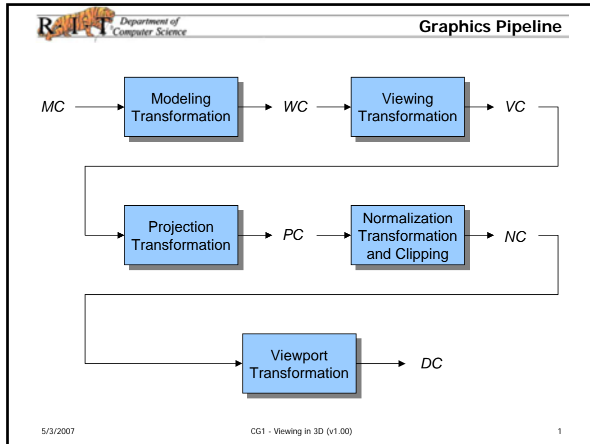
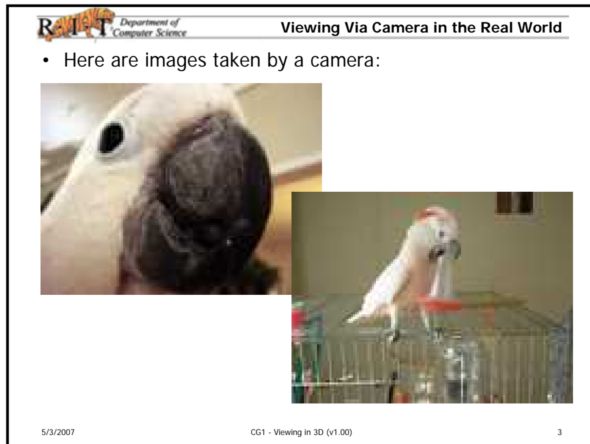
Computer Graphics 1



3D Viewing

- How do you take a picture with a camera?
  - Set up a scene
  - Grab a camera
  - Take a snapshot
    - Final print is a 2D representation
    - Of the 3D scene
    - Taken from a given perspective

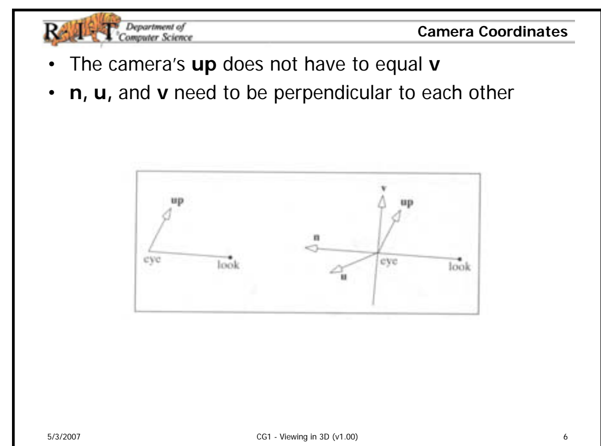


Viewing Via Camera in Computer Graphics

- Just like in photography, the camera defines what part of the scene you can see.
- Based on:
  - Projection type used by camera
  - Location of camera
  - Direction of camera
  - Orientation of camera
  - "Range" of your camera
- All of the above will (almost) define a *view volume*
  - All objects in the view volume are seen by the camera
- Camera "range" defined by near and far clipping planes
- Your thumbs never "get in the way" in graphics

Camera Coordinates

- Camera has its own 3D coordinate system based on its orientation
  - u, v, n
  - u corresponds to x (as seen by the camera)
  - v corresponds to y (as seen by the camera)
  - n corresponds to z (as seen by the camera)
    - Negative n is into the scene
- We define camera orientation in world coordinates
  - Provide the camera location (*eyepoint*)
  - Indicate what direction the camera is looking (*lookat*)
  - Give the "up" direction of the camera
  - Then
    - $n = eyepoint - lookat$ (normalized)
    - $u = up \times n$ (normalized)
    - $v = n \times u$



Camera Coordinates

- Default camera orientation has the camera/viewing/eye coordinate system coincident with the world axes, i.e.,
  - Eyepoint at (0, 0, 0)
  - Looking at (0, 0, -1)
  - Up vector (0,1,0) anchored at the eye
  - Then
    - ***n = eyepoint – lookat*** is (0, 0, 1) (normalized)
    - ***u = up x n*** is (1, 0, 0) (normalized)
    - ***v = n x u*** is (0, 1, 0)
- Remember:

m1 x o2 = (m1y*o2z – m1z*o2y, m1z*o2x-m1x*o2z, m2x*o2y-m1y*o2x)
Equivalent to a vector perpendicular to the plane of the 2 crossed vectors
Magnitude is equal to the area of the parallelogram formed by 2 vectors
Cross product of 2 parallel vectors is 0

What's different here?

