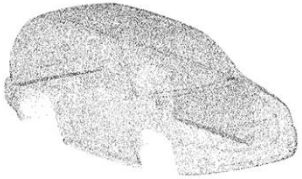
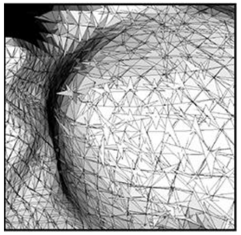
Mesh Data Structures and CSG

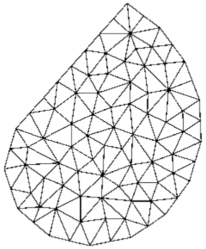
Representing Surface Data



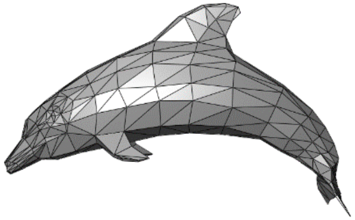
point cloud



triangle soup



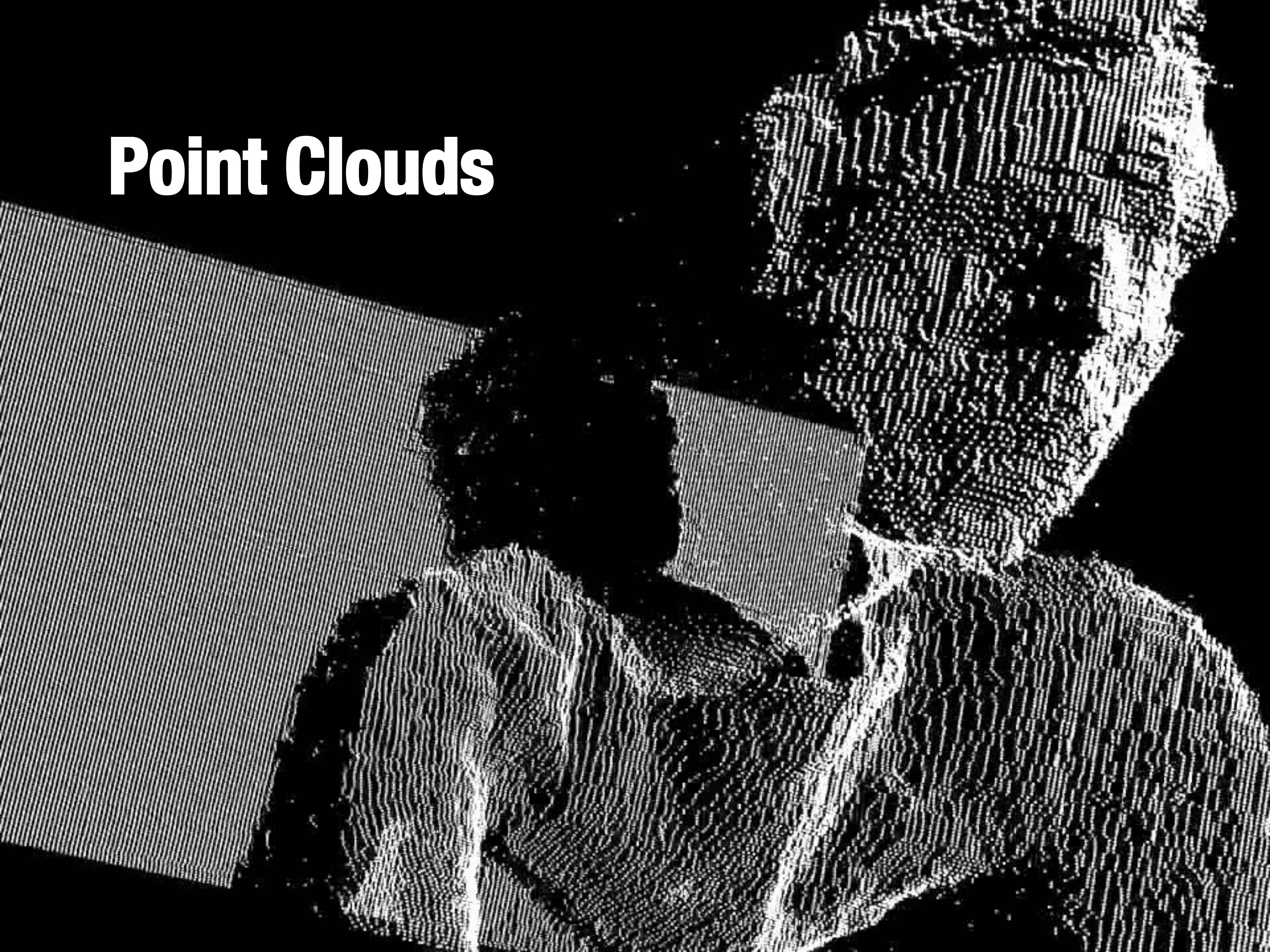
manifold mesh



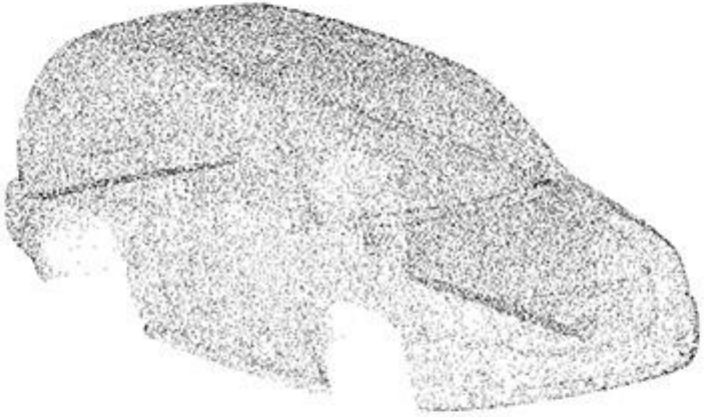
watertight mesh

more structure

Point Clouds



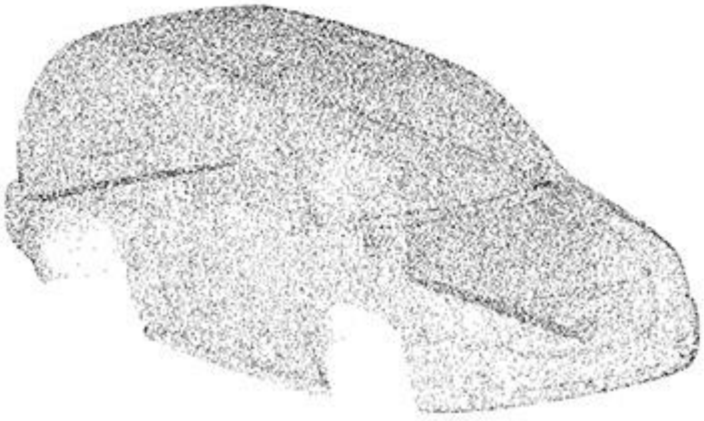
Point Clouds



List of points

- may or may not include normals

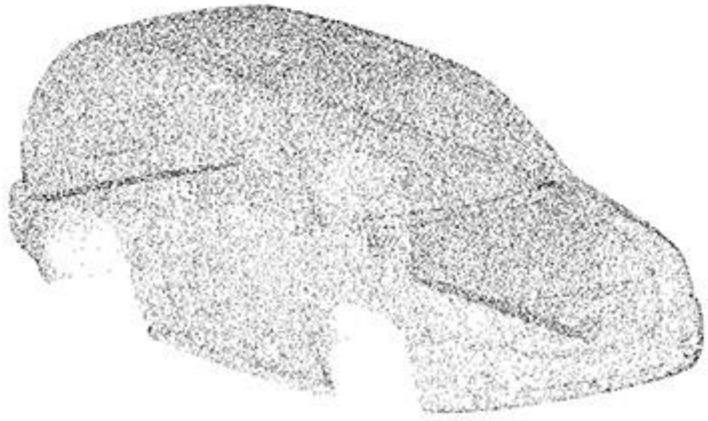
Point Clouds



List of points

- may or may not include normals
- normals estimated by plane-fitting

Point Clouds

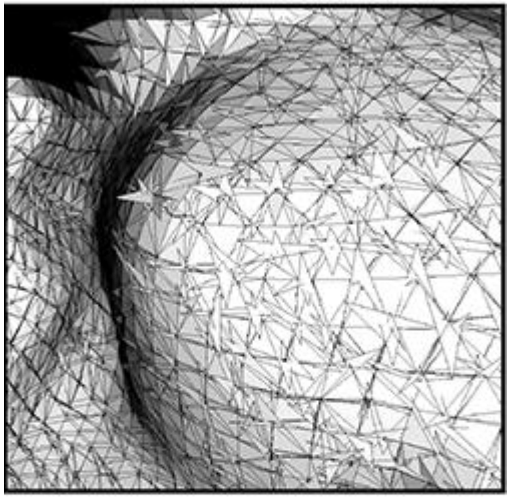


List of points

- may or may not include normals
- normals estimated by plane-fitting

Raw data from depth sensors

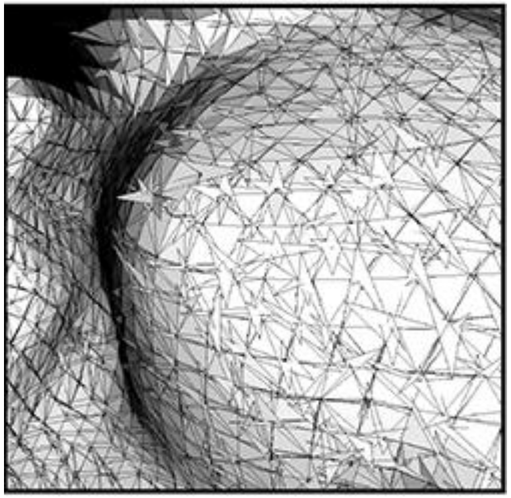
Triangle Soup



List of triangles

- each triangle has own verts

Triangle Soup



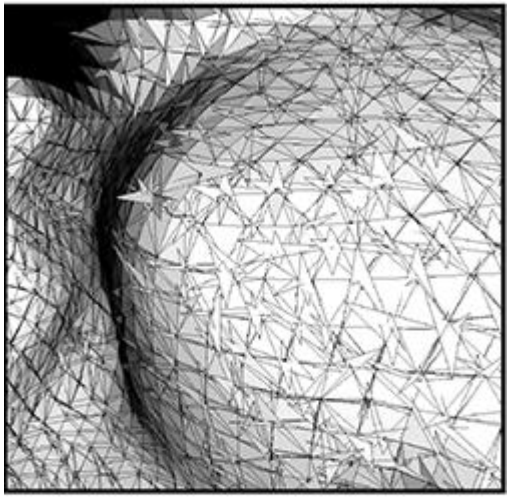
List of triangles

- each triangle has own verts

No notion of triangle neighbors

- (but can find nearby triangles)

Triangle Soup



List of triangles

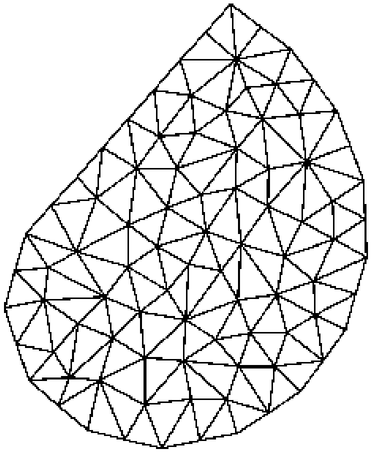
- each triangle has own verts

No notion of triangle neighbors

- (but can find nearby triangles)

Why do we need neighbors anyway?

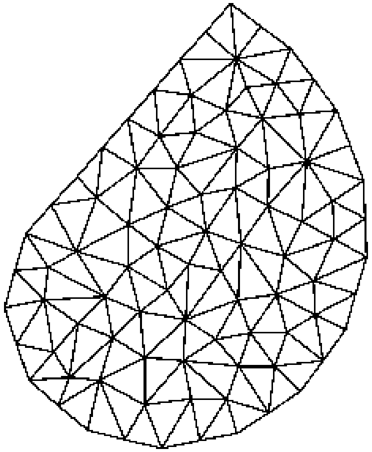
Manifold Mesh



Must satisfy three properties:

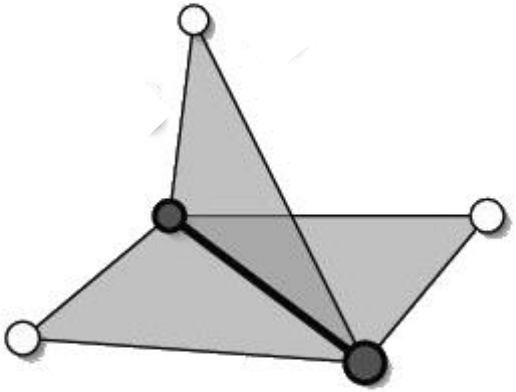
1. Every edge shared by one/two faces

Manifold Mesh



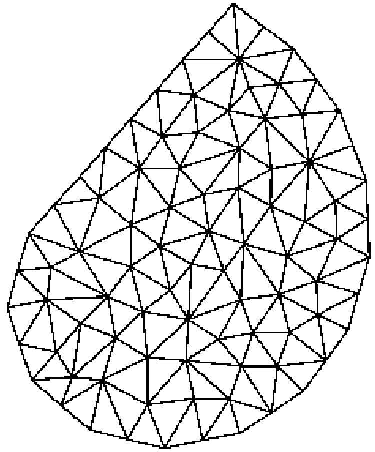
Must satisfy three properties:

1. Every edge shared by one/two faces



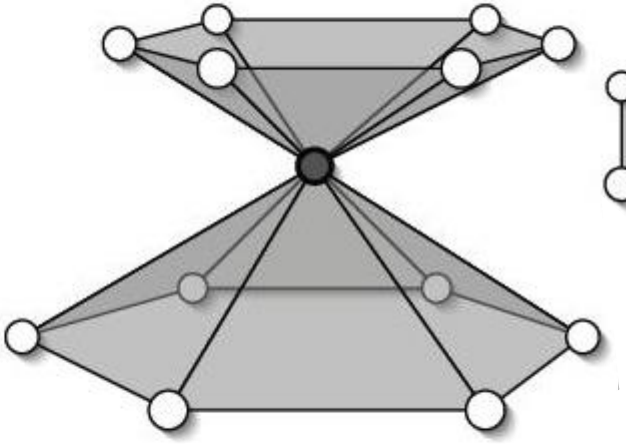
not manifold: has T junction

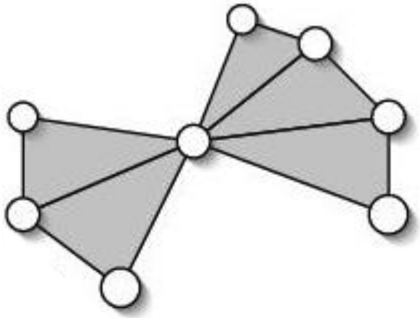
Manifold Mesh



Must satisfy three properties:

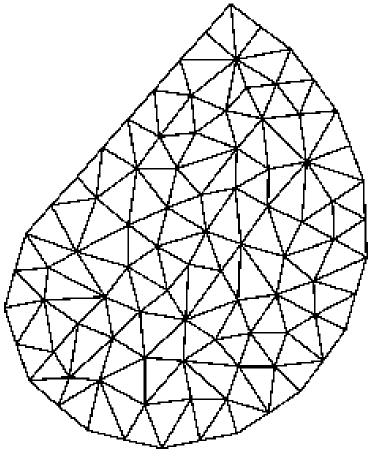
1. Every edge shared by one/two faces
2. Faces around verts are triangle fans





not manifold

Manifold Mesh

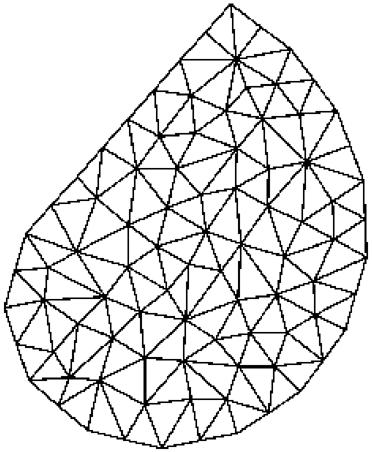


Must satisfy three properties:

1. Every edge shared by one/two faces
2. Faces around verts are triangle fans

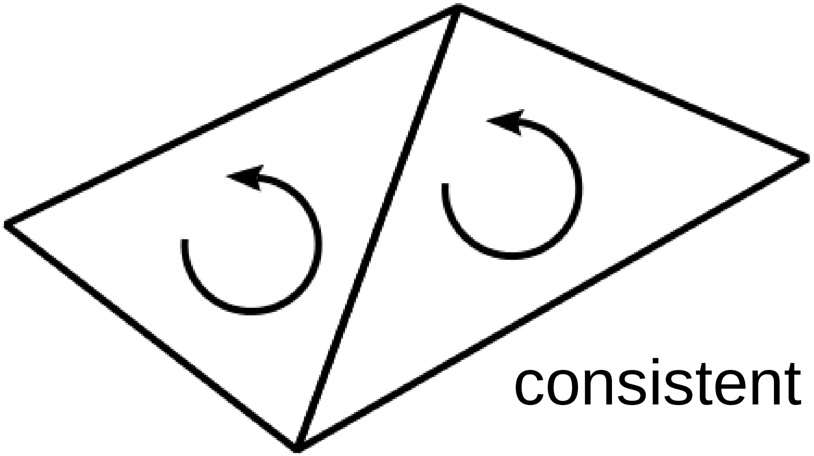
Intuitively: mesh locally “looks like a single surface”

Manifold Mesh

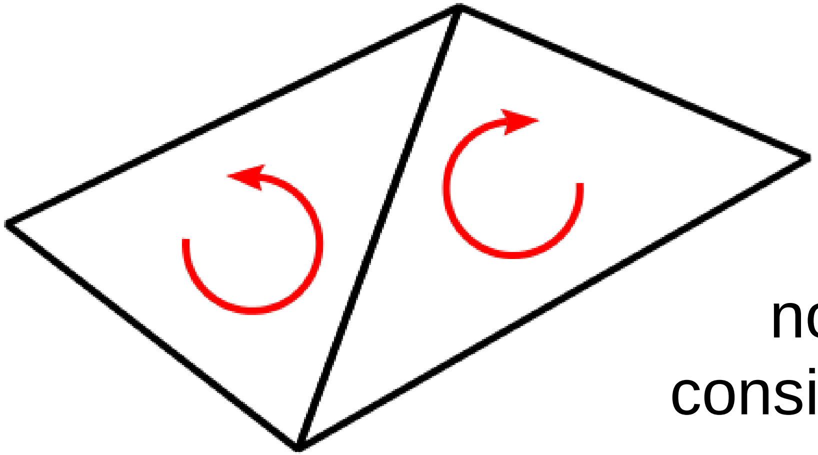


Must satisfy three properties:

1. Every edge shared by one/two faces
2. Faces around verts are triangle fans
3. Faces have consistent **orientation**

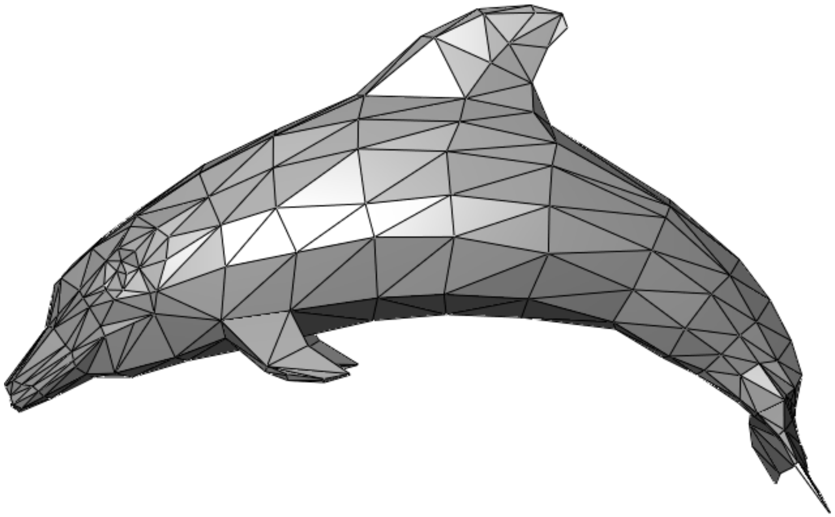


consistent



not consistent

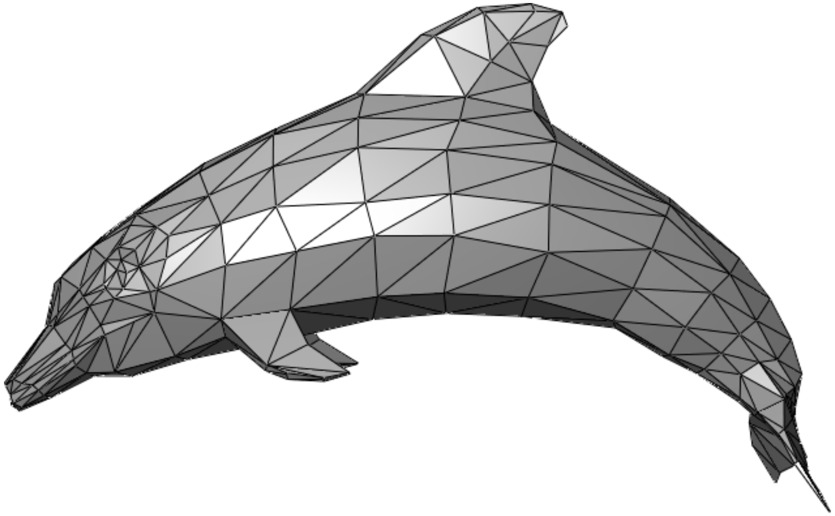
Watertight Mesh



Manifold mesh that

- is single piece
- has no boundary

Watertight Mesh



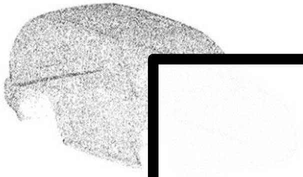
Manifold mesh that

- is single piece
- has no boundary

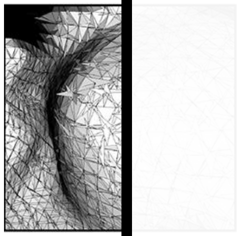
Splits space into well-defined inside/out

- can be “filled with water” without leaks

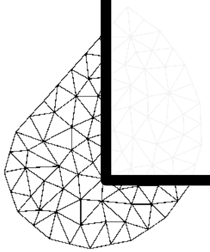
Representing Surface Data



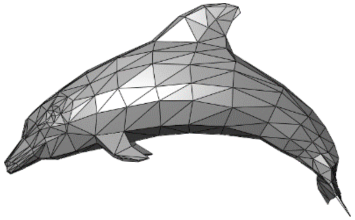
point cloud



triangle soup



manifold mesh



watertight mesh

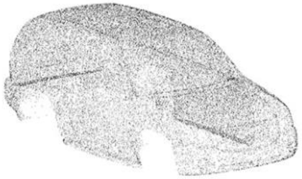
more structure

Graphics Grand Challenge

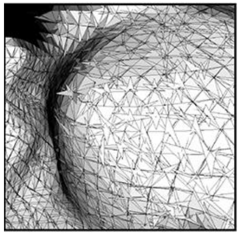
real-word data often **unstructured**

graphics algorithms usually need **structured** data

Representing Surface Data

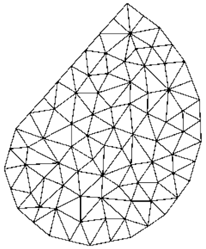


point cloud

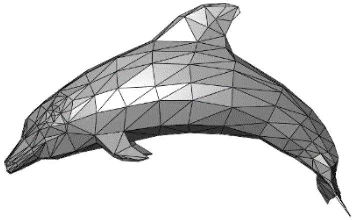


triangle soup

“mesh repair”
algorithms

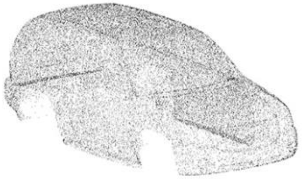


manifold mesh

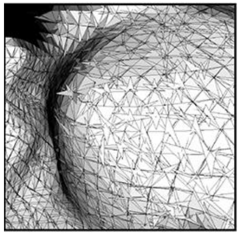


watertight mesh

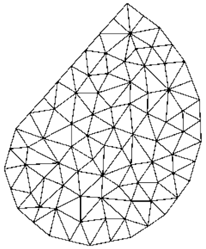
Representing Surface Data



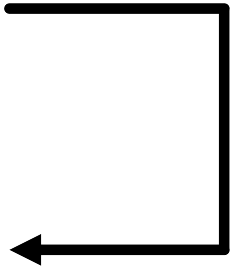
point cloud



triangle soup

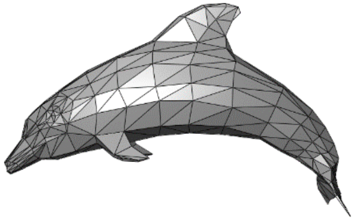


manifold mesh



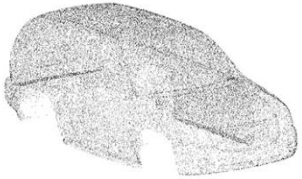
“mesh repair” algorithms

(rarely works)

