CS 428: Fall 2010

Introduction to Computer Graphics

Polygonal meshes

Topic overview

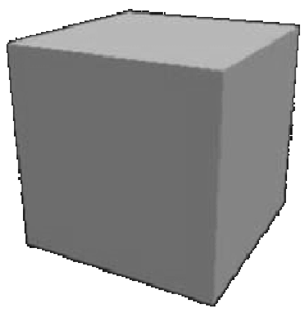
- Image formation and OpenGL
- Transformations and viewing
- **Polygons and polygon meshes**
  - **3D model/mesh representations**
  - **Piecewise linear shape approximations**
  - **Illumination and polygon shading**
- Modeling and animation
- Rendering

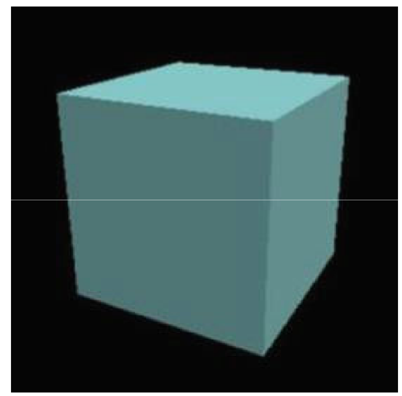
Polygon meshes

- Some objects are flat
- Some objects are smooth ← **approximate!**
  - Use many **planar** triangles/quadrilaterals to approximate the underlying smooth surface

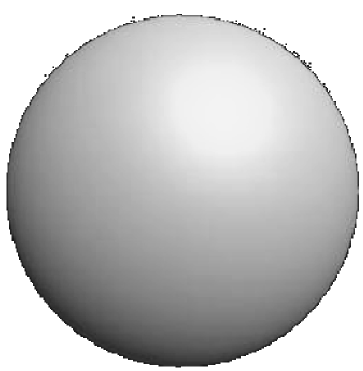
Approximating shapes with polygons

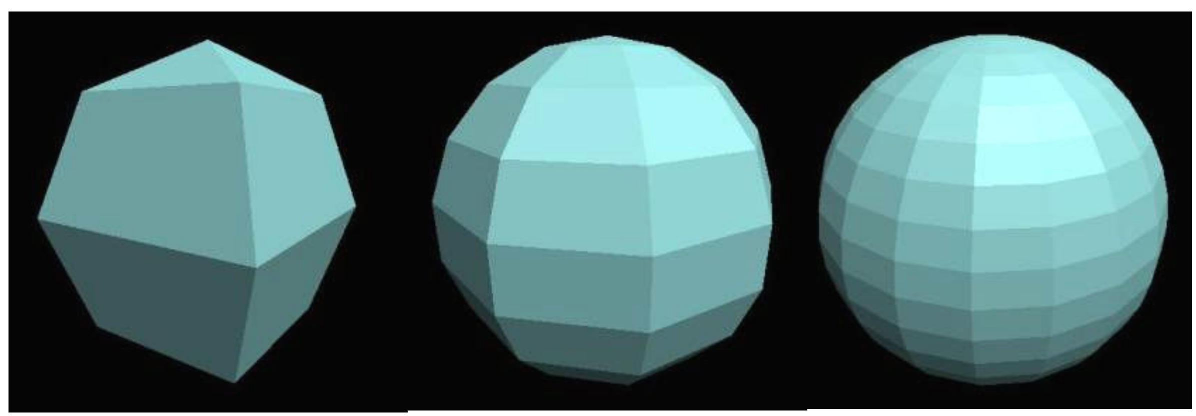
shape | **polygon mesh**





(exact)



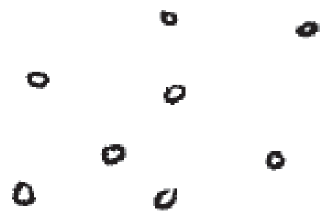


…

(approximated)

Polygon meshes

- Polygon mesh
  - Vertices

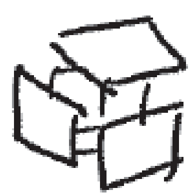


geometry (positions)

  - Edges

topology (connectivity)

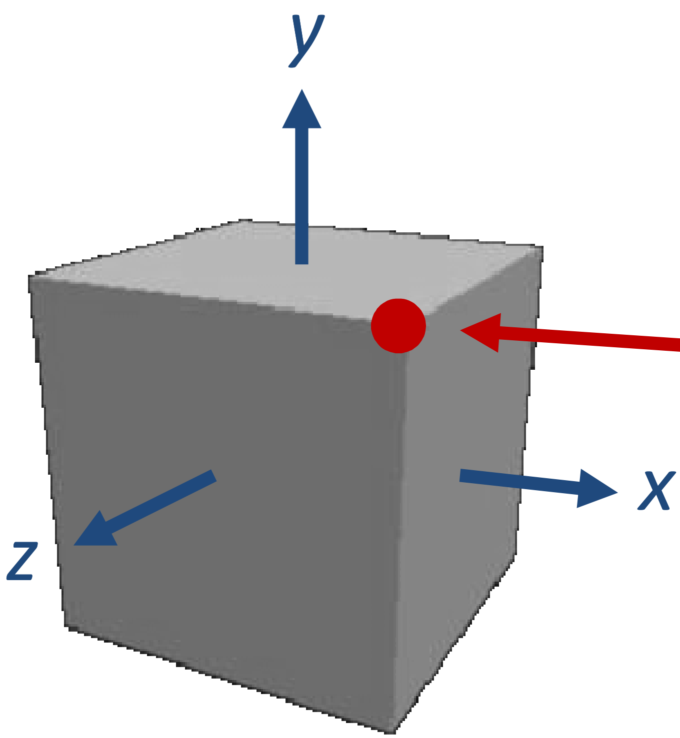
  - Faces



    - All three are redundant, but can lead to more efficient (neighborhood) computation

Representation

- Often just stored in a file
  - List of vertices $(x_1, y_1, z_1) \dots (x_n, y_n, z_n)$ followed by
  - List of polygons = ordered list of indices (1,2,3) …

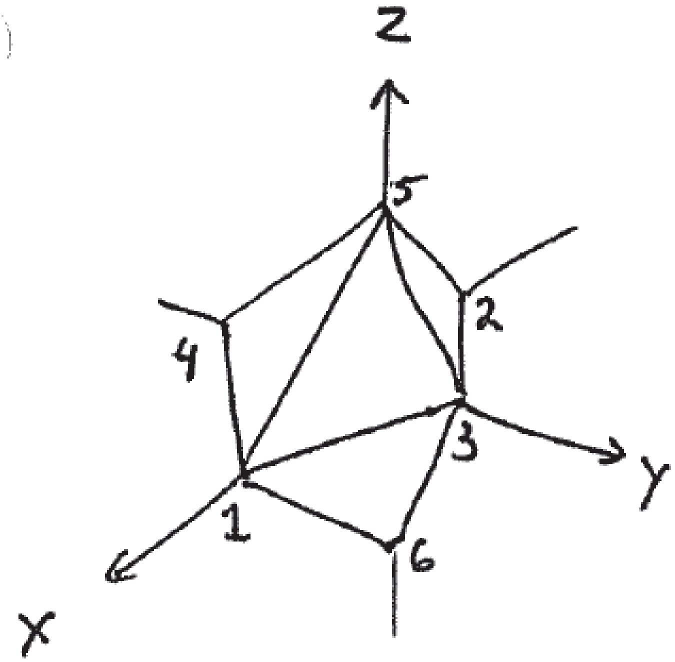


Vertices		**Polygons**
1	(-1, 1, 1)	{ 1, 2, 3, 4 }
2	(-1, -1, 1)	{ 8, 7, 6, 5 }
3	(1, -1, 1)	{ 4, 3, 7, 8 }
4	(1, 1, 1)	{ 5, 1, 4, 8 }
5	(-1, 1, -1)	{ 5, 6, 2, 1 }
6	(-1, -1, -1)	{ 2, 6, 7, 3 }
7	(1, -1, -1)	
8	(1, 1, -1)	

