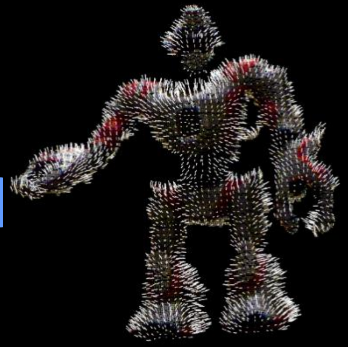
CS4495/6495
Introduction to Computer Vision



9C-L1 *3D perception*

Some slides by Kelsey Hawkins

Motivation

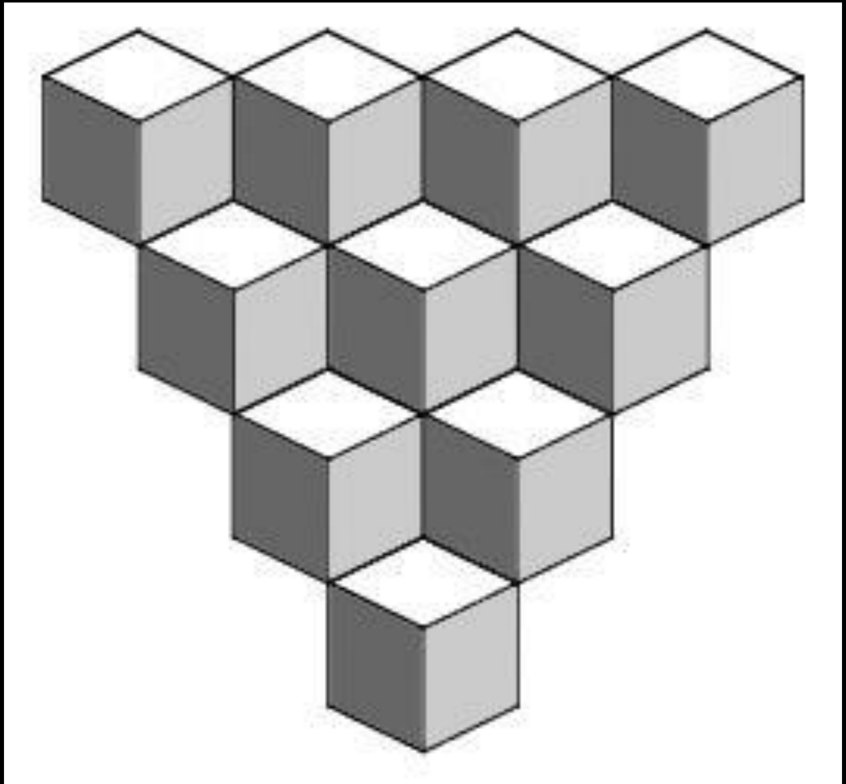
Why do animals, people & robots need vision?

- To detect and recognize objects/landmarks
  - Is that a banana or a snake? A cup or a plate?
- To find relative location of objects
  - Want to grasp fruit/tool, where should I put my body/arm?
  - Changes in elevation: steps, rocks, inclined planes

Motivation

- Determine shape
  - What is the physical 3D structure of this object?
  - Where does an object begin and the background begin?
- Find obstacles and map the environment
  - How do I get my body/arm from A to B without hitting things?
- Others – tracking, dynamics, etc.

Weaknesses of images



Surface Geometry

Weaknesses of images

Color Inconsistency

Weaknesses of monocular vision

Scale

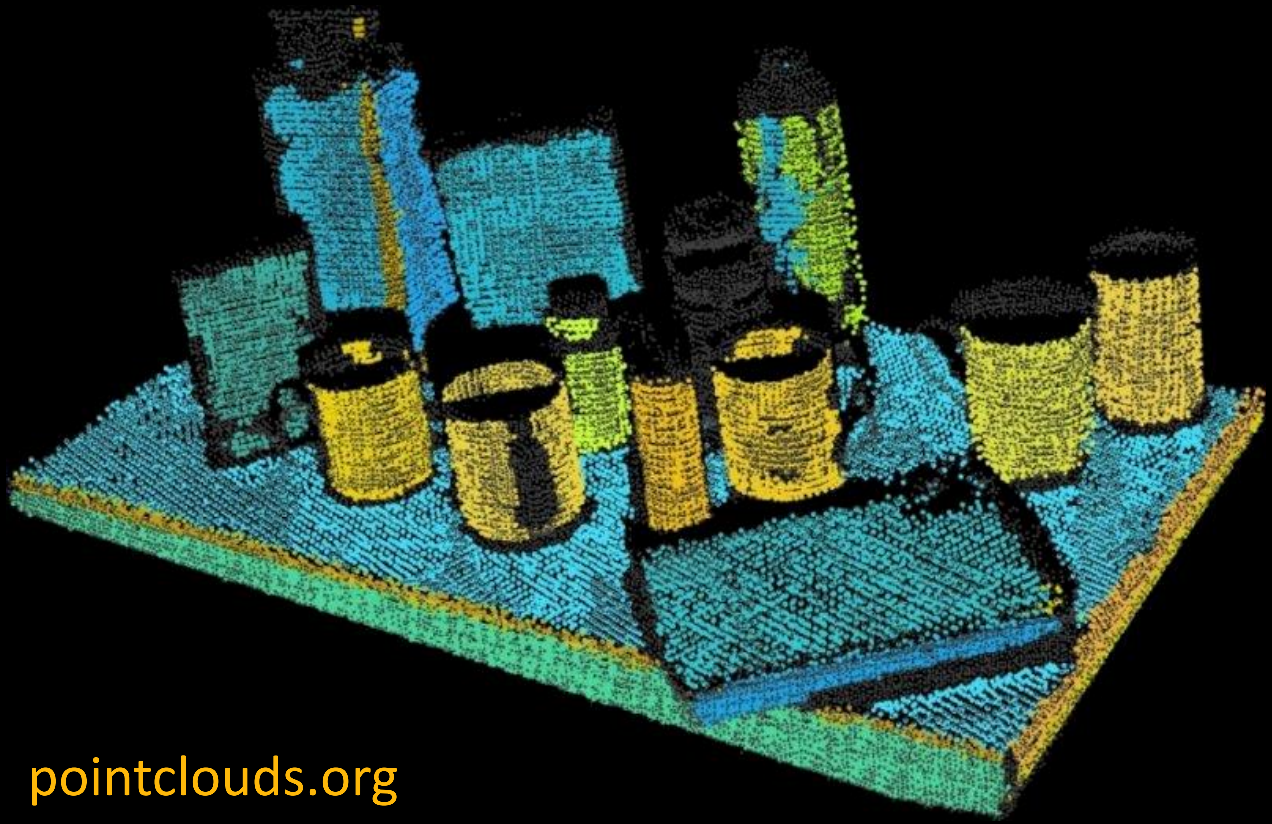
Weaknesses of monocular vision

Lack of texture

Weaknesses of monocular vision

Background-foreground similarity

Potential solution: 3D sensing



pointclouds.org

Types of 3D sensing

- Passive 3D sensing
  - Work with naturally occurring light
  - Exploit geometry or known properties of scenes

Passive: 3D sensors - stereo

Amateur Stereo Rigs

Passive: 3D sensors - stereo

Professional Stereo Rigs

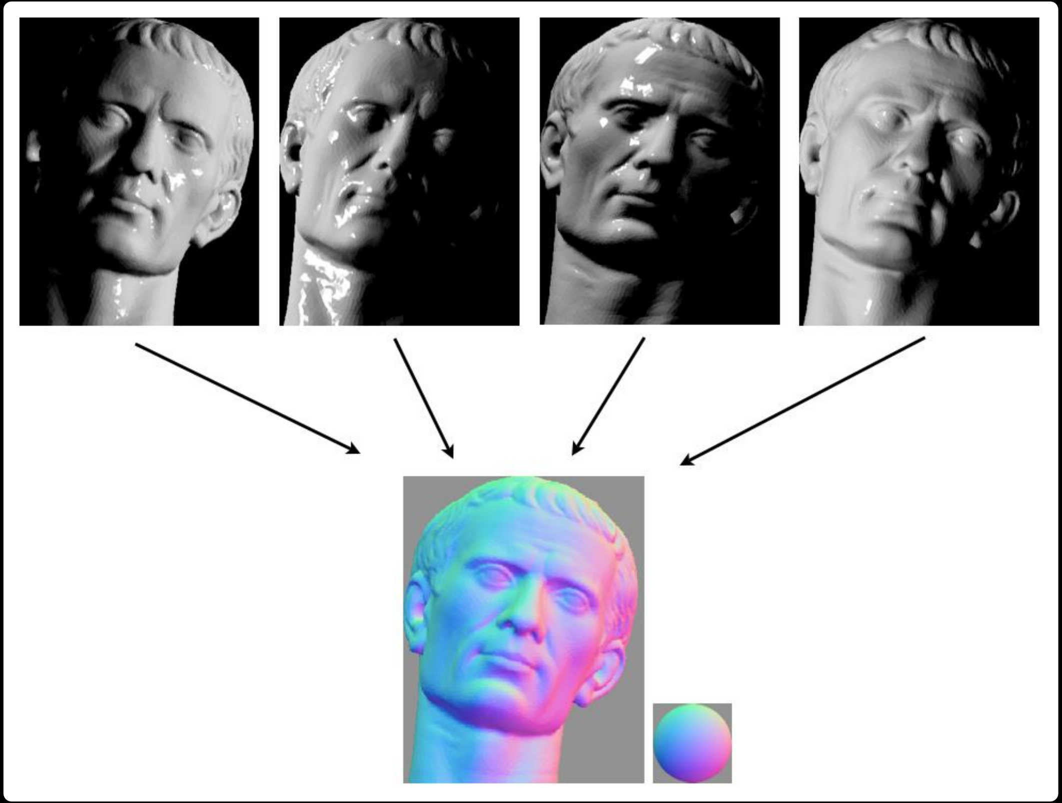
Passive: 3D sensors – shape from (de)focus

Nayar, Watanabe, and Noguchi 1996

Types of 3D sensing

- Passive 3D sensing
  - Work with naturally occurring light
  - Exploit geometry or known properties of scenes
- Active 3D sensing
  - Project light or sound out into the environment and see how it reacts
  - Encode some pattern which can be found in the sensor readings

