Mod. Geom & Sim.

Geometric modeling

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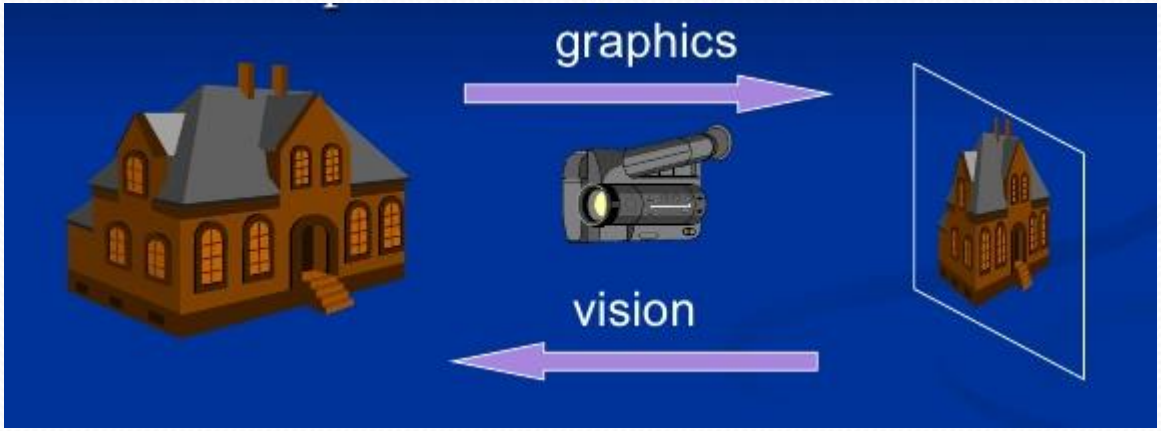
Partial credit to : G. C. Burdea, P. Coiffet, “Virtual Reality Technology”, Wiley-Interscience

Geometric modeling

- defining geometric objects using computer-compatible representation
- concerned with object representation, recognition, synthesis, and manipulation.
- important constituent of computer vision as well as computer graphics research.

CG vs CV:



Computer graphics

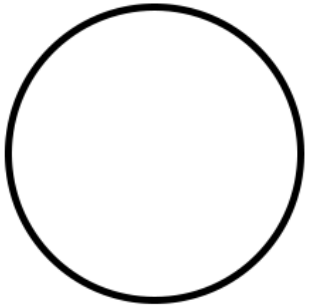
- A sub-field of computer science which studies methods for digitally synthesizing and manipulating visual content.
- Creating an image using a geometric model.

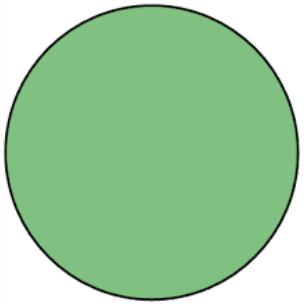
Computer vision

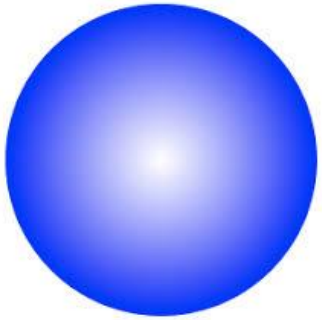
- Modeling and replicating human vision by using computer HW and SW
- Concerned with understanding the “content” of an image
- Often based on a model of the object

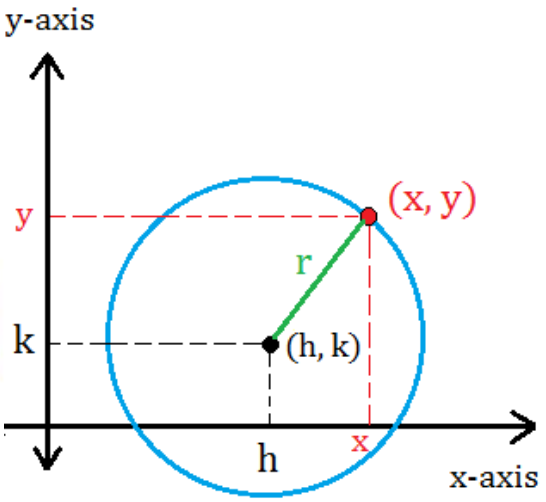
How to describe a 2D object?

Surface (boundary) vs volume representation

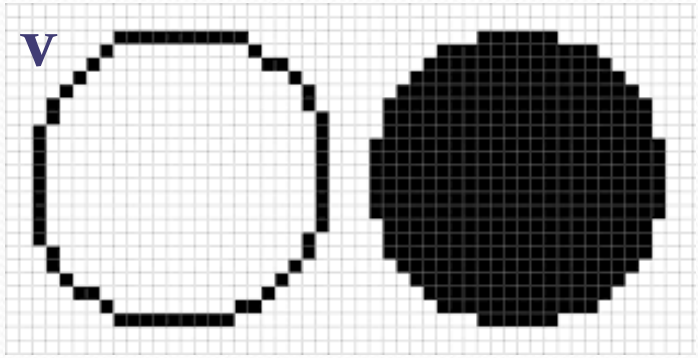








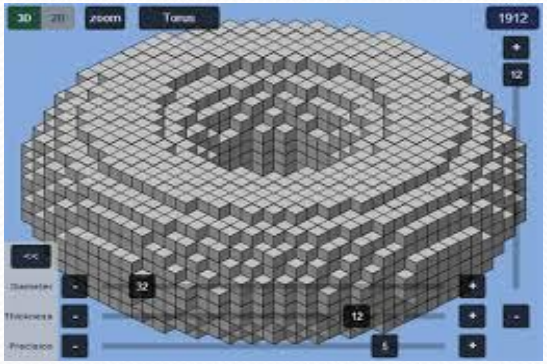
Continuous (functional) vs discreet representation