Projection

- The role of cameras can be described as *projecting* a 3D scene onto a 2D plane

Projection – Terminology

- *Center of projection*
  - During the projection, points in the scene will converge to a given point.
  - This point is the center of projection
- *Projection or view plane*
  - 2D plane upon which the 3D scene is getting projected (In OpenGL, it's the front or near clipping plane!)

A Hierarchy of Projections

Parallel Projection

- Sometimes called *orthographic* projection
- Objects of equal size appear the same size after being projected, regardless of the distance they are from the viewing plane.
- The Center of Projection is at infinity

Perspective Projection

- Sometimes called *frustum* projection
- Objects closer to the view plane will appear larger when projected than objects of the same size that are farther from the view point.
- The Center of Projection is at camera location
- This is the projection used by "real" cameras

Perspective Projections – Vanishing Points

- Vanishing points can appear on more than one axis
- One point is what we've seen
  - View plane parallel to x and y axes
- Add a second point (two-point):
  - View plane parallel to y axis only
- Add a third point (three-point):
  - View plane not parallel to any axis

Perspective vs. Parallel Projection

- Orthographic best for:
  - Architectural drawings where line up/same size checking essential
  - Not trying to fly through scene
- Perspective/frustum best for:
  - Realism
  - Moving through scene
  - Aligning/measuring is not an issue

View Volumes

View Volumes

- Comparison of orthographic and perspective view volumes:

zFar zNear zFar zNear

Parallel (Ortho) Projection Perspective (Frustum) Projection

View Volumes

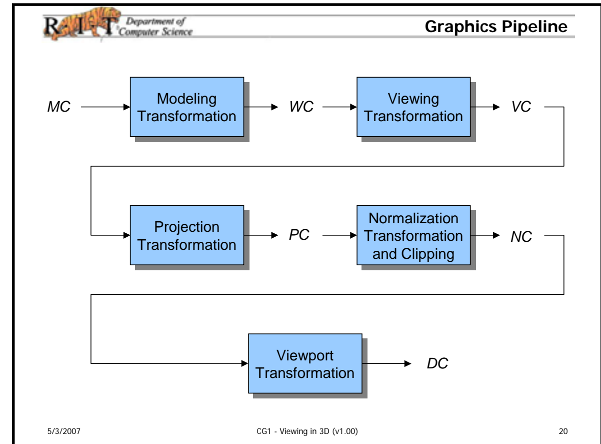
- Easier way to construct view volume for perspective projections:
  - *Field of view* (FOV)
    - Angle subtended from center of projection to top and bottom of the view plane
  - Aspect ratio
    - Width/height of view plane

Computer Graphics 1

Camera Coordinates

- Coordinates of objects in the 3D scene must be converted to the coordinate system of the camera
- In fact, the whole image generation process is nothing more than a series of concatenated transformations

Graphics Pipeline



Graphics Pipeline

- So how is all this implemented?
  - Using 4-D homogeneous matrices

$$\begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix} \cdot \begin{bmatrix} x_o \\ y_o \\ z_o \\ 1 \end{bmatrix}$$

view plane transformation object

Homogeneous Matrices

- Transformations are expressed as 4D matrices
  - World → Camera
  - Projection
  - Object transformations
  - Object hierarchy transformation
  - These matrices can be multiplied together to create a single composite matrix that does all the transformations in one shot

