



Structured-Light Based Acquisition (Part 1)

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Passive vs. Active Acquisition

- Passive
 - + Just take pictures
 - + Does not intrude in the environment (=passive)
 - Some surfaces cannot be acquired
 - Robustness is problematic
- Active
 - + Emit “light” into the scene so as to force the generation of robust correspondence
 - Environment is intruded (=active)

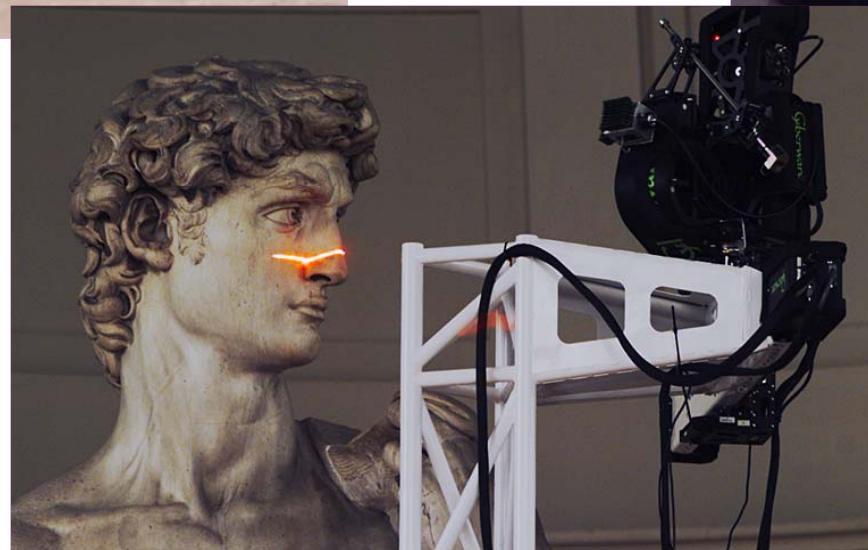
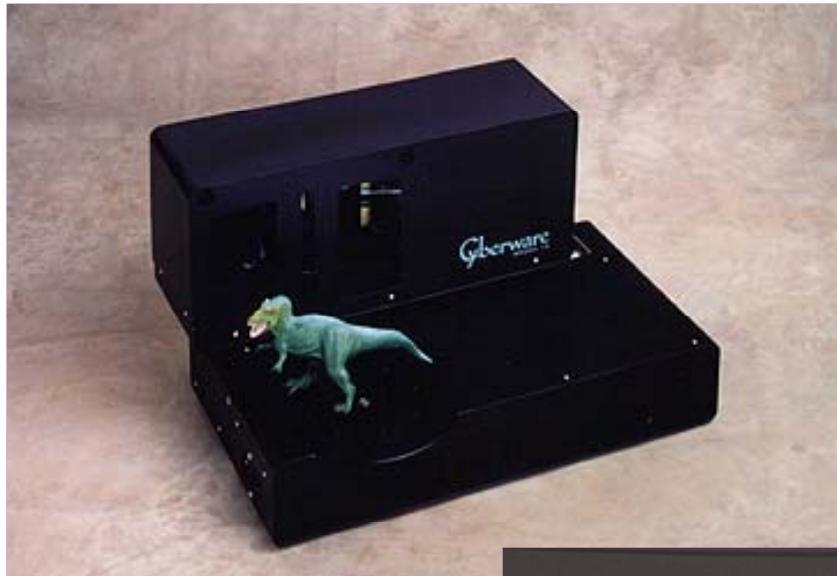


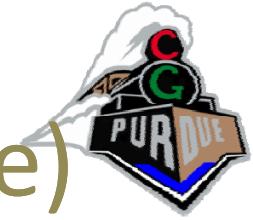
Active Acquisition

- Some options:
 - Laser scanning
 - “Structured Light”

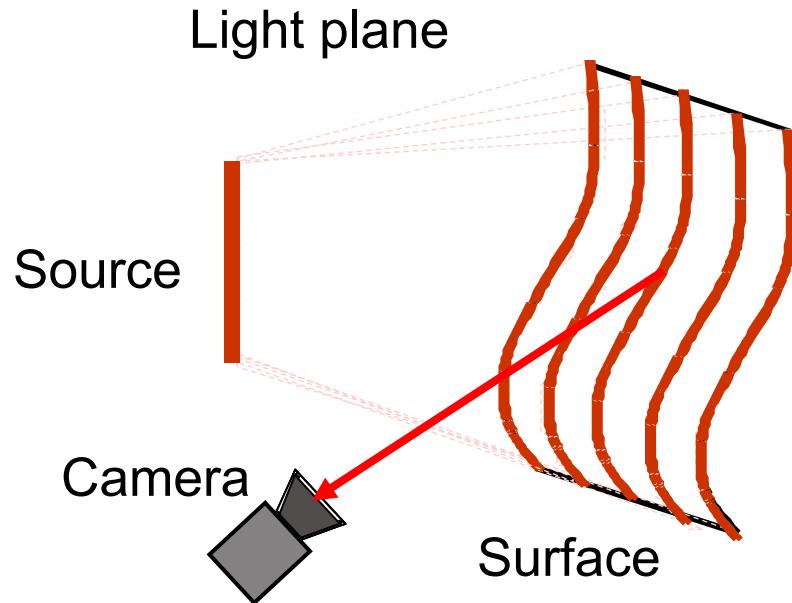


Laser Scanning





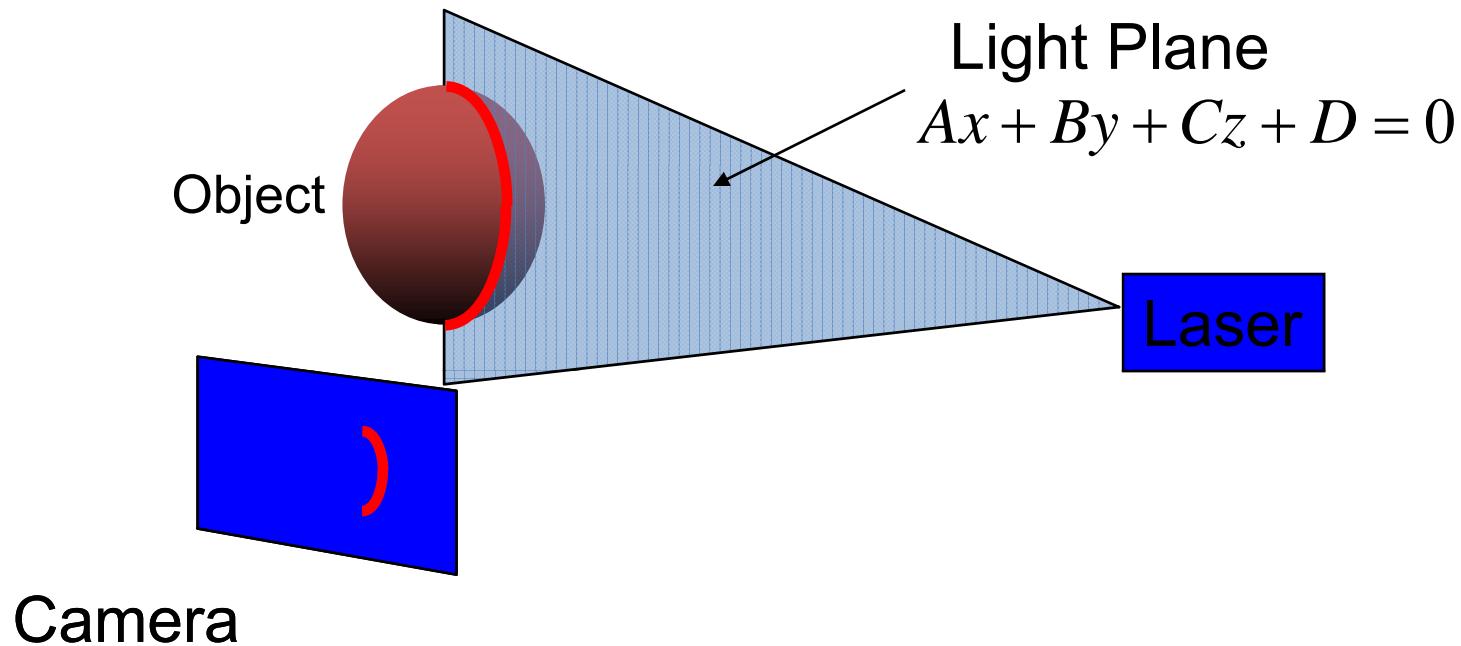
Light Stripe Scanning (Single Stripe)



