# Appearance Acquisition

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Slides show material by

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# Outline

1. 5D: Homogeneous Reflectance (BRDF)
2. 7D: Spatially-varying Reflectance (SV-BRDF)

3. Capturing Geometry

# Balancing Needs

1. (Per-object) Acquisition Time
2. Accuracy and Precision
3. Cost
4. Generality: how broad is the class of surfaces being considered?

# Homogeneous Reflectance

- BRDF: Five dimensional domain

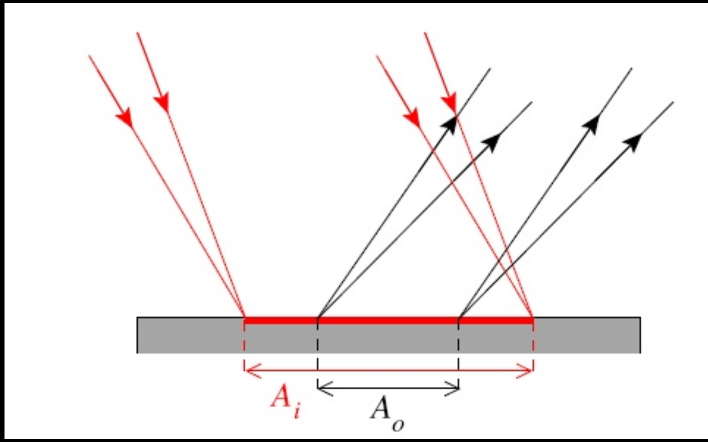
$$f(\lambda, \vec{\omega}_i, \vec{\omega}_o) = f(\lambda, \theta_i, \phi_i, \theta_o, \phi_o)$$

- Isotropic BRDF: Four dimensional domain

$$f(\lambda, \theta_i, \theta_o, |\phi_i - \phi_o|)$$

# BRDF: Measurement Scale

- One measures averages of the BRDF over finite intervals of surface area and solid angle.
- The measurement scale must be appropriate for the BRDF model to be valid (more on this later).



# The Gonioreflectometer

Four-axis gonioreflectometer

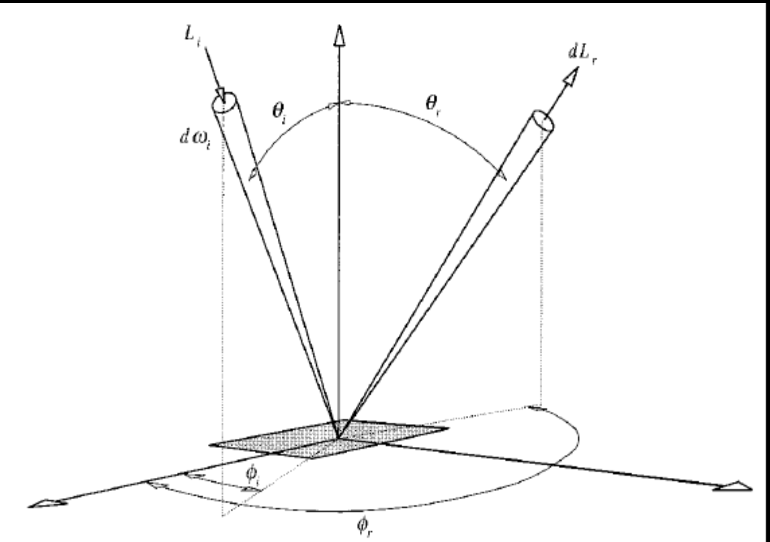
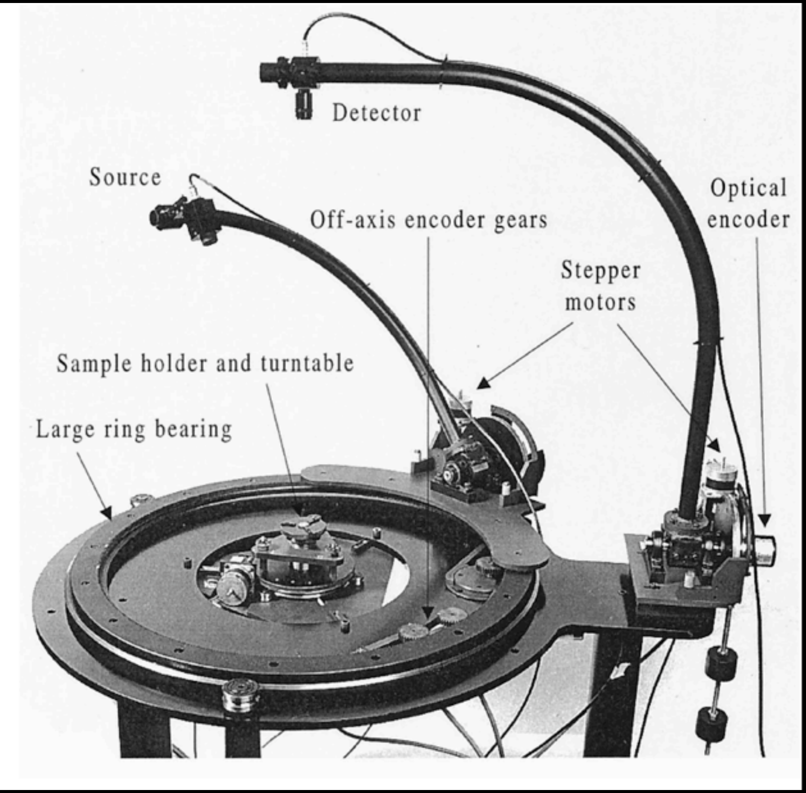



Fig. 1. Coordinate system for defining the BRDF.

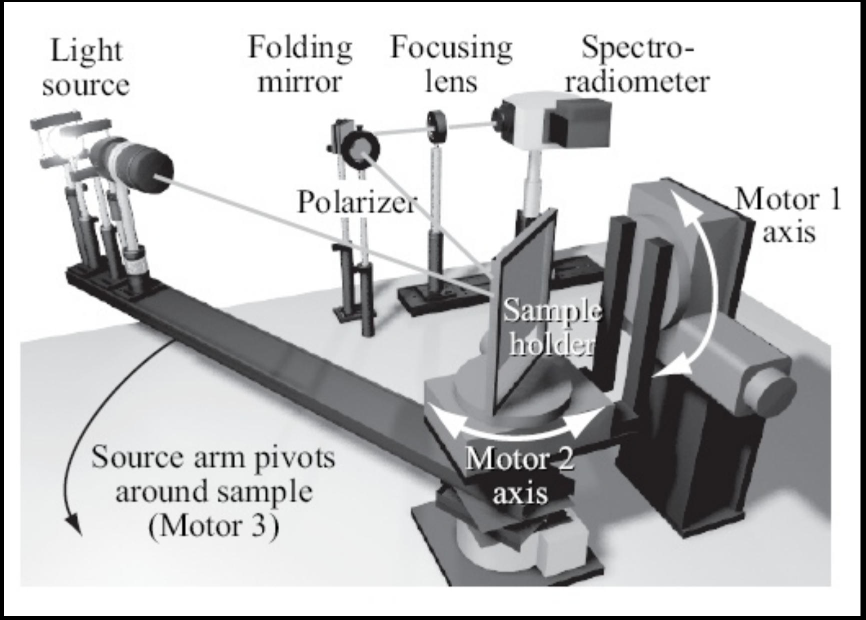



[White et al., 1998]

# The Gonioreflectometer

Three-axis gonioreflectometer

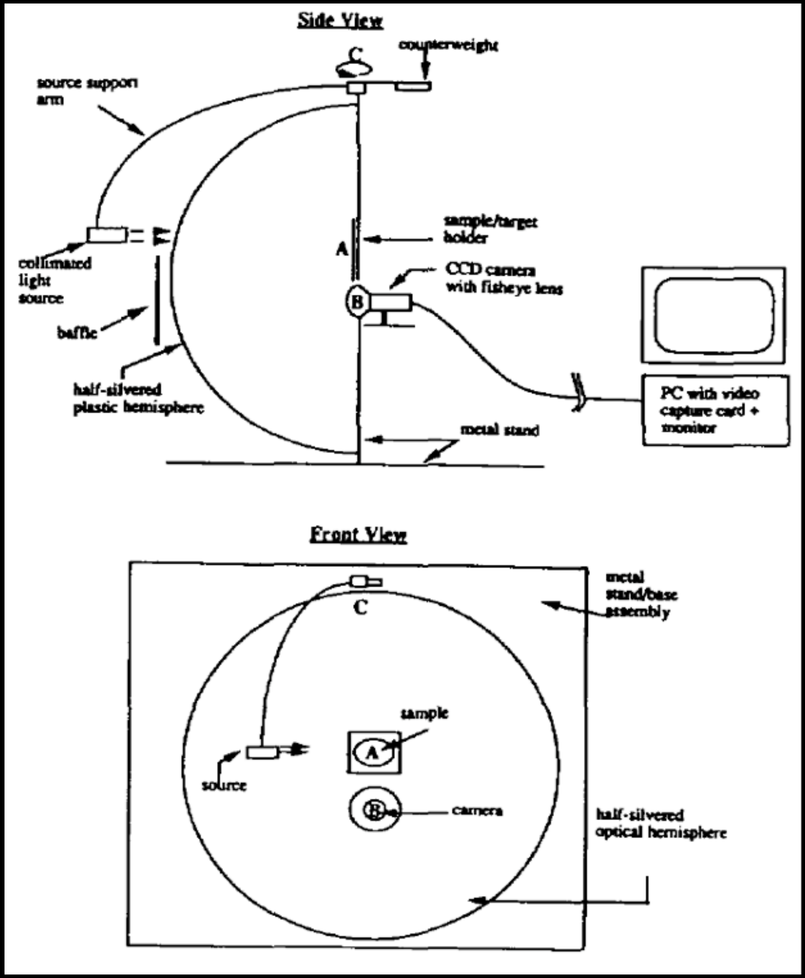
- Isotropic BRDF
- 1000 angular samples
- 31 spectral samples
- ~10 hours per BRDF




[Li et al., 2005]

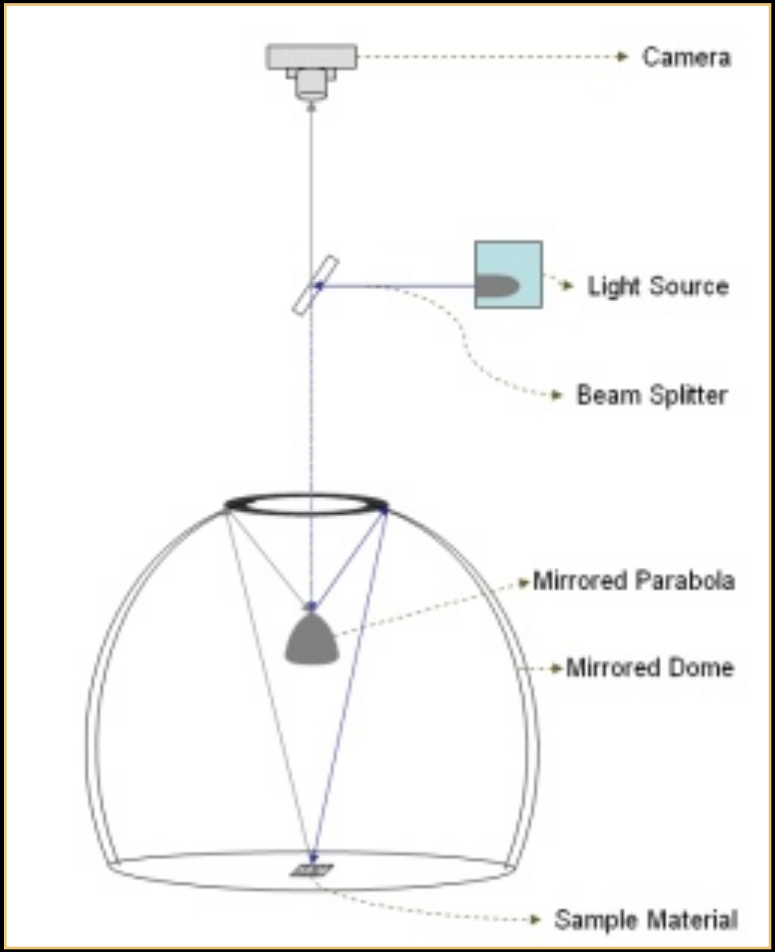
# Image-based measurement: planar

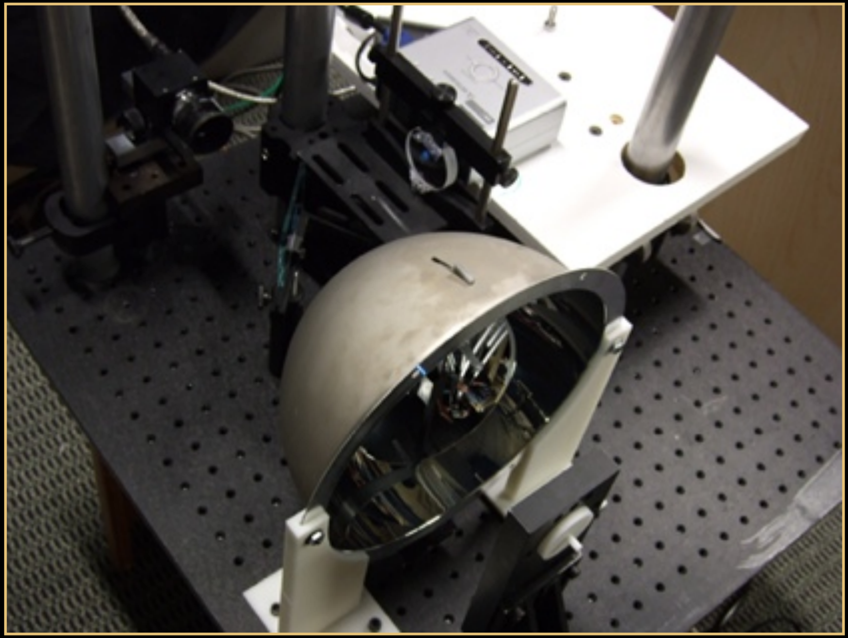
- Camera: Observe multiple output angles simultaneously
- Trade precision (and accuracy?) for efficiency




[Ward, 1992]

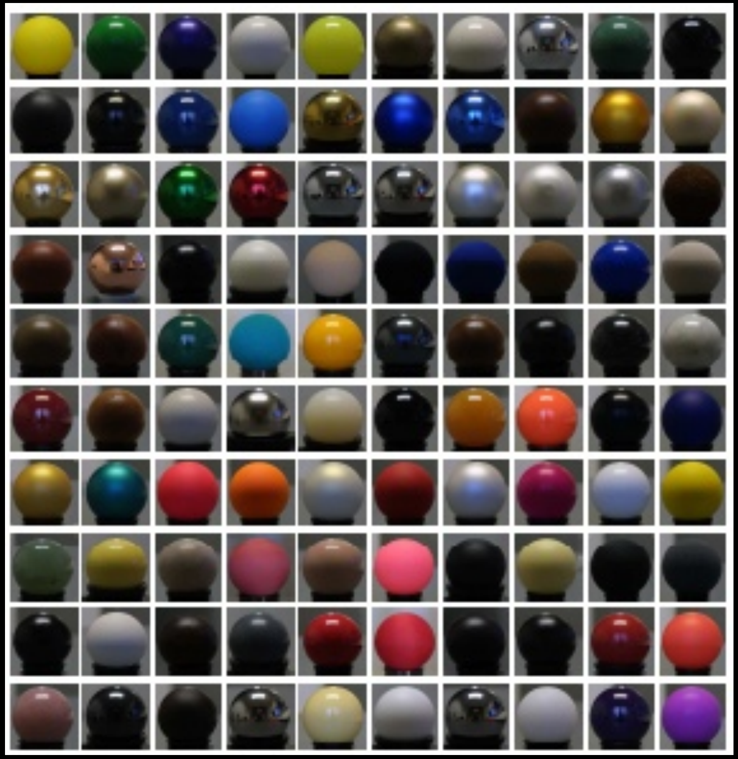
# Image-based measurement: planar



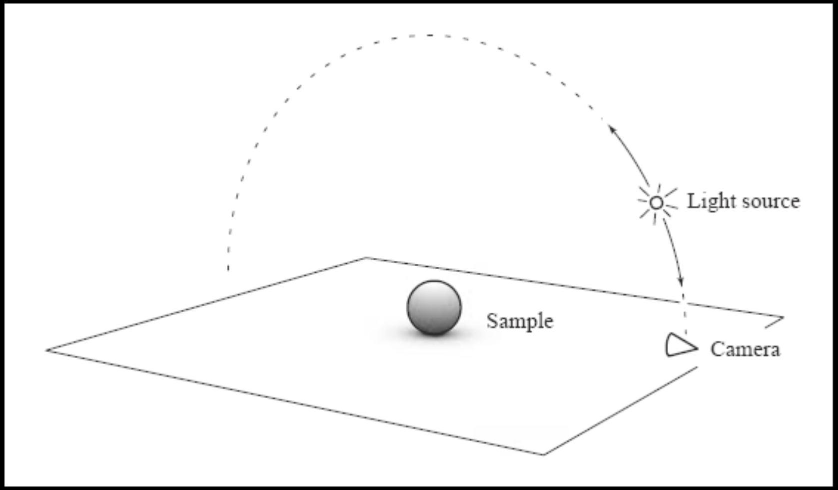



[Ghosh et al., 2007]

# Image-based measurement: curved

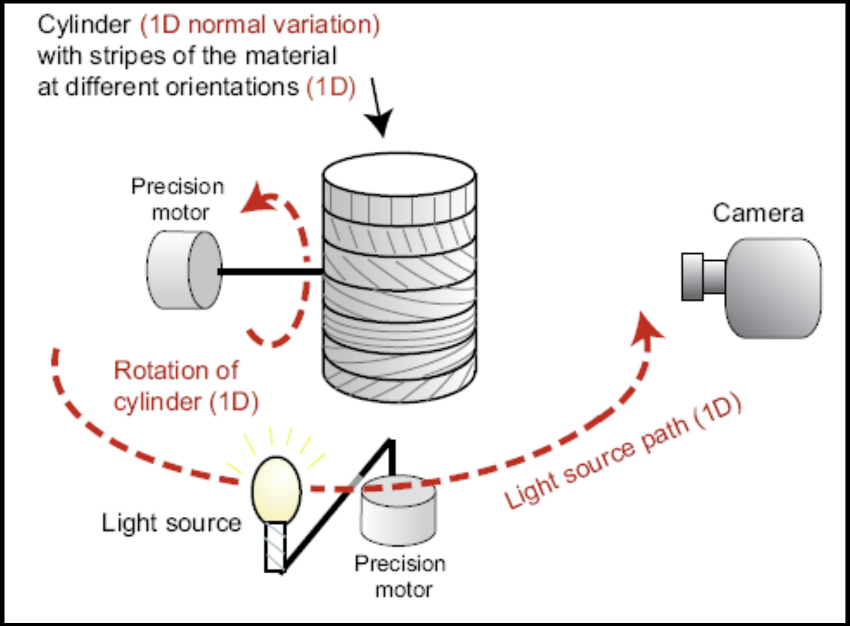


[Matusik et al., 2003]
[http://www.merl.com/brdf/]



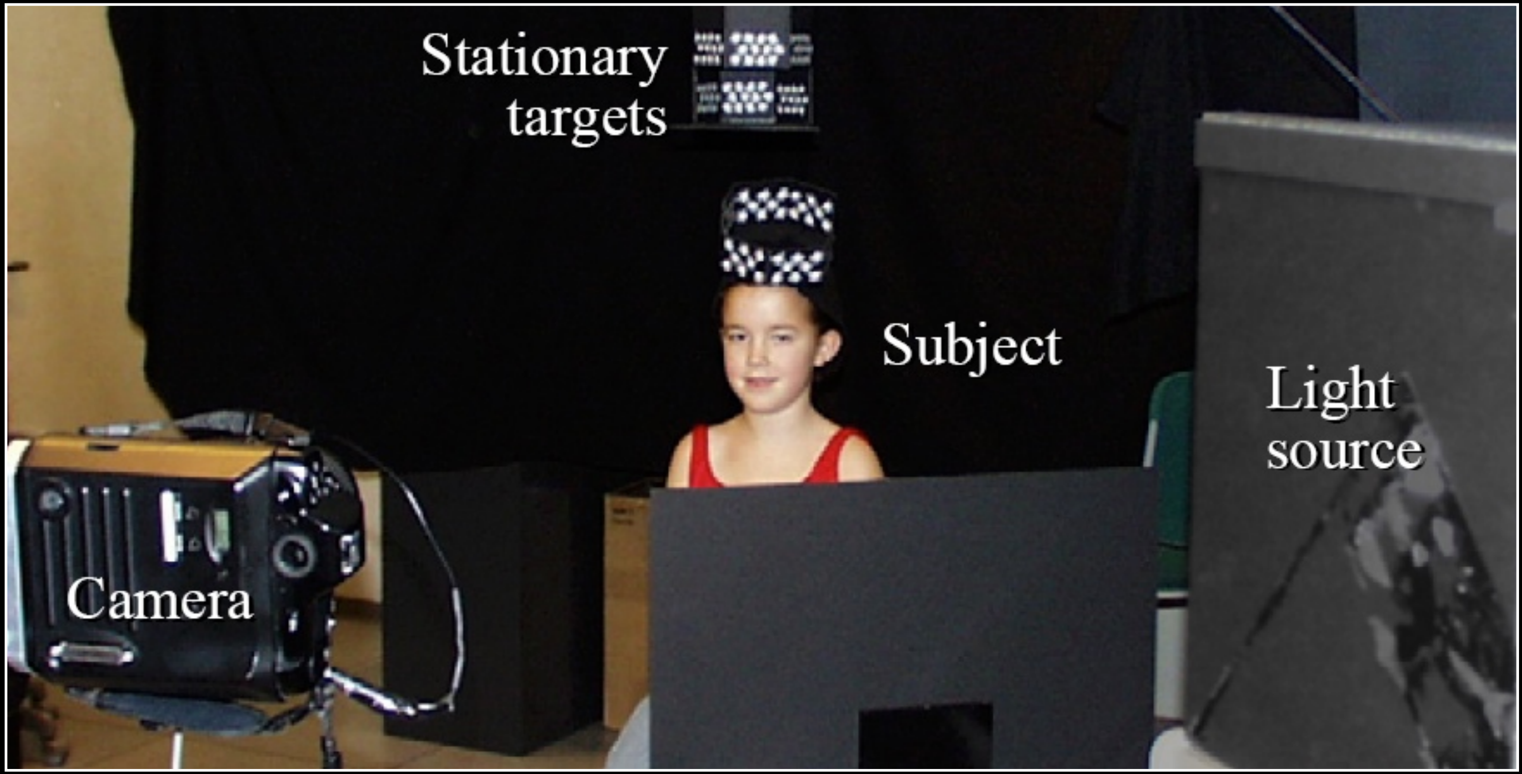

[Marschner, 1998; Lu et al., 1998]

# Image-based measurement: curved




[Ngan et al., 2005]

# Image-based measurement: general




[Marschner et al., 1999]

# Outline

1. 5D: Homogeneous Reflectance (BRDF)
2. 7D: Spatially-varying Reflectance (SV-BRDF)
3. Capturing Geometry

# Spatially-varying Reflectance

- SV-BRDF: Seven dimensional domain

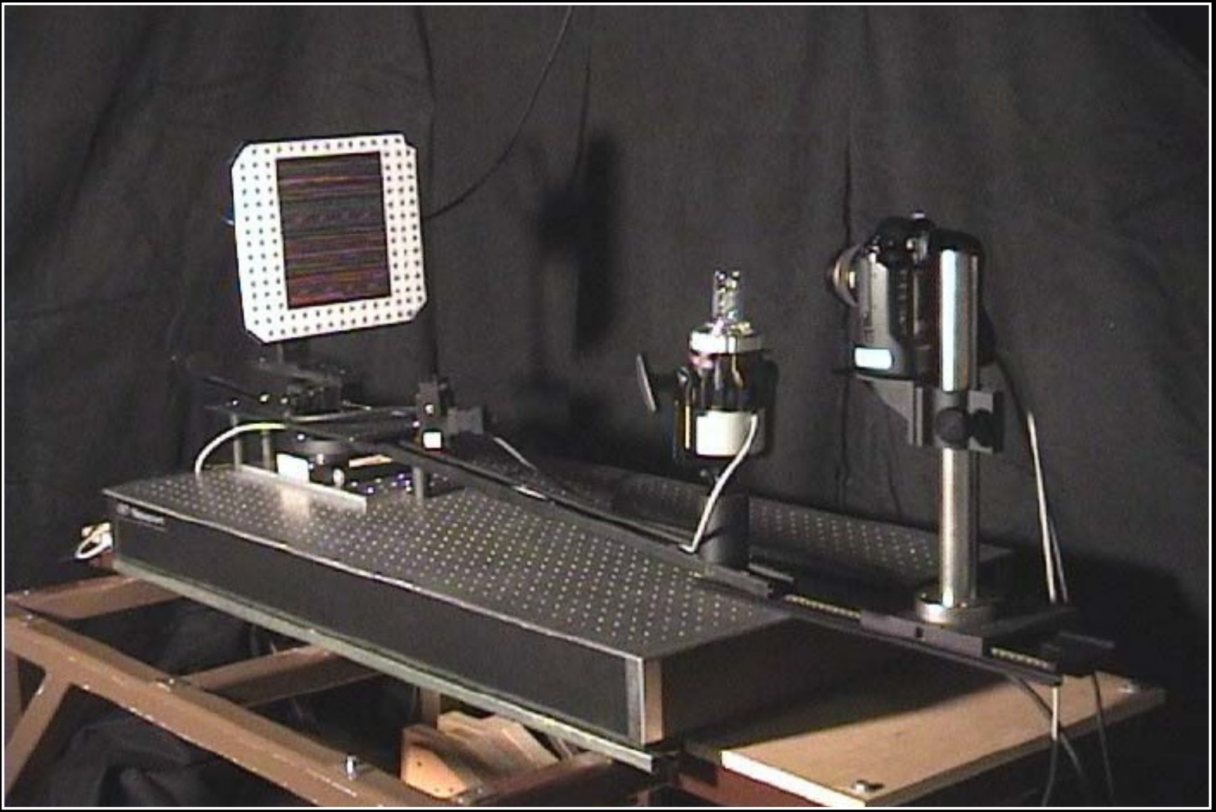
$$f(\lambda, \vec{x}, \vec{\omega}_i, \vec{\omega}_o) = f(\lambda, x, y, \theta_i, \phi_i, \theta_o, \phi_o)$$

- Isotropic SV-BRDF: Six dimensional domain

$$f(\lambda, x, y, \theta_i, \theta_o, |\phi_i - \phi_o|)$$

# Planar Surfaces: The Spatial Gonioreflectometer

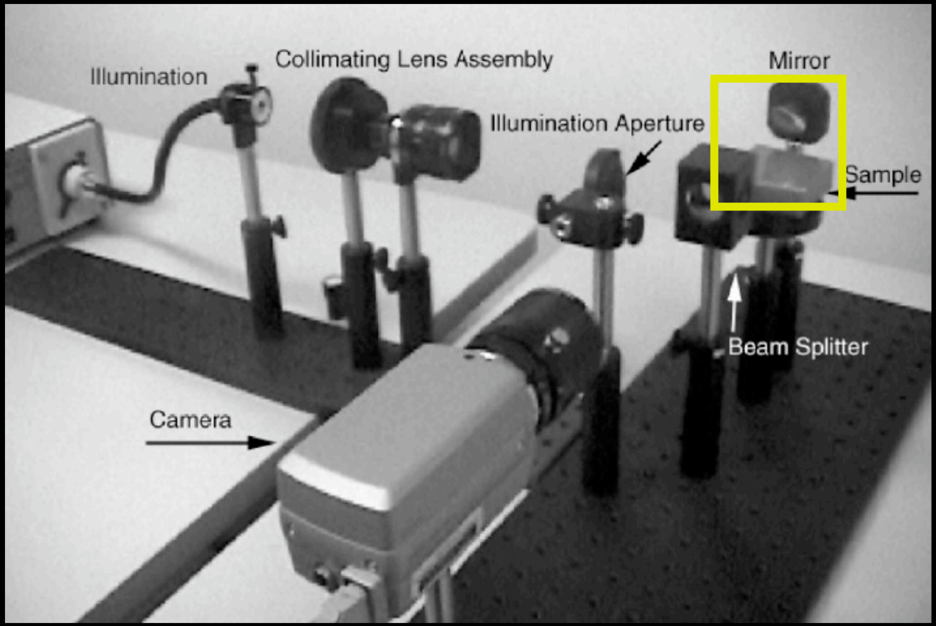
Three-axis spatial gonioreflectometer

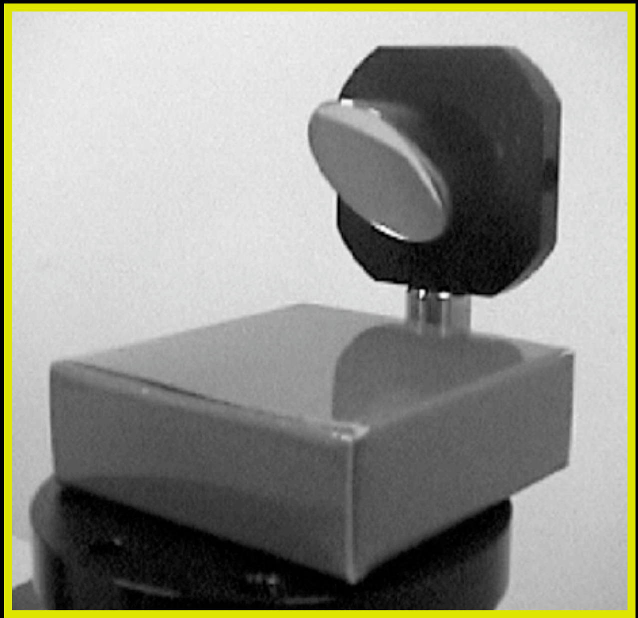


[Dana et al., 1997; McAllister, 2002]

# Planar Surfaces: Another Spatial Gonioreflectometer

- Can use catadioptrics to re-sort light rays and exchange spatial and angular resolution.



[Dana et al., 2004]

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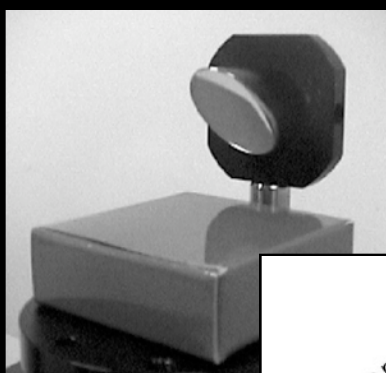
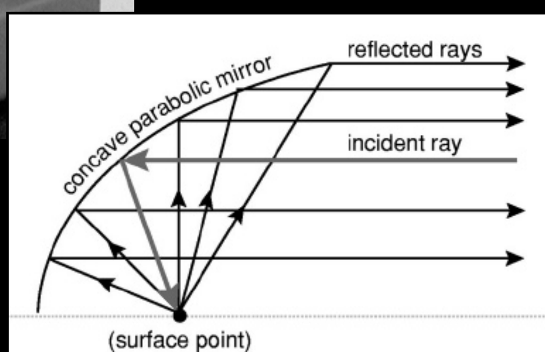
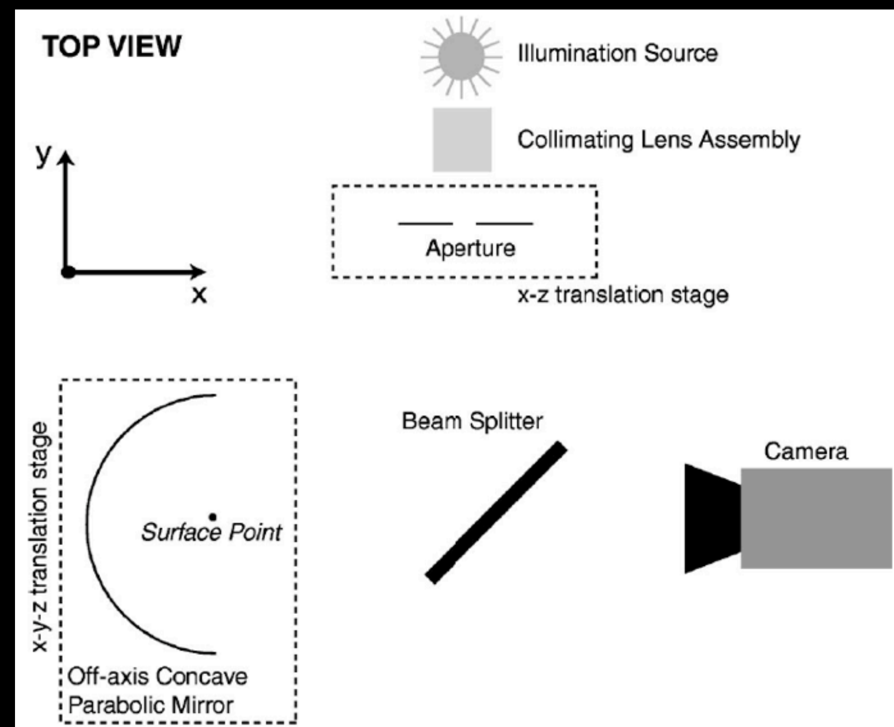




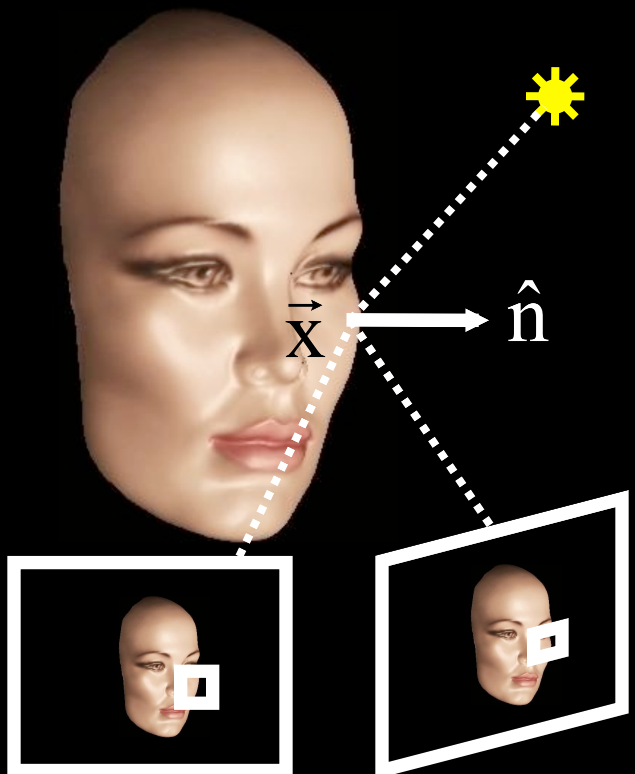

[Dana et al., 2004]

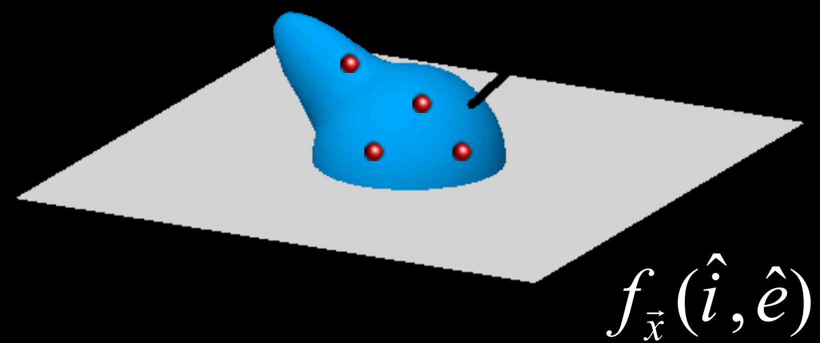
# Curved Surfaces

- Many interesting surfaces are not planar
- Non-planar shapes can be used, provided the shape is known
- Next lecture: 3D Scanning


[Stanford Spherical Gantry]
(also Cornell, UVA, UCSD,...)

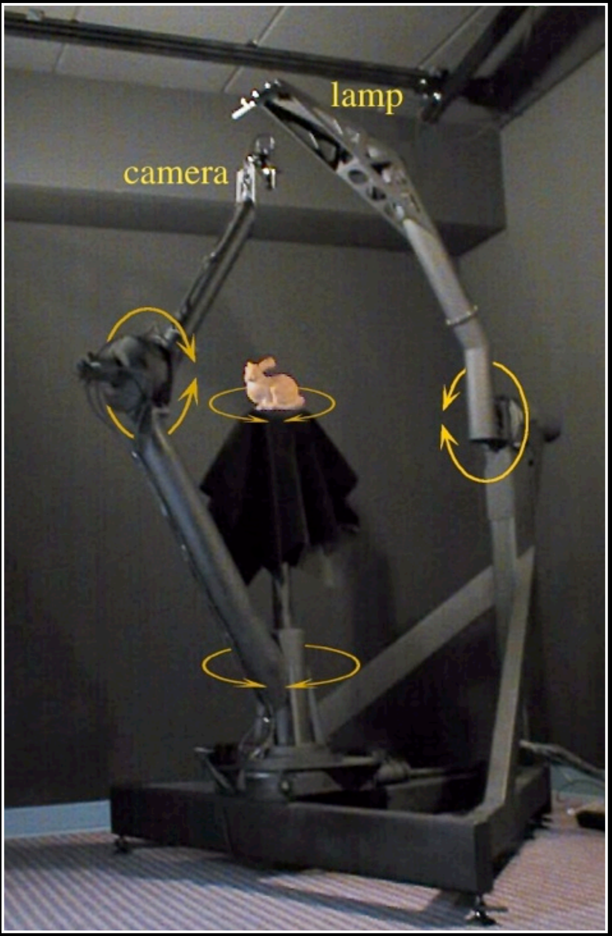
# Counting Images



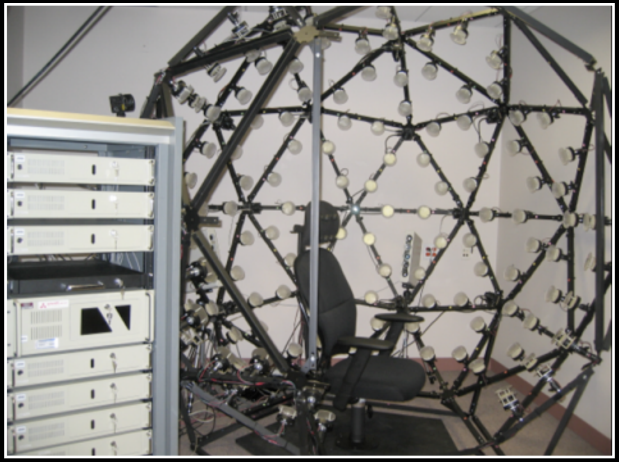

| | | |
|---|---|---|
| 5° sampling: | 1,000,000 images | $>10^6$ MB |
| 1° sampling: | 625,000,000 images | $>10^9$ MB |

# Acquisition Systems




[Stanford Graphics]

[USC-ICT]



[Weyrich et al. 2006]

# Outline

1. 5D: Homogeneous Reflectance (BRDF)
2. 7D: Spatially-varying Reflectance (SV-BRDF)
3. 9D: Subsurface Scattering (BSSRDF)

4. Capturing Geometry

# Acquiring Geometry

- 3D Scanning widely used
- Many applications
  - Computer graphics
  - Product inspection
  - Robot navigation
  - As-built floor plans
  - Product design
  - Archaeology
  - Clothes fitting
  - Art history
  - ...

# Industrial Inspection

- Determine whether manufactured parts are within tolerances

# Medicine

- Plan surgery on computer model, visualize in real time

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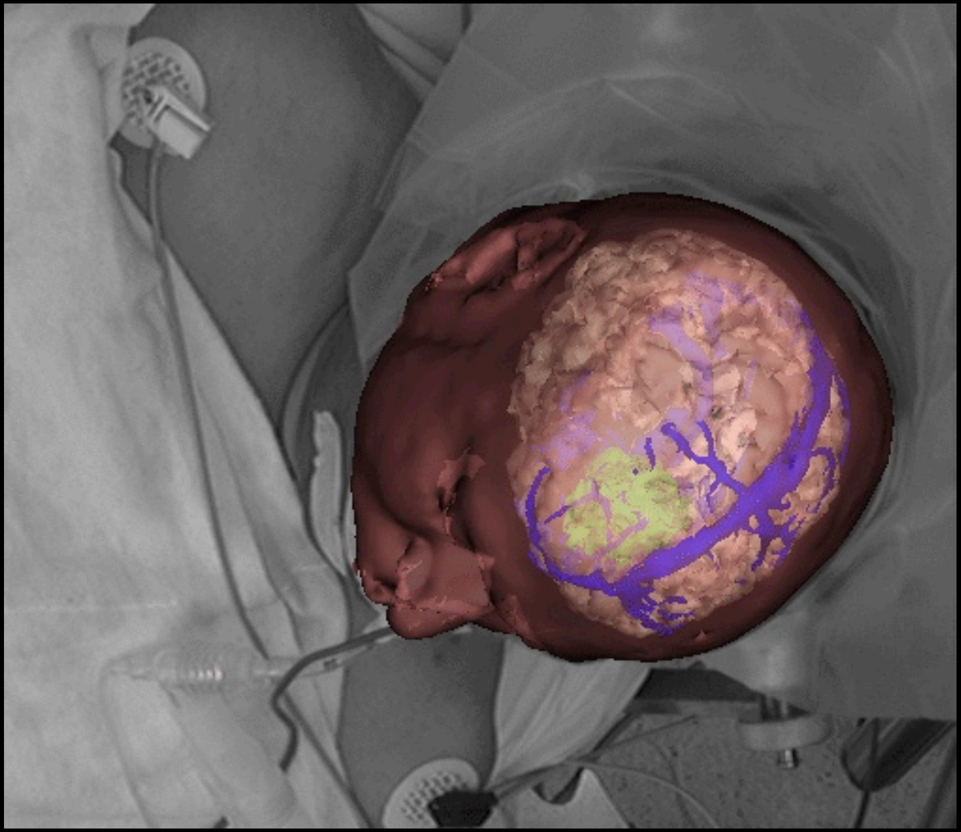

# Scanning Buildings

- Quality control during construction
- As-built models

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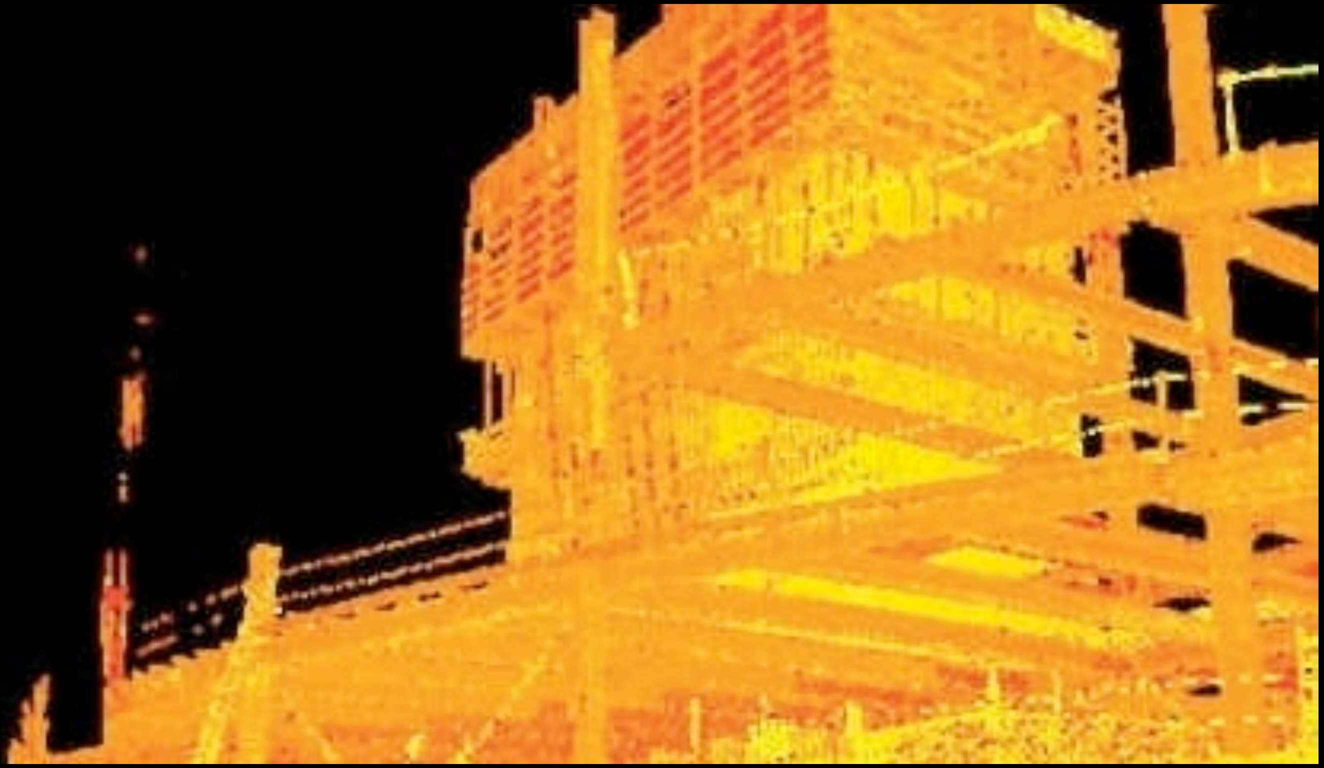


# Clothing

- Scan a person, custom-fit clothing
- U.S. Army; booths in malls

# Range Acquisition Taxonomy

- Range acquisition
  - Contact
    - Mechanical (CMM, jointed arm)
    - Inertial (gyroscope, accelerometer)
    - Ultrasonic trackers
    - Magnetic trackers
  - Transmissive
    - Industrial CT
    - Ultrasound
    - MRI
  - Reflective
    - Non-optical
      - Radar
      - Sonar
    - Optical

# Range Acquisition Taxonomy

- Optical methods
  - Passive
    - Shape from X:
      - stereo
      - motion
      - shading
      - texture
      - focus
      - defocus
  - Active
    - Active variants of passive methods
      - Stereo w. projected texture
      - Active depth from defocus
      - Photometric stereo
    - Time of flight
    - Triangulation

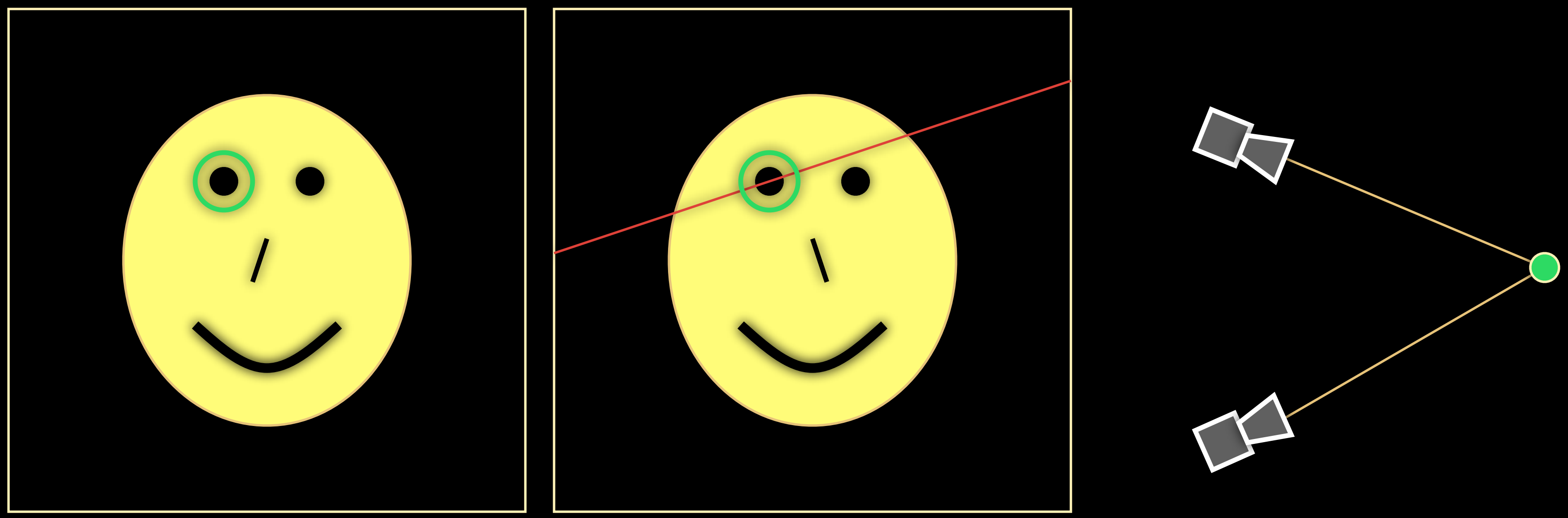
# Touch Probes

- Jointed arms with angular encoders
- Return position, orientation of tip

Faro Arm – Faro Technologies, Inc.

# Stereo

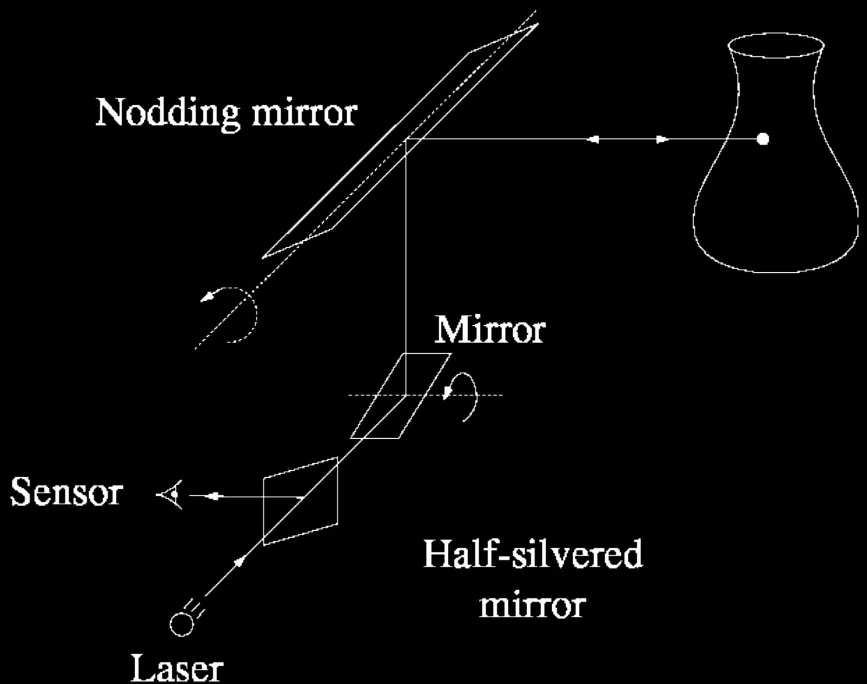
- Find feature in one image, search along epipolar line in other image for correspondence



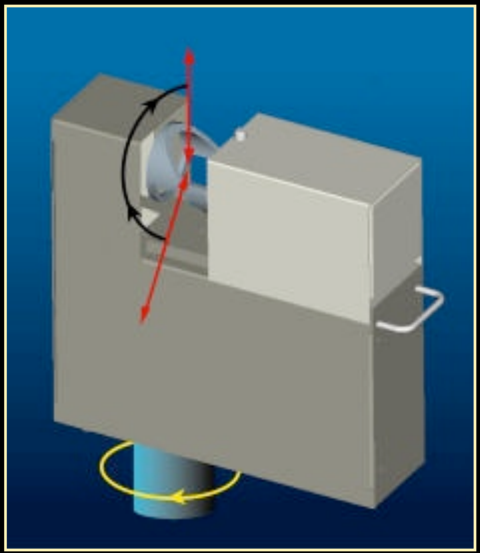
# Pulsed Time of Flight (TOF)

- Basic idea: send out pulse of light (usually laser), time how long it takes to return

$$d = \frac{1}{2} c \Delta t$$





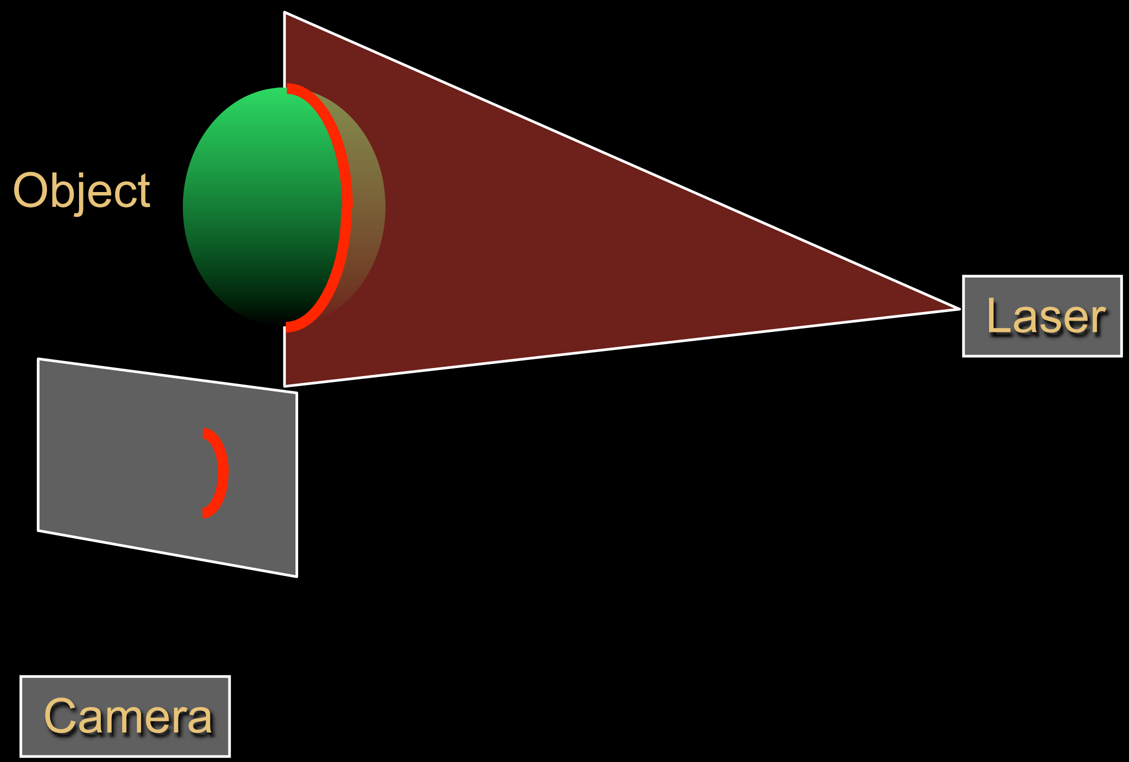


# Pulsed Time of Flight (TOF)

- Advantages:
  - Large working volume (up to 100 m.)
- Disadvantages:
  - Not-so-great accuracy (at best ~5 mm.)
    - Requires getting timing to ~30 picoseconds
    - Does not scale with working volume
- Often used for scanning buildings, rooms, archeological sites, etc.

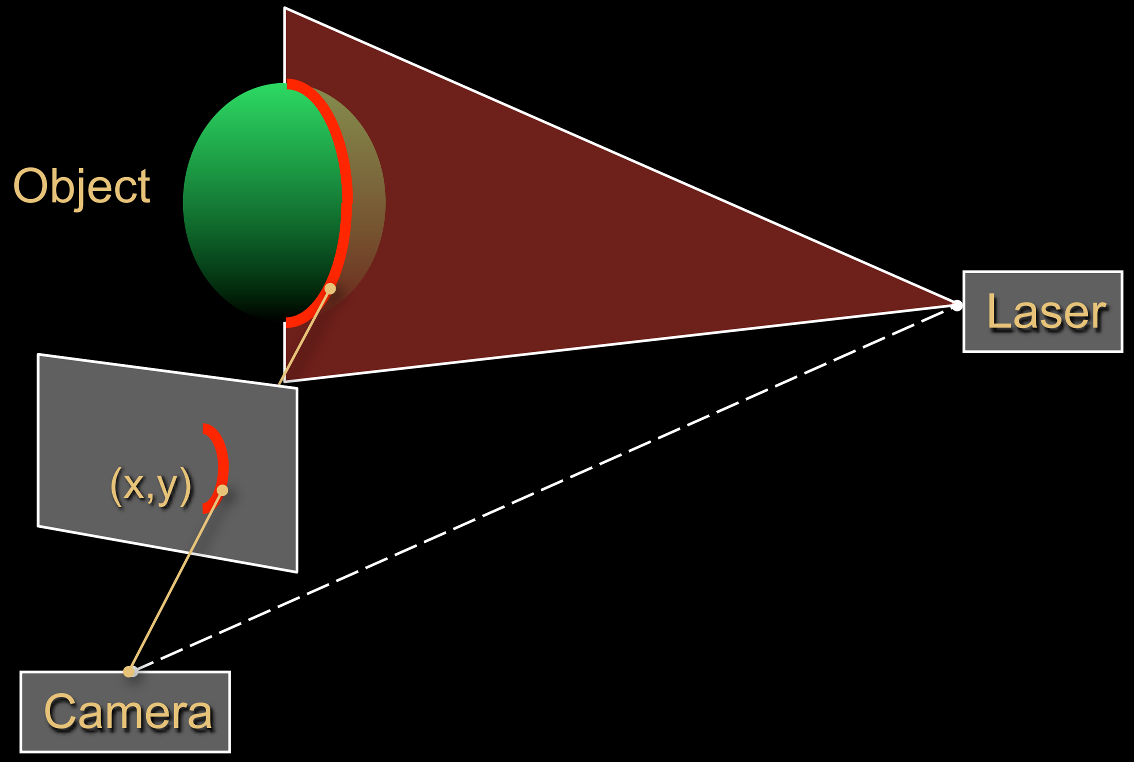
- Improved TOF: phase encoding (outside scope)

# Triangulation




- Project laser stripe onto object

# Triangulation

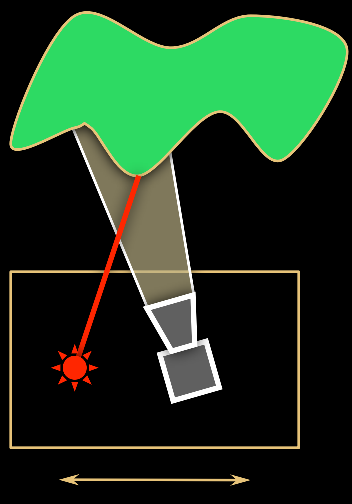


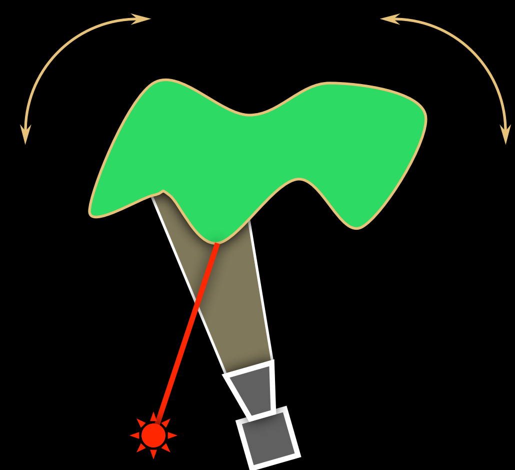

- Depth from ray-plane triangulation

# Triangulation: Moving the Camera and Illumination

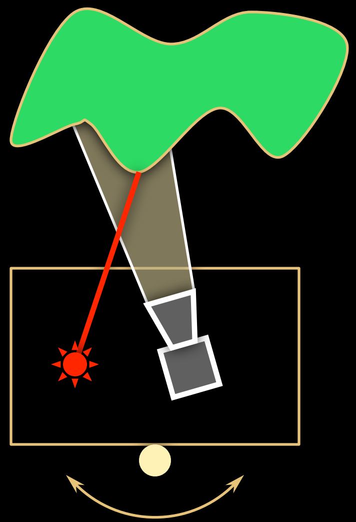
- Moving independently leads to problems with focus, resolution
- Most scanners mount camera and light source rigidly, move them as a unit

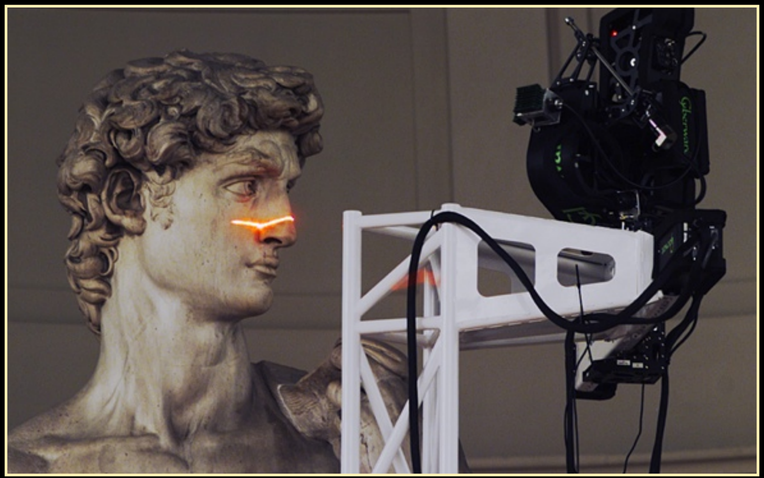
# Triangulation: Moving the Camera and Illumination

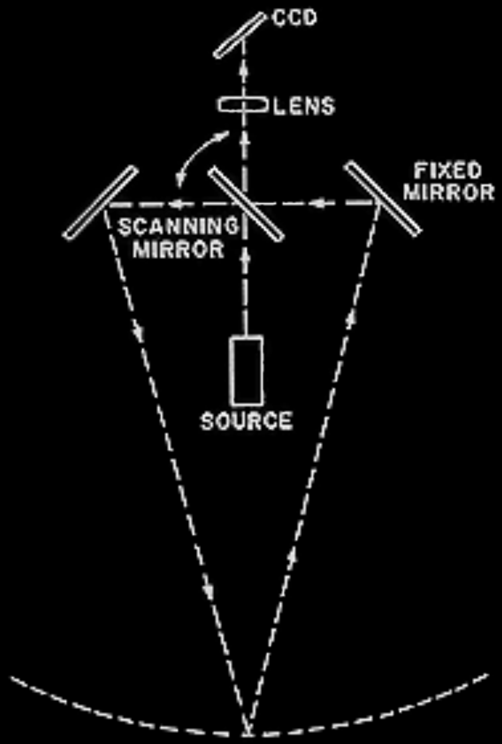





# Triangulation: Moving the Camera and Illumination







# Structured Light Scanning

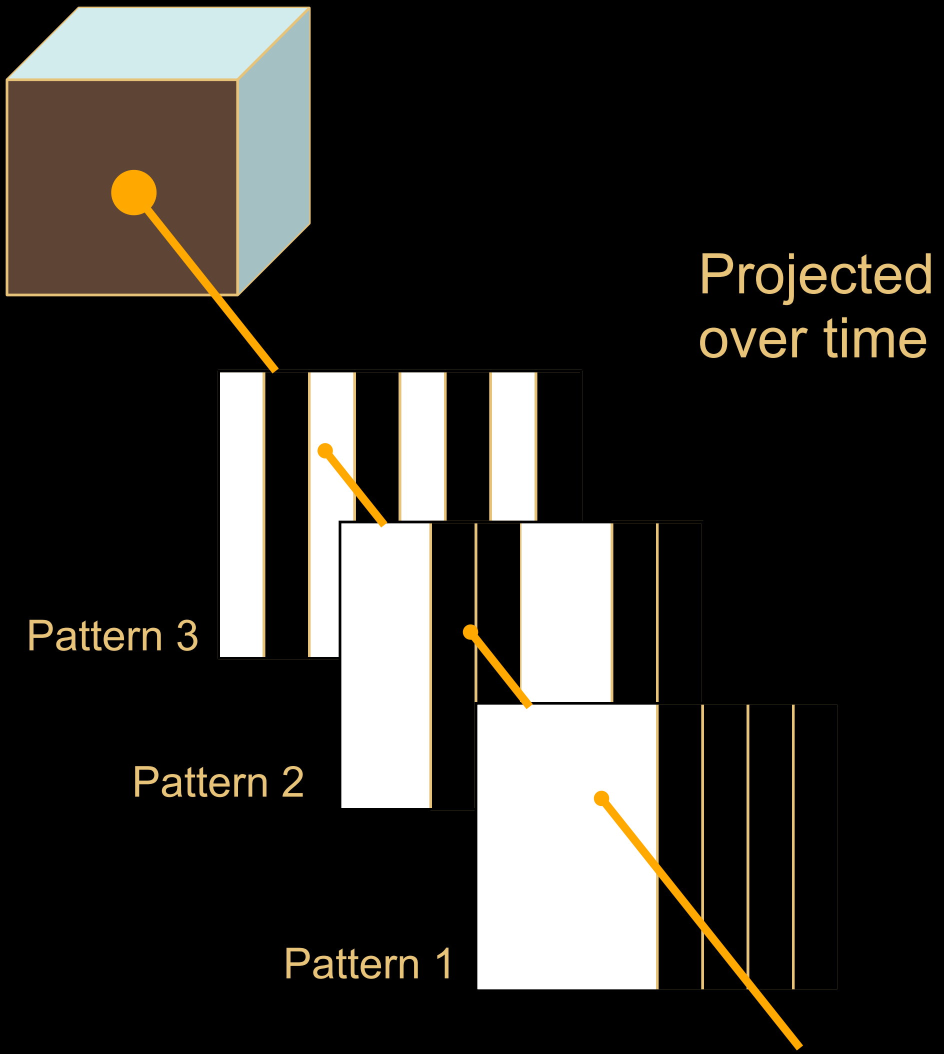
- Laser scans one surface slices at the time
- Can we project multiple stripes simultaneously?

- Correspondence problem: which stripe is which?
- Common types of patterns:
  - Binary coded light striping
  - Gray/color coded light striping

# Binary Coding

Faster:

stripes in images.