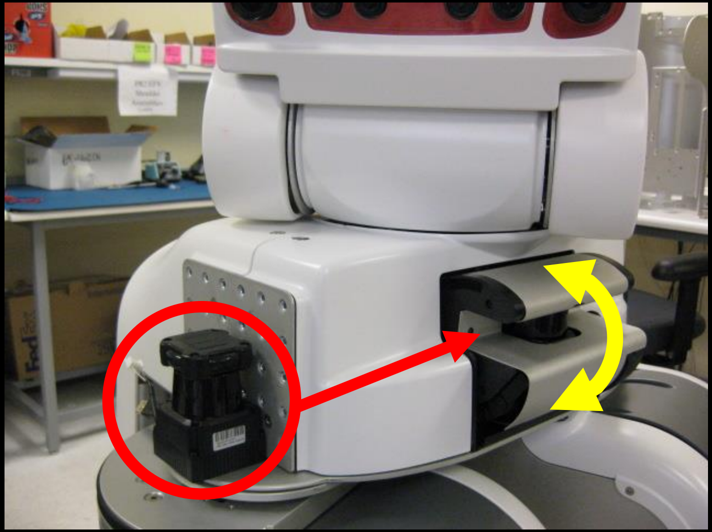
Active: Photometric stereo



Active: Time of flight

Bounce signal off of surface, record time to come back

$$d = v * t/2$$

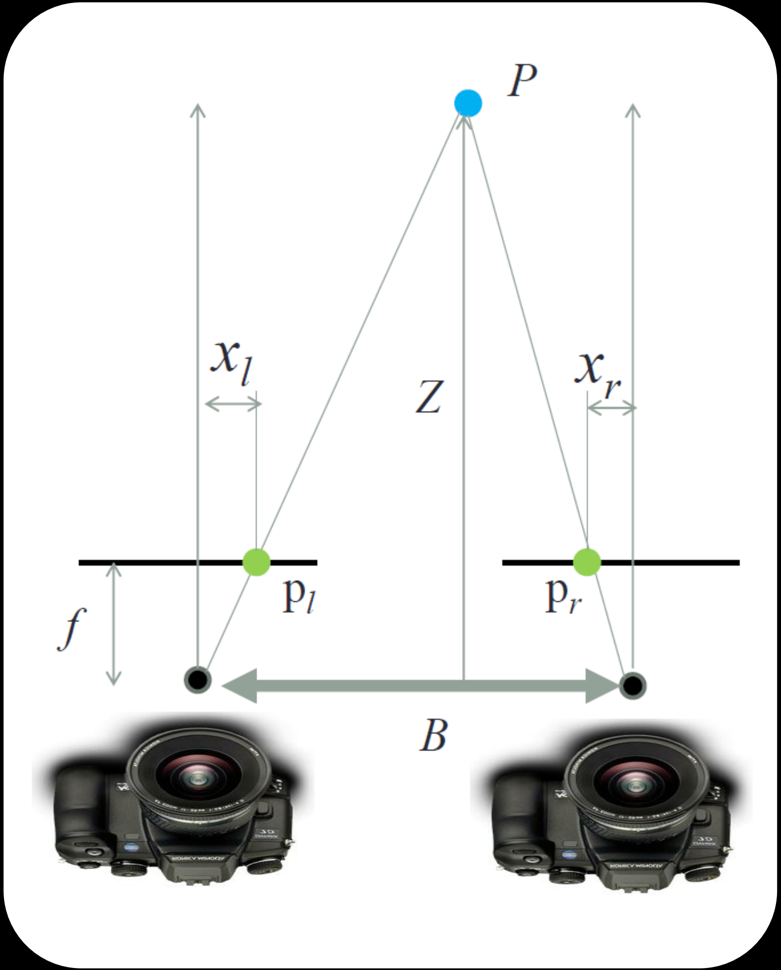


LIDAR: Laser Range finder

SONAR: Sound Transceiver

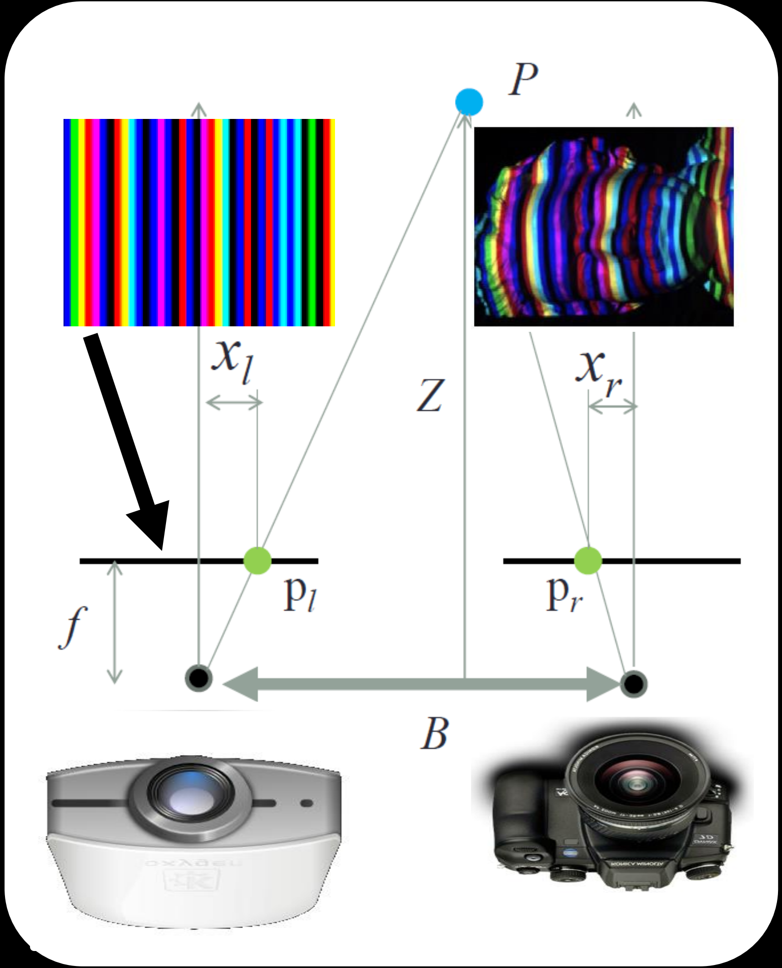
Structured light

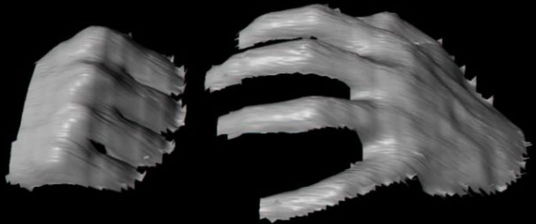
- Like stereo

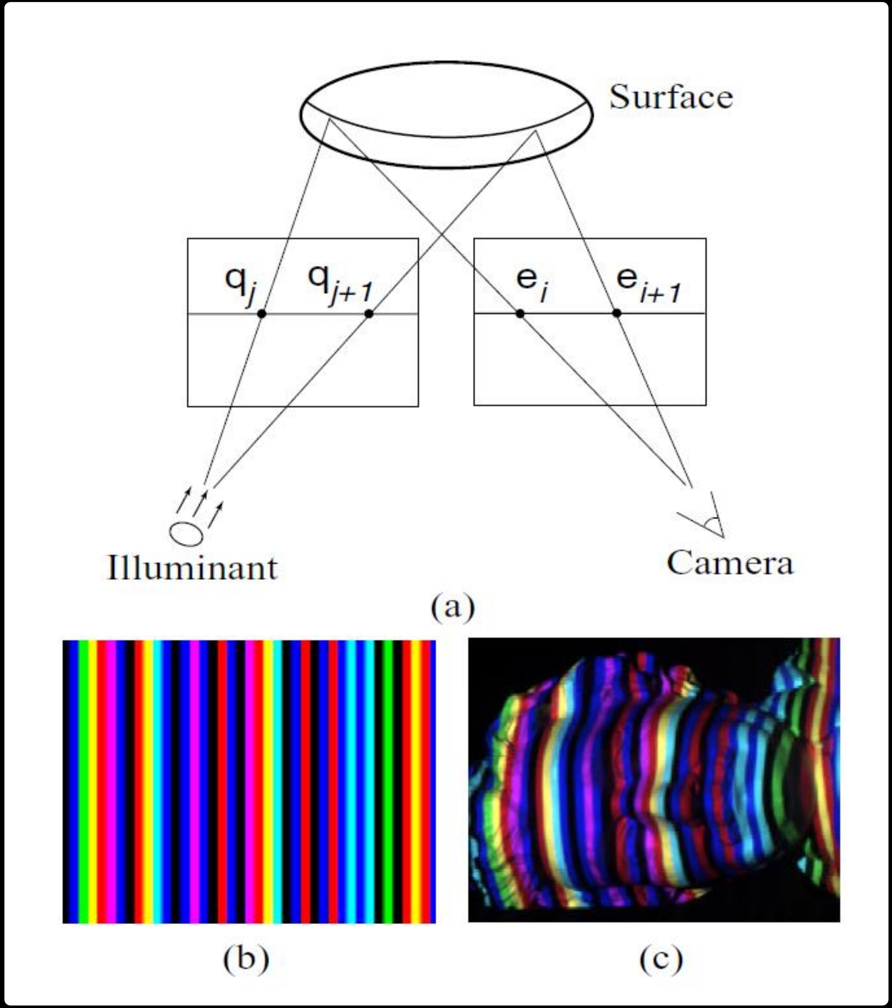


Structured light

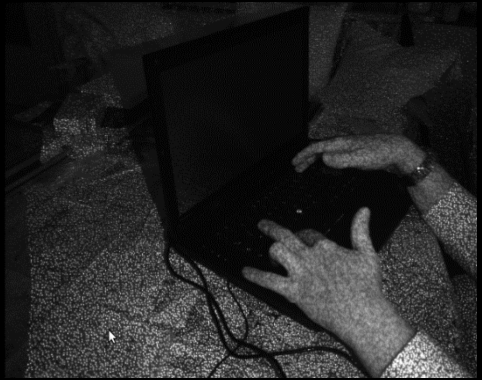
- Like stereo
- But replace one camera with a projector

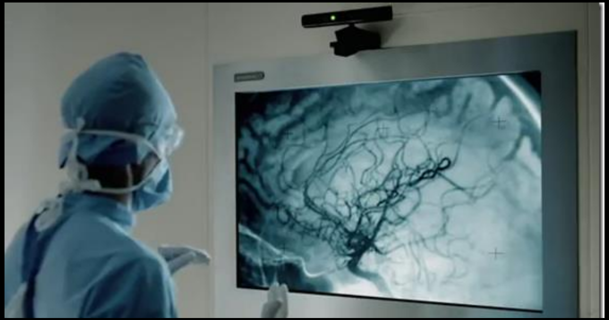




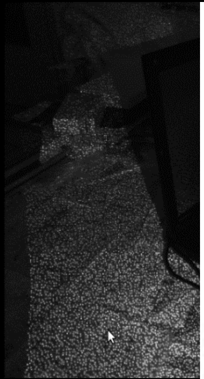

Surface
q_j
q_{j+1}
e_i
e_{i+1}
Illuminant
Camera
(a)
(b)
(c)

Infrared structured light





Infrared structured light



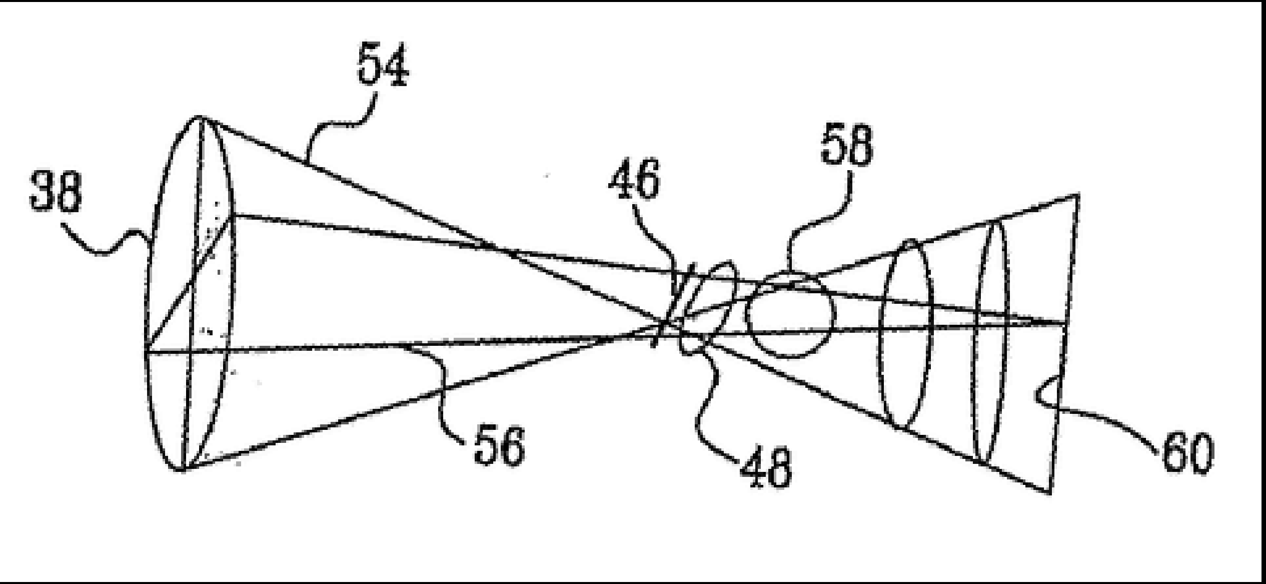
How does Kinect work?

