COMP 546

Lecture 12

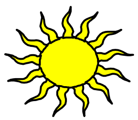
Illumination and Reflectance

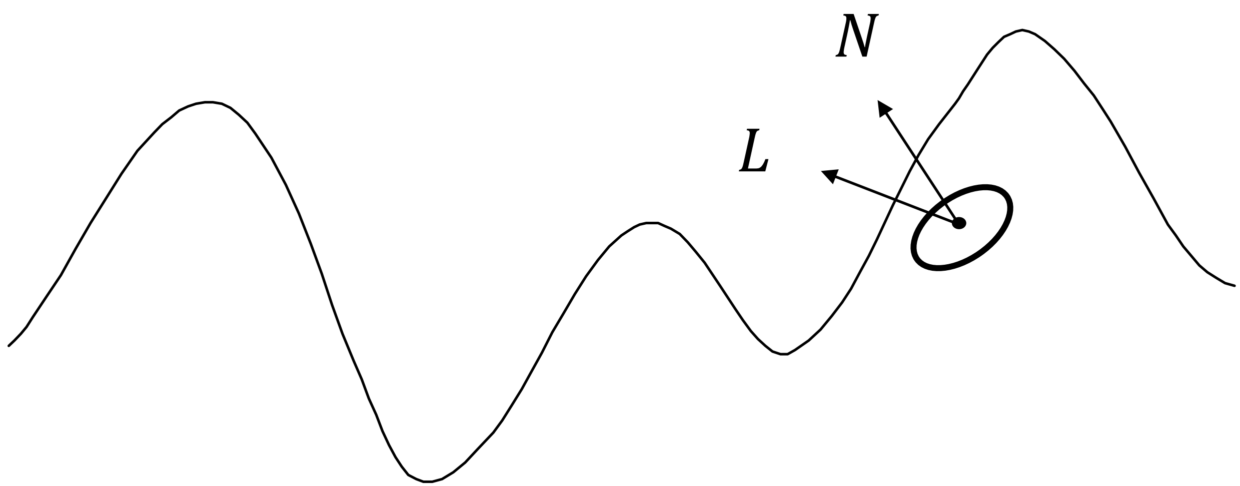
Tues. Feb. 20, 2018

Illumination and Reflectance

- Shading
- Brightness versus Lightness
- Color constancy

Shading on a sunny day



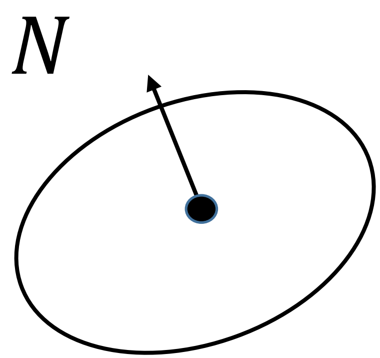


Lambert's (cosine) Law:

$$I(X) = N(X) \cdot L$$

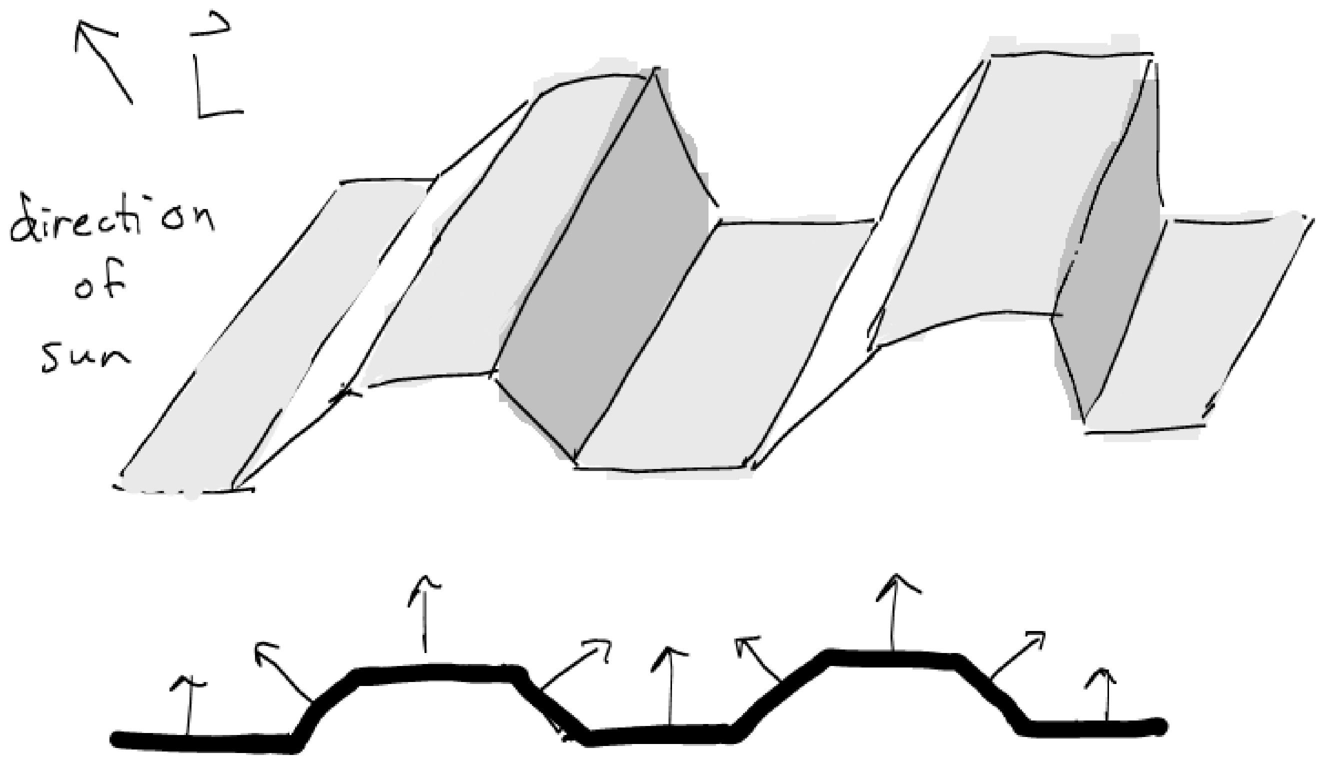
Unit Surface Normal

$$N \equiv \frac{1}{\sqrt{\left(\frac{\partial Z}{\partial X}\right)^2 + \left(\frac{\partial Z}{\partial Y}\right)^2 + 1}} \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}, -1\right)$$

