CS380: Computer Graphics

Interacting with a 3D World

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Course URL:
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Announcement

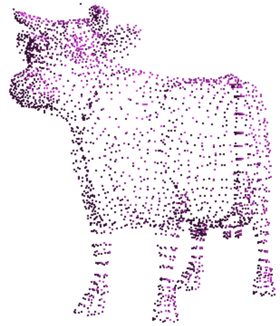
- Mid-term exam
  - 4:00pm ~ 5:40pm, Apr-22 (Tue.)

Class Objectives

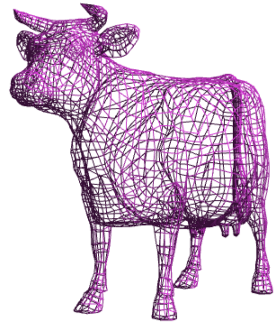
- Read a mesh representation
- Understand a selection method and a virtual-trackball interface
- Understand the modeling hierarchy

Primitive 3D

- How do we specify 3D objects?
  - Simple mathematical functions, $z = f(x,y)$
  - Parametric functions, $(x(u,v), y(u,v), z(u,v)$
  - Implicit functions, $f(x,y,z) = 0$



- Build up from simple primitives
  - Point – nothing really to see
  - Lines – nearly see through
  - Planes – a surface



Simple Planes

- Surfaces modeled as connected planar facets
  - N (>3) vertices, each with 3 coordinates
  - Minimally a triangle

Specifying a Face

- **Face or facet**

  Face [v0.x, v0.y, v0.z] [v1.x, v1.y, v1.z] … [vN.x, vN.y, vN.z]

- **Sharing vertices via indirection**

  Vertex[0] = [v0.x, v0.y, v0.z]

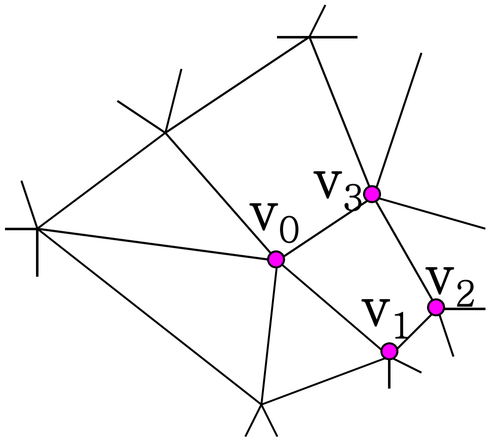
  Vertex[1] = [v1.x, v1.y, v1.z]

  Vertex[2] = [v2.x, v2.y, v2.z]

  :

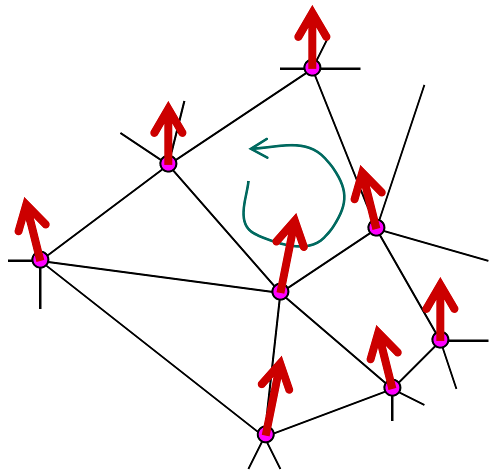
  Vertex[N] = [vN.x, vN.y, vN.z]

