CS559: Computer Graphics

Lecture 23: Shape Modeling

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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 $(\sin\phi\cos\theta, \sin\phi\sin\theta, \cos\phi)$

    $0 \le \theta < 2\pi, \quad 0 \le \phi \le \pi$
  - 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

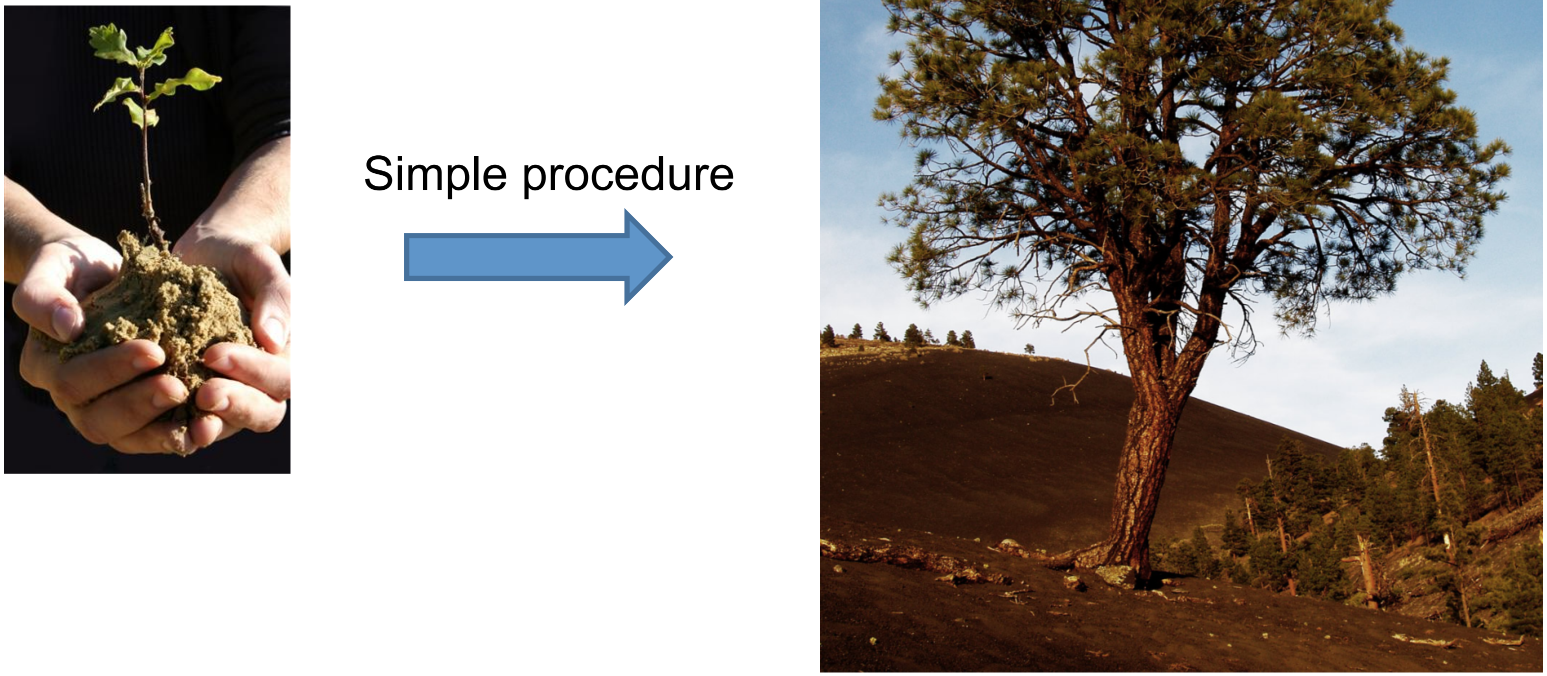
Parametric Model

- generates all the points on a surface (volume) by "plugging in a parameter"
  - Eg $(\sin\phi\cos\theta, \sin\phi\sin\theta, \cos\phi)$

    $0 \le \theta < 2\pi, \quad 0 \le \phi \le \pi$
  - 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