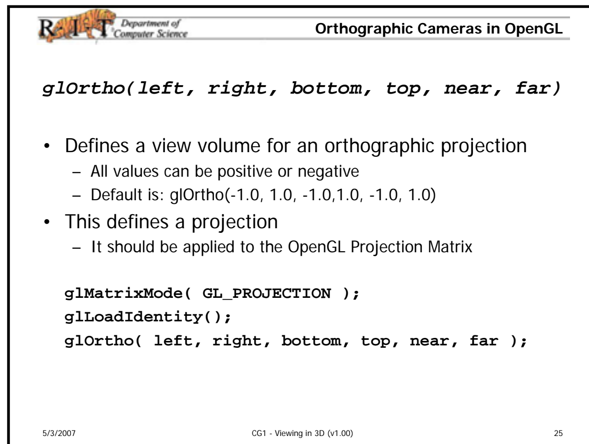
Homogeneous Matrices

$$\begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{bmatrix} \cdot \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix} \cdot \begin{bmatrix} x_o \\ y_o \\ z_o \\ 1 \end{bmatrix}$$

view plane projection world to camera object

Transformations in OpenGL

- OpenGL maintains 3 kinds of matrices:
  - *Modelview*
    - Handles all object transformations
    - Handles world to camera transformation
  - *Projection*
    - Handles projection
    - Equivalent to the camera view plane
  - *Viewport*
    - Handles view plane to view port (2D →2D)
- All matrix operations in OpenGL are performed on the "current" matrix as defined by the OpenGL *matrix mode*
- **`glMatrixMode()`** is used to select the mode