  Face v0, v1, v2, … vN



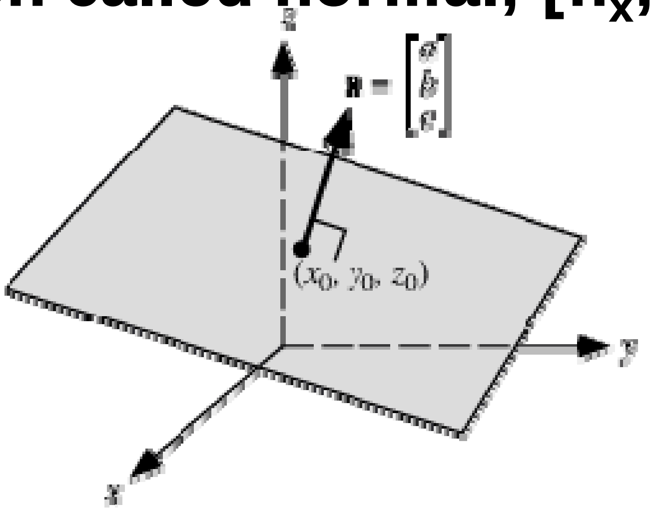
Vertex Specification

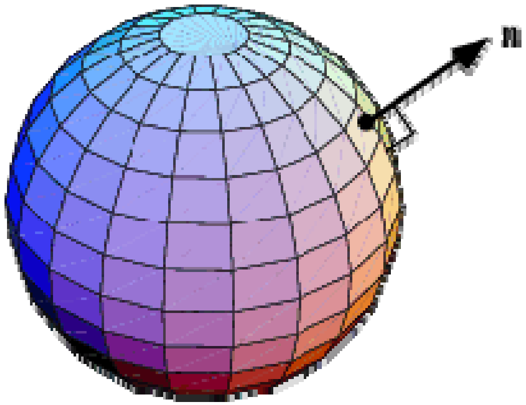
- **Where**
  - **Geometric coordinates [x, y, z]**
- **Attributes**
  - **Color values [r, g, b]**
  - **Texture Coordinates [u, v]**
- **Orientation**
  - **Inside vs. Outside**
  - **Encoded implicitly in ordering**
- **Geometry nearby**
  - **Often we'd like to "fake" a more complex shape than our true faceted (piecewise-planar) model**
  - **Required for lighting and shading in OpenGL**



Normal Vector

- **Often called normal, [n_x, n_y, n_z]**





- **Normal to a surface is a vector perpendicular to the surface**
  - **Will be used in illumination**
-
- **Normalized:** $\hat{n} = \frac{[n_x, n_y, n_z]}{\sqrt{n_x^2 + n_y^2 + n_z^2}}$

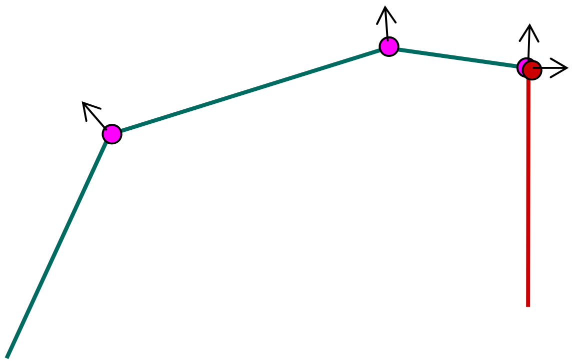
Drawing Faces in OpenGL

```
glBegin(GL_POLYGON);
foreach (Vertex v in Face) {
  glColor4d(v.red, v.green, v.blue, v.alpha);
  glNormal3d(v.norm.x, v.norm.y, v.norm.z);
  glTexCoord2d(v.texture.u, v.texture.v);
  glVertex3d(v.x, v.y, v.z);
}
glEnd();
```

- **Heavy-weight model**
  - **Attributes specified for every vertex**
- **Redundant**
  - **Vertex positions often shared by at least 3 faces**
  - **Vertex attributes are often face attributes (e.g. face normal)**

Decoupling Vertex and Face Attributes via Indirection

- Works for many cases
  - Used with vertex array or vertex buffer objects in OpenGL
- Exceptions:
  - Regions where the surface changes materials
  - Regions of high curvature (a crease)



3D File Formats

- MAX – Studio Max
- DXF – AutoCAD
  - Supports 2-D and 3-D; binary
- 3DS – 3D studio
  - Flexible; binary
- VRML – Virtual reality modeling language
  - ASCII – Human readable (and writeable)
- OBJ – Wavefront OBJ format
  - ASCII
  - Extremely simple
  - Widely supported

OBJ File Tokens

- **File tokens are listed below**

 # some text

Rest of line is a comment

v *float float float*

A single vertex's geometric position in space

vn *float float float*

A normal

vt *float float*

A texture coordinate

OBJ Face Varieties

f *int int int* ... **(vertex only)**

or

f *int/int int/int int/int* . . . **(vertex & texture)**

or

f *int/int/int int/int/int int/int/int* ... **(vertex, texture, & normal)**

- **The arguments are 1-based indices into the arrays**
  - **Vertex positions**
  - **Texture coordinates**
  - **Normals, respectively**

OBJ Example

- Vertices followed by faces
  - Faces reference previous vertices by integer index
  - 1-based