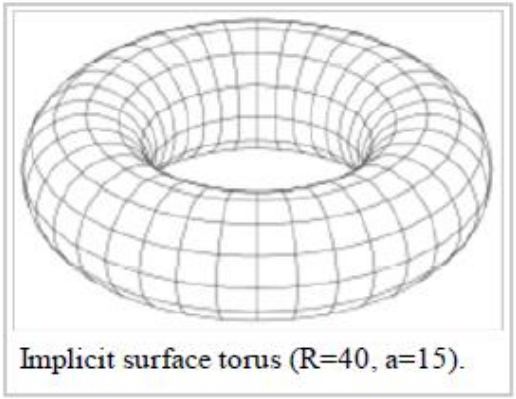
$$(x-h)^2+(y-k)^2=r^2$$

Shape representation in 3D

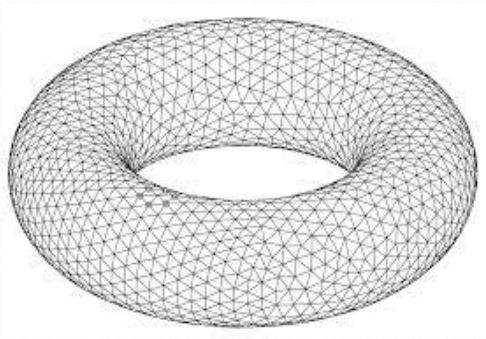
Surface (boundary) vs volume representation



Continuous (functional) vs discreet representation

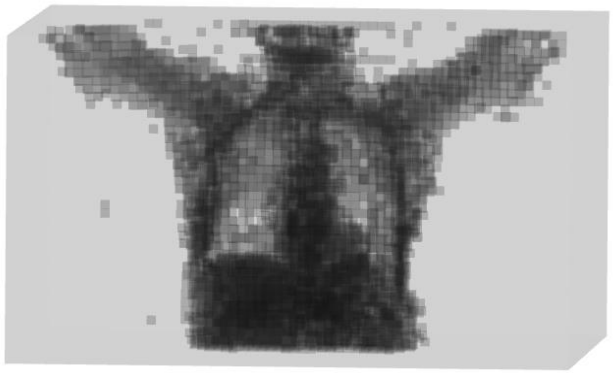


Implicit surface torus (R=40, a=15).



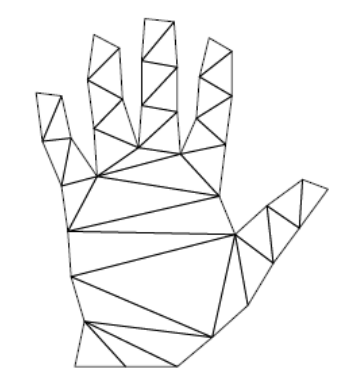
$$(x^2 + y^2 + z^2 + R^2 - a^2)^2 - 4R^2(x^2 + y^2) = 0$$

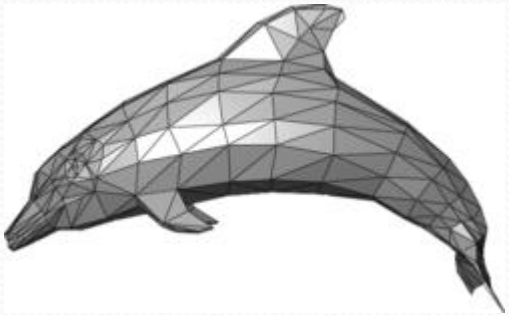
Can you tell what are these representations?

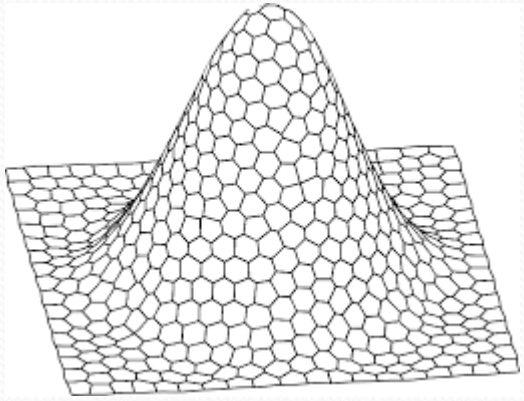


Definition of a polygonal mesh

- **"In 3D modeling, a polygon mesh is a collection of vertices, edges and faces that defines the shape boundary of an object."**
  - The faces usually consist of triangles (triangle mesh), quadrilaterals (quads), or other simple convex polygons (n-gons).

