Subdivision

Project Overview

Surface Subdivision

- Start with Polygon Mesh
- Refine mesh by creating new faces and vertices
- Repeat

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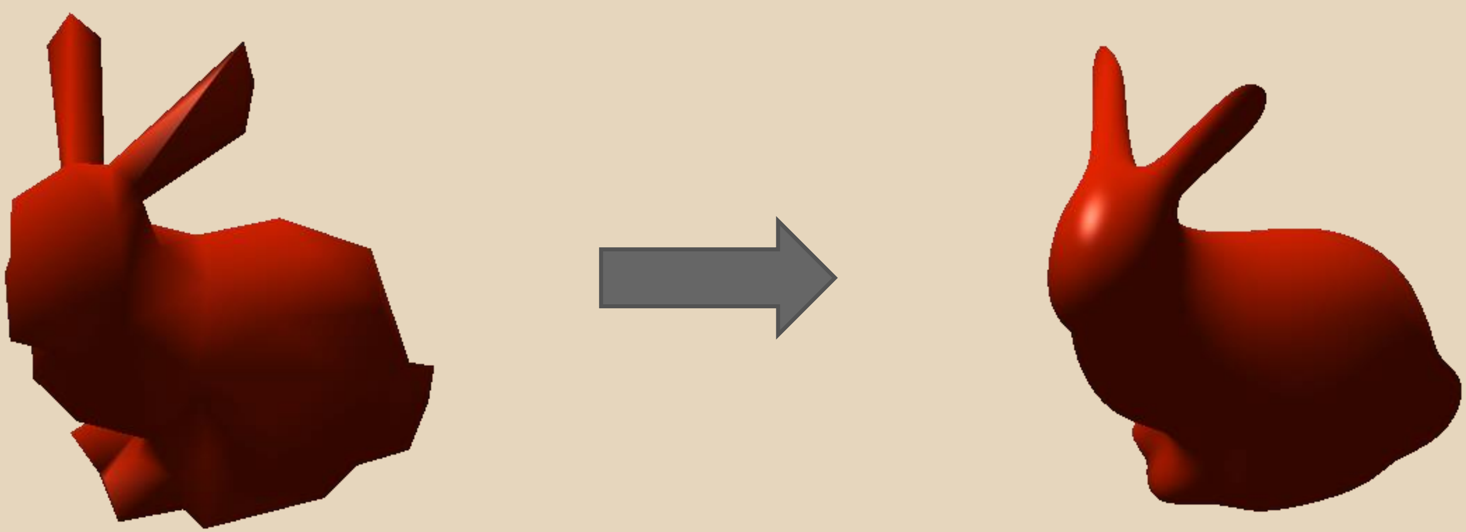
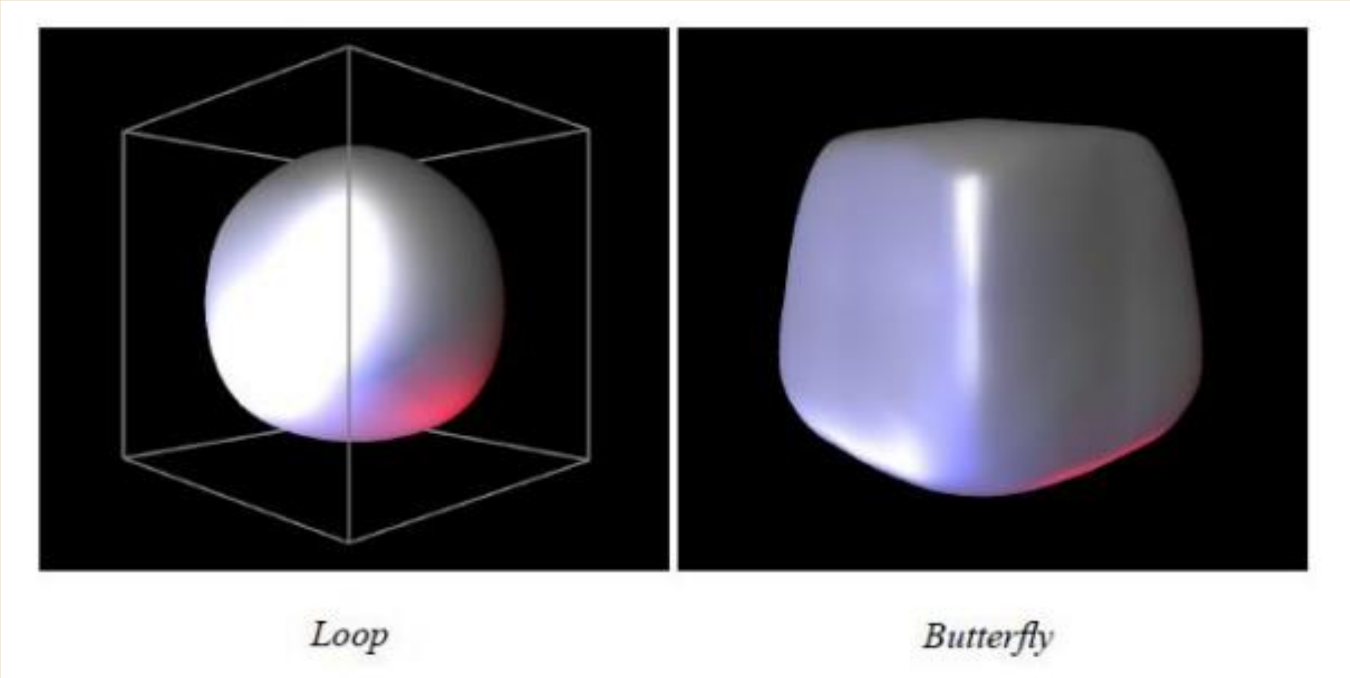


Subdivision

- Many different algorithms
  - Approximating v. Interpolating
  - Face Splitting v. Vertex Splitting
  - Continuity properties of final surface



