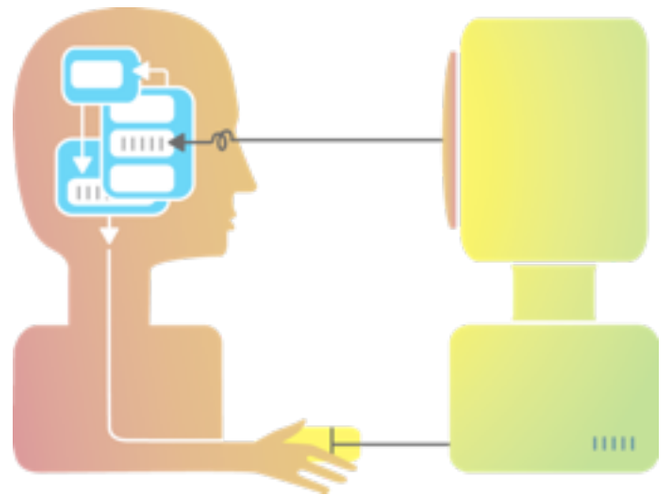
Fall 2014

CSCI 420: **Computer Graphics**



2.1 Input and Interaction

Hao Li

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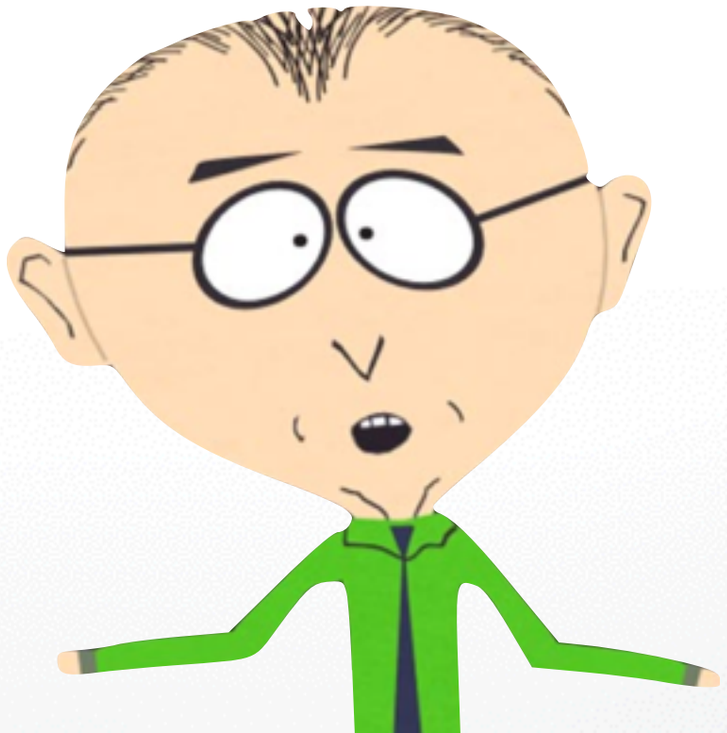
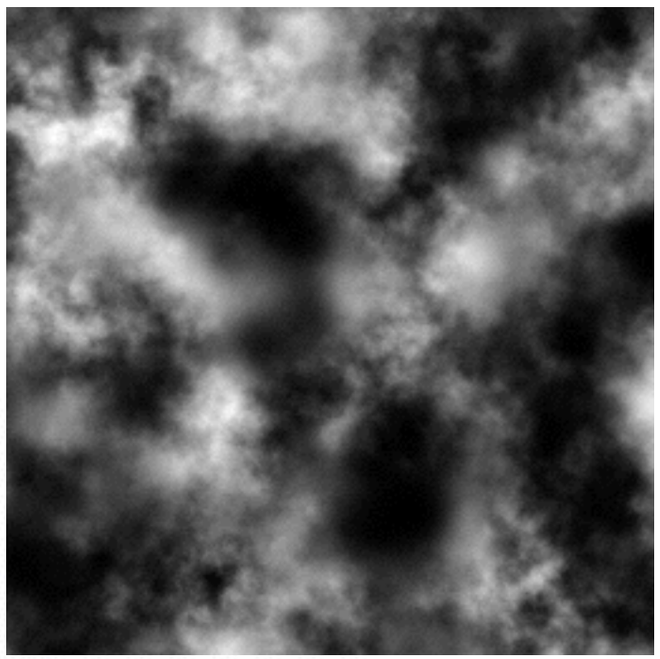
Administrative

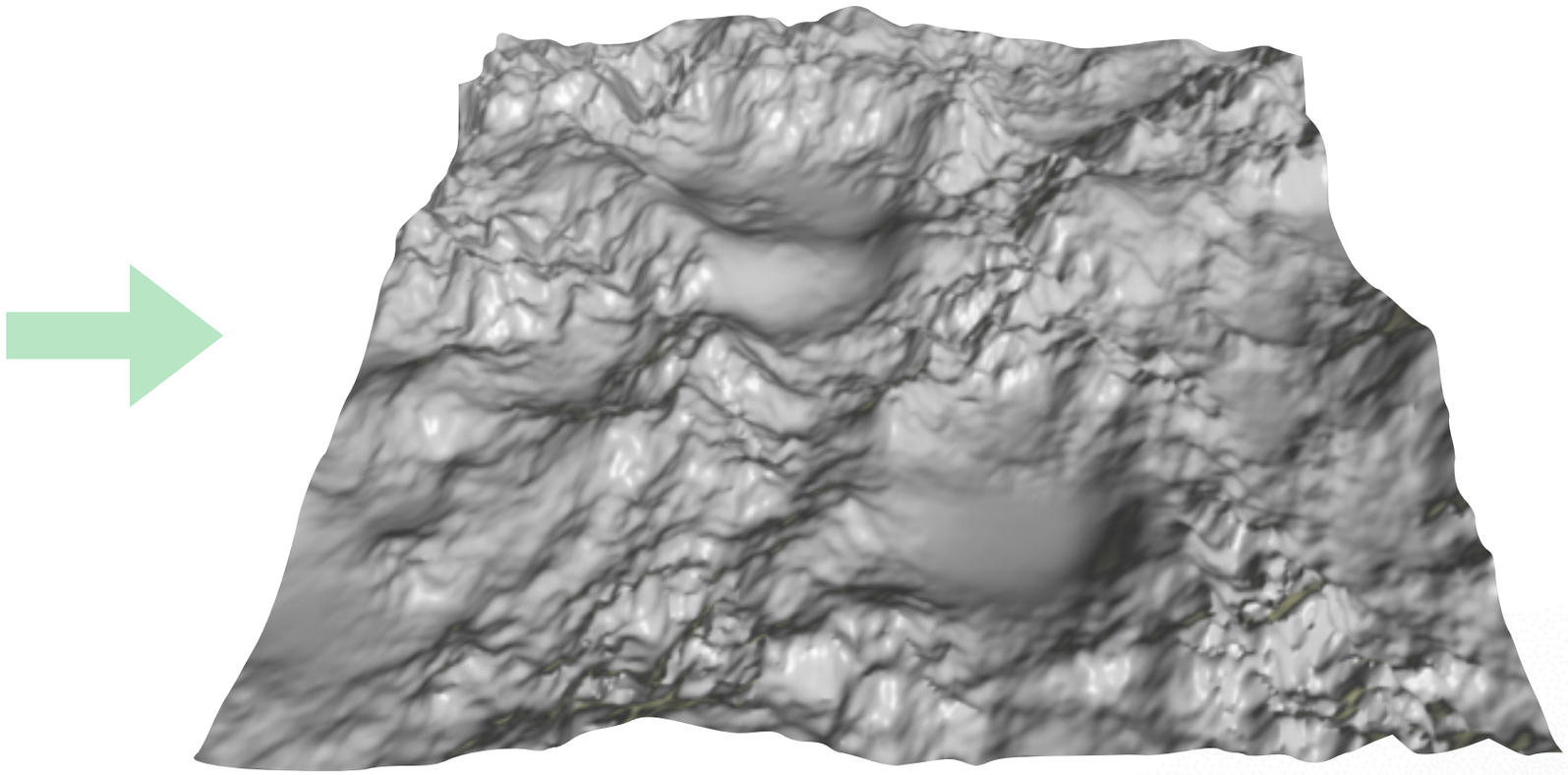
- **Exercise 1:** It's out today, discussion on Thursday
- **Exercise 1 handout:** 11:59 PM, Thursday, Sep 18
- **Hao Li (Me)**
  - Office Hour: Tue 2:00 PM - 4:00 PM, SAL 244
  - starting today



