GL Shading Language (GLSL)

- GLSL: high level C-like language
- Main program (e.g. example1.cpp) program written in C/C++
- Vertex and Fragment shaders written in GLSL
- From OpenGL 3.1, application must use shaders

What does keyword out mean?

```
const vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
out vec3 color_out;

void main(void){
  gl_Position = vPosition;
  color_out = red;
}
```

Example code of vertex shader

gl_Position not declared
Built-in types (already declared, just use)

Passing values

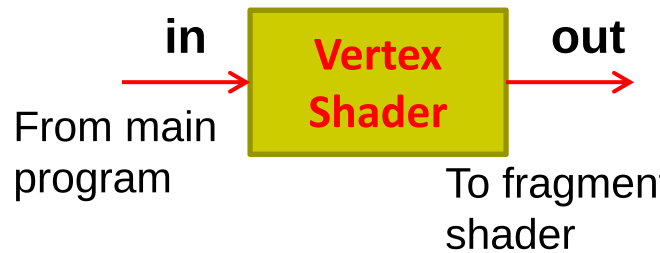
- Variable declared **out** in vertex shader can be declared as **in** in fragment shader and used
- Why? To pass result of vertex shader calculation to fragment shader

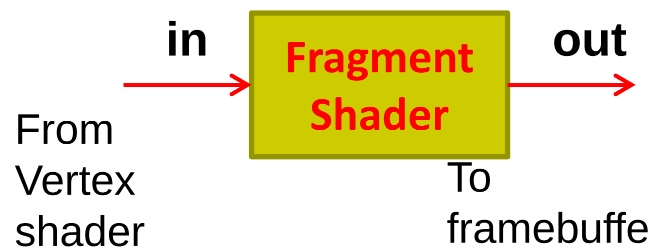
```
const vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
out vec3 color_out;

void main(void){
  gl_Position = vPosition;
  color_out = red;
}
```

Vertex shader

```
in vec3 color_out;

void main(void){
  // can use color_out here.
}
```

Fragment shader





Data Types

- **C types:** `int, float, bool`
- **GLSL types:**
  - `float vec2: e.g. (x,y)        // vector of 2 floats`
  - `float vec3: e.g. (x,y,z) or (R,G,B) // vector of 3 floats`
  - `float vec4: e.g. (x,y,z,w)     // vector of 4 floats`

```
Const float vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
out float vec3 color_out;

void main(void){
  gl_Position = vPosition;
  color_out = red;
}
```

Vertex shader

C++ style constructors

- Also:
  - int (ivec2, ivec3, ivec4) and
  - boolean (bvec2, bvec3,bvec4)

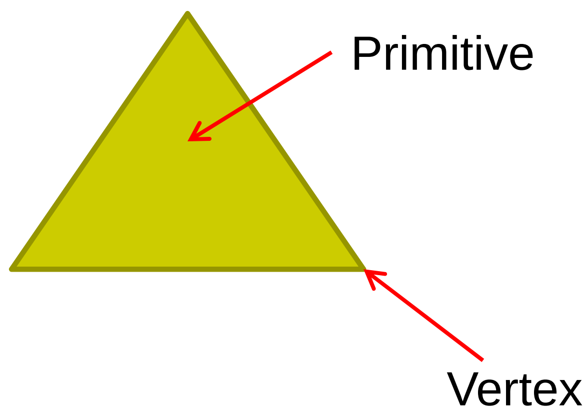
Data Types

- Matrices: mat2, mat3, mat4
  - Stored by columns
  - Standard referencing m[row][column]
- Matrices and vectors are basic types
  - can be passed in and out from GLSL functions
- E.g

  mat3 func(mat3 a)
- **No pointers** in GLSL
- Can use C structs that are copied back from functions

Qualifiers

- GLSL has many C/C++ qualifiers such as **`const`**
- Supports additional ones
- Variables can change
    - Once per vertex
    - Once per fragment
    - Once per primitive (e.g. triangle)
    - At any time in the application



- Example: variable vPosition may be assigned once per vertex

```
const vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
out vec3 color_out;

void main(void){
  gl_Position = vPosition;
  color_out = red;
}
```

Operators and Functions

- Standard C functions
  - **Trigonometric:** cos, sin, tan, etc
  - **Arithmetic:** log, min, max, abs, etc
  - Normalize, reflect, length
- Overloading of vector and matrix types

```
mat4 a;
vec4 b, c, d;
c = b*a;     // a column vector stored as a 1d array
d = a*b;    // a row vector stored as a 1d array
```

Swizzling and Selection

- Can refer to array elements by element using [] or selection (.) operator with
  - x, y, z, w
  - r, g, b, a
  - s, t, p, q
  - `vec4 a;`
  - `a[2], a.b, a.z, a.p` are the same
- **Swizzling** operator lets us manipulate components

```
a.yz = vec2(1.0, 2.0);
```

Computer Graphics (CS 4731)
Lecture 7: Building 3D Models

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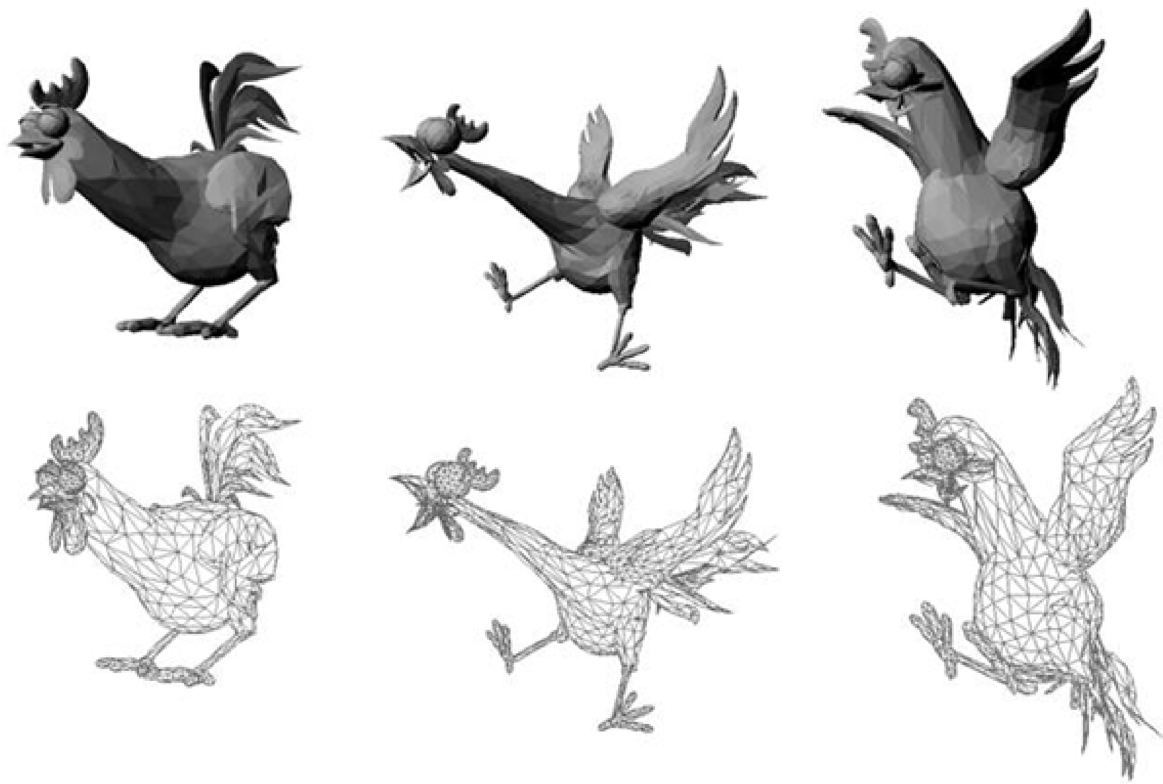
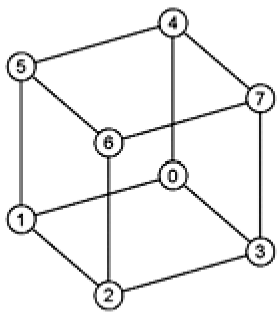
3D Applications

