Surface Orientation (Clarification)

- Right-hand rule
- Triangle strip drawn 0-1-2, 2-1-3, 2-3-4, etc.
- All triangles face same direction (here: back)
- Similarly for quad strips 0-1-3-2, 2-3-5-4, etc.
- Orientable surfaces; discard back faces:
  `glEnable(GL_CULL_FACE);`  
  `glCullFace(GL_BACK);`  
  `/* do not draw back faces */`

Choice of Programming Language

- OpenGL lives close to the hardware
- OpenGL is not object-oriented
- OpenGL is not functional
- Use C to expose and exploit low-level details
- Use C++, Java, O’Caml, ... for toolkits
- Support for C and C++ in assignments
- O’Caml soon?

Client/Server Model

- Graphics hardware and caching
- Important for efficiency
- Need to be aware where data are stored
- Examples: vertex arrays, display lists

Display Lists

- Encapsulate a sequence of drawing commands
- Optimize and store on server
  ```
  GLuint listName = glGenLists(1);  /* new name */
  glNewList(listName, GL_COMPILE);  /* new list */
  glColor3f(1.0, 0.0, 1.0);
  glBegin(GL_TRIANGLES);
  glVertex3f(0.0, 0.0, 0.0);
  ...
  glEnd();
  glTranslatef(1.5, 0.0, 0.0);  /* offset next object */
  glEndList();
  glCallList(listName);  /* draw one */
  ```

Display Lists Details

- Useful for sequences of transformations
- Important for complex surfaces
- Another example: fonts
- Hierarchical display lists supported
- Display lists cannot be changed
- Display lists can be replaced
- Not necessary in first assignment
Vertex Arrays

- Draw cube with 6*4=24 or with 8 vertices?
- Expense in drawing and transformation
- Strips help to some extent
- Vertex arrays provide general solution
- Advanced (new in OpenGL 1.2)
  - Define (transmit) array of vertices, colors, normals
  - Draw using index into array(s)
  - Vertex sharing for efficient operations
- Not needed for first assignment

Outline

- Client/Server Model
- Callbacks
- Double Buffering
- Hidden Surface Removal
- Simple Transformations
- Example

Main Event Loop

- Standard technique for interaction
- Main loop processes events
- Dispatch to functions specified by client
- Callbacks also common in operating systems
- Poor man’s functional programming
- Mediates between client and window system

Types of Callbacks

- Display ( ): when window must be drawn
- Idle ( ): when no other events to be handled
- Keyboard (unsigned char key, int x, int y): key
- Menu (...): after selection from menu
- Mouse (int button, int state, int x, int y): mouse
- Motion (...): mouse movement
- Reshape (int w, int h): window resize
- Any callback can be NULL

Screen Refresh

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

- One example of many
- glutInitDisplayMode (GLUT_SINGLE);
- glutInitDisplayMode (GLUT_DOUBLE);
- glutSwapBuffers();
- If something has no effect, check mode
- Example (cube.c)

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Hidden Surface Removal

- Classic problem of computer graphics
- What is visible after clipping and projection?
- Object-space vs image-space approaches
- Object space: depth sort (Painter’s algorithm)
- Image space: ray cast (z-buffer algorithm)
- Related: back-face culling

Object-Space Approach

- Consider objects pairwise
- Complexity $O(k^2)$ where $k =$ # of objects
- Painter’s algorithm: render back-to-front
- “Paint” over invisible polygons
- How to sort and how to test overlap?

Depth Sorting

- First, sort by furthest distance $z$ from viewer
- If minimum depth of $A$ is greater than maximum depth of $B$, $A$ can be drawn before $B$
- If either $x$ or $y$ extents do not overlap, $A$ and $B$ can be drawn independently

Some Difficult Cases

- Sometimes cannot sort polygons!
- One solution: compute intersections
- Do while rasterizing (difficult in object space)
Painter’s Algorithm Assessment

- **Strengths**
  - Simple (most of the time)
  - Handles transparency well
  - Sometimes, no need to sort (e.g., heightfield)

- **Weaknesses**
  - Clumsy when geometry is complex
  - Sorting can be expensive

- **Usage**
  - OpenGL (by default)
  - PostScript interpreters

Image-Space Approach

- **Raycasting**: intersect ray with polygons

- **O(k) worst case (often better)**
- **Images can be more jagged**

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 primitvies

- **Weaknesses**
  - Memory intensive (but memory is cheap now)
  - Tricky to handle transparency and blending
  - Depth-ordering artifacts

- **Usage**
  - OpenGL when enabled

Depth Buffer in OpenGL

- `glutInitDisplayMode(GLUT_DEPTH);`
- `glEnable(GL_DEPTH_TEST);`
- `glClear(GL_DEPTH_BUFFER_BIT);`
- Remember all of these!
- Some “tricks” use z-buffer read-only

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Specifying the Viewing Volume
- Clip everything not in viewing volume
- Separate matrices for transformation and projection
  
  ```
  glMatrixMode(GL_PROJECTION);
  glLoadIdentity();
  ... Set viewing volume ...
  glMatrixMode(GL_MODELVIEW);
  ```

Parallel Viewing
- Orthographic projection
- Camera points in negative z direction
  
  ```
  glOrtho(xmin, xmax, ymin, ymax, near, far)
  ```

Perspective Viewing
- Slightly more complex
- `glFrustum(xmin, xmax, ymin, ymax, near, far)`

Simple Transformations
- Rotate by given angle (in degrees) about ray from origin through `(x, y, z)`
  
  ```
  glRotate(fd)(angle, x, y, z);
  ```
- Translate by the given x, y, and z values
  
  ```
  glTranslate(fd)(x, y, z);
  ```
- Scale with a factor in the x, y, and z direction
  
  ```
  glScale(fd)(x, y, z);
  ```

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Example: Rotating Color Cube
- Adapted from [Angel, Ch. 4]
- Problem:
  - 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

```c
/* 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

```c
/* 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

```c
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

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

Step 4: Reshape Callback

- Enclose cube, preserve aspect ratio

```c
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

```c
   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();
       glutSwapBuffers();
   }
```

Step 6: Drawing Faces

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

```c
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

```c
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

```c
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

```c
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

```c
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);
}
```

Summary
- Client/Server Model
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Announcements
- Please verify access to graphics lab and login
- Follow account setup instruction on web page!
- Check web page for C++ instructions
- First guest lecture on Feb 20 on programmable pixel shaders (Cass Everitt, Nvidia)
- Assignment 1 movie from Fall'02