Ερευνητικό Κέντρο Αθηνά
Athena Research Center

Ερευνητικό Κέντρο Καινοτομίας στις Τεχνολογίες της Πληροφορίας, των Επικοινωνιών, της Γνώσης

Research and Innovation Center in Information, Communication and Knowledge Technologies

3D DIGITIZATION THEORY

Current state of the art techniques

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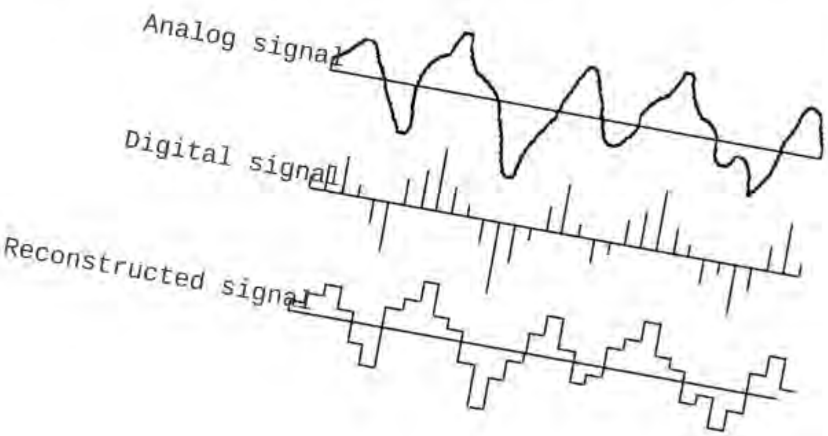
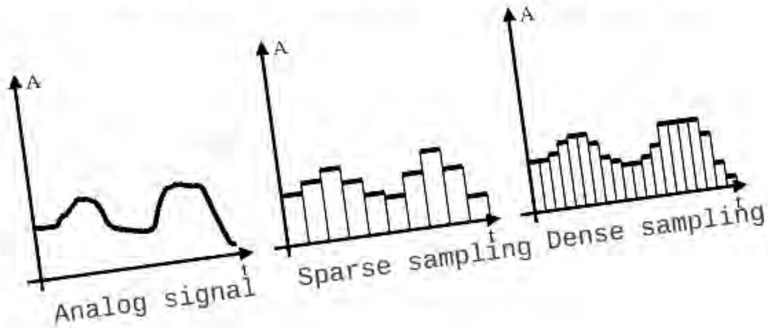
GRAPHICS AND 3D DIGITIZATION TECHNIQUES

Digitization

- Yet, another recording technique with benefits...
- Refers to the transformation of the real (analog) world to a virtual (digital) world
- Is based on sampling - can be dense or sparse - which relates to the 'fidelity' of a digital signal
- NOTE THAT: a digital replica is not a 'complete' replica of the real
  - the digital can be a good approximation under special conditions but it is always a subset of reality





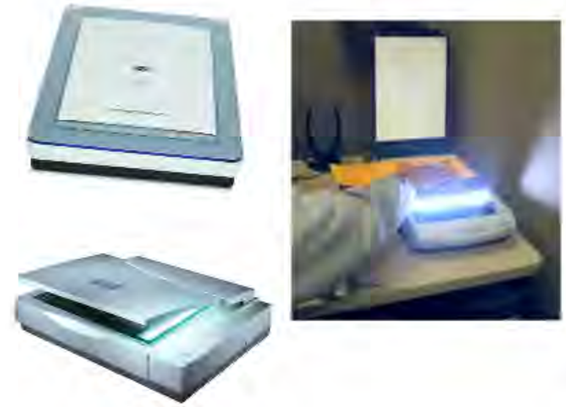
DIGITIZATION IN ARCHAEOLOGY AND CULTURAL HERITAGE?

Well yes indeed! Both in 2D and 3D...

2D DIGITIZATION

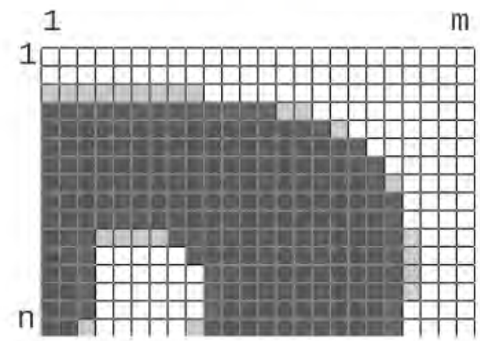
2D SCANNER

- A typical desktop tool
- One-button operation (automation)
- Robust technology - high quality outcome



STRUCTURE OF 2D IMAGE DATA

- Bitmap images
- Matrix of NxM dimensions (resolution)
- Pixel (picture element) is a matrix cell
- 3 chromatic components for each pixel (R,G,B)



3D DIGITIZATION

- Becomes a common practice in cultural heritage
- Google Scholar search:
  - query keywords:

    3D digitisation, 3D reconstruction, 3D artefact, virtual heritage, cultural heritage

  - query response:

    About 1590 results
    >350 (case studies) related to 3D digitization of cultural heritage
    A growing trend

3D DIGITIZATION

Why is it important?

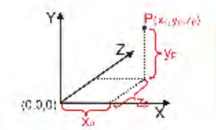
- Access to 3D information for scientists, researchers, and the laymen
- Dissemination through digital technologies and the Web
- Usage of the 3D replica in VR applications and interactive scientific visualizations
- Creation of digital collections with advanced functionality (such as content-based)
- 3D printing for conservation, dissemination

3D DATA STRUCTURES

Point Cloud

- Set of points (vertices) that share the same Cartesian coordinate system

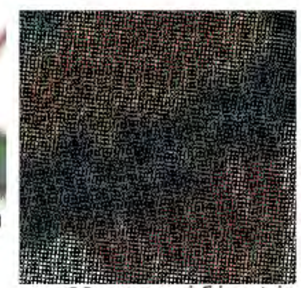
Without color information
Three (3) coordinates X,Y,Z only
spatial



20x magnification

Including color information
Six (6) coordinates
X,Y,Z spatial and R,G,B color

20x magnification

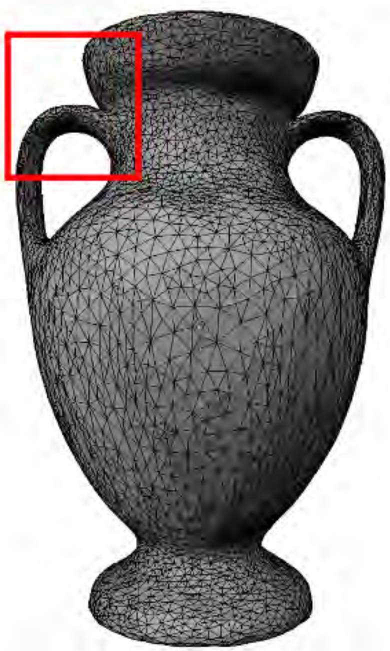


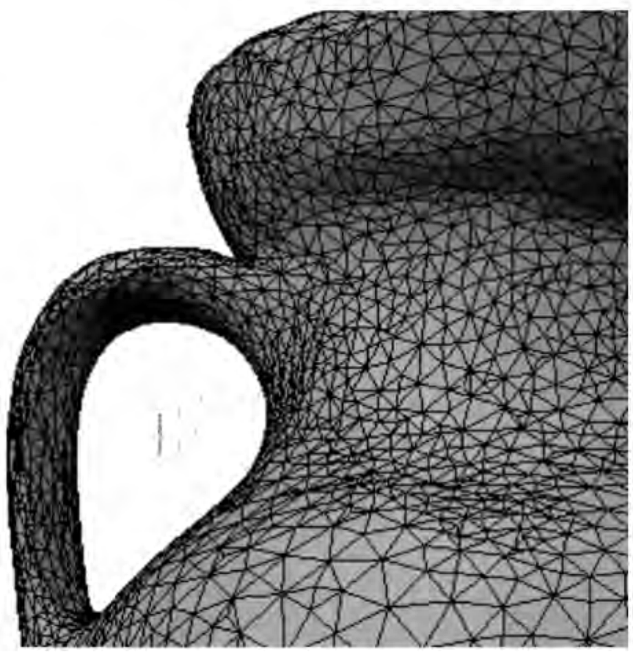
30x magnification

3D DATA STRUCTURES

Triangular mesh

- Most widespread technique to represent 3D data
- Triangles are enough to determine a plane in 3D
- Finite number of triangles can approximate any 3D object with specific accuracy





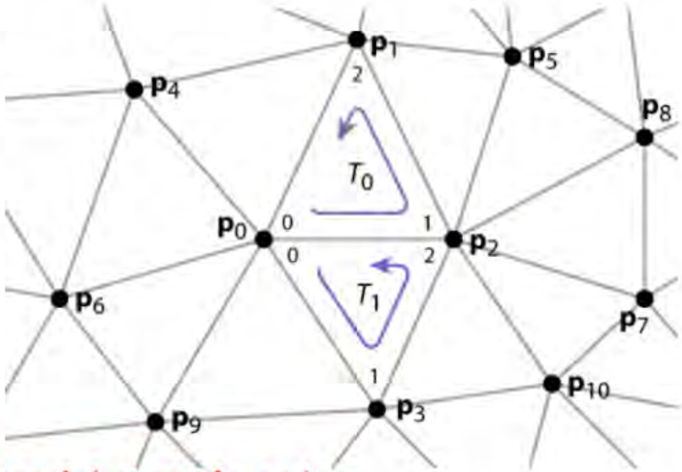
```
  X      Y    Z
123,234,154
145,225,178
167,200,140
123,231,189
…
230,250,130
```

```
1, 2, 3
3, 4, 5
…
128,129,130
```

