Computer Graphics

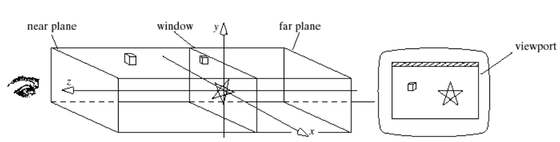
Transformations of Objects
Ch5 Sec 6

Drawing 3D Scenes in OpenGL

- We want to transform objects in order to orient and position them as desired in a 3D scene.
- OpenGL provides the necessary functions to build and use the required matrices.
- The matrix stacks maintained by OpenGL make it easy to set up a transformation for one object, and then return to a previous transformation, in preparation for transforming another object.

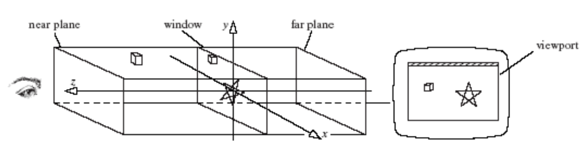
The Viewing Process and the Graphics Pipeline

- The 2D drawing so far is a special case of 3D viewing, based on a simple parallel projection.
- The eye is looking along the z-axis at the world window, a rectangle in the *xy*-plane.



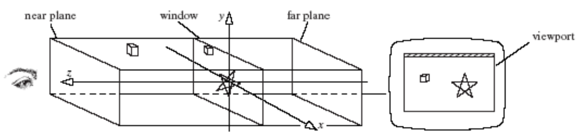
The Viewing Process and the Graphics Pipeline (2)

- *Eye* is simply a point in 3D space.
- The “orientation” of the eye ensures that the view volume is in front of the eye.
- Objects closer than *near* or farther than *far* are too blurred to see.



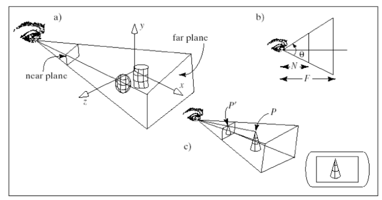
The Viewing Process and the Graphics Pipeline (3)

- The **view volume** of the camera is a rectangular parallelepiped (Orthographic Projection)
- Its side walls are fixed by the window edges; its other two walls are fixed by a **near plane** and a **far plane**.



The Viewing Process and the Graphics Pipeline (4)

- The **view volume** of the camera using Perspective Projection (to be discussed later)
- Its side walls are fixed by the window edges; its other two walls are fixed by a **near plane** and a **far plane**.

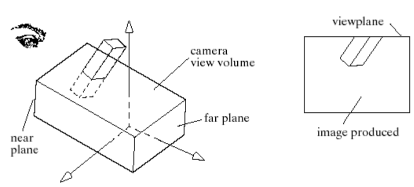


The Viewing Process and the Graphics Pipeline (5)

- Points inside the view volume are projected onto the window along lines parallel to the z-axis.
- We ignore their z-component, so that the 3D point (x_1 y_1, z_1) projects to (x_1, y_1, 0).
- Points lying outside the view volume are clipped off.
- A separate **viewport transformation** maps the projected points from the window to the viewport on the display device.

The Viewing Process and the Graphics Pipeline (6)

- In 3D, the only change we make is to allow the camera (eye) to have a more general position and orientation in the scene in order to produce better views of the scene.

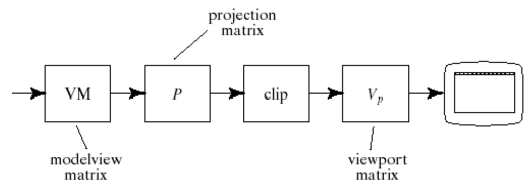


The Viewing Process and the Graphics Pipeline (7)

- The z axis points *toward* the eye. X and y point to the viewer's right and up, respectively.
- Everything outside the view volume is clipped.
- Everything inside it is projected along lines parallel to the axes onto the window plane (parallel projection).

The Viewing Process and the Graphics Pipeline (8)

- OpenGL provides functions for defining the view volume and its position in the scene, using matrices in the graphics pipeline.