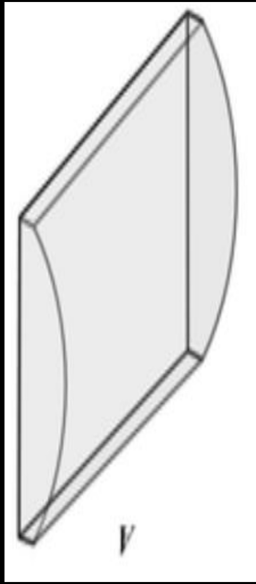
Not public, but PrimeSense patent(s) describe at least two methods:

- A very clever optics trick that changes the shape of a of projected pattern as a function of depth
- A more standard yet well engineered approach counting on have a known fixed geometry and a fixed pseudo random pattern of projected points

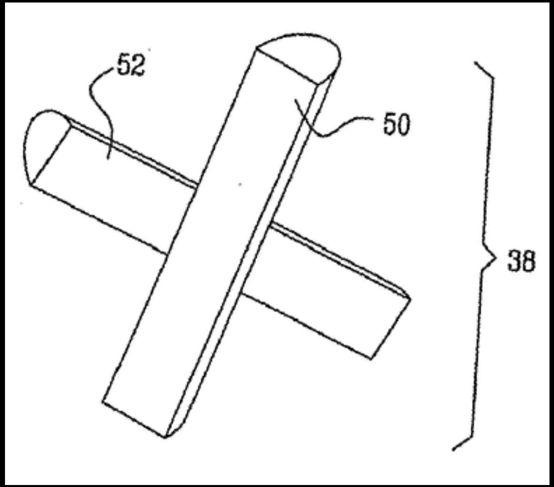
How the Kinect sensor works - focus

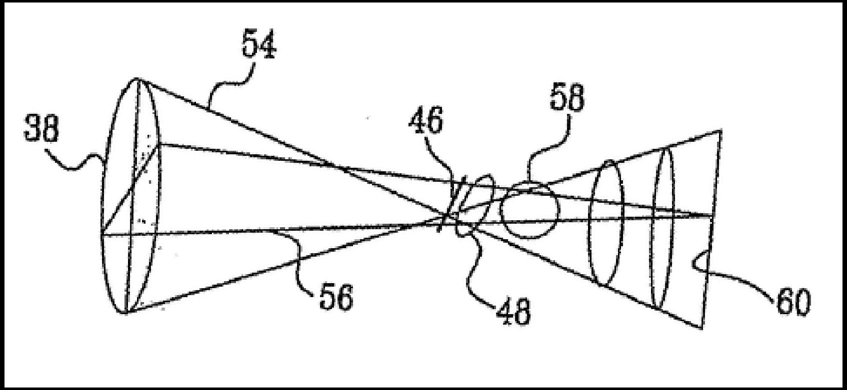
Cylindrical lens: Only focuses light in one direction

