# CS559: Computer Graphics

Lecture 33: Shape Modeling

Li Zhang

Spring 2008

# Today

- Shape Modeling

- Reading
  - (optional) Shirley: ch 13.1-13.3
  - Redbook: ch 2, if you haven't read it before

# Shape model

- You have some experience with shape modeling
  - Rails as curves
  - Tree = cone + cylinder
- There are many ways to represent the shape of an object
- choosing a representation depends on application and requirement

# Boundary vs. Solid Representations

- B-rep: boundary representation
  - Sometimes we only care about the surface
  - Rendering opaque objects
- Solid modeling
  - Some representations are best thought of defining the space filled, rather than the surface around the space
  - Medical data with information attached to the space
  - Transparent objects with internal structure
  - Taking cuts out of an object; “What will I see if I break this object?”

# Shape Representation

- Parametric models
- Implicit models
- Procedural models

# Parametric Model

- generates all the points on a surface (volume) by "plugging in a parameter"
  - Eg $$\left(\sin\phi\cos\theta, \sin\phi\sin\theta, \cos\phi\right)$$
    $$0 \le \theta < 2\pi, \quad 0 \le \phi \le \pi$$
  - Easy to render, how?
  - Easy to texture map

# Implicit Models

- Implicit models use an equation that is 0 if the point is on the surface
  - Essentially a function to test the status of a point
  - Eg $x^2 + y^2 + z^2 - 1 = 0$
  - Easy to test inside/outside/on
  - Hard to?
    - Render
    - Texture map

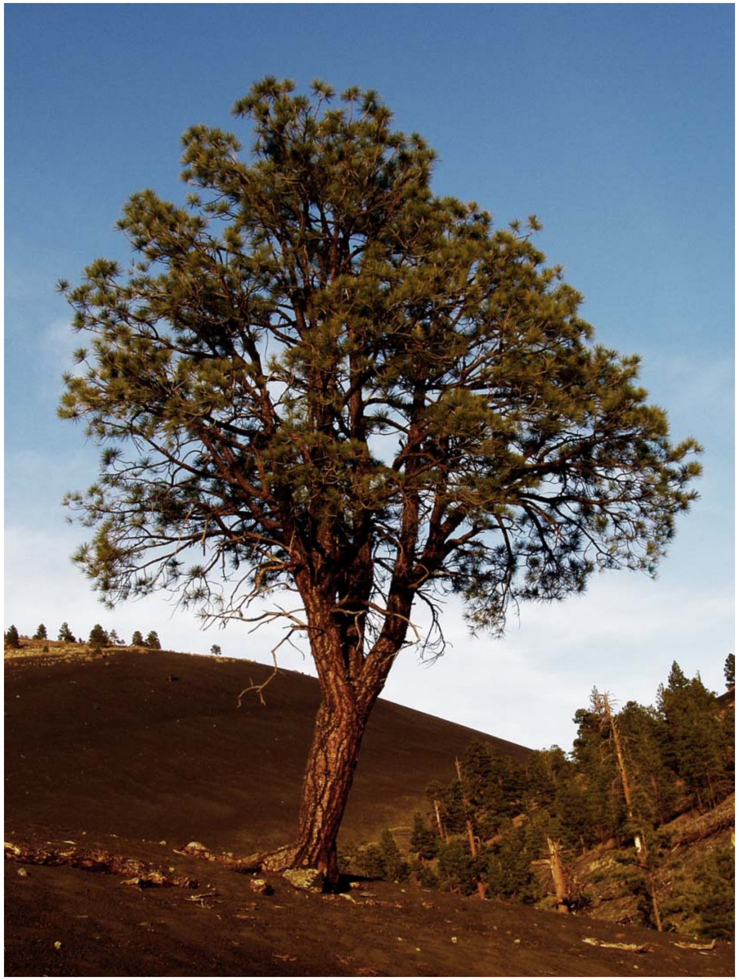
# Parametric Model

- generates all the points on a surface (volume) by "plugging in a parameter"
  - Eg $$\left(\sin\phi\cos\theta, \sin\phi\sin\theta, \cos\phi\right)$$ $$0 \le \theta < 2\pi, \quad 0 \le \phi \le \pi$$
  - Easy to render, how?
  - Easy to texture map
  - Hard to
    - Test inside/outside/on

