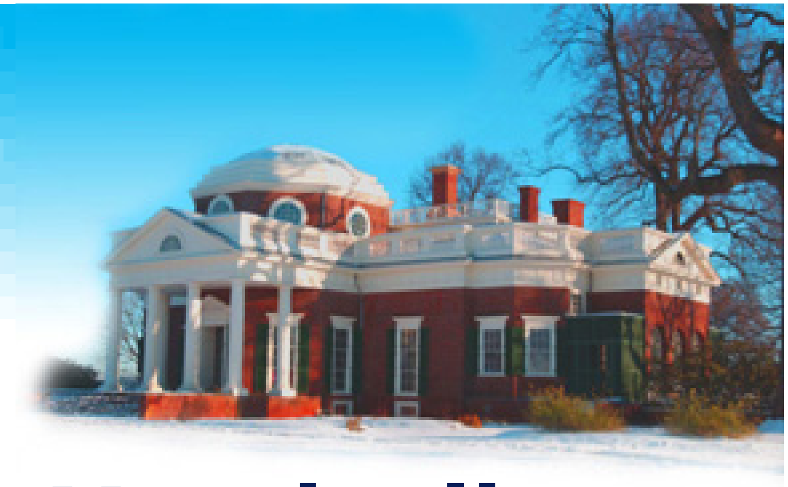

Movies, Museums, & Monticello

Reality, unreality, and a case study in virtual reality

David Luebke

University of Virginia

A matter of reality

- From the “Designing Matter Questions for Speakers to Consider”:

1. *What matter do you work with?*

   A: I don’t!

   To us matter is purely the stuff of imagination, abstraction.

2. *Where does it come from? How do you procure it?*

   A: Out of nowhere, as much as I want…

   We create and manipulate 3D computational models of matter, limited only by what we can figure out.

3. *What languages, symbols, designs, and ideas do you use to represent matter?*

   Now *this* is the right question…

A matter of reality

- Computer graphics is about *simulation*, *abstraction*, and *representation* of matter
  - Interaction of light with matter
    - To simulate the glossy sheen of car paint
    - Or the waxy translucence of leaves and human skin
    - Or the self-shadowing effects of hair
  - Interaction of matter with matter
    - Physics of objects colliding and deforming
    - Fluid mechanics of water, or fire, or smoke
    - Structural physics of cloth

Realism?

- The quest of computer graphics is often described as *photorealism*
  - Create images that cannot be distinguished from a photograph
  - This requires modeling and simulation of optics, physics, and human perception
- But much of computer graphics concerns directed *unreality*
  - Things that don't or can't exist: dinosaurs, ghosts, talking mice
  - Controlled simulation, e.g. a puff of smoke that forms a word
  - Shadows that obey director's sense of atmosphere, not optics
  - Nothing! Removing elements from images or scenes
- And sometimes the goal is not realism but *depiction* or *abstraction*

Distinction:
realism vs. speed

- Two general camps in computer graphics:
  - Realistic graphics (a.k.a. *image synthesis*, *CGI*)
    - Generate images offline for playback later
    - Use: movies, television
    - Rendering time frame: seconds to hours
    - Rendering resources: high-end computer cluster, gigabytes of data
  - Interactive graphics
    - Generate images dynamically as user interacts with system
    - Use: video games, CAD, virtual reality
    - Rendering time frame: 10-30 milliseconds
    - Rendering resources: cell phone to PC, megabytes of data

Computer graphics:
the view from ten thousand feet

- Modeling
  - How to represent shape computationally
- Animation
  - How to represent, simulate, and control how things move
- Illumination
  - How to model the interaction of light with matter
- Rendering
  - How to generate an image from these representations

Modeling

- How do we represent shape in computer graphics?
  - Many, many different ways
    - Splines, subdivision surfaces, voxels, metaballs, geometry images…
  - Lowest common denominator: the polygonal mesh
    - Represent surface with a faceted approximation
    - Mesh = list of vertices (3D points)
      + list of polygons (which vertices are connected to which)
    - Might also store geometric attributes (color, orientation, curvature…)

Animation

- How do we represent, simulate, and control how things move?
  - One possibility: purely with the laws of physics
    - E.g., the Navier-Stokes equations can guide a fluid mechanics simulation to produce realistic-looking water, smoke, and clouds
    - Computationally tricky, hard to control
  - Another possibility: purely by hand
    - E.g., the animators behind Stuart Little have a control panel with literally hundreds of dials…
    - Powerful technique, doesn't scale well
  - Another possibility: use measured data
    - Motion capture techniques record (for example) an actor performing
    - Can then play back that motion, using it to control simulated character
    - Tricky to blend motions or apply to different characters/situations

Illumination

- How do we model the interaction of light with matter?
  - Enormously complex problem: real-world light
    - Bounces off of every surface
    - Spans an incredible dynamic range
  - Common approximations:
    - Tricolor spectrum (RGB)
    - No shadows, no indirect illumination
    - No reflection/refraction/diffraction/polarization/participating media
  - Again, we often want controlled *un*realism
    - E.g., negative lights that cast shadows not illumination
    - Much of cinematic lighting is unrealistic, for effect and for balance

Rendering

- How do we generate an image from these representations?
  - Often very different answers for offline and interactive rendering
  - Offline rendering uses specialized software and techniques such as *path tracing* to model the optics of a scene
  - Interactive rendering requires specialized computer hardware for *rasterizing* polygons into pixels

An aside:
Computer graphics careers & studies

- Computer graphics in practice is wonderfully interdisciplinary
  - Science: study the phenomena we are trying to re-create
  - Engineering: build the hardware and software to make it happen
  - Art: conceive the vision that drives the process
  - Media studies: Examine this new media and its place in society
- Film and video game studios are teams of artists & engineers working side-by-side toward a shared vision
- UVA is a great place to get into this!
  - Several CS courses on graphics (CS program/degree in CLAS)
  - Media studies
  - Art
  - Digital Media Lab (Clemons Library)

Case study:
Virtual Monticello museum exhibit

- The rest of this talk will focus on a specific recent project and the underlying technology
- Roadmap
  - The technology: *Image-based rendering*
  - The application
  - The details

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  - The application: *Virtual Monticello*
  - The details: *Point clouds to textured meshes*

Image-based rendering

- Computer graphics typically turns three-dimensional computer models into images
- *Image-based rendering*: a relatively new field of computer graphics devoted to making images from images

Example: *Quicktime VR*

Images with depth

- Quicktime VR is really just a 2D panorama
  - Spin around, zoom in and out
- But what if we could assign depth to parts of the image?

Example: *Tour Into the Picture*

Click to play movie clip in new window
(requires toolkit password)

TIP.rotunda.mpg, 3.62MB

Depth per pixel

- Tour Into the Picture assigns depth to objects
  - Leads to “cardboard cutout” look
- What if we could assign an exact depth to every pixel?

Example: *MIT Image-Based Editing*

Click to play movie clip in new window
(requires toolkit password)

ibedit_360x240.mpg, 41.7MB

Depth per pixel continued

- Assigning depth by hand is laborious
  - Beautiful, compelling results, but…
  - 1 image = 50 hours
- What if we had a "camera" that *automatically* acquired depth at every pixel?

