University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2007

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Transformations IV

Week 3, Mon Jan 22

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007

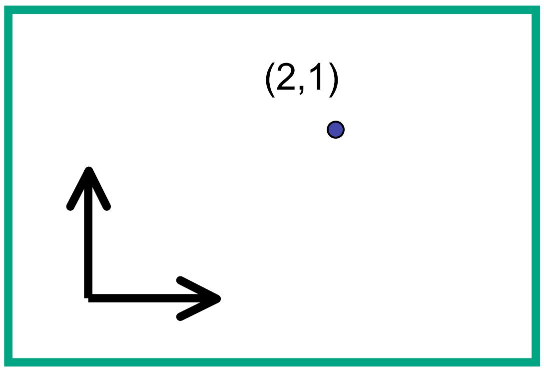
Readings for Jan 15-22

- FCG Chap 6 Transformation Matrices
  - *except* 6.1.6, 6.3.1
- FCG Sect 13.3 Scene Graphs
- RB Chap Viewing
  - Viewing and Modeling Transforms *until* Viewing Transformations
  - Examples of Composing Several Transformations *through* Building an Articulated Robot Arm
- RB Appendix Homogeneous Coordinates and Transformation Matrices
  - *until* Perspective Projection
- RB Chap Display Lists

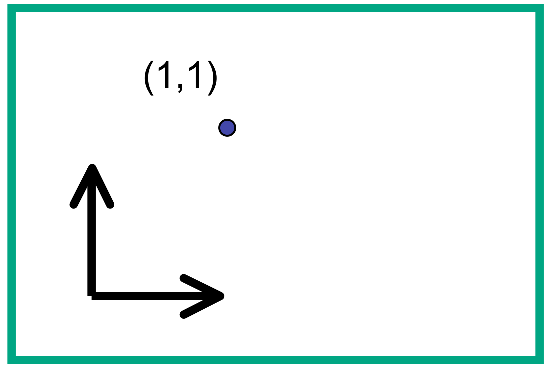
Review: Interpreting Transformations

$$\mathbf{p}' = \mathbf{T}\mathbf{R}\mathbf{p}$$

translate by (-1,0)

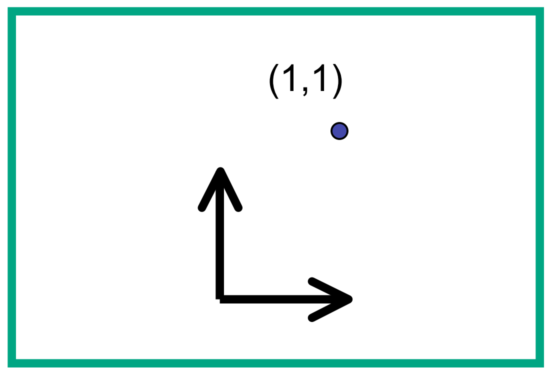


right to left: moving object



intuitive?

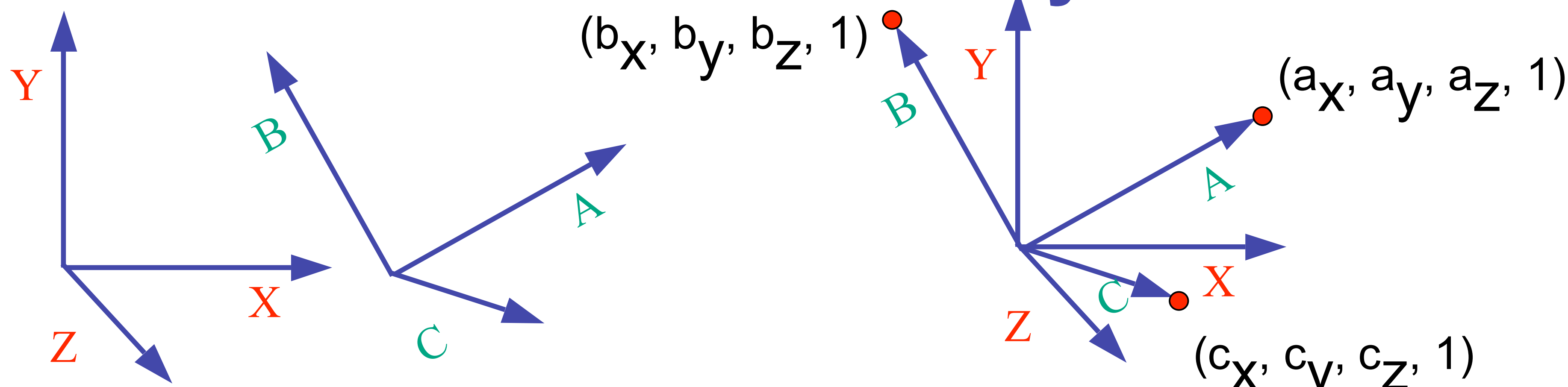
left to right: changing coordinate system



OpenGL

- same relative position between object and basis vectors

Correction/More: Arbitrary Rotation



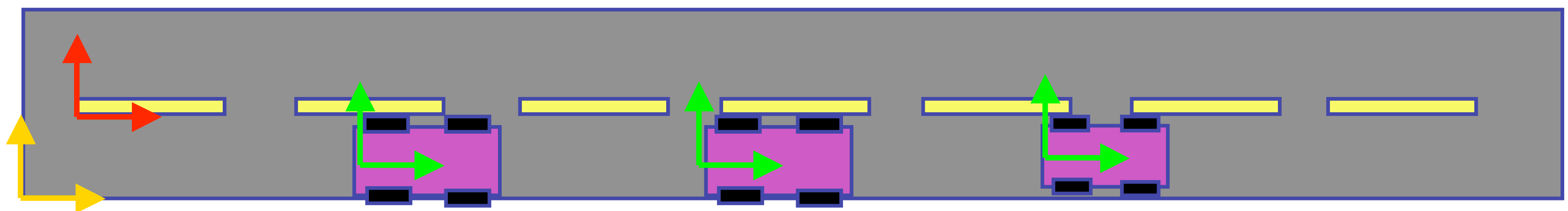
- arbitrary rotation: change of basis
  - given two orthonormal coordinate systems *XYZ* and *ABC*
    - *A*'s location in the XYZ coordinate system is $(a_x, a_y, a_z, 1)$, ...
- transformation from one to the other is matrix R whose columns are *A,B,C*:

$$R(X) = \begin{bmatrix} a_x & b_x & c_x & 0 \\ a_y & b_y & c_y & 0 \\ a_z & b_z & c_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \end{bmatrix} = (a_x, a_y, a_z, 1) = A$$

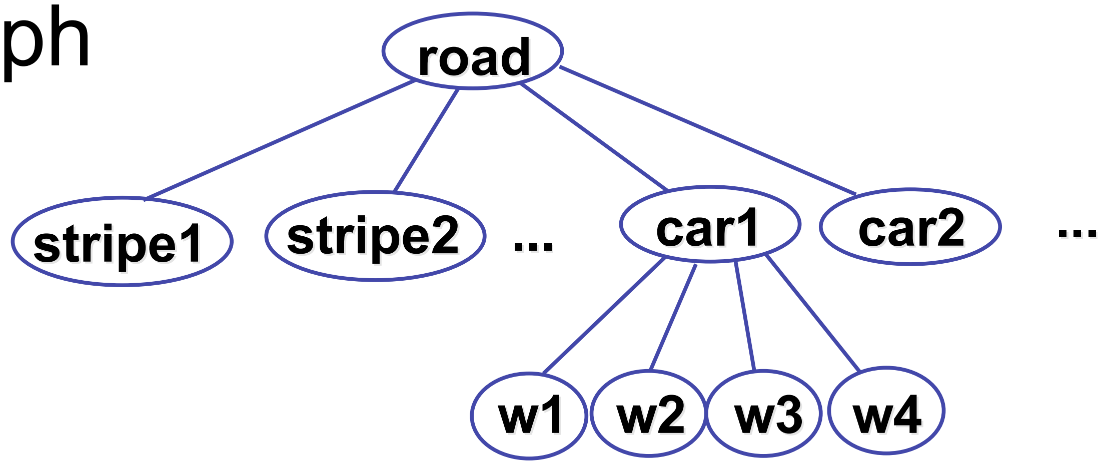
Transformation Hierarchies

Transformation Hierarchies

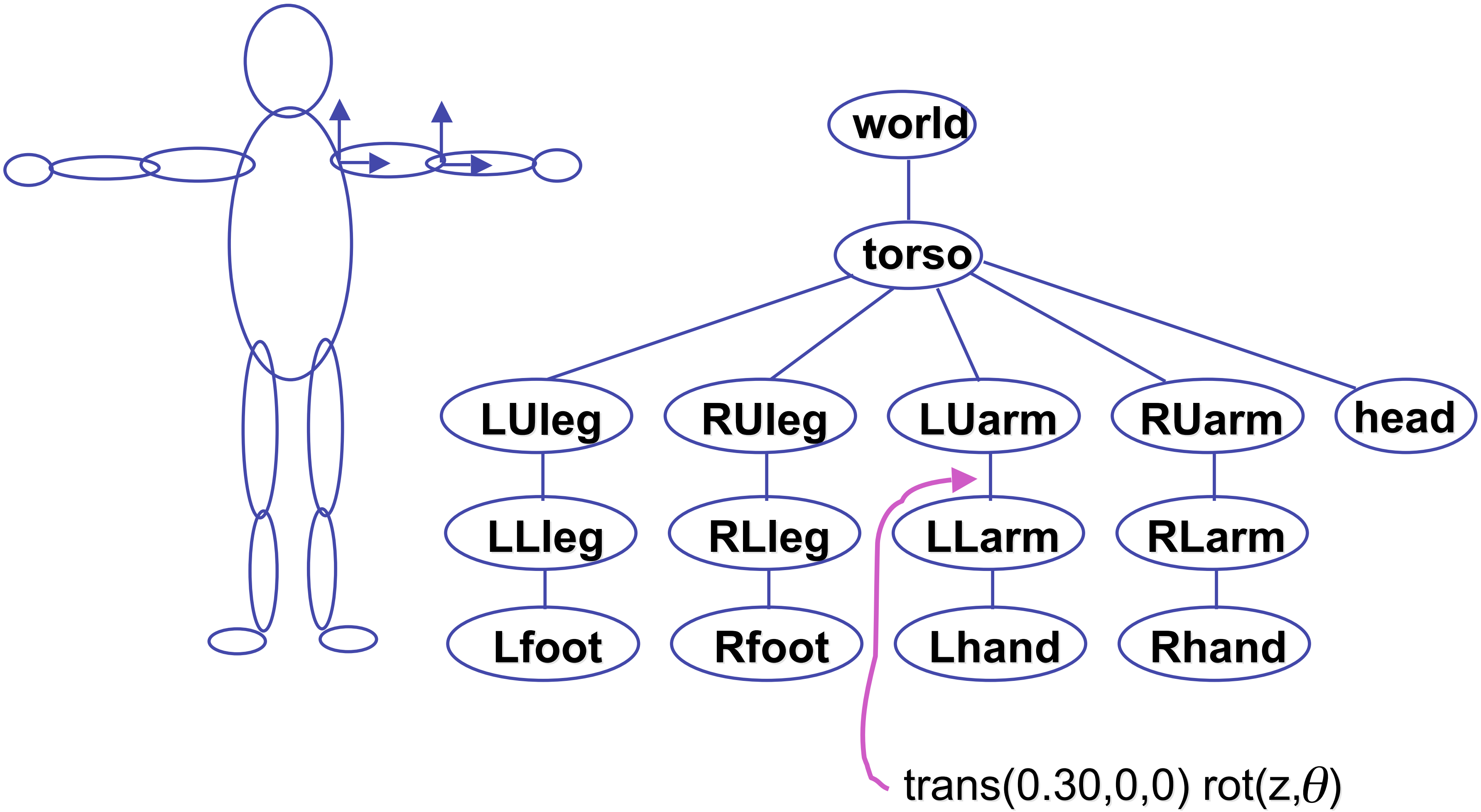
- scene may have a hierarchy of coordinate systems
  - stores matrix at each level with incremental transform from parent's coordinate system



