Structured Light

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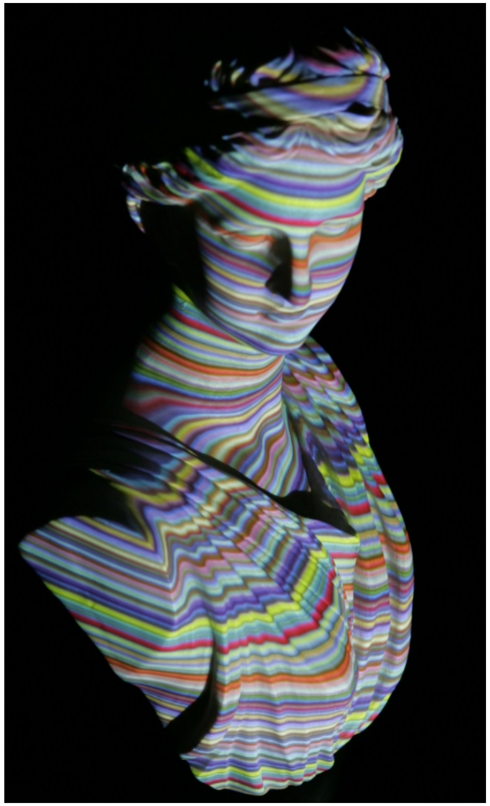
Passive Image Acquisition

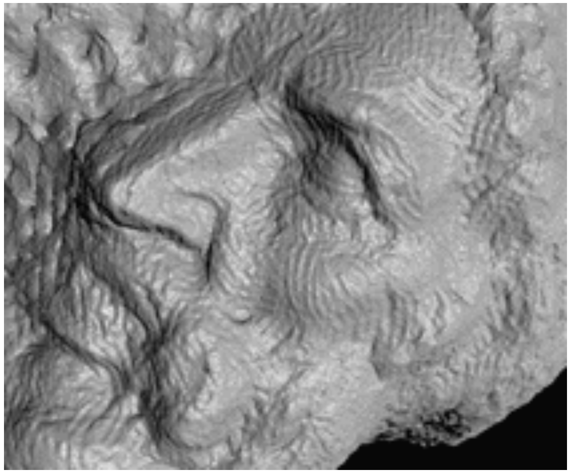
left image

right image

reconstruction

Active Image Acquisition





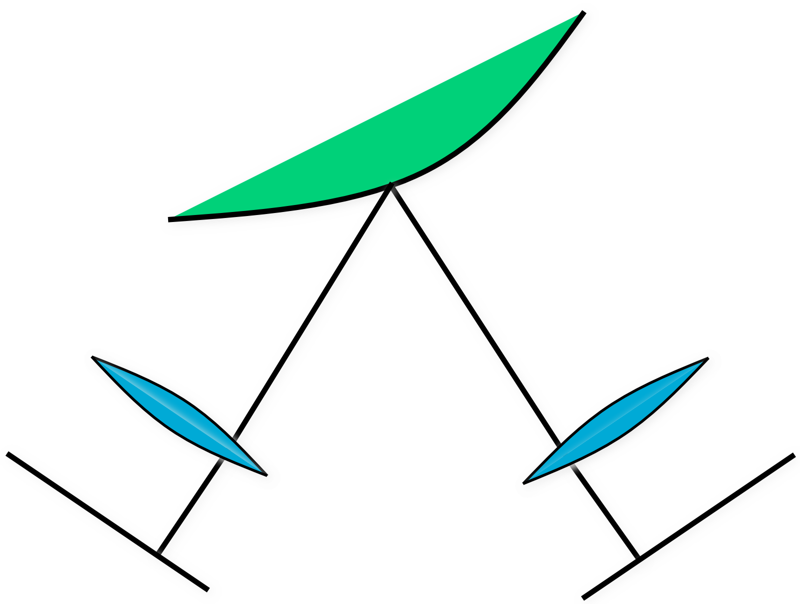
Passive versus Active Acquisition

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

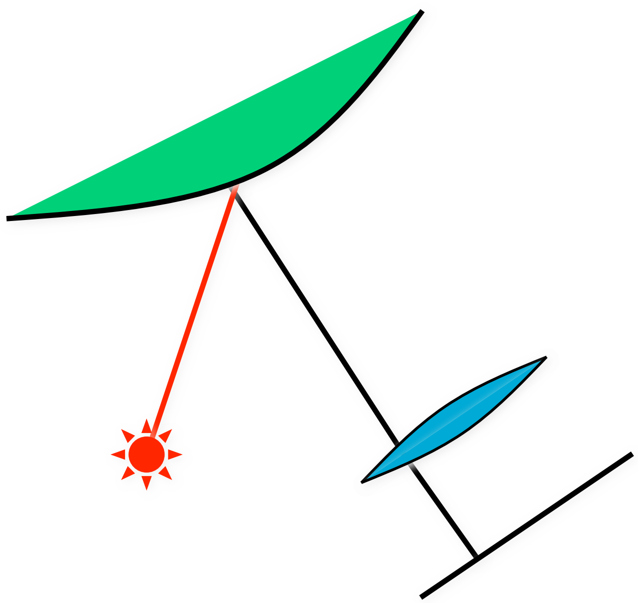
- Active (range scanning, ToF, structured light)
  - More robust correspondence.
  - Can recover data even at featureless parts of the scene.
  - Higher accuracy but possibly sparser depth maps.
  - Very popular in industrial setups
  - More complex data hardware.
  - Intrusive (active illumination may alter scene appearance)
  - Limited range of depth.