# Procedural Modeling

- a procedure is used to describe how the shape is formed

Simple procedure



# Parameterization

- Parameterization is the process of associating a set of parameters with every point on an object
  - For instance, a line is easily parameterized by a single value
  - Triangles in 2D can be parameterized by their barycentric coordinates
  - Triangles in 3D can be parameterized by 3 vertices and the barycentric coordinates (need both to locate a point in 3D space)
- Several properties of a parameterization are important:
  - The smoothness of the mapping from parameter space to 3D points
  - The ease with which the parameter mapping can be inverted
- We care about parameterizations for several reasons
  - Texture mapping is the most obvious one you have seen so far; require *(s,t)* parameters for every point in a triangle

# Popular Modeling Techniques

- Polygon meshes
  - Surface representation, Parametric representation
- Prototype instancing and hierarchical modeling (done)
  - Surface or Volume, Parametric
- Volume enumeration schemes
  - Volume, Parametric or Implicit
- Parametric curves and surfaces
  - Surface, Parametric
- Subdivision curves and surfaces
- Procedural models

# Polygon Modeling

- Polygons are the dominant force in modeling for real-time graphics
- Why?

# Polygons Dominate because

- Everything can be turned into polygons (almost everything)
  - Normally an error associated with the conversion, but with time and space it may be possible to reduce this error
- We know how to render polygons quickly
- Many operations are easy to do with polygons
- Memory and disk space is cheap
- Simplicity

# What’s Bad About Polygons?

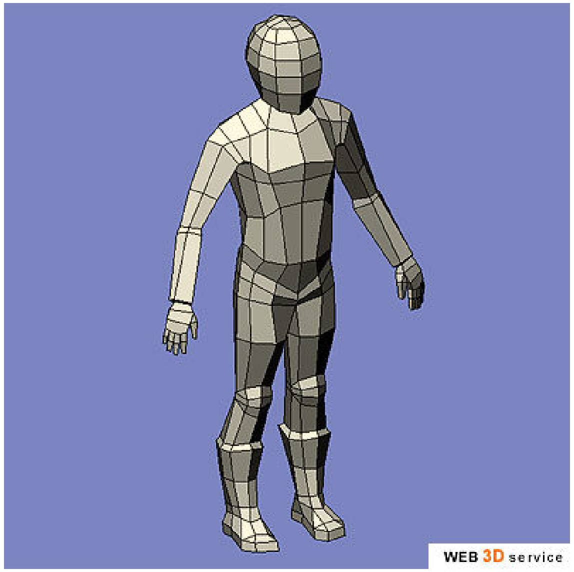
- What are some disadvantages of polygonal representations?

# Polygons Aren’t Great

- They are always an approximation to curved surfaces
  - Most real-world surfaces are curved, particularly natural surfaces
  - They throw away information
  - Normal vectors are approximate
  - But can be as good as you want, if you are willing to pay in size
- They can be very unstructured
- They are hard to globally parameterize (complex concept)
  - How do we parameterize them for texture mapping?
- It is difficult to perform many geometric operations
  - Results can be unduly complex, for instance

# Polygon Meshes

- A *mesh* is a set of polygons connected to form an object
- A mesh has several components, or geometric entities:
  - Faces
  - Edges
    - the boundary between faces
  - Vertices
    - the boundaries between edges,
    - or where three or more faces meet
  - Normals, Texture coordinates, colors, shading coefficients, etc
- What is the counterpart of a polygon mesh in curve modeling?



# Polygonal Data Structures

- Polygon mesh data structures are **application dependent**
- Different applications require different operations to be fast
  - Find the neighbor of a given face
  - Find the faces that surround a vertex
  - Intersect two polygon meshes
- You typically choose:
  - Which features to store explicitly (vertices, faces, normals, etc)
  - Which relationships you want to be explicit (vertices belonging to faces, neighbors, faces at a vertex, etc)