VARIOUS DEFINITIONS

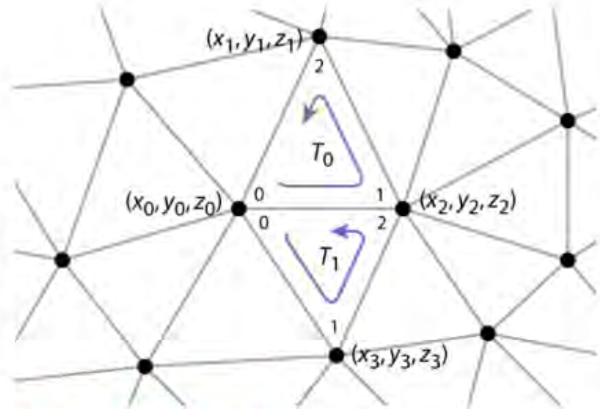
verts[0]	x_0, y_0, z_0
verts[1]	x_1, y_1, z_1
	x_2, y_2, z_2
	x_3, y_3, z_3
	⋮

tInd[0]	0, 2, 1
tInd[1]	0, 3, 2
	⋮



indexed triangle set

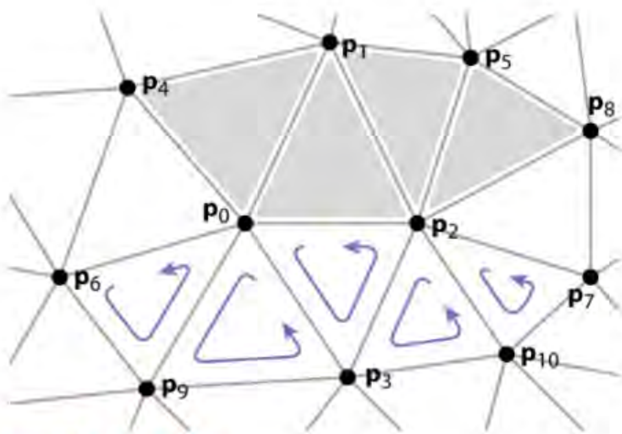
	[0]	[1]	[2]
tris[0]	x_0, y_0, z_0	x_2, y_2, z_2	x_1, y_1, z_1
tris[1]	x_0, y_0, z_0	x_3, y_3, z_3	x_2, y_2, z_2
	⋮	⋮	⋮



Separate triangle set

verts[0]	x_0, y_0, z_0
verts[1]	x_1, y_1, z_1
	x_2, y_2, z_2
	x_3, y_3, z_3
	⋮

tStrip[0]	4, 0 , 1, 2, 5, 8
tStrip[1]	6, 9, 0, 3, 2, 10, 7
	⋮

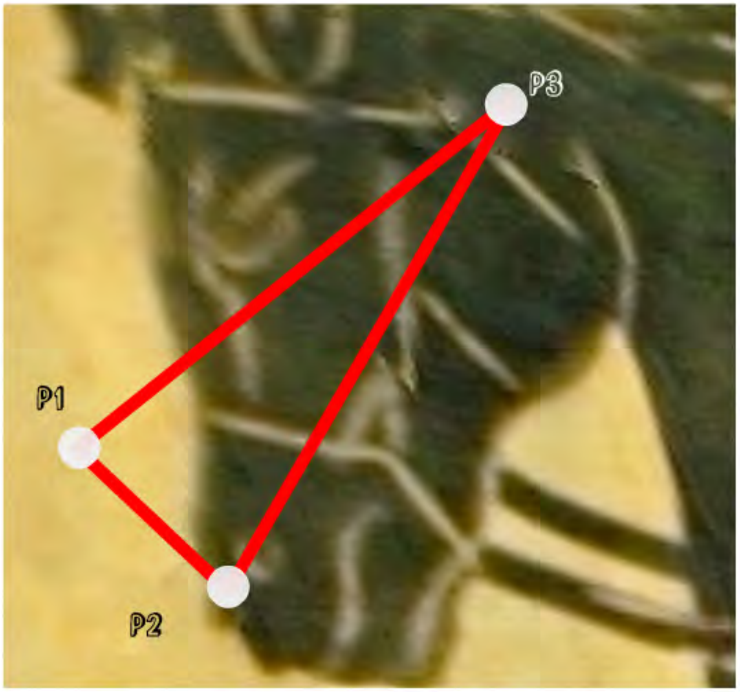


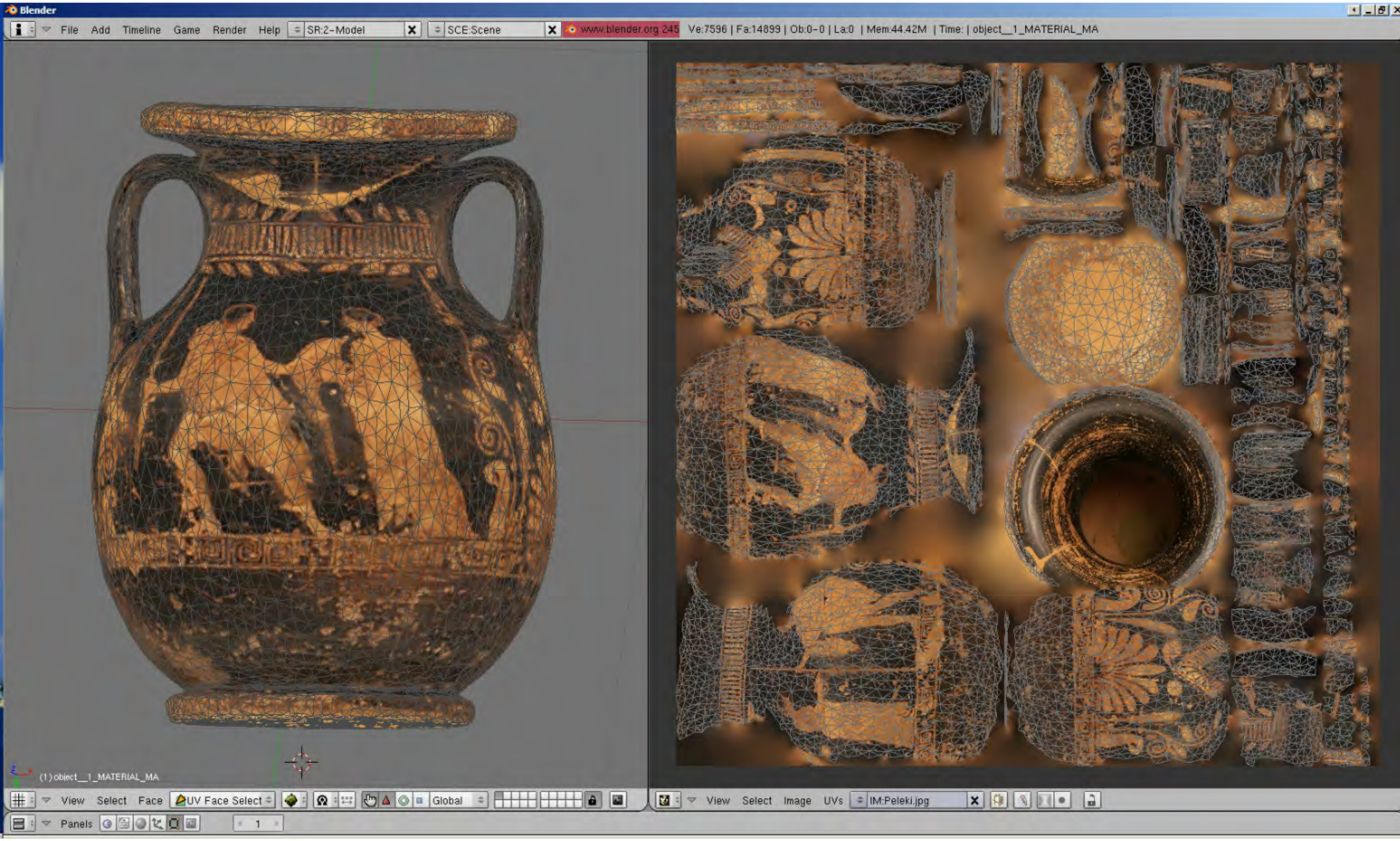
Triangle strips

3D DATA STRUCTURES

Triangular mesh

- UV-mapping: Mapping of raster data on the surface defined by triangles
- Most widespread technique for realistic texture representation




Blender
File
Add
Timeline
Game
Render
Help
SR:2-Model
SCE:Scene
www.blender.org 245
Ve:7596 | Fa:14899 | Ob:0-0 | La:0 | Mem:44.42M | Time: | object__1_MATERIAL_MA
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View
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View
Select
Image
UVs
IM:Peleki.jpg
Panels
1

METHODS FOR 3D DIGITIZATION

- Two major categories
- Some have already produced market-ready technologies

Optical

Active
- Laser scanning
- Range scanning
- Structured light
- Photometry
- Shading
- Shadow

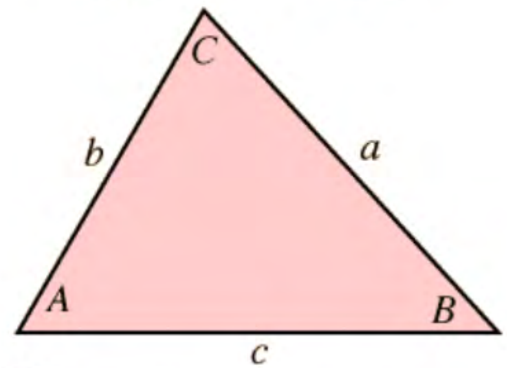
Passive
- Photogrammetry
- Shape/Structure-from-X
  - silhouette
  - stereo
  - motion/video
  - texture
  - zoom in/out

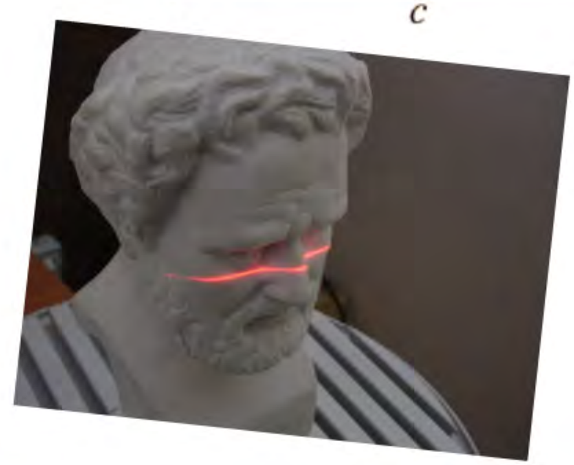
Non-optical
- Topographic
- Empirical
- Touch-sensing