Exercise 1

Interactive 3D Heighfield Viewer and Fly-through!





input

output

Exercise 1

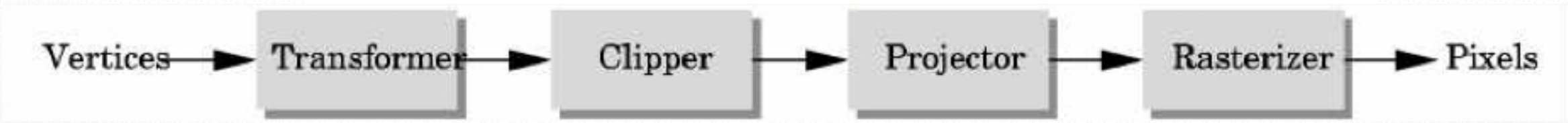
Where to find it?

Schedule

	Date	Topic	Material	Notes
1	Tue Aug 26, 2014	Introduction	[slides]	
	Thu Aug 28, 2014	Basic Graphics Programming	[slides] [example]	
2	Tue Sep 02, 2014	Input and Interaction		[Ex. 1 Out]
	Thu Sep 04, 2014	Transformations		
3	Tue Sep 09, 2014	Viewing and Projection		
	Thu Sep 11, 2014	Hierarchical Modeling		
4	Tue Sep 16, 2014	Polygonal Meshes, Curves, & Surfaces		
	Thu Sep 18, 2014	Splines		[Ex. 1 Due]

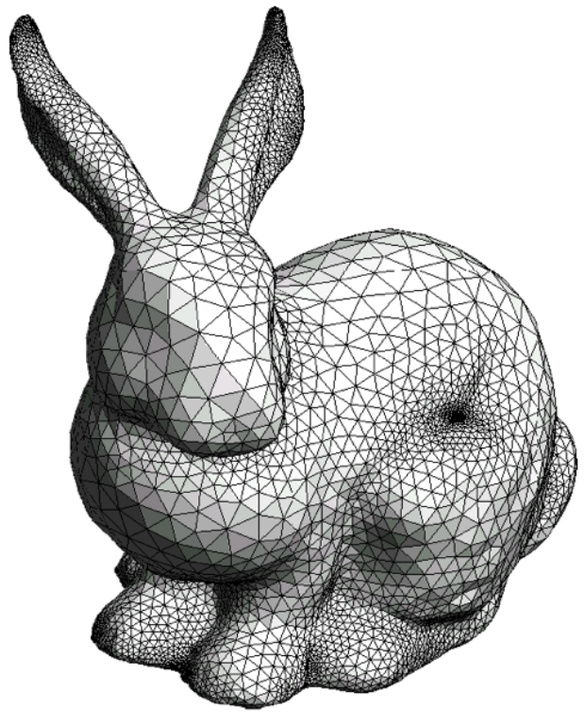
Last Time

- A Graphics Pipeline
- The OpenGL **API**
- **Primitives**: vertices, lines, polygons
- **Attributes**: color
- Example: drawing a **shaded triangle**