= Indexed face set

Representation

- Example: octahedron



	vertices	polygons
1	(1, 0, 0)	1, 3, 5
2	(-1, 0, 0)	3, 1, 6
3	(0, 1, 0)	4, 1, 5
4	(0, -1, 0)	1, 4, 6
5	(0, 0, 1)	3, 2, 5
6	(0, 0, -1)	2, 3, 6
		2, 4, 5
		4, 2, 6

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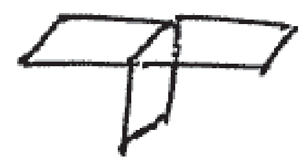
Connectivity

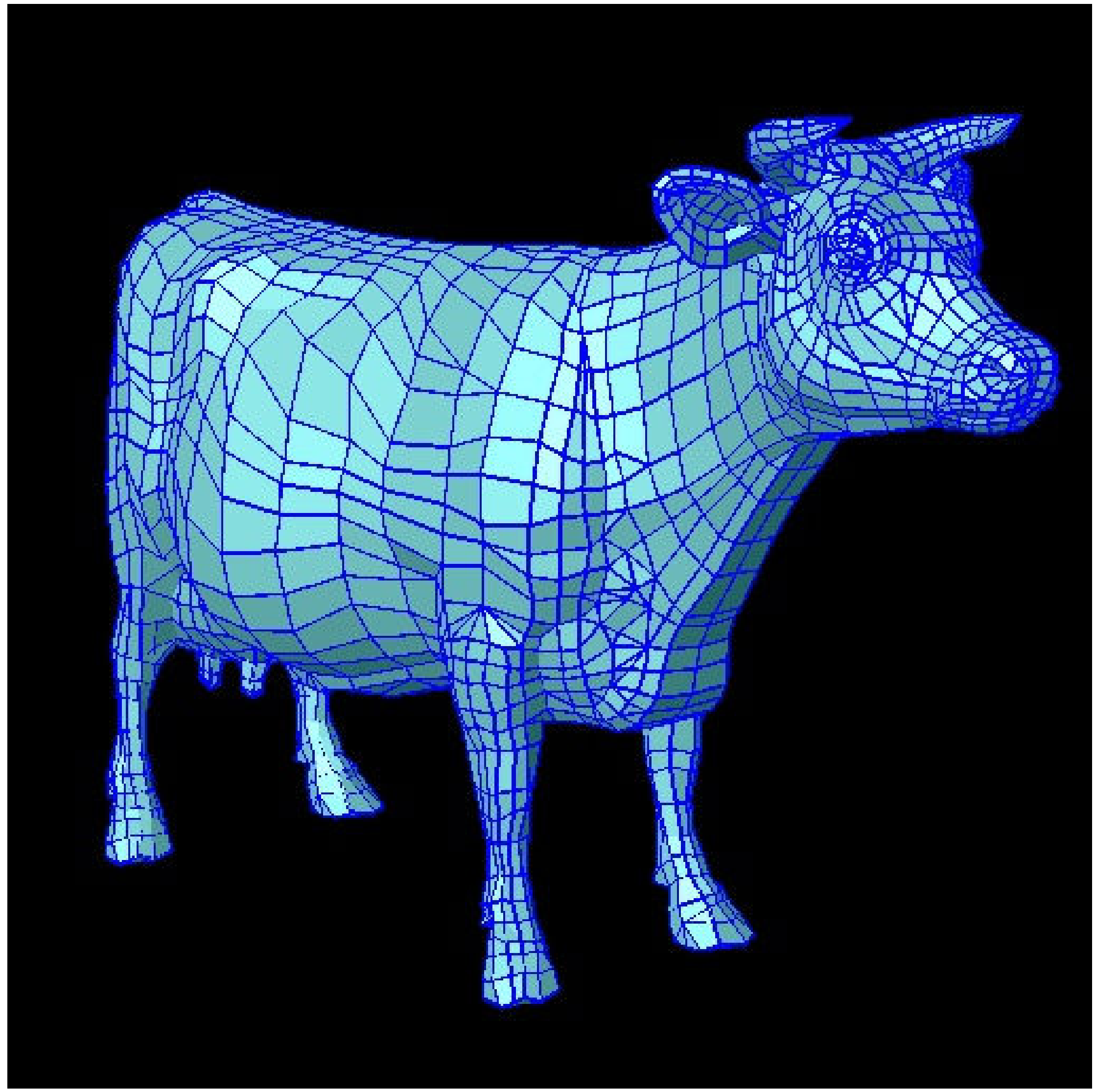
- Vertices and polygons are sufficient for rendering
- When adjacency information is needed
  - Edges: 2 vertices
  - 1 or 2 polygons, assuming no T-joins



  - Vertices store list of adjacent vertices, edges or polygons
  - Polygons store list of edges
- Sophisticated data structures exist (CS 523)

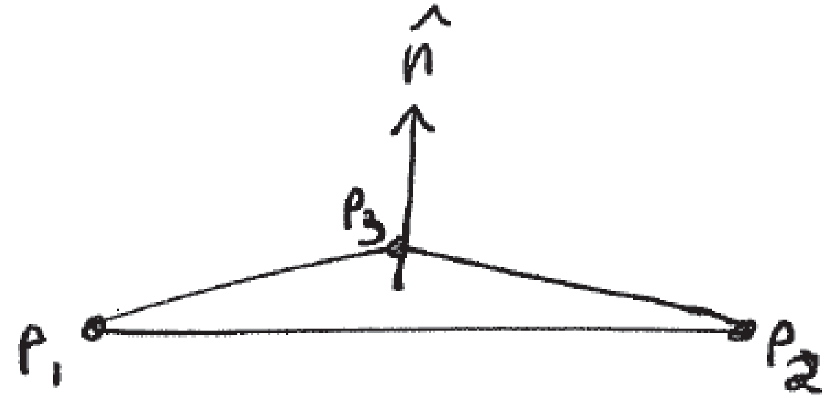
Polygon mesh example

2903 vertices
3263 polygons



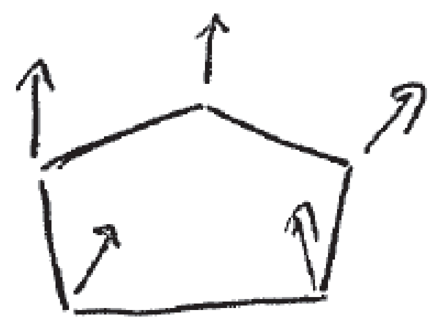
Polygon normals

- Triangles have a single normal vector



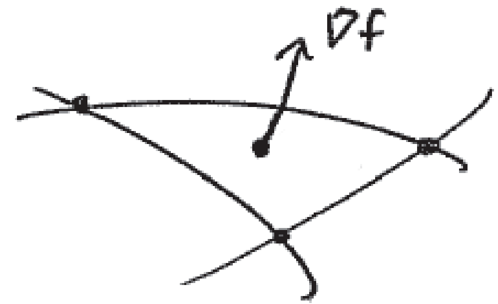
$$n = (p_1 - p_2) \times (p_1 - p_3)$$

- More than 3 points produces a normal at each vertex
  - If all points in a plane all normals are equal

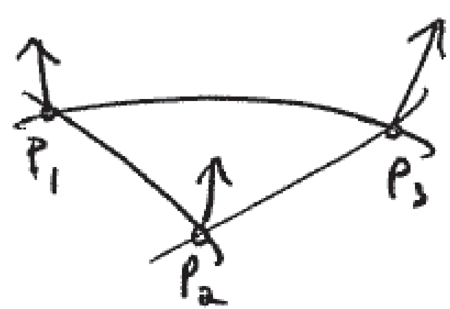


Polygon normals

- If the polygon is sampled from a surface, we can compute normals analytically
  - Disance field $f(x,y,z) = 0$ … a map from $R^3 \rightarrow R$
  - The gradient ∇f is the (un-normalized) normal at (x,y,z)

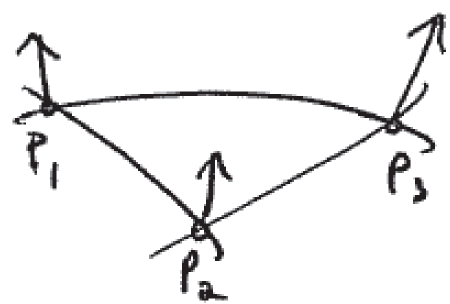


  - But we can find the normals at the vertices here
    - How?