- **2D points:** (x,y) coordinates
- **3D points:** have (x,y,z) coordinates



Setting up 3D Applications: Main Steps

- Programming 3D similar to 2D
  1. Load representation of 3D object into data structure

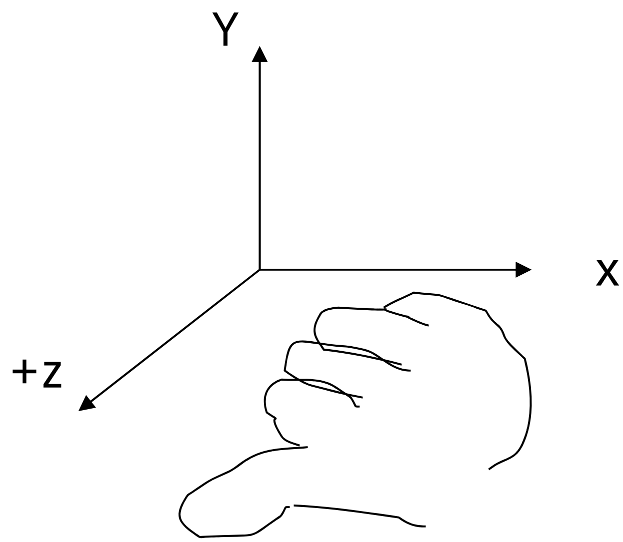


Each vertex has (x,y,z) coordinates. Store as **vec3 NOT vec2**

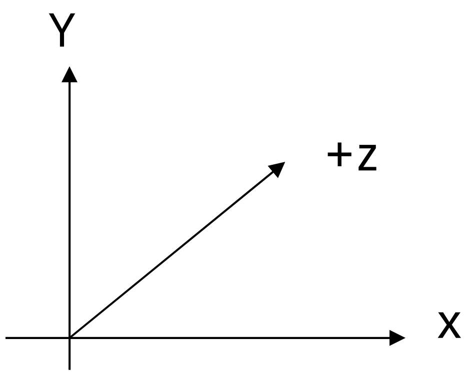
  2. Draw 3D object
  3. **Set up Hidden surface removal:** Correctly determine order in which primitives (triangles, faces) are rendered (e.g Blocked faces **NOT** drawn)

3D Coordinate Systems

- Vertex (x,y,z) positions specified on coordinate system
- OpenGL uses **right hand coordinate system**



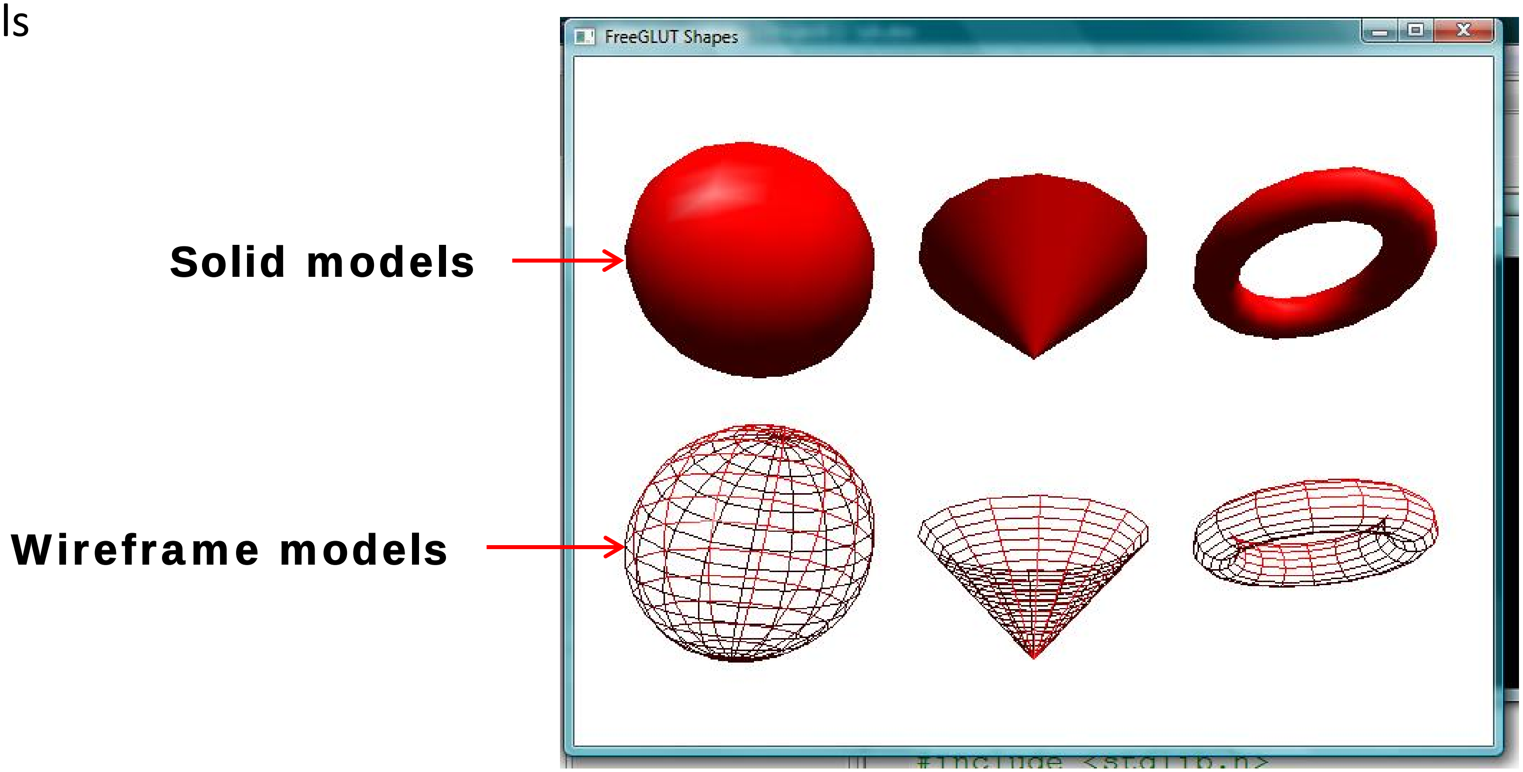
Right hand coordinate system
Tip: sweep fingers x-y: thumb is z