- 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



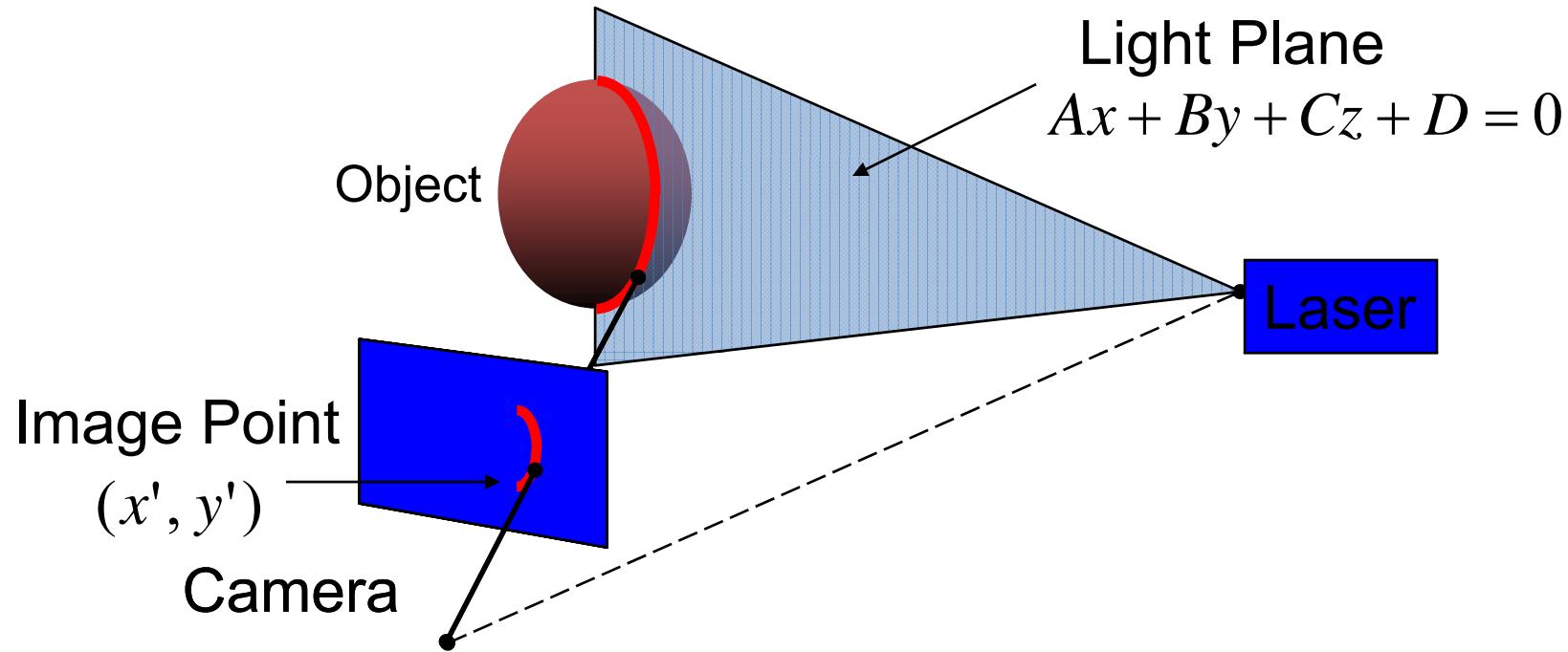
Stripe Triangulation



- Project laser stripe onto object



Stripe Triangulation

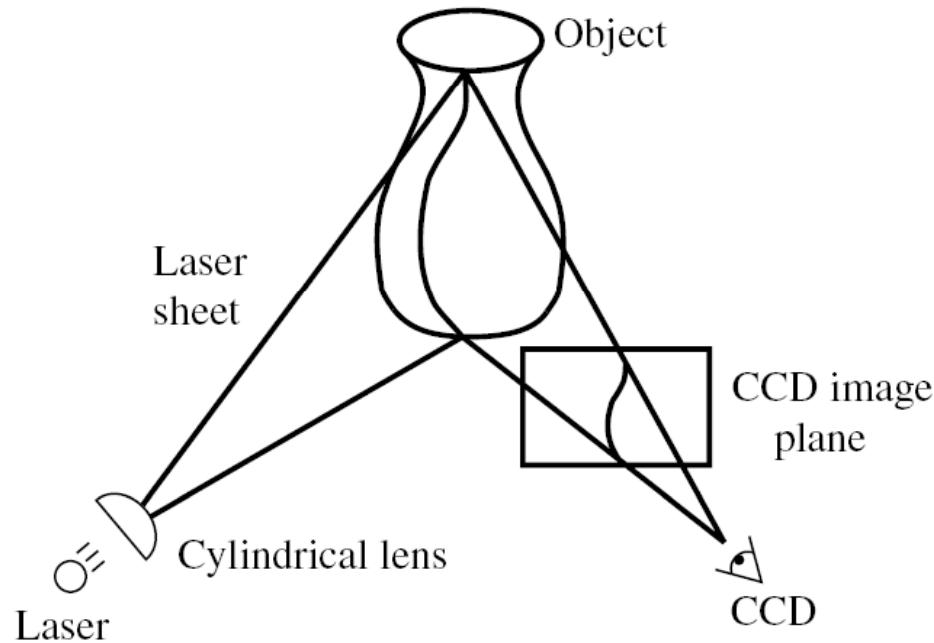


- Depth from ray-plane triangulation:
 - Intersect camera ray with light plane

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



Example: Laser scanner

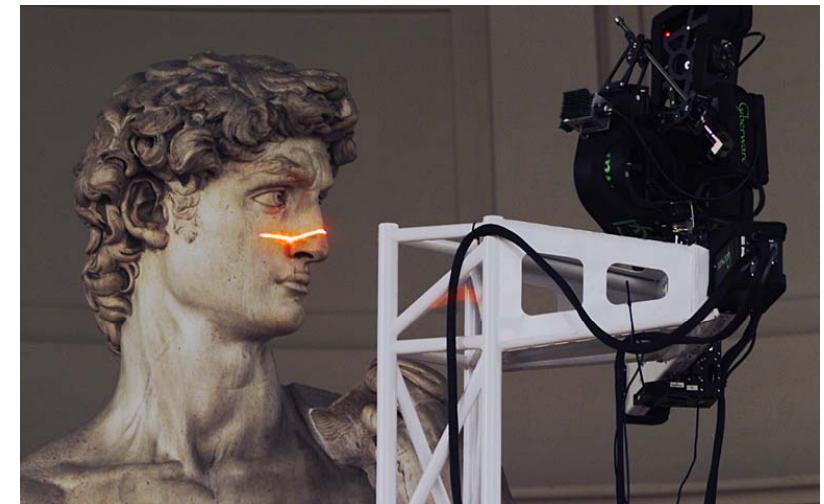
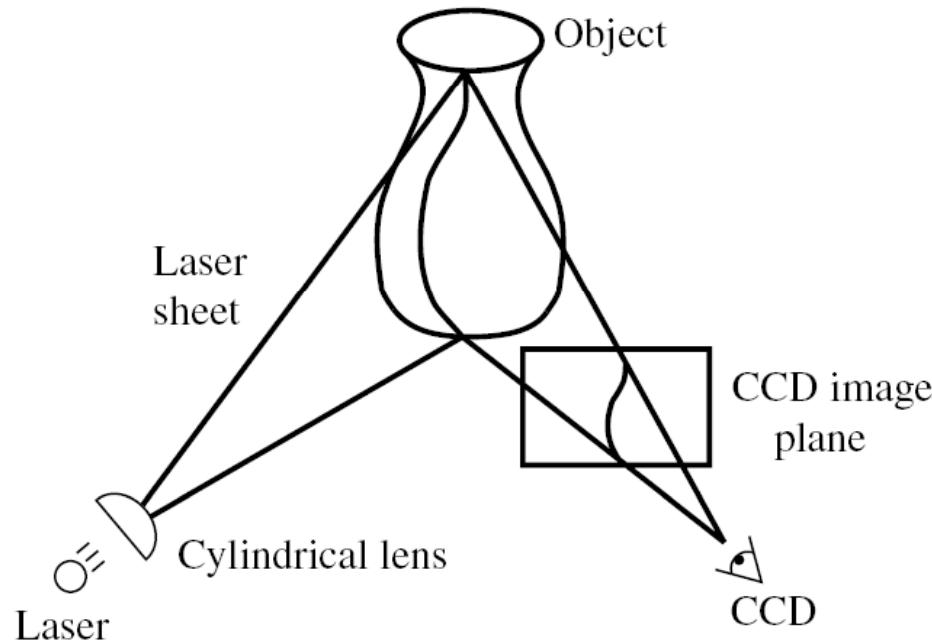


- + very accurate < 0.01 mm
- more than 10sec per scan

Cyberware® face and head scanner



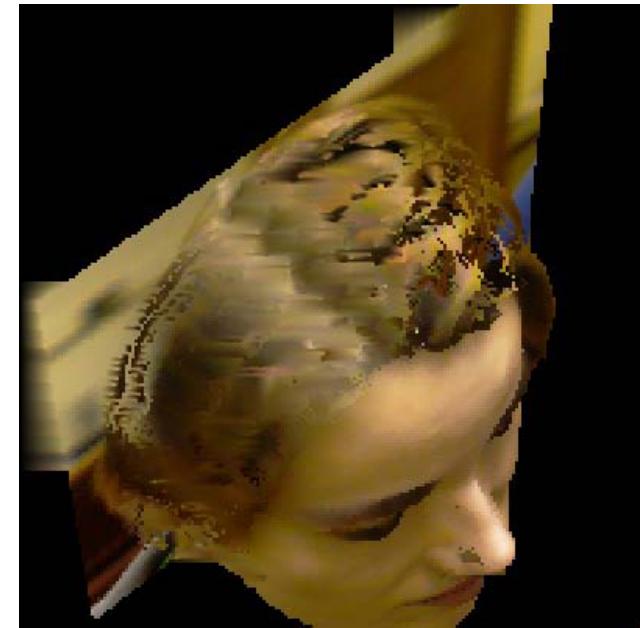
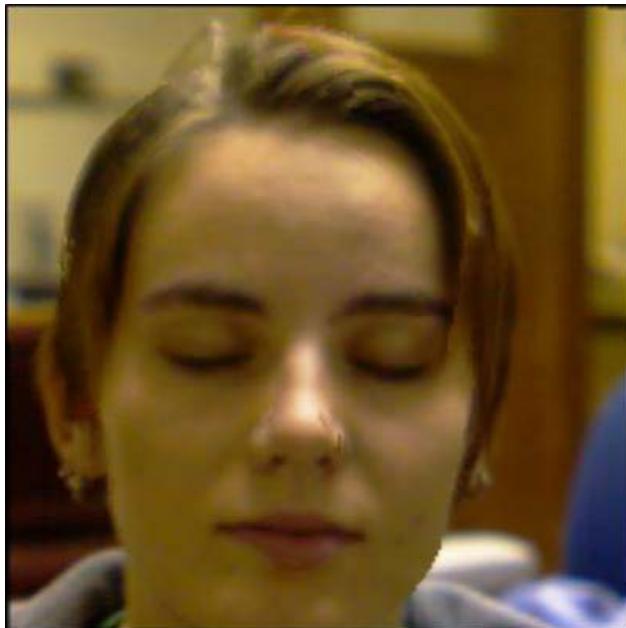
Example: Laser scanner



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



Example: Laser scanner



Portable scanner by Minolta



Digital Projector Structured Light

- Goal: generate correspondences so as to enable a robust 3D reconstruction



Digital Projector Structured Light

- Method:
 - Use the projector as a “pattern” generator
 - Have the camera see the “pattern” and generate 1 or more corresponded points





Digital Projector Structured Light

- What are possible patterns?
 - Spatial patterns
 - Temporal patterns
 - Color patterns
 - And combinations of the above



Digital Projector Structured Light

	Binary codes	Posdamer et al. Inokuchi et al. Minou et al. Trobina	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓
Time-multiplexing	n-ary codes	Valkenburg and McEvoy Skocaj and Leonardis Rocchini et al.	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓
	Gray code + Phase shifting	Caspi et al. Horn and Kiryati	✓ ✓	✓ ✓	✓ ✓
	Hybrid methods	Bergmann Sansoni et al. Wiora Gühring	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓
Spatial Neighborhood	Non-formal codification	Kosuke Sato Hall-Holt and Rusinkiewicz	✓ ✓	✓ ✓	✓ ✓
	De Bruijn sequences	Maruyama and Abe Durdle et al. Ito and Ishii Boyer and Kak Chen et al.	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓
Direct coding	M-arrays	Hügli and Maître Monks et al. Vuylsteke and Oosterlinck Salvi et al. Lavoie et al. Zhang et al.	✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓
	Grey levels	Morita et al. Petriu et al. Kiyasu et al. Spoelder et al. Griffin and Yee Davies and Nixon Morano et al.	✓ ✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓ ✓
Scene applicability	Colour	Carrihill and Hummel Chazan and Kiryati Hung	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓
		Tajima and Iwakawa Smutny and Pajdla Geng Wust and Capson Tatsuo Sato	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓
Pixel depth	Scene applicability	Static			
		Moving			
Coding strategy	Pixel depth	Binary			
		Grey levels			
Coding strategy	Coding strategy	Colour			
		Periodical			
Coding strategy	Coding strategy	Absolute			

Lets focus on
binary striped
patterns...