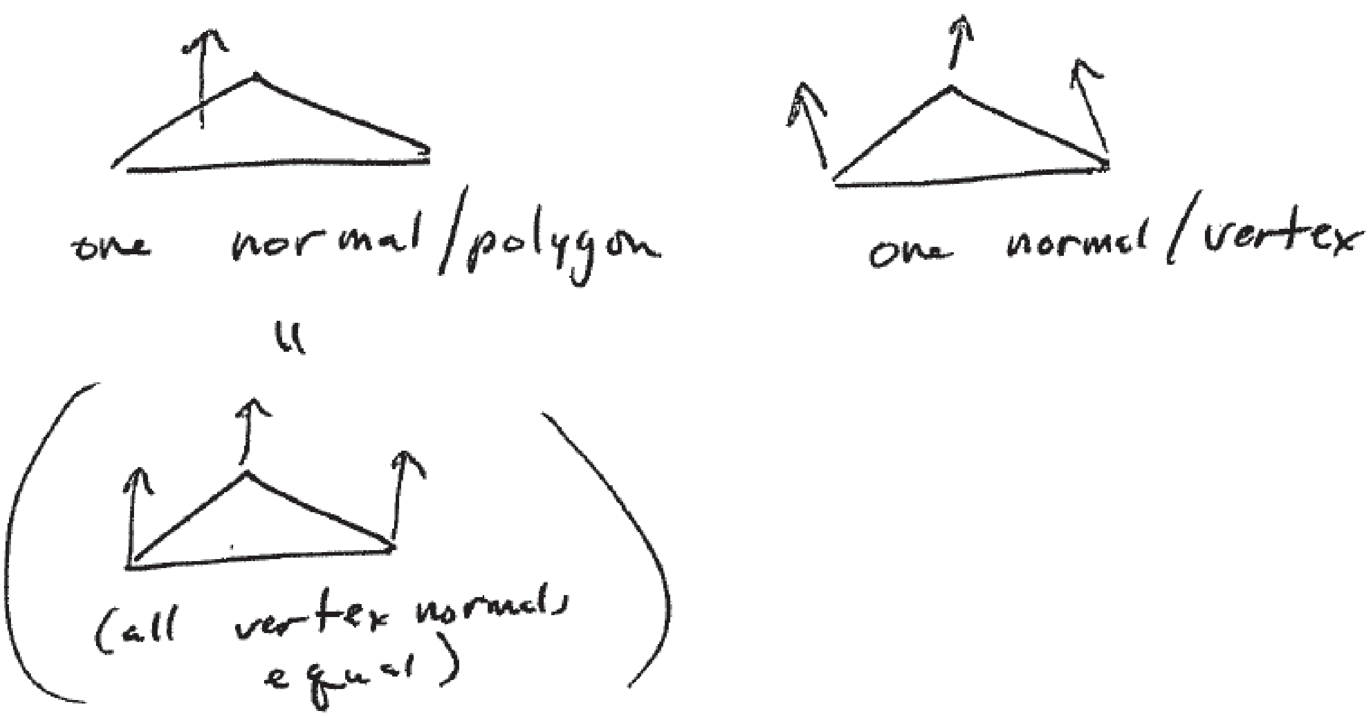
Vertex normals

- Average the normals of adjacent polygons
- For an arbitrary vertex
  - Compute the cross product between each two adjacent outgoing edges (= each adj. polygon)
  - Sum the resulting vectors into a single vector
  - Normalize this vector
- More sophisticated methods exist (CS 523)



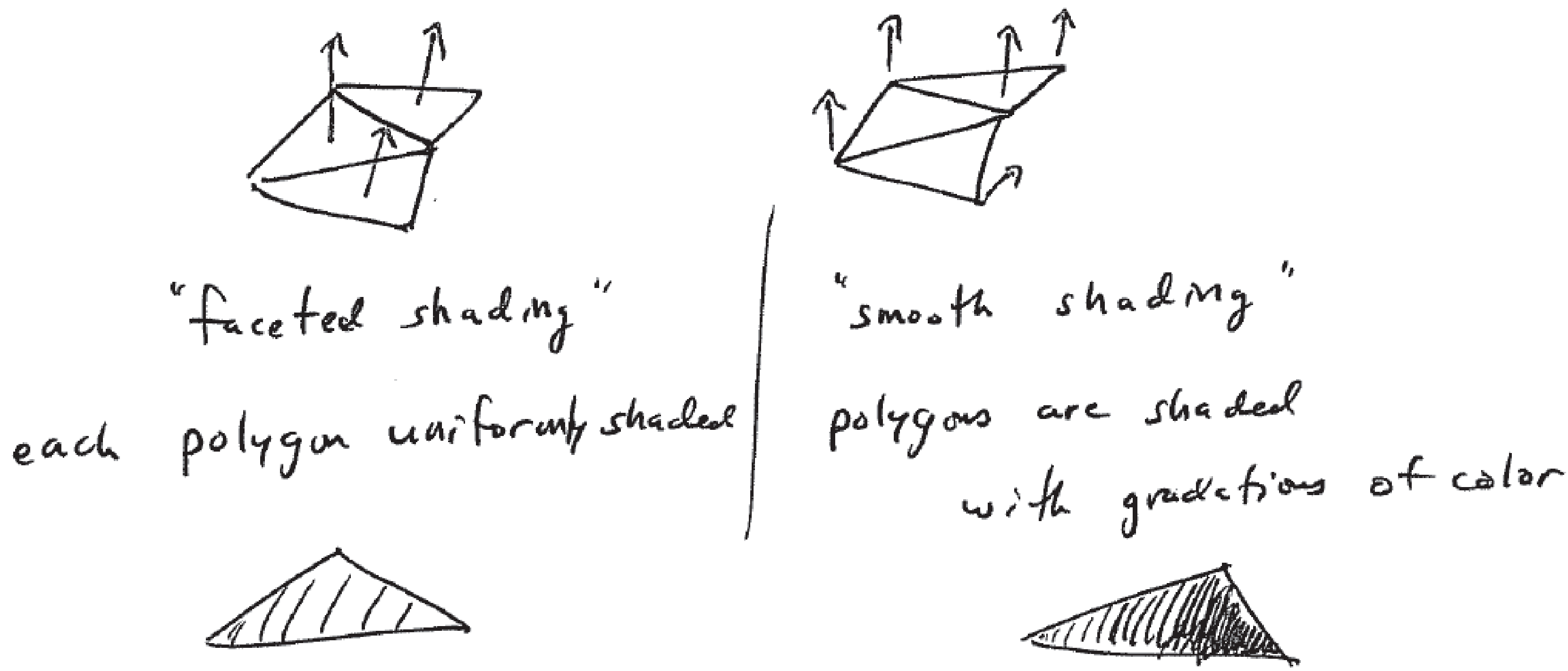
Polygon shading

- For now (more details later): normals are used for **shading** (= computing brightness values)
- One polygon



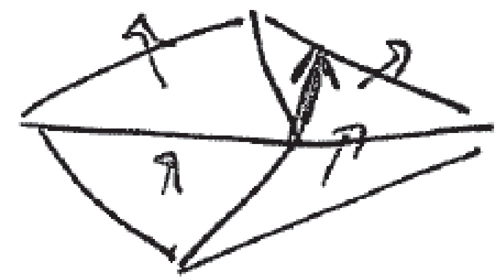
Polygon shading

- For now (more details later): normals are used for **shading** (= computing brightness values)
- Multiple polygons



Smooth shading

- Find average normal of adjacent polygons



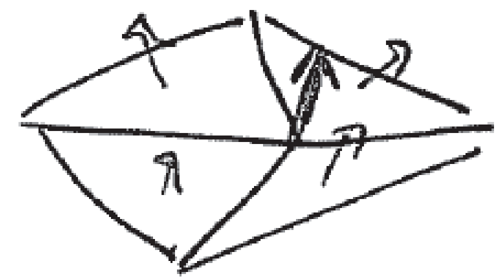
- How to compute?