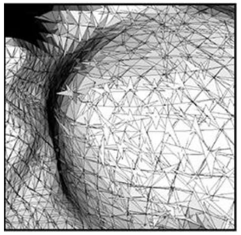


watertight mesh

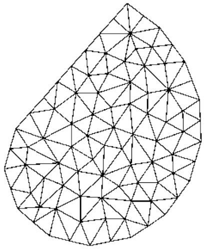
Representing Surface Data



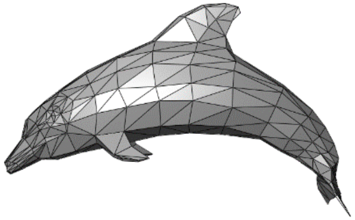
point cloud



triangle soup



manifold mesh

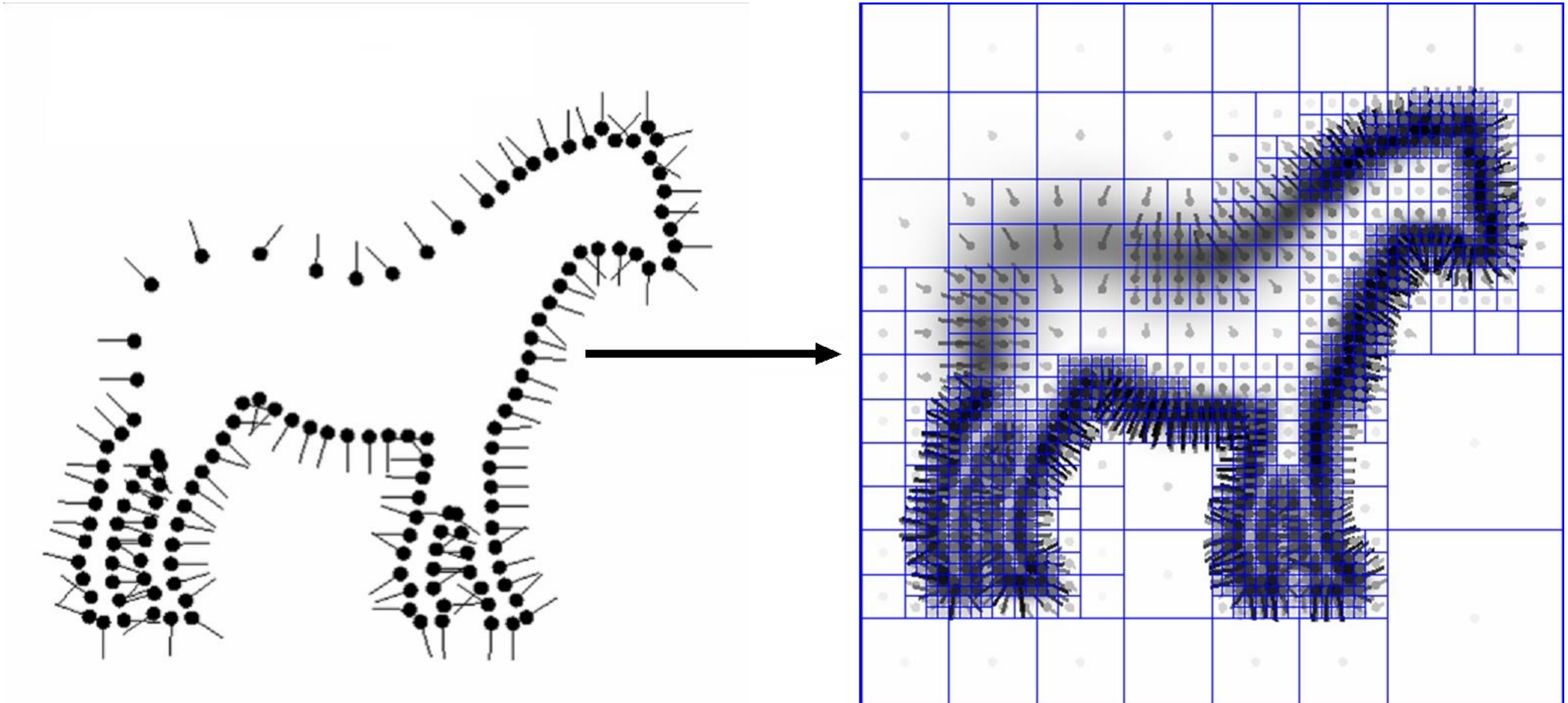


watertight mesh

Poisson surface reconstruction

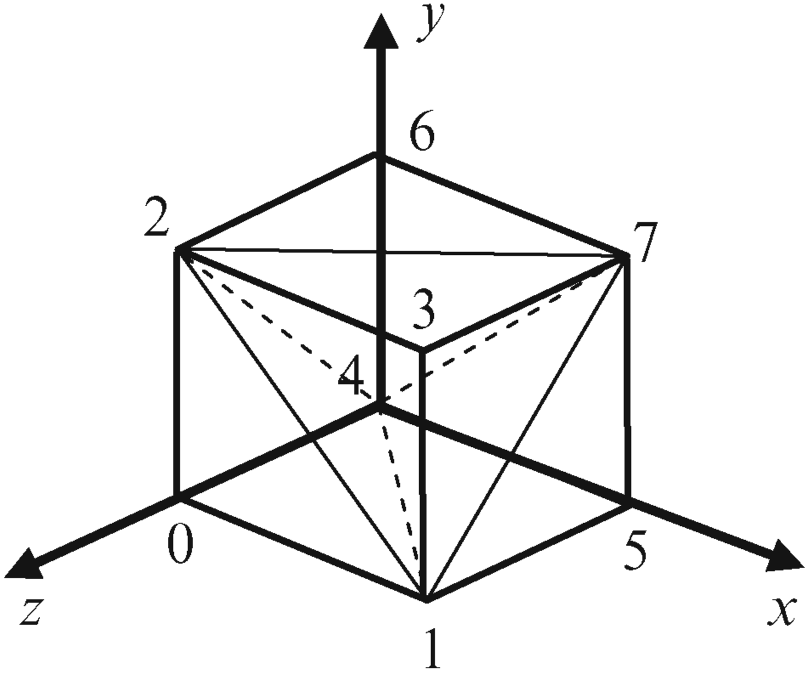
Poisson Surface Reconstruction

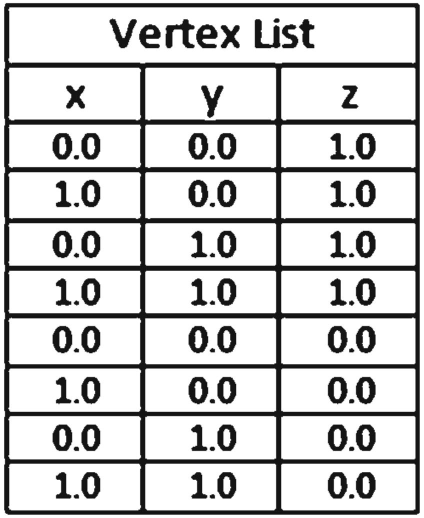
Interpolates point cloud and normals



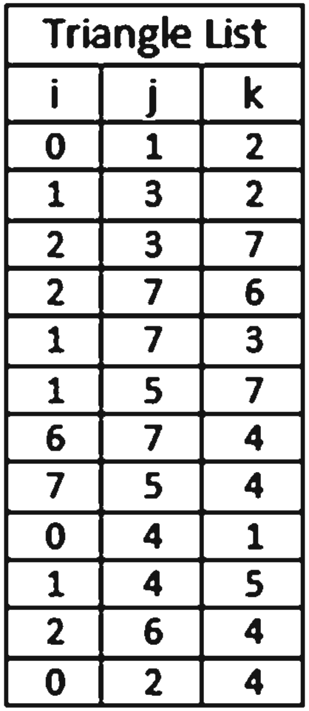
Triangle Mesh Data Structures

List of points & triangle indices





Vertex List		
x	y	z
0.0	0.0	1.0
1.0	0.0	1.0
0.0	1.0	1.0
1.0	1.0	1.0
0.0	0.0	0.0
1.0	0.0	0.0
0.0	1.0	0.0
1.0	1.0	0.0



Triangle List		
i	j	k
0	1	2
1	3	2
2	3	7
2	7	6
1	7	3
1	5	7
6	7	4
7	5	4
0	4	1
1	4	5
2	6	4
0	2	4

Triangle Mesh Data Structures

List of points & triangle indices

Pros:

- lightweight, compact
- native GPU data structure
- very common file data structure

Cons:

Triangle Mesh Data Structures

List of points & triangle indices

Pros:

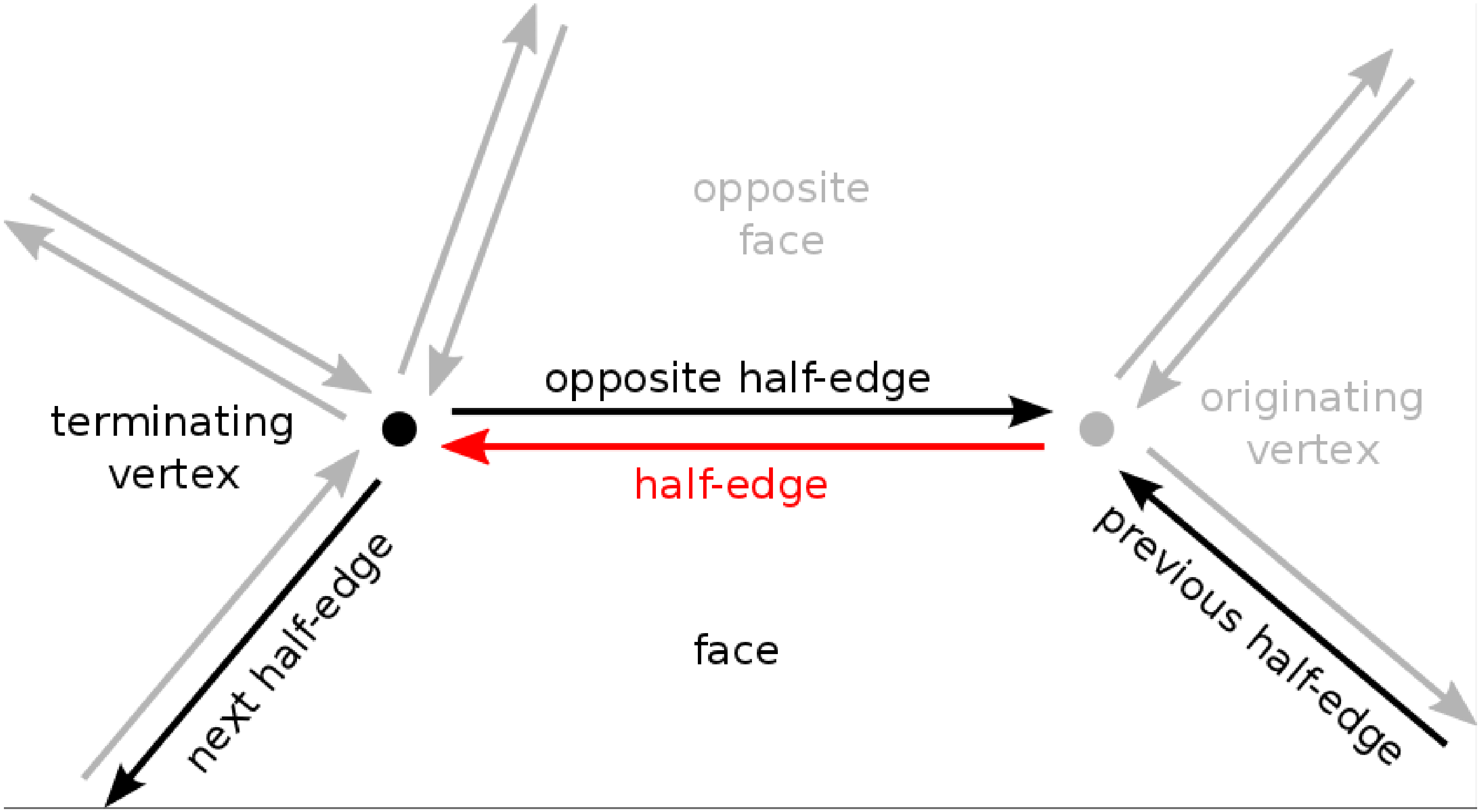
- lightweight, compact
- native GPU data structure
- very common file data structure

Cons:

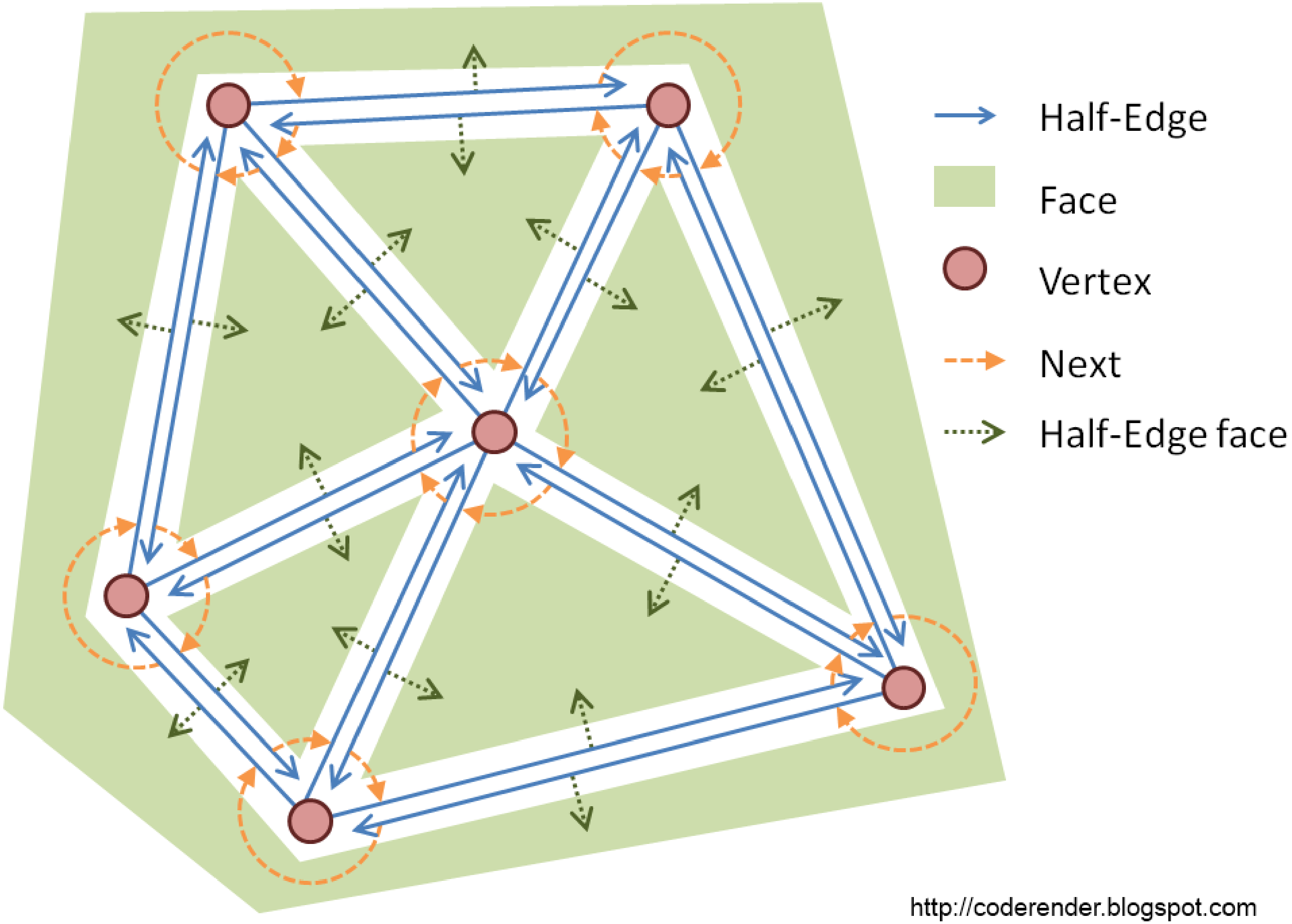
- neighbor queries **slow**
- finding boundaries **slow**

Half-edge Data Structure

Store mesh as set of **half-edges**



Half-edge Data Structure



http://coderender.blogspot.com

Half-edge Data Structure

Store mesh as set of **half-edges**

Pros:

- easy to “walk around” faces, vertices
- all kinds of neighbor queries easy

Half-edge Data Structure

Store mesh as set of **half-edges**

Pros:

- easy to “walk around” faces, vertices
- all kinds of neighbor queries easy

Cons:

- large memory footprint
- tricky to implement (tons of pointers!)