Left hand coordinate system
•Not used in OpenGL

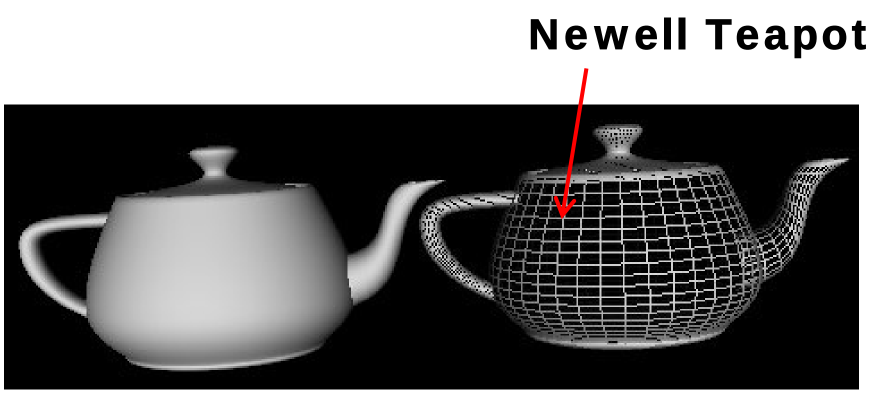
Generating 3D Models: GLUT Models

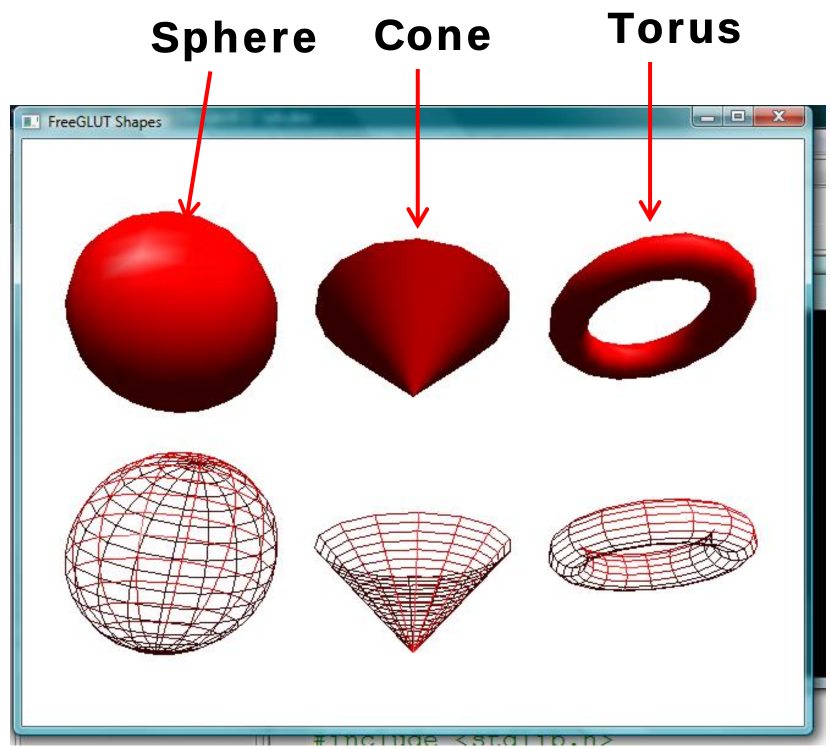
- Make GLUT 3D calls in **OpenGL program** to generate vertices describing different shapes (Restrictive?)
- Two types of GLUT models:
  - Wireframe Models
  - Solid Models



3D Modeling: GLUT Models

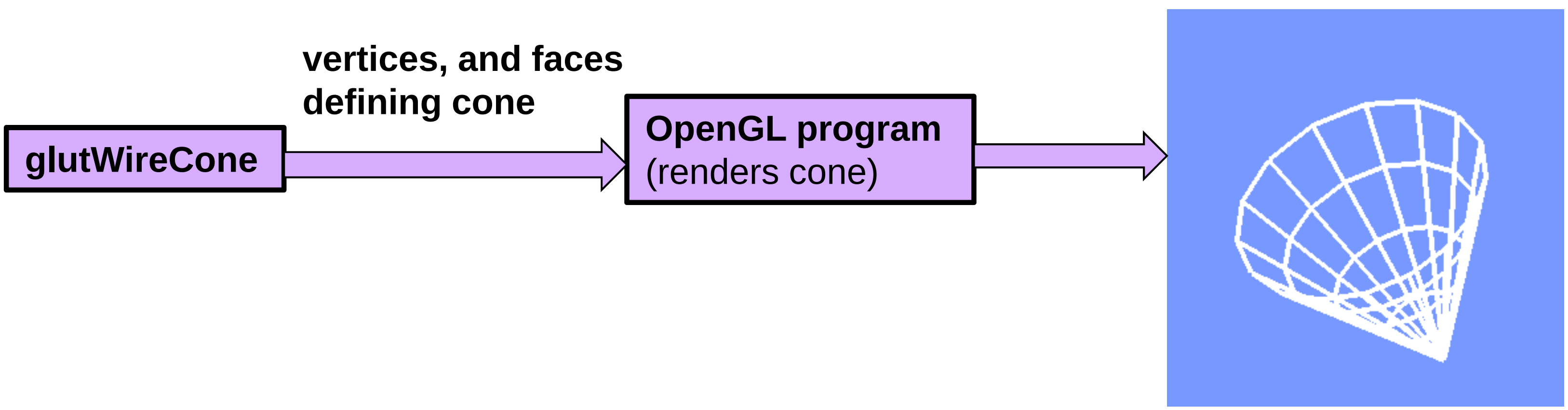
- Basic Shapes
  - **Cone:** glutWireCone( ), glutSolidCone( )
  - **Sphere:** glutWireSphere( ), glutSolidSphere( )
  - **Cube:** glutWireCube( ), glutSolidCube( )
- More advanced shapes:
  - Newell Teapot: (symbolic)
  - Dodecahedron, Torus





