Structured Light 3D Scanning

In the presence of Global Illumination

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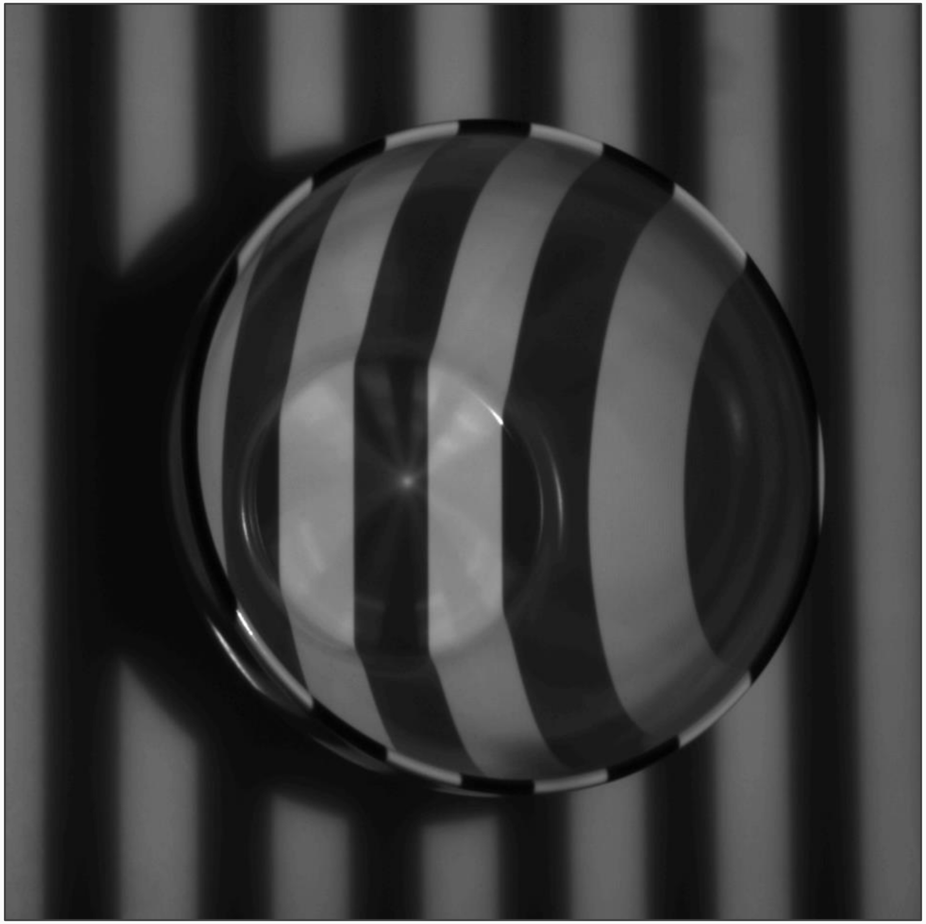
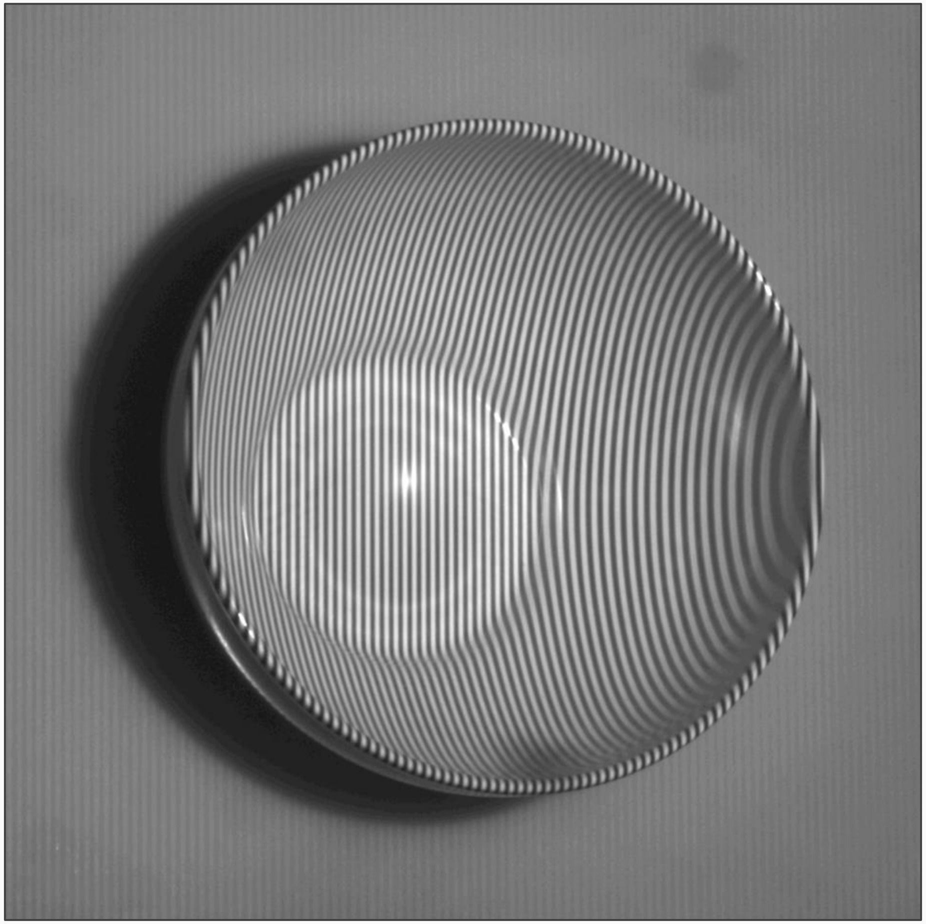
Presented by Noranart Vesdapunt, Utkarsh Sinha

Slide adapted from Srinivasa et al., Nayar et al.

Structured light

Structured Light





Structured Light

- Two views, one projector
- Different kinds of patterns
  - Binary
  - Grayscale
  - Colour
- As fast as 4000 Hz
- As precise as 30 μm

3D structure Light

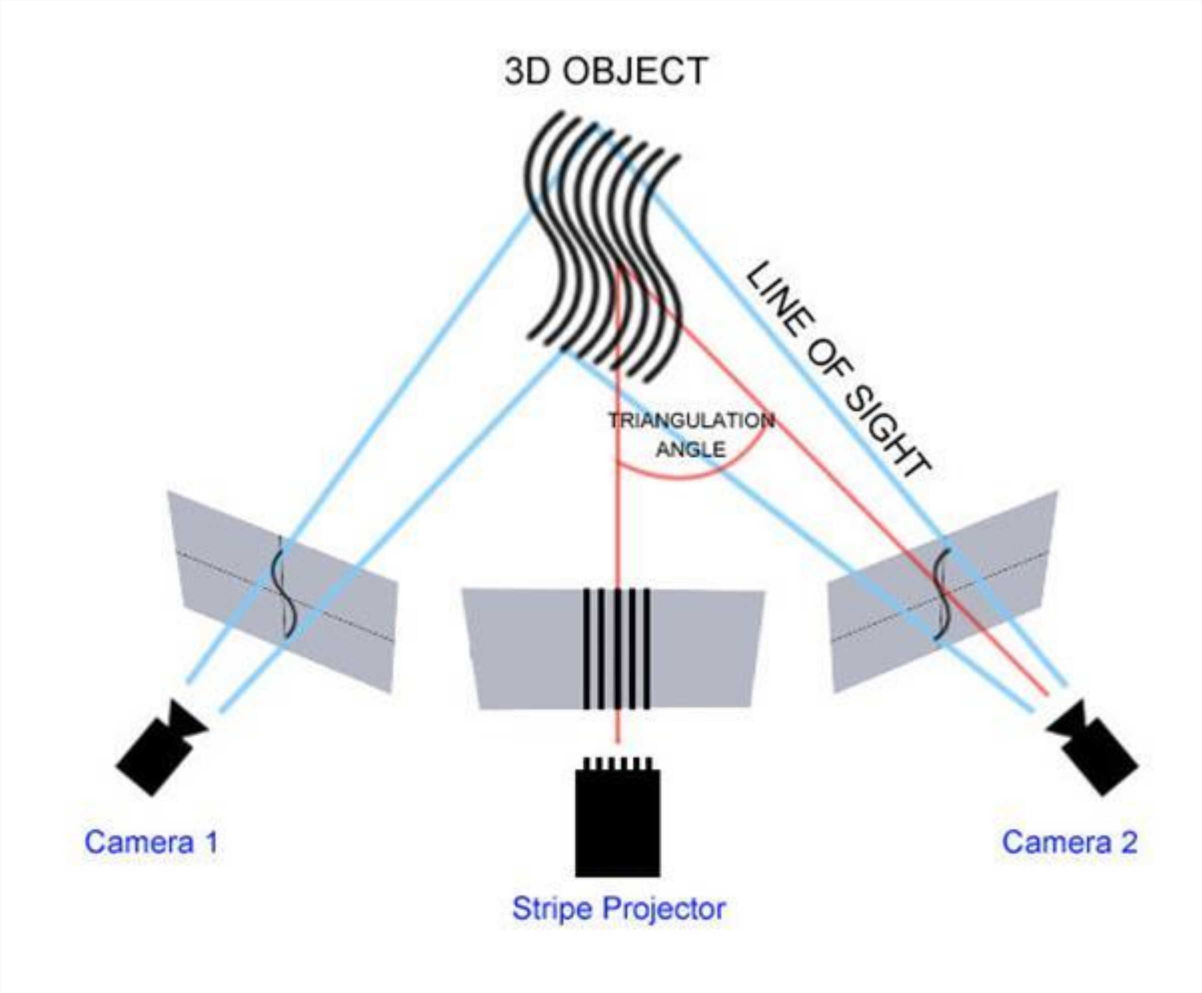


image from http://www.3ders.org/

3D structure Light (This Paper)

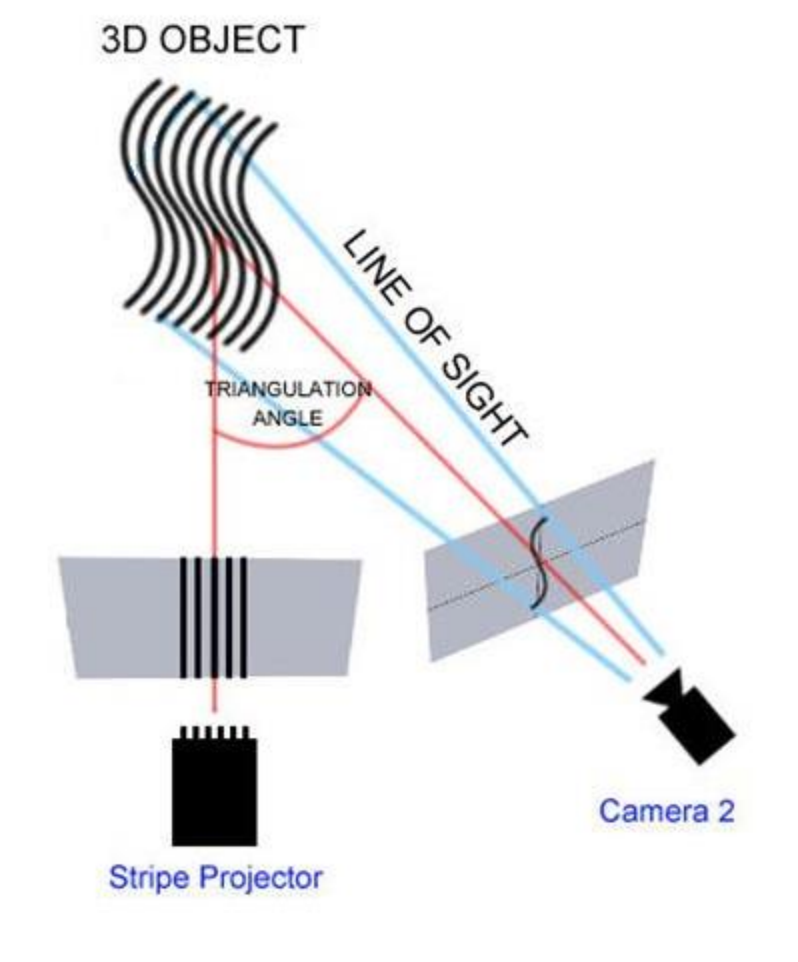


image from http://www.3ders.org/

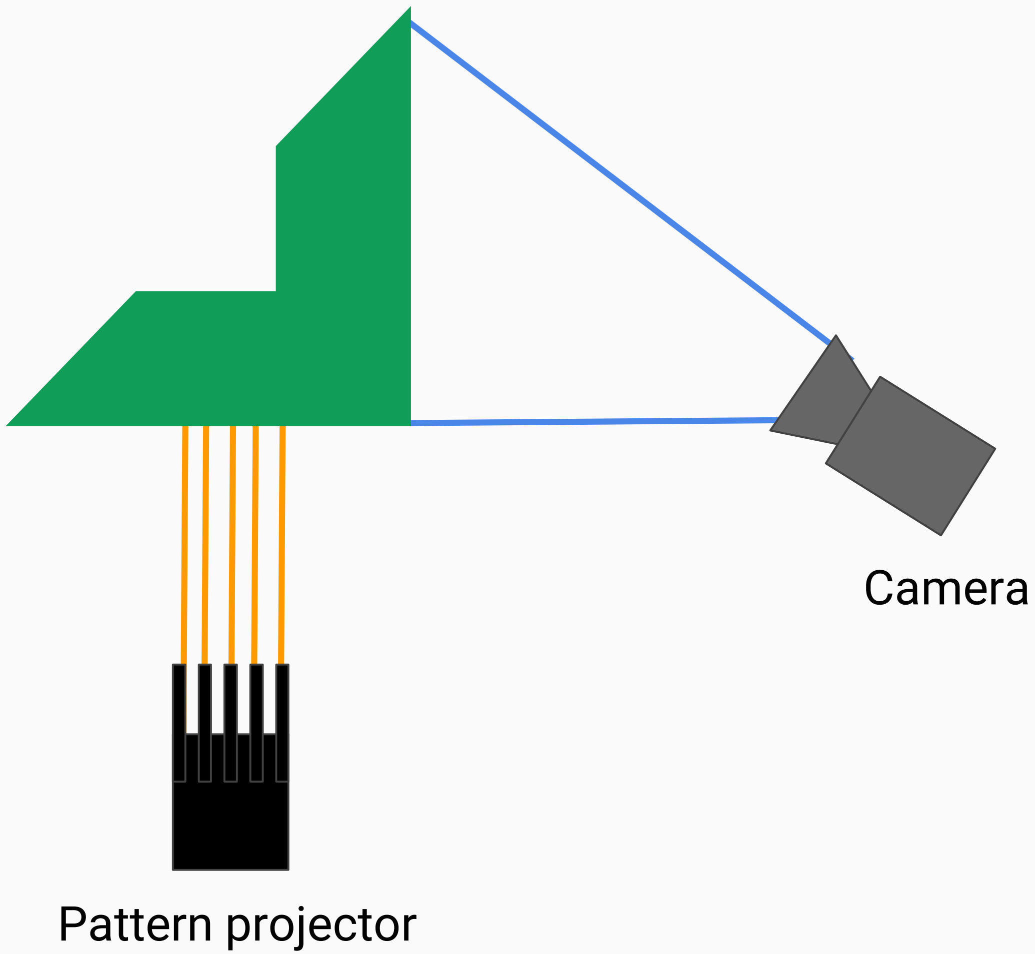
Issues with Structured Light

Structured light is highly dependent on finding exact correspondences

This would fail if:

- Illuminated pixels are occluded
- Camera Defocus blur
- Unexpected illumination due to GI

Illuminated pixels are occluded



Camera Defocus Blur

Issues with Structured Light

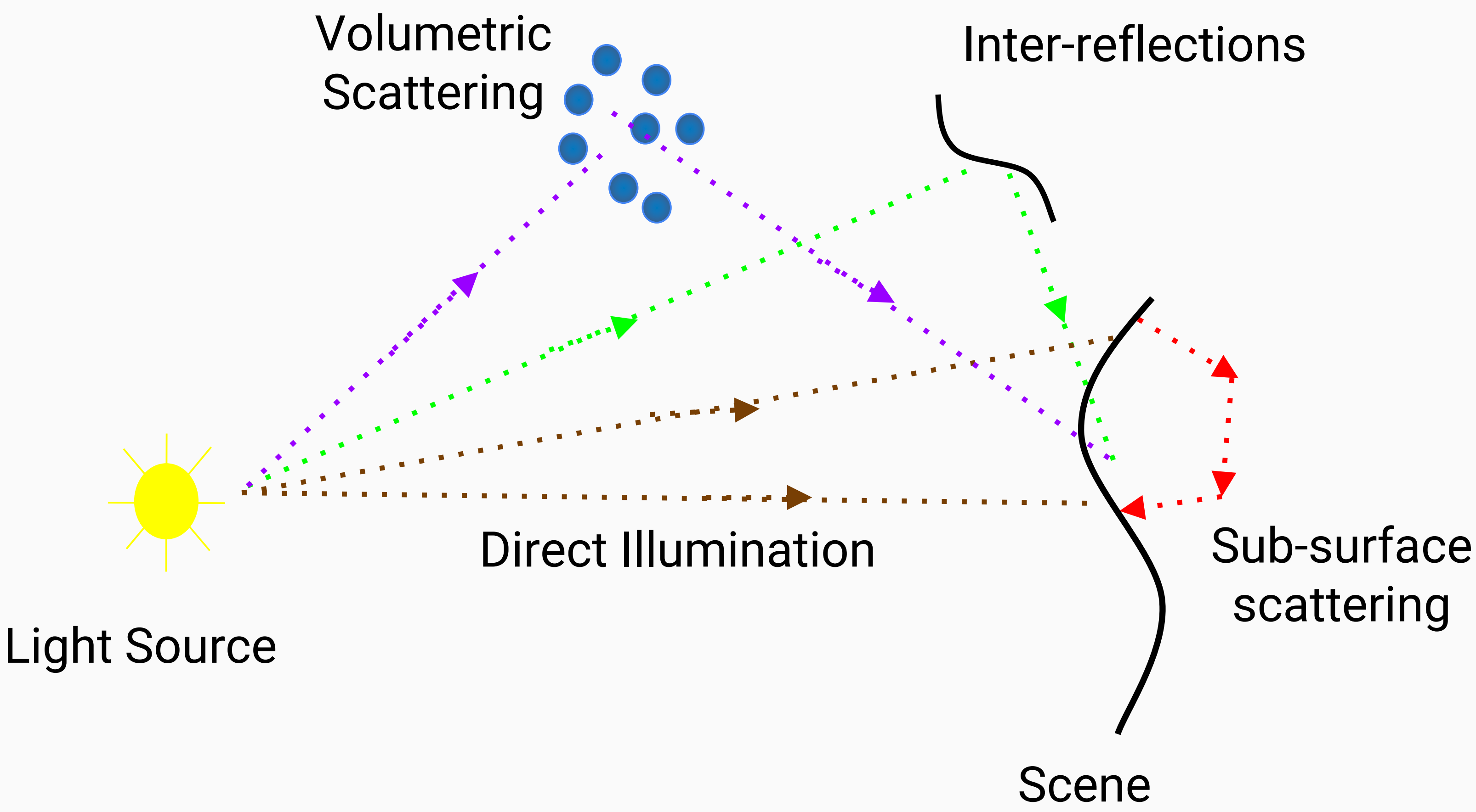
Structured light is highly dependent on finding exact correspondences