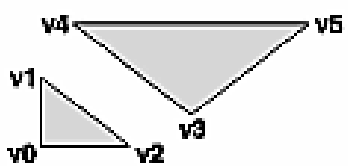
# Polygon Soup

- Many polygon models are just lists of polygons

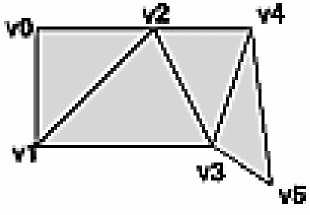
```
struct Vertex {
   float coords[3];
}
struct Triangle {
   struct Vertex verts[3];
}
struct Triangle mesh[n];

glBegin(GL_TRIANGLES)
   for ( i = 0 ; i < n ; i++ )
   {
        glVertex3fv(mesh[i].verts[0]);
        glVertex3fv(mesh[i].verts[1]);
        glVertex3fv(mesh[i].verts[2]);
   }
glEnd();
```

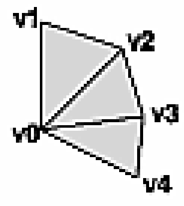
**Important Point:** OpenGL, and almost everything else, assumes a constant vertex ordering: clockwise or counter-clockwise. Default, and slightly more standard, is counter-clockwise




GL_TRIANGLES



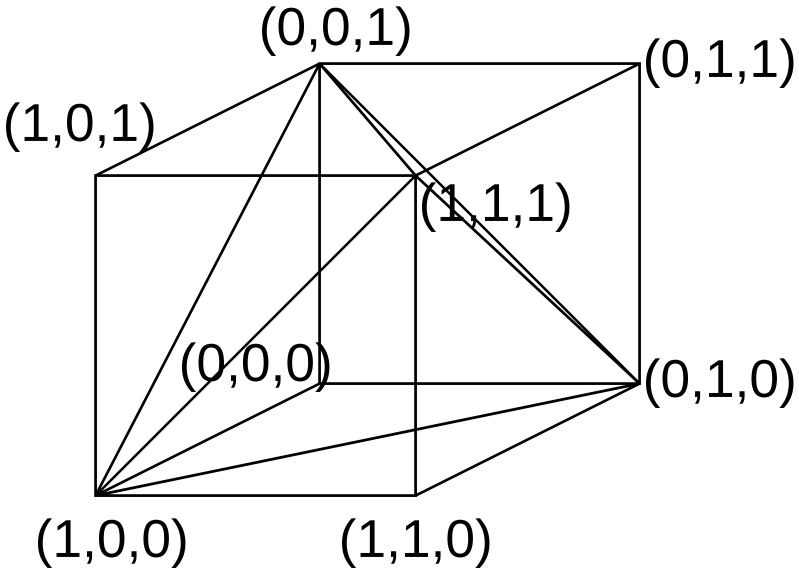

GL_TRIANGLE_STRIP




GL_TRIANGLE_FAN

# Cube Soup

```
struct Triangle Cube[12] =
        {{{1,1,1},{1,0,0},{1,1,0}},
         {{1,1,1},{1,0,1},{1,0,0}},
         {{0,1,1},{1,1,1},{0,1,0}},
         {{1,1,1},{1,1,0},{0,1,0}},
         …
        };
```



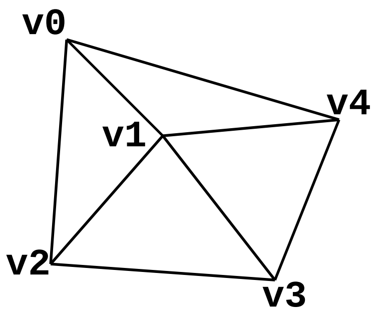
# Polygon Soup Evaluation

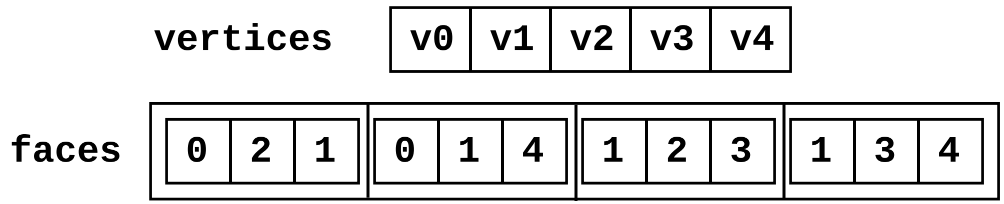
- What are the advantages?
- What are the disadvantages?

