CMSC 498M: Chapter 6
Modeling and Animation

Reading: (Not covered in our readings).
- Some material from Lecture Notes for by Steve Rotenberg at UCSD.

Overview:
- Animation basics and skeletal animation
- Skin and Bones
- Binding
- Motion blending

Kinematics & Dynamics

Forward Kinematics:
- Given a hierarchical scene graph and **joint angles** for an articulated structure, find the **locations of all end points**.

Inverse Kinematics:
- Given the positions of the root, end points, and lengths, **find a self-consistent set of joint angles**.
- **Much harder than forward kinematics**, multiple solutions possible.

Dynamics:
- Given initial **positions and forces**, compute the **final positions**.

Animation packages (e.g., Maya, Lightwave, Kinetix):
- Support for **kinematics** and **dynamics**.
- Limited support for **inverse kinematics**.

Skeletal Animation

Skeleton:
- Objects represented as **hierarchy of bones and joints**.
- Joints and their **types** (e.g., hinge, universal, ball and socket).
- Joint **degrees of freedom** (rotation axes).
- **Limits** on movement may be given.

Skin:
- Provides **smoothing**, **filling**, and **blending**.

Binding:
- **Correspondence** between skeleton and skin geometries.

Discussion:
- **Space efficient**, since only skeleton joints needs to be animated.
- Hierarchical structure of skeleton works well with **scene graphs**.
- Challenge is in making **skin movement appear natural**.

Character Animation

Skeleton

Skin

Binding

Motion Blending

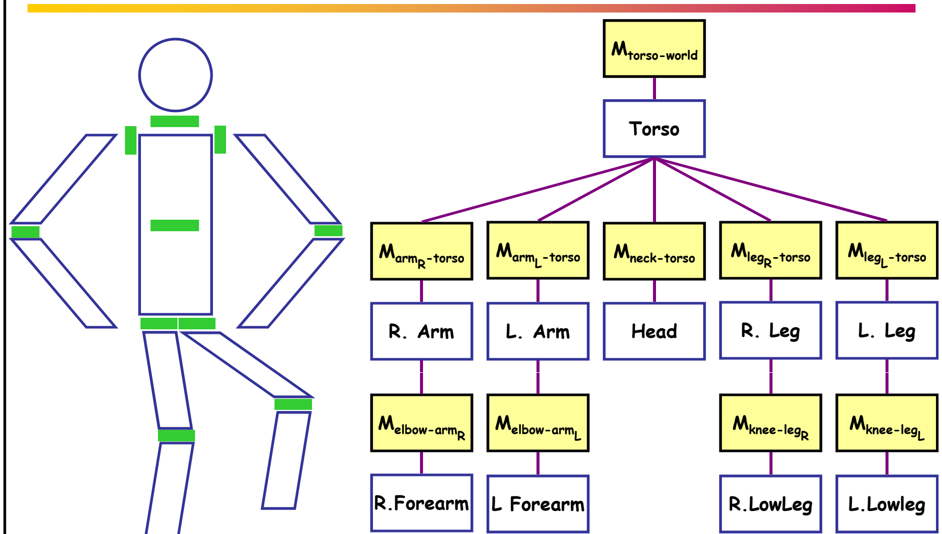
Skeletal Animation

Skeleton:
- A **pose-able framework of joints** arranged in a **tree structure**.
- An invisible **armature** upon which to attach the **skin** and other **geometric data** of the character.

Joint:
- A joint allows **relative movement** within the skeleton.
- Each joint is represented by a **transformation** (4x4 matrix).
- Joints can be **rotational**, **translational**, or some non-realistic types as well.

Bone:
- Bones connect joints. Skin is **placed relative to the bones**.
- In many systems joints are the main entities, **bones are implicit**.
- For example, one might refer to the **shoulder joint** or **upper arm bone** (humerus) and mean the same thing.

Character Skeleton



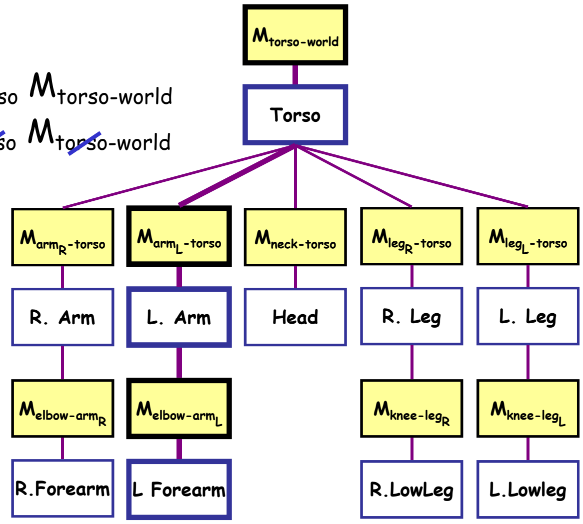
Character Skeleton: Forward Kinematics

Position of left arm:

$$M_{\text{elbow-arm}_L}\; M_{\text{arm}_L\text{-torso}}\; M_{\text{torso-world}}$$

$$= M_{\text{elbow-}\cancel{\text{arm}_L}}\; M_{\cancel{\text{arm}_L}\text{-}\cancel{\text{torso}}}\; M_{\cancel{\text{torso}}\text{-world}}$$

$$= M_{\text{elbow-world}}$$



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Character Skeleton: Animation

Moving the Joints:

- **Mapping Angles to Positions**: Each matrix is parameterized by its rotational **degrees of freedom**, each constrained to lie within some given **angular limits**:
  - E.g., $M_{\text{knee-Rleg}} = R_x(\varphi)$, where $-180^\circ \le \varphi \le 0^\circ$.
  - Each joint matrix also encodes a **joint offset** (length of the bone), thus in fact, $M_{\text{knee-Rleg}} = T(len) \cdot R_x(\varphi)$.
- **Animating Joints**: To generate the animation each joint's **motion parameter** (say the joint angle, $\varphi(t)$) is changed from **frame to frame**.
- **Joint Angles**: Changes (velocities, accelerations, etc) are specified by a **higher-level animation system** (e.g., keyframe, motion capture, or procedural).

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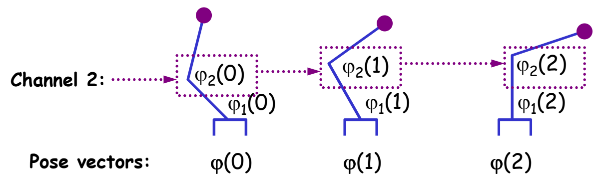
Character Skeleton: Animation

Pose:
- A list of parameters $\varphi = (\varphi_1, \varphi_2, \ldots, \varphi_n)$ defining the various **joint angles** of the skeleton.

Channel:
- A sequence of parameters for a **single joint angle** $\varphi_i(t)$.
- Often use **parametric curves** (Bezier, B-spline, NURBS, …) to edit, interpolate, approximate, or compress.

Animation:
- An array of **poses** $\varphi(t)$ or an array of **channels** $(\varphi_1(t), \varphi_2(t), \ldots, \varphi_n(t))$.
- Tradeoff **memory access coherence** vs. **CPU computation**.



Computer Animation

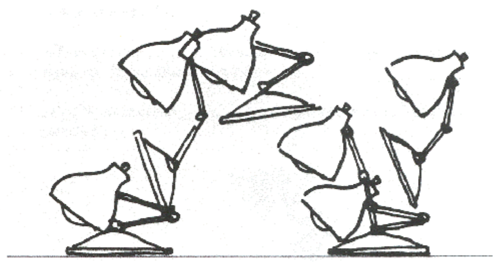
- Key-frame animation
- Procedural Animation
- Motion capture

Keyframe Animation

Keyframe Animation:

- Main animator draws a few **key frames**.
- Others (artists or computers) draw **intermediate frames**.
- Drawing is simplified by drawing layers of the scene on **translucent cels** (celular animation), superimposing, and photographing them.
- Traditional approach to **animation in movies**.

Pixar's "Luxo Jr."

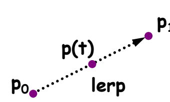


Interpolating Key Frames

Interpolation Methods:

Linear Interpolation: (**lerp**) Take weighted averages.

$$\mathbf{p}(t) = (1-t)\mathbf{p}_0 + t\mathbf{p}_1, \quad \text{for } 0 \le t \le 1.$$



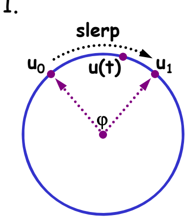
Appropriate for points, but not for angles.