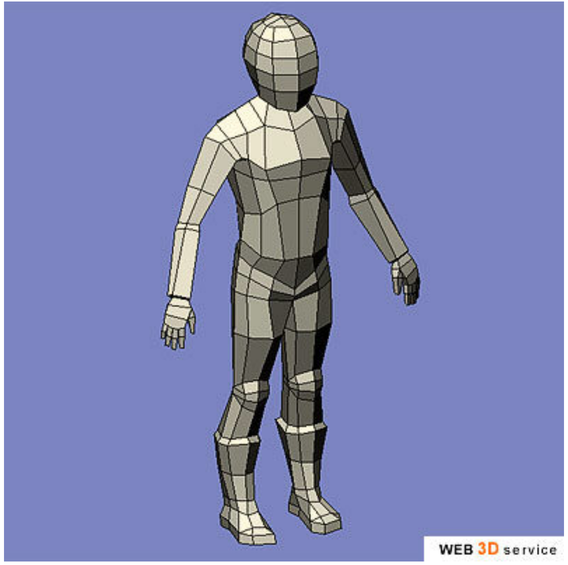
Simple procedure

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

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

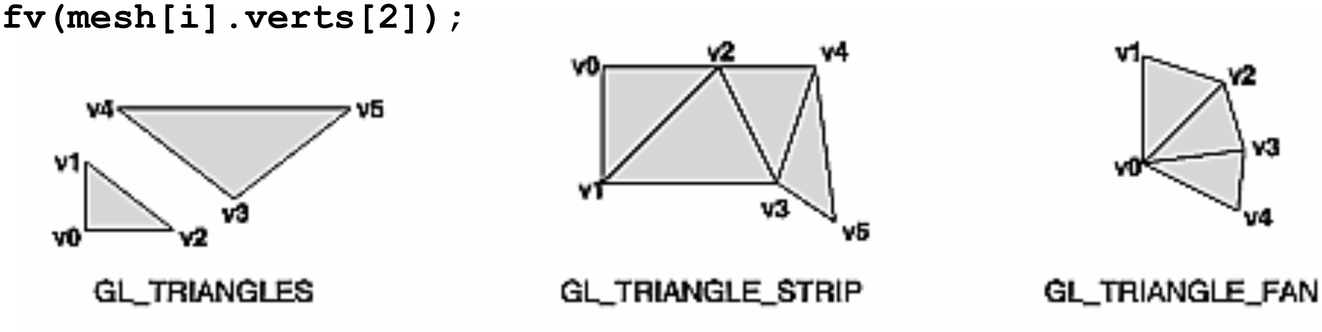
- Polygon mesh data structures are **application dependent**
- Different applications require different operations to be fast
  - Find the neighbor of a given face
  - Find the faces that surround a vertex
  - Intersect two polygon meshes
- You typically choose:
  - Which features to store explicitly (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

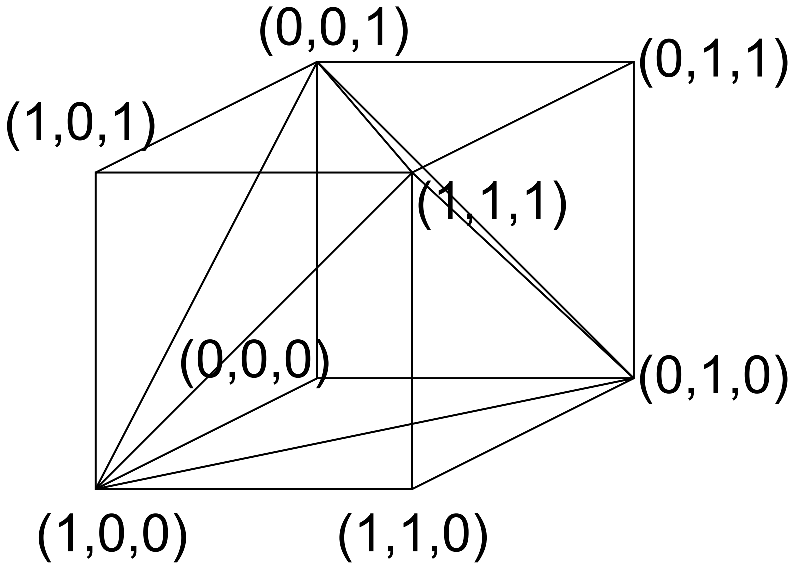
```
struct Vertex {
   float coords[3];
}
struct Triangle {
   struct Vertex verts[3];
}
struct Triangle mesh[n];

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



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}},
       …
      };
```



