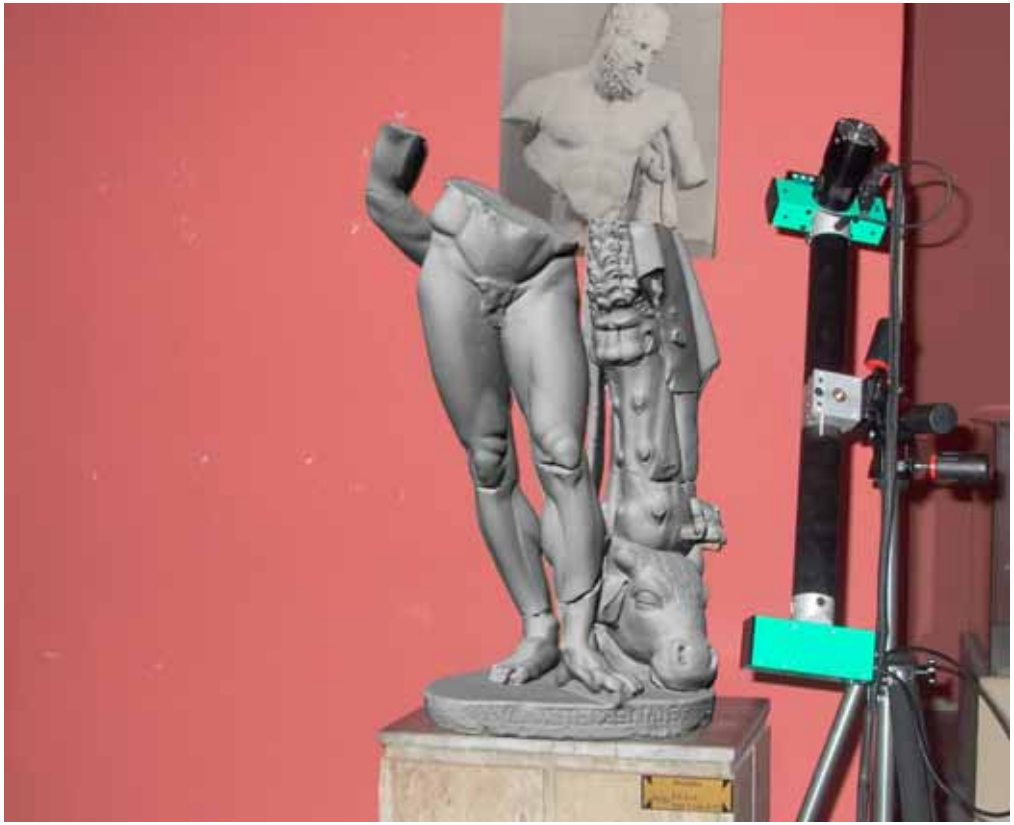

3D modeling of the Weary Herakles statue with a coded structured light system

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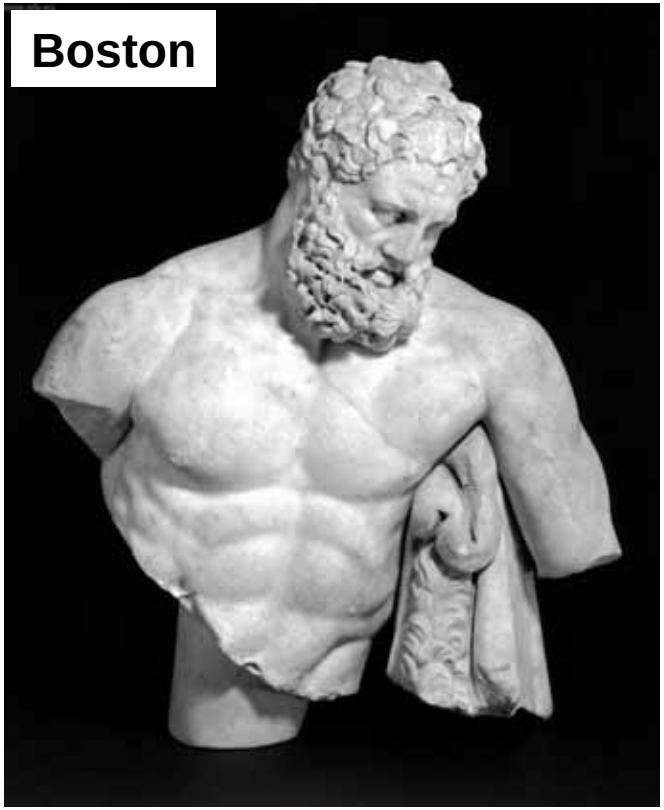
[4] InfoTRON Co., Istanbul, Turkey

The Weary Herakles Statue - Story



- Marble statue of the Greek demi-god Herakles (2nd c.AD).
- Copy of the original bronze statue of famous sculptor Lyssipos of Sicyon (4th c.BC)
- Broken in two parts.
- The upper half, seen in the USA in the early 1980s (Boston Museum of Fine Arts).
- The lower half, excavated in Perge (Antalya, TR) in 1980 by Prof. J. Inan, (now in the Antalya Museum).

