The Digital Michelangelo Project

Marc Levoy

Computer Science Department
Stanford University

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

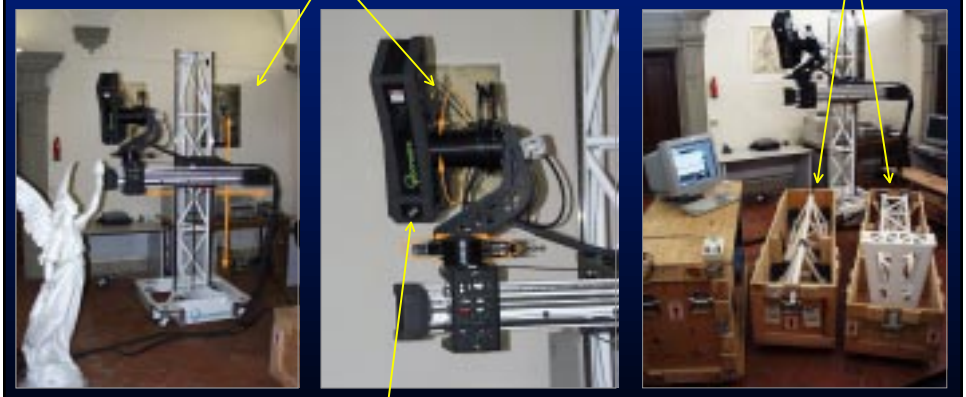
1. Cyberware
   - main 3D scanner for statues
   - planar light field scanner