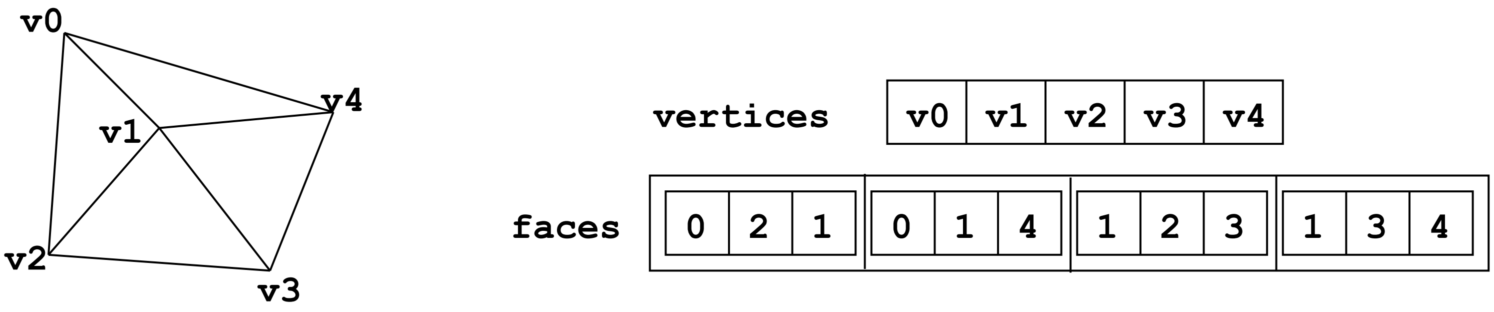
Polygon Soup Evaluation

- 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

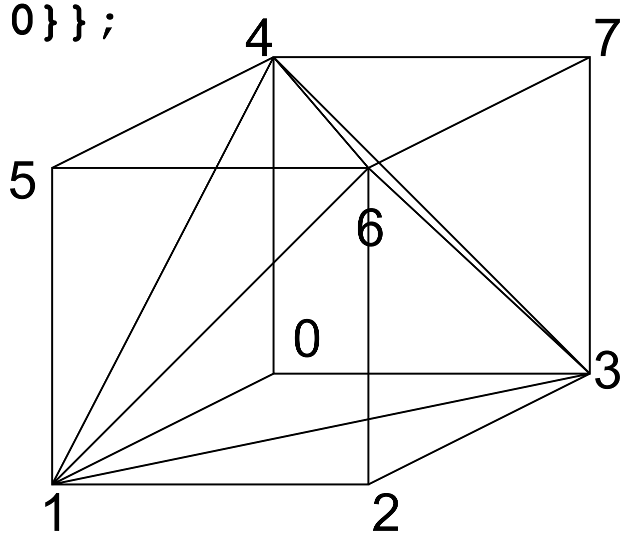
Vertex Indirection



- 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

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
- Texture mapping easily
- Memory and disk space is cheap
- Simplicity

What's Bad About Polygons?

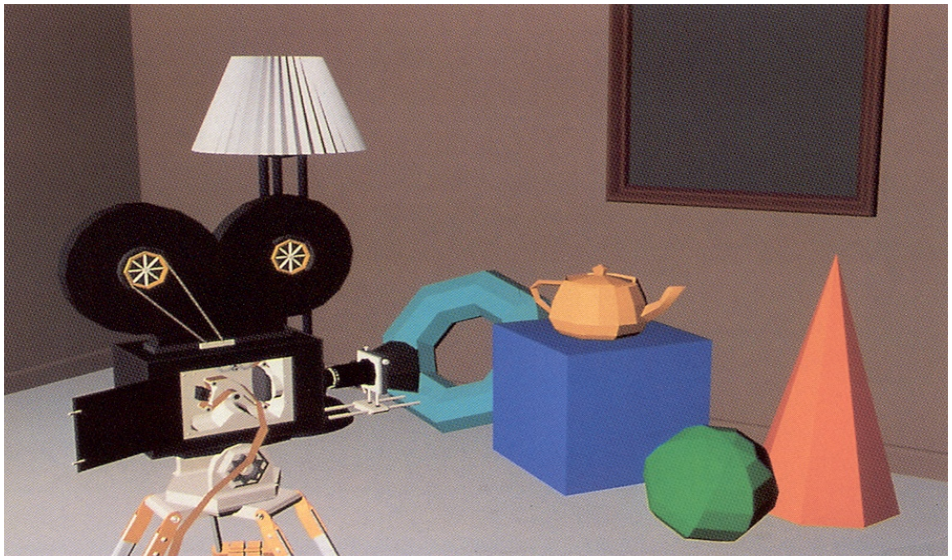
- What are some disadvantages of polygonal representations?