The Weary Herakles Statue - Story

Photos: Prof. F.Yildiz

- According to Turkish law, Turkish antiquities state property since Ottoman times 1906.
- The Turkish government asked the upper half.
- The Boston MFA refused the petition, saying that:

“the statue may have broken in ancient times and the upper torso may have been taken from Turkey before the year 1906”.

Aim of the Project

The Aim

- To record and model both the lower and the upper part and
- **bring these partial models together in the computer**,
- so that at least there the complete statue could be seen, appreciated and analyzed.

- The lower part in the Antalya Museum was scanned in September 2005.

- Access to the upper part in the Boston MFA was denied.

The Project

In cooperation with

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

breuckmann

info(+)TRON "Birlikte Geleceği Yaratıyoruz"

Contents

HERAKLES IN MYTHOLOGY

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- Visualization

CONCLUSIONS

Herakles in Mythology

In Greek Mythology:
Herakles (or Heracles)
In Roman Mythology:
Hercules

Naples National Archaeological Museum

- „Herakles Farnese“ type, due to similarity to a complete copy in Naples National Archaeological Museum (Italy).
- Mythical hero, demigod, best known for his superhuman strength.
- After to perform twelve great tasks (The Twelve Labours of Herakles), became a god.
- The first task: strangling the Nemean Lion.
- Killed, and used the its skin as armor.
- Mostly portrayed nude & leaning (hence Weary Herakles), with lion‘s skin.

Data Acquisition

- Digitization in the Antalya Museum in September 2005

- Breuckmann optoTOP-HE coded structural light system

Coded Structural Light System

- Coded Structural Light Technique
- A kind of active stereo triangulation technique for surface measurement
- Replacing one of the cameras with a pattern projector

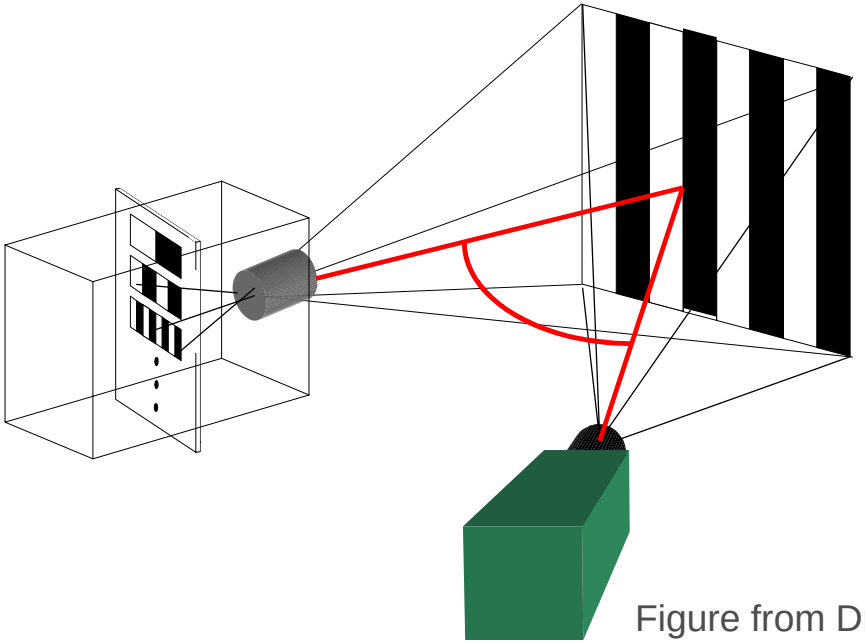
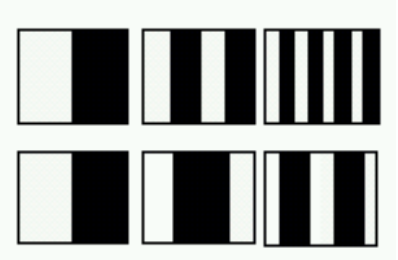


Figure from Dr. B. Breuckmann

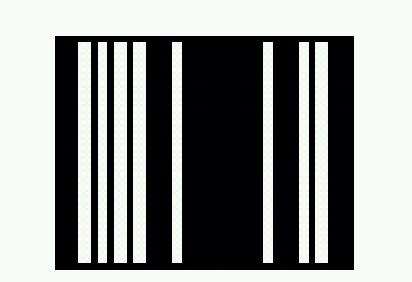
- Projecting a set of known patterns onto object
- Grabbing the images with the other camera
- Correspondence problem solved by system calibration parameters & known geometry of the patterns (decodification)

Coded Structural Light System - Pattern encoding techniques

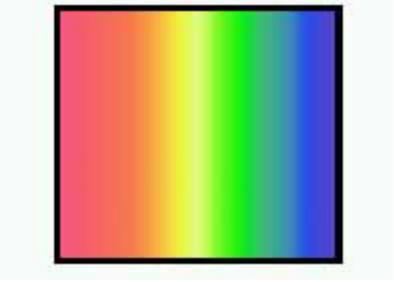
Time-multiplexing
- Binary codes
- n-ary codes
- **Gray code + phase shifting** (Breuckmann)
- Hybrid methods



