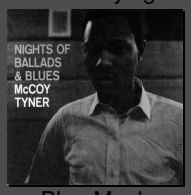
Now Playing:



Blue Monk
from "Nights of Ballads and Blues"
Recorded March 4, 1963
McCoy Tyner - Piano
Steve Davis - Bass
Lex Humphries - Drums
Music By Thelonius Monk

3D Transforms & Computer Animation

Rick Skarbez, Instructor
COMP 575
September 6, 2007

Announcements

- Homework 1 is out today
  - Due at the end of class next Thursday
- Tabitha Peck (tpeck@cs.unc.edu) is here to ask you to participate in her user study

Last Time

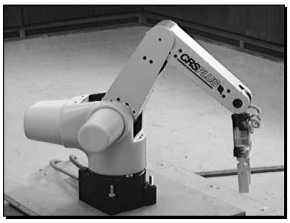
- Introduced the concept of vector spaces
- Learned the basic 2D transforms
  - Translation
  - Scaling
  - Rotation
  - Shearing
- Talked about why we use homogeneous coordinates and transform matrices
- Talked about how to compose transforms

Today

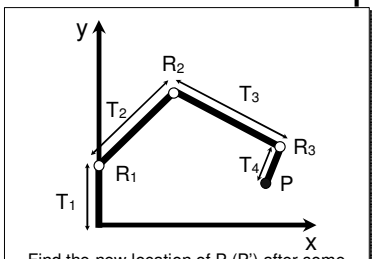
- Discuss robot arm example from last class
- Extend transforms to 3D
- Aside: Talk about some principles of computer animation

Robotic Arm Example

- Fingers first
- Then wrist
- Then elbow
- Finally, shoulder

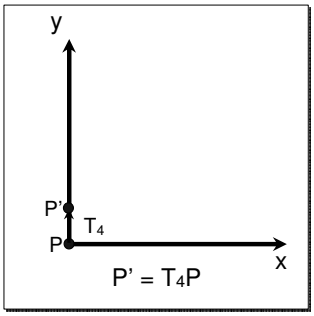


Robotic Arm Example



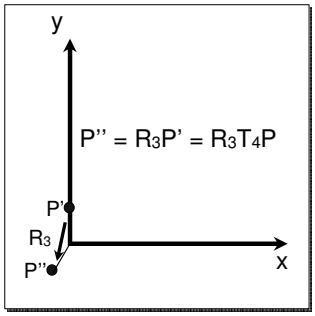
Find the new location of P (P') after some translations T_1, T_2, T_3, T_4 and rotations R_1, R_2, and R_3.
Express in terms of a matrix product, i.e.
$P' = R_1R_2R_3P$