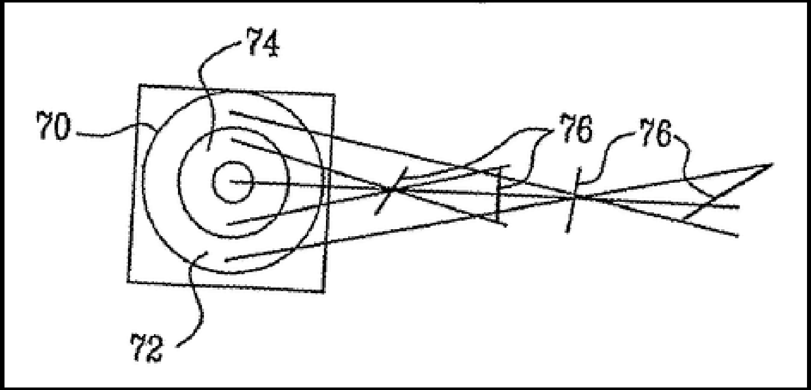




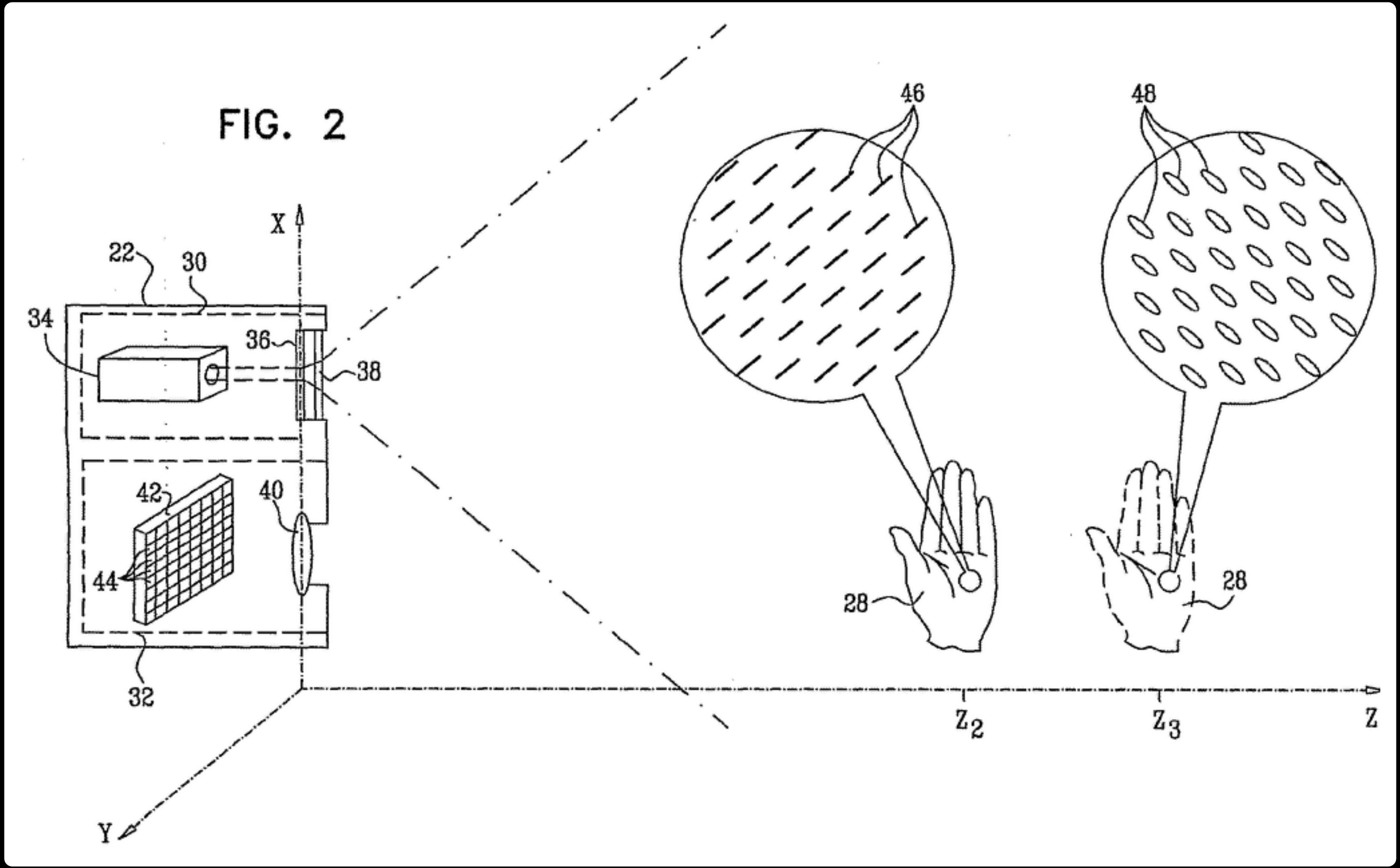
PrimeSense patent 2010/0290698





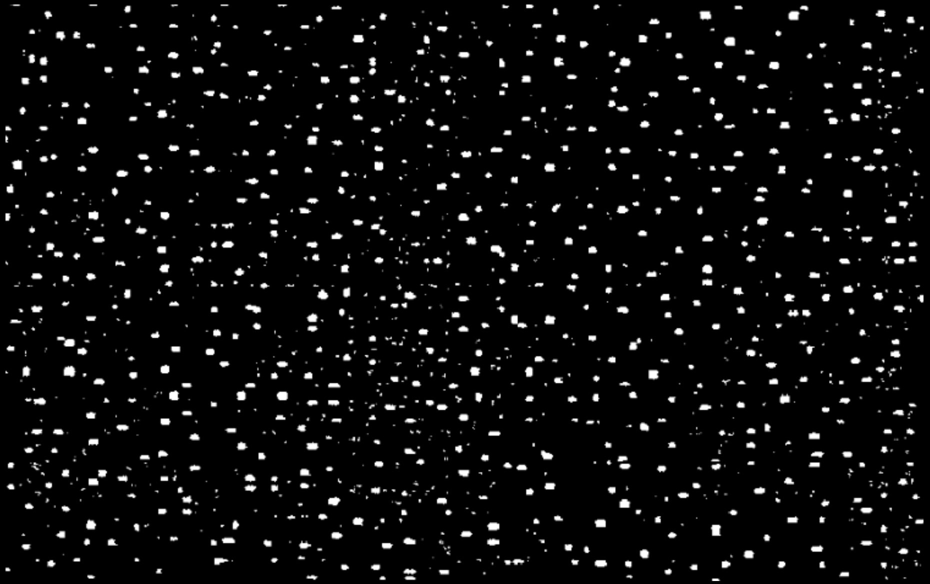


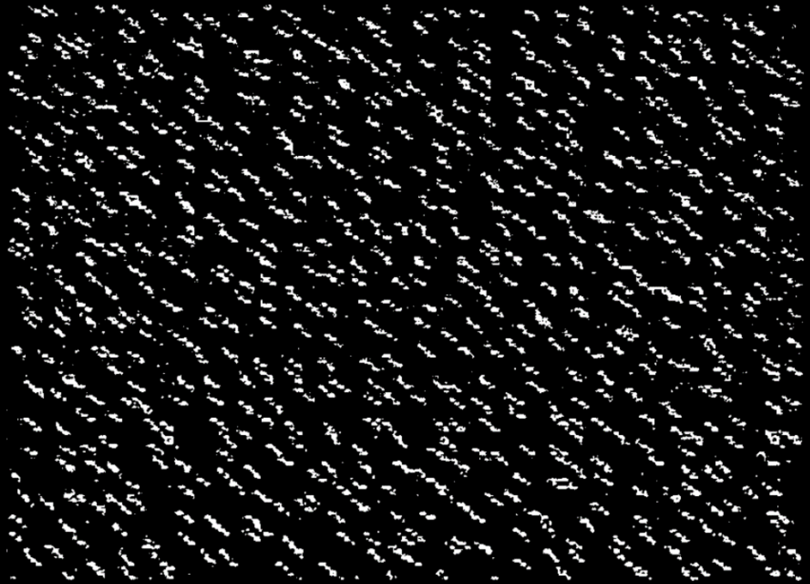
PrimeSense patent 2010/0290698



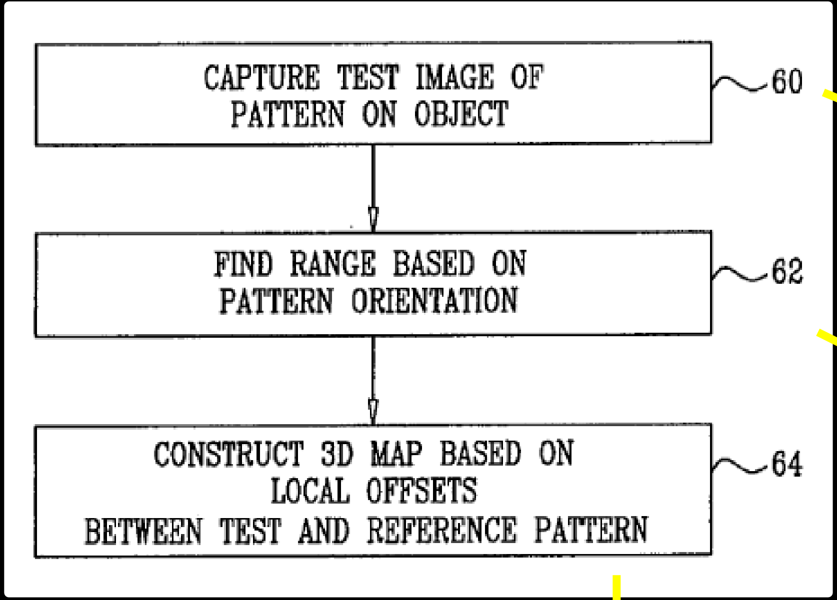
PrimeSense patent 2010/0290698

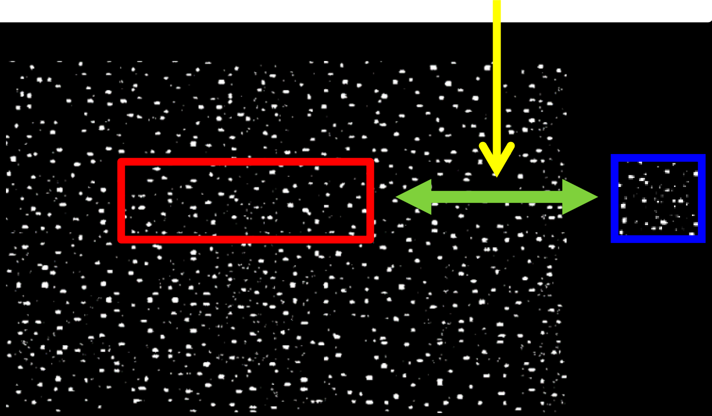
Orientation is a function of distance!

