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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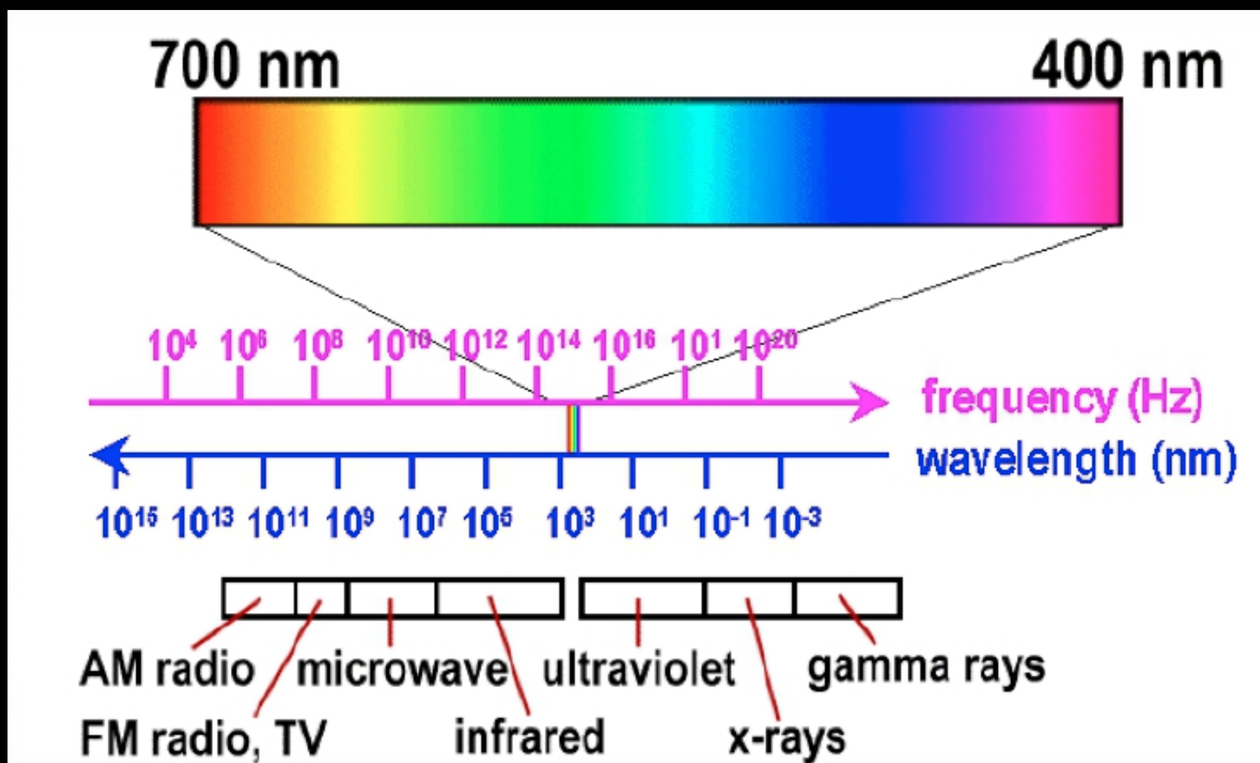
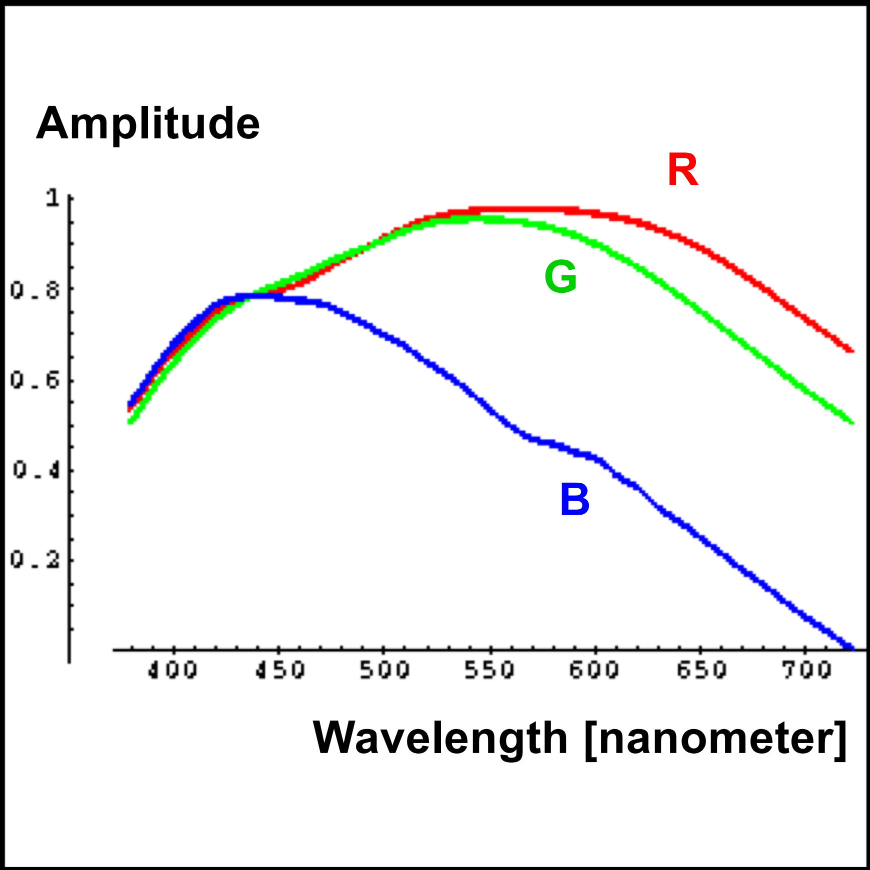
Physics of Color