- scene graph

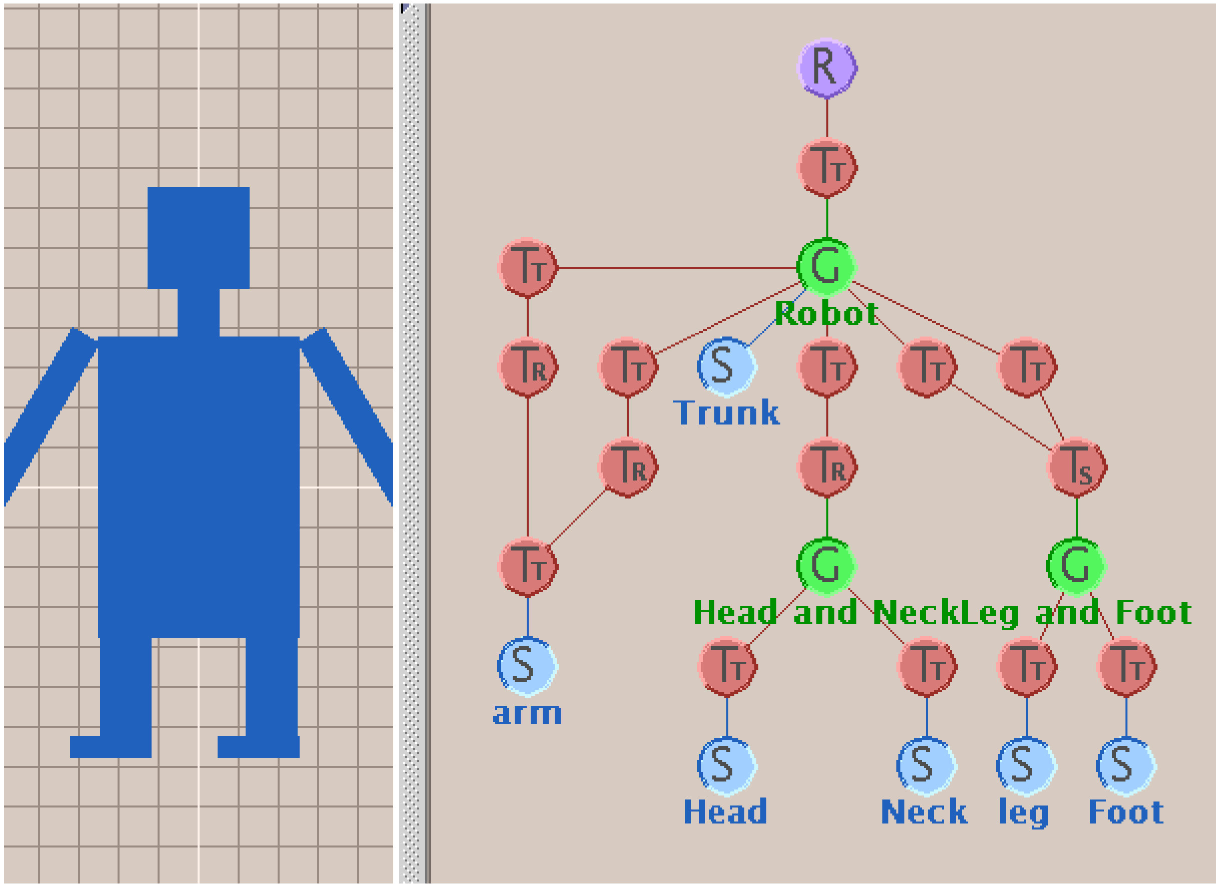


Transformation Hierarchy Example 1



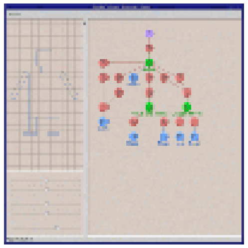
Transformation Hierarchies

- hierarchies don't fall apart when changed
- transforms apply to graph nodes beneath



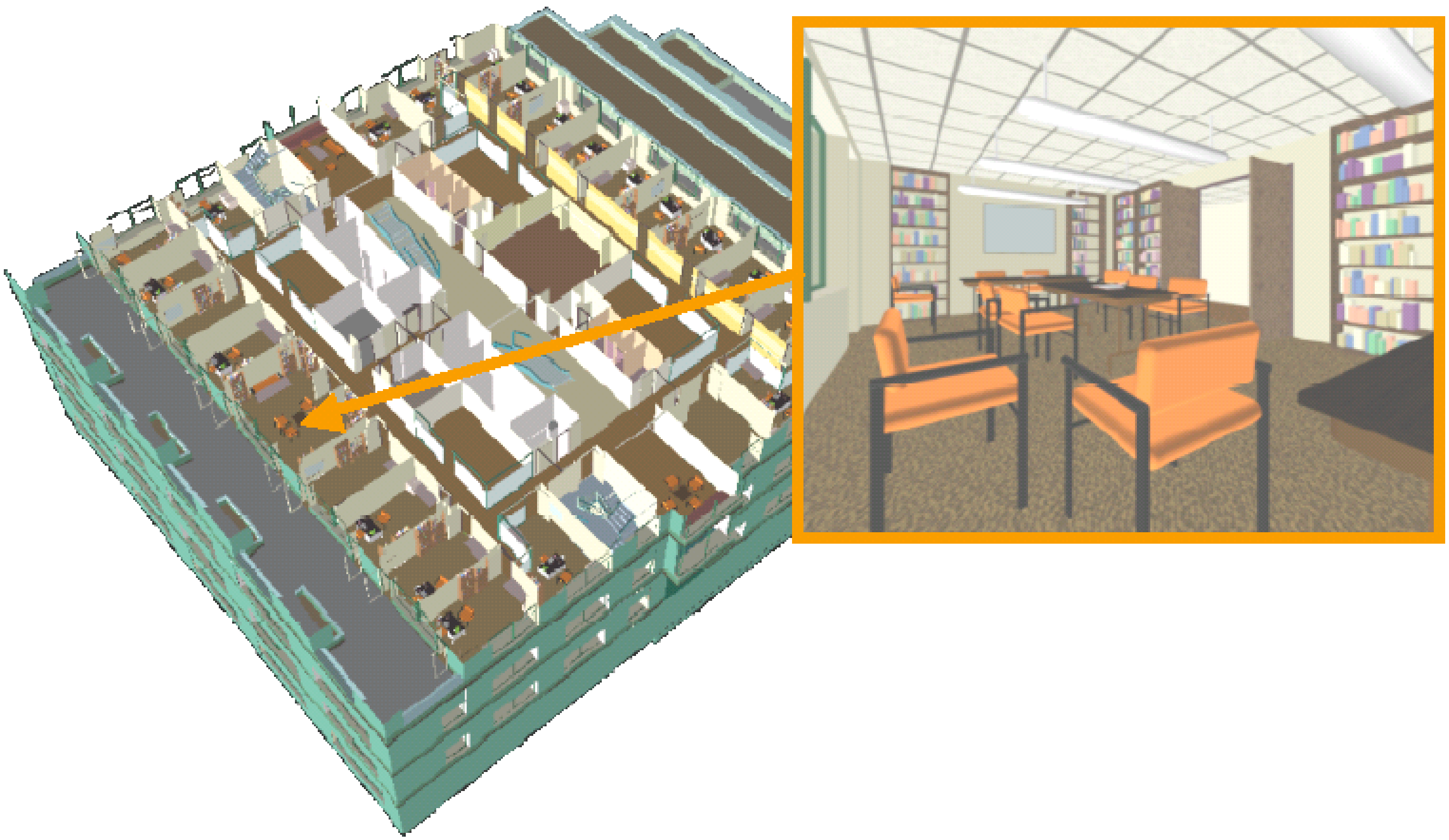
Demo: Brown Applets

`http://www.cs.brown.edu/exploratories/freeSoftware/catalogs/scenegraphs.html`



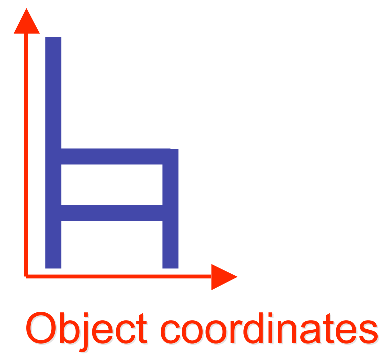
Transformation Hierarchy Example 2

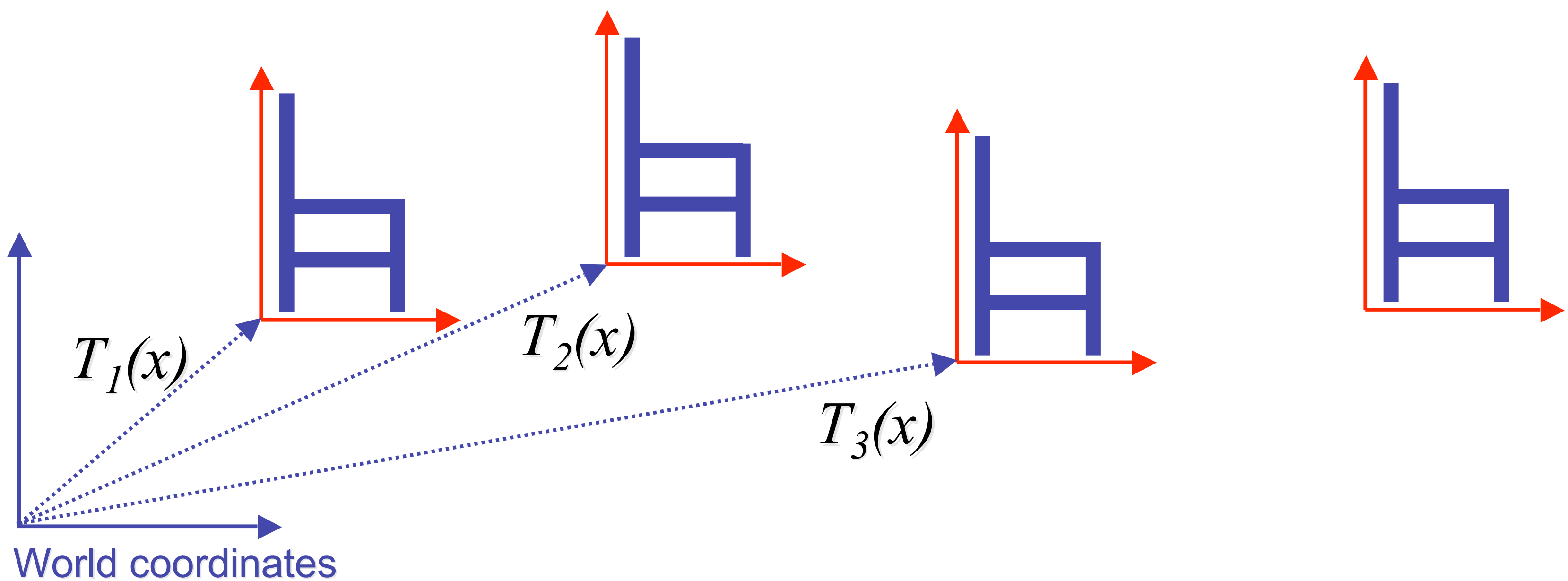
- draw same 3D data with different transformations: instancing



Matrix Stacks

- challenge of avoiding unnecessary computation
  - using inverse to return to origin
  - computing incremental T_1 -> T_2



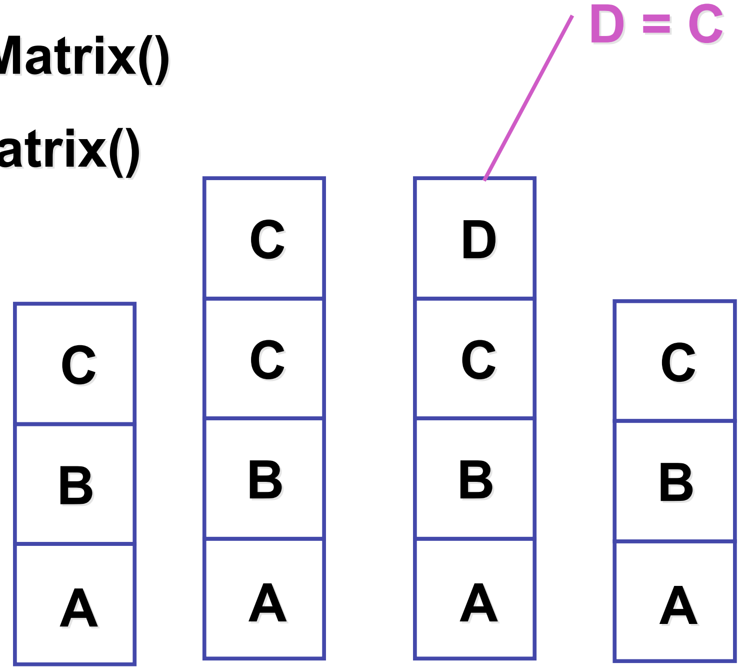


Matrix Stacks

glPushMatrix()

glPopMatrix()

