

Structured Light



Prof. Dr. Elli Angelopoulou

Pattern Recognition Lab (Computer Science 5)

University of Erlangen-Nuremberg

Passive Image Acquisition



left image



right image



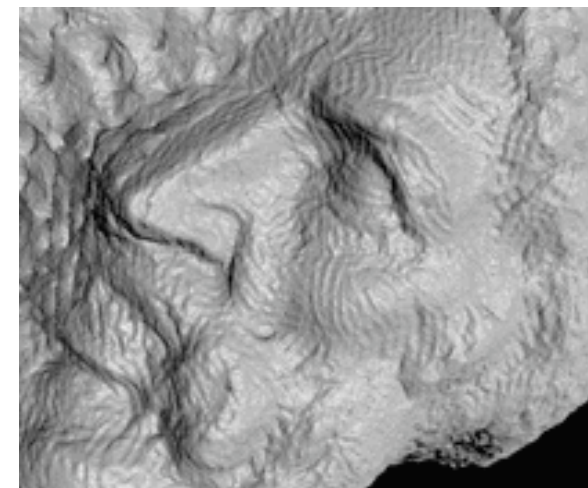
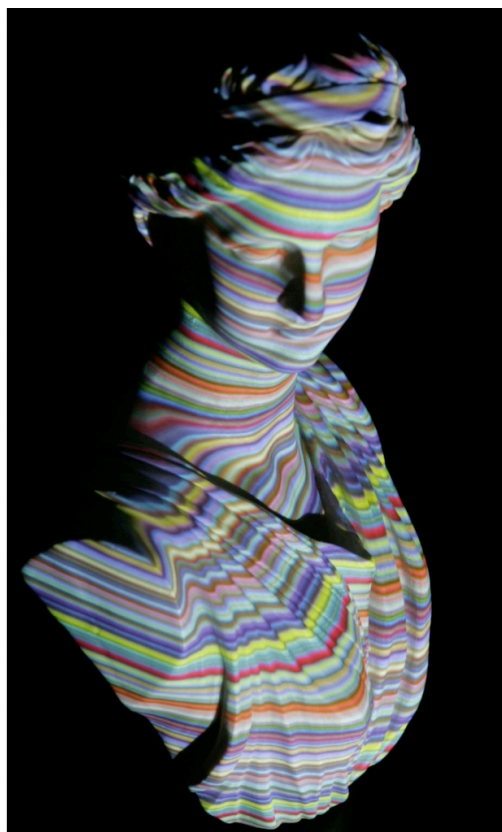
reconstruction

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Structured Light



Active Image Acquisition



Passive versus Active Acquisition



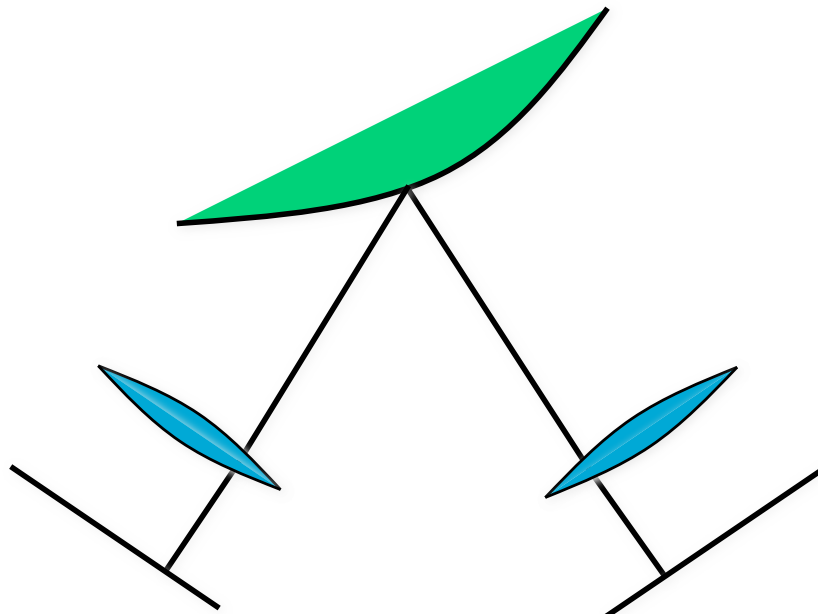
- **Passive (stereo, motion)**
 - Easy data collection (just take pictures).
 - Non-intrusive setup.
 - Can produce dense depth maps.
 - May not work for featureless surfaces.

- **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.

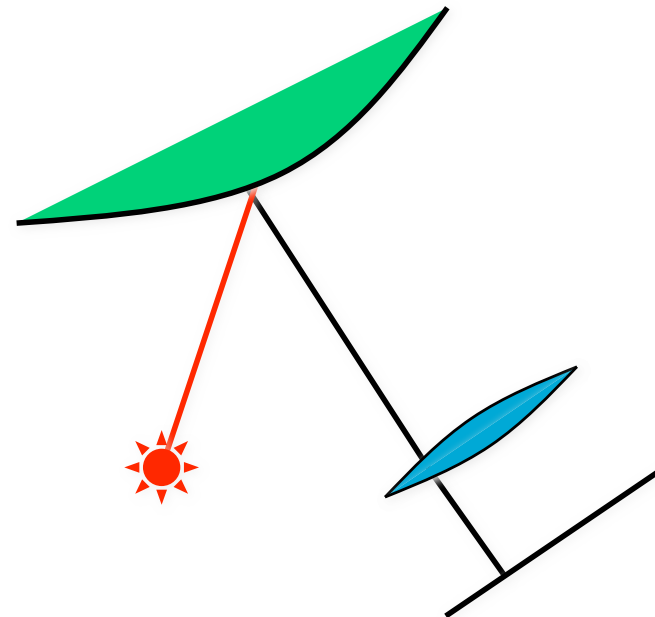
Passive versus Active Acquisition



- Both passive and active methods follow the same underlying principle of ray triangulation.

