University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2010

Tamara Munzner

## Transformations III

## Week 3, Mon Jan 18

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2010

## News

- CS dept announcements
- Undergraduate Summer Research Award (USRA)
  - applications due Feb 26
  - see Guiliana for more details



Department of Computer Science
Undergraduate Events

**Events this week**

**Drop-in Resume/Cover Letter Editing**
Date: Tues., Jan 19
Time: 12:30 – 2 pm
Location: Rm 255, ICICS/CS Bldg.

**Interview Skills Workshop**
Date: Thurs., Jan 21
Time: 12:30 – 2 pm
Location: DMP 201
Registration: Email dianejoh@cs.ubc.ca

**Project Management Workshop**
Speaker: David Hunter (ex-VP, SAP)
Date: Thurs., Jan 21
Time: 5:30 – 7 pm
Location: DMP 110

**CSSS Laser Tag**
Date: Sun., Jan 24
Time: 7 – 9 pm
Location: Planet Laser @ 100 Braid St., New Westminster

**Event next week**

**Public Speaking 11**
Date: Mon., Jan 25
Time: 5 – 6 pm
Location: DMP 101



## Assignments



## Assignments

- project 1
  - out today, due 5pm sharp Fri Jan 29
    - projects will go out before we've covered all the material
      - so you can think about it before diving in
  - build iguana out of cubes and 4x4 matrices
    - think cartoon, not beauty
  - template code gives you program shell, Makefile
    - http://www.ugrad.cs.ubc.ca/~cs314/Vjan2010/p1.tar.gz
- written homework 1
  - out today, due 5pm sharp Wed Feb 6
  - theoretical side of material

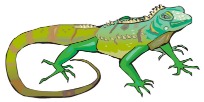


## Demo

- animal out of boxes and matrices



## Real Iguanas



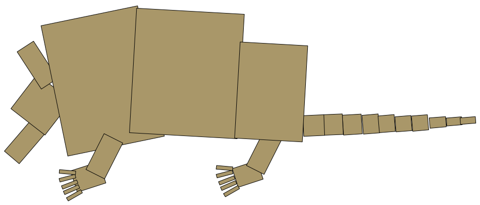
http://funkman.org/animal/reptile/iguana1.jpg

http://www.naturephoto-cz.com/photos/sevcik/green-iguana--iguana-iguana-1.jpg

http://www.mccullagh.org/db9/d30-3/iguana-closeup.jpg



## Armadillos!





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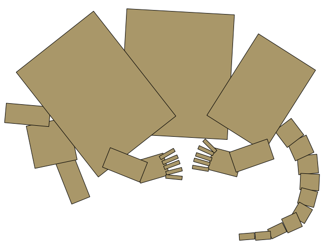
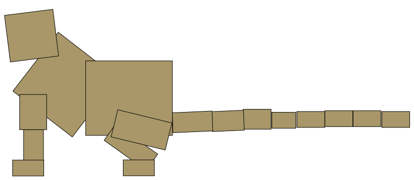


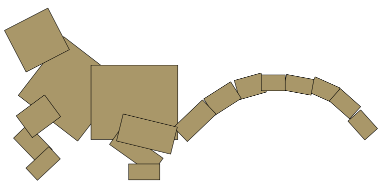


## Monkeys!



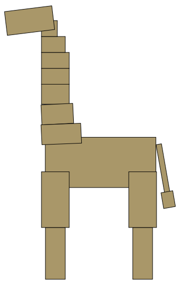


## Monkeys!





## Giraffes!





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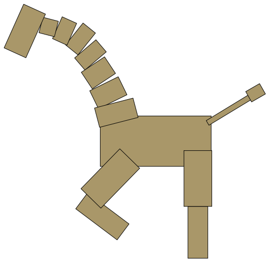



## Project 1 Advice

- do not model everything first and only then worry about animating
- interleave modelling, animation
  - for each body part: add it, then jumpcut animate, then smooth animate
  - discover if on wrong track sooner
  - dependencies: can't get anim credit if no model
  - use 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
  - make your cubes wireframe to see inside
- thinking about transformations
  - move physical objects around
  - play with demos
    - Brown scenegraph applets