Subdivision

- Face split vs. Vertex split

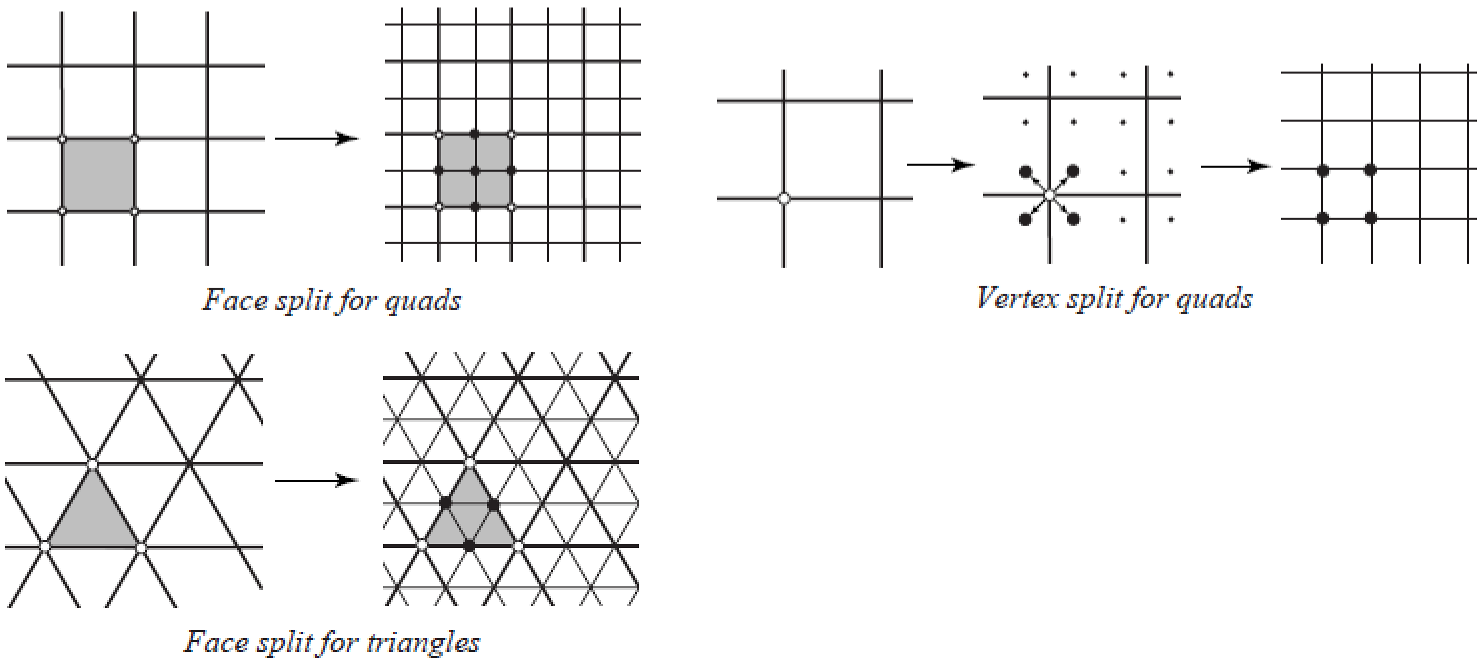
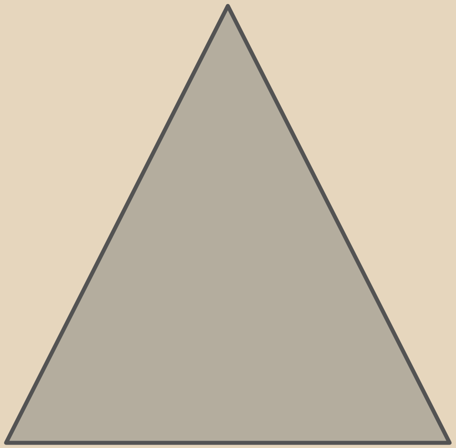


Figure 4.1: *Different refinement rules.*

Loop Subdivision

- Approximating
- Face Splitting
- C2 continuity on regular meshes



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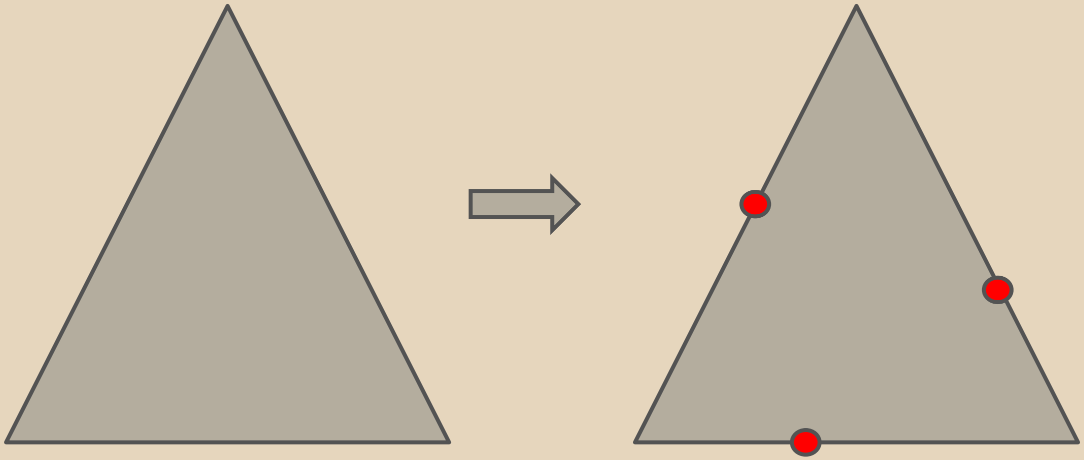

Loop Subdivision

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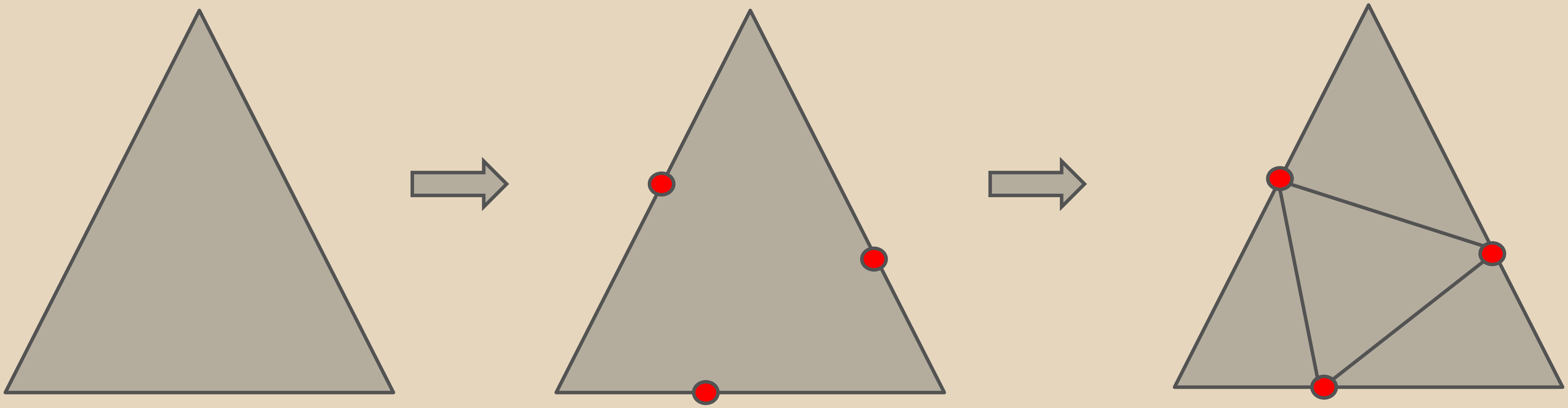
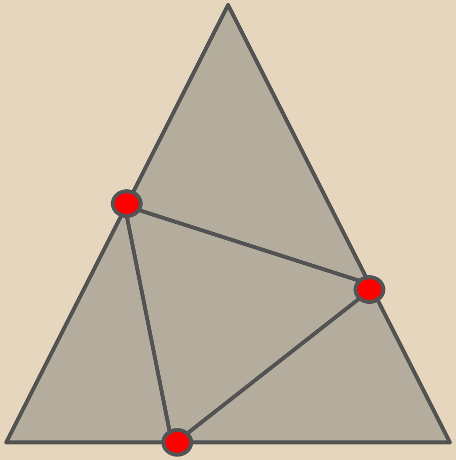