D = C scale(2,2,2) trans(1,0,0)



DrawSquare()

glPushMatrix()

glScale3f(2,2,2)

glTranslate3f(1,0,0)

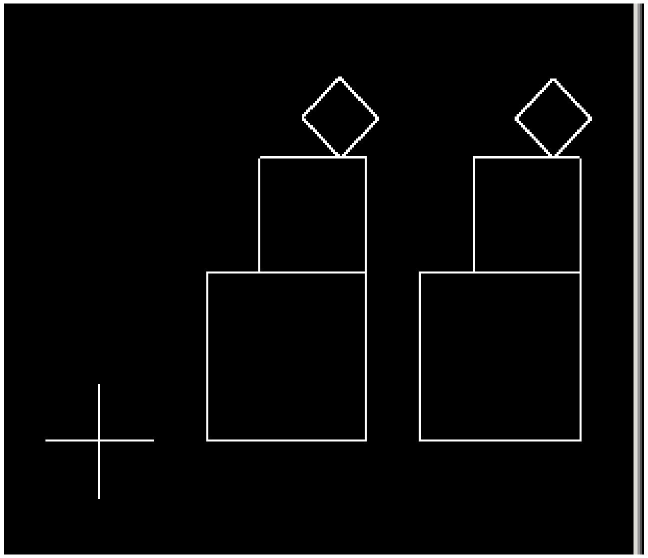
DrawSquare()

glPopMatrix()

Modularization

- drawing a scaled square
  - push/pop ensures no coord system change

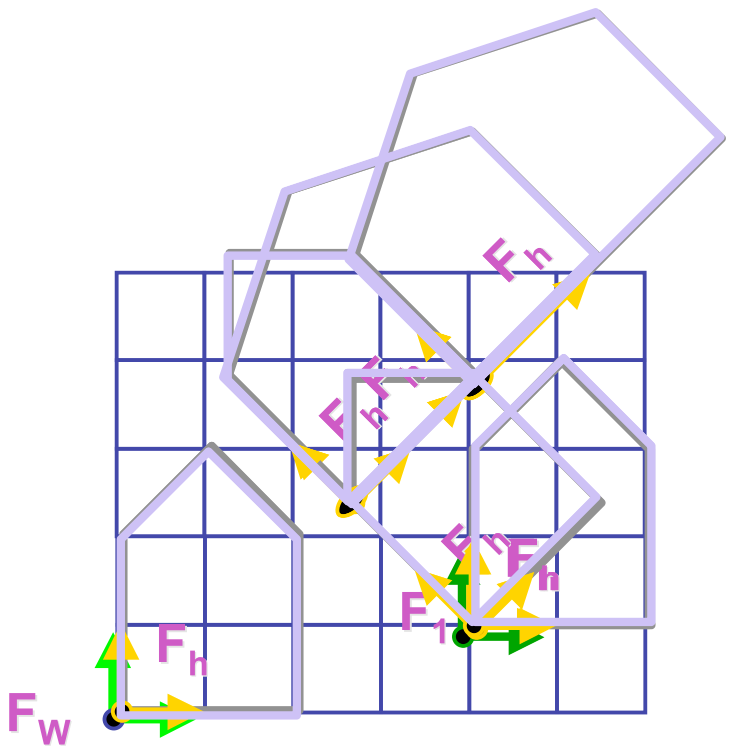
```
void drawBlock(float k) {
  glPushMatrix();

  glScalef(k,k,k);
  glBegin(GL_LINE_LOOP);
  glVertex3f(0,0,0);
  glVertex3f(1,0,0);
  glVertex3f(1,1,0);
  glVertex3f(0,1,0);
  glEnd();

  glPopMatrix();
}
```



Matrix Stacks

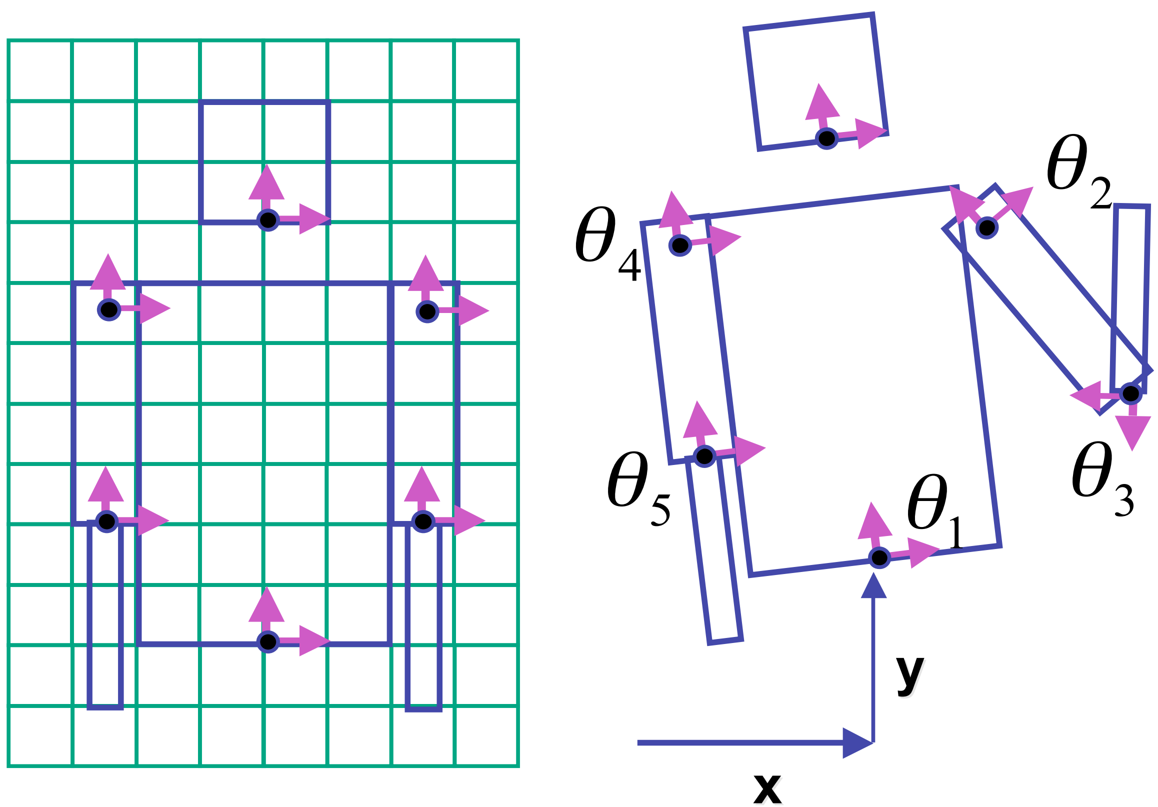
- advantages
  - no need to compute inverse matrices all the time
  - modularize changes to pipeline state
  - avoids incremental changes to coordinate systems
    - accumulation of numerical errors
- practical issues
  - in graphics hardware, depth of matrix stacks is limited
    - (typically 16 for model/view and about 4 for projective matrix)

Transformation Hierarchy Example 3




```
glLoadIdentity();
glTranslatef(4,1,0);
glPushMatrix();
glRotatef(45,0,0,1);
glTranslatef(0,2,0);
glScalef(2,1,1);
glTranslate(1,0,0);
glPopMatrix();
```

Transformation Hierarchy Example 4



glTranslate3f(x,y,0);
glRotatef(θ_1,0,0,1);
DrawBody();
glPushMatrix();
  glTranslate3f(0,7,0);
  DrawHead();
glPopMatrix();
glPushMatrix();
  glTranslate(2.5,5.5,0);
  glRotatef(θ_2,0,0,1);
  DrawUArm();
  glTranslate(0,-3.5,0);
  glRotatef(θ_3,0,0,1);
  DrawLArm();
glPopMatrix();
... (draw other arm)

Hierarchical Modelling

- advantages
  - define object once, instantiate multiple copies
  - transformation parameters often good control knobs
  - maintain structural constraints if well-designed
- limitations
  - expressivity: not always the best controls
  - can’t do closed kinematic chains
    - keep hand on hip
  - can’t do other constraints
    - collision detection
      - self-intersection
      - walk through walls

Single Parameter: Simple

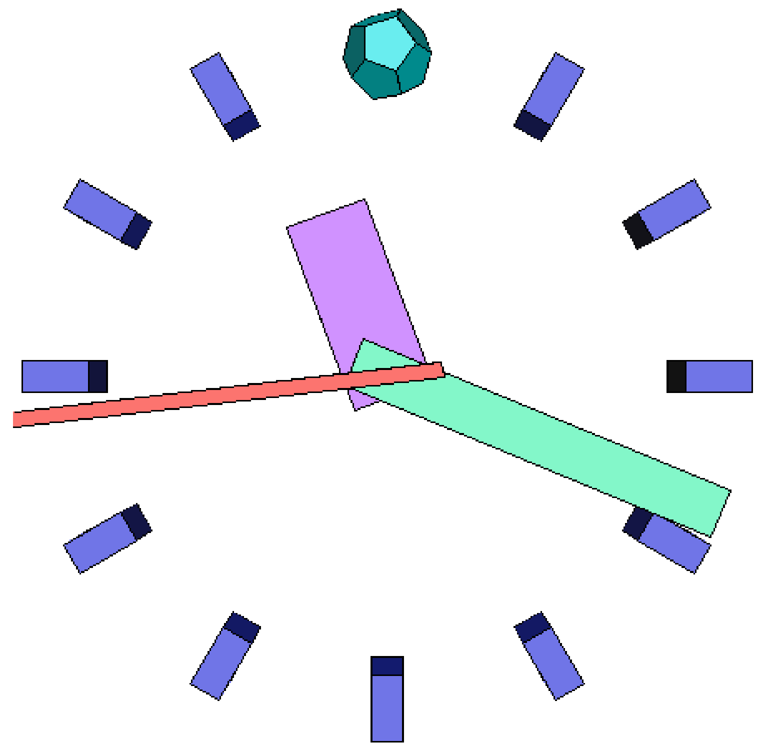
- parameters as functions of other params
  - clock: control all hands with seconds s

m = s/60, h=m/60,

theta_s = (2 pi s) / 60,

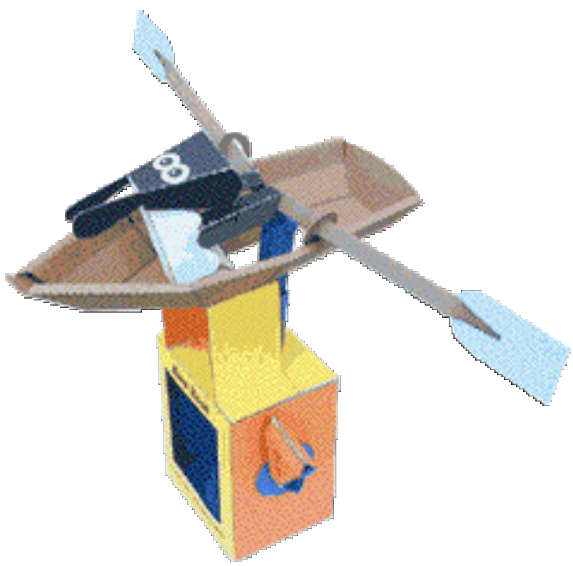
theta_m = (2 pi m) / 60,

theta_h = (2 pi h) / 60



Single Parameter: Complex

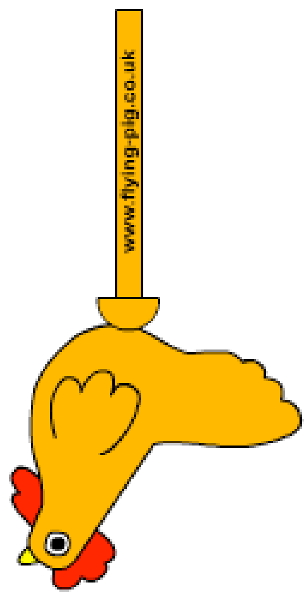
- mechanisms not easily expressible with affine transforms