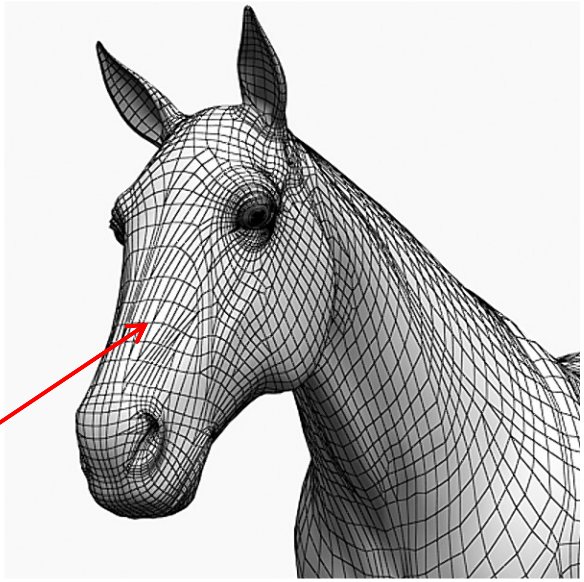
3D Modeling: GLUT Models

- Glut functions under the hood
  - generate sequence of points that define a shape
  - Generated vertices and faces passed to OpenGL for rendering
- **Example:** glutWireCone generates sequence of vertices, and faces defining cone and connectivity



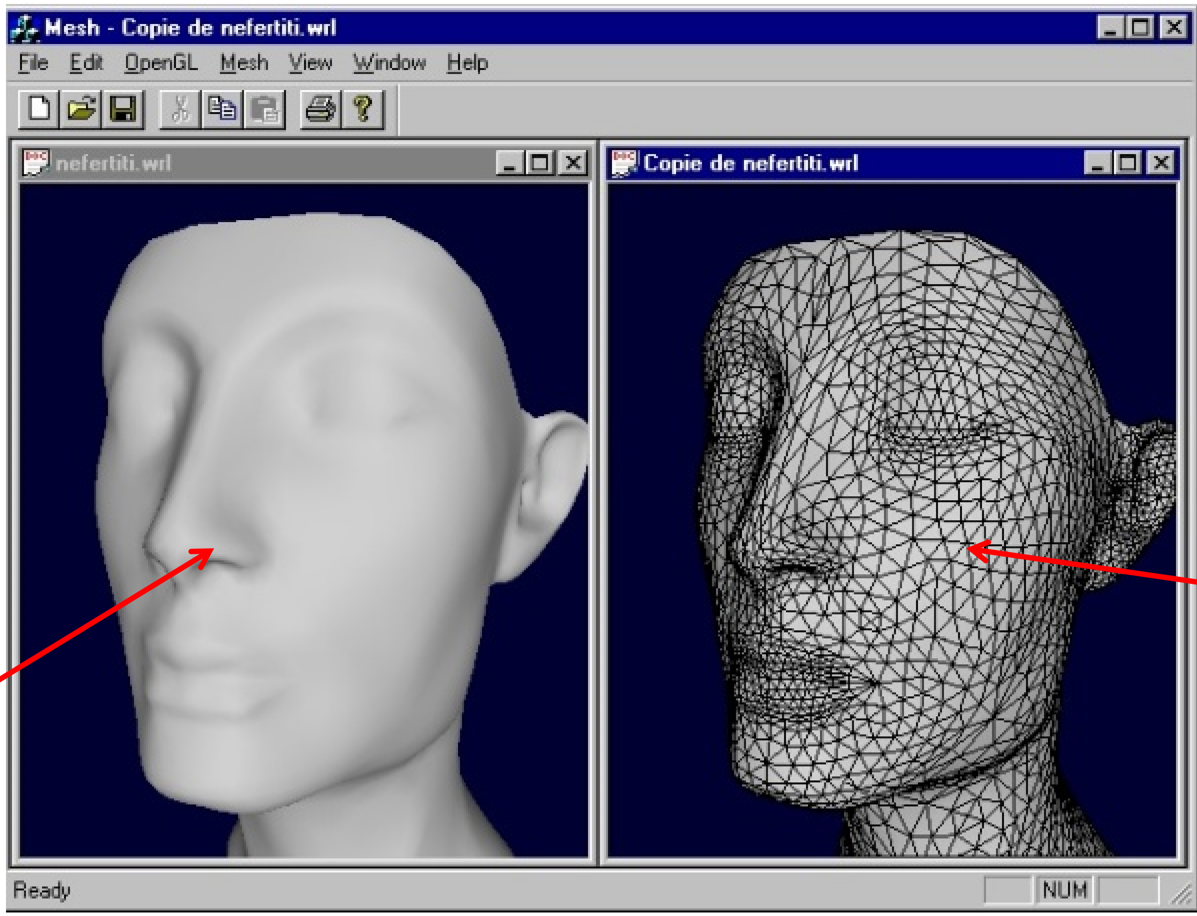
Polygonal Meshes

- Modeling with GLUT shapes (cube, sphere, etc) too restrictive
- Difficult to approach realism. E.g. model a horse
- Preferred way is using polygonal meshes:
  - Collection of polygons, or faces, that form “skin” of object
  - More flexible, represents complex surfaces better
  - Examples:
    - Human face
    - Animal structures
    - Furniture, etc



Each face of mesh is a polygon

Polygonal Mesh Example

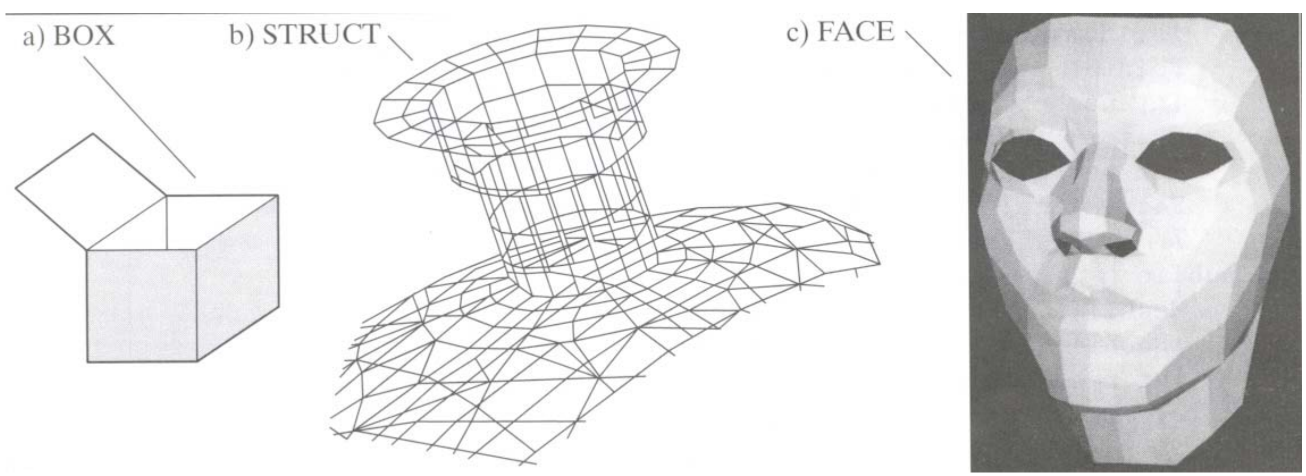


Smoothed Out with Shading (later)

