Structured Light

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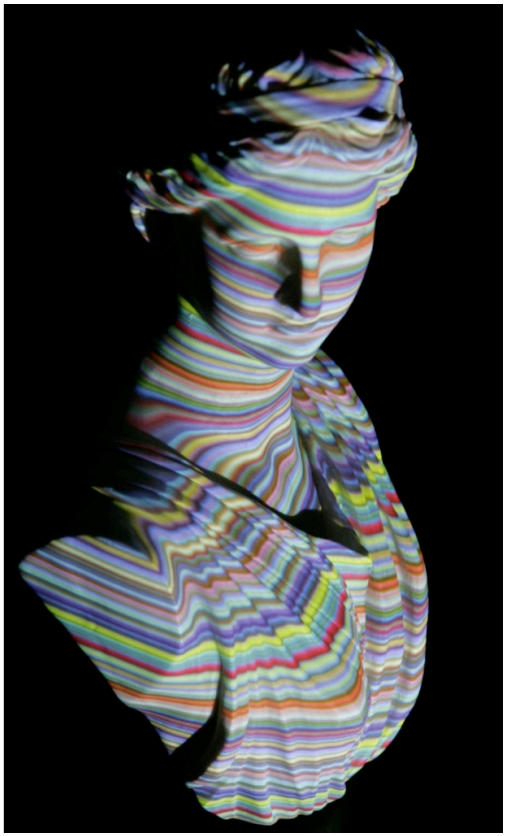
Passive Image Acquisition

