

Animation, Motion Capture, & Inverse Kinematics

Last Time?

- Navier-Stokes Equations
- Conservation of Momentum & Mass
- Incompressible Flow

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial uv}{\partial y} + \frac{\partial uw}{\partial z} = -\frac{\partial p}{\partial x} + g_x + \nu(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2})$$

$$\frac{\partial v}{\partial t} + \frac{\partial vu}{\partial x} + \frac{\partial v^2}{\partial y} + \frac{\partial vw}{\partial z} = -\frac{\partial p}{\partial y} + g_y + \nu(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2})$$

$$\frac{\partial w}{\partial t} + \frac{\partial wu}{\partial x} + \frac{\partial wv}{\partial y} + \frac{\partial w^2}{\partial z} = -\frac{\partial p}{\partial z} + g_z + \nu(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2})$$

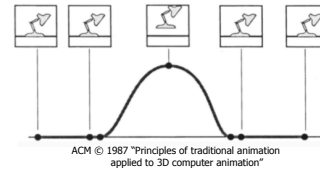
Today

- How do we animate?
 - Keyframing
 - Procedural Animation
 - Physically-Based Animation
 - Motion Capture
 - Forward and Inverse Kinematics
- Rigid Body Dynamics
- Finite Element Method



Keyframing

- Use spline curves to automate the in between
 - Good control
 - Less tedious than drawing every frame
- Creating a good animation still requires considerable skill and talent



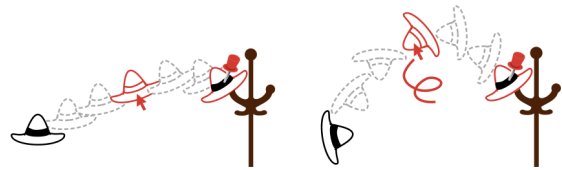
Procedural Animation

- 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

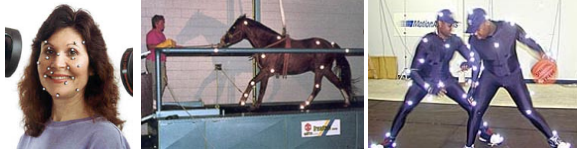
- Assign physical properties to objects (masses, forces, inertial properties)
- Simulate physics by solving equations
- Realistic but difficult to control



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

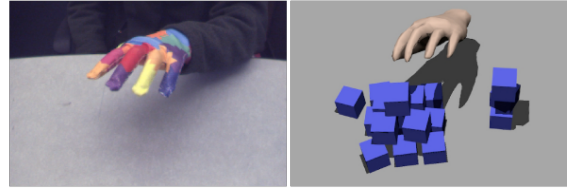
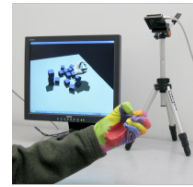
Motion Capture

- Optical markers, high-speed cameras, triangulation → 3D position
- Captures style, subtle nuances and realism
- You must observe someone do something



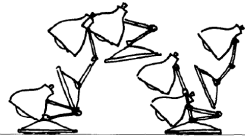
Reading for Today:

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



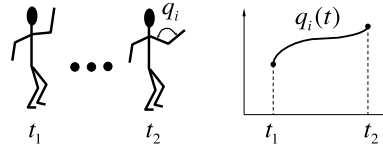
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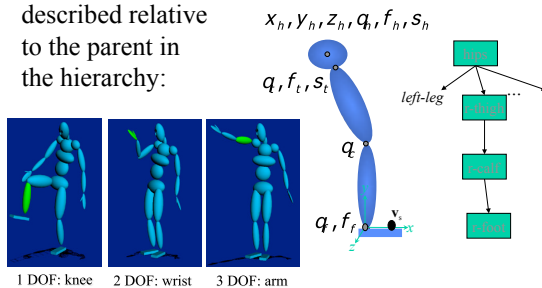
Articulated Models

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



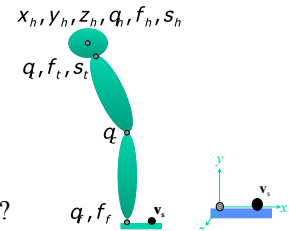
Skeleton Hierarchy

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



Forward Kinematics

- Given skeleton parameters p_i and the position of the effector in local coordinates V_{s_i} , what is the position of the effector in the world coordinates V_w ?

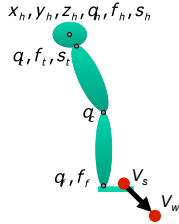


$$V_w = T(x_h, y_h, z_h)R(q_h, f_h, s_h)T_h R(q_i, f_i, s_i)T_i R(q_c)T_c R(q_i, f_i) V_s$$

$$V_w = S(p) V_s$$

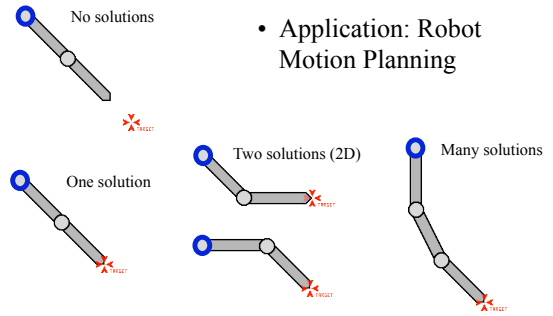
Inverse Kinematics (IK)

- Given the position of the effector 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 $S(p)V_s = V_w$

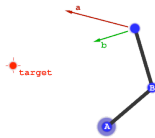
Under-/Over- Constrained IK



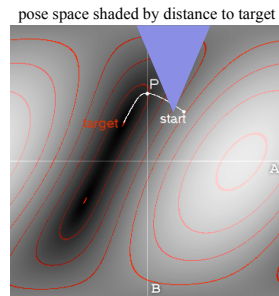
- Application: Robot Motion Planning

"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



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



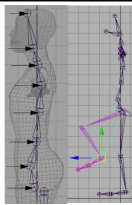
"The good-looking textured light-sourced bouncy fun smart and stretchy page"
Hugo Elias, http://freespace.virgin.net/hugo.elias/models/m_ik2.htm

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

How do they Animate Movies/Games?