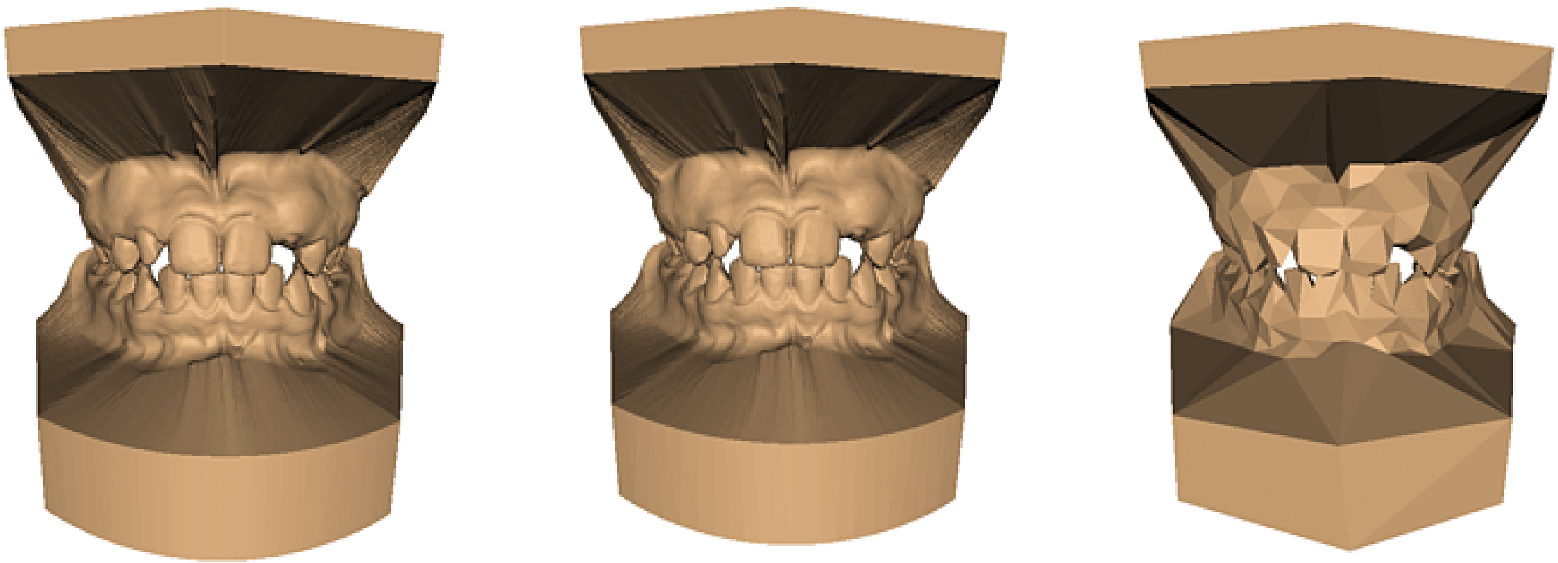
Mesh (wireframe)

Polygonal Meshes

- Meshes now standard in graphics
- OpenGL Good at drawing polygons, triangles
- Mesh = sequence of polygons forming thin skin around object
- Simple meshes exact. (e.g barn)
- Complex meshes approximate (e.g. human face)



Different Resolutions of Same Mesh



Original: 424,000 triangles

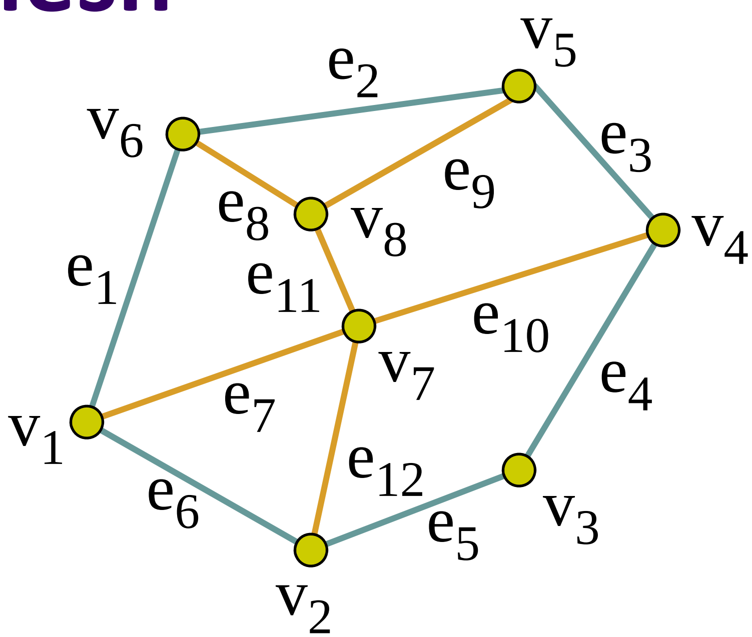
60,000 triangles (14%).

1000 triangles (0.2%)

(courtesy of Michael Garland and Data courtesy of Iris Development.)