$$\hat{n}_{avg} = \left(\sum_{\substack{i \in \text{adj} \\ \text{polygon}}} \hat{n}_i \right)$$

normalize

Smooth shading

- Find average normal of adjacent polygons
- Do we need a list of adjacent polygons?
  - Not if we want to compute **all** avg. normals
- This can be performed from an indexed face set on reading the file



[compute $\hat{n}_i$ for each face

$\forall$ nodes j

$(\hat{n}_{avg})_j = 0$

$\forall$ faces k

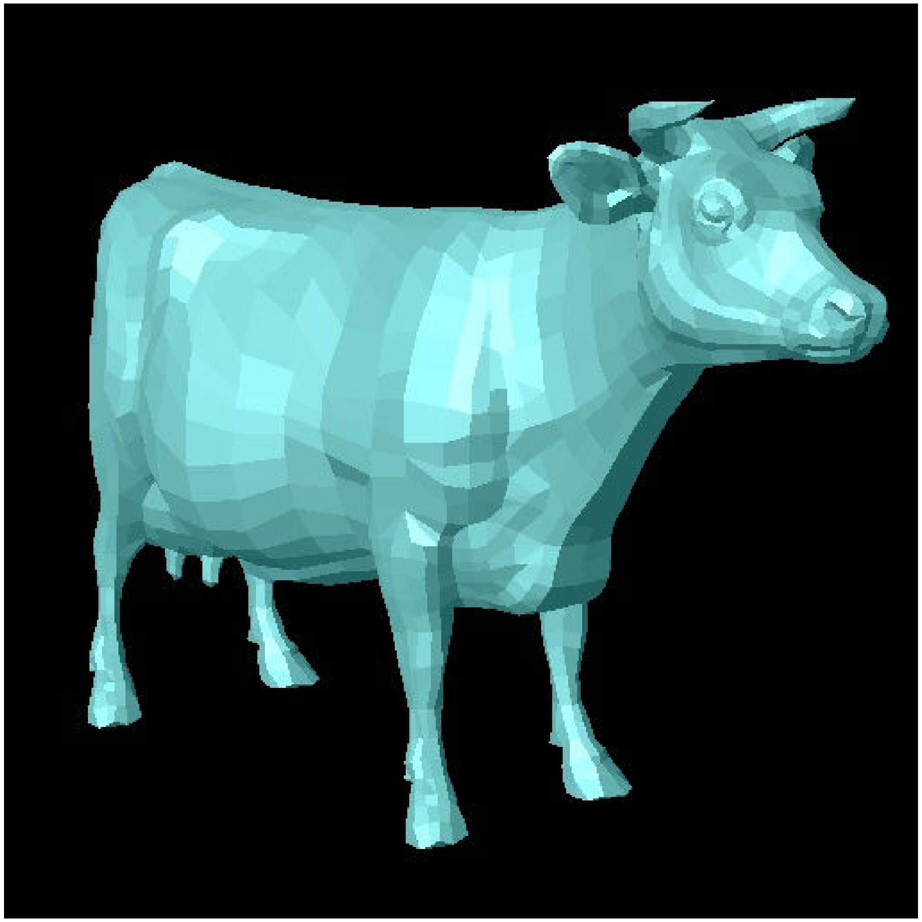
$\forall$ verts ℓ in face k

$(n_{avg})_\ell \mathrel{+}= \hat{n}_k$

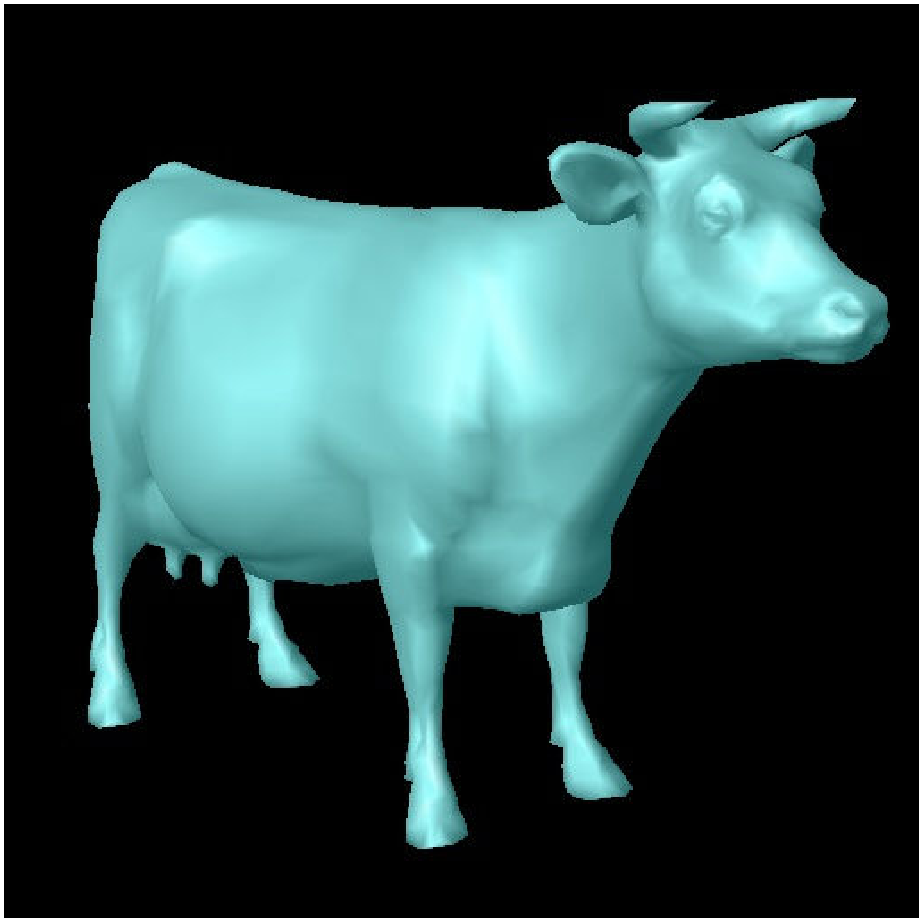
$\forall$ nodes j

normalize $(\hat{n}_{avg})_j$

Mesh rendering styles