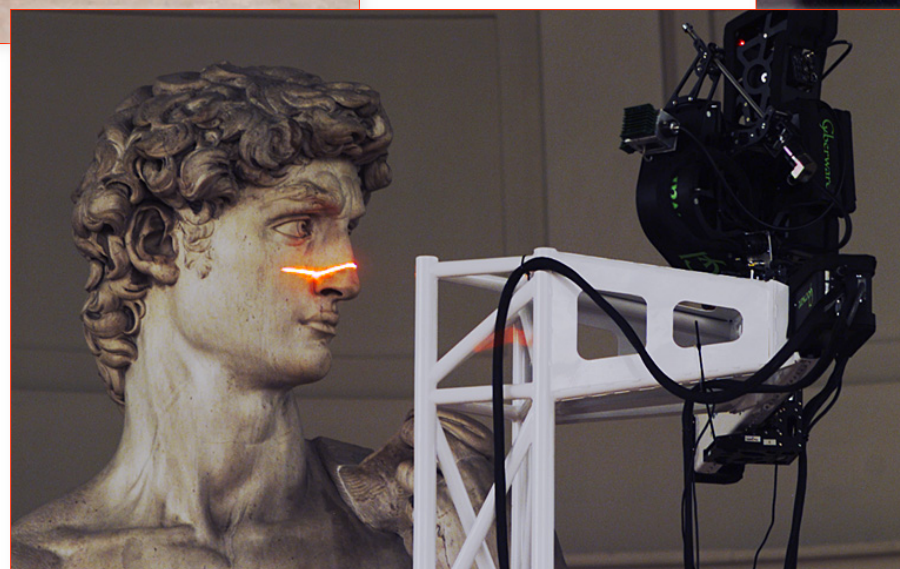


Passive Setup



Active Setup

Laser Scanning

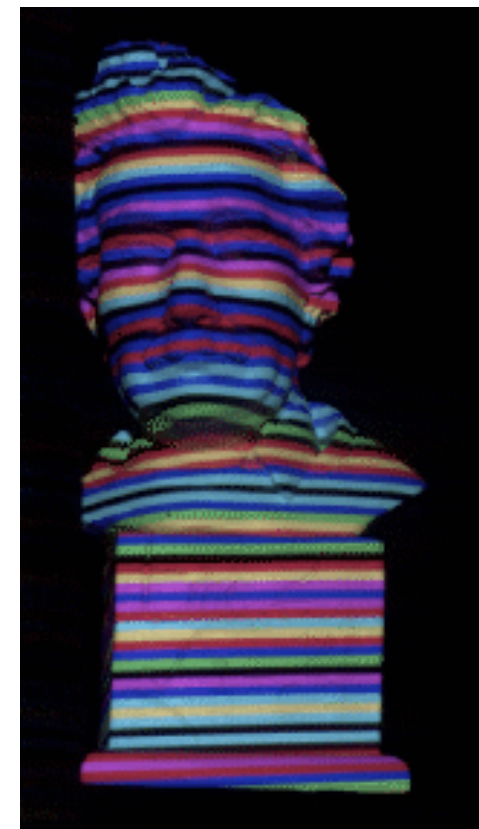
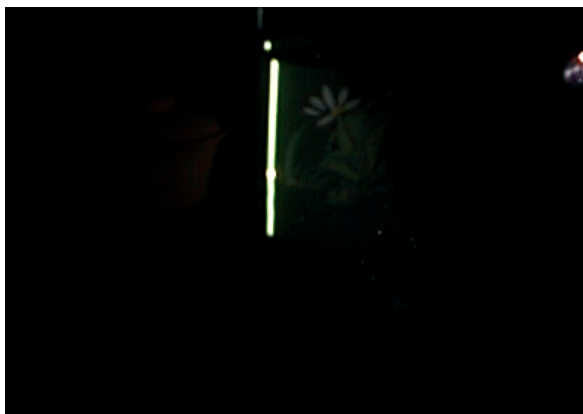


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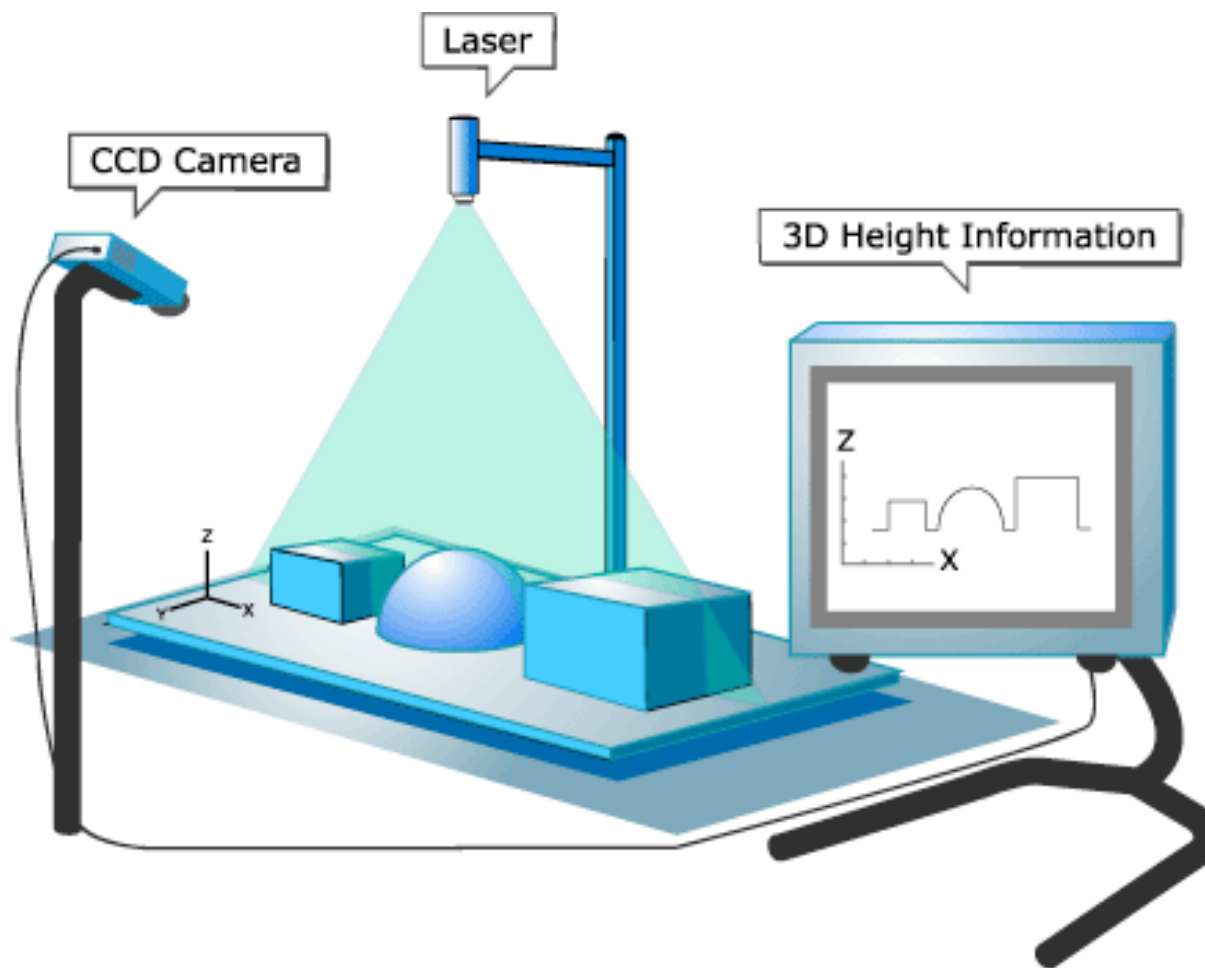
Structured Light