Representing a Mesh

- Consider a mesh



- There are 8 vertices and 12 edges
  - 5 interior polygons
  - 6 interior (shared) edges (shown in orange)
- Each vertex has a location $v_i = (x_i \; y_i \; z_i)$

Simple Representation

- Define each polygon by (x,y,z) locations of its vertices
- OpenGL code

```
vertex[i]   = vec3(x1, y1, z1);
vertex[i+1] = vec3(x6, y6, z6);
vertex[i+2] = vec3(x7, y7, z7);
i+=3;
```

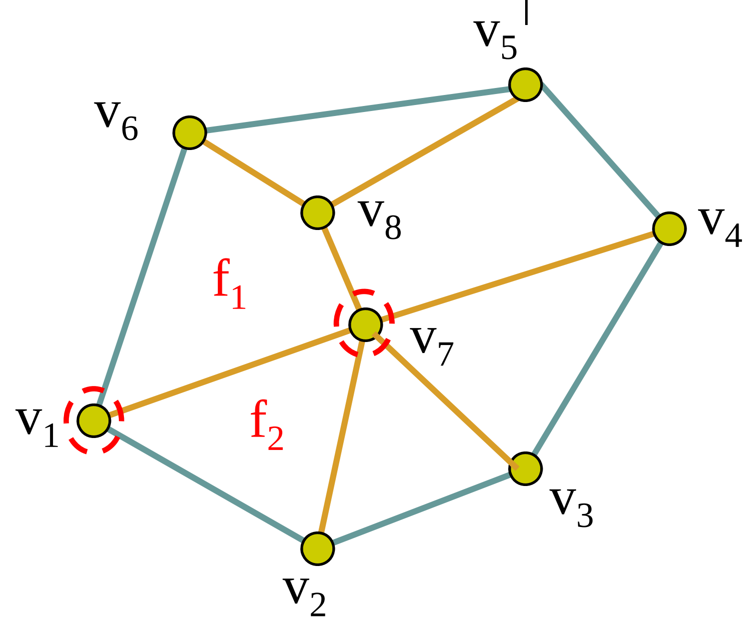
Issues with Simple Representation

- Declaring face f1

```
vertex[i]   = vec3(x1, y1, z1);
vertex[i+1] = vec3(x7, y7, z7);
vertex[i+2] = vec3(x8, y8, z8);
vertex[i+3] = vec3(x6, y6, z6);
```

- Declaring face f2

```
vertex[i]   = vec3(x1, y1, z1);
vertex[i+1] = vec3(x2, y2, z2);
vertex[i+2] = vec3(x7, y7, z7);
```

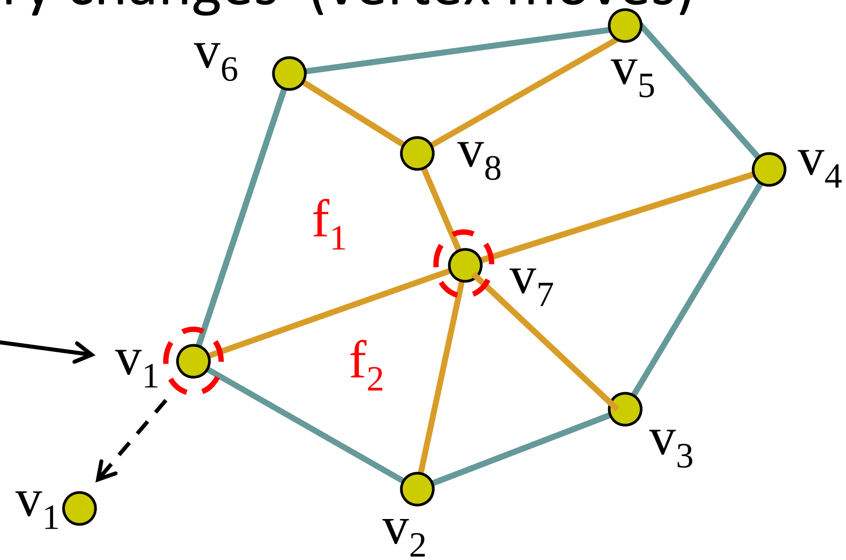


- Inefficient and unstructured
  - **Repeats:** vertices **v1 and v7 repeated** while declaring f1 and f2
  - Shared vertices shared declared multiple times
  - Delete vertex? Move vertex? Search for all occurences of vertex

Geometry vs Topology

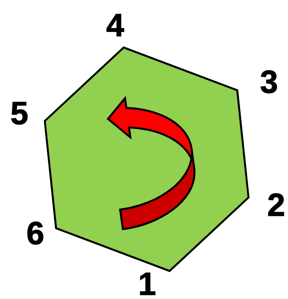
- Better data structures separate **geometry** from **topology**
  - **Geometry:** (x,y,z) locations of the vertices
  - **Topology:** How vertices and edges are connected
  - **Example:**
    - A polygon is **ordered list** of vertices
    - An edge connects successive pairs of vertices
  - Topology holds even if geometry changes (vertex moves)

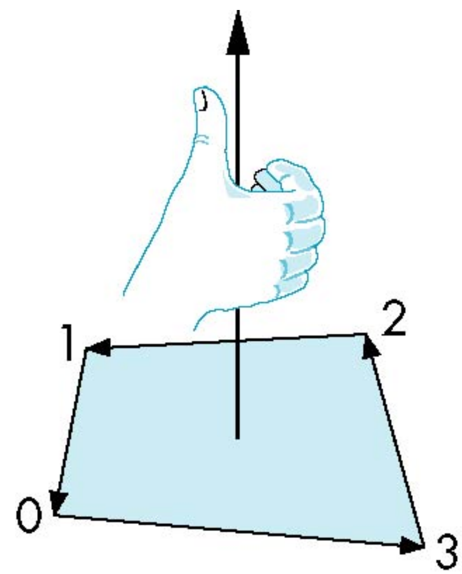
Example: even if we move (x,y,z) location of v1, v1 still connected to v6, v7 and v2



Polygon Traversal Convention

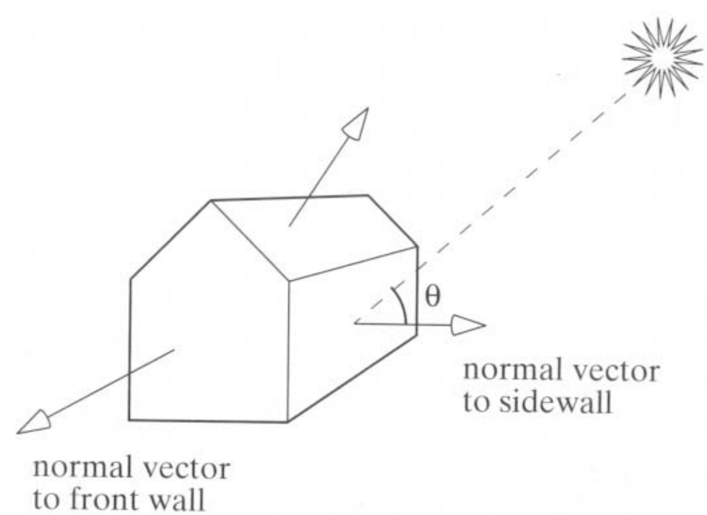
- Use the ***right-hand rule* = counter-clockwise** encirclement of outward-pointing normal
- Focus on direction of traversal
  - Orders $\{v_1, v_0, v_3\}$ and $\{v_3, v_2, v_1\}$ are same *(ccw)*
  - Order $\{v_1, v_2, v_3\}$ is different *(clockwise)*
- What is outward-pointing normal?