Robotic Arm Example

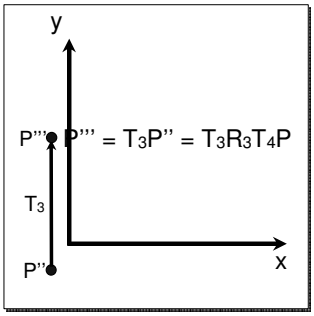


$P' = T_4P$

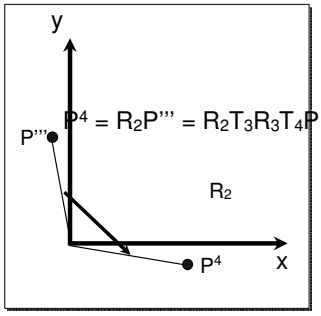
Robotic Arm Example



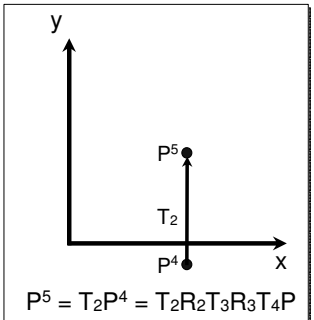
Robotic Arm Example



Robotic Arm Example

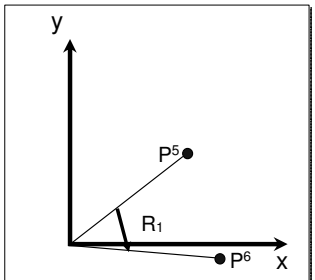


Robotic Arm Example



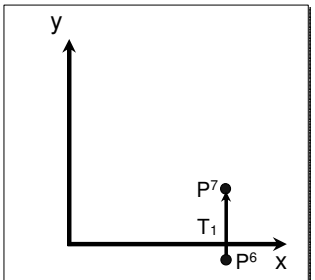
$P^5 = T_2P^4 = T_2R_2T_3R_3T_4P$

Robotic Arm Example



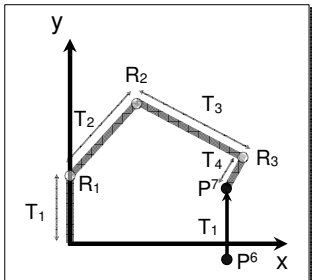
$P^6 = R_1P^5 = R_1T_2R_2T_3R_3T_4P$

Robotic Arm Example



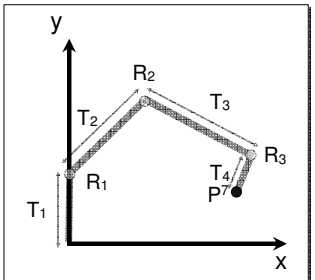
$P^7 = T_1P^6 = T_1R_1T_2R_2T_3R_3T_4P$

Robotic Arm Example



$P^7 = T_1P^6 = T_1R_1T_2R_2T_3R_3T_4P$

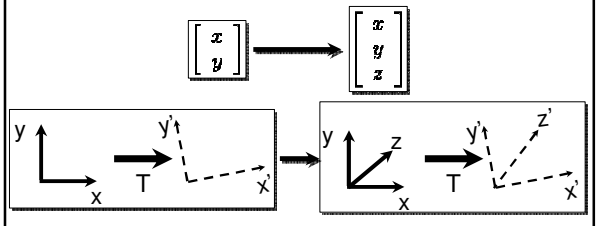
Robotic Arm Example



$P^7 = T_1P^6 = T_1R_1T_2R_2T_3R_3T_4P$

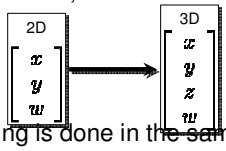
3D Transforms

Pretty much exactly the same as 2D transforms



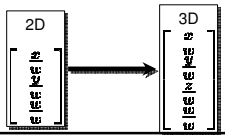
Homogenous Coordinates in 3D

- Just as with 2D, need to add a w term



Reminder:
w = 1 for points
w = 0 for vectors

- Normalizing is done in the same way as before



Cross Products

- We talked about the cross product operator in the math lecture
  - Defined as

$$\mathbf{P} \times \mathbf{Q} = \langle P_y Q_z - P_z Q_y, P_z Q_x - P_x Q_z, P_x Q_y - P_y Q_x \rangle$$

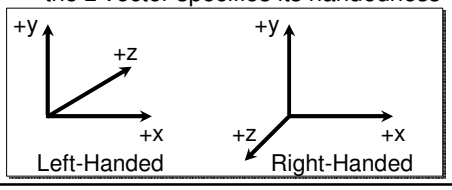
- The cross product of 2 vectors is a vector perpendicular to both of the other two vectors
  - Wasn't really applicable in 2D
- Note that 2 vectors can make this true

Cross Product Direction

- The direction of the resulting vector from a cross product can be determined by the "right hand rule"
- With your right hand, for P x Q
  - Point your thumb in the direction of P
  - Point your index finger in the direction of Q
  - Rotate your middle finger to be perpendicular to the thumb and index
    - This is the direction of P x Q

Coordinate Systems

- This is why coordinate systems are sometimes referred to as left or right handed
  - Given x and y vectors, the direction of the z vector specifies its handedness



Translation in 3D

- We will represent translation with a matrix of the following form:

$$\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & t \\ 0 & 1 & 0 & u \\ 0 & 0 & 1 & v \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

t is the x-offset
u is the y-offset
v is the z-offset

Scaling in 3D

- We will represent scaling with a matrix of the following form:

$$\mathbf{M} = \begin{bmatrix} \alpha & 0 & 0 & 0 \\ 0 & \beta & 0 & 0 \\ 0 & 0 & \gamma & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

