CSCI 420 Computer Graphics
Lecture 4

Color and Hidden Surface Removal

Client/Server Model
Callbacks
Double Buffering
Physics of Color
Flat vs Smooth Shading
Hidden Surface Removal
[Angel Ch. 2]

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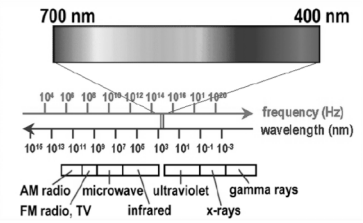
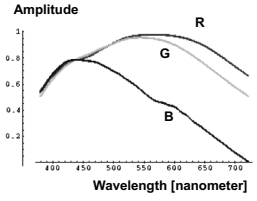
Physics of Color

- Electromagnetic radiation
- Can see only a tiny piece of the spectrum



Color Filters

- Eye can perceive only 3 basic colors
- Computer screens designed accordingly



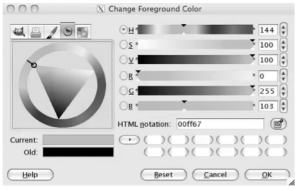
Source: Vos & Walraven

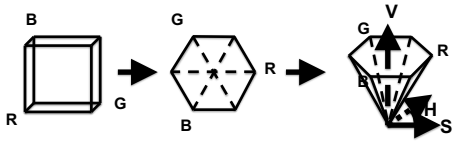
Color Spaces

- RGB (Red, Green, Blue)
  - Convenient for display
  - Can be unintuitive (3 floats in OpenGL)
- HSV (Hue, Saturation, Value)
  - Hue: what color
  - Saturation: how far away from gray
  - Value: how bright
- Other formats for movies and printing

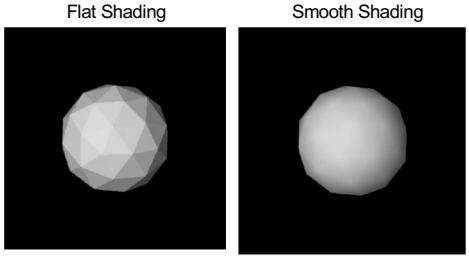
RGB vs HSV

Gimp Color Picker





Flat vs Smooth Shading



Flat vs Smooth Shading

color of last vertex

each vertex separate color smoothly interpolated

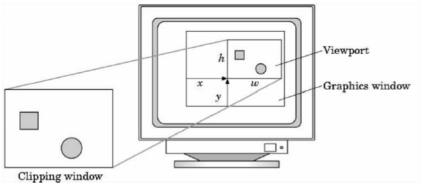
Compatibility profile: glShadeModel(GL_FLAT)

Compatibility profile: glShadeModel(GL_SMOOTH)

Core profile: use interpolation qualifiers in the fragment shader

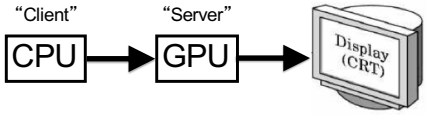
Viewport

- Determines clipping in window coordinates
- glViewport(x, y, w, h) (usually in reshape function)



Client/Server Model

- Graphics hardware and caching



- Important for efficiency
- Need to be aware where data are stored
- Graphics driver code is on the CPU
- Rendering resources (buffers, shaders, textures, etc.) are on the GPU

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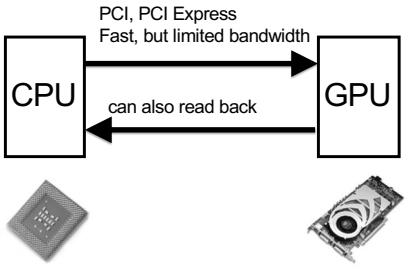
The CPU-GPU bus



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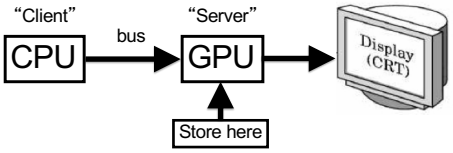
Buffer Objects

- Store rendering data: vertex positions, normals, texture coordinates, colors, vertex indices, etc.
- Optimize and store on server (GPU)



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Vertex Buffer Objects

- Caches vertex geometric data: positions, normals, texture coordinates, colors
- Optimize and store on server (GPU)
- Required for core OpenGL profile

```
/* vertices of the quad (will form two triangles;
   rendered via GL_TRIANGLES) */
float positions[6][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}};

/* colors to be assigned to vertices (4th value is the alpha channel) */
float colors[6][4] =
  {{0.0, 0.0, 0.0, 1.0}, {1.0, 0.0, 0.0, 1.0}, {0.0, 1.0, 0.0, 1.0},
   {0.0, 0.0, 1.0, 1.0}, {1.0, 1.0, 0.0, 1.0}, {1.0, 0.0, 1.0, 1.0}};
```