Loop Subdivision

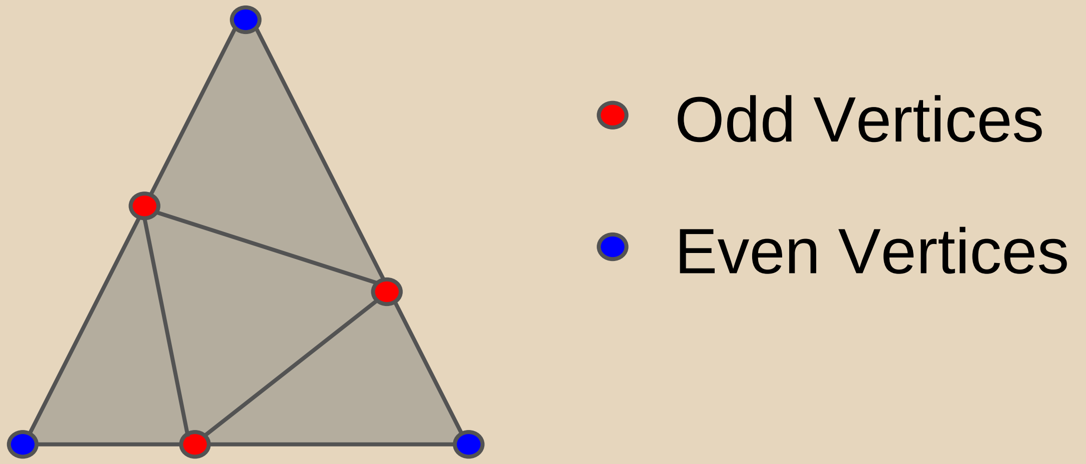
- Newly created vertices are called **odd vertices**



- Odd Vertices

Loop Subdivision

- Newly created vertices are called **odd vertices**
- Original vertices are called **even vertices**



Loop Subdivision

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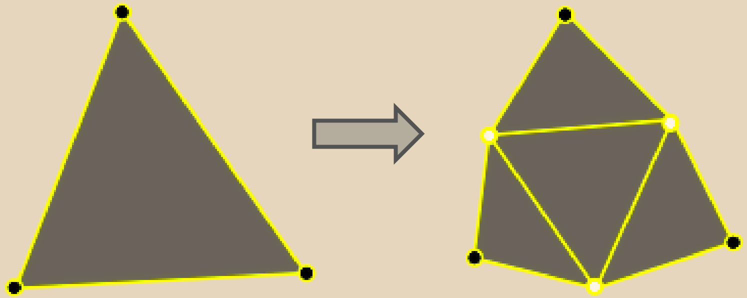
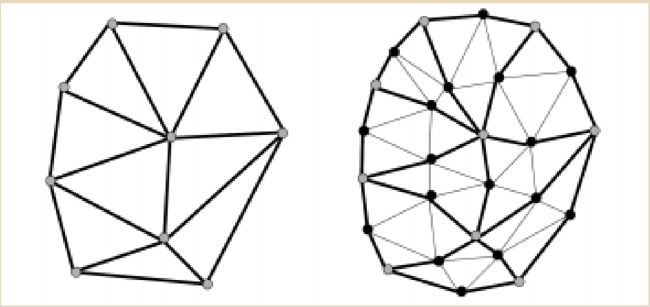
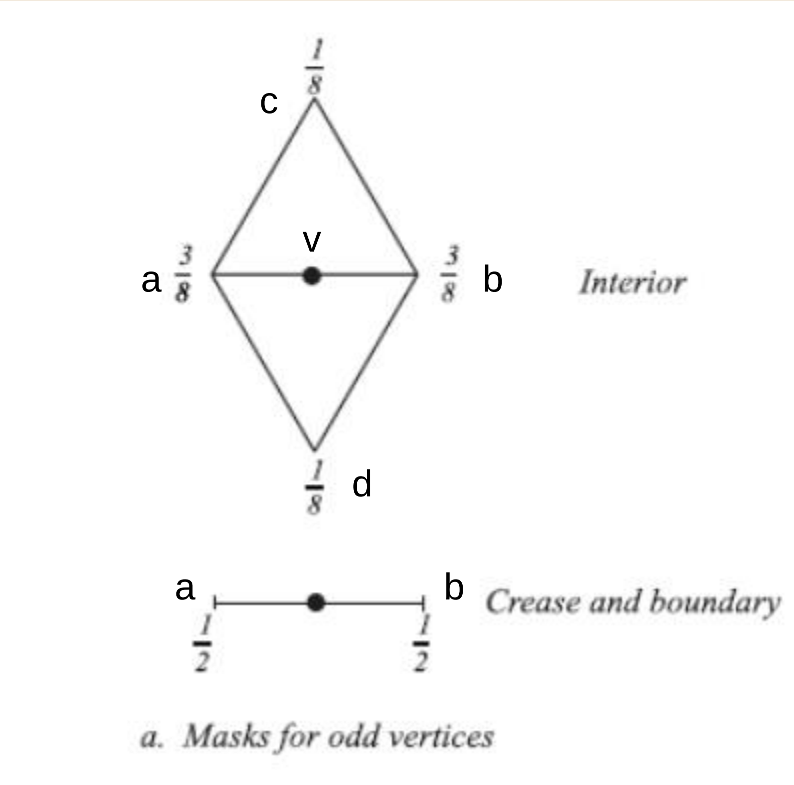




http://ezekiel.vancouver.wsu.edu/~cs442/lectures/winged-edge/subdivision/subdivision.html
http://www.cs.dartmouth.edu/~fabio/teaching/graphics08/lectures/10_SubdivisionSurfaces_Web.pdf