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 <u>and</u> color*

Laser triangulation scanner customized for large statues



Scanning St. Matthew

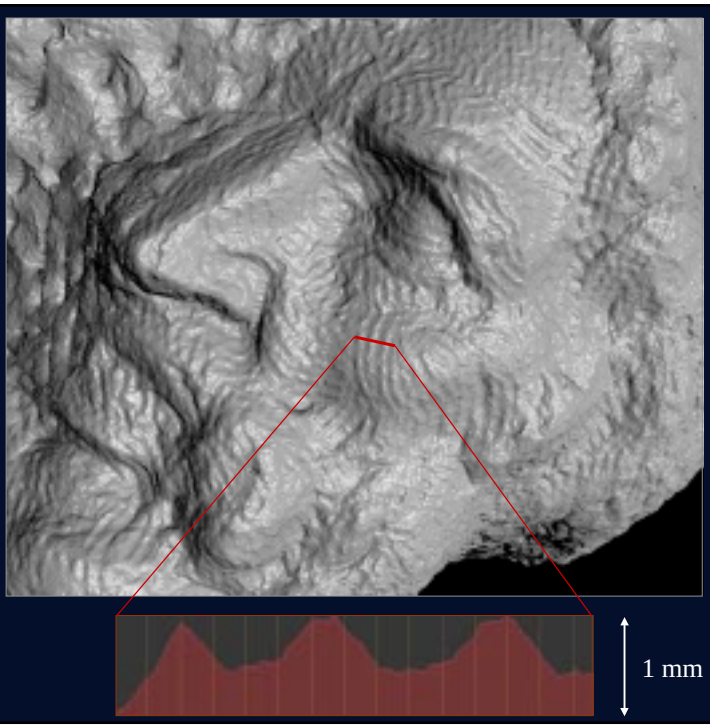
working in the museum

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

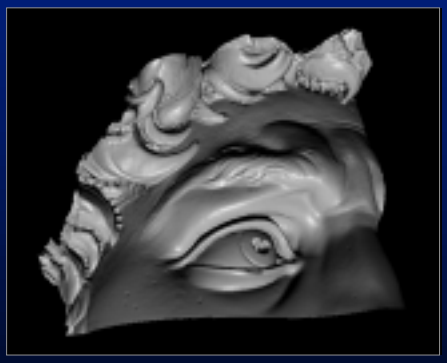
Statistics about the scan

- 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

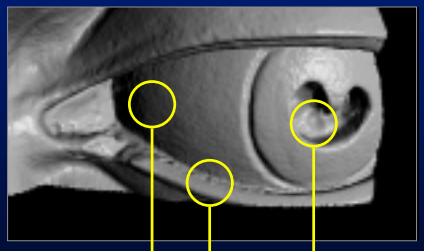
David's hairline and right eye

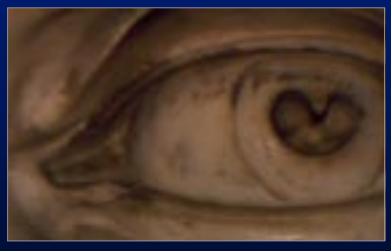


- 1mm model
- 500,000 polygons

David's left eye

- 0.25mm model
- space carving to fill holes



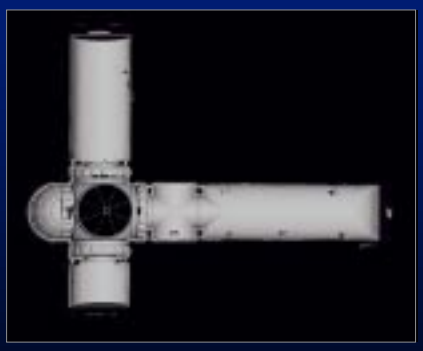


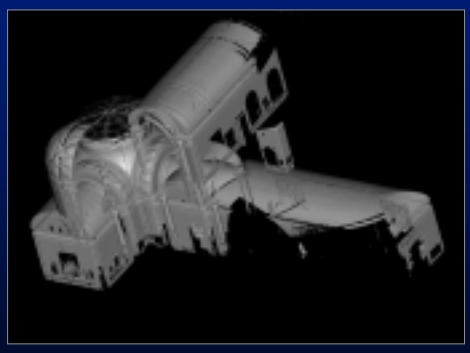
holes from Michelangelo's drill

artifacts from space carving

noise from laser scatter

Model of Galleria dell'Accademia





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

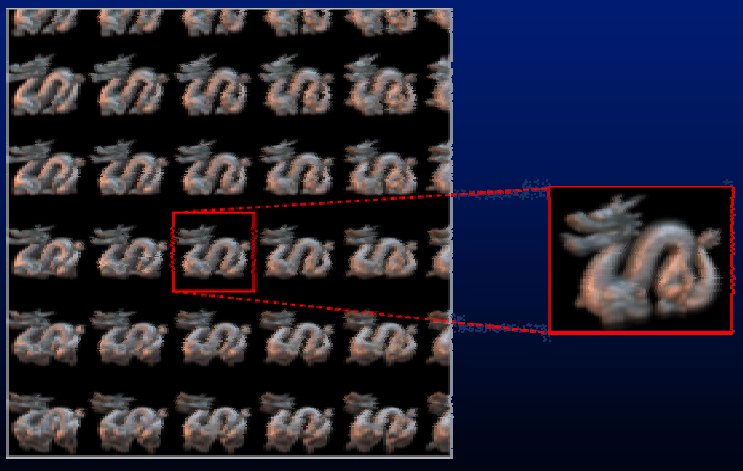
Computer representations of architectural objects

- 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 x 56 x 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

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.

Michelangelo’s Pieta

handmade replica

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 Roman census bureau

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

Fragment #10g

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

positioning...

Scanning the fragments

scanning...

Scanning the fragments

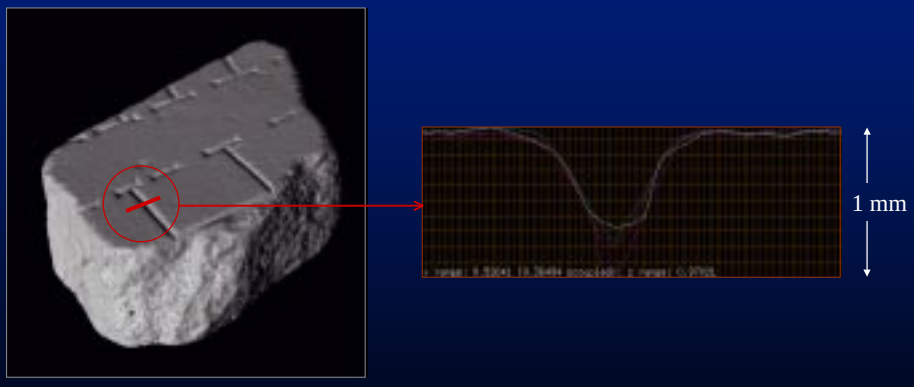
aligning...

Fragment #642

3D model

color photograph

Fragment #642



3D model

Acknowledgements

Faculty and staff

Prof. Brian Curless, John Gerth, Jelena Jovanovic, Prof. Marc Levoy, Lisa Pacelle, Domi Pitturo, Dr. Kari Pulli

Graduate students

Sean Anderson, Barbara Caputo, James Davis, Dave Koller, Lucas Pereira, Szymon Rusinkiewicz, Jonathan Shade, Marco Tarini, Daniel Wood

Undergraduates

Alana Chan, Kathryn Chinn, Jeremy Ginsberg, Matt Ginzton, Unnur Gretarsdottir, Rahul Gupta, Wallace Huang, Dana Katter, Ephraim Luft, Dan Perkel, Semira Rahemtulla, Alex Roetter, Joshua David Schroeder, Maisie Tsui, David Weekly

In Florence

Dott.ssa Cristina Acidini, Dott.ssa Franca Falletti, Dott.ssa Licia Bertani, Alessandra Marino, Matti Auvinen

In Rome

Prof. Eugenio La Rocca, Dott.ssa Susanna Le Pera, Dott.ssa Anna Somella, Dott.ssa Laura Ferrea

In Pisa

Roberto Scopigno

Sponsors

Interval Research, Paul G. Allen Foundation for the Arts, Stanford University

Equipment donors

Cyberware, Cyra Technologies, Faro Technologies, Intel, Silicon Graphics, Sony, 3D Scanners

http://graphics.stanford.edu/projects/mich/ levoy@cs.stanford.edu