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

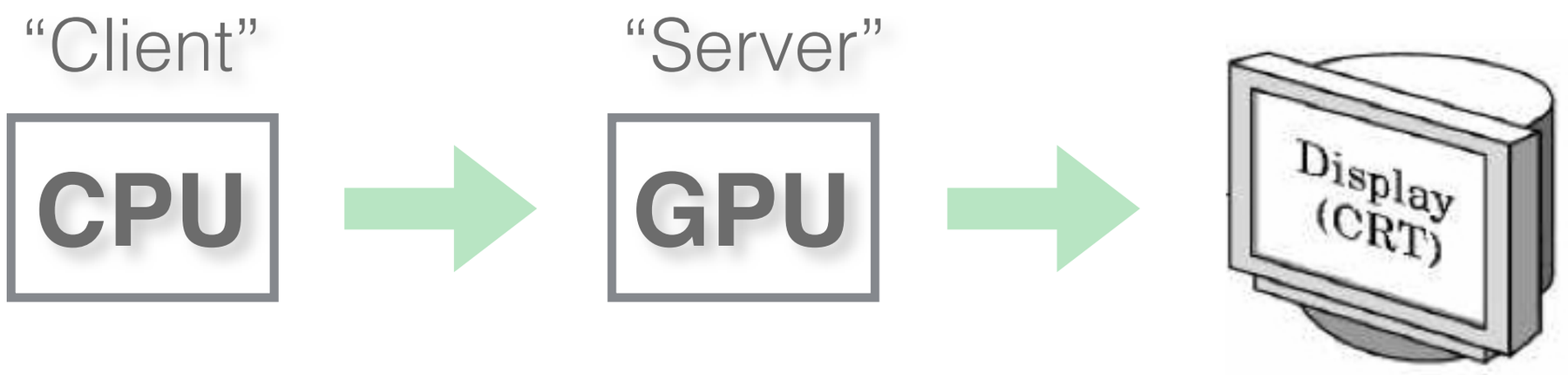


Choice of Programming Language

- 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

Client/Server Model

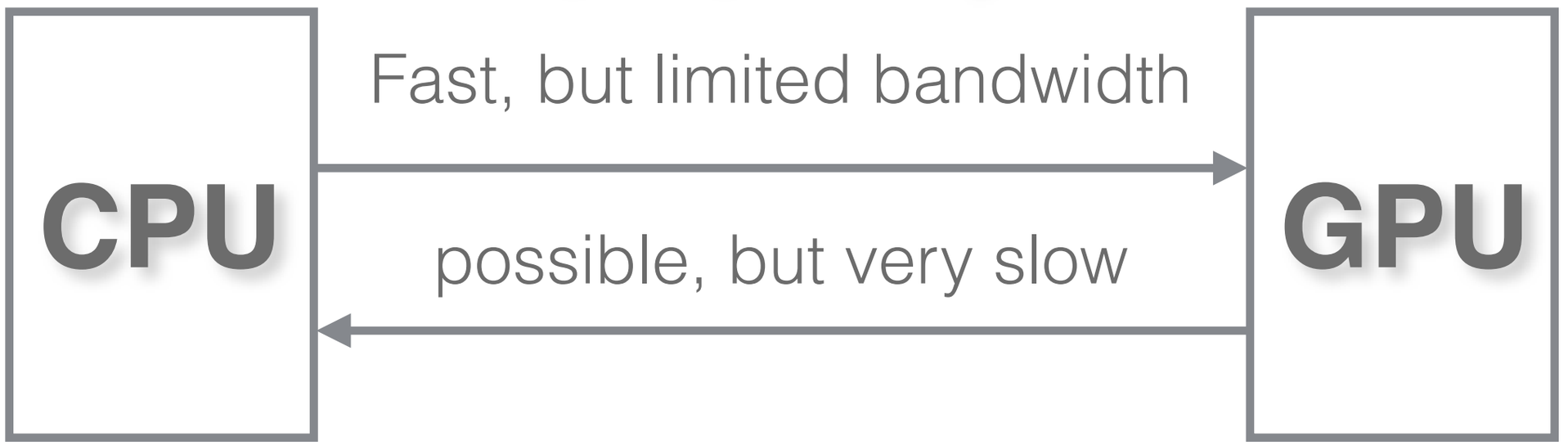
- Graphics hardware and caching



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

The CPU-GPU bus

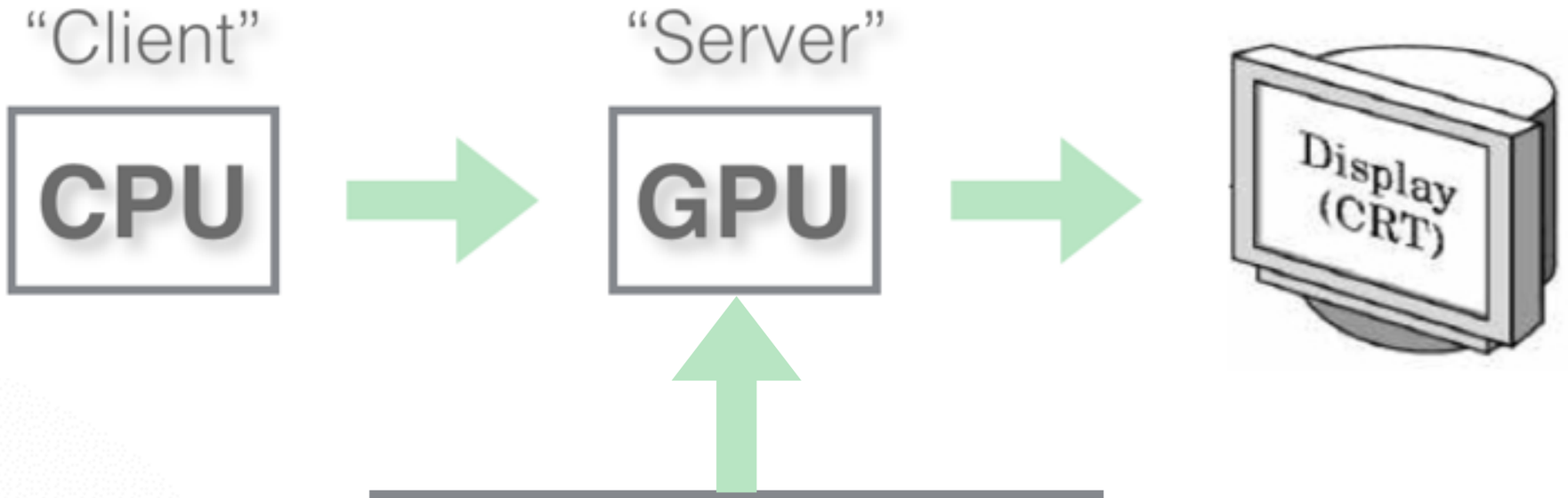
AGP, PCI, PCI Express



We need performance!

Display Lists

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



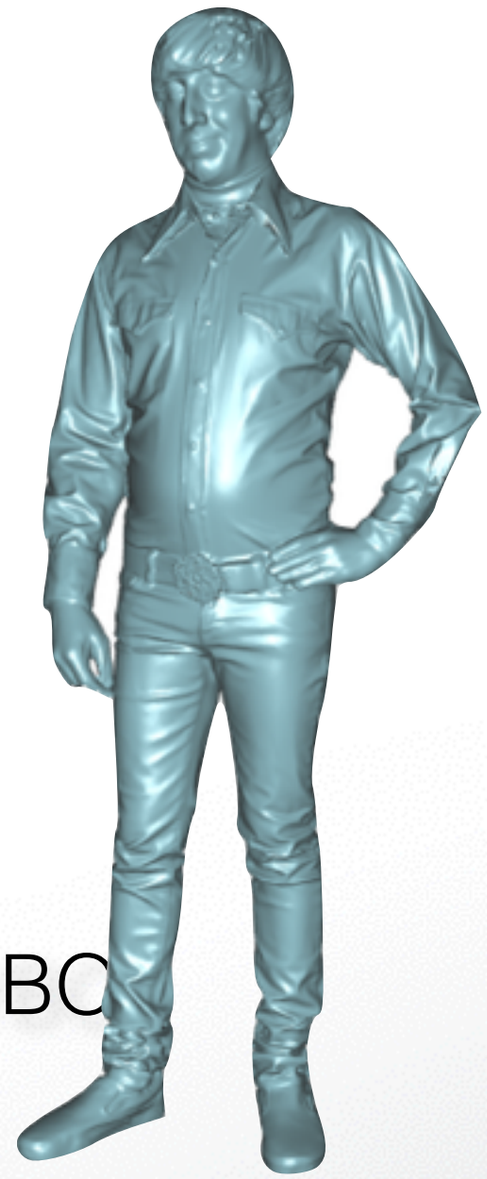
Display Lists

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

```
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);
        ...
    glEnd();
glEndList(); /* at this point, OpenGL compiles the list */
glCallList(listName);    /* draw the object */
```

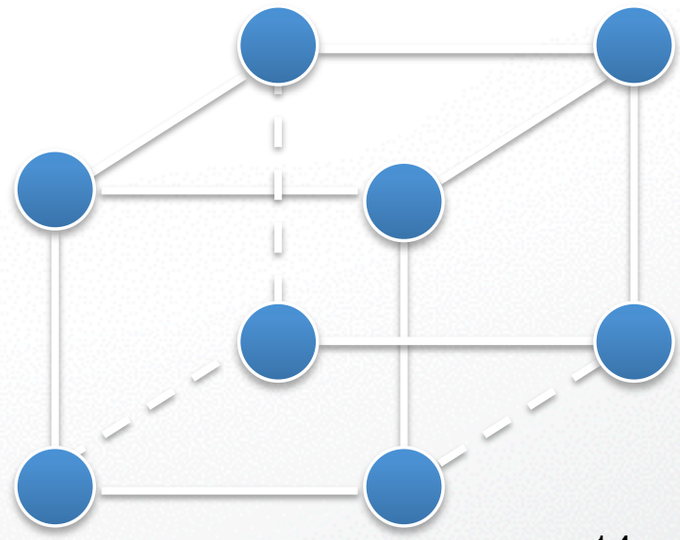
Display Lists Details

- 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*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



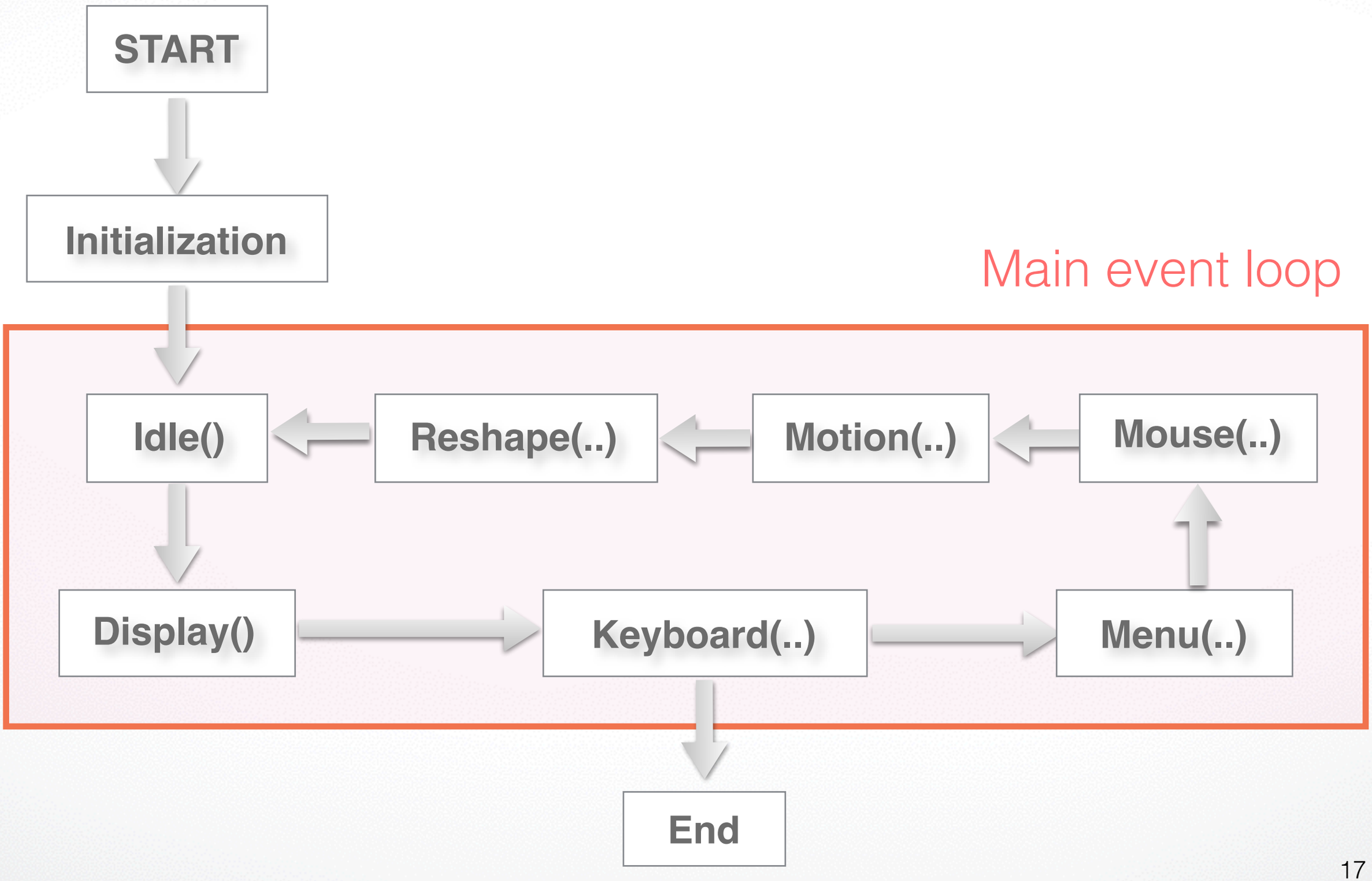
Vertex Buffer Objects (VBOs)