## Project 1 Advice

- smooth transition
  - change happens gradually over X frames
  - key click triggers animation
  - one way: redraw happens X times
    - linear interpolation:
      each time, param += (new-old)/30
  - or redraw happens over X seconds
    - even better, but not required

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## Project 1 Advice

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

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## 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

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## 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

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## 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, svn/subversion
  - all are installed on lab machines
  - svn tutorial is part of next week's lab

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## 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

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## Readings for Transformations I-IV

- 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

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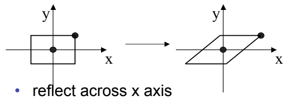
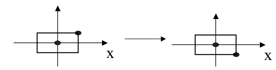
## Review: Shear, Reflection

- shear along x axis
  - push points to right in proportion to height




$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & sh_x \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

- reflect across x axis
  - mirror




$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

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## Review: 2D Transformations

matrix multiplication

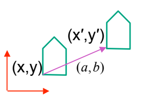
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & 0 \\ 0 & b \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

*scaling matrix*

matrix multiplication

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

*rotation matrix*




vector addition

$$\begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} x+a \\ y+b \end{bmatrix} = \begin{bmatrix} x' \\ y' \end{bmatrix}$$

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} x' \\ y' \end{bmatrix}$$

*translation multiplication matrix??*

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## Review: Linear Transformations

- linear transformations are combinations of
  - shear
  - scale
  - rotate
  - reflect

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad \begin{aligned} x' &= ax + by \\ y' &= cx + dy \end{aligned}$$

- properties of linear transformations
  - satisifes T(*s***x**+*t***y**) = *s* T(**x**) + *t* T(**y**)
  - origin maps to origin
  - lines map to lines
  - parallel lines remain parallel
  - ratios are preserved
  - closed under composition

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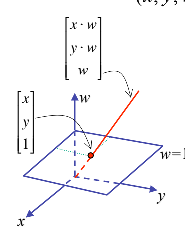
## Review: Homogeneous Coordinates

homogeneous → cartesian

$$(x, y, w) \xrightarrow{/\,w} \left(\frac{x}{w}, \frac{y}{w}\right)$$




- point in 2D cartesian + weight w = point P in 3D homog. coords
  - multiples of (x,y,w) form 3D line L
  - all homogeneous points on L represent same 2D cartesian point
- homogenize to convert homog. 3D point to cartesian 2D point:
  - divide by w to get (x/w, y/w, 1)
  - projects line to point onto w=1 plane
  - like normalizing, one dimension up

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## Review: Homogeneous Coordinates

- 2D transformation matrices are now 3x3:

$$\mathbf{Rotation} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \mathbf{Scale} = \begin{bmatrix} a & 0 & 0 \\ 0 & b & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{Translation} = \begin{bmatrix} 1 & 0 & T_x \\ 0 & 1 & T_y \\ 0 & 0 & 1 \end{bmatrix}$$

use rightmost column!

$$\begin{bmatrix} 1 & 0 & a \\ 0 & 1 & b \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x*1+a*1 \\ y*1+b*1 \\ 1 \end{bmatrix} = \begin{bmatrix} x+a \\ y+b \\ 1 \end{bmatrix}$$

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## Review: Affine Transformations

- affine transforms are combinations of
  - linear transformations
  - translations

$$\begin{bmatrix} x' \\ y' \\ w \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ w \end{bmatrix}$$

- properties of affine transformations
  - origin does not necessarily map to origin
  - lines map to lines
  - parallel lines remain parallel
  - ratios are preserved
  - closed under composition

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## Review: 3D Transformations

**shear(hxy,hxz,hyx,hyz,hzx,hzy)**

$$\begin{bmatrix} 1 & hyx & hzx & 0 \\ hxy & 1 & hzy & 0 \\ hxz & hyz & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

