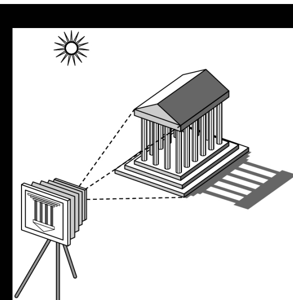
OpenGL and Assignment #1

Intensive introduction to OpenGL – whirlwind tour of:

- window setup (using glut)
- displaying polygons
- drawing smooth shaded polygons
- transform commands
- camera setup
- double buffering (for smooth animation)
- z-buffer (depth test) for hidden surface removal
- event handling in OpenGL
- display lists

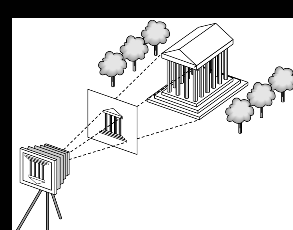
OpenGL



- C programming language

- OpenGL libraries
  for defining a 3D scene
  convert scene description to pixels
  use state variables (current color, current transform...)
  platform independent

- GLUT libraries
  handle windows, menus,
  keyboard input



OpenGL – “Hello World” example

```
int main (int argc, char *argv[]) {

   glutInit(&argc, argv);
   glutInitDisplayMode(GLUT_RGB);
   glutInitWindowSize(640, 480);
   glutCreateWindow(“Hello World”);

   glutDisplayFunc(display);

   glutMainLoop( );
   return(0);
}
```

OpenGL – “Hello World” example

```
void display( ) {

   glClearColor(0.5, 0.5, 0.5, 1);
   glClear(GL_COLOR_BUFFER_BIT);

   glColor3f(1, 0, 0);
   glBegin(GL_TRIANGLES);
   glVertex2f(-0.5, -0.5);
   glVertex2f( 0.5, -0.5);
   glVertex2f( 0  ,  0.5);
   glEnd( );
   glFlush( );
}
```

Aside: State variables in OpenGL

- `glColor3f(r,g,b);`

  All subsequent primitives will be this color.

  Colors are not attached to objects.

  `glColor3f(r,g,b)` *changes the system state.*

OpenGL – “Hello World” example

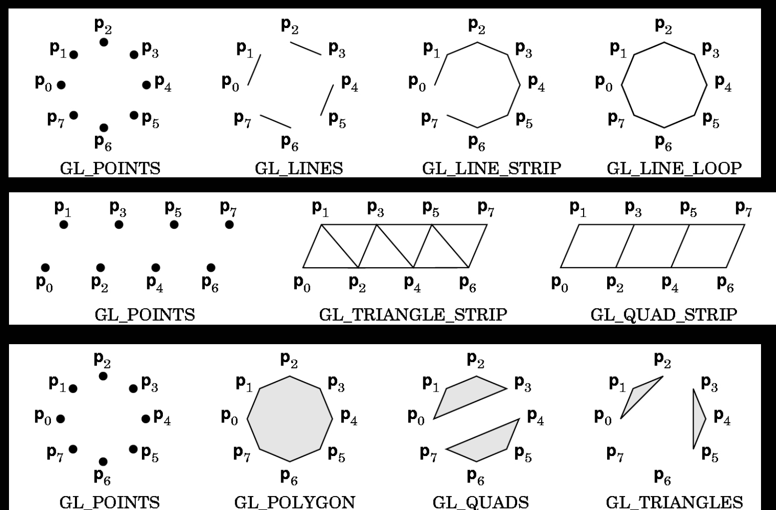
- You also need headers:

```
#include <stdlib.h>
#include <GL/gl.h>
#include <GL/glu.h>
#include <GL/glut.h>
```

- ..and a Makefile that links in the proper libraries

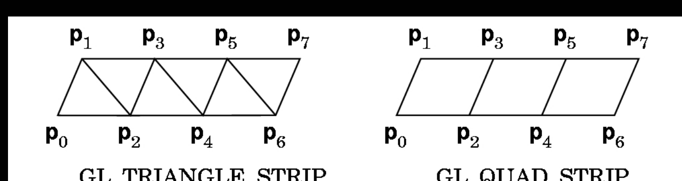
  See the starter code!

OpenGL functionality --- Primitives



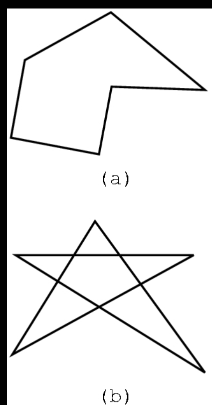
Primitives

- **Why triangles, quads, and strips?**



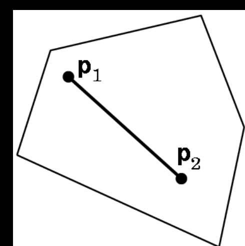
Polygon Restrictions

- OpenGL Polygons must be simple
- OpenGL Polygons must be convex



(a) simple, but not convex

convex



(b) non-simple

Why Polygon Restrictions?