Passive versus Active Acquisition

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

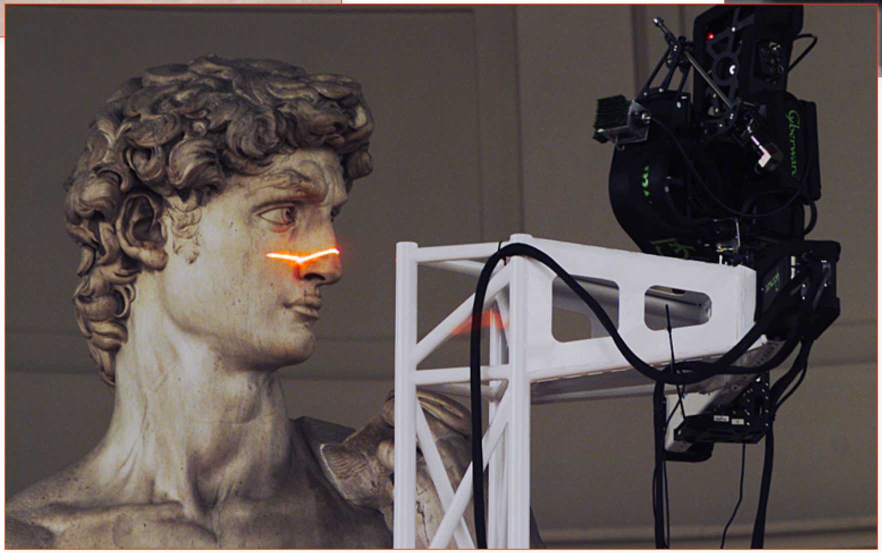


Passive Setup

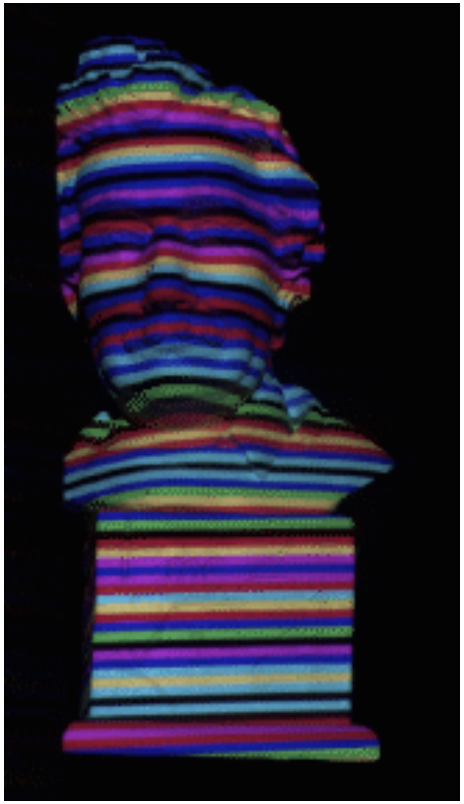


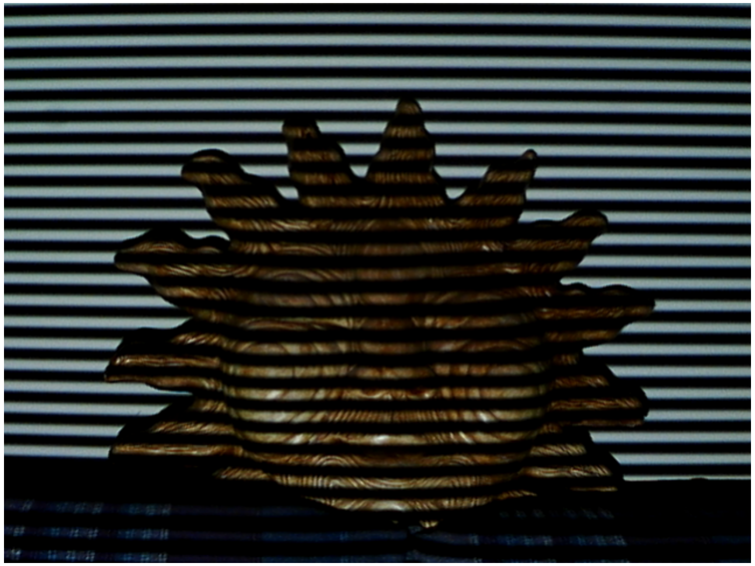
Active Setup

Laser Scanning

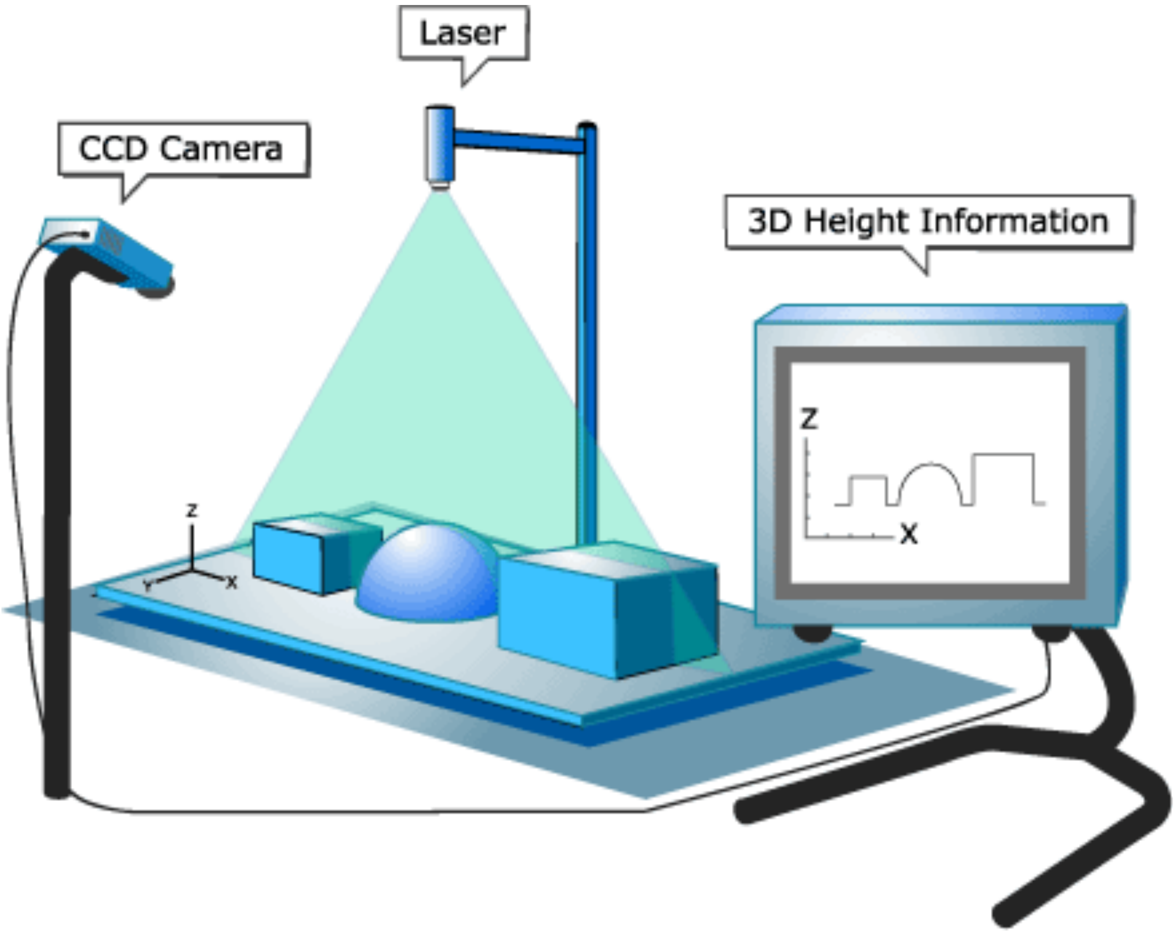


Structured Light



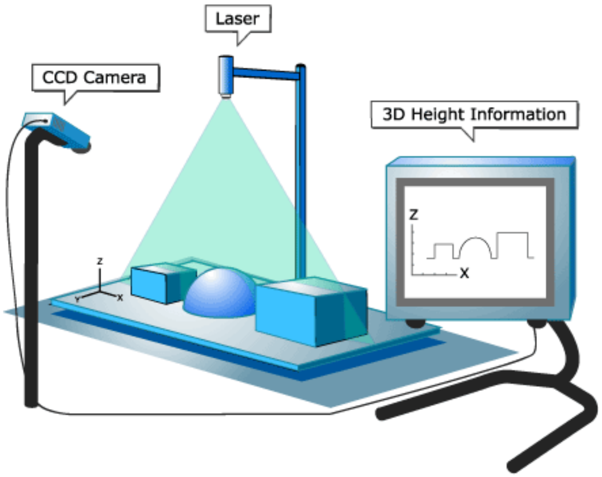


Basic Concept

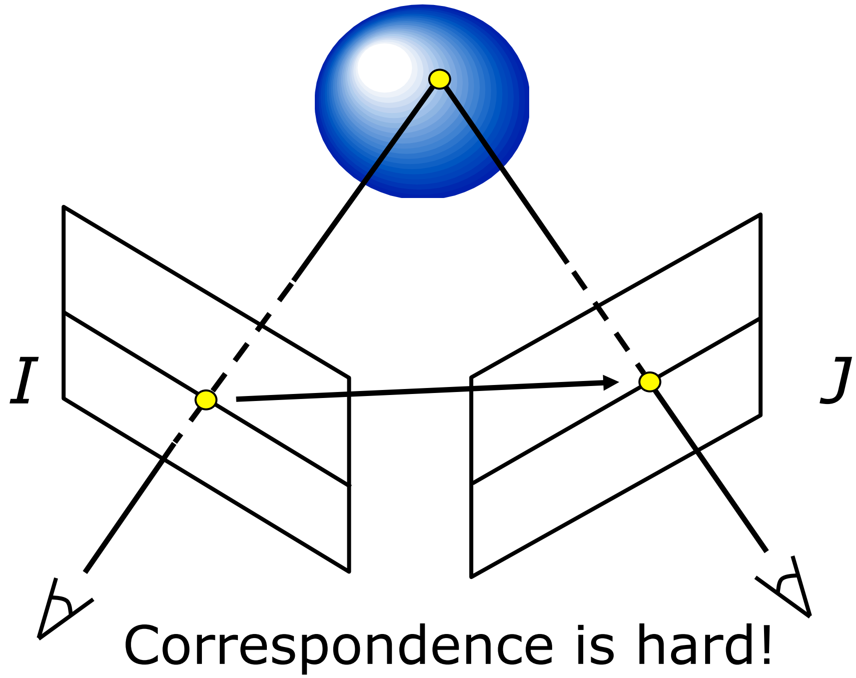


Basic Concept

- 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 **main** source of illumination
- Depending on the shape of the object the pattern is distorted.
- A camera captures the distorted pattern.
- Prior knowledge:
  - known geometry of light pattern
  - known relative position of light and camera.

