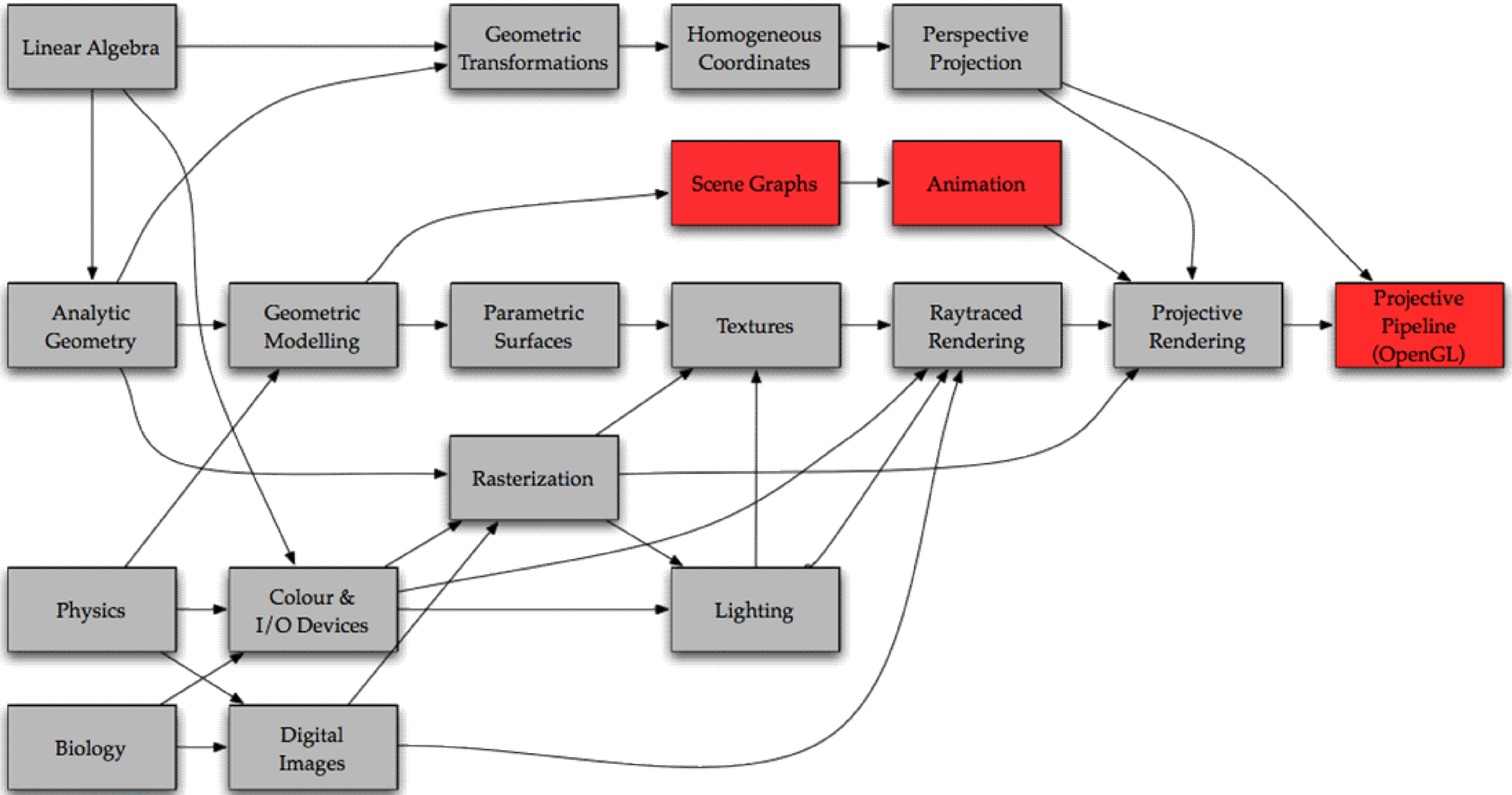
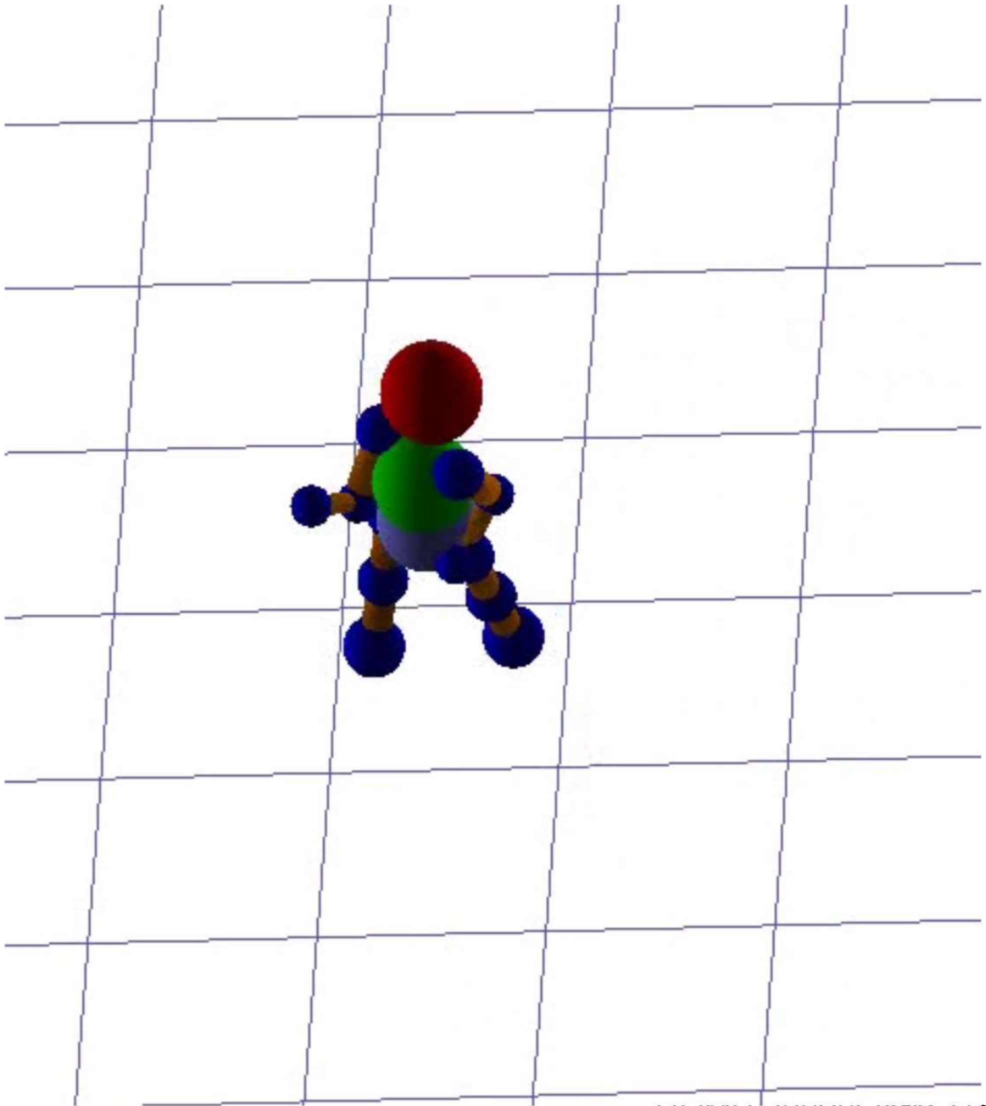
Hierarchical Animation