Department of Computer Science
Orthographic Cameras in OpenGL
glOrtho(left, right, bottom, top, near, far)
• Defines a view volume for an orthographic projection
– All values can be positive or negative
– Default is: glOrtho(-1.0, 1.0, -1.0,1.0, -1.0, 1.0)
• This defines a projection
– It should be applied to the OpenGL Projection Matrix
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
glOrtho(left, right, bottom, top, near, far);
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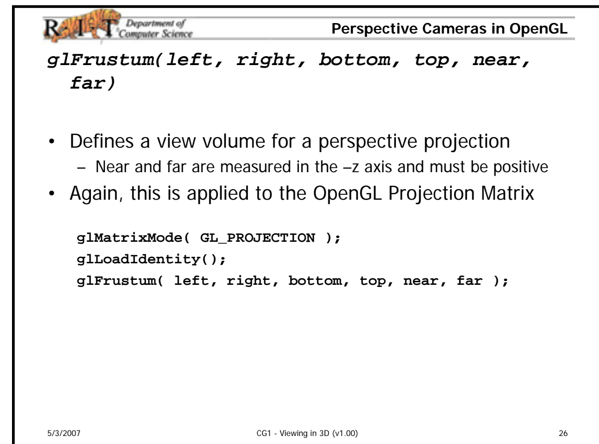
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Perspective Cameras in OpenGL
glFrustum(left, right, bottom, top, near, far)
• Defines a view volume for a perspective projection
– Near and far are measured in the –z axis and must be positive
• Again, this is applied to the OpenGL Projection Matrix
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
glFrustum(left, right, bottom, top, near, far);
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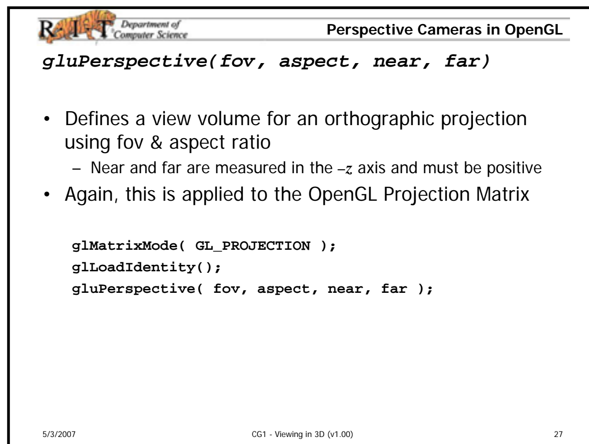
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Perspective Cameras in OpenGL
gluPerspective(fov, aspect, near, far)
• Defines a view volume for an orthographic projection using fov & aspect ratio
– Near and far are measured in the –z axis and must be positive
• Again, this is applied to the OpenGL Projection Matrix
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
gluPerspective(fov, aspect, near, far);
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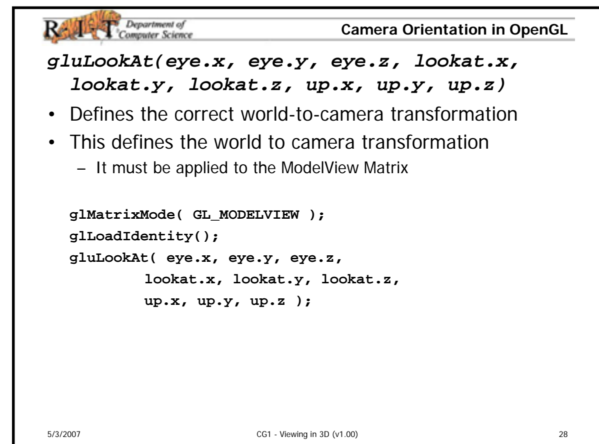
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Camera Orientation in OpenGL
gluLookAt(eye.x, eye.y, eye.z, lookat.x, lookat.y, lookat.z, up.x, up.y, up.z)
• Defines the correct world-to-camera transformation
• This defines the world to camera transformation
– It must be applied to the ModelView Matrix
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(eye.x, eye.y, eye.z,
lookat.x, lookat.y, lookat.z,
up.x, up.y, up.z);
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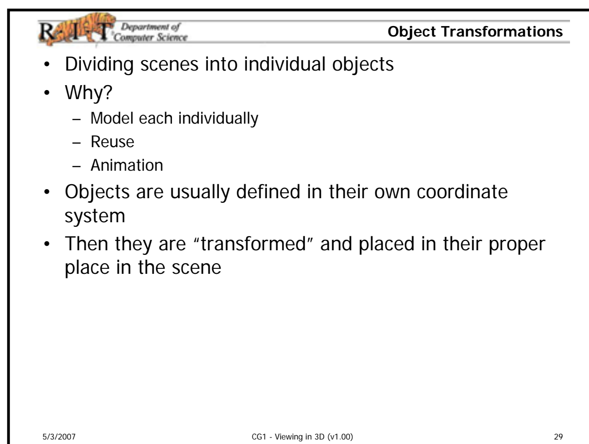
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Object Transformations
• Dividing scenes into individual objects
• Why?
– Model each individually
– Reuse
– Animation
• Objects are usually defined in their own coordinate system
• Then they are “transformed” and placed in their proper place in the scene
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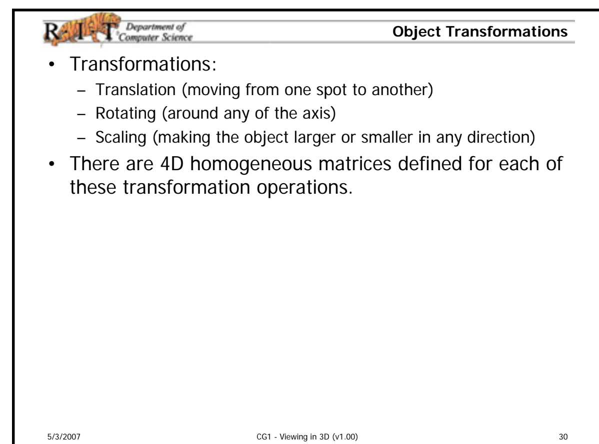
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Object Transformations
• Transformations:
– Translation (moving from one spot to another)
– Rotating (around any of the axis)
– Scaling (making the object larger or smaller in any direction)
• There are 4D homogeneous matrices defined for each of these transformation operations.
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Object Transformation Example

- Successive transformations are performed by multiplying matrices for individual transformations into a single transformation matrix
- If you want to:
  - Rotate an object about the y axis by 30 degrees, then
  - Rotate an object about the z axis by 45 degrees, then
  - Scale the object to twice its size in each dimension, then
  - Translate the object to (1, 2, 3)
- You can create the matrix:
  - $M = T(1,2,3) \cdot S(2, 2, 2) \cdot R_z(45) \cdot R_y(30)$
  - Then transform each point of your object by multiplying by M