Spatial codification
- Non-formal codification
- De Bruijn sequences
- M-arrays



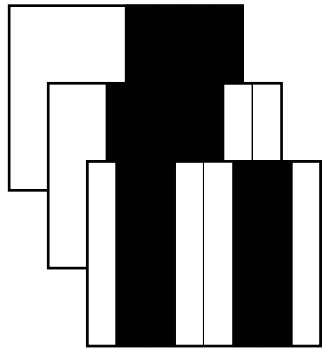
Direct Codification
- Grey levels
- Color



Salvi et al., 2003
http://eia.udg.es/~jpages/ReportCodedLight03.pdf

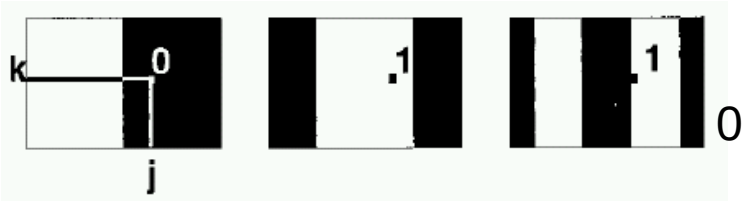
Coded Structural Light System - Gray code + phase shifting

Gray code: (Frank Gray, 1953)



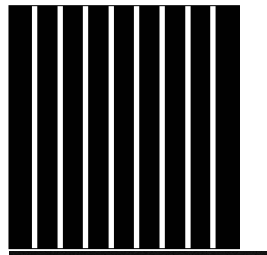
- A sequence of (Gray encoded) binary fringe patterns are projected, dividing into sections.
- A codeword is associated for each pixel,

establishing the correspondence: image pixel -> projector stripe no



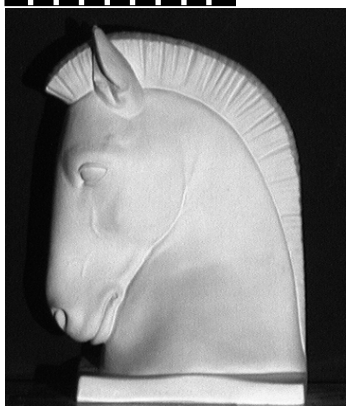
011

- 3D coordinates by triangulation
- Resolution limit, half the size of the finest pattern



Phase shifting:

- A periodical pattern (sinusoidal) is projected several times by shifting it in one direction
- Phase unwrapping
- Each camera pixel -> projector stripe number (sub-stripe accuracy)



http://eia.udg.es/~jpages/examples/examples.html

Figure: Line shifting, Gühring, 2001

The Scanner: Breuckmann optoTOP-HE

- Gray code + phase shifting
- Field of view (FOV): 480x360 mm
- measuring depth: 320 mm
- acquisition time: <1sec.
- weight: 2-3 kg
- digitization: 1280x1024 = 1.25M points
- base length: 600 mm
- triangulation angle: 30^0

- Lateral resolution: ~360 microns
- feature accuracy: 1/15000 of img. diagonal
- feature accuracy: ~50 microns

http://www.breuckmann.com

Scanning in the Antalya Museum

- Breuckmann optoTOP-HE system
- 1 ½ days on site work with 67 scans (56+11)
- Each scan 1.25M points
- Totally 83.75M points

preparation

scanning

Scanning in the Antalya Museum

optoTOP-HE, very flexible system

Postprocessing Workflow

- Registration
  - + Pairwise registration
  - + Global registration

(LS3D)

- Point cloud editing
  - + Cropping the Area Of Interest
  - + Noise reduction
  - + Down-sampling

(Geomagic Studio 6)

- Surface triangulation and editing

(Geomagic Studio 6)

- Texture Mapping

(VCLab's 3D Scanning Tool, CNR, Pisa)

- Visualization

(PolyWorks 9.0.2)

Registration – Pairwise registration

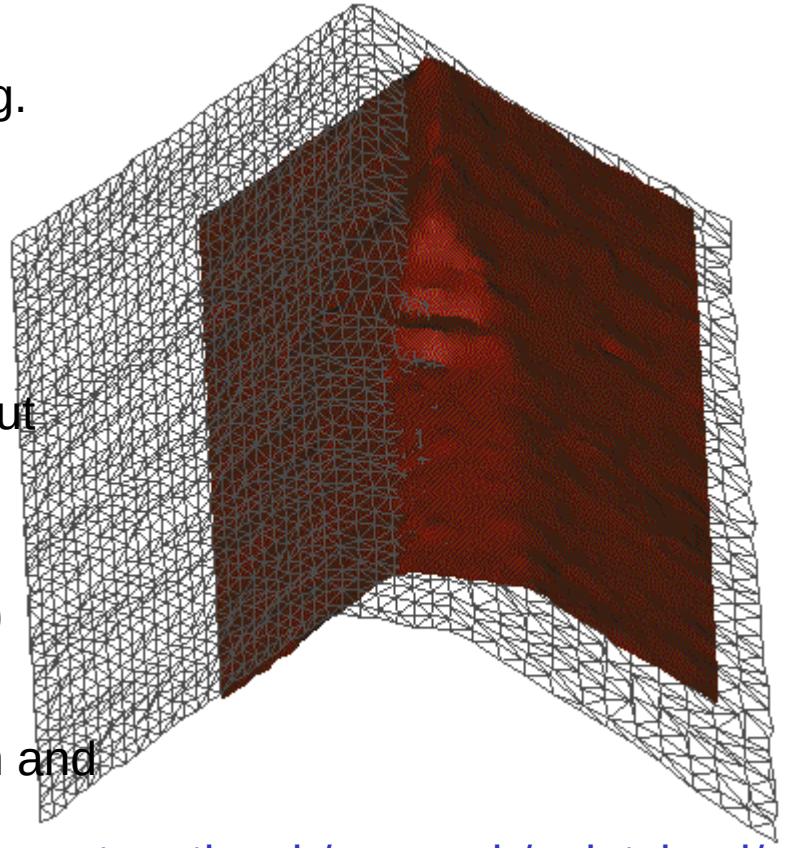
• Pairwise registration with the Least Squares 3D Surface Matching (LS3D) method, in-house developed.