- Many studios still use keyframing
- Articulated figures, inverse kinematics, motion capture, crowd simulation
- 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
- Physical simulation for secondary motion
 - Hair, cloth, water



Images from the Maya tutorial

Questions?

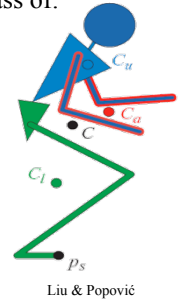
“Synthesis of Complex Dynamic Character Motion from Simple Animation”, Liu & Popović, 2002.



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

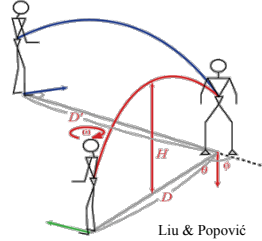
What’s a Natural Pose?

- 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



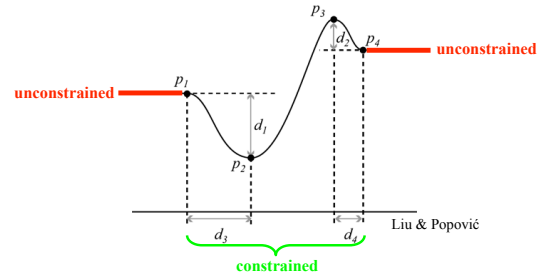
Linear and Angular Momentum

- 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



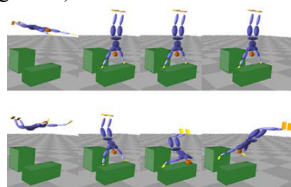
During Constrained Motion

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



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)



Questions?

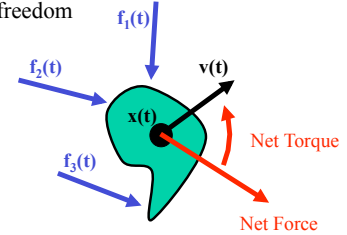
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- **Finite Element Method**



Rigid Body Dynamics

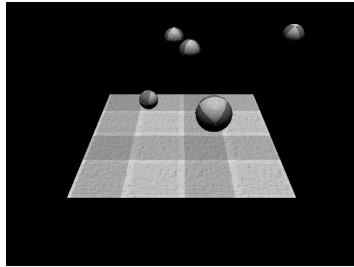
- Could use particles for all points on the object
 - But rigid body does not deform
 - Few degrees of freedom
- Use only one particle at the center of mass
- Compute Net Force & Net Torque



Nice Reference Material: <http://www.pixar.com/companyinfo/research/pbm2001/>

Rigid Body Dynamics

- Physics
 - Velocity
 - Acceleration
 - Angular Momentum
- Collisions
- Friction



from: Darren Lewis

<http://www-cs-students.stanford.edu/~dalewis/cs448a/rigidbody.html>

See also: <http://www.myphysicslab.com/collision.html>

Simulation of Non-Rigid Objects

- We modeled string & cloth using mass-spring systems. Can we do the same for deformable solids?
- Yes... But a more physically accurate model uses *volumetric elements*:

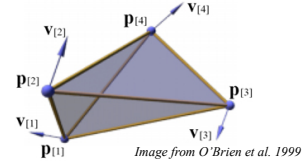
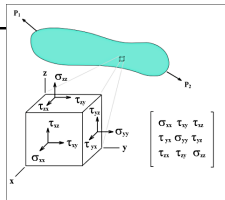


Image from O'Brien et al. 1999

Strain & Stress

- Stress
 - the internal distribution of forces within a body that balance and react to the loads applied to it
 - *normal stress & shear stress*
- Strain
 - material deformation caused by stress.
 - measured by the change in length of a line or by the change in angle between two lines



http://en.wikipedia.org/wiki/Image:Stress_tensor.png

$$\epsilon = \frac{\Delta l}{l_0}$$

Finite Element Method

- To solve the continuous problem (deformation of all points of the object)
 - Discretize the problem
 - Express the interrelationship
 - Solve a big linear system
- More principled than Mass-Spring

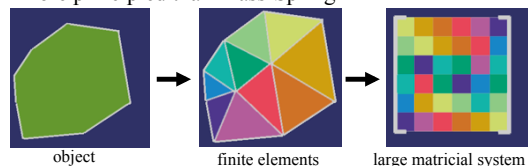
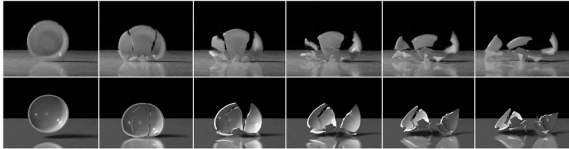


Diagram from Debunne et al. 2001

Reading for Tuesday 3/2:

- James O'Brien & Jessica Hodgins "*Graphical Modeling and Animation of Brittle Fracture*" SIGGRAPH 1999.



- Post a comment or question on the LMS discussion by 10am on Friday 2/15