Interaction

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Client/Server Model
Callbacks
Double Buffering
Hidden Surface Removal
Simple Transformations
[Angel Ch. 3]
Triangles (Clarification)

- Can be any shape or size
- Well-shaped triangles have advantages for numerical simulation
- Shape quality makes little difference for basic OpenGL rendering
Choice of Programming Language

• OpenGL lives close to the hardware
• OpenGL is not object-oriented
• OpenGL is not a functional language (as in, ML)
• Use C to expose and exploit low-level details
• Use C++, Java, ... for toolkits
• Support for C in assignments
Client/Server Model

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

**AGP, PCI, PCI Express**
Fast, but limited bandwidth

Possible, but very slow
Display Lists

- Cache a sequence of drawing commands
- Optimize and store on server (GPU)

“Client” — CPU — GPU

“Server”

Store geometry, colors, lighting properties of objects on the GPU

Client — bus — Server

Display (CRT)
Display Lists

- Cache a sequence of drawing commands
- Optimize and store on server (GPU)

```c
GLuint listName = glGenLists(1); /* new list name */
glNewList(listName, GL_COMPILE); /* new list */
glColor3f(1.0, 0.0, 1.0);
glBegin(GL_TRIANGLES);
    glVertex3f(0.0, 0.0, 0.0);
    ...
    glVertex3f(0.0, 0.0, 0.0);
  glEnd();

  glEndList(); /* at this point, OpenGL compiles the list */
glCallList(listName); /* draw the object */
```
Display Lists Details

- Very useful with complex objects that are redrawn often (e.g., with transformations)
- Another example: fonts (2D or 3D)
- Display lists can call other display lists
- Display lists cannot be changed
- Display lists can be erased / replaced
- Not necessary in first assignment

- Display lists are now deprecated in OpenGL
- For complex usage, use the VertexBufferObject (VBO) extension
Vertex Arrays

- Draw cube with $6 \times 4 = 24$ or with 8 vertices?
- Expense in drawing and transformation
- Strips help to some extent
- Vertex arrays provide general solution
- Advanced (since 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
GLUT Program with Callbacks

START

Initialization

Idle() \rightarrow Reshape(..) \rightarrow Motion(..) \rightarrow Mouse(..)

Display() \rightarrow Keyboard(..) \rightarrow Menu(..)

Main event loop

END
Main Event Loop

• Standard technique for interaction (GLUT, Qt, wxWidgets, ...)

• Main loop processes events

• Dispatch to functions specified by client

• Callbacks also common in operating systems

• “Poor man’s functional programming”
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 pressed
- **Menu (...)**: after selection from menu
- **Mouse (int button, int state, int x, int y)**: mouse button
- **Motion (...)**: mouse movement
- **Reshape (int w, int h)**: window resize
- Any callback can be NULL
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Screen Refresh

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

- glutInitDisplayMode(GLUT_SINGLE);
- glutInitDisplayMode(GLUT_DOUBLE);

- Single buffering:
  Must call `glFinish()` at the end of `Display()`

- Double buffering:
  Must call `glutSwapBuffers()` at the end of `Display()`

- Must call `glutPostRedisplay()` at the end of `Idle()`

- If something in OpenGL has no effect or does not work, check the modes in `glutInitDisplayMode`
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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: 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 & subdivide
- 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**
  – PostScript interpreters
  – OpenGL: not supported
    (must implement Painter’s Algorithm manually)
Image-Space Approach

- Raycasting: intersect ray with polygons

- $O(k)$ worst case (often better)
- Images can be more jagged (need anti-aliasing)
The z-Buffer Algorithm

- z-buffer stores depth values $z$ for each pixel
- Before writing a pixel into framebuffer:
  - Compute distance $z$ of pixel 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

• **Usage**
  – z-Buffering comes standard with OpenGL; disabled by default; must be enabled
Depth Buffer in OpenGL

- `glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGBA | GLUT_DEPTH);`
- `glEnable (GL_DEPTH_TEST);`

- Inside Display():
  
  `glClear (GL_DEPTH_BUFFER_BIT);`

- Remember all of these!
- Some “tricks” use z-buffer in read-only mode
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Specifying the Viewing Volume

- Clip everything not in viewing volume
- Separate matrices for transformation and projection

```c
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
- \texttt{glFrustum(xmin, xmax, ymin, ymax, near, far)}
Simple Transformations

- Rotate by given angle (in degrees) about axis given by \((x, y, z)\)
  
  \[
  \text{glRotate}^{\text{fd}}(\text{angle}, x, y, z); \]

- Translate by the given \(x\), \(y\), and \(z\) values
  
  \[
  \text{glTranslate}^{\text{fd}}(x, y, z); \]

- Scale with a factor in the \(x\), \(y\), and \(z\) direction
  
  \[
  \text{glScale}^{\text{fd}}(x, y, z); \]
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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

/* 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 vertices */
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 z-buffer 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");
glutReshapeFunc(myReshape);
glutDisplayFunc(display);
glutIdleFunc(spinCube);
glutMouseFunc(mouse);
glutKeyboardFunc(keyboard);
```
Step 4: Reshape Callback

- Set projection and viewport, 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 the cube delta degrees about selected axis */
    theta[axis] += delta;
    if (theta[axis] > 360.0) theta[axis] -= 360.0;

    /* display result (do not forget this!) */
    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
- Callbacks
- Double Buffering
- Hidden Surface Removal
- Simple Transformations
- Example
Announcements

• Assignment 1 will be posted this week
• Microsoft Visual Studio (Windows) access enabled via Microsoft’s MSDN
• Please start early
• Check web page for instructions