Gruen and Akca, 2005. ISPRS Journal of Photogrammetry & RS, (59)3: 151-174.

Least Squares 3D Surface Matching (LS3D)

• Generalization of 2D LSM => 3D surface matching.

• Estimates 3D transformation parameters,
Generalized Gauss-Markoff model,
min = SUM(SQR(Euclidean distances)).



• Matching of arbitrarily oriented 3D surfaces, without using explicit tie points.

• Non-linear model, need for initial approximations.

• Few iterations, 5-6 typically, (ICP, 20-30-50-more)

• Provides internal quality indicators, (K_{xx}).

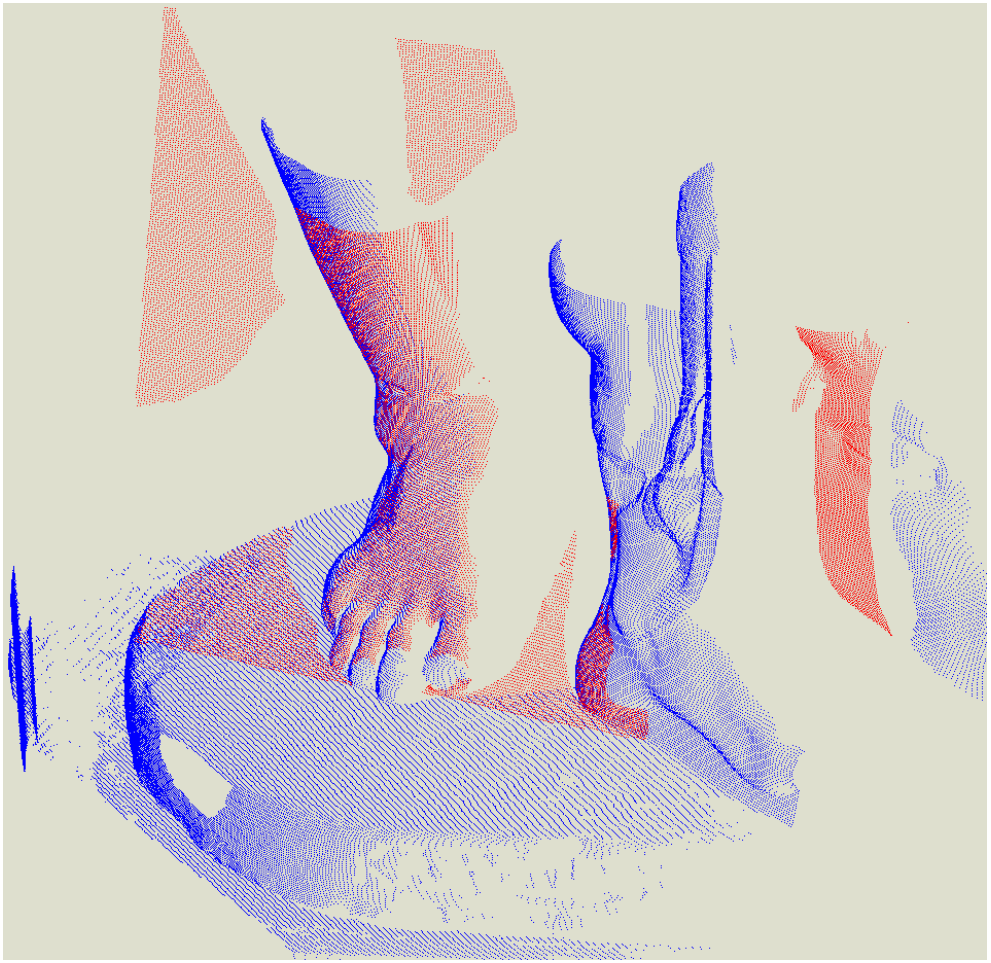
• Capability to match surfaces in different resolution and quality.