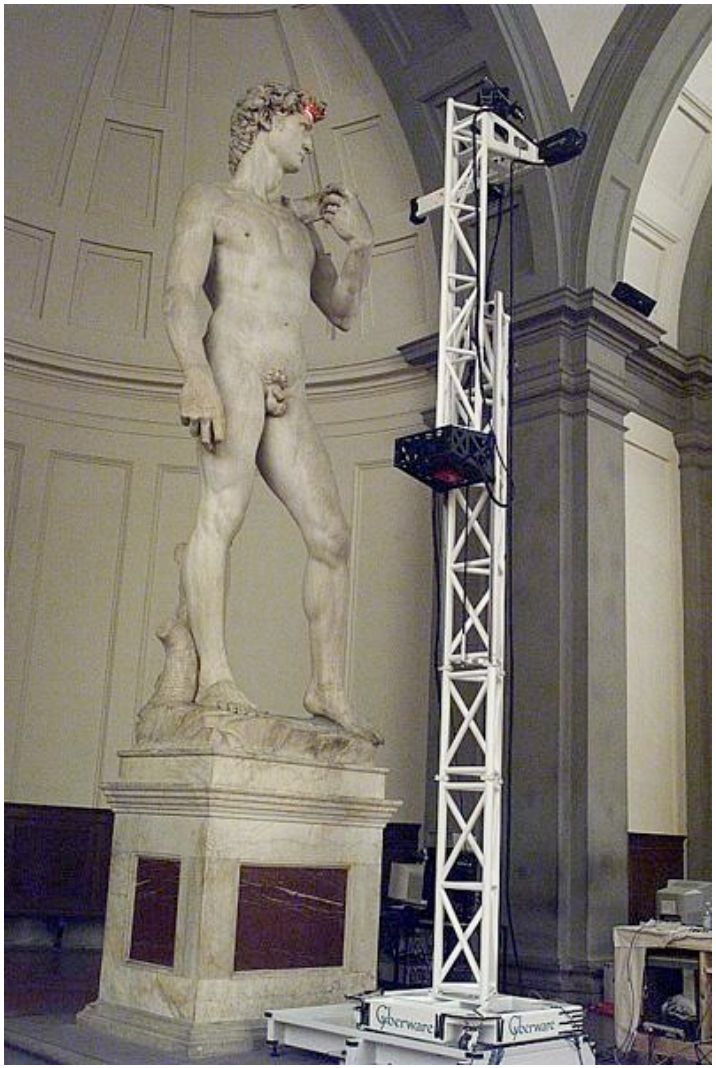
left image

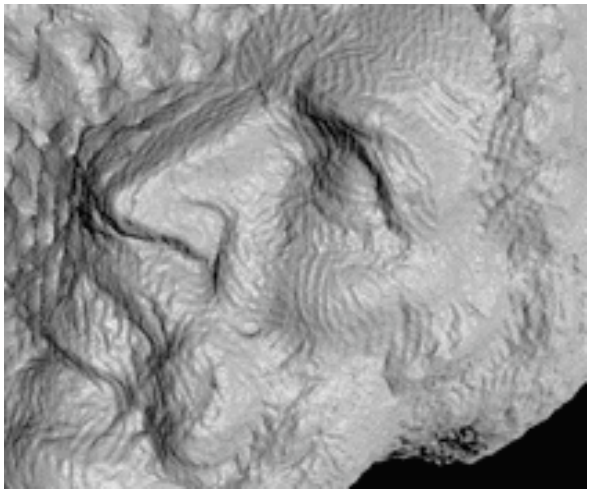
right image

reconstruction

Active Image Acquisition



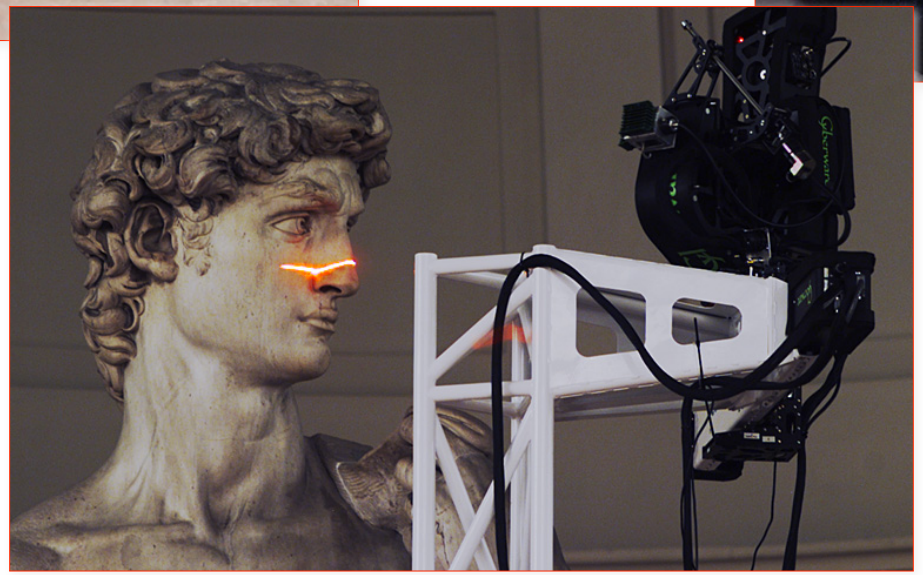




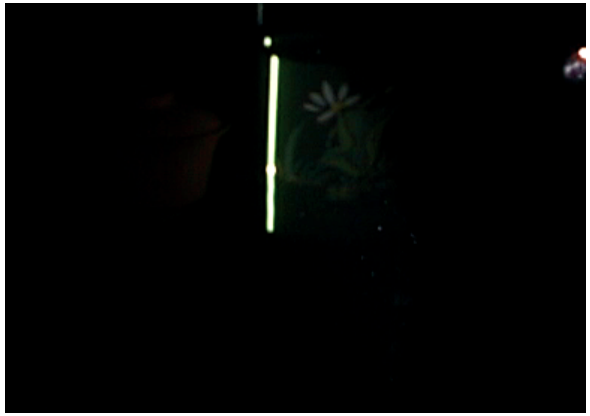
Passive versus Active Acquisition

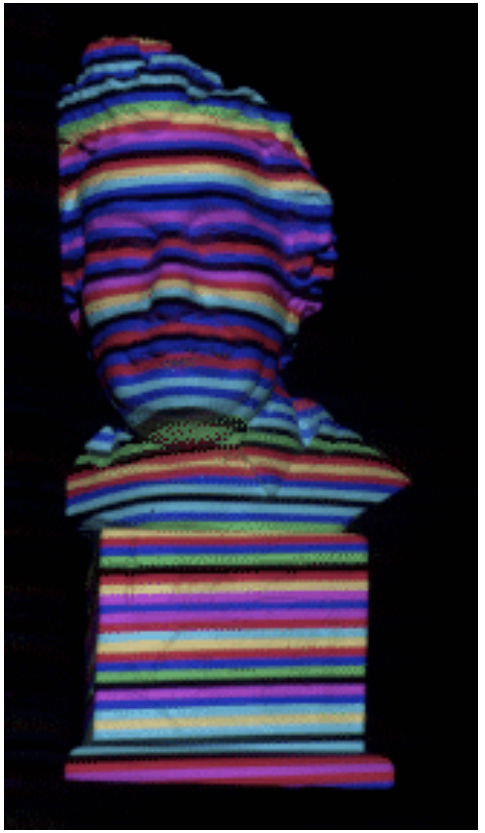
- Passive (stereo, motion)
  - Easy data collection (just take pictures).
  - Non-intrusive setup.
  - Can produce dense depth maps.
  - May not work for featureless surfaces.
- Active (range scanning, ToF, structured light)
  - More robust correspondence.
  - Can recover data even at featureless parts of the scene.
  - Higher accuracy but possibly sparser depth maps.
  - Very popular in industrial setups
  - More complex data hardware.
  - Intrusive (active illumination may alter scene appearance)
  - Limited range of depth.