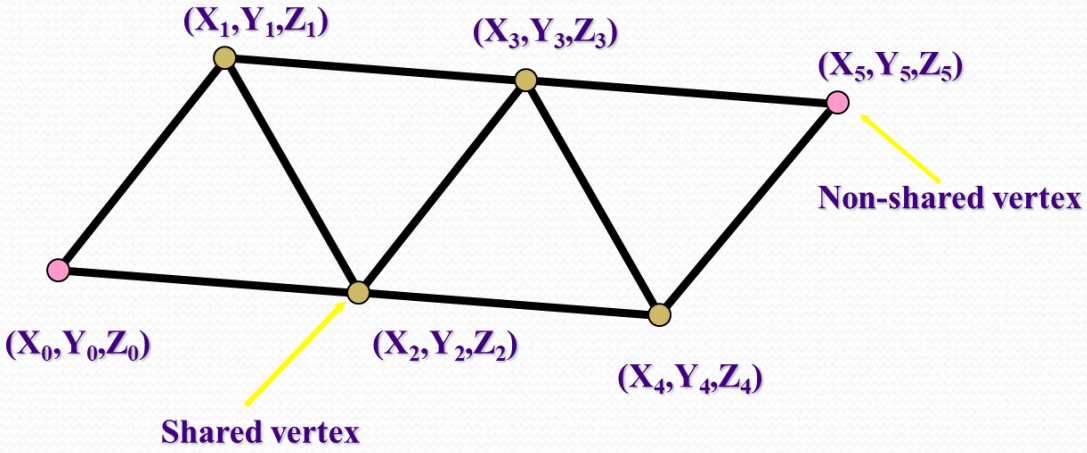




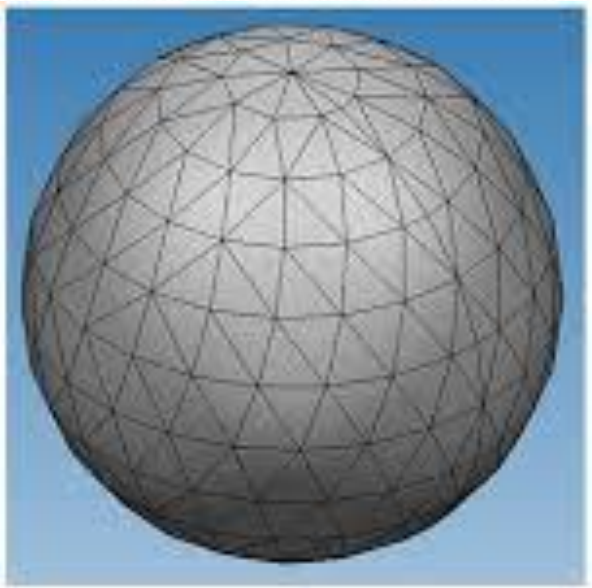


Why mesh representation?

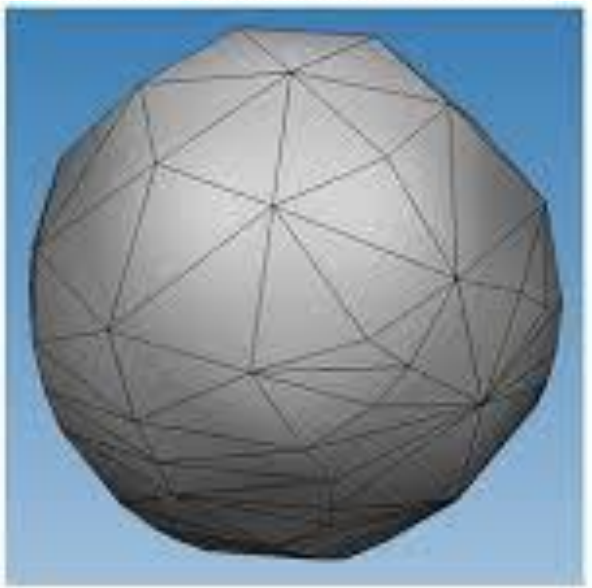
- **It simplifies rendering…**
  - In most cases, it's the **surface** of the object that **contributes to the image**
- **'Triangle' meshes are preferred since they are memory and computationally efficient**
  - All 3 vertices in a triangle lie on a same plane
  - Hardwares are optimized to render triangle meshes



Polygonal mesh: an example



Sphere in polygonal representation (418 triangles)



Sphere in polygonal representation (105 triangles)

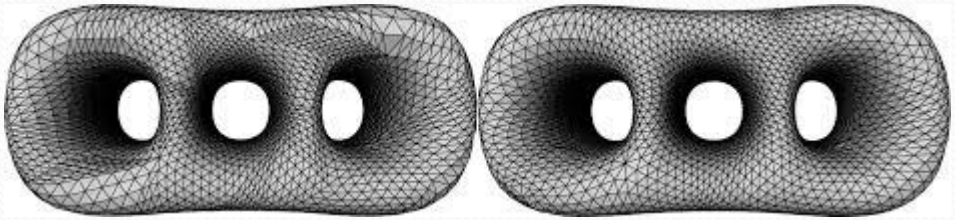
Detailed/fine vs coarse mesh

Simplification/decimation

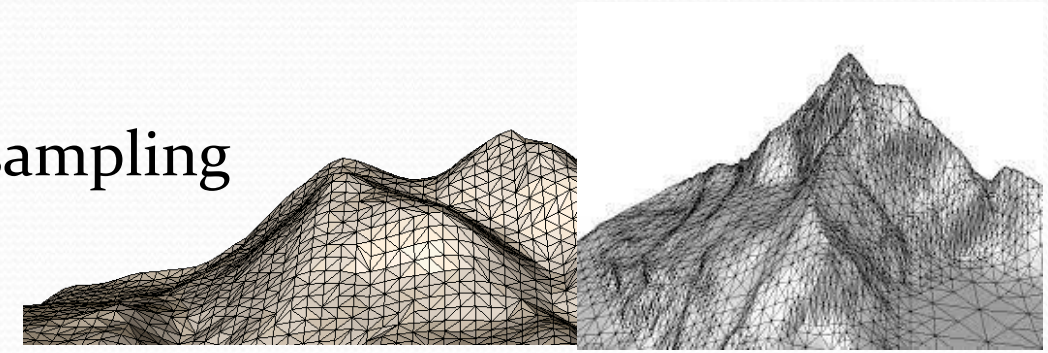
Remeshing

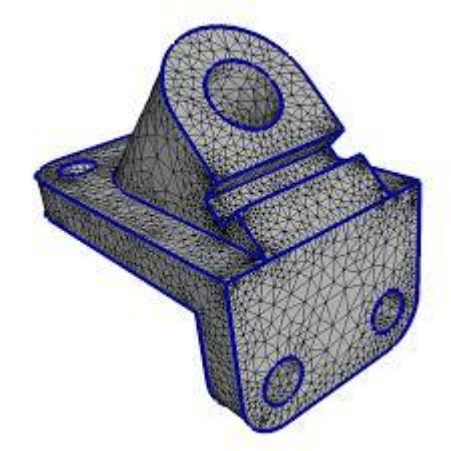
Given a 3D triangular mesh, find a "better" discrete representation of the underlying surface

What is a good mesh?



- Equal edge lengths
- Equilateral triangles
  - ⇔ sliver
- Uniform vs. adaptive sampling





- Feature preservation

Acquisition of the data

1. Programmed using OpenGL or other toolkit editor
   - tedious and requires skill;
2. Obtained from existing CAD files
3. Created using a 3-D digitizer (stylus), or a 3-D scanner
4. Purchased from online databases (i.e. Viewpoint database)

Our approach during the programming practice!

- Files have **vertex location** and **connectivity** information, but are mostly static

Vertex location and **connectivity** information?