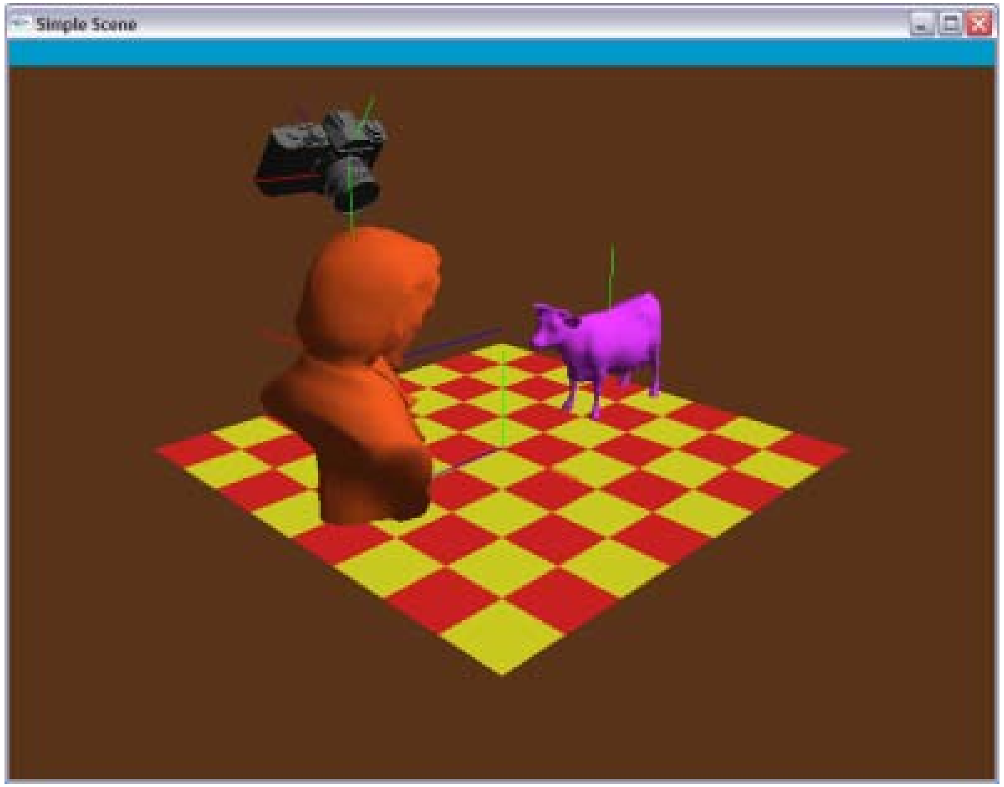
```
# A simple cube
v 1 1 1
v 1 1 -1
v 1 -1 1
v 1 -1 -1
v -1 1 1
v -1 1 -1
v -1 -1 1
v -1 -1 -1
f 1 3 4
f 5 6 8
f 1 2 6
f 3 7 8
f 1 5 7
f 2 4 8
```

OBJ Sources

- **Avalon – Viewpoint (http://avalon.viewpoint.com/) old standards**
- **3D Café – (http://www.3dcafe.com/asp/meshes.asp) Nice thumbnail index**
- **Others**
- **Most modeling programs will export .OBJ files**
- **Most rendering packages will read in .OBJ files**

Picking and Selection

- Basic idea: Identify objects selected by the user
  - Click-selection: select one object at a time
  - Sweep-selection: select objects within a bounding rectangle



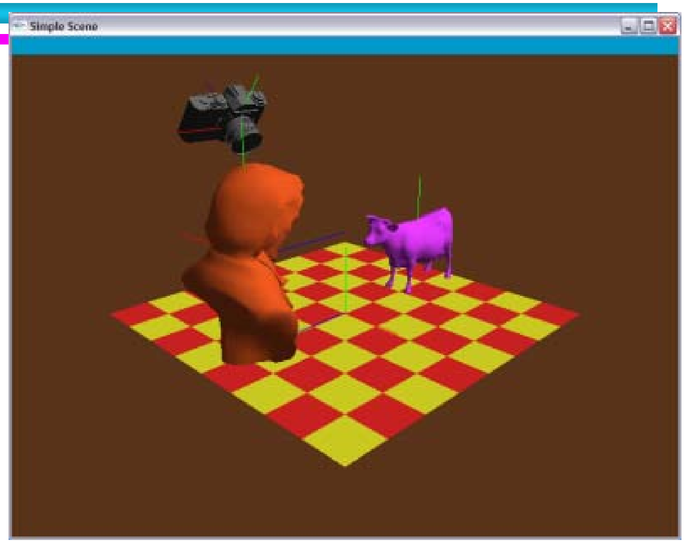
Demo

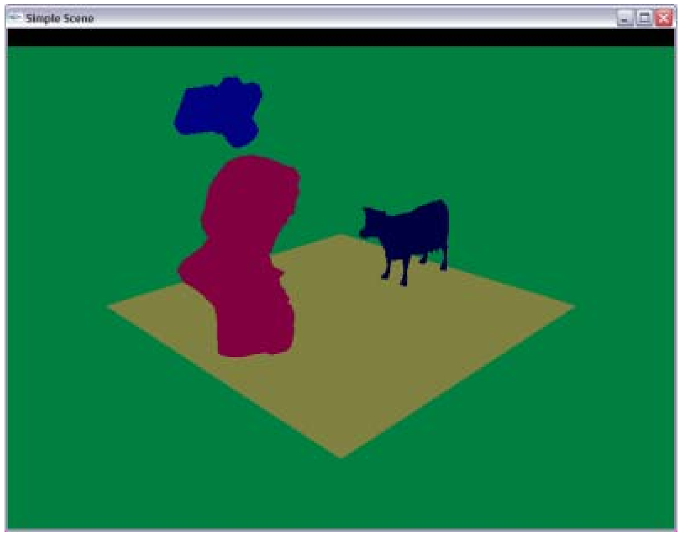
Picking and Selection

- Several ways to implement selection:
    - Find screen space bounding boxes contained in pick region
    - Compute a pick ray and ray trace to find intersections
    - OpenGL selection buffers
    - Render to back buffer using colors that encode object IDs and return ID under pick point