Binary Pattern Structured Light



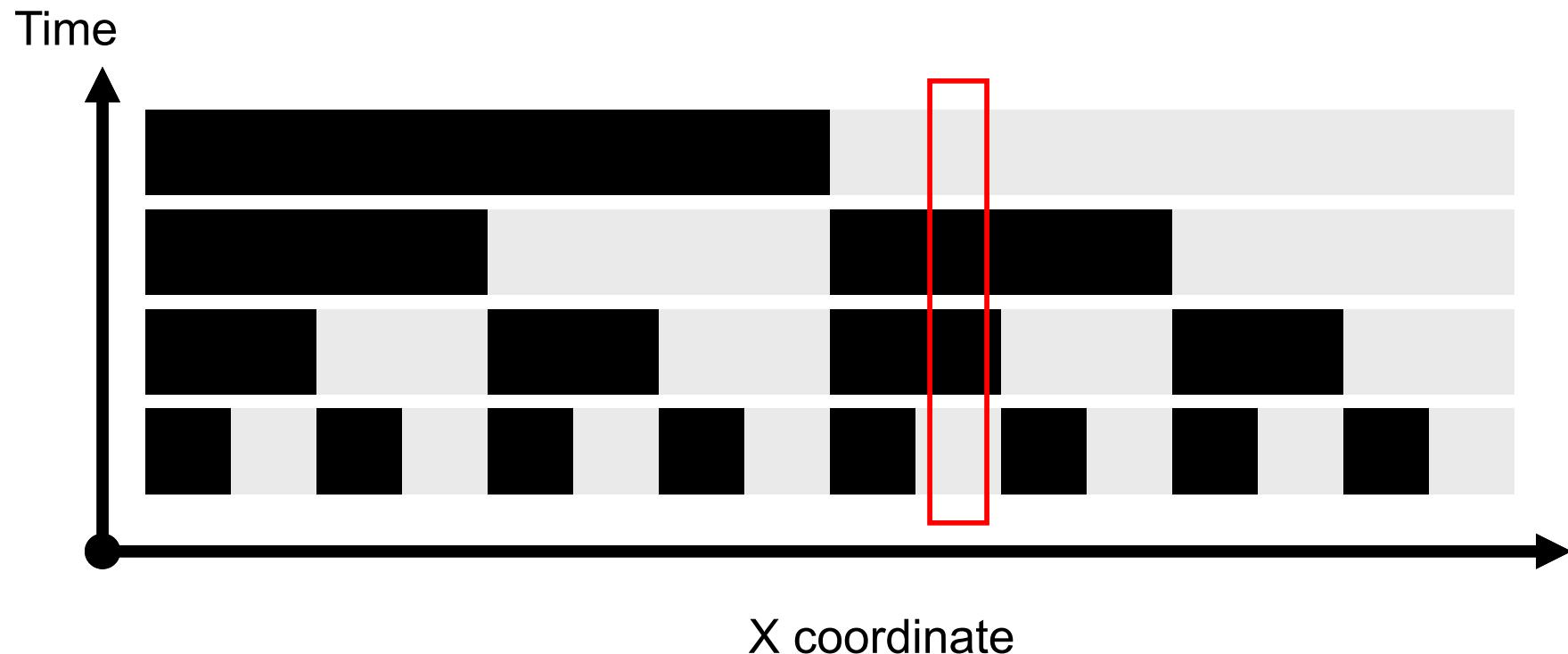
YX1 For a structured light system, we can use a calibrated projector and camera pair. We can also use a uncalibrated projector and a pair of calibrated cameras.

YI XU, 5/23/2007



Binary Coding

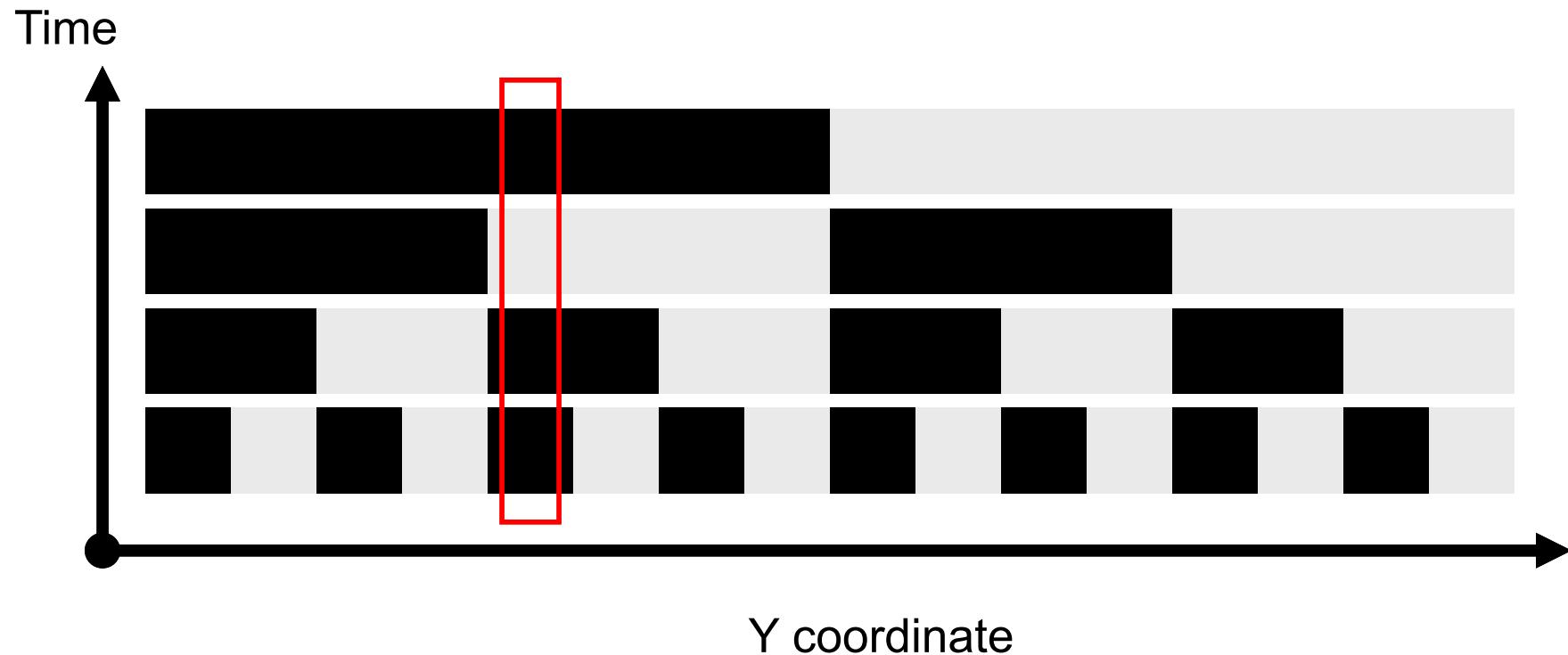
- Assign each pixel a unique illumination code over time [Posdamer 82]





Binary Coding

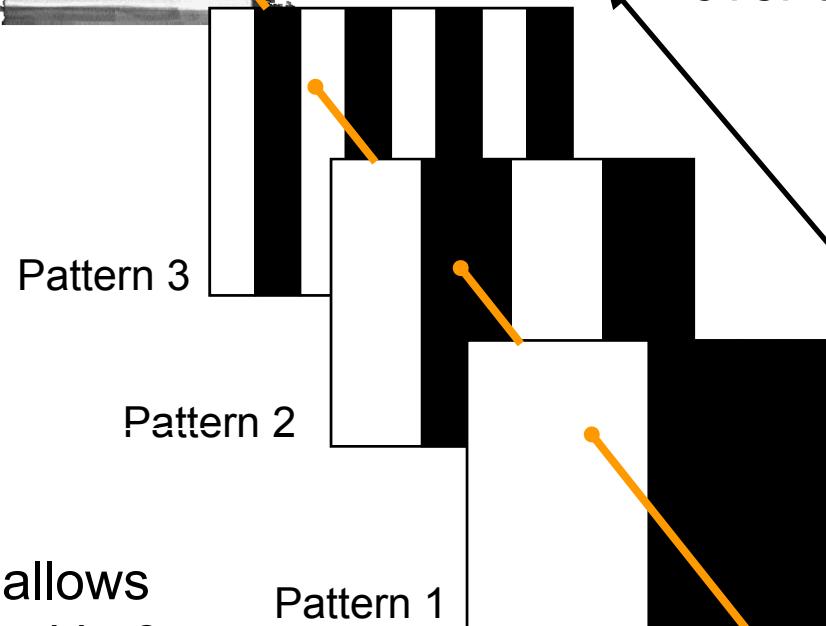
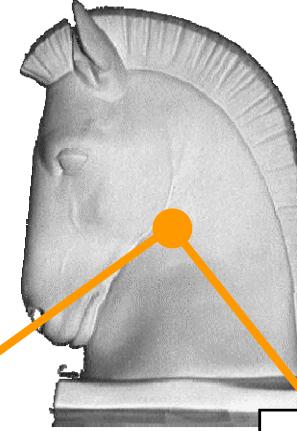
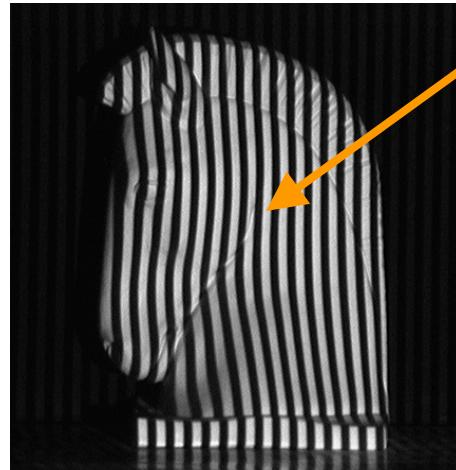
- Assign each pixel a unique illumination code over time [Posdamer 82]





Binary Coding

$2^n - 1$ stripes in n images



Example:

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



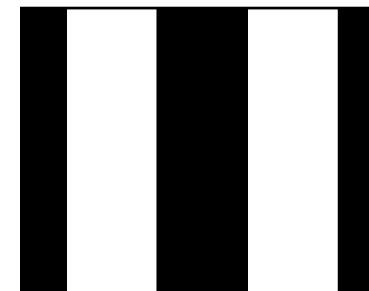
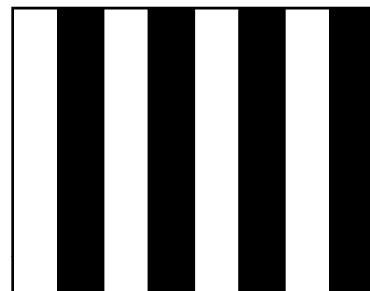
Binary vs Gray Codes

Decimal	Binary	Gray Code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

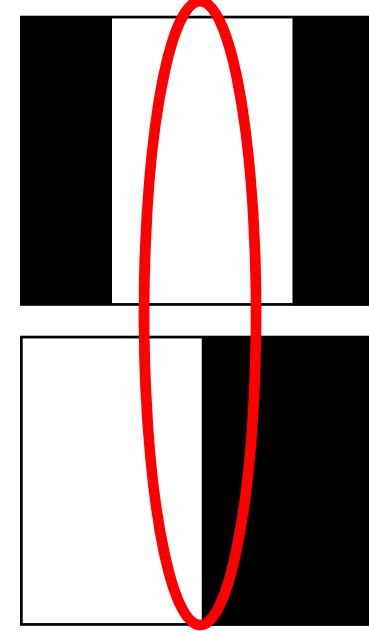
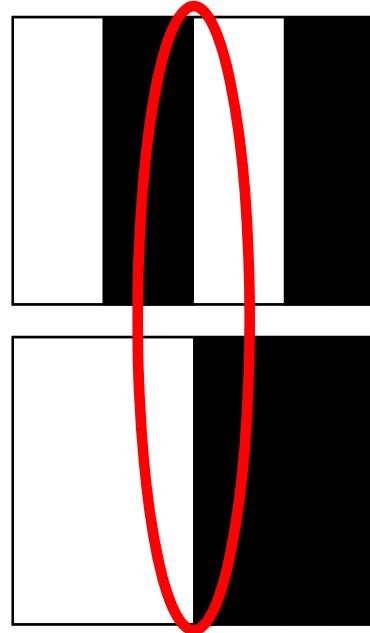


