Computer Graphics (CS 543)
Lecture 4 (part 1): Building 3D Models (Part 1)

Prof Emmanuel Agu

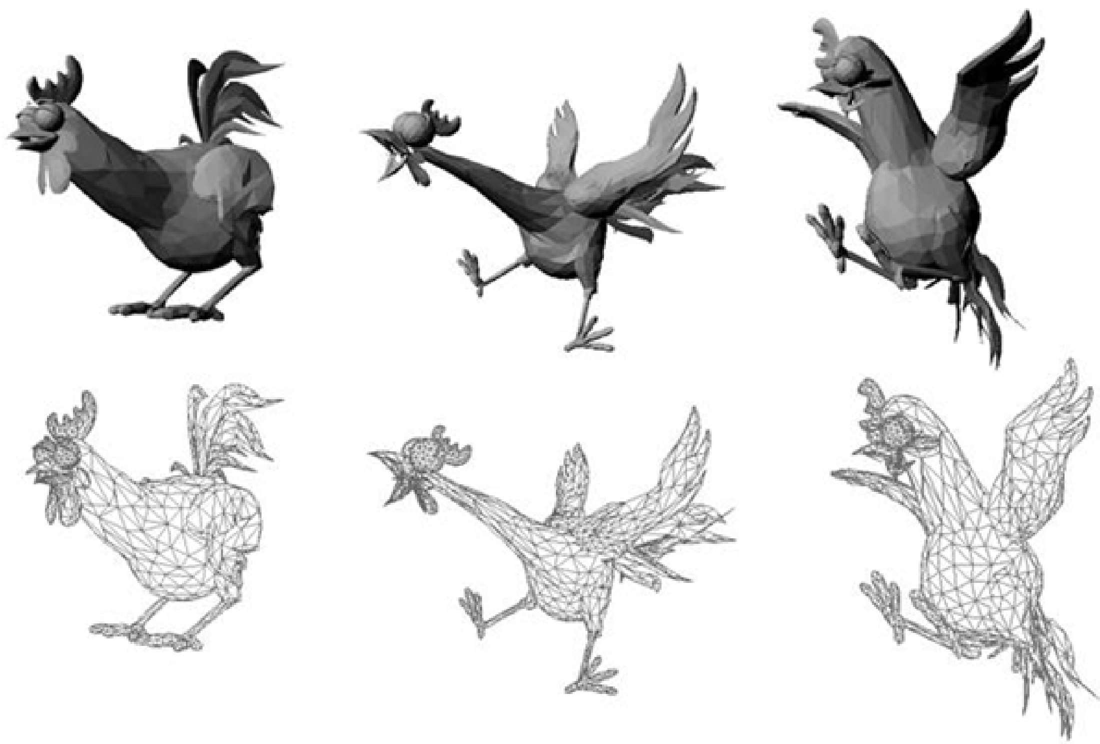
Computer Science Dept.
Worcester Polytechnic Institute (WPI)

Objectives

- Introduce 3D set up
- Introduce simple data structures for 3D models
  - Vertex lists
  - Edge lists
- Deprecated OpenGL vertex arrays
- Drawing 3D objects

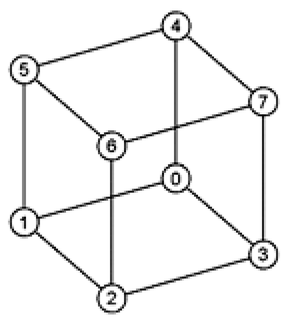
3D Applications

- 2D points: (x,y) coordinates
- 3D points: have (x,y,z) coordinates
- In OpenGL, 2D graphics are special case of 3D graphics



Setting up 3D Applications

- Programming 3D, not many changes from 2D
  1. Load representation of 3D object into data structure

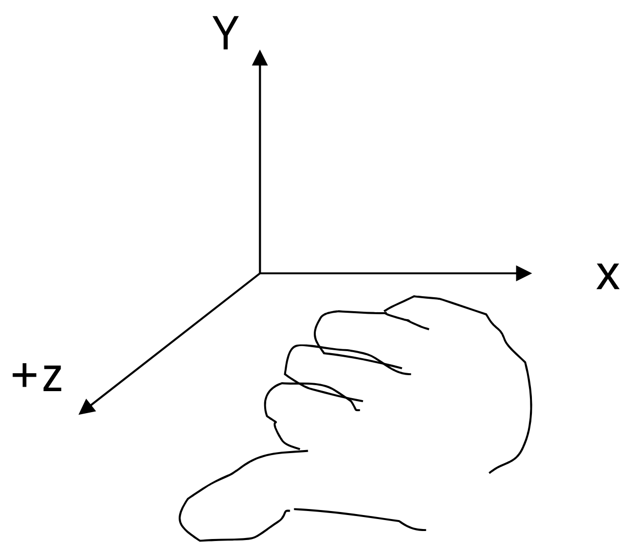


Each vertex has (x,y,z) coordinates.
Store as vec3, glUniform3f **NOT** vec2

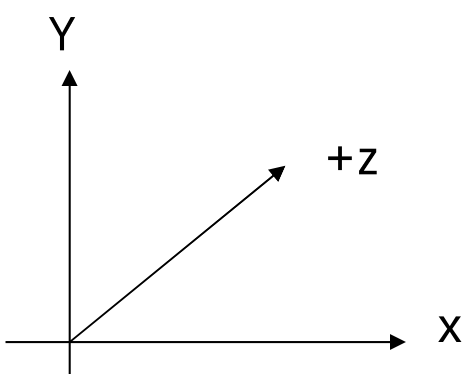
  2. Draw 3D object
  3. **Set up Hidden surface removal:** Correctly determine order in which primitives (triangles, faces) are rendered (e.g Blocked faces **NOT** drawn)

3D Coordinate Systems

- All vertex (x,y,z) positions are with respect to a coordinate system
- OpenGL uses **right hand coordinate system**



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



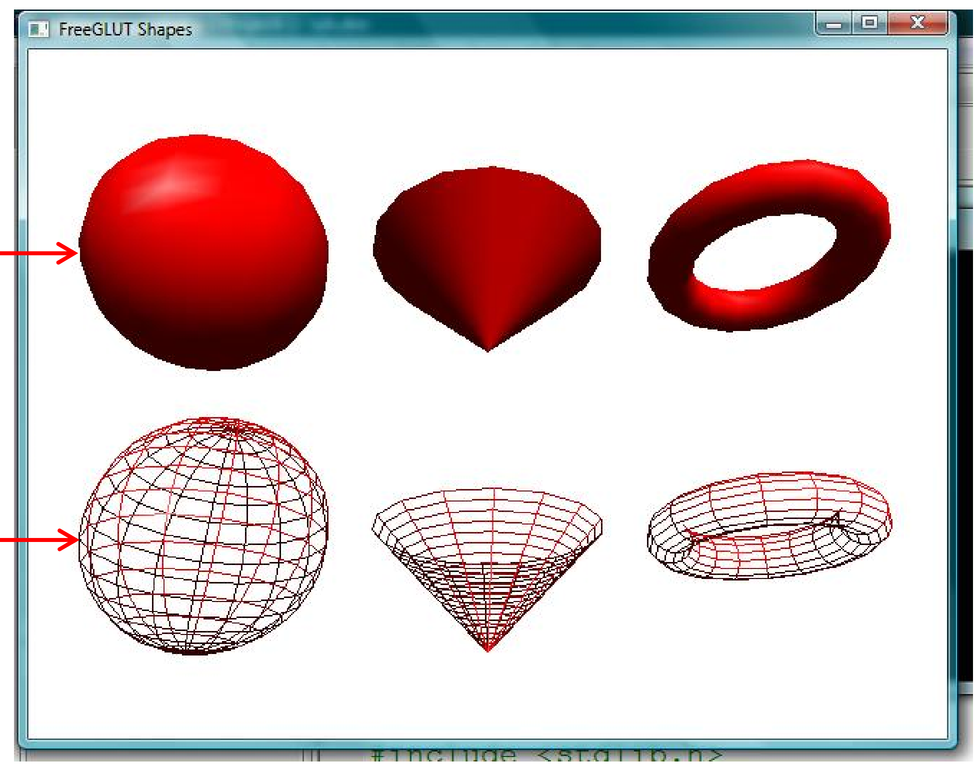
Left hand coordinate system
•Not used in OpenGL

Generating 3D Models: GLUT Models

- One way of generating 3D shapes is by using GLUT 3D models (Restrictive?)
- **Note:** Simply make GLUT 3D calls in **OpenGL program** to generate vertices describing different shapes
- Two types of GLUT models:
  - Wireframe Models
  - Solid Models

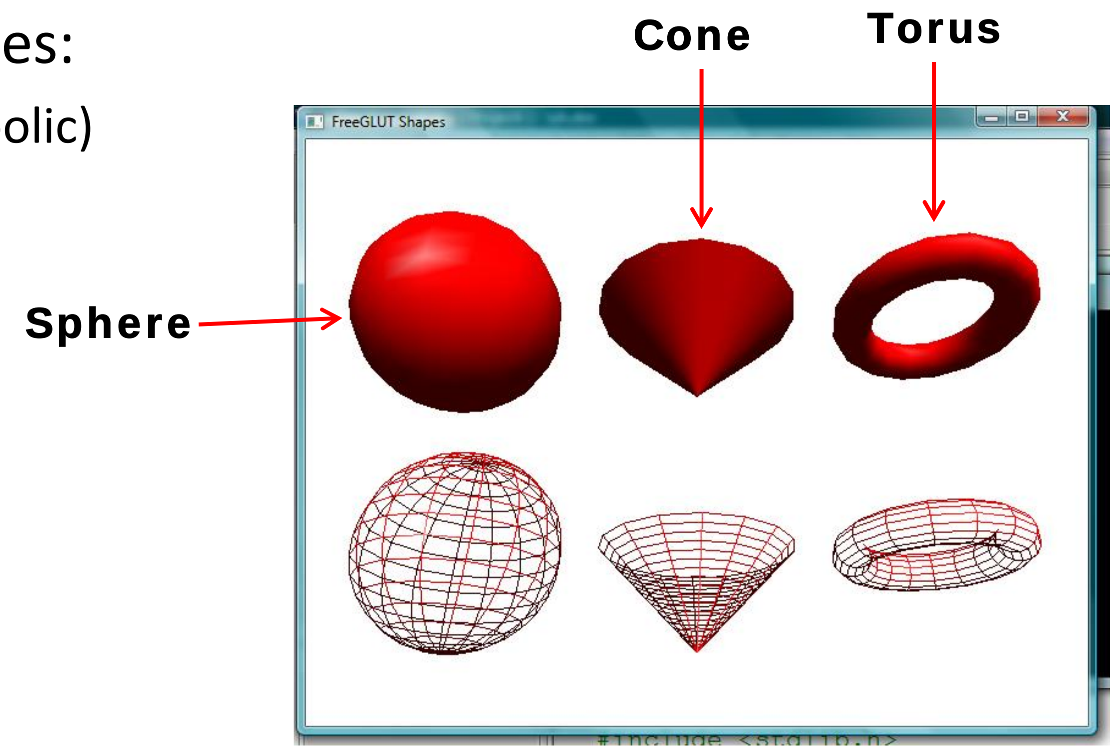
Solid models

Wireframe models



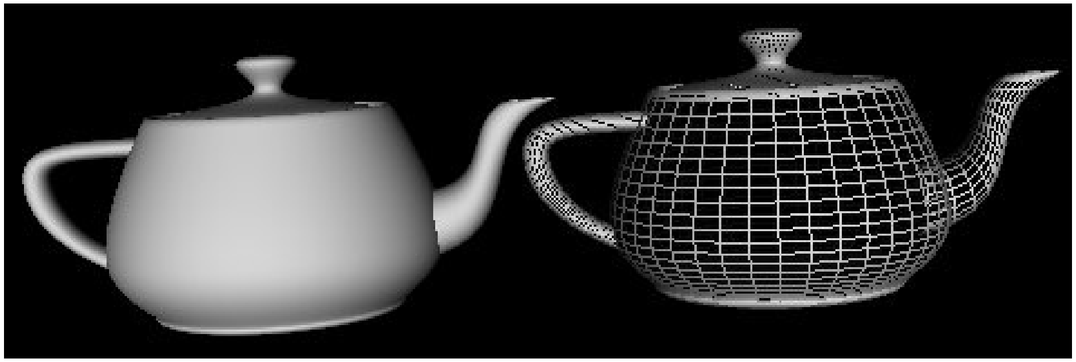
3D Modeling: GLUT Models

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



GLUT Models: glutwireTeapot( )

- Famous Utah Teapot: unofficial computer graphics mascot



glutWireTeapot(0.5) - Create teapot of size 0.5, center positioned at (0,0,0)

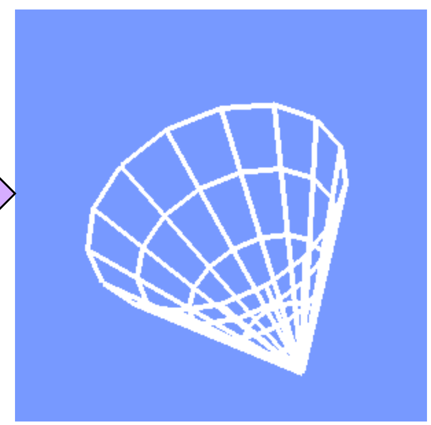
Also glutSolidTeapot( )

You need to apply transformations to position, scale and rotate it

3D Modeling: GLUT Models

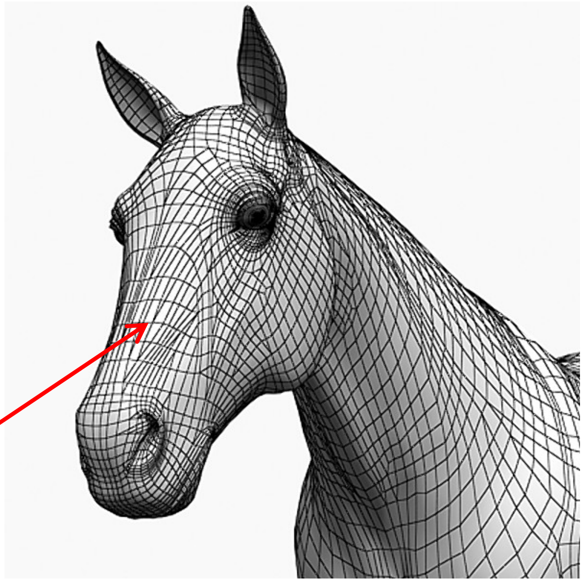
- Glut functions under the hood
  - generate sequence of points that define a shape
- **Example:** **glutWireCone** generates sequence of vertices, and faces defining **cone** and connectivity
- Generated vertices and faces passed to OpenGL for rendering

glutWireCone generates sequence of vertices, and faces defining cone → **OpenGL program** receives vertices and Faces, renders them →



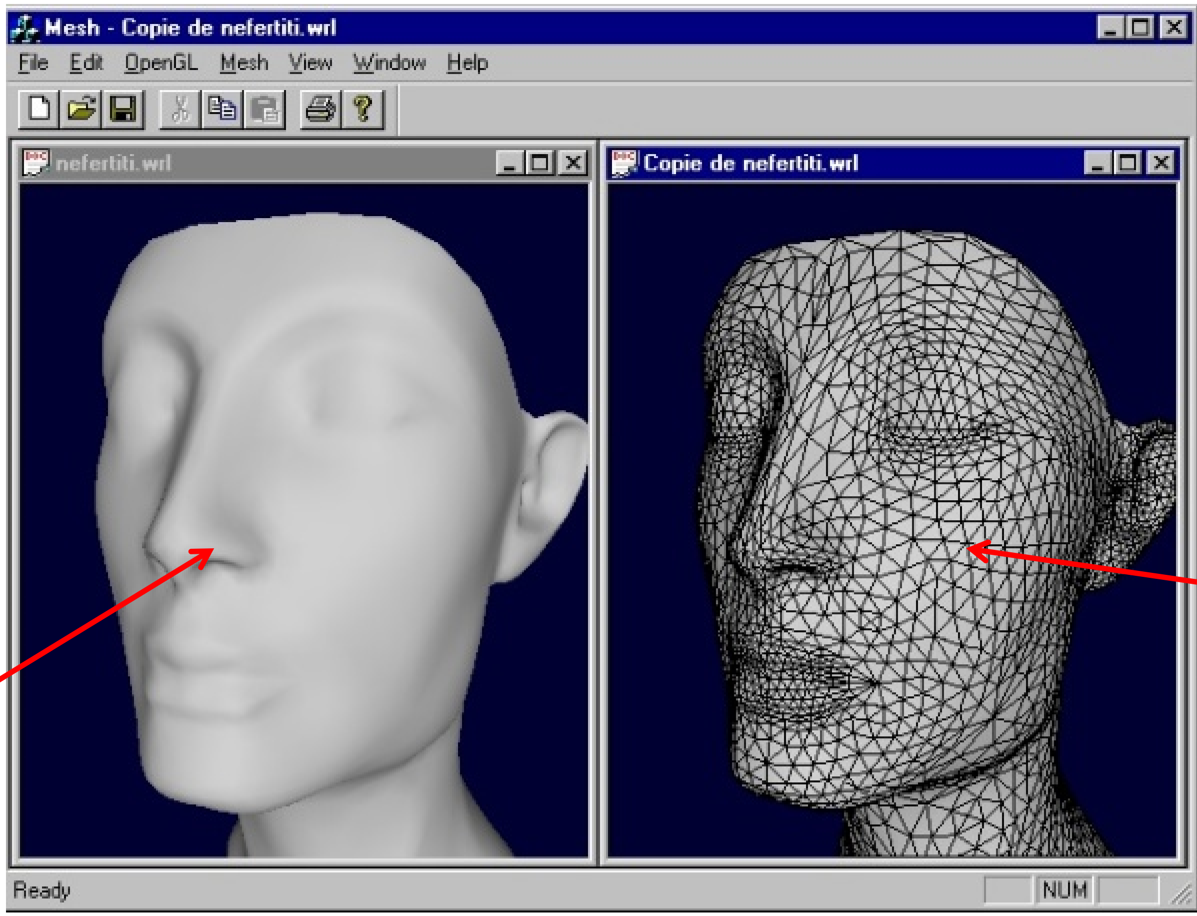
Polygonal Meshes

- Modeling with GLUT shapes (cube, sphere, etc) too restrictive
- Difficult to approach realism
- Other (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

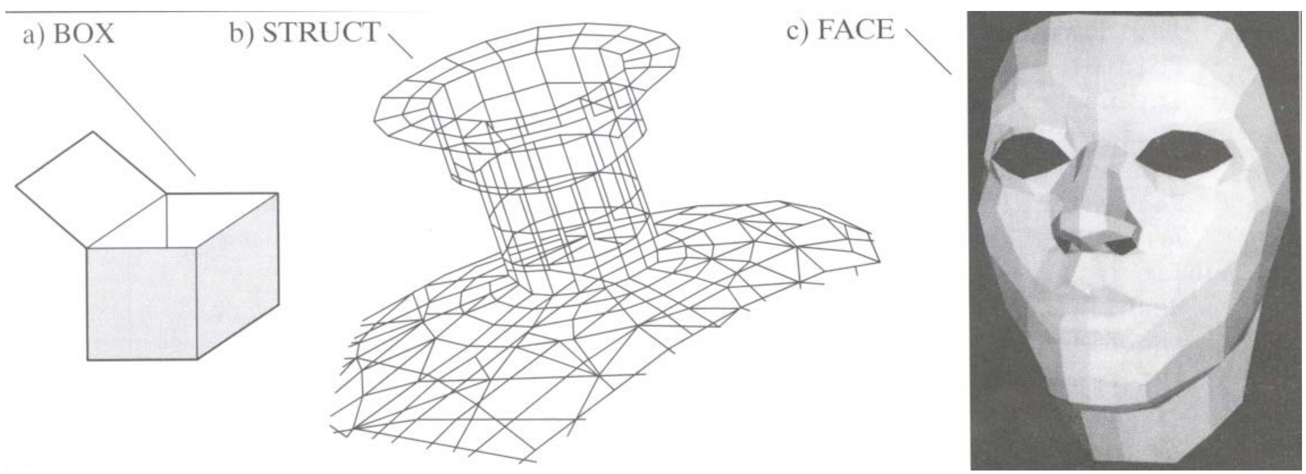


Smoothed Out with Shading (later)

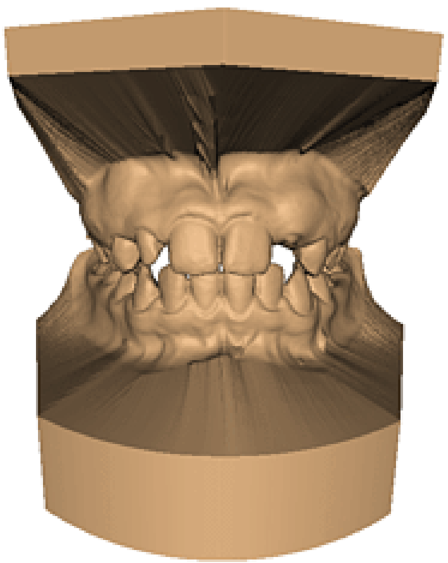
Mesh (wireframe)

Polygonal Meshes

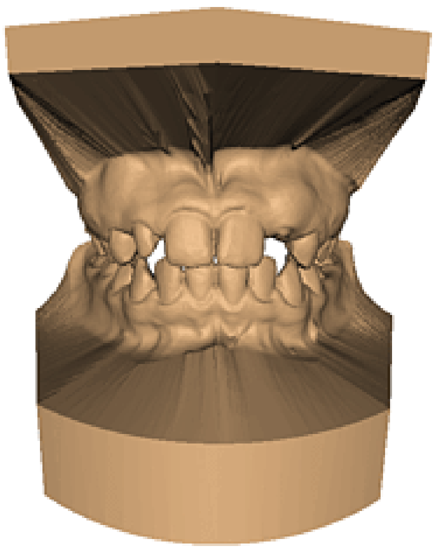
- Meshes now standard in graphics
- OpenGL
  - Good at drawing polygons, triangles
  - Mesh = sequence of polygons forming thin skin around object
- Simple meshes exact. (e.g barn)
- Complex meshes approximate (e.g. human face)



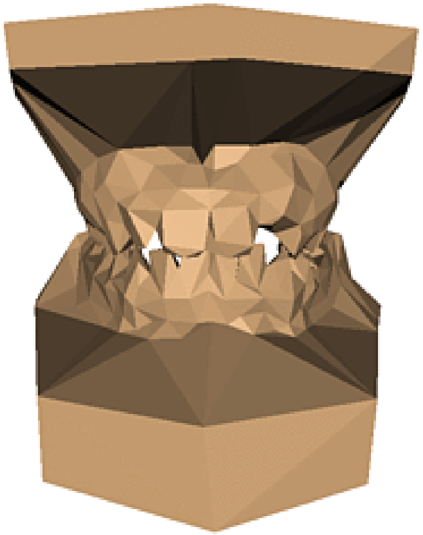
Meshes at Different Resolutions



Original: 424,000 triangles



60,000 triangles (14%).

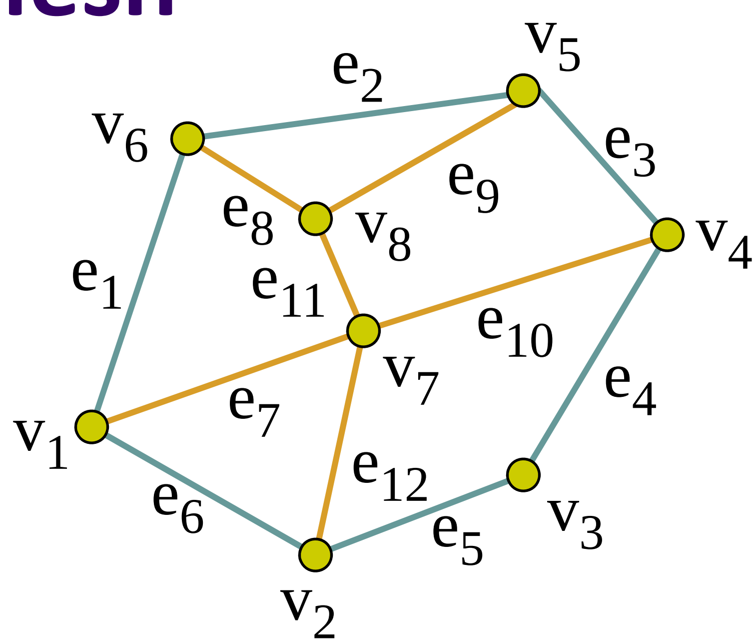


1000 triangles (0.2%)

(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;
```

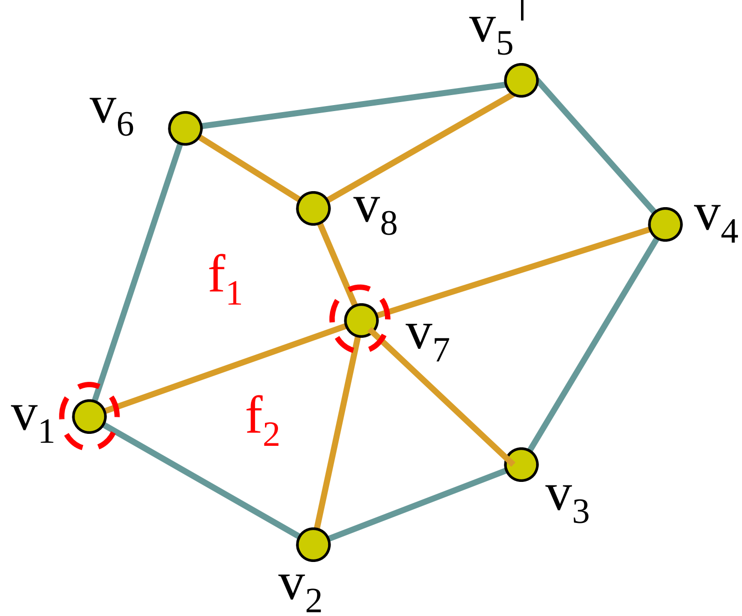
Issues with Simple Representation

- 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);
```

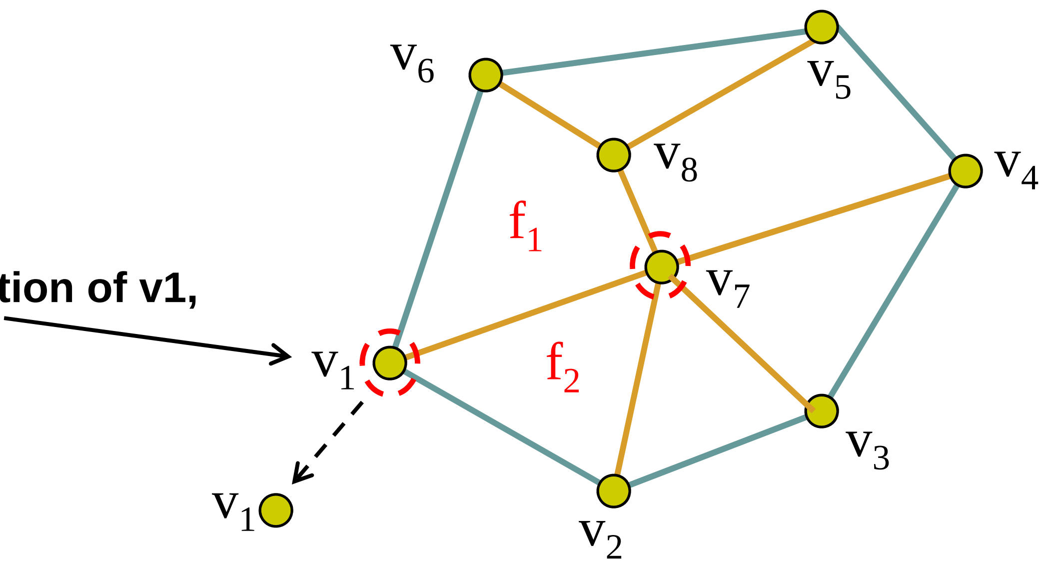


- Inefficient and unstructured
  - In example, vertices v1 and v7 repeated while declaring f1 and f2
  - Vertices shared by many polygons are declared multiple times
  - Consider deleting vertex, moving vertex to new location
  - Must search for all faces in which vertex occurs

Geometry vs Topology

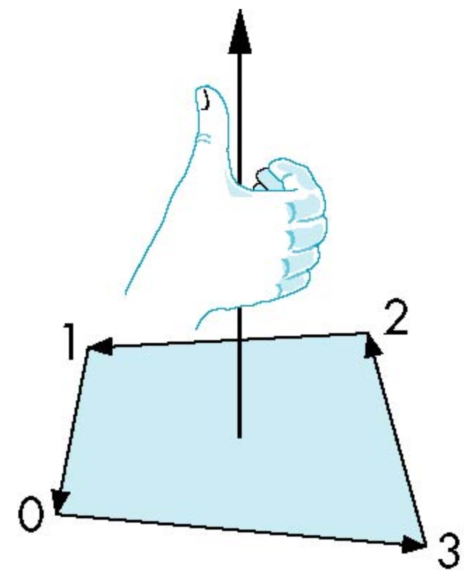
- Better data structures separate **geometry** from **topology**
  - **Geometry:** (x,y,z) locations of the vertices
  - **Topology:** How vertices and edges are connected
  - **Example:** a polygon is an **ordered list** of vertices with an edge connecting successive pairs of vertices
  - Topology holds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

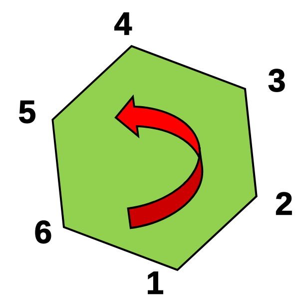
Example: even if we move (x,y,z) location of v1, v1 still connected to v6, v7 and v2



Polygon Traversal Convention

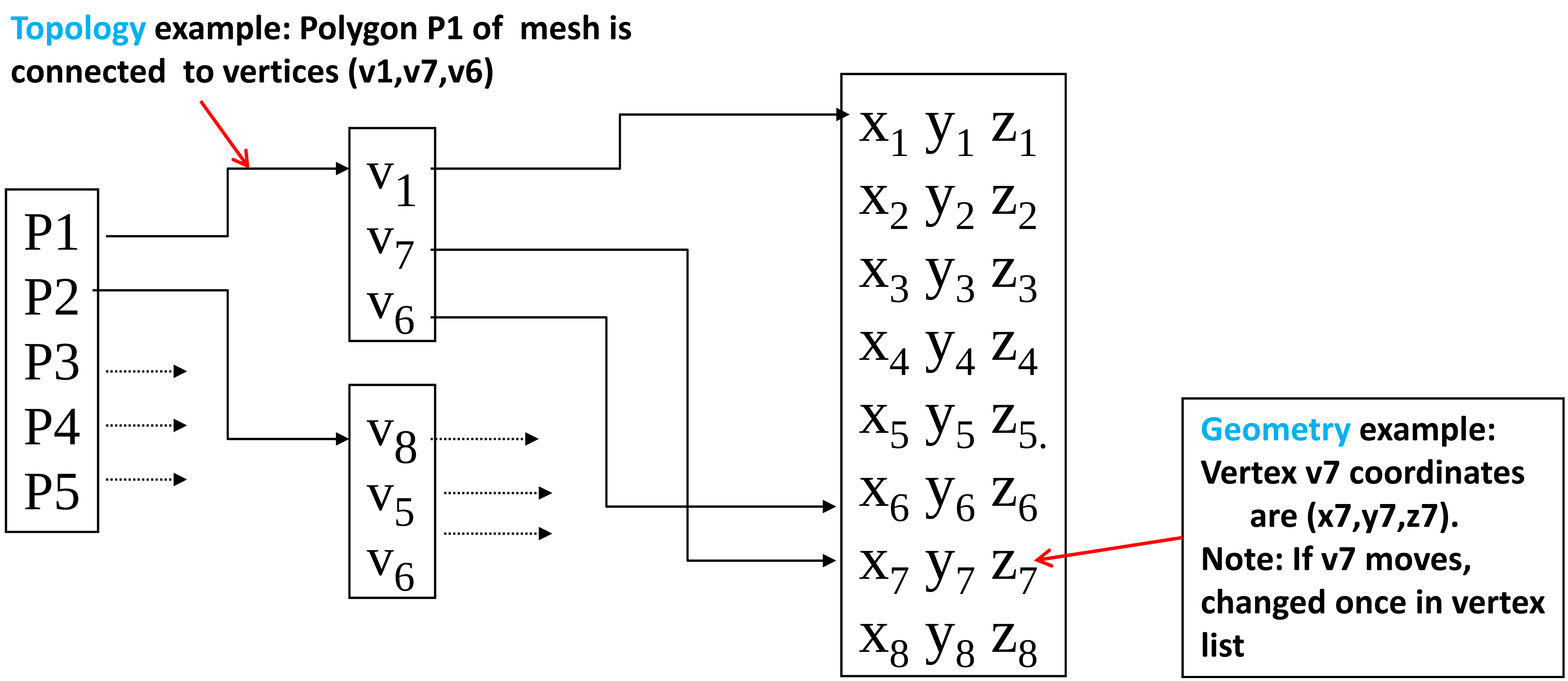
- Use the ***right-hand rule* = counter-clockwise** encirclement of outward-pointing normal
- OpenGL can treat inward and outward facing polygons differently
- The order $\{v_1, v_0, v_3\}$ and $\{v_3, v_2, v_1\}$ are equivalent in same polygon, rendered same way rendered by OpenGL
- But order of $\{v_1, v_2, v_3\}$ is different
- The first two describe *outwardly facing* polygons





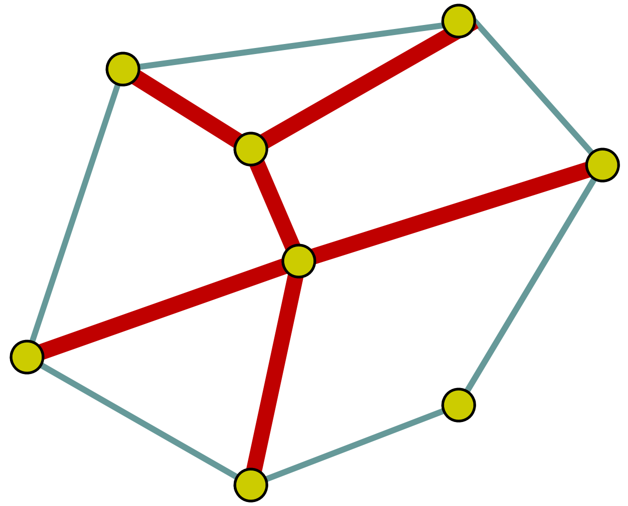
Vertex Lists

- **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)



Vertex List Issue: Shared Edges

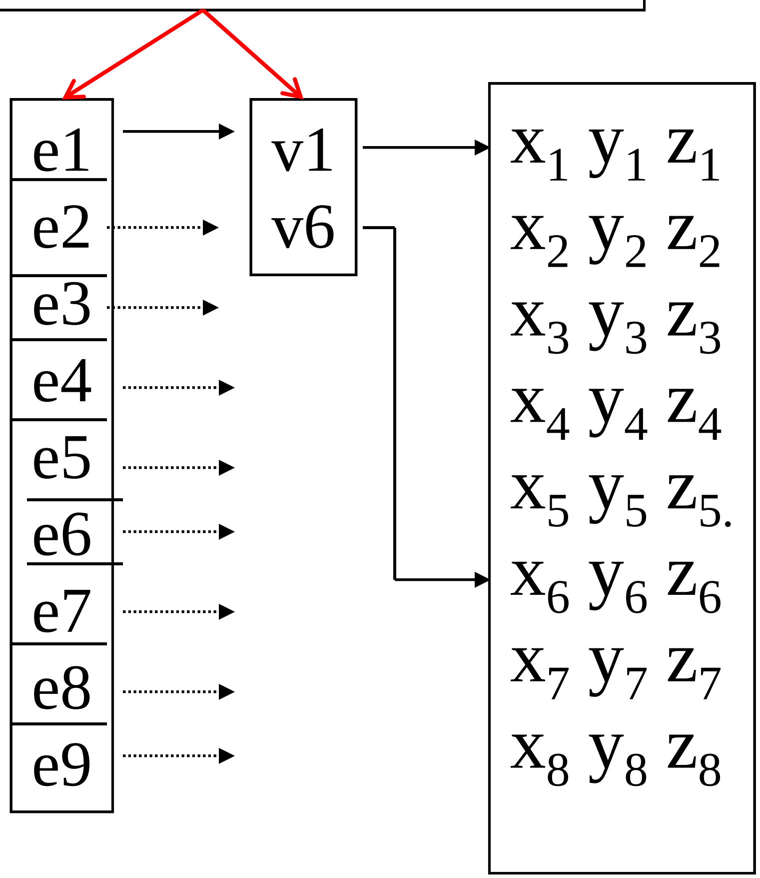
- Vertex lists draw filled polygons correctly
- If each polygon is drawn by its edges, shared edges are drawn twice

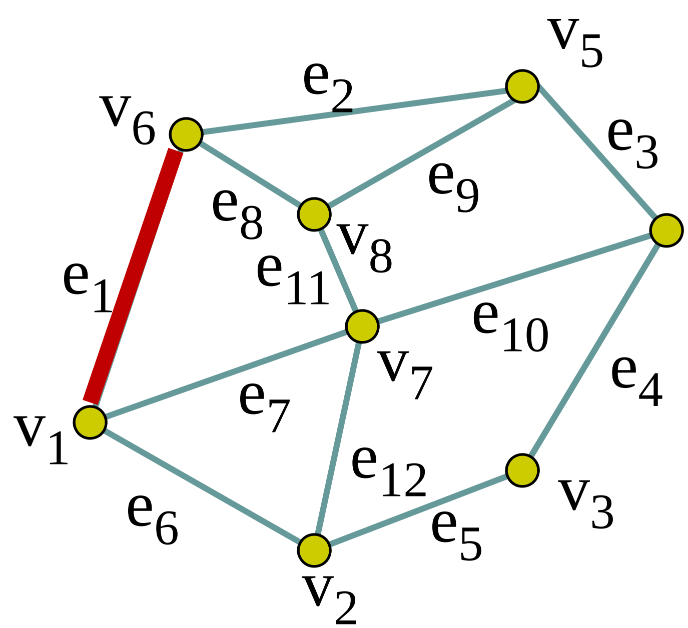


- **Alternatively:** Can store mesh by *edge list*

Edge List

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

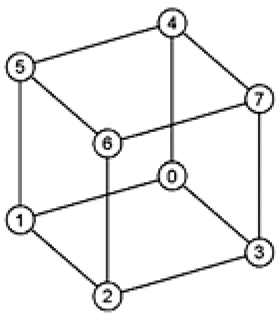




Note polygons are not represented

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)};
```

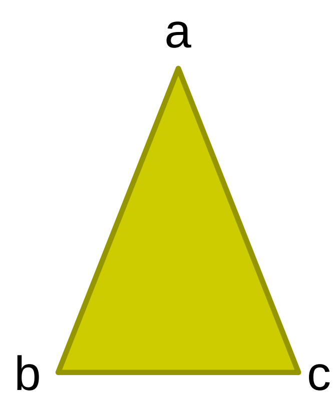
r g b

```
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

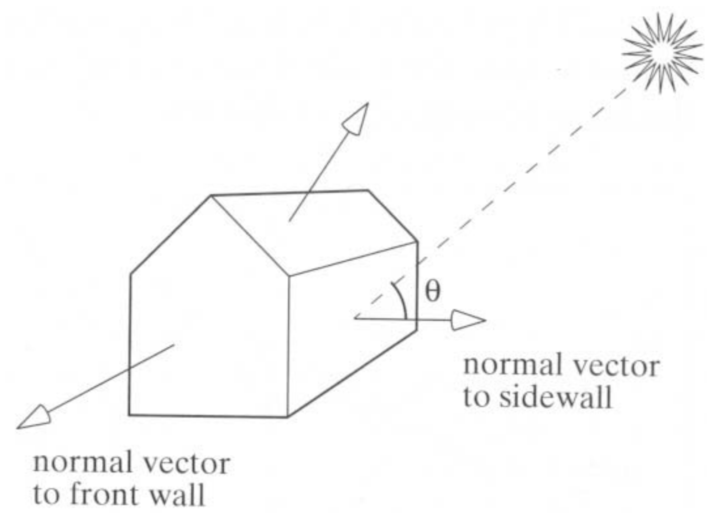
```
void triangle(int a, int b, int c, int d)
{
   vcolors[i] = colors[d];
   position[i] = vertices[a];
   vcolors[i+1] = colors[d]);
   position[i+1] = vertices[b];
   vcolors[i+2] = colors[d];
   position[i+2] = vertices[c];
   i+=3;
 }
```



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

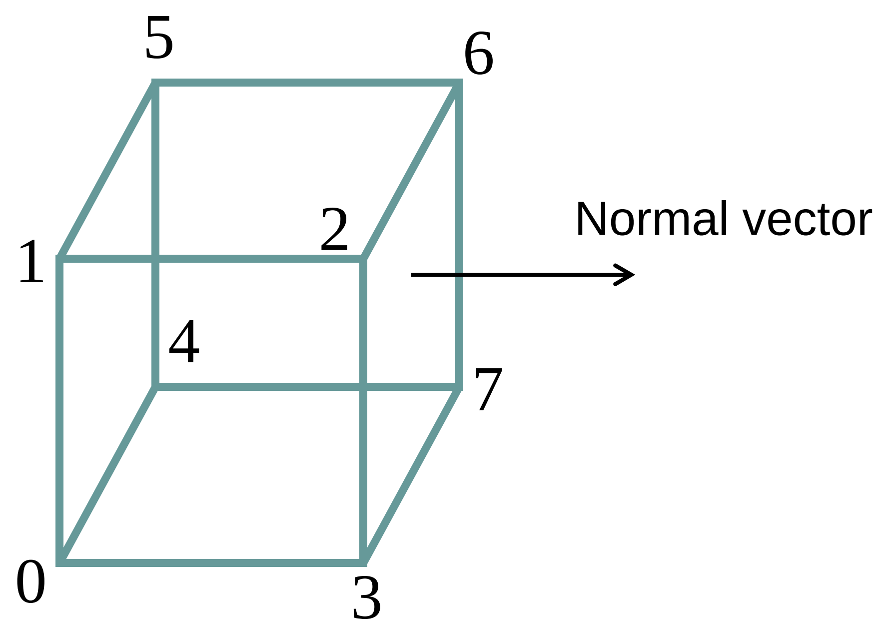
Normal Vector

- **Normal vector:** Direction each polygon is facing
- Each mesh polygon has a **normal vector**
- Normal vector used in shading
- **Normal vector • light vector** determines shading (Later)



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