This would fail if:

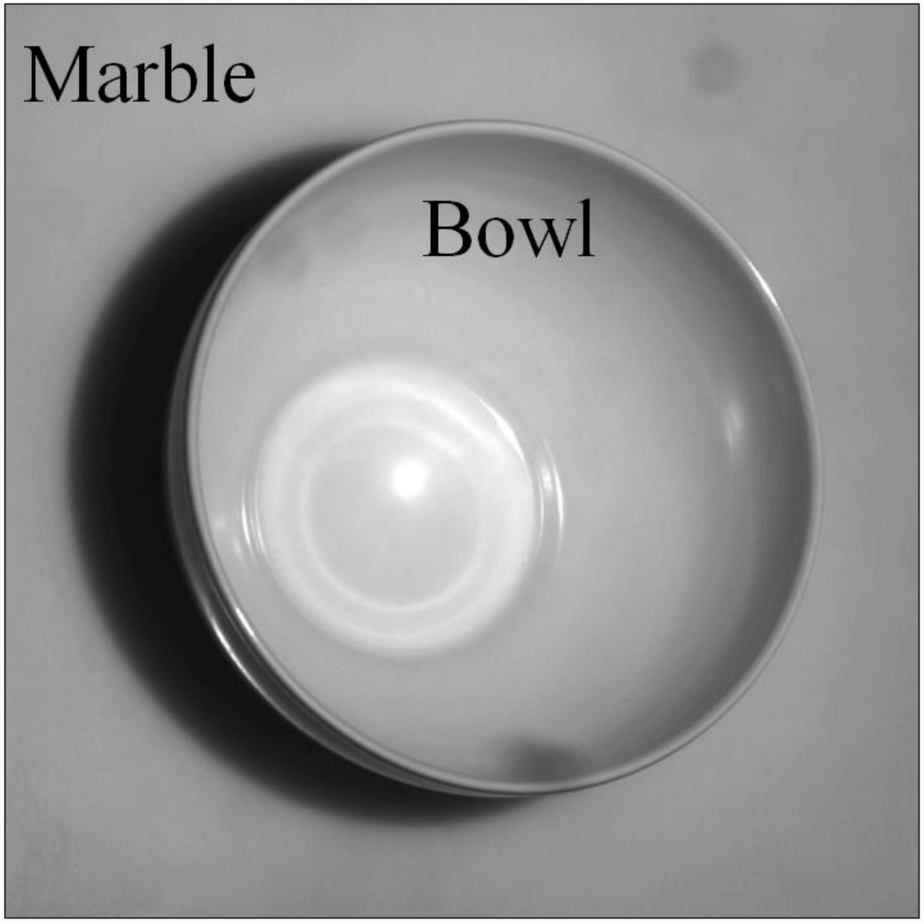
- Illuminated pixels are occluded
- Defocus blur
- **Unexpected illumination due to GI**