Spherical Interpolation: (**slerp**) Let φ denote the angle between the unit vectors $\mathbf{u}_0$ and $\mathbf{u}_1$ ($\varphi = \mathrm{acos}(\mathbf{u}_0 \cdot \mathbf{u}_1)$). The spherical interpolation is given by:

$$\mathbf{u}(t) = \frac{\sin((1-t)\varphi)}{\sin\varphi}\mathbf{u}_0 + \frac{\sin(t\varphi)}{\sin\varphi}\mathbf{u}_1, \quad \text{for } 0 \le t \le 1.$$

Normalized Lerp: (**nlerp**) Do a lerp, then normalize to unit length. A quick-and-dirty cheat for slerp.

$$\mathbf{u}'(t) = (1-t)\mathbf{u}_0 + t\mathbf{u}_1; \quad u(t) = \frac{u'(t)}{\|u'(t)\|}, \quad \text{for } 0 \le t \le 1.$$



Interpolating Key Frames

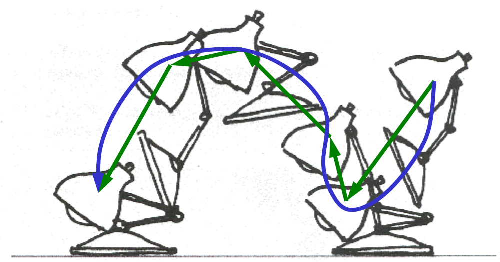
Smoother Interpolation:

Why: A sequence of linear interpolations joined end-to-end can result in sudden **changes in speed** at joint points.

Better: Use **B-Spline** or **Bezier curves** to interpolate position.

Objectives: Local control, smooth motion, robustness.

Challenge: Maintain the right **balance** between interpolated position and timing (controlling velocity and acceleration). Almost an **art**.



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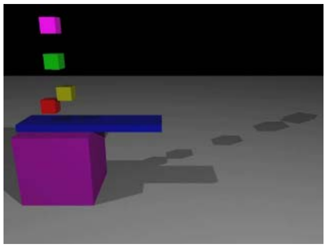
Procedural Animation

Procedural Animation:

- Specify the motion in terms in purely **mathematical terms** (e.g. equations, procedures, solution of differential equations).
- Usually best for **natural objects/scenes**:
  - Smoke, fire, explosions via **particle systems**.
  - **Physical simulations** like collisions.
  - **Periodical motion** like waves in water, blinking eyes, walking.
- Add **random noise** to periodic motion.
  - Players notice identical gait/blink cycles.
- Tricky to **fine tune** parameters to produce natural-looking motion.



Source: Kaufman, Edmunds, and Pai (SIGGRAPH 2005)

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Motion Capture

Motion Capture:

- Attach **virtual reality trackers** on a person or use cameras and attach **markers** on the person.
- **Record tracker/marker motion** and play back the motion.

Pros: Real-time, easy to capture **complex human motions**.

Cons: May **not be feasible**. May be **hard to edit** if changes needed.

Character Animation

Skeleton

Skin

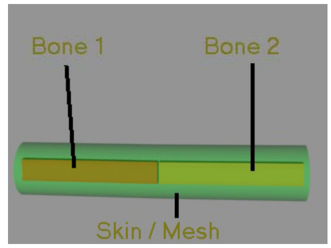
Binding

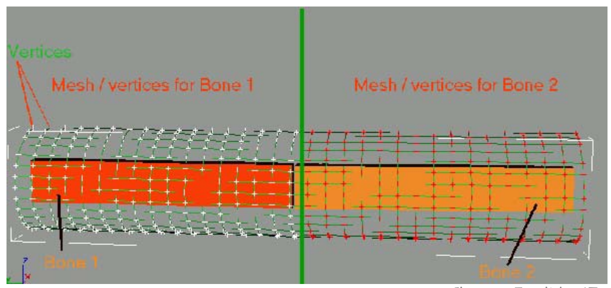
Motion Blending

Skin and Bones

Skin:

- A **mesh** attached to each bone.
- Each **vertex** of this mesh is placed relative to (one or more) bones.





Source: http://www.flipcode.com/articles/article_dx8shaders.shtml

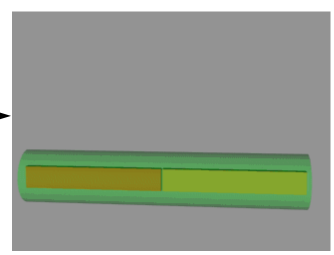
Skin and Bones

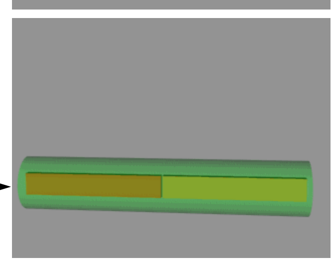
Problems:

- When joints flex, vertices attached to them **move rigidly**.
- While this definition is simple, it is **not very realistic**.
- Flexing of joints cause mesh to **stretch** and/or **self-intersect**.

Smooth Skin:

- Want a system that **flexes naturally**.