Normal Vector

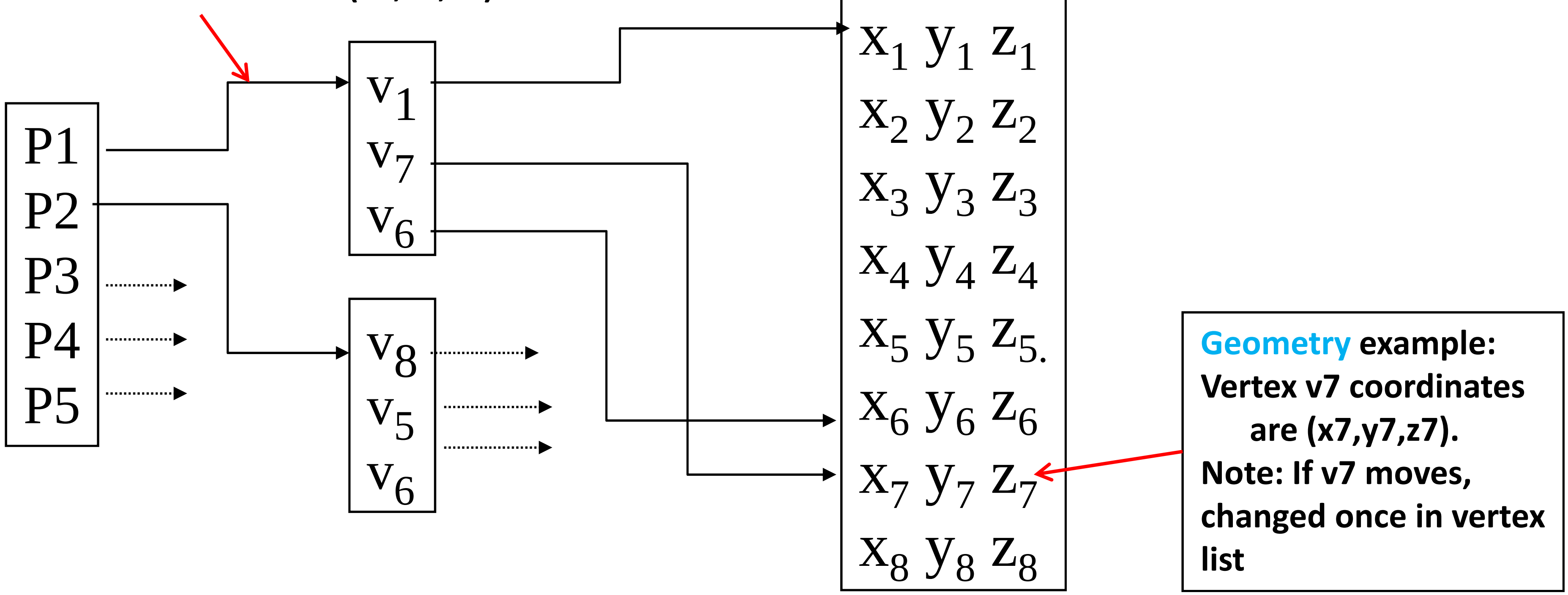
- **Normal vector:** Direction each polygon is facing
- Each mesh polygon has a **normal vector**
- Normal vector used in shading



Vertex Lists

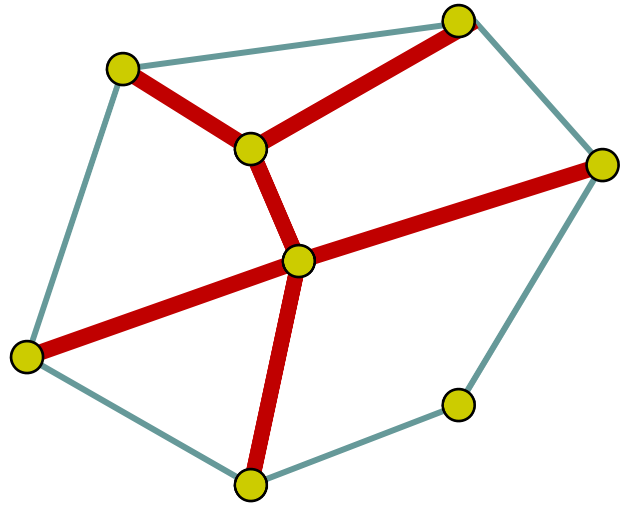
- **Vertex list:** (x,y,z) of vertices (its geometry) are put in array
- Use pointers from vertices into vertex list
- **Polygon list:** vertices connected to each polygon (face)

Topology example: Polygon P1 of mesh is connected to vertices (v1,v7,v6)



Vertex List Issue: Shared Edges

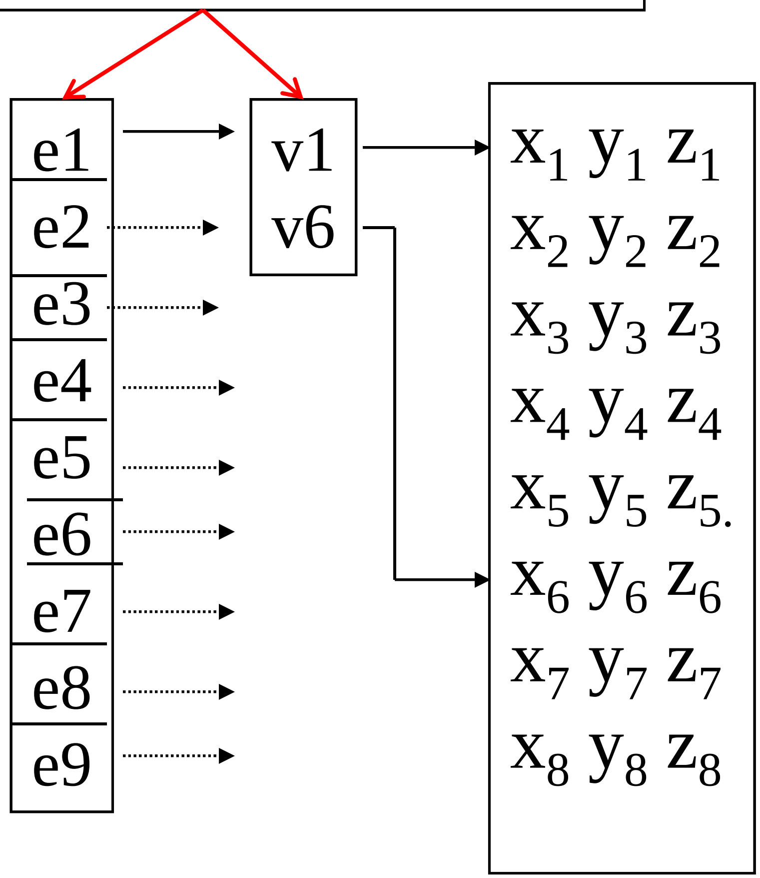
- Vertex lists draw filled polygons correctly
- If each polygon is drawn by its edges, shared edges are drawn twice