Binary vs Gray Codes

Pattern 3



Pattern 2

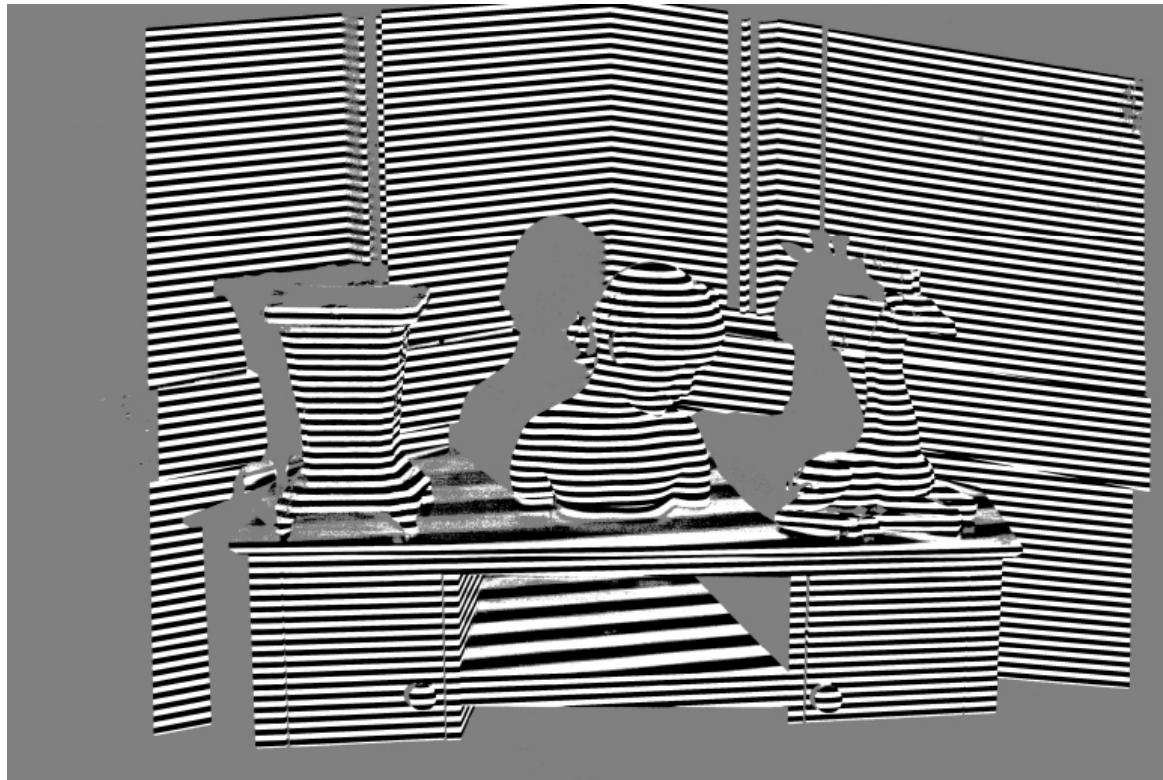


Binary code

Gray code



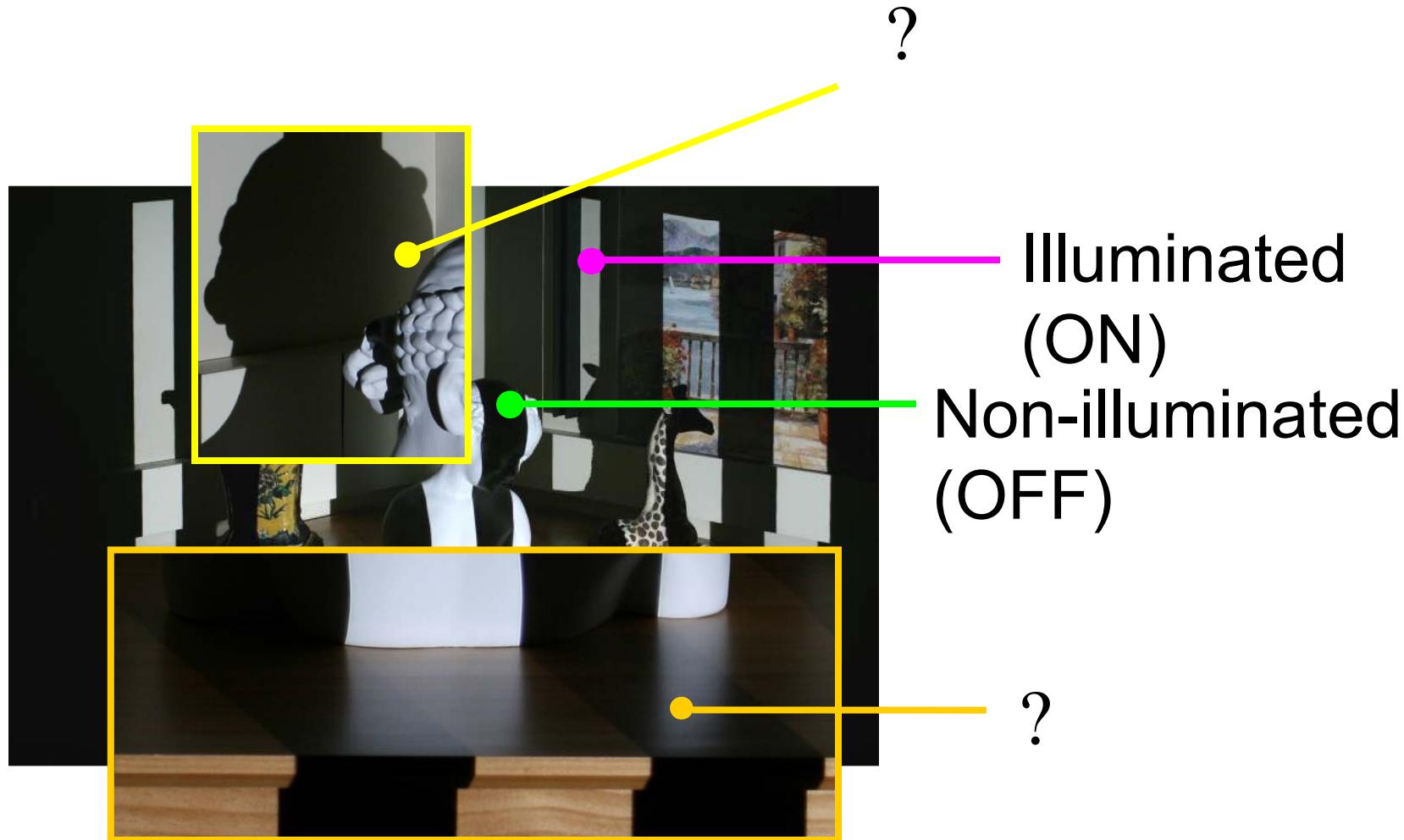
Standard Pixel Classification



ON(1) OFF(0) Uncertain



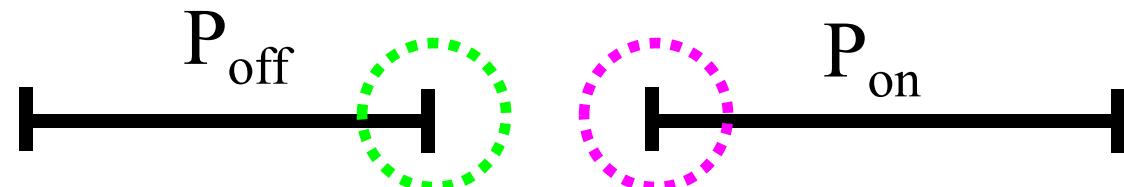
Pixel Classification Challenges





Standard Pixel Classification

- Interval

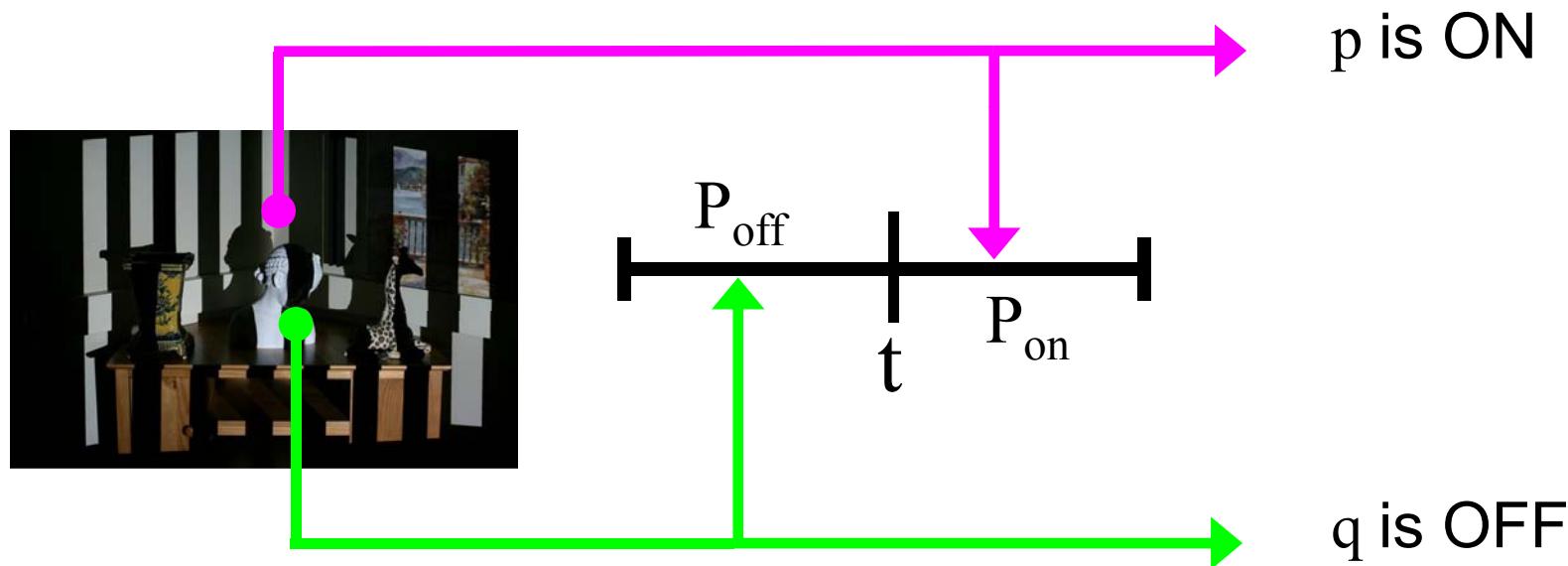


- Common methods
 - Simple threshold
 - Albedo threshold
 - Dual pattern



1. Simple Threshold

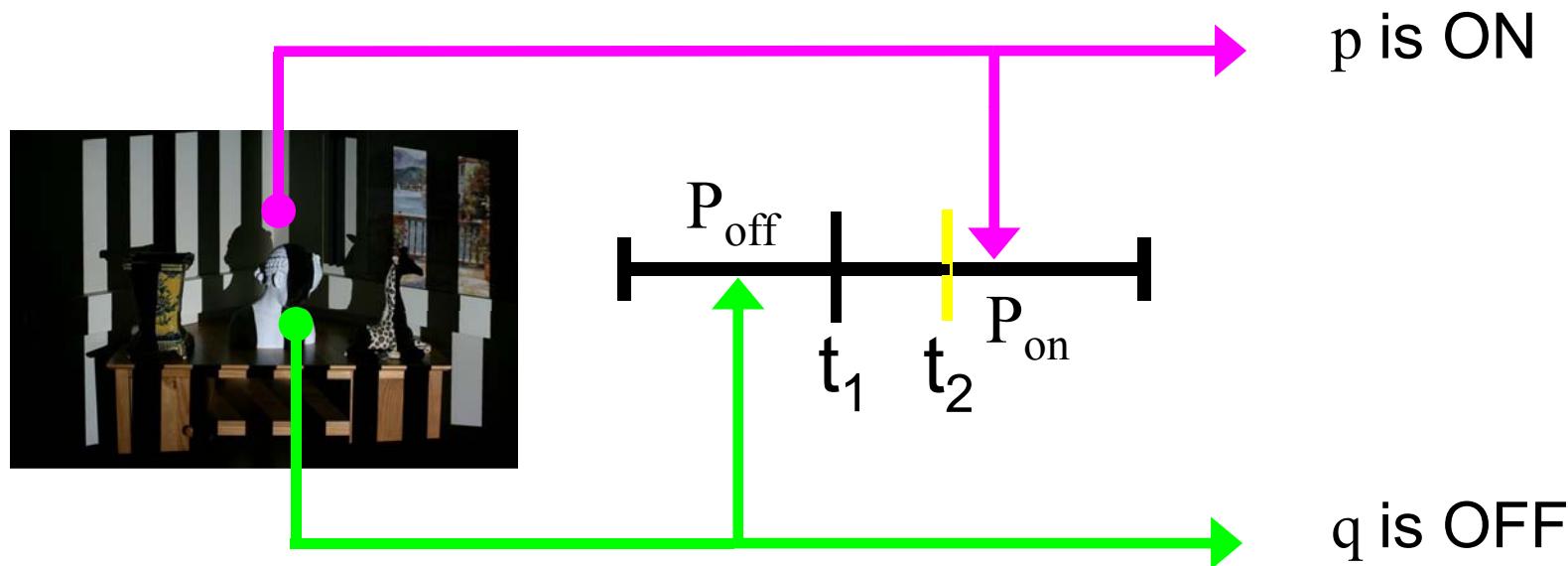
User specifies one threshold t for all pixels