Source: http://www.flipcode.com/articles/article_dx8shaders.shtml

Rigid vs. Smooth Skin

Rigid Skin:

- Every vertex is associated with **exactly one joint**. It is expressed relative to the **joint's local coordinate system**:

$$\mathbf{v}'(t) = \mathbf{M}_{joint}(t) \cdot \mathbf{v}$$

Smooth Skin:

- Each vertex is associated with **multiple joints** (usually two).
- It is expressed as a **weighted average** of joint coordinates:

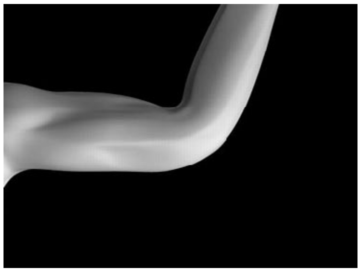
$$\mathbf{v}'(t) = w_1\, \mathbf{M}_{joint1}(t) \cdot \mathbf{v} + w_2\, \mathbf{M}_{joint2}(t) \cdot \mathbf{v} + \ldots + w_n\, \mathbf{M}_{jointn}(t) \cdot \mathbf{v},$$
$$\text{where } w_1 + w_2 + \ldots + w_n = 1.$$

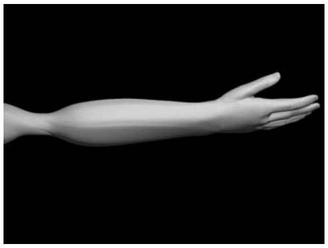
- This is called **geometry blending**.
- **Direct3D** supports geometry blending. (I don't know about OpenGL).

Smooth Skin

Problems with Smooth Skin:

- Although smooth skin produces smooth results, it is still **only a heuristic**.
- Flexing and twisting can result in unnatural **collapsing** at joints.
- **More sophisticated** approaches are needed to achieve better realism.





Source: Lewis, Cordner, Fong, SIGGRAPH 00

Character Animation

Skeleton

Skin

Binding

Motion Blending

Binding Skin with Bones

Layering:
- Animation is usually easiest to do with a **skeleton**.
- Final appearance involves additional **layers**: skin, muscles, clothes, …
- Character layers are modeled in a **natural pose** (e.g., standing).
- This pose **may not** correspond to the skeleton's **zero pose** ($\varphi_i = 0$).

Binding: A three-step process:
1. Pose the skeleton in a natural pose, called the **binding pose**.
2. Establish **correspondence** (and weights) between **skin vertices** and the **skeleton** (several heuristics).
3. Transform **skin vertices** to **local coordinate system** of joint(s).

Establishing Correspondences:

By Proximity: Assign each skin vertex to the **closest** bone(s).

Manually: Create **bounding volumes** (spheres, ellipsoids, cubes) for each bone to enclose skin vertices that belong to it.

Character Animation

Skeleton

Skin

Binding

Motion Blending

Blending: Unique to Games

Need for Blending:
- Characters in games have a **library of actions** that need to be sequenced (generally seamlessly) **on demand**, at interactive rates.
- **Examples**:
  - **General**: Sitting, walking, running, climbing.
  - **Battle**: Sword fighting, punching.
  - **Sports**: Throwing a ball, swinging a bat, kicking.

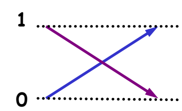
Motion blending:
- Interpolate between:
  - **ending pose** of **previous action** and
  - **starting pose** of **next action**.

Assassin's Creed

Cross Dissolve

Cross Dissolve:

- **Lerp** or **Slerp** from one pose to the next.
- The **simplest** type of blend.
- The term "**cross**" comes from increasing one weight while decreasing the other.
- Unfortunately, does **not** always produce **realistic results**.



Challenges: How can we produce more realistic transitions?

Ensuring phase synchronization: E.g., running to kicking.

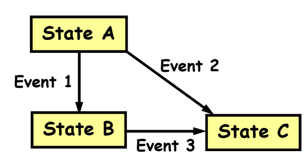
Adapting to changes in velocity: E.g., walking to running.

Mixing rotations and translations: E.g., sitting to walking.

Animation State Machine

Animation State Machine:

- A **finite state machine** where:
  - **States**: represent **animation clips**.
  - **Transitions**: represent **motion blends**.



Features:

- Enables **complex motion sequences**:
  - Sitting to walking should have an intermediate stage of standing.
- **Object-oriented** way to build complex motions:
  - Encapsulate simpler motions (state machine) as a **single state** of a more complex motions.
- Allows greater **control of transitions** between selected states.
- **Simplifies design** of animated games:
  - Transitions triggered by **user events**, game AI, randomness, …

Summary

Summary:
- Animation basics and skeletal animation
- Skin and Bones
- Binding
- Motion blending