Where We Are


Linear Algebra
Geometric Transformations
Homogeneous Coordinates
Perspective Projection
Scene Graphs
Animation
Analytic Geometry
Geometric Modelling
Parametric Surfaces
Textures
Raytraced Rendering
Projective Rendering
Projective Pipeline (OpenGL)
Rasterization
Physics
Colour & I/O Devices
Lighting
Biology
Digital Images

Animation Example:



What is Animation?

- The *illusion* of motion:
  - making things appear to move
  - by drawing things too fast for the eye
- So we go back to what the eye can do

The Illusion of Motion

- The eye sees events in about 1/24 sec.
- Anything shorter, the eye mostly misses
- So, we show more than 24 *frames*/sec.
  - the eye *interprets* this as motion
  - but each image is static
- In practice, it's more complex

Movies

- Movies used to run at 16 *frames per second*
  - so they looked jerky
- Modern movies run at 24 fps or better
- Each frame is a single image
  - computed "off-line" & stored on film
  - projected one at a time at fixed speed

Computers

- Generate images on the fly
  - it takes most of the time just to draw
  - most of the 1/24 sec you see nothing
  - you see some objects longer than others
  - last objects drawn look ghostly

Tearing

- Video output refreshes constantly
  - doesn’t wait for frame to finish
  - so you get half a frame visible
- CRT’s scan from top down
  - so you get a similar problem
  - we’ll come back to this later

Double-buffering

- We can get rid of the first problem
  - Use ***<u>TWO</u>*** copies of the framebuffer
  - Draw one, show the other
  - When finished drawing, swap them
    - glutSwapBuffers()

Dropped Frames

- Show a new frame every 1/30 second
- What if we are late?
    - the eye sees the same frame twice
    - motion no longer looks smooth
- Solution: render faster & we won’t notice
- Result: we want 60 fps or better

Simulating Motion

- For each frame, we compute:
  - new transformations for each object
  - new lighting (sometimes)
  - new colour / textures (occasionally)
  - new geometry (rarely)

Time & Motion

- We treat *position p* as a function of *time*
  - We *compute p* given a particular *t*
  - Usually in parametric form