Loop Subdivision

- Computing odd vertices



Interior:

```
v = 3.0/8.0*(a + b)+
    1.0/8.0*(c + d)
```

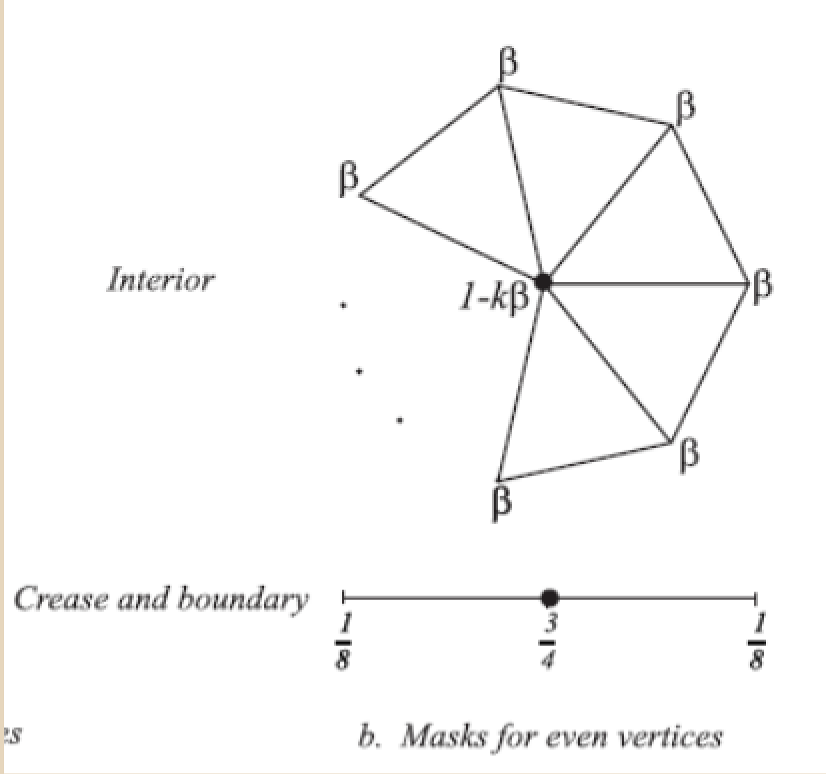
Boundary:

```
v = 1.0/2.0*(a + b)
```

Notice that to compute v we need some to know the nearby vertices.

Loop Subdivision

- Computing even vertices



Interior:

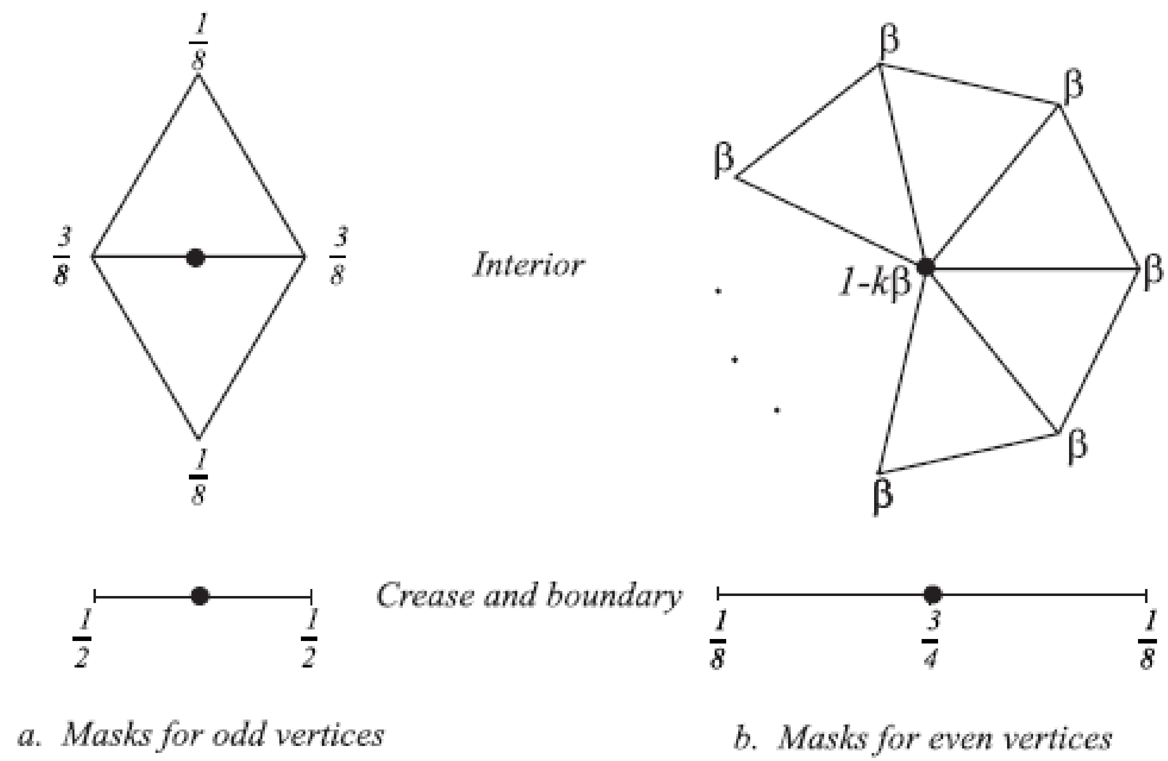
```
v = v*(1-k*BETA) +
(sum of all k neighbor
vertices)*BETA
```

Boundary:

```
v = 1.0/8.0*(a + b) +
    3.0/4.0*(v)
```

Notice that to compute v we need know all neighboring vertices

Loop Subdivision - Picking Beta



a. Masks for odd vertices

b. Masks for even vertices

Figure 4.3: *Loop subdivision: in the picture above,* β *can be chosen to be either* $\frac{1}{n}(5/8-(\frac{3}{8}+\frac{1}{4}\cos\frac{2\pi}{n})^2)$ *(original choice of Loop [16]), or, for* $n > 3$, $\beta = \frac{3}{8n}$ *as proposed by Warren [33]. For* $n = 3$, $\beta = 3/16$ *can be used.*

Loop Subdivision

- Computing odd vertices
- Computing even vertices

Important:

1. We need to be able to query adjacency information about the mesh.
2. We need to be able to tell if a vertex is a boundary or interior vertex.

Loop Subdivision

Algorithm (one iteration)

1. Build adjacency data structure

    Tricky

2. Compute odd vertices

    Straightforward once you finish step 1.