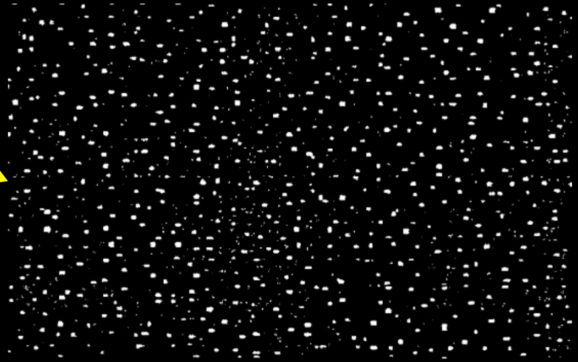


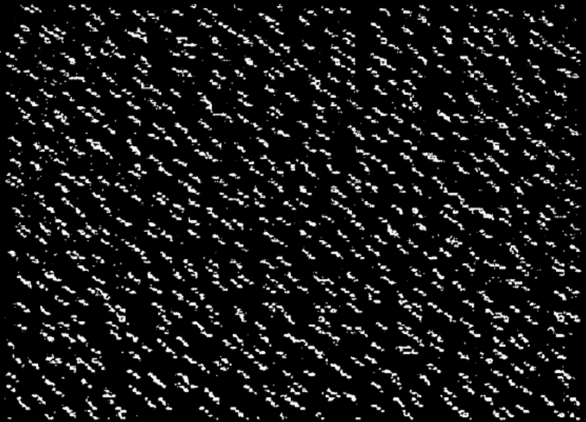


PrimeSense patent 2010/0290698







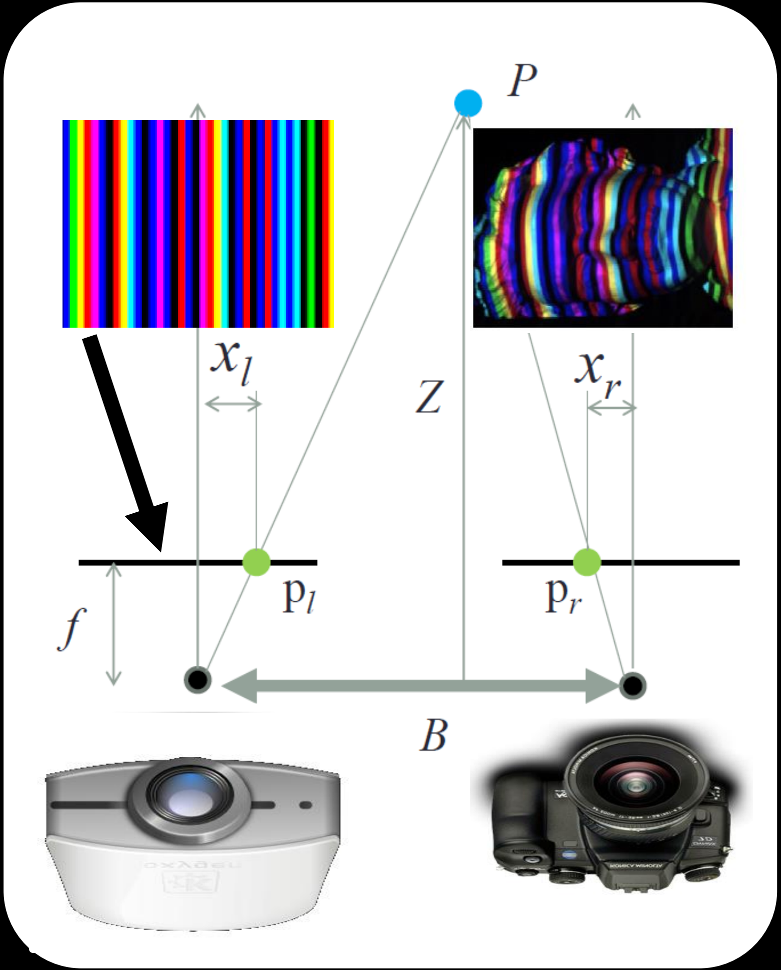


Psuedo-random speckle pattern

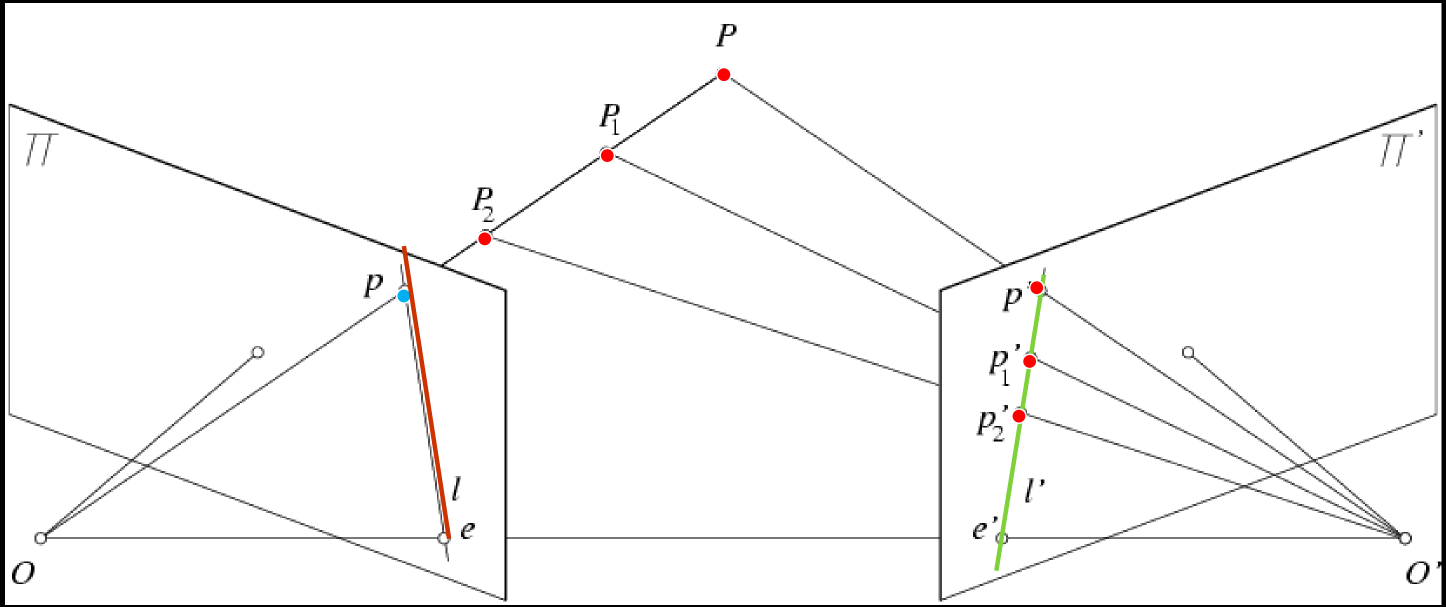
PrimeSense patent 2010/0290698

Structured light

- Like stereo
- But replace one camera with a projector



Same stereo algorithms apply

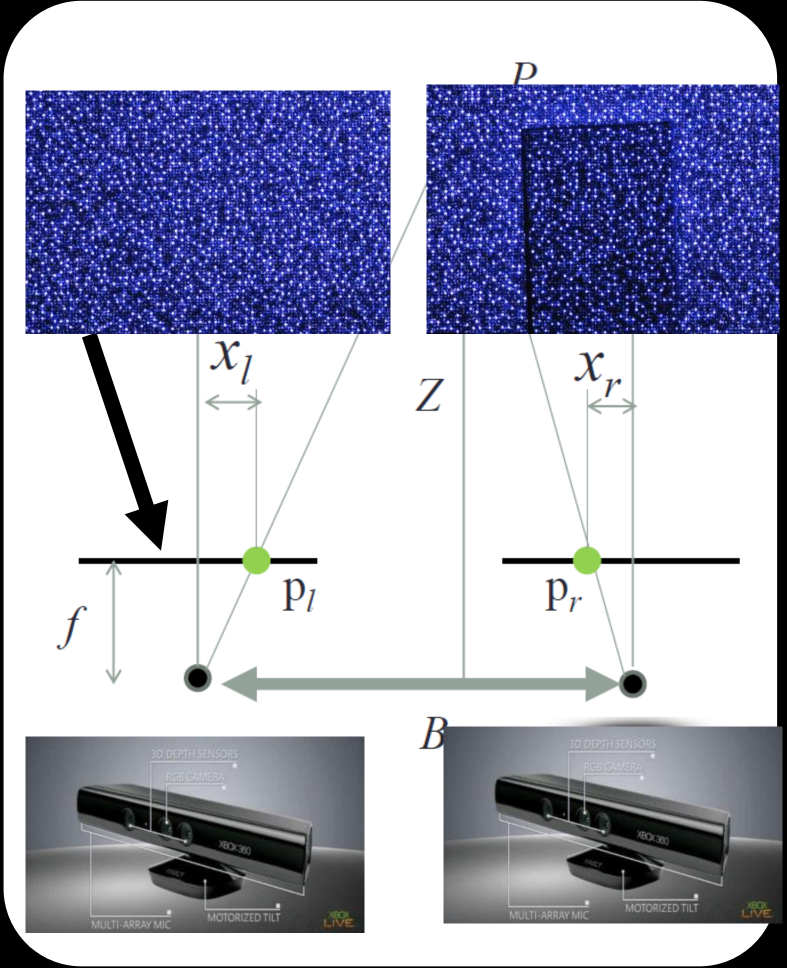


Projector Sensor

Structured light

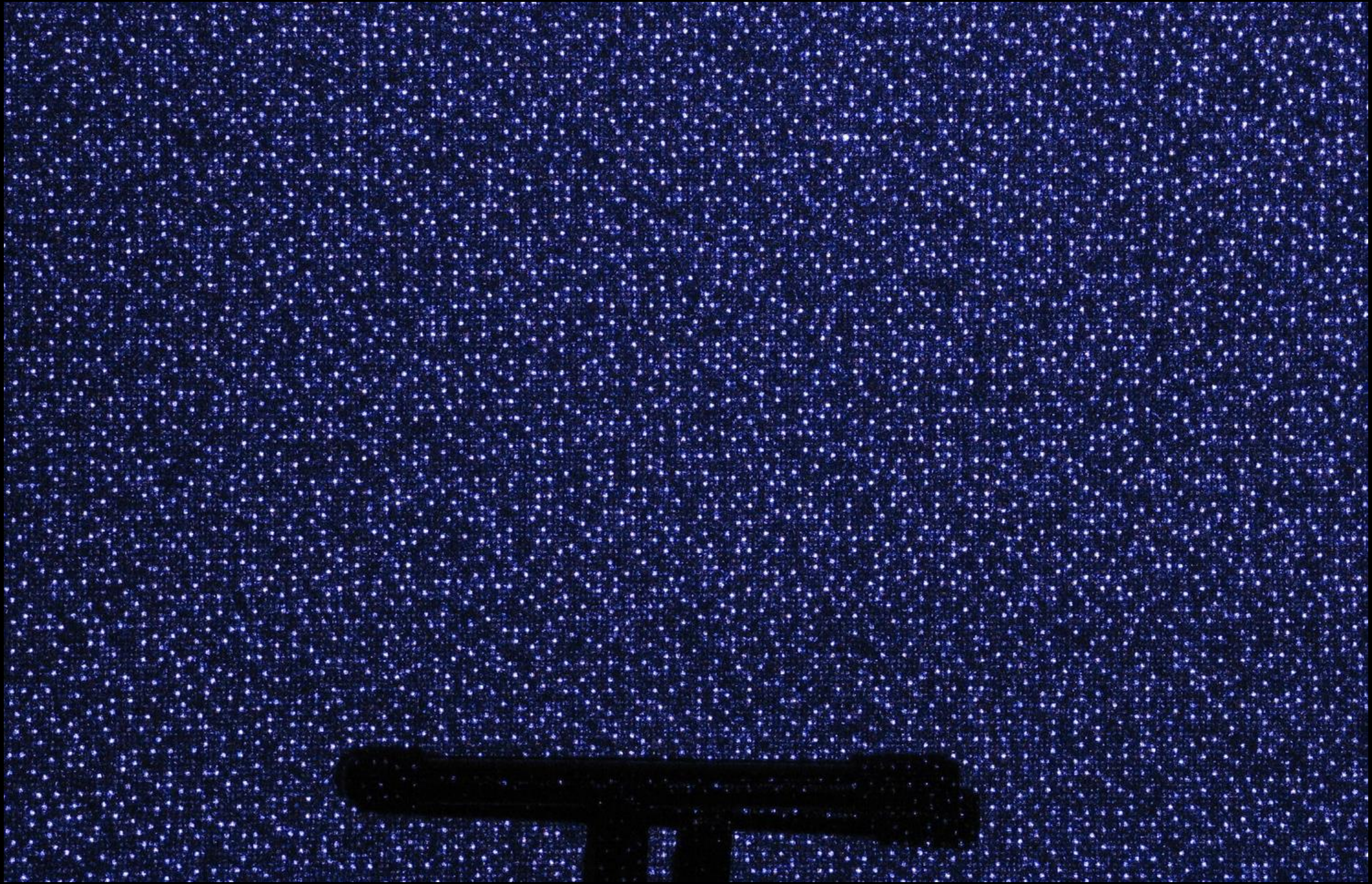
- Like stereo
- But replace one camera with a projector

- Can do it with speckle pattern too…



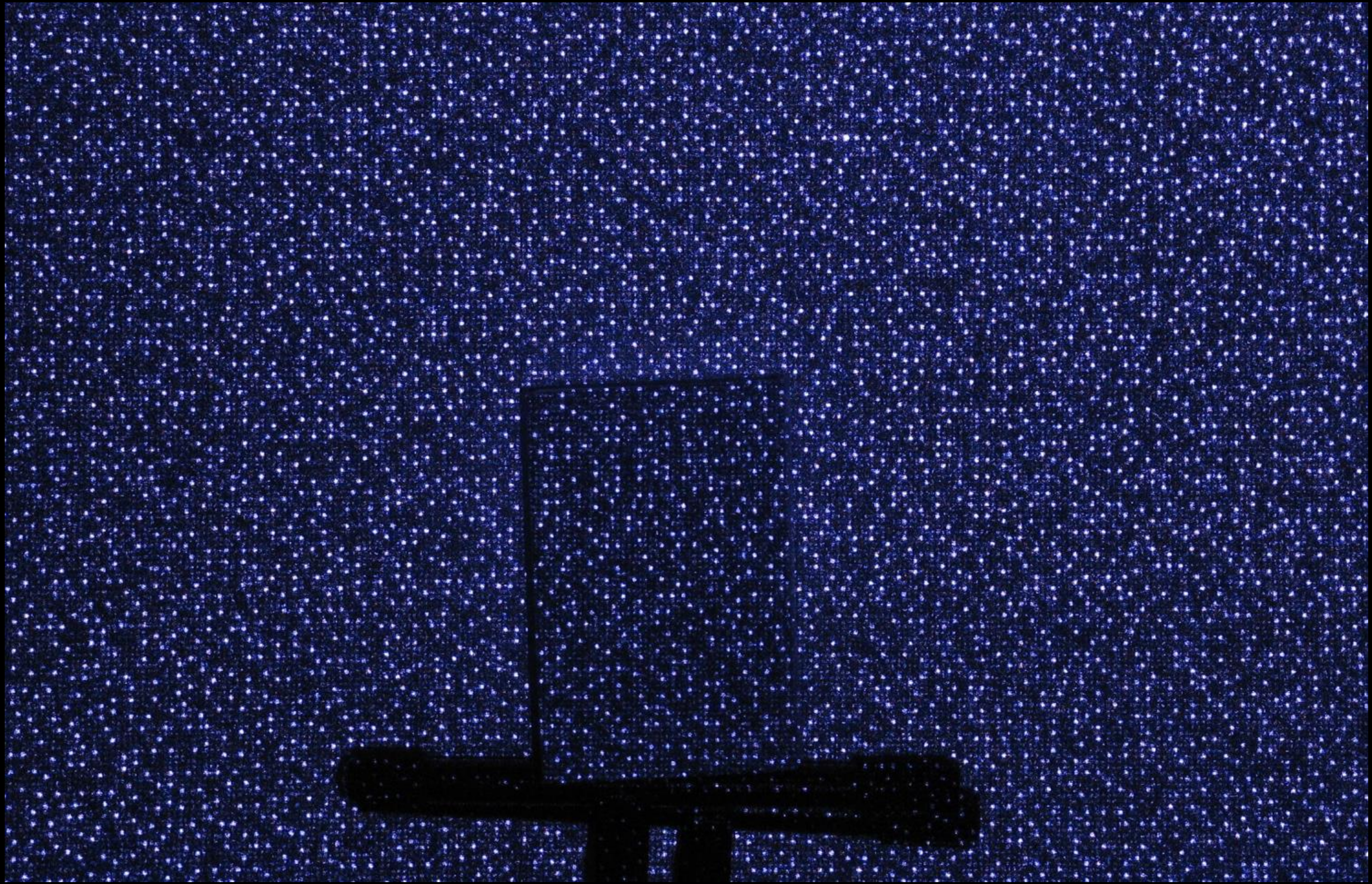
Example: Book vs. No Book

futurepicture.org/?p=97



Example: Book vs. No Book

futurepicture.org/?p=97



1. Detect dots ("speckles") and label them unknown

http://www.wipo.int/patentscope/search/en/WO2007043036

2. Randomly select a region anchor, a dot with unknown depth
   a) Windowed search via normalized cross correlation along scanline
      - Check that best match score is greater than threshold; if not, mark as “invalid” and go to 2
   b) Region growing
      1. Neighboring pixels are added to a queue
      2. For each pixel in queue, initialize by anchor’s shift; then search small local neighborhood; if matched, add neighbors to queue
      3. Stop when no pixels are left in the queue

http://www.wipo.int/patentscope/search/en/WO2007043036

3. Stop when all dots have known depth or marked “invalid”

http://www.wipo.int/patentscope/search/en/WO2007043036

Projected IR vs. Natural Light Stereo

- What are the advantages of IR?
  - Works in low light conditions
  - Does not rely on having textured objects
  - Not confused by repeated scene textures
  - *Can tailor algorithm to produced pattern*

