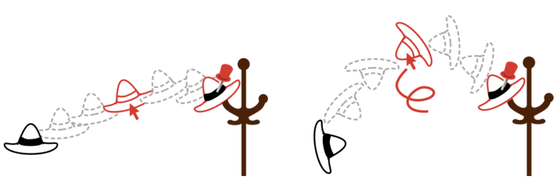
"Interactive Manipulation of Rigid Body Simulations"
SIGGRAPH 2000, Popović, Seitz, Erdmann, Popović & Witkin

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



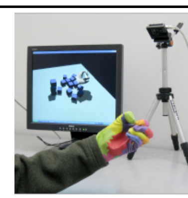
Reading for Today:

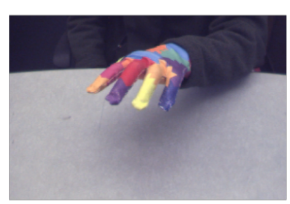


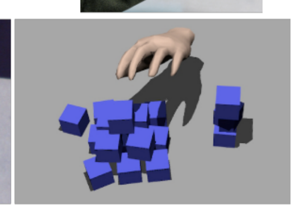
"Interactive Manipulation of Rigid Body Simulations"
SIGGRAPH 2000, Popović, Seitz, Erdmann, Popović & Witkin

Reading for Today:

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







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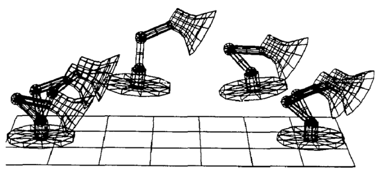
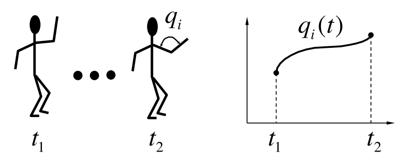


"Spacetime Constraints", Witkin & Kass, SIGGRAPH 1988

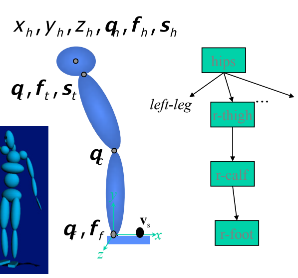
Articulated Models

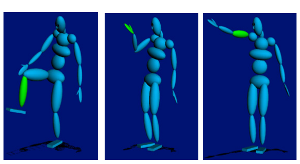
- Articulated models:
  - rigid parts
  - connected by joints
- They can be animated by specifying the joint angles as functions of time.



Skeleton Hierarchy

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



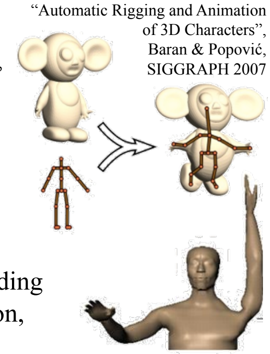


1 DOF: knee 2 DOF: wrist 3 DOF: arm

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 time is spent building the 3D models, its skeleton, and its controls

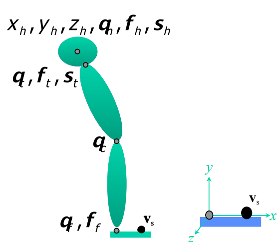
"Automatic Rigging and Animation of 3D Characters", Baran & Popović, SIGGRAPH 2007



Maya tutorial

Forward Kinematics

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

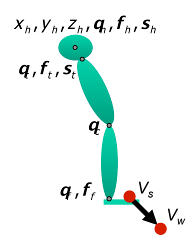


$V_w = T(x_h,y_h,z_h)R(q_h,f_h,s_h)T_hR(q_t,f_t,s_t)T_tR(q_c)T_cR(q_f,f_f)V_s$

$V_w = S(p)V_s$

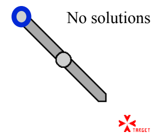
Inverse Kinematics (IK)

- Given the position of the effecter in local coordinates V_s 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:

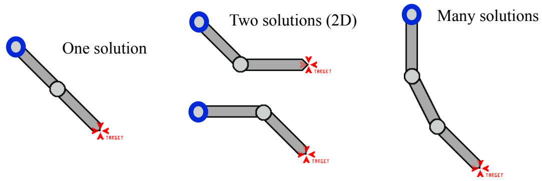


find p *such that* $S(p)V_s = V_w$

Under-/Over- Constrained IK

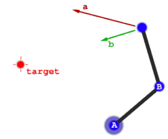


- Application: Robot Motion Planning

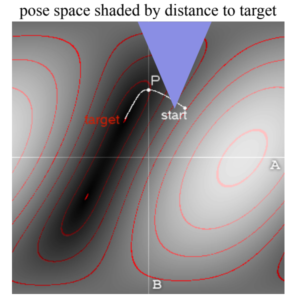


"The good-looking textured light-sourced bouncy fun smart and stretchy page"
Hugo Elias, `http://freespace.virgin.net/hugo.elias/models/m_ik.htm`

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?

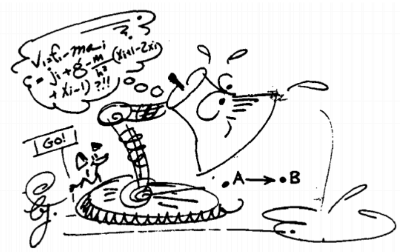
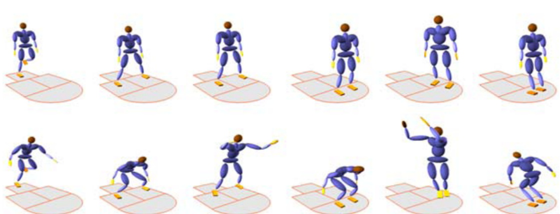


Figure 8: Spacetime constraints: a cartoonist's view. (c) 1988 by Laura Green, used by permission.

"Spacetime Constraints", Witkin & Kass, SIGGRAPH 1988

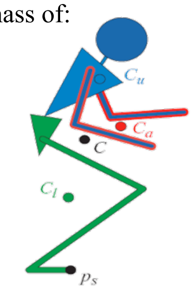
"Synthesis of Complex Dynamic Character Motion from Simple Animation", Liu & Popović, 2002.



- 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?

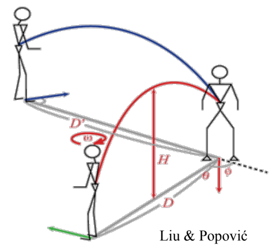
- Training database of ~50 "natural poses"
- For each, compute center of mass of:
  - Upper body
  - Arms
  - Lower body
- The relative COM of each generated pose is matched to most the most similar database example



Liu & Popović

Linear and Angular Momentum

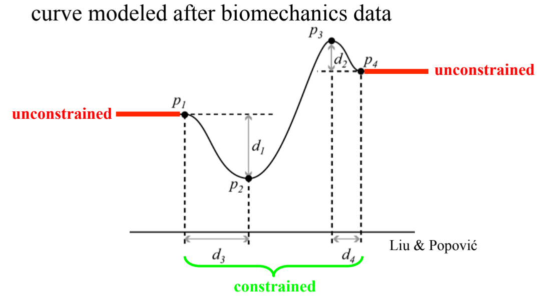
- In unconstrained animation (no contacts), both linear & angular momentum should be conserved
- The center of mass should follow a parabolic trajectory according to gravity
- The joints should move such that the angular momentum of the whole body remains constant



Liu & Popović

During Constrained Motion

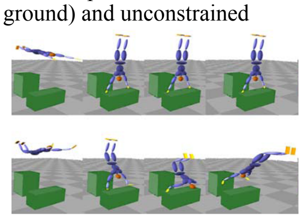
- During *constrained* motion (when in contact with the ground), the angular momentum follows a spline curve modeled after biomechanics data



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 projected to ground is outside of constraints)



Readings for Tuesday 3/1: *read one for Tuesday, read other before HW3*

- "An improved illumination model for shaded display" Turner Whitted, 1980.
- "Distributed Ray Tracing", Cook, Porter, & Carpenter, SIGGRAPH 1984.