http://www.flying-pig.co.uk

Single Parameter: Complex

- mechanisms not easily expressible with affine transforms



http://www.flying-pig.co.uk/mechanisms/pages/irregular.html

Display Lists

Display Lists

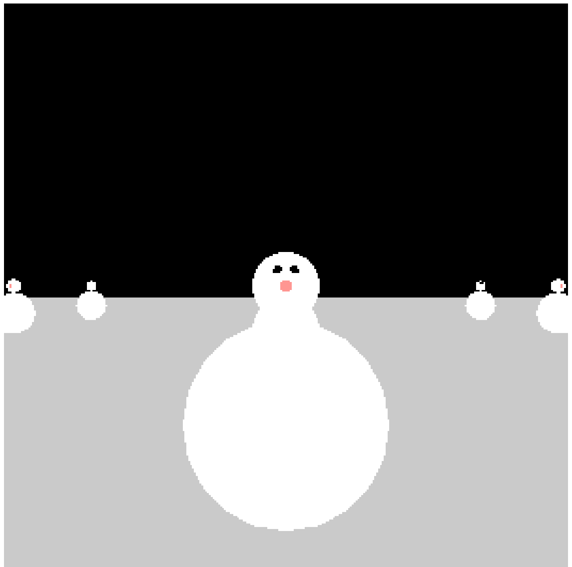
- precompile/cache block of OpenGL code for reuse
  - usually more efficient than immediate mode
    - exact optimizations depend on driver
  - good for multiple instances of same object
    - but cannot change contents, not parametrizable
  - good for static objects redrawn often
    - display lists persist across multiple frames
    - interactive graphics: objects redrawn every frame from new viewpoint from moving camera
  - can be nested hierarchically
- snowman example

  http://www.lighthouse3d.com/opengl/displaylists

One Snowman

```
void drawSnowMan() {

glColor3f(1.0f, 1.0f, 1.0f);

// Draw Body
glTranslatef(0.0f ,0.75f, 0.0f);
glutSolidSphere(0.75f,20,20);

// Draw Head
glTranslatef(0.0f, 1.0f, 0.0f);
glutSolidSphere(0.25f,20,20);

// Draw Eyes
glPushMatrix();
glColor3f(0.0f,0.0f,0.0f);
glTranslatef(0.05f, 0.10f, 0.18f);
glutSolidSphere(0.05f,10,10);
glTranslatef(-0.1f, 0.0f, 0.0f);
glutSolidSphere(0.05f,10,10);
glPopMatrix();

// Draw Nose
glColor3f(1.0f, 0.5f , 0.5f);
glRotatef(0.0f,1.0f, 0.0f, 0.0f);
glutSolidCone(0.08f,0.5f,10,2);
}
```

Instantiate Many Snowmen



```
// Draw 36 Snowmen
for(int i = -3; i < 3; i++)
   for(int j=-3; j < 3; j++) {
   glPushMatrix();
   glTranslatef(i*10.0, 0, j * 10.0);
   // Call the function to draw a snowman
   drawSnowMan();
   glPopMatrix();
}
```

36K polygons, 55 FPS

Making Display Lists

```
GLuint createDL() {
GLuint snowManDL;
// Create the id for the list
snowManDL = glGenLists(1);
glNewList(snowManDL,GL_COMPILE);
drawSnowMan();
glEndList();
return(snowManDL); }

snowmanDL = createDL();
for(int i = -3; i < 3; i++)
  for(int j=-3; j < 3; j++) {
    glPushMatrix();
    glTranslatef(i*10.0, 0, j * 10.0);
    glCallList(Dlid);
    glPopMatrix(); }
```

36K polygons, 153 FPS

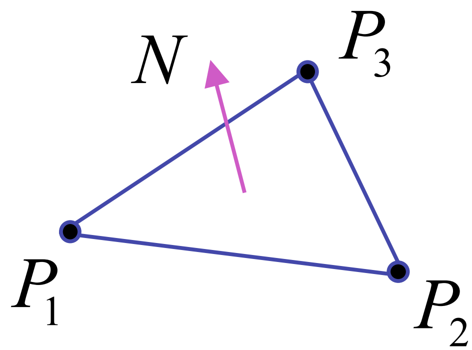
Transforming Normals

Transforming Geometric Objects

- lines, polygons made up of vertices
- just transform the vertices, interpolate between
- does this work for everything? no!

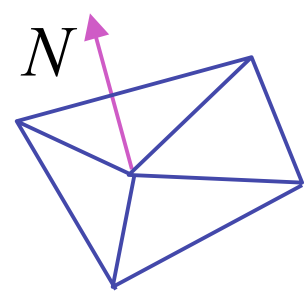
Computing Normals

- polygon:



$$N = (P_2 - P_1) \times (P_3 - P_1)$$

- assume vertices ordered CCW when viewed from visible side of polygon
- normal for a vertex
  - specify polygon orientation
  - used for lighting
  - supplied by model (i.e., sphere), or computed from neighboring polygons



Transforming Normals

- what is a normal?
  - a **direction**
    - homogeneous coordinates: w=0 means direction
  - often normalized to unit length
  - vs. points/vectors that are object vertex locations
- what are normals for?
    - specify orientation of polygonal face
    - used when computing lighting

- so if points transformed by matrix **M**, can we just transform normal vector by **M** too?

Transforming Normals

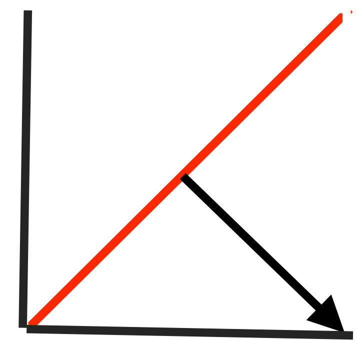
$$\begin{bmatrix} x' \\ y' \\ z' \\ 0 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & T_x \\ m_{21} & m_{22} & m_{23} & T_y \\ m_{31} & m_{32} & m_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 0 \end{bmatrix}$$

- translations OK: w=0 means unaffected
- rotations OK
- uniform scaling OK

- these all maintain direction

Transforming Normals

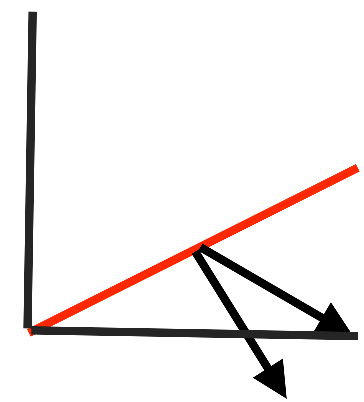
- nonuniform scaling does not work
- x-y=0 plane
  - line x=y
  - normal: [1,-1,0]
    - direction of line x=-y
    - (ignore normalization for now)



Transforming Normals

- apply nonuniform scale: stretch along x by 2
  - new plane x = 2y
- transformed normal: [2,-1,0]

$$\begin{bmatrix} 2 \\ -1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 2 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ -1 \\ 0 \\ 0 \end{bmatrix}$$



  - normal is direction of line x = -2y or x+2y=0
  - not perpendicular to plane!
  - should be direction of 2x = -y

Planes and Normals

- plane is all points perpendicular to normal
  - $N \cdot P = 0$ (with dot product)
  - $N^{\mathbf{T}} P = 0$ (matrix multiply requires transpose)

$$N = \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix}, P = \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

- explicit form: plane = $ax + by + cz + d$

Finding Correct Normal Transform

- transform a plane

$$P \qquad\qquad P' = MP$$

$$N \longrightarrow N' = QN$$

given M,
what should Q be?

$$N'^T P' = 0$$

stay perpendicular

$$(QN)^T (MP) = 0$$

substitute from above

$$N^T \underbrace{Q^T M} P = 0$$

$$(\mathbf{AB})^{\mathrm{T}} = \mathbf{B}^{\mathrm{T}} \mathbf{A}^{\mathrm{T}}$$

$$Q^T M = I$$

$$\mathbf{N}^{\mathrm{T}}\mathbf{P} = 0 \text{ if } \mathbf{Q}^{\mathrm{T}}\mathbf{M} = \mathbf{I}$$

$$\boxed{\mathbf{Q} = \left(\mathbf{M}^{-1}\right)^{\mathrm{T}}}$$

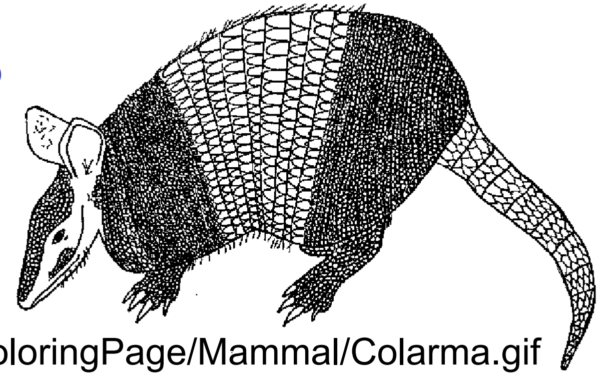
thus the normal to any surface can be transformed by the inverse transpose of the modelling transformation

Assignments

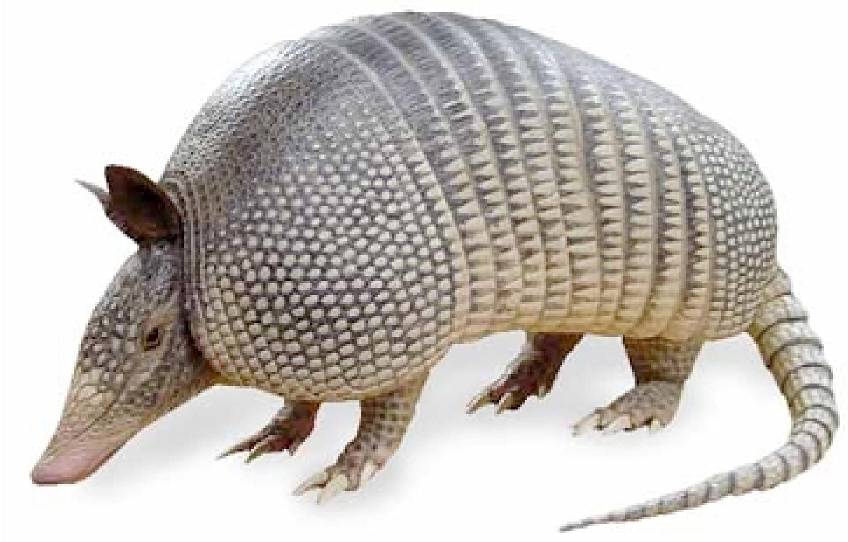
Assignments

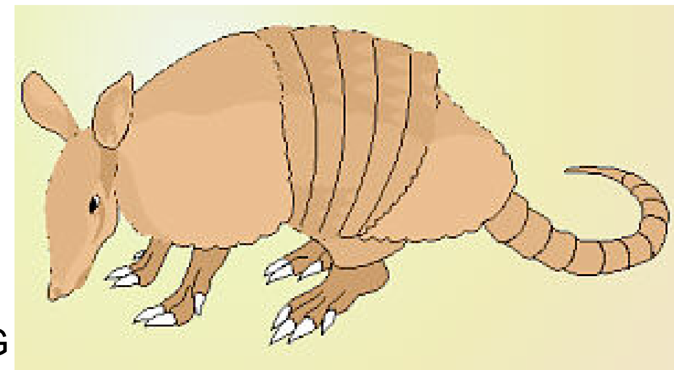
- project 1
  - out today, due 5:59pm Fri Feb 2
    - you should start very soon!
  - build armadillo out of cubes and 4x4 matrices
    - think cartoon, not beauty
  - template code gives you program shell, Makefile
    - http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007/p1.tar.gz
- written homework 1
  - out today, due 3pm Fri Feb 2
  - theoretical side of material