3. Compute even vertices

    Straightforward once you finish step 1.

4. Rebuild mesh / Connect vertices to create new faces

    Similar to Project 1 (when you created a mesh from a heightmap)

Adjacency Data Structure

What properties do you want?

- Efficient traversal and lookup
  - `get_adjacent_faces(&mesh, &edge)`
  - `get_neighbor_vertices(&mesh, &vertex)`
- Efficient memory usage
- Efficient creation and update

Adjacency Data Structure

What data do you need in the structure?

Mesh Data

- Some combination of Vertices, Faces, Edges
- Adjacency information

Loop Subdivision Metadata

- implicit
  - all edges of index < i have been subdivided
- explicit
  - `if (!mesh.edge[i].is_subdivided) ...`

Adjacency Data Structure

Useful Mesh Attributes

- Every triangle has 3 vertices
- Every triangle is adjacent to up to 3 other triangles

Adjacency Data Structure

Useful Mesh Attributes

- Every triangle has 3 vertices
- Every triangle is adjacent to up to 3 other triangles
- A given vertex has N neighbor vertices
- The same vertex is part of either N-1 or N triangles
  - *Why?*
  - *There is a useful implication of this for Loop Subdivision*

Adjacency Data Structure

Useful Adjacency Attributes

- Triangle -> Vertex
- Triangle -> Triangle

- Vertex -> Vertex
- Vertex -> Triangle

This is a simple representation that can handle the queries you need.

Adjacency Data Structure

Implementation

- How you implement (storing and building) the adjacency data structure can be more important than what you represent.
- Stick to C data structures (arrays and structs) for the best speed
- Be mindful that `malloc/new` and `free/delete` are slow

Other Subdivision Algorithms

- Modified Butterfly: interpolating algorithm

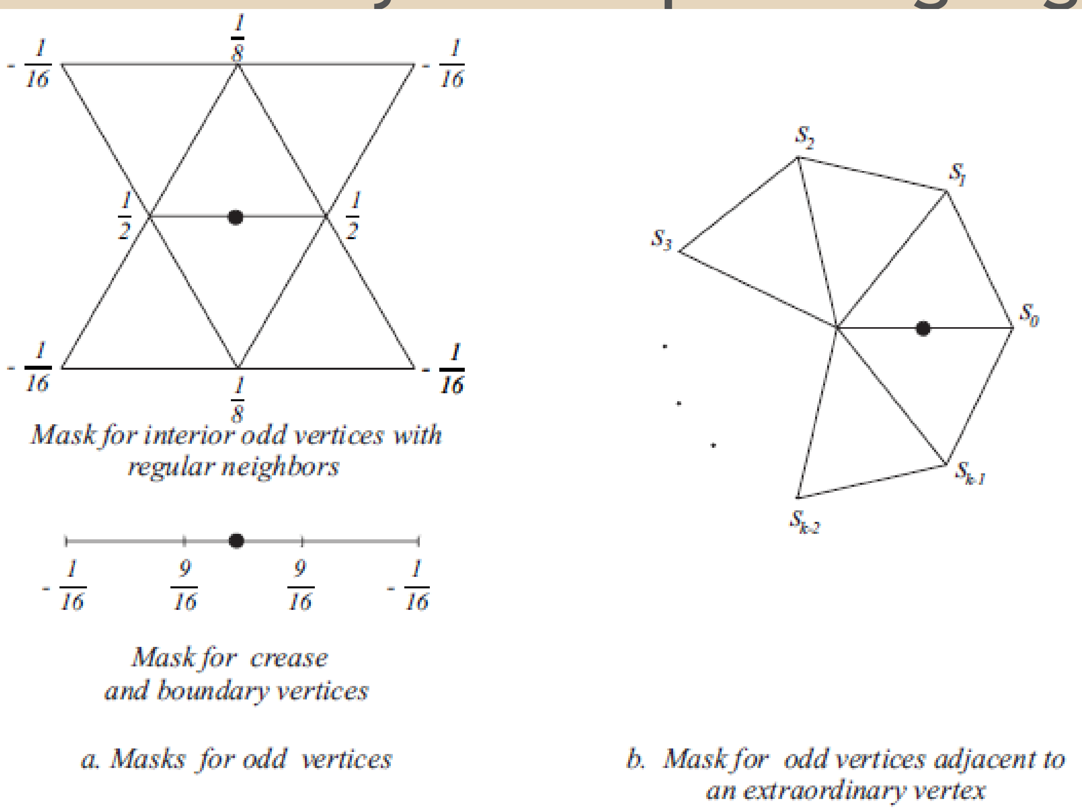
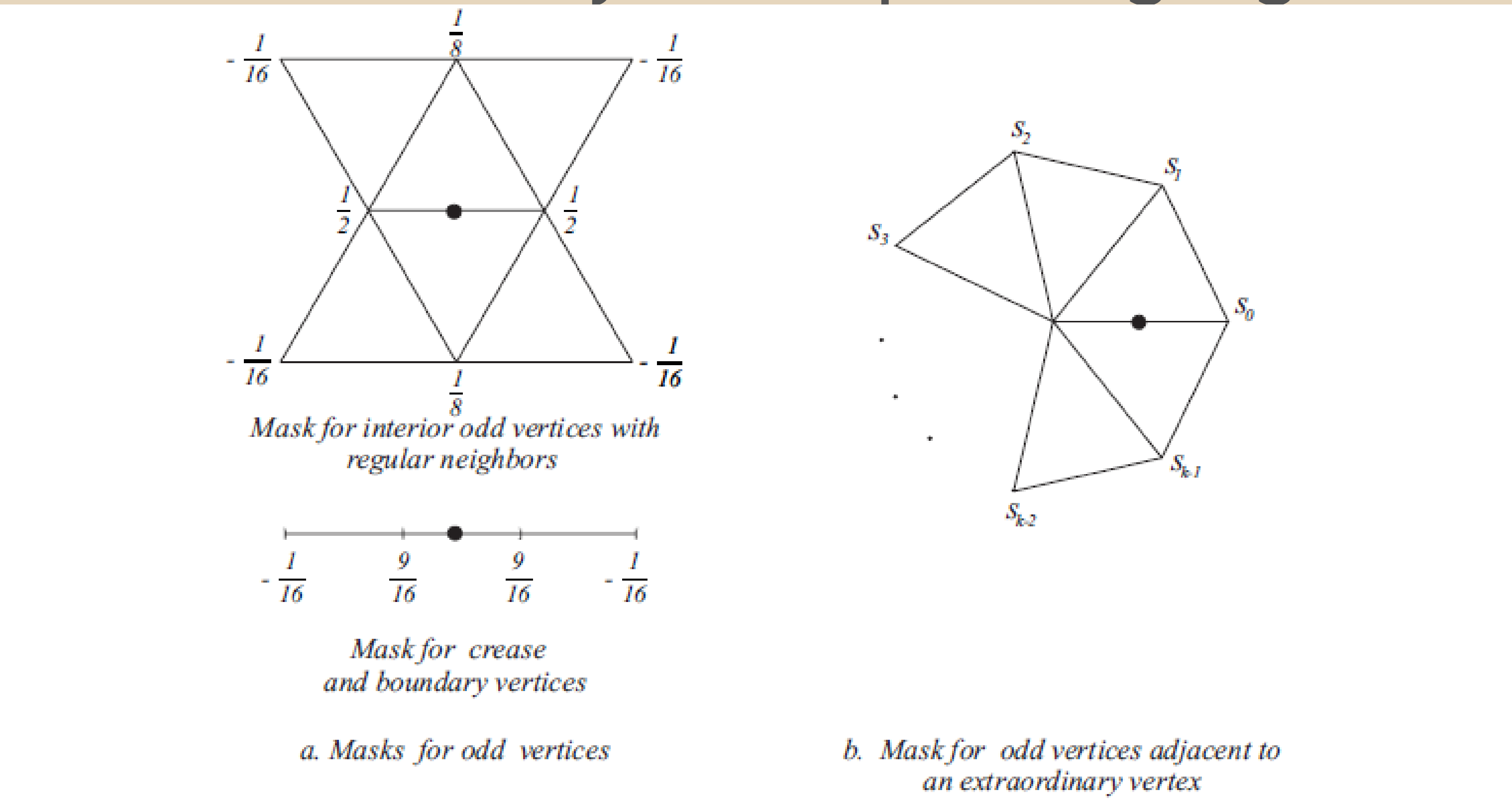