Face-Vertex Meshes

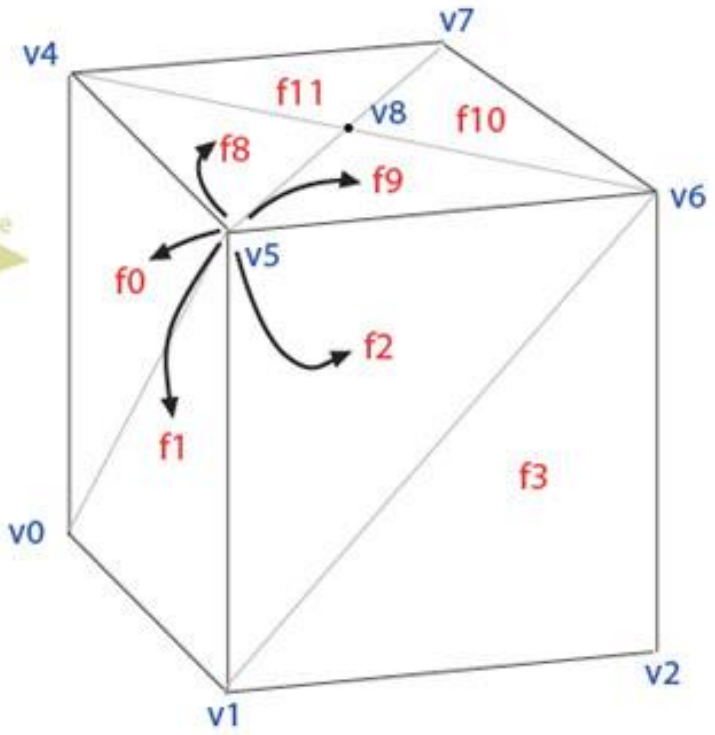
Face List

f0	v0 v4 v5
f1	v0 v5 v1
f2	v1 v5 v6
f3	v1 v6 v2
f4	v2 v6 v7
f5	v2 v7 v3
f6	v3 v7 v4
f7	v3 v4 v0
f8	v8 v5 v4
f9	v8 v6 v5
f10	v8 v7 v6
f11	v8 v4 v7
f12	v9 v5 v4
f13	v9 v6 v5
f14	v9 v7 v6
f15	v9 v4 v7

Vertex List

v0	0,0,0	f0 f1 f12 f15 f7
v1	1,0,0	f2 f3 f13 f12 f1
v2	1,1,0	f4 f5 f14 f13 f3
v3	0,1,0	f6 f7 f15 f14 f5
v4	0,0,1	f6 f7 f0 f8 f11
v5	1,0,1	f0 f1 f2 f9 f8
v6	1,1,1	f2 f3 f4 f10 f9
v7	0,1,1	f4 f5 f6 f11 f10
v8	.5,.5,0	f8 f9 f10 f11
v9	.5,.5,1	f12 13 14 15

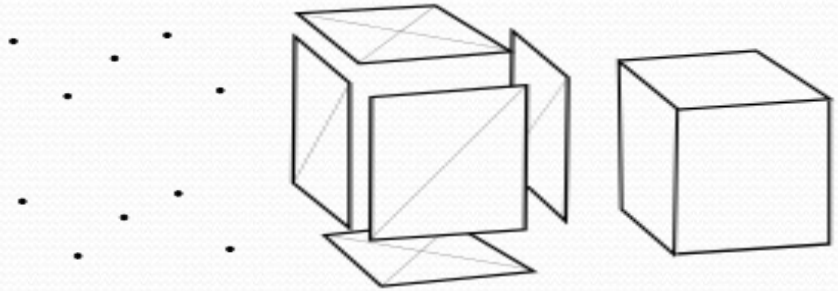
example



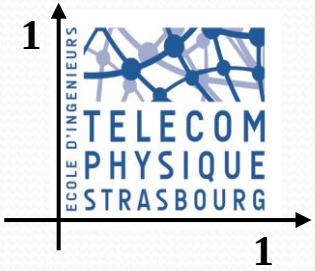
[wikipedia: Polygon mesh]

1. Programming

- Vertex list
- Face list



- Texture coordinate
- Vertex mapping to texture



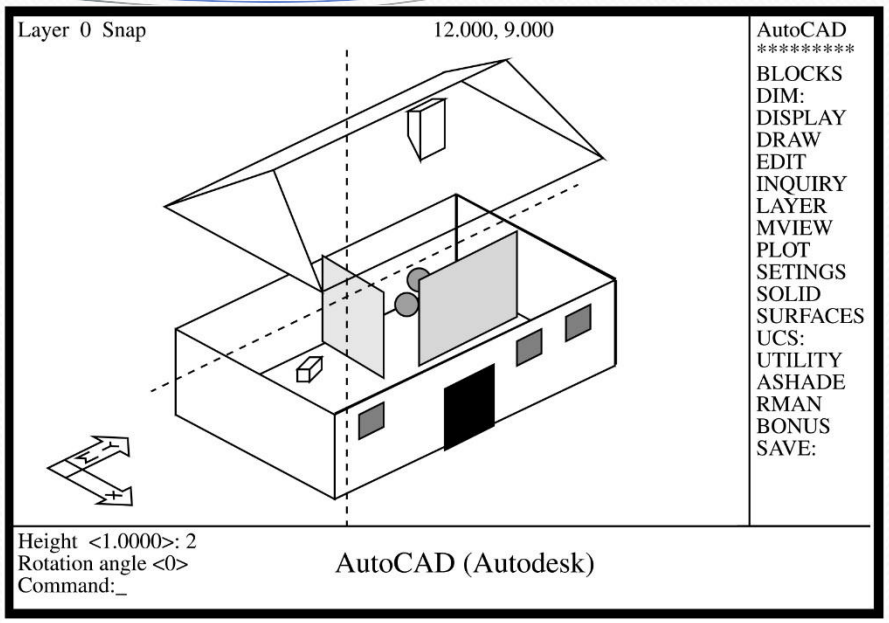

```
glBegin(GL_QUADS);
// Front Face
glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f,  1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);
// Back Face
glTexCoord2f(1.0f, 0.0f); glVertex3f(-1.0f, -1.0f, -1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f(-1.0f,  1.0f, -1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f( 1.0f,  1.0f, -1.0f);
glTexCoord2f(0.0f, 0.0f); glVertex3f( 1.0f, -1.0f, -1.0f);
// Top Face
glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f, -1.0f);
glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f,  1.0f,  1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f,  1.0f,  1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f, -1.0f);
// Bottom Face
glTexCoord2f(1.0f, 1.0f); glVertex3f(-1.0f, -1.0f, -1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f( 1.0f, -1.0f, -1.0f);
glTexCoord2f(0.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);
// Right face
glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f, -1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f, -1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f( 1.0f,  1.0f,  1.0f);
glTexCoord2f(0.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);
// Left Face
glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f, -1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f, -1.0f);
glEnd();
```