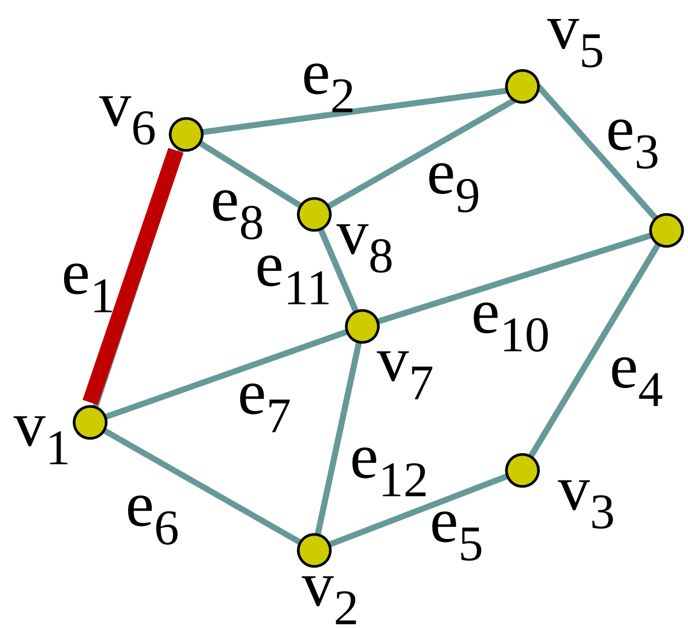


- **Alternatively:** Can store mesh by *edge list*

Edge List

Simply draw each edges once
E.g e1 connects v1 and v6

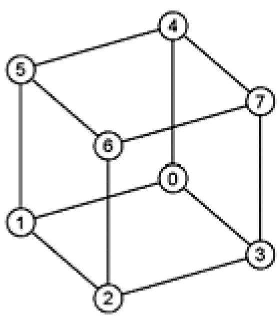




Note polygons are not represented

Modeling a Cube

- In 3D, declare vertices as (x,y,z) using **point3 v[3]**
- Define **global arrays** for vertices and colors



x y z

```
typedef vec3 point3;
point3 vertices[] = {point3(-1.0,-1.0,-1.0),
  point3(1.0,-1.0,-1.0), point3(1.0,1.0,-1.0),
  point3(-1.0,1.0,-1.0), point3(-1.0,-1.0,1.0),
  point3(1.0,-1.0,1.0), point3(1.0,1.0,1.0),
  point3(-1.0,1.0,1.0)};
```

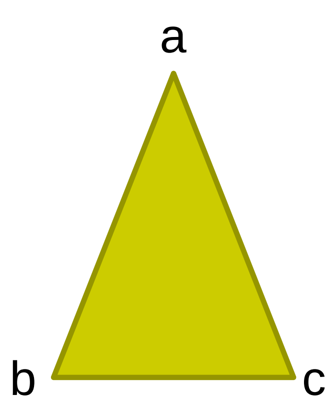
r g b

```
typedef vec3 color3;
color3 colors[] = {color3(0.0,0.0,0.0),
  color3(1.0,0.0,0.0), color3(1.0,1.0,0.0),
  color(0.0,1.0,0.0), color3(0.0,0.0,1.0),
  color3(1.0,0.0,1.0), color3(1.0,1.0,1.0),
  color3(0.0,1.0,1.0});
```

Drawing a triangle from list of indices

Draw a triangle from a list of indices into the array `vertices` and assign a color to each index

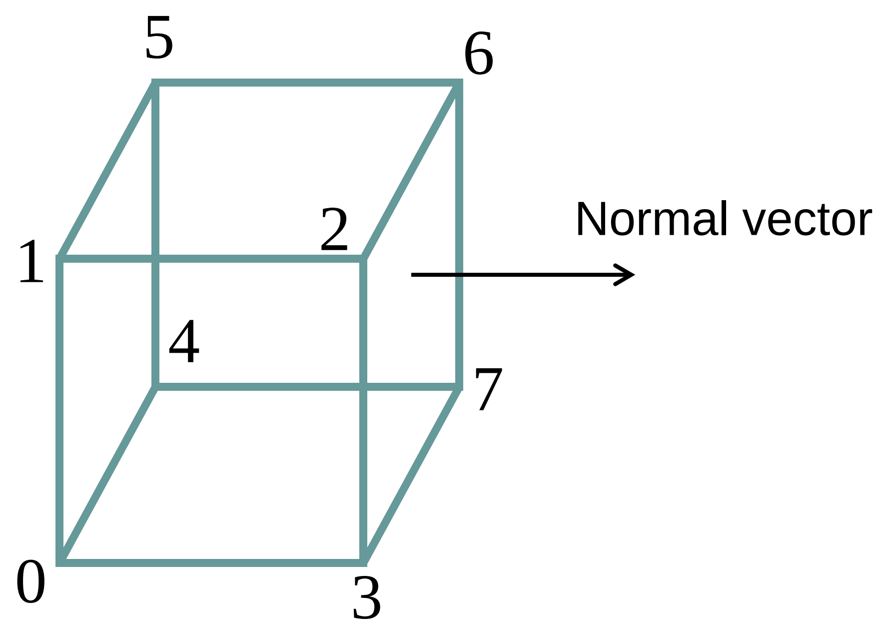
```
void triangle(int a, int b, int c, int d)
{
   vcolors[i] = colors[d];
   position[i] = vertices[a];
   vcolors[i+1] = colors[d]);
   position[i+1] = vertices[b];
   vcolors[i+2] = colors[d];
   position[i+2] = vertices[c];
   i+=3;
 }
```



Variables a, b, c are indices into vertex array
Variable d is index into color array
Note: Same face, so all three vertices have same color

Draw cube from faces

```
void colorcube( )
{
    quad(0,3,2,1);
    quad(2,3,7,6);
    quad(0,4,7,3);
    quad(1,2,6,5);
    quad(4,5,6,7);
    quad(0,1,5,4);
}
```



Note: vertices ordered (**counterclockwise**)
so that we obtain correct outward facing normals

References

- Angel and Shreiner, Interactive Computer Graphics, 6th edition, Chapter 3
- Hill and Kelley, Computer Graphics using OpenGL, 3rd edition