- Display Lists: Fast / inflexible
- Immediate mode: Slowest / flexible
- Vertex Array: Slow with shared vertices / flexible
- Vertex Buffer Objects (VBOs): Best of between Display List and Vertex Array: Fast / flexible
  - memory manager optimizes for buffer location in memory
  - mapping buffer into client memory space

Outline

- Client / Server Model
- **Callback**
- Double Buffering
- Hidden Surface Removal
- Simple Transformation
- Example

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(…)**: mouse movement
- **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

Outline

- Client / Server Model
- Callback
- **Double Buffering**
- Hidden Surface Removal
- Simple Transformation
- Example

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/sec)

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()

Outline

- Client / Server Model
- Callback
- Double Buffering
- **Hidden Surface Removal**
- Simple Transformation
- Example

Hidden Surface Removal

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

- Object-space vs image-space approaches

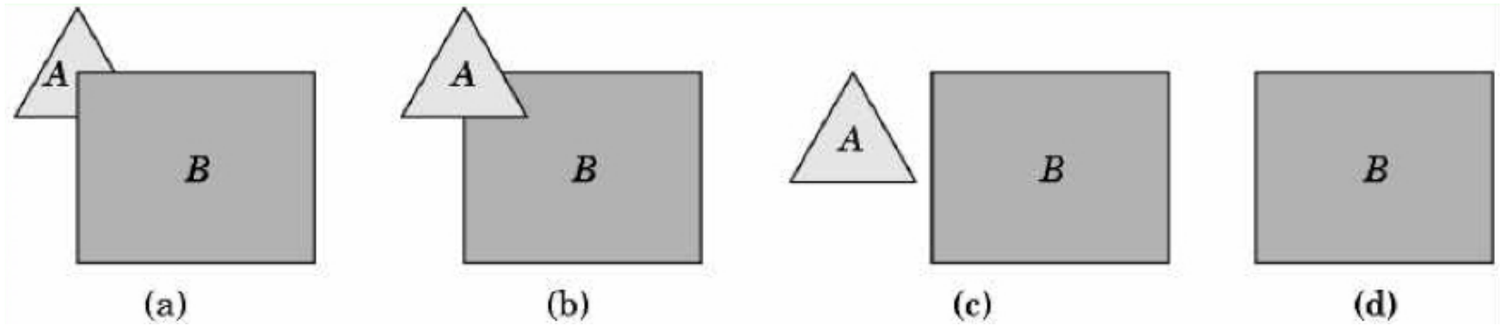
  Object space: depth sort (Painter's algorithm)

  Image space: z-buffer algorithm

- Related: back-face culling

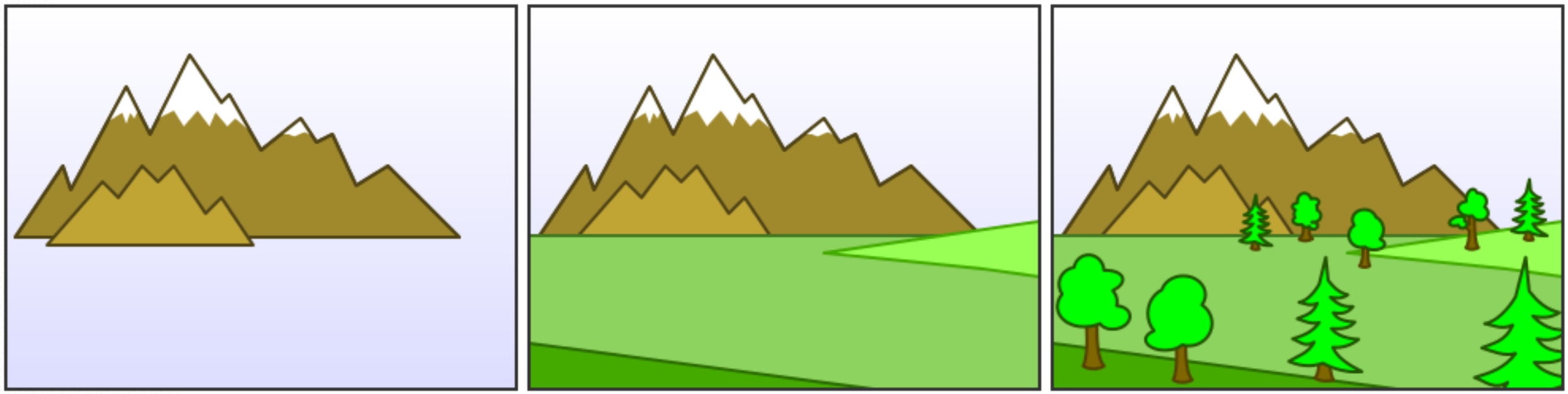
Object-Space Approach

- 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?