Real Armadillos



http://pelotes.jea.com/ColoringPage/Mammal/Colarma.gif





http://armadillo.blueprint.org/images/armadillo.bmp

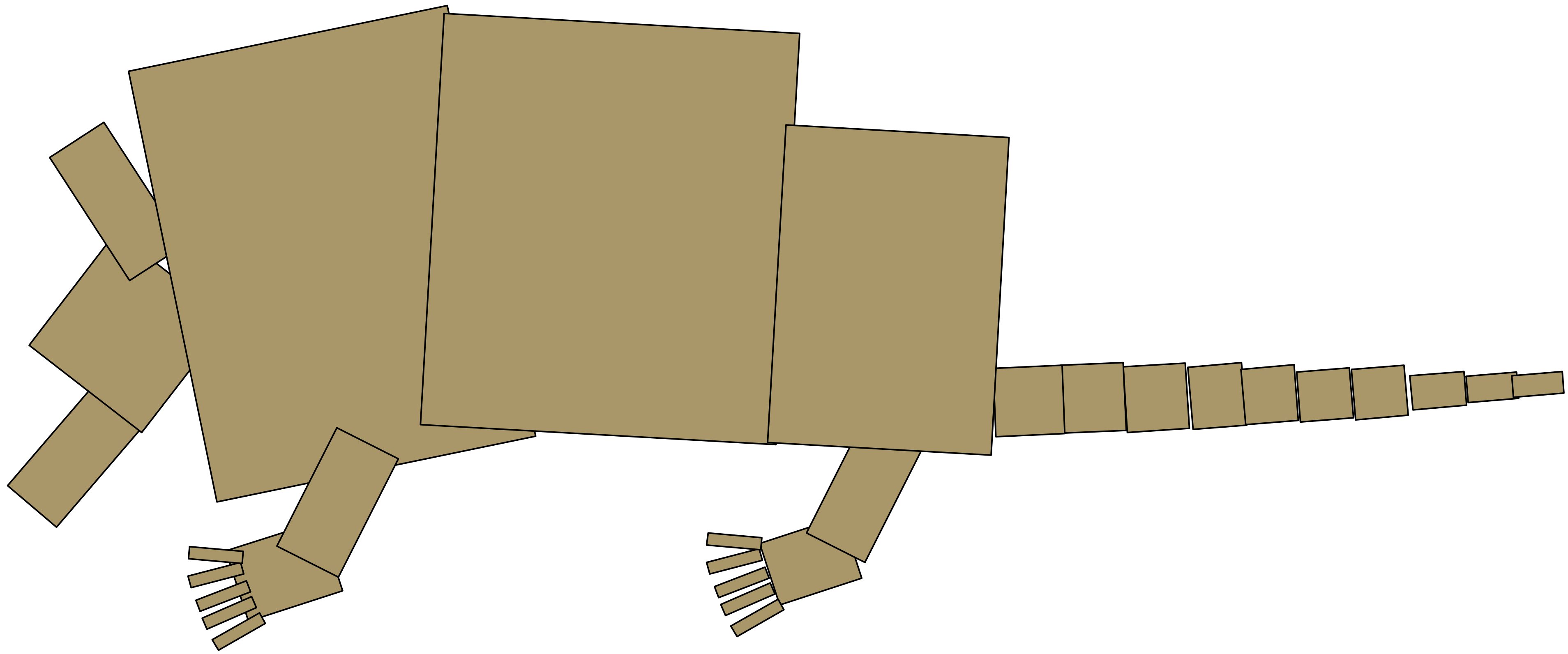
http://biology.clc.uc.edu/graphics/bio106/armadillo.JPG

http://www.phillyist.com/attachments/philly_mike/armadillo.jpg

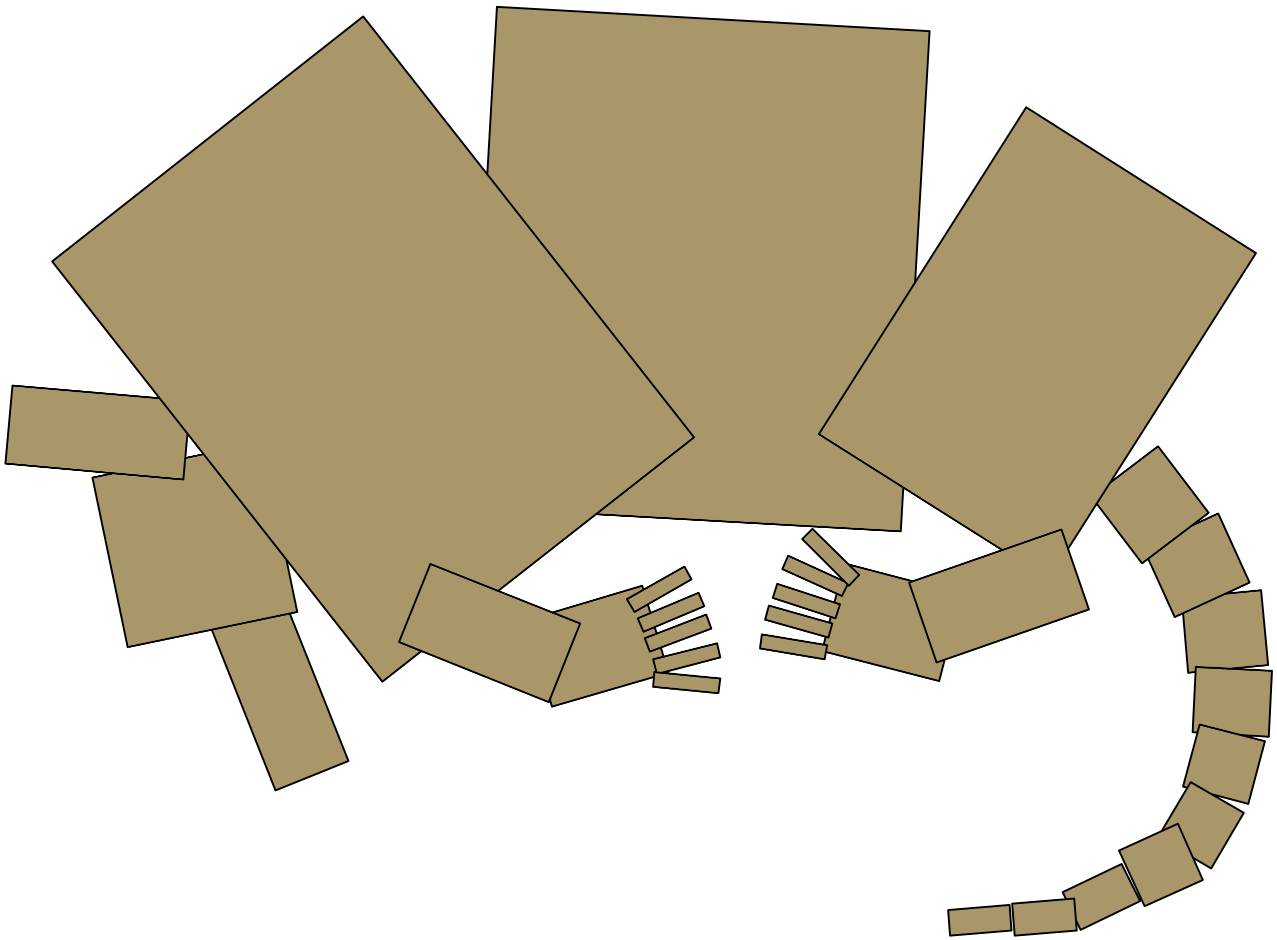
http://www.delargy.com/images/2004_2_Fla/armadillo.JPG