LASER TRIANGULATION

- Trigonometry - Law of sines and properties of similar triangles

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

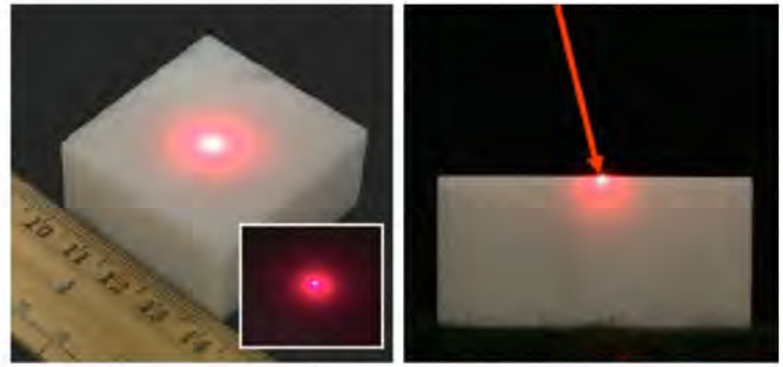


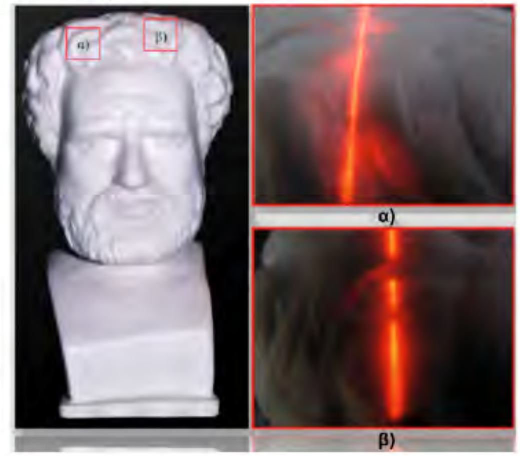


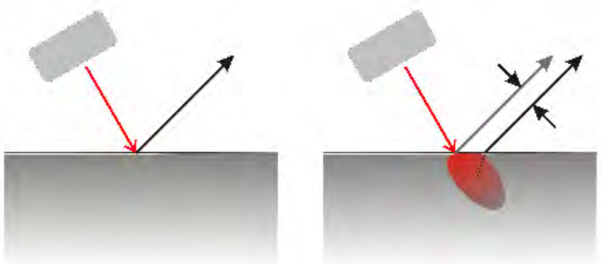
LASER TRIANGULATION

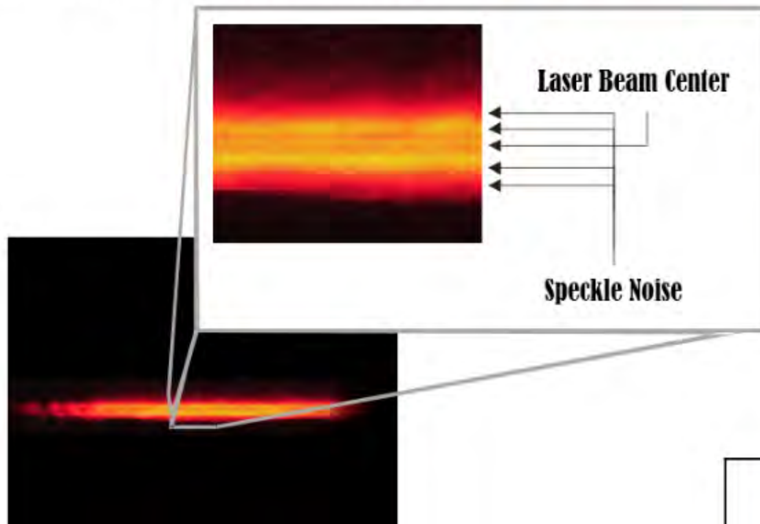
Characteristics and issues

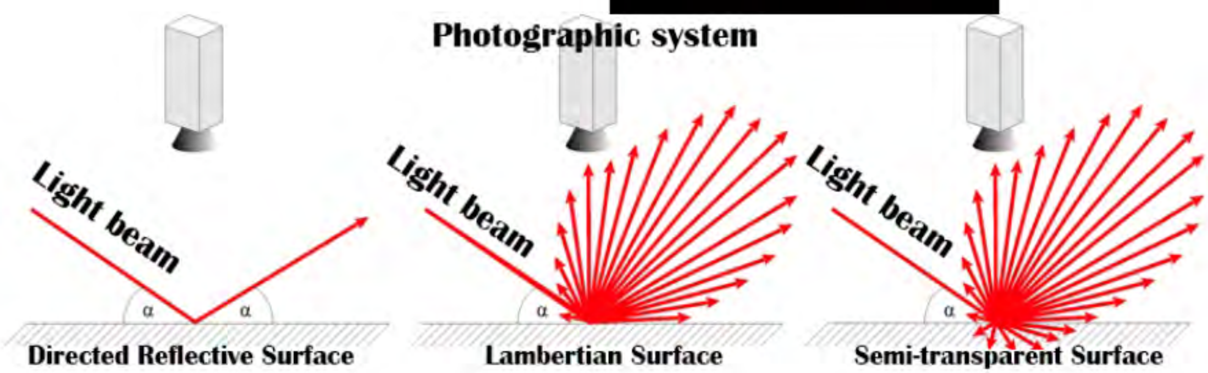
- Various patterns can be used
- Diffusion - Measurement uncertainty
- Reflection - Erroneous distance measurement
- Refraction - Erroneous distance measurement

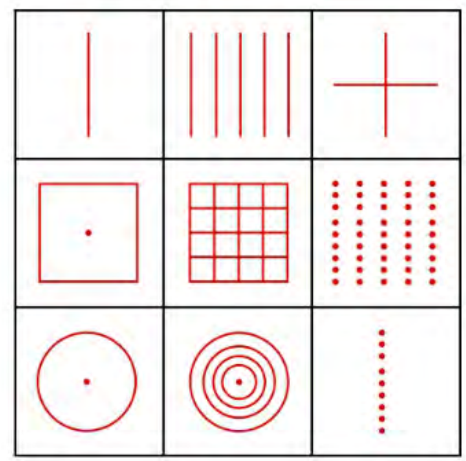






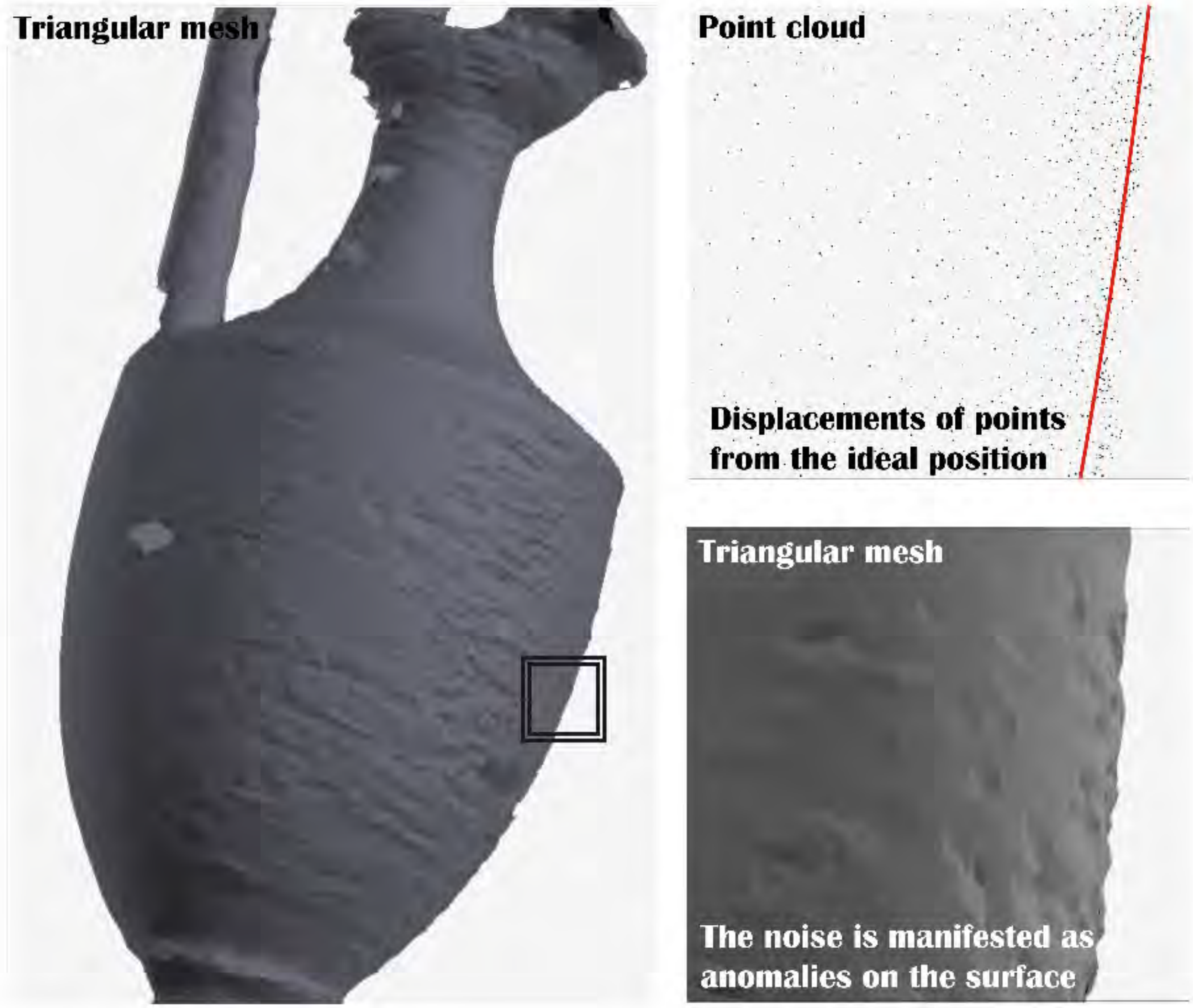






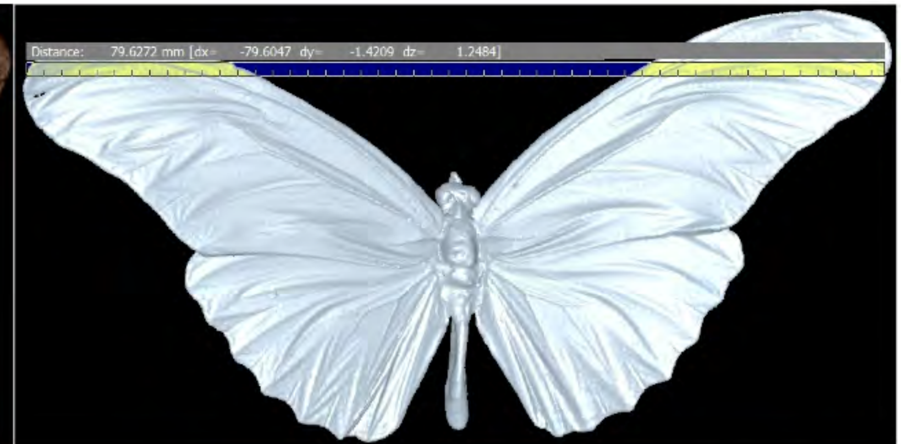
LASER TRIANGULATION
Noise in the data

- Displacement of the points in the 3D space
- Surface 'anomalies'