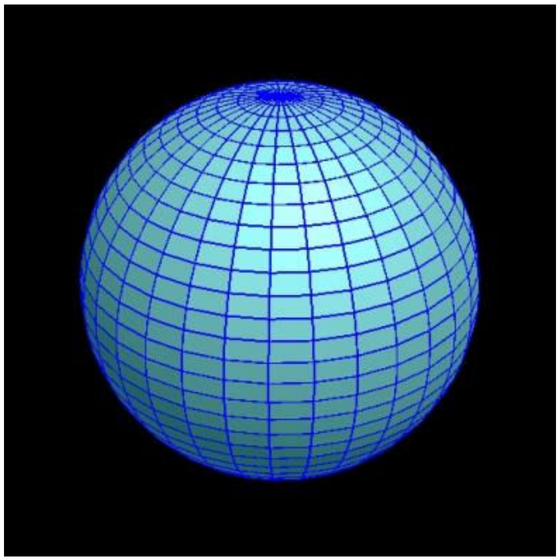


Flat (faceted) shading

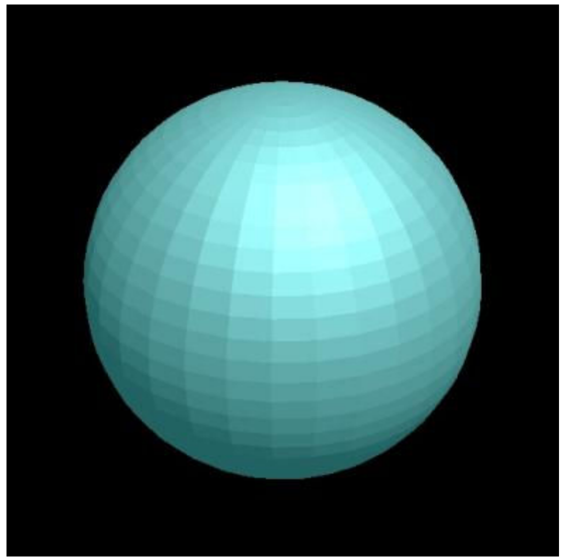


Smooth (Gouraud) shading

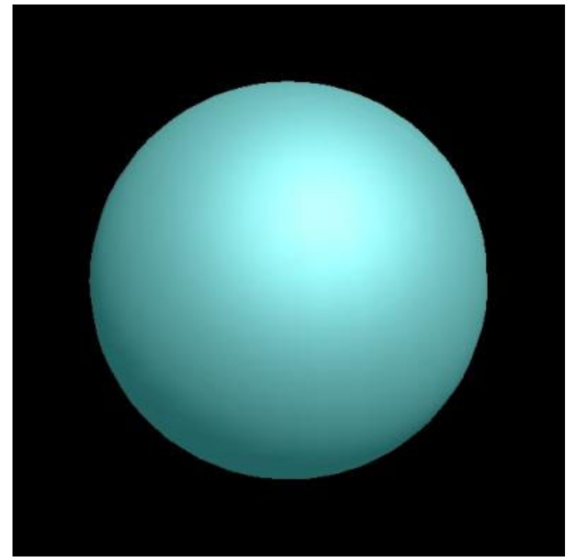
Sphere



Polygons and wireframe



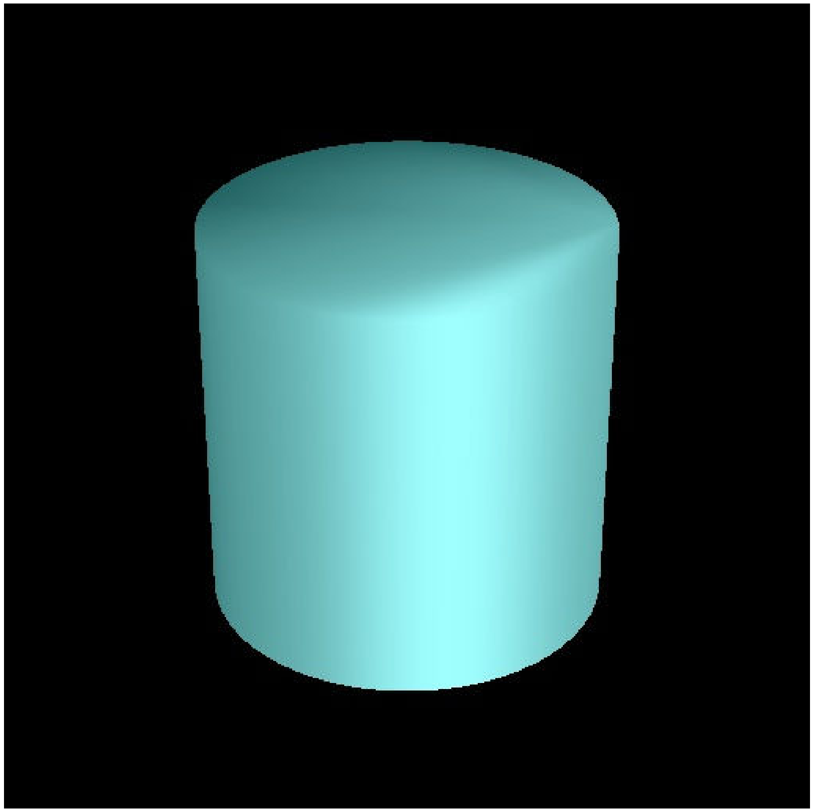
Flat



Smooth

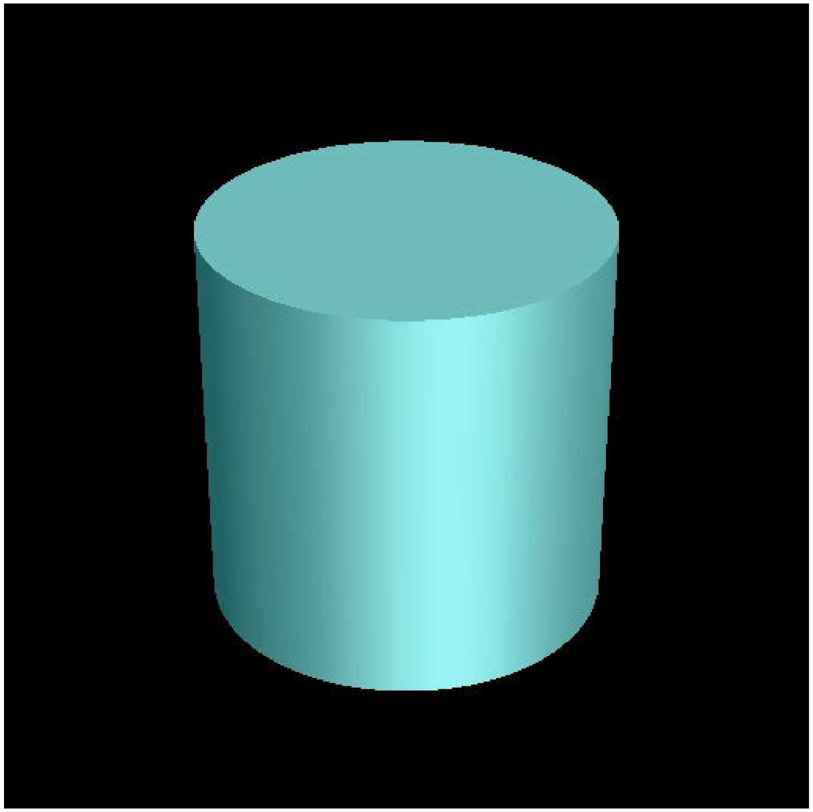
Vertex normals and smooth shading

Creases lost



Normal stored in vertex

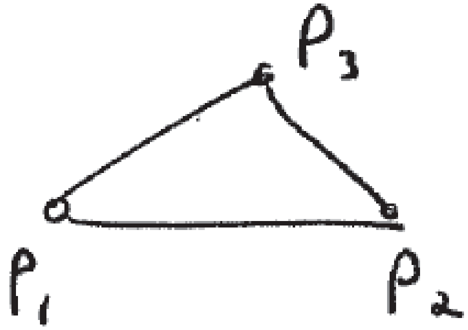
Creases retained



Normals stored in polygon (per vertex)

Polygon/surface orientation

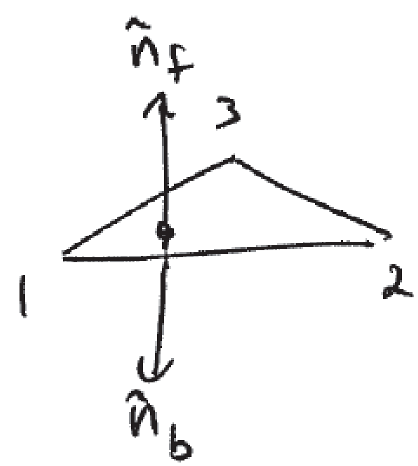
- Order of vertices specifies a polygon
- Backwards and forwards = same polygon



