Introduction to OpenGL
“3D Geometry”

Reading: Angel Ch.4 and Woo Ch.2

Points and Vectors

Points/Vectors are basic primitives for geometric representation

OpenGL does not define point/vector objects

In C we can define types for points:

```
typedef GLfloat point3[3]; /* array of 3 floats */
typedef GLfloat vector3[3];
```

We can then instantiate a point or vector as:

```
point3 p={1,2,3};
vector3 v={1,3,5};
```

Functions can be used to define operations for each type:

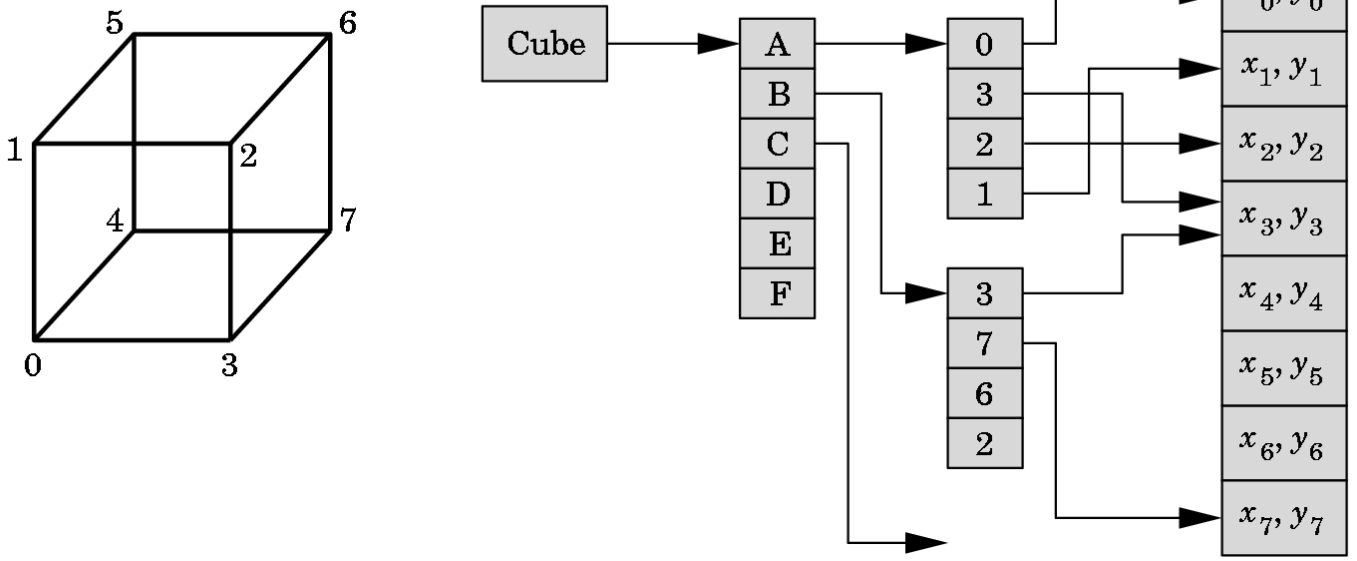
```
w = add(u,v);          /* vectors u,v,w */
w = dot(u,v);
w = subtract(p1,p2); /* vector w &  points p1,p2 */
```

In an object oriented language such as C++ point/vectors
can be classes with a set of operations (add/dot product….)

Example - Representing a Cube

```
typedef GLfloat point3[3];

point3 cube_vertices[8] = {{-1.0,-1.0,-1.0},{1.0,-1.0,-1.0},
                           {1.0,1.0,-1.0}, {-1.0,1.0,-1.0},
                           {-1.0,-1.0,1.0},{1.0,-1.0,0.0},
                            {1.0,1.0,1.0},{-1.0,1.0,1.0}};

/* define a quadrilateral for each side of cube */

glBegin(GL_POLYGON);                          /* 1st face */
       glVertex3fv(cube_vertices[0]);
       glVertex3fv(cube_vertices[3]);
       glVertex3fv(cube_vertices[2]);
       glVertex3fv(cube_vertices[1]);
glEnd();

…. remaining 5 faces
```

Example- Cube vertex data



Vertex Arrays

Using repeated OpenGL function calls to define polygonal objects is inefficient

~ 30 calls for one cube

Vertex Arrays encapsulate data for verticies polyhedral objects

6 types: vertex,color, normal, texture_coordiate, color_index, edge_flag

Each type contains an array of data for the verticies

Functions to use vertex arrays:

(1) Enable type of array

```
glEnableClientState(type-of-array);
```

(2) Identify array of vertex data

```
glVertexPoint(nvertex,array-data-type,step, pointer-to-array);
```

(3) Render array of faces

```
glDrawElements(face-type, nface,index-type,pointer-to-index);
```

Using Vertex Arrays

(1) **Enable functionality of vertex arrays**

```
glEnableClientState(GL_VERTEX_ARRAY); /* verticies */
glEnableClientState(GL_COLOR_ARRAY);  /*vertex colours*/
```