http://www.photogalaxy.com/pic/mattbl-69/armadillo.jpg

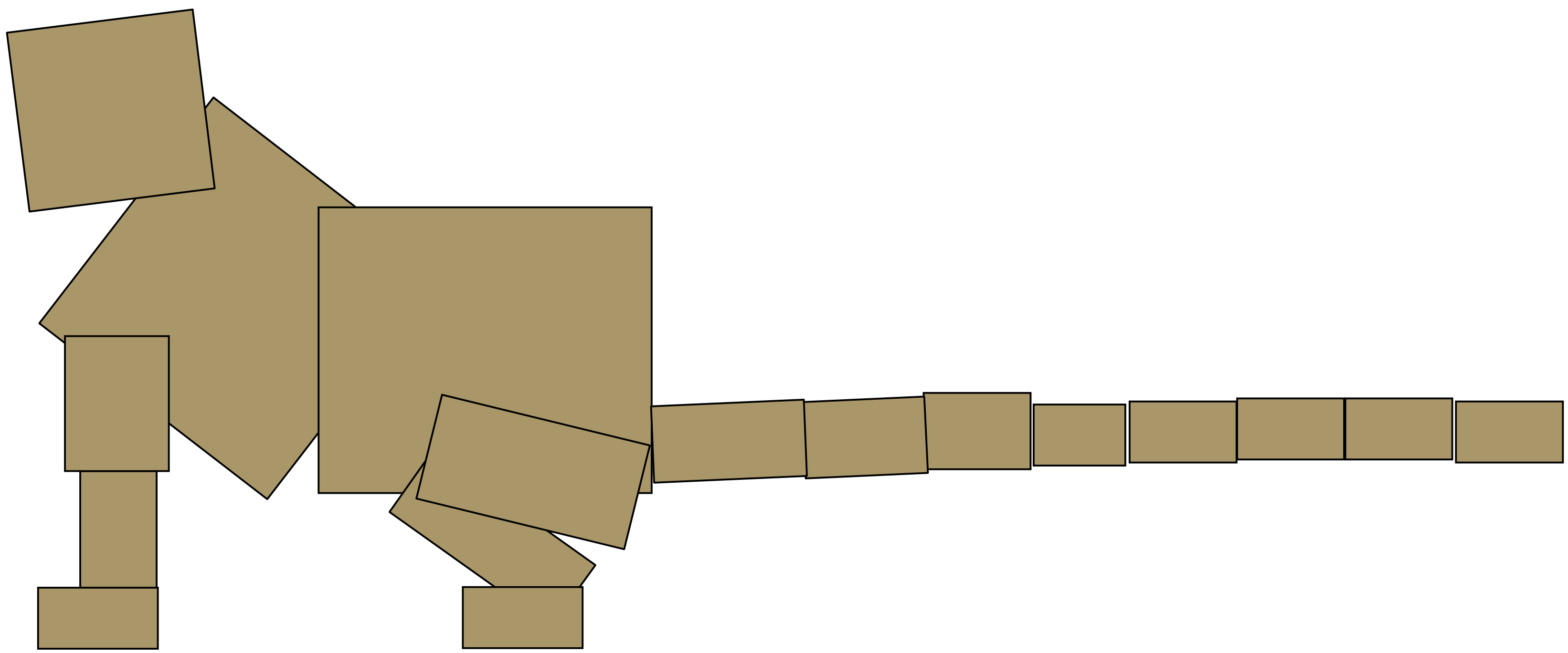
Articulated Armadillo



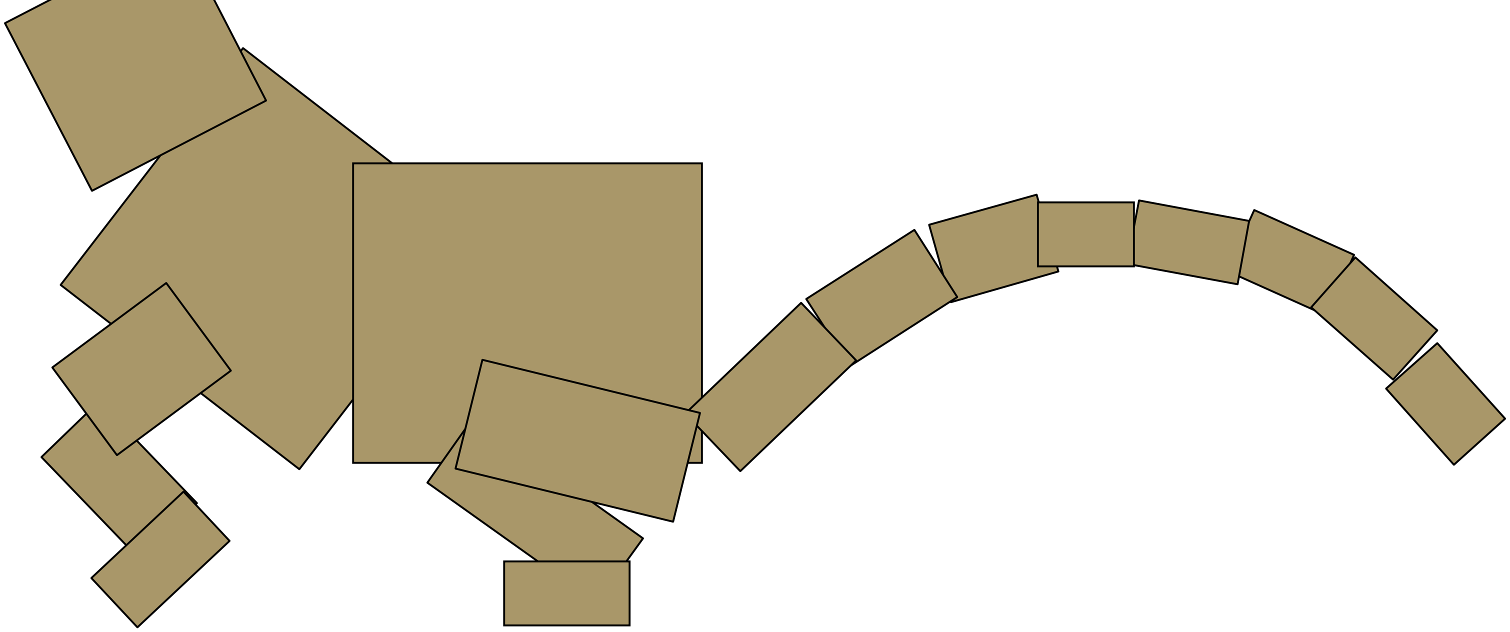
Articulated Armadillo



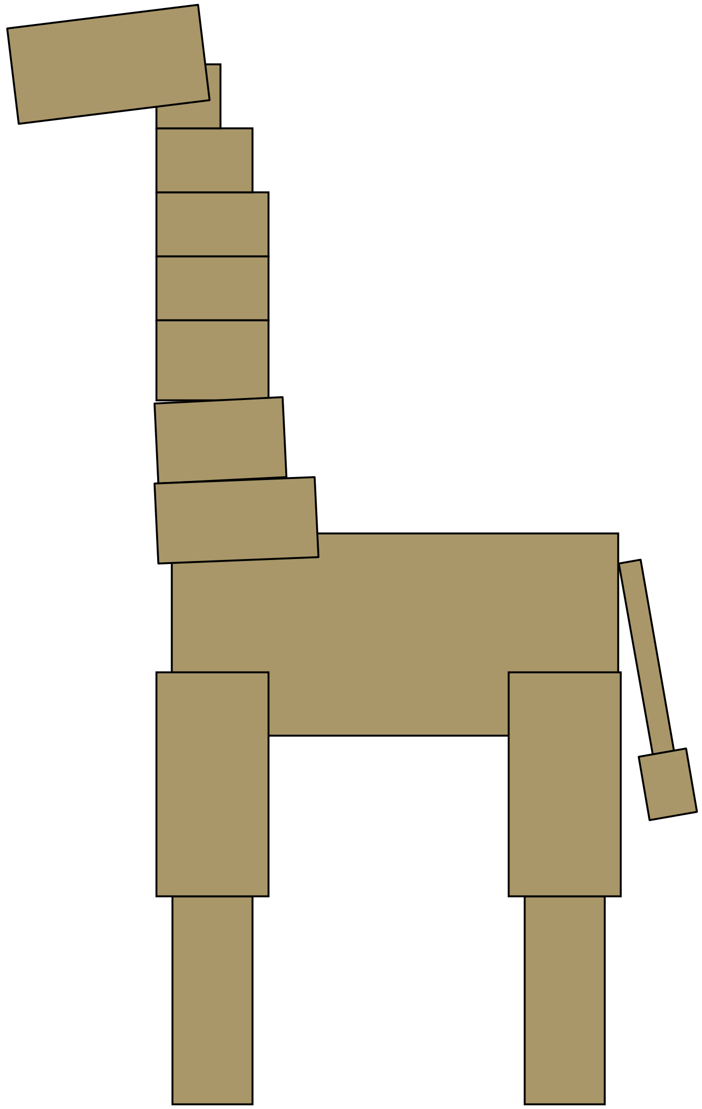
More Fun With Boxes and Matrices:



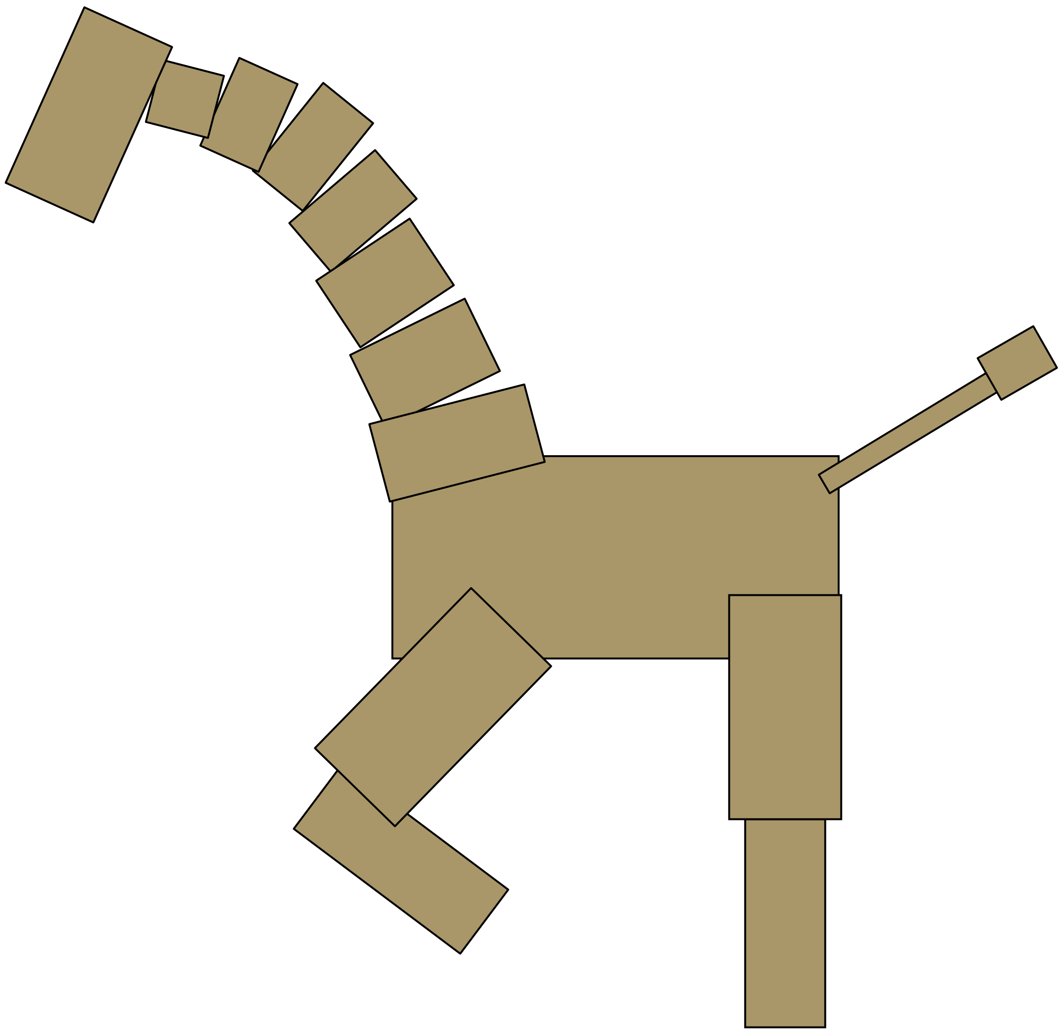
Lemurs!



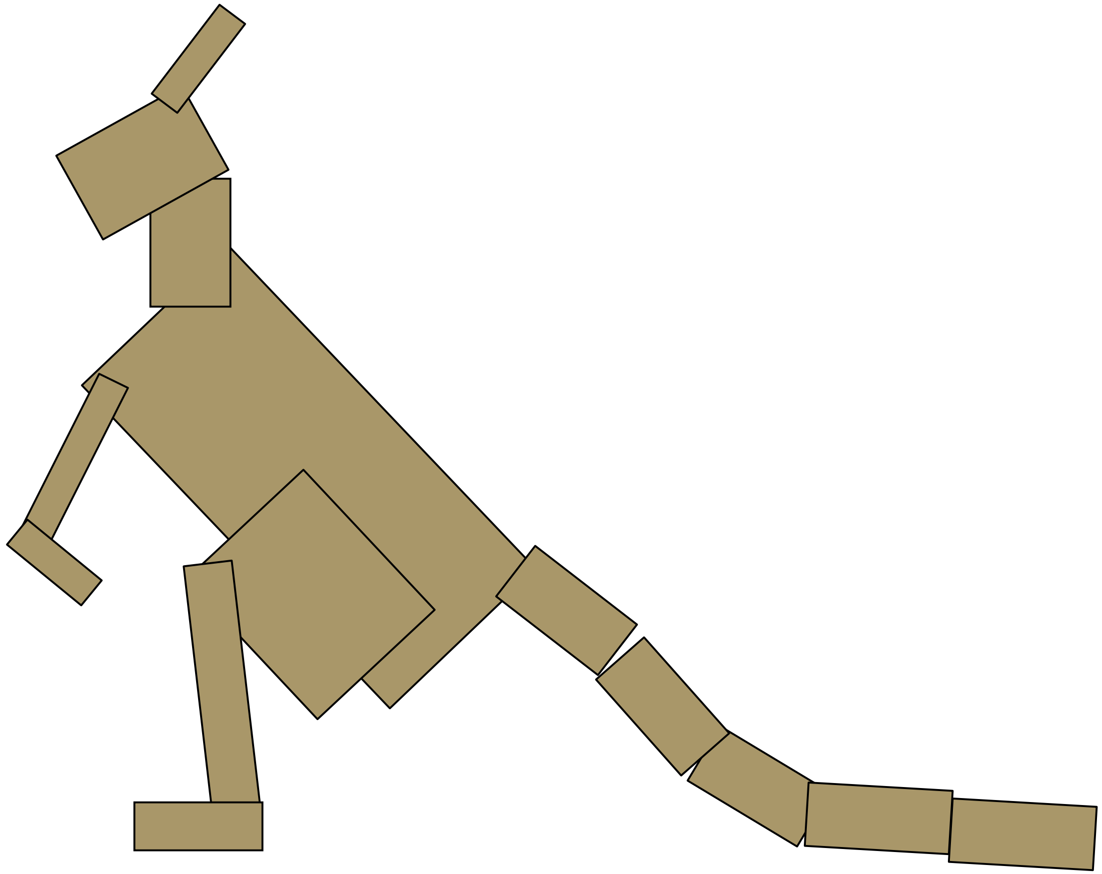
Giraffes!



Giraffes!



Kangaroos!