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
  - Collision, intersection

Normal Vectors in Mesh

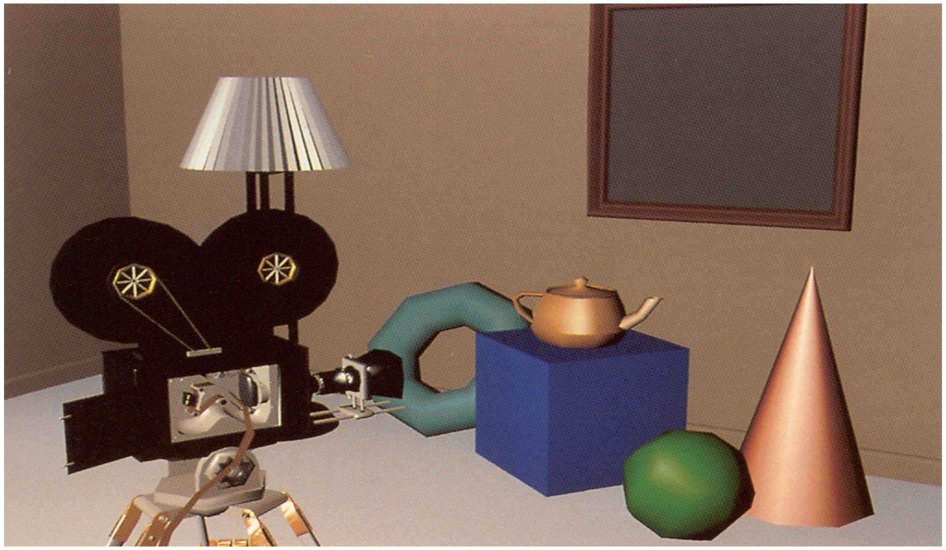
- Normal vectors give information about the true surface shape
- Per-Face normals:
  - One normal vector for each face, stored as part of face (Flat shading)



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

Normal Vectors in Mesh

- Normal vectors give information about the true surface shape
- Per-Vertex normals:
  - A normal specified for every vertex (smooth shading)



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

Storing Other Information

- Colors, Texture coordinates and so on can all be treated like vertices or normals
- Lighting/Shading coefficients may be per-face, per-object, or per-vertex

Other Data in Mesh

- Normal vectors give information about the true surface shape
- Per-Vertex normals:
  - A normal specified for every vertex (smooth shading)
- Per-Vertex Texture Coord

```
struct Vertex {
        float coords[3];
        float normal[3];
        float texCoords[2];
}
struct Triangle {
        GLuint verts[3];
}
struct Mesh {
        Vertex vertices[m];
        Triangle triangles[n];
}
```

Other Data in Mesh

- Normal vectors give information about the true surface shape
- Per-Vertex normals:
  - A normal specified for every vertex (smooth shading)
- Per-Vertex Texture Coord, Shading Coefficients

```
struct Vertex {
       float coords[3];
       float normal[3];
       float texCoords[2], diffuse[3], shininess;
}
struct Triangle {
       GLuint verts[3];
}
struct Mesh {
       Vertex vertices[m];
       Triangle triangles[n];
}
```

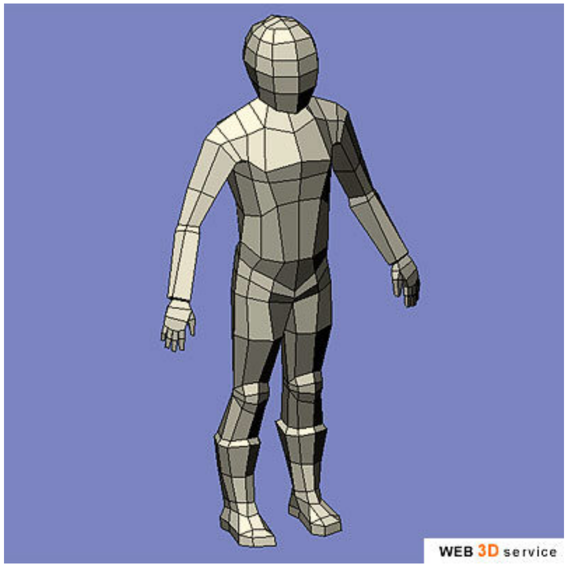
Other Data in Mesh

- Normal vectors give information about the true surface shape
- Per-Vertex normals:
  - A normal specified for every vertex (smooth shading)
- Per-Vertex Texture Coord, Shading Coefficients

```
struct Vertex {
       float coords[3];
}
struct Triangle {
       GLuint verts[3];
}
struct Mesh {
       Vertex vertices[m];
       float normals[3*m];
       float texCoords[2*m], diffuse[3*m], shininess[m];
       Triangle triangles[n];
}
```