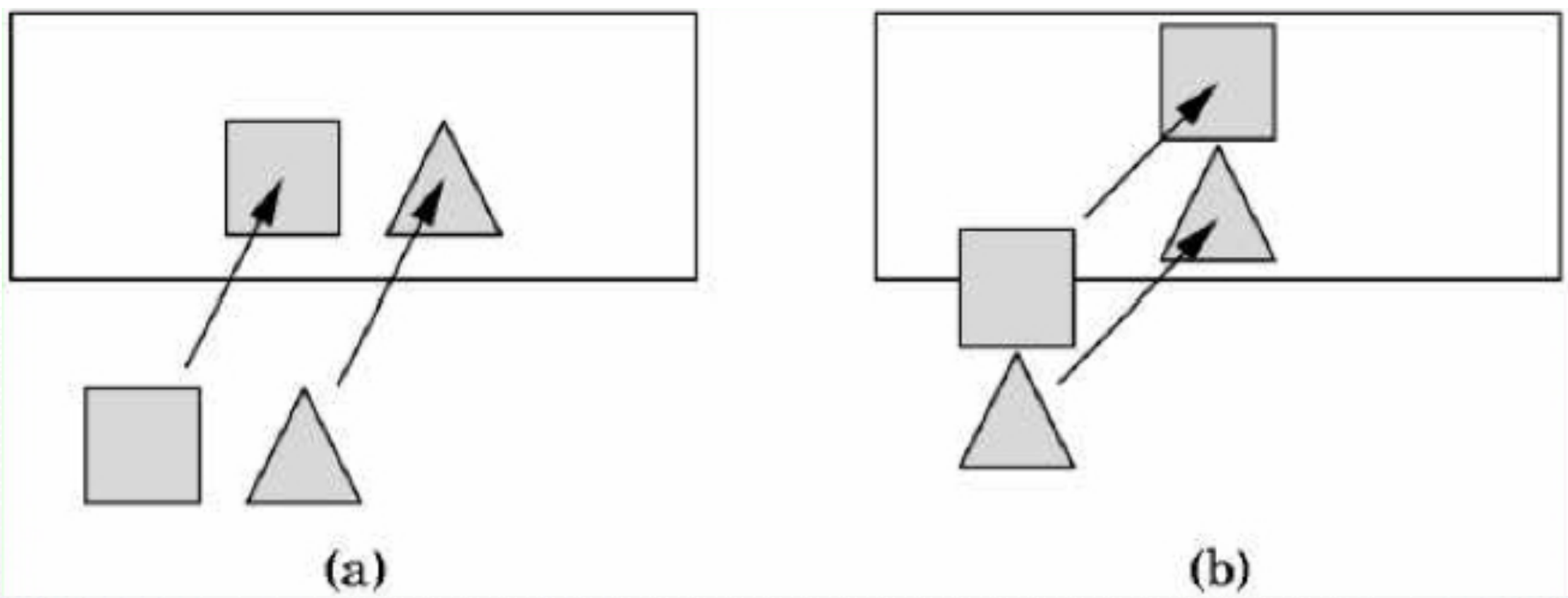
Painter’s Algorithm



- Painter’s VS reverse painter’s algorithm

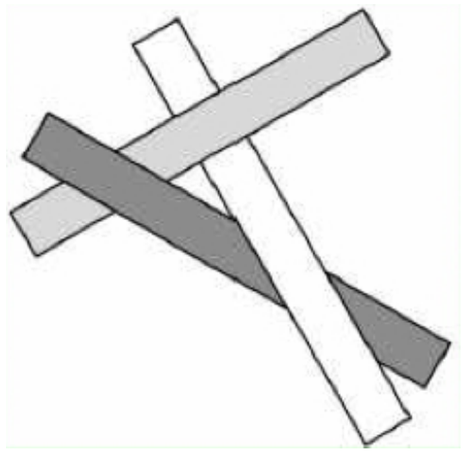
Depth Sorting

- 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

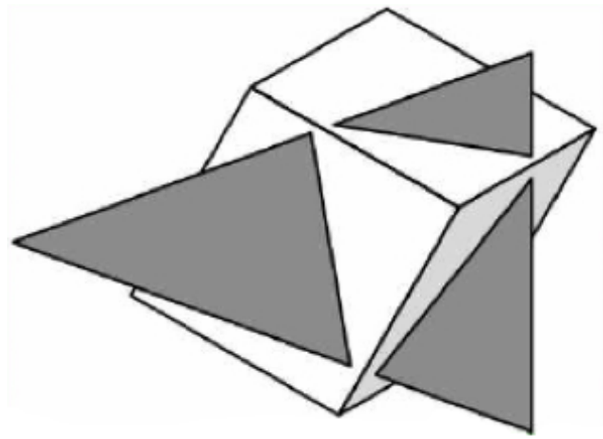


Some Difficult Cases

- Sometimes cannot sort polygons



Cyclic overlap



Piercing Polygons

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

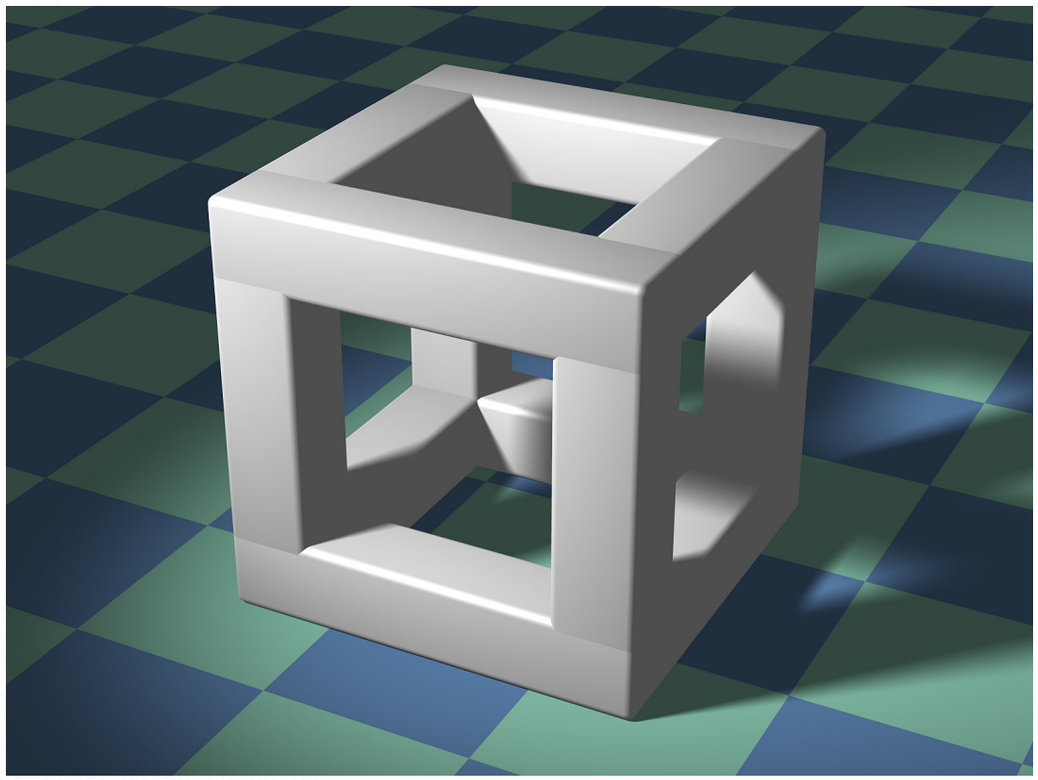
Painter's Algorithm Assessment

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

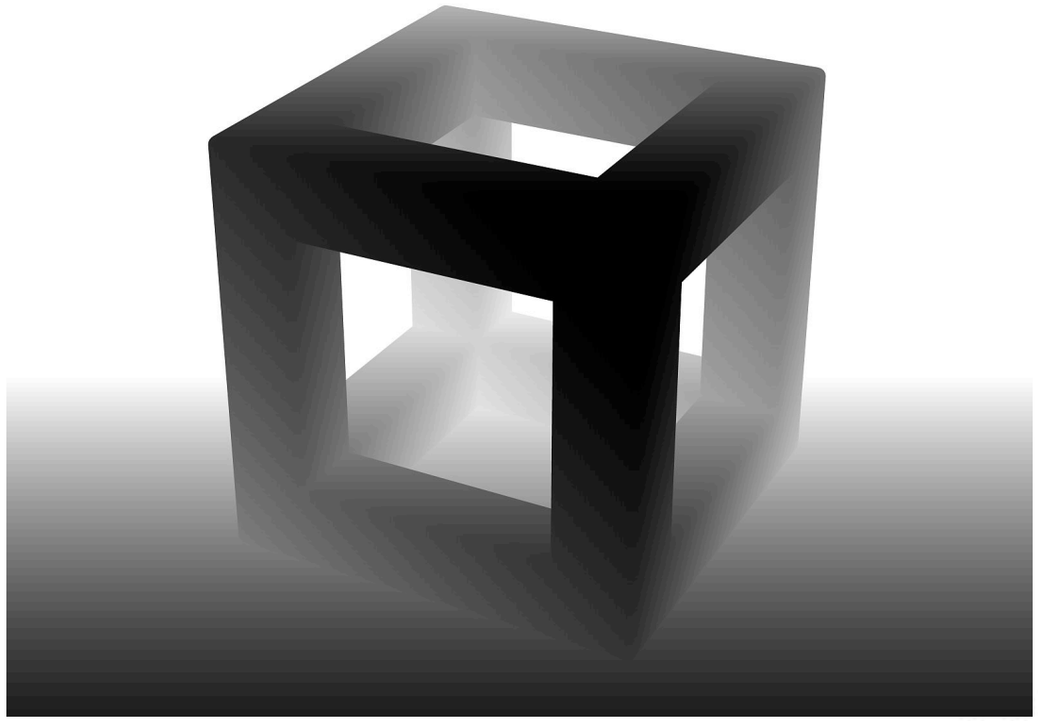
- Weaknesses
  - Clumsy when geometry is complex
  - Sorting can be expensive