Simple Example

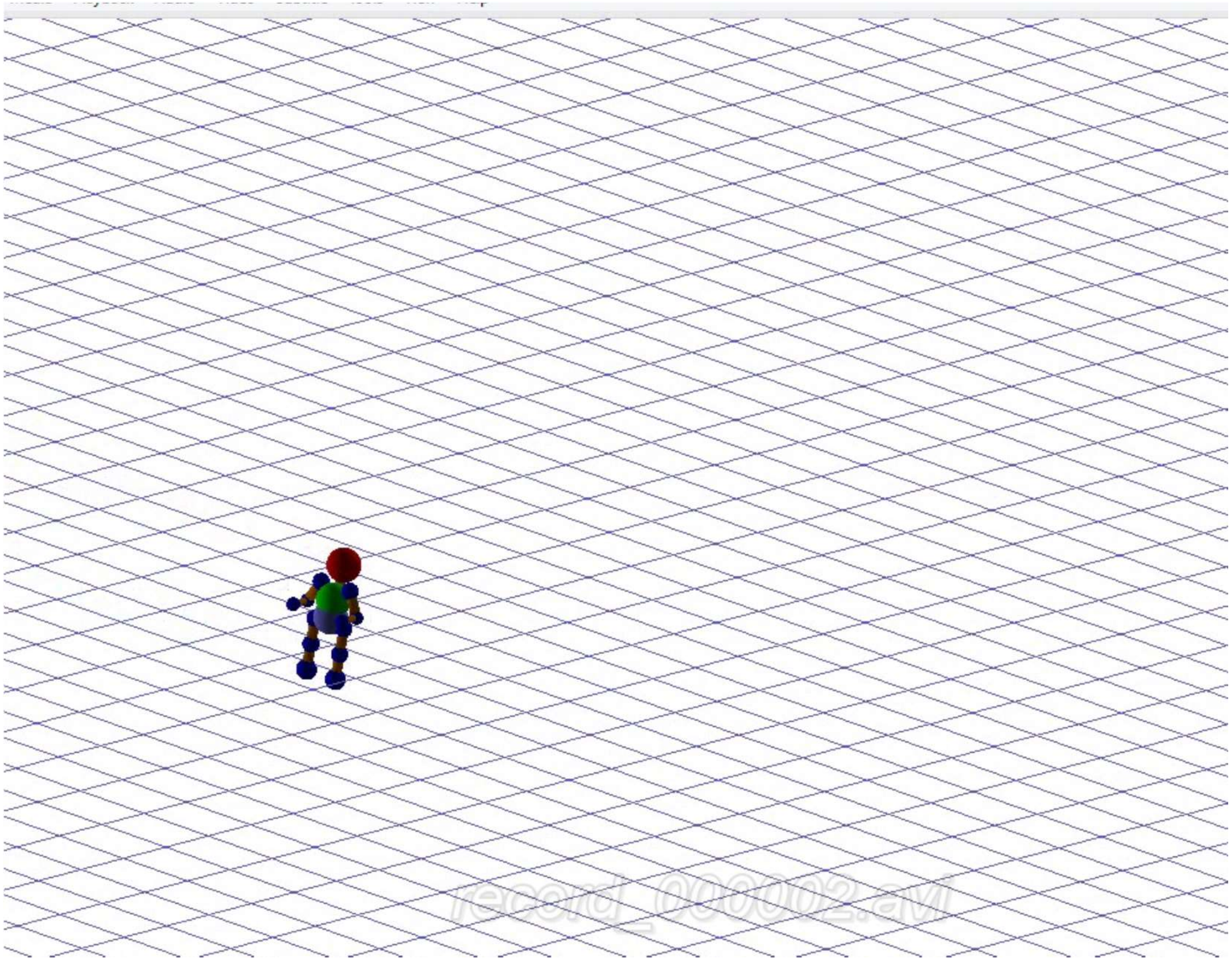
```
void animateTrain()
  { /* animateTrain() */
  for (timeStep = 0; timeStep < 600; timeStep++)
    { /* each frame */
    computePosition(timeStep);
    drawTrain();
    } /* each frame */
  } /* animateTrain() */
```

Computing Position

- Given the *time step*, compute position:

```
void computePosition(int time)
  { /* computePosition() */
  theta = (time / 600) * 2 * PI;
  posn_x = cos(theta);
  posn_y = sin(theta);
  glTranslatef(posn_x, posn_y, 0.0);
  } /* computePosition() */
```

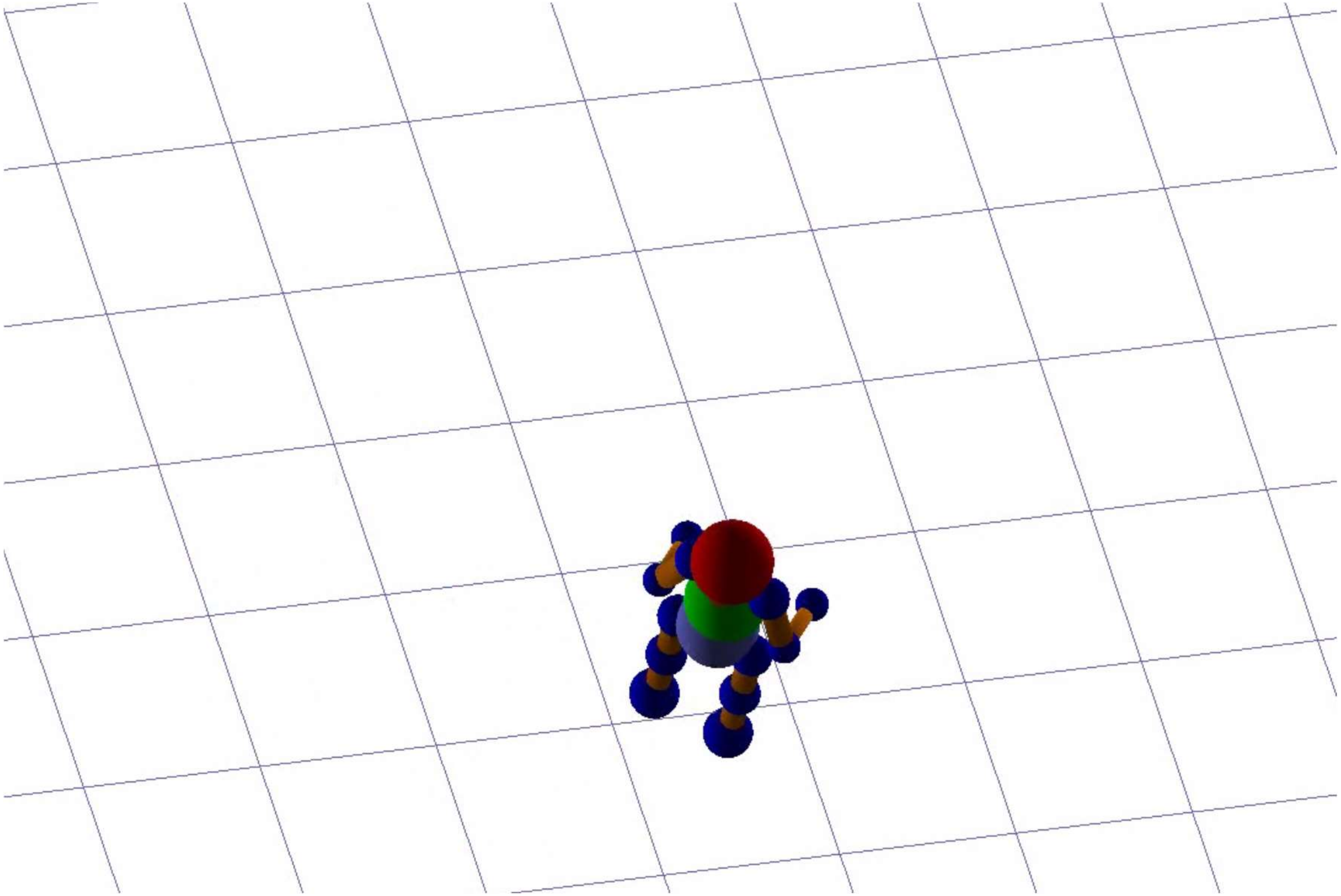
Oops ...