Structured Light



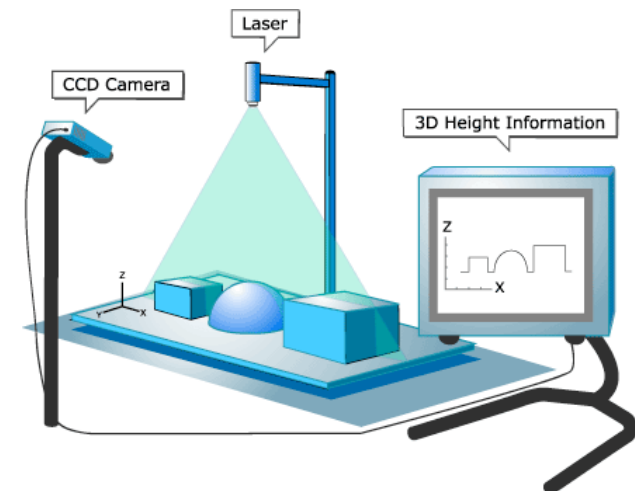
Basic Concept



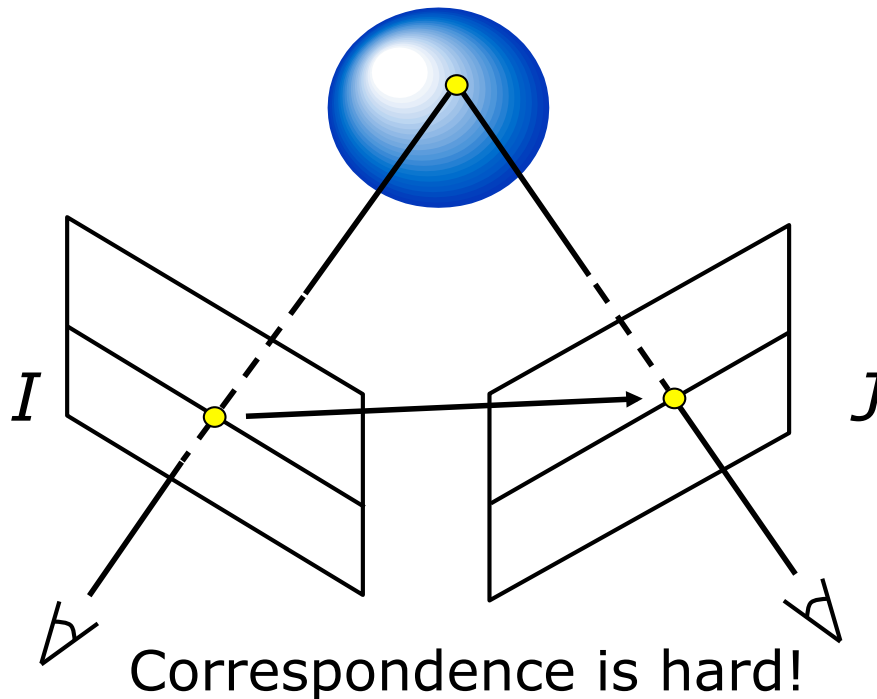
Basic Concept



- 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.