Selection with the Back Buffer

- Selects only objects that are visible
- Render objects to back buffer with color that encodes ID
- Use glReadPixels() to read the pixel at the pick point
- Back buffer is never seen





An Example of Reading the Back Buffer

```
void onMouseButton(int button, int state, int x, int y)
{ ...
if (button == GLUT_LEFT_BUTTON  && state == GLUT_DOWN)
   {
     printf( "Left mouse click at (%d, %d)\n", x, y );
     selectMode = 1;
     display();
     glReadBuffer(GL_BACK);
     unsigned char pixel[3];
     glReadPixels(x, y, 1, 1, GL_RGB, GL_UNSIGNED_BYTE, pixel);
     printf( "pixel = %d\n", unmunge(pixel[0],pixel[1],pixel[2]));
     selectMode = 0;
    }
...
}
```

Buffer Operations in OpenGL

- glReadBuffer (mode)
  - GL_FRONT, GL_BACK, etc.

- glReadPixels(x, y, w, h, pixel_format, data_type, * buffers)
  - Pixel_format: GL_RGB, GL_RGBA, GL_RED, etc.
  - Data_type: GL_UNSIGNED_BYTE, GL_FLOAT, etc.

- Other related APIs
  - glDrawPixels

Interaction Paradigms

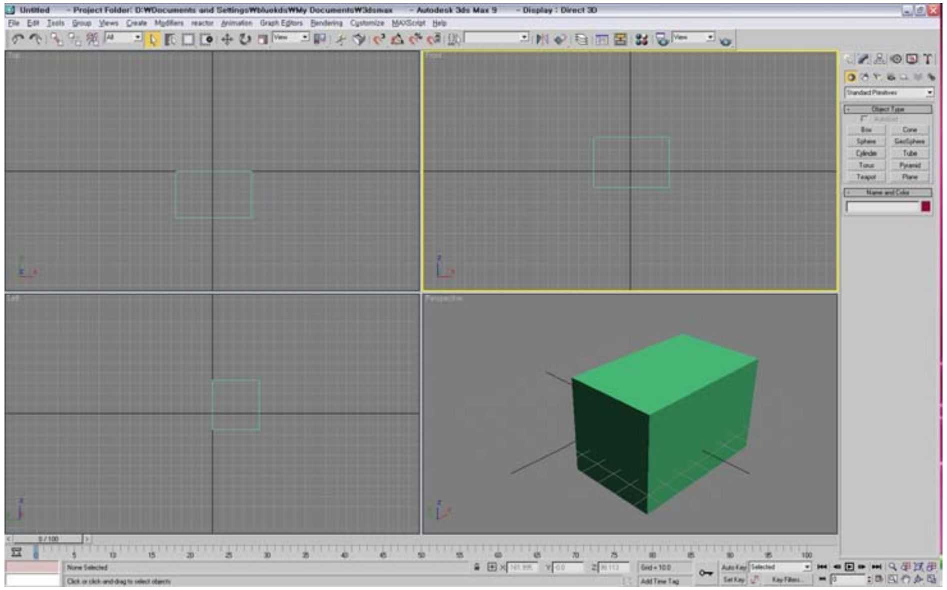
- **Can move objects or camera**
  - **Object moving is most intuitive if the object "sticks" to the mouse while dragging**

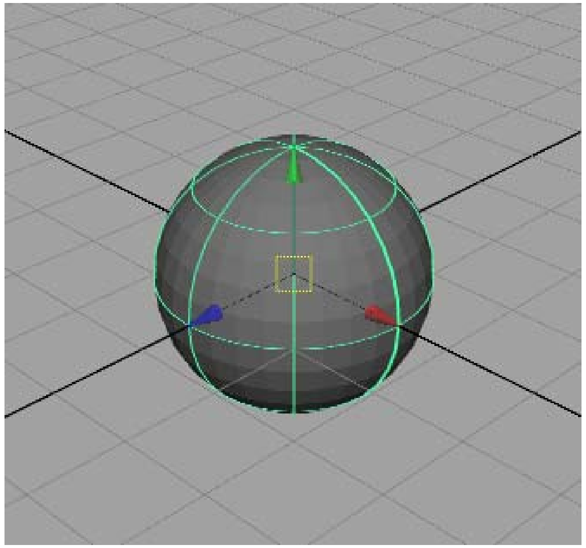
Interaction Paradigms

- **Move w.r.t. to camera frame**
  - **Pan – move in plane perpendicular to view direction**
  - **Dolly – move along the view direction**
  - **Zoom - looks like dolly: objects get bigger, but position remains fixed**
  - **Rotate**
    - **up/down controls elevation angle**
    - **left/right controls azimuthal angle**
  - **Roll – spin about the view direction**
  - **Trackball – can combine rotate and roll**