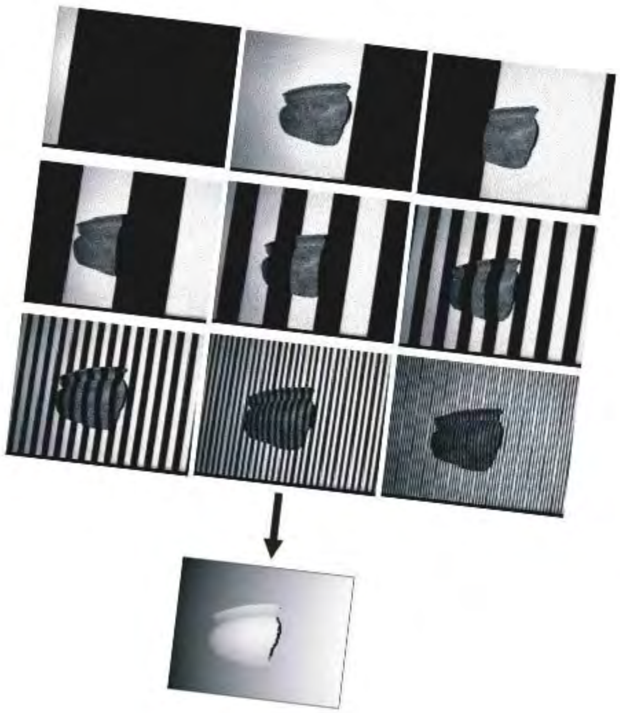
LASER TRIANGULATION

Dense sampling (resolution) and high accuracy



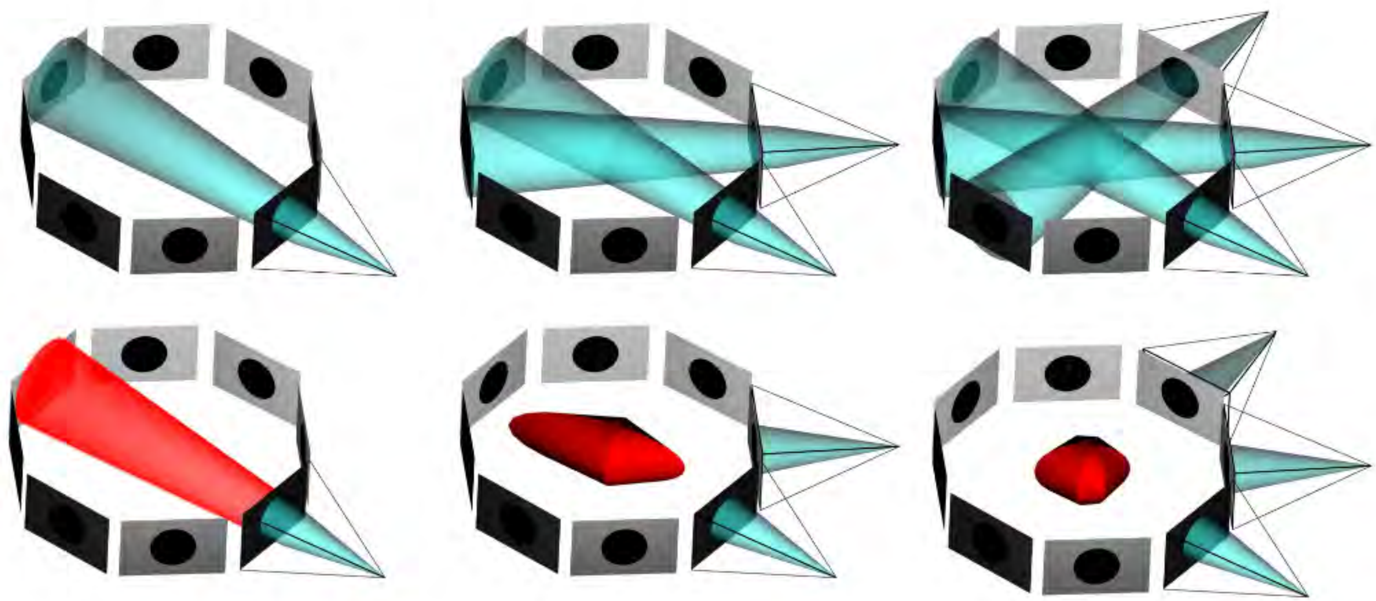
STRUCTURED LIGHT

- Projection of a pattern on the surface of the object
- Detection of the pattern distortions
- Additional photos provide data for the texture



Shape from Silhouette

- Mupliple-view photography of a still object
  - usually from fixed positions
- A turn-table is used in most cases
- The morphology of an object is extracted from the photographed silhouettes
- Texture mapping using additional photos



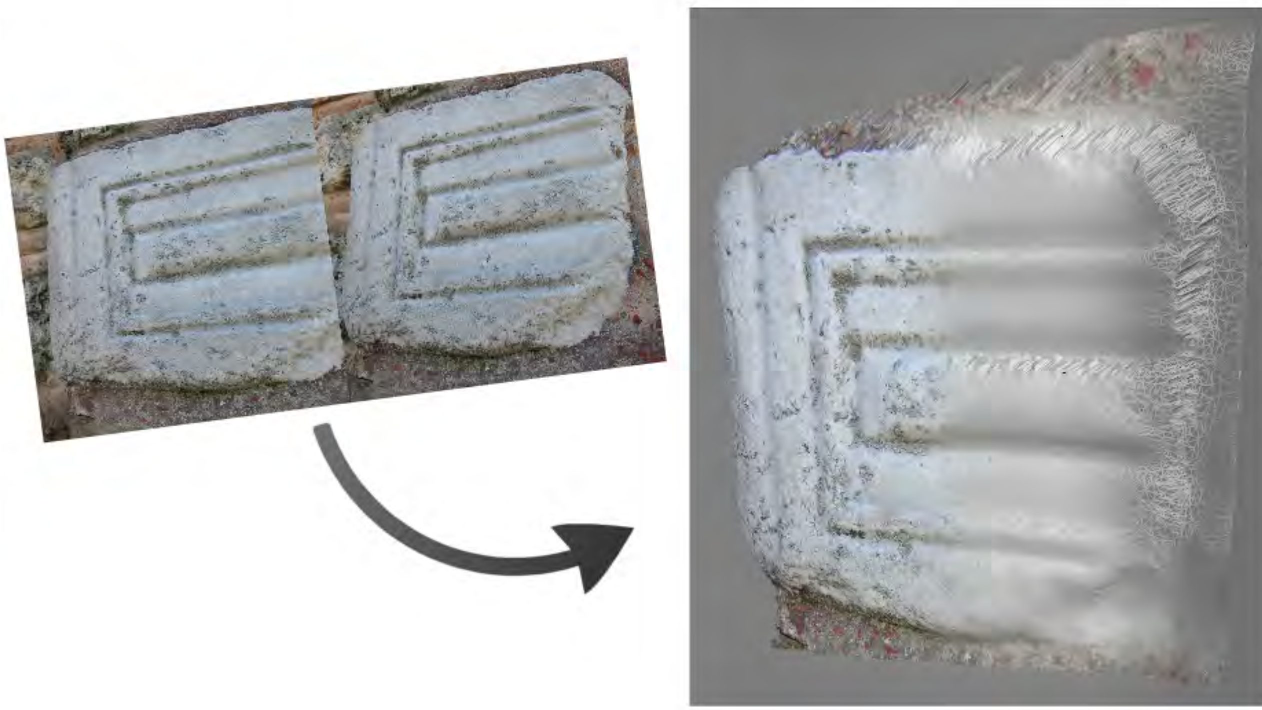
SHAPE FROM SILHOUETTE

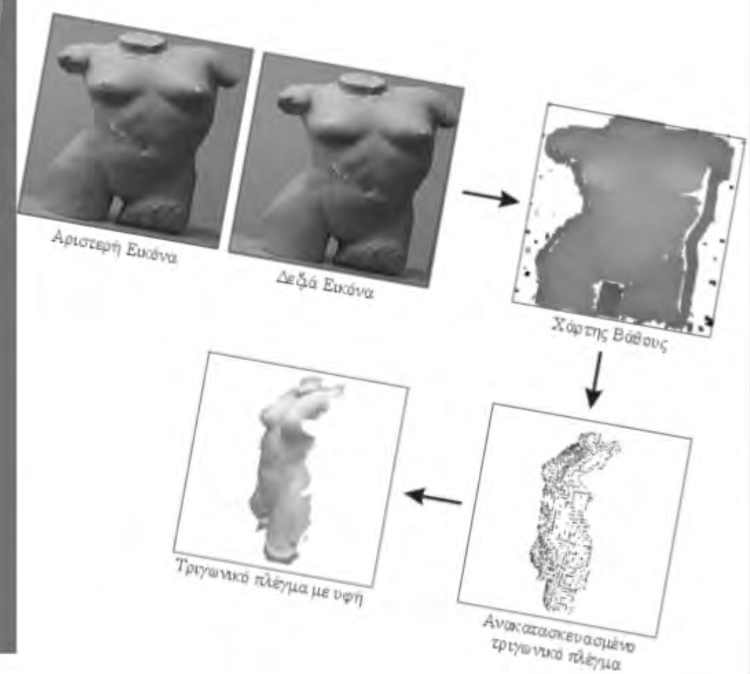
Characteristics and issues

- High-degree of process automation
- High productivity
- Issues in reconstructing the cavities that do not appear in silhouettes

STEREO-PHOTOGRAPHY

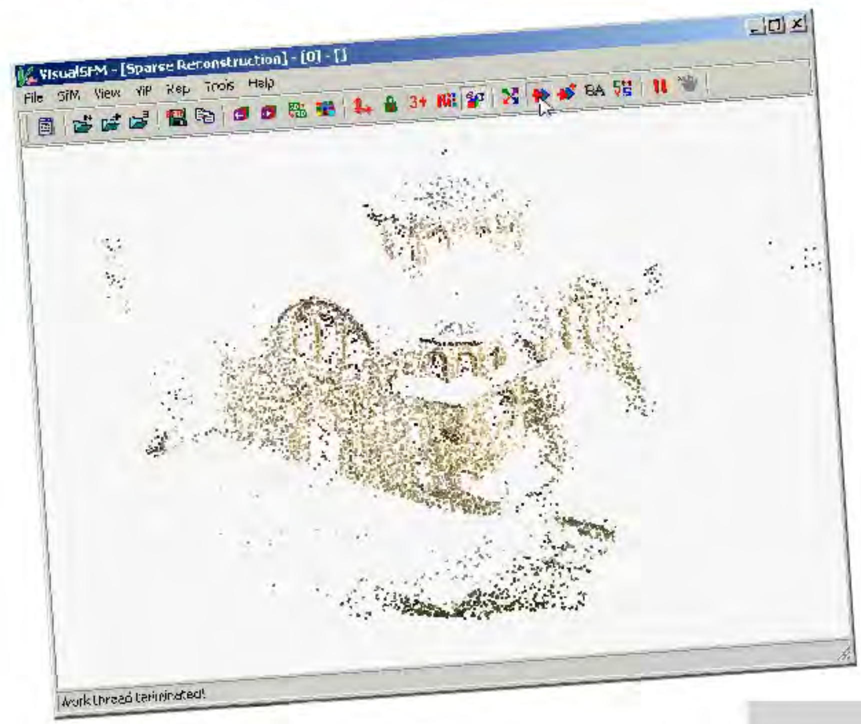
- Usage of stereo-pairs for the extraction of geometry
- Requires stereo-pair photography
  - Either by two cameras or by a stereo-pair
- Simulation of the human visual system