- Non-convex and non-simple polygons are expensive to process and render
- Convexity and simplicity is expensive to test
- Better to fix polygons as a pre-processing step
- Behavior of OpenGL implementation on disallowed polygons is “undefined”
- Triangles are most efficient in hardware

Specifying Primitives

shapes.exe

Code for all of today's examples available from
http://www.xmission.com/~nate/tutors.html

Shading: How do we draw a smooth shaded polygon?

```
/* glShadeModel (GL_FLAT); */
  glShadeModel (GL_SMOOTH);
```

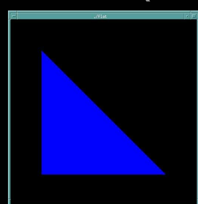
called once, in main

Smooth shaded polygon

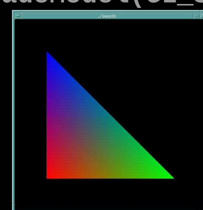
```
glBegin (GL_TRIANGLES);
  glColor3f (1.0, 0.0, 0.0); /* red */
  glVertex2f (5.0, 5.0);
  glColor3f (0.0, 1.0, 0.0); /* green */
  glVertex2f (25.0, 5.0);
  glColor3f (0.0, 0.0, 1.0); /* blue */
  glVertex2f (5.0, 25.0);
glEnd();
```

...in display function

`glShadeModel(GL_FLAT)`



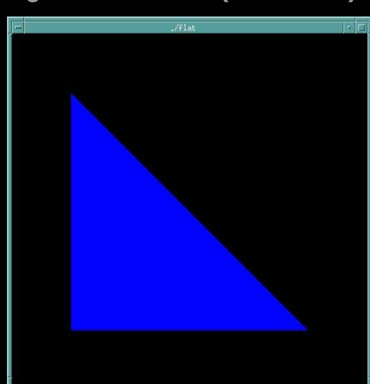
`glShadeModel(GL_SMOOTH)`



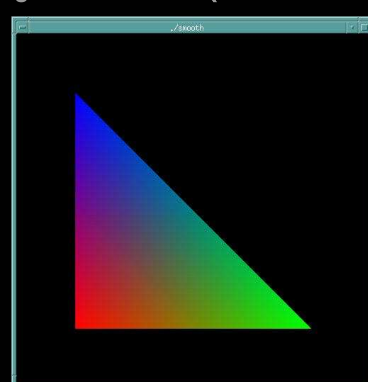
The Image

- Color of last vertex with flat shading

`glShadeModel(GL_FLAT)`



`glShadeModel(GL_SMOOTH)`



Transforms

transformation.exe

Transform order

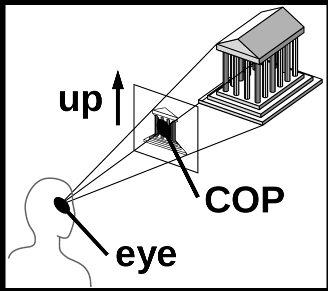
- Read transforms from the description of the geometry upward. The following produce very different effects:

```
glTranslate3f( ... );
glRotate3f( ... );
glScale3f( ... );
glBegin(GL_TRIANGLES);
   ...
glEnd( );
```

```
glScale3f( ... );
glRotate3f( ... );
glTranslate3f( ... );
glBegin(GL_TRIANGLES);
   ...
glEnd( );
```

Camera

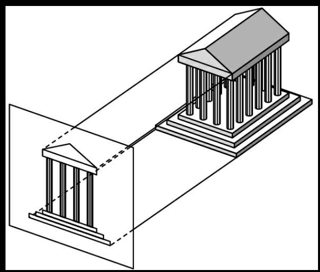
```
void gluLookAt
(eyex,eyey,eyez,
 centerx,centery,centerz,
 upx,upy,upz )
```



- **Perspective projection**
- Default camera is
  - at the origin,
  - pointing in the –z direction,
  - with y as the up vector

Camera

```
void glOrtho(left, right,
 bottom, top, near, far);
```



- **Orthographic projection**
  - long telephoto lens.
- Flat but preserving distances and shapes. All the projectors are now parallel.