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Vertex Buffer Object: Initialization

```
GLuint vbo;

void initVBO()
{
  glGenBuffers(1, &vbo);
  glBindBuffer(GL_ARRAY_BUFFER, vbo);
  glBufferData(GL_ARRAY_BUFFER, sizeof(positions) + sizeof(colors),
    nullptr, GL_STATIC_DRAW);   // init VBO's size, but don't assign any data to it

  // upload position data
  glBufferSubData(GL_ARRAY_BUFFER, 0, sizeof(positions), positions);

  // upload color data
  glBufferSubData(GL_ARRAY_BUFFER, sizeof(positions), sizeof(colors), colors);
}
```

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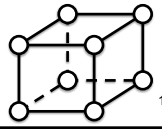
Element Arrays

- Draw cube with 6*2*3=36 or with 8 vertices?
- Expense in drawing and transformation
- Triangle strips help to some extent
- Element arrays provide general solution
- Define (transmit) array of vertices, colors, normals
- Draw using index into array(s) :

```
// (must first set up the GL_ELEMENT_ARRAY_BUFFER) …
glDrawElements(GL_TRIANGLES, 36, GL_UNSIGNED_INT, 0);
```

- Vertex sharing for efficient operations
- Extra credit for first assignment



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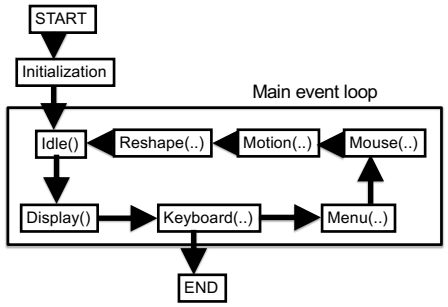
GLUT Program with Callbacks



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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"

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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)

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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

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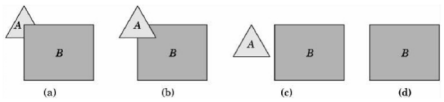
Object-Space Approach

- Consider objects pairwise



- Painter's algorithm: render back-to-front
- "Paint" over invisible polygons
- How to sort and how to test overlap?

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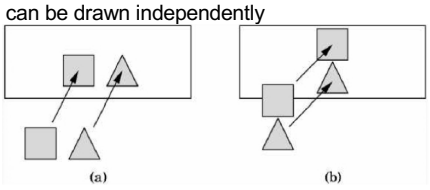
Depth Sorting

- 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



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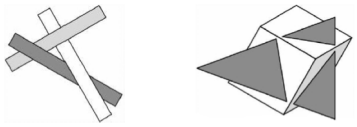
Some Difficult Cases

- Sometimes cannot sort polygons!



Cyclic overlap Piercing Polygons

- One solution: compute intersections & 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
- Usage
  - PostScript interpreters
  - OpenGL: not supported
    (must implement Painter's Algorithm manually)

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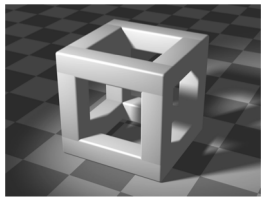
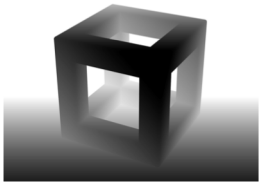
Image-space approach



3D geometry



Depth image

darker color is closer

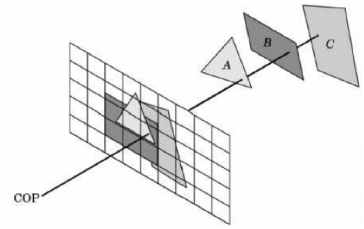
Source: Wikipedia

Depth sensor camera

KINECT for XBOX 360.

Image-Space Approach

- Raycasting: intersect ray with polygons

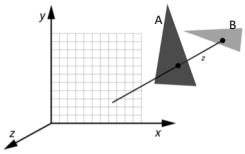


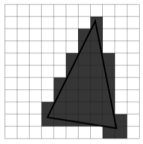
- O(k) worst case (often better)
- Images can be more jagged (need anti-aliasing)

The z-Buffer Algorithm

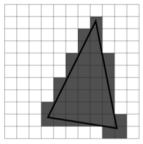
- z-buffer stores depth values z for each pixel
- Before writing a pixel into framebuffer:
  - Compute distance z of pixel from viewer
  - If closer, write and update z-buffer, otherwise discard

After rendering A:





color

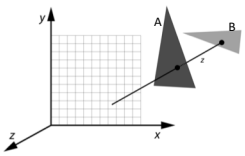


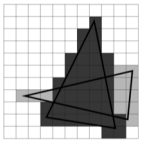
depth

The z-Buffer Algorithm

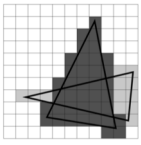
- z-buffer stores depth values z for each pixel
- Before writing a pixel into framebuffer:
  - Compute distance z of pixel from viewer
  - If closer, write and update z-buffer, otherwise discard

After rendering A and B:





color



depth

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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Note for Mac computers

Must use the GLUT_3_2_CORE_PROFILE flag to use the core profile:

```
glutInitDisplayMode(GLUT_3_2_CORE_PROFILE |
   GLUT_DOUBLE | GLUT_RGBA | GLUT_DEPTH);
```

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Summary

- Client/Server Model
- Callbacks
- Double Buffering
- Physics of Color
- Flat vs Smooth Shading
- Hidden Surface Removal

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