Demo

Project 1 Advice

- do not model everything first and only then worry about animating
- interleave modelling, animation
  - add body part, then animate it
  - discover if on wrong track sooner
  - depenencies: can’t get anim credit if no model
  - use middle body as scene graph root
- check from all camera angles

Project 1 Advice

- finish all required parts before
  - going for extra credit
  - playing with lighting or viewing
- ok to use glRotate, glTranslate, glScale
- ok to use glutSolidCube, or build your own
  - where to put origin? your choice
    - center of object, range - .5 to +.5
    - corner of object, range 0 to 1

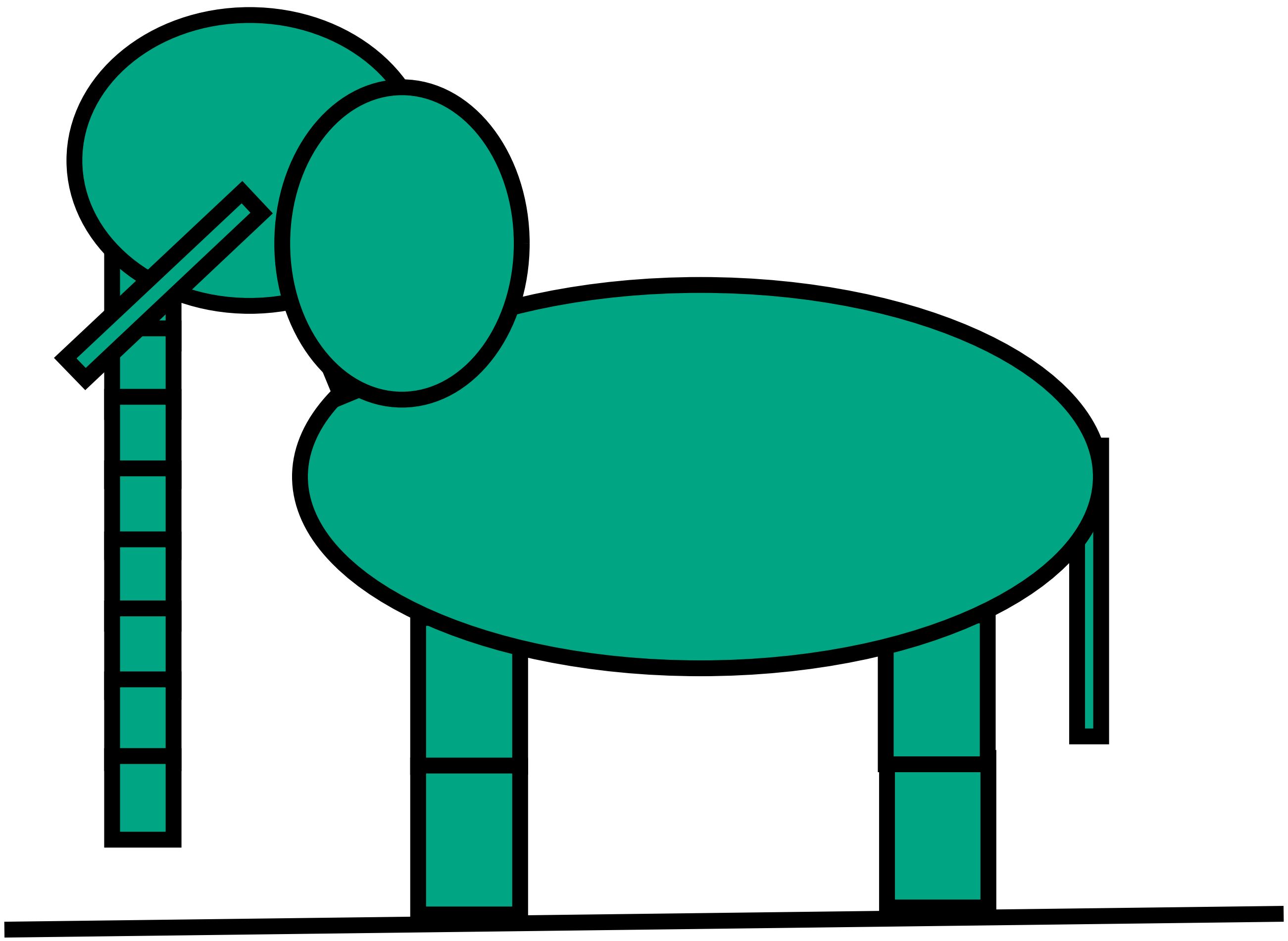
Project 1 Advice

- visual debugging
  - color cube faces differently
  - colored lines sticking out of glutSolidCube faces
- thinking about transformations
  - move physical objects around
  - play with demos
    - Brown scenegraph applets

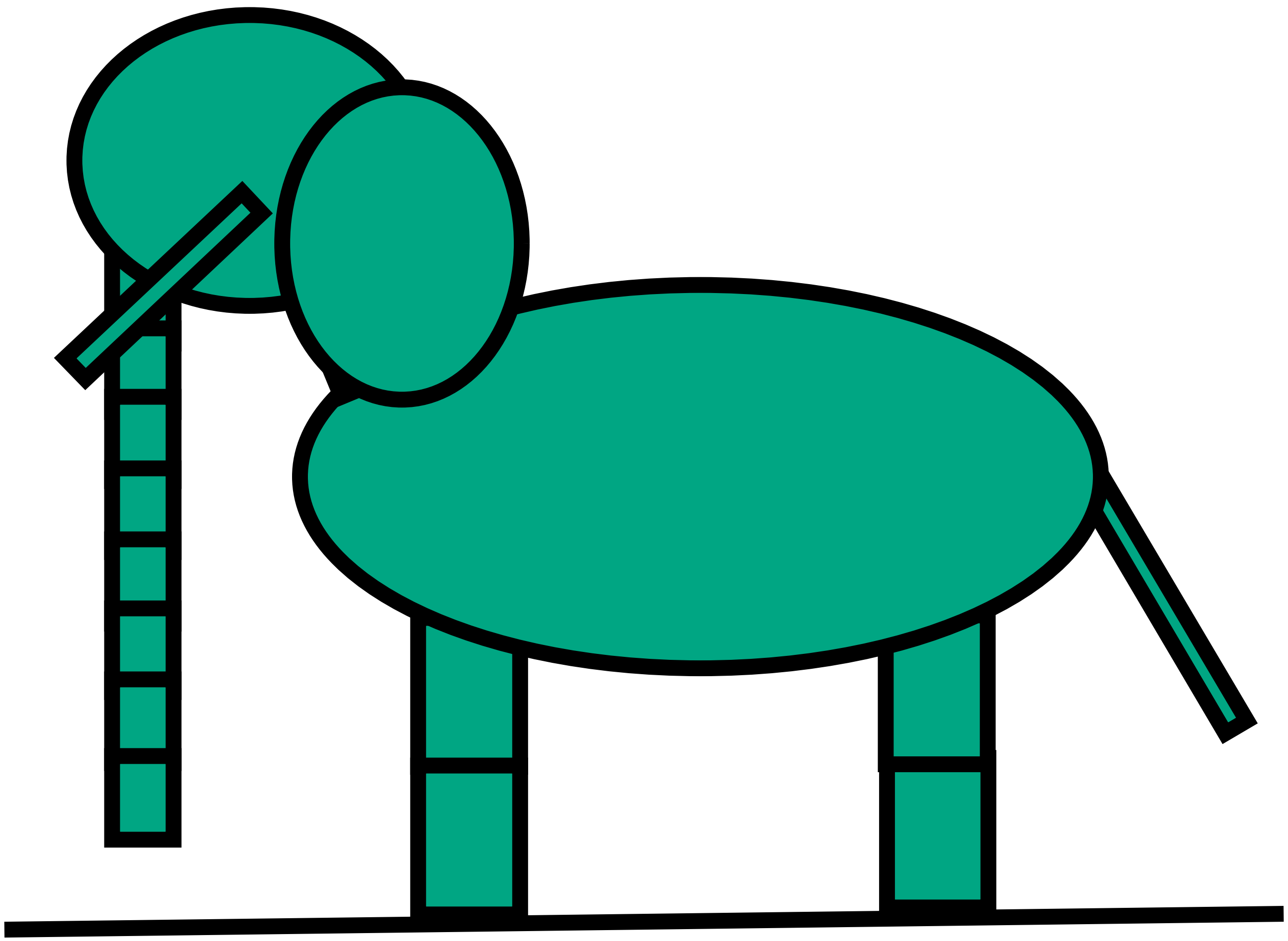
Project 1 Advice

- first: jump cut from old to new position
  - all change happens in single frame
- do last: add smooth transition
  - change happens gradually over 30 frames
  - key click triggers animation loop
    - explicitly redraw 30 times
    - linear interpolation:
      each time, param += (new-old)/30
  - example: 5-frame transition