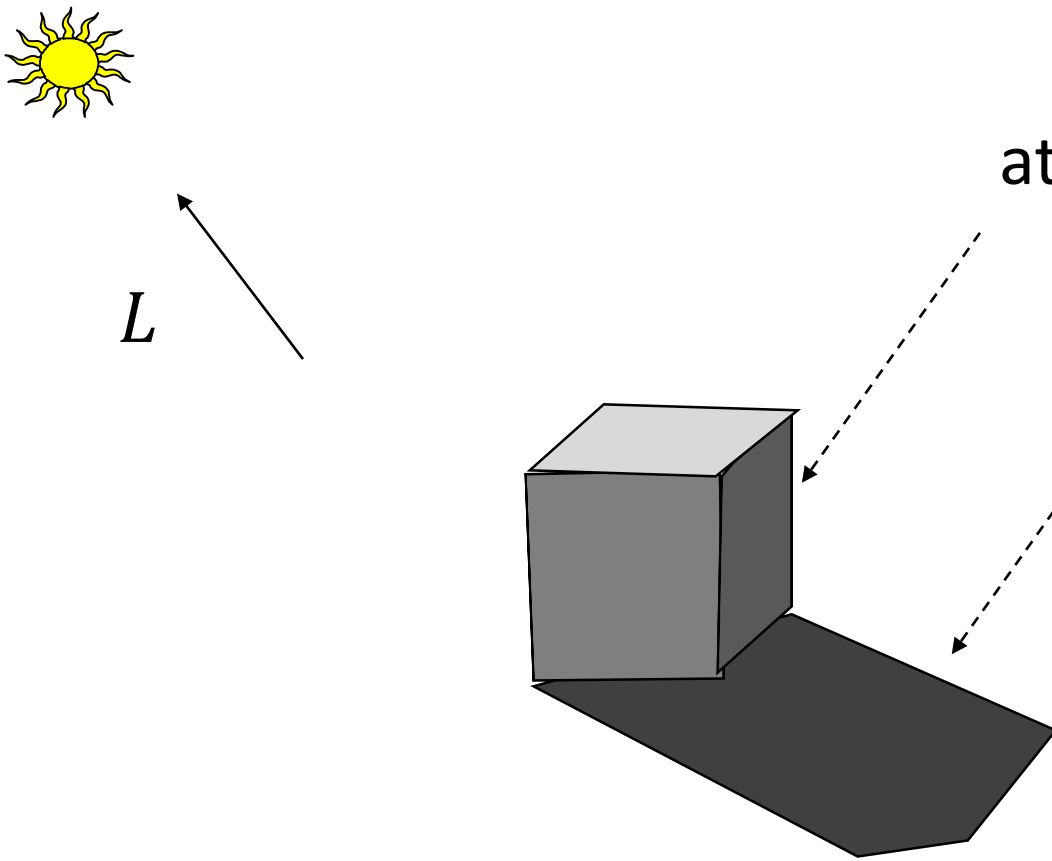


Shading on a sunny day

$$I(x,y) = N(x,y) \cdot L$$



Cast and Attached Shadows



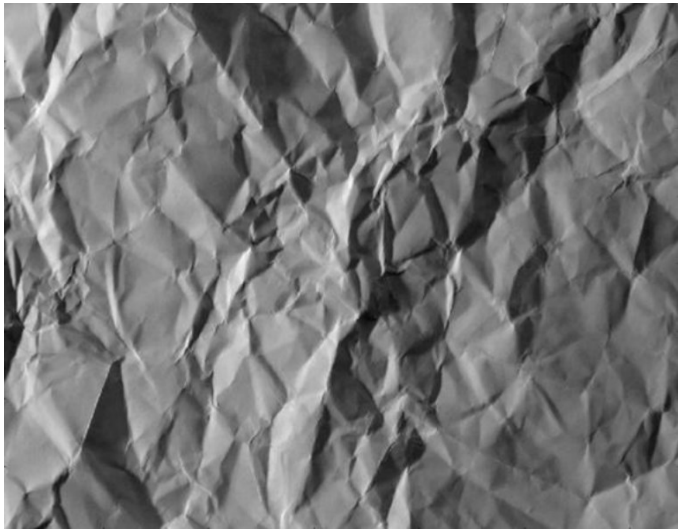
attached : $N(X) \cdot L < 0$

cast : $N(X) \cdot L > 0$ but light is occluded

Shading models

- sunny day (last lecture)
- sunny day + low relief
- cloudy day

Examples of low relief surfaces



(un)crumpled paper

Low relief surface

Suppose $\left|\frac{\partial Z}{\partial X}\right|$ and $\left|\frac{\partial Z}{\partial Y}\right|$ are both small.

Thus,

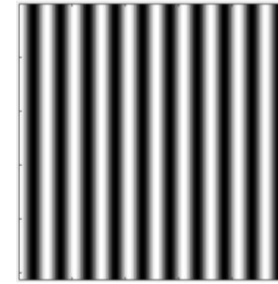
$$N \equiv \frac{1}{\sqrt{\underbrace{\cancel{\left(\frac{\partial Z}{\partial X}\right)^2}}_{\approx 0} + \underbrace{\cancel{\left(\frac{\partial Z}{\partial Y}\right)^2}}_{\approx 0} + 1}} \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}, -1\right)$$

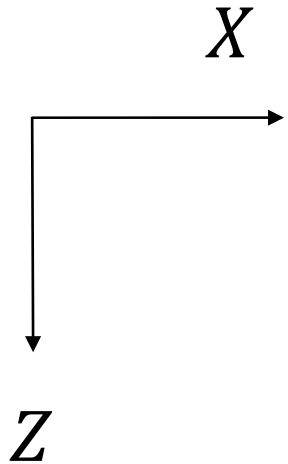
Linear shading model for low relief

$$I(X,Y) \approx \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}, -1\right) \cdot (L_X, L_Y, L_Z)$$

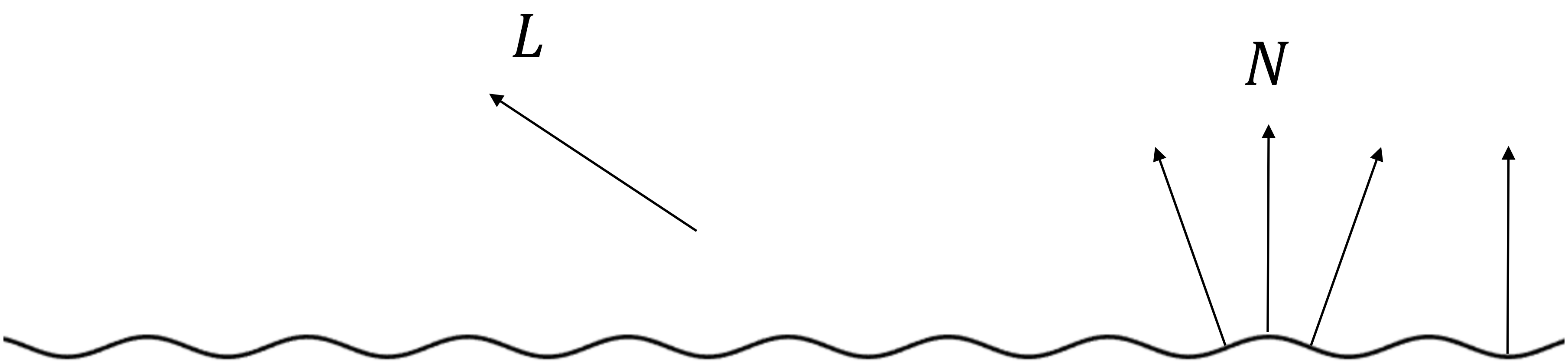
- shadows can still occur
- one equation per point but two unknowns