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



Color Filters

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



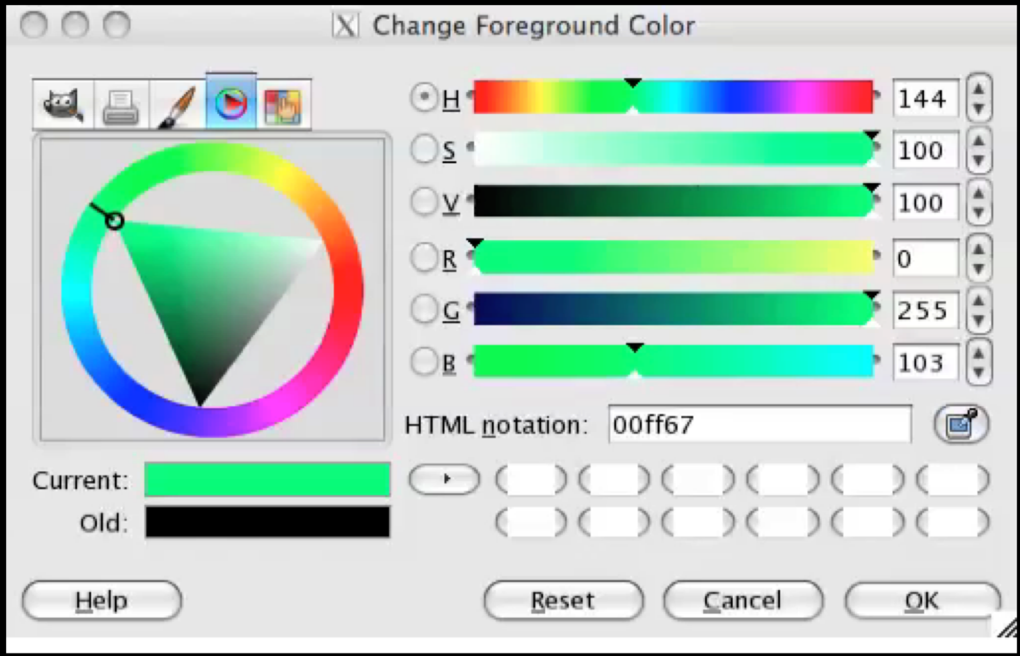
Source: Vos & Walraven

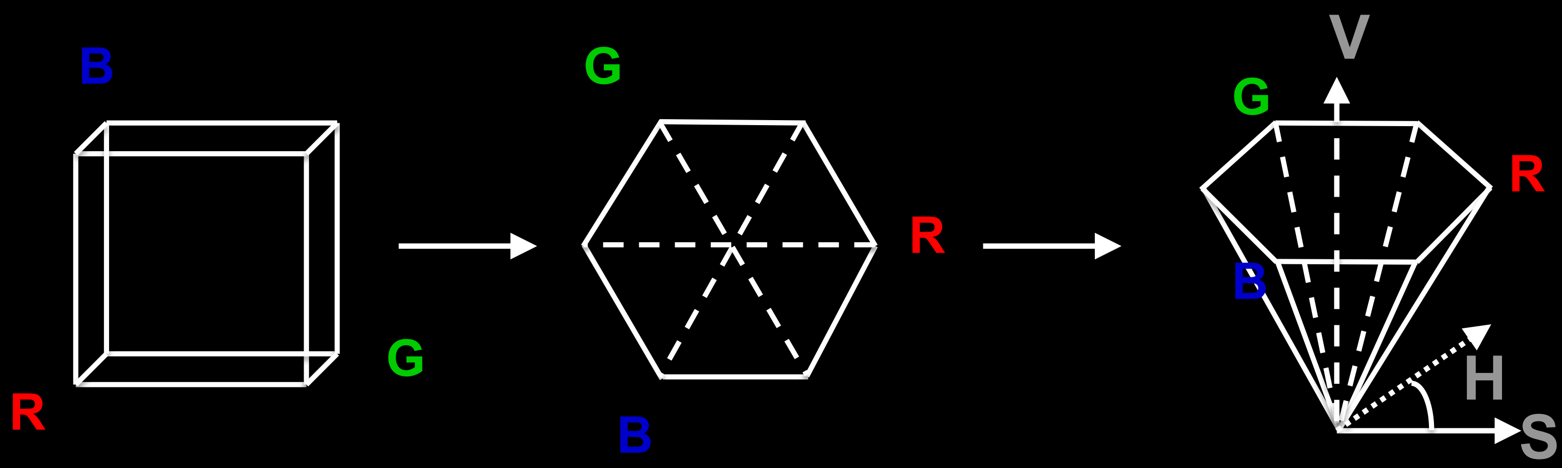
Color Spaces

- 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





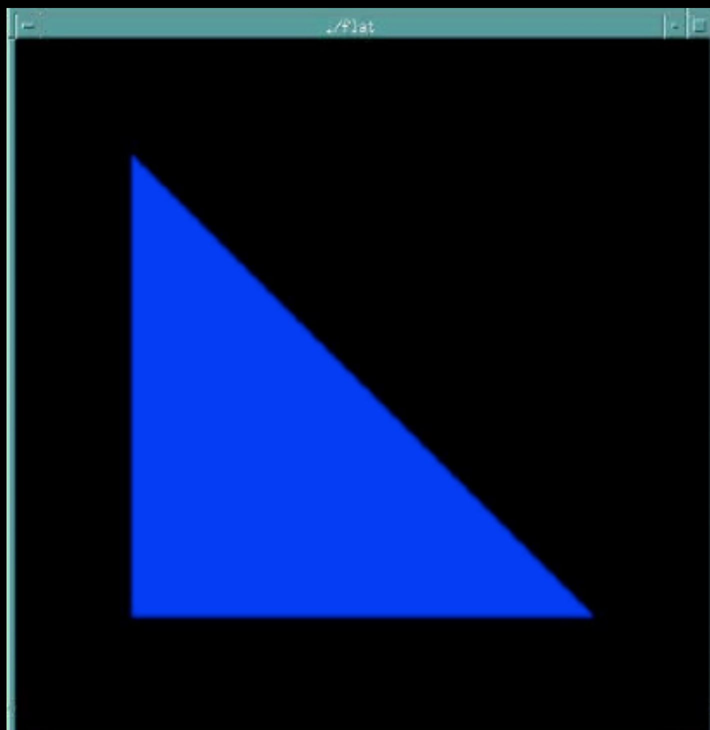