The Viewing Process and the Graphics Pipeline (9)

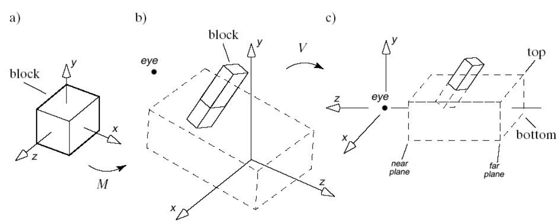
- Each vertex of an object is passed through this pipeline using glVertex3d(x, y, z).
- The vertex is multiplied by the various matrices, clipped if necessary, and if it survives, it is mapped onto the viewport.
- Each vertex encounters three matrices:
  - The **modelview matrix;**
  - The **projection matrix;**
  - The **viewport matrix;**

The Modelview Matrix

- The **modelview matrix** is the *CT* (current transformation).
- It combines modeling transformations on objects and the transformation that orients and positions the camera in space (hence *modelview*).
- It is a single matrix in the actual pipeline.
  - For ease of use, we will think of it as the product of two matrices: a modeling matrix *M*, and a viewing matrix *V*. The modeling matrix is applied first, and then the viewing matrix, so the modelview matrix is in fact the product *VM.*

The Modelview Matrix

- A modeling transformation *M* scales, rotates, and translates the cube into the block.

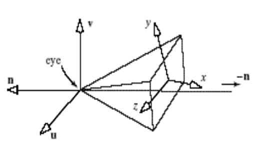


The Modelview Matrix (V)

- The camera moves from its position in the scene to its generic position (eye at the origin and the view volume aligned with the *z*-axis).
- The coordinates of the block's vertices are changed so that projecting them onto a plane (e.g., the near plane) displays the projected image properly.

The Modelview Matrix (V)

- The matrix *V* changes the coordinates of the scene vertices into the **camera's coordinate system,** or into **eye coordinates**.
- To inform OpenGL that we wish it to operate on the modelview matrix we call glMatrixMode (GL_MODELVIEW);



Setting Up the Scene

```
glMatrixMode (GL_MODELVIEW);
   // set up the modelview matrix
glLoadIdentity ();
   // initialize modelview matrix
   // set up the view part of the matrix
   // do any modeling transformations on the scene
```

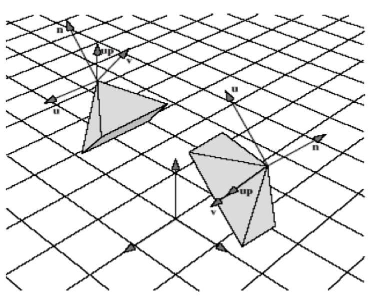
Setting Up the Camera (View Matrix)

```
glMatrixMode (GL_MODELVIEW);
   // make the modelview matrix current
glLoadIdentity();
   // start with identity matrix
   // position and aim the camera
gluLookAt (eye.x, eye.y, eye.z,    // eye position
   look.x, look.y, look.z,      // the "look at" point
   0, 1, 0)   // approximation to true up direction
   // Now do the modeling transformations
```


Setting Up the Camera (2)

- What gluLookAt does is create a camera coordinate system of three mutually orthogonal unit vectors: **u**, **v**, and **n.**
- **n** = eye - look; **u** = **up** x **n**; **v** = **n** x **u**
- Normalize **n**, **u**, **v** (in the camera system) and let **e** = eye - O in the camera system, where O is the origin.

The effect of gluLookAt



Setting Up the Camera (3)

- Then gluLookAt () sets up the view matrix

$$V = \begin{pmatrix} u_x & u_y & u_z & d_x \\ v_x & v_y & v_z & d_y \\ n_x & n_y & n_z & d_z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where **d** = (-**e**·**u**, -**e**·**v**, -**e**·**n**)

- **up** is usually (0, 1, 0) (along the y-axis), *look* is frequently the middle of the window, and *eye* frequently looks down on the scene.

Practice Question

- Given: gluLookAt (4, 4, 4, 0, 1, 0, 0, 1, 0);

What is the View matrix V?