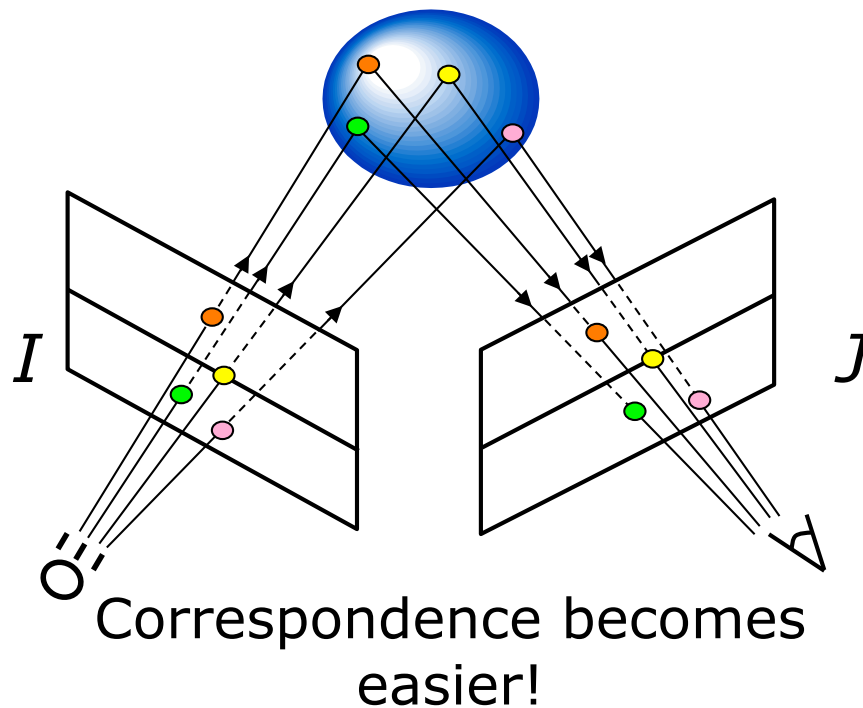


Stereo Triangulation



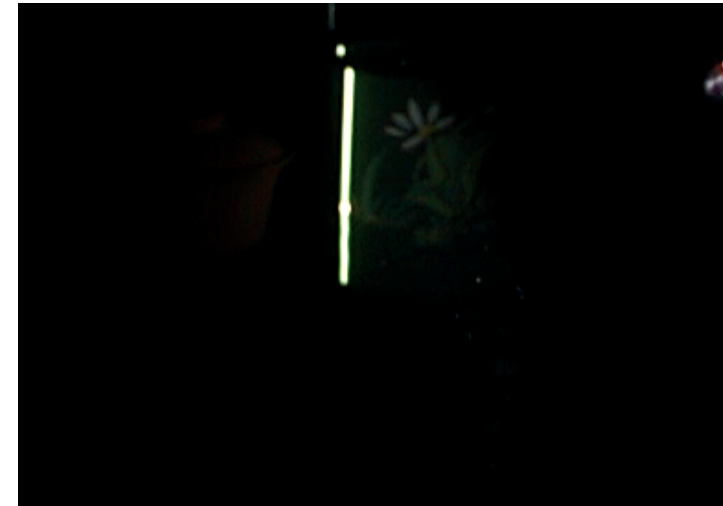
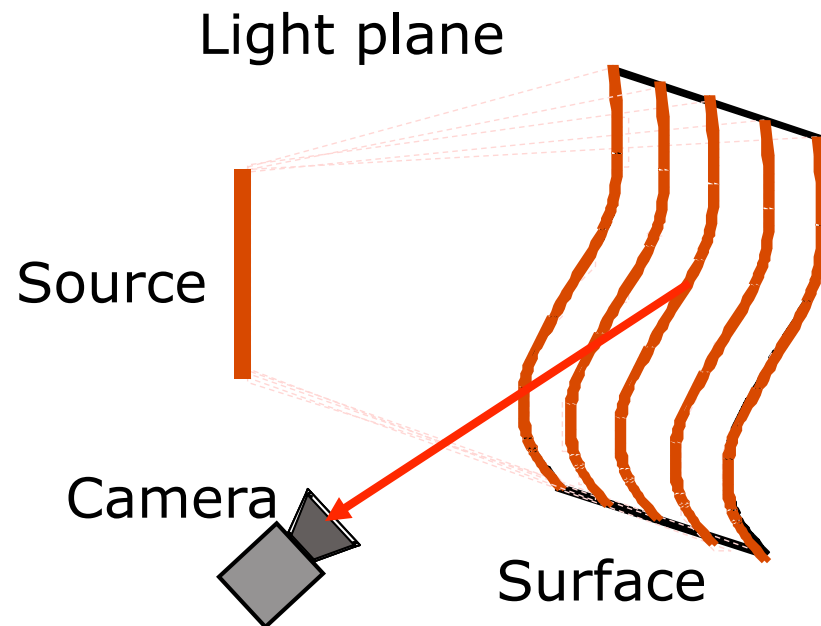
- In traditional stereo, correspondence can be quite challenging.
- For each pixel in one image, we look for corresponding pixel in the other image.
- Typical method: Look for pixels on the conjugate epipolar line choose the pixel with most similar value. This can be done by minimizing the following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

Structured Light Triangulation



- 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.

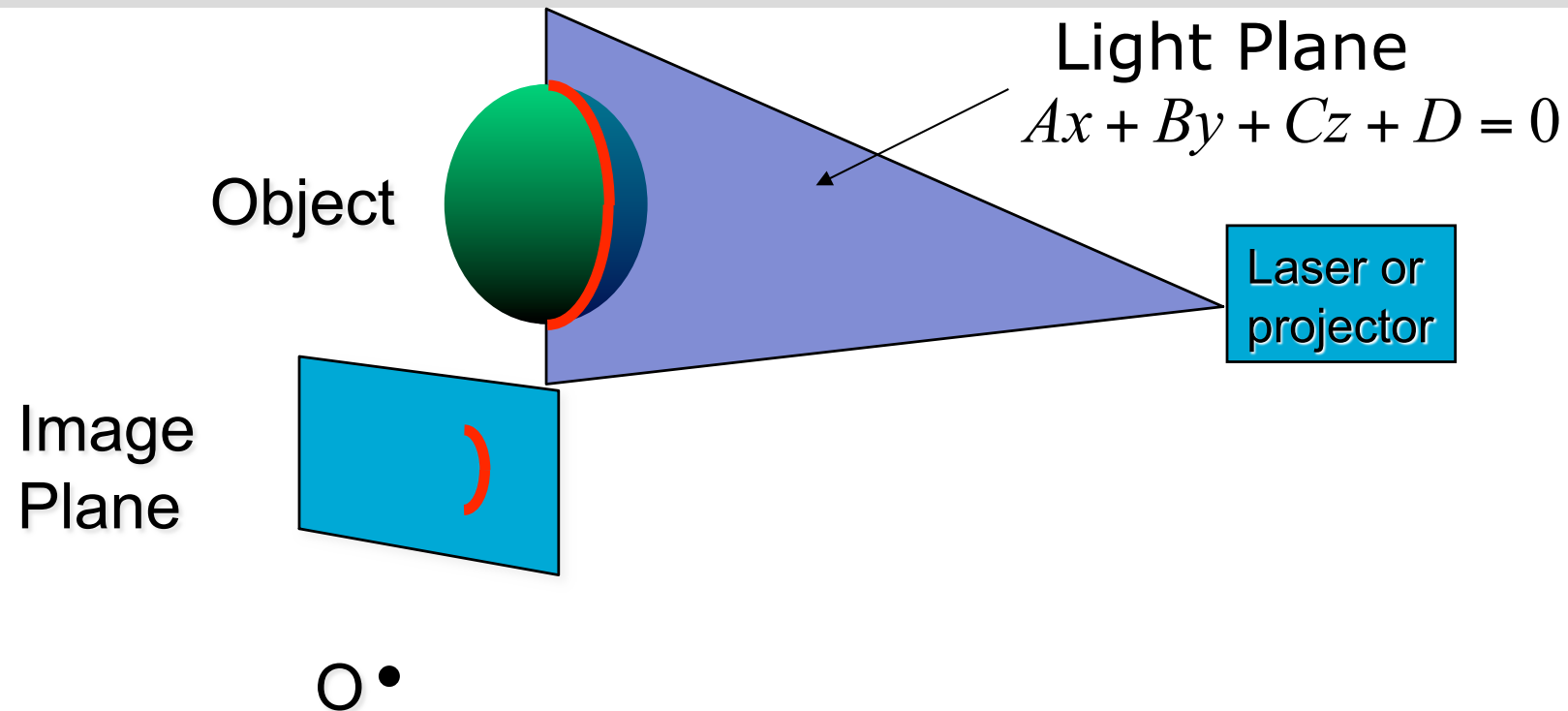
Single Stripe Scanning



- Optical triangulation
 - Project a single stripe of light (from laser or projector)
 - 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