Half-edge Data Structure

Store mesh as set of **half-edges**

Pros:

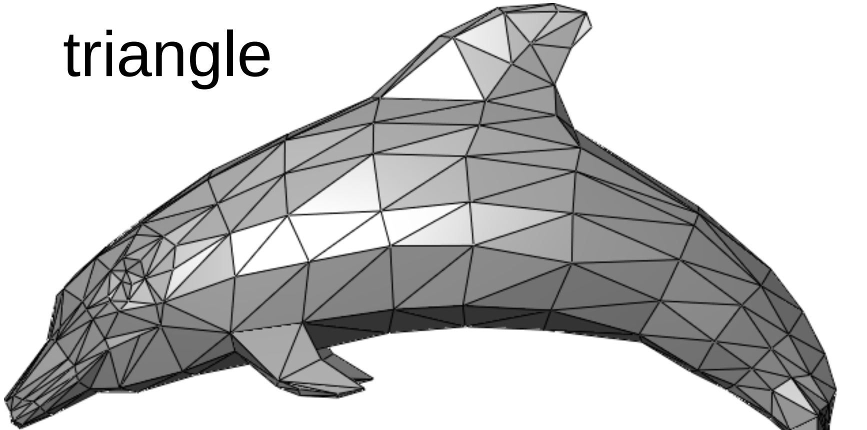
- easy to “walk around” faces, vertices
- all kinds of neighbor queries easy

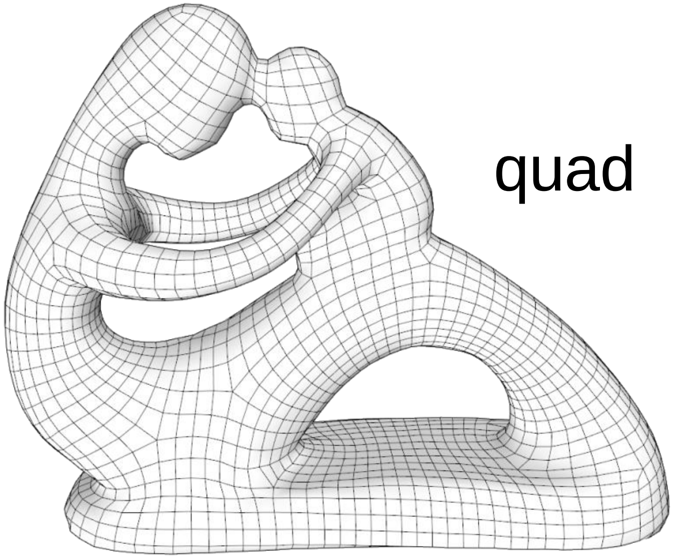
Cons:

- large memory footprint
- tricky to implement (tons of pointers!)
    - use existing libraries (e.g. OpenMesh)

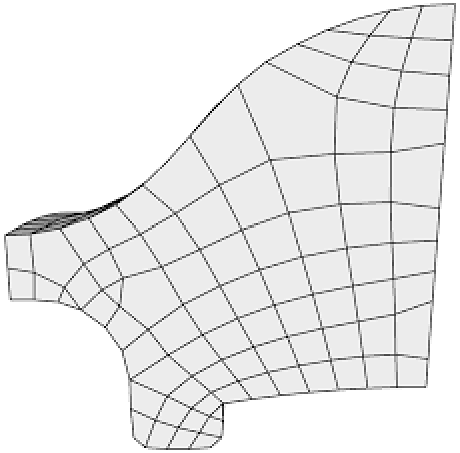
Types of Manifold Meshes

triangle

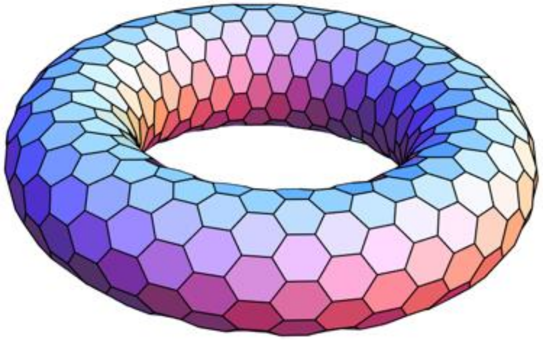




quad

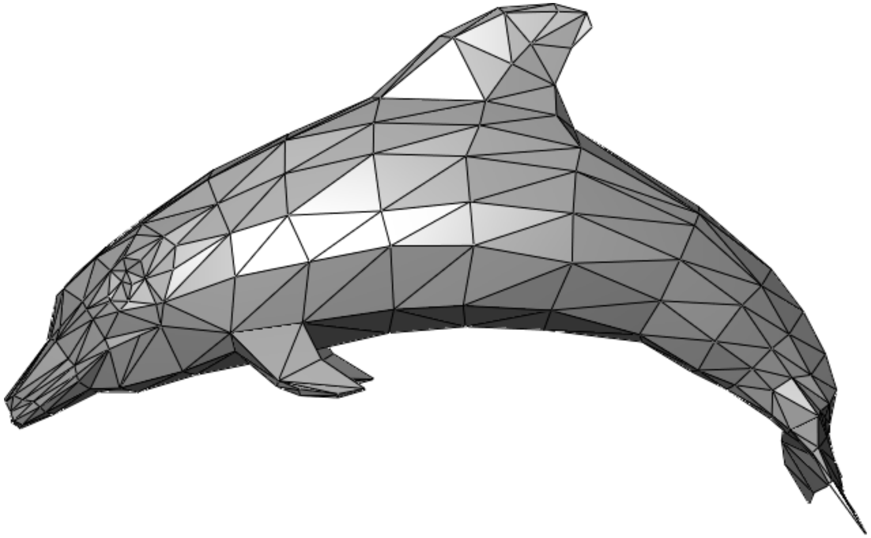


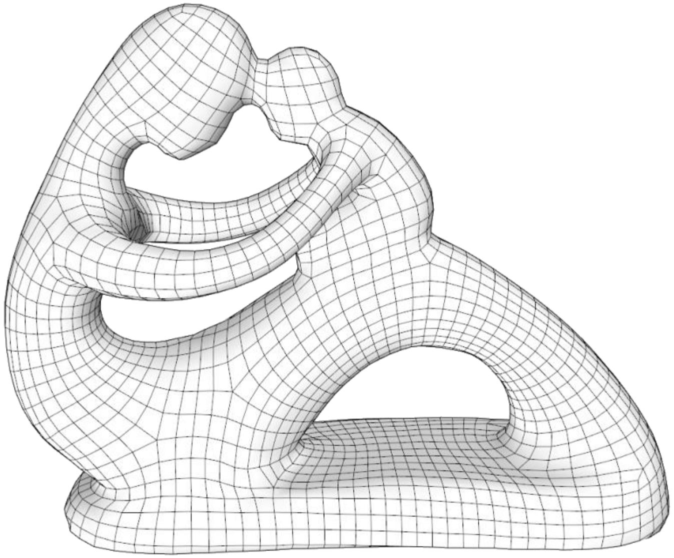
quad-dominant



exotic (hexagonal, etc)

Triangles vs Quads

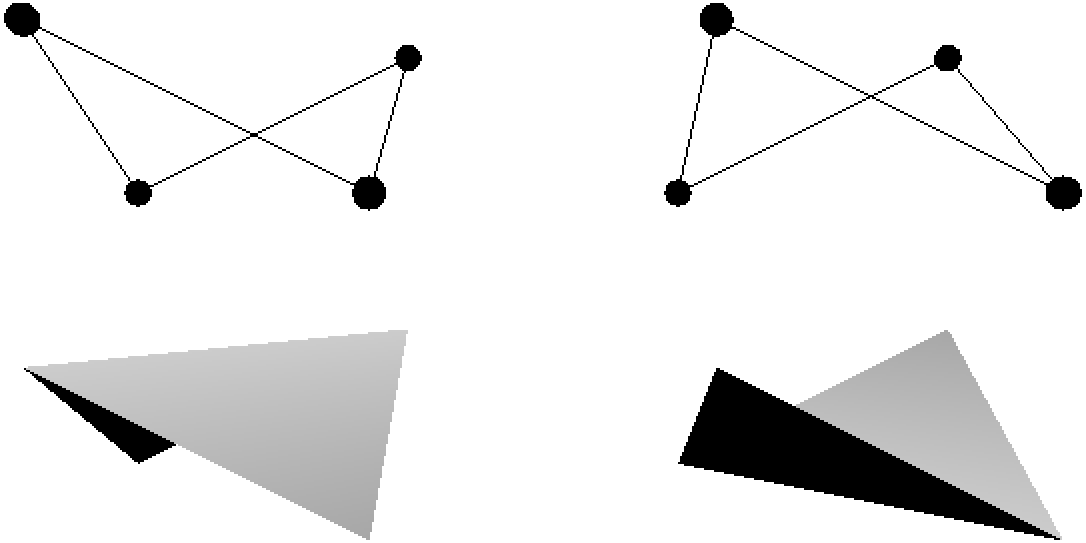




Triangles simpler

Quads more natural for flat & cylindrical geometry

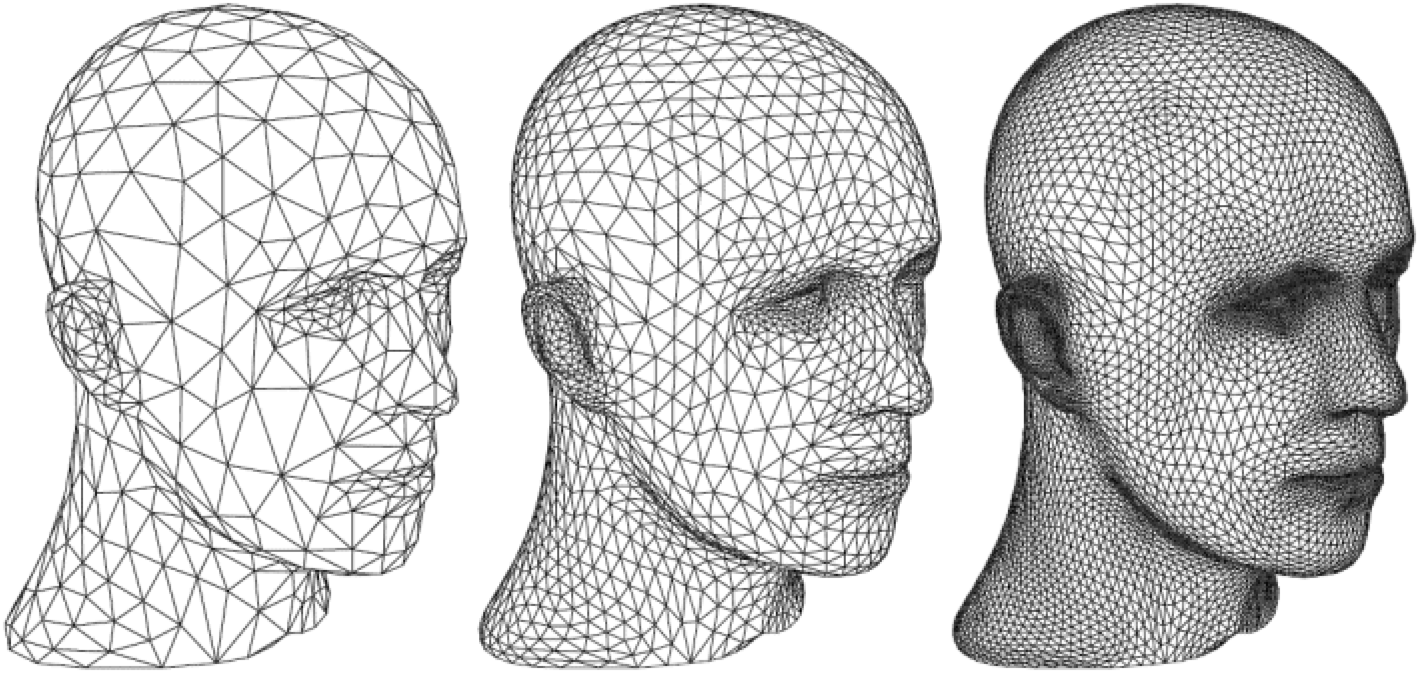
Arbitrary Quads Are Not Planar!