α is the scale factor in the x-direction
β is the scale factor in the y-direction
γ is the scale factor in the z-direction

Rotation in 3D

- Extending rotation to 3D is somewhat more complicated than either translation or scaling
  - In 2D, you could only rotate around 1 point
  - In 3D, you can rotate around any of the 3 axes
    - Each axis produces a slightly different rotation matrix

Rotation in 3D

- Rotation about the z-axis is most familiar
  - Essentially, this is what we already did, in the z=0 plane

$$\mathbf{M} = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 & 0 \\ \sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation in 3D

Rotation About The Z-Axis

$$\mathbf{M} = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 & 0 \\ \sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation About The X-Axis

$$\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha & 0 \\ 0 & \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

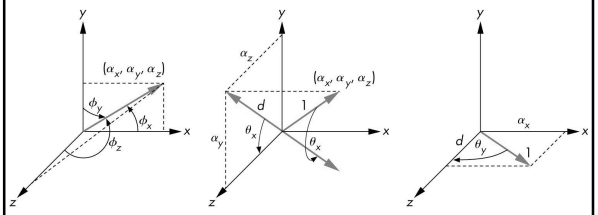
Rotation About The Y-Axis

$$\mathbf{M} = \begin{bmatrix} \cos\alpha & 0 & \sin\alpha & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\alpha & 0 & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation about any axis in 3D

- How can we extend this to rotation about *any* axis, not just the principle axes?
  - Need to move the axis we want to rotate about to one of the principle axes (say, the z axis)
  - First, apply a rotation about x, to move the axis into the yz-plane (R_x)
  - Then, apply a rotation about y, to move the axis onto the z-axis (R_y)
  - Then apply your desired rotation, followed by the inverses of the other two (to reverse

Rotation about any axis in 3D



$R_{total} = R_x^{-1} R_y^{-1} R_z R_y R_x$

Rotation about any point and any axis in 3D

- To rotate about a non-origin point, extend in the same way as in 2D
  - First, translate to the origin (T_{xyz}^{-1})
  - Then apply your rotation (in the most general case, $R_x^{-1} R_y^{-1} R_z R_y R_x$)
  - Then translate back (T_{xyz})

$R_{total} = T_{xyz}\, R_x^{-1} R_y^{-1} R_z R_y R_x\, T_{xyz}^{-1}$

Transforms Recap

- Robot Arm example
- 3D transforms
  - Very similar to 2D transforms
    - Rotation is a bit more complex
      - Can rotate about any axis
- Cross products
- Coordinate systems
  - Left vs. right handed

Computer Animation

- Can think of animation as objects being transformed over time
- We have a "timeline" that says what transforms are applied at what times
- Each rendered image is one frame
  - The duration of each frame (say, 1/60 of a second for 60fps) is a single time step

"Principles of Traditional Animation Applied to 3D Computer Graphics"

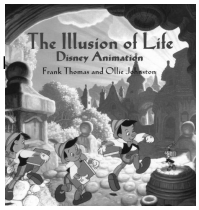
John Lasseter (Pixar), SIGGRAPH 1987

- Lasseter noticed a trend
  - Computers were making animation easier than ever before
  - But animation was not getting better
    - Actually, it was often worse
    - Why?

The Problem with Good Tools

- Why was there so much bad animation?
  - New tools were allowing users with no experience to animate

The Illusion of Life



- Many of the principles behi traditional animation were developed by Disney animators in the 1930s
  - *The Illusion of Life*
- Lasseter's talk was intended to extend these principles to computer animation

The Principles

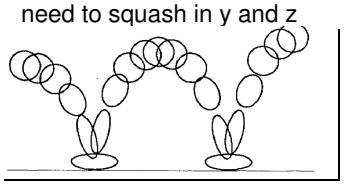
1. Squash and Stretch
2. Timing and Motion
3. Anticipation
4. Staging
5. Follow-through and Overlapping Action
6. Straight-ahead and Pose-to-pose Action
7. Slow In and Out
8. Arcs
9. Exaggeration
10. Secondary Action