**translate(a,b,c)**

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & & & a \\ & 1 & & b \\ & & 1 & c \\ & & & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

**scale(a,b,c)**

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a & & & \\ & b & & \\ & & c & \\ & & & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$\text{Rotate}(x,\theta)$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & & & \\ & \cos\theta & -\sin\theta & \\ & \sin\theta & \cos\theta & \\ & & & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$\text{Rotate}(y,\theta)$

$$\begin{bmatrix} \cos\theta & & \sin\theta & \\ & 1 & & \\ -\sin\theta & & \cos\theta & \\ & & & 1 \end{bmatrix}$$

$\text{Rotate}(z,\theta)$

$$\begin{bmatrix} \cos\theta & -\sin\theta & & \\ \sin\theta & \cos\theta & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

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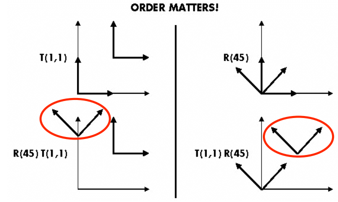
## Review: Composing Transformations




**Ta Tb = Tb Ta, but Ra Rb != Rb Ra and Ta Rb != Rb Ta**

- translations commute
- rotations around same axis commute
- rotations around different axes do not commute
- rotations and translations do not commute

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## Review: Composing Transformations

$$\mathbf{p'} = \mathbf{TRp}$$

- which direction to read?
  - right to left
    - interpret operations wrt fixed coordinates
    - moving object
  - left to right **OpenGL pipeline ordering!**
    - interpret operations wrt local coordinates
    - changing coordinate system
    - OpenGL updates current matrix with postmultiply
      - glTranslatef(2,3,0);
      - glRotatef(-90,0,0,1);
      - glVertexf(1,1,1);
    - specify vector last, in final coordinate system
    - first matrix to affect it is specified second-to-last

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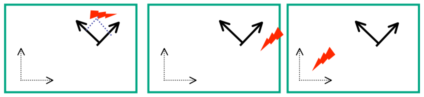
## More: Composing Transformations

$$\mathbf{p'} = \mathbf{TRp}$$

- which direction to read?
  - right to left
    - interpret operations wrt fixed coordinates
    - moving object
      - draw thing
      - rotate thing by -90 degrees wrt origin
      - translate it (-2, -3) over



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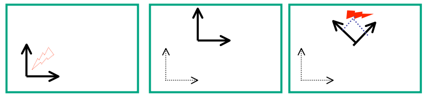
## More: Composing Transformations

$$\mathbf{p'} = \mathbf{TRp}$$

- which direction to read?
  - left to right
    - interpret operations wrt local coordinates
    - changing coordinate system
      - translate coordinate system (2, 3) over
      - rotate coordinate system 90 degrees wrt origin
      - draw object in current coordinate system
    - in OpenGL, cannot move object once it is drawn!!



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## General Transform Composition

- transformation of geometry into coordinate system where operation becomes simpler
  - typically translate to origin
- perform operation
- transform geometry back to original coordinate system

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## Rotation About an Arbitrary Axis

- axis defined by two points
- translate point to the origin
- rotate to align axis with z-axis (or x or y)
- perform rotation
- undo aligning rotations
- undo translation

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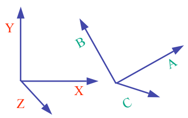
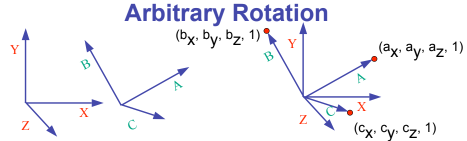
## Arbitrary Rotation




- arbitrary rotation: change of basis
  - given two orthonormal coordinate systems *XYZ* and *ABC*
    - *A*'s location in the XYZ coordinate system is $(a_x, a_y, a_z, 1)$, ...