Example: curtains

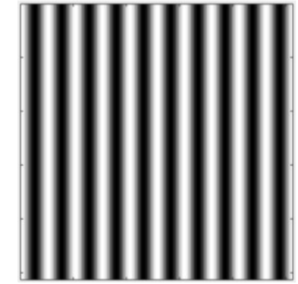


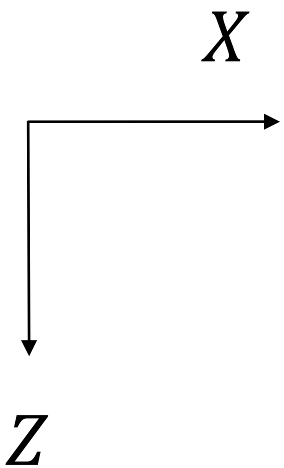


$$Z(X,Y) = Z_0 + a \sin(k_X X)$$



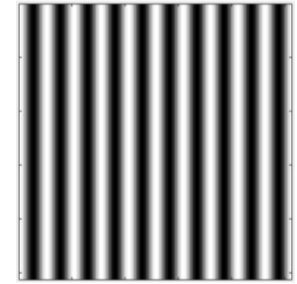
Example: curtains





$$Z(X,Y) = Z_0 + a \sin(k_X X)$$

$$\frac{\partial Z}{\partial X} = a \; k_X \cos(k_X \; X) \;, \qquad \frac{\partial Z}{\partial Y} = 0$$



Example: curtains

$$I(X,Y) \approx \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}, -1\right) \cdot (L_X, L_Y, L_Z)$$

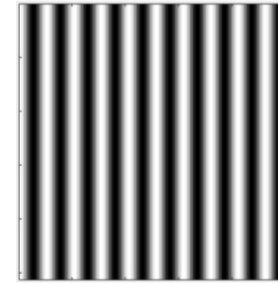
$$Z(X,Y) = Z_0 + a \sin(k_X X)$$

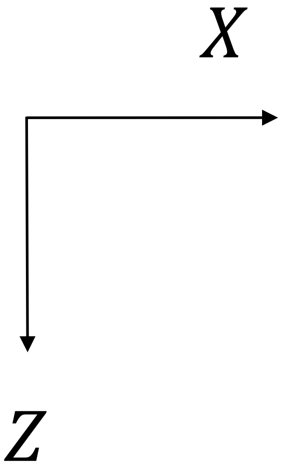
$$\frac{\partial Z}{\partial X} = a\, k_X \cos(k_X X), \quad \frac{\partial Z}{\partial Y} = 0$$

$$I(X,Y) = a\, k_X \cos(k_X X)\, L_X - L_Z$$

$$I(X,Y) \approx \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}, -1\right) \cdot (L_X, L_Y, L_Z)$$