# Polygon Soup Evaluation

- What are the advantages?
  - It's very simple to read, write, transmit, etc.
  - A common output format from CAD modelers
  - The format required for OpenGL
- BIG disadvantage: No higher order information
  - No information about neighbors
  - No open/closed information
  - No guarantees on degeneracies

# Vertex Indirection

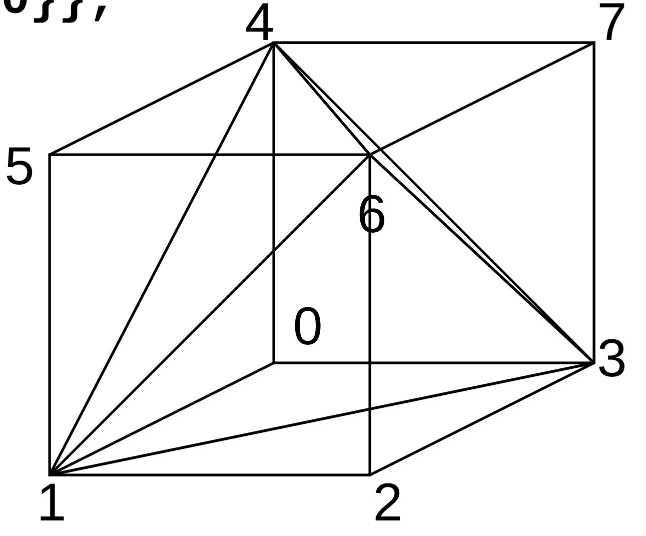



- There are reasons not to store the vertices explicitly at each polygon
  - Wastes memory - each vertex repeated many times
  - Very messy to find neighboring polygons
  - Difficult to ensure that polygons meet correctly
- Solution: Indirection
  - Put all the vertices in a list
  - Each face stores the indices of its vertices
- Advantages? Disadvantages?

# Cube with Indirection

```
struct Vertex CubeVerts[8] =
       {{0,0,0},{1,0,0},{1,1,0},{0,1,0},
        {0,0,1},{1,0,1},{1,1,1},{0,1,1}};
struct Triangle CubeTriangles[12] =
       {{6,1,2},{6,5,1},{6,2,3},{6,3,7},
        {4,7,3},{4,3,0},{4,0,1},{4,1,5},
        {6,4,5},{6,7,4},{1,2,3},{1,3,0}};
```



# Indirection Evaluation

- Advantages:
  - Connectivity information is easier to evaluate because vertex equality is obvious
  - Saving in storage:
    - Vertex index might be only 2 bytes, and a vertex is probably 12 bytes
    - Each vertex gets used at least 3 and generally 4-6 times, but is only stored once
  - Normals, texture coordinates, colors etc. can all be stored the same way
- Disadvantages:
  - Connectivity information is not explicit

# OpenGL and Vertex Indirection

```
struct Vertex {
   float coords[3];
}
struct Triangle {
   GLuint verts[3];
}
struct Mesh {
   struct Vertex vertices[m];
   struct Triangle triangles[n];
}

glEnableClientState(GL_VERTEX_ARRAY)
glVertexPointer(3, GL_FLOAT, sizeof(struct Vertex),
                 mesh.vertices);
glBegin(GL_TRIANGLES)
   for ( i = 0 ; i < n ; i++ )
   {
        glArrayElement(mesh.triangles[i].verts[0]);
        glArrayElement(mesh.triangles[i].verts[1]);
        glArrayElement(mesh.triangles[i].verts[2]);
   }
glEnd();
```

# OpenGL and Vertex Indirection (v2)

```
glEnableClientState(GL_VERTEX_ARRAY)
glVertexPointer(3, GL_FLOAT, sizeof(struct Vertex),
                  mesh.vertices);
for ( i = 0 ; i < n ; i++ )
   glDrawElements(GL_TRIANGLES, 3, GL_UNSIGNED_INT,
                   mesh.triangles[i].verts);
```

- Minimizes amount of data sent to the renderer
- Fewer function calls
- Faster!
- Other tricks to accelerate using array, see Red book, Ch 2 on vertex arrays