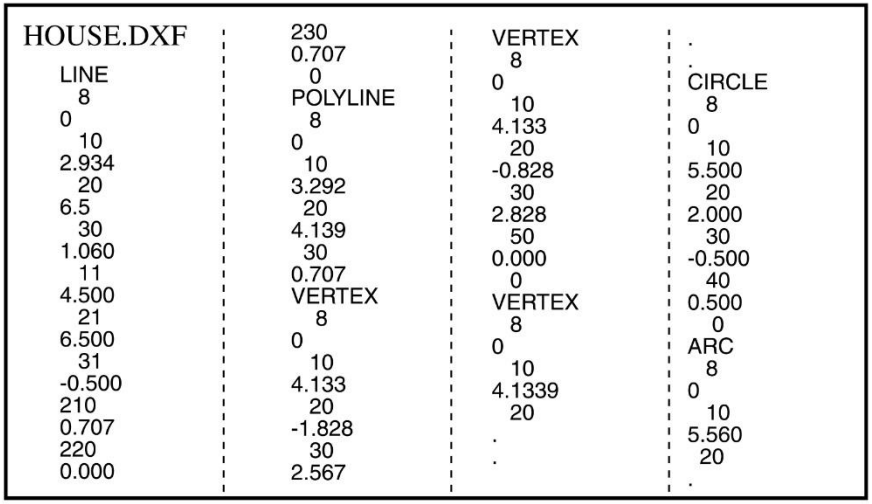
Matlab example

```
verts =
[0 0 0 ;
0 0 1 ;
0 1 0 ;
0 1 1 ;
1 0 0 ;
1 0 1 ;
1 1 0 ;
1 1 1 ];

faces =
[1 5 6 2;
1 3 7 5;
1 2 4 3;
5 7 8 6;
3 4 8 7;
2 6 8 4];

patch('Faces', faces,'Vertices',verts);
```

CAD-file based models:

- Done using AutoCAD;
- Each semantic part in a separate file;
- Files need to be converted to formats compatible with other softwares;
- Advantage – use of preexisting models in manufacturing applications.

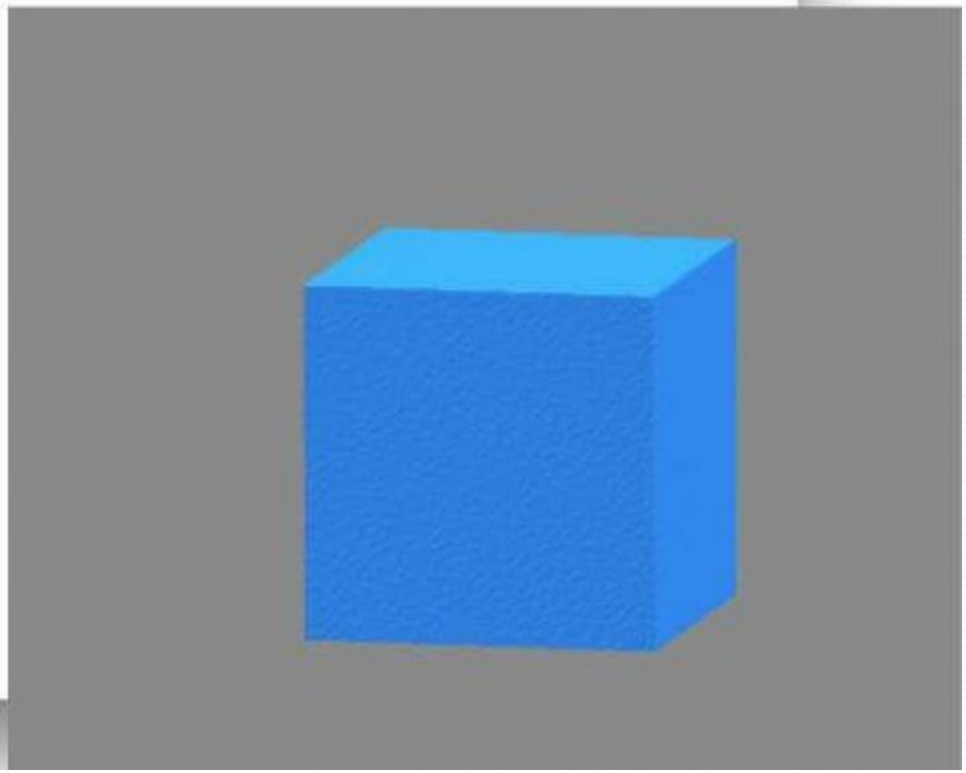




CAD files can also be downloaded from the Internet

cube.obj

```
# Wavefront obj exported by Sculpteo
# number of vertices : 8
# number of faces    : 12
#

v 1.000000 1.000000 0.000000
v 1.000000 0.000000 0.000000
v 0.000000 0.000000 0.000000
v 1.000000 1.000000 1.000000
v 0.000000 0.000000 1.000000
v 0.999999 -0.000000 1.000000
v 0.000000 1.000000 1.000000
v 0.000000 1.000000 0.000000
g label 0
f 1 2 3
f 1 3 8
f 4 7 5
f 4 5 6
f 1 4 6
f 1 6 2
f 2 6 5
f 2 5 3
f 3 5 7
f 3 7 8
f 4 1 8
f 4 8 7
```