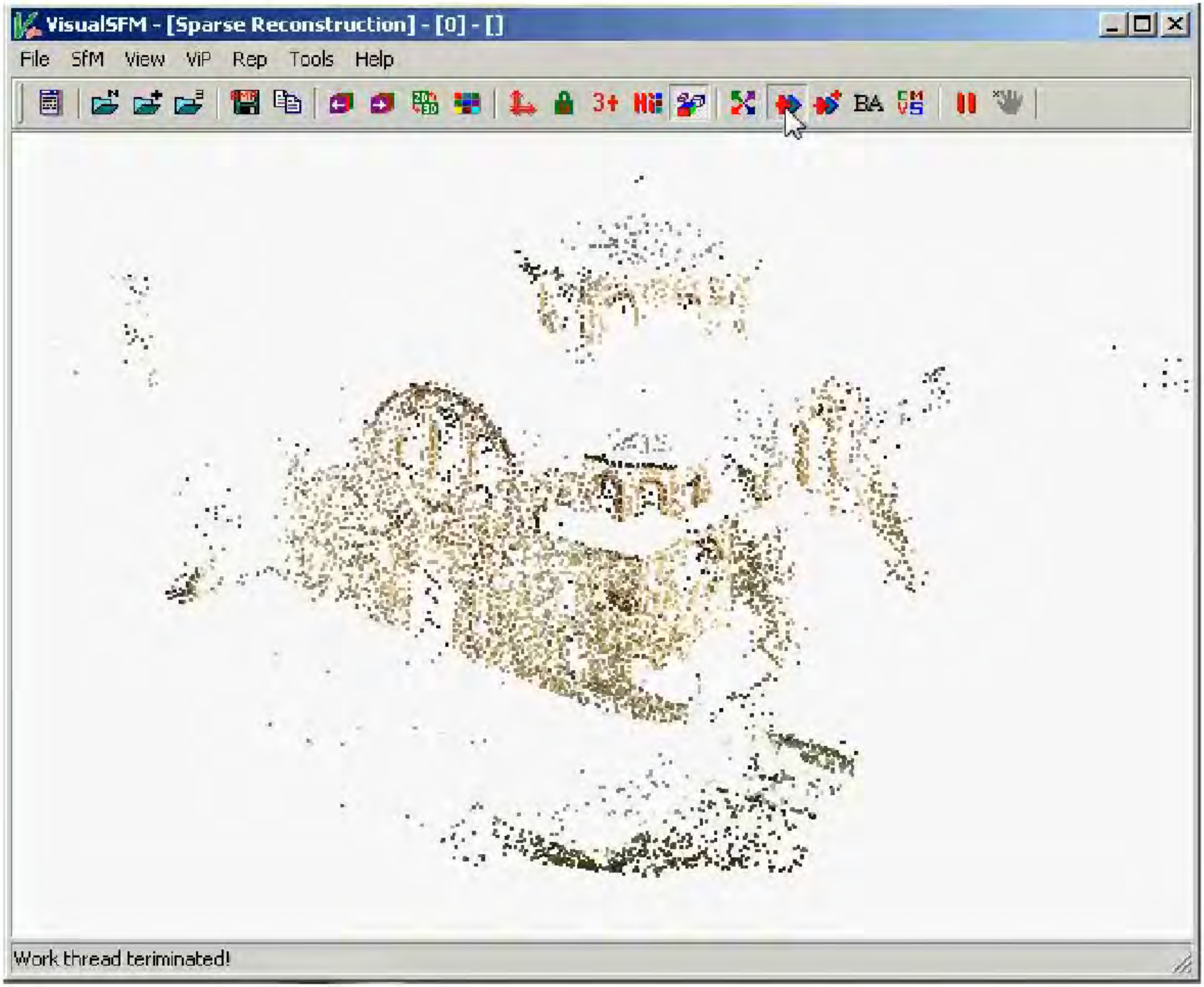




STRUCTURE FROM MOTION

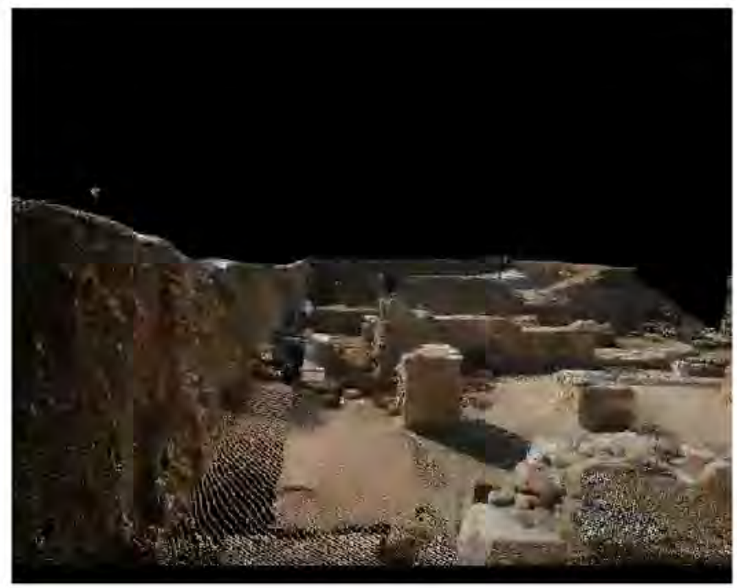
- Generalization (somehow) of stereo-photography (two-view photography) into multiple-view
- Recording of sequences of photos using a moving camera
- Requires a static scene (the object should be still)
- Based on the recognition of salient points (corners, edges, etc) and their matching in a set of images
- Provides solution to the relative location of points in 3D space
- Provides solution to the camera tracking problem




VisualSFM - [Sparse Reconstruction] - [0] - []
File SfM View ViP Rep Tools Help
3+
BA
Work thread terminated!

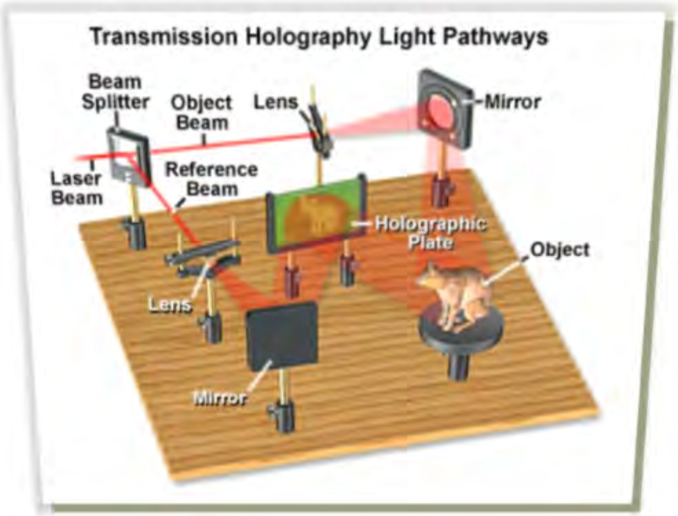
RANGE SCANNING Time of Flight

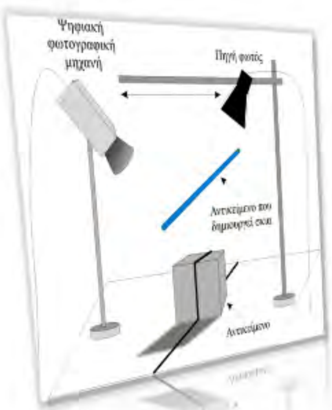
- Trasmission of laser pulses to the measured surface
- Computation of the time the laser pulses take to be detected by the scanner after surface reflection
  - Distance = c*t/2
- The resolution of the system is a function of the distance
- Typical characteristics
  - Min distance 3m
  - Max distance 1.5Km
  - Sampling rate 2500 points/sec
  - Accuracy of measurement 3mm@100m
  - Diameter of pulse 29mm@100m
  - Laser wavelength 1500nm, Class 1
  - Angular range horizontal 360 deg.
  - Angular range vertical 90 deg.

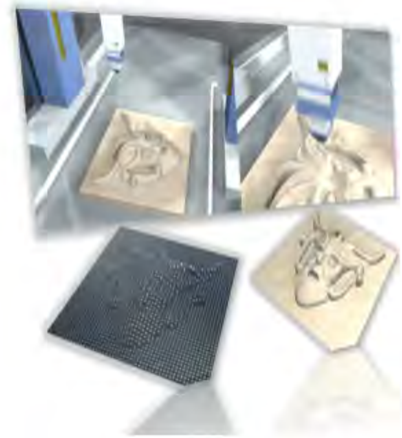


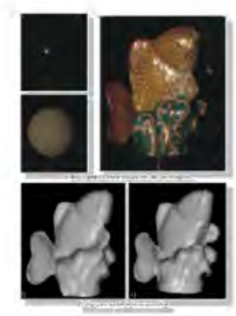
OTHER METHODS

- Shape from
  - Shading
  - Photometry
  - Zoom in/out
  - Shadow
- Touch probing
- Holography
- ...