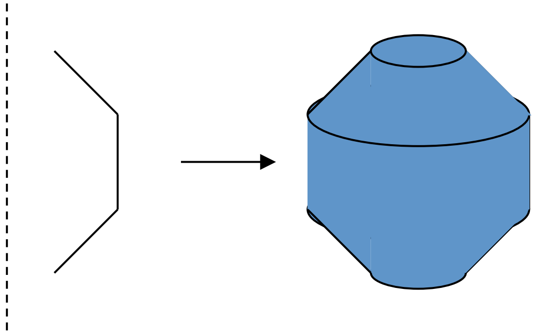
Issues with Polygons

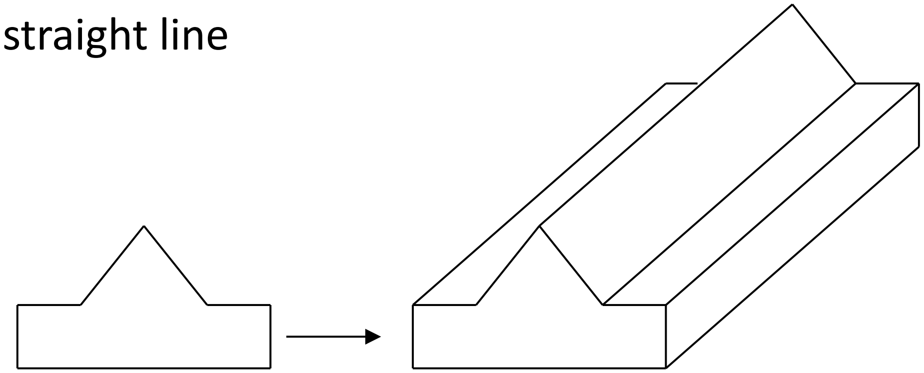
- They are inherently an approximation
  - Things like silhouettes can never be perfect without very large numbers of polygons, and corresponding expense
  - Normal vectors are not specified everywhere
- Interaction is a problem
  - Dragging points around is time consuming
  - Maintaining things like smoothness is difficult
- Low level representation
  - Eg: Hard to increase, or decrease, the resolution
  - Hard to extract information like curvature



In Project 3, we use Sweep Objects

- Define a polygon by its edges
- Sweep it along a path
- The path taken by the edges form a surface - the sweep surface
- Special cases
  - Surface of revolution: Rotate edges about an axis
  - Extrusion: Sweep along a straight line