Issues due to GI

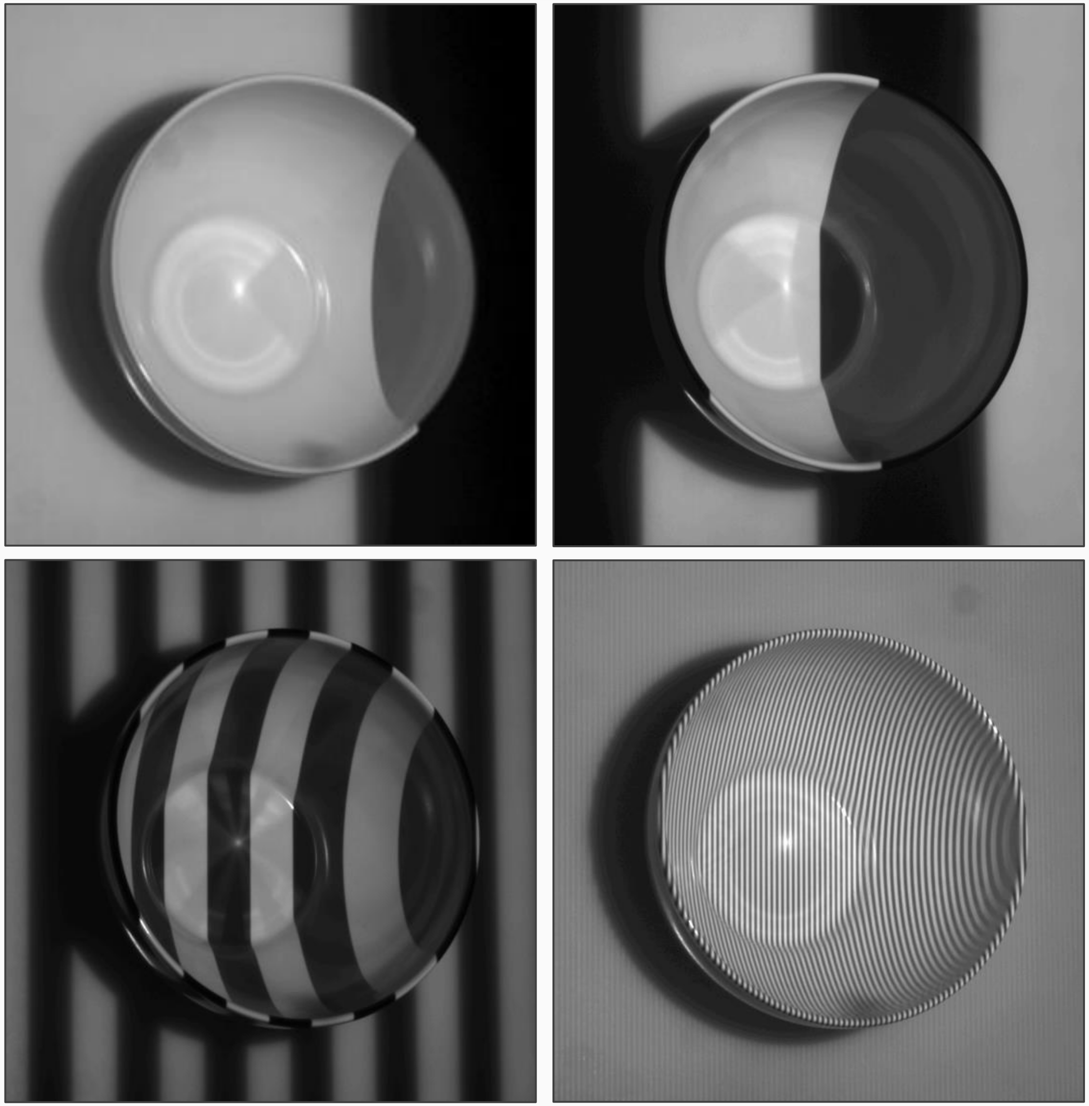
Light Transport



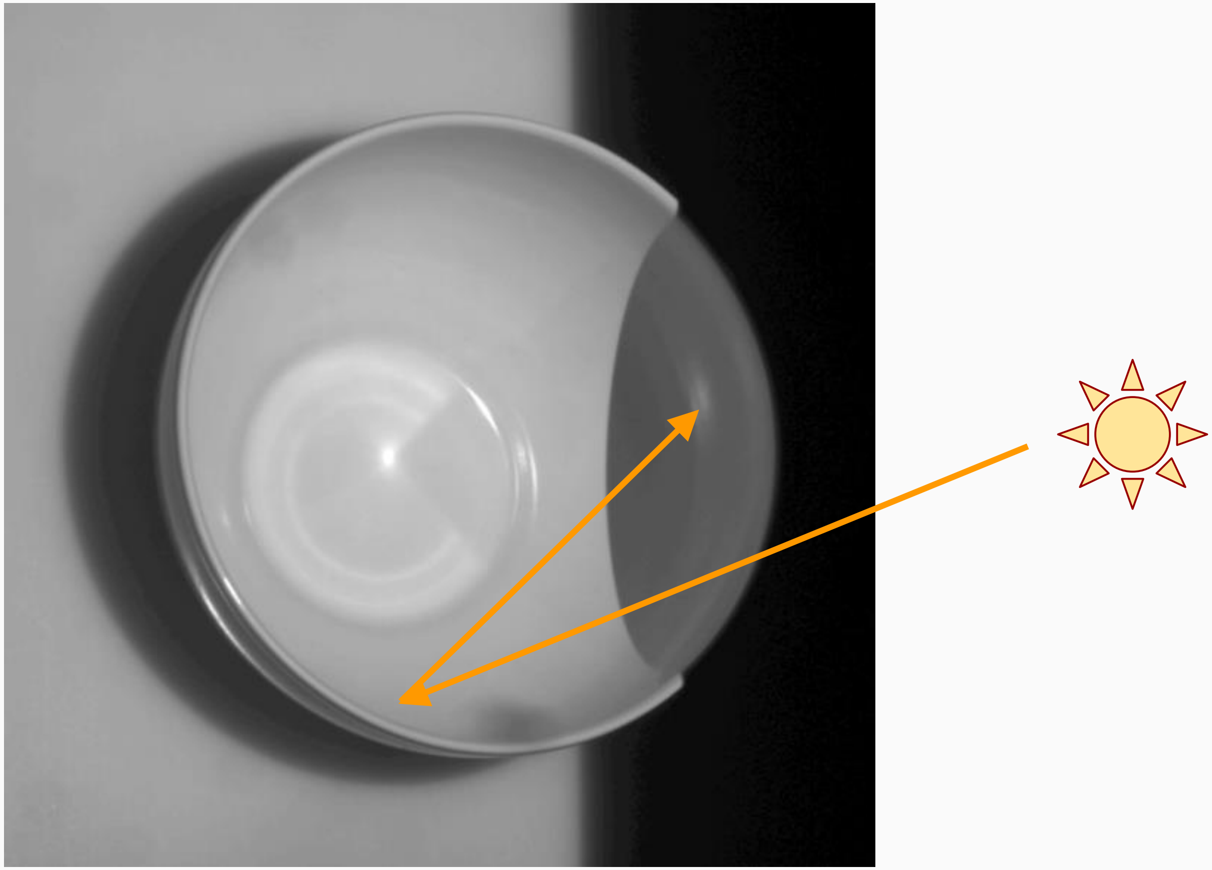
Bowl on a Marble Slab



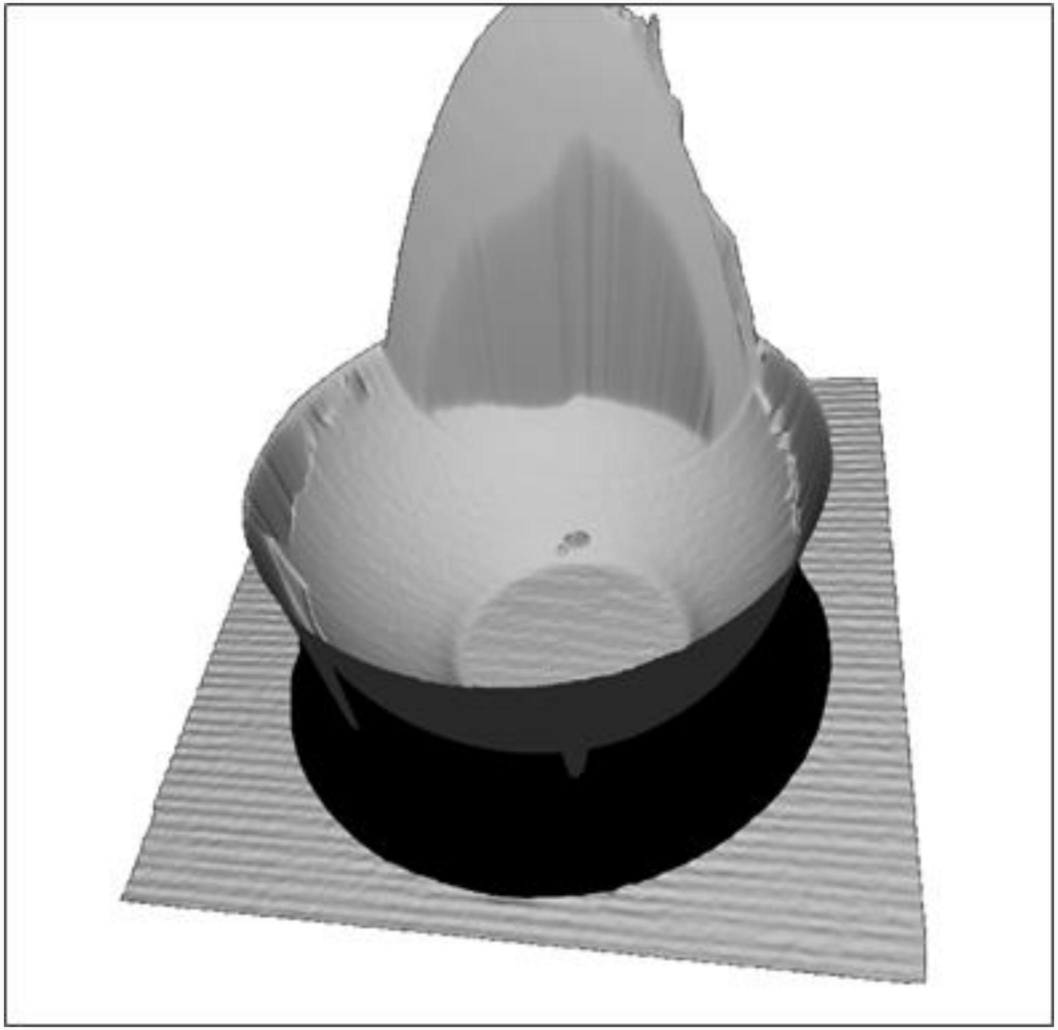
Pattern with Different Frequencies



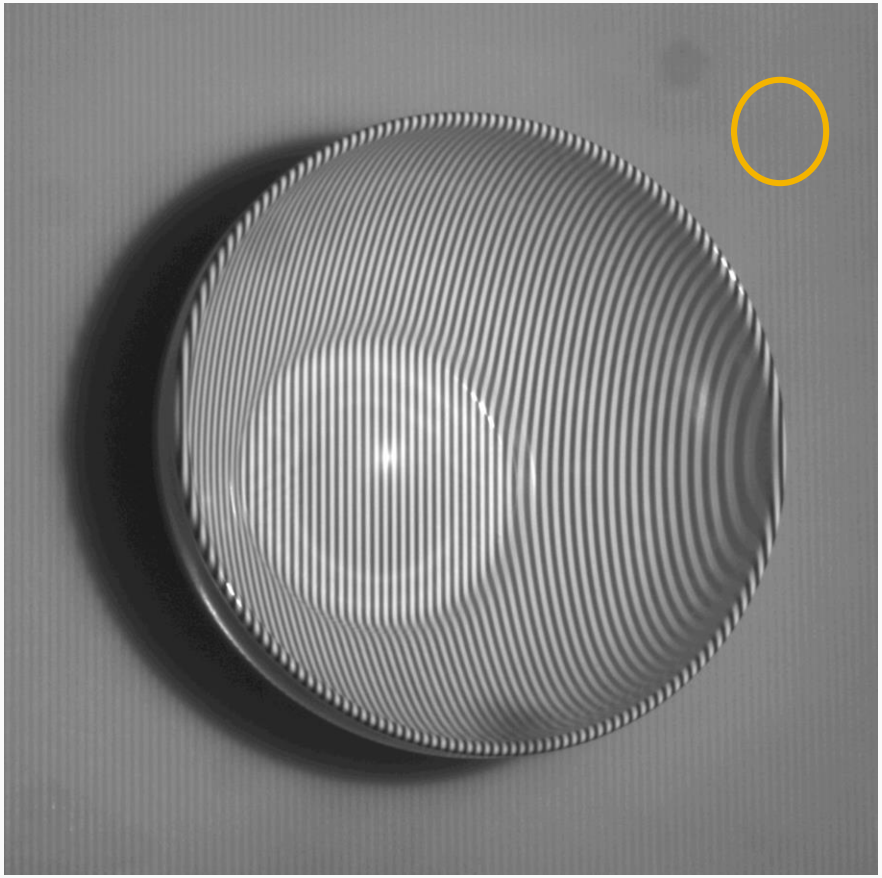
Low Frequency: Interreflections



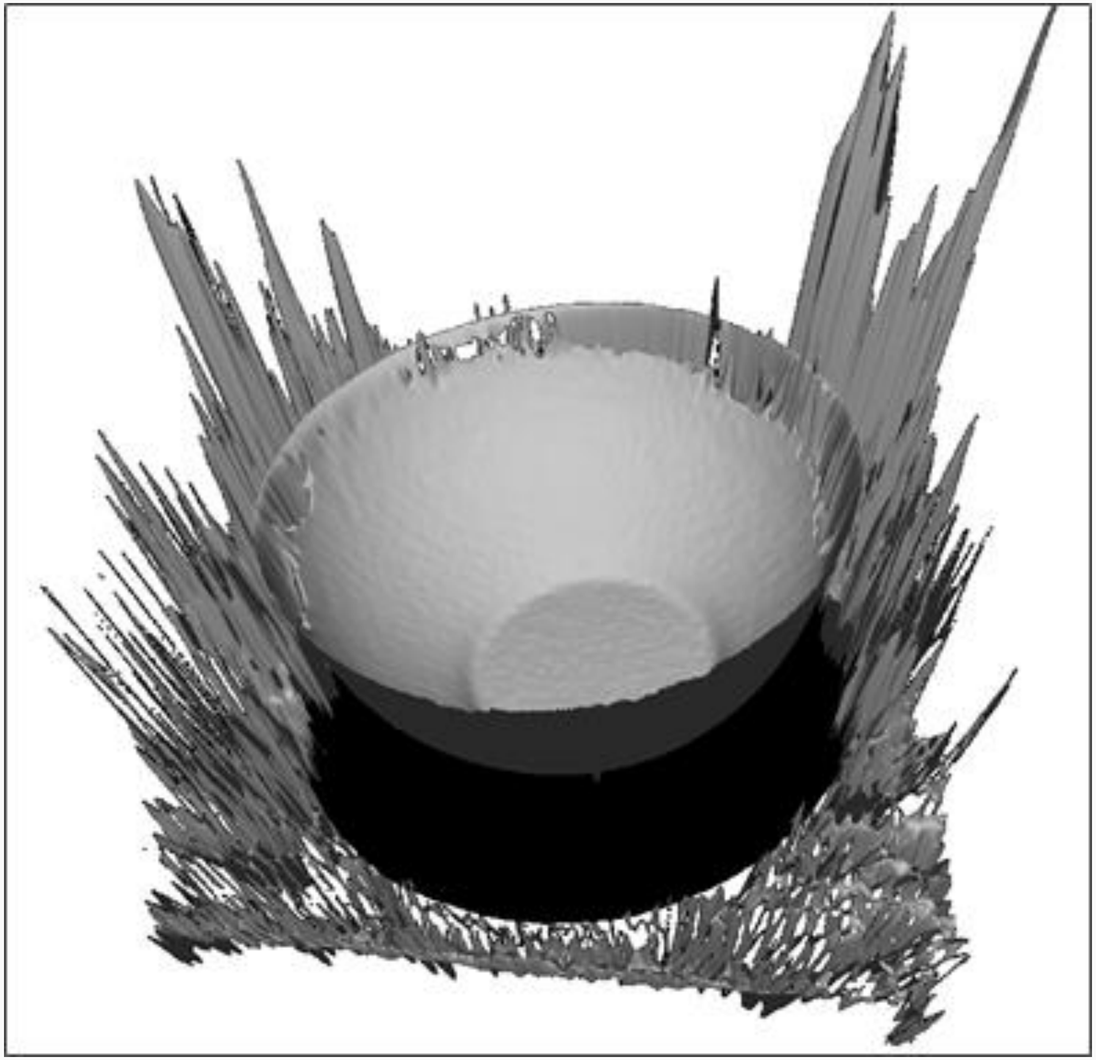
Long range effects



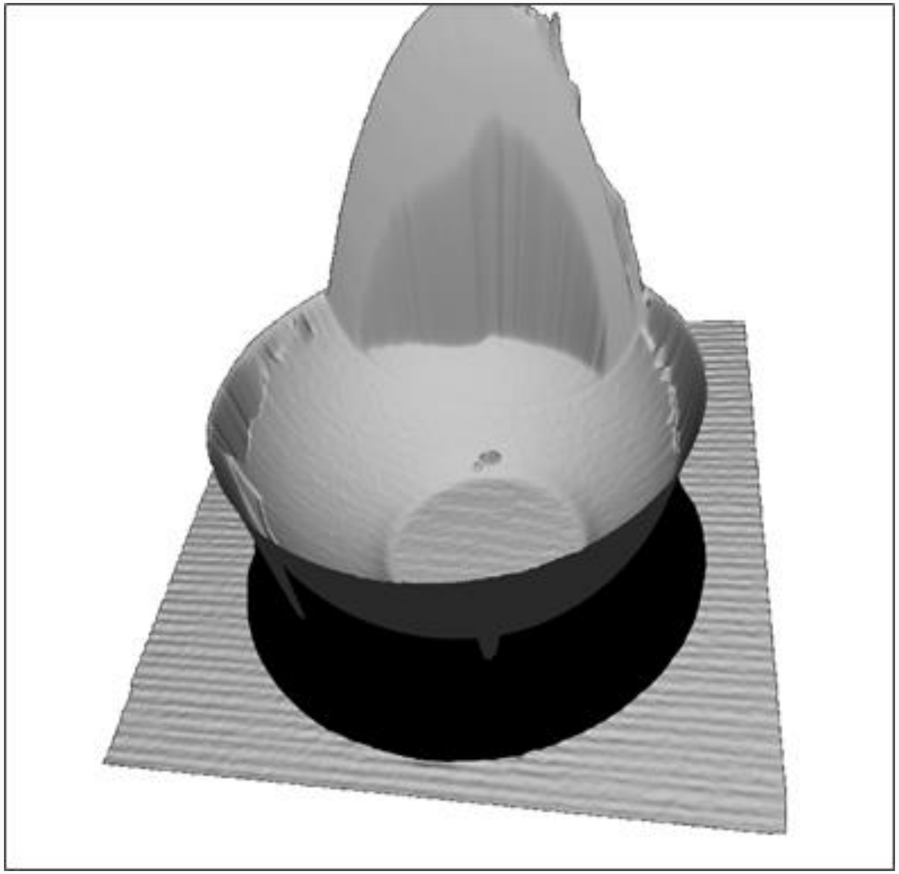
High Frequency: Subsurface Scattering

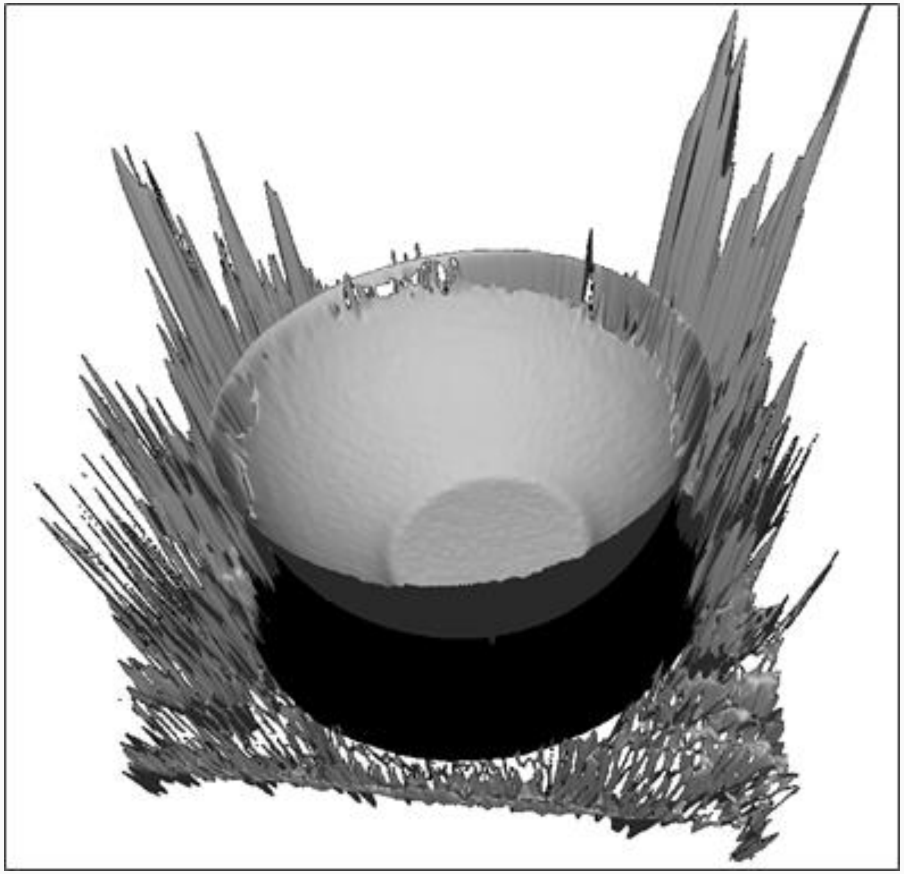


Short range effects

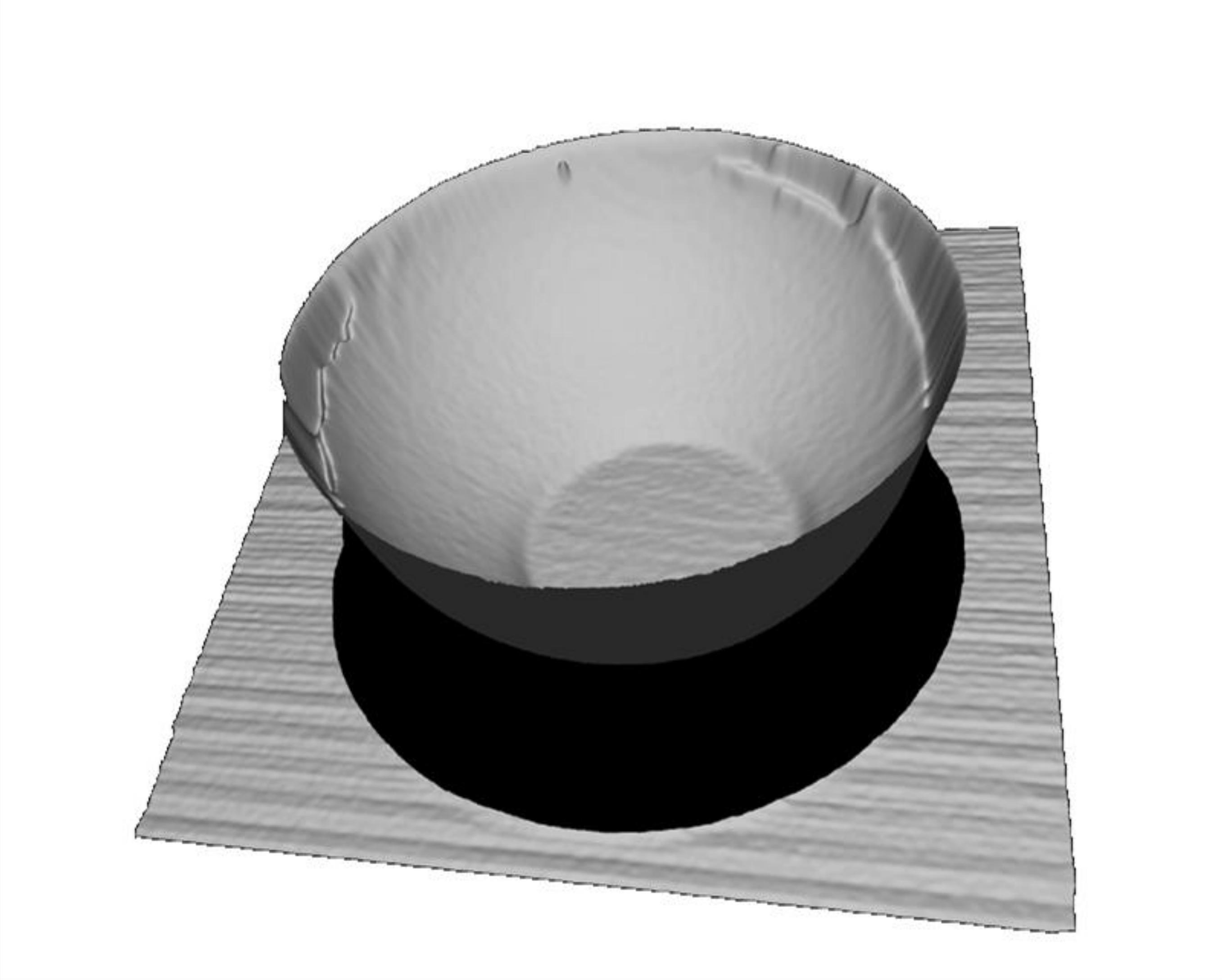


Combine Both



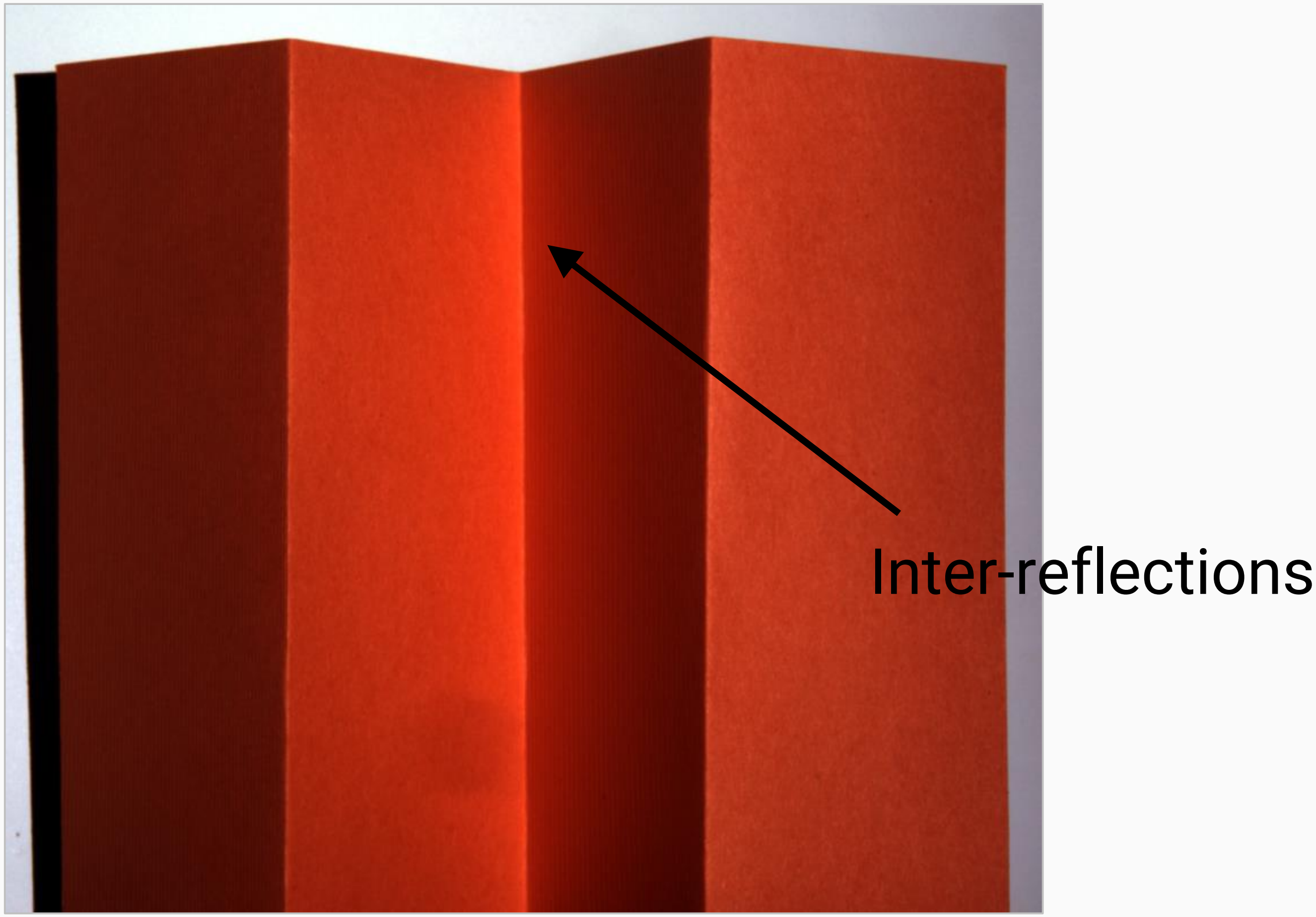


This Paper

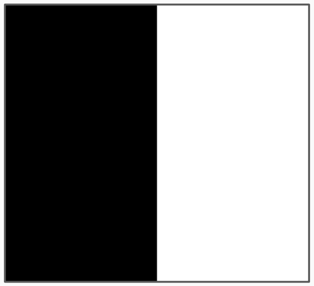


Formulating the problem

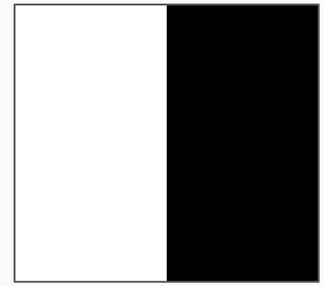
V-Groove Scene



Conventional Gray codes

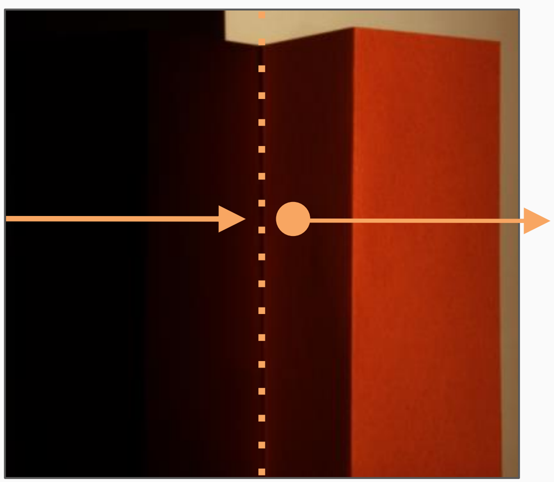


Low frequency pattern

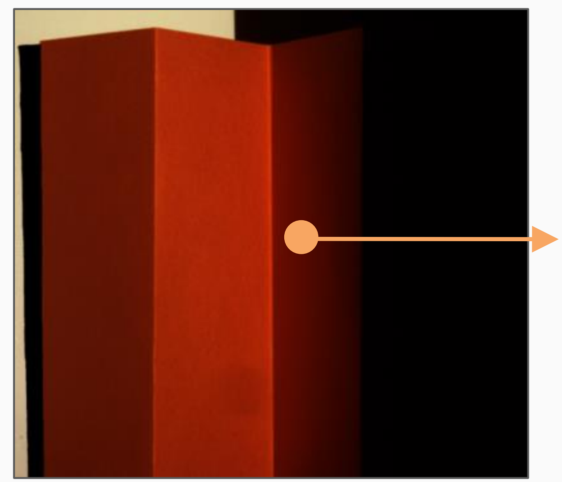


Inverse Pattern

Pattern Edge



L = 0.16

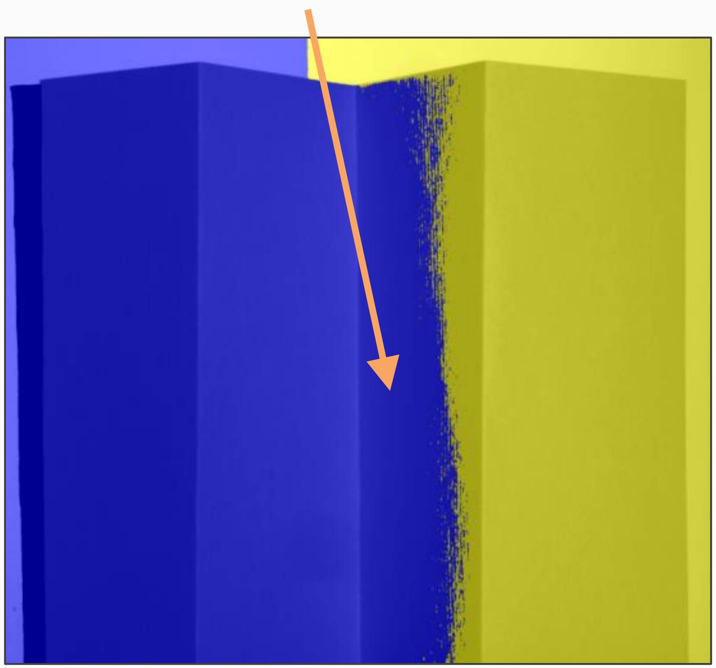


$\bar{L}$ = 0.25

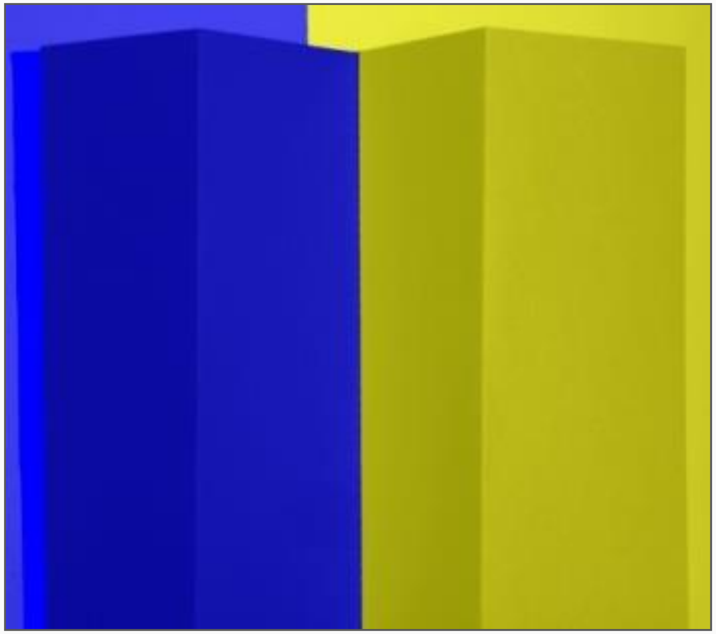
Captured Image

Binarization error (long-range effects)

Errors due to inter-reflections



Incorrect Binarization

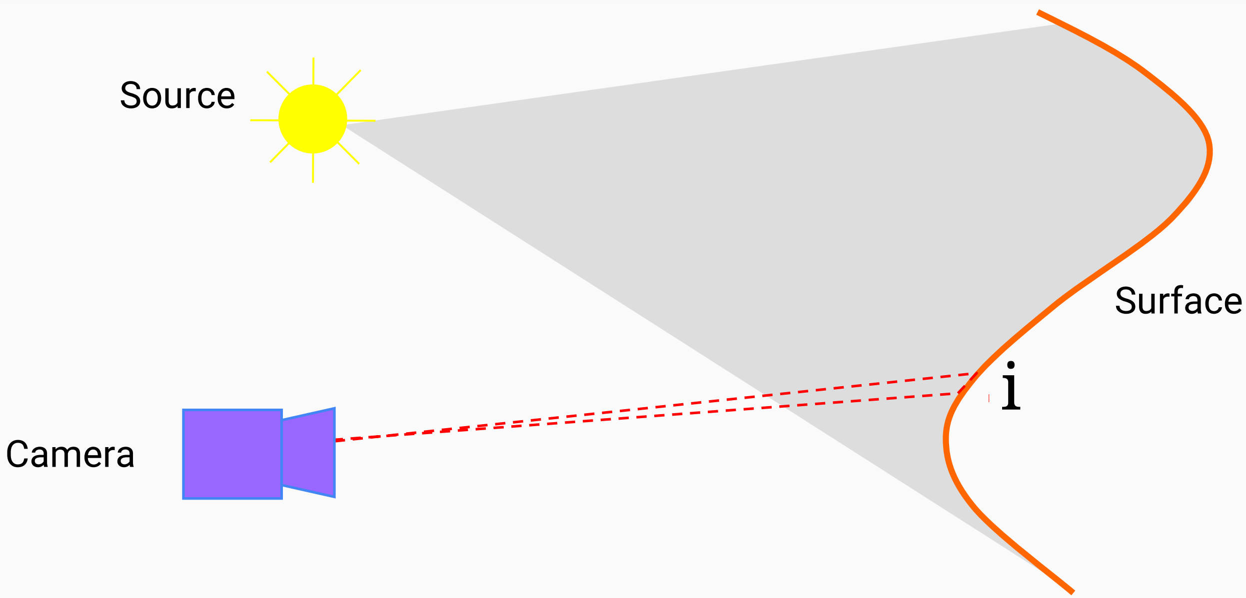


Ground-truth Binarization

One (illuminated)

Zero (not-illuminated)

Point Light Source Illuminating the Scene

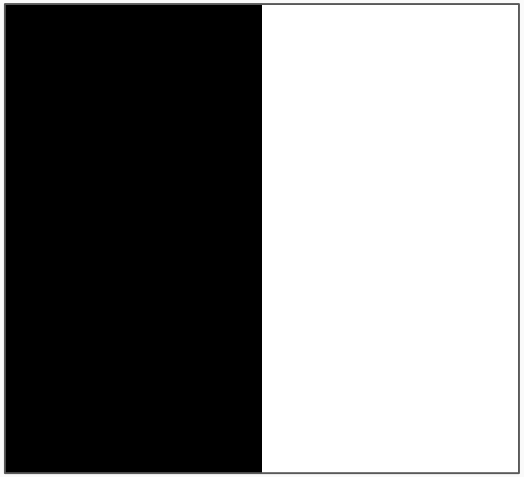


$$L[i] = \alpha \, L_d[i] + \beta \, L_g[i]$$

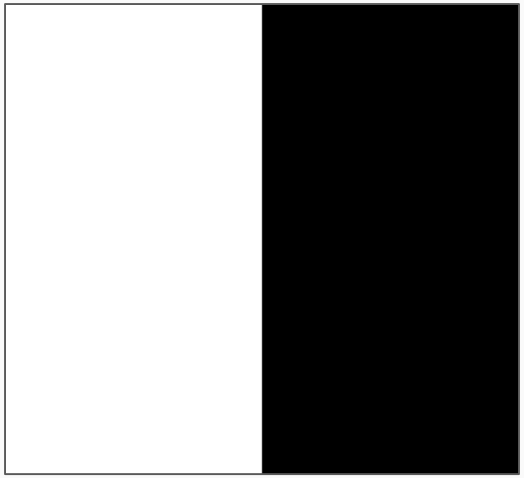
