Today

• Shape Modeling

• Reading
  – 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 $(\sin \phi \cos \theta, \sin \phi \sin \theta, \cos \phi)$
    \[ 0 \leq \theta < 2\pi, \quad 0 \leq \phi \leq \pi \]
  
  – 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

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  – Eg \((\sin \phi \cos \theta, \sin \phi \sin \theta, \cos \phi)\)
    
    \[0 \leq \theta < 2\pi, \quad 0 \leq \phi \leq \pi\]

  – 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
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

```c
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.
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

```c
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

```c
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)

```c
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