Animation and Double Buffering

- (on the board)

Double Buffering Summary

- Screen refreshing technique
- Common refresh rate: 60-100 Hz
- Flicker if drawing overlaps screen refresh
- Problem during animation
- Example (cube_single.c)
- Solution: *use two frame buffers*
  - –Draw into one buffer
  - –Swap and display, while drawing other buffer
- Desirable frame rate >= 30 fps
  (fps = frames/second)

Double Buffering in OpenGL

- `glutInitDisplayMode(GLUT_DOUBLE);`

called once, in main

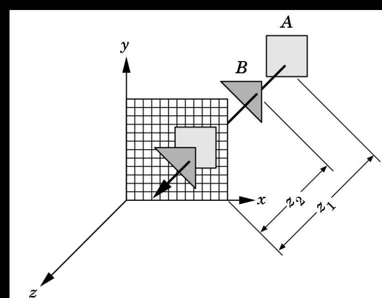
- `glSwapBuffers( );`

called when a new image
is ready to be displayed
(in the display function)

How do objects get correctly hidden behind other objects?

The z-Buffer Algorithm

- z-buffer with depth value z for each pixel
- Before writing a pixel into framebuffer
  - Compute distance z of pixel origin from viewer
  - If closer write and update z-buffer, otherwise discard



z-Buffer Algorithm Assessment

- **Strengths**
  - Simple (no sorting or splitting)
  - Independent of geometric primitives
- **Weaknesses**
  - Memory intensive (but memory is cheap now)
  - Tricky to handle transparency and blending
  - Depth-ordering artifacts for similar distances
  - Render some wasted polygons
- **Usage**
  - OpenGL when enabled

z-buffer algorithm is implemented using the Depth Buffer in OpenGL

- `glutInitDisplayMode(GLUT_DEPTH);`
- `glEnable(GL_DEPTH_TEST);`

called once, in main

- `glClear(GL_DEPTH_BUFFER_BIT);`

called before the new image is rendered into the frame buffer

(in the display function)

Event handling is done through callbacks

```
glutDisplayFunc(display);
glutReshapeFunc(reshape);
glutKeyboardFunc(keyboard);
glutMouseFunc(mousebutton);
glutMotionFunc(mousedrag);
glutPassiveMotionFunc(mouseidle);
glutIdleFunc(doIdle);
```

called once, in main

```
g_iMenuId = glutCreateMenu(menufunc);
glutSetMenu(g_iMenuId);
glutAddMenuEntry(“Quit”,0);
glutAttachMenu(GLUT_RIGHT_BUTTON);
```

Event handling – Routines you might write to handle various events

- `display( )` when window must be drawn
- `doIdle( )` when no other events to be handled
- `keyboard(unsigned char key, int x, int y)` key events
- `menufunc (int value)` after selection from menu
- `mousebutton (int button, int state, int x, int y)` mouse
- `mousedrag (int x, int y)` mouse movement
- `reshape (int w, int h)` window resize
- Any callback can be `NULL`

Example: Rotating Color Cube

- Draw a color cube
- Rotate it about x, y, or z axis, depending on left, middle or right mouse click
- Stop when space bar is pressed
- Quit when q or Q is pressed

Step 1: Defining the Vertices

- Use parallel arrays for vertices and colors

```
/* vertices of cube about the origin */
GLfloat vertices[8][3] =
  {{-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, 1.0}, {1.0, 1.0, 1.0}, {-1.0, 1.0, 1.0}};

/* colors to be assigned to edges */
GLfloat colors[8][3] =
  {{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}};
```

Step 2: Set Up

- Enable depth testing and double buffering

```
int main(int argc, char **argv)
{
    glutInit(&argc, argv);
    /* double buffering for smooth animation */
    glutInitDisplayMode
     (GLUT_DOUBLE | GLUT_DEPTH | GLUT_RGB);
    ...     /* window creation and callbacks here */
    glEnable(GL_DEPTH_TEST);
    glutMainLoop();
    return(0);
}
```

Step 3: Install Callbacks

- Create window and set callbacks

```
glutInitWindowSize(500, 500);
glutCreateWindow("cube");
glutReshapeFunc(myReshape);
glutDisplayFunc(display);
glutIdleFunc(spinCube);
glutMouseFunc(mouse);
glutKeyboardFunc(keyboard);
```

Step 4: Reshape Callback

- Enclose cube, preserve aspect ratio

```
void myReshape(int w, int h)
{
    GLfloat aspect = (GLfloat) w / (GLfloat) h;
    glViewport(0, 0, w, h);
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
    if (w <= h) /* aspect <= 1 */
      glOrtho(-2.0, 2.0, -2.0/aspect, 2.0/aspect, -10.0, 10.0);
    else /* aspect > 1 */
      glOrtho(-2.0*aspect, 2.0*aspect, -2.0, 2.0, -10.0, 10.0);
    glMatrixMode(GL_MODELVIEW);
}
```