http://www.photogrammetry.ethz.ch/research/pointcloud/

Registration – Pairwise registration

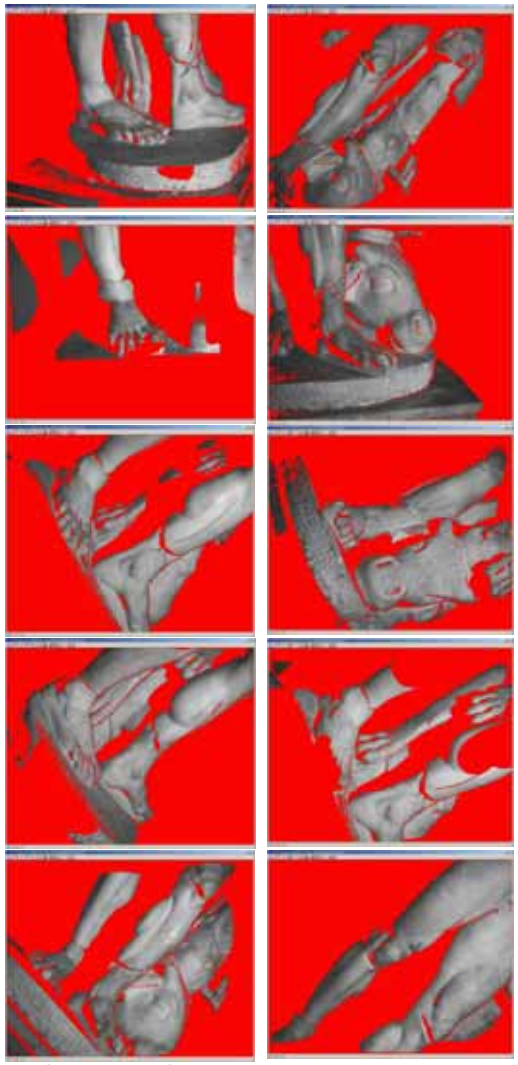
- 234 consecutive pairwise LS3D matching. The average sigma naught is **81 microns**.

Example: Registration of 1st and 2nd scans
Note: 3x3 down-sampling for better visualization