Example: curtains





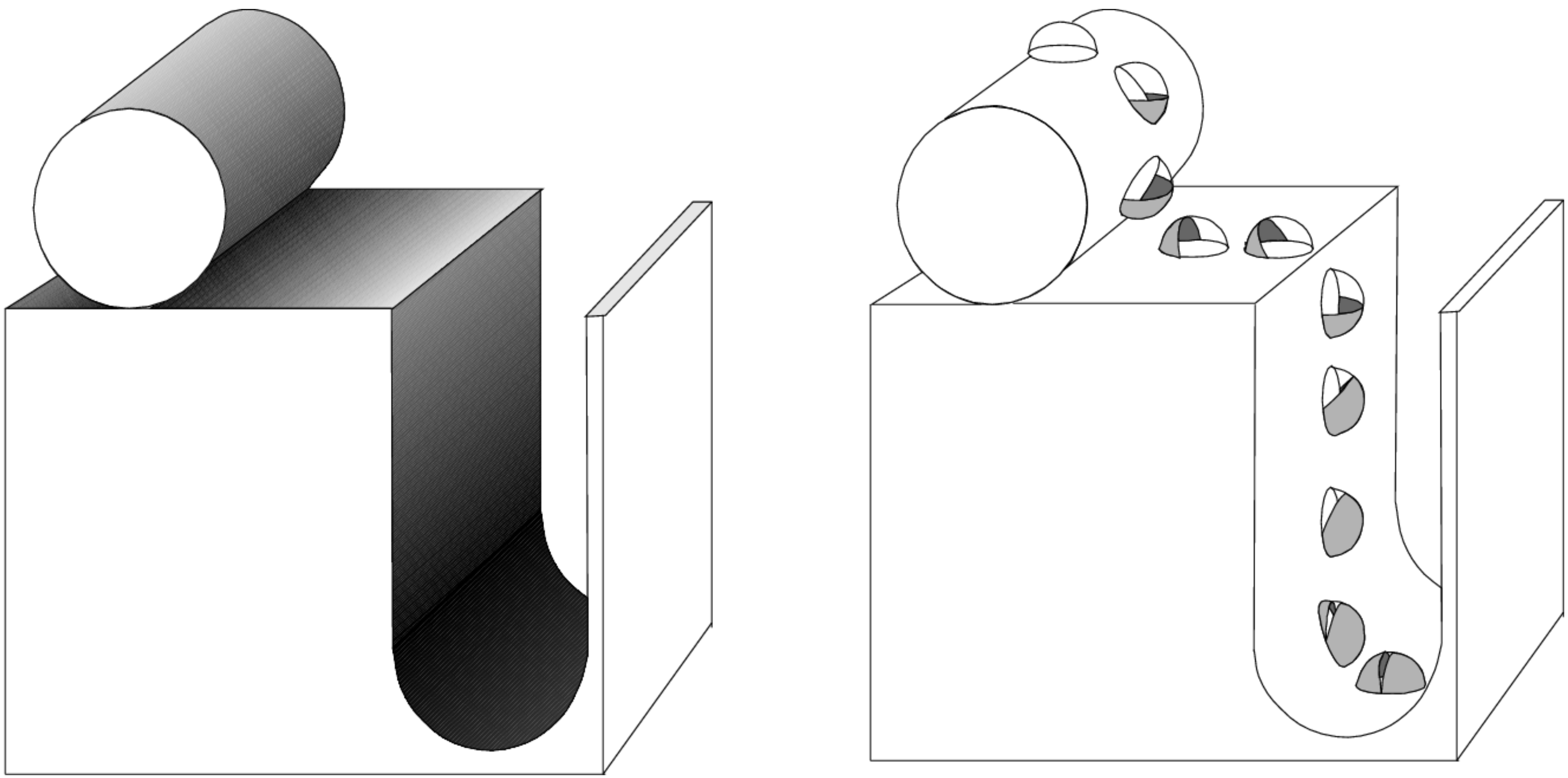
$$Z(X,Y) = Z_0 + a \sin(k_X X)$$

$$I(X,Y) = - L_Z + a\, k_X\, L_X \cos(k_X X)$$

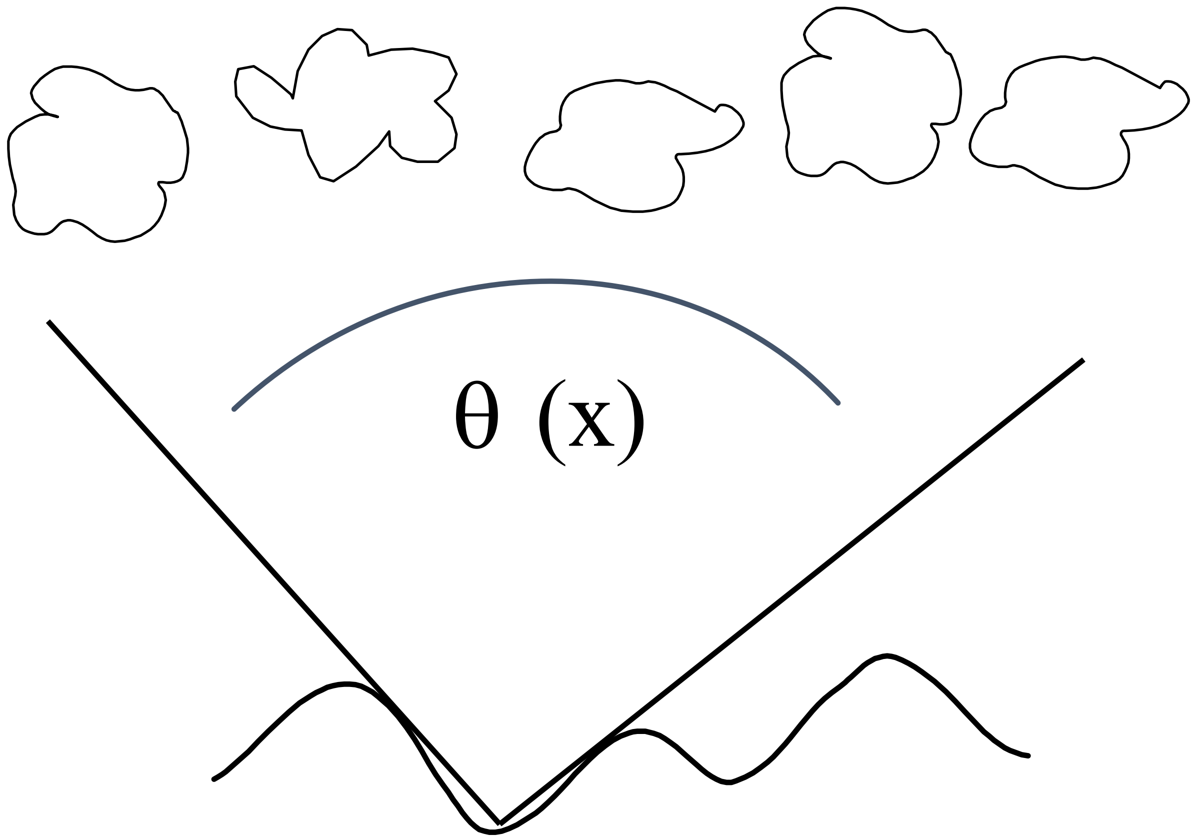
Q: where do the intensity maxima and minima occur?

Shading on a cloudy day

(my Ph.D. thesis)