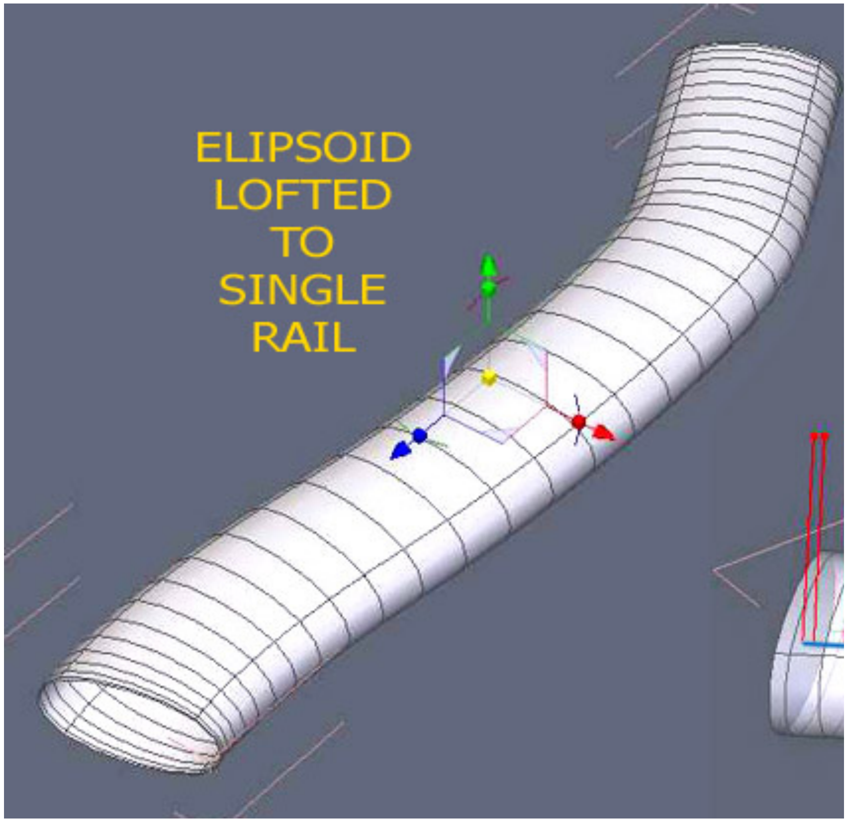


Rendering Sweeps

- Convert to polygons
  - Break path into short segments
  - Create a copy of the sweep polygon at each segment
  - Join the corresponding vertices between the polygons
  - May need things like end-caps on surfaces of revolution and extrusions
- Normals?
  - Normals come from sweep polygon and path orientation
- Texture Coord?
  - Sweep polygon defines one texture parameter, sweep path defines the other

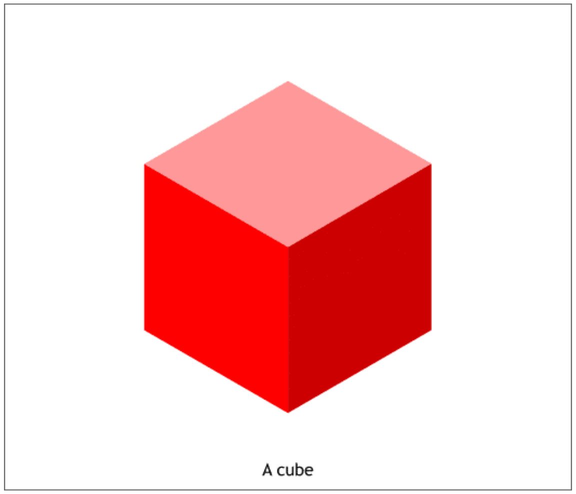
General Sweeps

- The path maybe any curve

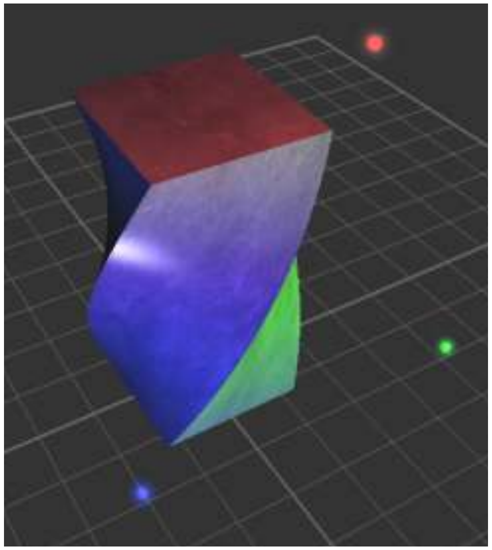


General Sweeps

- The path maybe any curve
- The polygon that is swept may be transformed as it is moved along the path
    - Scale, rotate with respect to path orientation, …



Cube



Twisted Cube

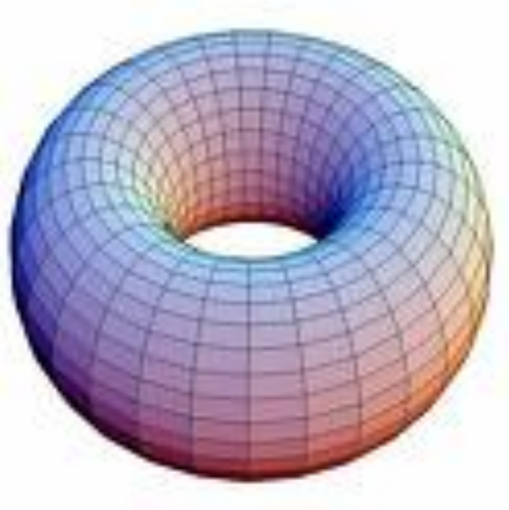
General Sweeps

- The path maybe any curve
- The polygon that is swept may be transformed as it is moved along the path
  - Scale, rotate with respect to path orientation, …