Flat vs Smooth Shading

Flat Shading

Smooth Shading

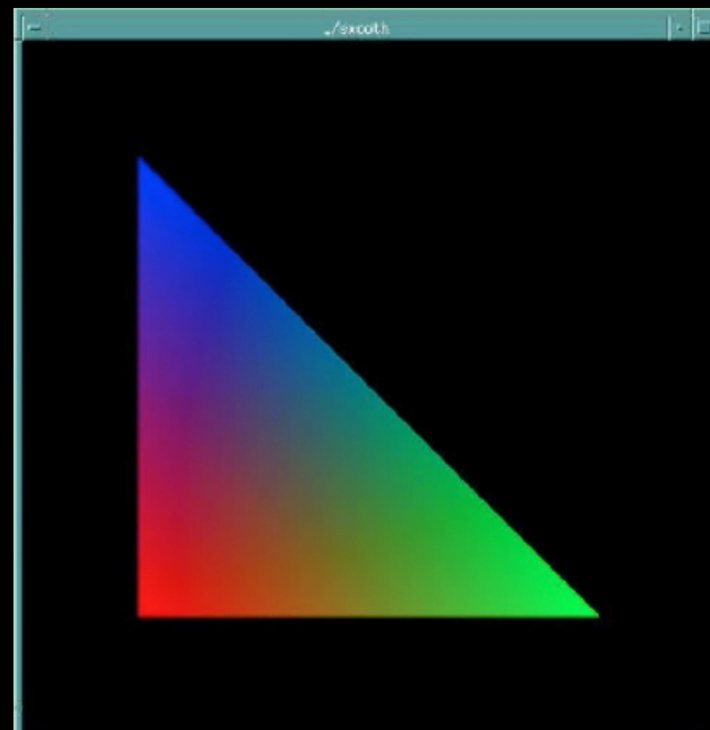
Flat vs Smooth Shading

color of last vertex



Compatibility profile:
glShadeModel(GL_FLAT)

each vertex separate color smoothly interpolated

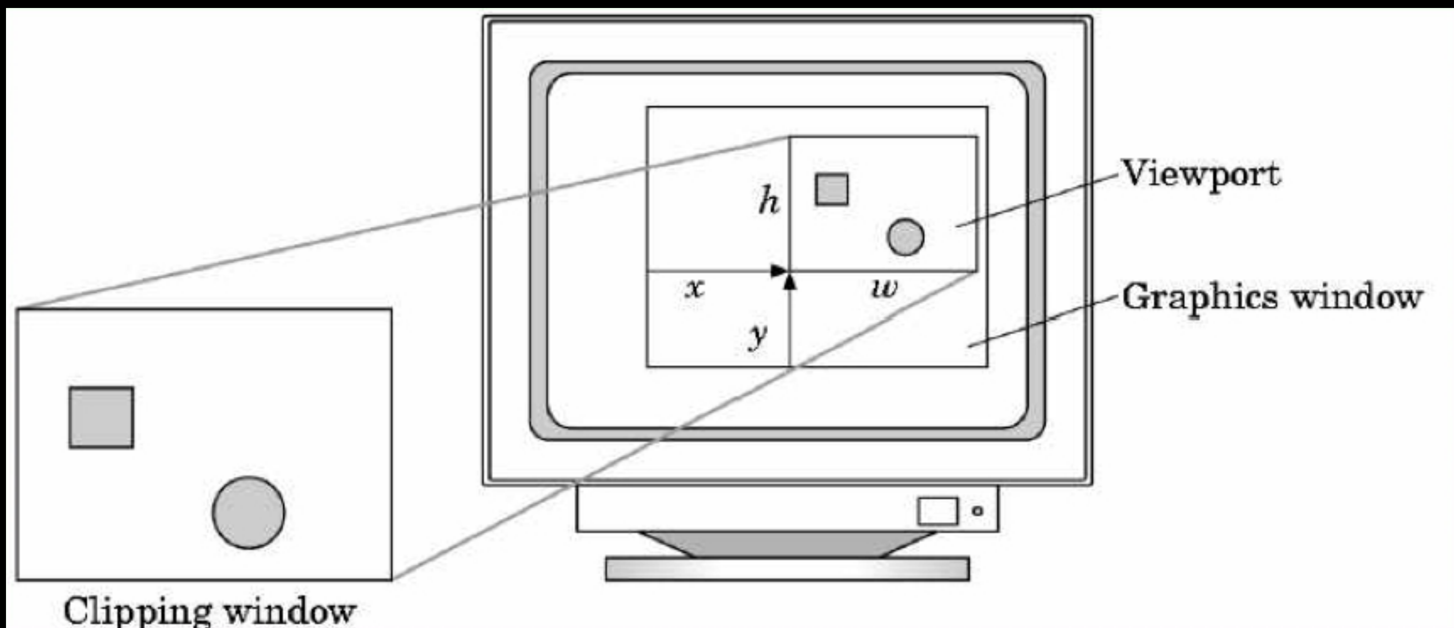


Compatibility profile:
glShadeModel(GL_SMOOTH)