Direct Component

Global Component

Point Light Source Illuminating the Scene



Low frequency pattern



Inverse Pattern

$$L[i] = \alpha L_d[i] + \beta L_g[i]$$

$$\overline{L}[i] = (1-\alpha) L_d[i] + (1-\beta) L_g[i]$$

Point Light Source Illuminating the Scene

$$L[i] = \alpha \, L_d[i] + \beta \, L_g[i]$$

Defocus Parameter

no projector defocus blur: $\alpha = 1$

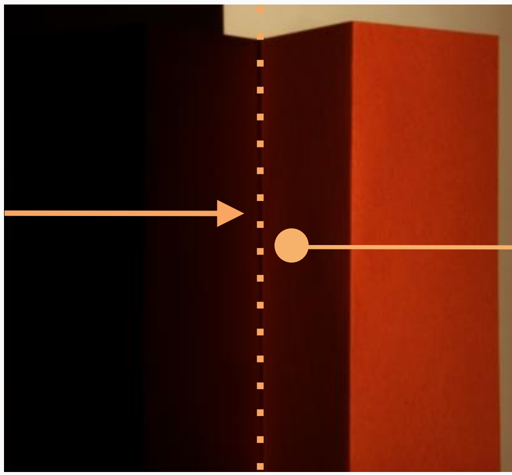
$$L[i] = L_d[i] + \beta \, L_g[i]$$

$$\bar{L}[i] = (1-\beta) \, L_g[i]$$

$$L[i] > \bar{L}[i]$$

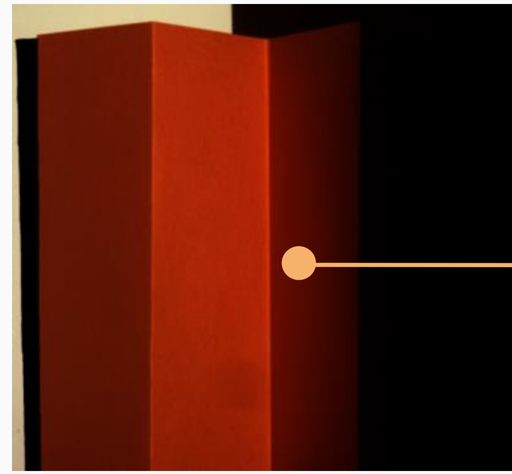
Incorrect decoding for low-frequencies

Pattern Edge



$L = 0.16$

Captured Image



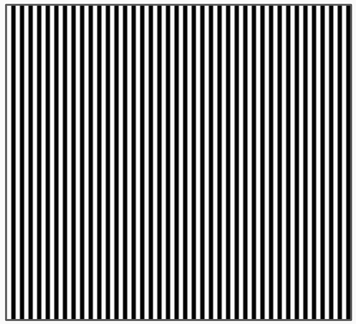
$\bar{L} = 0.25$

Captured Image

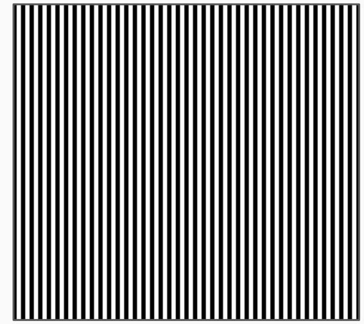
$$L = \text{Direct} + \beta \cdot \text{Global} \qquad \bar{L} = (1 - \beta) \cdot \text{Global}$$

$$\beta \sim= 0, \quad \text{Direct} < \text{Global} \longrightarrow \bar{L} < L$$

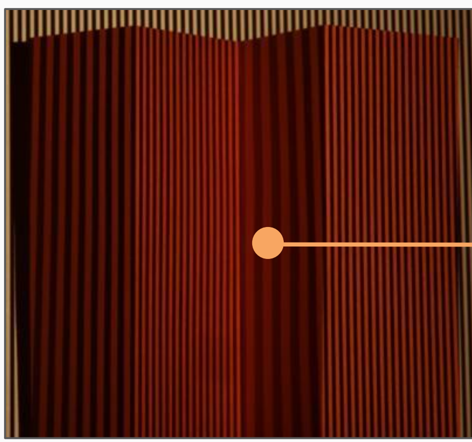
Binarization for high-frequency pattern



Pattern

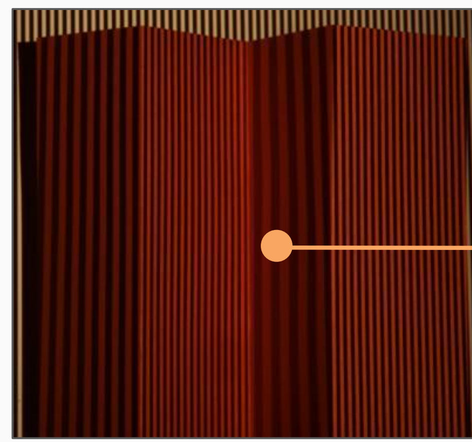


Inverse Pattern



$L = 0.25$

Captured Image

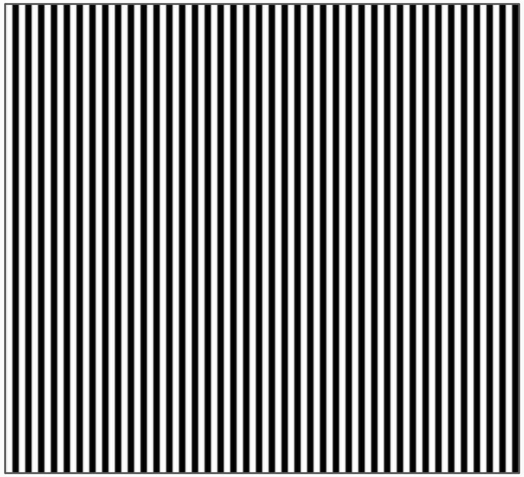


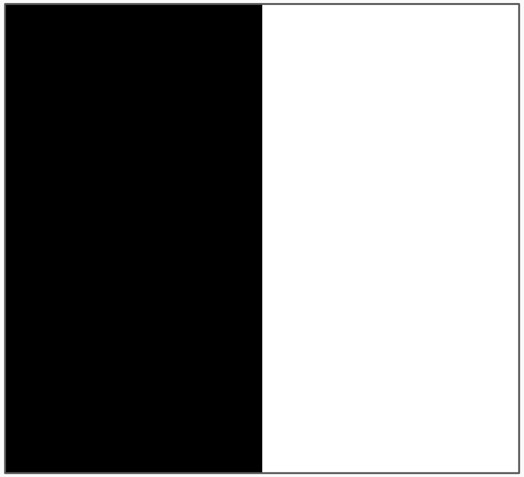
$\bar{L} = 0.16$

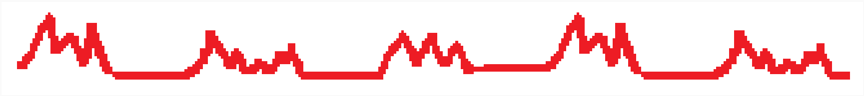
Captured Image

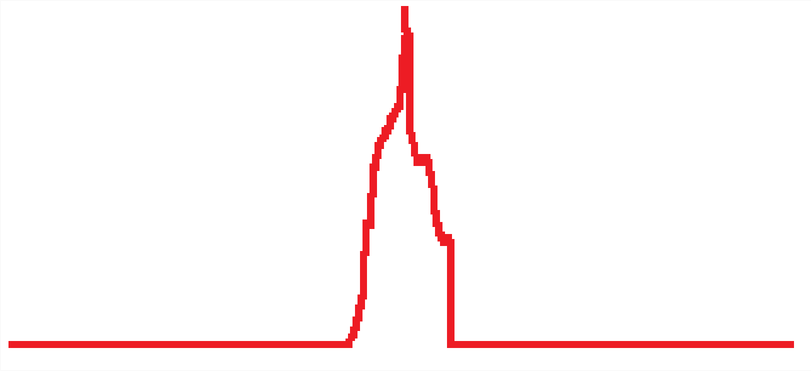
$$L = \text{Direct} + 0.5\ \text{Global} > \bar{L} = 0.5\ \text{Global}$$