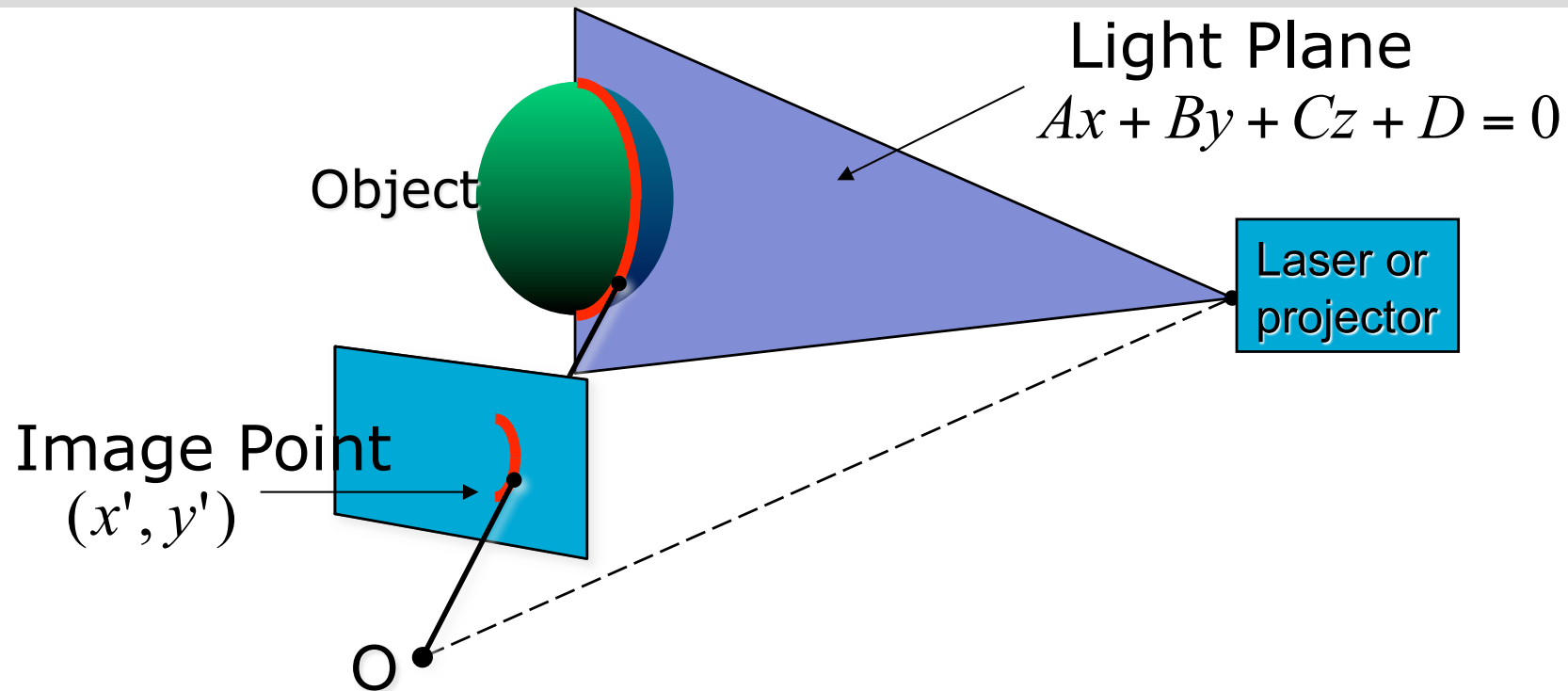
Triangulation with Light Plane



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



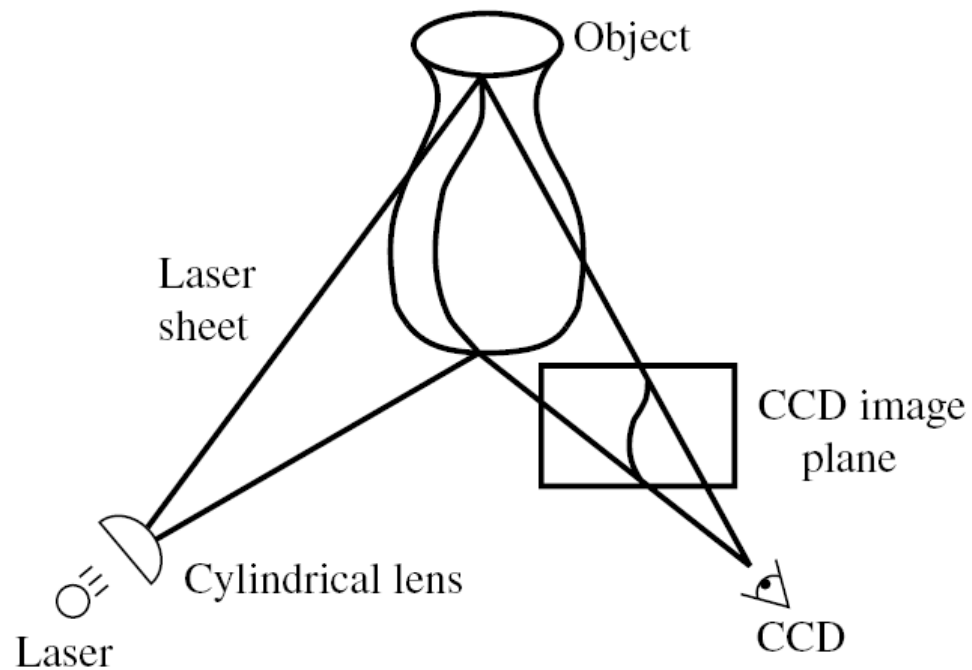
Triangulation with Light Plane



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

$$\begin{aligned} x &= x' z / f \\ y &= y' z / f \end{aligned} \quad z = \frac{-Df}{Ax' + By' + Cf}$$

Example: Laser Scanner



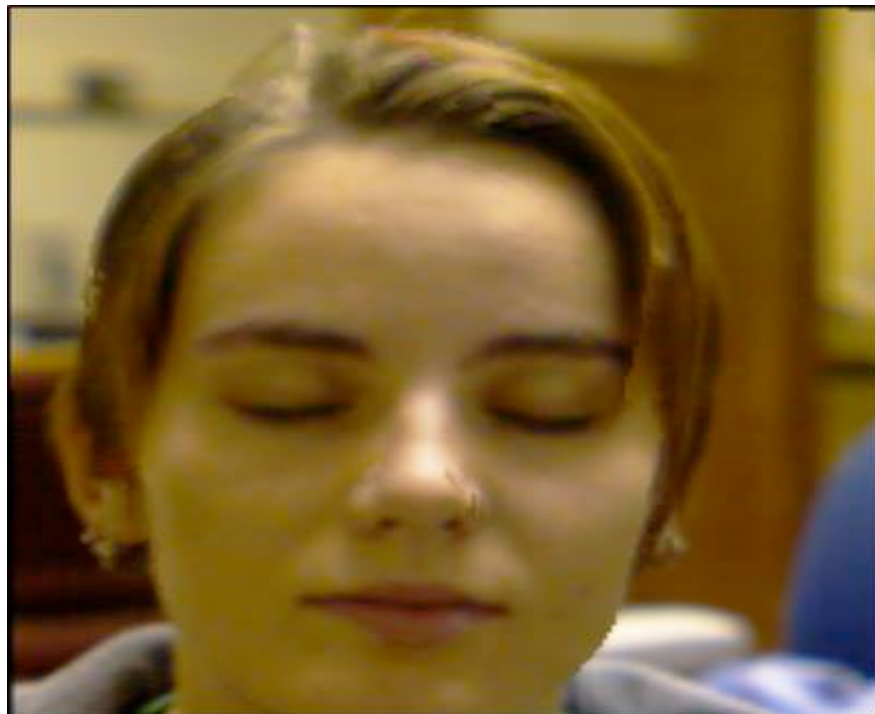
Cyberware[®] face and head scanner

- + 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

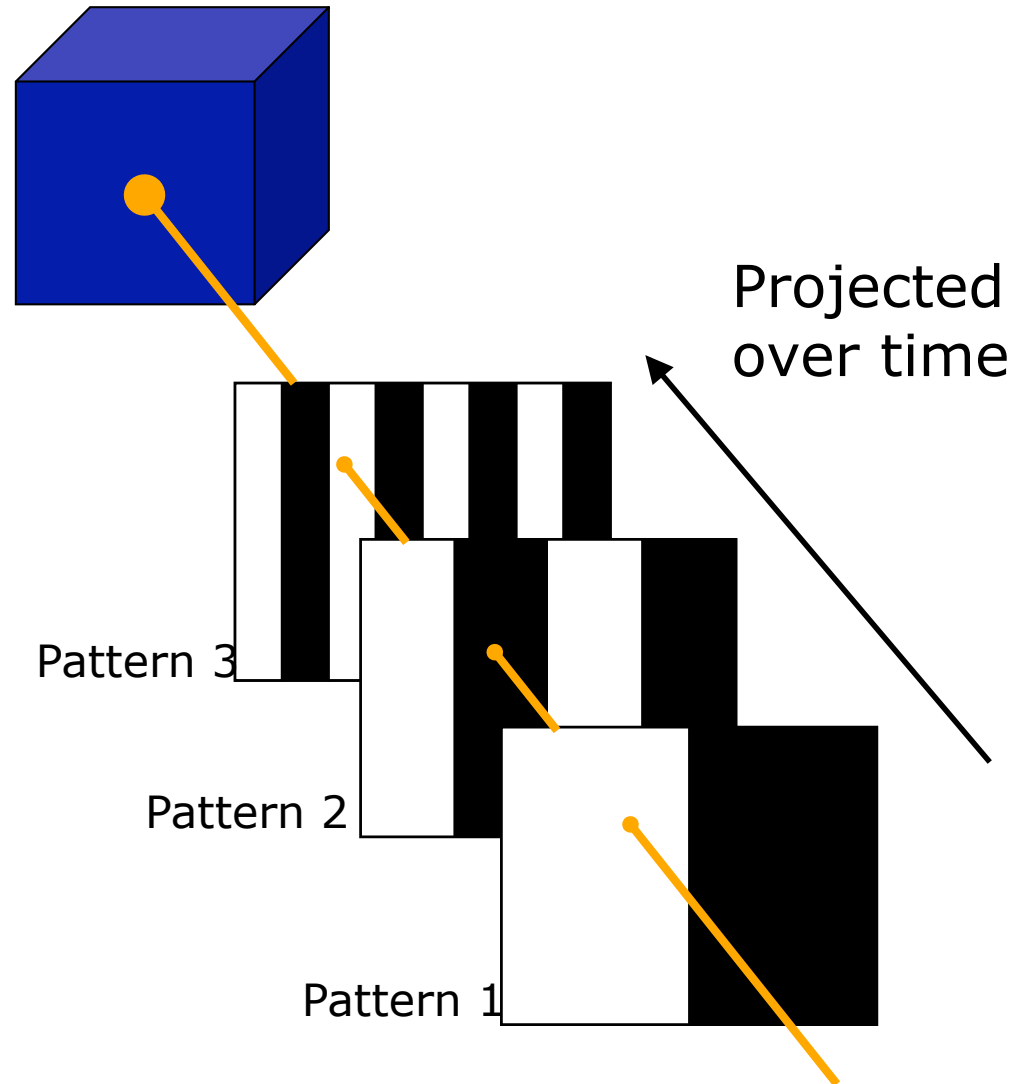


Faster:

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

Example:

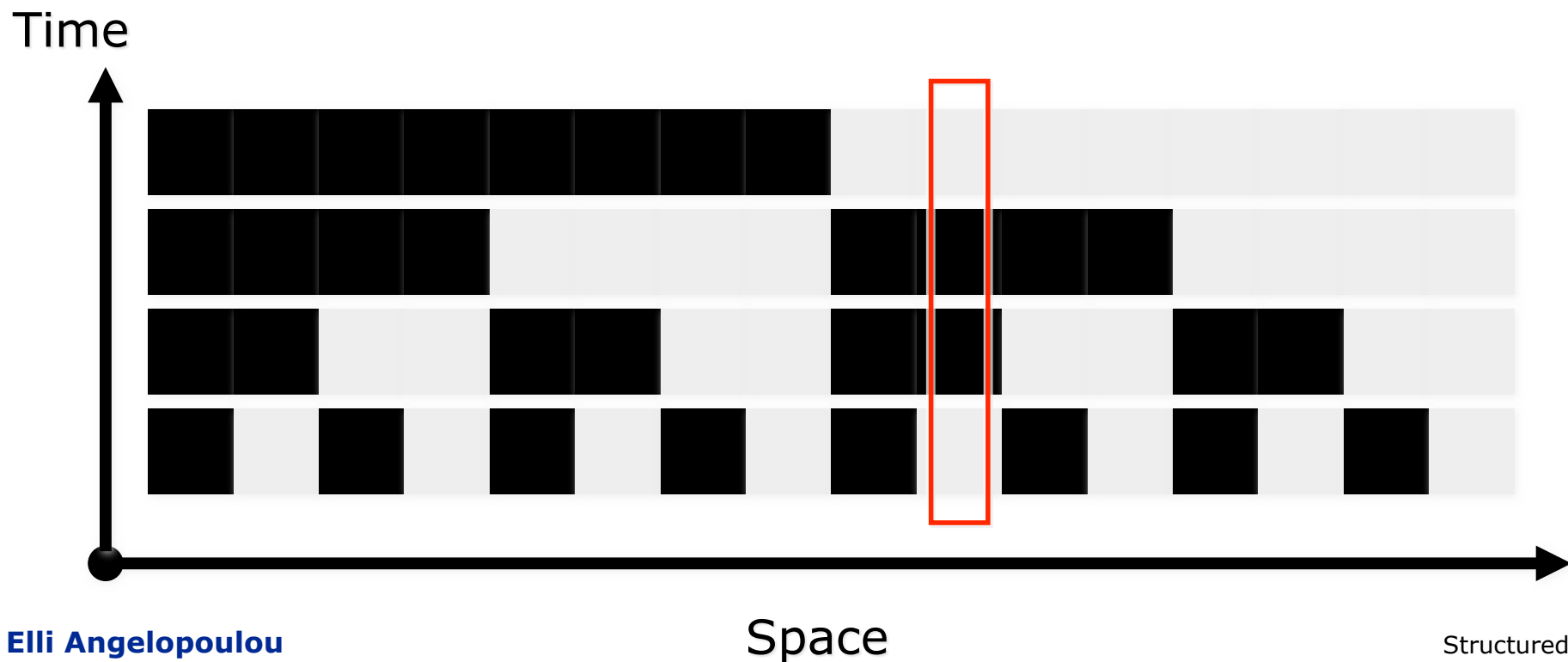
3 binary-encoded patterns which allows the measuring surface to be divided in 8 sub-regions



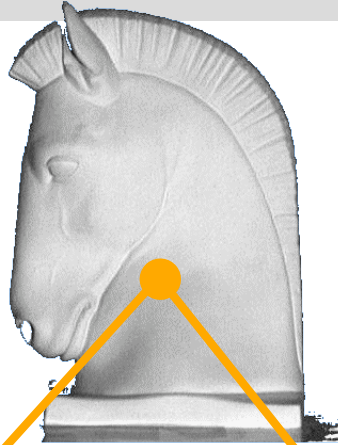
Uniqueness of Binary Coding



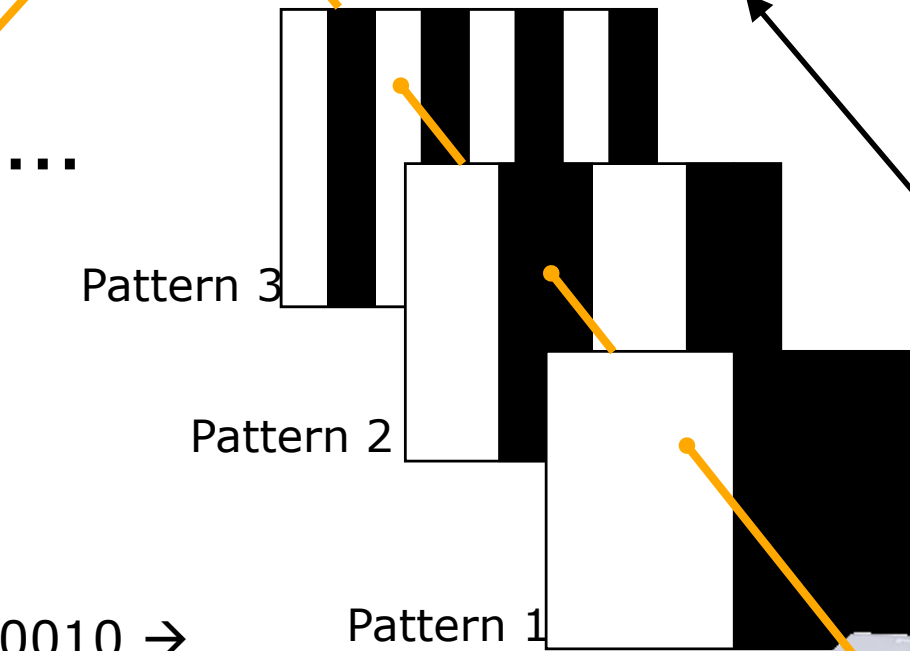
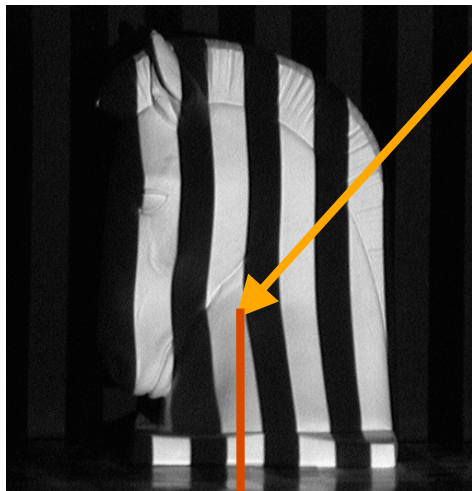
- Assign each stripe a unique illumination code over time [Posdamer 82].
- A single position in space (i.e., a single pixel), has a unique on/off pattern over the frames.
- Thus, it is easy to identify the plane of illumination.