Interaction Paradigms

- Move w.r.t to modeling (or world) frame

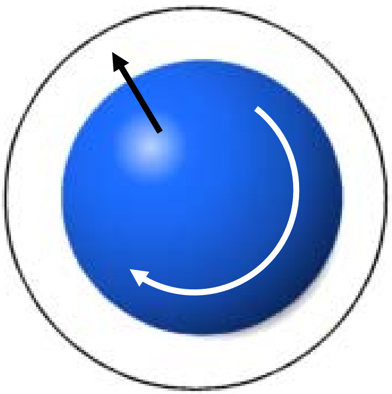




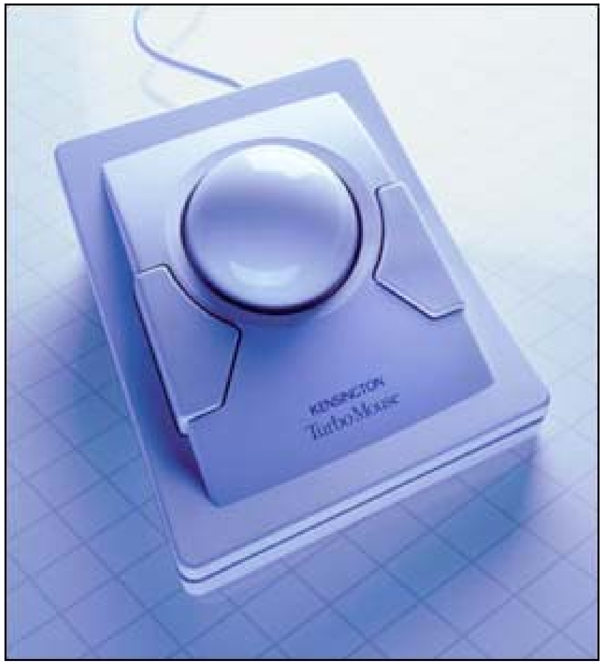
- Maya combines both
  - Presents a frame where you can drag w.r.t the world axes
  - Dragging origin moves w.r.t. to camera frame

Interaction - Trackball

- A common UI for manipulating objects
- 2 degree of freedom device
- Differential behavior provides a intuitive rotation specification