Steps:

1. Compute vectors n, u, v
2. Normalize n, u, v
3. Compute vector: **e** = eye – O

   d = (-**e**·**u**, -**e**·**v**, -**e**·**n**)
4. Put the view matrix together

Practice Question

$\mathbf{n} = eye - look = (4, 3, 4)$

$$\mathbf{u} = \mathbf{up} \times \mathbf{n} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 1 & 0 \\ 4 & 3 & 4 \end{vmatrix} = (4, 0, -4)$$

$\mathbf{v} = \mathbf{n} \times \mathbf{u} = (-12, 32, -12)$

Normalize **u**, **v**, and **n**,

$\mathbf{n} = (0.6247, 0.4685, 0.6247)$

$\mathbf{u} = (0.70711, 0, -0.70711)$

$\mathbf{v} = (-0.3313, 0.8834, -0.3313)$

dx =-**eye**.**u** =(-4, -4, -4) **.** (0.70711, 0, -0.70711) = 0

dy =-**eye**.**v** =(-4, -4, -4) **.** (-0.3313, 0.8834, -0.3313) = -0.88345

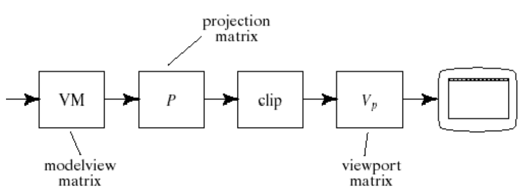
dz =-**eye**.**n** =(-4, -4, -4) **.** (0.6247, 0.4685, 0.6247) = -6.872

So that,

$$V = \begin{pmatrix} .70711 & 0 & -.70711 & 0 \\ -.3313 & .88345 & -.3313 & -.88345 \\ .6247 & .4685 & .6247 & -6.872 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The Viewing Process and the Graphics Pipeline

- OpenGL provides functions for defining the view volume and its position in the scene, using matrices in the graphics pipeline.



The Projection Matrix

- The **projection matrix** scales and translates each vertex so that those inside the view volume will be inside a *standard cube* that extends from -1 to 1 in each dimension (Normalized Device Coordinates).
- This cube is a particularly efficient boundary against which to clip objects.
- The image is distorted, but the viewport transformation will remove the distortion.
- The projection matrix also reverses the sense of the z-axis; increasing values of *z* now represent increasing values of depth from the eye.

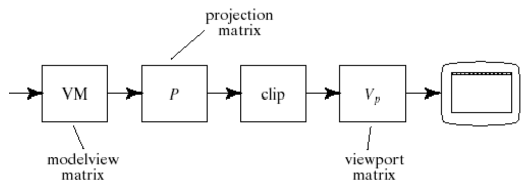
Setting Up the Projection

glMatrixMode(GL_PROJECTION);
// make the projection matrix current
glLoadIdentity();
// set it to the identity matrix
glOrtho(left, right, bottom, top, near, far);
// multiply it by the new matrix

- Using 2 for *near* places the near plane at $z = -2$, that is, 2 units in front of the eye.
- Using 20 for *far* places the far plane at -20, 20 units in front of the eye.

The Viewing Process and the Graphics Pipeline

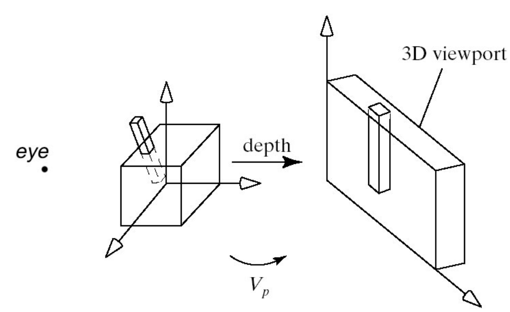
- OpenGL provides functions for defining the view volume and its position in the scene, using matrices in the graphics pipeline.



The Viewport Matrix

- The **viewport matrix** maps the standard cube into a 3D viewport whose *x* and *y* values extend across the viewport (in screen coordinates), and whose *z*-component extends from 0 to 1 (a measure of the depth of each point).
- This measure of depth makes hidden surface removal (do not draw surfaces hidden by objects closer to the eye) particularly efficient.