Step 5: Display Callback

- Clear, rotate, draw, flush, swap

```
GLfloat theta[3] = {0.0, 0.0, 0.0};

void display(void)
{
  glClear(GL_COLOR_BUFFER_BIT
        | GL_DEPTH_BUFFER_BIT);
  glLoadIdentity();
  glRotatef(theta[0], 1.0, 0.0, 0.0);
  glRotatef(theta[1], 0.0, 1.0, 0.0);
  glRotatef(theta[2], 0.0, 0.0, 1.0);
  colorcube();
  glFlush();
  glutSwapBuffers();
}
```

Step 6: Drawing Faces

- Call `face(a,b,c,d)` with vertex index
- Orient consistently

```
void colorcube(void)
{
  face(0,3,2,1);
  face(2,3,7,6);
  face(0,4,7,3);
  face(1,2,6,5);
  face(4,5,6,7);
  face(0,1,5,4);
}
```

Step 7: Drawing a Face

- Use vector form of primitives and attributes

```
void face(int a, int b, int c, int d)
{
  glBegin(GL_POLYGON);
    glColor3fv (colors[a]);
    glVertex3fv(vertices[a]);
    glColor3fv (colors[b]);
    glVertex3fv(vertices[b]);
    glColor3fv (colors[c]);
    glVertex3fv(vertices[c]);
    glColor3fv (colors[d]);
    glVertex3fv(vertices[d]);
  glEnd();
}
```

Step 8: Animation

- Set idle callback: `spinCube()`

```
GLfloat delta = 2.0;
GLint axis = 2;
void spinCube()
{
  /* spin cube delta degrees about selected axis */
  theta[axis] += delta;
  if (theta[axis] > 360.0) theta[axis] -= 360.0;

  /* display result */
  glutPostRedisplay();
}
```

Step 9: Change Axis of Rotation

- Mouse callback

```
void mouse(int btn, int state, int x, int y)
{
  if (btn==GLUT_LEFT_BUTTON
      && state == GLUT_DOWN) axis = 0;
  if (btn==GLUT_MIDDLE_BUTTON
      && state == GLUT_DOWN) axis = 1;
  if (btn==GLUT_RIGHT_BUTTON
      && state == GLUT_DOWN) axis = 2;
}
```

Step 10: Toggle Rotation or Exit

- Keyboard callback

```
void keyboard(unsigned char key, int x, int y)
{
  if (key==’q’ || key == ’Q’) exit(0);
  if (key==’ ’) {stop = !stop;};
  if (stop)
    glutIdleFunc(NULL);
  else
    glutIdleFunc(spinCube);
}
```

How do we display complex objects efficiently?

Display Lists

- Encapsulate a sequence of drawing commands
- Optimize and store on server
- *Retained mode* (instead of *immediate mode*)

```
Gluint myObject;
...
myObject = glGenLists(1);
glNewList (myObject, GL_COMPILE);  /* new list */
    glColor3f(1.0, 0.0, 1.0);
    glBegin(GL_TRIANGLES);
        glVertex3f(0.0, 0.0, 0.0);
        ...
    glEnd();
glEndList();
...
glCallList(myObject);    /* draw one */
```

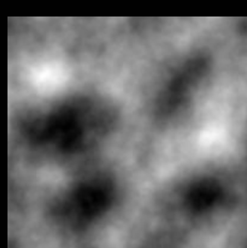
Display Lists

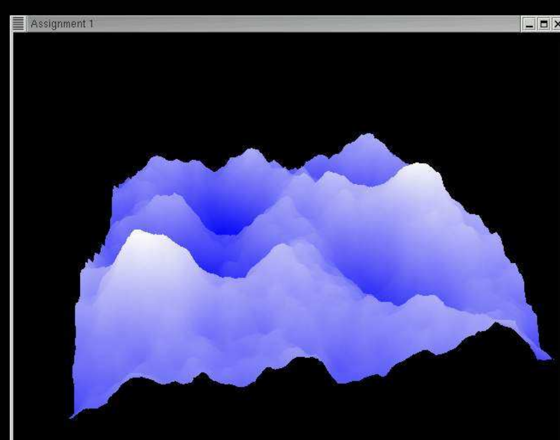
- Important for complex surfaces

- Display lists cannot be changed
- Display lists can be replaced

- Not necessary in first assignment

Height Fields





- -- Due midnight Tuesday, September 21