The Digital Michelangelo Project

Marc Levoy

Executive overview

Create a 3D computer archive of the principal statues and architecture of Michelangelo

Scholarly motivations
- pushes technology
- scientific tool
- cultural experiment
- lasting archive

Commercial motivations
- virtual museums
- art reproduction
- 3D stock photography
- 2nd generation multimedia
Outline of talk

- hardware and software
- scanning the David
- acquiring a big light field
- implications of 3D scanning
- lessons learned from the project
- the problem of the Forma Urbis Romae

Scanners used in the Digital Michelangelo Project

1. Cyberware
   - main 3D scanner for statues
   - planar light field scanner

2. Faro + 3D Scanners
   - for tight spots
   - handheld light field scanner?

3. Cyra
   - for architecture
   - low-res models for view planning?

• All scanners acquire range and color
Laser triangulation scanner customized for large statues

4 motorized axes

laser, range camera, white light, and color camera

truss extensions for tall statues

Scanning St. Matthew

working in the museum

scanning geometry

scanning color
Our scan of St. Matthew

- 104 scans
- 800 million polygons
- 4,000 color images
- 15 gigabytes
- 1 week of scanning
Post-processing pipeline

- range data
  - align scans from different gantry positions
  - combine using a volumetric algorithm
  - fill holes using space carving

- color data
  - compensate for ambient lighting
  - discard shadows or reflections
  - factor out surface orientation

Artificial surface reflectance
Estimated diffuse reflectance

Scanning the David

maximum height of gantry: 7.5 meters
weight including subbase: 800 kilograms
Statistics about the scan

- 480 individually aimed scans
- 2 billion polygons
- 7,000 color images
- 32 gigabytes
- 30 nights of scanning
- 1,080 man-hours
- 22 people

Head of Michelangelo’s David

- 2 mm model
- 1 million polygons
David’s hairline and right eye

- 1mm model
- 500,000 polygons

David’s left eye

- 0.25mm model
- space carving to fill holes

holes from Michelangelo’s drill
artifacts from space carving
noise from laser scatter
Model of Galleria dell’Accademia

- 4mm model
- 15 million polygons
- Cyra time-of-flight scanner

Computer representations of architectural objects

- unstructured mesh
- line drawings
- structured 3D model
Light field rendering

- a form of image-based rendering (IBR)
- make new views by rebinning old views

- Advantages
  - doesn’t need a 3D model
  - less computation than rendering a model
  - rendering cost independent of scene complexity

- Disadvantages
  - fixed lighting
  - static scene geometry
  - must stay outside convex hull of object

A light field is an array of images
Our planned light field of the Medici Chapel

What got in the way of this plan
Acquiring a light field of Michelangelo’s statue of Night

The light field consists of 7 slabs, each 70cm x 70cm

Each slab contains 56 x 56 images spaced 12.5mm apart

The camera is always aimed at the center of the statue
Sample image from center slab

Statistics about the light field

- 1300 x 1000 pixels per image
- $56 \times 56 \times 7 = 21,952$ images
- 16 gigabytes (using 6:1 JPEG)
- 35 hours of shooting (over 4 nights)
- also acquired a 0.25mm 3D model of statue
Implications of 3D scanning on the viewing of art

- type of reproduction
  - scripted computer graphics
  - interactive computer graphics
  - physical copy

- pros and cons
  - flexible viewing
  - increased accessibility
  - increased ubiquity
  - separation from context

Flexible viewpoint

classic 3/4 view  left profile
Flexible lighting

lit from above  lit from below

Flexible shading

natural coloring  accessibility shading
Implications of 3D scanning for art historians

- restoration record
- permanent archive
- diagnostic maps
- geometric calculations
- projection of images onto statues

Diagnostic imaging of David

under white light  under ultraviolet light
Implications of 3D scanning for educators and museums

- virtual exhibitions
- augmented exhibitions
- enhanced documentaries
- interactive multimedia
- physical replicas

Letting the tourists play with our model of Dawn

They came...
Letting the tourists play with our model of Dawn

They saw...

Letting the tourists play with our model of Dawn

They played...
### What really happened?

- Kids immediately crowd around. Some adults step right up; others need invitations.
- Kids but don't take turns very well. Some adults don't either.
- A woman will try it only if a man is not nearby. Same for girls and boys.
- Adults usually rotate the statue slowly. Kids fly around wildly, but are surprisingly good at it.

### What really happened?

- It's amazing how much trouble people can get into. Zooming too close is the worst offender.
- People enjoy changing the lighting as much as they do rotating the statue.
- People are fascinated by the raw 3D points, which they see when the model is in motion.
- People spend a lot of time looking back and forth between the screen and the real statue.
Logistical challenges

• size of the datasets
• access to the statues
• safety for the statues
• intellectual property rights
Lessons learned

• hardware and software
  – variable standoff distance
  – tracking of gantry, not manual alignment of scans
  – autocalibration, not stiff gantry
  – automatic view planning

• logistics
  – scan color quickly - things change
  – need a large team - scanning is tedious work
  – post-processing takes time and people
  – 50% of time on first 90%, 50% on next 9%, ignore last 1%

Il Plastico:
a model of ancient Rome

• made in the 1930’s
• measures 60 feet on a side
• at the Museum of Roman Civilization
The Forma Urbis Romae: a map of ancient Rome

- carved circa 200 A.D.
- 60 wide x 45 feet high
- marble, 4 inches thick
- showed the entire city at 1:240
- single most important document about ancient Roman topography
Fragment #10g

18 cm on map
43 meters on the ground

interior courtyard with
columned portico

staircase

room with door
Solving the jigsaw puzzle

- 1,163 fragments
  - 200 identified
  - 500 unidentified
  - 400 unincised
- 15% of map remains
  - but strongly clustered
- available clues
  - fragment shape (2D or 3D)
  - incised patterns
  - marble veining
  - matches to ruins

Scanning the fragments

uncrating...
Scanning the fragments

aligning...

Fragment #642

3D model  color photograph
Fragment #642

3D model

Acknowledgements

Faculty and staff

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