Projected IR vs. Natural Light Stereo

- What are advantages of natural light?
  - ***Works outside***, anywhere with sufficient light
  - Resolution limited only by sensors, not projector

Projected IR vs. Natural Light Stereo

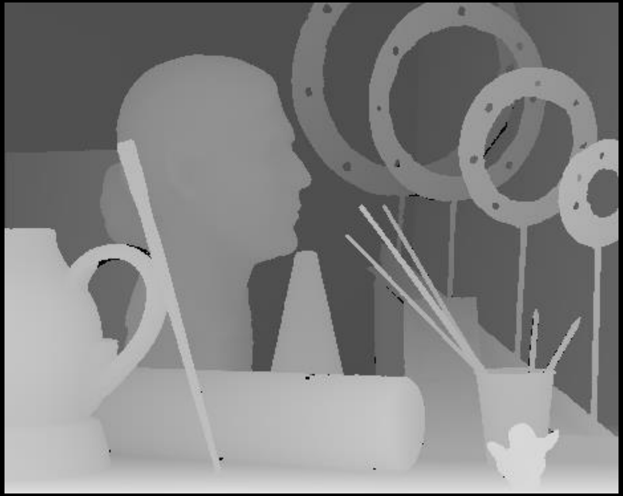
- Difficulties with both
  - Very dark surfaces may not reflect enough light
  - Specular reflection in mirrors or metal causes trouble

Representing depth scenes

- Natural: depth image
- A little more nuanced: point clouds

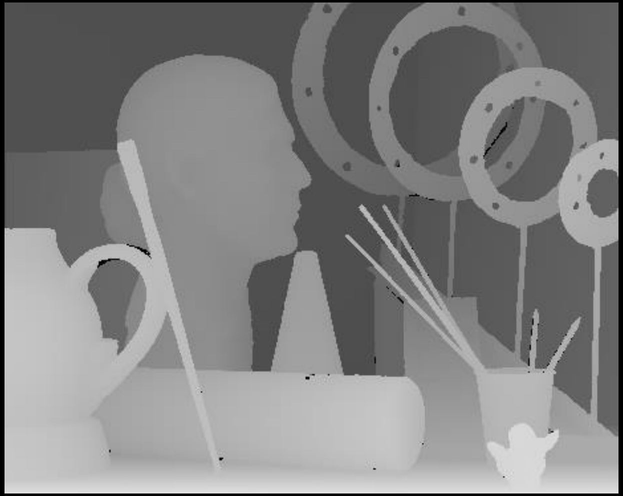
Depth Images

- Advantages
  - Dense representation
  - Gives intuition about occlusion and free space
  - Depth discontinuities are just edges on the image



Depth Images

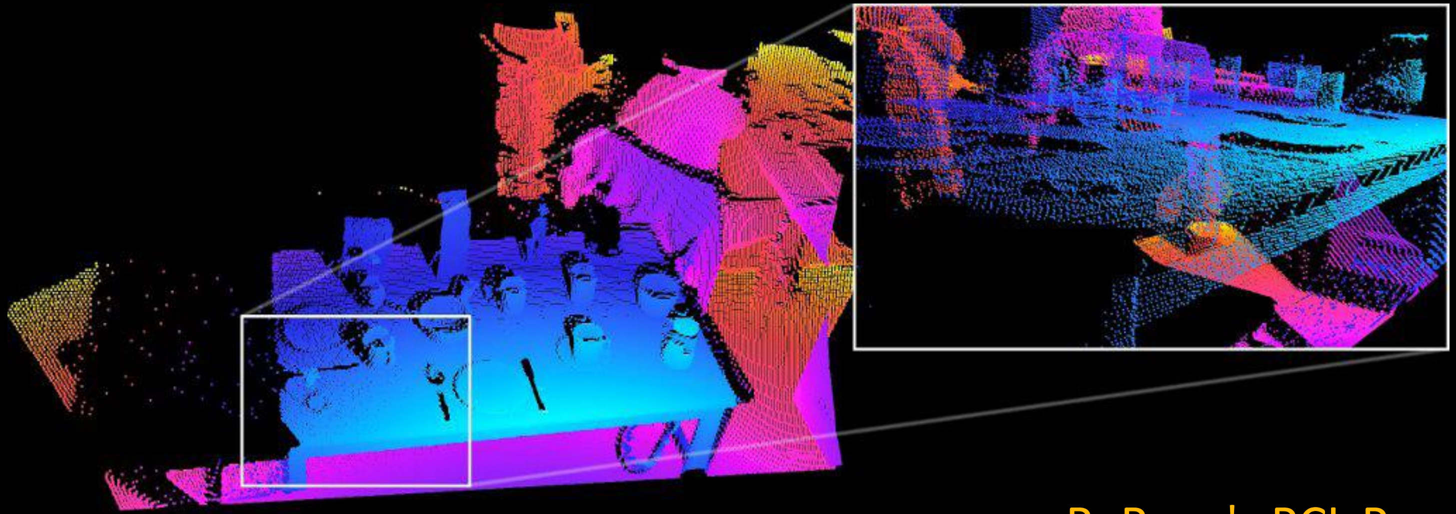
- Disadvantages
  - Viewpoint dependent, can't merge
  - Doesn't capture physical geometry
  - Need actual 3D locations of camera(s)



Point Clouds

Take every depth pixel and put it out in the world

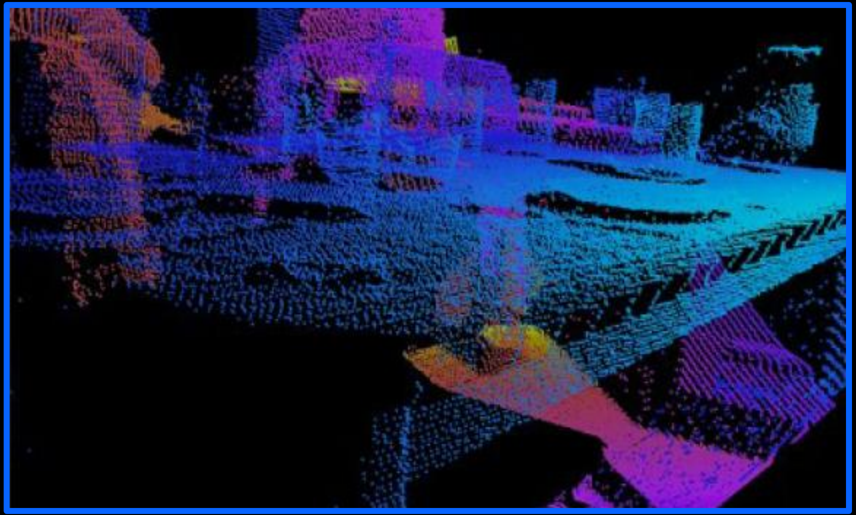
- What can this representation tell us?
- What information do we lose?



R. Rusu's PCL Presentation

Point Clouds

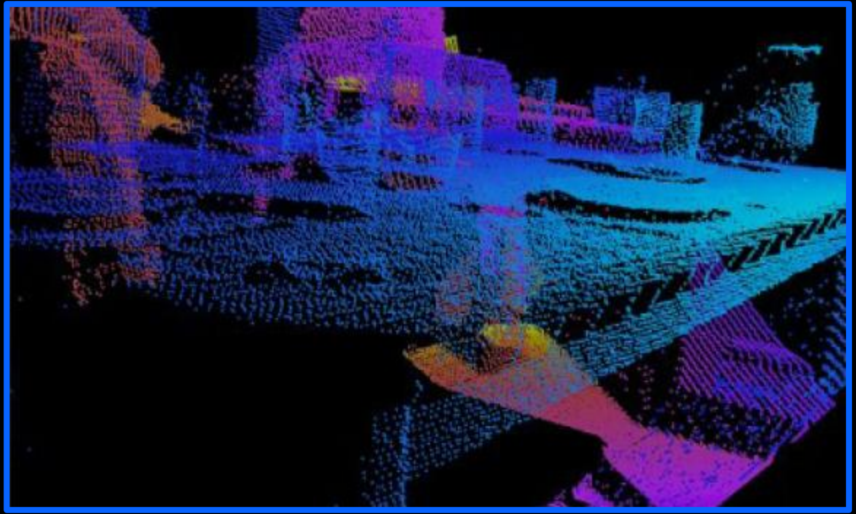
- Advantages
  - Viewpoint independent
  - Captures surface geometry
  - Points represent physical locations



R. Rusu's PCL Presentation

Point Clouds

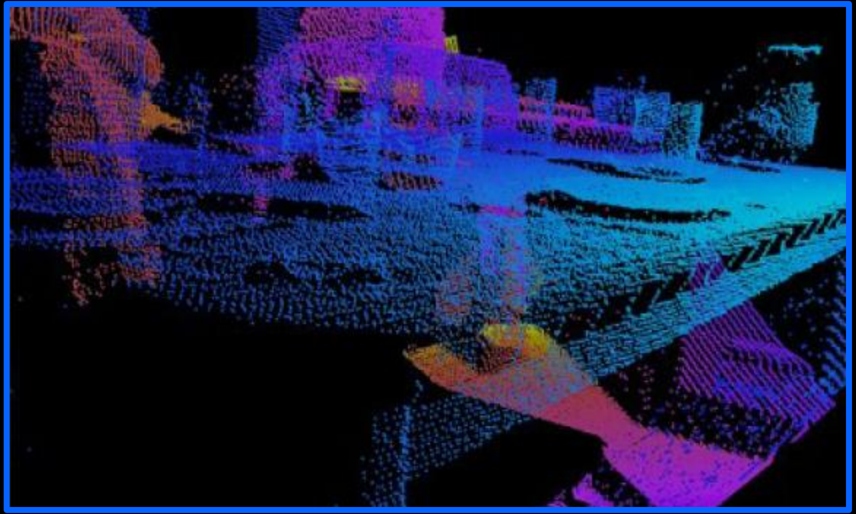
- Disadvantages
  - Sparse representation
  - Lost information about free space and unknown space
  - Variable density based on distance from sensor