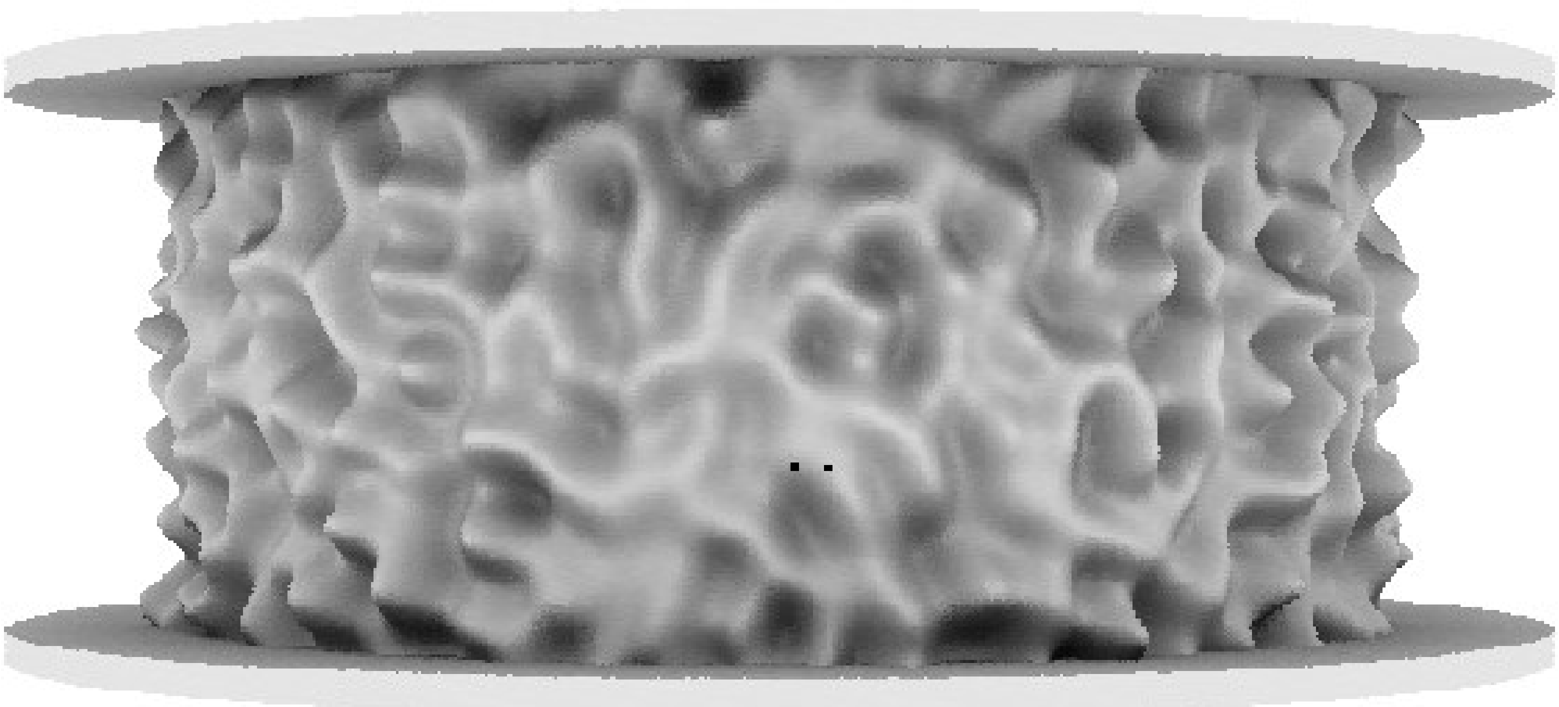


Shading on a Cloudy Day



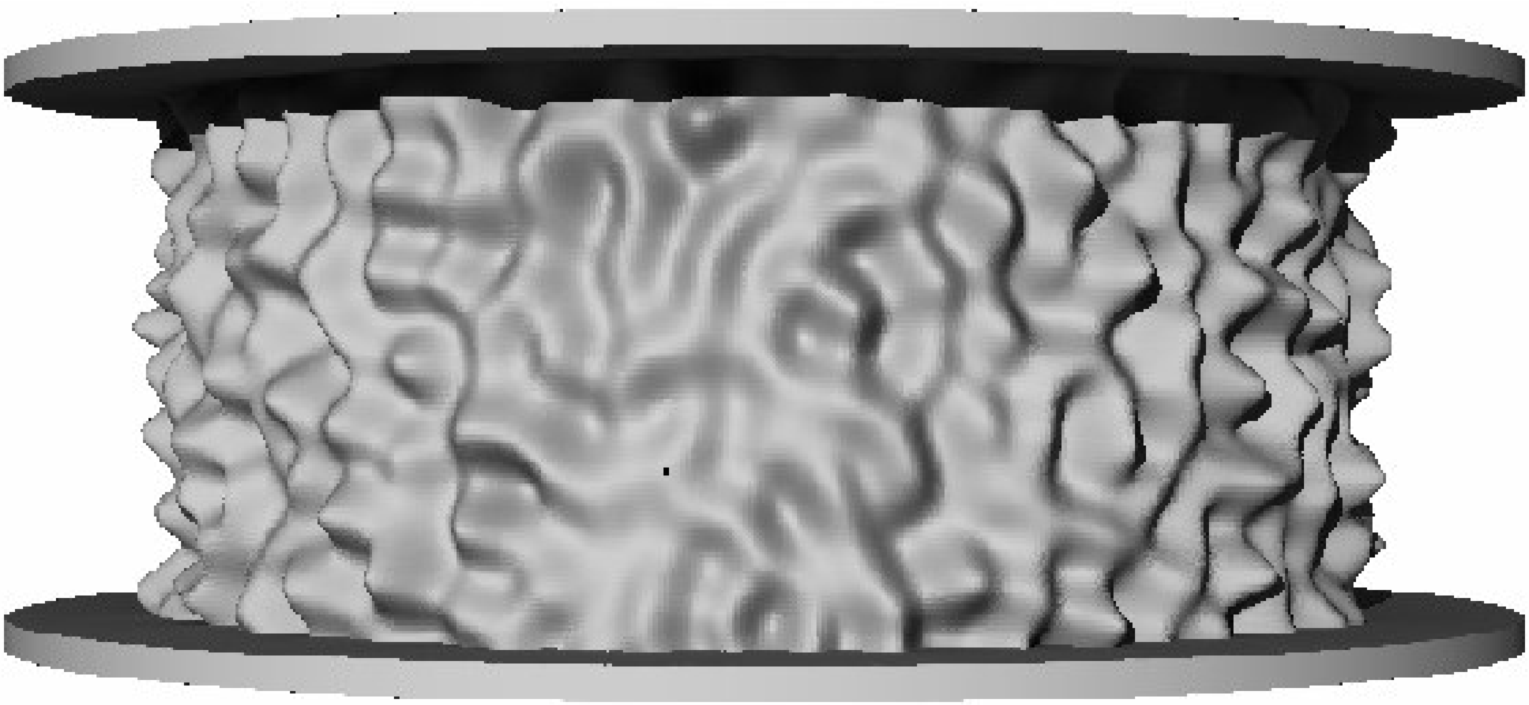
Shadowing effects cannot be ignored.

Shading on a Cloudy Day



Shading is determined by shadowing and surface normal.

Shading on a Sunny Day



Shading determined by surface normal only.

Shape from shading

Q: What is the task ?
What problem is being solved?

A: Estimate surface slant, tilt, curvature.

How to account for (or estimate) the lighting ?

Illumination and Reflectance

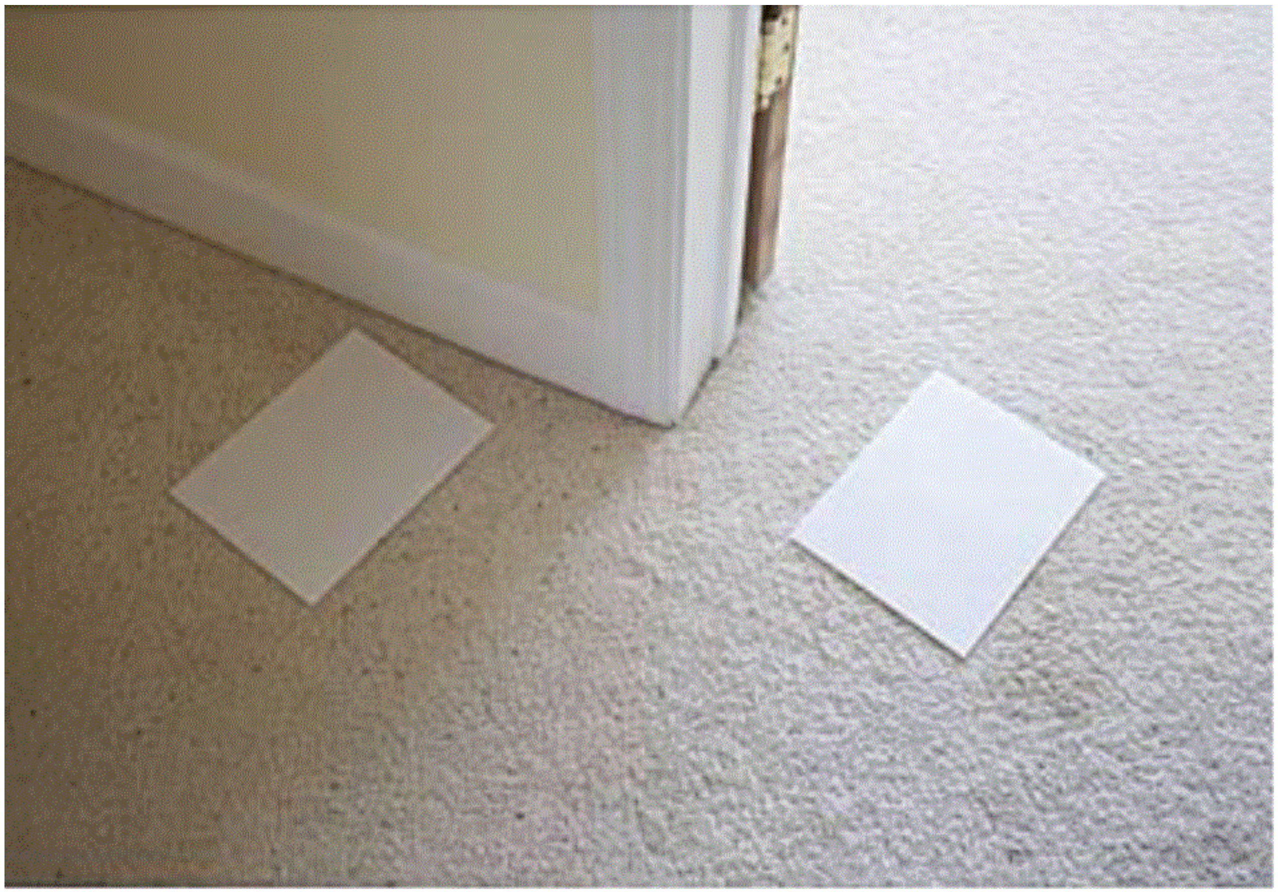
- Shading

[Shading and shadowing models assume that intensity variations on a surface are entirely due to illumination.   But surfaces have reflectance variations too.]

- Brightness versus Lightness

- Color constancy

Which paper is *lighter* ?



Paper on the left is in shadow. It has lower physical intensity and it appears darker. But do both papers seem to be of same (white) material?

Which paper is lighter ?

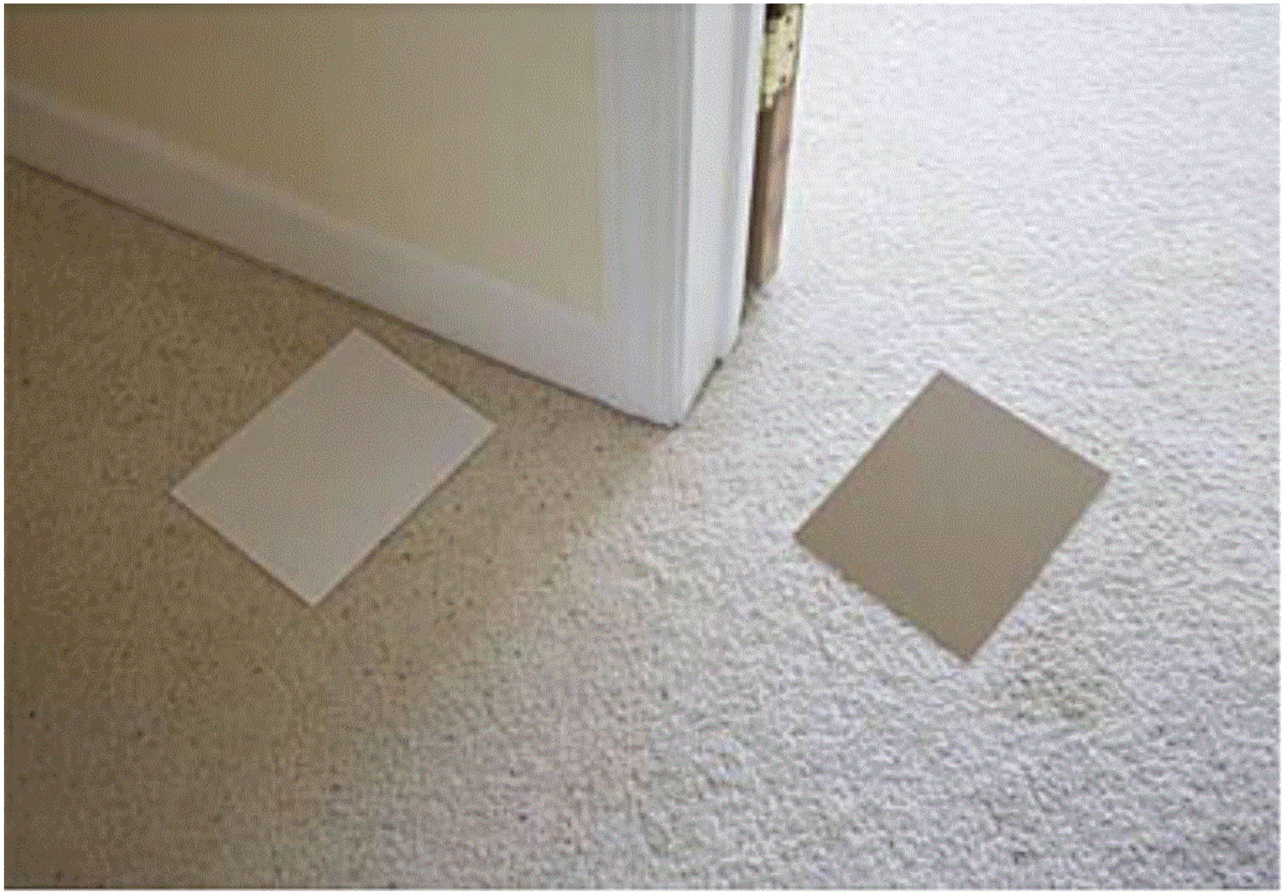
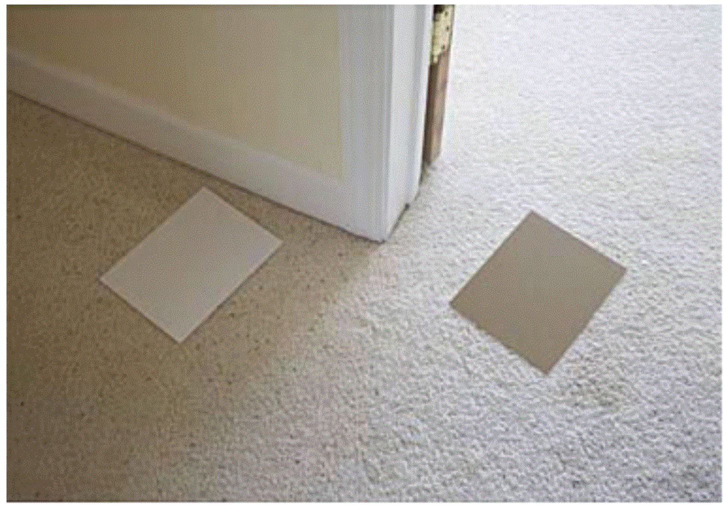


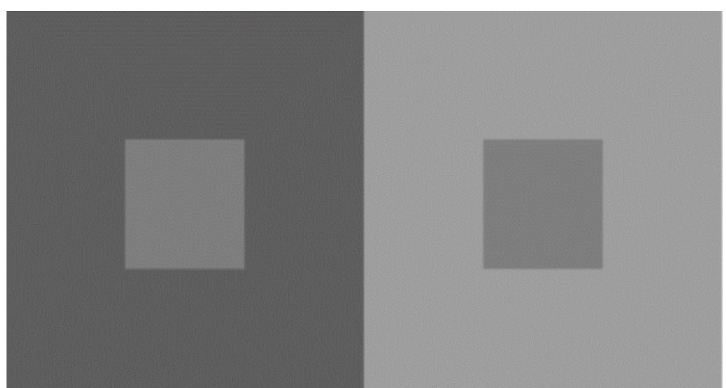
Image is processed so that the right paper is given same image intensities as left paper. Now, right paper appears to be made of different material. Why?