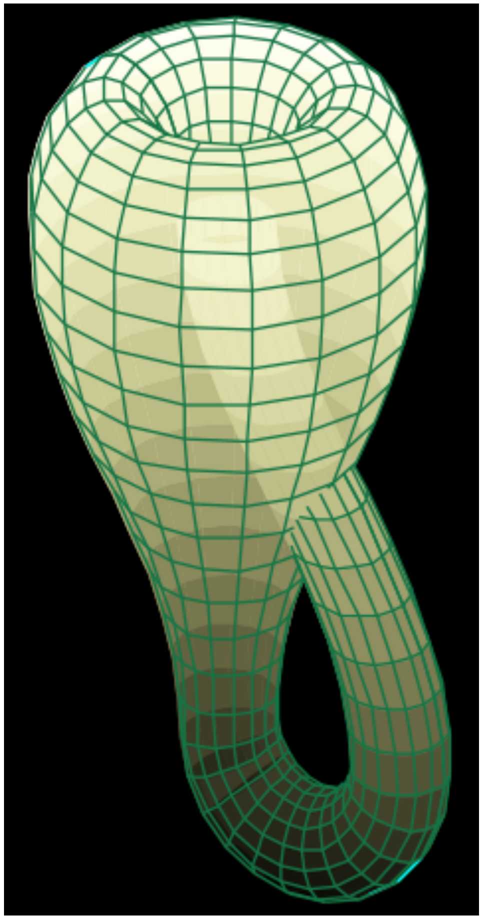
General Sweeps

- The path maybe any curve
- The polygon that is swept may be transformed as it is moved along the path
  - Scale, rotate with respect to path orientation, …
- One common way to specify is:
  - Give a poly-line (sequence of line segments) as the path
  - Give a poly-line as the shape to sweep
  - Give a transformation to apply at the vertex of each path segment
- Texture Coord?
- Difficult to avoid self-intersection

Klein Bottle

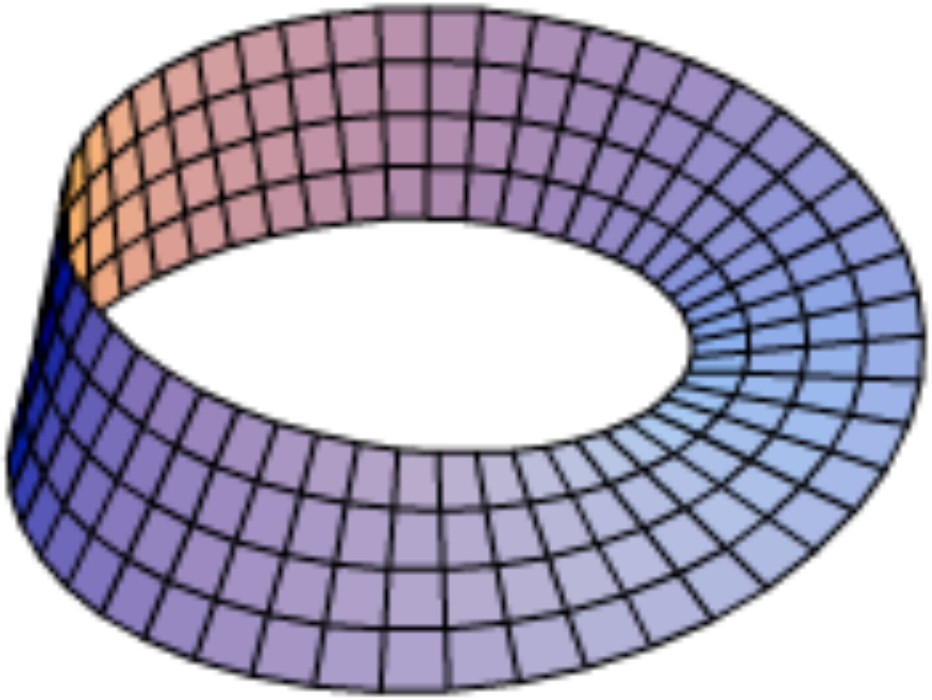


Torus



Klein Bottle

Mobious Strip



Non-orientable surfaces

Change Topology when Sweeping