## Arbitrary Rotation

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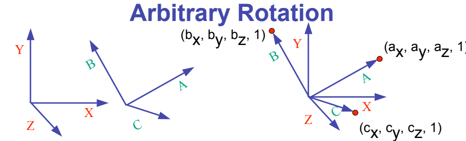
## Arbitrary Rotation




- 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

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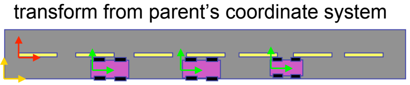
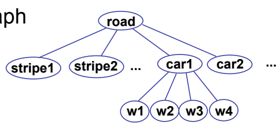
## Transformation Hierarchies

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



- scene graph

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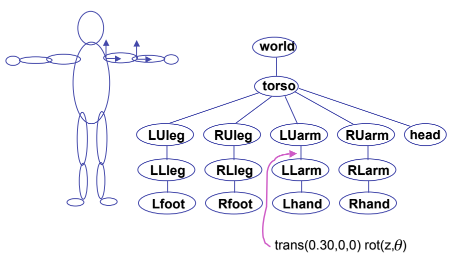
## Transformation Hierarchy Example 1

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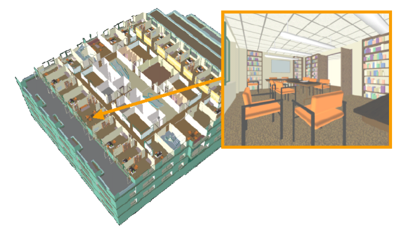
## Transformation Hierarchy Example 2

- draw same 3D data with different transformations: instancing



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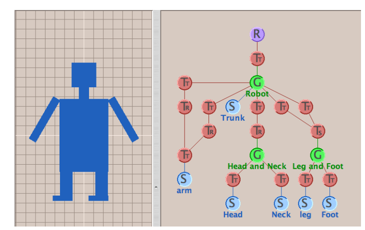
## Transformation Hierarchies Demo

- transforms apply to graph nodes beneath



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

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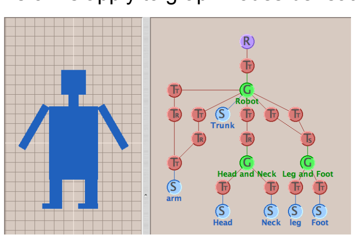
## Transformation Hierarchies Demo

- transforms apply to graph nodes beneath



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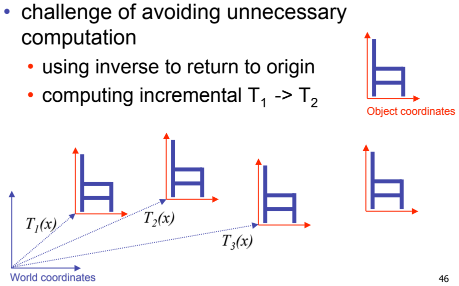
## Matrix Stacks

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

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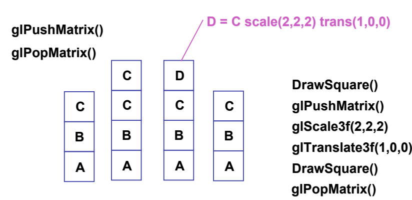
## Matrix Stacks

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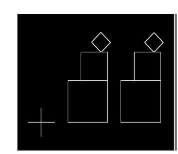
## Modularization

- 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();
}
```



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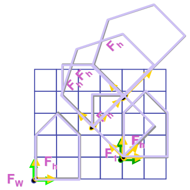
# Matrix Stacks

- 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)



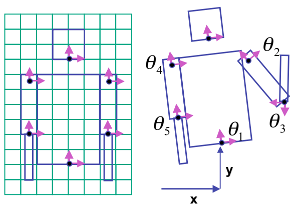
# Transformation Hierarchy Example 3




```
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(θ1,0,0,1);
DrawBody();
glPushMatrix();
  glTranslate3f(0,7,0);
  DrawHead();
glPopMatrix();
glPushMatrix();
  glTranslate(2.5,5.5,0);
  glRotatef(θ2,0,0,1);
  DrawUArm();
  glTranslate(0,-3.5,0);
  glRotatef(θ3,0,0,1);
  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