Long Range Effects

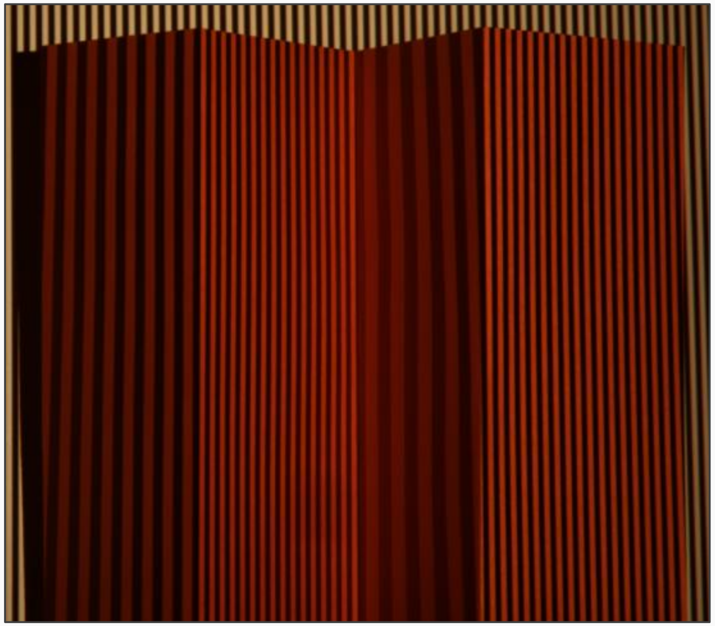




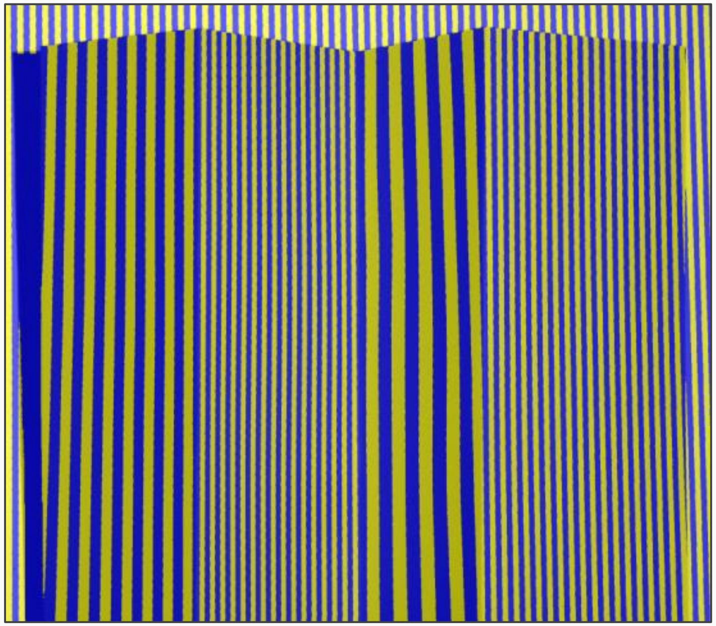




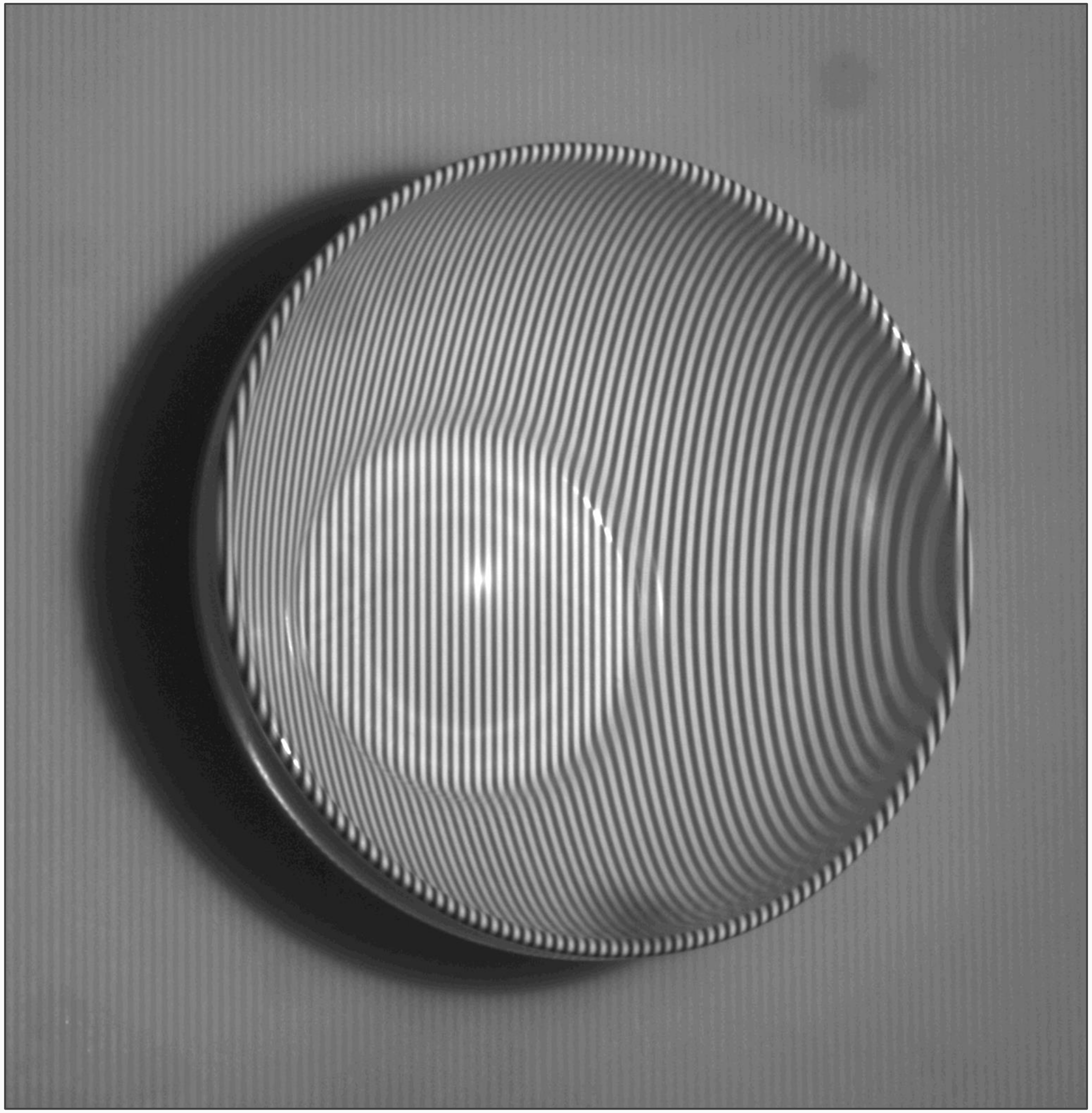
High-frequency patterns


Captured Image

Decoded correctly


Binary Decoding

Short Range Effects



Fixing these problem

Key Ideas

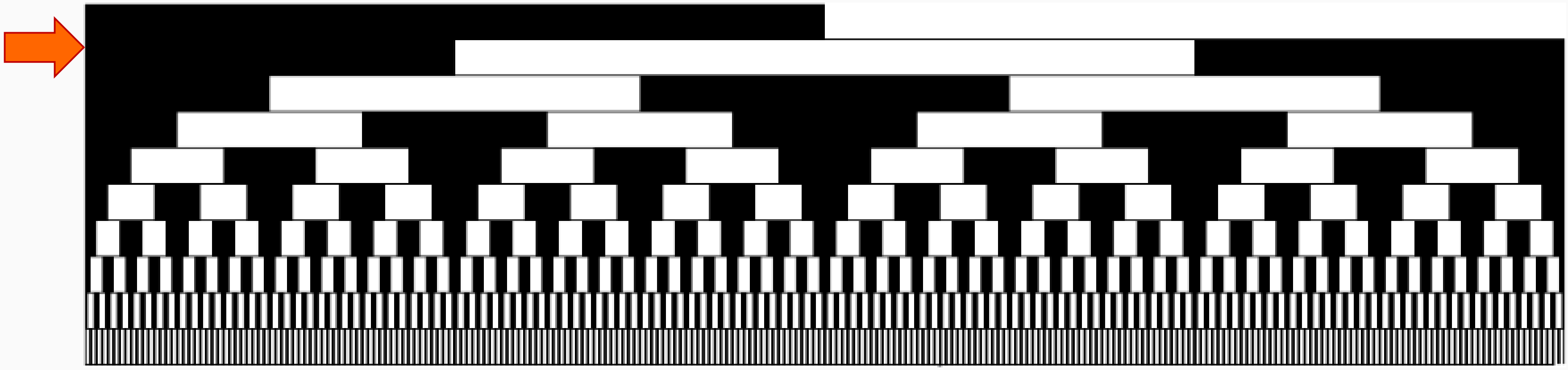
Inter-reflections: Use high frequency patterns

Subsurface scattering: Use low frequency patterns

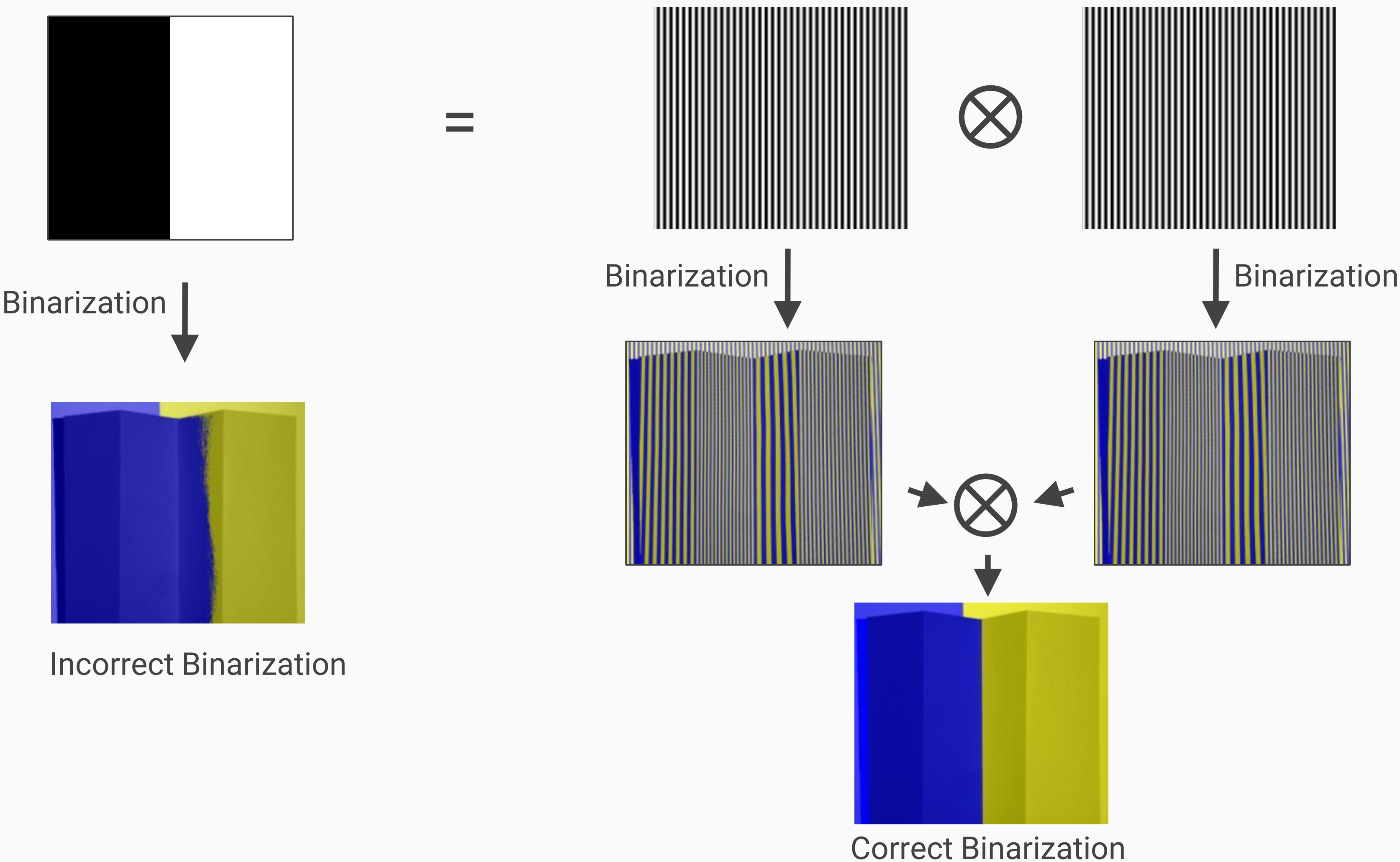
Design a system to deal with both simultaneously

Fixing Long Range Effects

Replace low frequency patterns with high frequency patterns

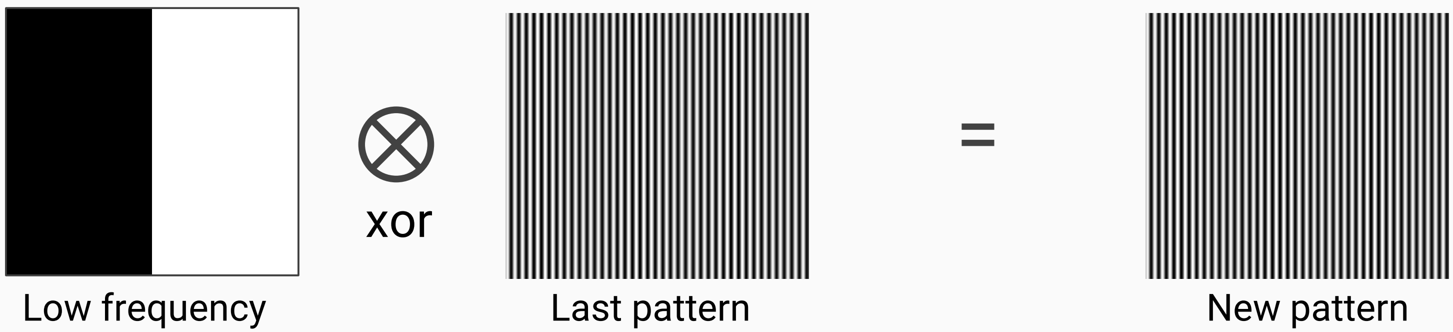


Fixing Long Range Effects

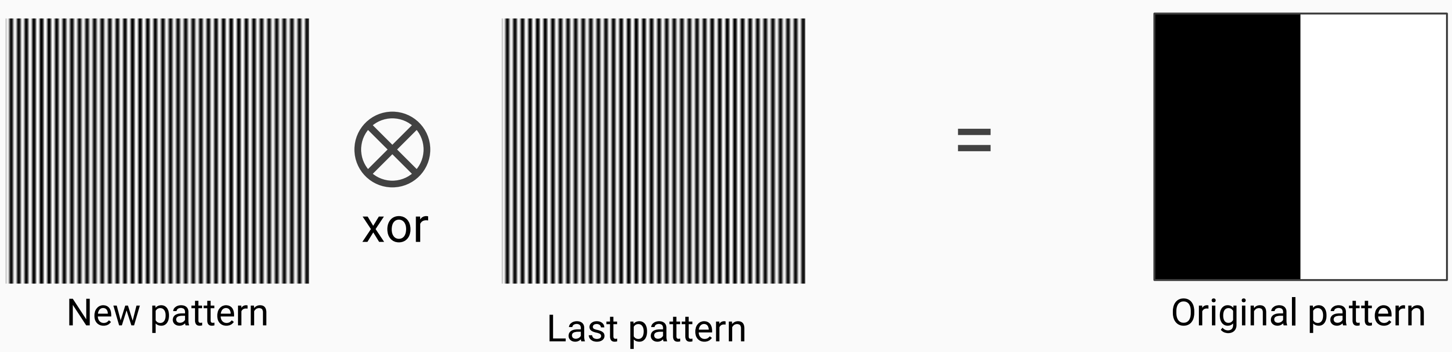


Fixing Long Range Effects

Producing patterns



While scanning



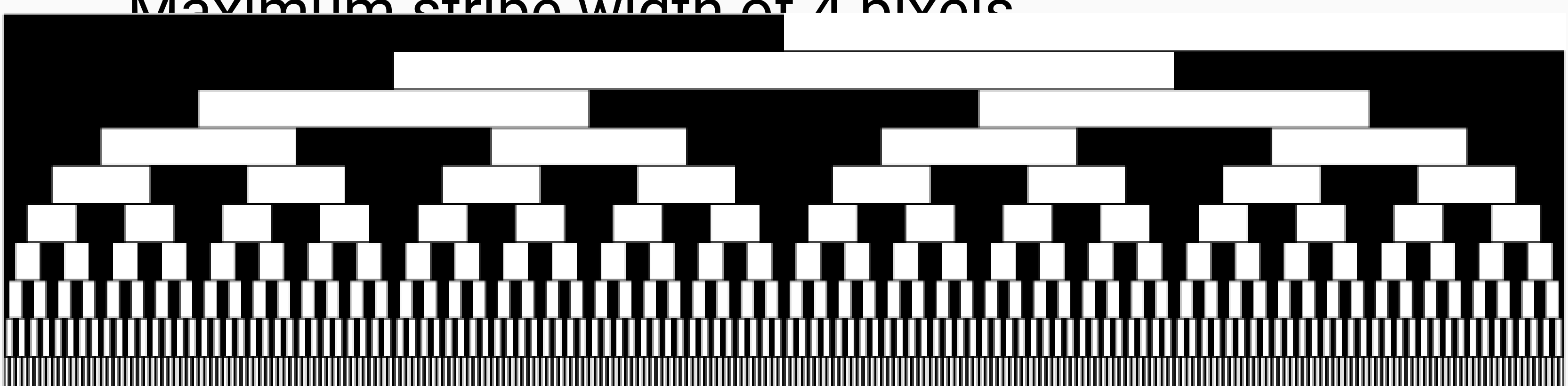
Fixing Long Range Effects

XOR'd with the last pattern

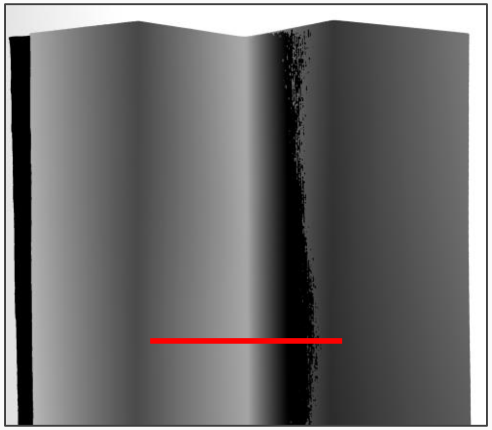
- Maximum stripe width of 2 pixels
- Called **XOR-02**