R. Rusu's PCL Presentation

Point Clouds

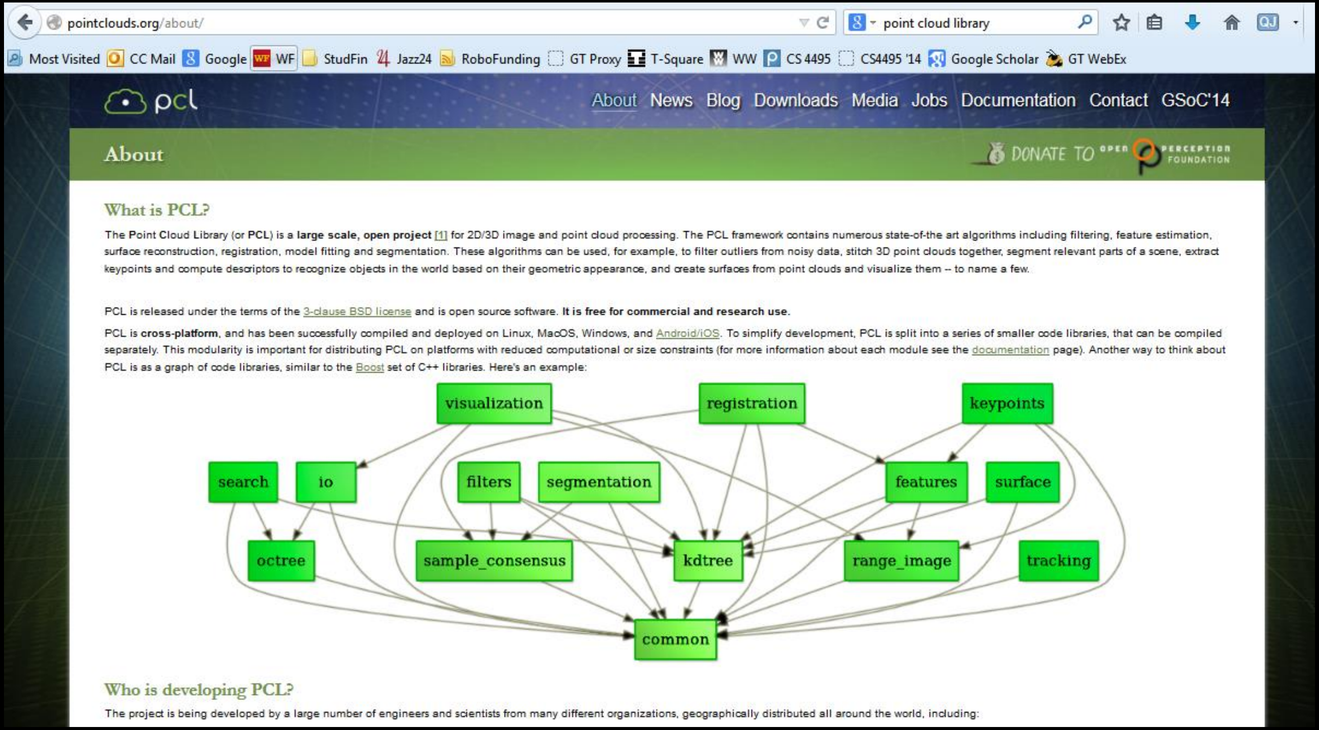
- Biggest advantage:
  - PCL – Point Cloud Library



R. Rusu's PCL Presentation

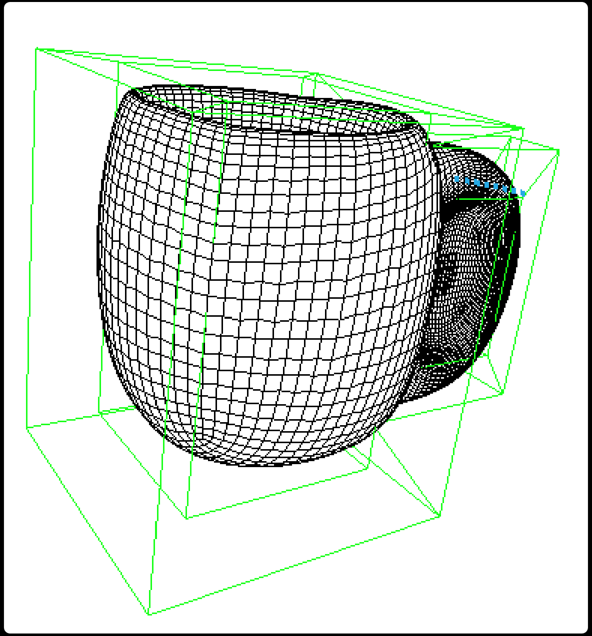
Point Clouds

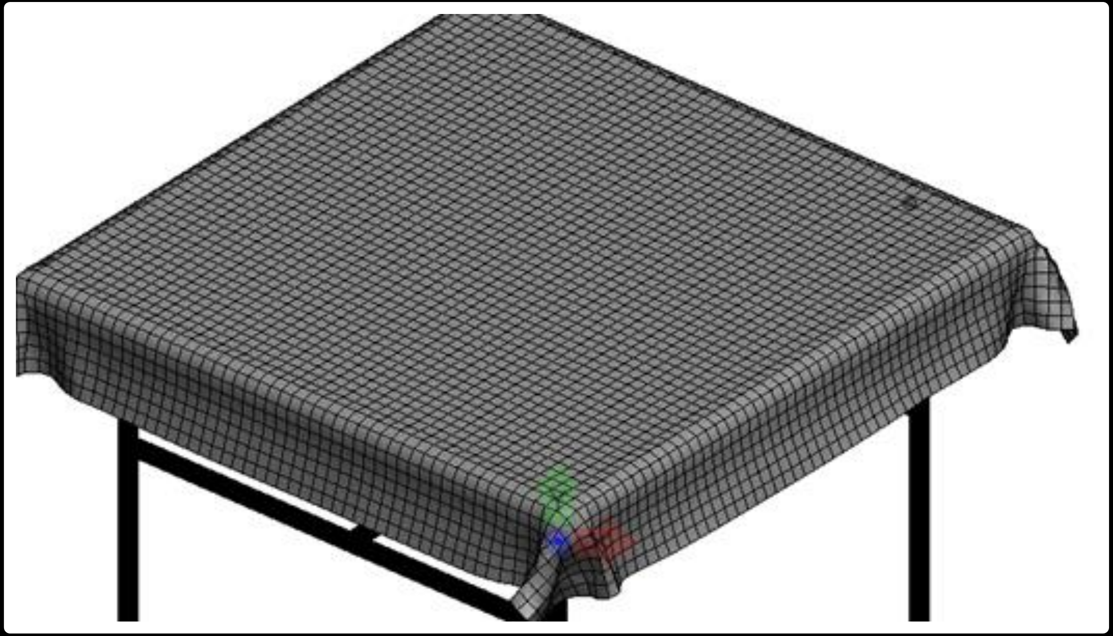
- http://pointclouds.org



Point Clouds and Surfaces

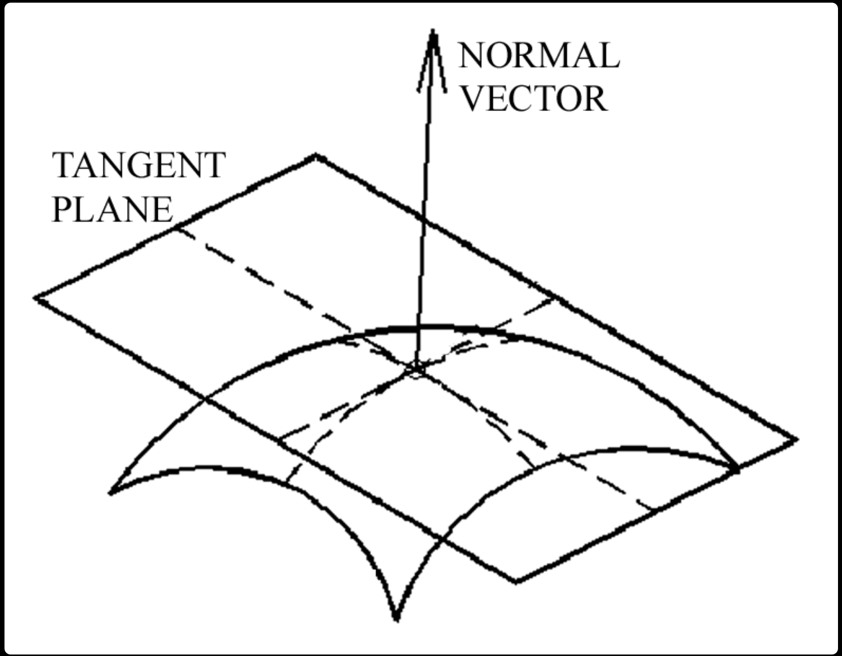
- Point clouds are sampled from object surfaces
- The concept of volume is inferred, not perceived