Figure 4.5: *Modified Butterfly subdivision. The coefficients* s_i *are* $\frac{1}{k}\left(\frac{1}{4}+\cos\frac{2i\pi}{k}+\frac{1}{2}\cos\frac{4i\pi}{k}\right)$ *for* $k>5$. *For* $k=3$, $s_0=\frac{5}{12}$, $s_{1,2}=-\frac{1}{12}$; *for* $k=4$, $s_0=\frac{3}{8}$, $s_2=-\frac{1}{8}$, $s_{1,3}=0$.

Other Subdivision Algorithms

- Modified Butterfly: interpolating algorithm



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Other Subdivision Algorithms

- Catmull-Clark: approximating

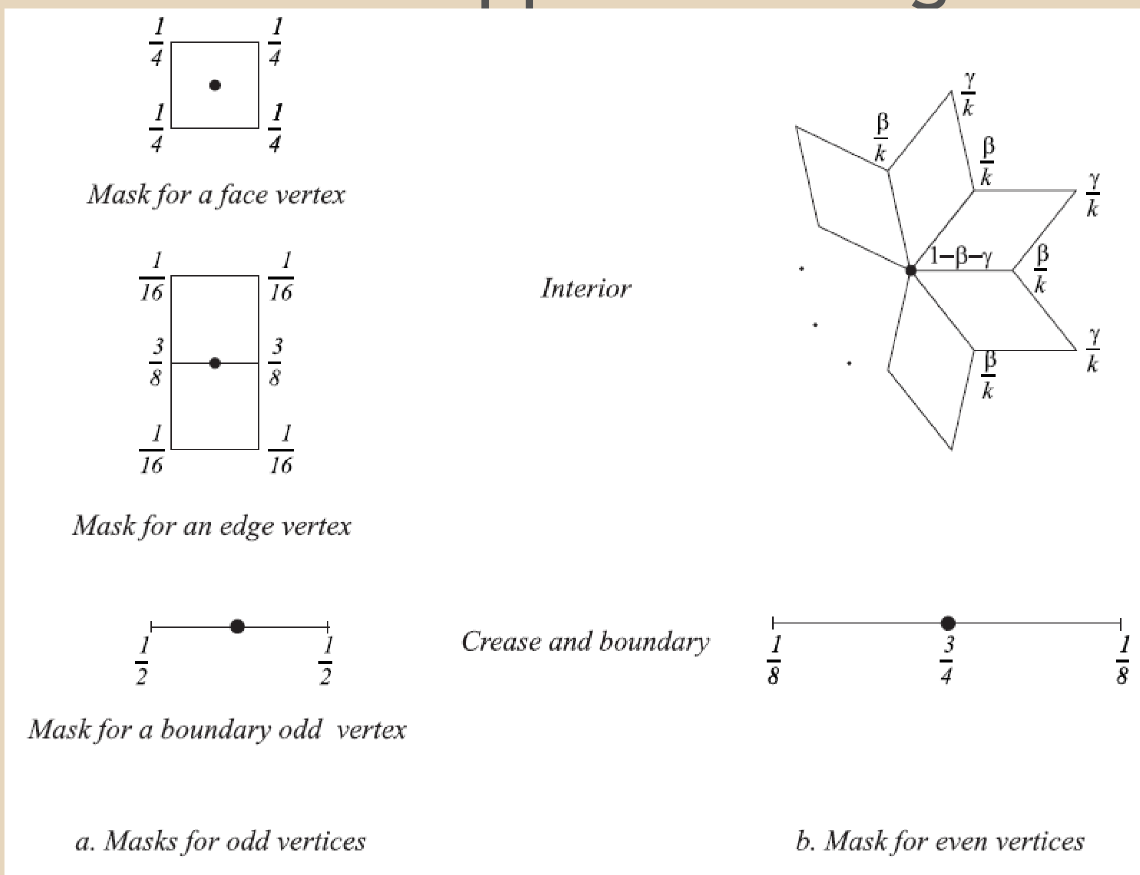


Figure 4.8: *Catmull-Clark subdivision. Catmull and Clark [4] suggest the following coefficients for rules at extraordinary vertices:* $\beta = \frac{3}{2k}$ *and* $\gamma = \frac{1}{4k}$

