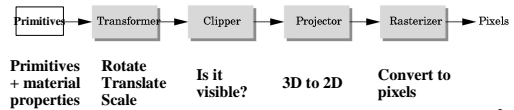
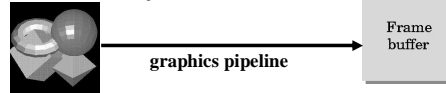


More on the graphics pipeline
 Event driven programming
 Nintendo Wii (Michael De Rosa)

Review

geometric objects
 properties: color...
 move camera and objects around



2

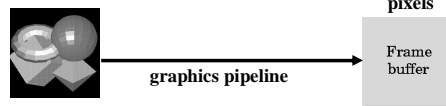
Outline

- Double Buffering
- Hidden Surface Removal
- Back-Face Culling



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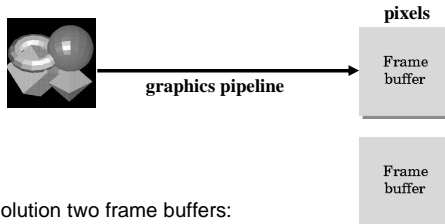
Double Buffering: Screen Refresh



- Common: 60-100 Hz
- Flicker if drawing overlaps screen refresh
- Problem during animation
- Example (cube_single.c)



Double Buffering: Screen Refresh



- 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

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

- draw your scene
- `glutSwapBuffers ();`

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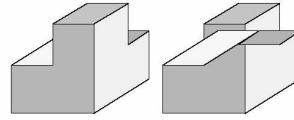
Outline

- Double Buffering
- Hidden Surface Removal
- Back-Face Culling

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Hidden Surface Removal

- What is visible after clipping and projection?



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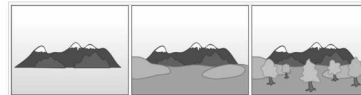
Hidden Surface Removal

- Object-space vs image-space approaches
- Object space: depth sort (Painter's algorithm)
- Image space: ray cast (z-buffer algorithm)

We'll get back to this later in the semester in much more detail!

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Painter's Algorithm

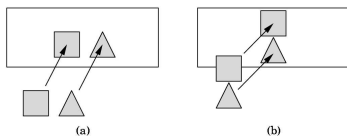


- Render back-to-front
- "Paint" over invisible polygons
- How to sort and how to test overlap?

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Depth Sorting

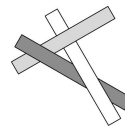
- First, sort by furthest distance z from viewer
- If minimum depth of A is greater than maximum depth of B, A can be drawn before B
- If either x or y extents do not overlap, A and B can be drawn independently



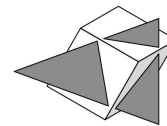
11

Some Difficult Cases

- Sometimes cannot sort polygons!



Cyclic overlap



Piercing Polygons

- One solution: compute intersections and subdivide
- Do while rasterizing (difficult in object space)

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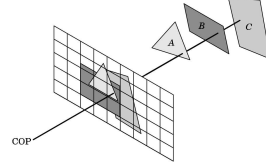
Painter's Algorithm Assessment

- 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

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Image-Space Approach

- Raycasting: intersect ray with polygons



- $O(k)$ worst case (often better) where $k = \#$ of objects

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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



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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

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Depth Buffer in OpenGL

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

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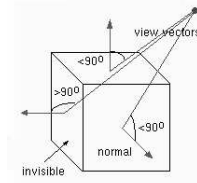
Outline

- Double Buffering
- Hidden Surface Removal
- Back-Face Culling

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Back-Face Culling

Eliminate polygons not facing the viewer



```
glCullFace(GL_BACK);
```

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More on the graphics pipeline
Event driven programming
Nintendo Wii (Michael De Rosa)

Interactive Graphics Applications

- Games
- Simulation-based training
 - pilot training
- Windows-based programs



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Control-driven programming

```
main()  
  while user does not press quit  
    draw cube  
    check if mouse pressed  
    if mouse pressed  
      change axis of rotation  
  
    check if key pressed  
    .....
```

Continuous polling of user commands → wasting machine resources
Many actions performed by user are non-application specific

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Event-driven programming

GUI program should remain idle by default
Do not waste machine resources
Become active only in presence of events
Automatically take care of standard actions

```
main() → MainEventLoop()  
        Initialization  
        loop forever  
        wait for next event  
        process event
```

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Event-driven programming

GUI program should remain idle by default
Do not waste machine resources
Become active only in presence of events
Automatically take care of standard actions

```
register event service routines with GUI  
wait for next event  
process event
```

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GLUT

- Initialization
 - Open window
 - Set display mode
 - Register call backs
- Enter main loop
 - `glutMainLoop();`

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Types of Callbacks

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

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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



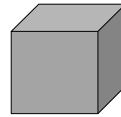
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Step 1: Defining the Vertices

- 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}};
```



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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();
}
```

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Step 3: Install Callbacks

- Create window and set callbacks

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

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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);
}
```



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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();
}
```

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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);
}
```

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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(); }
```

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Step 8: Animation

- Set idle callback

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

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

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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;
}
```

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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);
}
```

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More on the graphics pipeline Event driven programming Nintendo Wii (Michael De Rosa)

Nintendo Wii



- PowerPC CPU @ 729 MHz
- ATI GPU @ 243 MHz
- 88 MB RAM
- WiFi
- Bluetooth

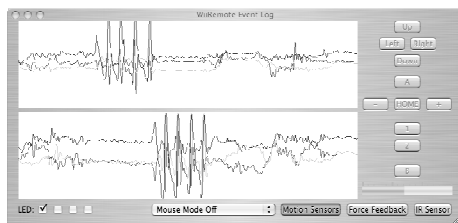
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Wii Controller



- Wiimote
 - Position sensing (via IR triangulation)
 - 3 axis accelerometer
 - 12 buttons
 - Speaker
 - Vibration
 - Nonvolatile storage
- Nunchuk
 - 3 axis accelerometer
 - 2 buttons
 - Analog joystick

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Input Channels

- Accelerometer readings (x6)
- Button state (x14)
- Position
- Joystick angle & deflection
- Wireless connection status

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Wii Sports Bowling

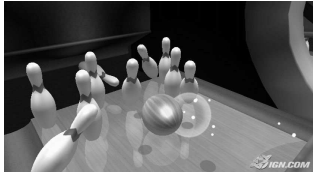


- Depress B button (starts approach)
- Swing controller back, then forward
- Release B button (releases ball)
- Spin can be applied by tilting the controller

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Callbacks for Bowling

- `glutDisplayFunc(display);` [to display the scene]
- `glutKeyboardFunc(keyboard);` [to start/stop the swing]
- `glutMotionFunc(mouse);` [to control swing params]
- Any others?



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The Importance of Interaction Design

- The Wii has significantly less processing/graphics power than the PS3 (and no high def. output)
- Wii sold 600k units over Christmas (vs. 491k for PS3)
- Wii was on the annual "Hot Toy" list
- 05-650 Interface and Interaction Design
- 53-500 Fundamentals of Entertainment Technology

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Tech Demo