Object Transformation

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix} \cdot \begin{bmatrix} x_o \\ y_o \\ z_o \\ 1 \end{bmatrix}$$

transformed coords transformation object

Complete Matrix Application

$$\begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} = \begin{bmatrix} Projection \end{bmatrix} \cdot \begin{bmatrix} World \\ to \\ Camera \end{bmatrix} \cdot \begin{bmatrix} Transformation \end{bmatrix} \cdot \begin{bmatrix} x_o \\ y_o \\ z_o \\ 1 \end{bmatrix}$$

view plane local object coords

Doing This in OpenGL

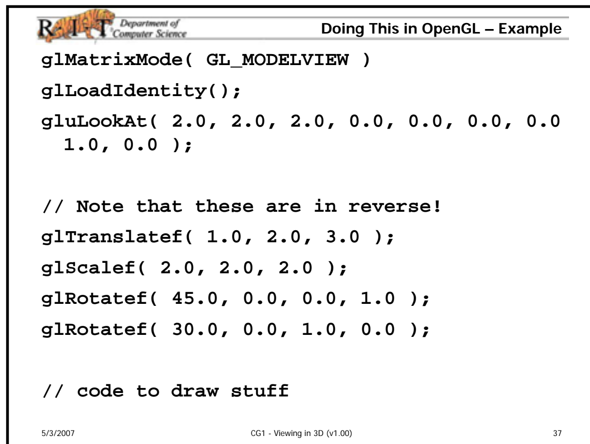
- OpenGL provides functions that will apply translations, rotations, and scaling transformations to a "current" matrix
- These are applied to the ModelView Matrix
  - They are the Model part of this matrix

Doing This in OpenGL

- Translation (using world coords)
```
glTranslated( dx, dy, dz )
glTranslatef( dx, dy, dz )
```
- Scaling
```
glScaled( sx, sy, sz )
glScalef( sx, sy, sz )
```
- Rotation
```
glRotated( angle, x, y, z )
glRotatef( angle, x, y, z )
```
where (**x, y, z**) gives the axis of rotation