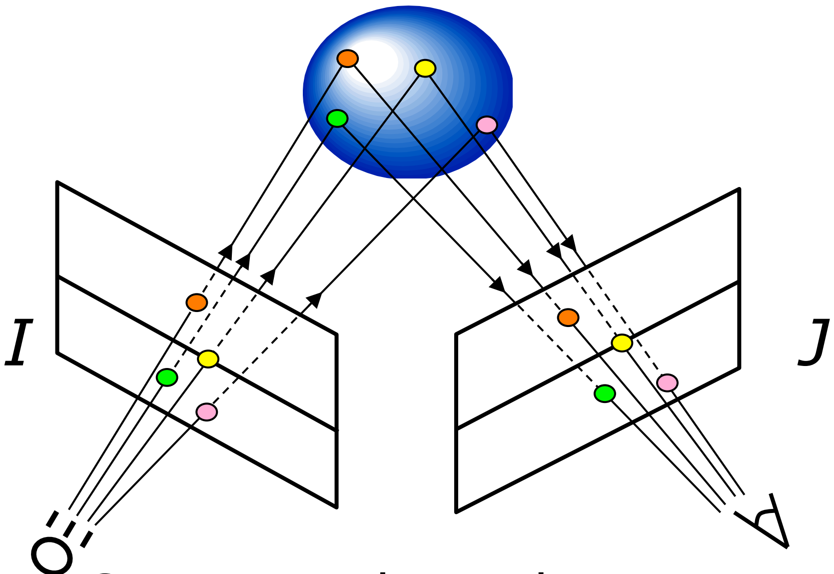


Stereo Triangulation



- 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 is often done in an error (dissimilarity) minimization framework.

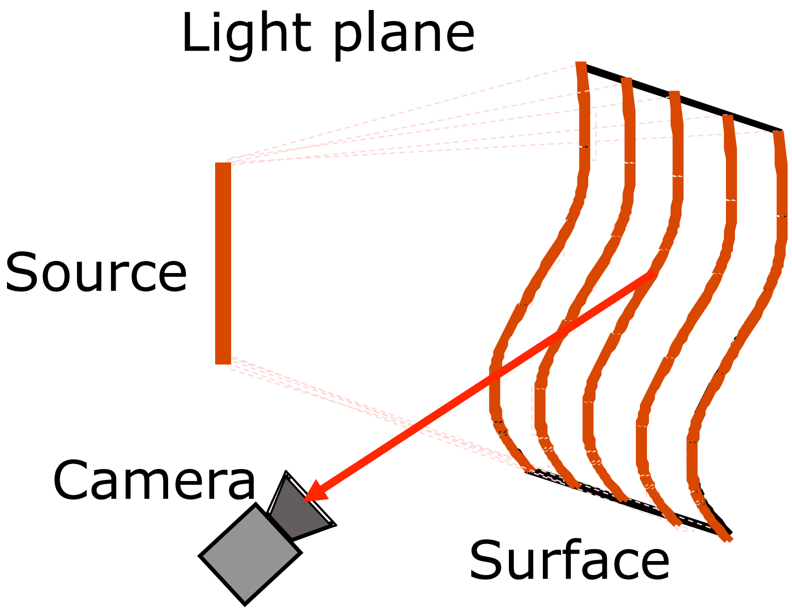
Structured Light Triangulation



Correspondence becomes easier!

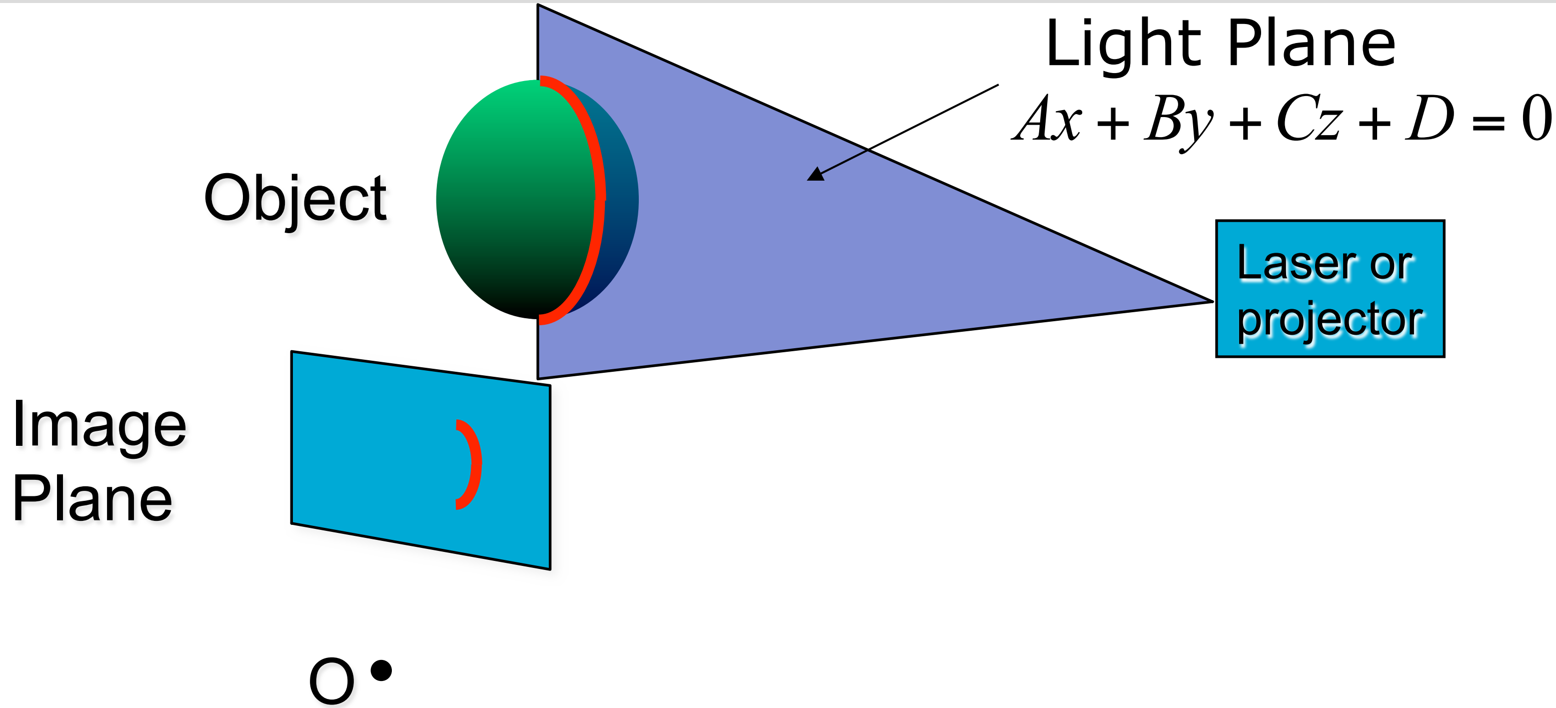
- In structured light correspondence is more constrained.
- We add information by using either a single stripe of light or a relatively unique light pattern.
- Either match across a single laser stripe.
- Or, instead of matching one pixel at a time, we can exploit the knowledge about the light pattern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

Single Stripe Scanning



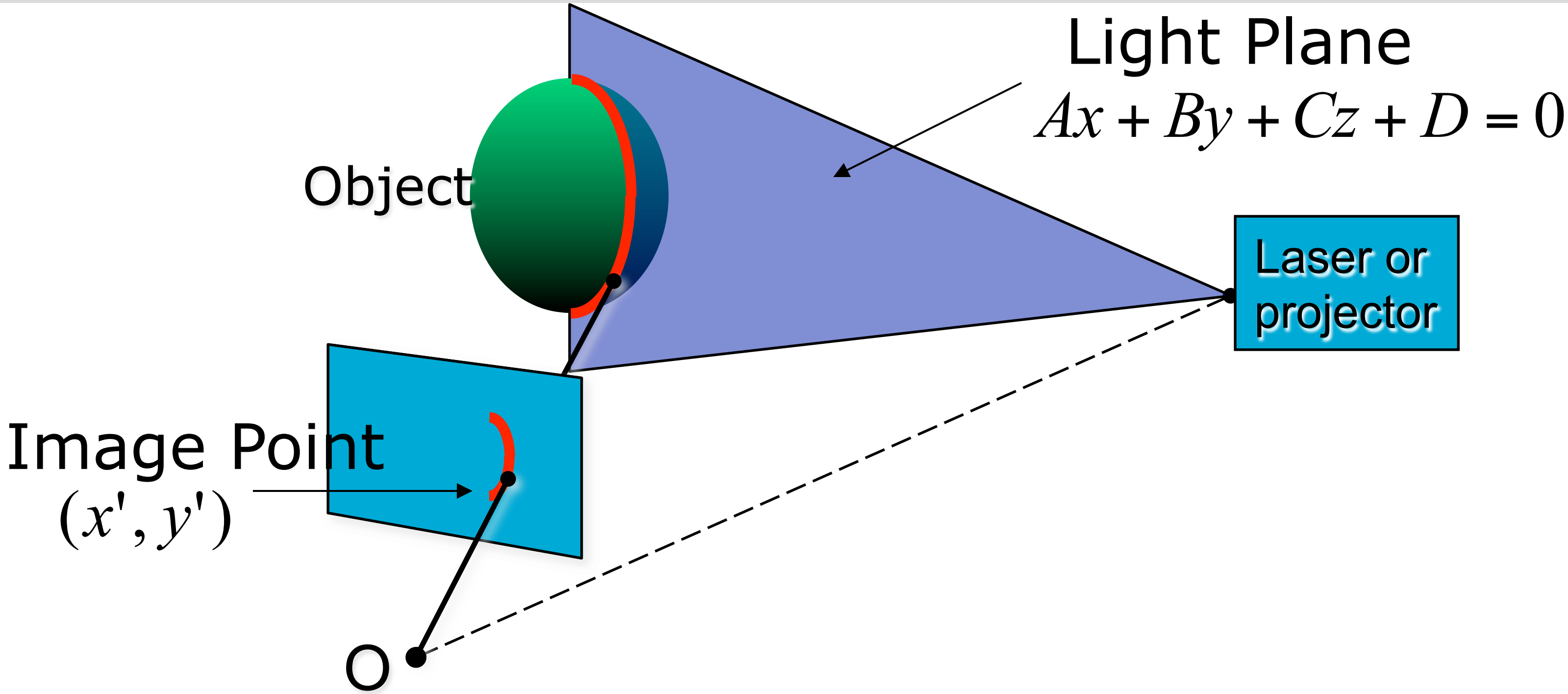
- Optical triangulation
  - Project a single stripe of light (from laser or projector)
  - Scan it across the surface of the object
  - This is a very precise version of structured light scanning
  - Good for high resolution 3D, but needs many images and takes time

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

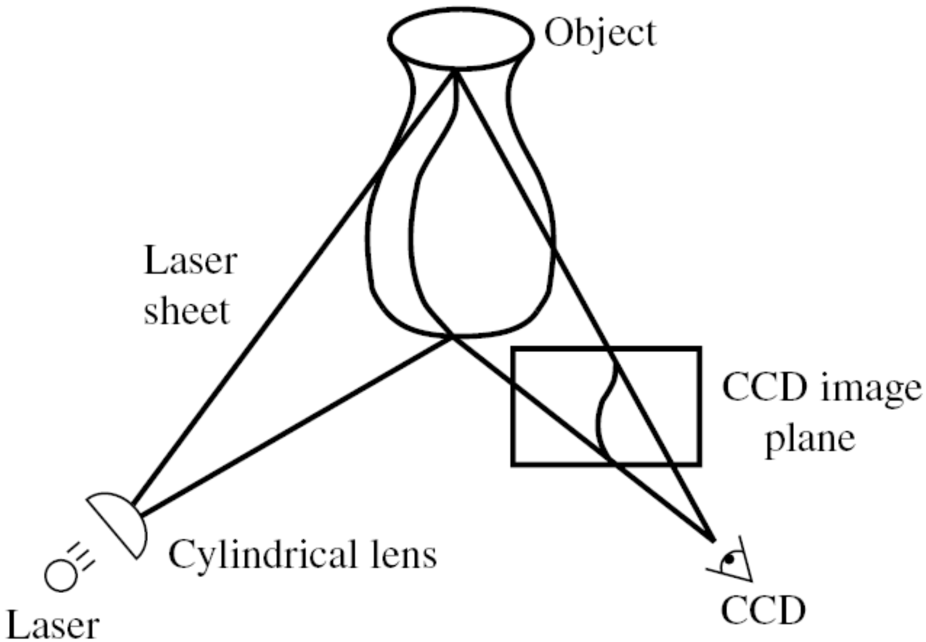


- Depth from ray-plane triangulation:
  - Intersect camera ray with light plane

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

$$y = y' z / f$$

Example: Laser Scanner

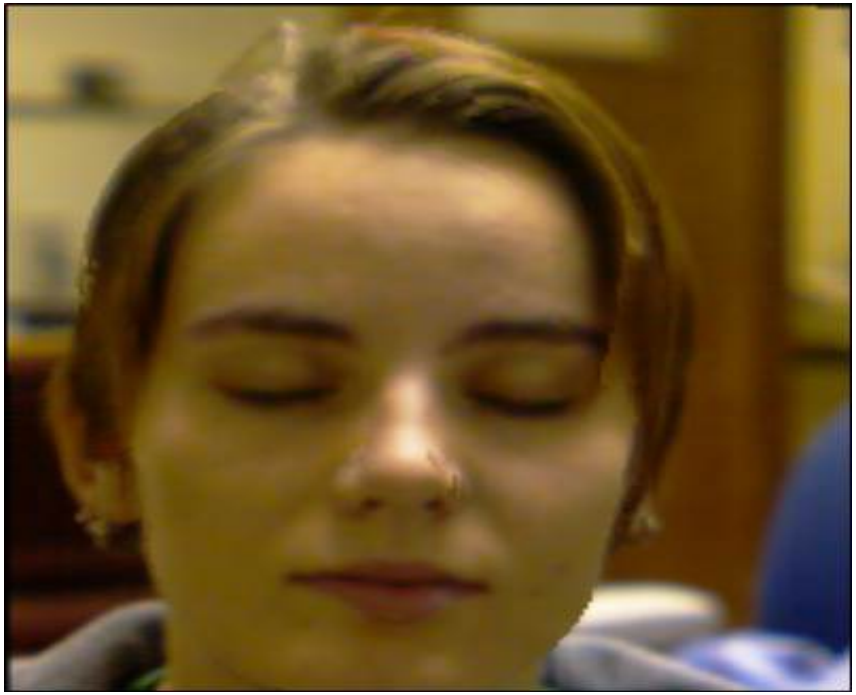


Cyberware® face and head scanner

+ 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

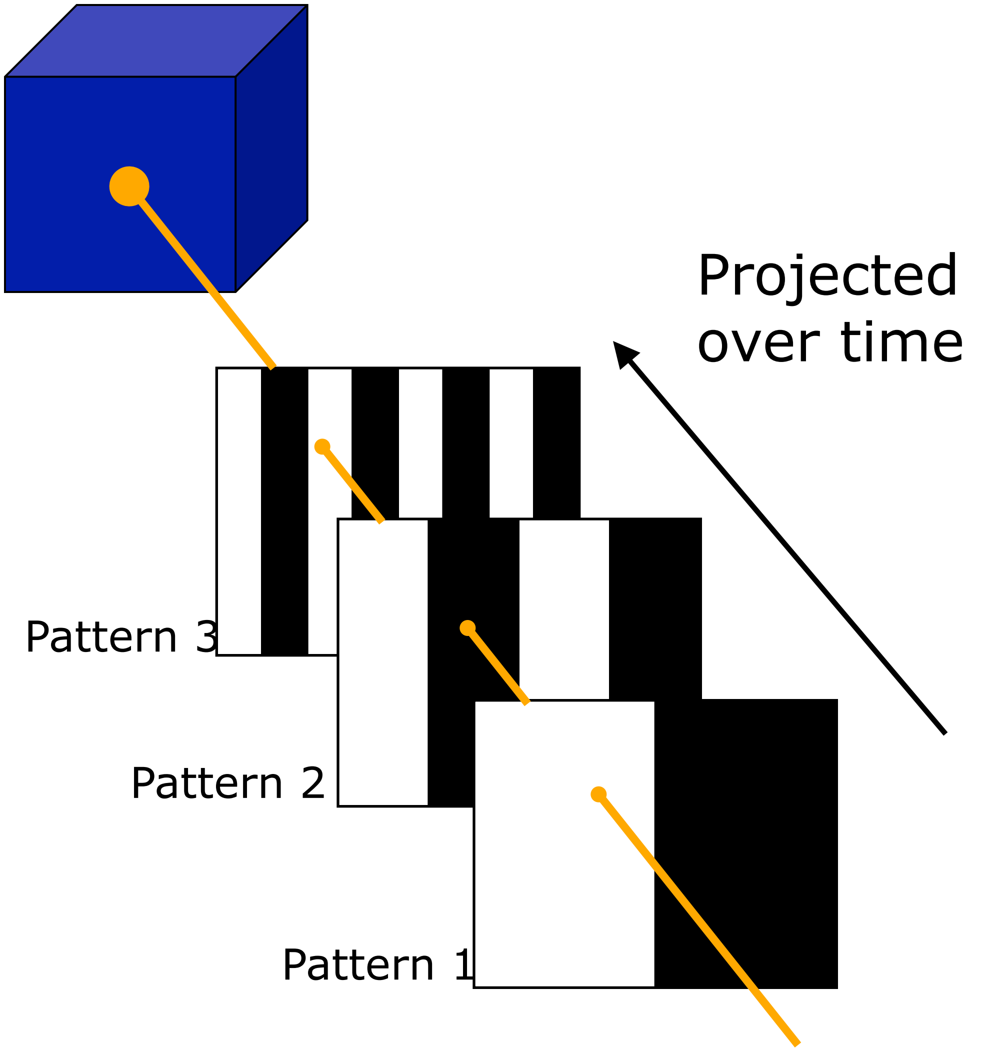
Binary Coding Idea

Faster:

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

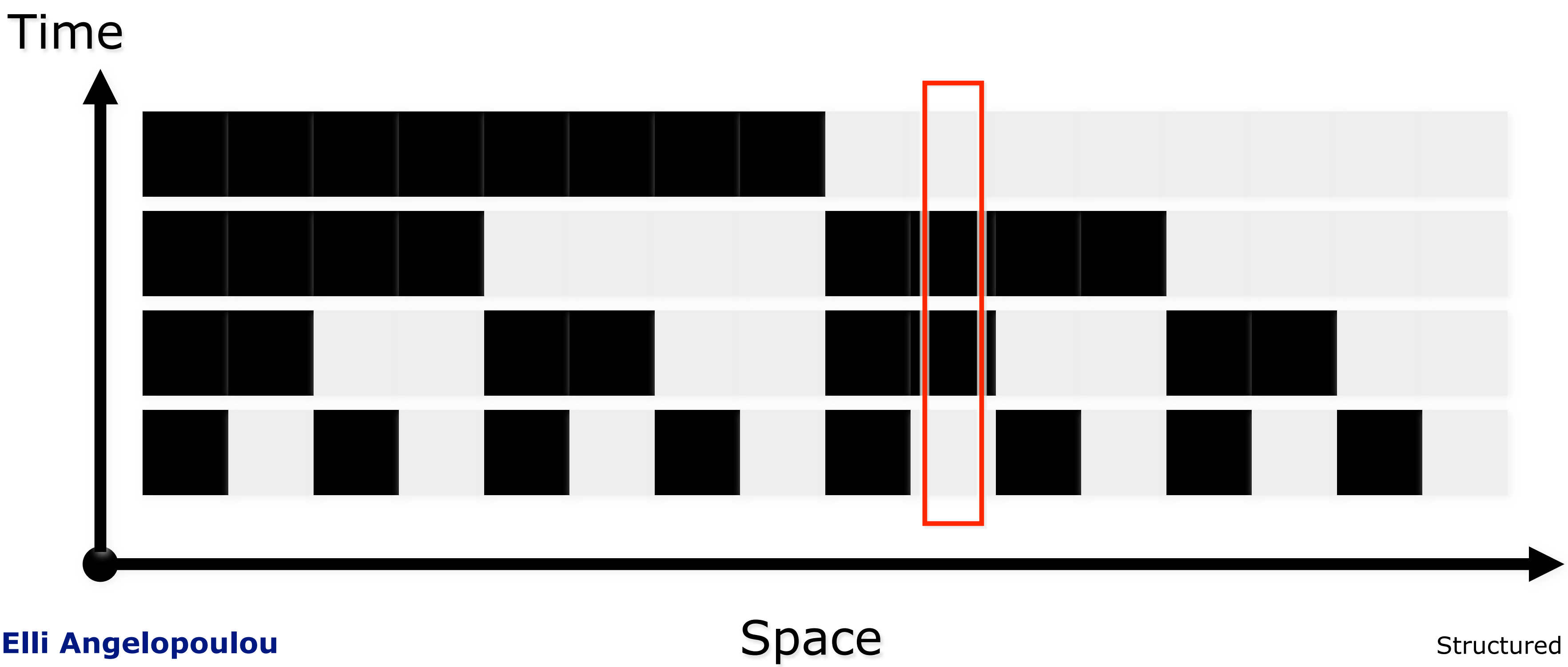
Example:

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

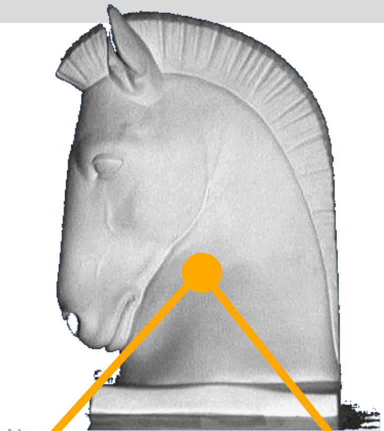


Uniqueness of Binary Coding

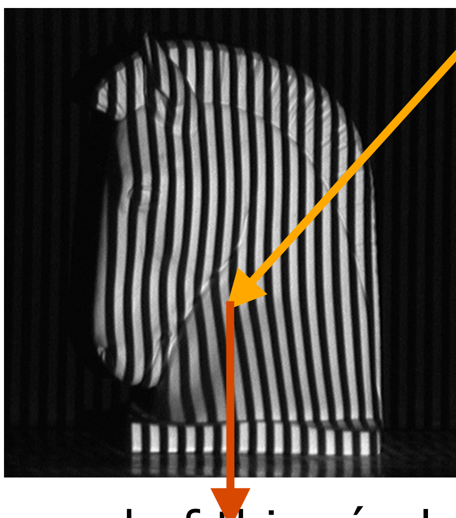
- Assign each stripe a unique illumination code over time [Posdamer 82].
- A single position in space (i.e., a single pixel), has a unique on/off pattern over the frames.
- Thus, it is easy to identify the plane of illumination.



Binary Coding Example



Example: 7 binary patterns proposed by Posdamer & Altschuler



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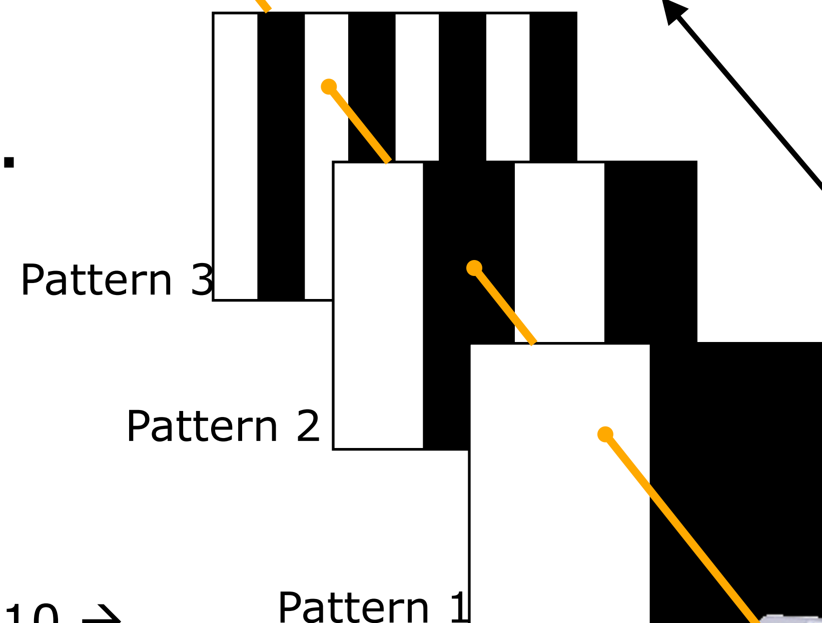
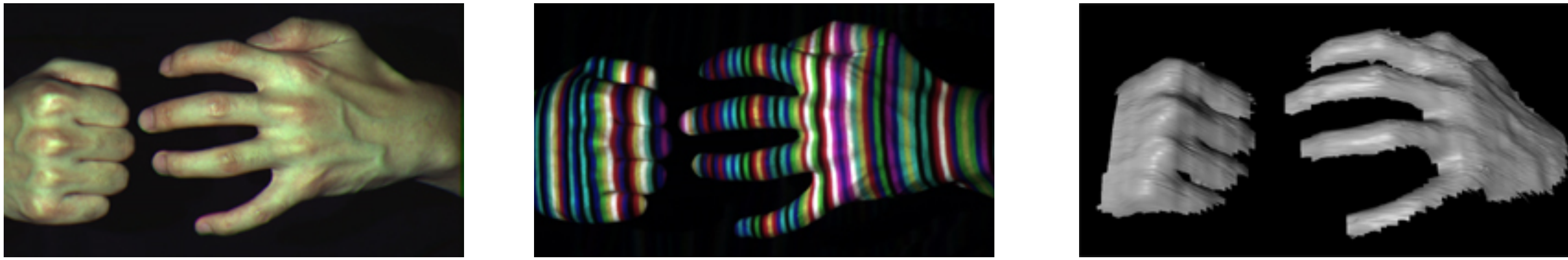


