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

Animation, Motion Capture, & Inverse Kinematics

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

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
  - $\text{Abs}(\sin(\omega t + \theta_0))e^{-kt}$

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

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
Today: How do we Animate?

- Keyframing
- Procedural Animation
- Physically-Based Animation
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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:

Skeleton 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

Forward Kinematics

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

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

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**

- No solutions
- One solution (2D)
- 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](http://freespace.virgin.net/hugo.elias/models/m_ik.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

\[
\text{Force: Newton (N)} = \text{kg} \times \text{m} / \text{s}^2
\]
\[
\text{Work: Joule (J)} = \text{N} \times \text{m} = \text{kg} \times \text{m}^2 / \text{s}^2
\]
\[
\text{Power: Watt (W)} = \text{J/s} = \text{kg} \times \text{m}^2 / \text{s}^3
\]

**Questions?**

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Figure 8: Spacetime constraints: a cartoonist’s view. (c) 1988 by Laura Green, used by permission.
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“Spacetime Constraints”, Witkin & Kass, SIGGRAPH 1988

**Searching Configuration Space**

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

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Hugo Elias, [http://freespace.virgin.net/hugo.elias/models/m_ik2.htm](http://freespace.virgin.net/hugo.elias/models/m_ik2.htm)

**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.

![Diagram of linear and angular momentum](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.

![Diagram of constrained motion](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).

![Diagram of system features](Liu & Popović)

### Readings for Tuesday 3/1: