Computer Vision

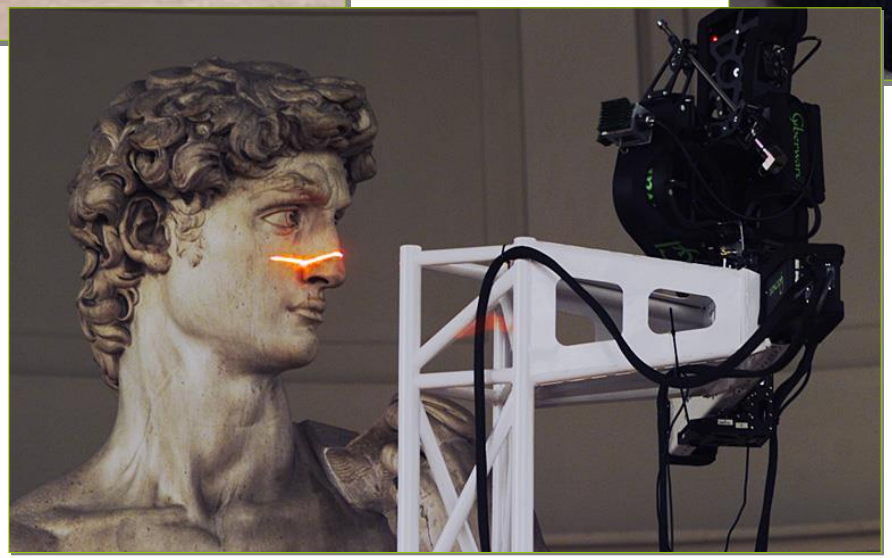
Fall 2019 16720

Instructor: Matthew O’Toole (Guest Lecturer)

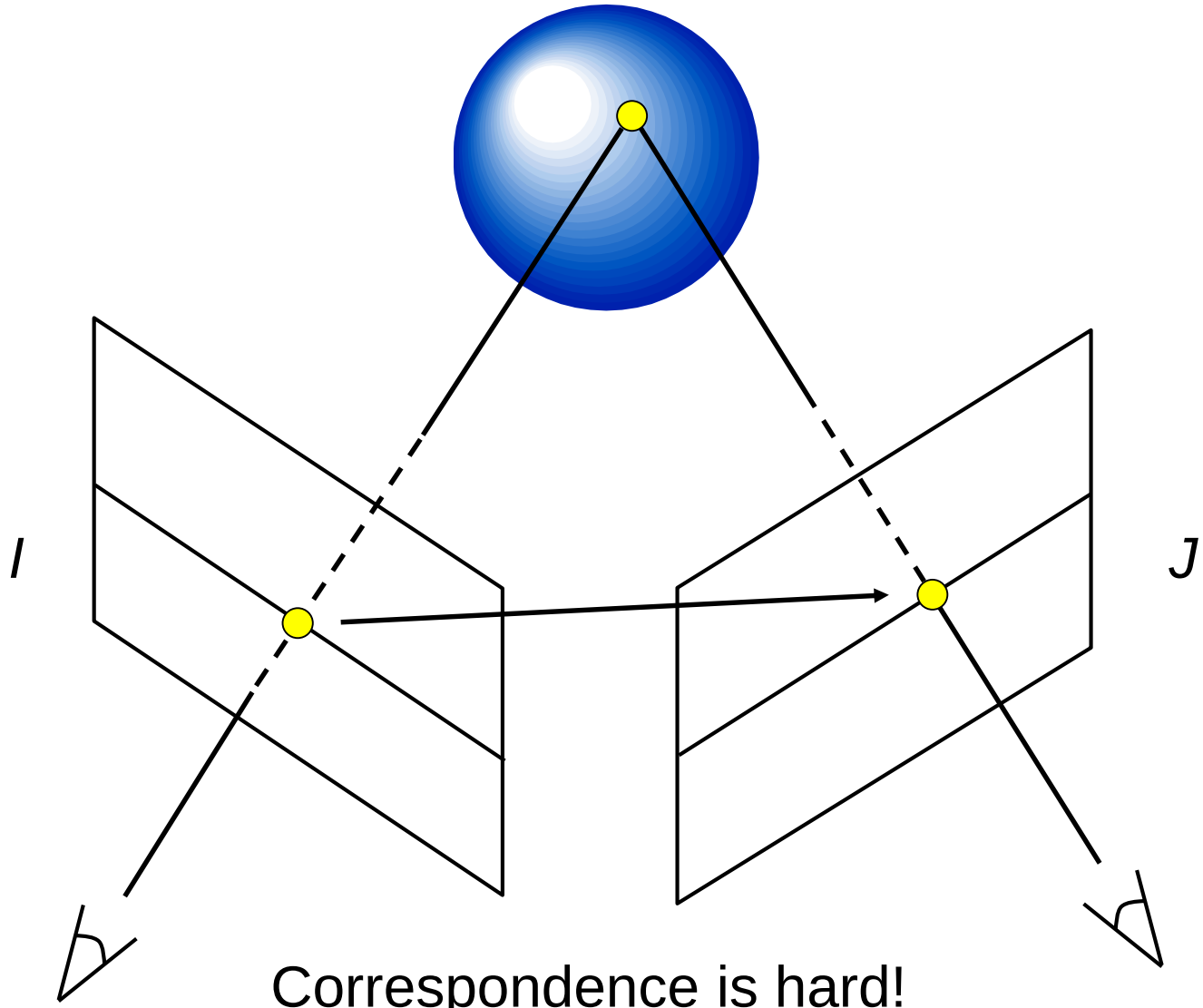
Structured Light + Range Imaging

(Thanks to Content from Levoy, Rusinkiewicz, Bouguet, Perona, Hendrik Lensch)

3D Scanning

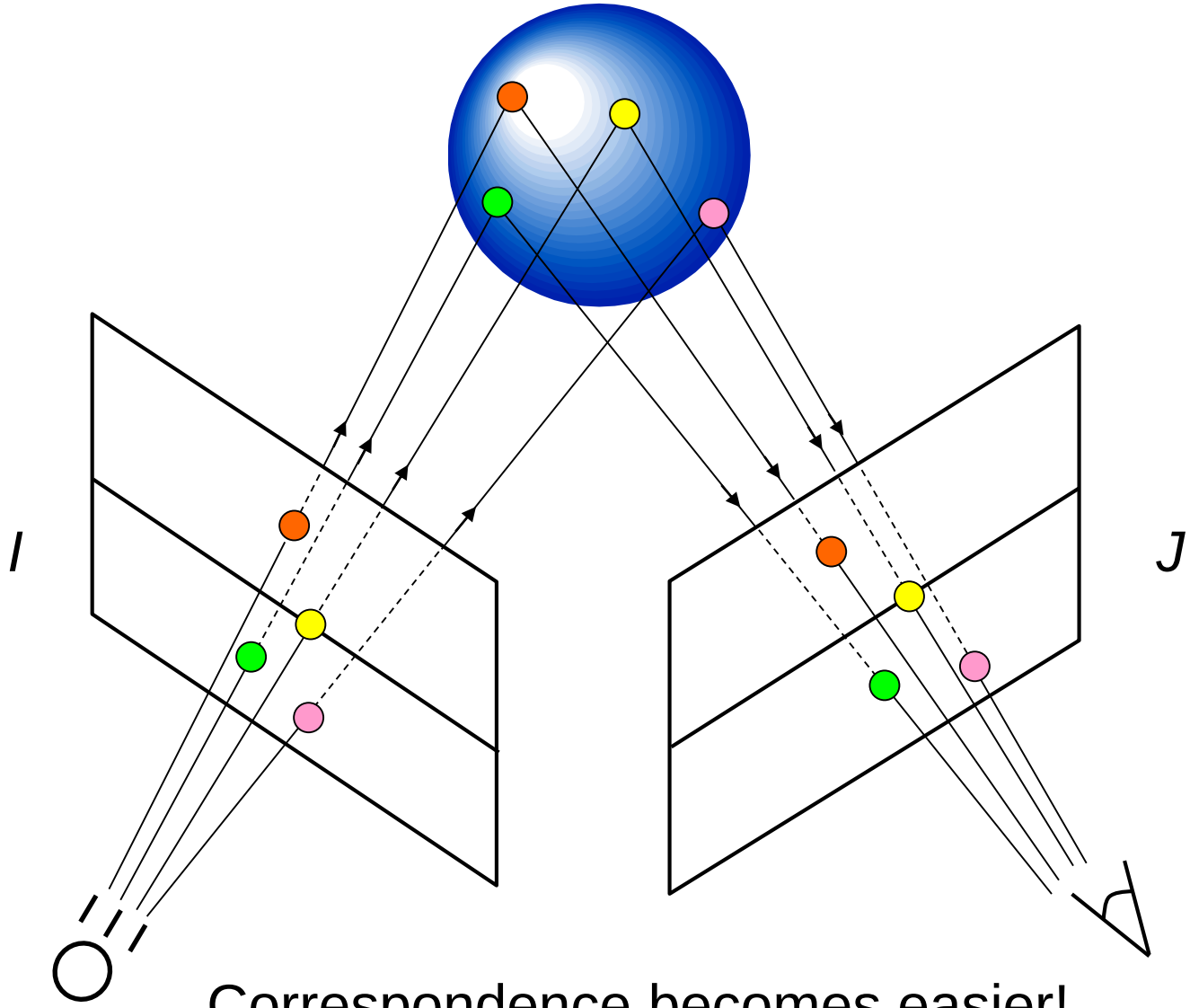


Stereo Triangulation



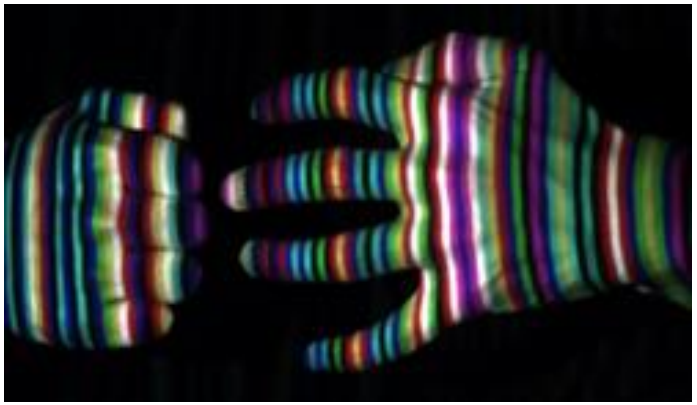
Correspondence is hard!

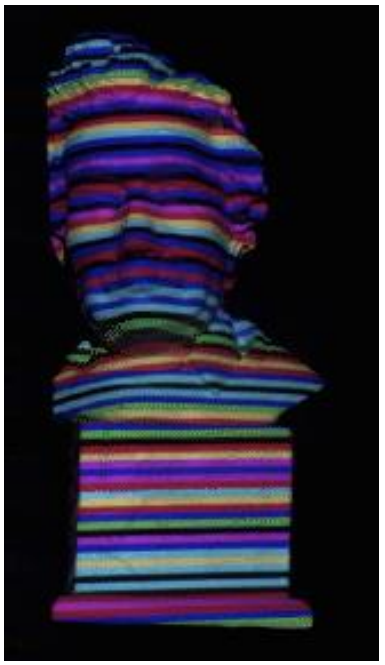
Structured Light Triangulation



Correspondence becomes easier!

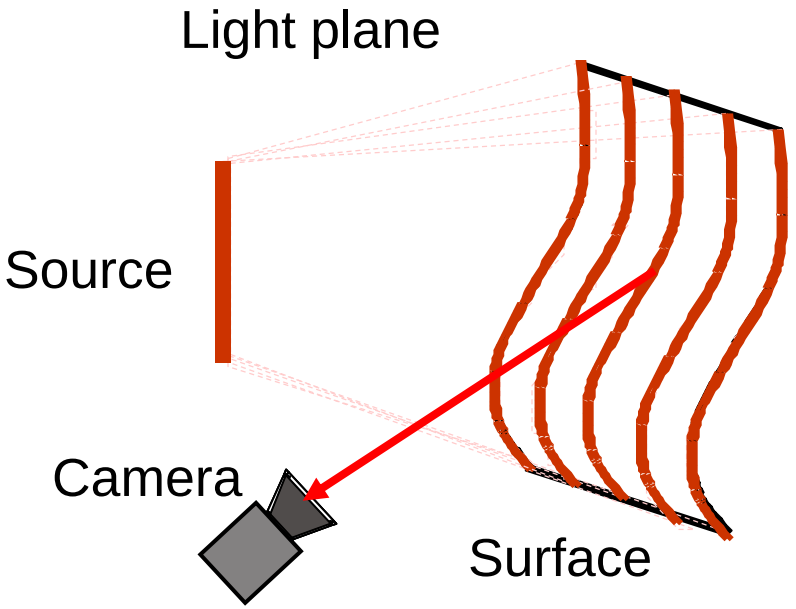
Structured Light





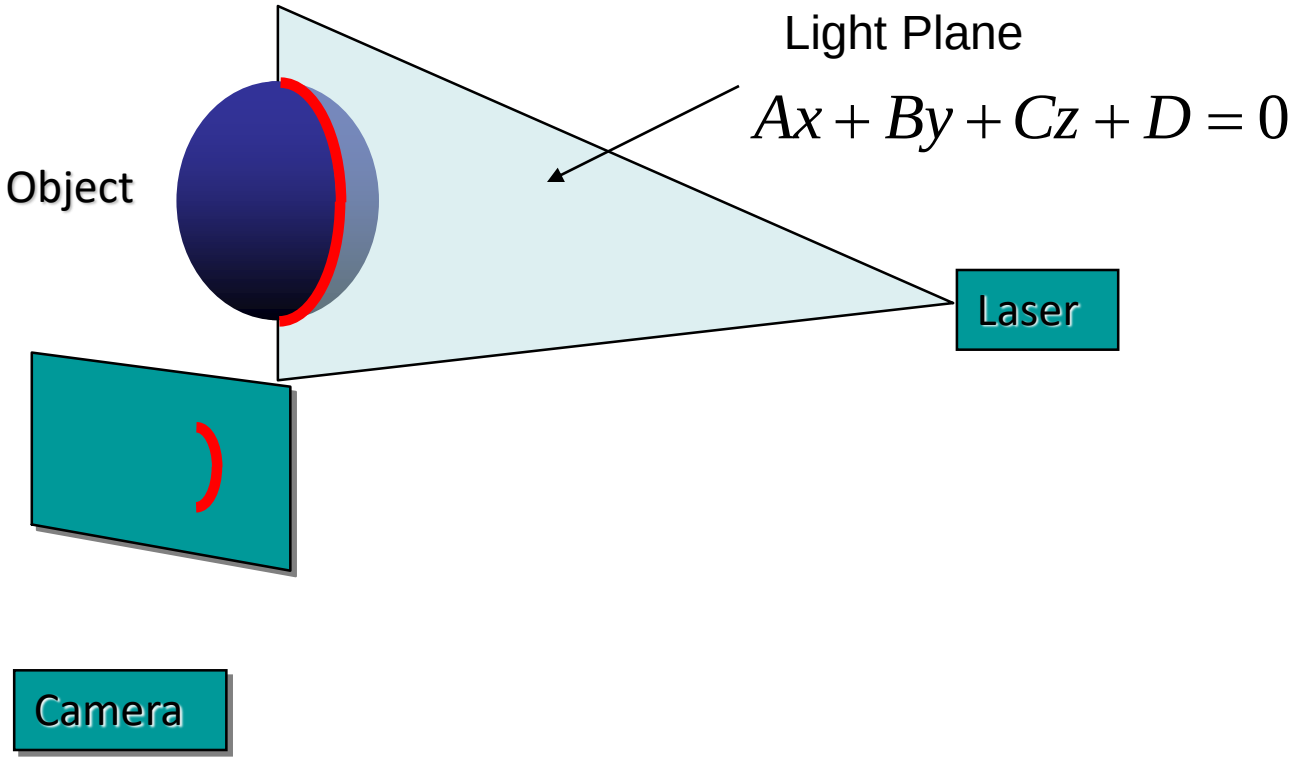
- Any spatio-temporal pattern of light projected on a surface (or volume).
- Cleverly illuminate the scene to extract scene properties (eg., 3D).
- Avoids problems of 3D estimation in scenes with complex texture/BRDFs.
- Very popular in vision and successful in industrial applications (parts assembly, inspection, etc).

Light Stripe Scanning – Single Stripe



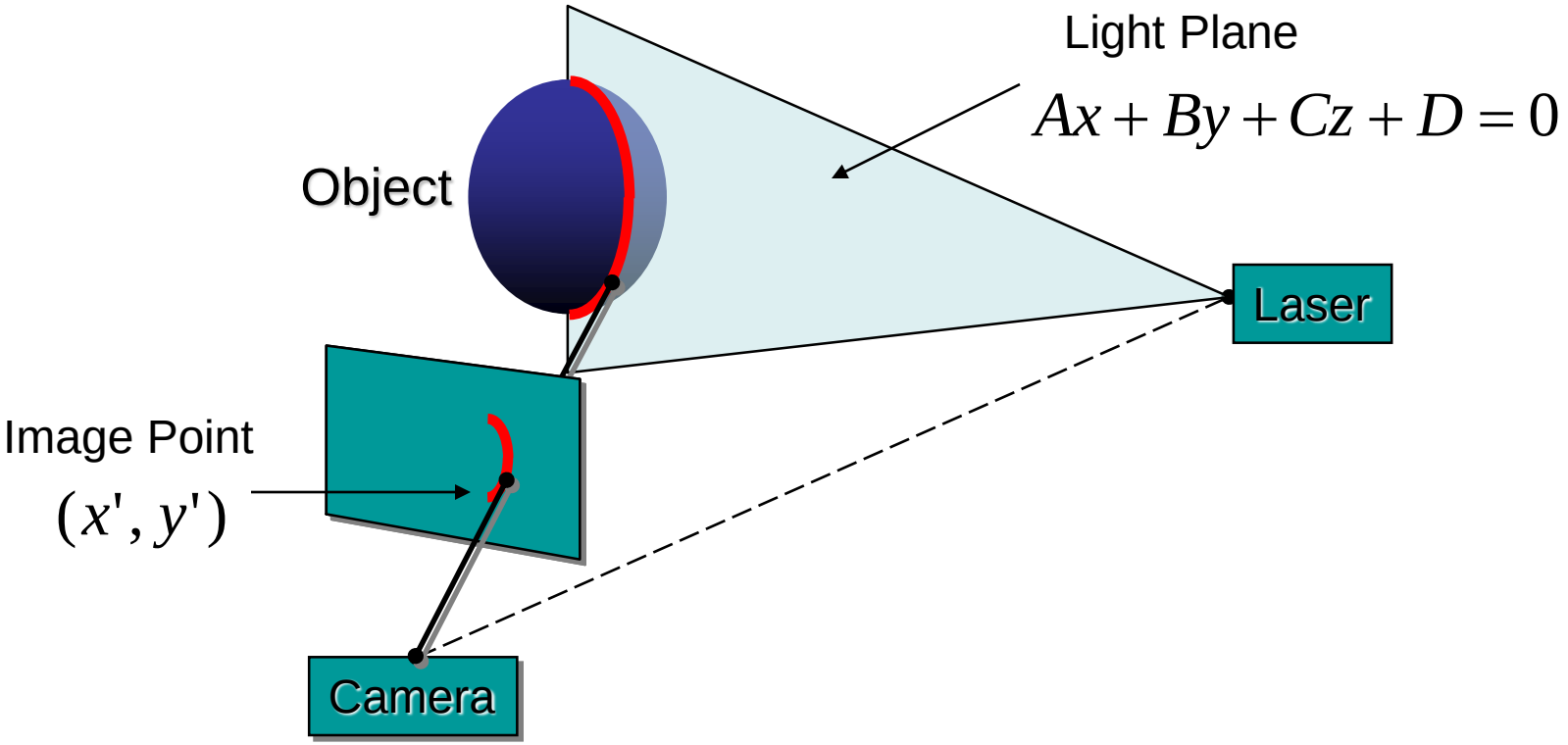
- Optical triangulation
  - Project a single stripe of laser light
  - Scan it across the surface of the object
  - This is a very precise version of structured light scanning
  - Good for high resolution 3D, but needs many images and takes time

Triangulation



- Project laser stripe onto object

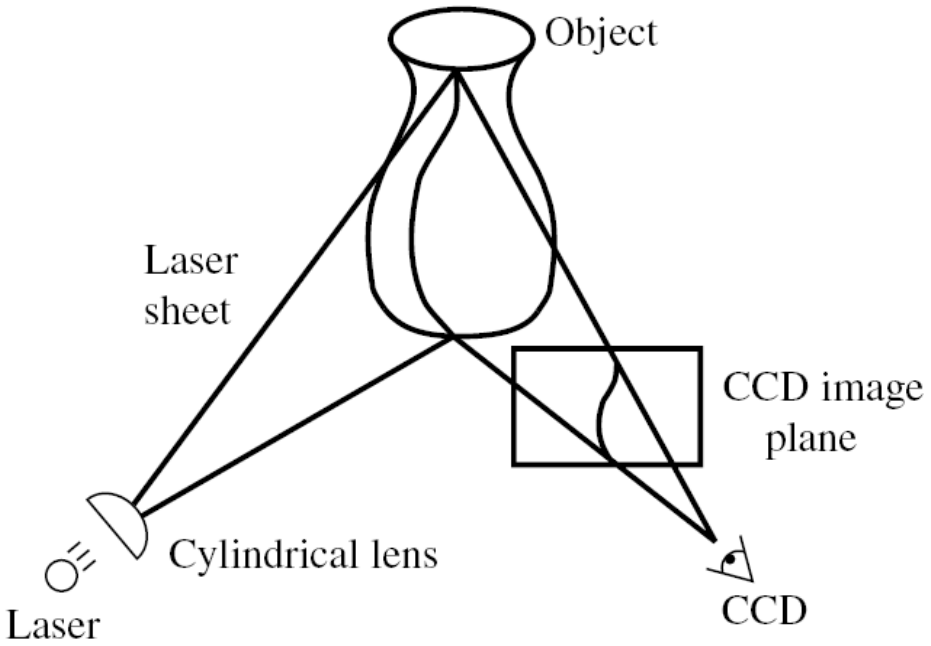
Triangulation



- Depth from ray-plane triangulation:
  - Intersect camera ray with light plane

$$x = x'z / f \qquad y = y'z / f \qquad z = \frac{-Df}{Ax' + By' + Cf}$$

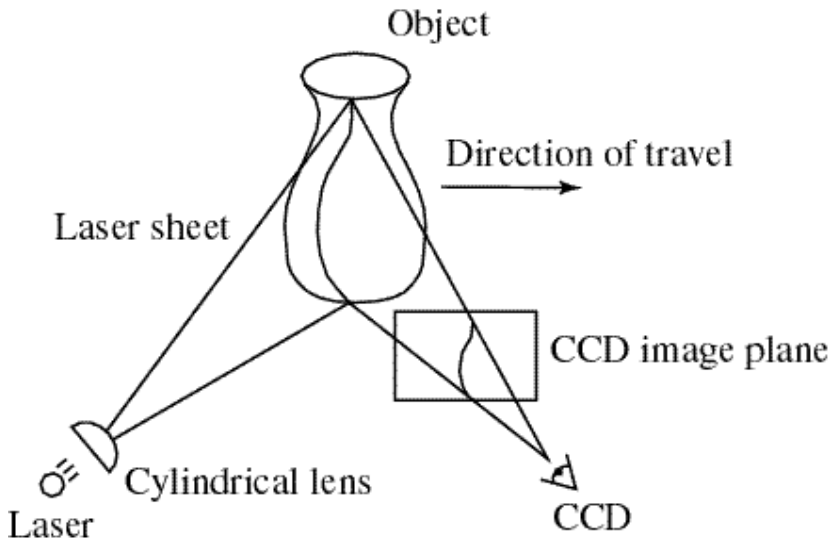
Example: Laser scanner

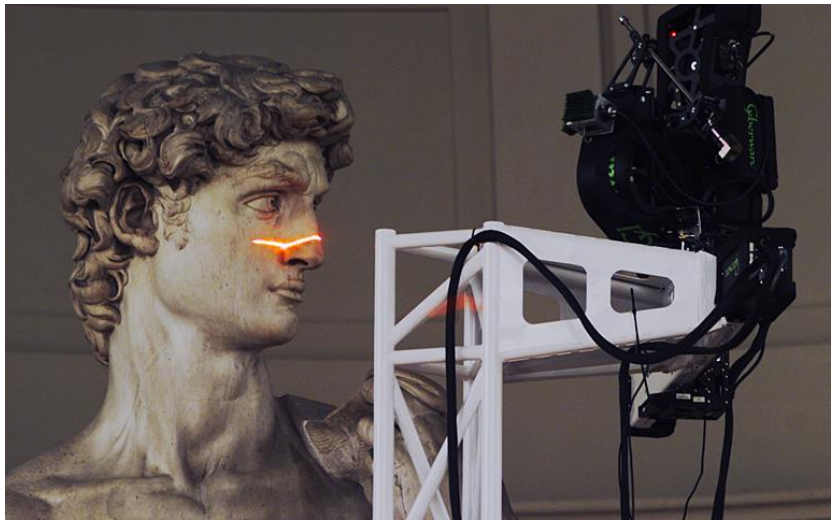


Cyberware® face and head scanner

+ very accurate < 0.01 mm
− more than 10sec per scan

Example: Laser scanner



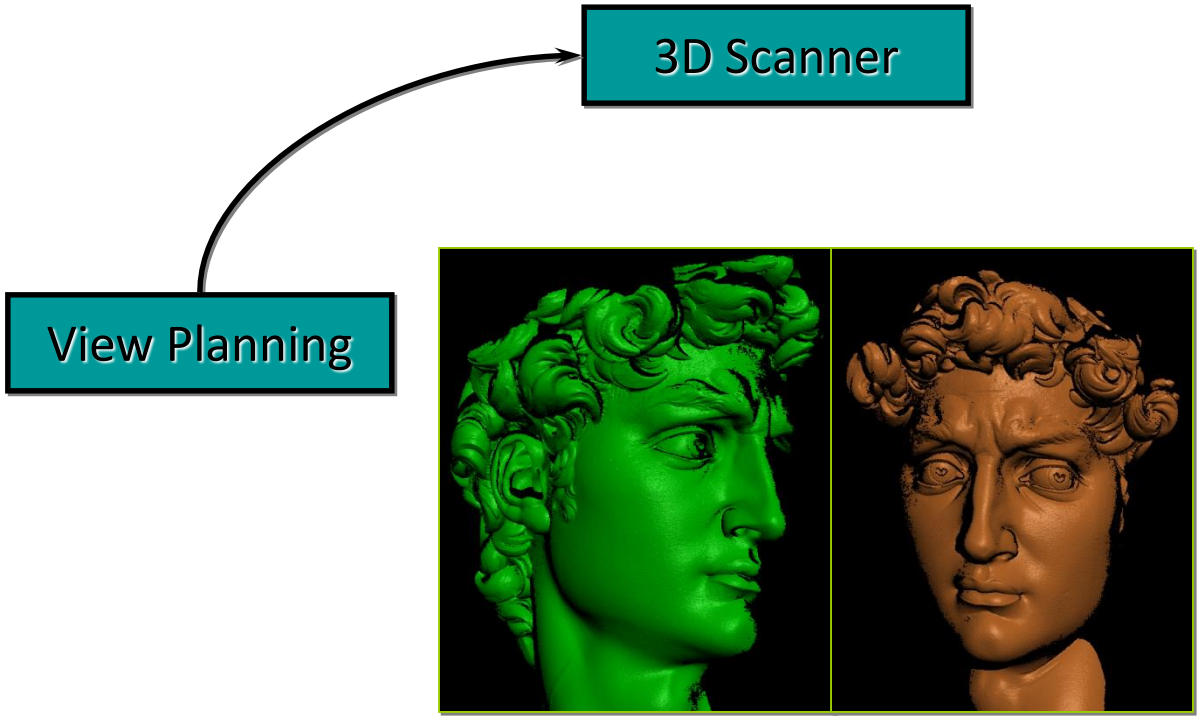


Digital Michelangelo Project
http://graphics.stanford.edu/projects/mich/

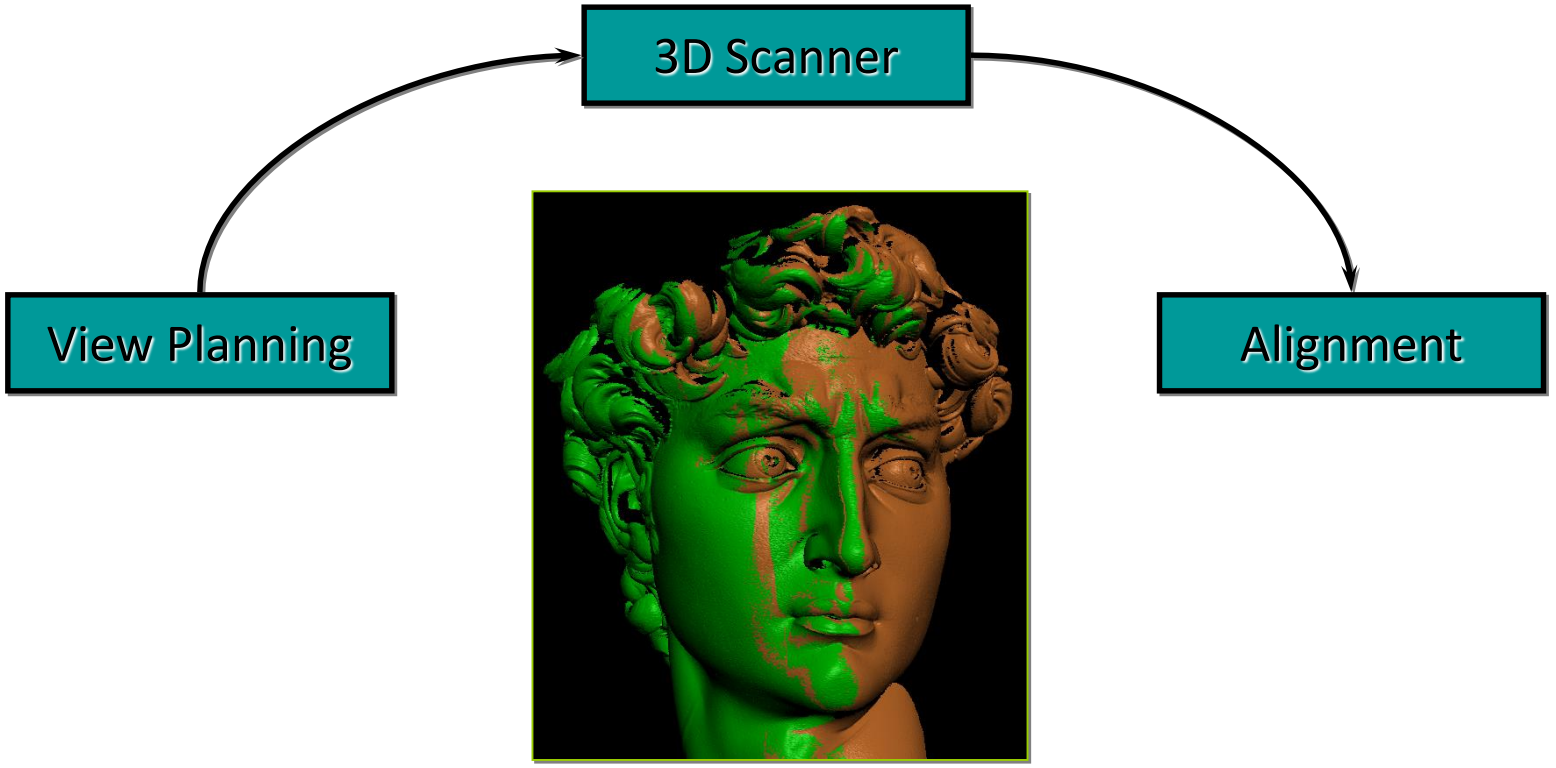
3D Model Acquisition Pipeline

3D Scanner

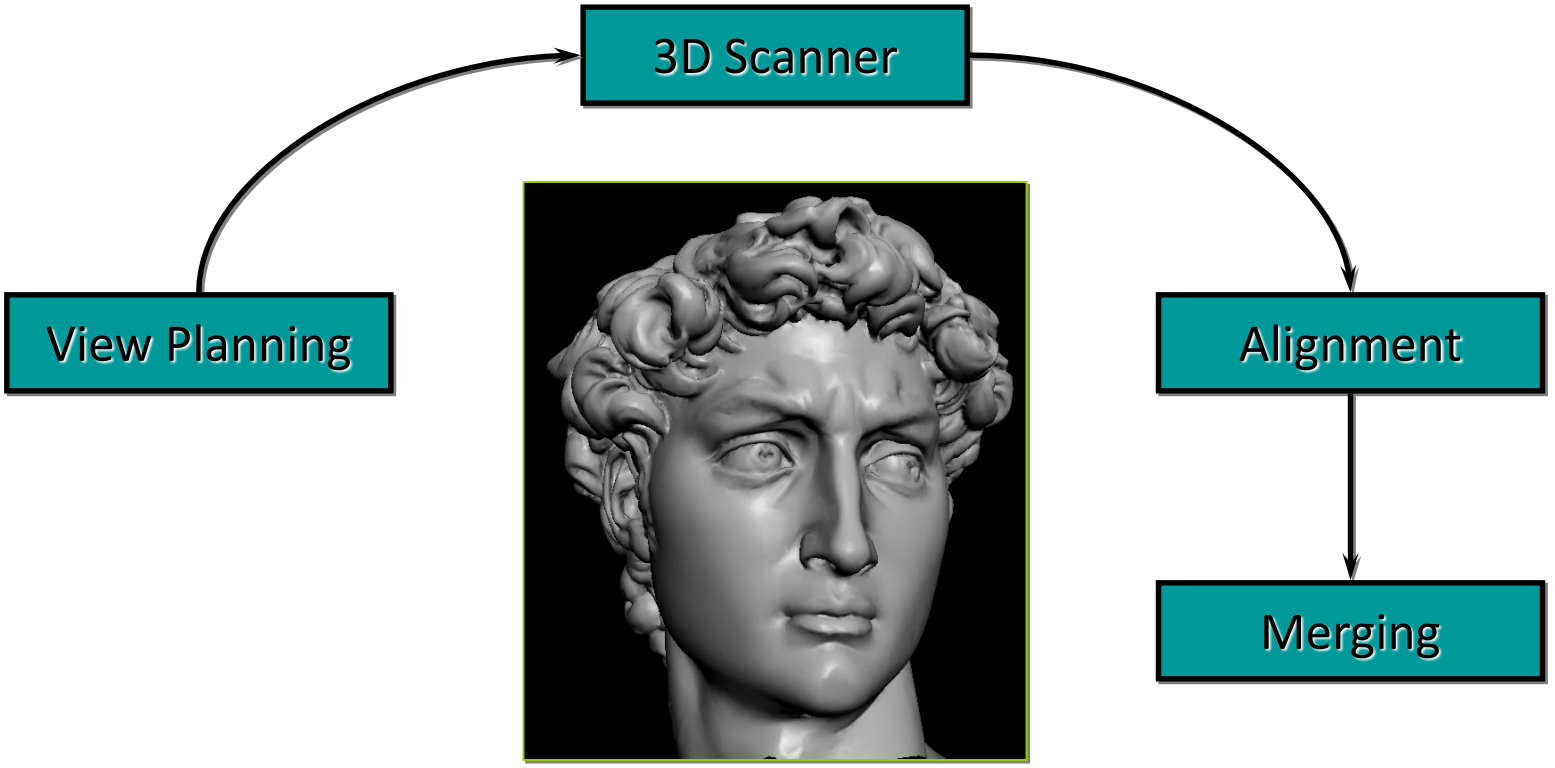
3D Model Acquisition Pipeline



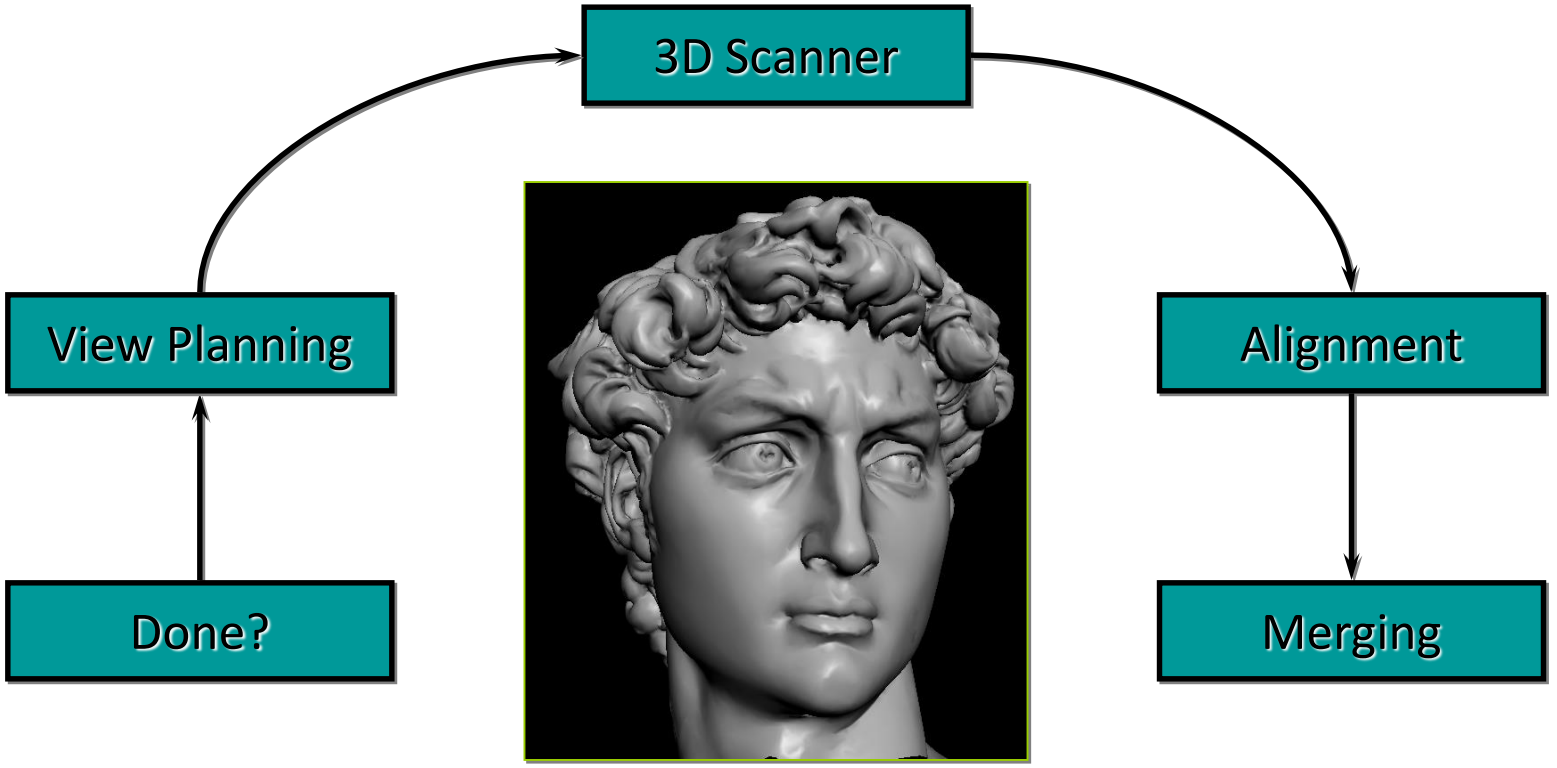
3D Model Acquisition Pipeline



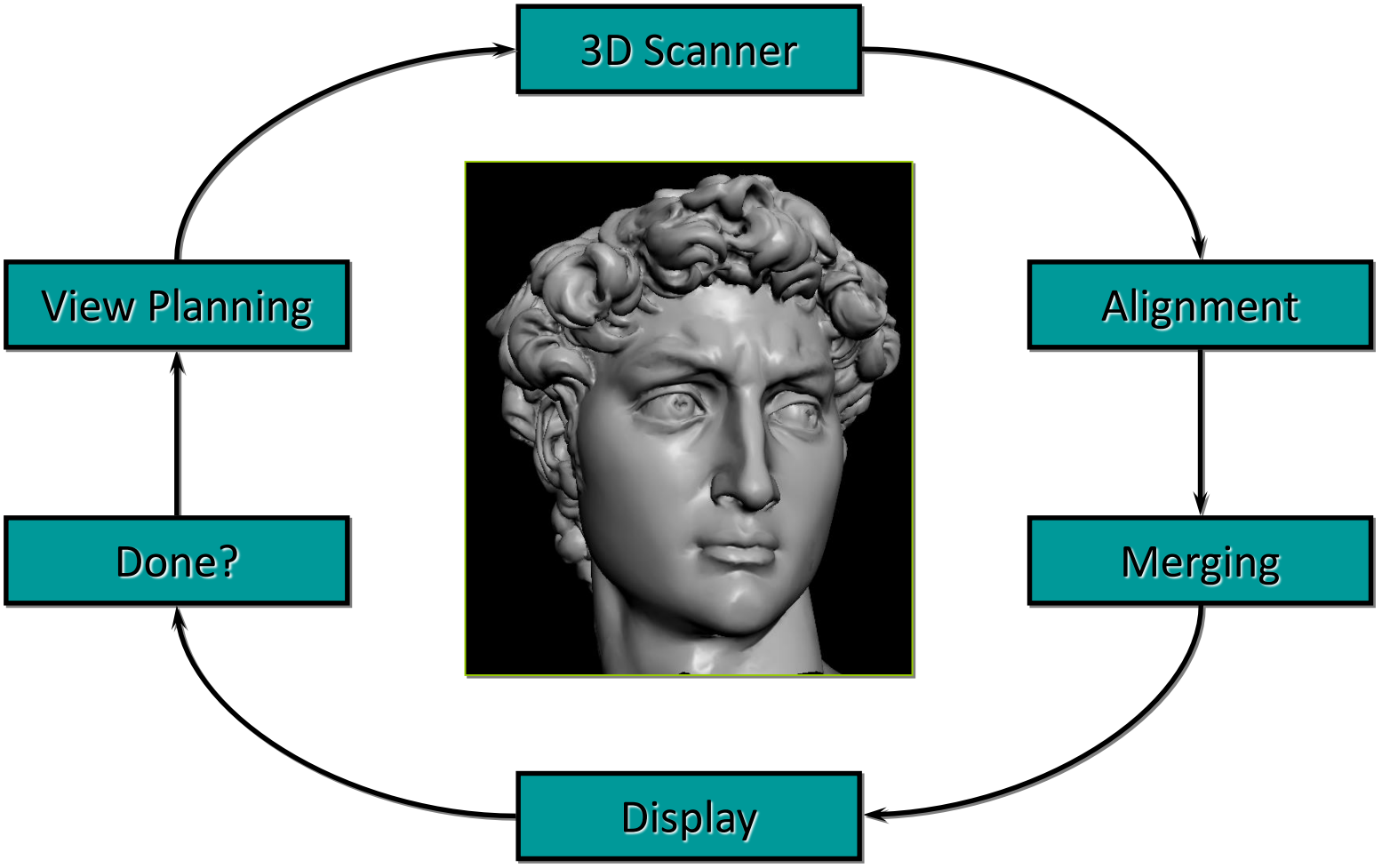
3D Model Acquisition Pipeline



3D Model Acquisition Pipeline

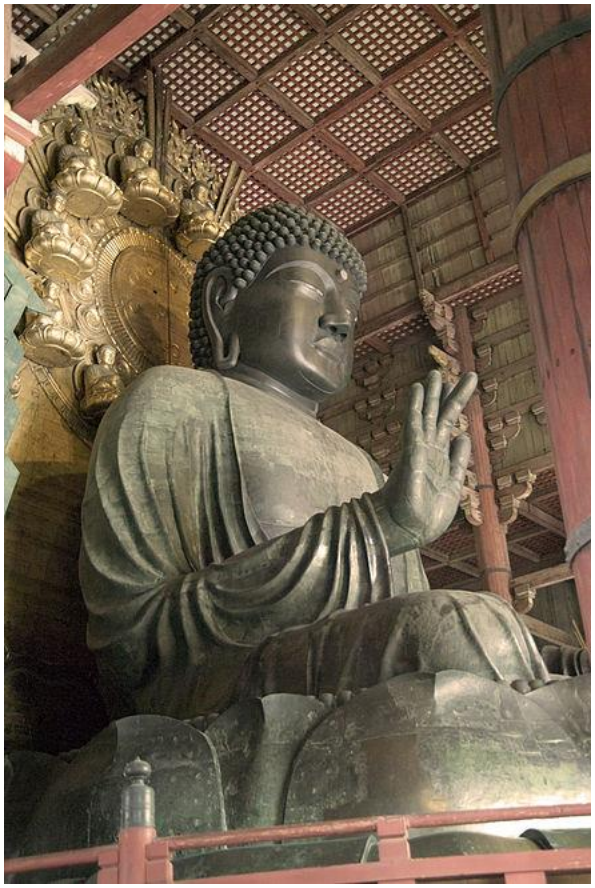


3D Model Acquisition Pipeline



http://graphics.stanford.edu/projects/mich/

Great Buddha of Nara

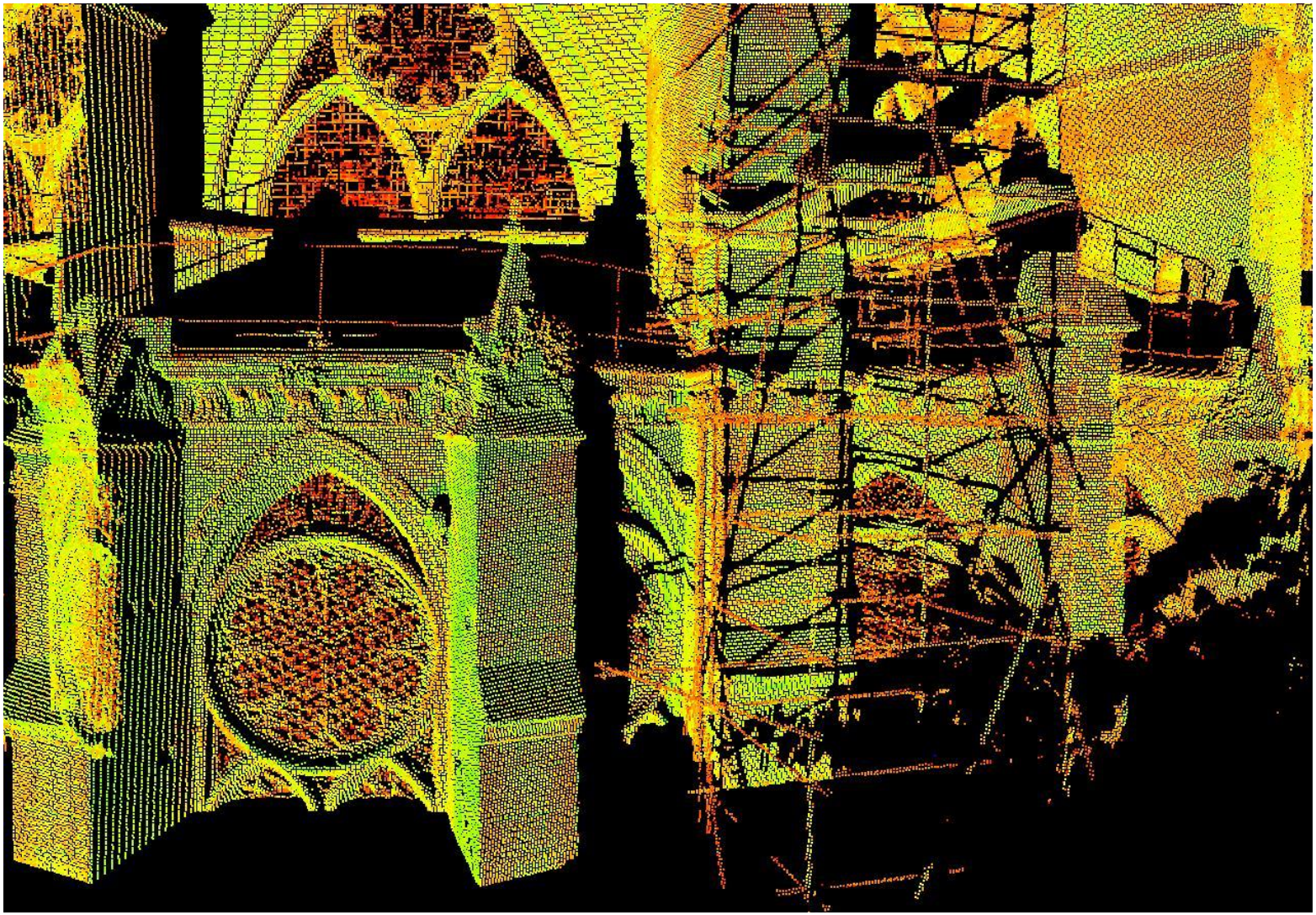


http://www.cvl.iis.u-tokyo.ac.jp/gallery_e/nara-hp/nara.html

Scanning and Modeling the Cathedral of Saint Pierre, Beauvais, France

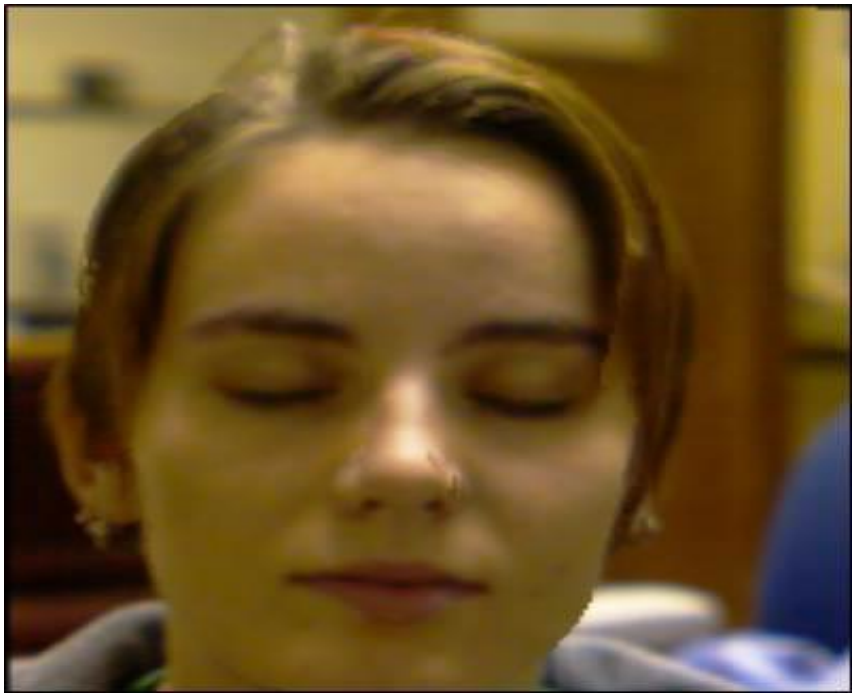
http://www1.cs.columbia.edu/~allen/BEAUVAIS/

Scanning and Modeling the Cathedral of Saint Pierre, Beauvais, France



http://www1.cs.columbia.edu/~allen/BEAUVAIS/

Portable 3D laser scanner (this one by Minolta)



Faster Acquisition?

- Project multiple stripes simultaneously
- Correspondence problem: which stripe is which?

- Common types of patterns:
    - Binary coded light striping
    - Gray/color coded light striping

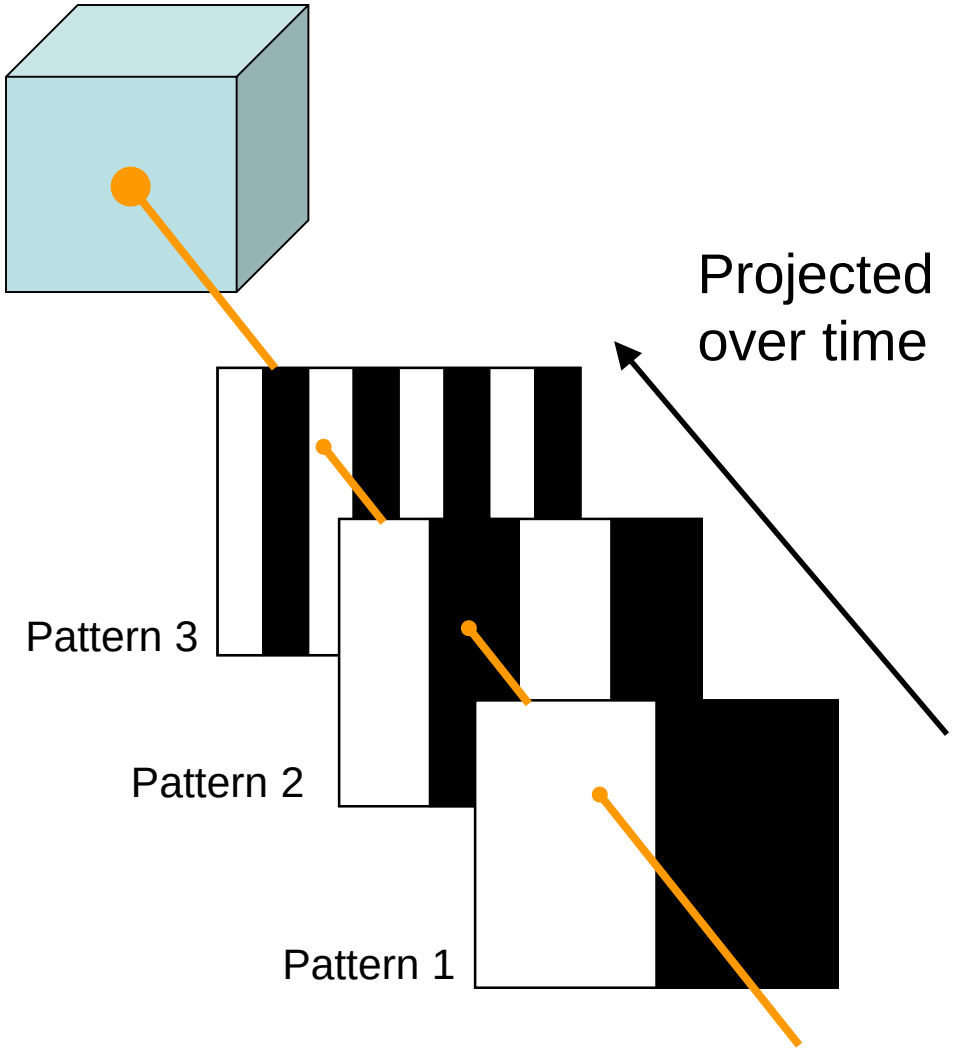
Binary Coding

Faster:

$2^n - 1$ stripes in n images.

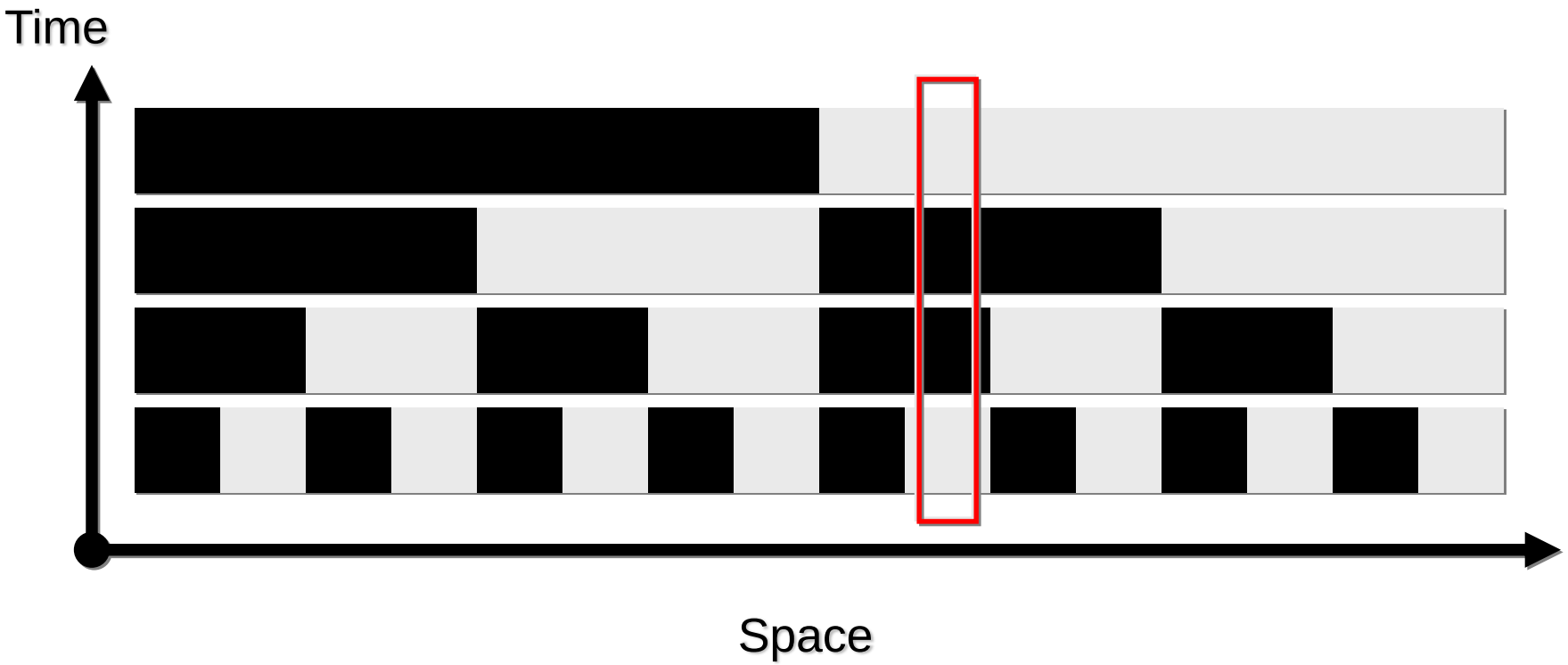
Example:

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

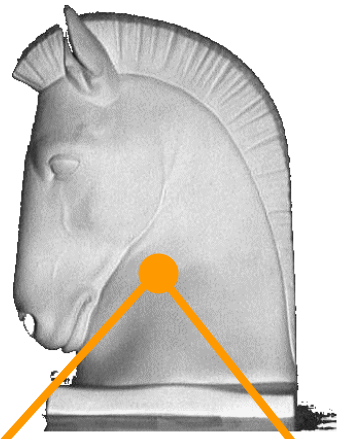


Binary Coding

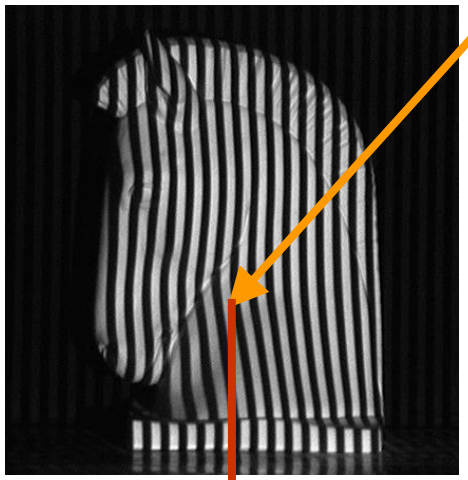
- Assign each stripe a unique illumination code over time [Posdamer 82]



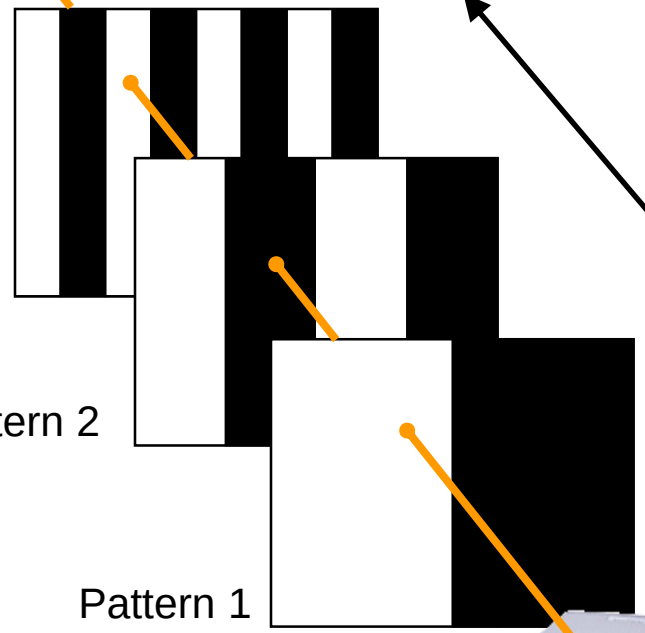
Binary Coding



Example: 7 binary patterns proposed by Posdamer & Altschuler



. . .

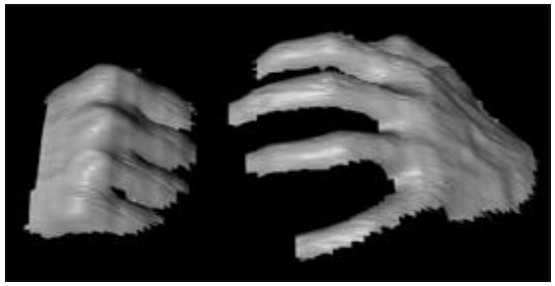


Projected over time

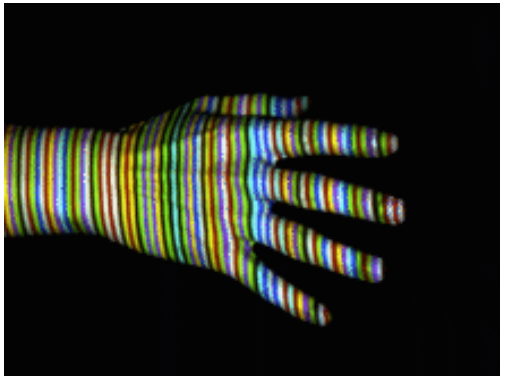
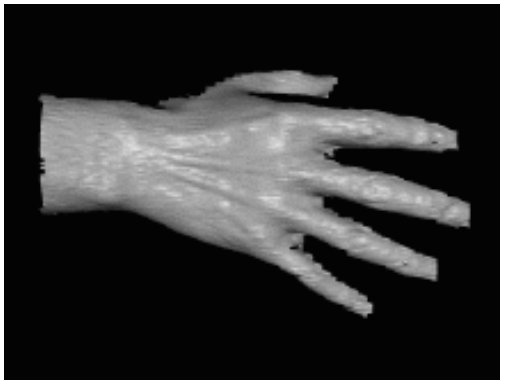
Codeword of this píxel: 1010010 → identifies the corresponding pattern stripe

More complex patterns





Works despite complex appearances

Works in real-time and on dynamic scenes

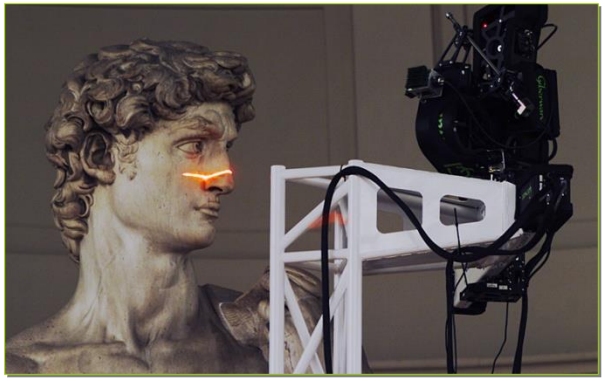
- Need very few images (one or two).
- But needs a more complex correspondence algorithm

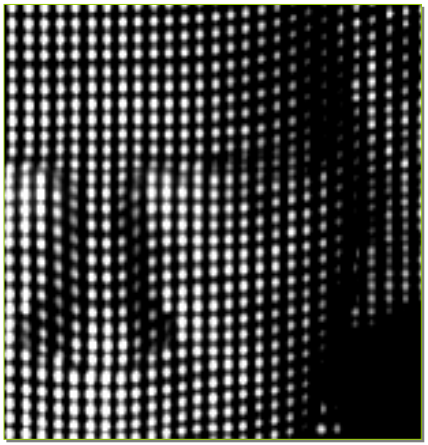
Zhang et al

Real-Time 3D Model Acquisition

http://graphics.stanford.edu/papers/rt_model/

Continuum of Triangulation Methods





Multi-stripe
Multi-frame

Single-stripe

Single-frame

Slow, robust

Fast, fragile

Microsoft Kinect

Microsoft Kinect

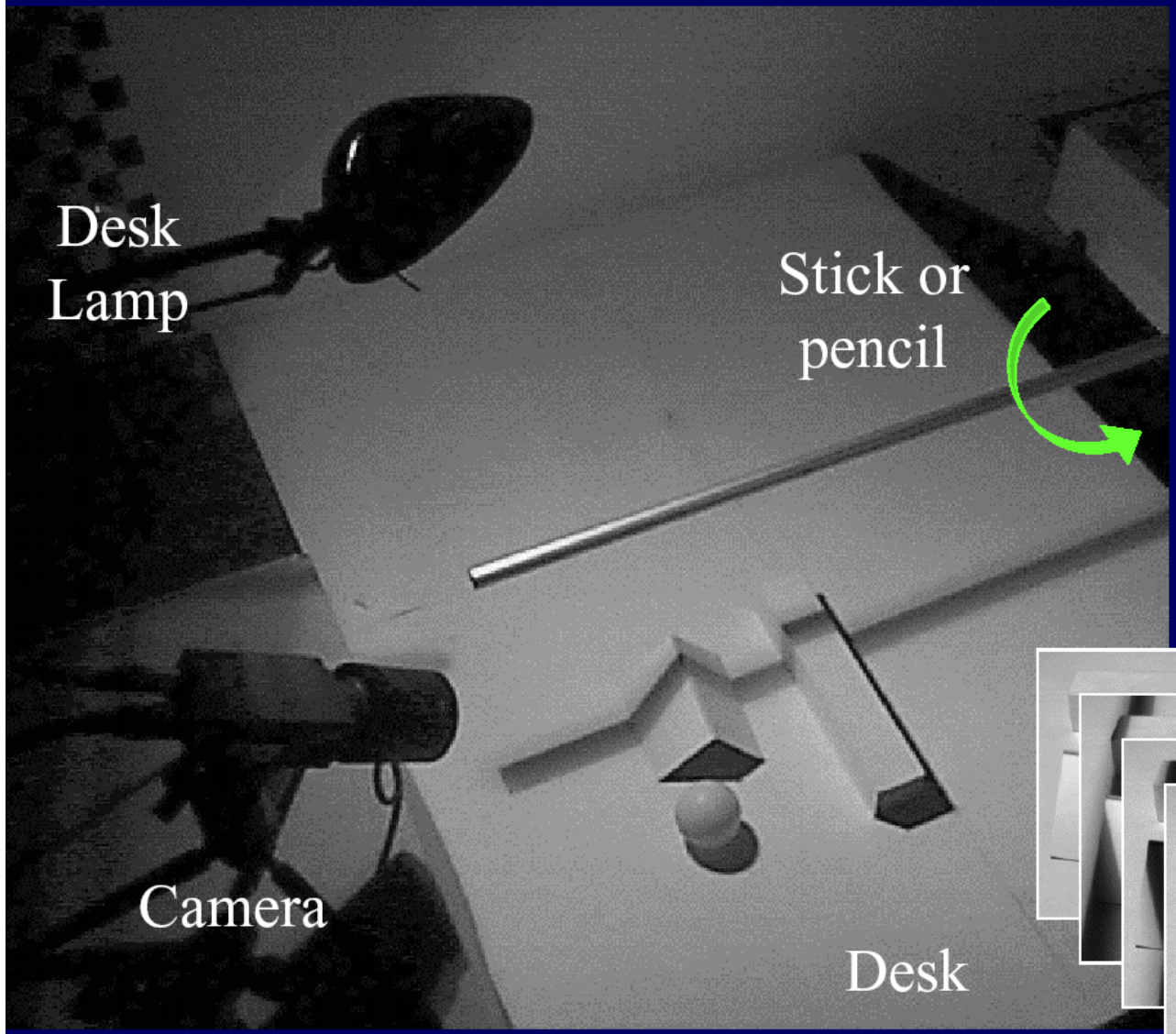
Speckled IR Pattern

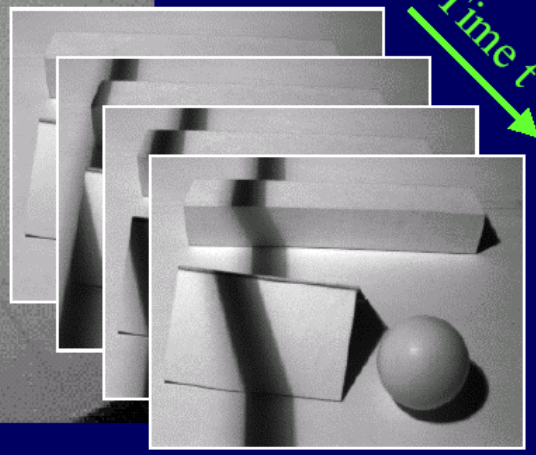
Depth map

3D Acquisition from Shadows

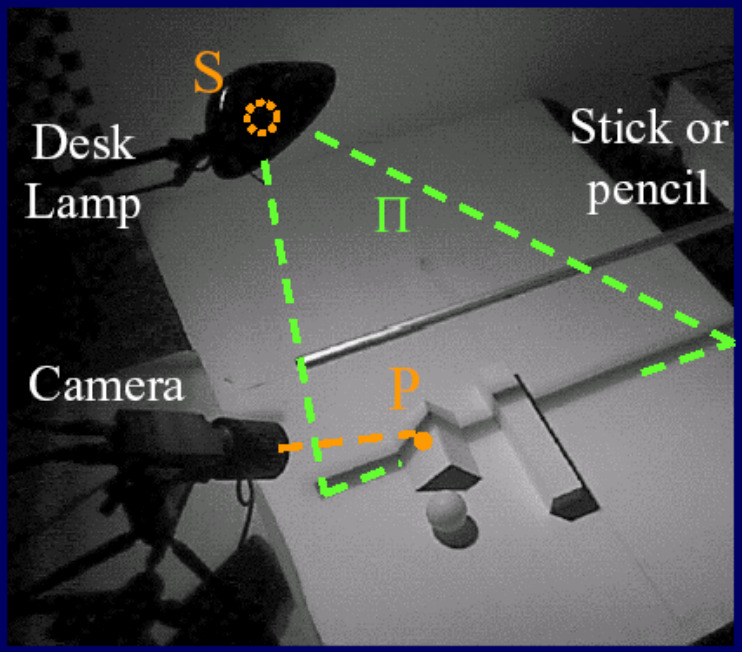
Bouguet-Perona, ICCV 98

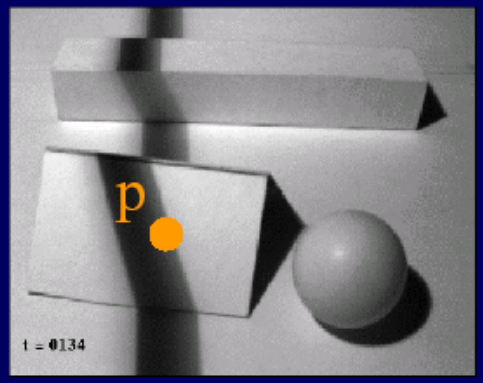
The idea

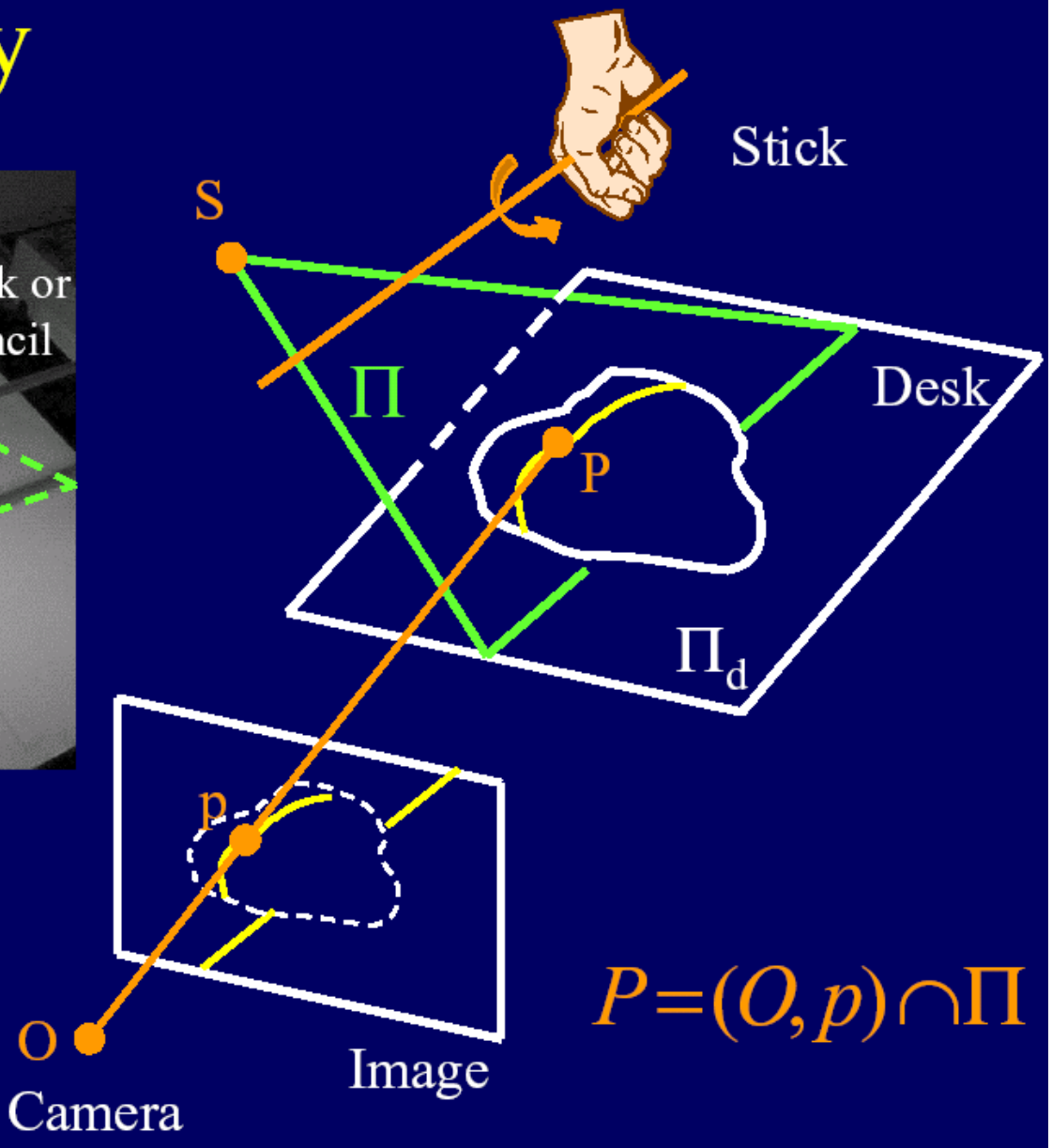




The geometry

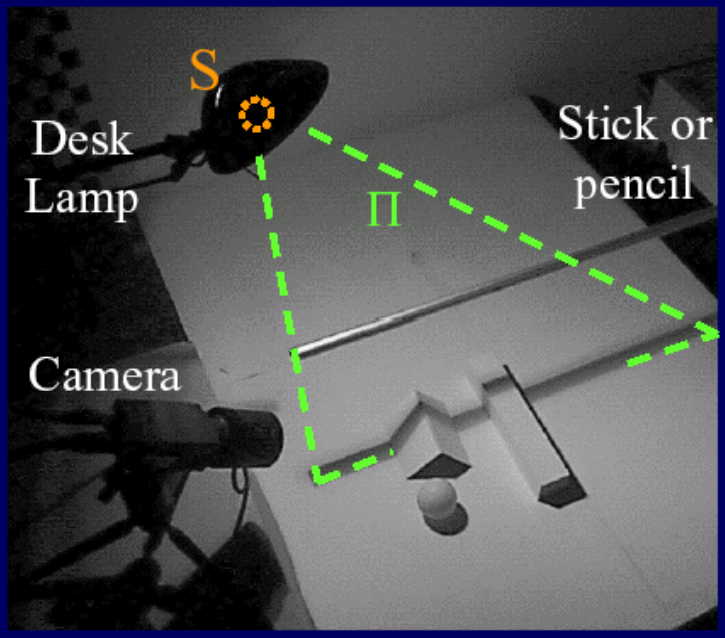


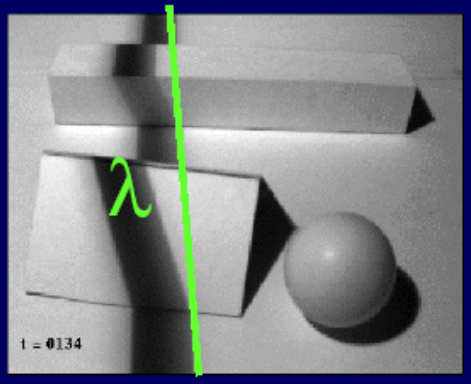


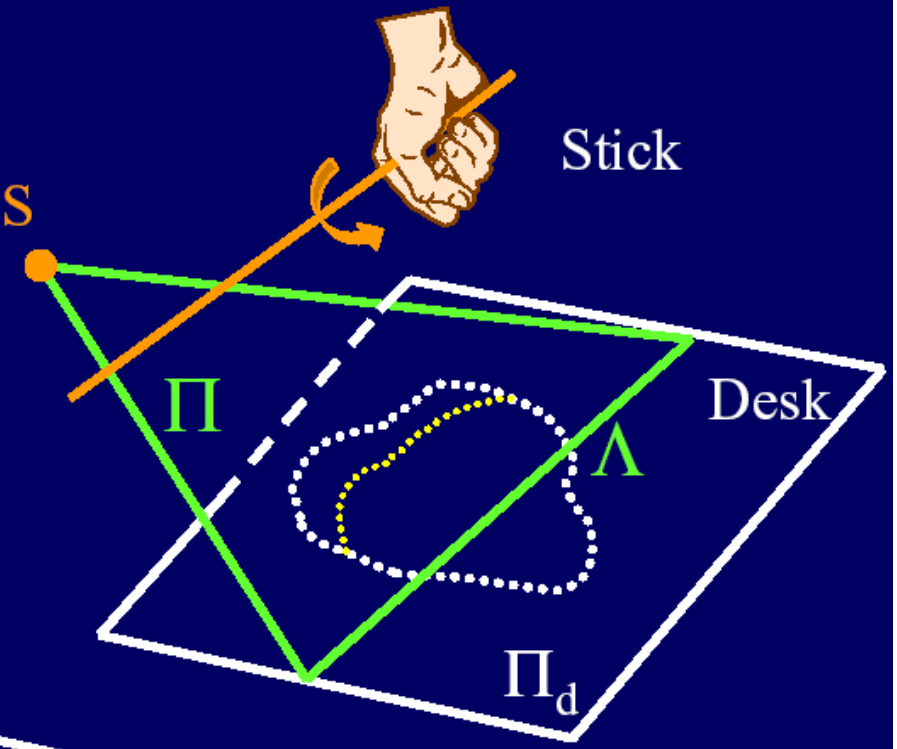


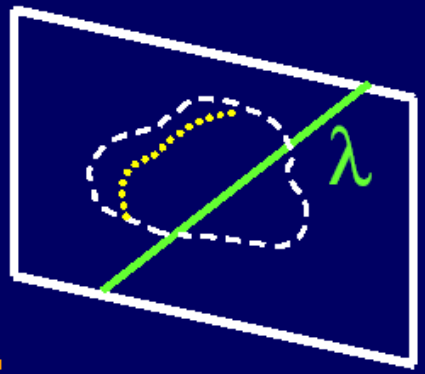
$$P=(O,p)\cap\Pi$$

The geometry







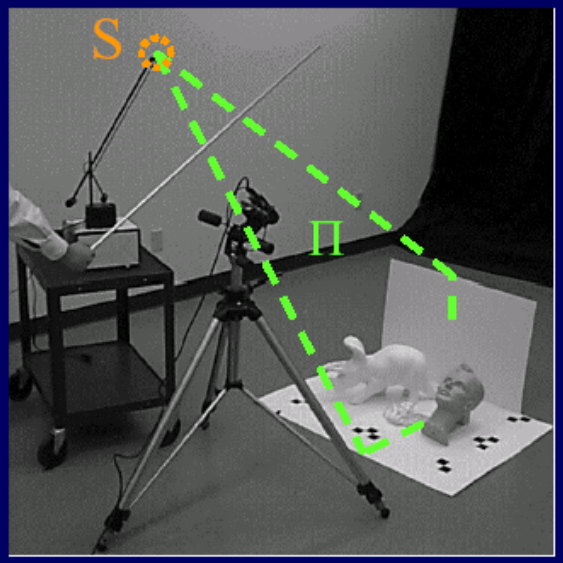


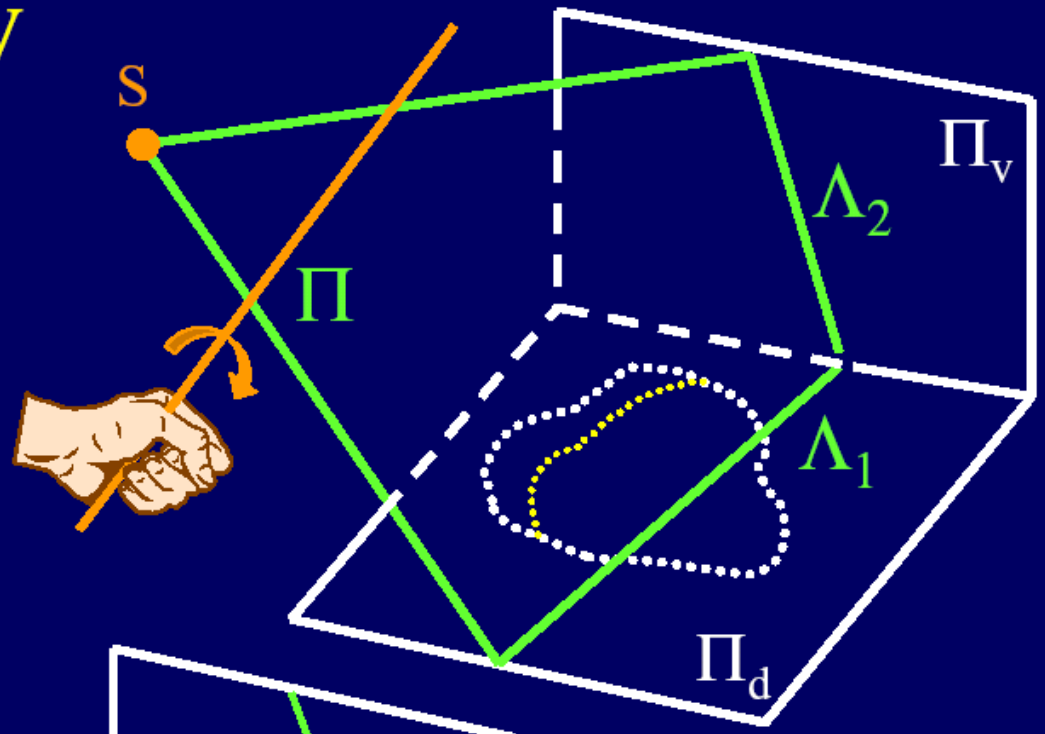
O
Camera

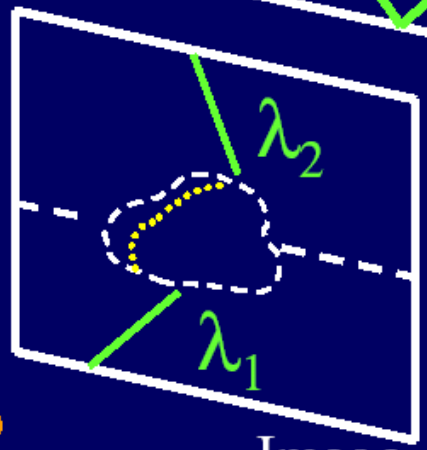
$\Lambda = (O, \lambda) \cap \Pi_d$

$\Pi = (S, \Lambda)$

The geometry







O
Camera

$\Lambda_1 = (O, \lambda_1) \cap \Pi_d$

$\Lambda_2 = (O, \lambda_2) \cap \Pi_v$

$\Pi = (\Lambda_1, \Lambda_2)$

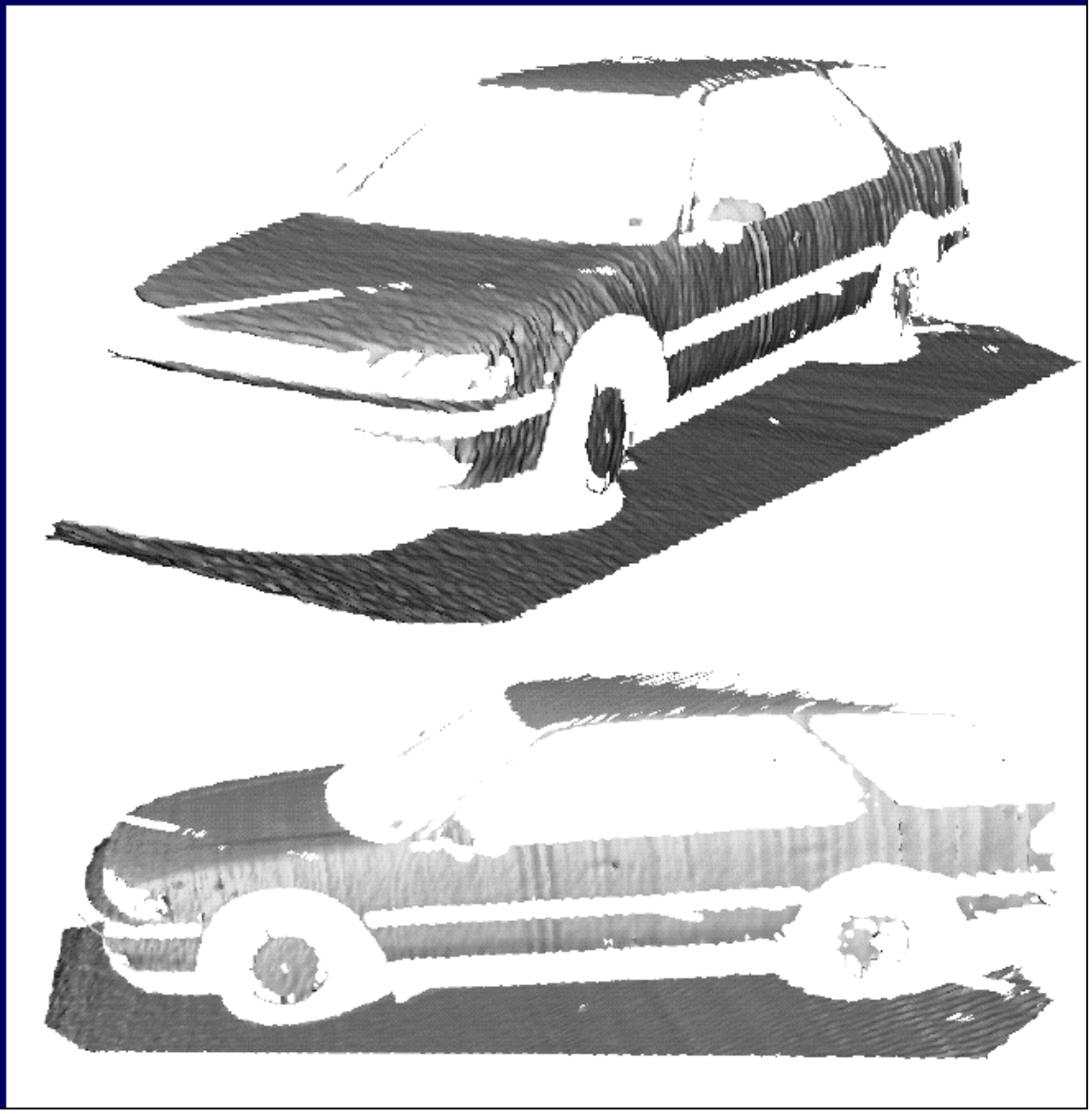
Angel experiment

Accuracy: 0.1mm over 10cm → ~ 0.1% error

Scanning with the sun

Accuracy: 1cm over 2m

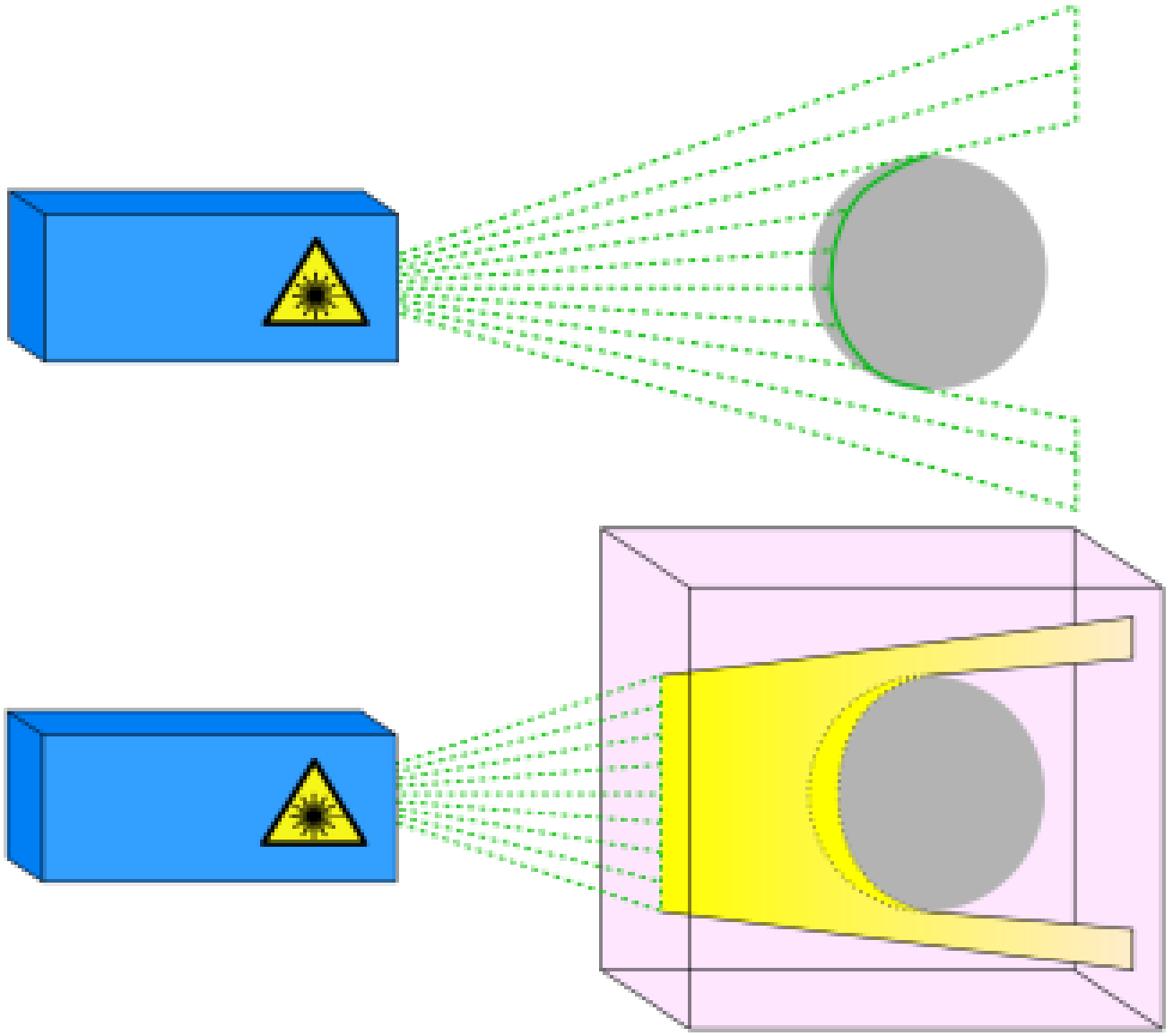
~ 0.5% error



Fluorescent Immersion Range Scanning

http://www.mpi-inf.mpg.de/resources/FIRS/

Fluorescent Immersion Range Scanning



http://www.mpi-inf.mpg.de/resources/FIRS/

Structured Light Reconstruction

- Avoid problems due to correspondence
- Avoid problems due to surface appearance
- Much more accurate
- Very popular in industrial settings

- Reading:
  - Marc Levoy's webpages (Stanford)
  - Katsu Ikeuchi's webpages (U Tokyo)
  - Peter Allen's webpages (Columbia)