Squash and Stretch

- In the real world, only totally rigid objects (i.e. chairs, rocks) remain rigid when moving
  - Living things deform
  - So, if you want something to look "alive", you can't just rigidly slide it around
    - Squash and stretch to emphasize motion

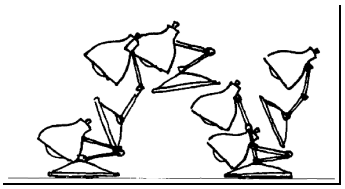
Squash and Stretch

- Squash on contact
- Stretch with motion (more → faster)
  - Need to conserve volume
    - That is, if you're stretching in x, need to squash in y and z



Squash and Stretch

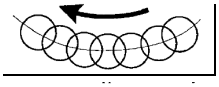
- Hinged objects (i.e. Luxo Jr.) can squash and stretch without deforming



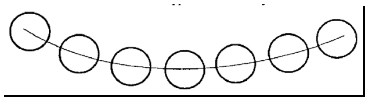
Squash and Stretch

If objects overlap between frames, the eye can smooth the motion

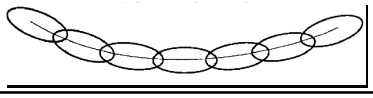
Slow Motion



Fast Motion



Fast Motion w/S&S



Timing

- The speed of motion gives us cues about
  - Weight
  - Size
  - Meaning
- Motion must be "readable"
  - Must take long enough for the viewer to see and understand
  - Must be quick enough to hold attention

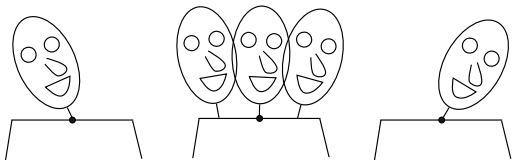
Timing

- Small and light objects should be fast and nimble
- Large and heavy objects should be slow and lumbering

Keyframes and In-Betweening

- Keyframes are frames in a sequence of animation that mark the beginning and end of a smooth transition
- In-Betweens are the frames between a beginning and end keyframe
  - The in-betweens make the animation sequence appear smooth

Keyframes and In-Betweening



Before In-betweens After

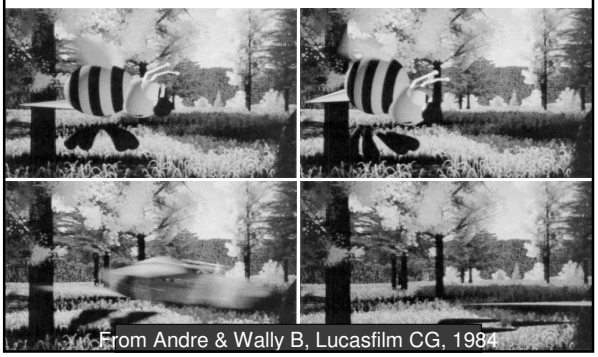
Timing

- Imagine an animation where a person is looking over his left shoulder, then his right
  - No in-betweens: Hit by a strong force, head nearly snapped off
  - 1 in-between: Hit by a frying pan
  - 3 in-betweens: Dodging a flying object
  - 5 in-betweens: Giving an order ("Come over here")
  - 7 in-betweens: Looking around for something
  - 10 in-betweens: Stretching a sore neck
- All from the same 2 keyframes!