3. 3D Digitizers

- Venus de Milo created using the HyperSpace 3D digitizer
- Highly precise but can damage the object

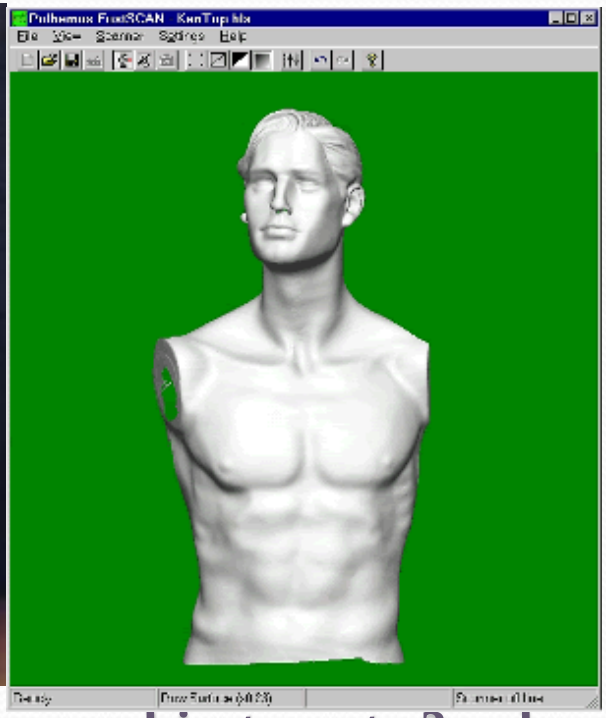
Venus de Milo created using the HyperSpace 3D digitizer

Polhemus 3-D scanners

- Eliminate direct contact with object
- Uses two cameras, a laser, and magnetic trackers (if movable objects are scanned)
- Uses time-of-flight to measure the distance from the light source

- Scanning resolution : 0.5 mm at 200 mm range;
- Scanning speed : 50 lines/sec;
- Range : 75-680 mm scanner-object range.

3. 3D scanners



Polhemus FastScan 3D scanner (can scan objects up to 3 m long).

https://www.youtube.com/watch?v=SyzgBycPxyw&t=56s

Polhemus scanner

DeltaSphere 3000 3D scanner

www.3rdtech.com

Feature	Polhemus scanner	DeltaSphere scanner
Range	0.56 m	14.6 m
Resolution	0.5 mm @ 0.2 m	0.25 mm
Control	manual	automatic
Speed	50 lines/sec	25,000 samples/sec

DeltaSphere 3000 image

www.3rdtech.com

Nowadays: movements are tolerated while scaning

Nowadays: dynamic scan data

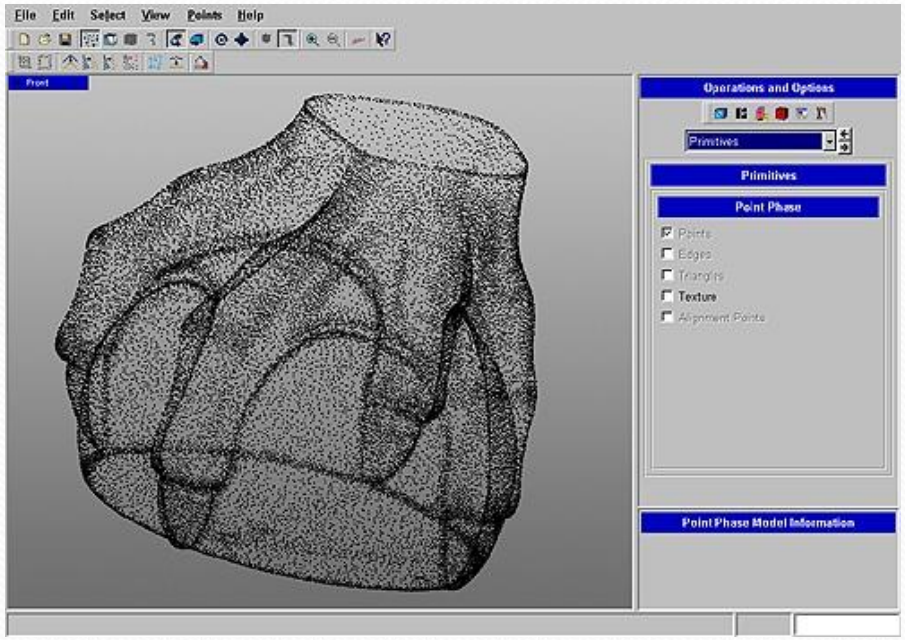
- Video scanners: scan objects under movement
- Works especially well on human faces or bodies
- Representation of it is an open problem

https://www.youtube.com/watch?v=jh6msLkwqhE

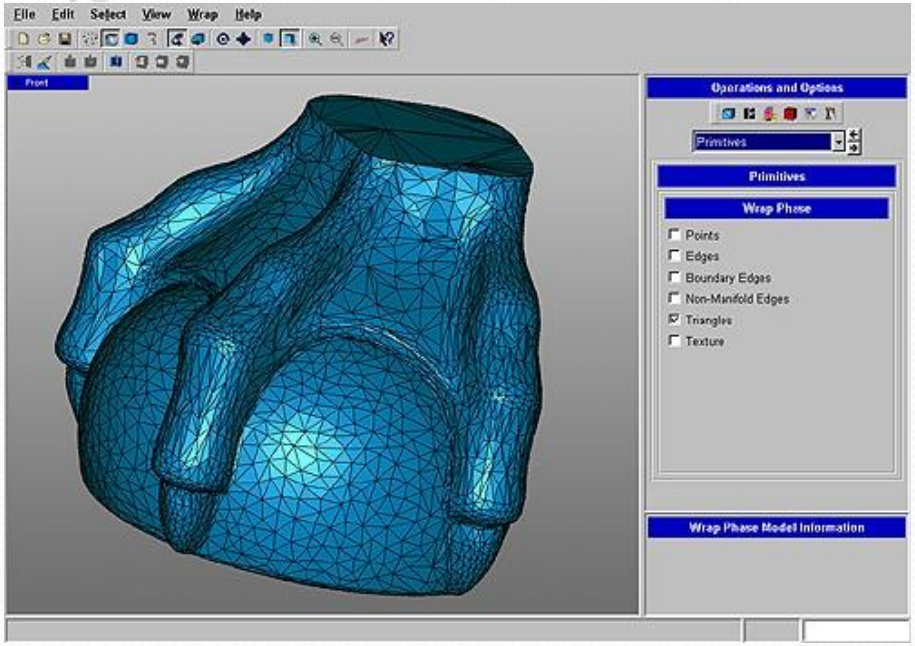
Conversion of scanner data

- Scanners produce a dense “cloud” of vertices
- Using such packages as Meshlab, the point data is transformed into surface data (including editing and decimation)