Arbitrarily triangulate to render them…

Subdivision

Input: coarse **control** mesh



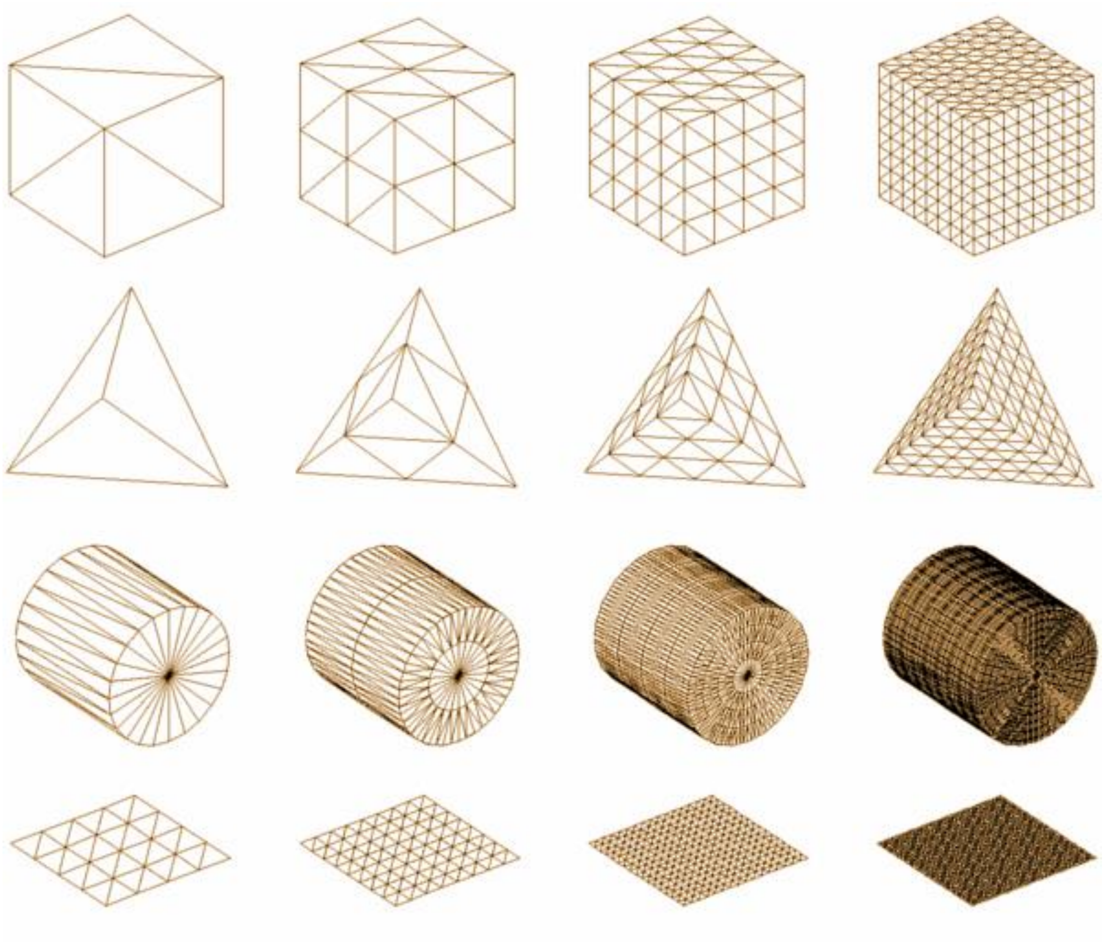
Output: finer mesh with smoother details

Linear Subdivision

Split faces 1:4

Insert verts at
edge midpts

Adds faces,
but doesn’t
change shape

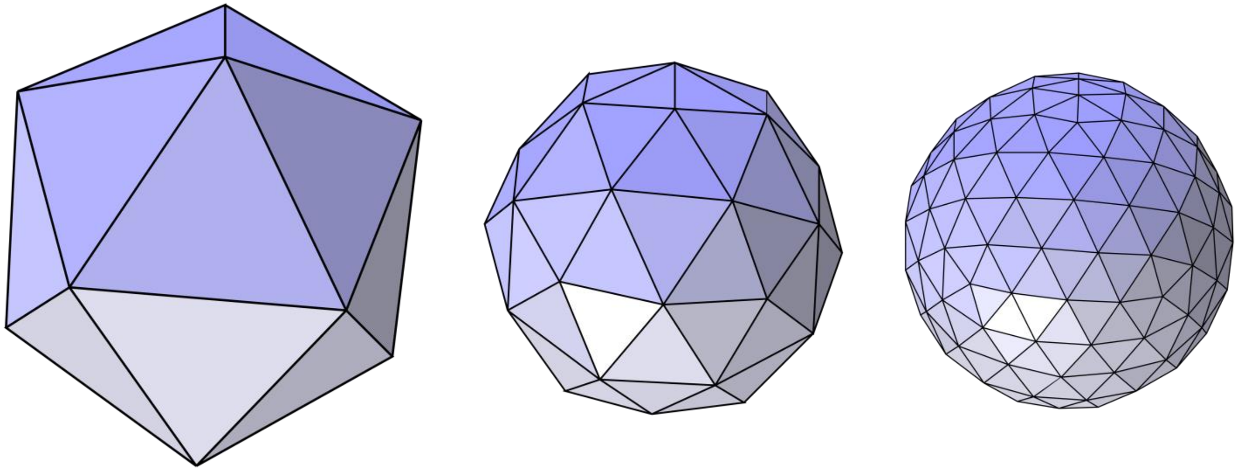


Nonlinear Subdivision

Everybody has pet subdivision method

Most popular:

- triangle meshes: **Loop** subdivision

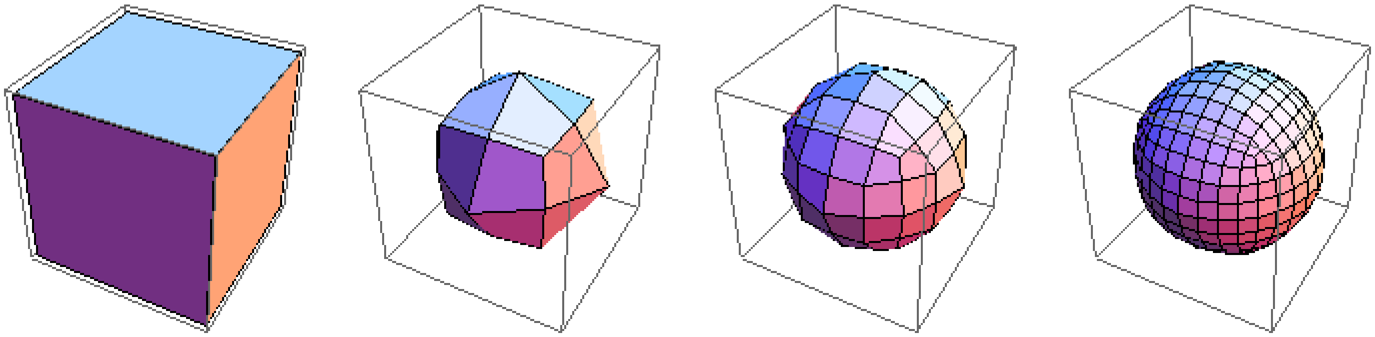


Nonlinear Subdivision

Everybody has pet subdivision code

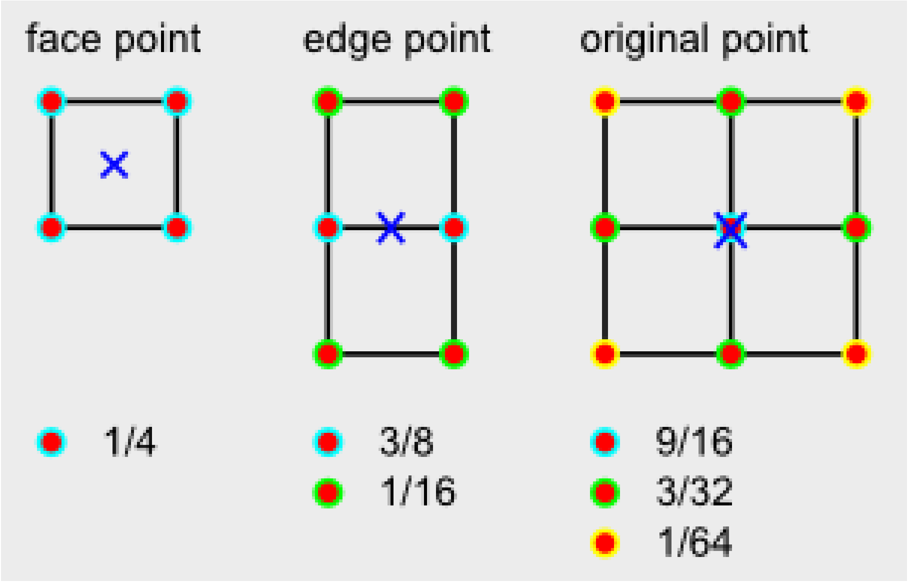
Most popular:

- triangle meshes: **Loop** subdivision
- quad meshes: **Catmull-Clark**



Catmull-Clark Subdivision

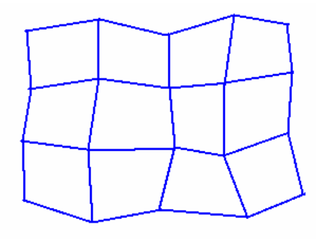
Rules for adding new points and replacing old points



Works best for **regular** quad meshes

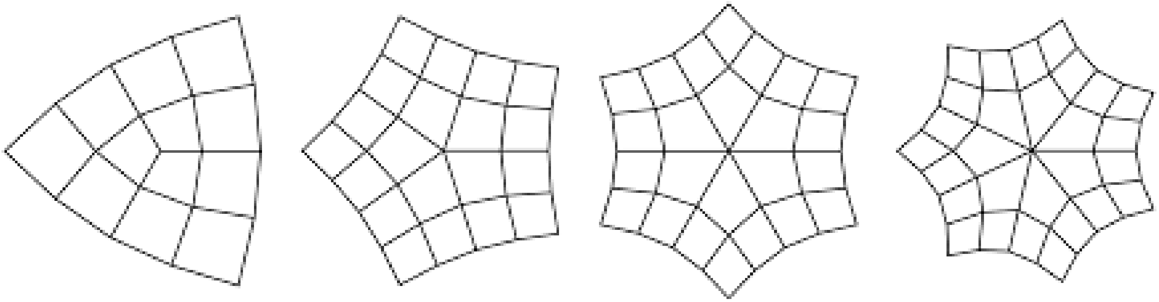
Regular vs Irregular Vertices

Regular vertices have four edges



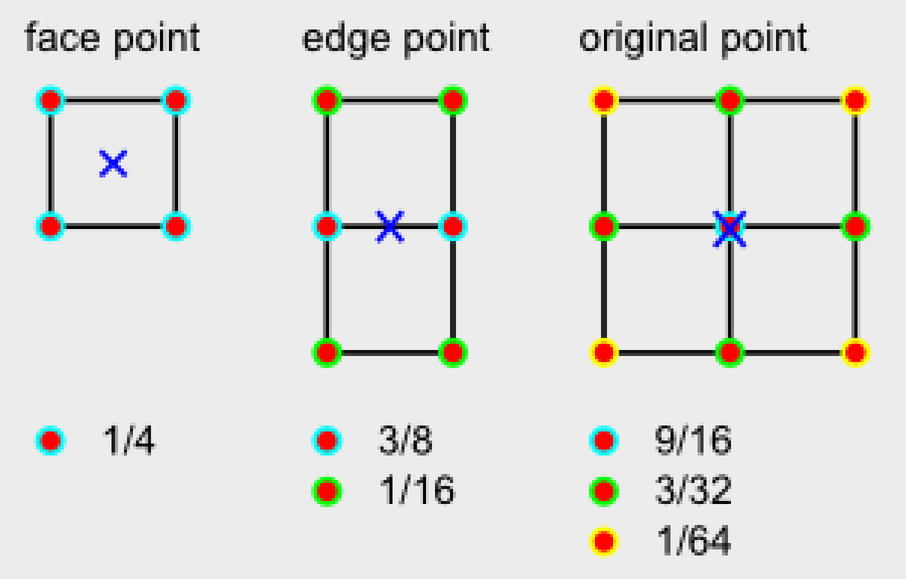
Irregular vertices have 3 or 5+ edges

- also called **extraordinary** vertices



Catmull-Clark Subdivision

Rules for adding new points and replacing old points



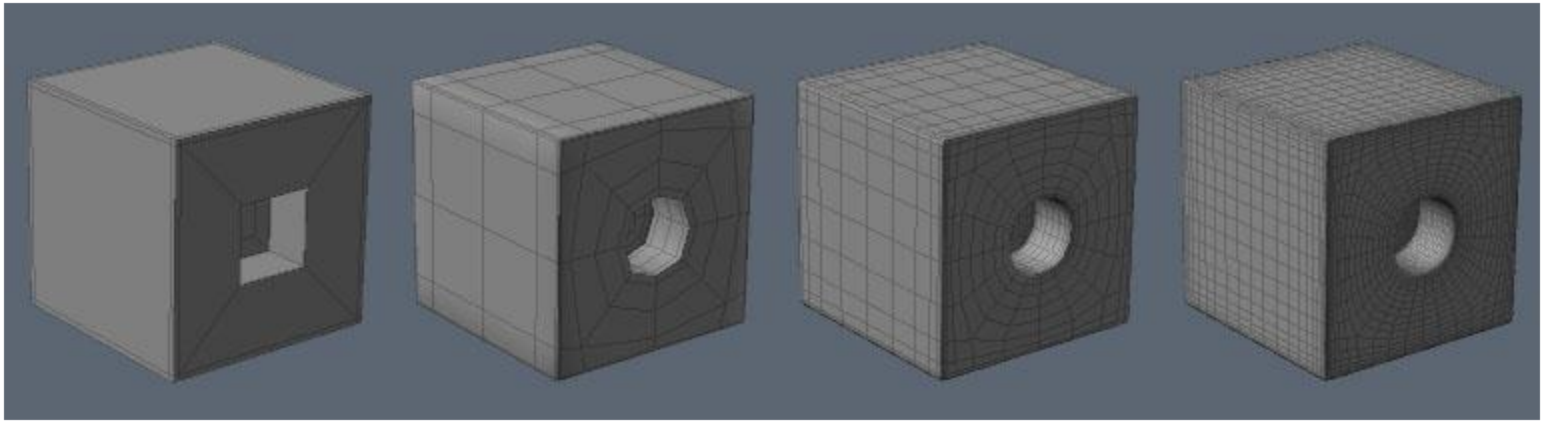
Many schemes for handling irregular verts