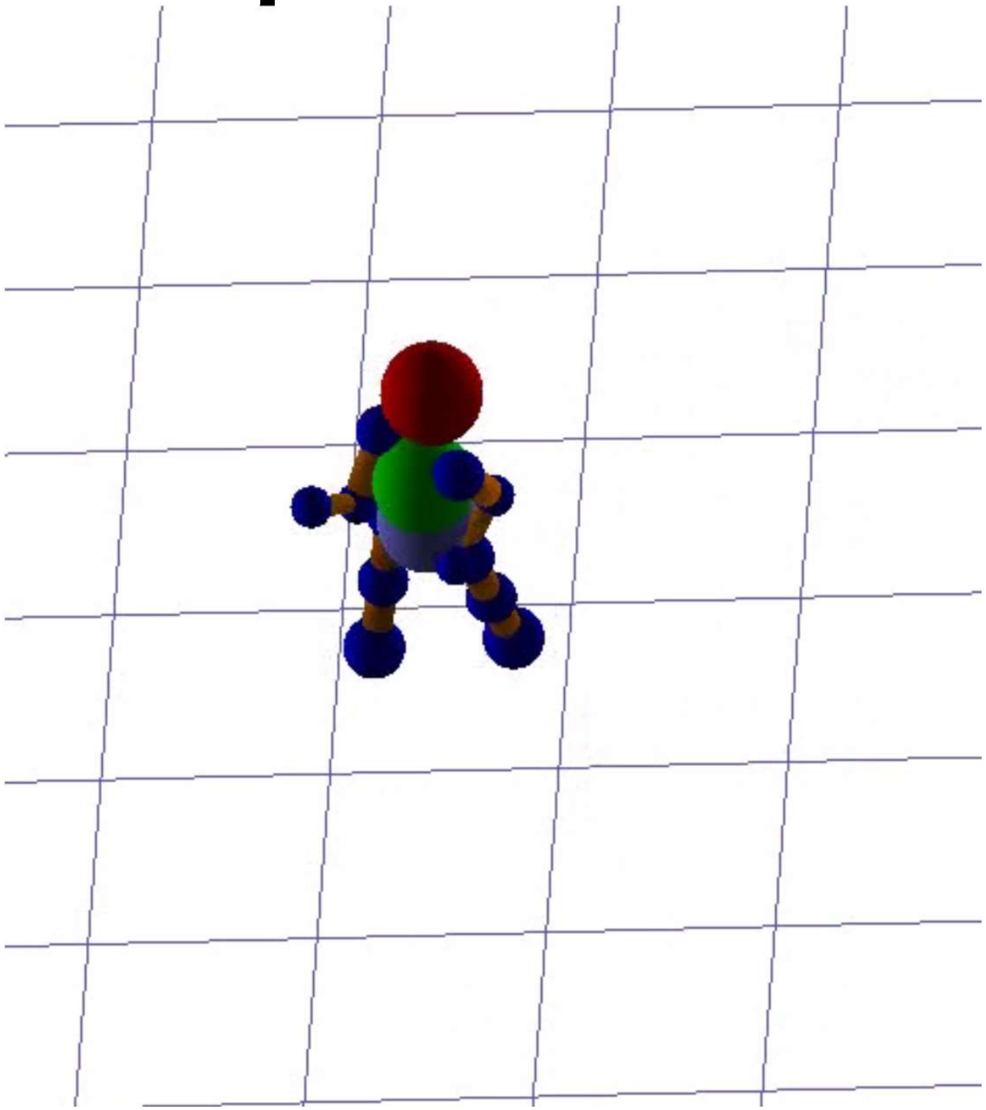
Position & Orientation

```
void computePosition(int time)
  { /* computePosition() */
  thetaDeg = (time / 600) * 360;
  thetaRad = (time / 600) * 2 * PI;
  posn_x = cos(thetaRad);
  posn_y = sin(thetaRad);
glTranslatef(posn_x, posn_y, 0.0);
glRotatef(thetaDeg, 0.0, 0.0, 1.0);
  } /* computePosition() */
```