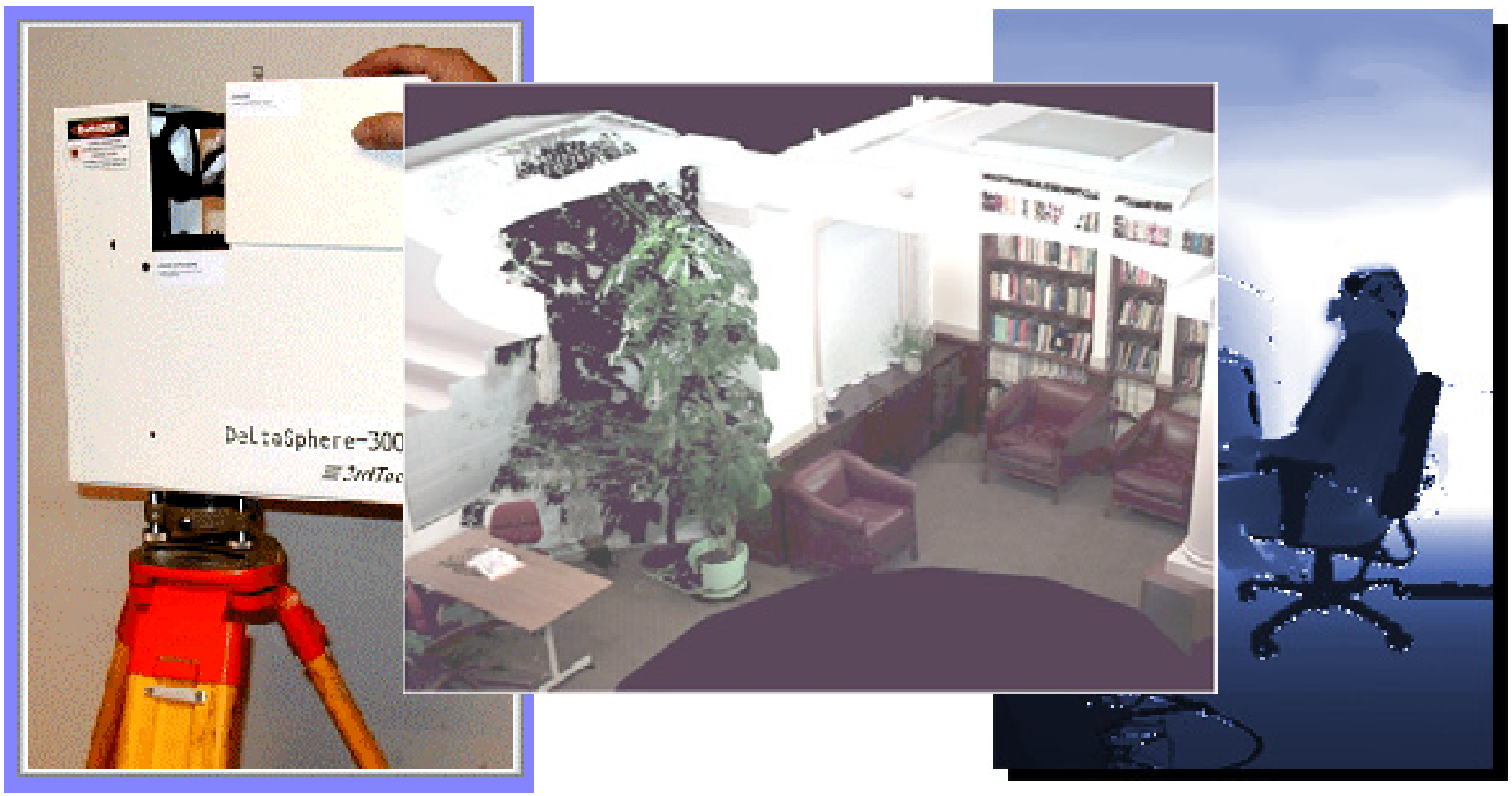
Example: DeltaSphere

Laser rangefinder scanner

- Deltasphere 3000 by 3rdTech
  - Time of flight laser rangefinder
    - Infrared or red visible
    - 20,000 samples per second
    - 40 foot range
    - Accuracy ~ 1 mm
  - Panoramic scanner with spinning mirror to scan all directions in spherical coordinates
  - 6 megapixel digital camera with same nodal point
- Similar products exist, none as well suited for indoor scanning

3D Scanning

- Fairly new technology: scanning the world



Scanning Monticello

- Wanted a flagship project to showcase this
- Idea: scan Thomas Jefferson's Monticello!
  - Virtual tourism
  - Historic preservation
  - Archeological and architectural research, documentation, and dissemination
  - Great driving problem for scanning and rendering research

Jefferson and Monticello

- Thomas Jefferson
  - Wrote the Declaration of Independence
  - Third President of the United States of America
  - Founded and designed the University of Virginia

- Monticello
  - Jefferson's "essay in architecture"
  - Designed in the Roman neoclassicist style
  - One of 21 UNESCO World Heritage Sites in America

Scanning Monticello:
First Steps

Scanning Monticello:
Initial scan

- Summer 2000:
  - Months of planning & negotiating
  - 2 nights (5 PM-1 AM) and 2 mornings (5-8 AM)
    - Accompanied everywhere by curatorial staff
    - Learned to be *very careful* around priceless artifacts
  - Prototype of DeltaSphere
    - Buckets of equipment
    - Heavy, bulky, slow to set up and move