Subdivision: Complications

Dealing with irregular vertices

Dealing with creases

- some edges shouldn’t be smoothed…



Subdivision: Complications

Dealing with irregular vertices

Dealing with creases

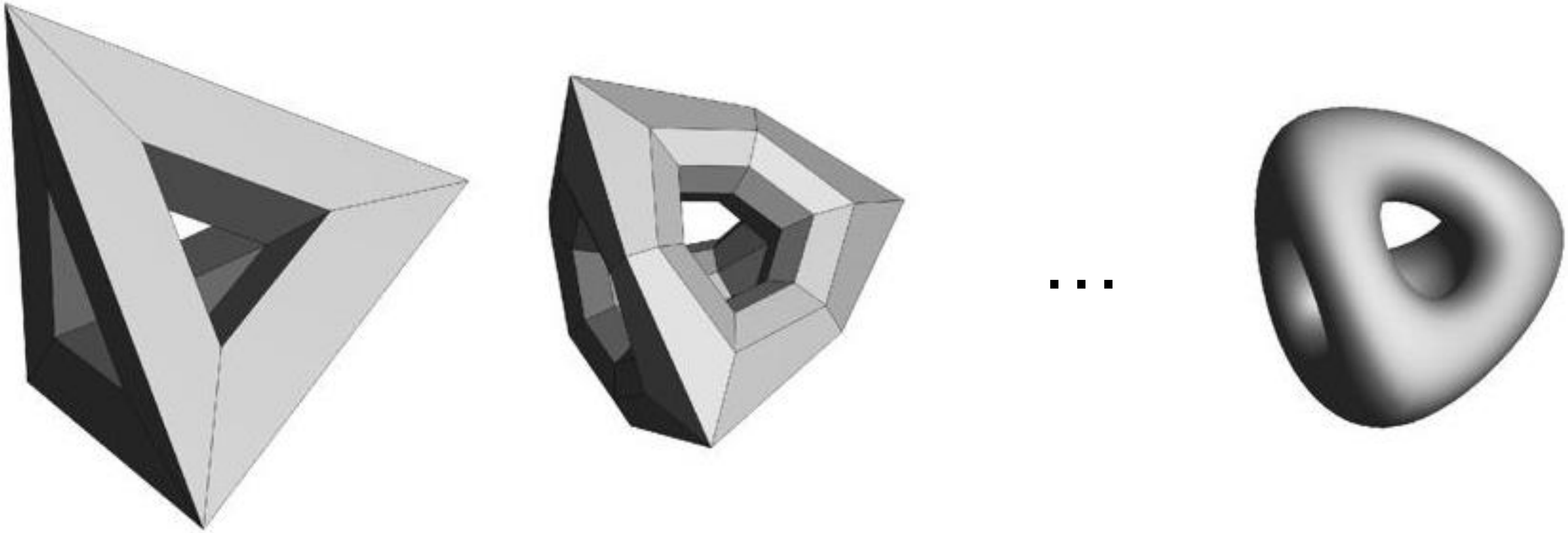
- some edges shouldn’t be smoothed…

Dealing with boundaries

In general, allowing finer-grained control
of subdivision process

Subdivision Surface

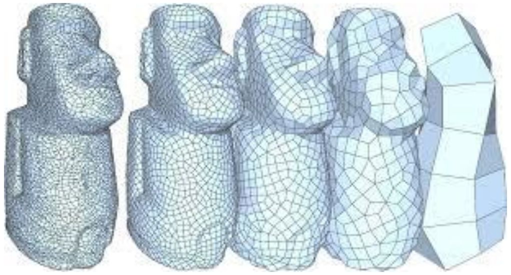
Smooth surface at **limit** of subdivision



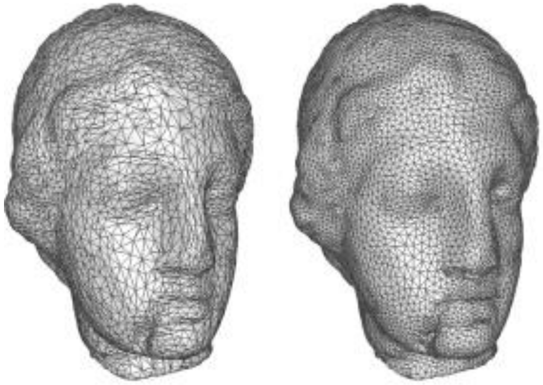
Fundamental building block of Pixar’s
Renderman engine

Other Mesh Operations

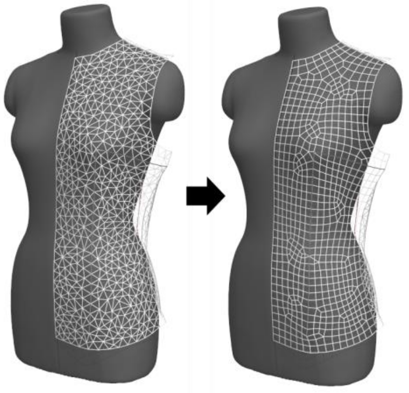
Decimation



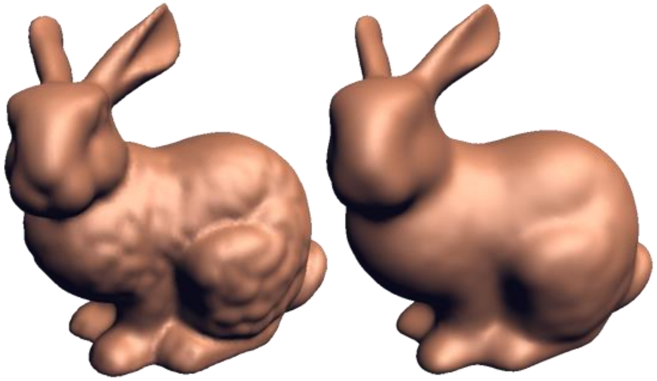
Remeshing



Quadrangulation



Smoothing



Other Mesh Operations

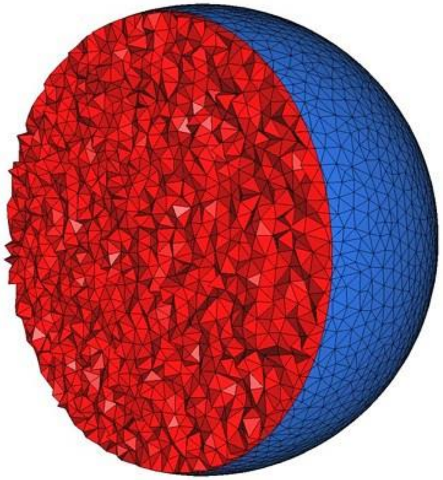
Graphics subfield: **geometry processing**

- uses sophisticated theory from linear algebra, differential geometry, etc.

In practice: several good packages

- CGAL – general purpose
- OpenMesh – halfedge, subdivision

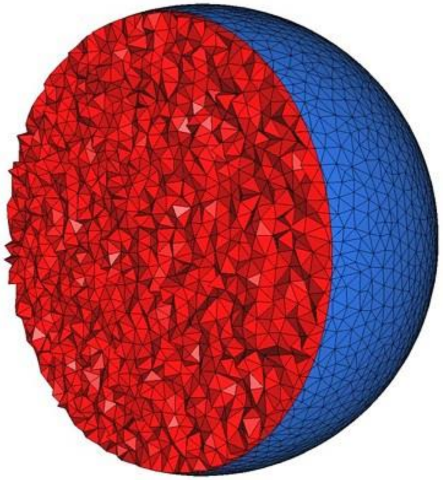
Volume Data



Who cares about volumes?

- just render outer skin?

Volume Data

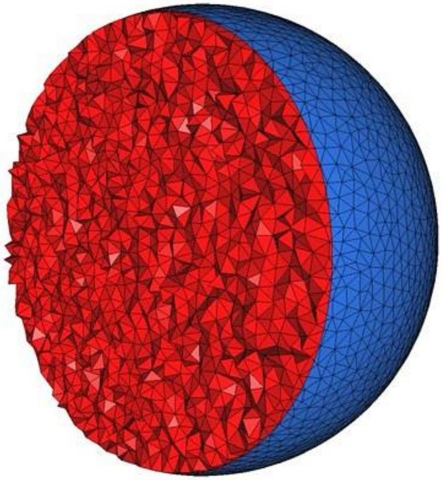


Who cares about volumes?

- just render outer skin?

Translucent object (colored glass, fog,…)

Volume Data



Who cares about volumes?

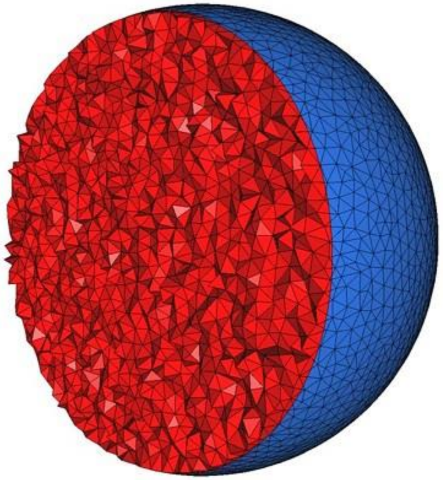
- just render outer skin?

Translucent object (colored glass, fog,…)

Physical simulations & deformations

- fracture

Volume Data



Who cares about volumes?

- just render outer skin?

Translucent object (colored glass, fog,…)