Core profile: use interpolation qualifiers in the fragment shader

Viewport

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

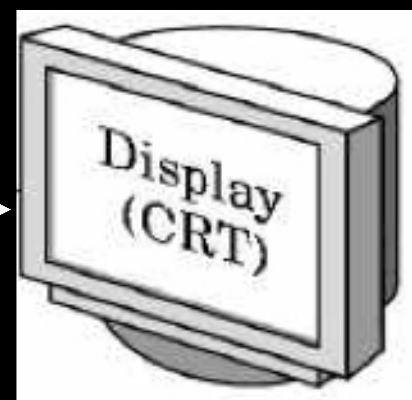


Client/Server Model

- Graphics hardware and caching

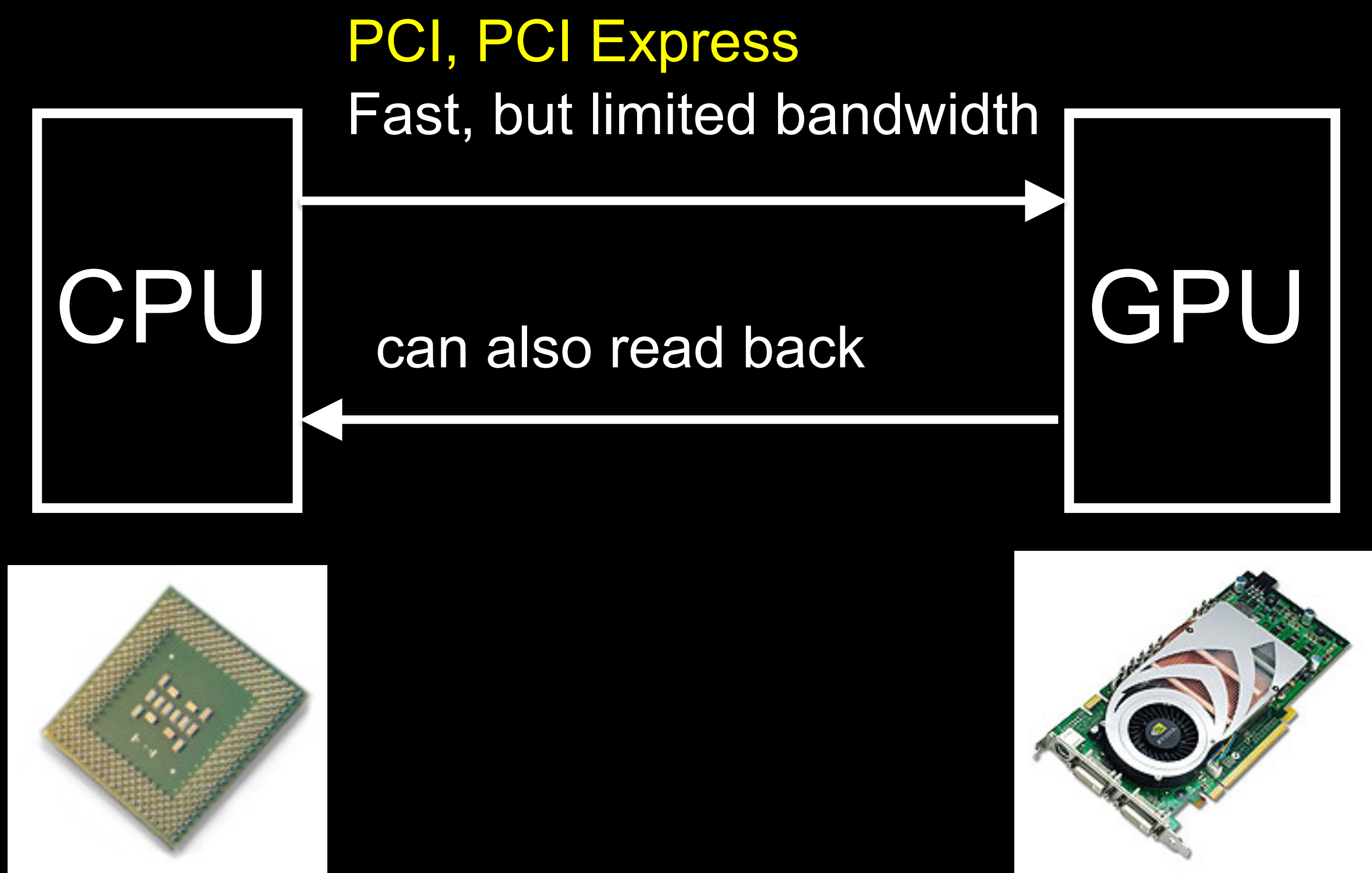
“Client” “Server”

CPU → GPU →



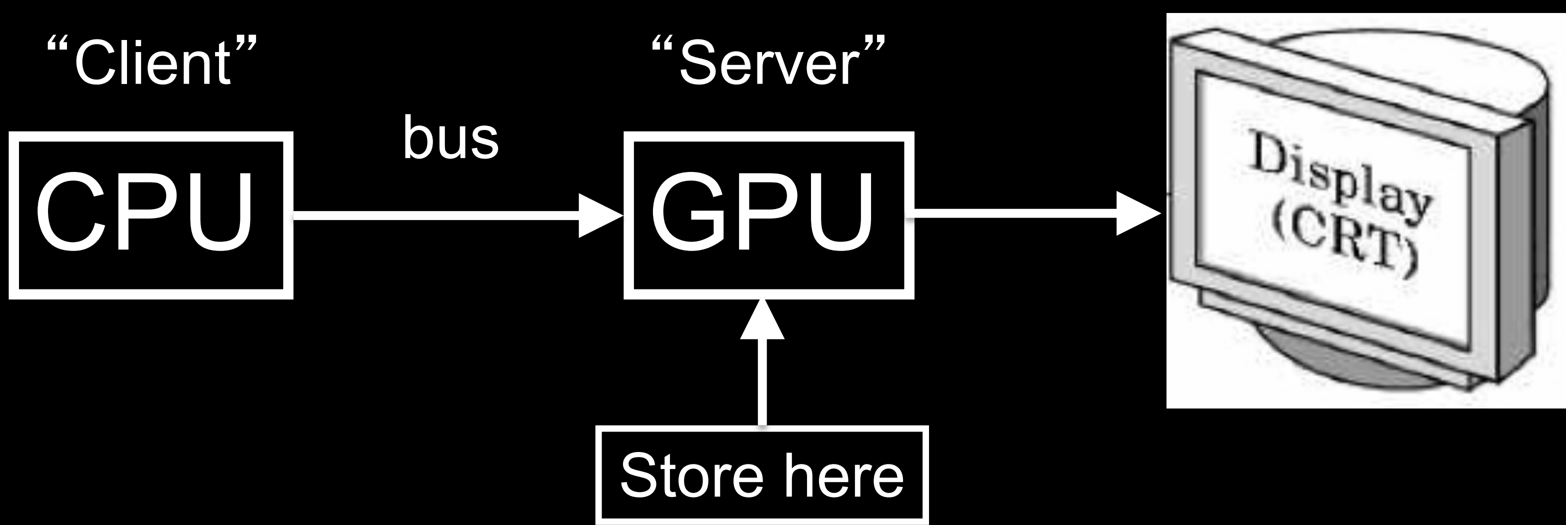
- Important for efficiency
- Need to be aware where data are stored
- Graphics driver code is on the CPU
- Rendering resources (buffers, shaders, textures, etc.) are on the GPU