XOR'd with the second last pattern

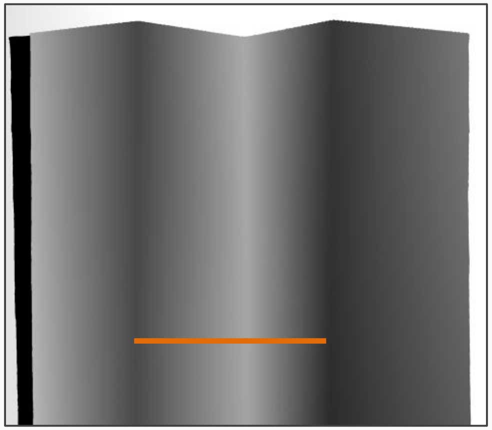
- Maximum stripe width of 4 pixels



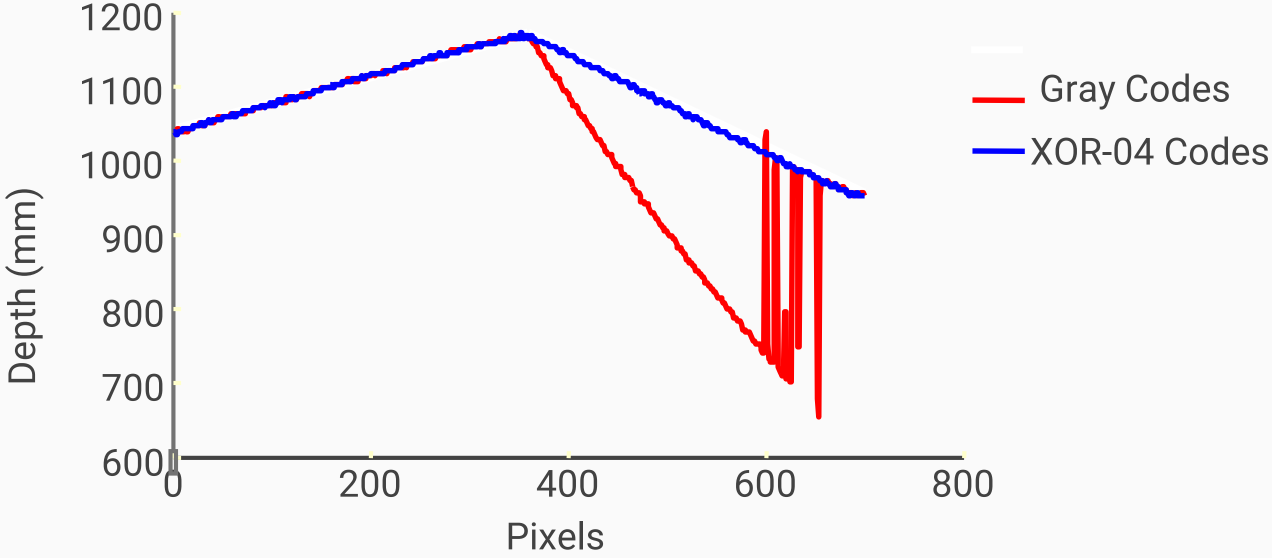
Fixing Long Range Effects



Conventional Gray Codes (11 images)

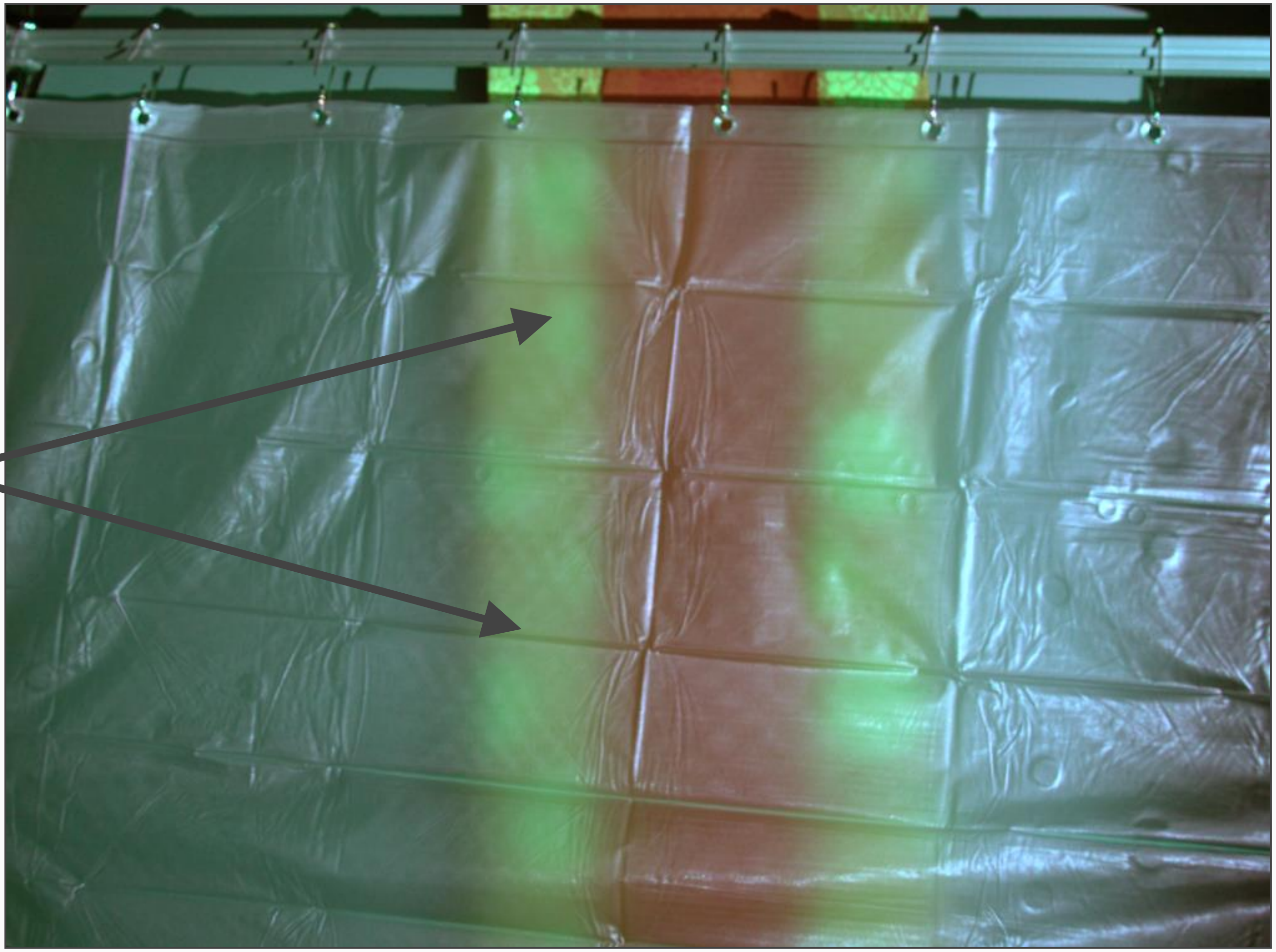


XOR-04 Codes (11 images)

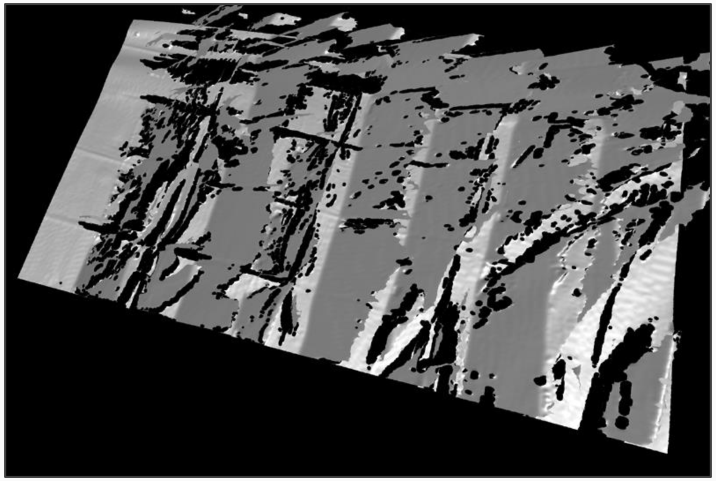


Fixing Long Range Effects

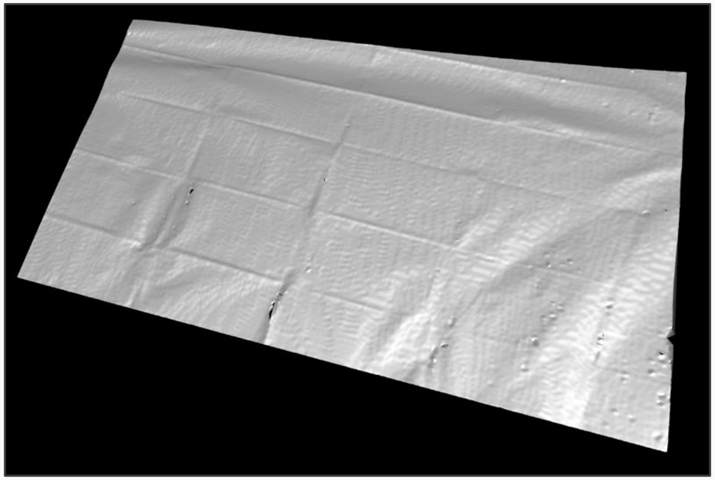
Diffusion +
Inter-reflections



Fixing Long Range Effects



Regular Gray Codes (11 images)



XOR Codes (11 images)

Fixing Long Range Effects

Pro: No additional overhead

Pro: Perfect on shots with only inter-reflections

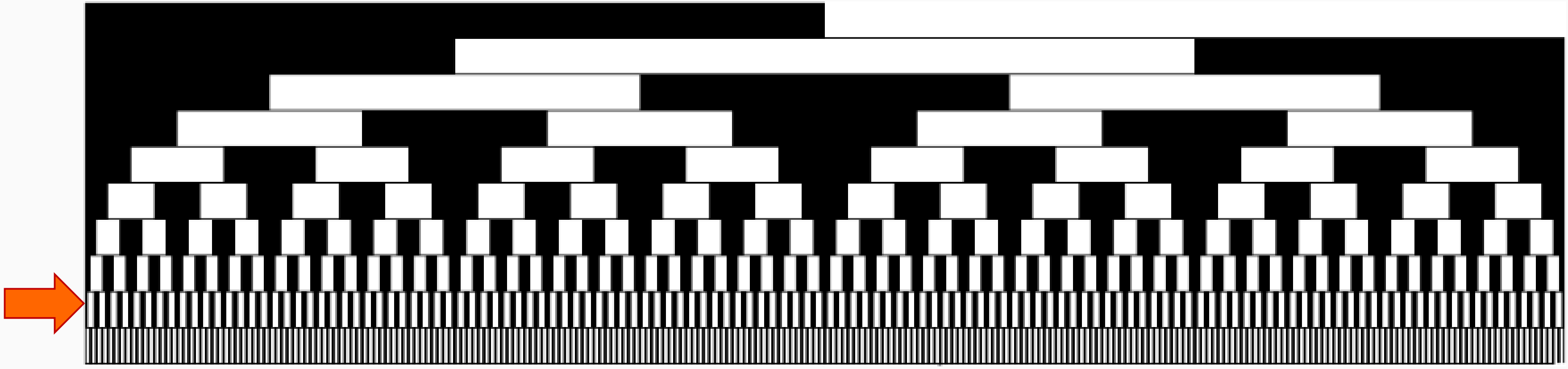
Con: Thin stripes can succumb to defocus blur

Con: Short range effects are magnified

Subsurface scattering makes patterns blurred

Fixing Short Range Effects

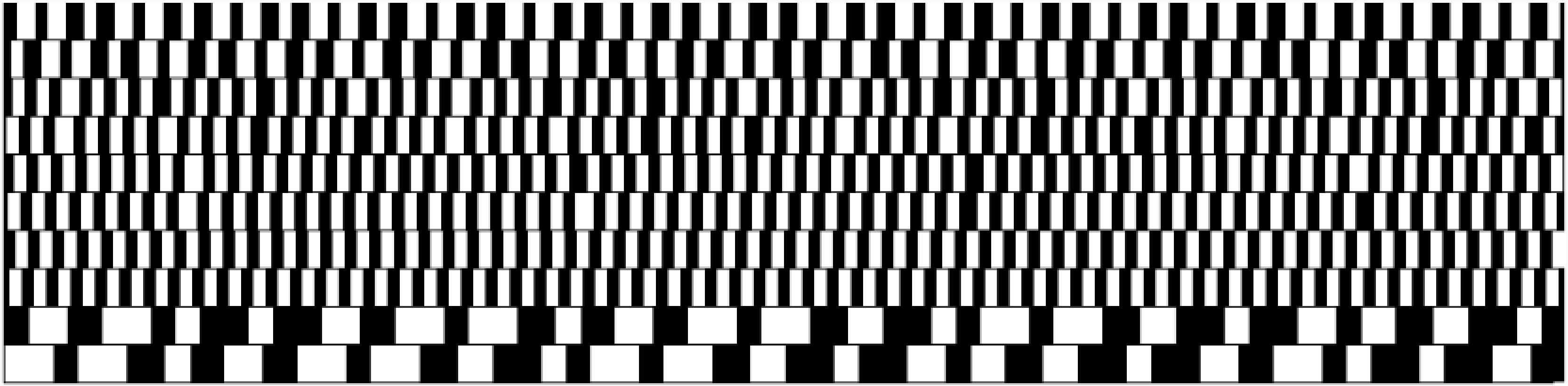
Maximize the smallest stripe width



Fixing Short Range Effects

Can be posed as a mathematical question

Binary gray codes with long bit runs



Fixing Short Range Effects

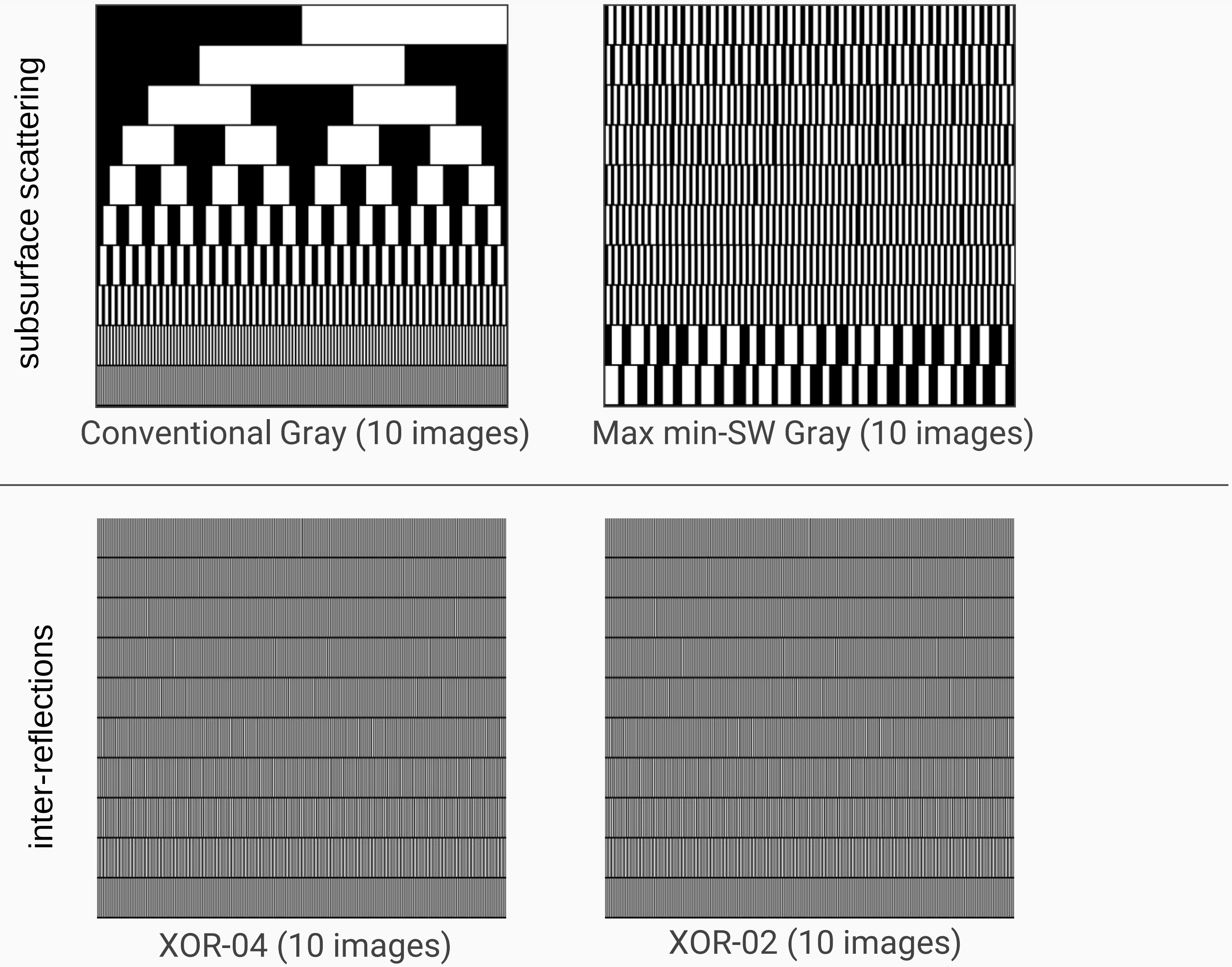
Pro: Immune to subsurface scattering

Pro: No additional overhead

Pro: Less prone to defocus blur

Con: Succumbs to inter-reflections

Can we do better?



An ensemble of patterns

An ensemble of patterns

We don’t know what the scene contains

Construct a system immune to these effects

- Fast
- Accurate

Project all four light patterns

Calculate depth maps from all four

Fuse data from all depth maps

An ensemble of patterns

All four of them will probably not agree

The errors can be considered random

- Light bounces around depending on the scene

If two depths are similar, that is the correct depth

An ensemble of patterns

What if none of the depths match?

- All four depth measurements disagree

Construct a pattern for just the error pixels

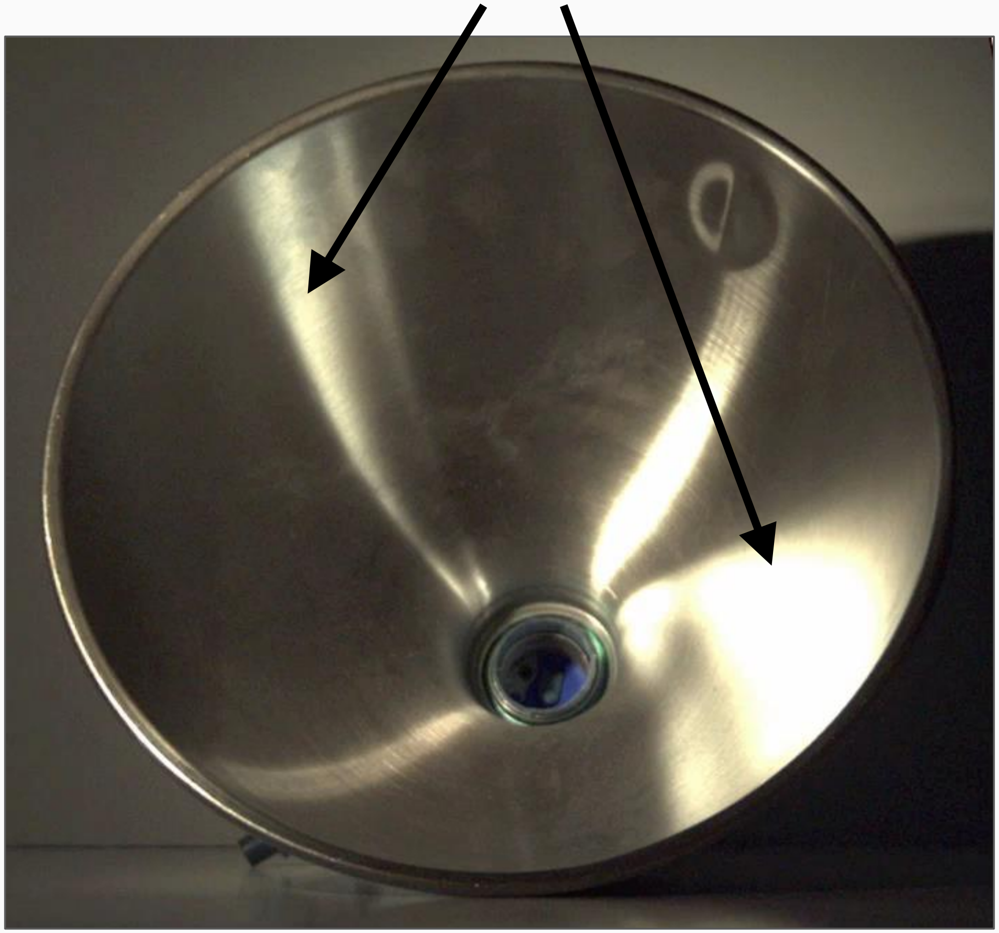
- This reduces the error due to GI

Estimate depth for error pixels using new patterns

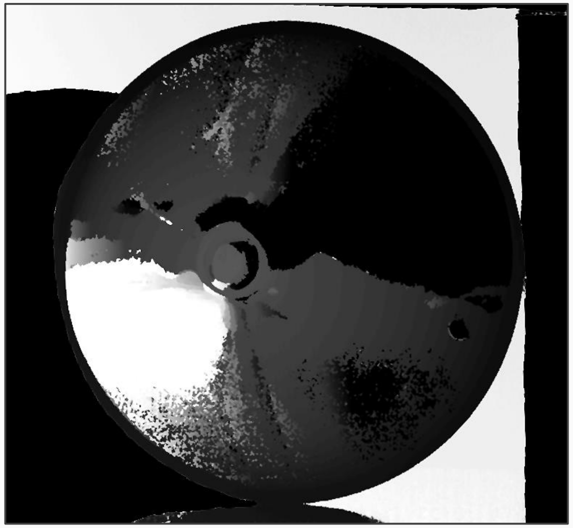
Loop until all pixels are resolved

An ensemble of patterns

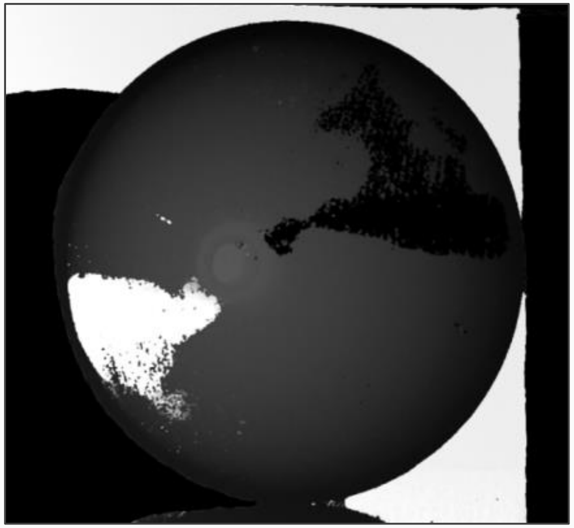
Strong and high-frequency inter-reflections



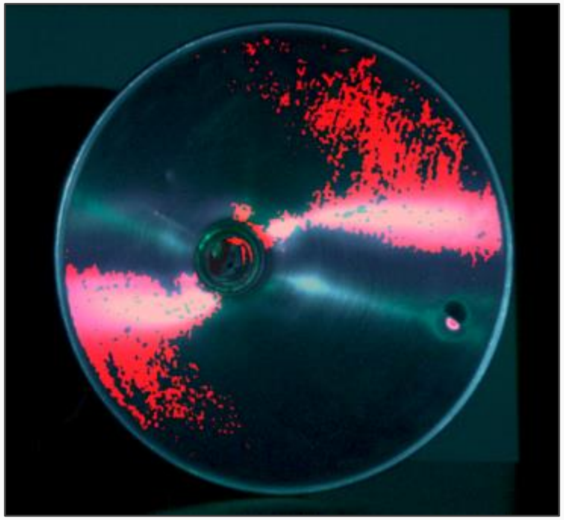
An ensemble of patterns



Regular Gray (11 images)



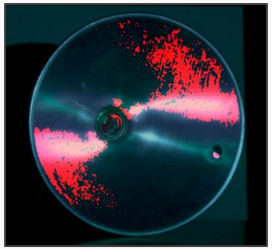
Ensemble Codes (41 images)

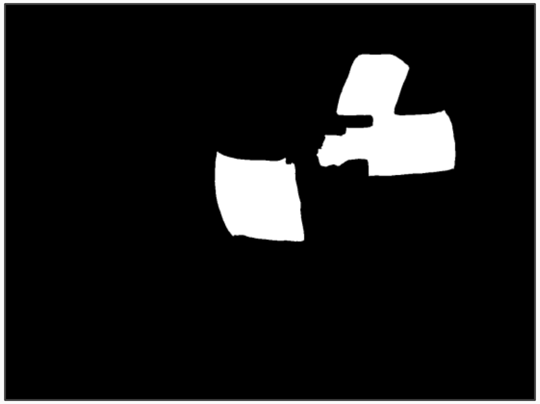


Error pixels

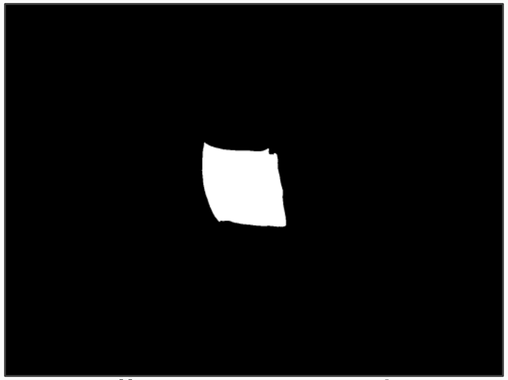
An ensemble of patterns

Error map

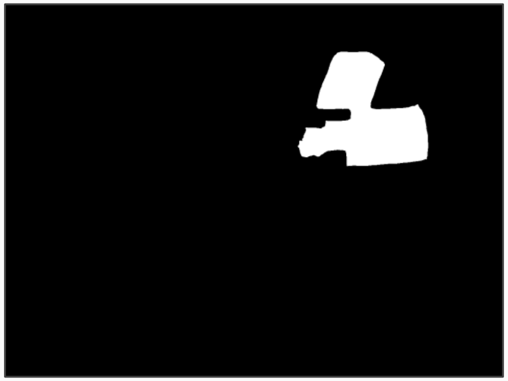




Illumination Mask

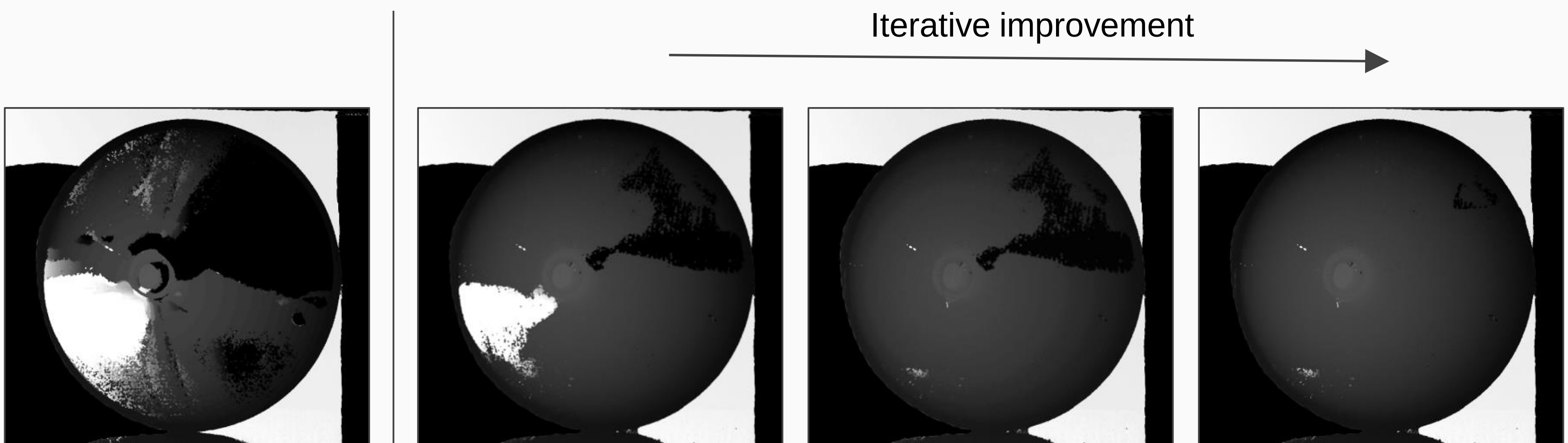


Illumination Mask
(Iteration 2)



Illumination Mask
(Iteration 3)

An ensemble of patterns



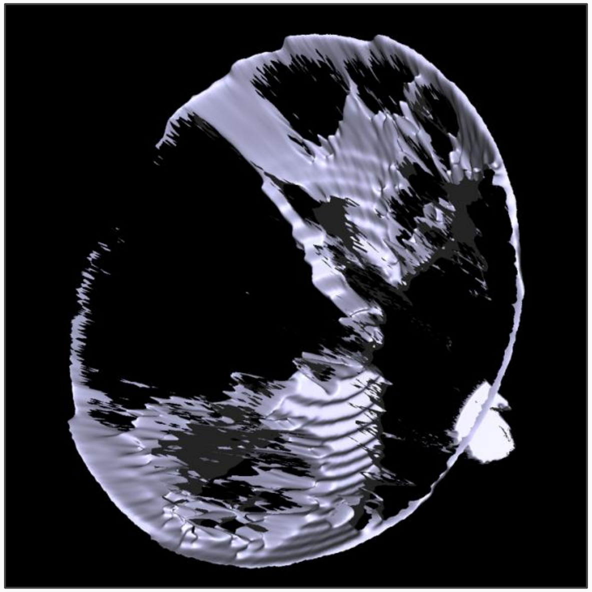
Only regular pattern
(11 images)

Ensemble
(41 images)

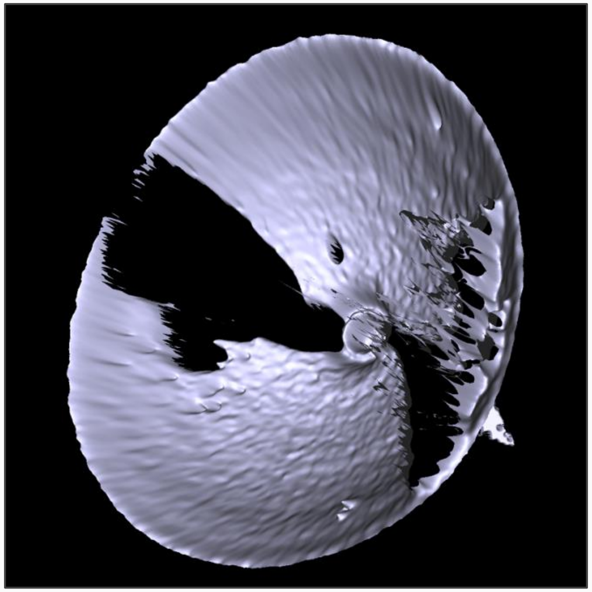
Iteration 2
(61 images)

Iteration 3
(81 images)

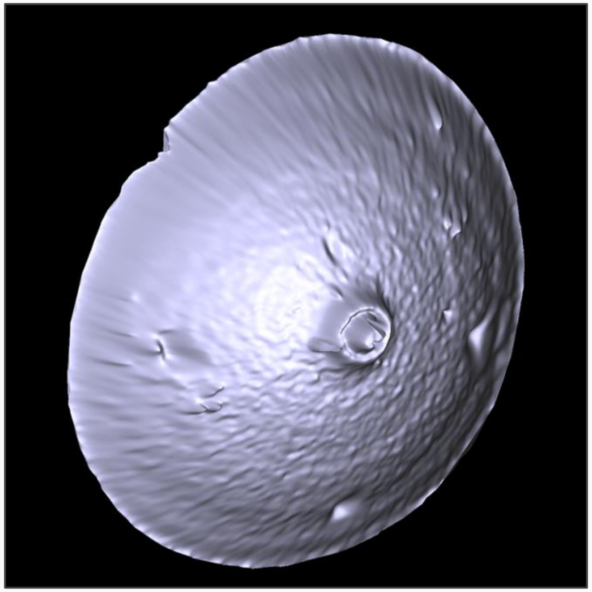
An ensemble of patterns



Conventional gray code
(11 images)



Ensemble Codes
(41 images)



Error Correction:
2 iterations (81 images)

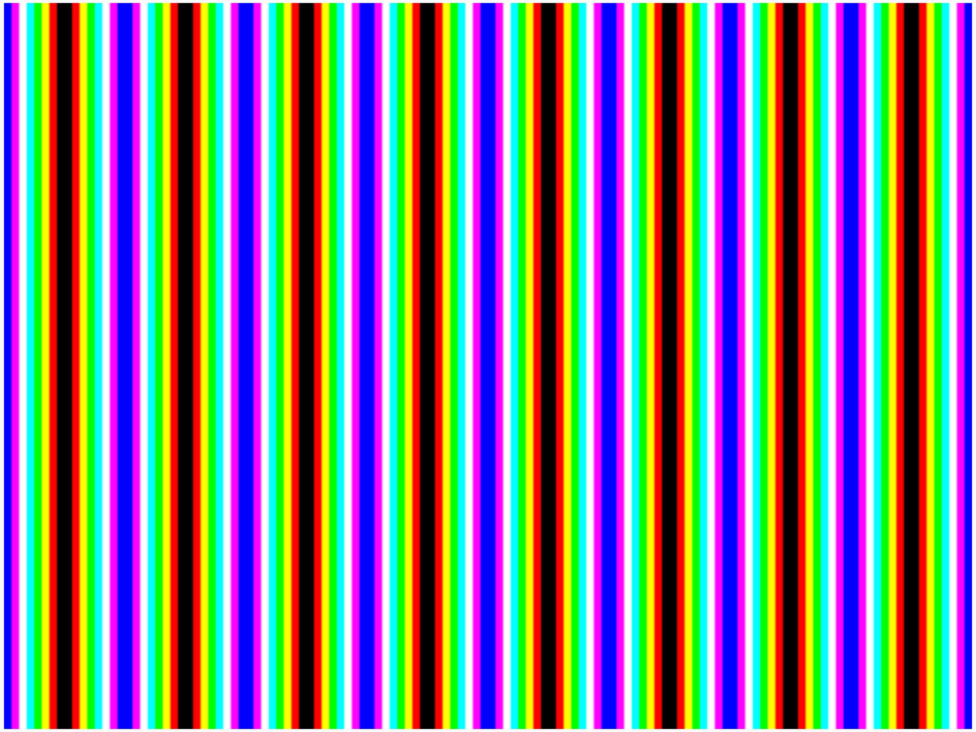
An ensemble of patterns

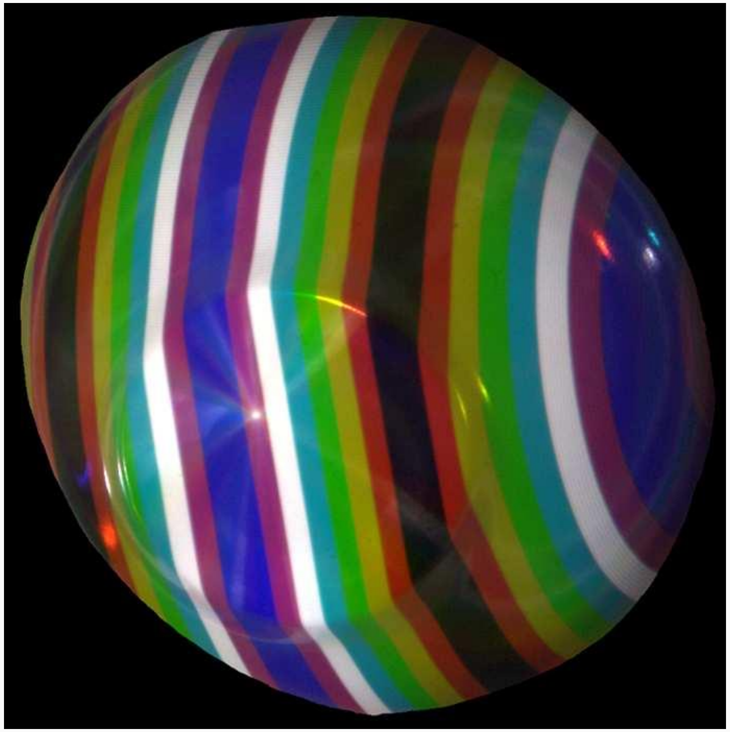
Pro: Accurate 3D reconstruction

Con: Requires more acquisition time

- Can be fixed with colored patterns
- Still better than other approaches (about ~2.5x fewer images)

Colored Pattern





Limitations

Volumetric scattering

Acquisition speed (binary code)

Violation of low and high frequency pattern condition

Classification of indirect illumination

Conclusion / Score

Full Score - 1

Good methodology

Strong reasoning

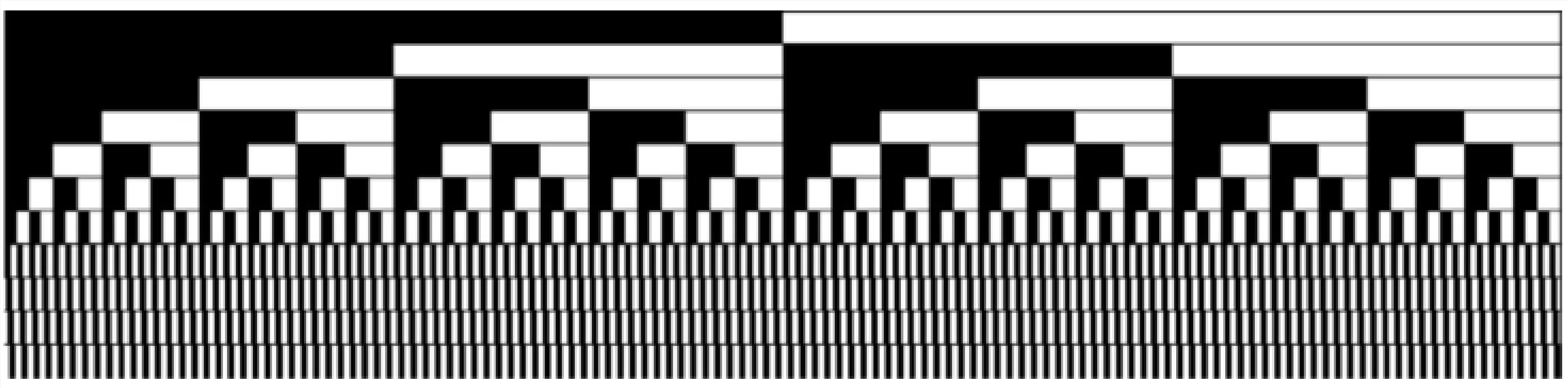
Clear Limitation and future works

Creative Idea

Q & A

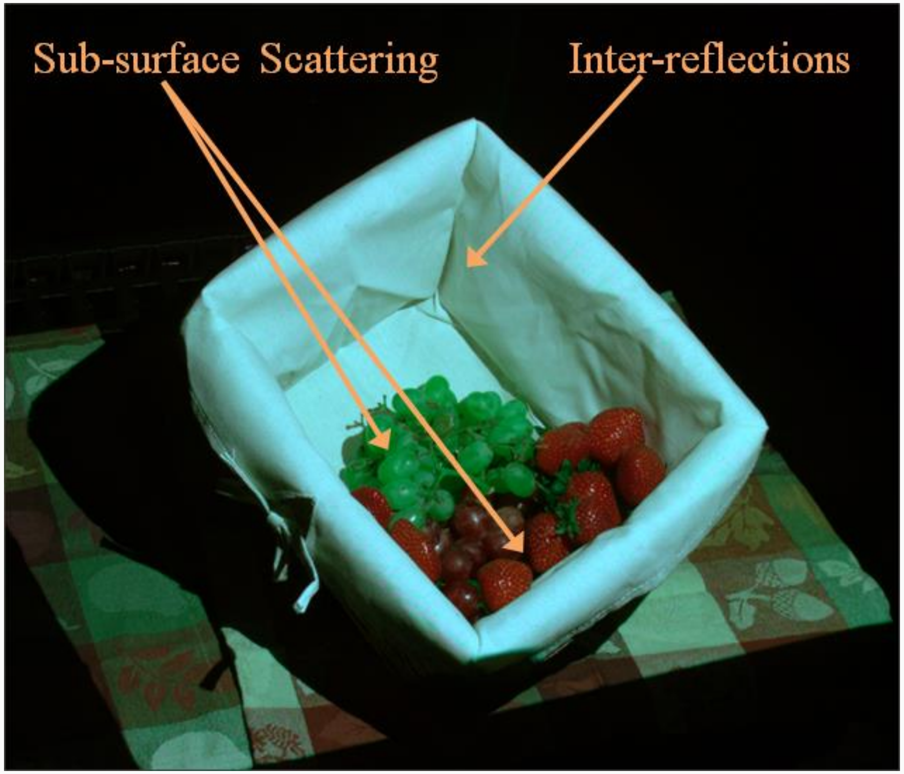
Further Research

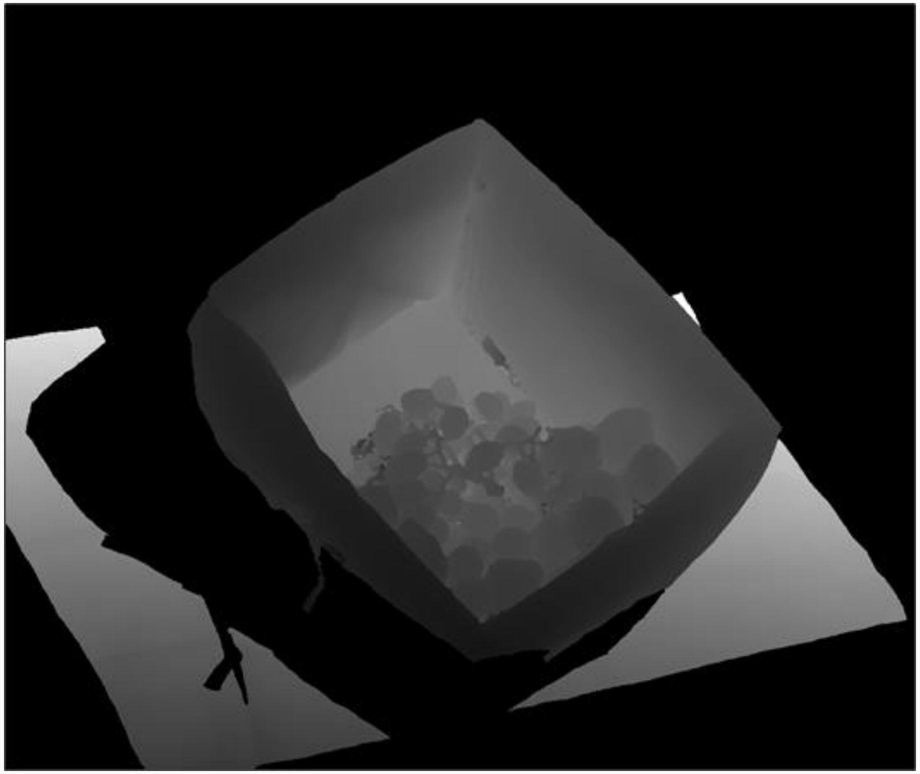
How do we design patterns?



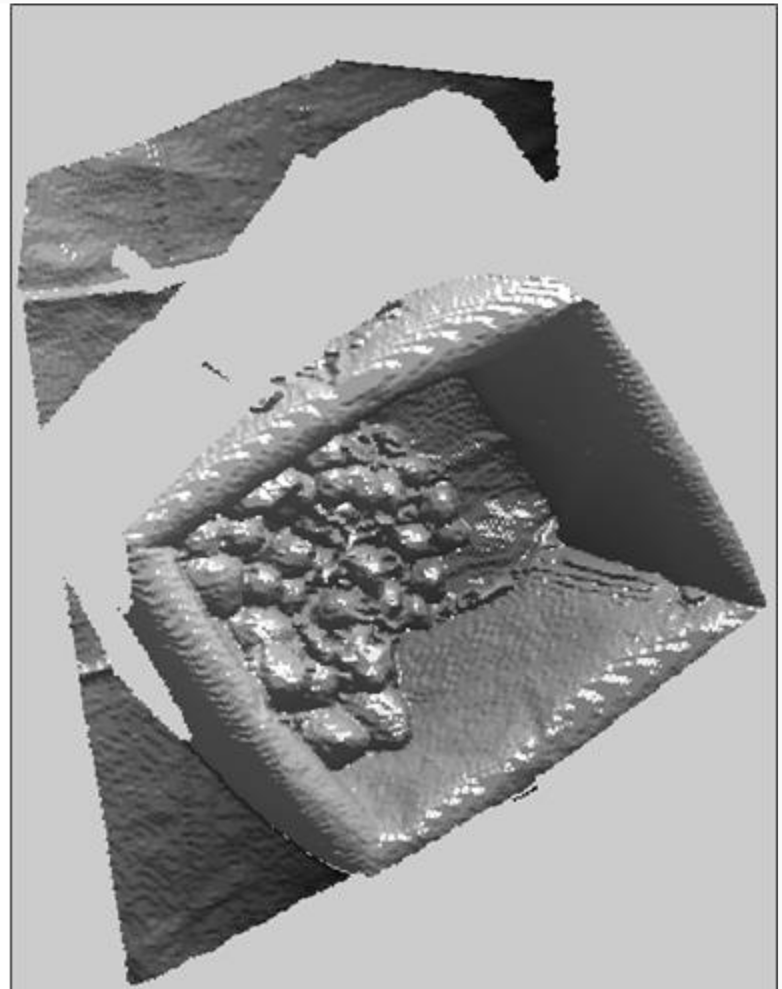
Xida Chenn , Yee-Hong Yang (2015)

More results: Depth Map

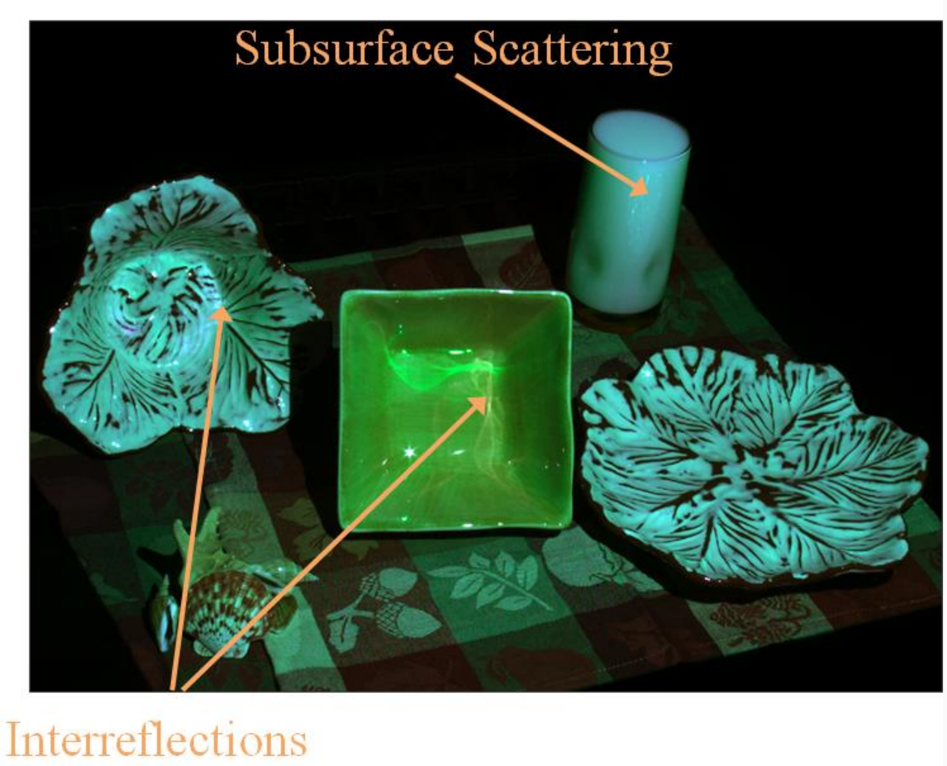


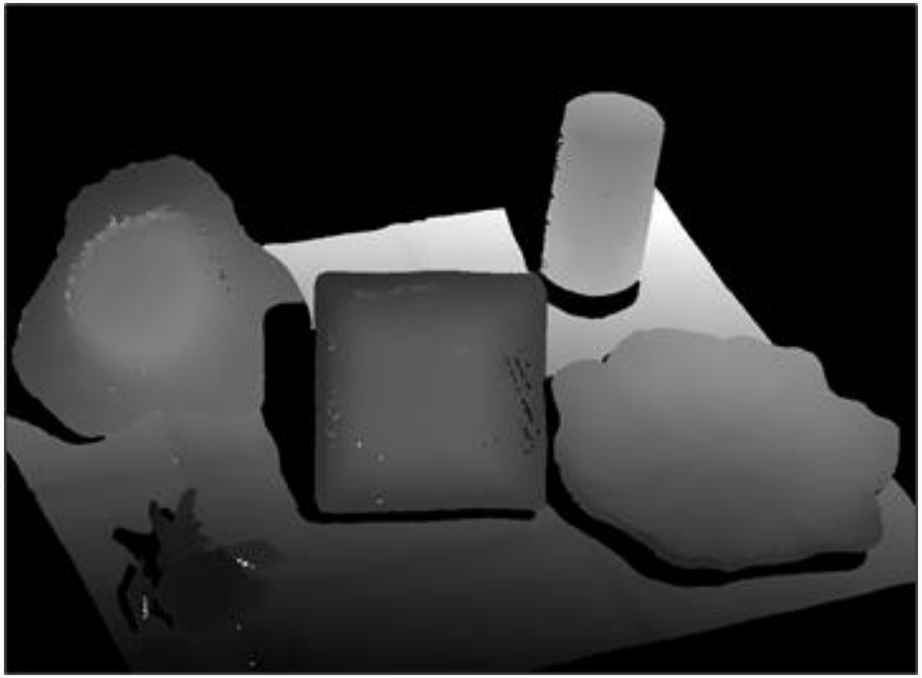


More results: 3D Visualization

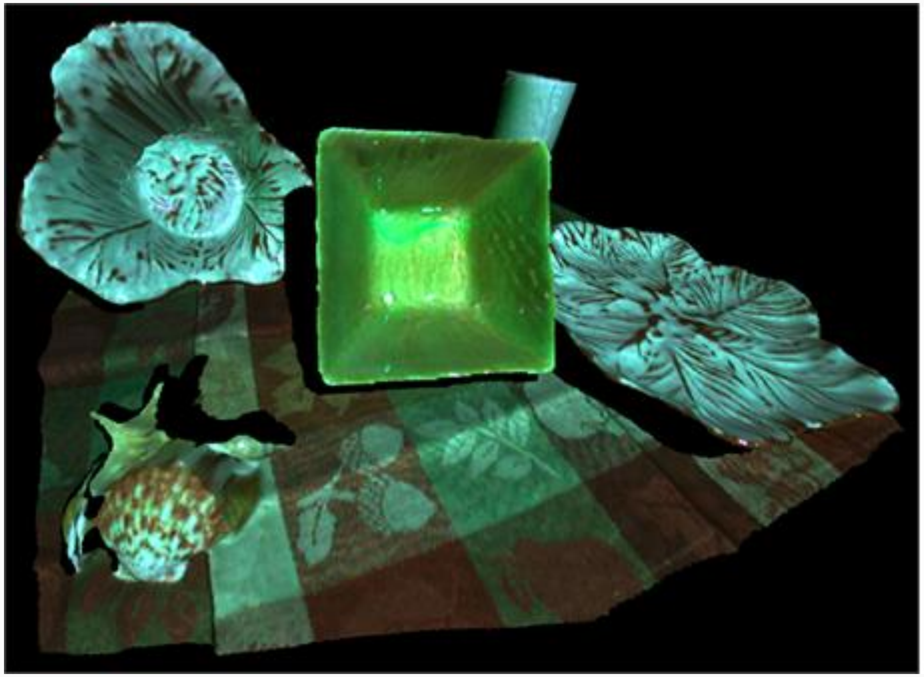


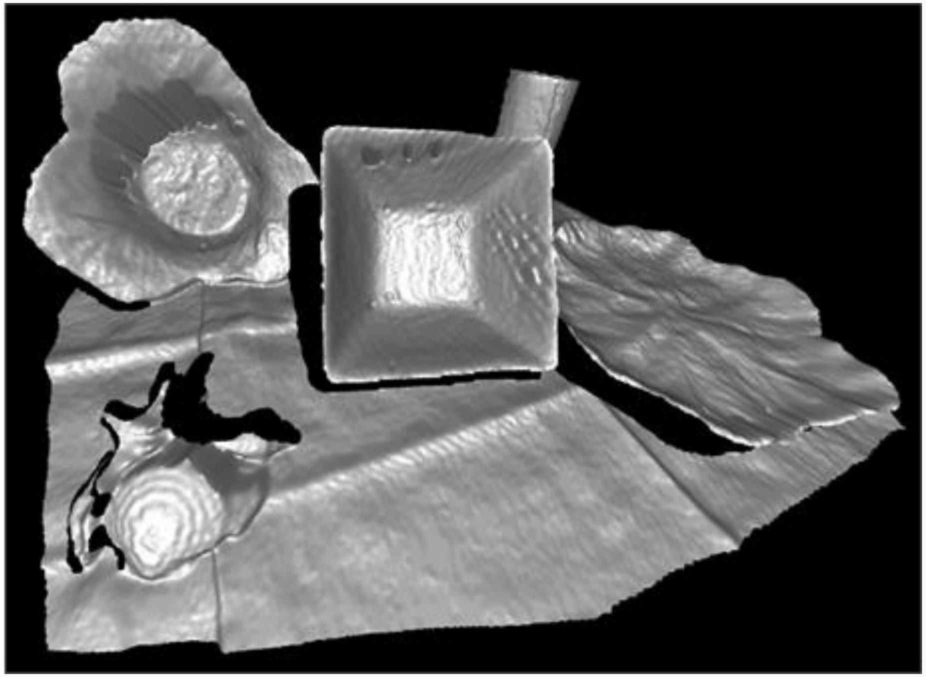
More results: Depth Map





More results: 3D Visualization





Extra slide

How is the error correcting illumination pattern created for the projector's point of view?