Doing This in OpenGL – Example

- Task:
  - Rotate an object about the y axis by 30 degrees, then
  - Rotate an object about the z axis by 45 degrees, then
  - Scale the object to twice its size in each dimension, then
  - Translate the object to (1, 2, 3)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Doing This in OpenGL – Example
glMatrixMode(GL_MODELVIEW)
glLoadIdentity();
gluLookAt(2.0, 2.0, 2.0, 0.0, 0.0, 0.0, 0.0
1.0, 0.0);
// Note that these are in reverse!
glTranslatef(1.0, 2.0, 3.0);
glScalef(2.0, 2.0, 2.0);
glRotatef(45.0, 0.0, 0.0, 1.0);
glRotatef(30.0, 0.0, 1.0, 0.0);
// code to draw stuff
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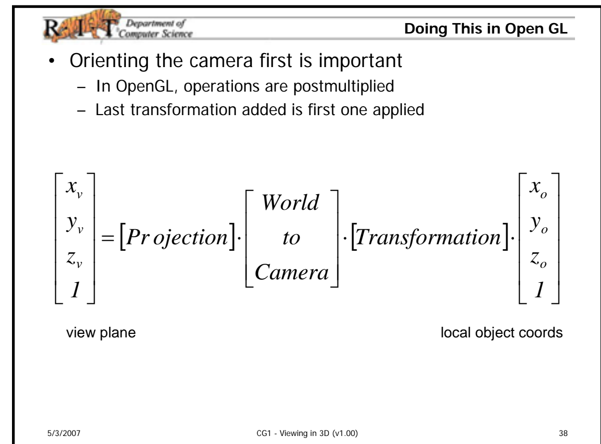
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Doing This in Open GL
Orienting the camera first is important
In OpenGL, operations are postmultiplied
Last transformation added is first one applied
$\begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} = [Projection] \cdot \begin{bmatrix} World \\ to \\ Camera \end{bmatrix} \cdot [Transformation] \cdot \begin{bmatrix} x_o \\ y_o \\ z_o \\ 1 \end{bmatrix}$
view plane
local object coords
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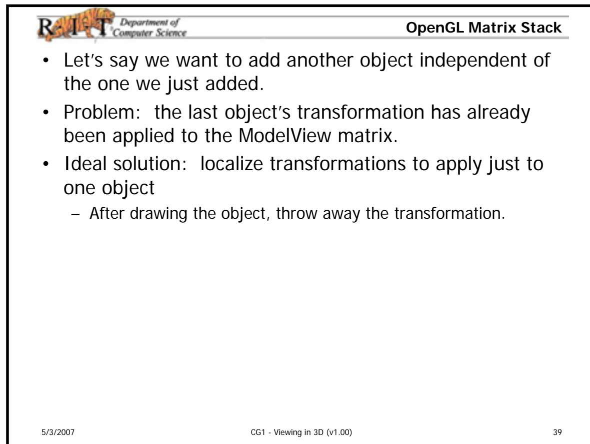
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OpenGL Matrix Stack
Let's say we want to add another object independent of the one we just added.
Problem: the last object's transformation has already been applied to the ModelView matrix.
Ideal solution: localize transformations to apply just to one object
After drawing the object, throw away the transformation.
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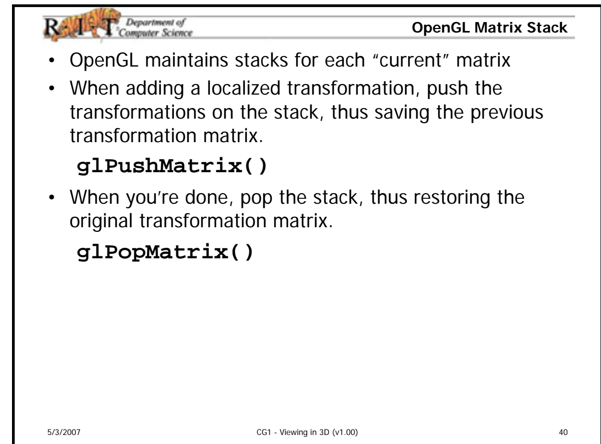
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OpenGL Matrix Stack
OpenGL maintains stacks for each "current" matrix
When adding a localized transformation, push the transformations on the stack, thus saving the previous transformation matrix.
glPushMatrix()
When you're done, pop the stack, thus restoring the original transformation matrix.
glPopMatrix()
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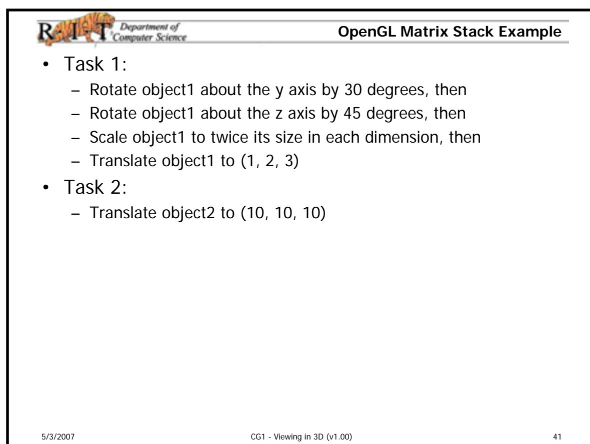
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OpenGL Matrix Stack Example
Task 1:
Rotate object1 about the y axis by 30 degrees, then