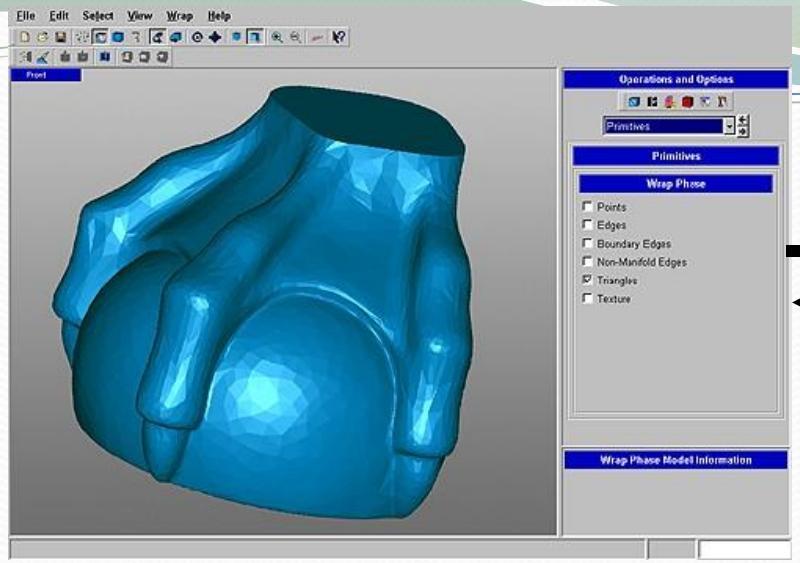
Point cloud from scanner



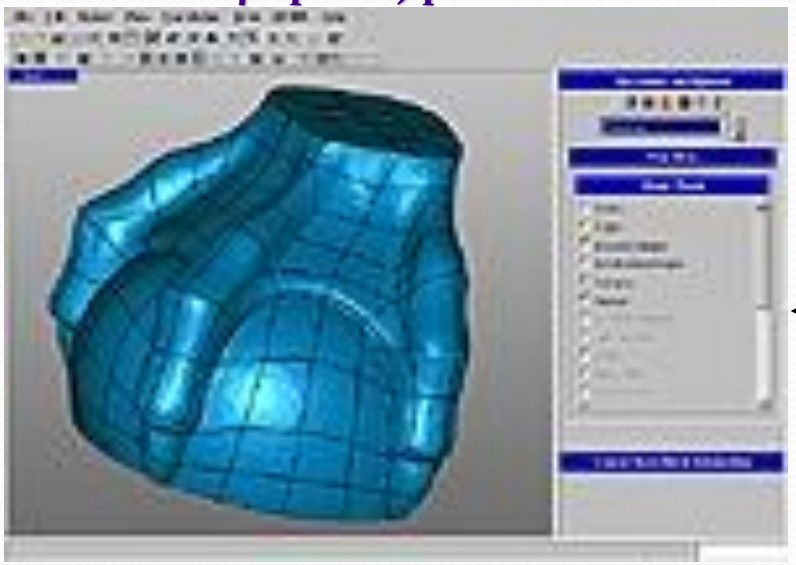
Polygonal mesh after decimation



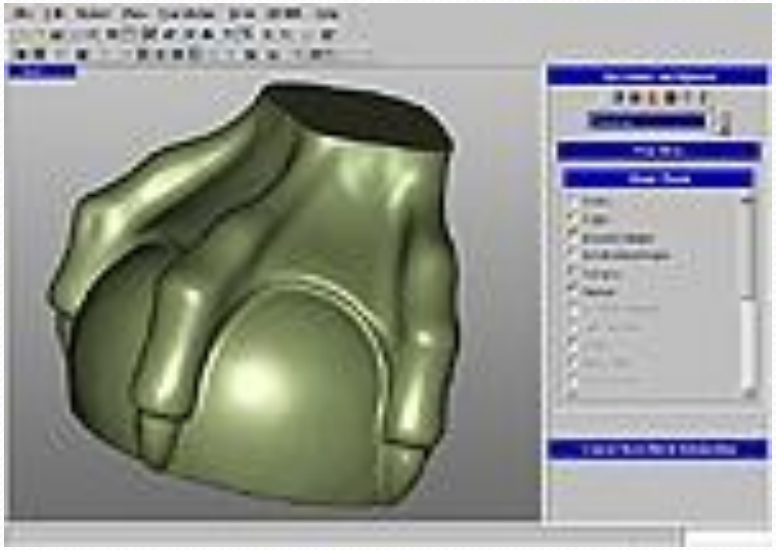
Polygonal surface



NURBS (non-uniform rational β-splines) patches



NURBS surface



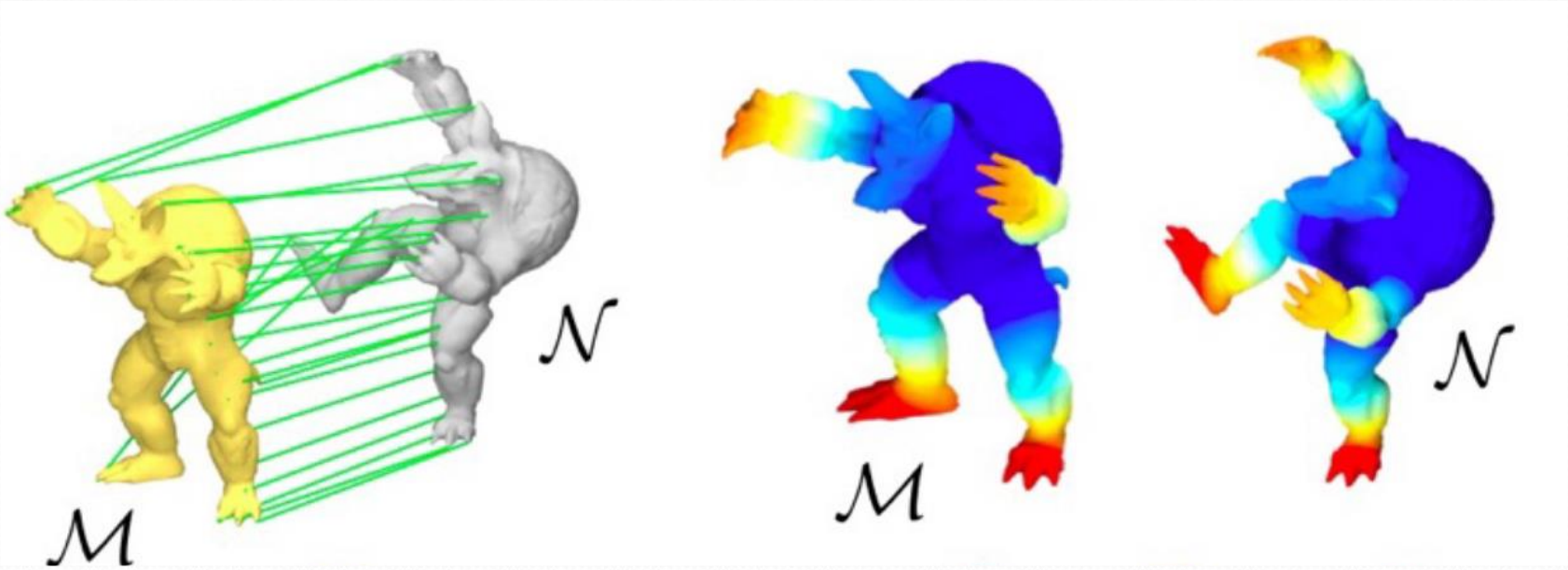