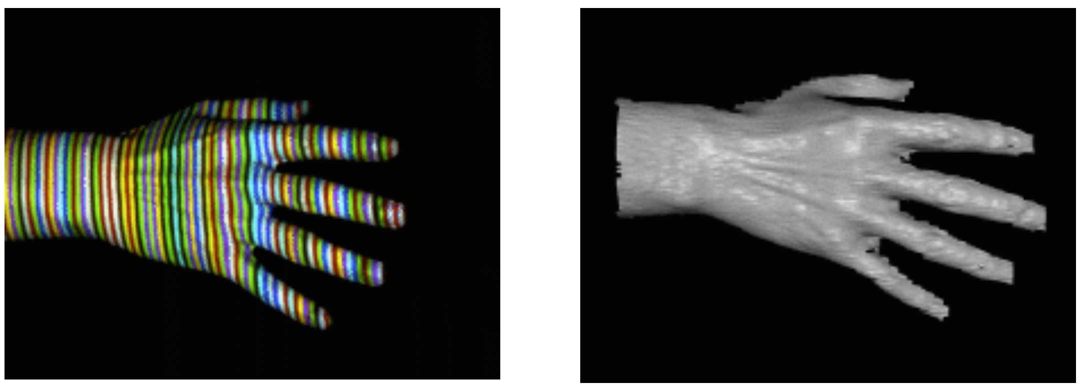
Projected over time

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

More Complex Light Patterns



Works despite complex appearances

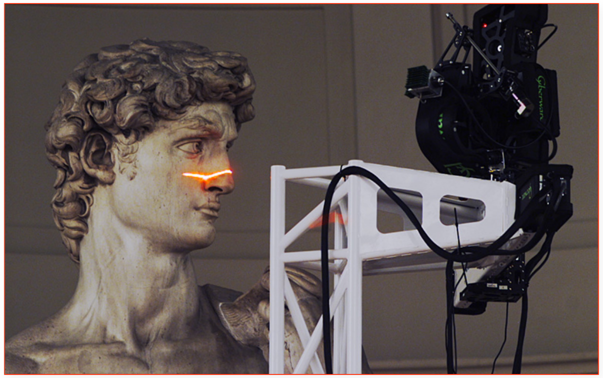


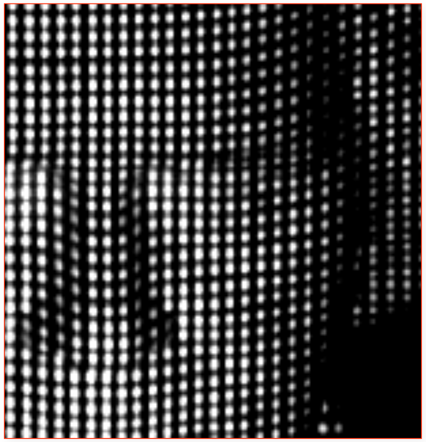
Works in real-time and on dynamic scenes

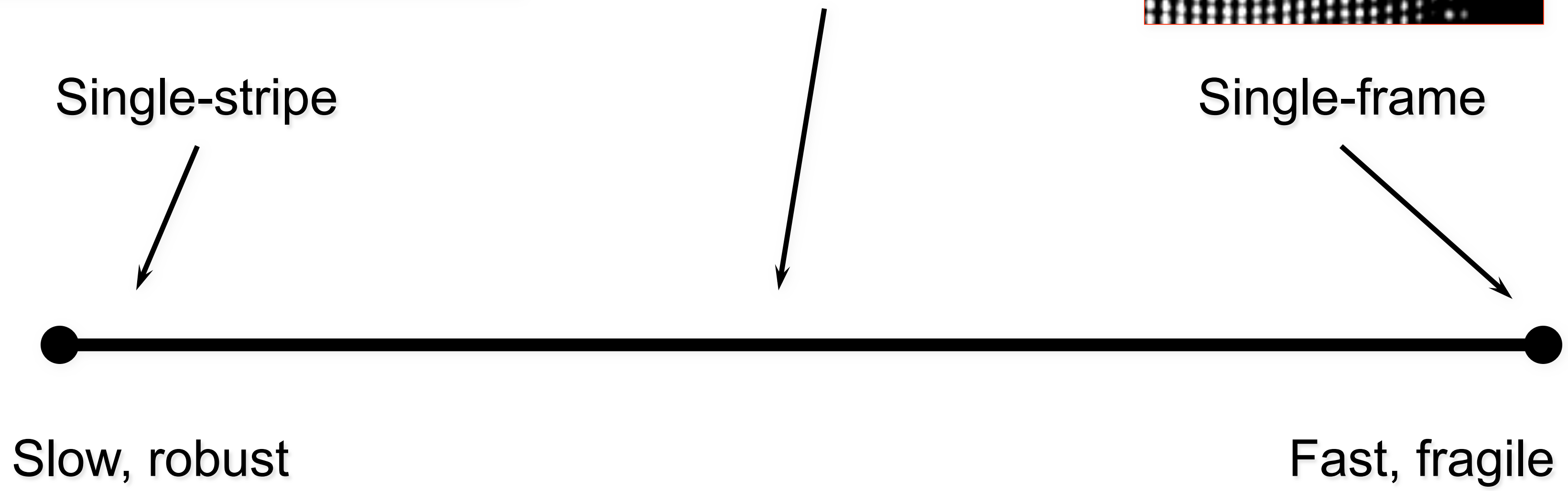
- Need very few images (one or two).
- But needs a more complex correspondence algorithm

By Zhang et al.