Rotate object1 about the z axis by 45 degrees, then
Scale object1 to twice its size in each dimension, then
Translate object1 to (1, 2, 3)
Task 2:
Translate object2 to (10, 10, 10)
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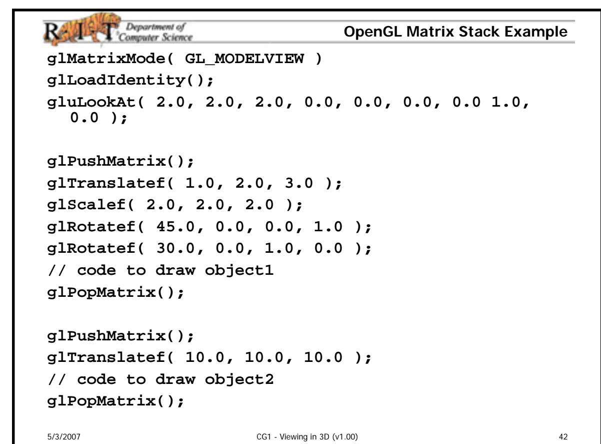
Department of Computer Science
OpenGL Matrix Stack Example
glMatrixMode(GL_MODELVIEW)
glLoadIdentity();
gluLookAt(2.0, 2.0, 2.0, 0.0, 0.0, 0.0, 0.0 1.0,
0.0);
glPushMatrix();
glTranslatef(1.0, 2.0, 3.0);
glScalef(2.0, 2.0, 2.0);
glRotatef(45.0, 0.0, 0.0, 1.0);
glRotatef(30.0, 0.0, 1.0, 0.0);
// code to draw object1
glPopMatrix();
glPushMatrix();
glTranslatef(10.0, 10.0, 10.0);
// code to draw object2
glPopMatrix();
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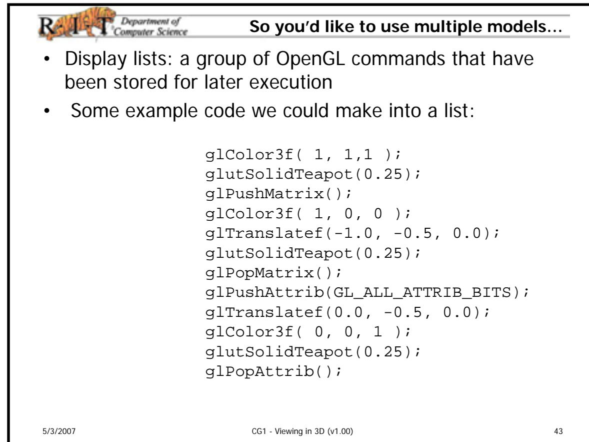
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So you'd like to use multiple models…
• Display lists: a group of OpenGL commands that have been stored for later execution
• Some example code we could make into a list:
glColor3f(1, 1,1);
glutSolidTeapot(0.25);
glPushMatrix();
glColor3f(1, 0, 0);
glTranslatef(-1.0, -0.5, 0.0);
glutSolidTeapot(0.25);
glPopMatrix();
glPushAttrib(GL_ALL_ATTRIB_BITS);
glTranslatef(0.0, -0.5, 0.0);
glColor3f(0, 0, 1);
glutSolidTeapot(0.25);
glPopAttrib();
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glNewList(TEAPOTS, GL_COMPILE);
glColor3f(1, 1,1);
glutSolidTeapot(0.25);
glPushMatrix();
glColor3f(1, 0, 0);
glTranslatef(-1.0, -0.5, 0.0);
glutSolidTeapot(0.25);
glPopMatrix();
glPushAttrib(GL_ALL_ATTRIB_BITS);
glTranslatef(0.0, -0.5, 0.0);
glColor3f(0, 0, 1);
glutSolidTeapot(0.25);
glPopAttrib();
glEndList();
– Can call list with: glCallList(TEAPOTS)
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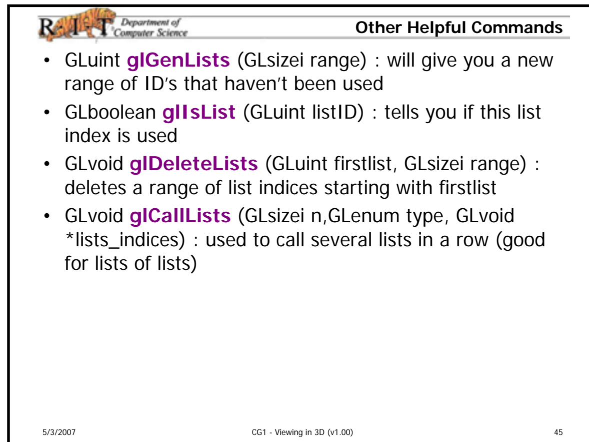
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Other Helpful Commands
• GLuint glGenLists (GLsizei range) : will give you a new range of ID's that haven't been used
• GLboolean glIsList (GLuint listID) : tells you if this list index is used
• GLvoid glDeleteLists (GLuint firstlist, GLsizei range) : deletes a range of list indices starting with firstlist
• GLvoid glCallLists (GLsizei n,GLenum type, GLvoid *lists_indices) : used to call several lists in a row (good for lists of lists)
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