Other Subdivision Algorithms

- Kobbelt: approximating

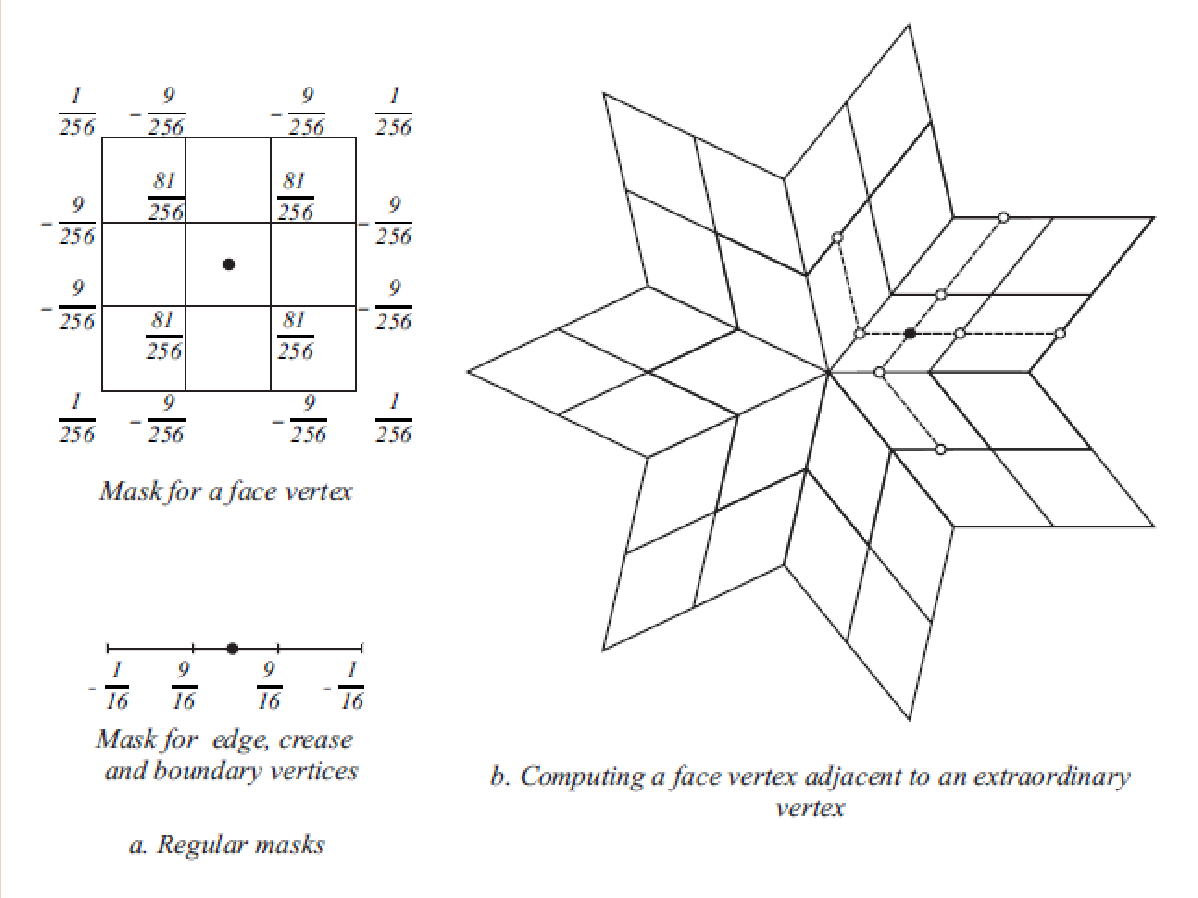
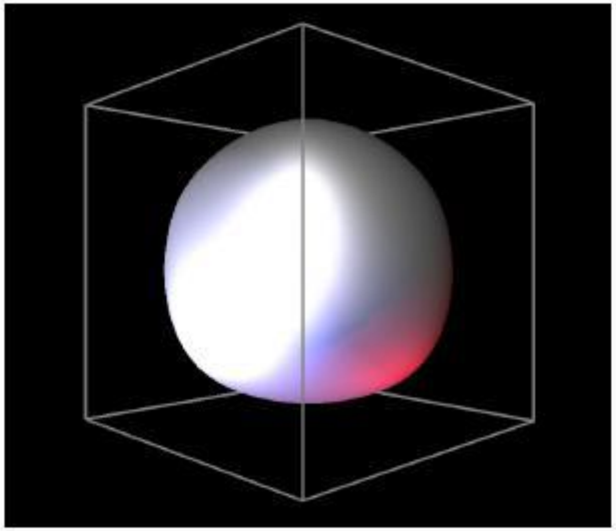
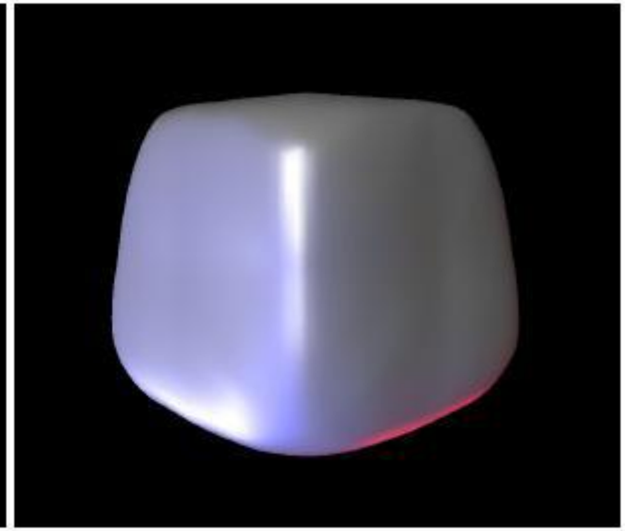