Scanning Monticello: Next steps

- Exhibit at New Orleans Museum of Art
  - Commemorate bicentennial of Louisiana Purchase
  - Focus on Jefferson and Napoleon
  - Wanted a “Digital Monticello” experience
- Proposal to National Science Foundation
  - Develop image-based acquisition & rendering
  - Applications: virtual tourism, historic preservation, forensic analysis
  - Partners: UNC, UVA, Monticello, NOMA, FBI

Scanning Monticello: Next steps

- NSF grant funded ($1.7 M): Summer 2002
  - Included $50,000 for museum exhibit
- Returned to Monticello for much more careful scans (Oct 10-11, Dec 6-7, Dec 19-21)
  - Multiple scanners, large teams
  - Professional photographer for lighting
- Began designing museum exhibit
  - Consult with museum administration, curators, exhibition design firm
  - Lots of trips to New Orleans (poor Dave)

The Exhibition

Jefferson's & Napoleon's

AMERICA FRANCE

The Premier Exhibition of the Louisiana Purchase Bicentennial

APRIL 12 - AUGUST 31, 2003

New Orleans Museum of Art

Virtual Monticello: Objectives

- A “Virtual Monticello” experience
  - Cultural heritage via virtual tourism
  - Convey presence through fine detail plus a sense of scale
- Demonstrate graphics to the public
  - Show that there is more than movies and games
- Further our research agenda
  - Image-based modeling and rendering

Virtual Monticello:
Design criteria

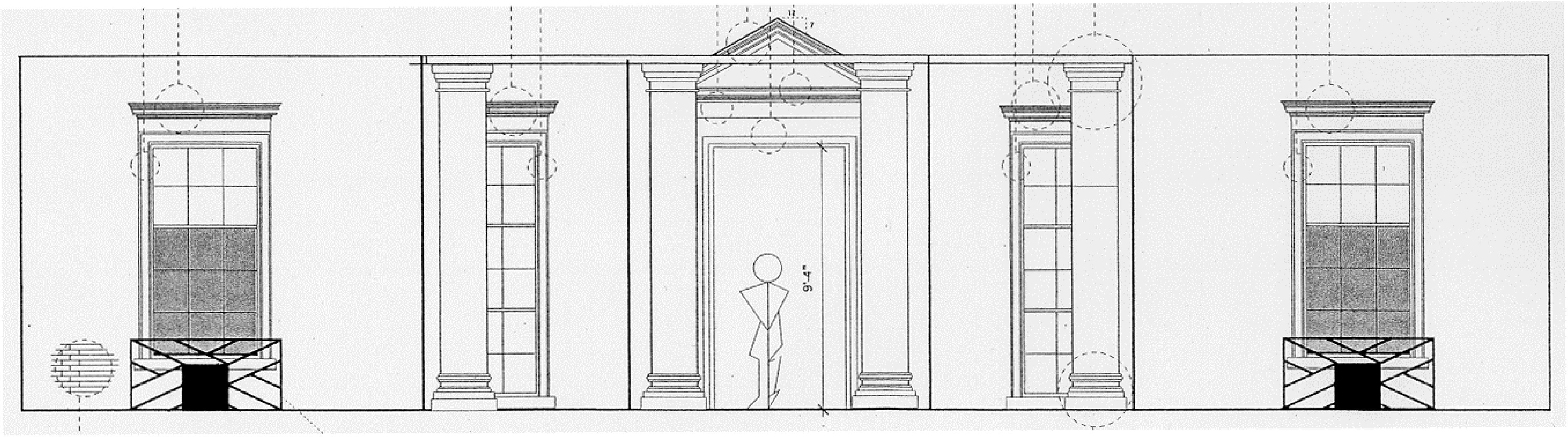
- Cost ($50,000 funded by the NSF)
- Quality of the experience
- Visitor throughput
- Robustness
- Space