- Usage
  - PostScript interpreters
  - OpenGL: not supported
    (must implement Painter's Algorithm manually)

Image-space approach



3D geometry



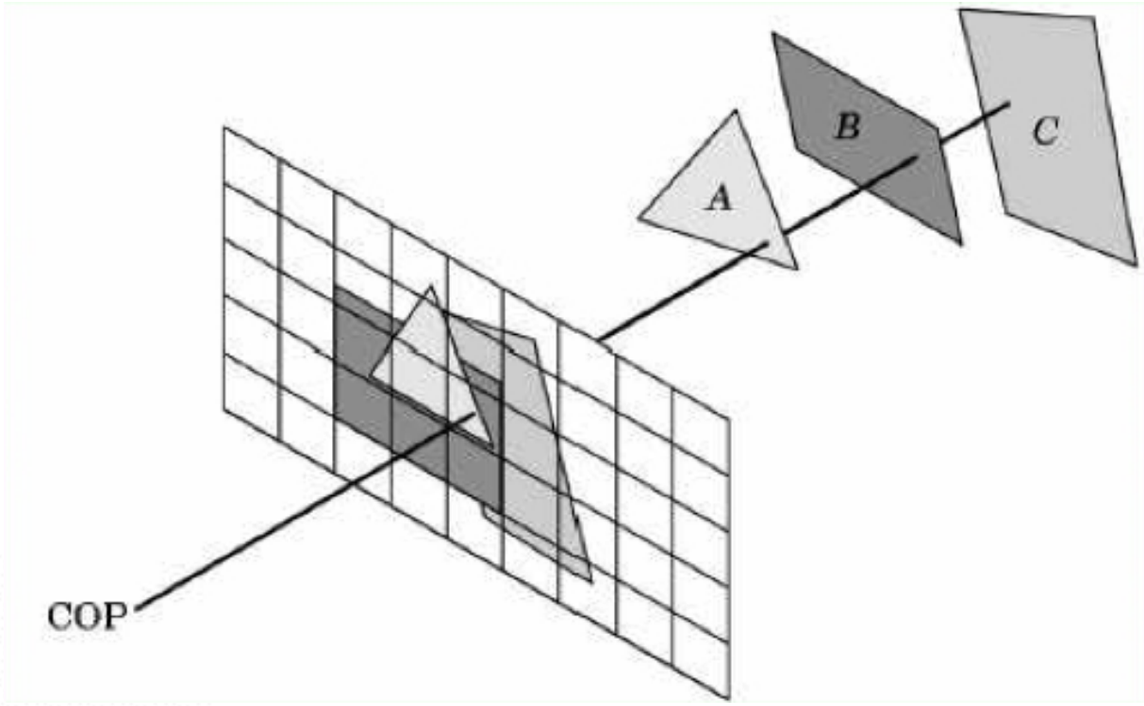
Depth Image
darker color is closer

Source: Wikipedia

Depth sensor camera

Image-Space Approach

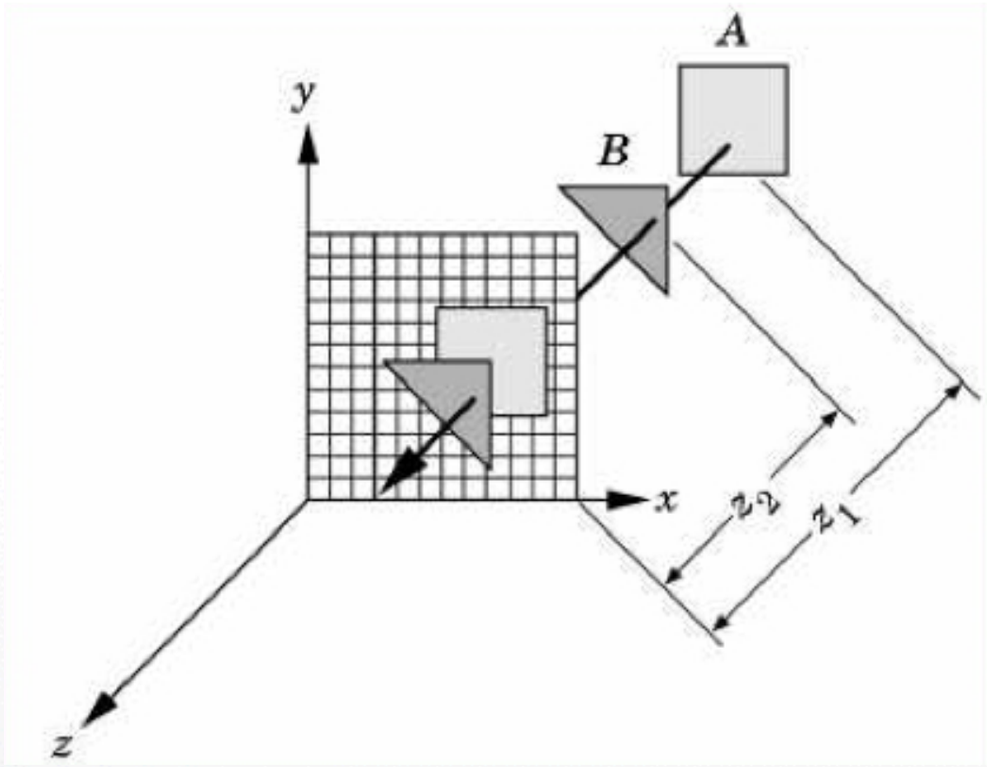
- Raycasting: intersect ray with polygons



- 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



The z-Buffer Algorithm Assessment

- Strengths
  - Simple (no sorting or splitting)
  - Independent of geometric primitives

- Weaknesses
  - Memory intensive 24 bit (but memory is cheap now)
  - Tricky to handle transparency and blending
  - Depth-ordering artifacts (numerical issues)

- 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

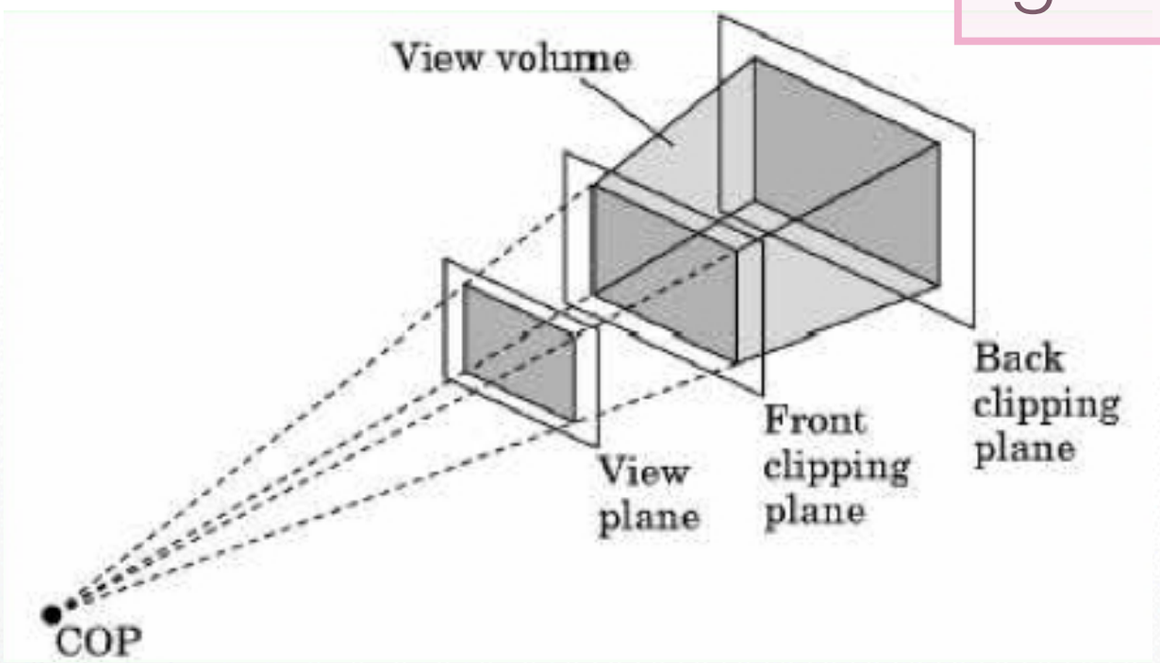
Outline

- Client / Server Model
- Callback
- Double Buffering
- Hidden Surface Removal
- **Simple Transformation**
- Example