$$f = \{(1,2,3), (2,3,1), (3,1,2)\}$$

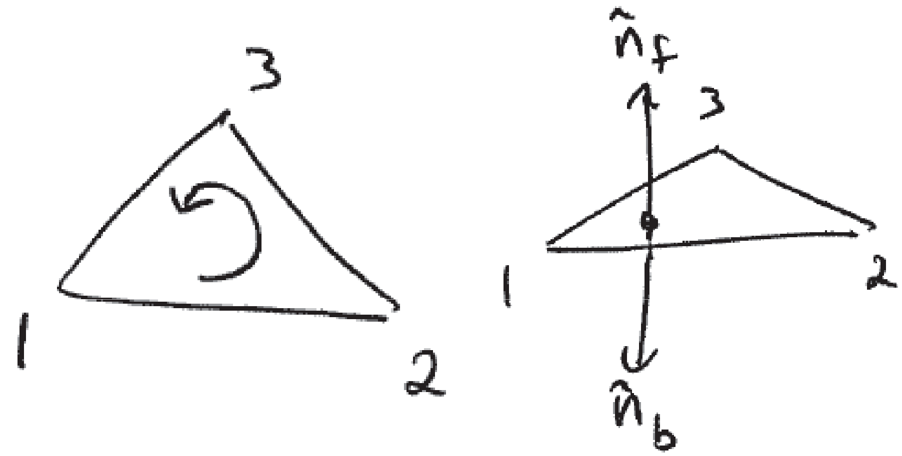
$$b = \{(3,2,1), (2,1,3), (1,3,2)\}$$

- But the normal direction flips



Polygon/surface orientation

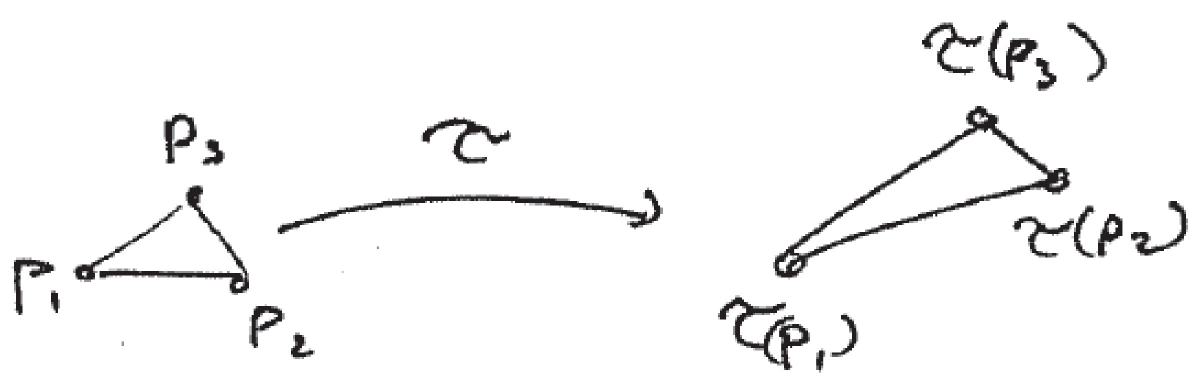
- Use right-hand rule to determine normal direction
  - Counter clockwise: normal comes out of “slide”
  - Convention: list vertices in CCW order



- Mesh should be consistently oriented
  - All point out!

Polygon transformation

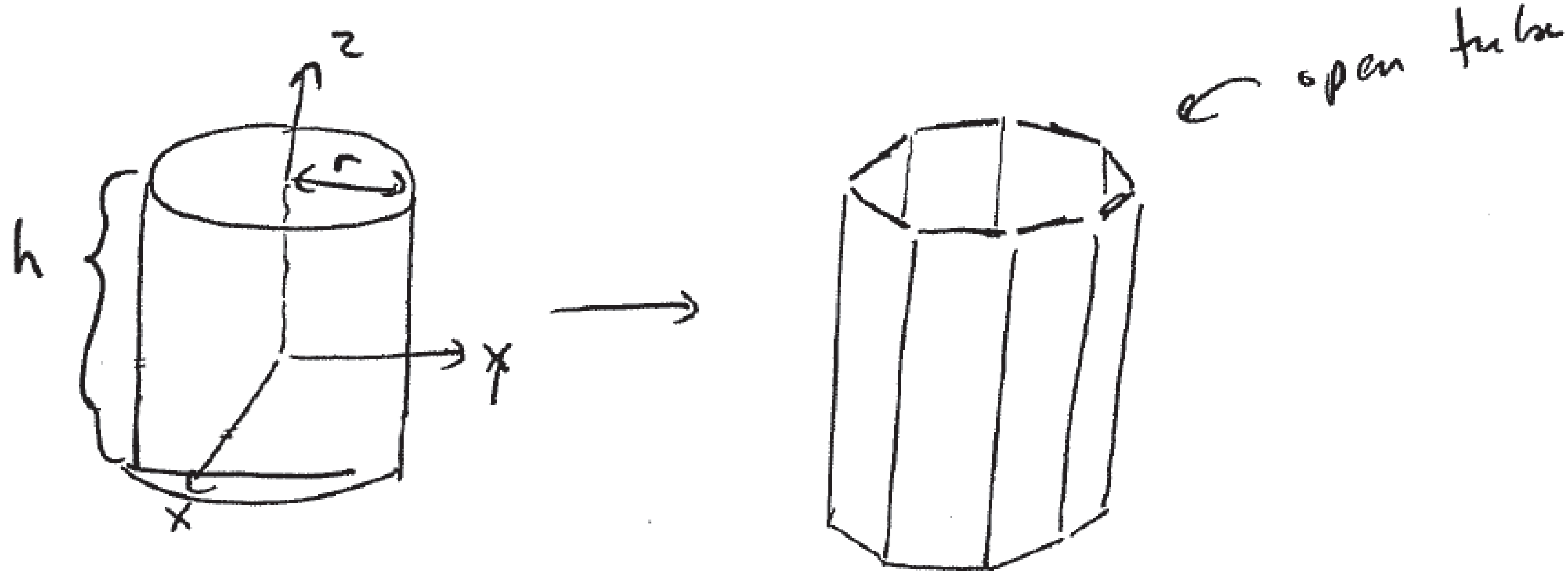
- Transform points



- Draw polygon using these
  - Affine transformations map lines to lines (planes to planes, etc.)

Meshes from smooth surfaces

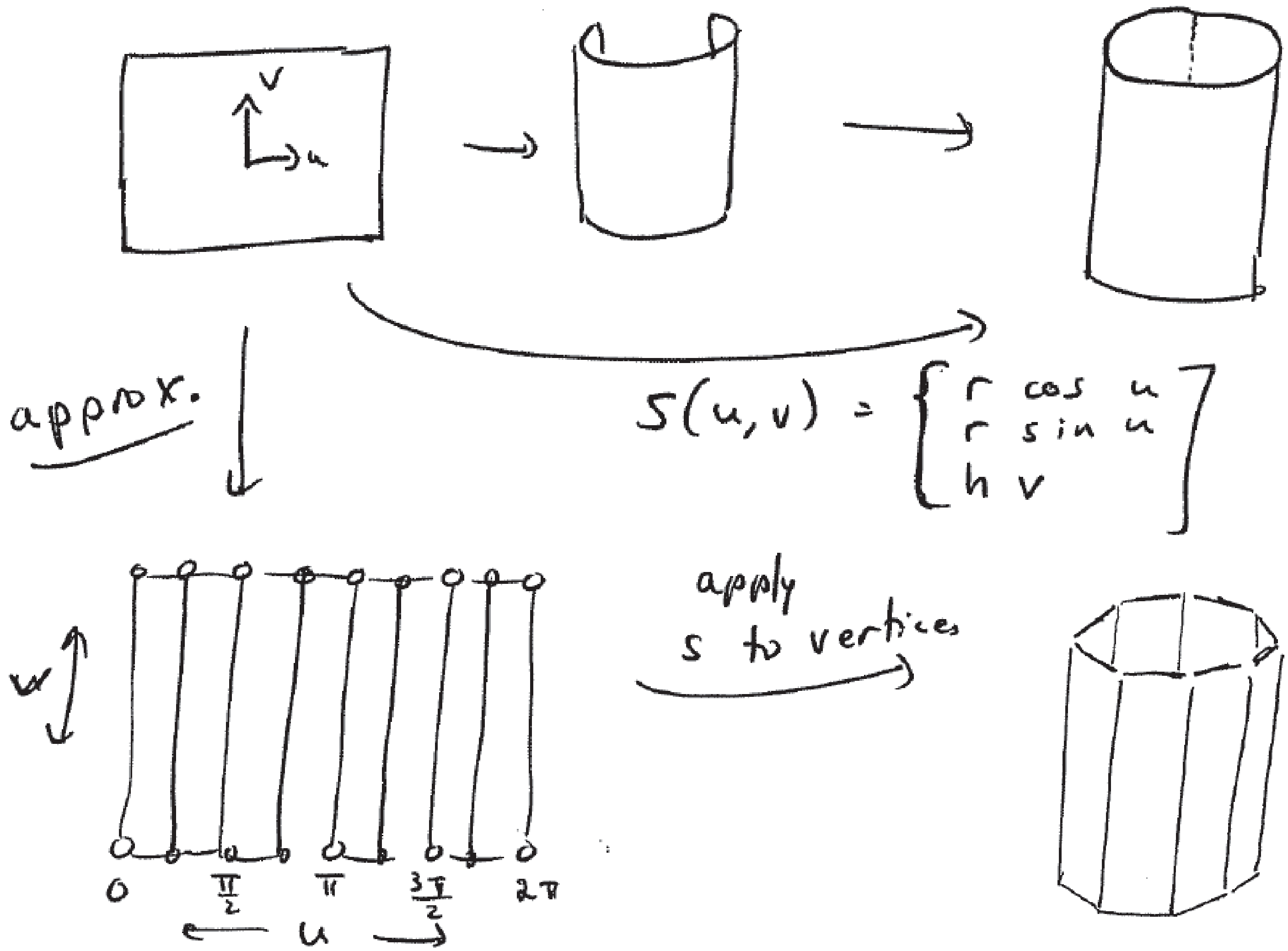
Tessellation



$$x = r\cos u \qquad u \in [0, 2\pi)$$
$$y = r\sin u \qquad v \in [0, 1]$$
$$z = h\,v$$