Virtual Monticello:
Exhibit Design

- "Through the window" tracked stereo display
  - Two polarized projectors, tracked viewer with polarized glasses (à la 3D movie)
  - Pros:
    - Life size tracked stereo → compelling VR
    - Well-understood, robust technology
    - Very intuitive
  - Cons:
    - Only one user at a time gets full experience
    - Glasses, computer, projectors, tracker can all break
    - Medium expensive ($25,000 - $50,000)
    - Magnetic tracker → need non-metallic environment

Virtual Monticello:
Realization

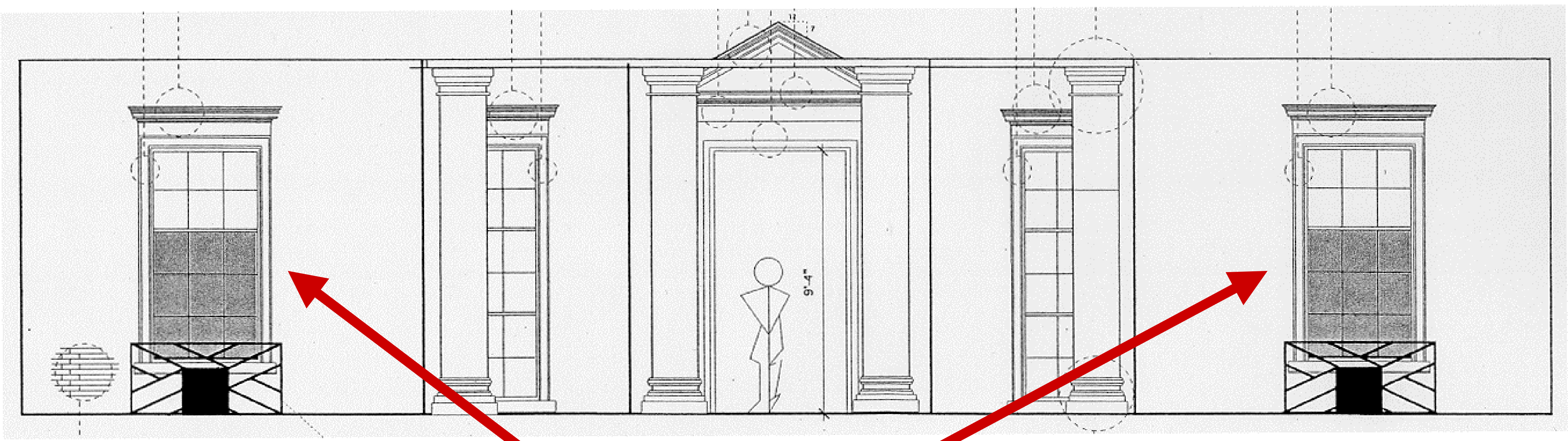
- Final design: “through the window” display



Museum built 40-ft façade of Monticello’s west portico

Virtual Monticello:
Realization

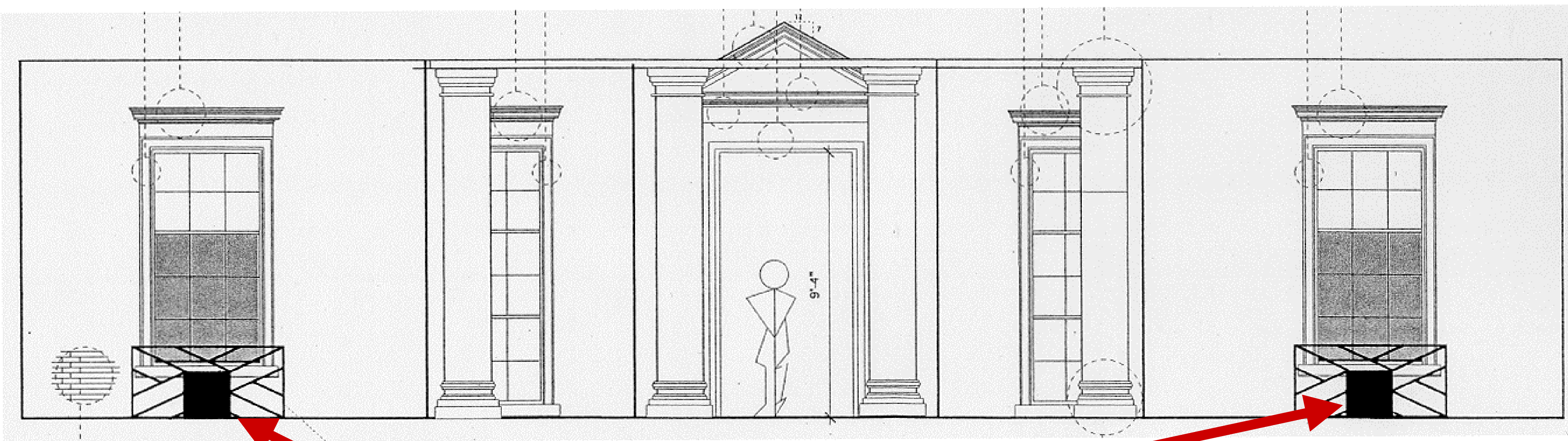
- Final design: “through the window” display