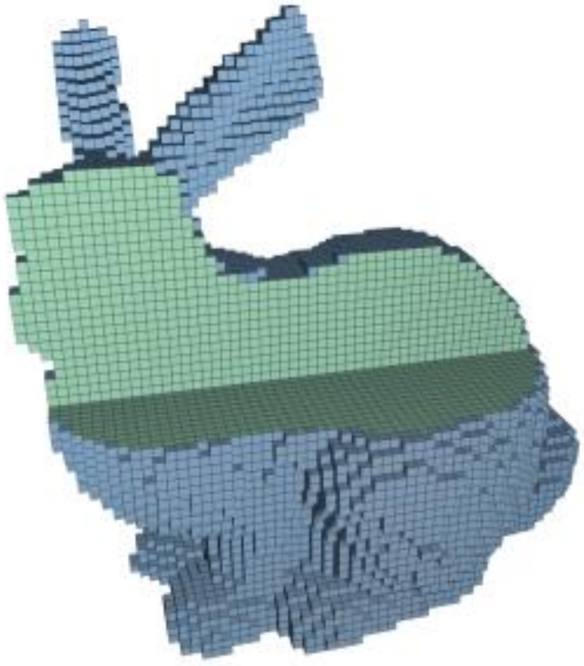
Physical simulations & deformations

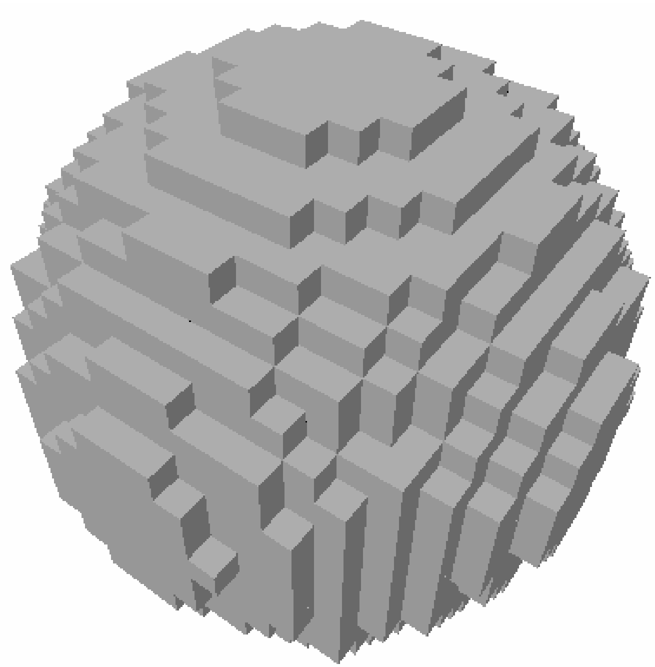
- fracture

Modeling primitive for cutting & sculpting

Representing Volumes

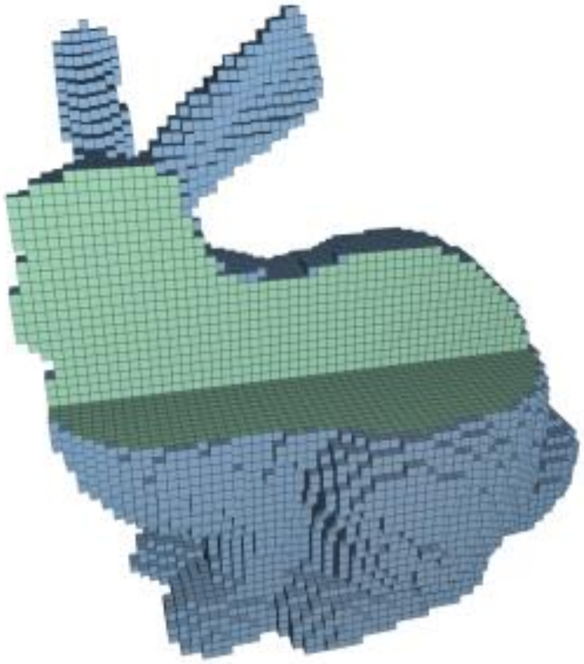
Voxelization: 3D rasterization

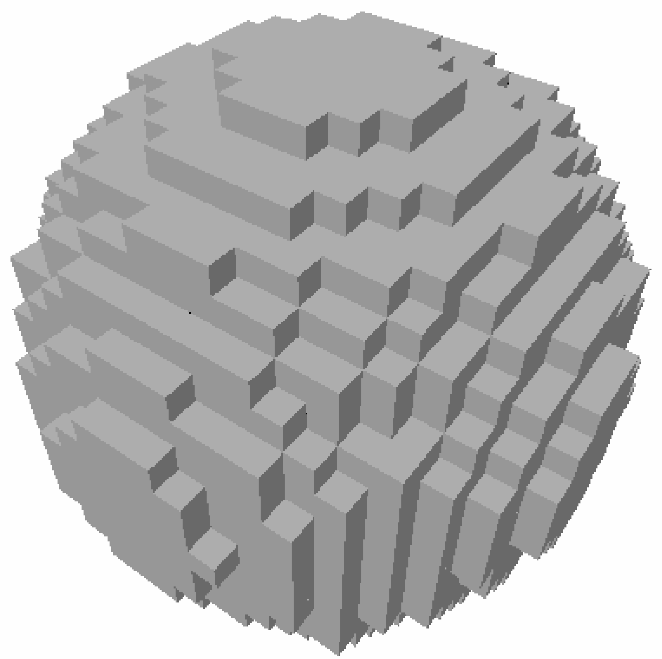




Representing Volumes

Voxelization: 3D rasterization



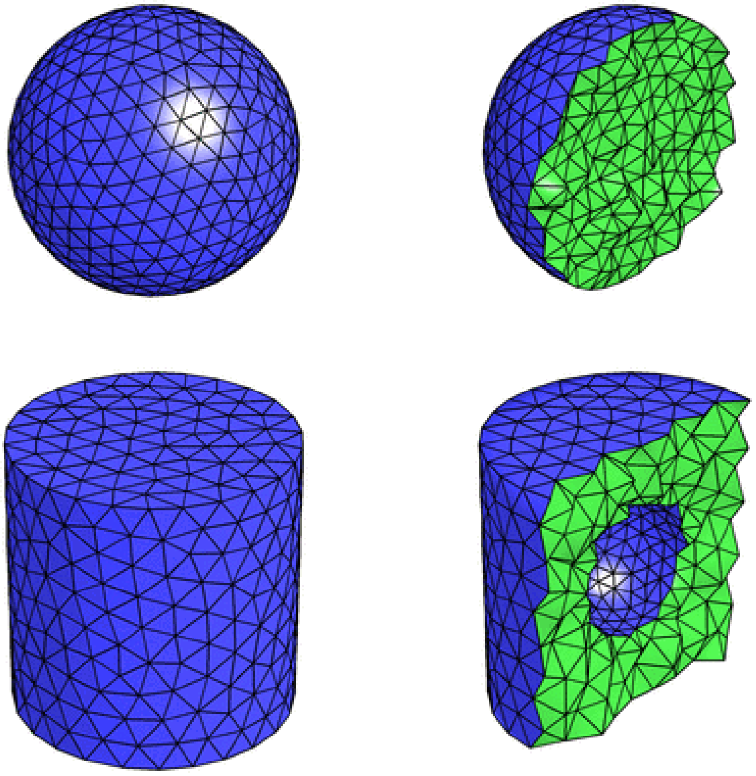


really easy… but boundary chunky

Representing Volumes

Tetrahedral (tet) mesh: 3D analogue of triangle mesh

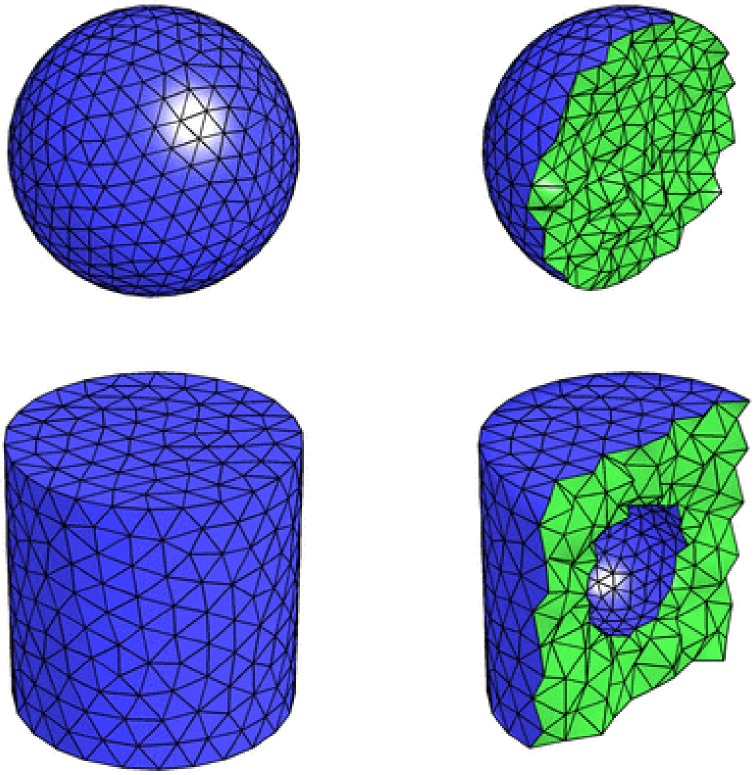
- each tet "hyperface" has 4 faces, 6 edges, 4 verts



Representing Volumes

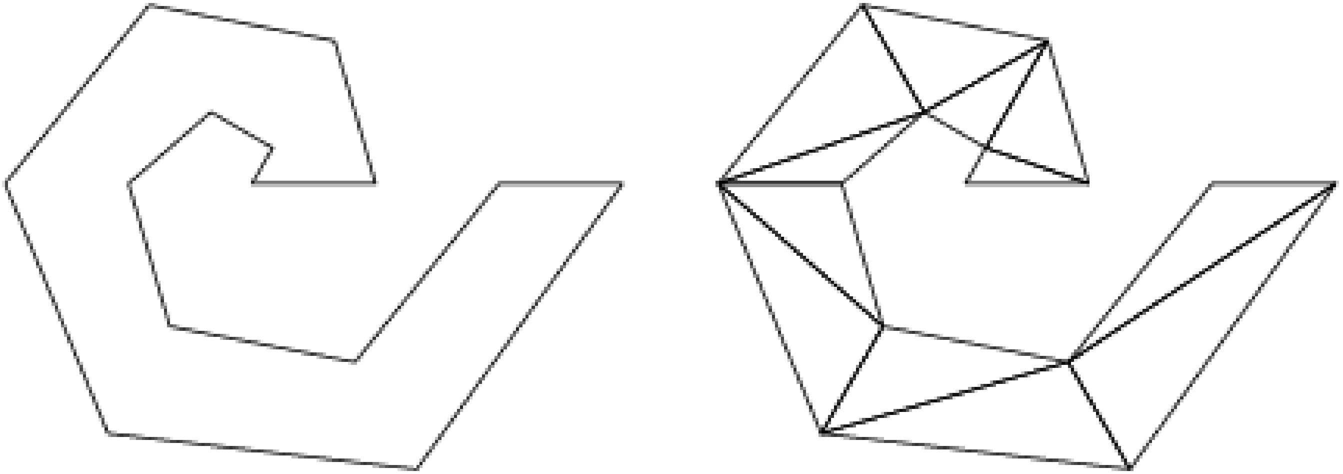
Tetrahedral (tet) mesh: 3D analogue of triangle mesh

- each tet “hyperface” has 4 faces, 6 edges, 4 verts
- bdry is watertight triangle mesh



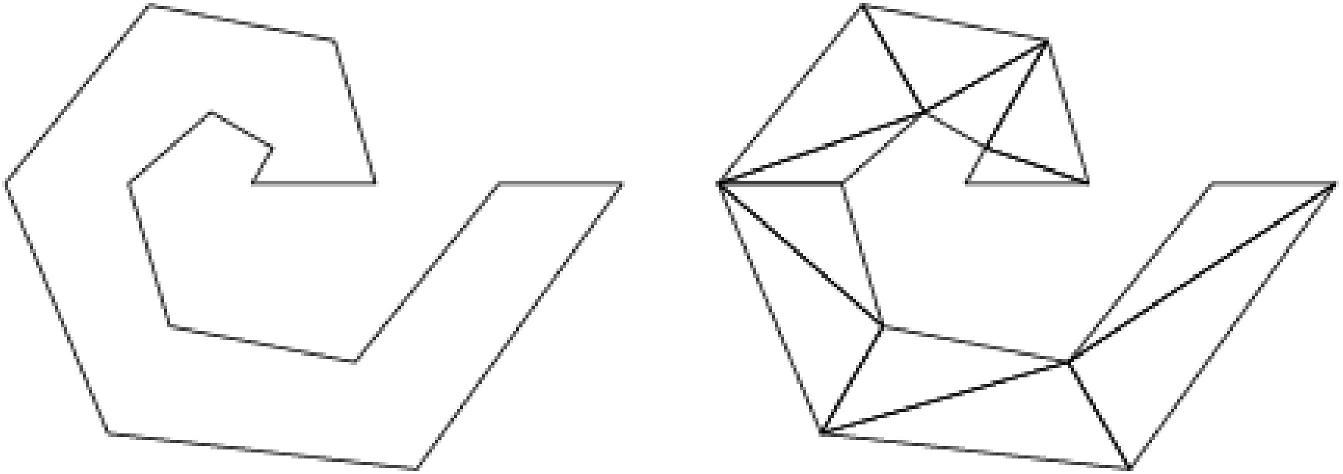
Generating 2D Mesh From Curve

Can be done by **triangulation**



Generating 2D Mesh From Curve

Can be done by **triangulation**

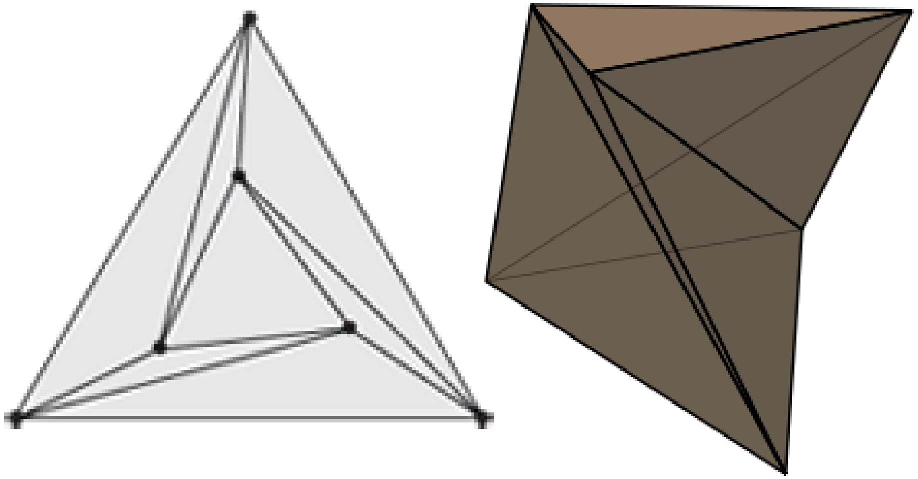


Greedy “ear-cutting” always works

Generating 3D Mesh From Surface

“Tetrahedralization” not always possible!

Shoenhardt Polytope

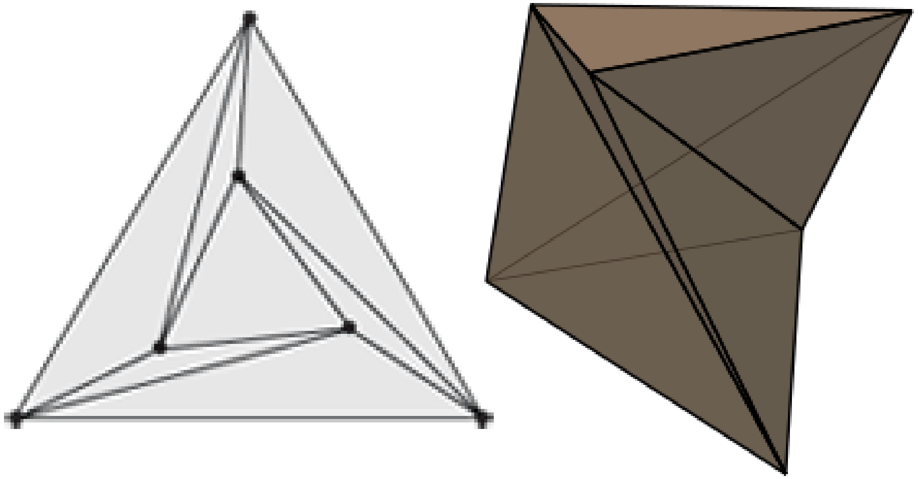


Generating 3D Mesh From Surface

“Tetrahedralization” not always possible!