$$I(x,y) = illumination(x,y) \ * \ reflectance\ (x,y)$$

"Real" example



Abstract version



Physical quantities

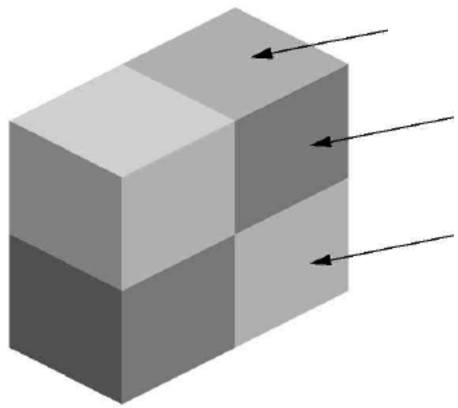
luminance

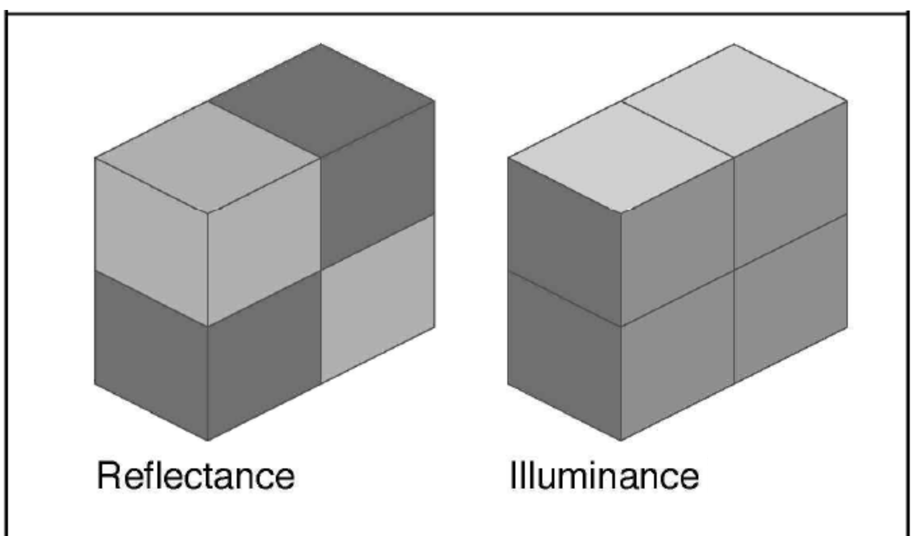
$$I(x, y) = illumination(x, y) \ * \ reflectance\,(x, y)$$

shading & shadows

material

$$I(x,y) = illumination(x,y) \ * \ reflectance\,(x,y)$$





Perceptual quantities

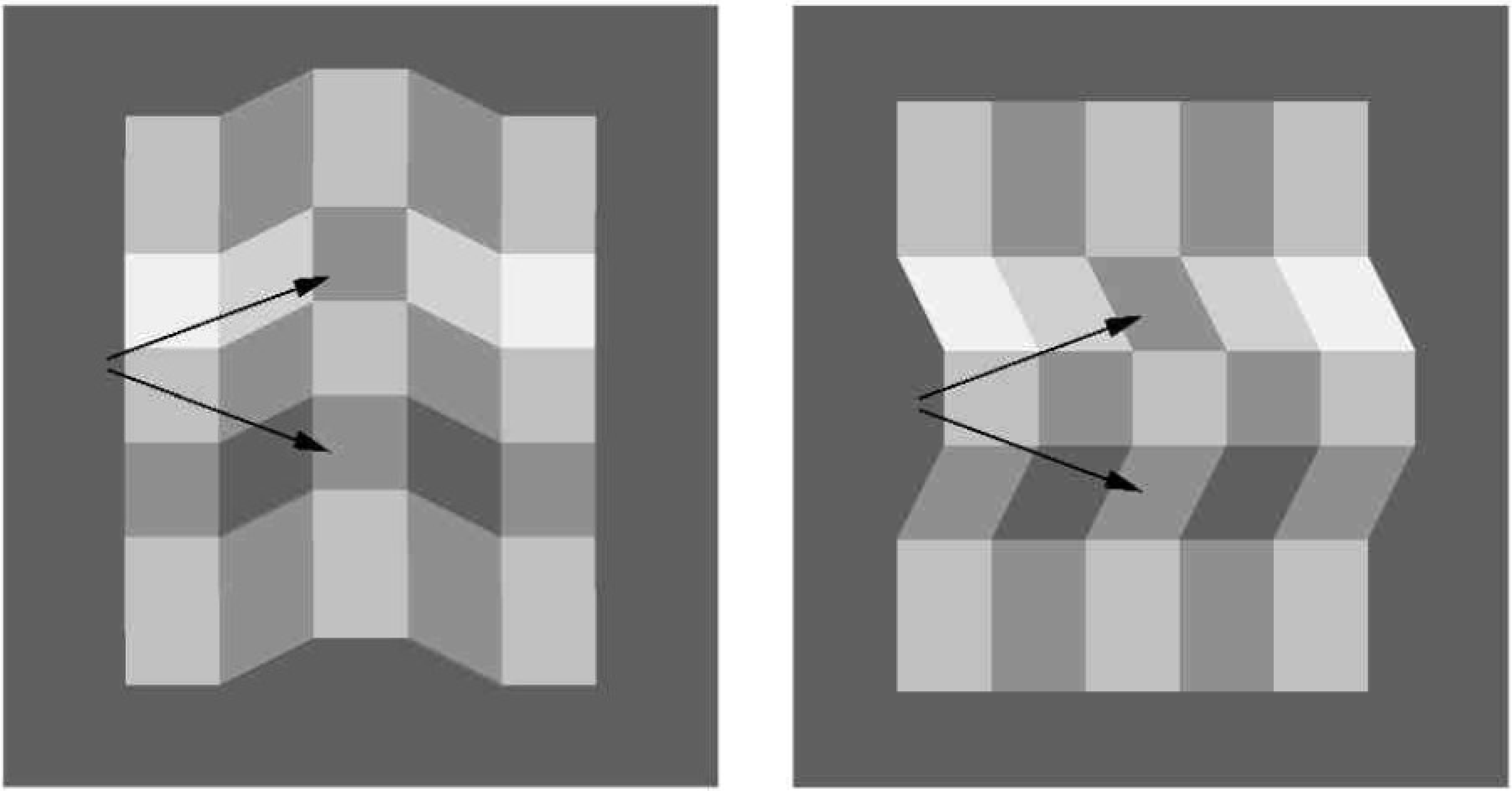
"brightness"

$$I(x, y) = illumination(x, y) \; * \; reflectance\,(x, y)$$

(no standard term for perceived illumination)

"lightness"

Adelson's corrugated plaid illusion.