3D DIGITIZATION IN PRACTICE

Characteristics of cultural objects

- Morphological characteristics: **Size and shape**
  - Enormous range of sizes and shapes

Coins
Tooks and wooden objects
Ceramics
Jewelry
Pottery
Sculpture
Figurines
Clothing
Furniture
Wall decorations
Signs
tombstones
Busts
Arms
Musical instruments
Objects
ecclesiastical art
Paintings

3D DIGITIZATION IN PRACTICE

Characteristics of cultural objects

Morphological complexity: **Level of detail**

3D DIGITIZATION IN PRACTICE

Characteristics of cultural objects

Diversity of materials

- Surface properties such as transparency, reflectivity, diffraction, color and texture

3D DIGITIZATION IN PRACTICE

Other factors that influence the system selection

- Required geometric accuracy
  - depends on the goal
- Additional restrictions
  - Size and position of subject
  - Accessibility
  - Protection and security issues
  - Budget
  - Human/machine resources

3D DIGITIZATION IN PRACTICE

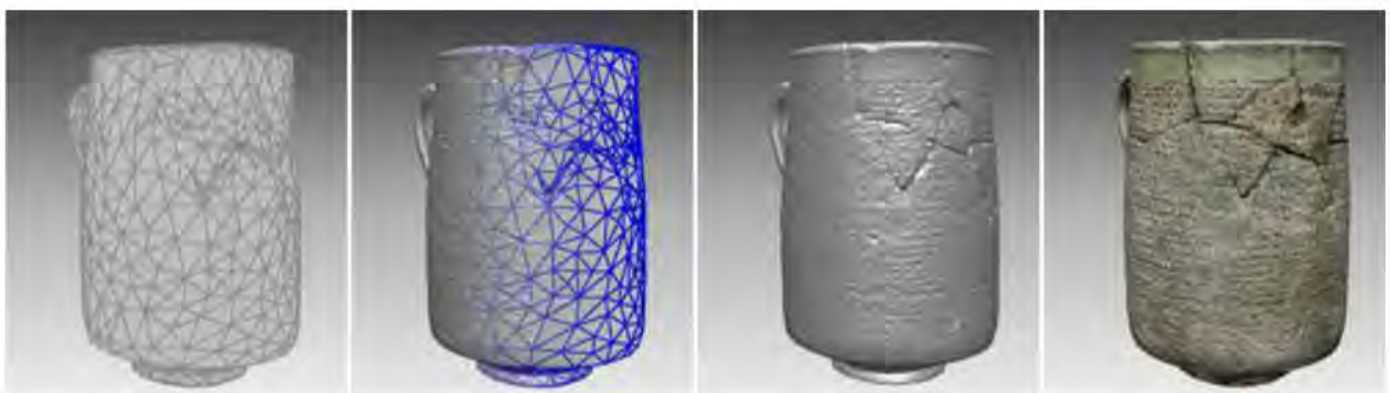
More challenges in 3D digitization

- "Non-cooperative" surfaces --> glass, dark colors
- Blocking of the visual field of the scanner --> can only scan what it sees
- Digitization of large objects with high accuracy
- Management end handling of large amounts of data
- Digital archiving and storage of large amounts of data

3D DIGITIZATION IN PRACTICE

Basic 3D digitization processes

- Recording geometric and color data
- Filtering of data (noise removal, etc)
- Alignment of partial scans
- Transformation in various 3D data structures
- Decimation of 3D data for various goals (ex. web)



3D DIGITIZATION IN PRACTICE

Basic 3D digitization processes

Recording of geometric and color data

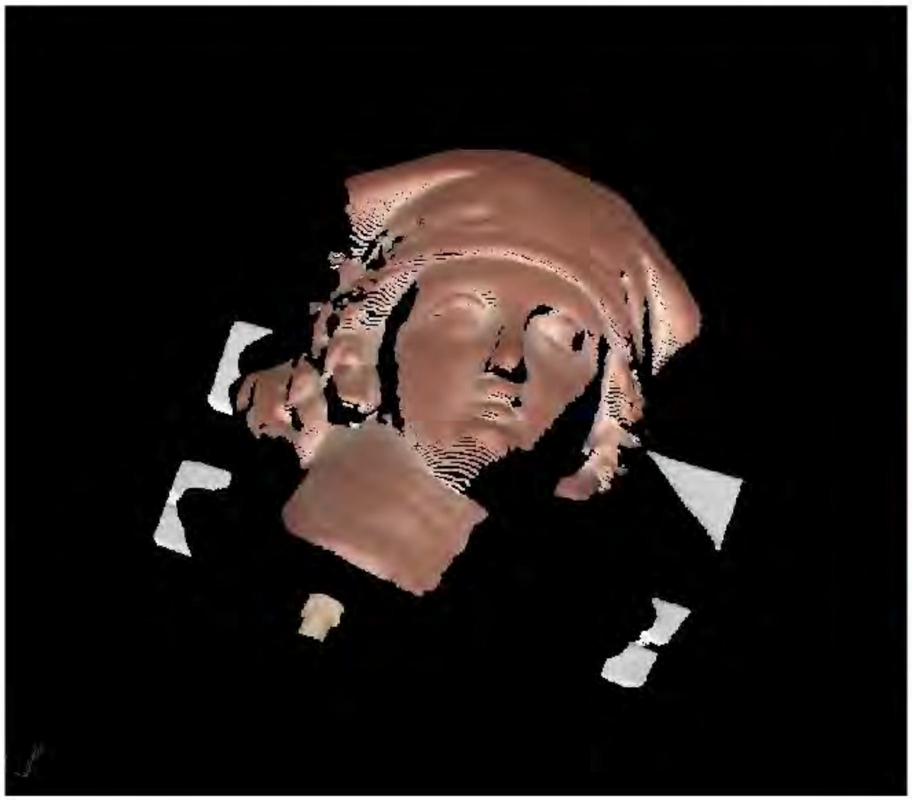
- Transportation of equipment at the site
- Almost always we end up with a number of partial scans