Binary Coding Example



Example: 7 binary patterns proposed by Posdamer & Altschuler



Projected over time

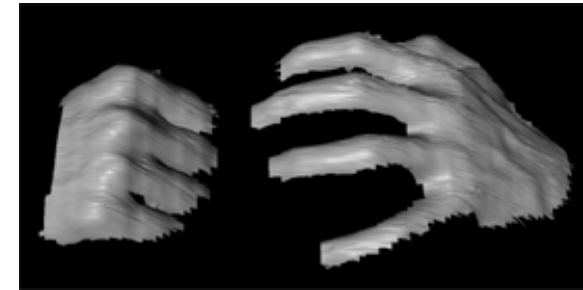
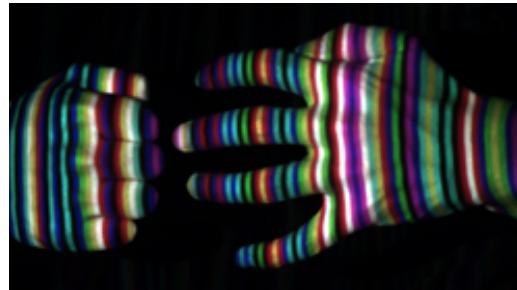
Codeword of this píxel: 1010010 → identifies the corresponding pattern stripe

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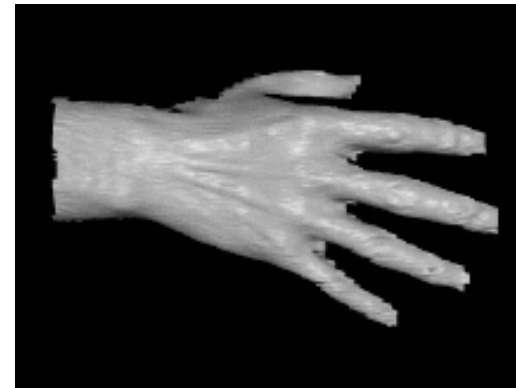
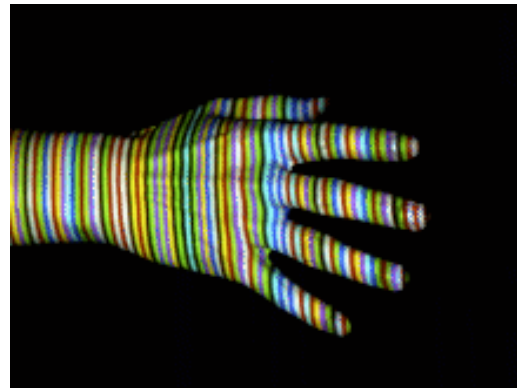


Structured Light

More Complex Light Patterns



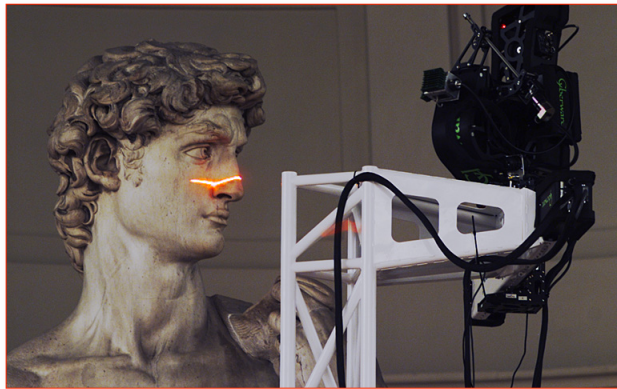
Works despite complex appearances



Works in real-time and on dynamic scenes

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

Continuum of Triangulation Methods



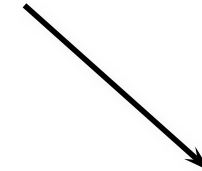
Single-stripe



Multi-stripe
Multi-frame



Single-frame



Slow, robust

Fast, fragile



Structured Light and Texture

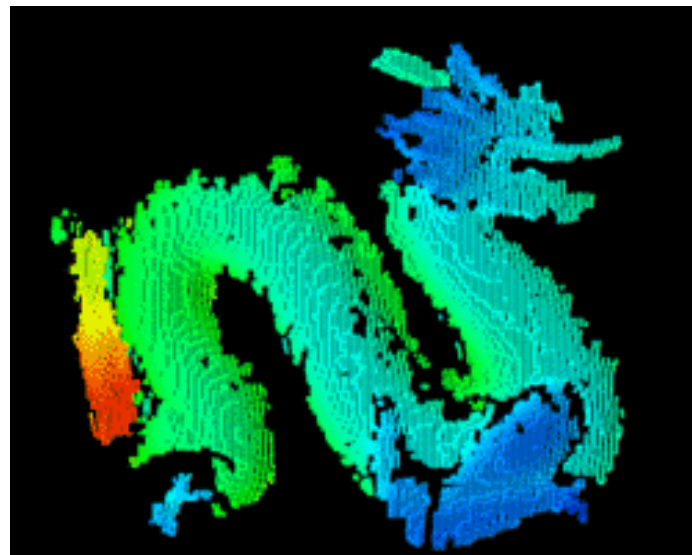
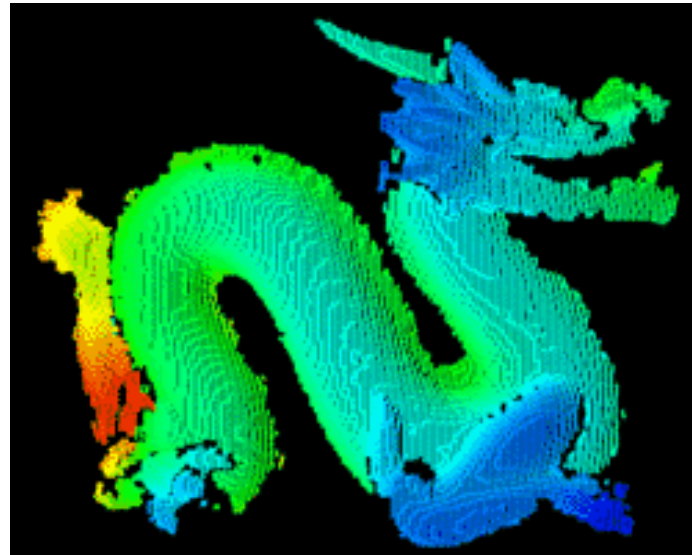


Image Sources



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 shown 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://www.cs.cmu.edu/afs/cs/academic/class/15385-s06/lectures/ppts/lec-17.ppt>