Two virtual windows (identical views)

Virtual Monticello:
Realization

- Final design: “through the window” display



Magnetic trackers (Ascension “Flock-of-Birds”)

Virtual Monticello: Realization

- Final design: "through the window" display

Polarized "opera glasses" goggles
(circular polarization)

Virtual Monticello:
Realization

- Final design: "through the window" display

Dave in a tuxedo

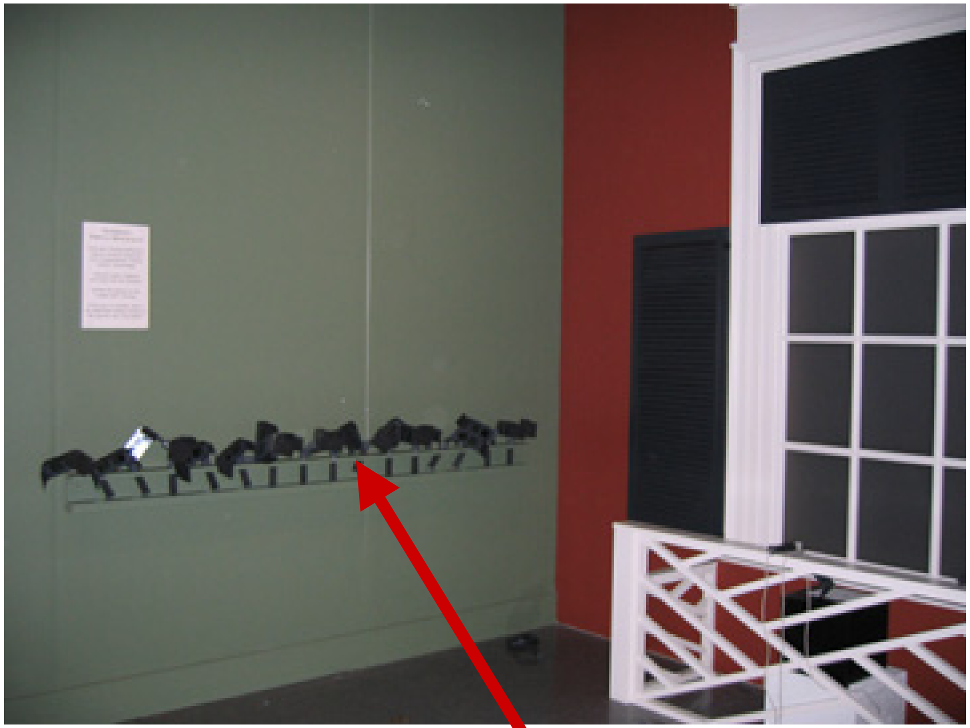
Virtual Monticello:
Realization

- Final design: “through the window” display

One visitor at each window gets tracked glasses

Virtual Monticello: Realization

- Final design: “through the window” display

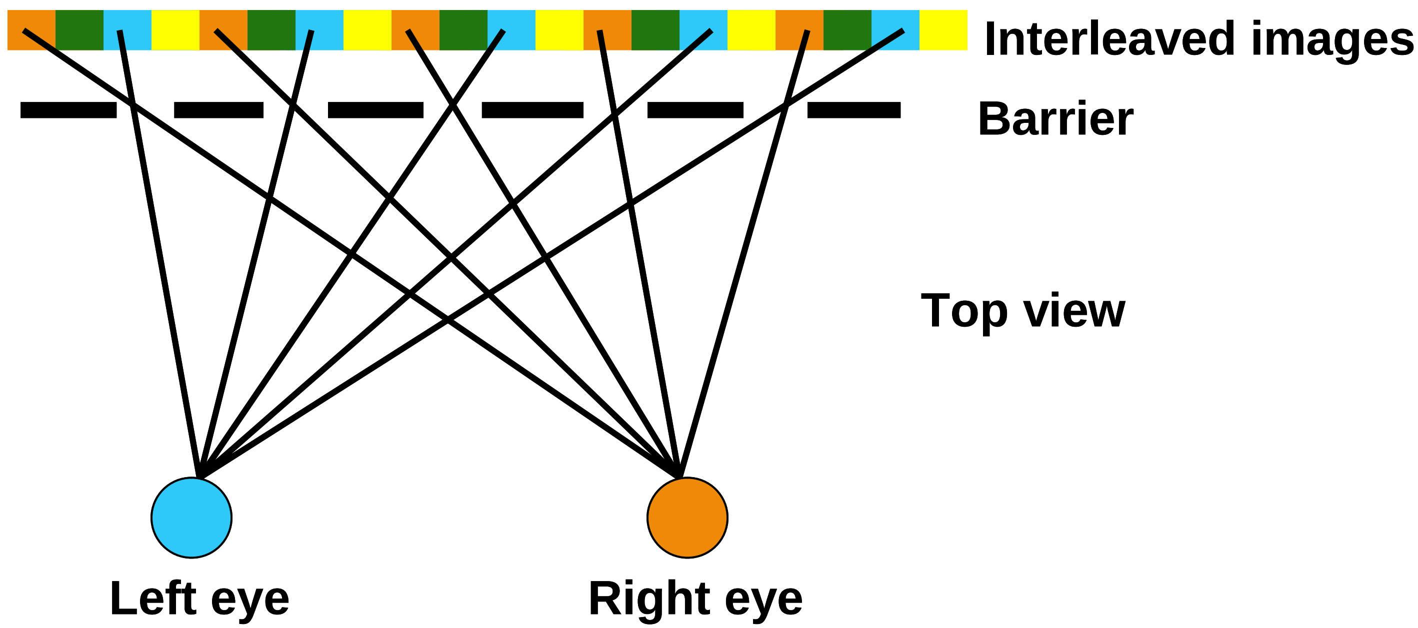


Others can use non-tracked glasses

Virtual Monticello:
Realization

Virtual Monticello:
Barrier Stereogram

- We also created a stereogam for the exhibit



The stereogram: eyes see different interleaved images

Virtual Monticello:
Barrier Stereogram

- We also created a stereogram for the exhibit

Built a *railcam* to take 64 pictures spaced 1 cm apart

Virtual Monticello:
Barrier Stereogram

- We also created a stereogram for the exhibit

High-resolution camera, optical rail, stepper motor

Virtual Monticello:
Barrier Stereogram

- We also created a stereogram for the exhibit

Hours of Photoshop to blank out windows

Virtual Monticello:
Barrier Stereogram

- We also created a stereogram for the exhibit

Final stereogram in the museum

Virtual Monticello:
Barrier Stereogram

- We also created a stereogram for the exhibit

Cross-eyed stereo pair from two constituent images

Jefferson’s Cabinet:
Barrier Stereogram Realized

Stereogram now in the Rotunda (Lower East Oval)

Virtual Monticello:
Results

- 110,000 visitors in 142 days

Virtual Monticello: Building the model

- I've glossed over the process of constructing a 3D model from the laser scans
- Active, difficult area of research
  - Computer graphics
  - Computer vision
  - Computational geometry
- Many approaches; I'll summarize ours

The Goal:
From this...


…to this…


...to this...


…to this.