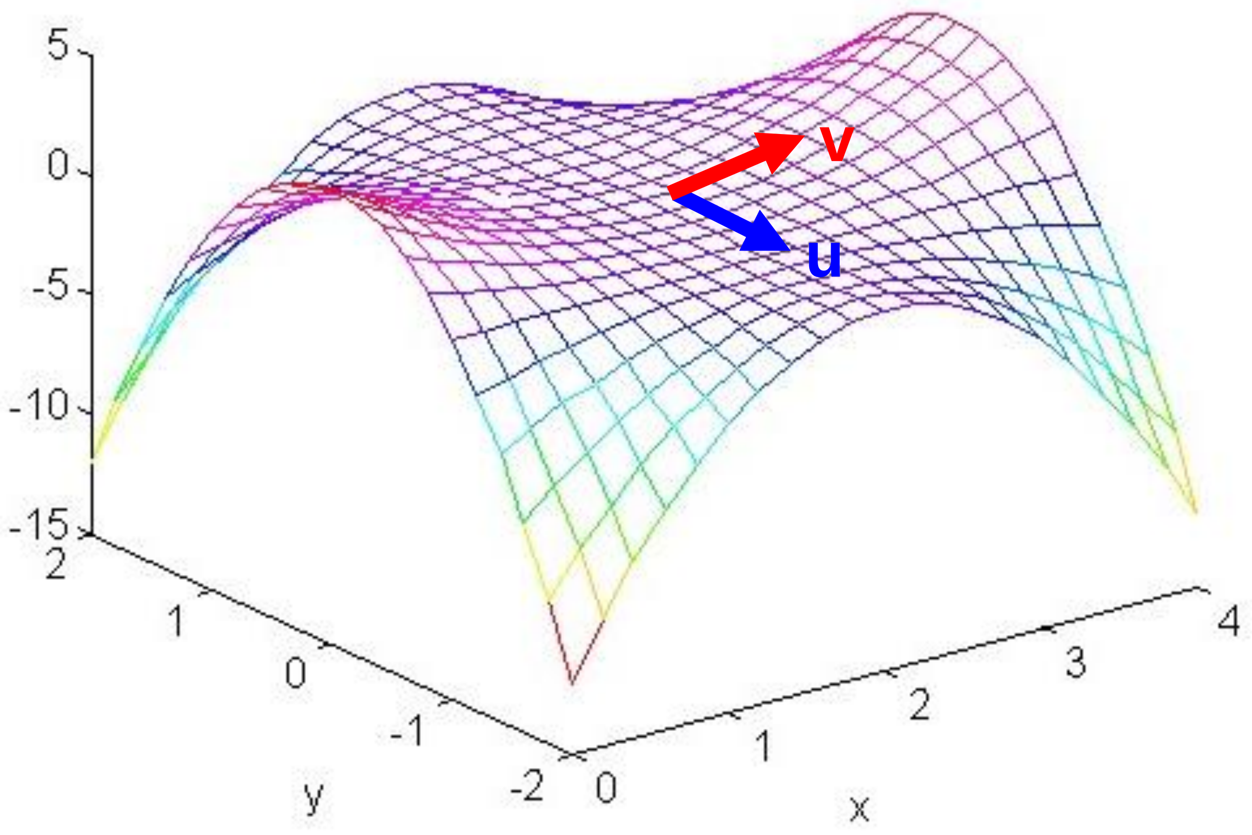




Surfaces

- Tangent plane – defined by normal
- First-order approximation

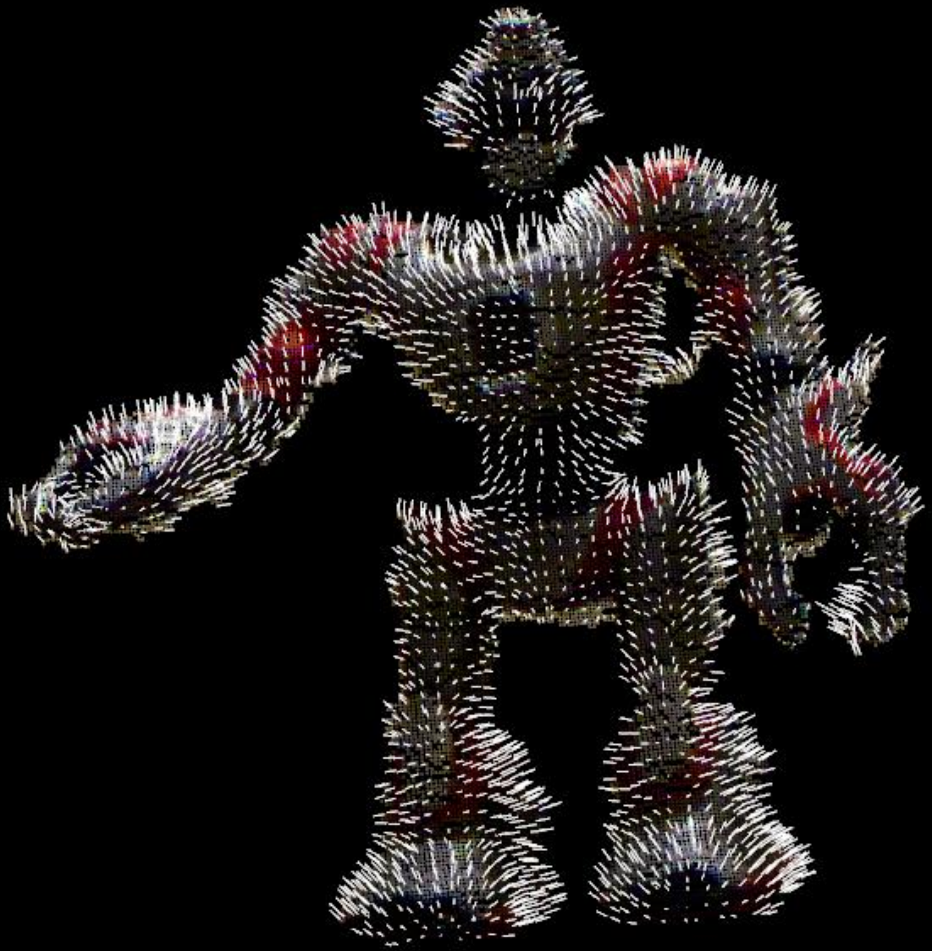




5
0
-5
-10
-15
v
u
2
1
0
-1
-2
y
0
1
2
3
4
x

Surface Normals

- Size of patch is like width of Gaussian in image gradient calculation
- We can use them to find planes

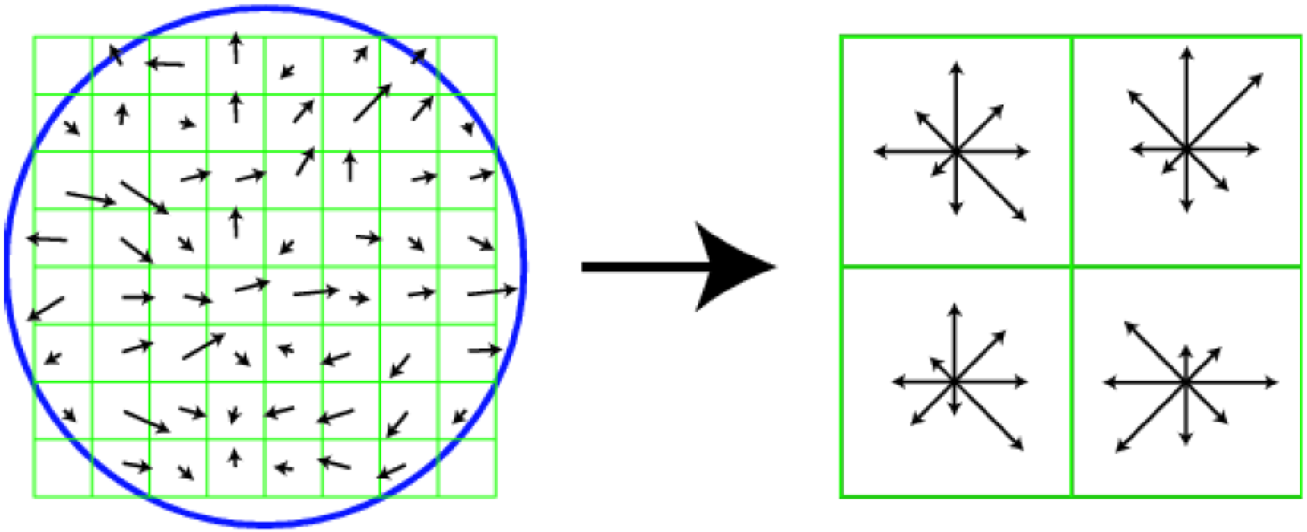


Viewpoint Invariance

- Want to find unique patches of surface geometry
- What type of invariance do we need?
- Need *viewpoint* invariance
  - Translation + orientation
  - Color and texture come automatically!

Point Feature Histograms

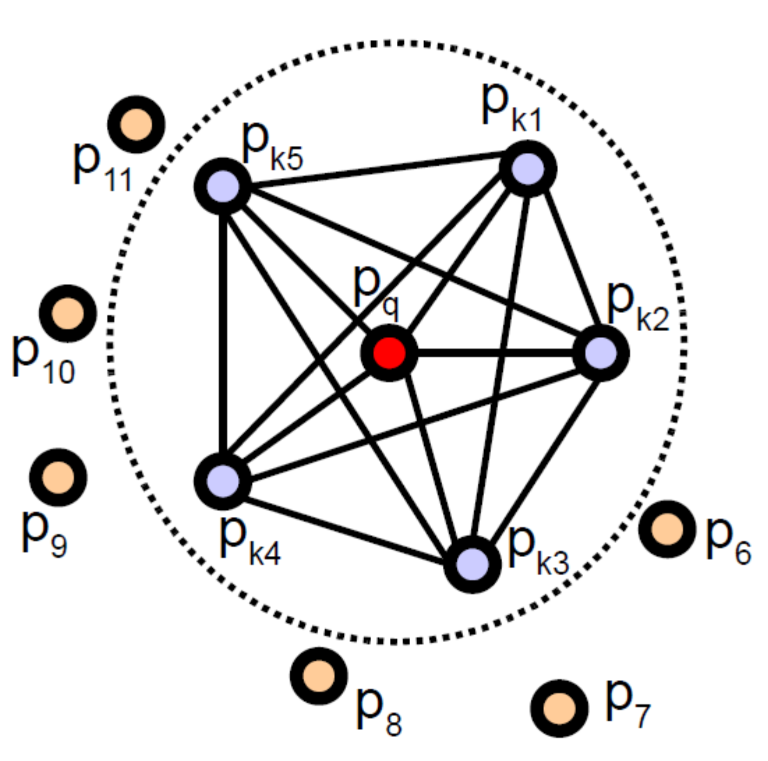
Remember SIFT?



(a) image gradients (b) keypoint descriptor

Point Feature Histograms

- At a point, take a ball of points around it
- For every pair of points, find the relationship between the two points and their normals
- Must be frame independent



R. Rusu

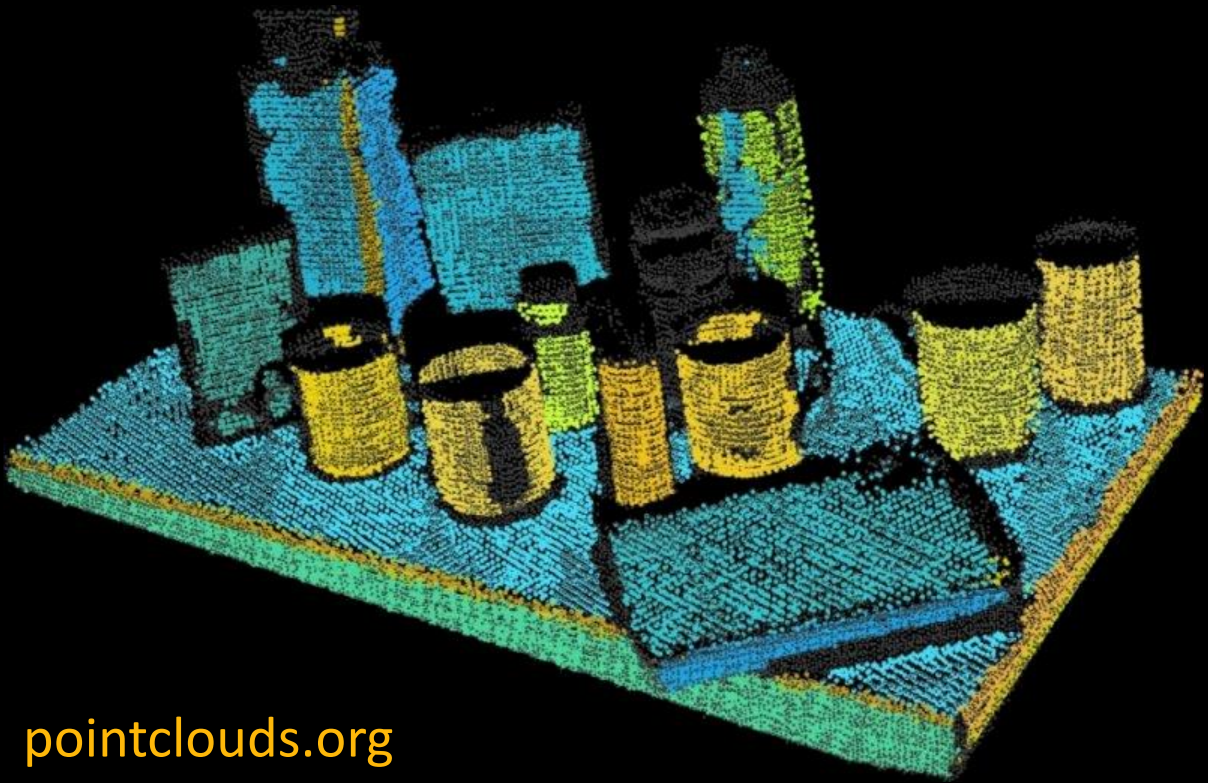
Point Feature Histograms

- Find these for variables for every pair in the ball
- Build a 5x5x5x5 histogram of the variables
  - Often the distance variable is excluded
  - In this case, we have a 125-long feature vector
- Use this just like a SIFT feature descriptor
- Usually, a sped-up version called Fast Point Feature Histograms is used for real-time applications

Point Cloud Software

- Point Cloud Library (PCL)
  - http://pointclouds.org
- Robot Operating System (ROS)
  - Framework for building systems
  - http://www.ros.org
- Drivers for Kinect and other PrimeSense sensors
  - http://www.ros.org/wiki/openni_launch

PCL Example: RANSAC Cylinder Segmentation



pointclouds.org