Must add extra
inner points

- “Steiner pts”



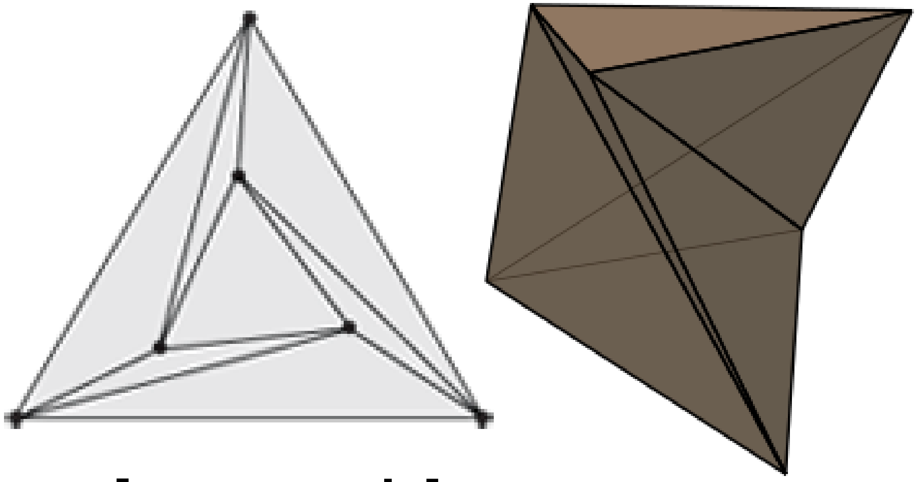
Shoenhardt Polytope

Generating 3D Mesh From Surface

“Tetrahedralization” not always possible!

Must add extra inner points

- “Steiner pts”



Shoenhardt Polytope

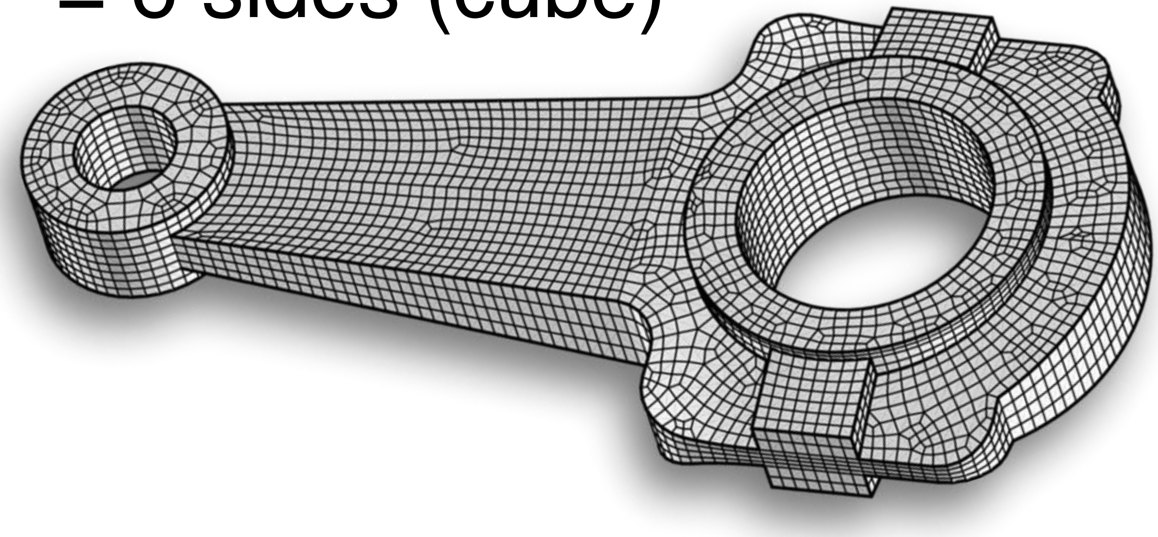
Algorithm is **complex** and **bug-prone**

- popular library: TetGen

Representing Volumes

Hexahedral mesh: 3D version of quad mesh

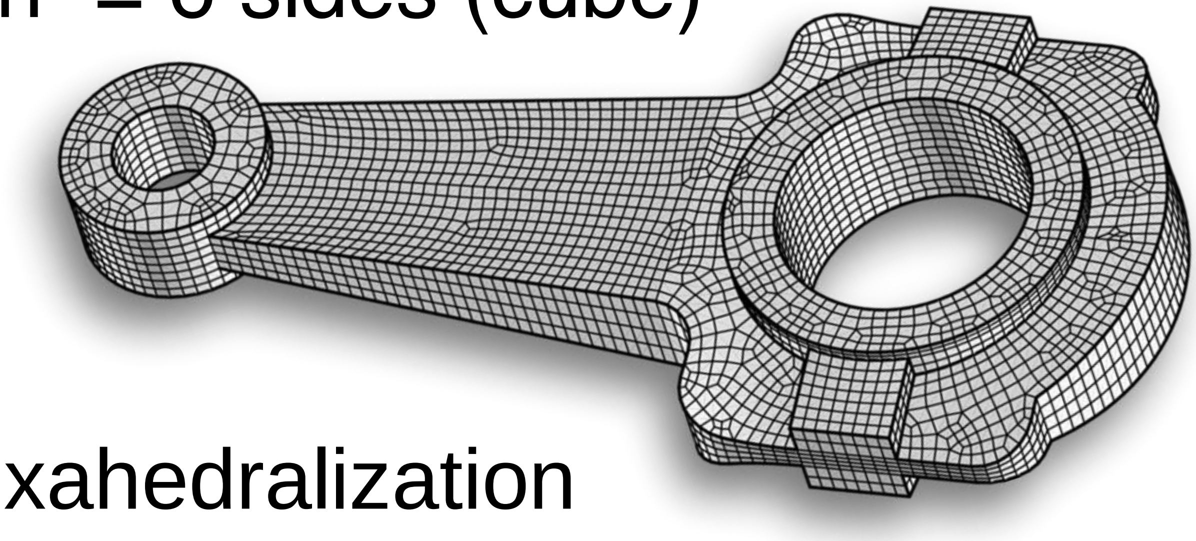
- "hexahedron" = 6 sides (cube)



Representing Volumes

Hexahedral mesh: 3D version of quad mesh

- “hexahedron” = 6 sides (cube)



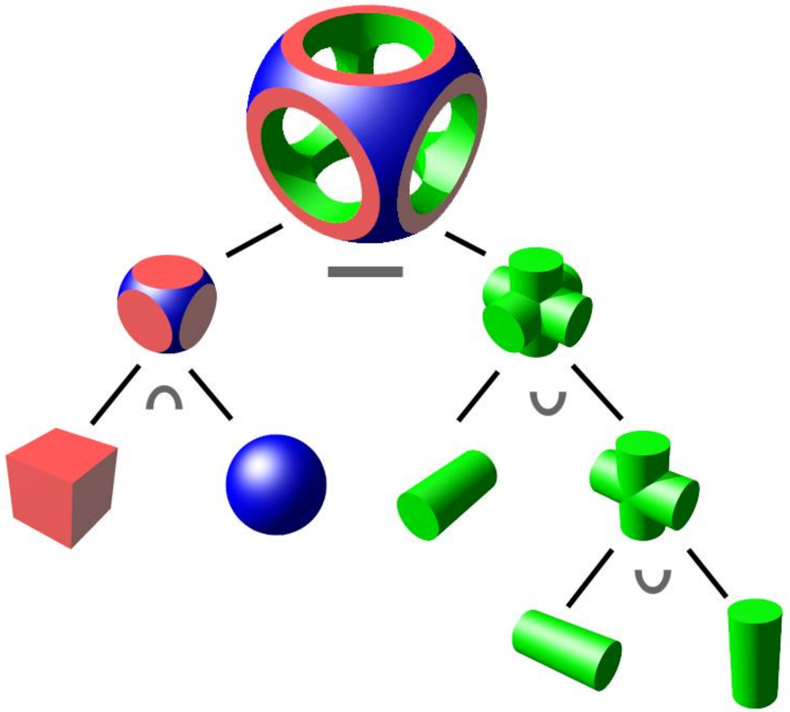
No general hexahedralization algorithm exists (!)

Constructive Solid Geometry

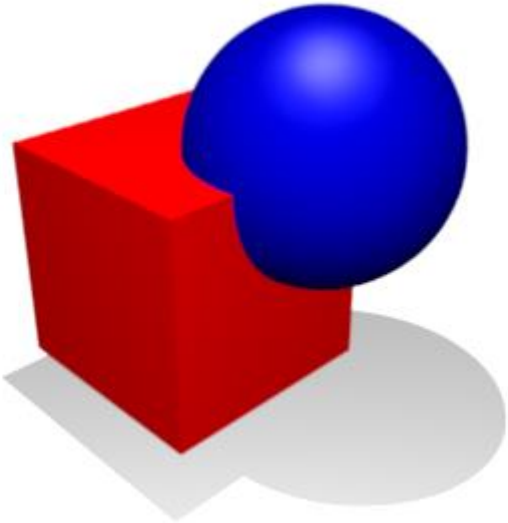
Start with simple buildings blocks

- sphere, cubes, cylinders, …

Build complicated objects using **tree of operations**



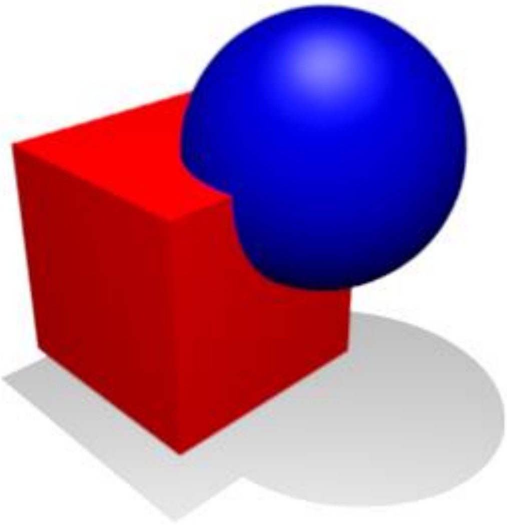
CSG Operations



union

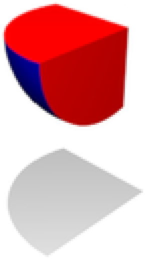
$A \cup B$

CSG Operations



union

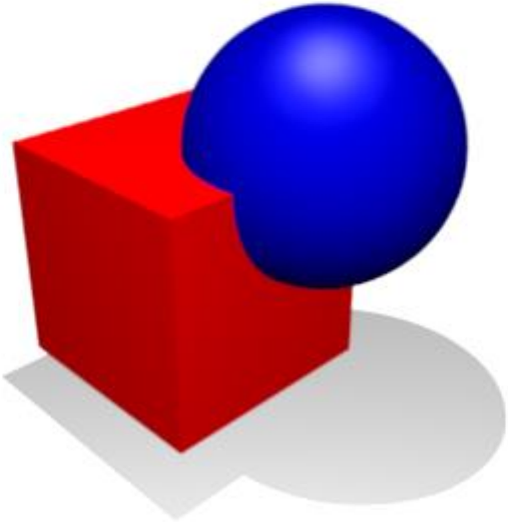
$A \cup B$



intersection

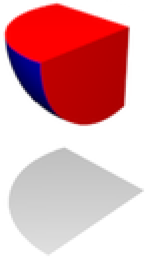
$A \cap B$

CSG Operations



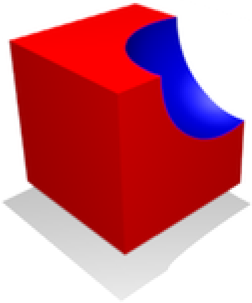
union

$A \cup B$



intersection

$A \cap B$



set difference

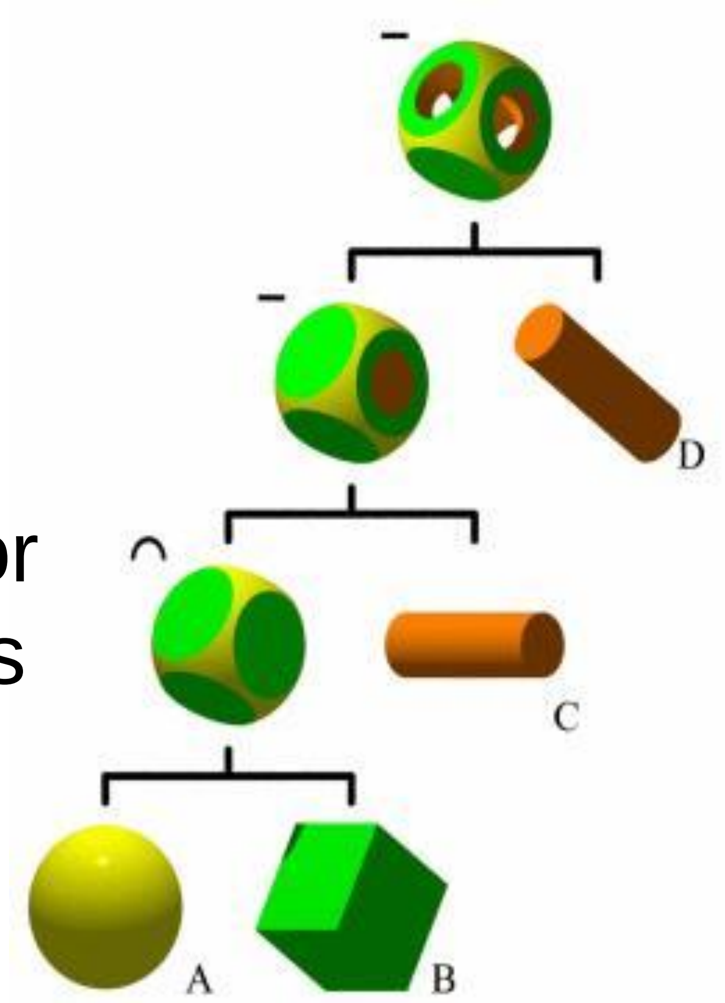
$A - B$

$A \backslash B$

CSG Tree

Pros:

- geometry is **exact**
- simple representation for visually-complex shapes



CSG Tree

Pros:

- geometry is **exact**
- simple representation for visually-complex shapes

Cons:

- some shapes difficult to model

Used in many game engines (e.g. Unreal)