The Viewport Matrix (2)



Example

```
glMatrixMode (GL_PROJECTION);
   // set the view volume (world coordinates)
glLoadIdentity();
glOrtho (-3.2, 3.2, -2.4, 2.4, 1, 50);

glMatrixMode (GL_MODELVIEW);
   // place and aim the camera
glLoadIdentity ();
gluLookAt (4, 4, 4, 0, 1, 0, 0, 1, 0);
   // modeling transformations go here
```


Drawing 3D Shapes in OpenGL

- GLUT provides several 3D objects: a sphere, a cone, a torus, the five Platonic solids, and the teapot.
- Each is available as a **wireframe** model (one appearing as a collection of wires connected end to end) and as a solid model with faces that can be shaded.
- All are drawn by default centered at the origin.
- To use the solid version, replace Wire by Solid in the functions.

Drawing 3D Shapes in OpenGL (2)

- **cube:** glutWireCube (GLdouble size);
  - Each side is of length size.
- **sphere:** glutWireSphere (GLdouble radius, GLint nSlices, GLint nStacks);
  - nSlices is the number of "orange sections" and nStacks is the number of disks.
  - Alternately, nSlices boundaries are longitude lines and nStacks boundaries are latitude lines.

Drawing 3D Shapes in OpenGL (3)

- **torus:** glutWireTorus (GLdouble inRad, GLdouble outRad, GLint nSlices, GLint nStacks);
- **teapot:** glutWireTeapot (GLdouble size);
  - Why teapots? A standard graphics challenge for a long time was both making a teapot look realistic and drawing it quickly.

Drawing 3D Shapes in OpenGL (4)

- **tetrahedron:** glutWireTetrahedron ();
- **octahedron:** glutWireOctahedron ();
- **dodecahedron:** glutWireDodecahedron ();
- **icosahedron:** glutWireIcosahedron ();
- **cone:** glutWireCone (GLdouble baseRad, GLdouble height, GLint nSlices, GLint nStacks);

Drawing 3D Shapes in OpenGL (5)

- **tapered cylinder:** gluCylinder (GLUquadricObj * qobj, GLdouble baseRad, GLdouble topRad, GLdouble height, GLint nSlices, GLint nStacks);
- The **tapered cylinder** is actually a *family* of shapes, distinguished by the value of topRad.
  - When topRad is 1, there is no taper; this is the classic **cylinder**.
  - When topRad is 0, the tapered cylinder is identical to the **cone**.

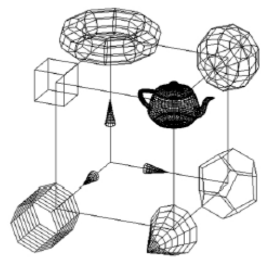
Drawing 3D Shapes in OpenGL (6)

- To draw the tapered cylinder in OpenGL, you must
  1. define a new quadric object,
  2. set the drawing style (GLU_LINE: wireframe, GLU_FILL: solid), and
  3. draw the object:

```
GLUquadricObj * qobj = gluNewQuadric ();
   // make a quadric object
gluQuadricDrawStyle (qobj,GLU_LINE);
   // set style to wireframe
gluCylinder (qobj, baseRad, topRad, nSlices, nStacks);
 // draw the cylinder
```


Demo Example

- Quadric objects with display list
- glu objects arranged in 3D



Demo
Solid 3D Drawing in OpenGL

- A solid object scene is rendered with shading. The light produces highlights on the sphere, teapot, and jack.

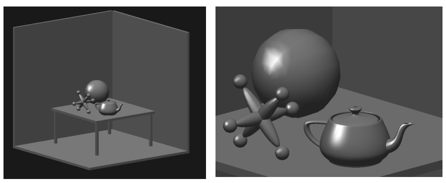
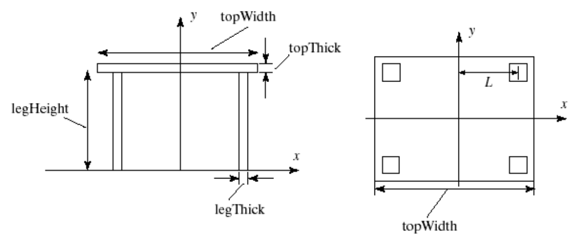


Table Construction



Solid 3D Drawing in OpenGL (4)

- A routine tableLeg() draws each leg and is called four times within the routine table() to draw the legs in the four different locations.
- The different parameters used produce different modeling transformations within tableLeg(). As always, a glPushMatrix(), glPopMatrix() pair surrounds the modeling functions to isolate their effect.