And the result



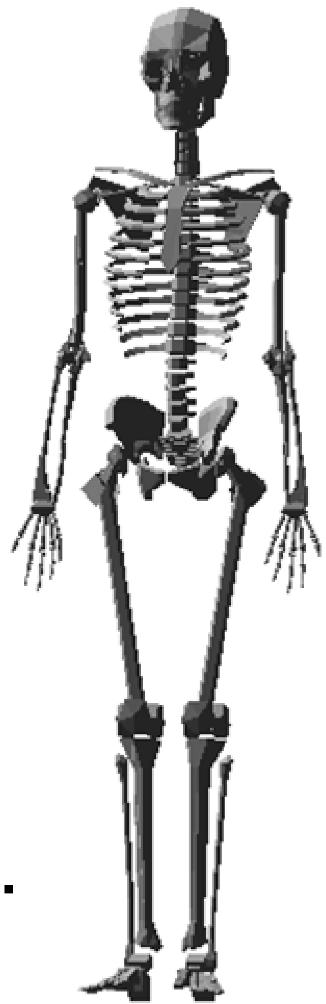
A Complex Example



Articulation

- Humans are different from toy trains
  - they are *articulated*
    - composed of *bones* (i.e. limbs)
    - connected by *joints*
  - so we will model them this way

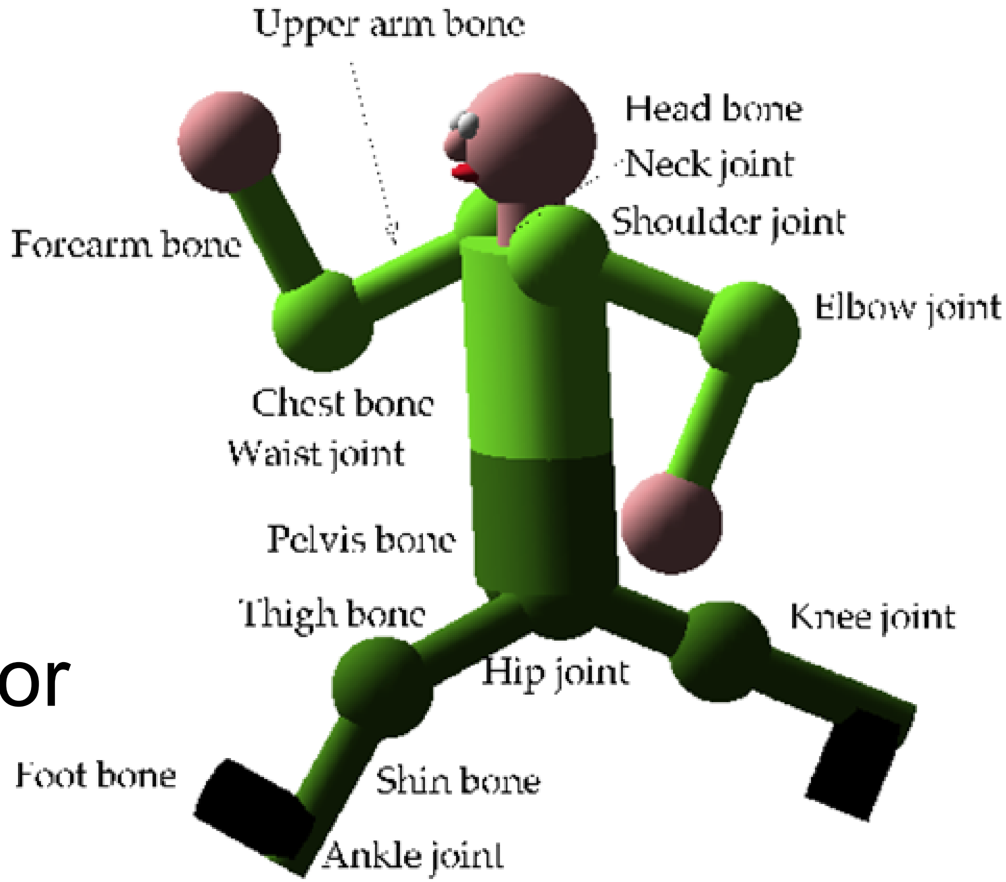
Bones



- How many bones do we have?
  - 208 (I think)
  - but many don't matter
- A *bone* is a separately transformed piece of the object - often a limb
- Even trains have *bones* - wheels, &c.

How many Bones?

- Number of bones depends on detail
- Sometimes need fingers, toes, &c.
- Even need “bones” for facial expressions



Bone Coordinates

- Each bone has its own coordinates
  - i.e. *local coordinate systems*
- But we know how to deal with these
- Bones are connected by *joints*
  - points where two bones meet

Joints

- *Joints* are points at which bones meet
  - one bone rotates around the joint
- Joint is fixed in stationary bone’s coords
- Joint is *origin* of other bone’s coords
  - to move the bone, rotate around joint
  - “simple” rotation matrix

Degrees of Freedom

- Not all rotations are possible at joints:
- *degrees of freedom* = number of rotations
- Elbow & knee: 1 *d.o.f.*, 135° *range*
- Shoulder / hip:
- Wrist / ankle:
- Waist / neck:

Direction of Axes

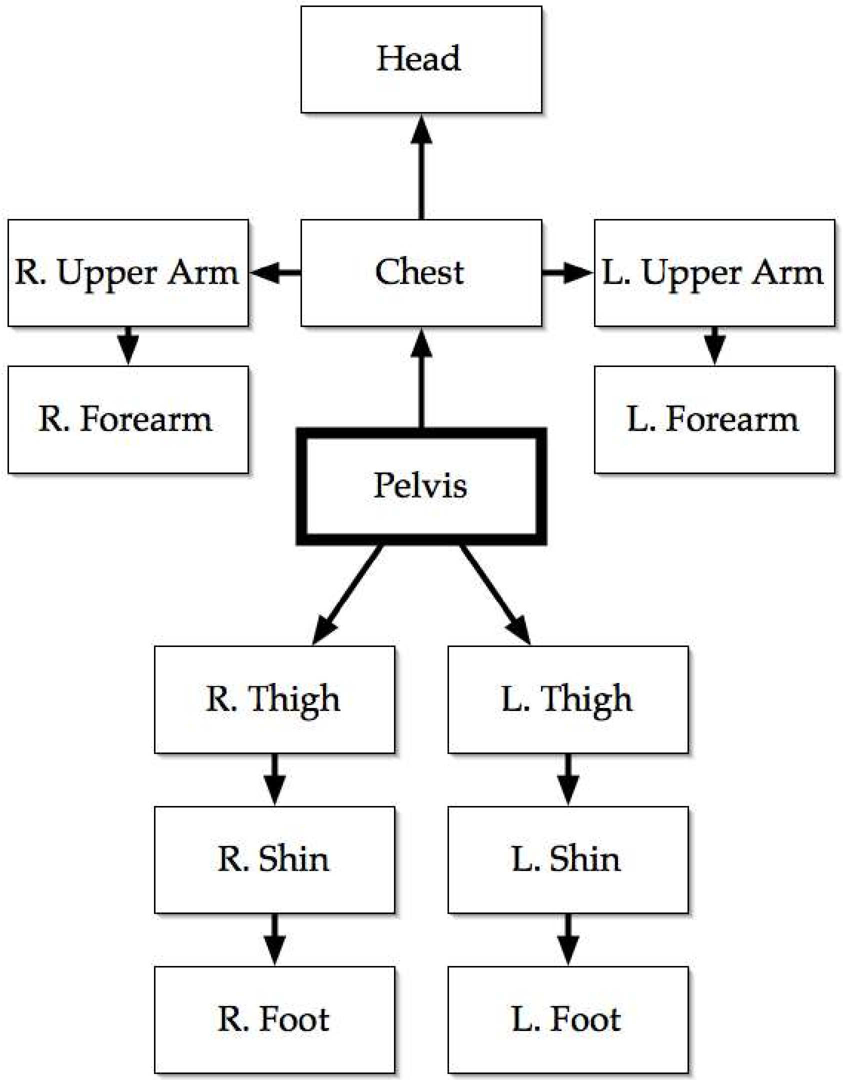
- Axes for bone are up to you
  - convenient if rotations are simple
  - e.g. elbow y-axis sticks out sideways
  - so all elbow rotations are y-rotations
- I like putting z-axis down centre of bone

Which Bone Rotates?

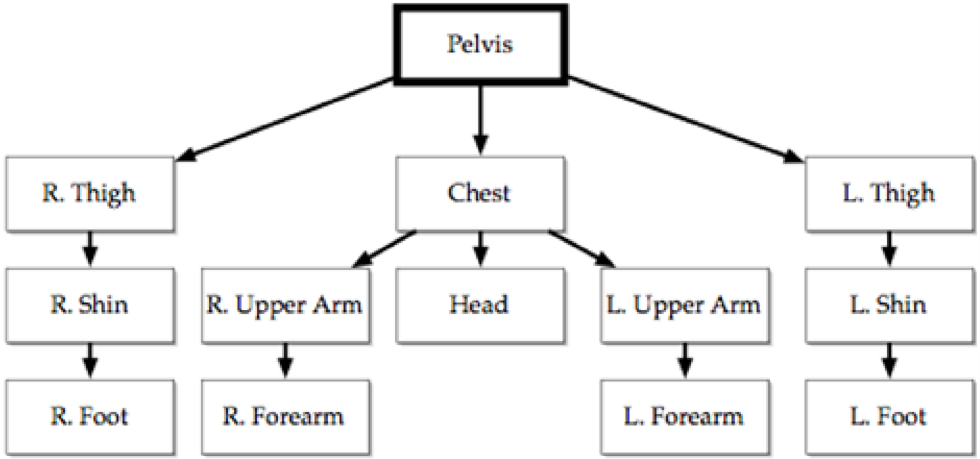
- Both, unless there is another force acting
- Ultimately, motion pushes against ground
- But the feet move a lot!
  - Human motion keeps body / head stable
  - So pelvis is treated as stationary
    - if it moves or rotates, the body does too

Bone Diagram

- Pelvis is master bone
  - all others hang off it
- So let's redraw this diagram:



Bone Hierarchy



- This hierarchy makes drawing easier
- Let’s look at drawing the left hand

Drawing Left Hand

- Left hand is part of forearm
  - defined in forearm’s *local coordinates*
  - transform to upper arm’s *LCS*
  - then transform to chest’s *LCS*
  - then to pelvis’ *LCS*
  - finally to *WCS*