Scanning Monticello:
Challenges

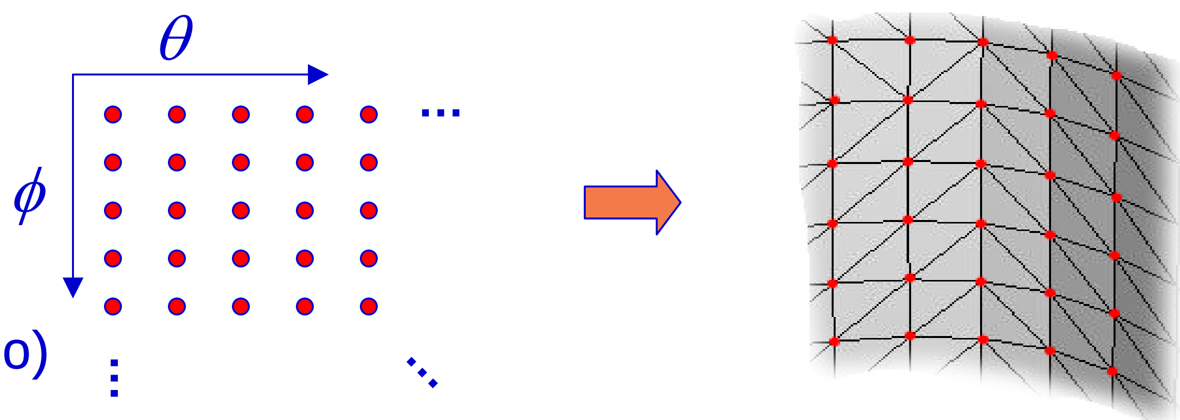
Single scan: 5-10 million points

Each room: 4-6 scans

Jefferson's private suite: 5 rooms

Point cloud → mesh

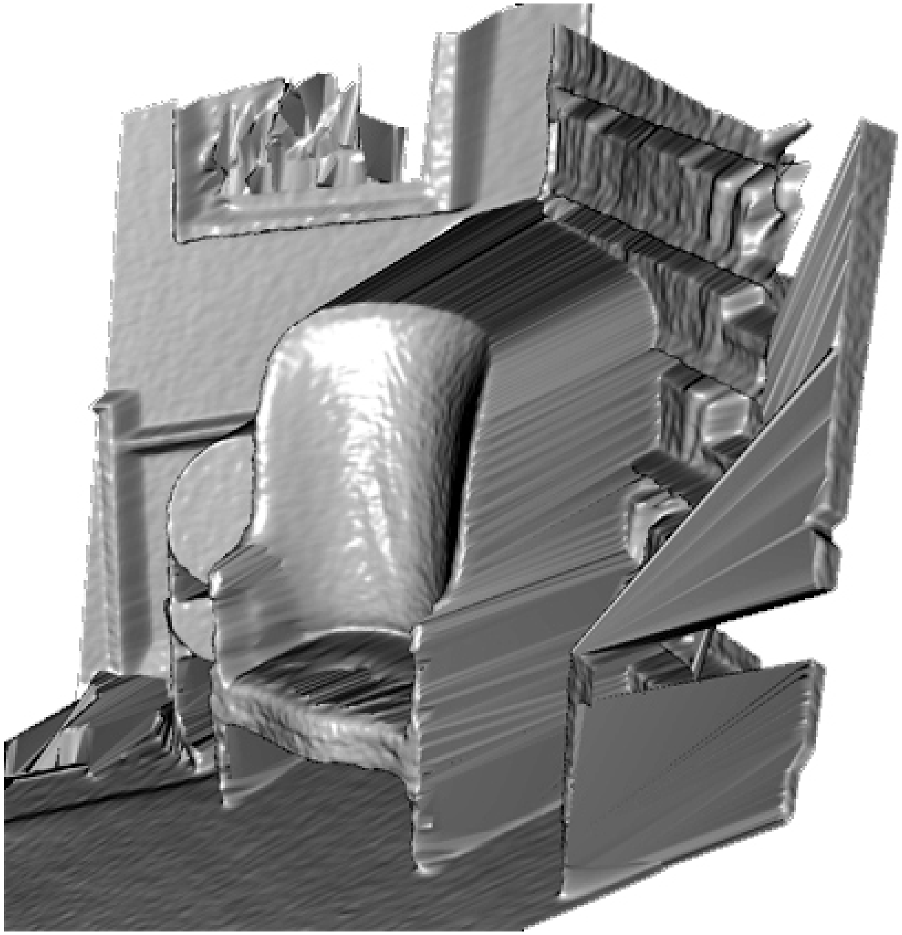
- Simplest approach: connect the dots



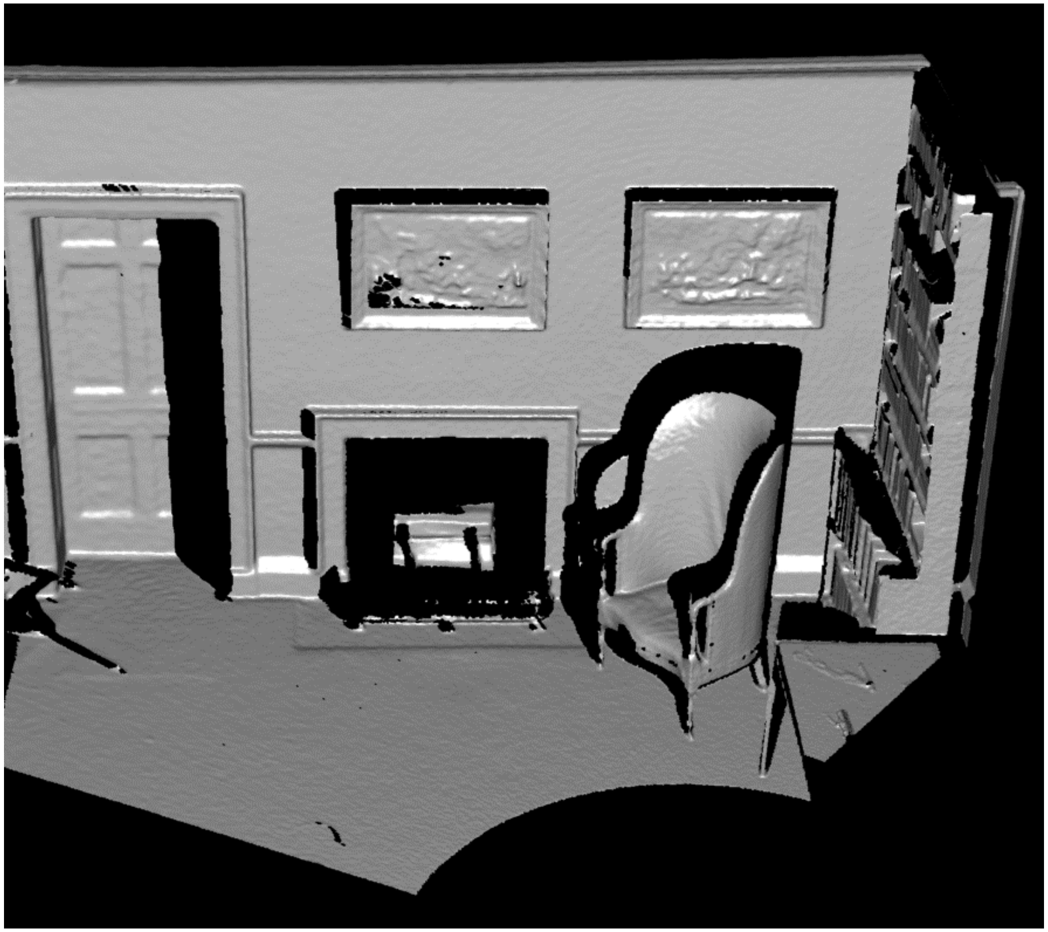
- (Demo)