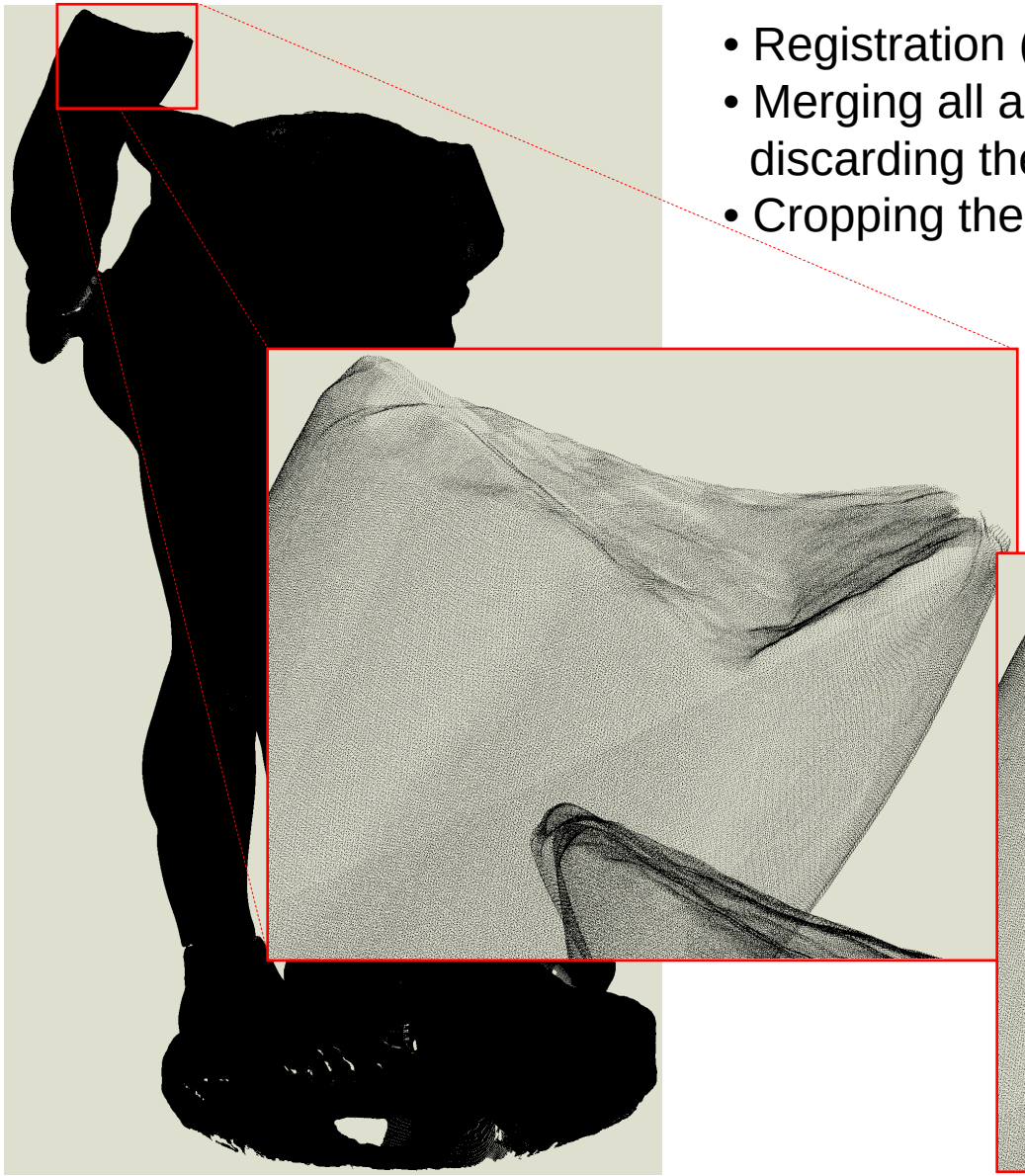
Registration – Global registration

- Global registration with the block adjustment by independent models solution
- Sigma naught **47 microns**, in agreement with the system specifications



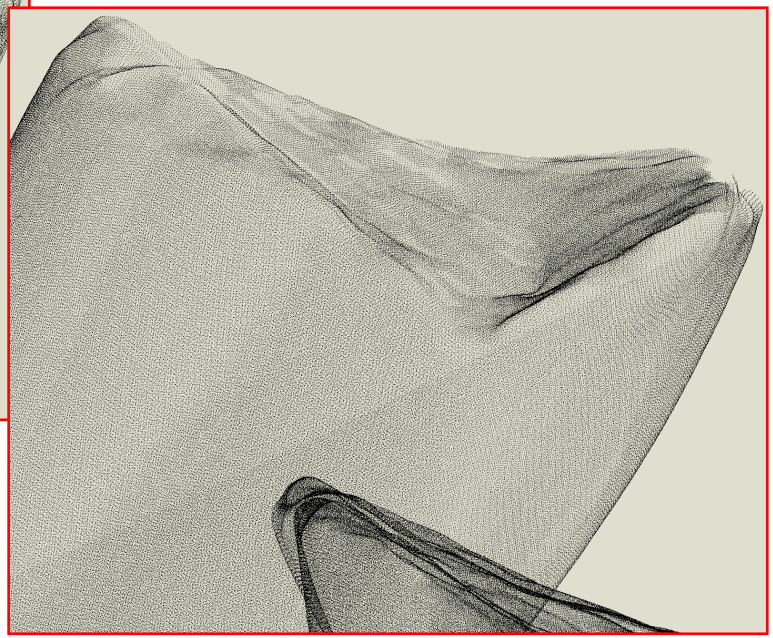
Example: Registration of first 10 scans
Note: 3x3 down-sampling for better visualization