(2) **Setup arrays** of verticies

```
point3 vertices[8] ={….};
point3 colors[8]={…};
```

(3) **Identify arrays** by passing a pointer to the array

```
glVertexPointer(3,GL_FLOAT, 0,vertices);
glColorPointer(3,GL_FLOAT,0,colors);
```

(4) **Define faces** by indicies refering to the faces

```
Glubyte cubeIndices[24] = {0,3,2,1,……,0,1,5,4}
```

(5) **Render**

```
for (i=0,i<6;i++)
 glDrawElements(GL_POLYGON, 4, GL_UNSIGNED_BYTE,&cubeIndices[4*i])
```

or

```
glDrawElements(GL_QUADS,24,GL_UNSIGNED_BYTE,cubeIndices);
```

Example - Drawing a Cube

```
typedef GLfloat point3[3];

point3 vertices[8] = {{-1.0,-1.0,-1.0},{1.0,-1.0,-1.0},
                      {1.0,1.0,-1.0}, {-1.0,1.0,-1.0},
                      {-1.0,-1.0,1.0},{1.0,-1.0,0.0},
                        {1.0,1.0,1.0},{-1.0,1.0,1.0}};

point3 color[8] = {{0.0,0.0,0.0},{1.0,0.0,0.0},
                   {1.0,1.0,0.0}, {0.0,1.0,0.0},
                   {0.0,0.0,1.0},{1.0,0.0,1.0},
                   {1.0,1.0,1.0},{0.0,1.0,1.0}};

Glubyte cubeIndices[24]={0,3,2,1, 2,3,7,6, 0,4,7,3,
                         1,2,6,5, 4,5,6,7, 0,1,5,4};

glVertexPointer(3,GL_FLOAT,0,vertices);
glColorPointer(3,GL_FLOAT,0,color);

glDrawElements(GL_QUADS, 24, GL_UNSIGNED_BYTE, cubeIndices);
```

Frames in OpenGL

2 frames: camera frame and world frame

Model-view matrix positions world frame relative to camera

- 4x4 homogenous matrix
- part of OpenGL state
- set model view matrix by:
  - (1) set current state to Model-view
    `glMatrixMode(GL_MODELVIEW)`
  - (2) set current model view to identity
    `glLoadIdentity()`
  - (3) transform model view
    `glMultMatrixf(pointer_to_matrix)` -general transform
    `glRotatef(45.0,0.0,0.0,1.0)` - rotate 45deg about axis [001]
    `glTranslatef(1.0,2.0,3.0)` - translate by vector [123]
    `glScalef(sx,sy,sz)` - scale

Transformations

Rule: the most recent transformation is applied first

```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glTranslatef(1.0,2.0,3.0);
glRotatef(45.0,0.0,0.0,1.0);
glTranslatef(-1.0,-2.0,-3.0);
```

Tranform T= Identity * Translation(1,2,3)*Rotation(45,001)*Translation(-1-2-3)

Now for a point P in world coordinates the resulting position Q after the model view transformation above is:

$$Q = T P$$

where T is a 4x4 homogenous transformation matrix

Example - Spinning the Cube

Pushing and Popping Matrices

OpenGL provides matrix stacks which allow us to switch between transformations
- upto 32 model view matricies (maybe more)

glPushMatrix(); - put the current model view matrix on the stack
glPopMatrix(); - pops the most recent model view matrix off the stack

For example to perform a transformation and then return to the previous

```
glMatrixMode(GL_MODELVIEW);

glPushMatrix();

/* setup new model view */
glLoadIdentity();
glTranslatef(1.0,2.0,3.0);
glRotatef(45.0,0.0,0.0,1.0);
glTranslatef(-1.0,-2.0,-3.0);

glPopMatrix();
```

Display Lists

Display lists allow us to define an object once and to use it many times.

- The object is defined once and put in a display list
- Object is redisplayed by a single call

Functions:

`glNewList(index,type)` - create list

'type' GL_COMPILE - send to server only

GL_COMPILE_EXECUTE send & display

`glEndList()` - end list

`glCallList(index)` - draw the list on the server using current state

`base= glGenLists(nlist)` - create 'nlist' consecutive lists which start at base list

`glListBase(base)` - set offset to base list

`glCallLists(nlist_display, array_data_type, array_pointer)`

- display lists referred to by array_pointer

Example - Display List for a Cube

```
#define CUBE 1   /* number for cube display list */

… define cube vertex + face ….

glNewList(CUBE,GL_COMPILE); /* create and send list */
    glDrawElements(GL_QUADS, 24, GL_UNSIGNED_BYTE, cubeIndices);
glEndList();


glCallList(CUBE);   /* display cube according to current state*/

… change state (transform/projection/color)….
glCallList(CUBE);  /* display another cube */
```

Summary

- Vertex Arrays used to specify lists of points
- Transformation applied to OpenGL ‘ModelView’ matrix (in reverse order: last transform applied first)
- OpenGL supports a stack of upto 32 model view matricies
- Display lists used to efficiently create multiple instances of an object