Specifying the Viewing Volume

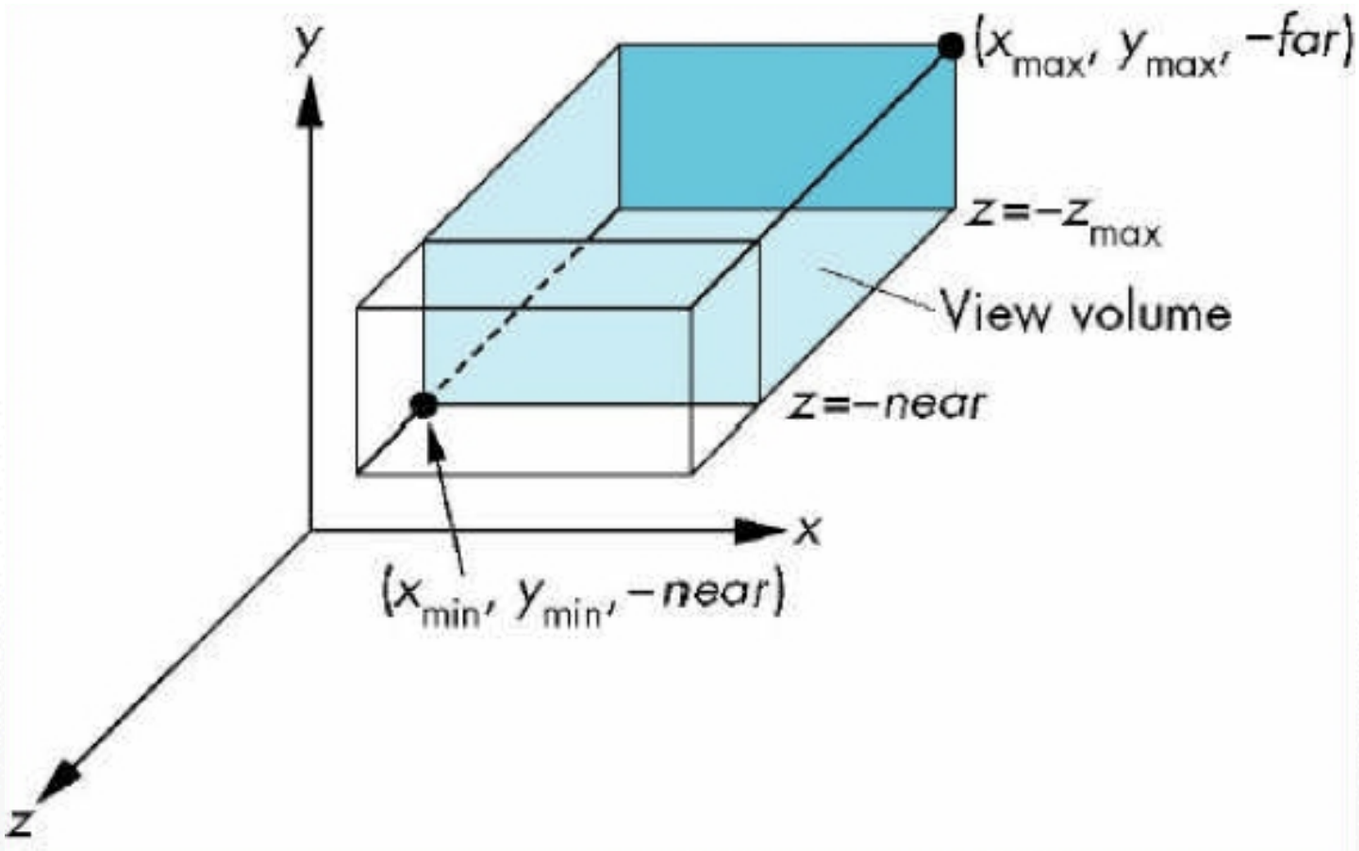
- Clip everything not in viewing volume
- Separate matrices for transformation and projection

```
glMatrixMode (GL_PROJECTION);
glLoadIdentity();
... Set viewing volume …
glMatrixMode(GL_MODELVIEW);
```



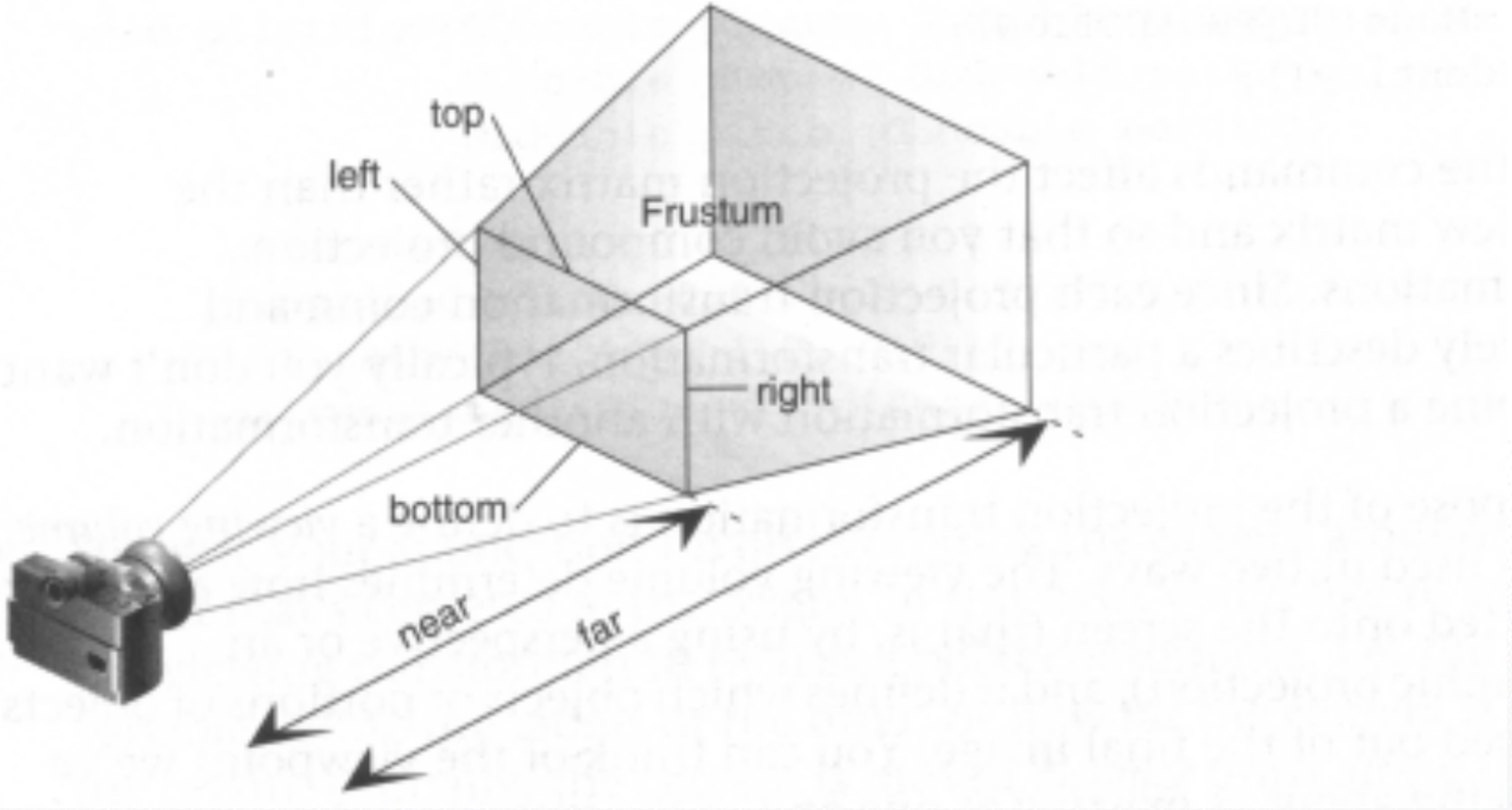
Parallel Viewing

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



Perspective Viewing

- Slightly more complex
- glFrustum(left, right, bottom, top, near, far)