Anticipation

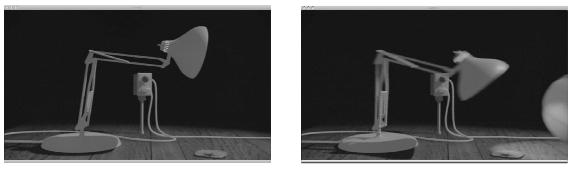
- There are 3 parts to any action
  1. The preparation for the action (anticipation)
  2. The action
  3. The termination of the action (follow-through)
- Can be anatomical preparation
  - Pulling back your foot before kicking
- Or just to draw the viewers' attention
  - A character looking at something off-screen

Anticipation



From Andre & Wally B, Lucasfilm CG, 1984

Anticipation



From Luxo Jr., Pixar, 1987

Staging

- When an action occurs
  - Make sure it is clear
  - Make sure it is visible
- Only stage 1 important action at a time
  - In *Luxo Jr*, it is always clear which character is the center of attention
- Action is more clearly visible in silhouette

Follow-through and Overlapping Action

- When throwing a ball, your hand doesn't just stop after the ball is released
- When a multi-part object moves, usually one part will lead and the others will follow
  - *i.e.* In walking, motion starts at the hip, then the leg moves, then finally the foot
  - Therefore, sub-objects will begin and end their motions at different times

Follow-through and Overlapping Action

- Overlapping means that you start a second motion before the first has completely finished
  - Blend the follow-through of one action into the anticipation of the next
- "When a character knows what he is going to do he doesn't have to stop before each individual action and think to do it. He has planned in advance in his mind." - Walt Disney

Straight-Ahead and Pose-to-Pose Action

- Straight-ahead action is when an animator hand-composes all the frames in a scene
  - Sort of like a scene of all keyframes
  - Action looks wild and out-of-control
- Pose-to-pose action is when an animator carefully composes individual important poses, and then tweens them
  - Used when timing and smoothness matter

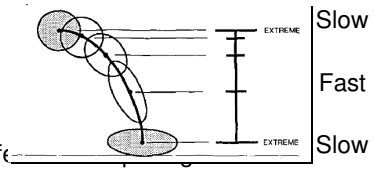
Pose-to-Pose Action

- To achieve smooth motions, you would normally work hierarchically
  - First, draw the keyframes
  - Then draw some inbetweens
  - Finally, draw all the remaining inbetweens

Pose-to-Pose Action

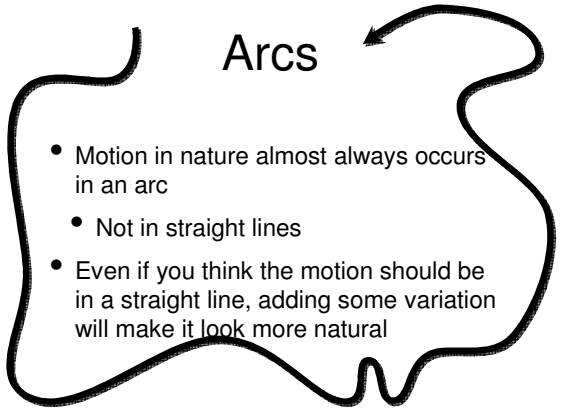
- Computer animation is naturally hierarchical, but slightly different
  - Consider a jump
    - Create translation keyframes for the entire model
    - Add rotation/translation keyframes for arms
    - Add rotation/translation keyframes for legs
    - etc.

Slow In and Out



- Refe… betweens
- Instead of having an object move with constant velocity, allow the velocity to vary
  - Enforce continuity of 2nd and 3rd

Arcs



- Motion in nature almost always occurs in an arc
  - Not in straight lines
- Even if you think the motion should be in a straight line, adding some variation will make it look more natural

Exaggeration

- Can exaggerate
  - Shape of objects
  - Motion of objects
  - Sound
  - Character emotions
- Exaggeration is "accentuating the essence of an idea"
  - Not just amplification, but removal of distraction

Exaggeration

- Exaggeration should be used carefully
  - Use it too little, and the exaggerated things will stand out too much
  - Use it too much, and the scene will become unrealistic

Secondary Action

- Include the actions that happen as a result of the primary action
  - One example would be the facial expression, while the body expresses the primary action
  - Another would be Luxo Jr.'s cord, which moves because it is attached to a moving body

Personality

- The sum total of all the principles discussed before
- The goal of animation is to produce something that a viewer wants to watch
- The animator should have a consistent personality in mind when decided how to apply the principles
  - Need to know what you want before you start

Personality

Simple things, like breaking symmetry add an level of complexity (and subtlety) to the character

Next Time

- Introduction to OpenGL programming