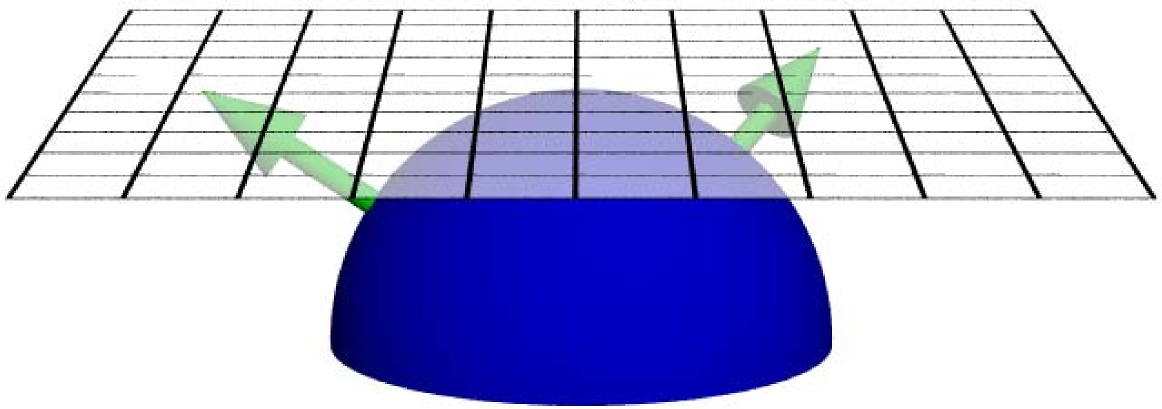


Trackball demo



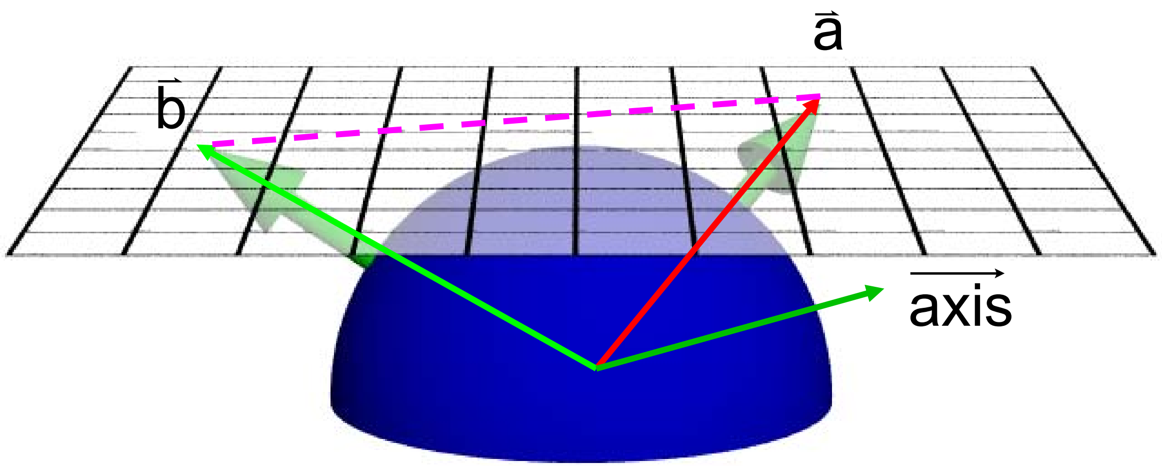
A Virtual Trackball

- Imagine the viewport as floating above, and just touching an actual trackball
- You receive the coordinates in screen space of the MouseDown() and MouseMove() events
- What is the axis of rotation?
- What is the angle of rotation?



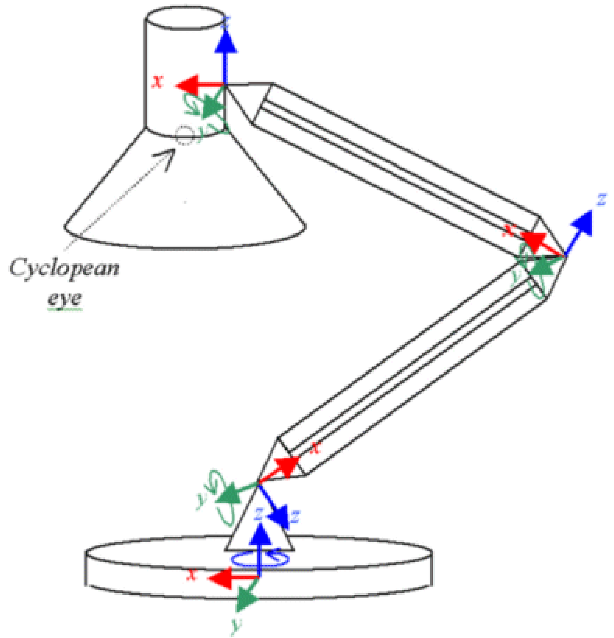
Computing the Rotation

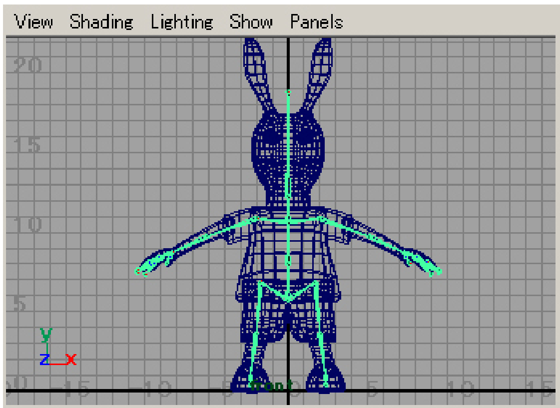
- **Construct a vector $\vec{a}$ from the center of rotation of the virtual trackball to the point of the MouseDown() event**
- **Construct a 2nd vector $\vec{b}$ from the center of rotation for a given MouseMove() event**
- **Normalize $\hat{a} = \frac{\vec{a}}{|\vec{a}|}$, and $\hat{b} = \frac{\vec{b}}{|\vec{b}|}$, and then compute $\overrightarrow{axis} = \hat{a} \times \hat{b}$**
- **Then find the $angle = \cos^{-1}(\hat{a} \cdot \hat{b})$ and construct $\mathbf{R} = Rotate(angle, \frac{\overrightarrow{axis}}{|\overrightarrow{axis}|})$**



Transformation Hierarchies

- **Many models are composed of independent moving parts**
- **Each part defined in its own coordinate system**
  - **Compose transforms to position and orient the model parts**
- **A simple “One-chain” example**



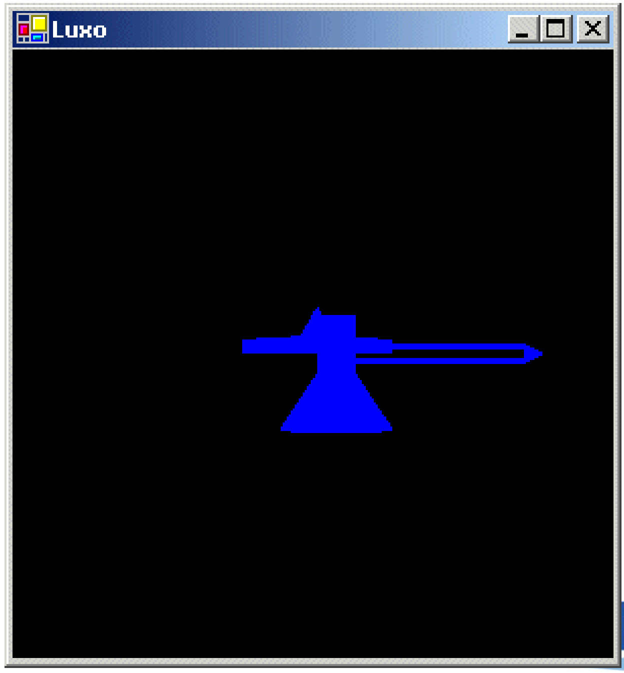


http://www.imanishi.com

Code Example (Take One)