Point cloud → mesh

- Problems:
  - Shouldn’t always fill holes
  - Need to merge multiple scans



Some Results

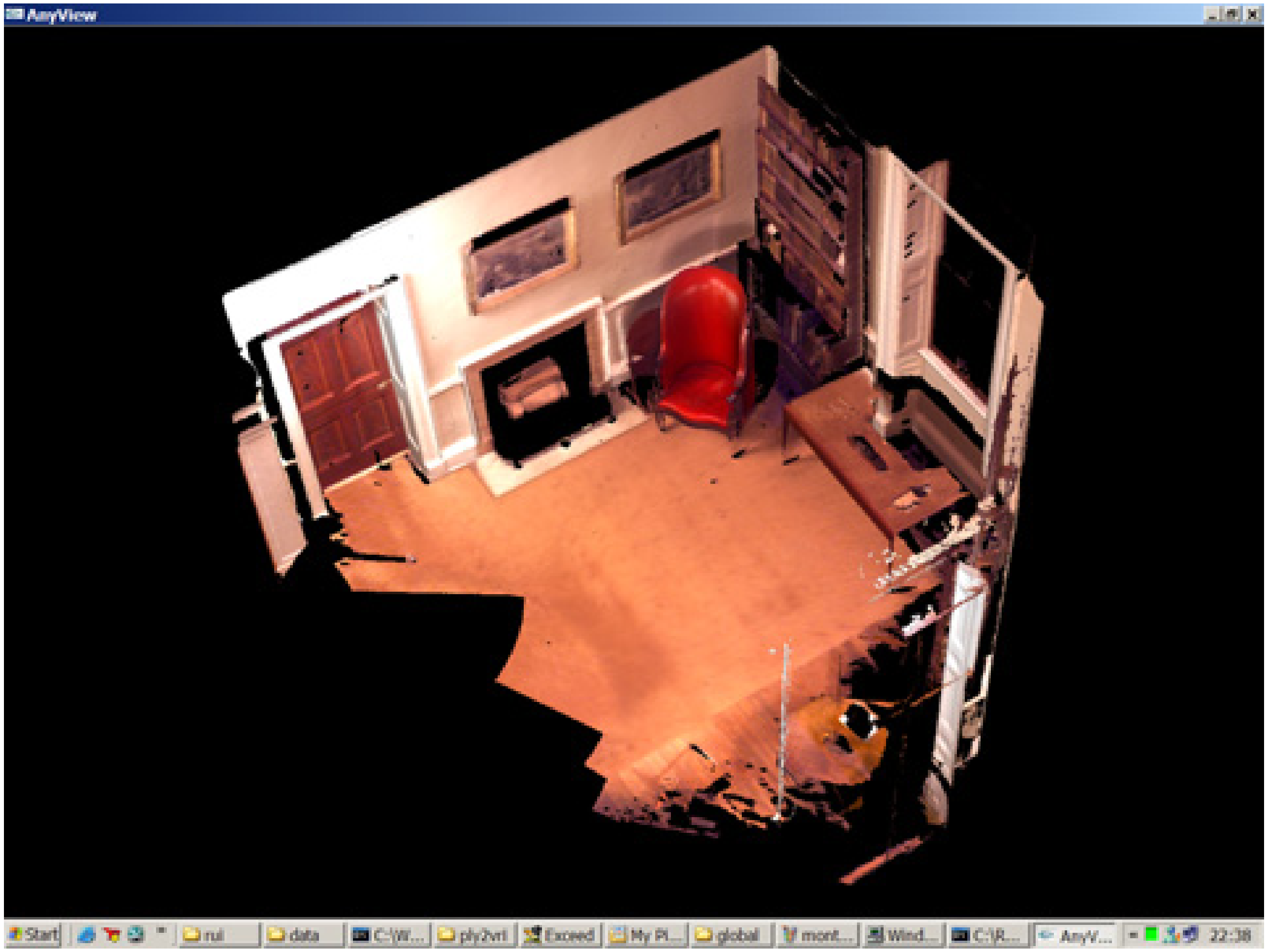


A single scan of Monticello library room
(after range noise reduction)

Some Results

Reconstructed model: 2.86 million vertices, 5.53 million triangles.
Simplified to 1 million triangles.

Some Results



The end

- Any questions?

Other Interesting Work

- Another interesting related project:
  High Dynamic Range Images
  - Camera can capture contrast of ~100:1
  - Monitor can display ~50:1
  - Human eye can perceive 1,000,000:1
- Idea: *Make images that capture the full range of lighting in a scene*

Ex: Monticello images