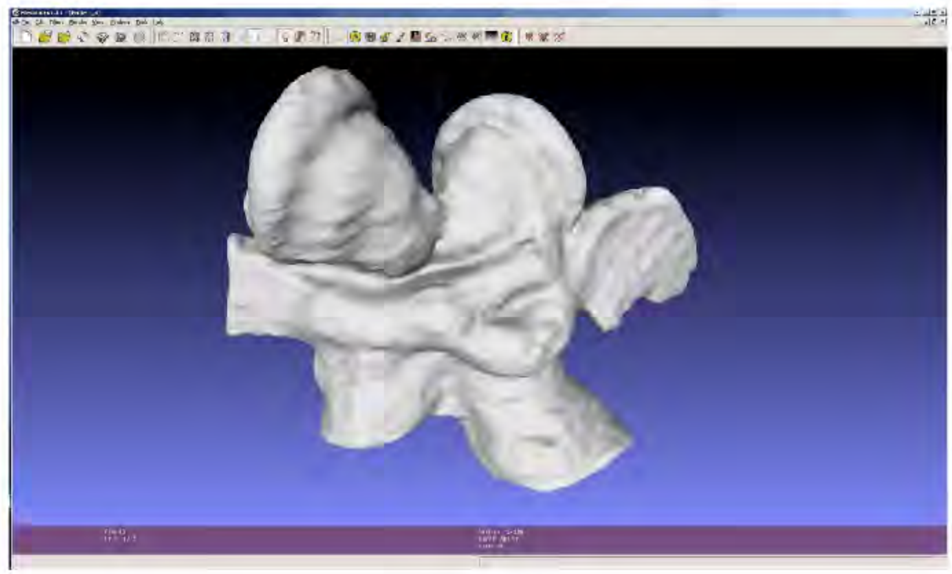
3D DIGITIZATION IN PRACTICE

Basic 3D digitization processes

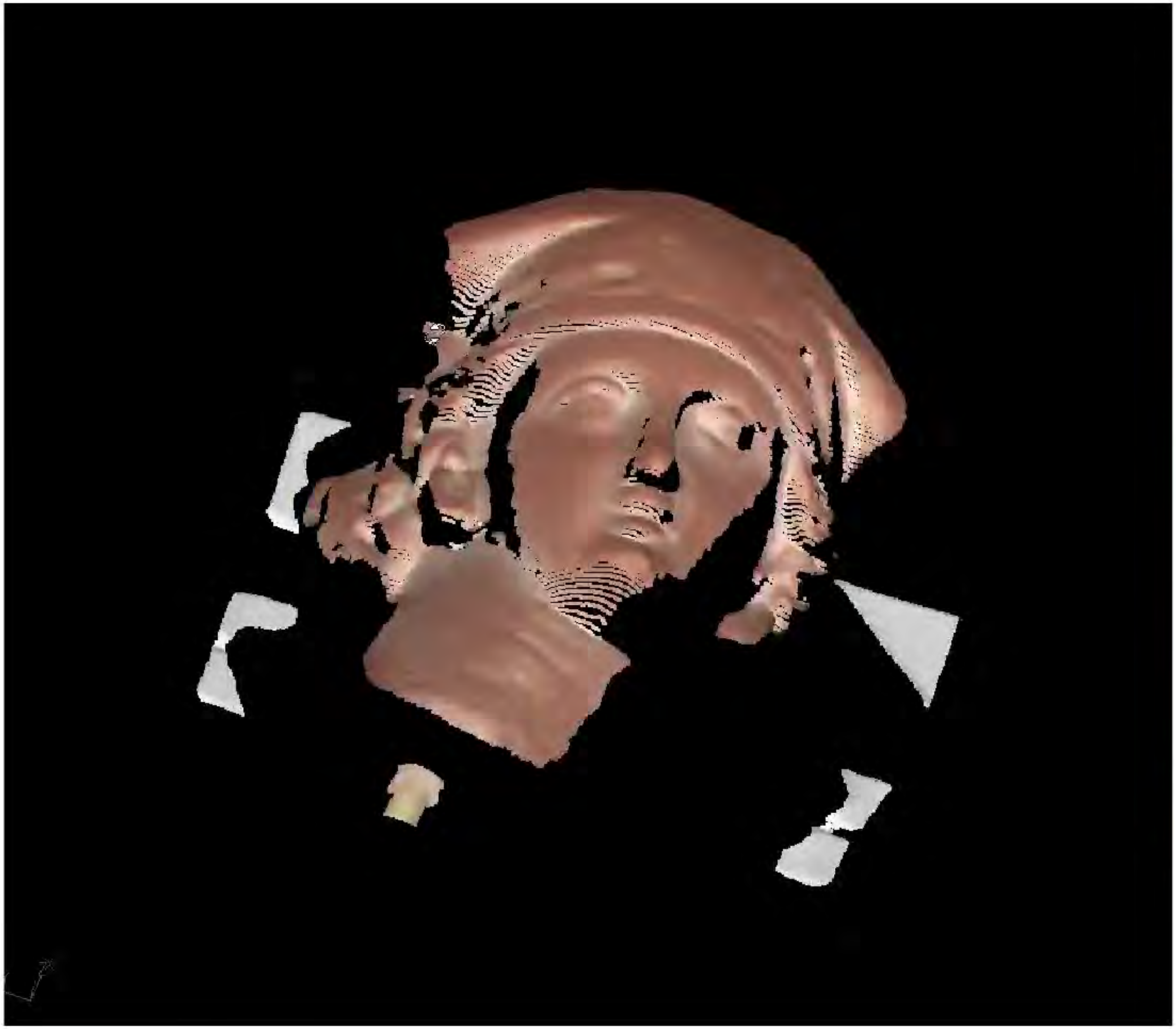
Filtering of geometric data

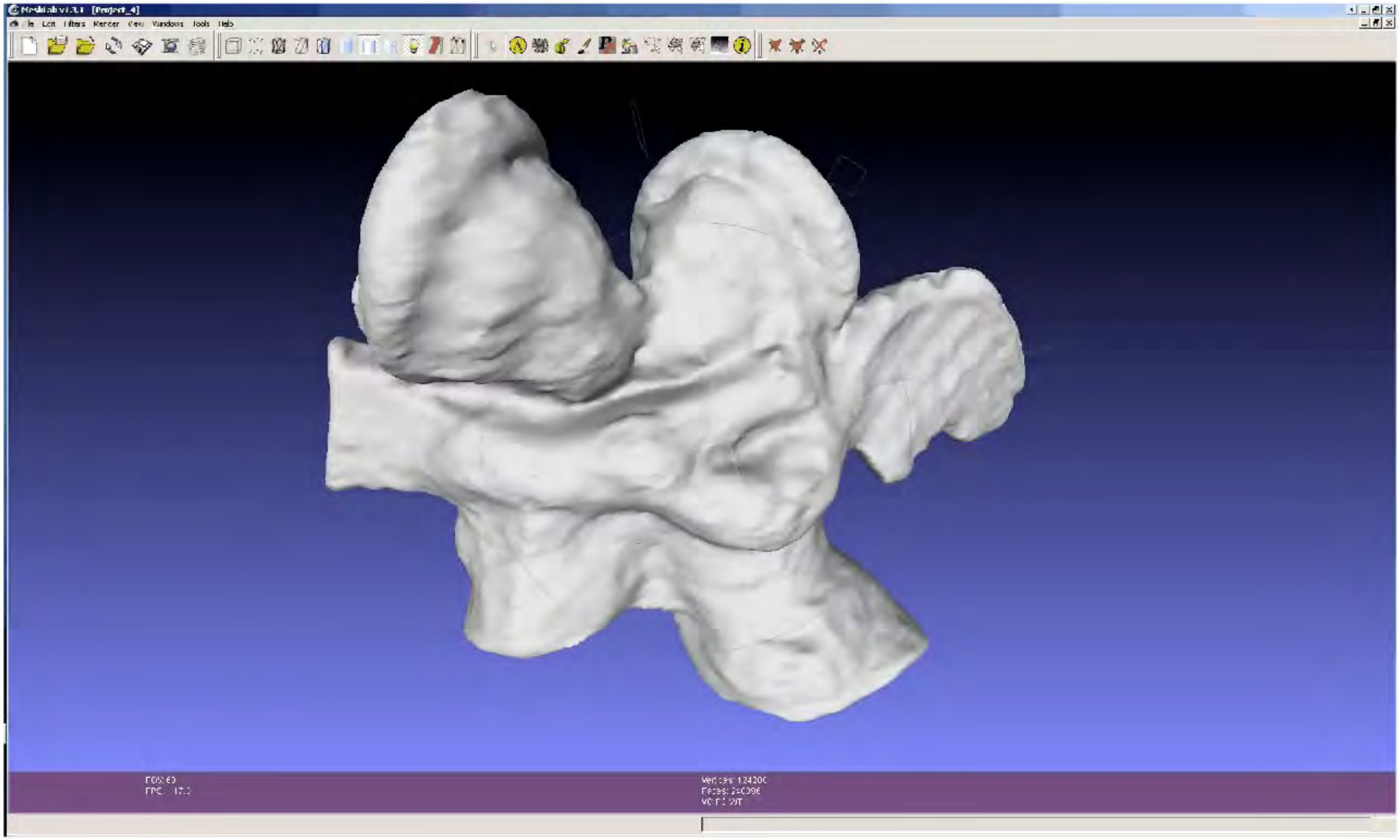
- Discard of parts not belonging to the object
- Noise reduction (could result in data loss)