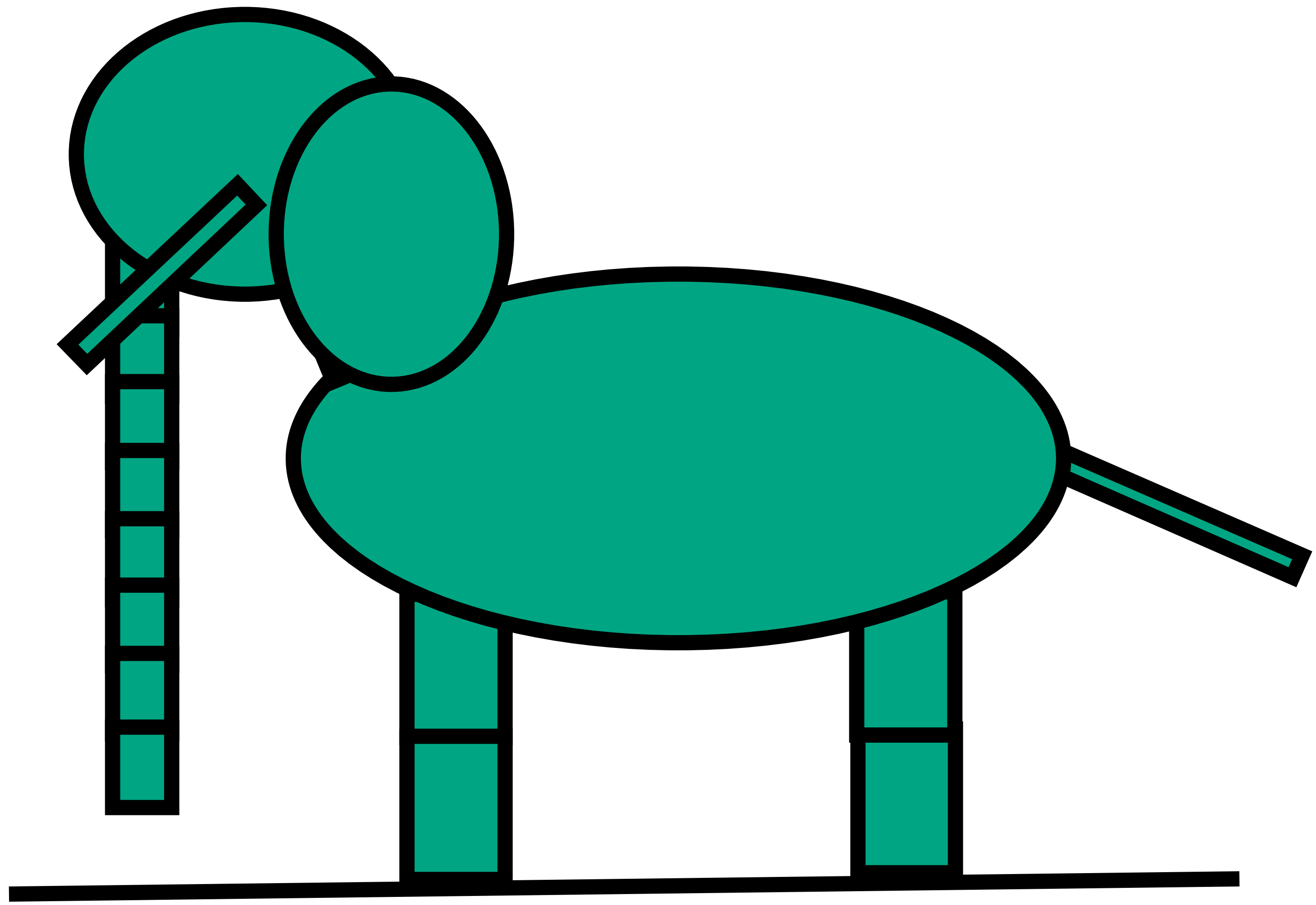
Tail Wag Frame 0



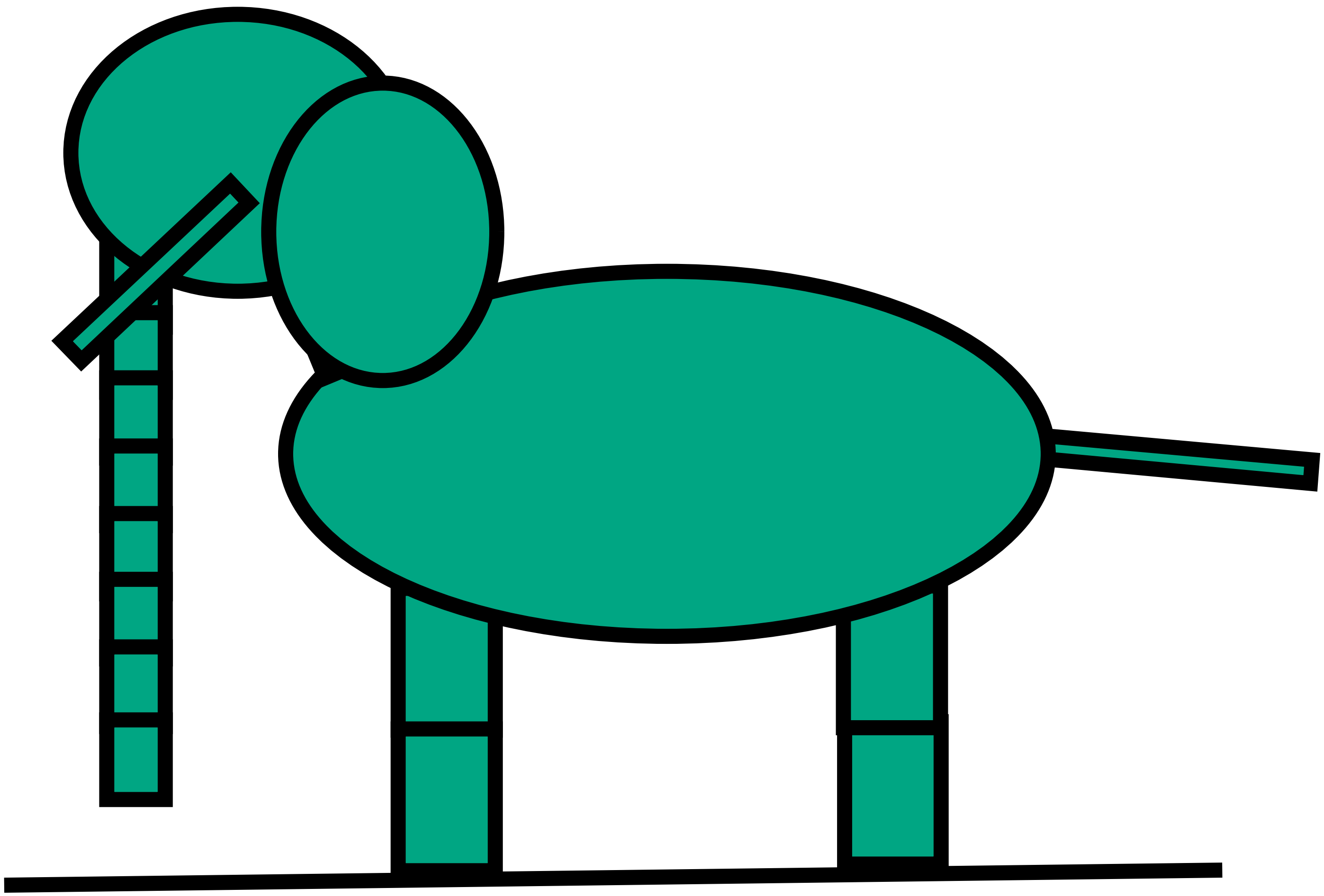
Tail Wag Frame 1



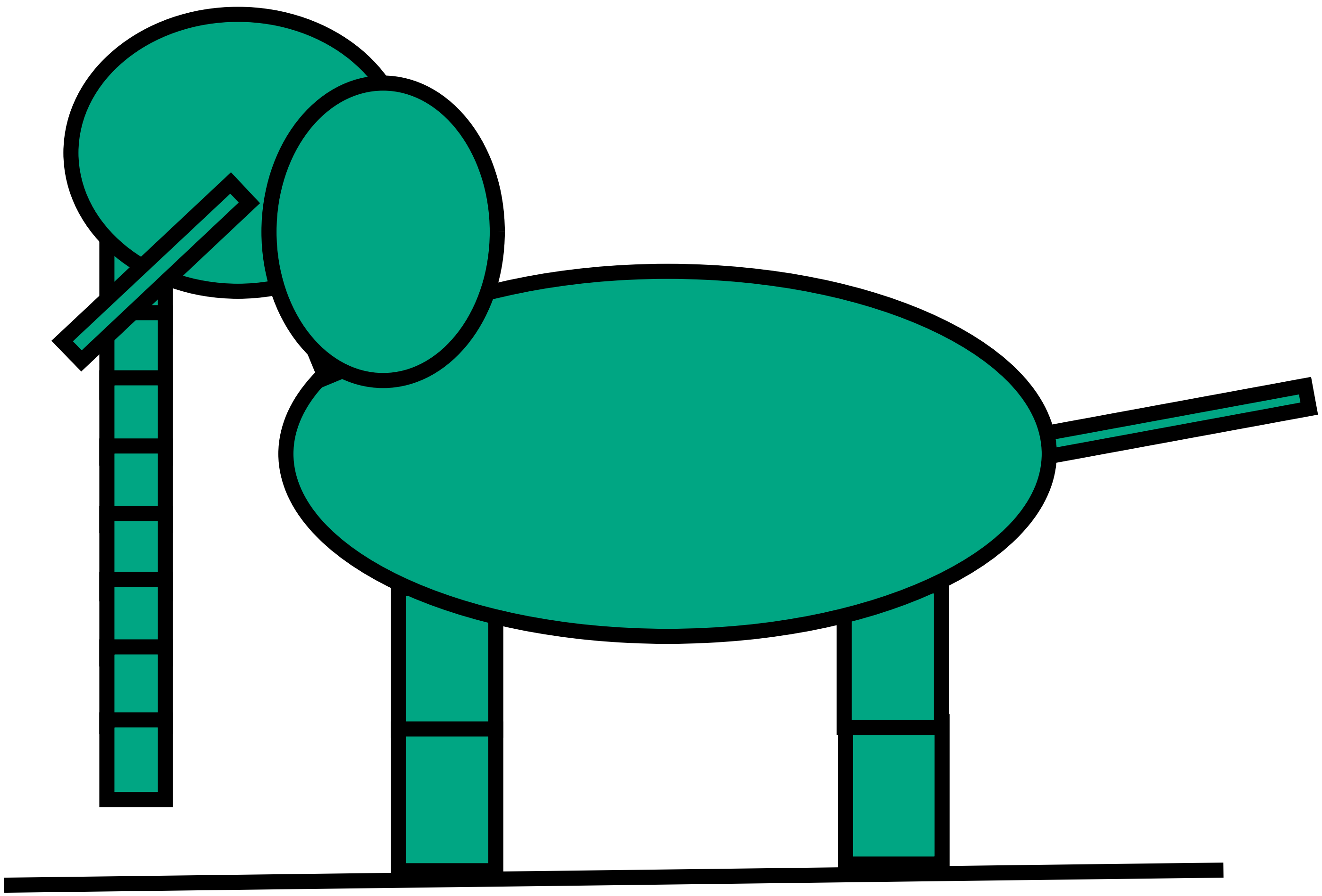
Tail Wag Frame 2



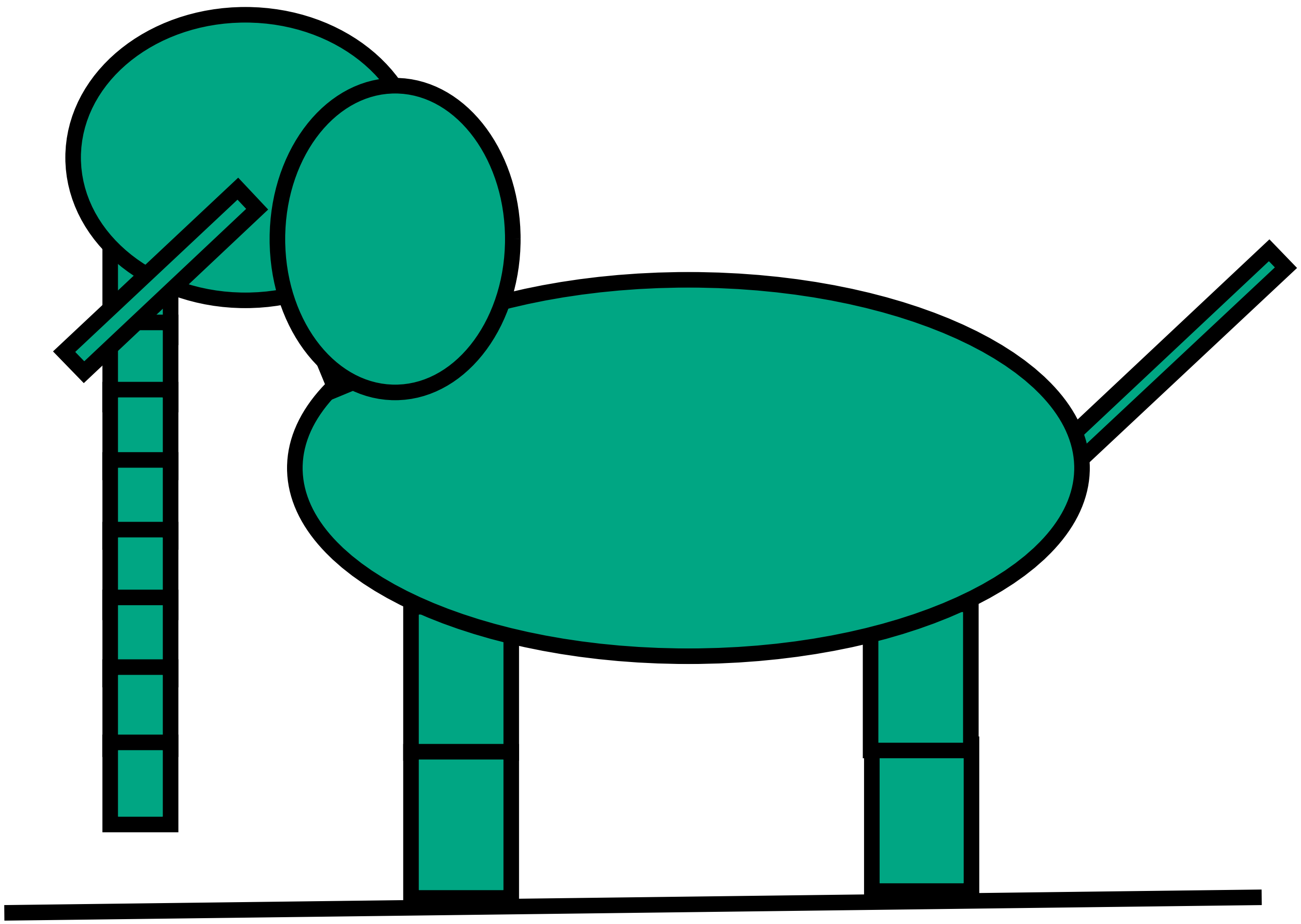
Tail Wag Frame 3



Tail Wag Frame 4



Tail Wag Frame 5



Project 1 Advice

- transitions
  - safe to linearly interpolate parameters for glRotate/glTranslate/glScale
  - do not interpolate individual elements of 4x4 matrix!

Style

- you can lose up to 15% for poor style
- most critical: reasonable structure
  - yes: parametrized functions
  - no: cut-and-paste with slight changes
- reasonable names (variables, functions)
- adequate commenting
  - rule of thumb: what if you had to fix a bug two years from now?
- global variables are indeed acceptable

Version Control

- bad idea: just keep changing same file
- save off versions often
  - after got one thing to work, before you try starting something else
  - just before you do something drastic
- how?
  - not good: commenting out big blocks of code
  - a little better: save off file under new name
    - p1.almostworks.cpp, p1.fixedbug.cpp
- much better:use version control software
  - strongly recommended

Version Control Software

- easy to browse previous work
- easy to revert if needed
- for maximum benefit, use meaningful comments to describe what you did
    - “started on tail”, “fixed head breakoff bug”, “leg code compiles but doesn’t run”
- useful when you’re working alone
- critical when you’re working together
- many choices: RCS, CVS, subversion
  - RCS is a good place to start
    - easy to use, installed on lab machines

RCS Basics

- setup, just do once in a directory
  - mkdir RCS

- checkin
  - ci –u p1.cpp
- checkout
  - co –l p1.cpp
- see history
  - rcs log p1.cpp
- compare to previous version
  - rcsdiff p1.cpp
- checkout old version to stdout
  - co –p1.5 p1.cpp > p1.cpp.5

Graphical File Comparison

- installed on lab machines
  - xfdiff4 (side by side comparison)
  - xwdiff (in-place, with crossouts)
- Windows: windiff
  - http://keithdevens.com/files/windiff
- Macs: FileMerge
  - in /Developer/Applications/Utilities