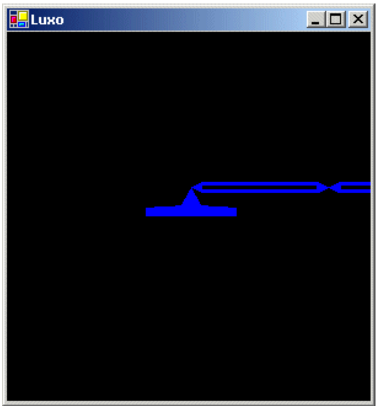
```
public void Draw() {
        glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
        glLoadIdentity();
        gluLookat(0, 0,-60,  0,0,0,   0,1,0); // world-to-camera transform

        glColor3d(0,0,1);
        glRotated(-90, 1, 0, 0);          // base-to-world transform
        Draw(Lamp.BASE);
        Draw(Lamp.BODY);
        Draw(Lamp.NECK);
        Draw(Lamp.HEAD);
        glFlush();
}
```



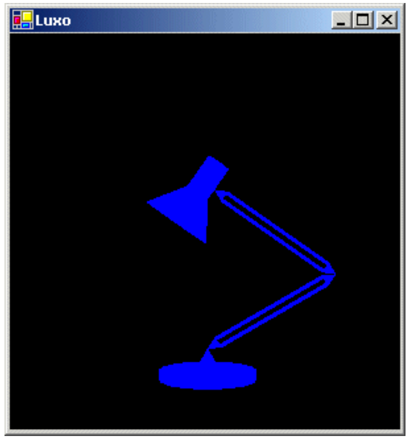
Code Example (Take Two)

```
public void Draw() {
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glLoadIdentity();
    glTranslated(0.0, 0.0, -60.0);    // world-to-view transform
    glColor3d(0,0,1);
    glRotated(-90, 1, 0, 0);           // base-to-world transform
    Draw(Lamp.BASE);
    glTranslated(0,0,2.5);             // body-to-base transform
    Draw(Lamp.BODY);
    glTranslated(12,0,0);              // neck-to-body transform
    Draw(Lamp.NECK);
    glTranslated(12,0,0);              // head-to-neck transform
    Draw(Lamp.HEAD);
    glFlush();
}
```



Code Example (Take Three)

```
public void Draw() {
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glLoadIdentity();
    glTranslated(0.0, -12.0, -60.0);   // world-to-view transform
    glColor3d(0,0,1);
    glRotated(-90, 1, 0, 0);           // base-to-world transform
    Draw(Lamp.BASE);
    glTranslated(0,0,2.5);             // body-to-base transform
    glRotated(-30, 0, 1, 0);           // rotate body at base pivot
    Draw(Lamp.BODY);
    glTranslated(12,0,0);  // neck-to-body transform
    glRotated(-115, 0, 1, 0);  // rotate neck at body pivot
    Draw(Lamp.NECK);
    glTranslated(12,0,0);  // head-to-neck transform
    glRotated(180, 1, 0, 0);// rotate head at neck pivot
    Draw(Lamp.HEAD);
    glFlush();
}
```



Model Hierarchies

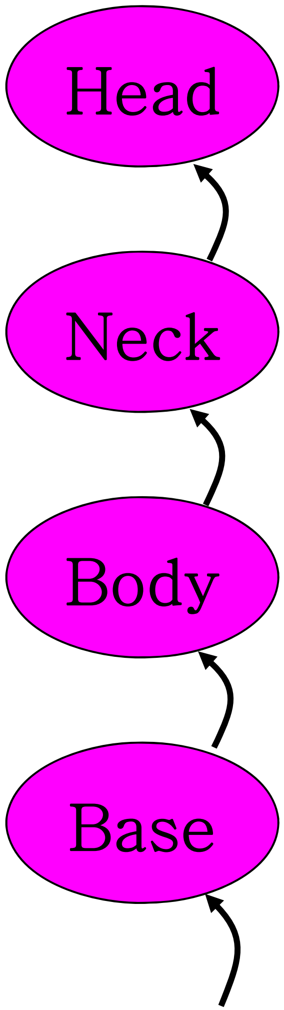
- **Model parts are nodes and transforms are edges**
- **What transform is applied to the head part to get it into world coordinates?**

$$\dot{m}_4^t = \dot{w}^t \, \mathbf{T}_{world}^{base} \mathbf{T}_{base}^{body} \mathbf{T}_{body}^{neck} \mathbf{T}_{neck}^{head}$$