1. Simple Threshold

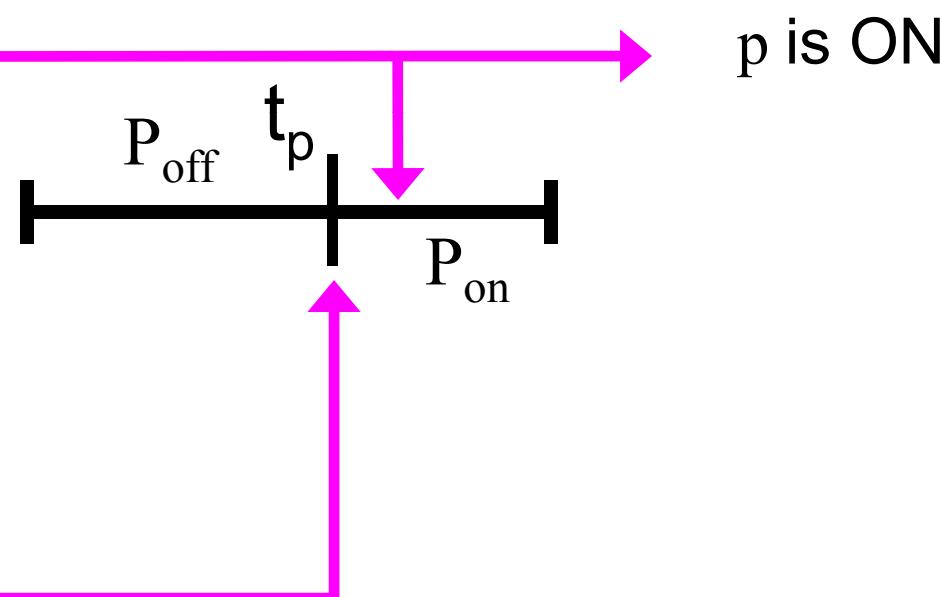
User specifies two thresholds t_1, t_2





2. Albedo Threshold

Compute the albedo t_p for each pixel

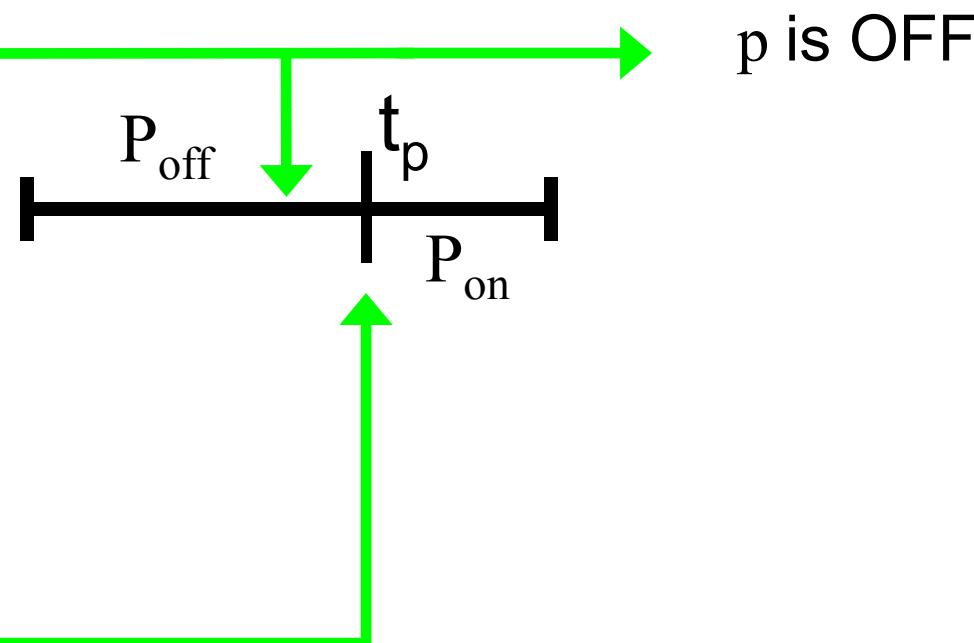


Albedo image



2. Albedo Threshold

Compute the albedo t_p for each pixel

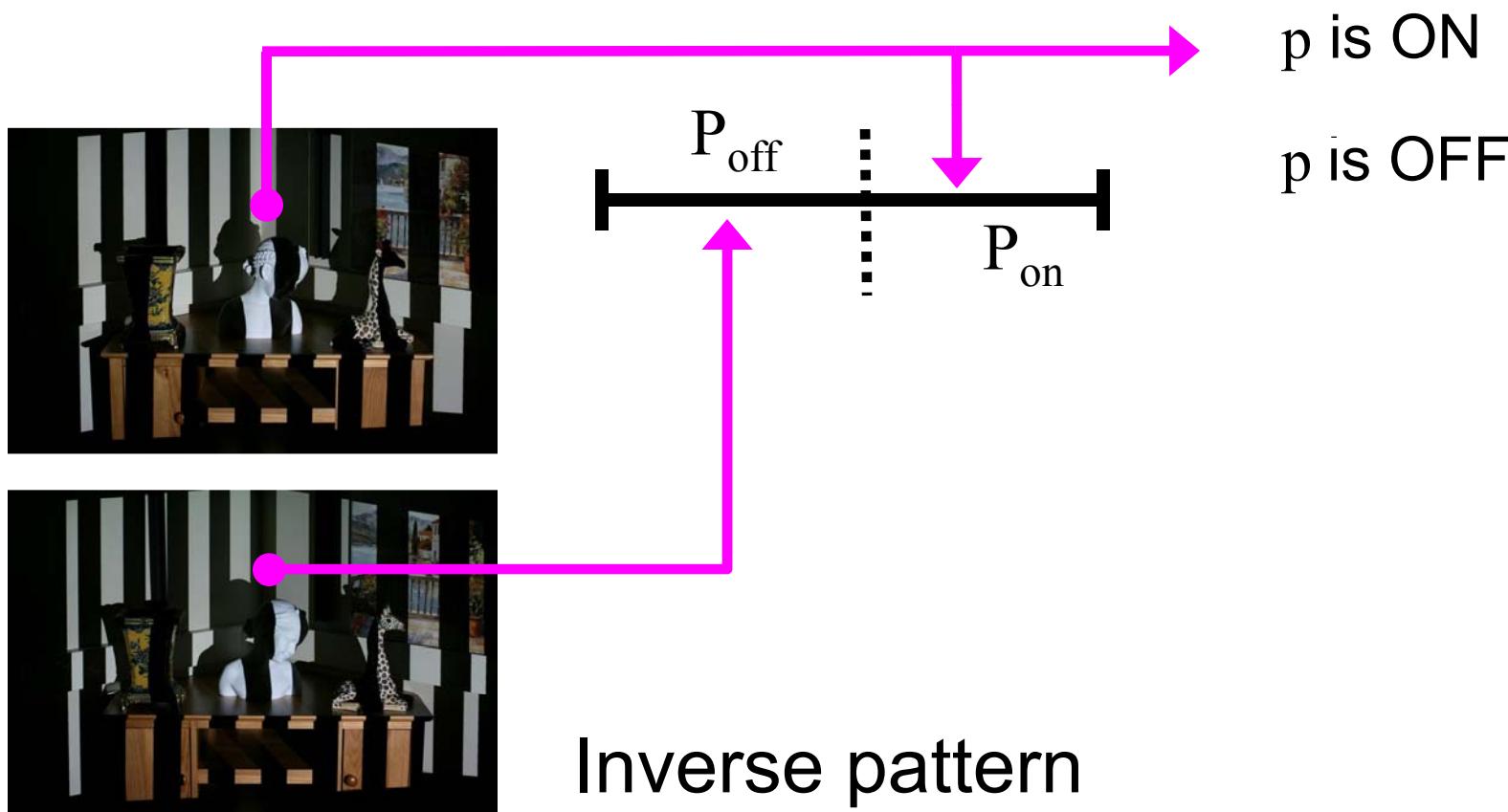


Albedo image



3. Dual Pattern: Pattern and Inverse

Without explicitly computing t_p



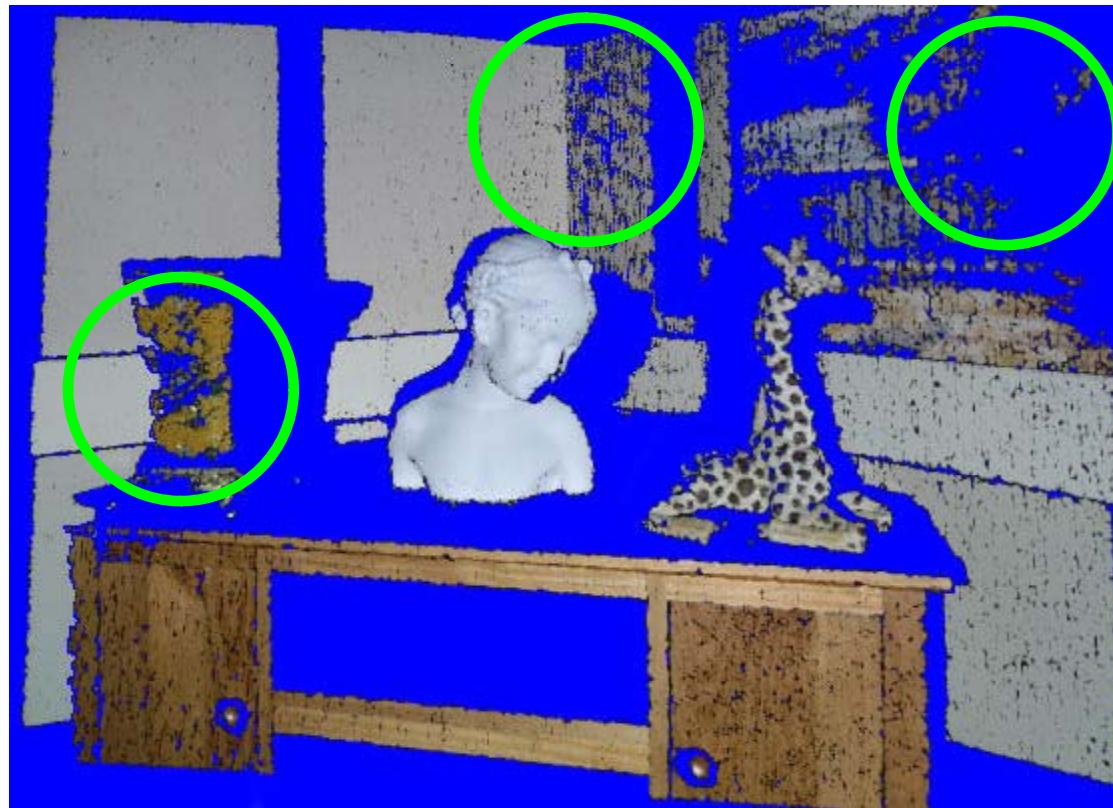


Limitations of Standard Methods

- All three methods assume the two intervals do not overlap
 - This is incorrect when there is strong indirect (global) light
- Haven't actually established the correct bounds



Example Reconstruction



(lost samples are due to missing and incorrect classifications)



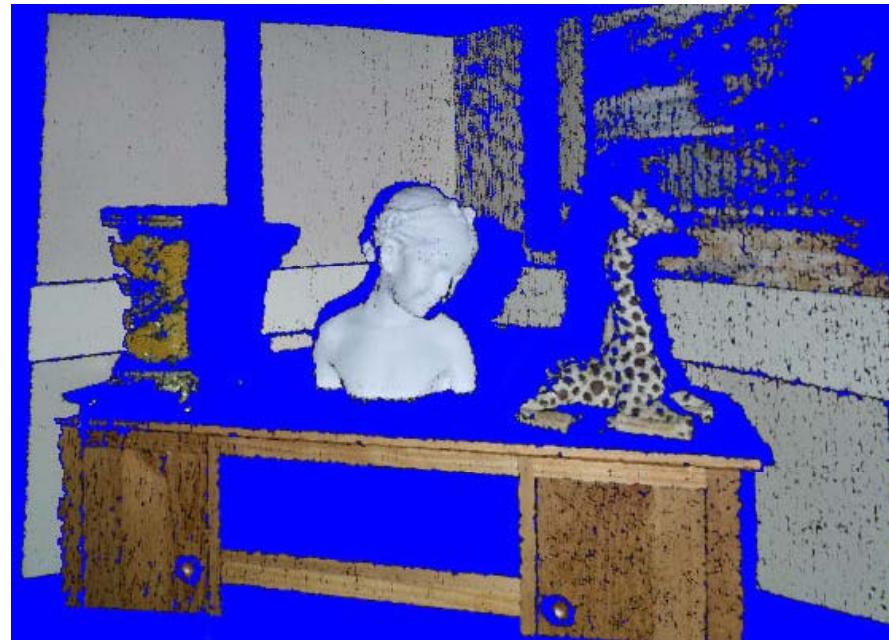
Key Observations

- We can estimate tight intensity value bounds for when the pixel is ON and for when it is OFF.
- A pixel is classifiable when its intensity value falls into one interval but not in the other.

[Xu07, Xu09]



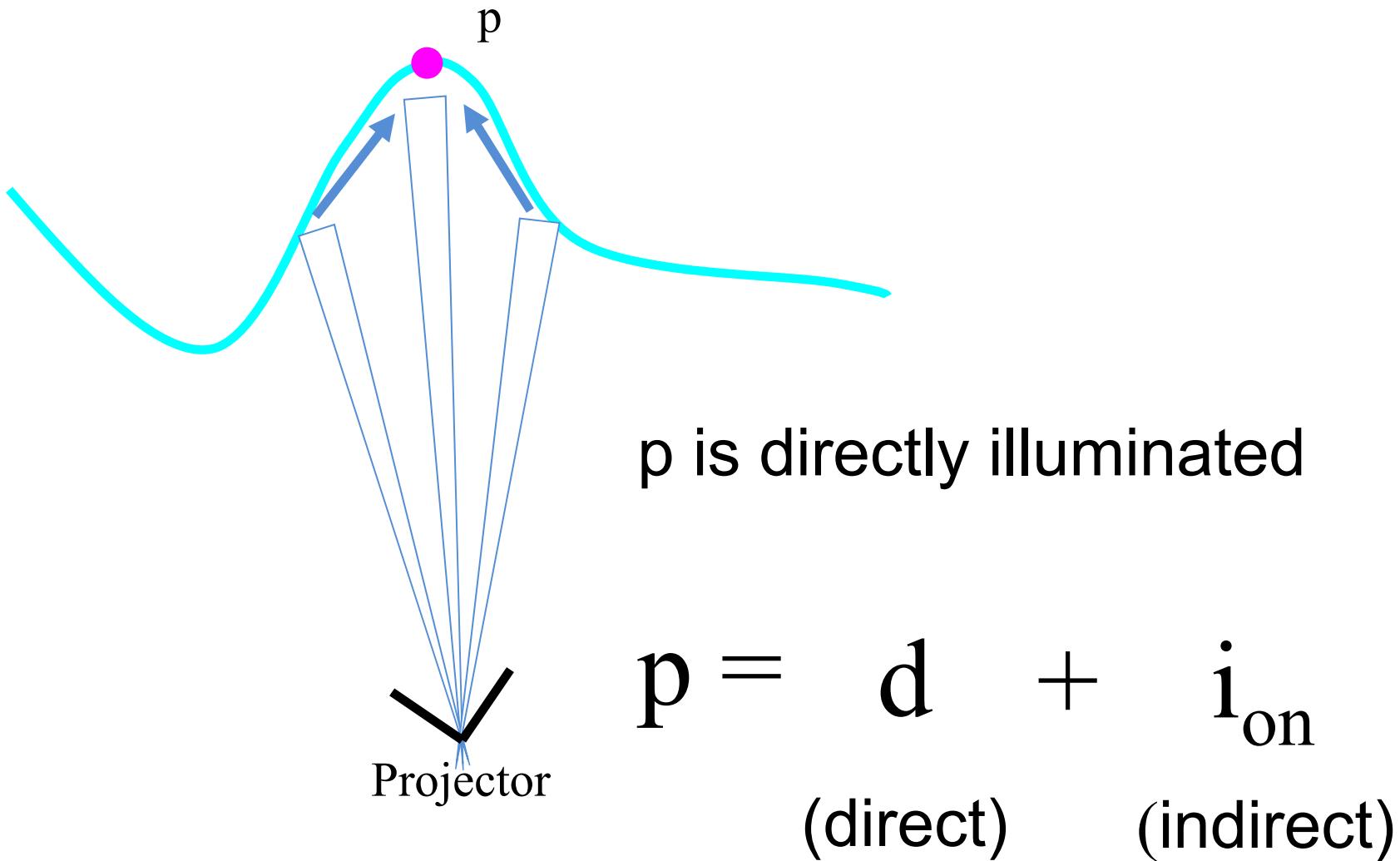
Example Comparison



Using standard pixel classification

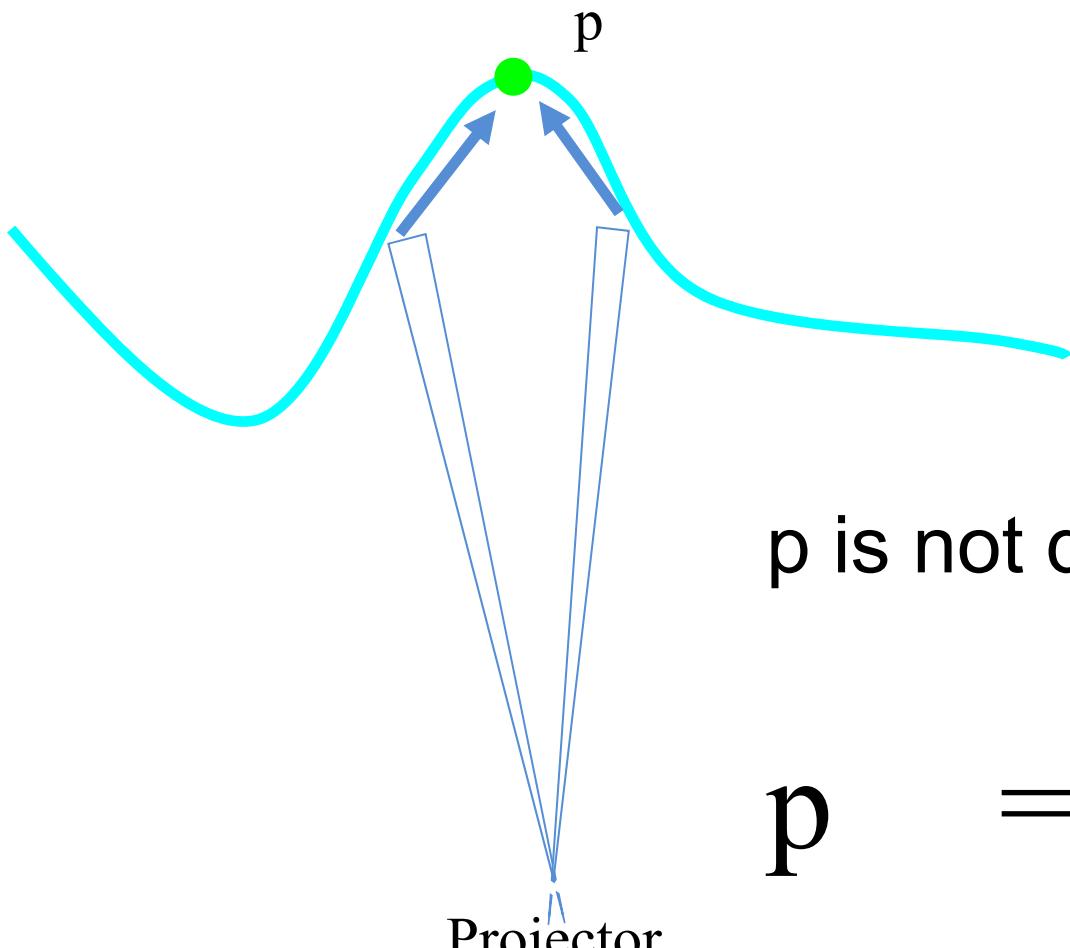


Pixel Intensity (p is ON)





Pixel Intensity (p is OFF)



p is not directly illuminated

$$p = i_{\text{off}} \quad (\text{indirect})$$



Pixel Intensity

$$p = \begin{cases} d + i_{on} & \text{If } p \text{ is ON} \\ i_{off} & \text{If } p \text{ is OFF} \end{cases}$$

- Chicken and egg problem is
 - Need to know d, i_{on}, i_{off} to classify a pixel.
 - ~~Need to classify a pixel to know d, i_{on}, i_{off}~~

ALL white pattern

(all projector pixels on)



Direct and Indirect Separation

- Direct and indirect (global) components of each pixel under ALL white pattern can be separated easily (Nayar et al. SIGGRAPH'06).



$$p = d_{\text{total}} + i_{\text{total}}$$



Direct and Indirect Separation

- Project high frequency binary pattern and its inverse to separate light components.
- Structured light patterns include the separation patterns.
 - Thus, separation can be applied to previously captured data to obtain per pixel

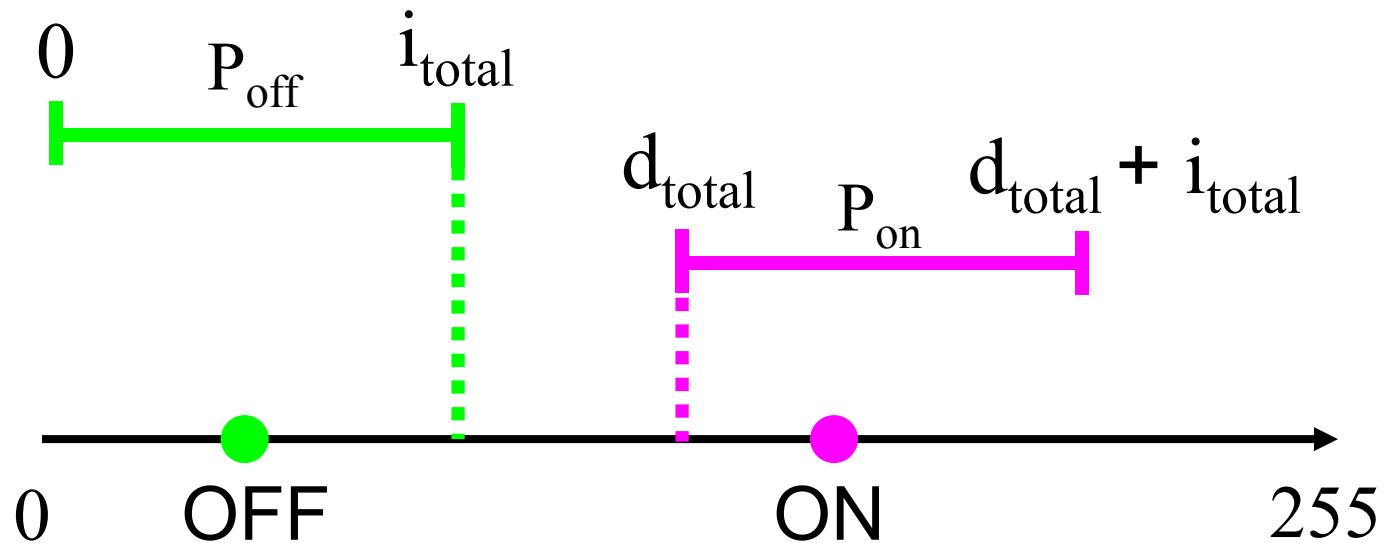
$$p = d_{total} + i_{total}$$



Pixel Classification Scenarios



$$d_{\text{total}} > i_{\text{total}}$$

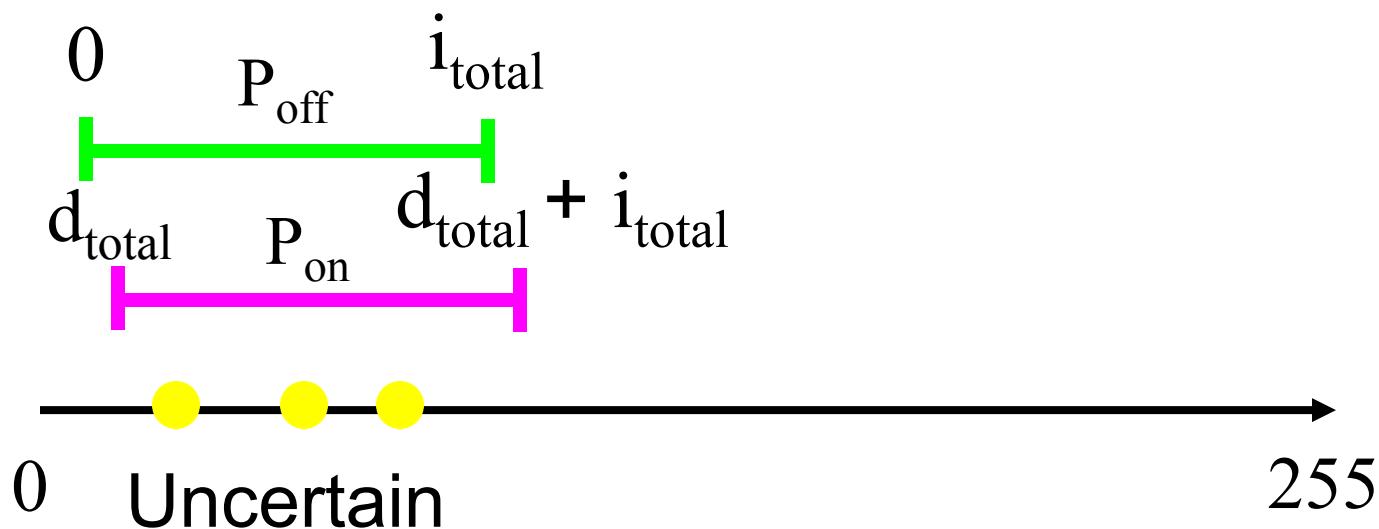




Pixel Classification Scenarios



$$d_{\text{total}} \approx 0$$

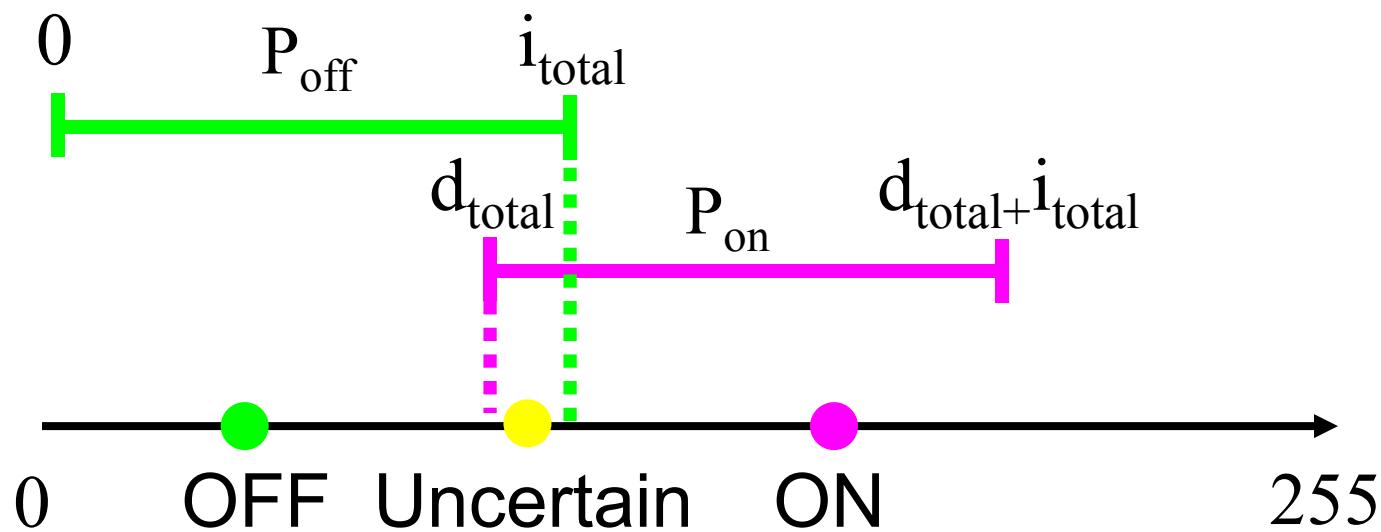




Pixel Classification Scenarios



$$d_{\text{total}} \leq i_{\text{total}}$$





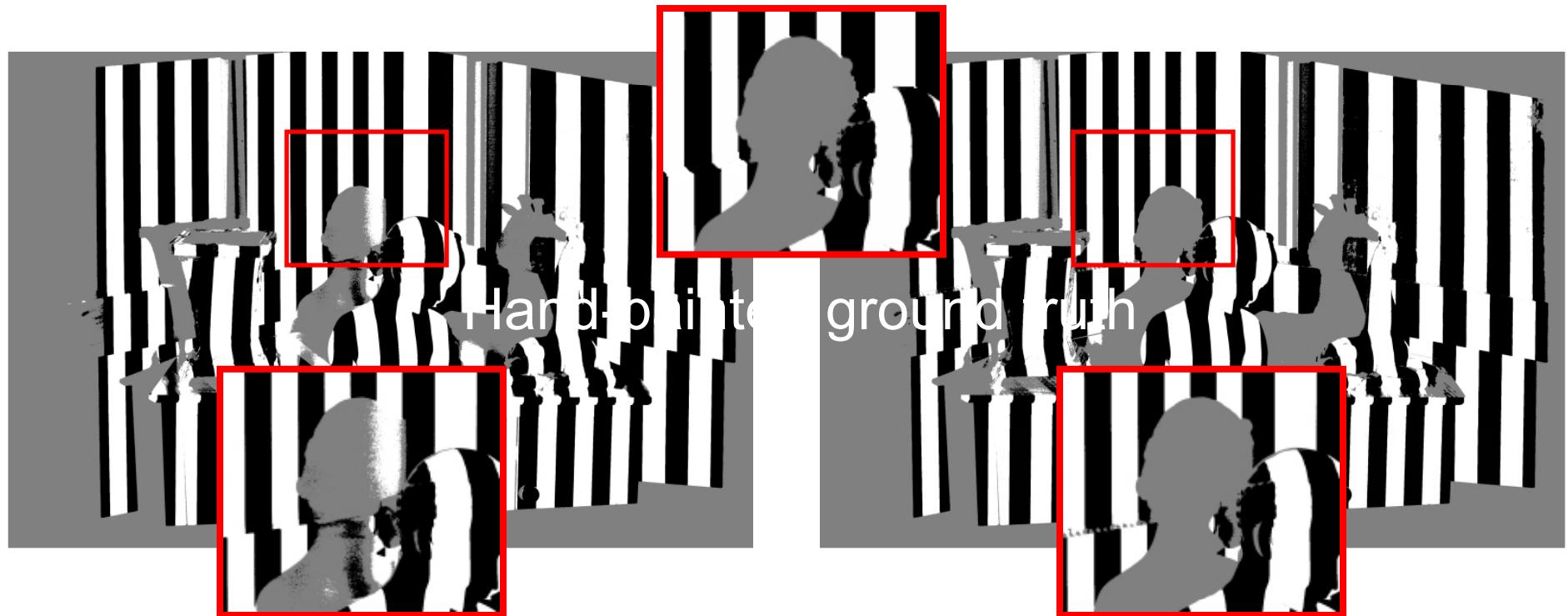
Single Pattern Classification Rules

- $d_{\text{total}} < m \rightarrow$ pixel is *uncertain*
- $p < \min(d_{\text{total}}, i_{\text{total}}) \rightarrow$ pixel is *off*
- $p > \max(d_{\text{total}}, i_{\text{total}}) \rightarrow$ pixel is *on*
- otherwise \rightarrow pixel is *uncertain*