Simple Transformations

- Rotate by given angle (in degrees) about axis given by (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);
```

Outline

- Client / Server Model
- Callback
- Double Buffering
- Hidden Surface Removal
- Simple Transformation
- **Example**

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

```
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

```
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

```
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

```
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

```
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

```
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

```
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

```
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

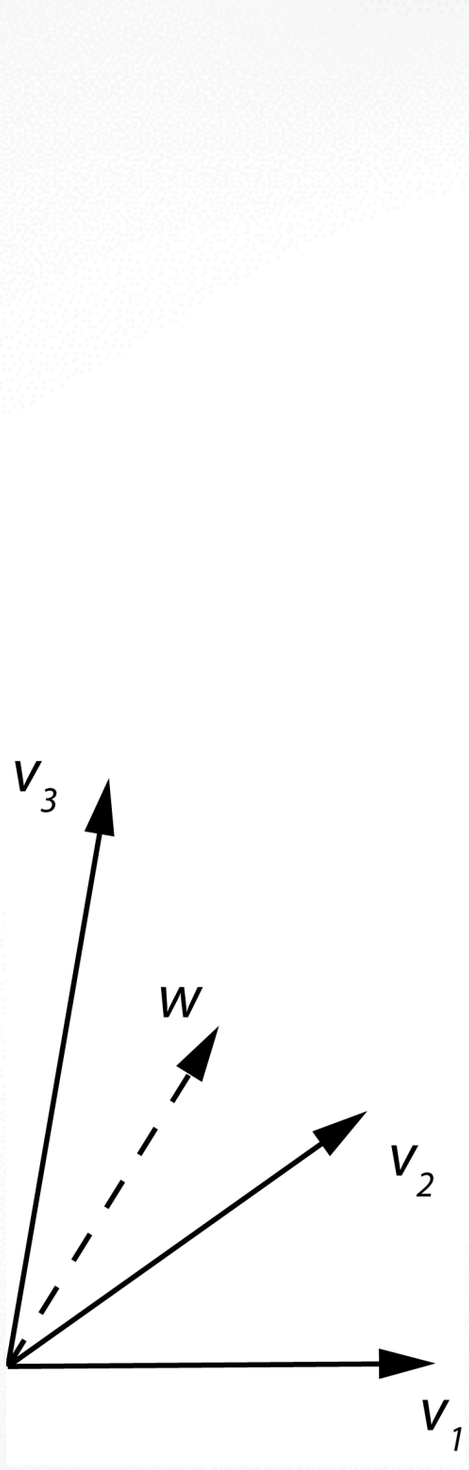
- Keyboard callback

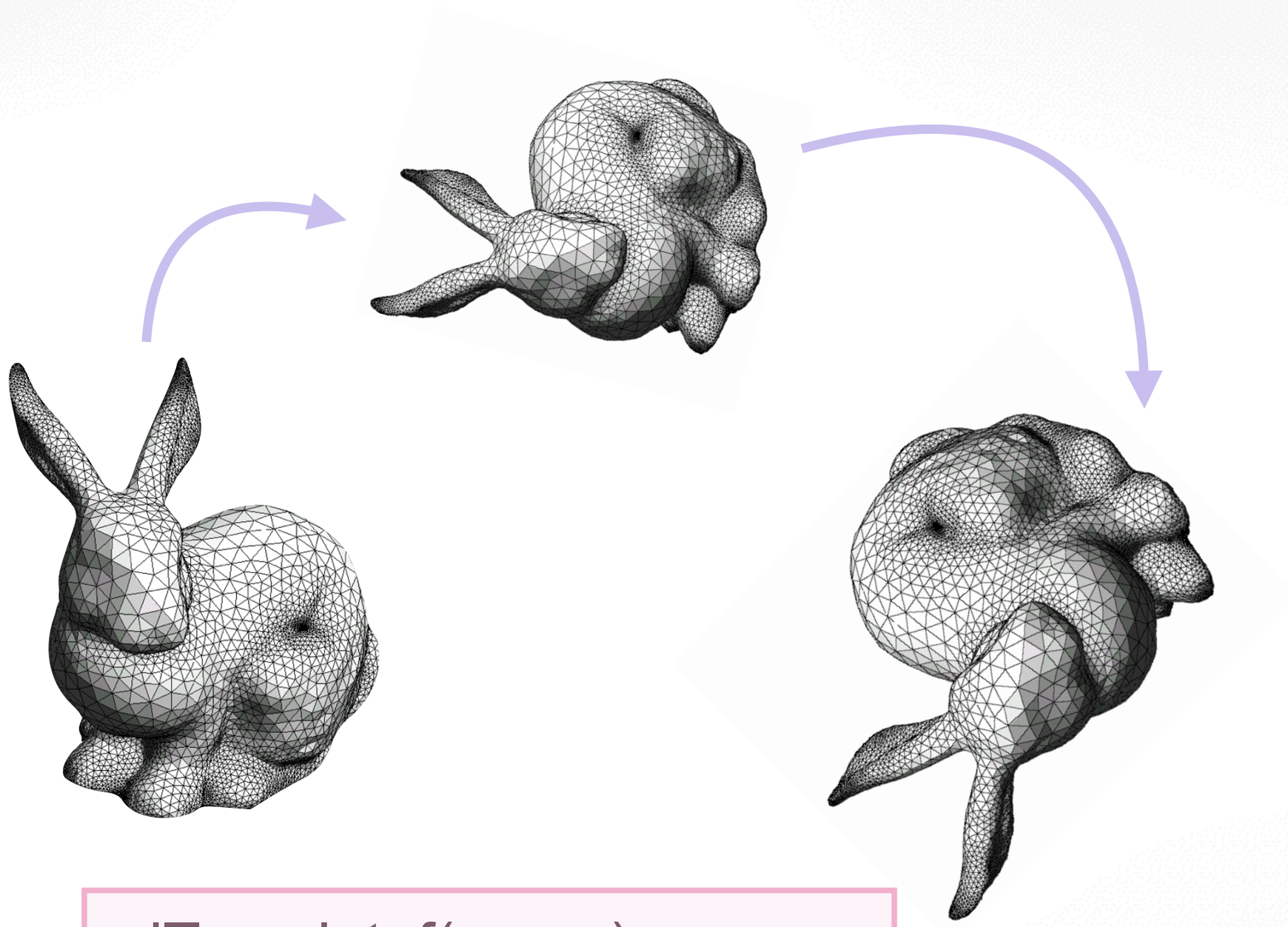
```
void keyboard(unsigned char key, int x, int y)
    {
        if (key=='q' || key == 'Q')
            exit(0);
      if (key==' ')
        stop = !stop;
      if (stop)
            glutIdleFunc(NULL);
      else
            glutIdleFunc(spinCube);
}
```

Summary

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

Next Time: Transformations





```
glTranslatef(x, y, z);
glRotatef(angle, ax, ay, az);
glScalef(sx, sy, sz);
```

http://cs420.hao-li.com

Thanks!