- **Suppose that you'd like to rotate the Neck joint at the point where it meets the Body. Then what is the Head's transform to world space?**

$$\dot{m}_3^t = \dot{m}_2^t \, \mathbf{T}_{body}^{neck} \mathbf{R}$$

$$\dot{m}_4^t = \dot{w}^t \, \mathbf{T}_{world}^{base} \mathbf{T}_{base}^{body} \mathbf{T}_{body}^{neck} \mathbf{R} \mathbf{T}_{neck}^{head}$$



$$\dot{m}_4^t = \dot{m}_3^t \, \mathbf{T}_{neck}^{head}$$

$$\dot{m}_3^t = \dot{m}_2^t \, \mathbf{T}_{body}^{neck}$$

$$\dot{m}_2^t = \dot{m}_1^t \, \mathbf{T}_{base}^{body}$$

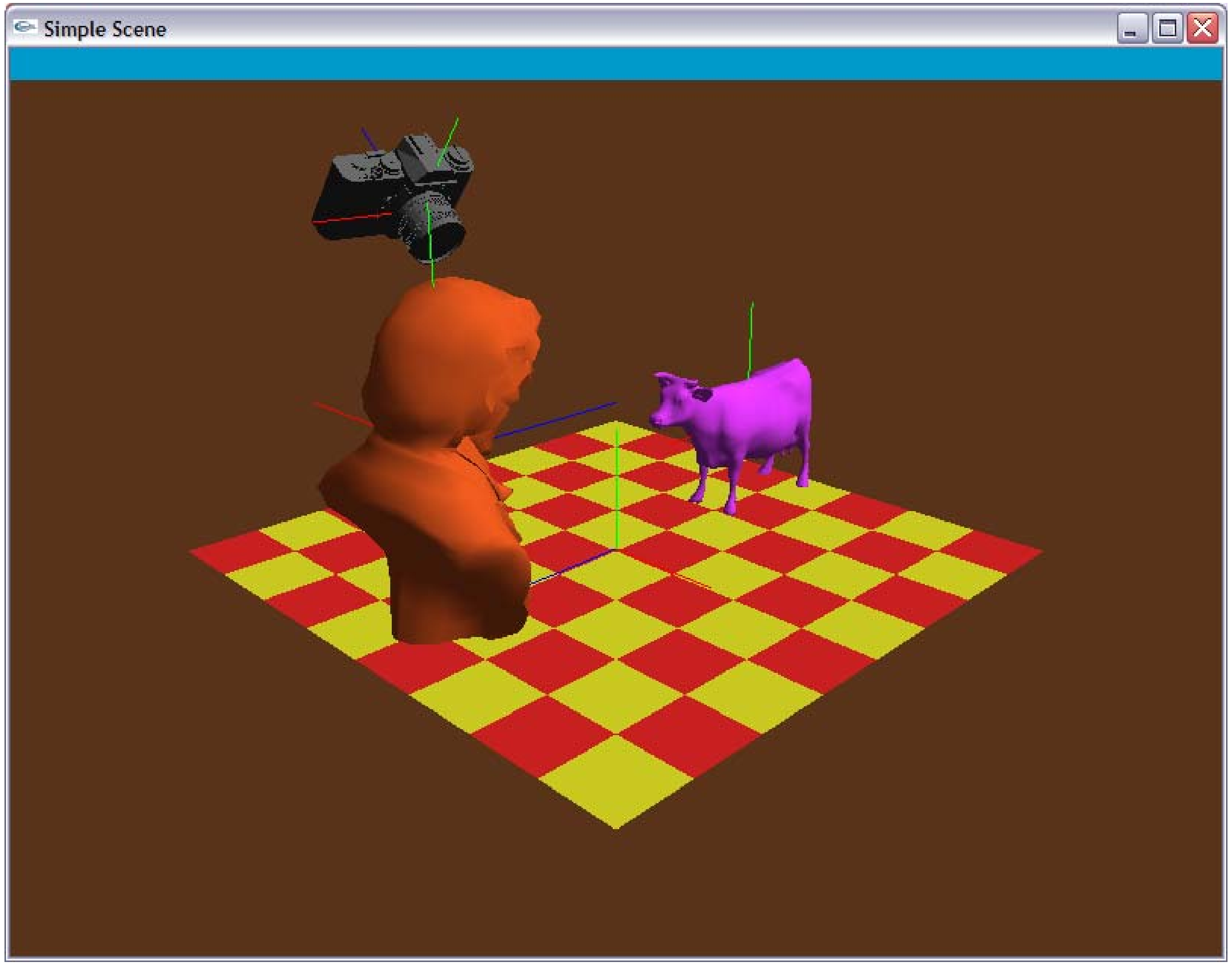
$$\dot{m}_1^t = \dot{w}^t \, \mathbf{T}_{world}^{base}$$

Class Objectives were:

- Read a mesh representation
- Understand a selection method and a virtual-trackball interface
- Understand the modeling hierarchy

Program Assignment 4

- **Use the previous skeleton codes**



Reading Assignment

- **Read Chapter “A Full Graphics Pipeline”**