Left Hand Transformations

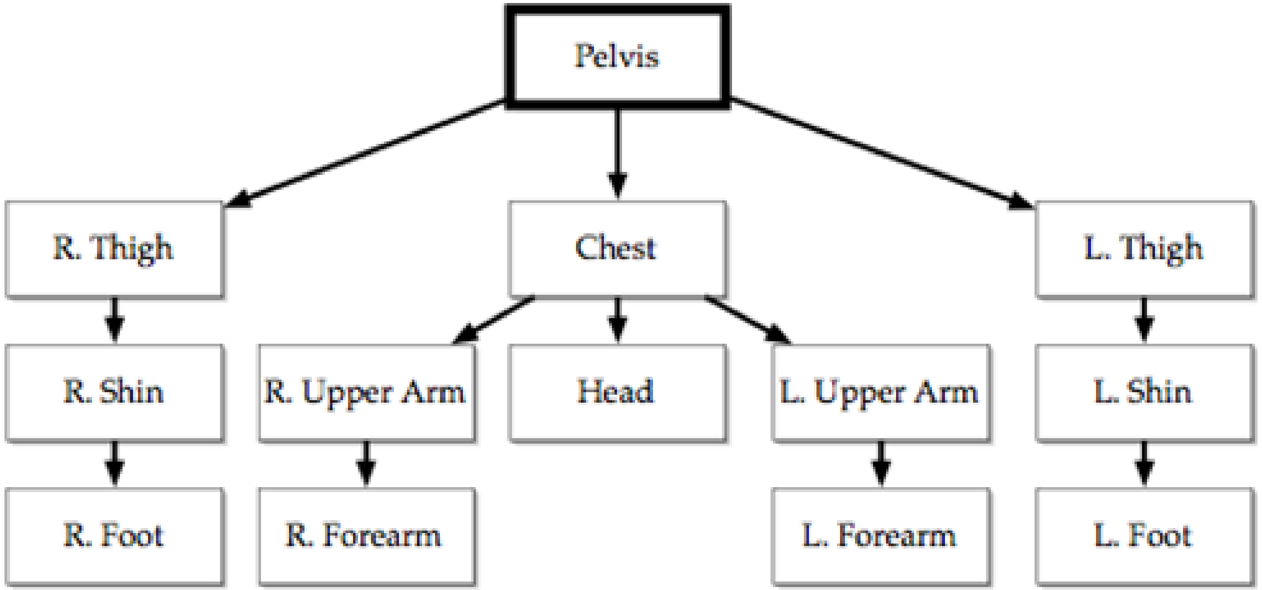
$$T_{pelvis} T_{chest} T_{left\ arm} T_{left\ forearm}(hand)$$

- Transformations inherited from hierarchy
  - we call them *hierarchical transformations*
  - diagram is the *transformation hierarchy*
- Right hand shares some of these

$$T_{pelvis} T_{chest} T_{right\ arm} T_{right\ forearm}(hand)$$

Drawing the Man

```
Apply T_pelvis
Draw Pelvis
Apply T_chest
Draw Chest
Apply T_L_arm
Draw L Upper Arm
Apply T_L_forearm
Draw L Forearm
Remove T_L_forearm
Remove T_L_arm
Apply T_head
Draw head
Remove T_head
Apply T_R_arm
Draw R Upper Arm
```



Traverse the hierarchy:
- going down, apply matrix
- going up, remove it

Matrix Stacks

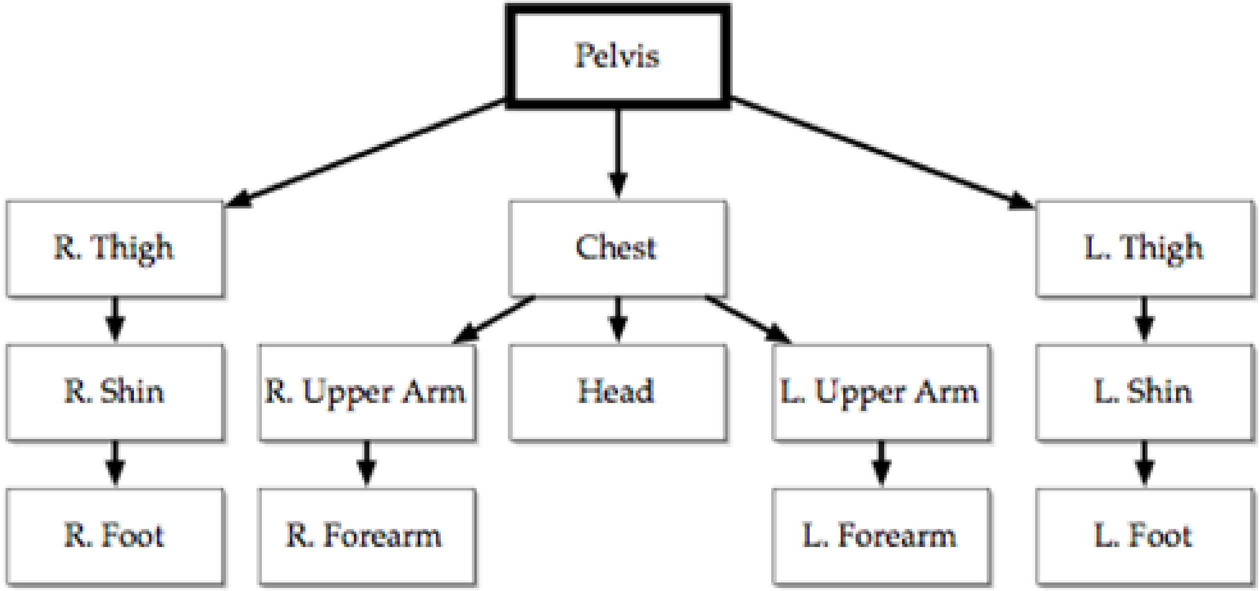
- Since this is Computer Science
  - we can represent this with *stacks*
    - *push* another matrix going down
    - *pop* a matrix going up
  - and OpenGL has this built in

glPushMatrix()