The CPU-GPU bus



Buffer Objects

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



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}};
```

Vertex Buffer Object: Initialization

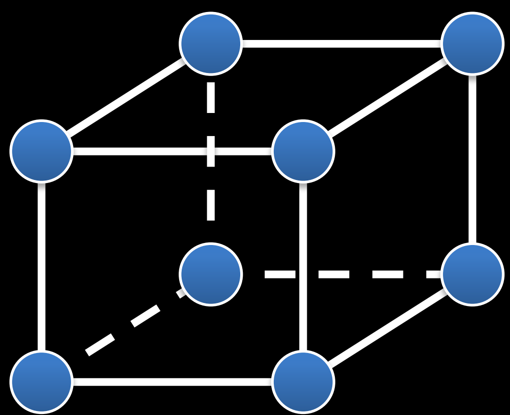
```
GLuint vbo;

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);
}
```

Element Arrays

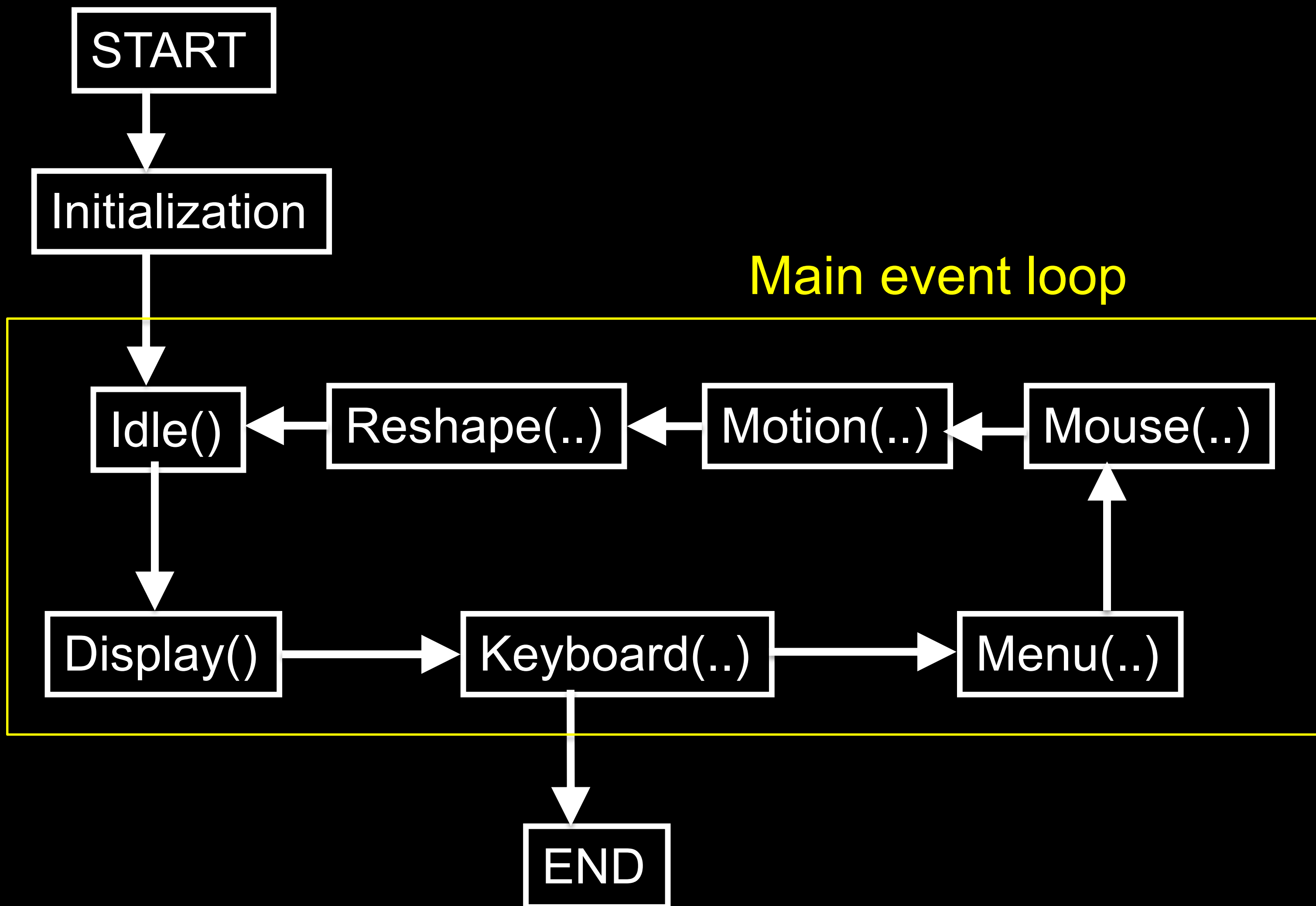
- Draw cube with 6*2*3=36 or with 8 vertices?
- Expense in drawing and transformation
- Triangle strips help to some extent
- Element arrays provide general solution
- Define (transmit) array of vertices, colors, normals
- Draw using index into array(s) :

```
// (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



GLUT Program with Callbacks



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

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

Hidden Surface Removal

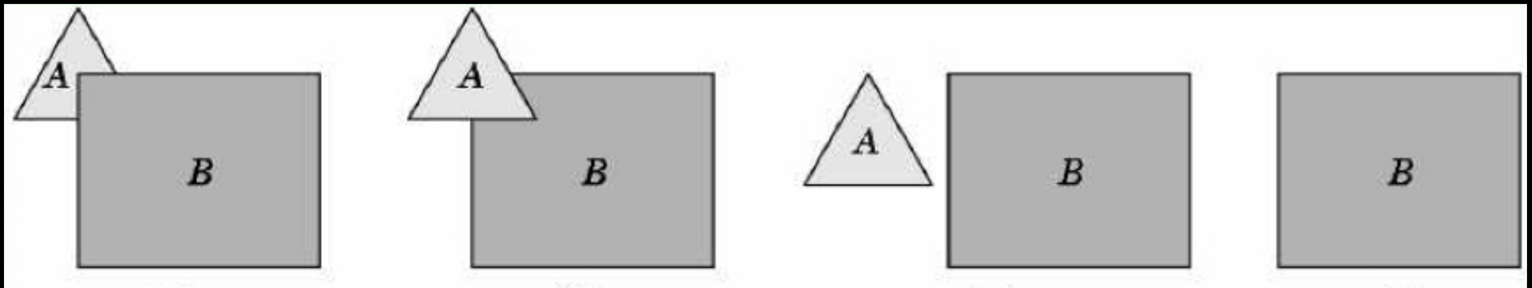
- Classic problem of computer graphics
- What is visible after clipping and projection?