Laser Scanning

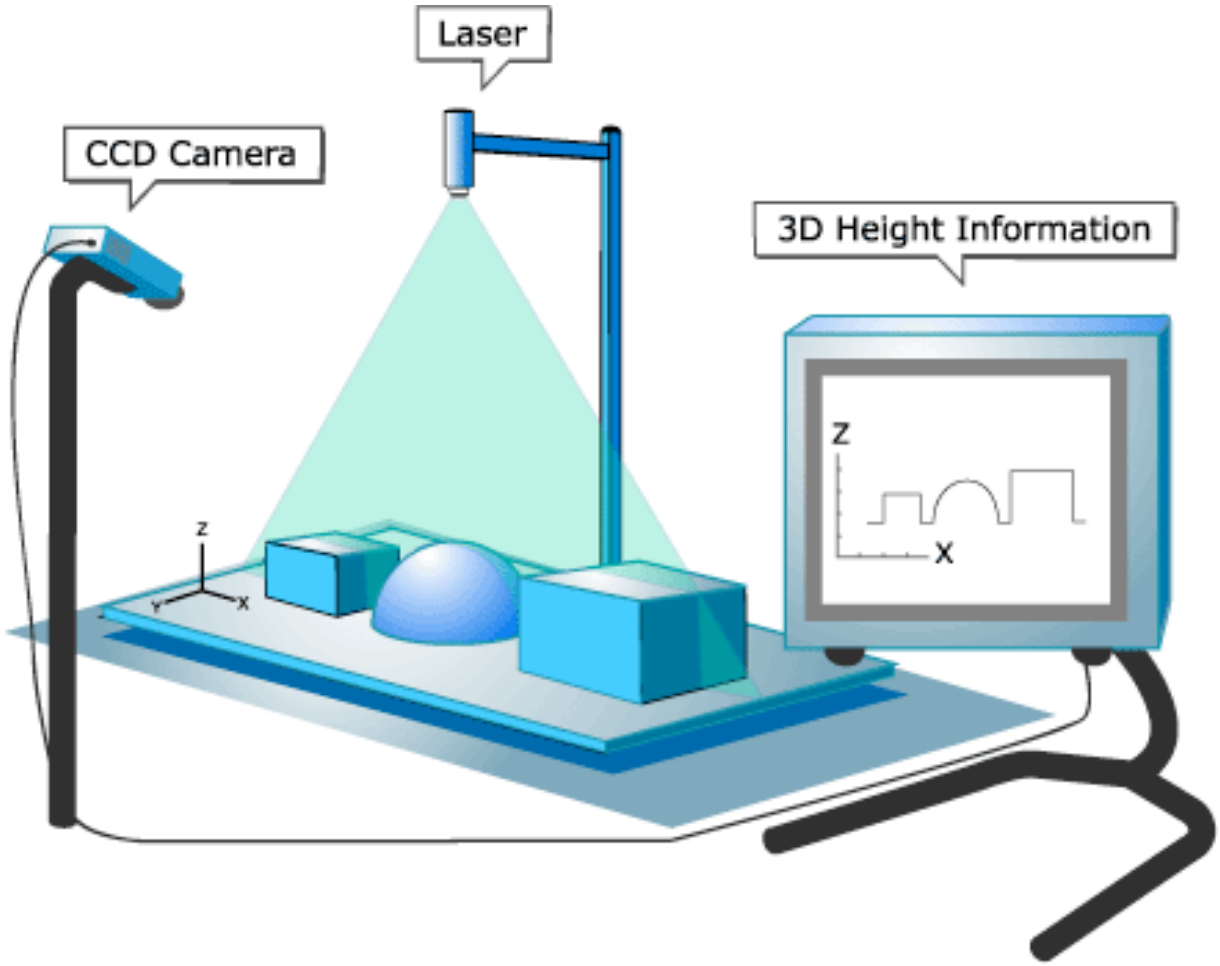


Structured Light



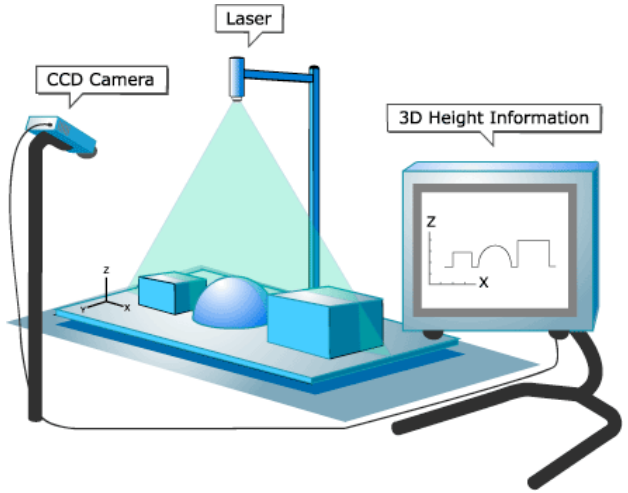


Basic Concept

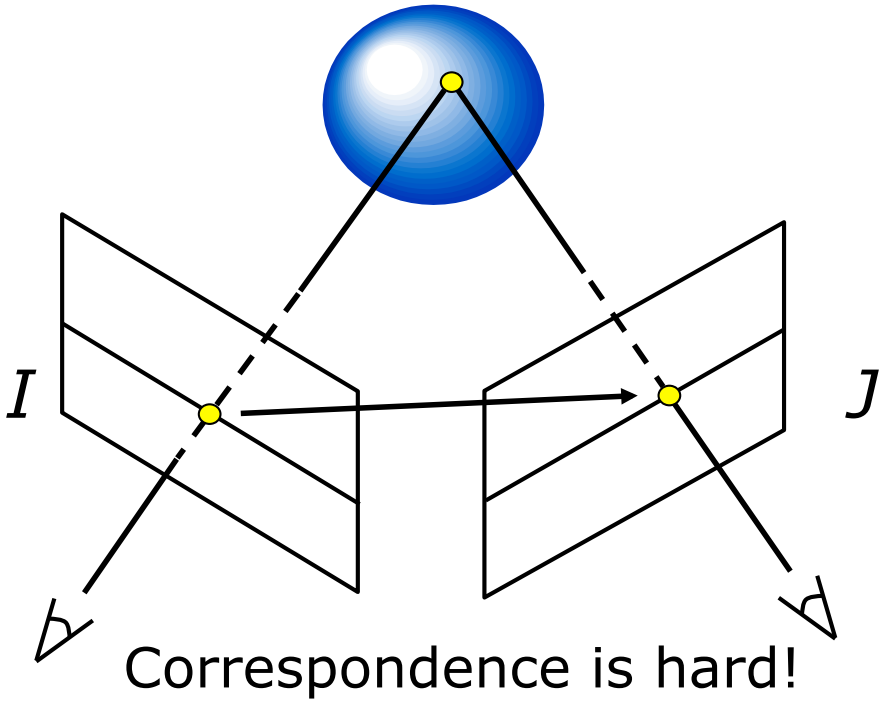


Basic Concept

- The triangulation idea can be applied in a setup that uses a projector (or laser beam) and a camera, instead of 2 cameras. The ray of the controlled incident light replaces the projection ray of the 2nd camera.
- Object surfaces are illuminated with a known pattern of light.
- The structured light is the only source of illumination.
- Depending on the shape of the object the grid is distorted.
- A camera captures the distorted pattern.
- Prior knowledge:
  - known geometry of light pattern
  - known relative position of light and projector.