Point Cloud Editing – Noise reduction

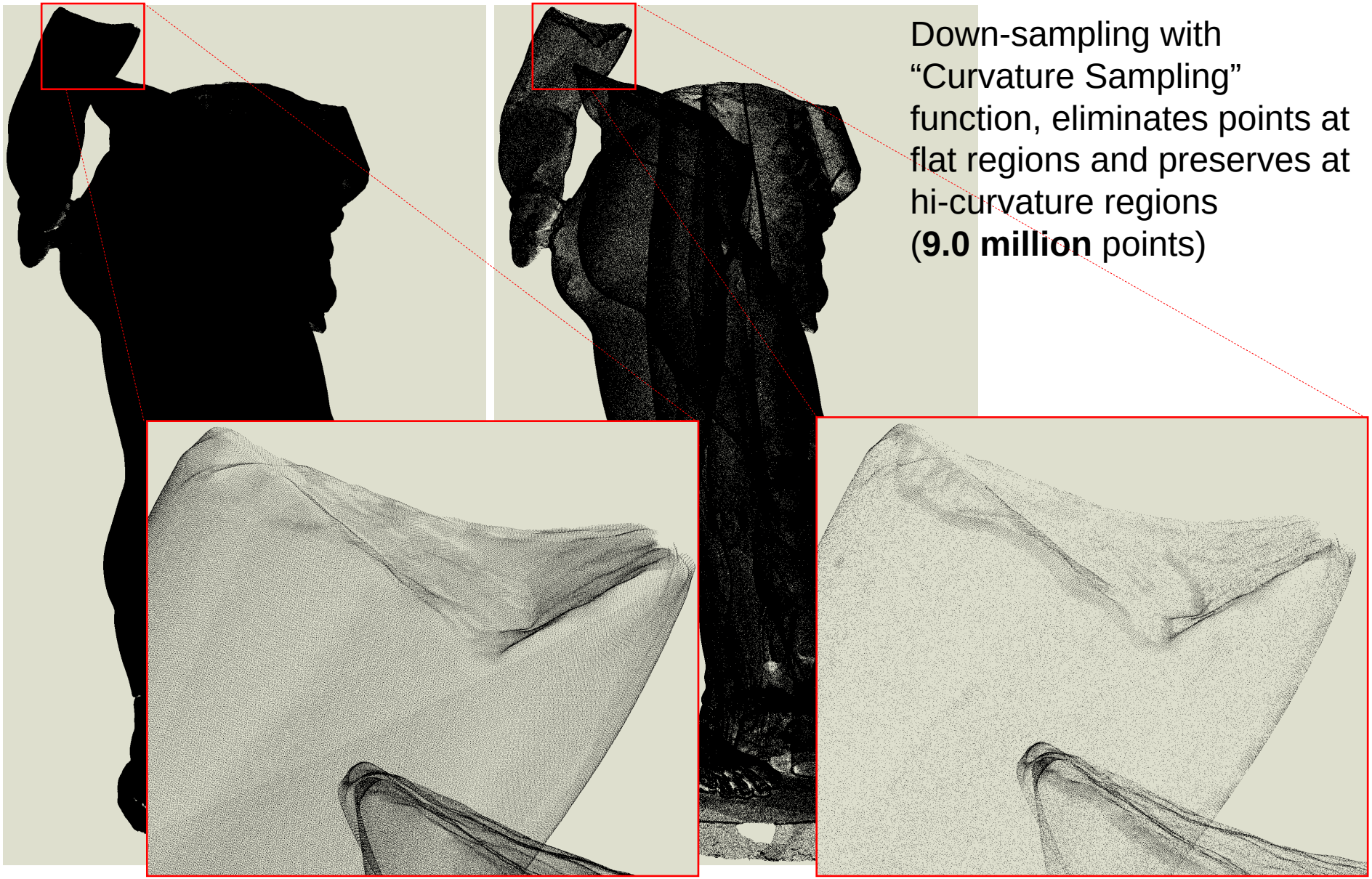


- Registration (ALL= 83.75M = **87.8 million** points)
- Merging all as one XYZ file, discarding the NODATA points (**36.2 million** points)
- Cropping the AOI (**33.9 million** points)

- Noise reduction with “Reduce Noise” function (medium level)



Point Cloud Editing – Down-sampling

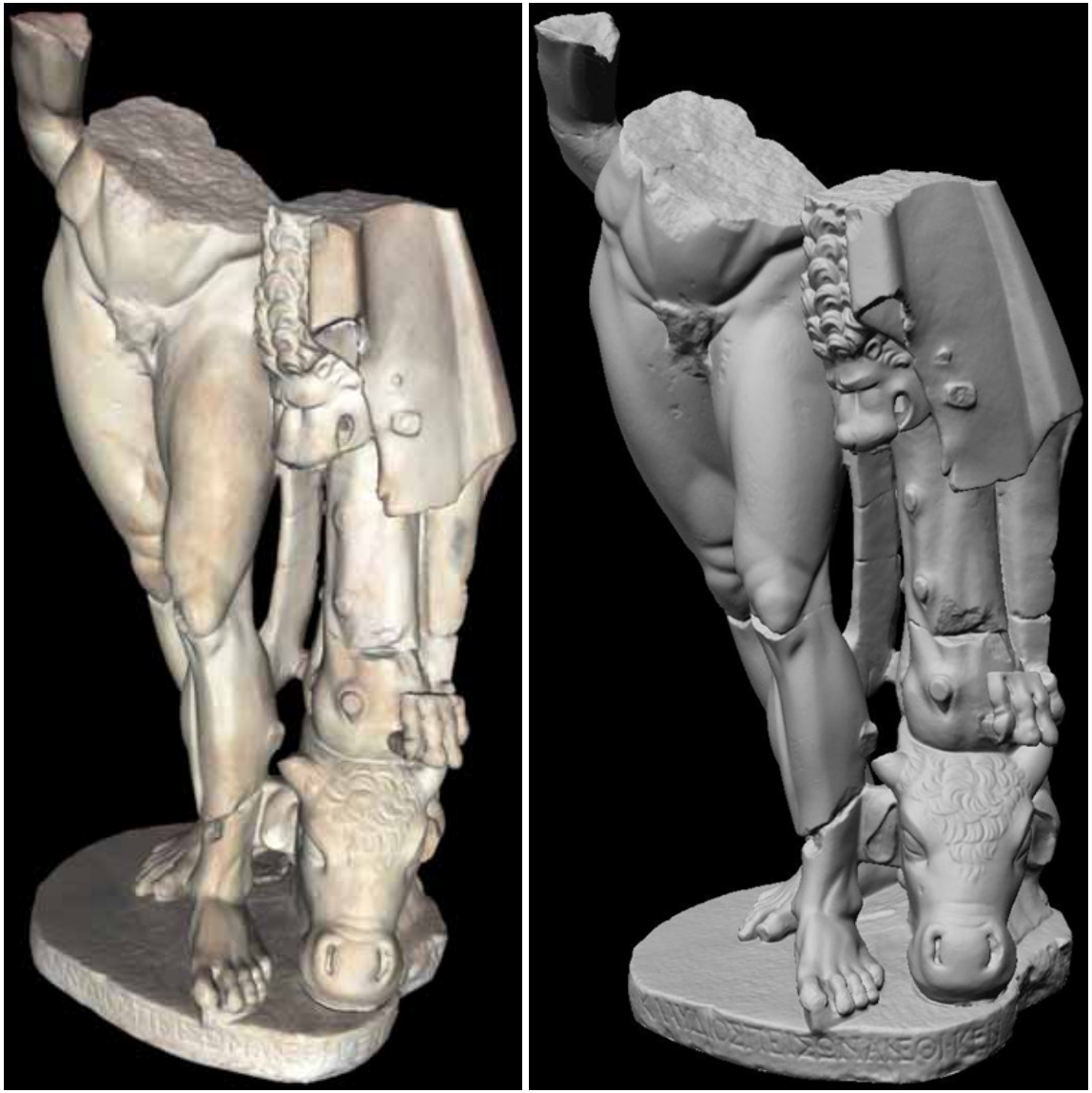


Down-sampling with "Curvature Sampling" function, eliminates points at flat regions and preserves at hi-curvature regions (**9.0 million** points)