- 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



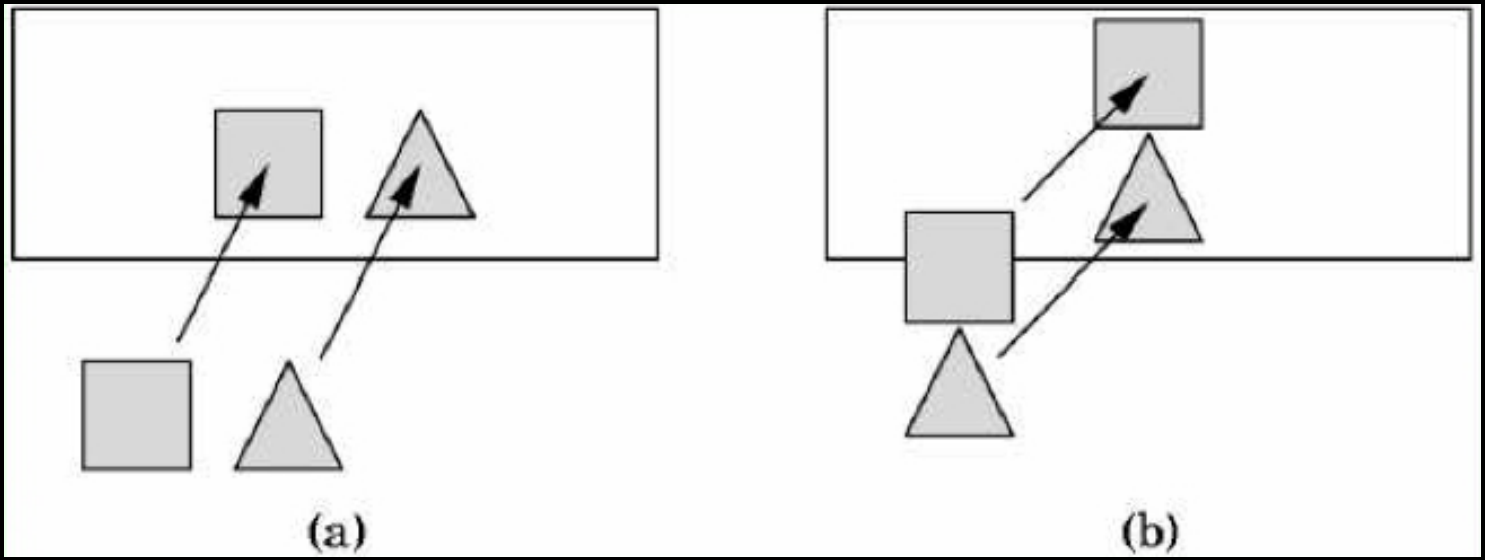
(a) (b) (c) (d)

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

Depth Sorting

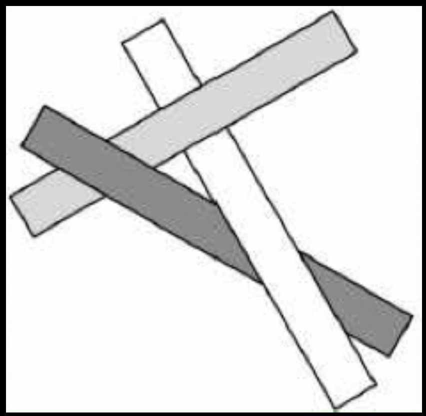
- First, sort by furthest distance z from viewer
- If minimum depth of A is greater than maximum depth of B, A can be drawn before B

- If either x or y extents do not overlap, A and B can be drawn independently

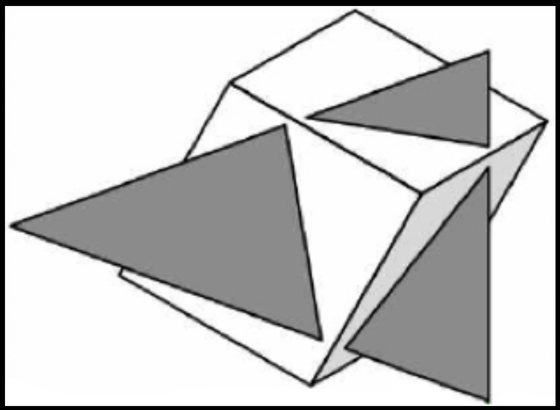


Some Difficult Cases

- Sometimes cannot sort polygons!