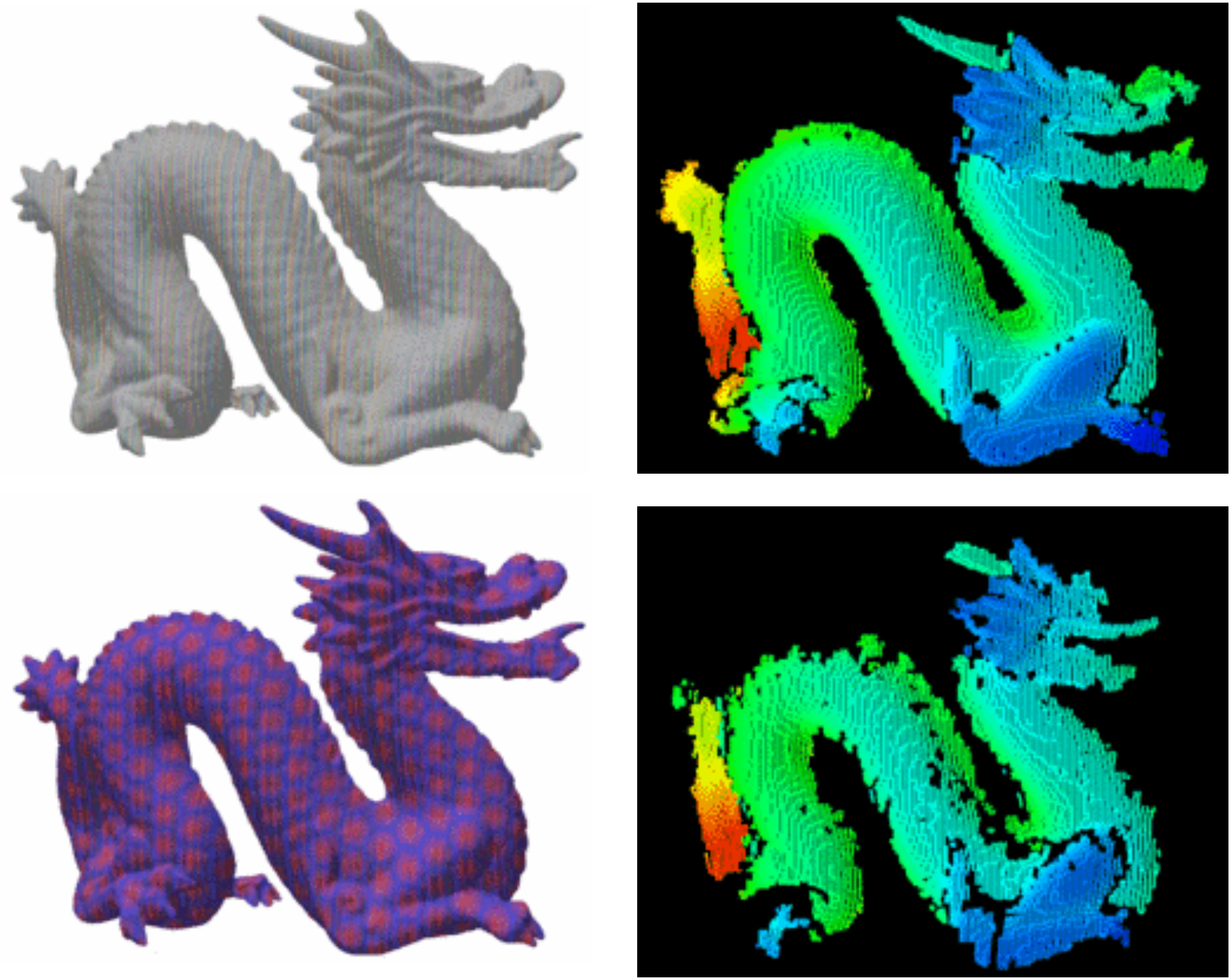
Continuum of Triangulation Methods







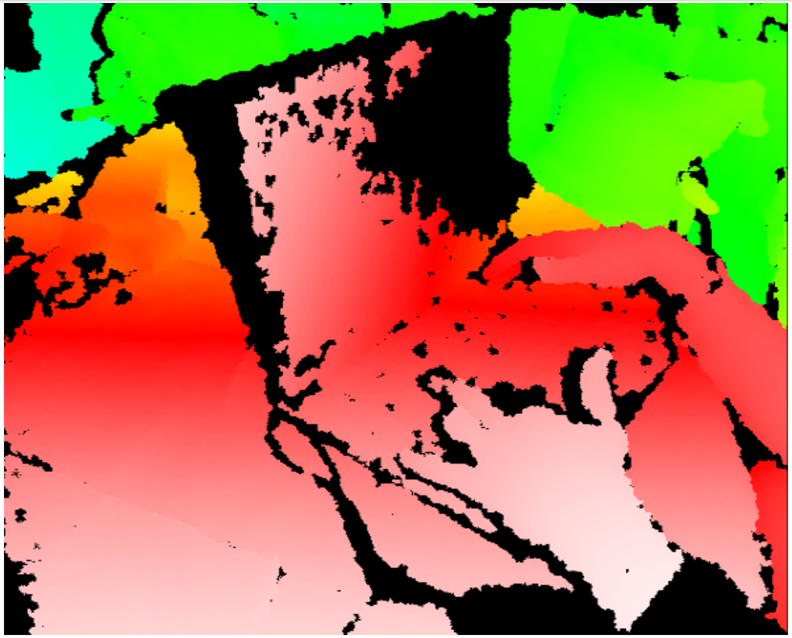
Structured Light and Texture



Kinect Sensor

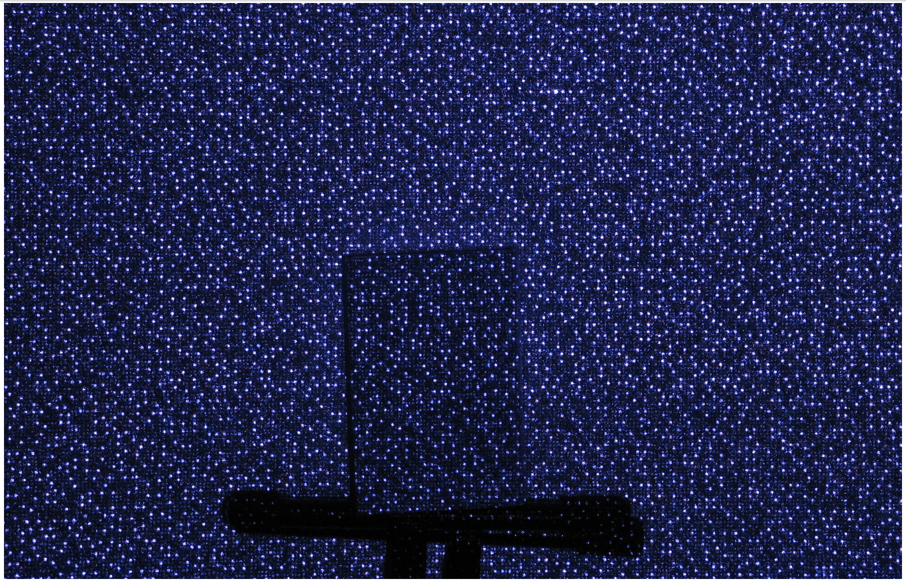
- Kinect is marketed as a motion sensing device.
- It has a number of sensors:
  - An RGB camera (the middle of the 3 lenses)
  - A unique structured-light system (projector is on the left and gray-scale camera is on the right)
  - 4 microphones distributed along its length, to better locate (via triangulation) the sources of voices.

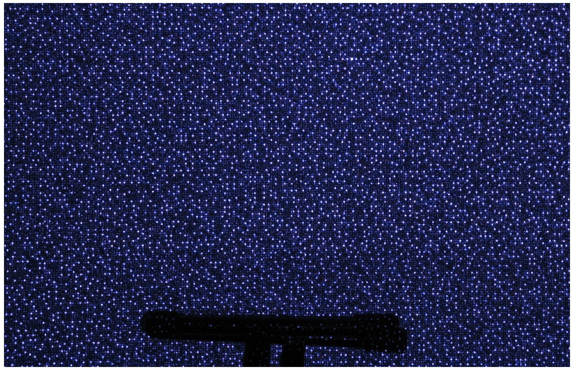
Kinect "Range Camera"

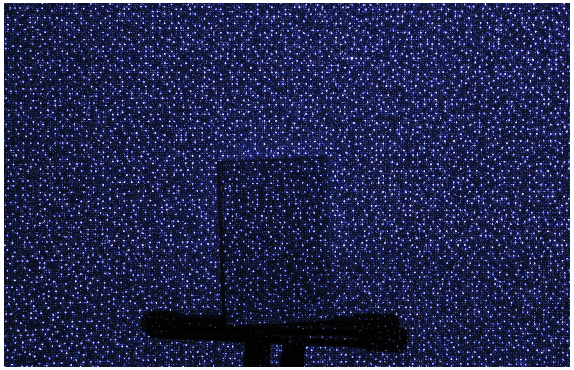


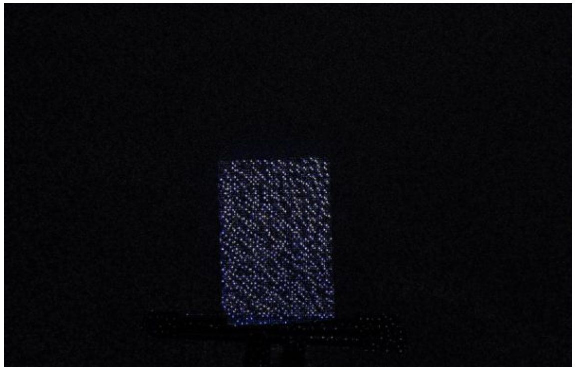
- The projector projects an imperceptible infrared light pattern.
- Adjustable depth sensing range between 1.2 and 3.5m.
- The patent is on the "special laser point pattern".
- It generates a speckle pattern that varies along the Z direction.
- It is created by positioning a holographic diffuser in-front of a near IR laser. The diffuser causes the speckle pattern.

Kinect "Range Camera" - continued









- Depth is computed by measuring the relative shift of the features of the random pattern in the image relative to the pattern in a known reference image.
- The shift (much like the binocular stereo shift) is identified by using window-based normalized cross-correlation.

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
12. The Kinect Speckle Field information is from "Kinect Hacking 101", http://www.futurepicture.org/?p=97 , "Kinect Hacking 103", http://www.futurepicture.org/?p=116