Noise reduction (could re



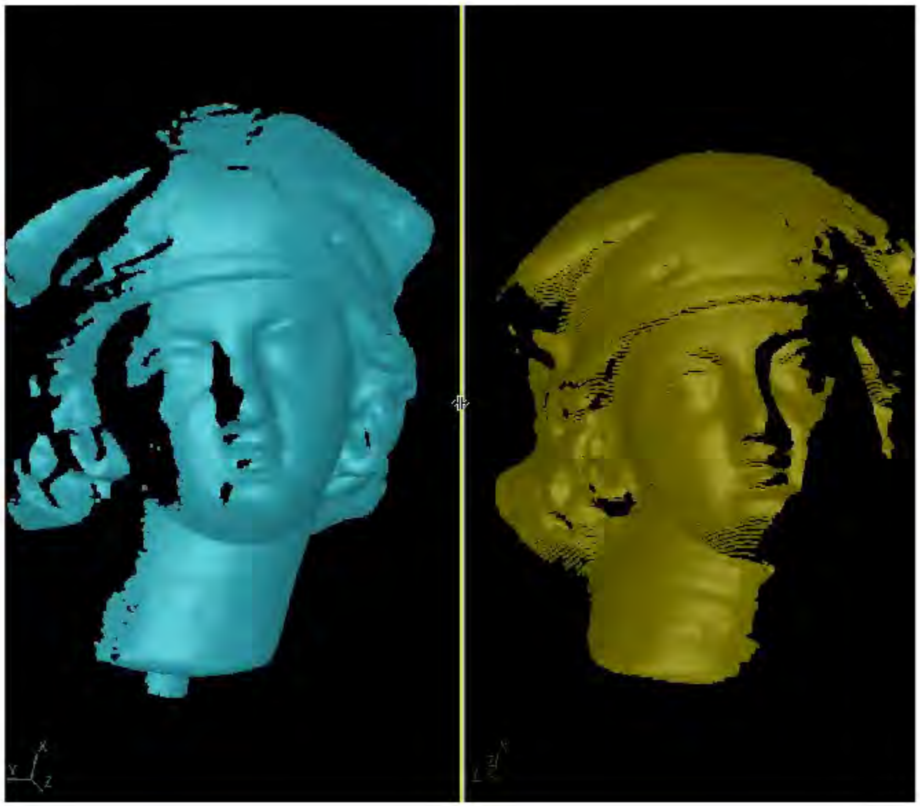


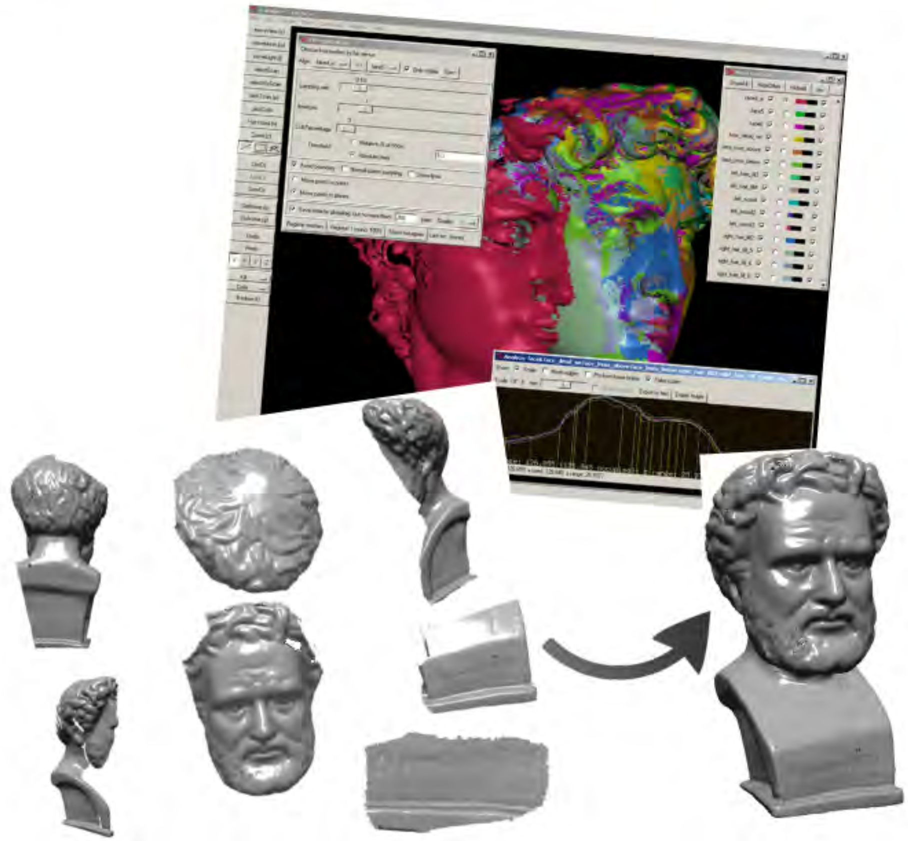
3D DIGITIZATION IN PRACTICE

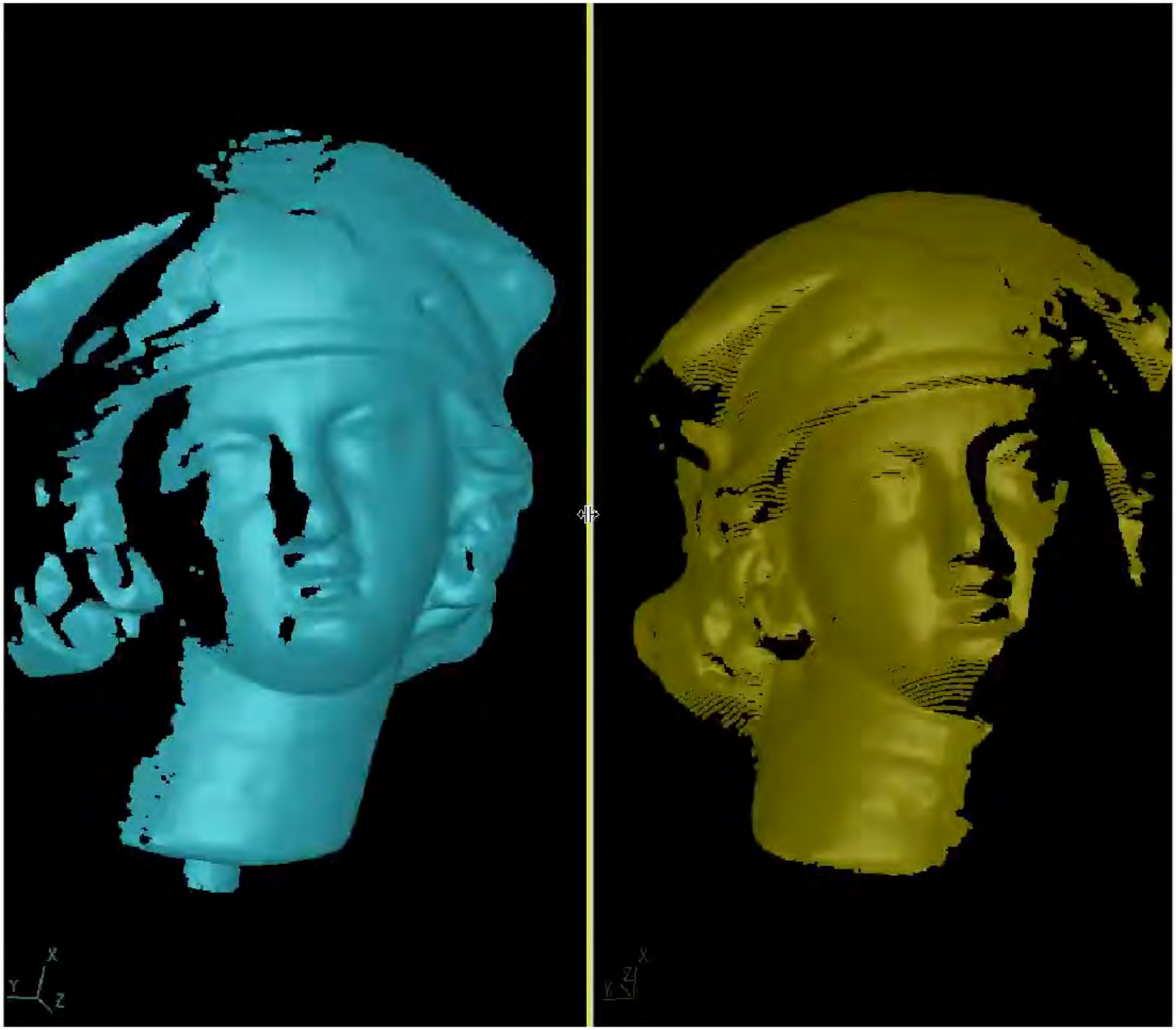
Basic 3D digitization processes

Alignment and integration of partial scans

- Requires overlapping between the partial scans





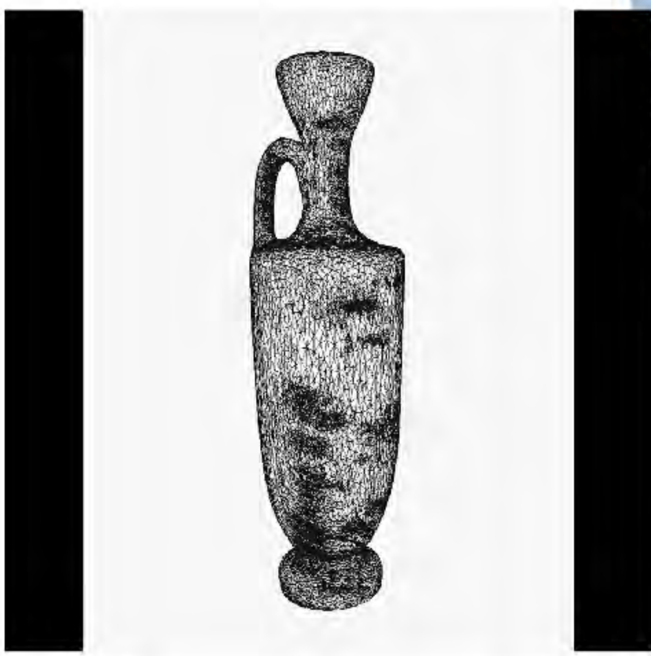


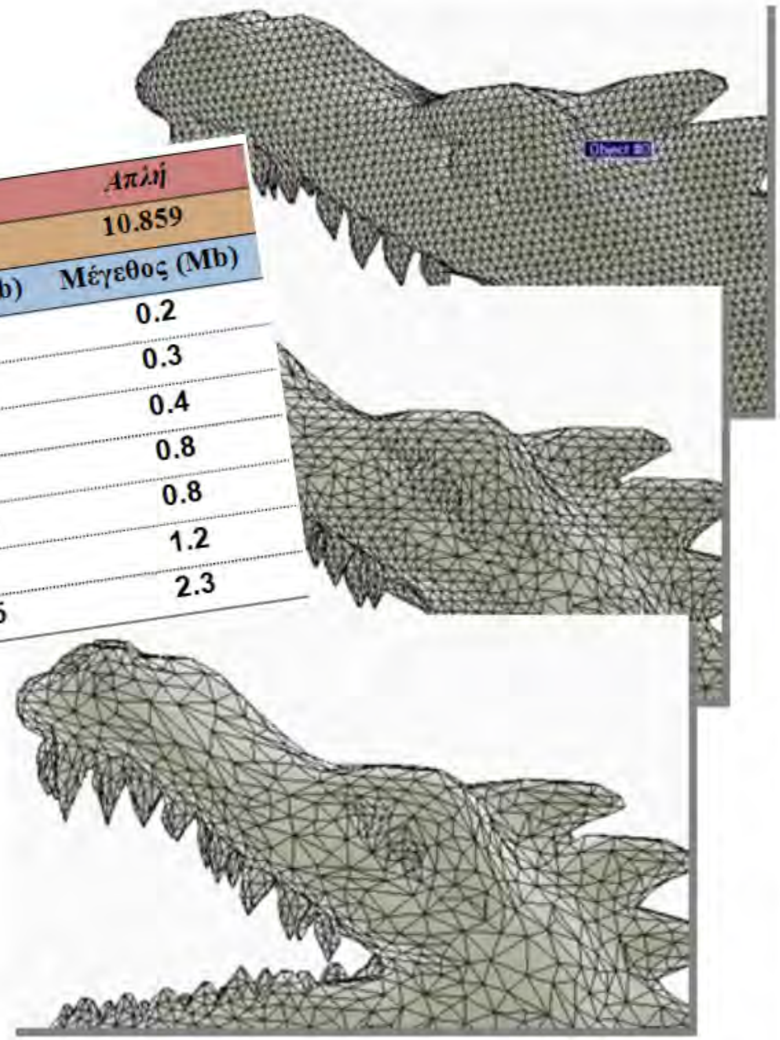
3D DIGITIZATION IN PRACTICE

Basic 3D digitization processes

Decimation of data for web applications

Γεωμετρία	Λεπτομερής	Μέση	Απλή
Τρίγωνα	108.588	54.294	10.859
Αρχείο	Μέγεθος (Mb)	Μέγεθος (Mb)	Μέγεθος (Mb)
3ds	2	1	0.2
Off	3	1.5	0.3
Obj	3.5	2	0.4
X	8	4	0.8
Raw	6.5	3.5	0.8
Asc	12	6	1.2
Dxf	23	11.5	2.3





Αρχείο	Μέγ
3ds	
Off	
Obj	
X	
Raw	
Asc	
Dxf	

3D DIGITIZATION IN PRACTICE

Some conclusions

- 3D digitization is a multi-dimensional process that depends upon
  - Morphological characteristics of the objects
  - The envisaged usage of the 3D data
- There is not one solution that covers all digitization projects
  - Optimal results require a combination of methods
- Data collection time < Data processing time
- There are numerous digitization systems available in the market
- There is a continuous development of 3D technologies
  - Better data quality scanning systems
  - Better 3D visualization/processing hardware and software
  - Better 3D printing techniques

3D DIGITIZATION IN PRACTICE

DIY 3D digitization

- **Laser triangulation**
  - David 3D - http://www.david-laserscanner.com
- **Structured light**
  - David 3D - http://www.david-laserscanner.com
- **Shape from silhouette**
  - 3D SOM - http://www.3dsom.com
- **Shape from stereo**
  - StereoScan - http://www.agisoft.ru/products/stereoscan
- **Structure from motion**
  - Autodesk 123D Catch - http://www.123dapp.com/catch
  - 3D ARC Automatic Reconstruction Conduit - http www.arc3d.be
  - VisualSFM - http://www.cs.washington.edu/homes/ccwu/vsfm
- **3D data processing**
  - Meshlab - http://meshlab.sourceforge.net
- **3D processing and photorealism - Animation**
  - Blender – http://http://www.blender.org

3D DIGITIZATION IN PRACTICE

Some examples

David - Michelangelo - Digital Michelangelo Project - Stanford University

Goal: The recording of the footprint of the chisel on the marble

STATUE FACTS

Height: 5.17 m
Surface: 19 m^2
Volume: 2.2 m^3
Weight: 5800 kg

ADDITIONAL DATA

Digitization personel: 22
Num of persons at the museum: 3/avg
Time: 360 hours/30 days
Man-hours: 1080
Man-hours proc.: 1500

DIGITIZATION DATA

Polygons: 2 billion
Photos: 7000
Compressed data: 32 GB

Sampling (resolution) 0.25 mm
Accuracy 0.50 mm

3D DIGITIZATION IN PRACTICE

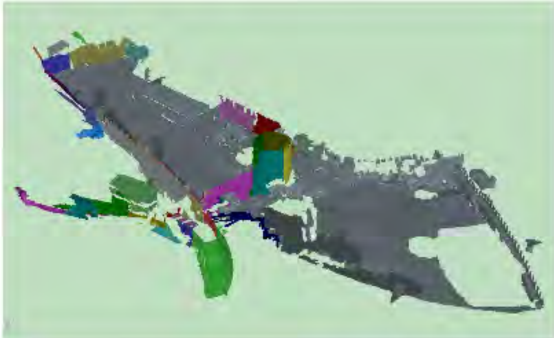
Some (more humble) examples

3D digitization of pottery for web applications

- Average 3D model size: 3 MB

3D DIGITIZATION IN PRACTICE

Some (not so humble) examples



Byzantine Castle at the city of Kavala, Northern Greece
Goal: Web dissemination as a virtual tour

Digitization time (time on site): 3 days
Data processing time: 1.5 months
Team: 2 highly skilled professionals

Internal parts of the Castle:
14 partial scans

Raw data:
Colored point cloud 36 M XYZRGB

Final web version: 17 MB
2 MB geometry
15 MB texture

rofessionals

:

RGB