Cyclic overlap



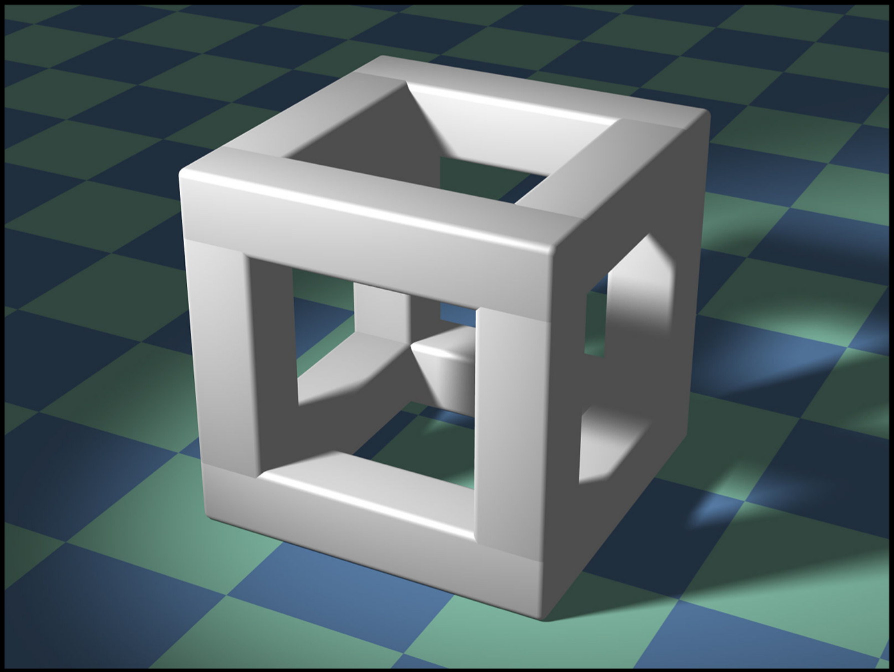
Piercing Polygons

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

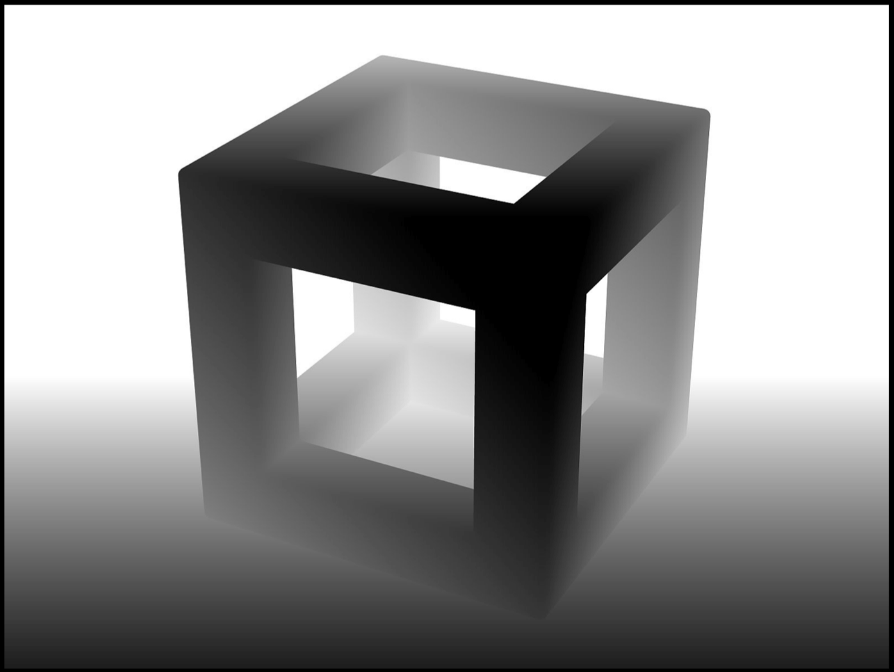
Painter's Algorithm Assessment

- 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



3D geometry



Depth image

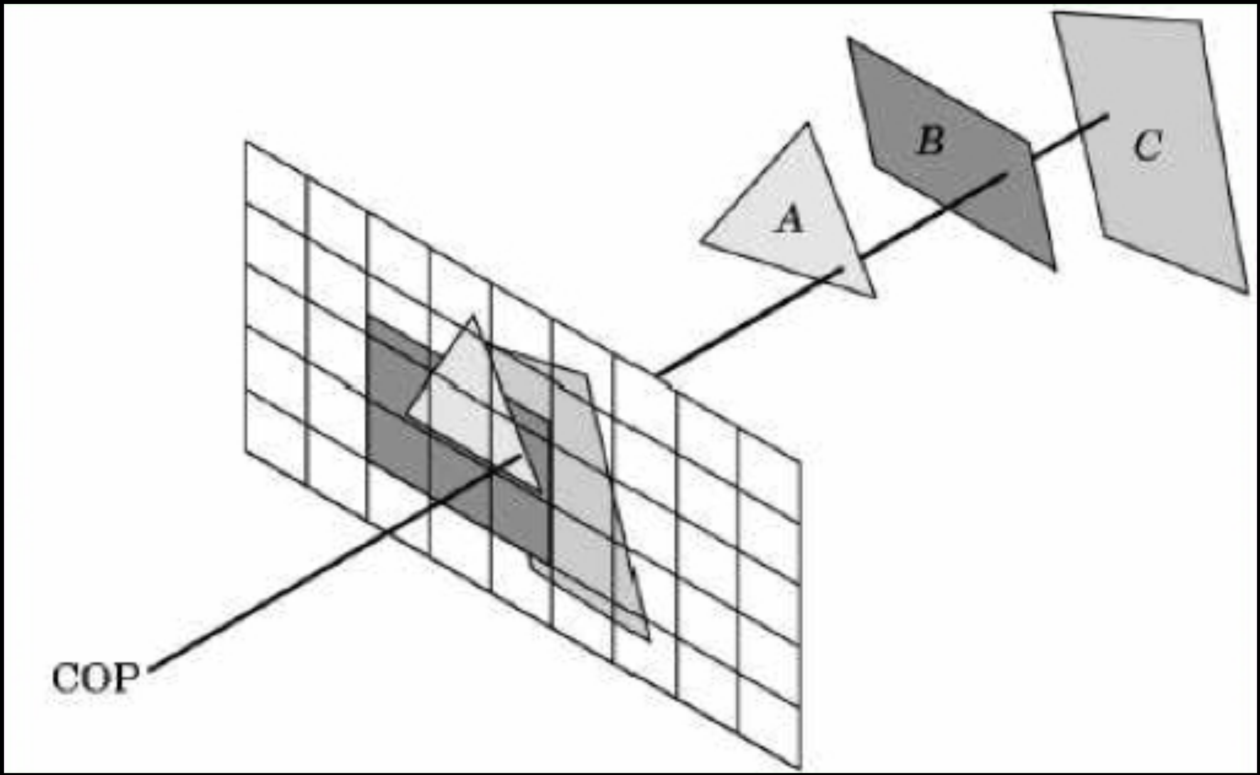
darker color is closer

Source: Wikipedia

Depth sensor camera

Image-Space Approach

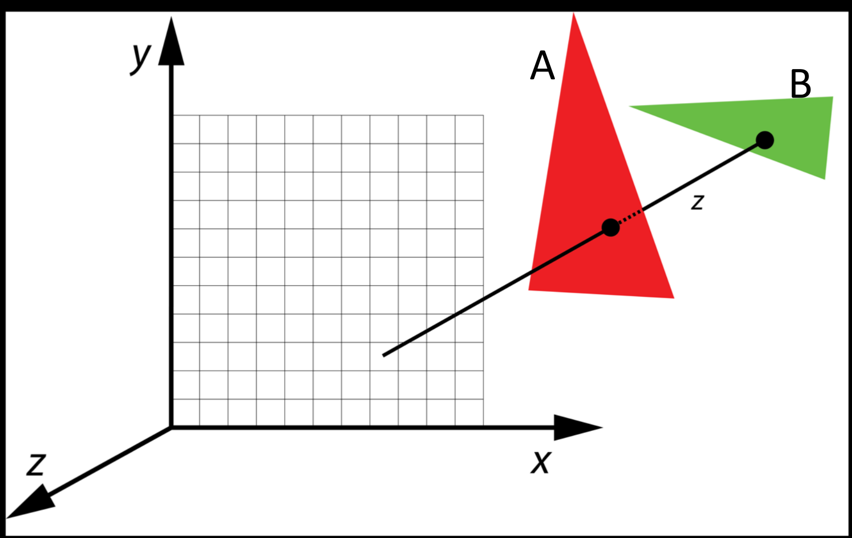
- Raycasting: intersect ray with polygons