- glPushMatrix() pushes current matrix
  - and gives you a copy to work with
- glPopMatrix() gets rid of copy
  - and reverts to last version on stack
- Like glBegin(), OpenGL doesn’t balance them
  - make sure you do

Drawing the Man

```
glPushMatrix()
Apply T_pelvis
Draw Pelvis
glPushMatrix()
Apply T_chest
Draw Chest
glPushMatrix()
Apply T_L_arm
Draw L Upper Arm
glPushMatrix()
Apply T_L_forearm
Draw L Forearm
glPopMatrix()
glPopMatrix()
glPushMatrix()
Apply T_head
Draw head
glPopMatrix(), &c. &c.
```

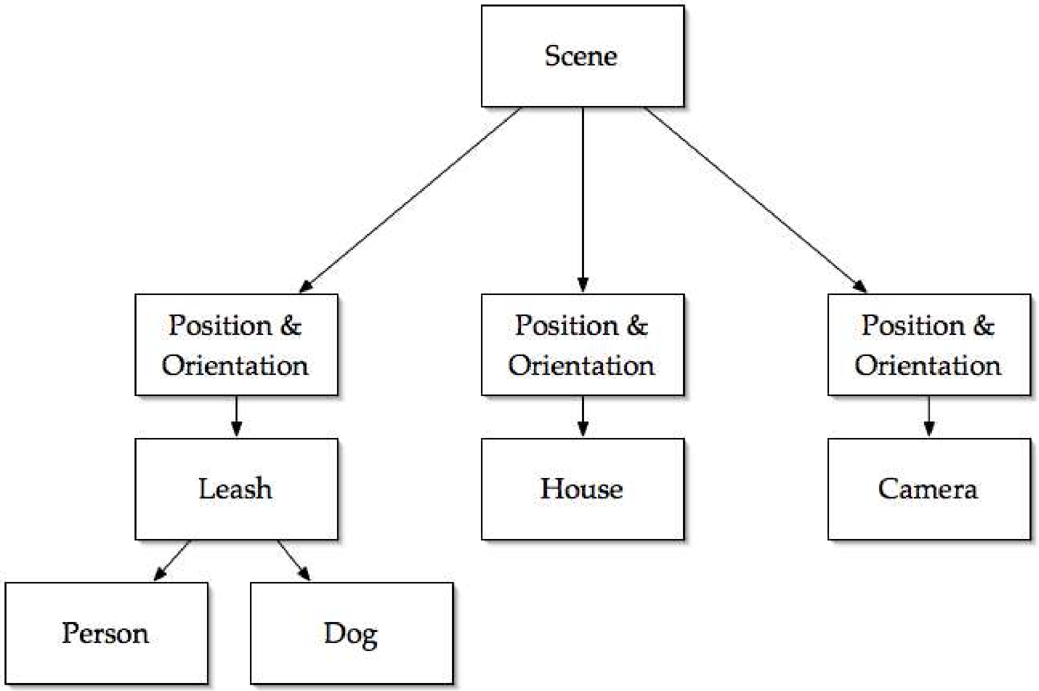


Traverse the hierarchy:

- going down, apply matrix
- going up, remove it

Scene Graphs

- General form of animation hierarchy
- Hierarchical description of a *scene*



Terminology

- A *frame* is a single image in a sequence
- A *bone* is a piece of an articulated object
- A *joint* is where two bones meet
- A *pose* is the set of rotations for a frame

Generating Poses

- How *do* we determine the poses?
  - motion capture
  - keyframe interpolation
  - physical simulation
  - inverse kinematics

Motion Capture

- Measure the joint angles of a person
  - then build a model of the person
- Commonly used in
  - movies (Planet of the Apes)
  - sports games (FIFA)
  - Starting to become a potential VR interface
- The ideal solution ?

Mocap Problems

- Motion only works for one character
  - looks wrong on smaller / larger
- Hard to measure joint angles
  - surface occlusion, markers off-centre
- Requires expensive hardware & people
- Only works for real animals / humans

Mocap – New inexpensive Methods

- **Using Time of Flight methods**
  - Leap Motion
  - Microsoft's KINECT
- **Using just inertia sensors -**
  - Perception Neuron
    - **Developed here in Beijing**
    - **No need for external optical tracking**
    - **No large setup area as directly attached to the body**
- **Measuring muscle movement using EMG's**
  - **Myo Gesture Control Armband**
    - **Advantage that the movement is sensed before your hand actual moves, thus a perfect tool for tele-presence as you can synchronise interactions in real time across the world.**

Keyframe Interpolation

- Some frames are important (i.e. *key*)
  - artist specifies joint angles at keyframes
  - compute angles for frames in between
  - simple interpolation
- Requires well-trained artists

Physics Simulation

- Simulate Newtonian mechanics
- Much more complex than it sounds
  - and doesn't give humans control
- Best for inanimate objects
  - we must detect collisions
  - even for human motions

Inverse Kinematics

- Artist sketches approximate path
- We compute suitable joint angles
  - use physics simulation
  - try to minimize energy used
    - human motion is efficient
- Lots of work to be done here

Animation Problems

- Collision detection & response
- Smooth interpolation (*blending*) of poses
- Smooth *skinning* between joints
- Mapping to different characters
- Controls for artists