Classification Results

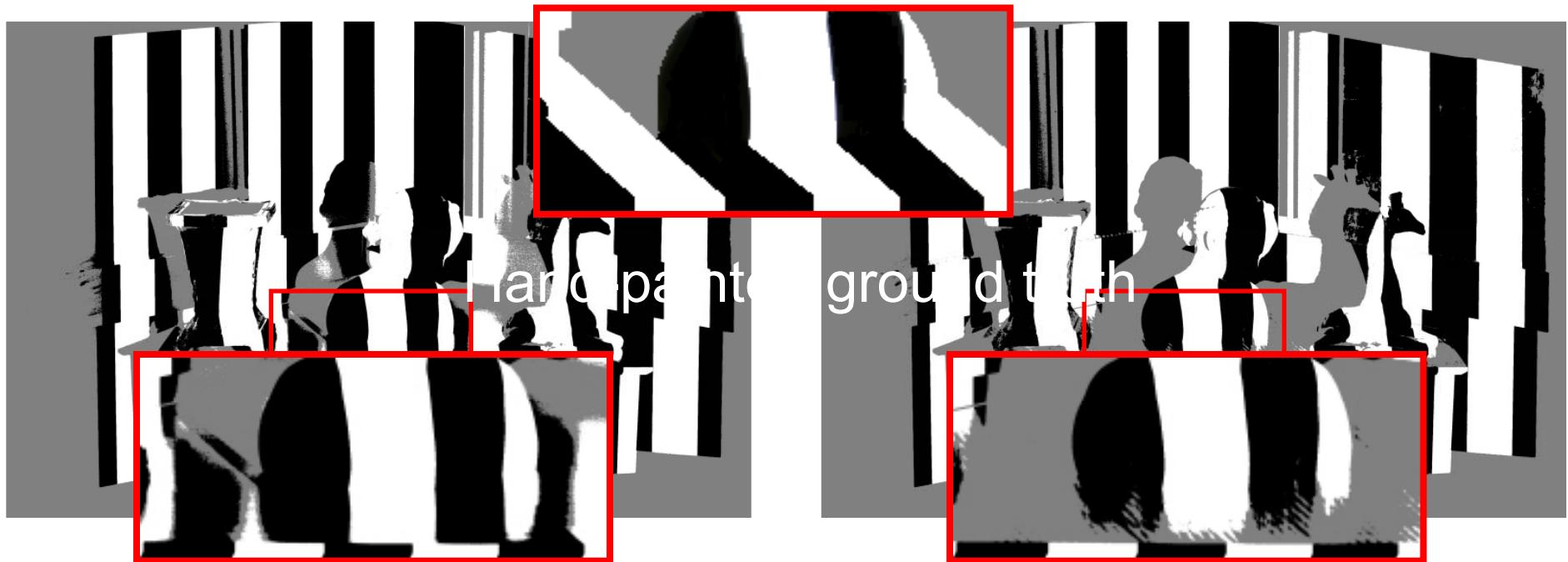
ON(1) OFF(0) Uncertain





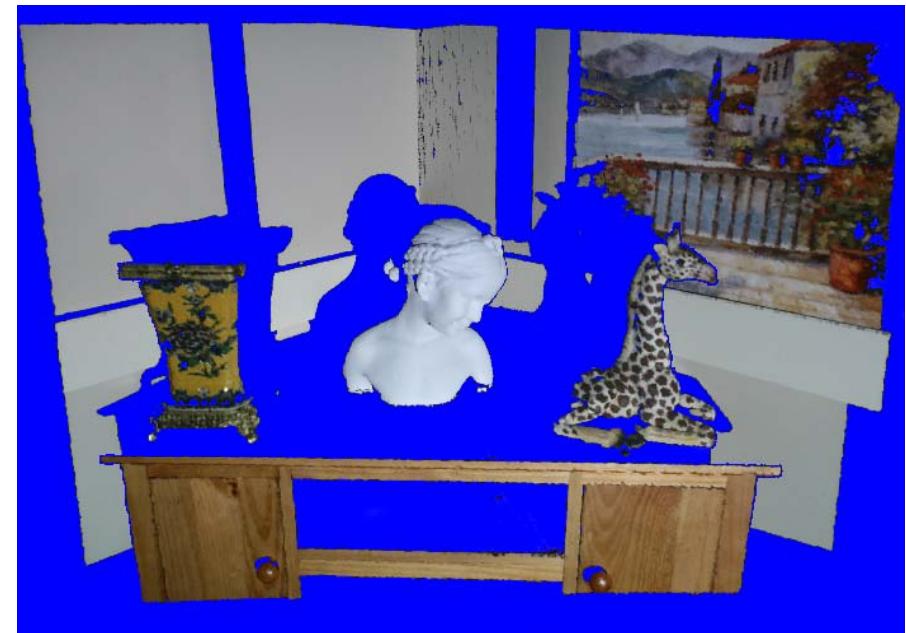
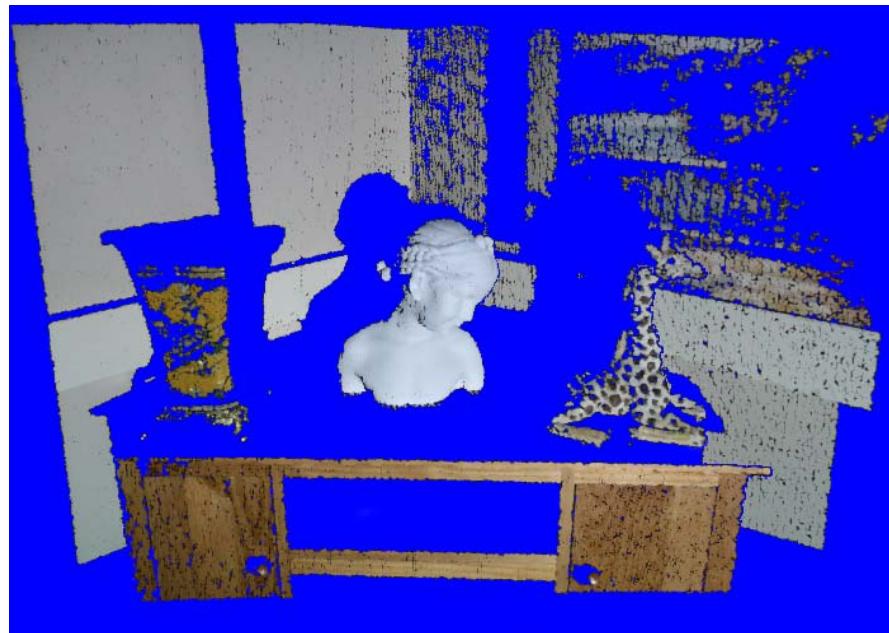
Classification Results

ON(1) OFF(0) Uncertain





Increased Reconstructed Points



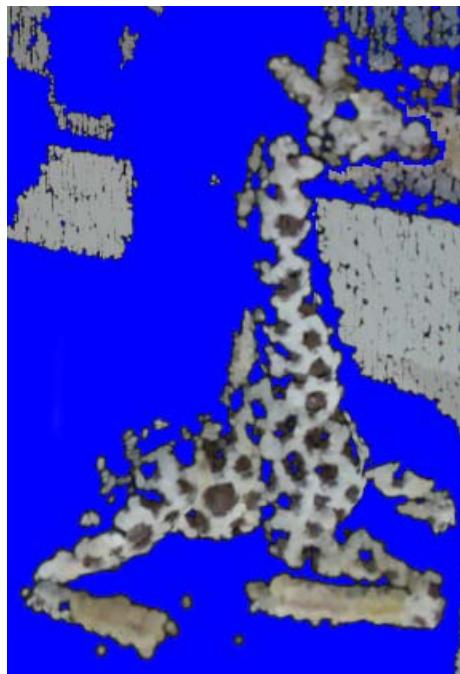


Increased Reconstructed Points



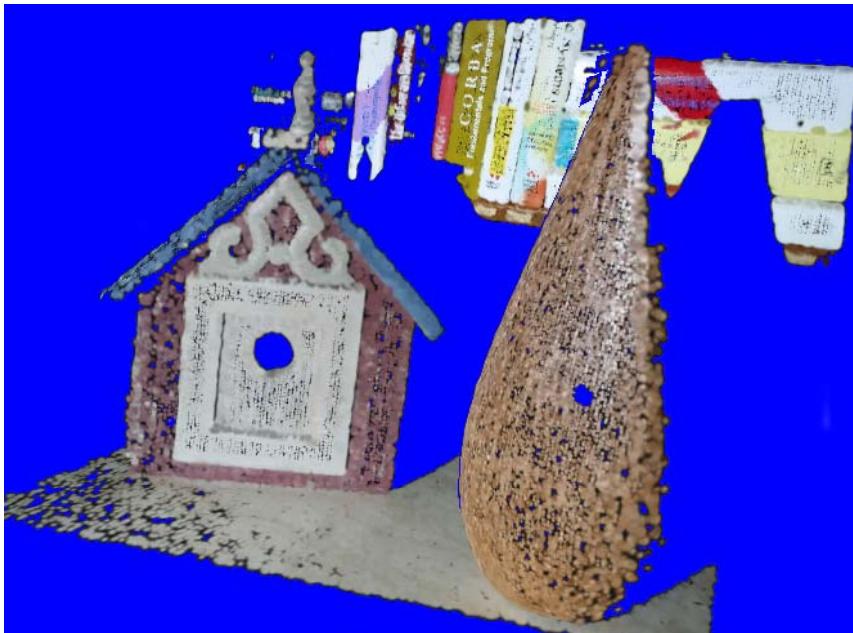


Increased Reconstructed Points



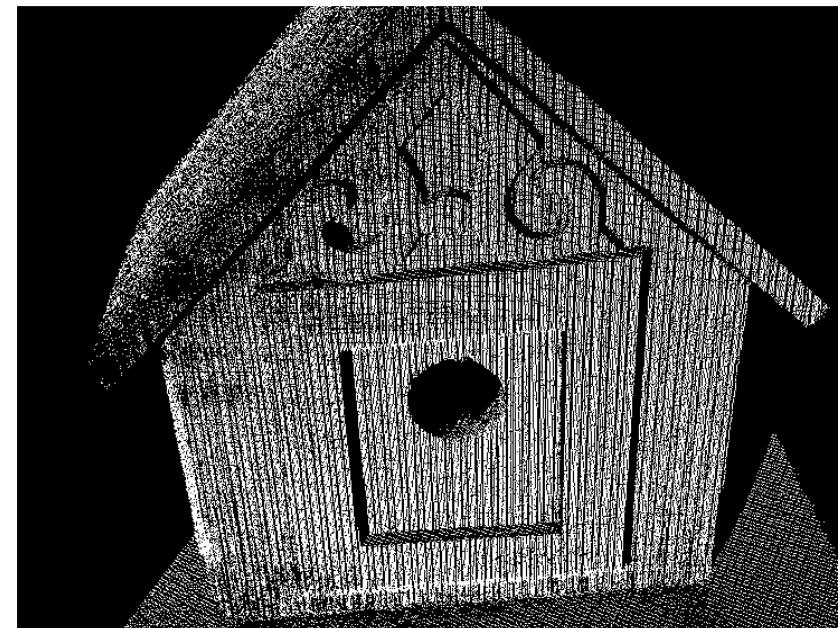
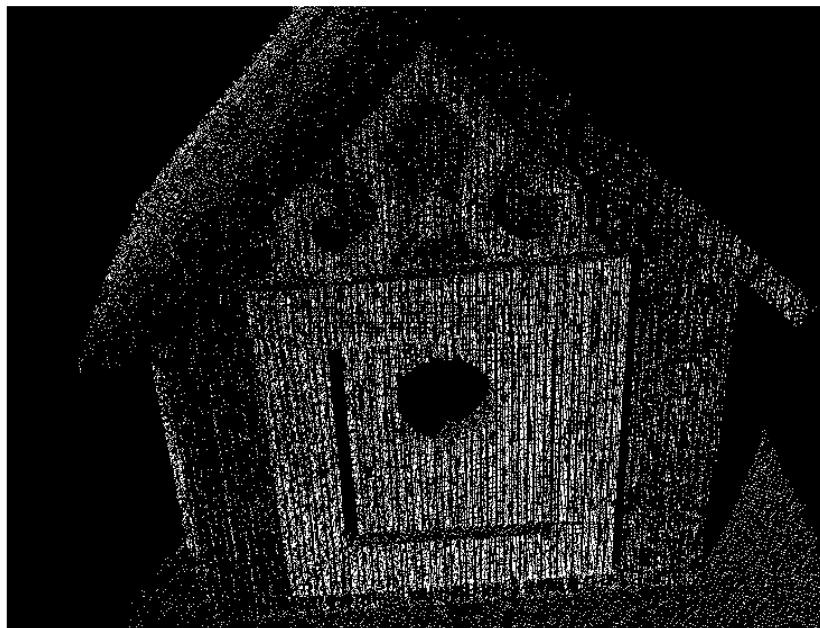


Increased Reconstructed Points





Increased Reconstructed Points





Increased Reconstructed Points





Another issue...





Another issue...

- Classify...
 - pixels at stripe boundaries?
 - pixels at strip middle?
 - all pixels?