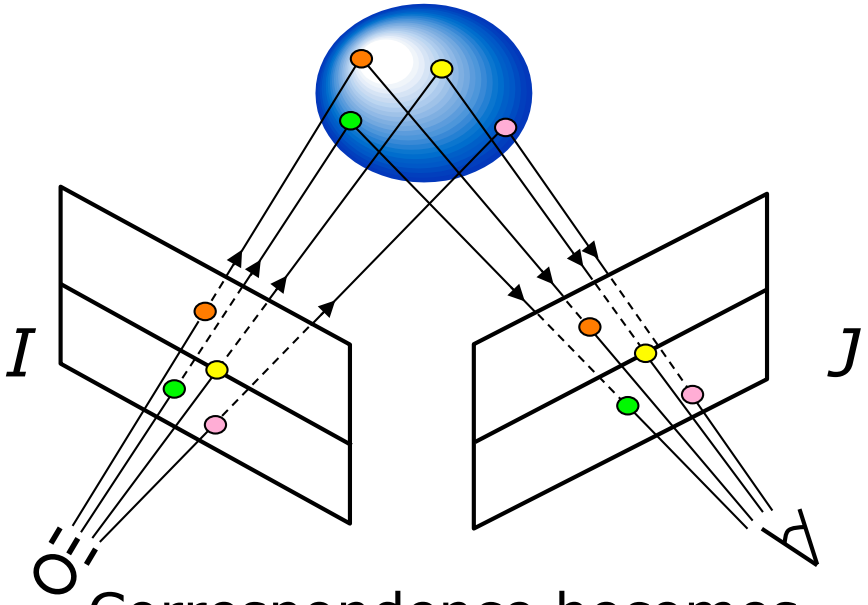


Stereo Triangulation



- In traditional stereo, correspondence can be quite challenging.
- For each pixel in one image, we look for corresponding pixel in the other image.
- Typical method: Look for pixels on the conjugate epipolar line choose the pixel with most similar value. This can be done by minimizing the following error function.

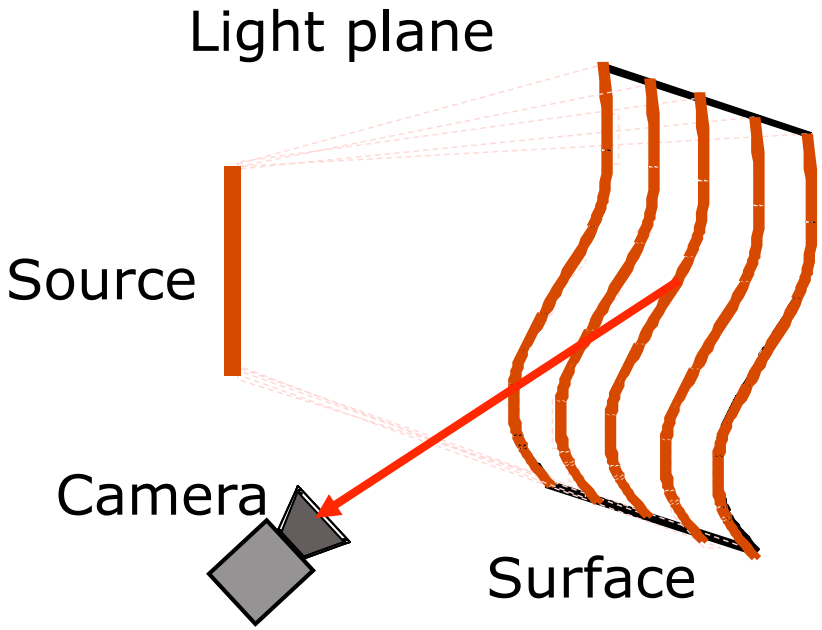
Structured Light Triangulation

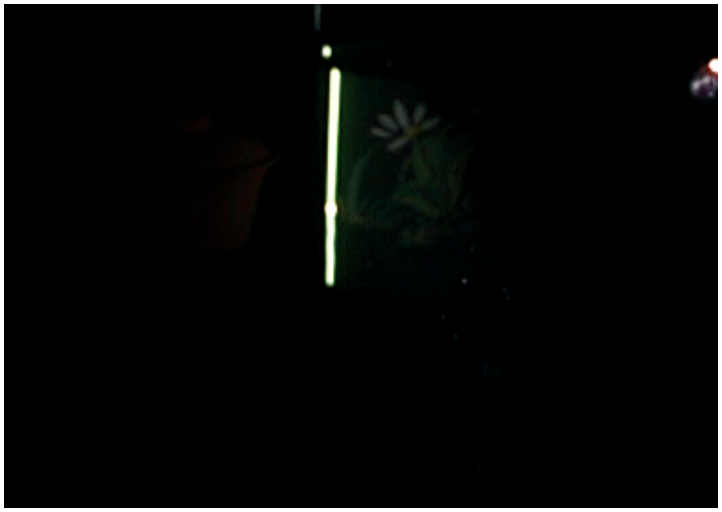


Correspondence becomes easier!

- In structured light correspondence is more constrained.
- We add information by using either a single stripe of light or a relatively unique light pattern.
- Either match across a single laser stripe.
- Or, instead of matching one pixel at a time, we can exploit the knowledge about the light pattern and try to match a set of points at a time.

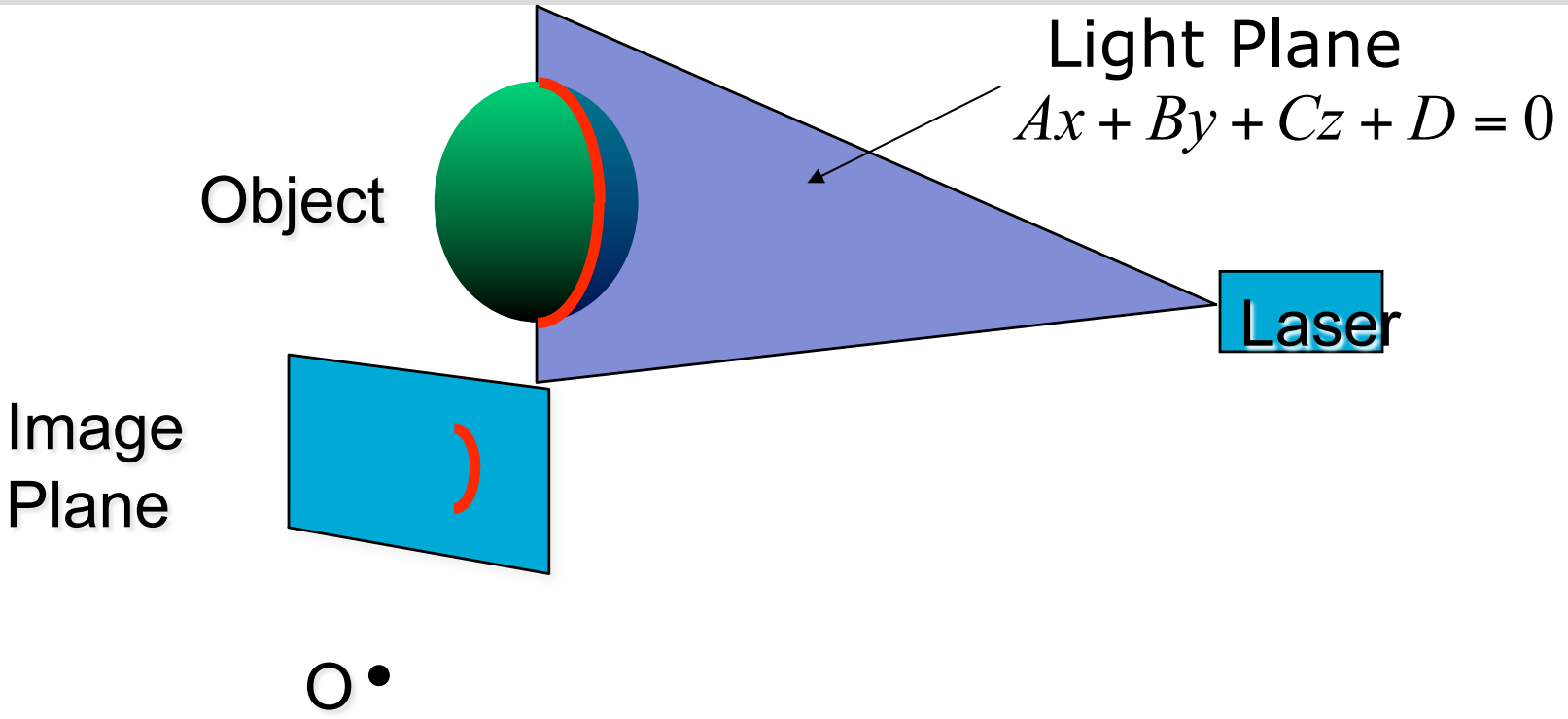
Single Stripe Scanning





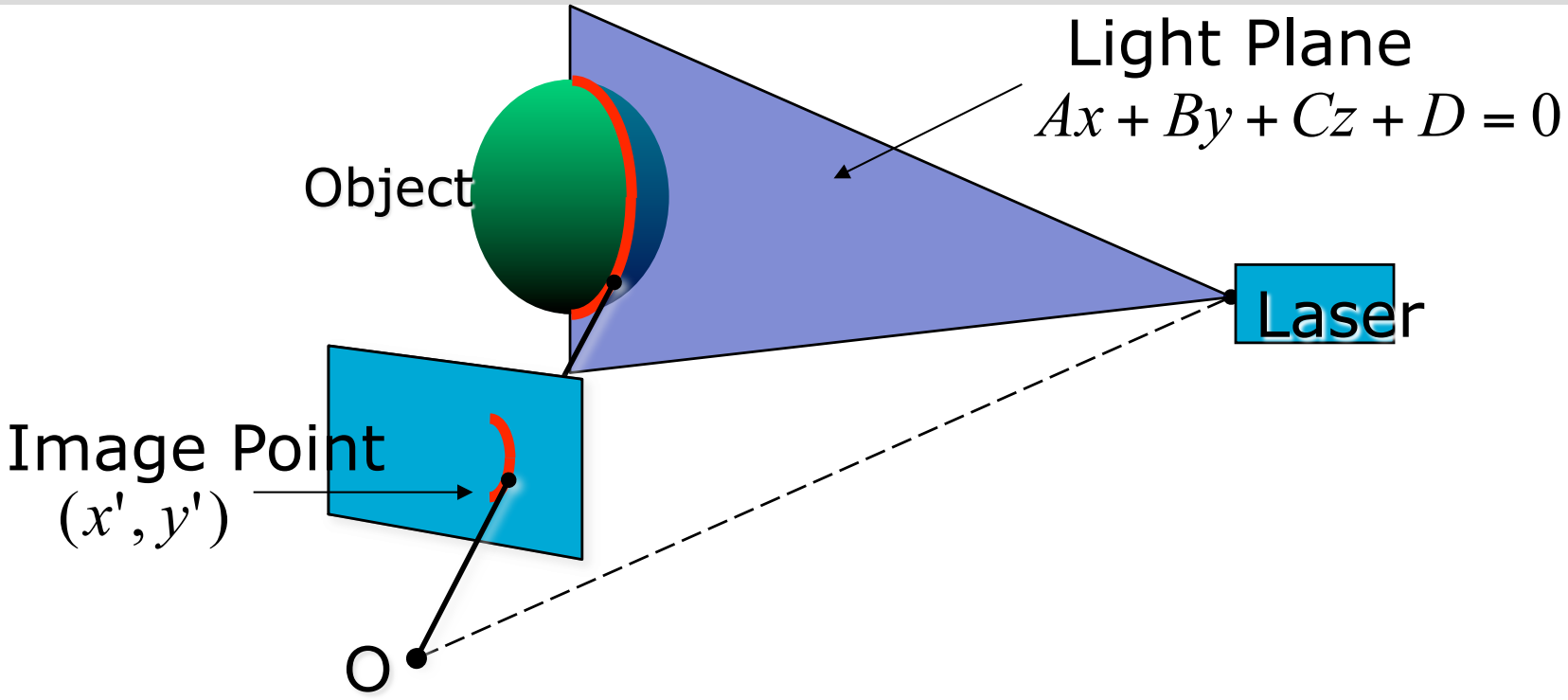
- Optical triangulation
  - Project a single stripe of laser light
  - Scan it across the surface of the object
  - This is a very precise version of structured light scanning
  - Good for high resolution 3D, but needs many images and takes time

Triangulation with Light Plane



- Project laser stripe onto object
- Capture the scene with a camera with COP O.
  The camera is at an angle with the laser source.

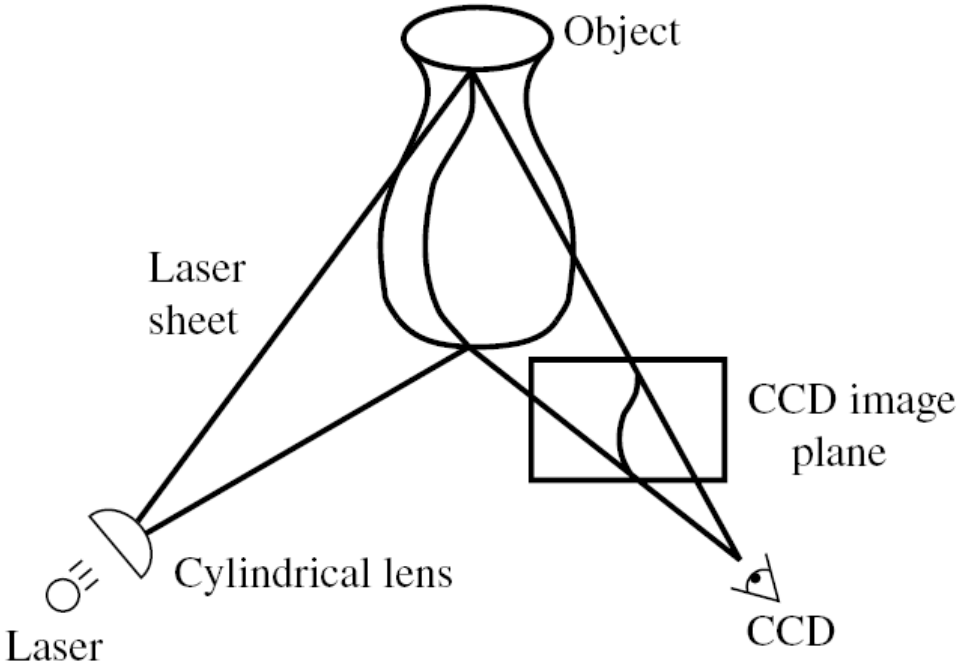
Triangulation with Light Plane



- 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: Portable Laser Scanner

Minolta VIVID 910
3D Laser Scanner

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

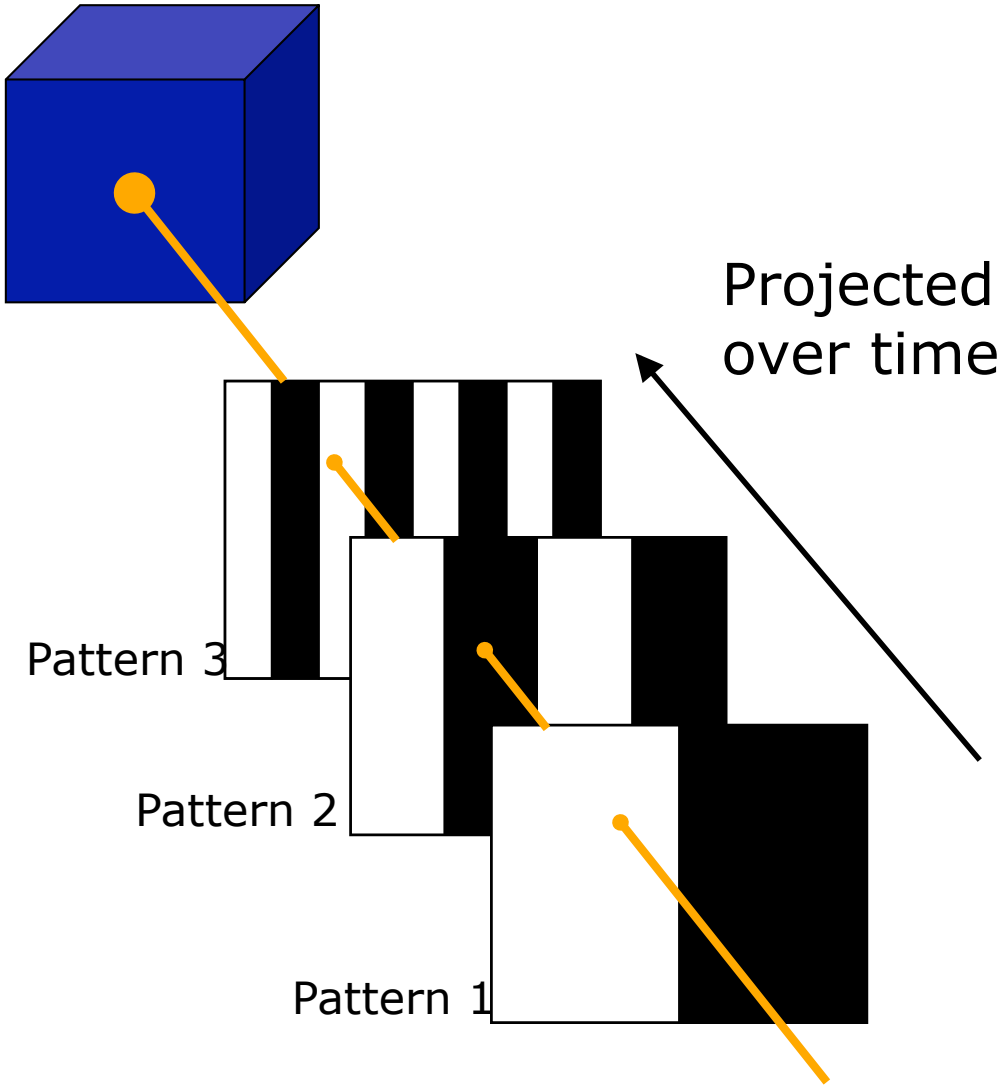
Binary Coding Idea

Faster:

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

Example:

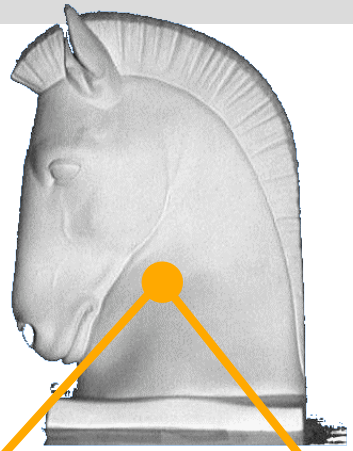
3 binary-encoded patterns which allows the measuring surface to be divided in 8 sub-regions



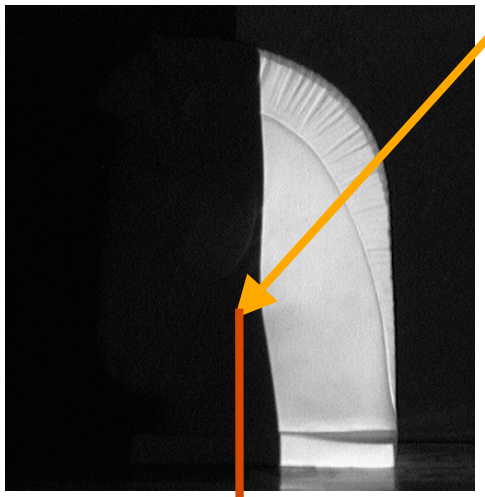
Uniqueness of Binary Coding

- Assign each stripe a unique illumination code over time [Posdamer 82].
- A single position in space (i.e., a single pixel), has a unique on/off pattern over the frames.
- Thus, it is easy to identify the plane of illumination.

Binary Coding Example



Example: 7 binary patterns proposed by Posdamer & Altschuler



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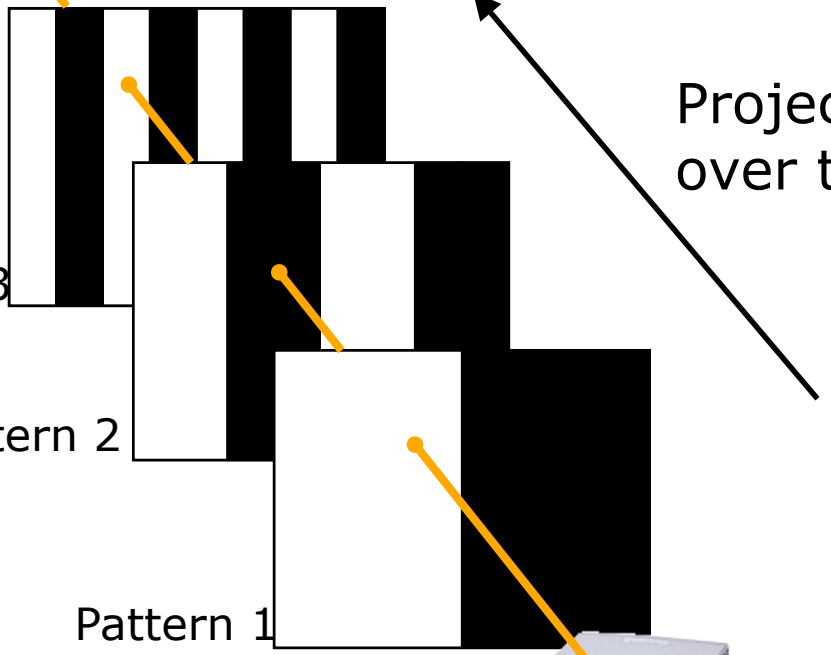
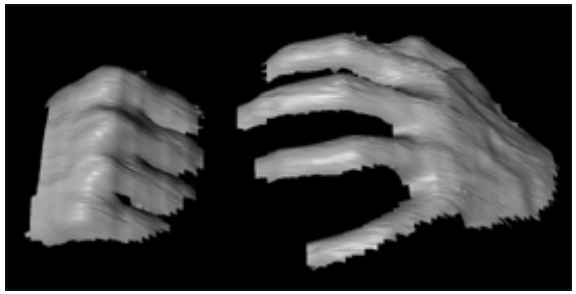


Projected over time

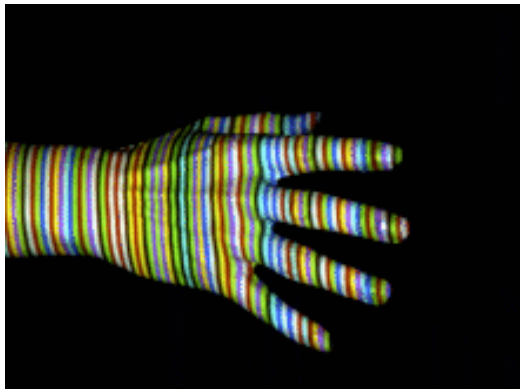
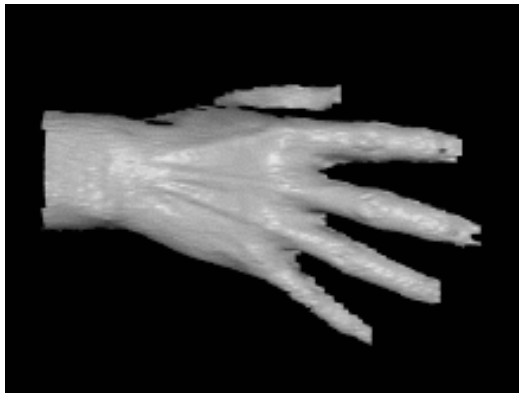
Codeword of this píxel: 1010010 → identifies the corresponding pattern stripe

More Complex Light Patterns





Works despite complex appearances

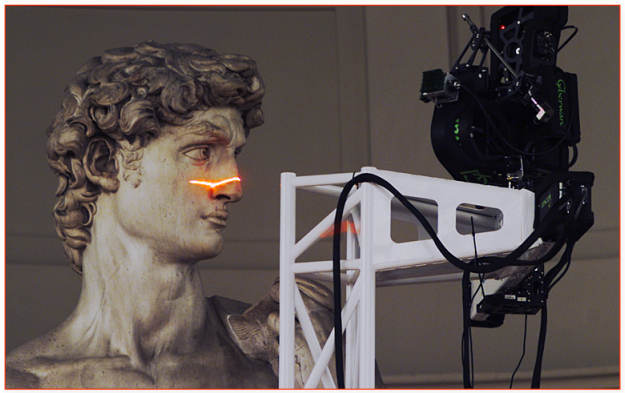



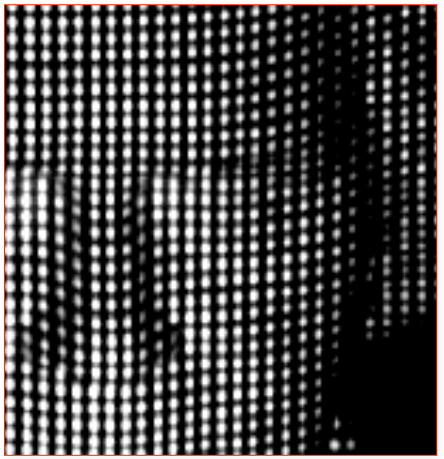
Works in real-time and on dynamic scenes

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

By Zhang et al.

Continuum of Triangulation Methods





Multi-stripe
Multi-frame

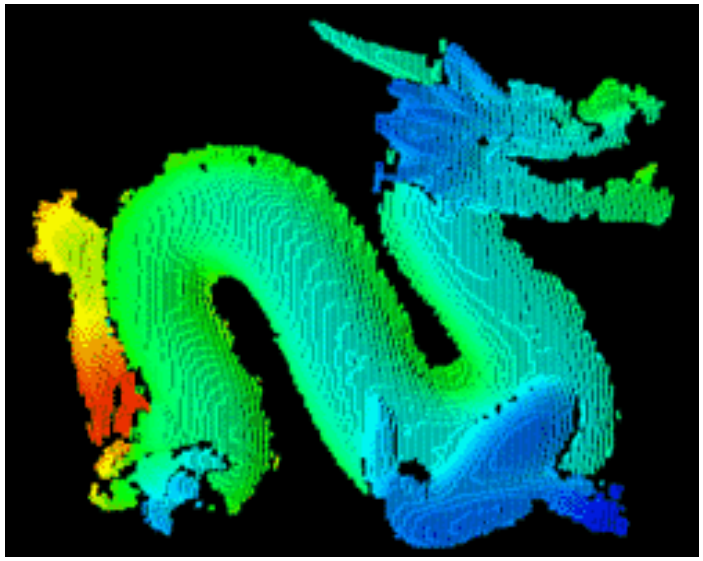
Single-stripe

Single-frame

Slow, robust

Fast, fragile

Structured Light and Texture



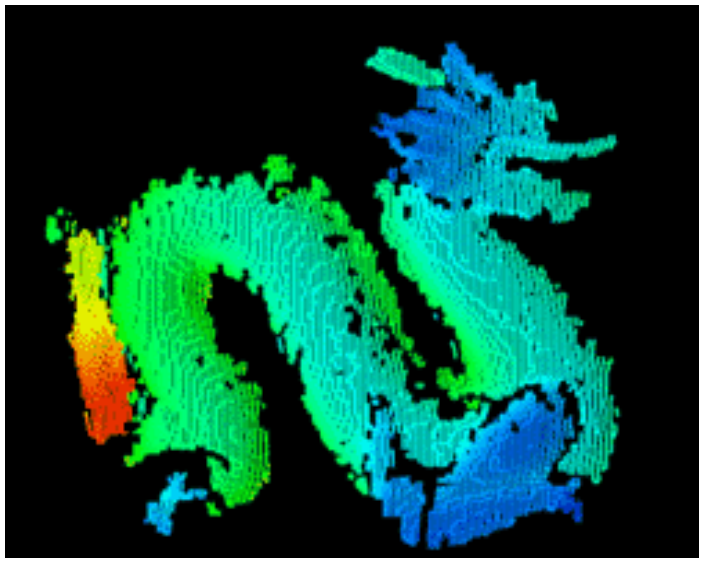


Image Sources

1. The commercial stereo sensor is the Bumblebee2 from "Point Grey" http://www.ptgrey.com/products/bumblebee2/images/BB2_white_background_large.jpg
2. The homemade stereo setup is courtesy of the "Grau goes Color" blog http://grauonline.de/wordpress/
3. The stereo eyeglasses are the "Vuzix Wrap 920AR Video Eyewear" as shwon in http://www.trendygadget.com/category/digital-cameras/
4. The stereo example is from H. Tao et al. "Global matching criterion and color segmentation based stereo"
5. The structured light example of the female-bust sculpture is courtesy of S. Yamazaki http://www.dh.aist.go.jp/~shun/research/dlp/fig/structured.jpg
6. The example of the recovered unfinished face sculpture is from "The Digital Michelangelo Project" http://www.graphics.stanford.edu/projects/mich/
7. The picture of the scanner used in the Michelangelo project is courtesy of Cyberware http://www.cyberware.com/products/scanners/lss.html
8. The "Head and Face Scanner" is by Cyberware http://www.cyberware.com/guides/cyscan/info/pxPlatform.html
9. The figure that shows the basic concept behind structured light is courtesy of "Stocker Yale" http://www.stockeryale.com/i/lasers/structured_light.htm
10. The example of the black and white structured light pattern projected on the sun sculpture is from Google's code on structured light http://code.google.com/p/structured-light/updates/list
11. A number of slides in this presentation have been adapted by the presentation of S. Narasimhan, http://ww.cs.cmu.edu/afs/cs/academic/class/15385-s06/lectures/ppts/lec-17.ppt