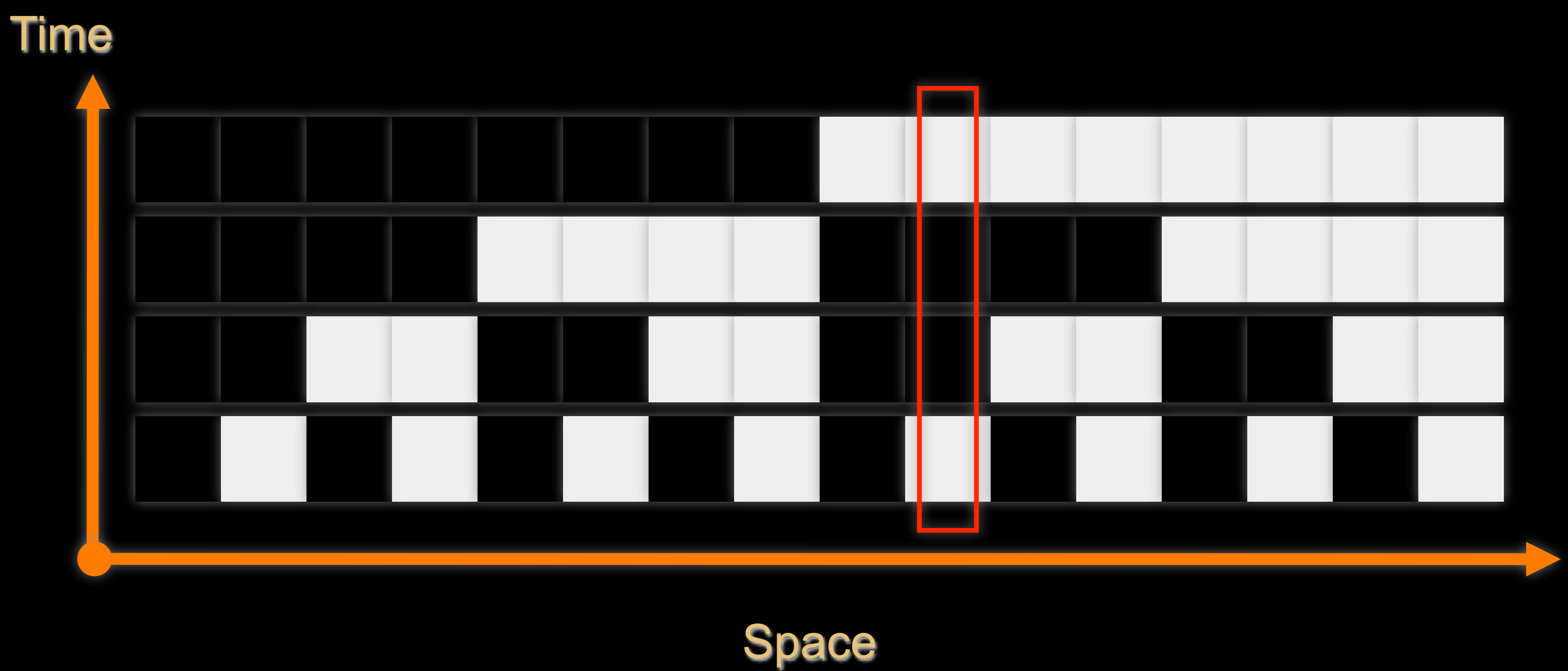



Example:

3 binary-encoded patterns which allows the measuring surface to be divided in 8 sub-regions

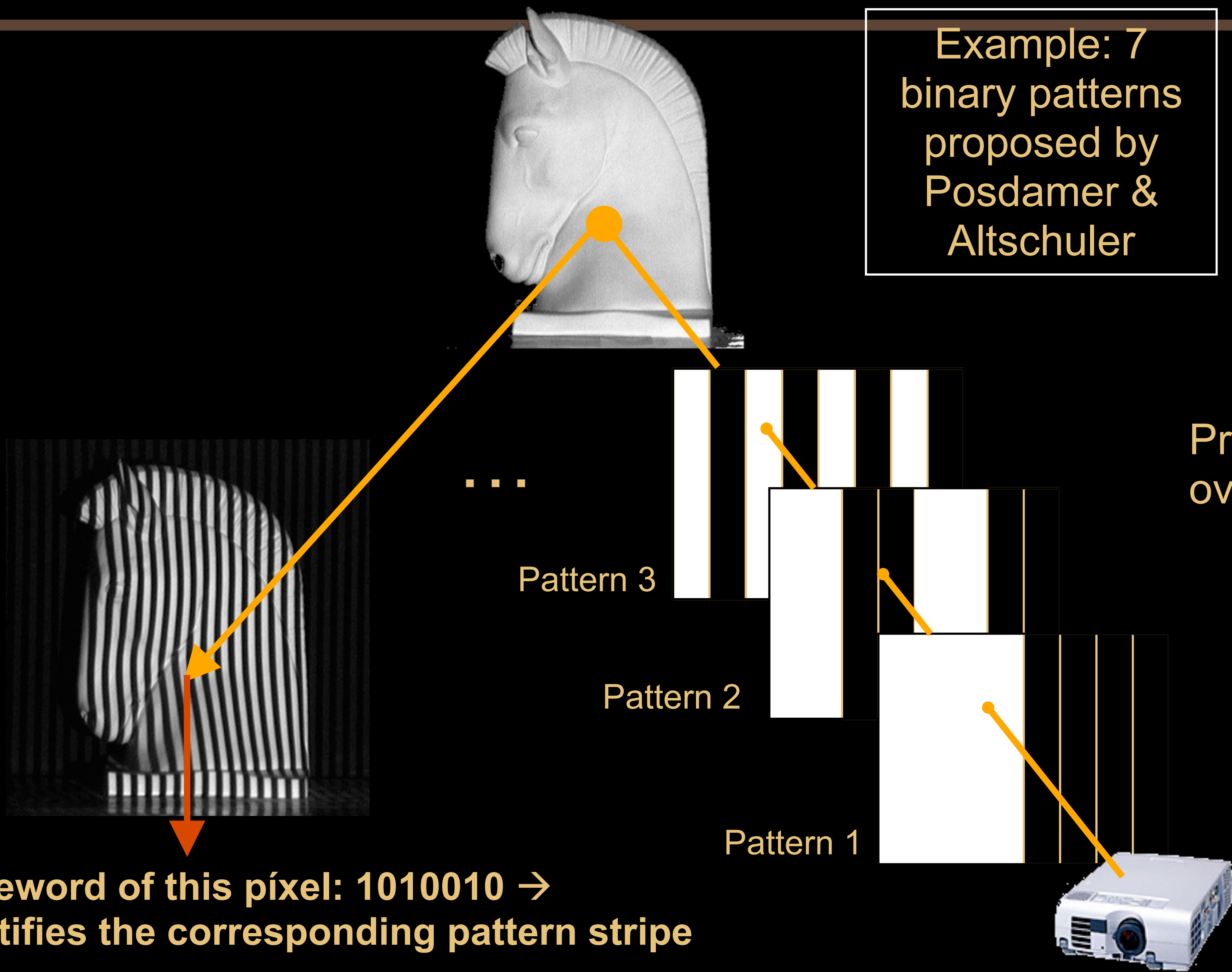
# Binary Coding

- Assign each stripe a unique illumination code over time [Posdamer 82]



# Binary Coding

Example: 7 binary patterns proposed by Posdamer & Altschuler

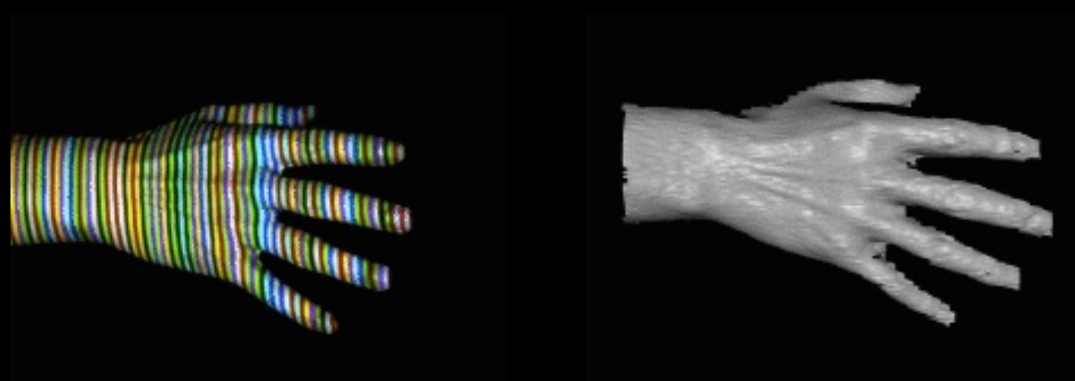



Projected over time

**Codeword of this píxel: 1010010 → identifies the corresponding pattern stripe**

# More Complex Patterns

Works despite complex appearances

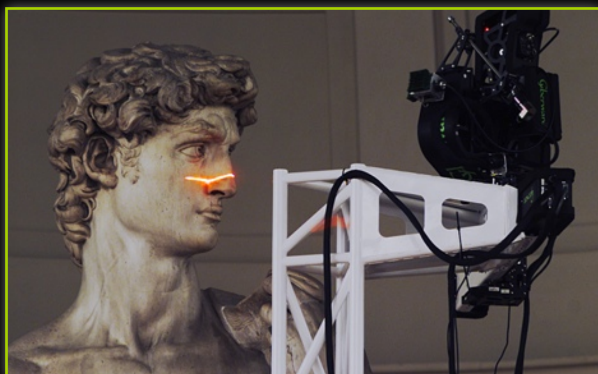


Works in real-time and on dynamic scenes

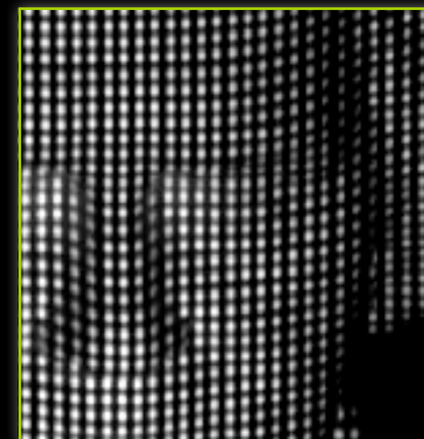
Need very few images (one or two).
But needs a more complex correspondence algorithm

Zhang et al

# Continuum of Triangulation Methods



Multi-stripe
Multi-frame



Single-stripe

Single-frame

Slow, robust

Fast, fragile

# Artefacts in Optical 3D Scanning

- Dark surface material
  - low signal-to-noise ratio (SNR) in reflection
- Specular surfaces
  - May not diffusely reflect light to camera
  - Inter-reflection: stripes are seen at virtual position
  - Spurious reflection of laser's or projector's lens scatter
- Stripe decoding errors
  - Codes are designed to be robust (e.g. Gray code)
  - But: low SNR may "flip" too many bits

# Types of Reconstruction Artefacts

- Noise
  - due to low SNR
- Outliers
  - due to low SNR
  - due to spurious inter-reflection (-> ambiguities)
- Holes
  - due to shadowing of projector
  - due to occlusion of camera
  - points filtered out where SNR is too low