Code for the Solid Example (Fig. 5.60)

- The solid version of each shape, such as glutSolidSphere (), is used.
- To create shaded images, the position and properties of a light source and certain properties of the objects' surfaces must be specified, in order to describe how they reflect light (Ch. 8).
- We just present the various function calls here; using them as shown will generate shading.

Scene Description Language (SDL)

- Previous scenes were described through specific OpenGL calls that transform and draw each object, as in the following code:

```
glTranslated (0.25, 0.42, 0.35);
glutSolidSphere (0.1, 15, 15);
// draw a sphere
```

- The objects were "hard-wired" into the program. This method is cumbersome and error-prone.

SDL (2)

- We want the designer to be able to specify the objects in a scene using a simple language and place the description in a file.
- The drawing program becomes a general-purpose program:
  - It reads a scene file at run-time and draws whatever objects are encountered in the file.

Example SDL Scene

```
! example.dat: simple scene: 1 light and 4 shapes
! beginning ! is a comment; extends to end of line
background 0 0 1        ! create a blue background
light 2 9 8 1 1 1       ! put a white light at (2, 9, 8)
diffuse .9 .1 .1        ! make following objects reddish
translate 3 5 –2 sphere   ! put a sphere at 3 5 –2
translate –4 –6 8 cone    ! put a cone in the scene
translate 1 1 1 cube      ! add a cube
diffuse 0 1 0           ! make following objects green
translate 40 5 2 scale .2 .2 .2 sphere   ! tiny sphere
```


Using SDL

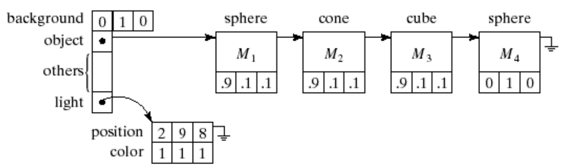
- The **Scene Description Language (SDL)**, provides a Scene class that supports the reading of an SDL file and the drawing of the objects described in the file.
- A global Scene object is created:

```
Scene scn; // create a scene object
```

- Read in a scene file using the read method of the class:

```
scn.read("example.dat");  // read the scene file & build an object list
```

SDL Data Structure



The SDL Scene (2)

- Once the light list and object list have been built, the application can render the scene:

  scn.makeLightsOpenGL(),
  scn.drawSceneOpenGL(); // render scene with OpenGL
- The first instruction passes a description of the light sources to OpenGL. The second uses the method drawSceneOpenGL() to draw each object in the object list.
- The code for this method is very simple:

```
void Scene :: drawSceneOpenGL()
{
    for(GeomObj* p = obj; p ; p = p->next)
    p->drawOpenGL(); // draw it
}
```


The SDL Scene (3)

- The function moves a pointer through the object list, calling drawOpenGL() for each object in turn.
- Each different shape can draw itself; it has a method drawOpenGL() that calls the appropriate routine for that shape (next slide).
- Each first passes the object's material properties to OpenGL, then updates the modelview matrix with the object's specific affine transformation.
- The original modelview matrix is pushed and later restored to protect it from being affected after this object has been drawn.

Examples of Objects which can Draw Themselves

```
void Sphere :: drawOpenGL()
{
  tellMaterialsGL();  //pass material data to OpenGL
  glPushMatrix();
  glMultMatrixf(transf.m); // load this object's matrix
  glutSolidSphere(1.0,10,12); // draw a sphere
  glPopMatrix();
}
void Cone :: drawOpenGL()
{
  tellMaterialsGL();//pass material data to OpenGL
  glPushMatrix();
  glMultMatrixf(transf.m); // load this object's matrix
  glutSolidCone(1.0,1.0, 10,12); // draw a cone
  glPopMatrix();
}
```