Purchase of 3D mesh data

- Can cost dozens to several thousand euros

Firefighter models from http://www.poserworld.com

Subaru 360 model from http://www.quality3dmodels.net

Correspondence problems



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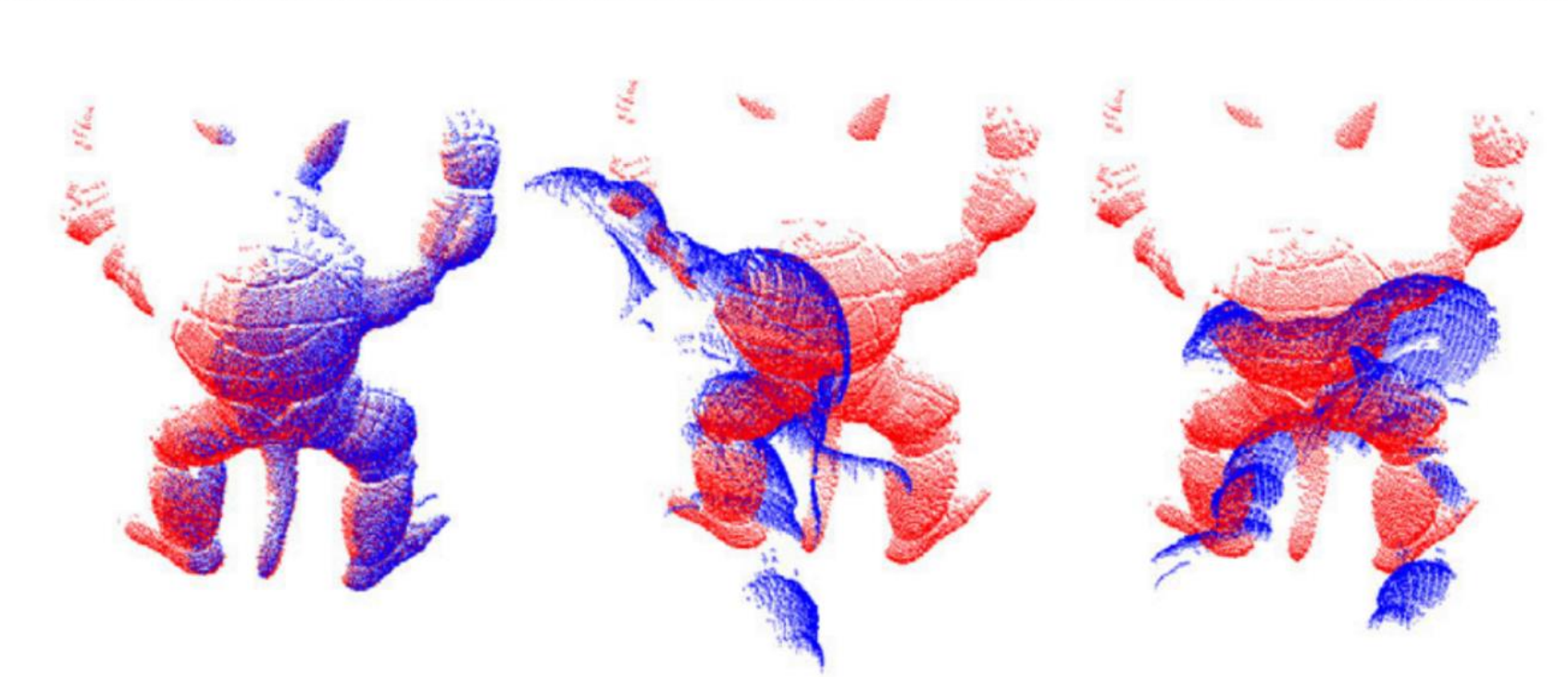

Correspondence problems