Meshes from smooth surfaces

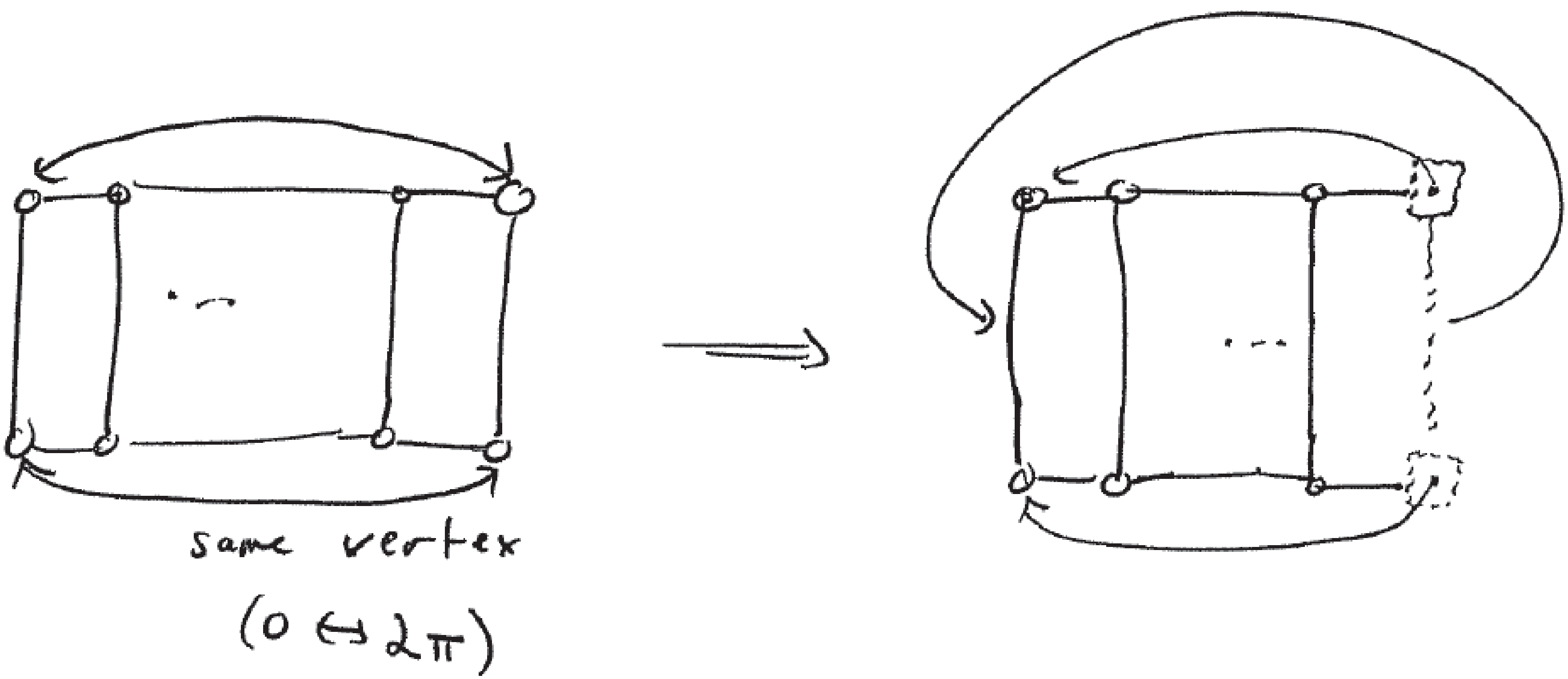
Tessellation



Meshes from smooth surfaces

Tessellation

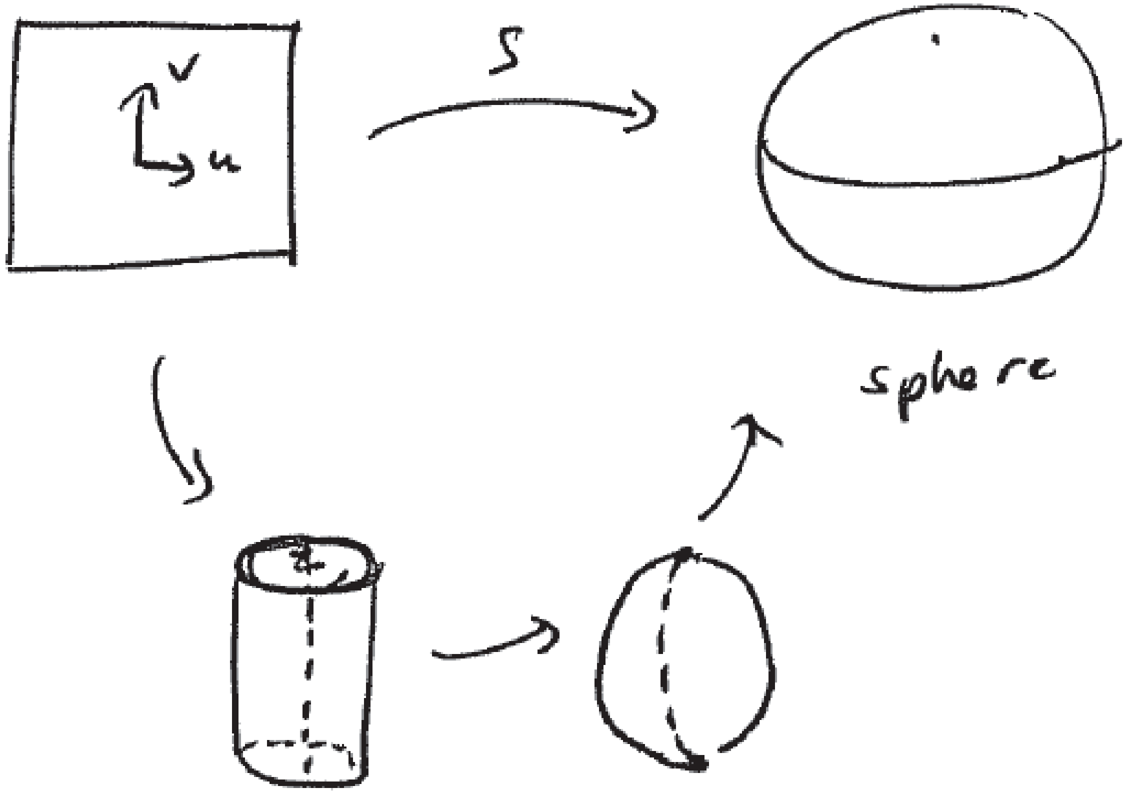
- What about the seam?