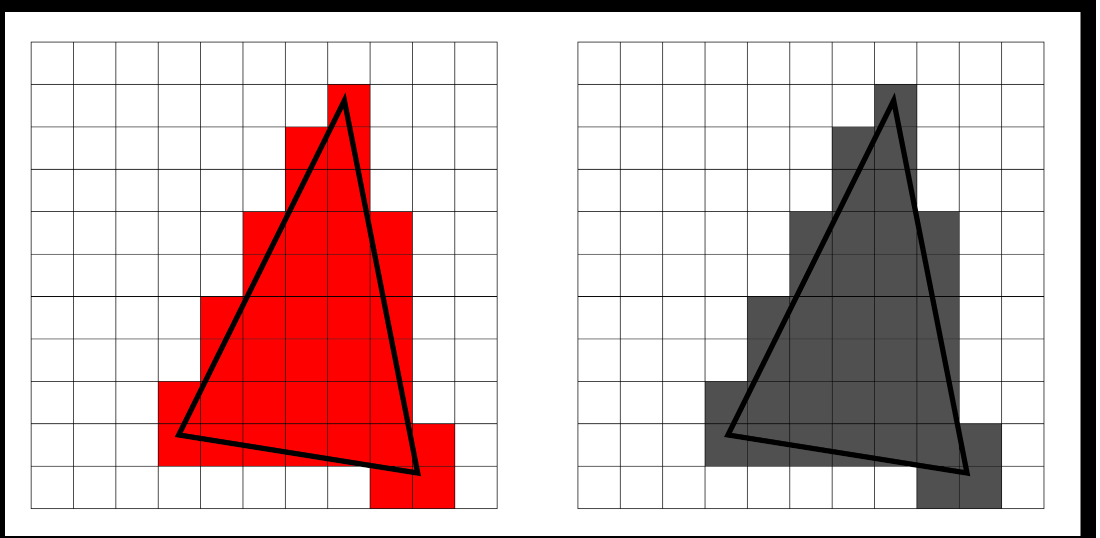
- O(k) worst case (often better)
- Images can be more jagged (need anti-aliasing)

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

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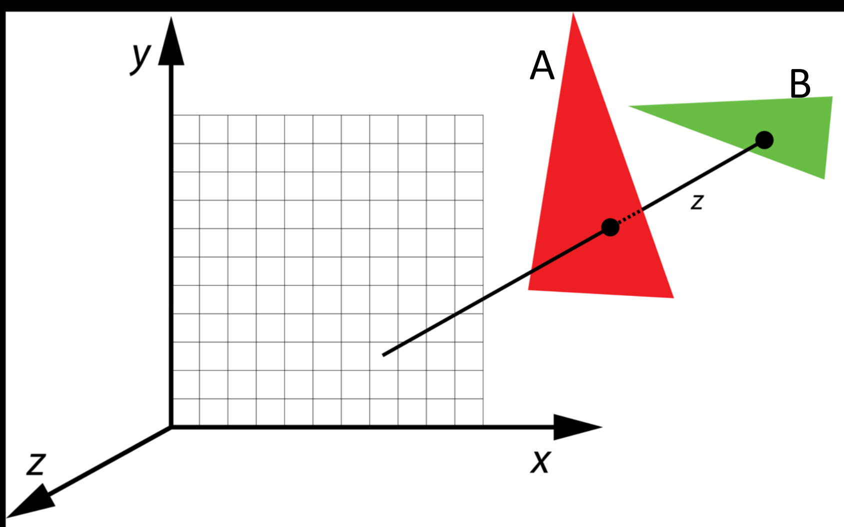
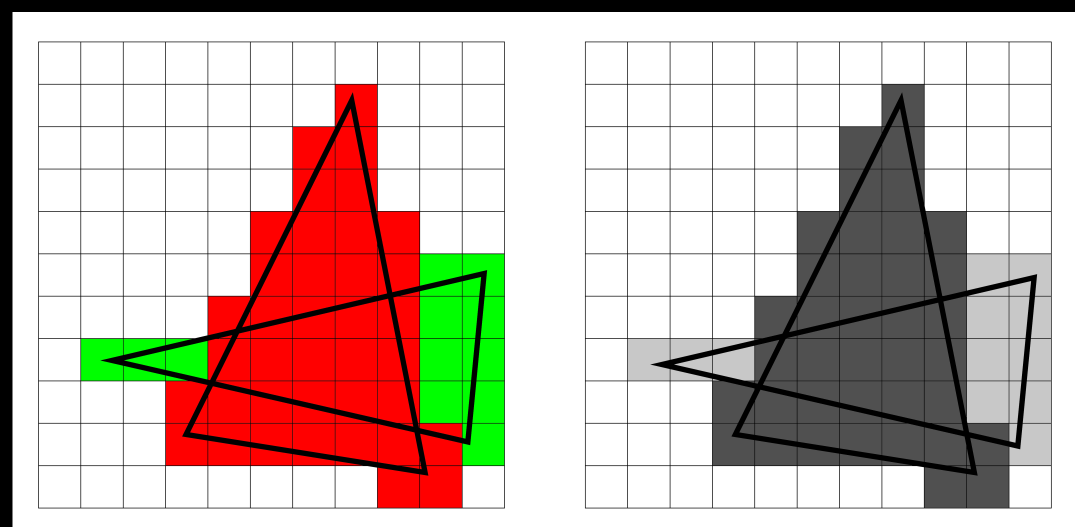


After rendering A and B:



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

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);
```

Summary

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