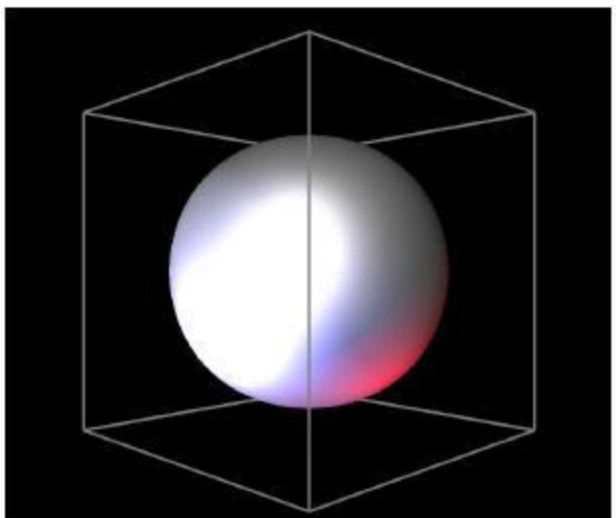
Figure 4.11: *Kobbelt subdivision.*



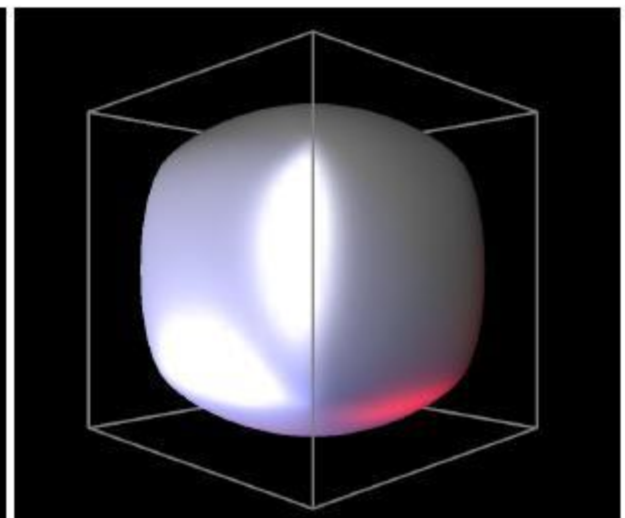
Loop



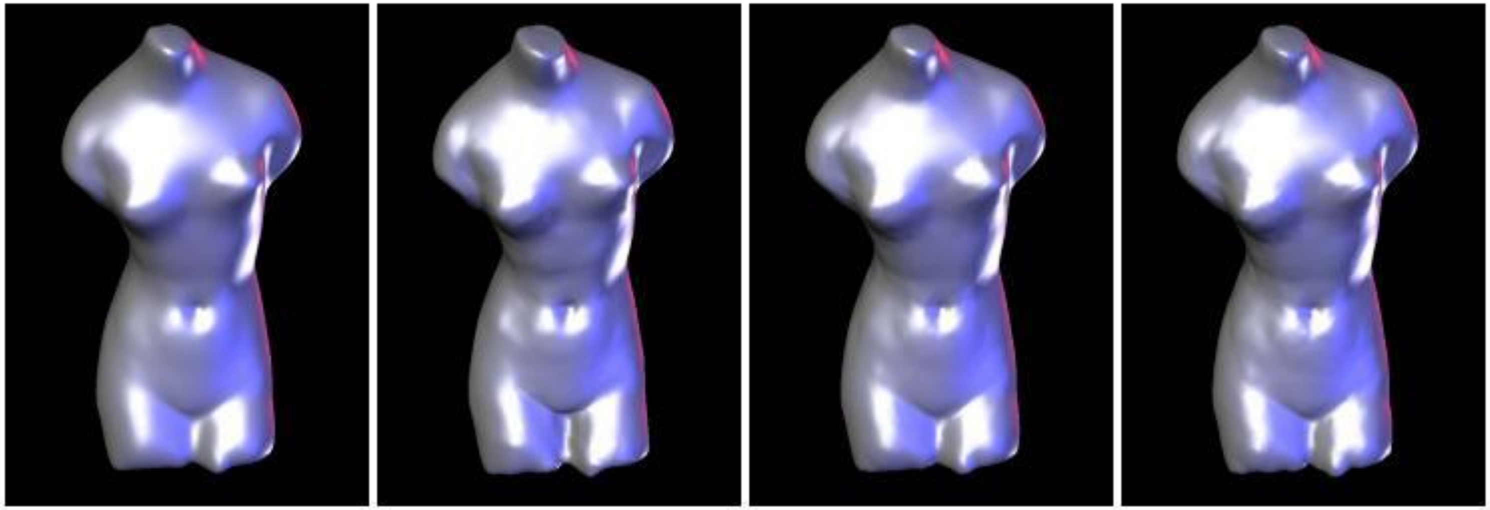
Butterfly



Catmull-Clark

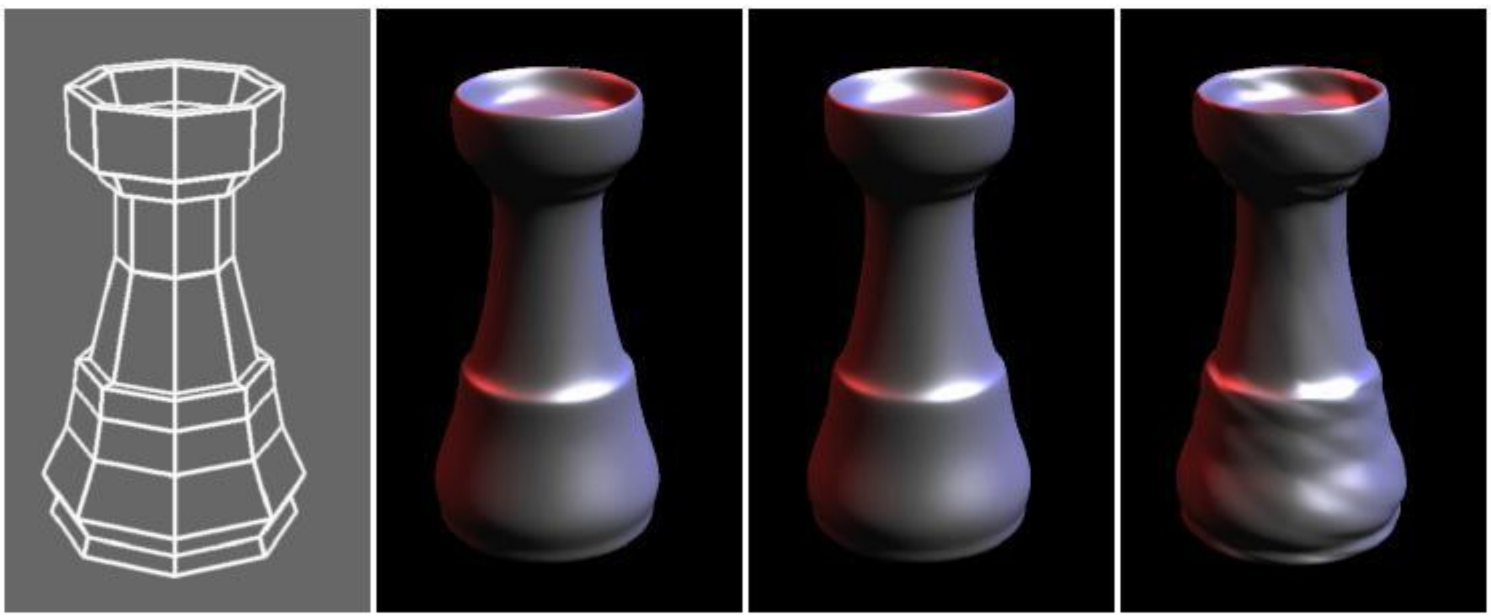


Doo-Sabin



Loop *Butterfly* *Catmull-Clark* *Doo-Sabin*

Figure 4.20: *Different subdivision schemes produce similar results for smooth meshes.*



Initial mesh *Loop* *Catmull-Clark* *Catmull-Clark,after triangulation*