Meshes from smooth surfaces

Tessellation

- This can get much more complicated



can be r_1, r_2, r_3

$$S(u,v) = \begin{bmatrix} a_x \cos u \cos v \\ a_y \sin u \cos v \\ a_z \sin v \end{bmatrix}$$

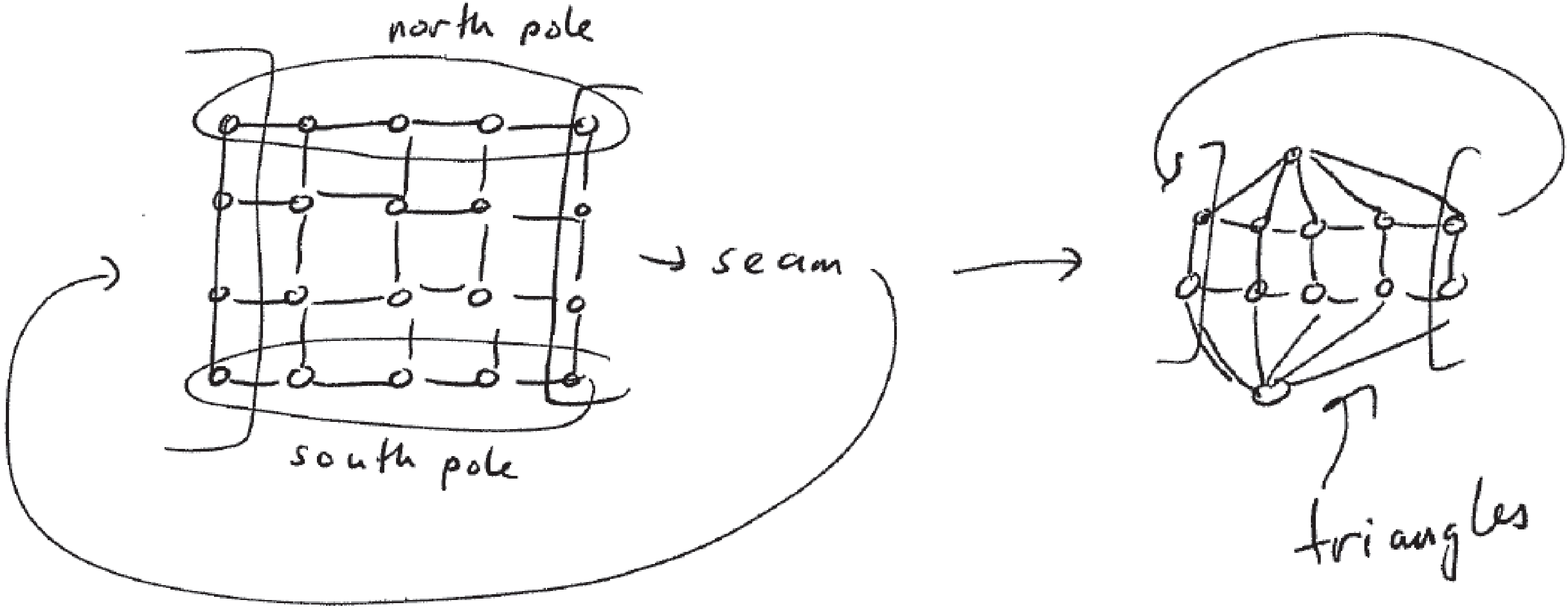
$u \in [0, 2\pi)$ long.

$v \in [-\frac{\pi}{2}, \frac{\pi}{2}]$ lat.

Meshes from smooth surfaces

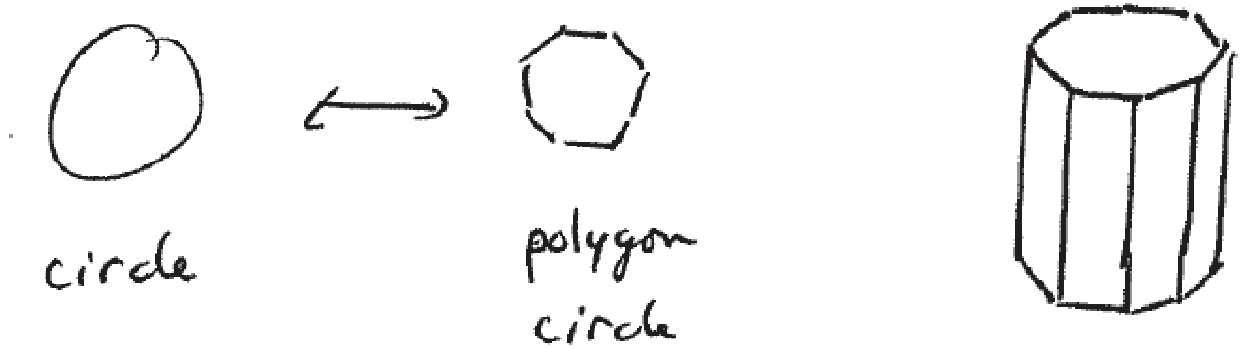
Tessellation

- This can get much more complicated

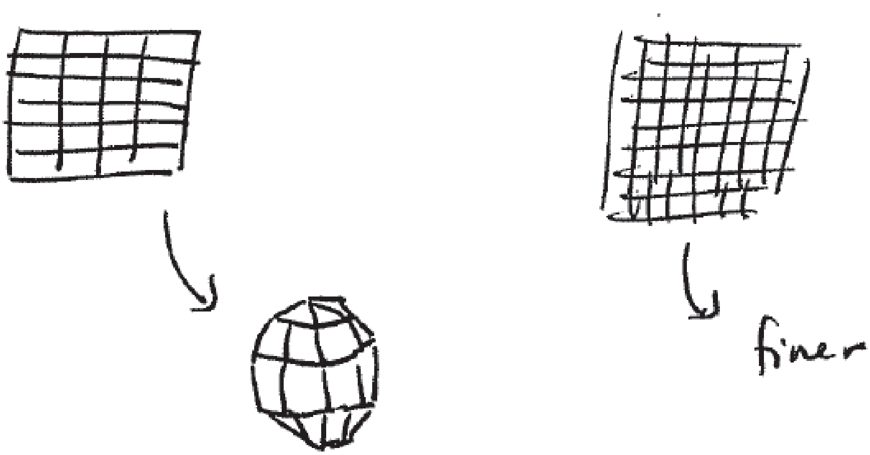


Tessellation resolution

- How many points to use?

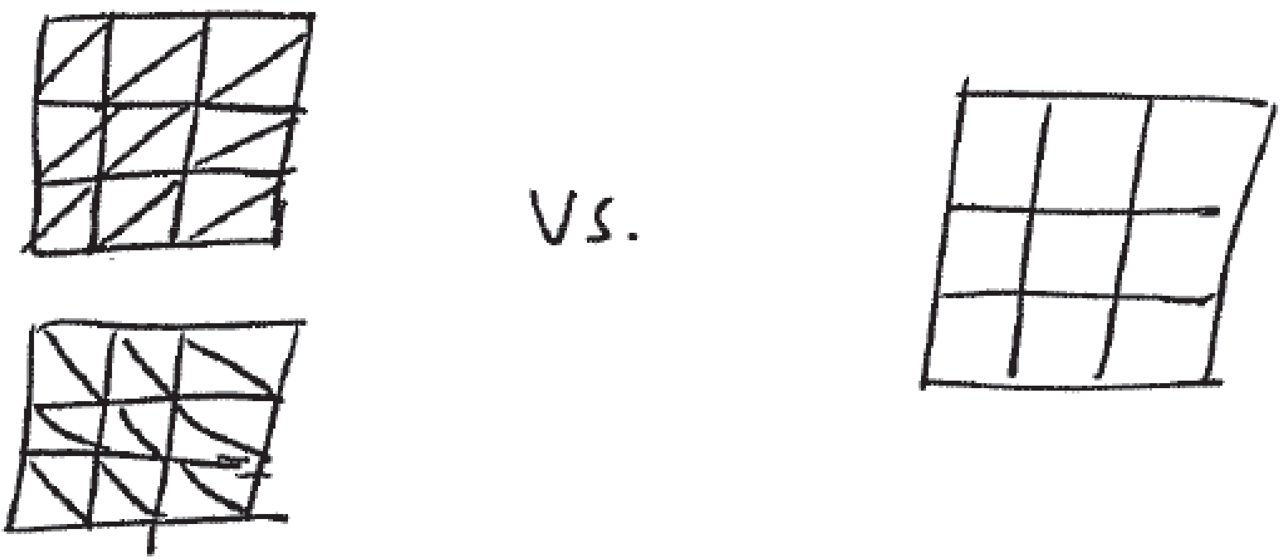


- How many faces ↔ how fine is the uv grid



Tessellation resolution

- Triangles vs. quadrilaterals



- Triangles always planar
- Some triangles collapse in sphere

- Not always planar
- Sometimes better for surface modeling