Surface Triangulation and Editing

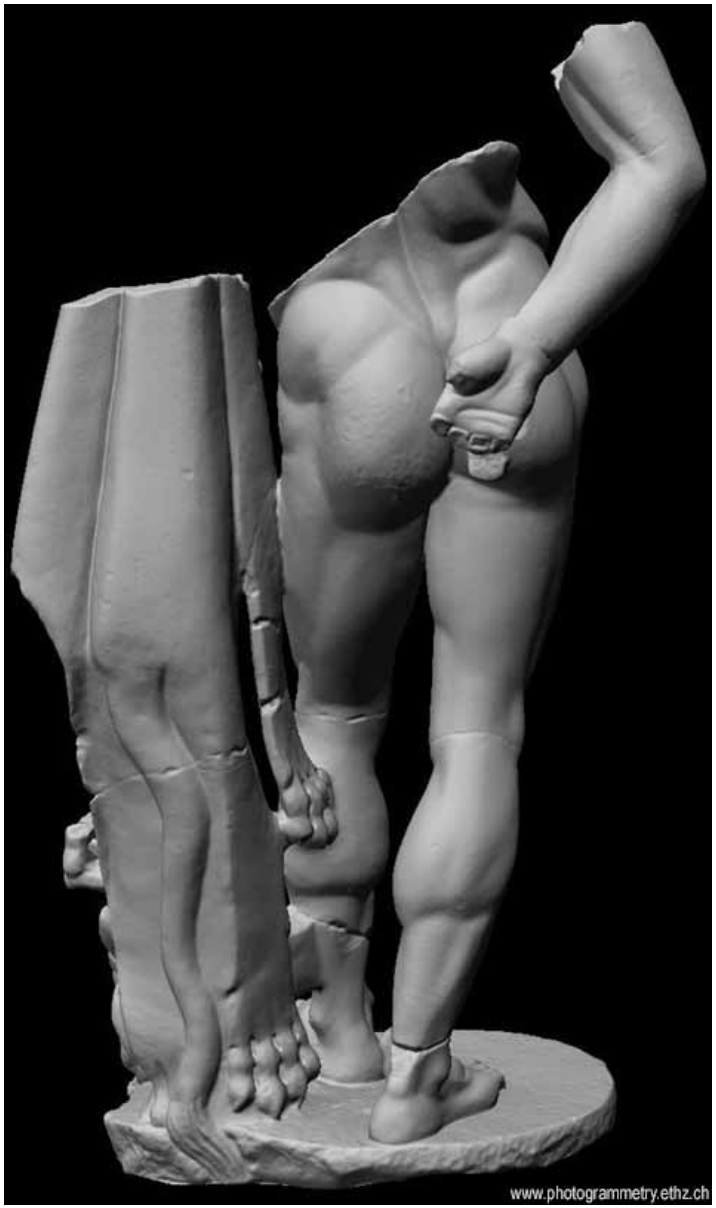
- Finally **9.0 million points** => **5.2 million triangles**
- Memory problems with Geomagic if greater number of target triangles, e.g. 10 million
- Data holes due to complexity & inner concave parts
- Filling the holes is the most tedious step of the project

Texture Mapping



- Leica Digilux1, 4Mpixel CCD camera
- The Veawer module of VCLab‘s 3D Scanning Tool (ISTI-CNR, Pisa, Italy)

Visualization – (gray shaded)



- Better lighting & shading with PolyWorks IMView.

Visualization

Back projection of the 3D model into image space

http://www.photogrammetry.ethz.ch/research/herakles/

Visualization – result of OPTOCAD (Breuckmann)

Conclusions

• The coded structural light system is a mature technology and allows high resolution documentation of cultural heritage objects.

• The hardware component, optoTOP-HE worked well.

Triangulation based systems	**Laser**	**Coded light**
Weight and price	Identical	Identical
Speed		Faster
Sensitivity to ambient light	Less	
Speckle noise		Less
Penetration into object surface		No
Imaging for texture mapping		Yes
Depth of view	Larger	
Eye safety		Better

• Editing the surface is the most tedious step of the whole modeling pipeline. Need for sophisticated algorithms & software.

• Texture mapping is not fully available in either software.

http://www.photogrammetry.ethz.ch/research/herakles/

Conclusions

THANK YOU FOR YOUR ATTENTION

Thanks to
Prof. Orhan Altan
Personnel of the Antalya Museum

http://www.photogrammetry.ethz.ch/research/herakles/