All four indicated "squares" have same intensity.

What is the key difference between the two configurations ?

“Lightness” perception

Q: What is the task ?

What problem is being solved?

A:

“Lightness” perception

Q: What is the task ?

What problem is being solved?

A: Estimate the surface reflectance, *by discounting the illumination.*

$$I(x, y) = \cancel{illumination(x, y)} * reflectance\,(x, y)$$

?

"Lightness" perception:
solution sketch

Q: What is the task ?

What problem is being solved?

A: Estimate the surface reflectance*, by discounting illumination effects.*

Compare points that have same illumination.

$$\frac{I(x_1, y_1)}{I(x_2, y_2)} = \frac{\cancel{illumination} * reflectance\,(x_1, y_1)}{\cancel{illumination} * reflectance\,(x_2, y_2)}$$

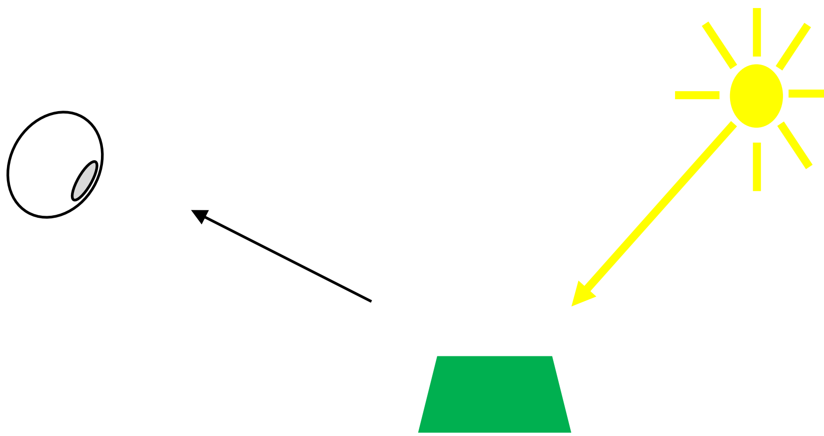
Illumination and Reflectance

- Shading
- Brightness versus Lightness
- Color constancy

Recall lecture 3 - color

Absorption
by photoreceptors
(fraction)

Illumination



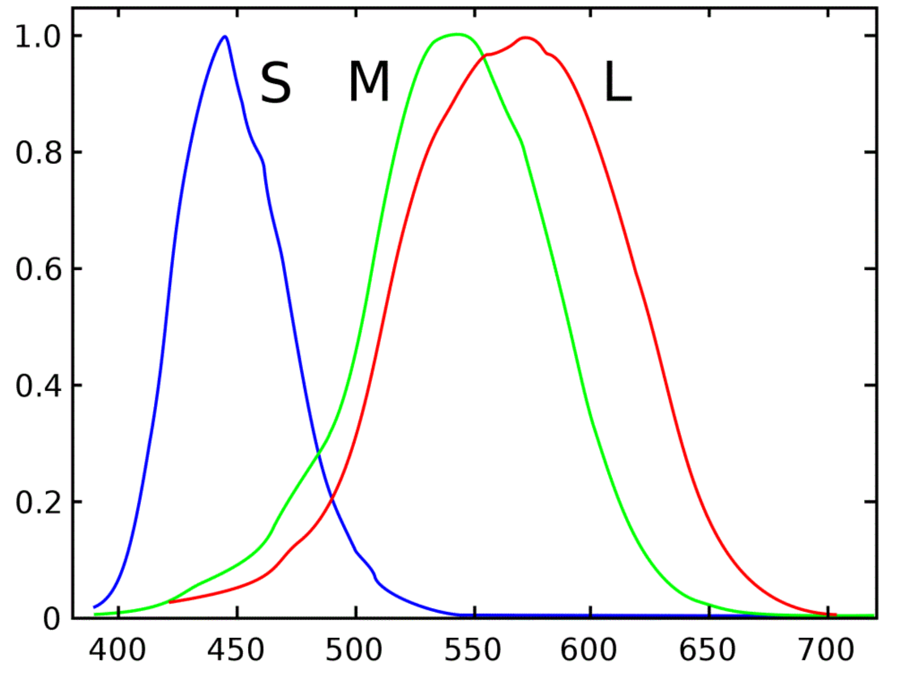
Surface Reflectance (fraction)

There are three different spectra here.

LMS cone responses

Cone response

$$\int I(x, y, \lambda)\, C_{LMS}(\lambda)\, d\lambda$$

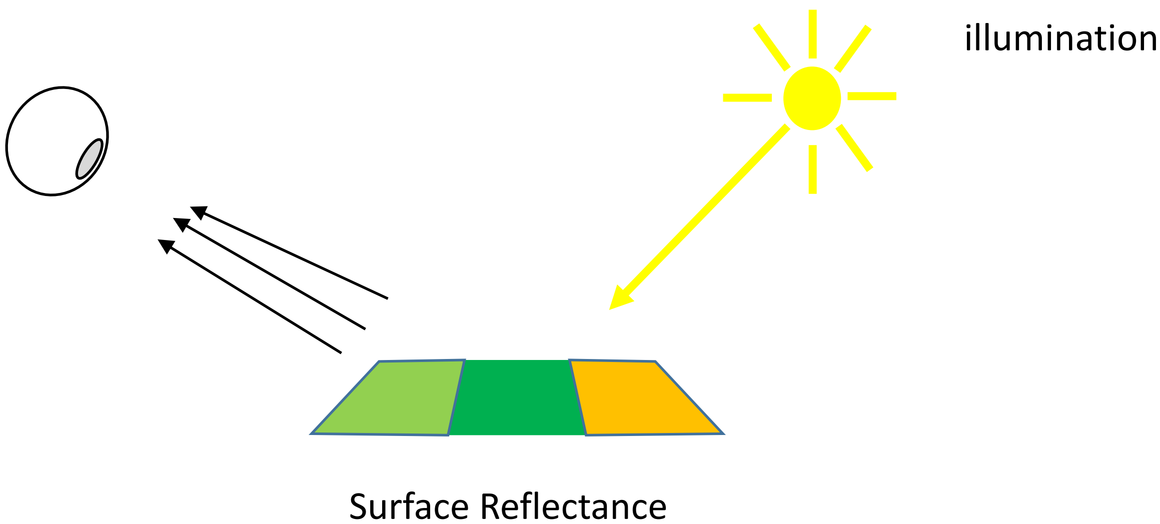


$$I(x, y, \lambda) = illumination(x, y, \lambda) * reflectance(x, y, \lambda)$$

Surface Color Perception

Q: What is the task? What is the problem to be solved?

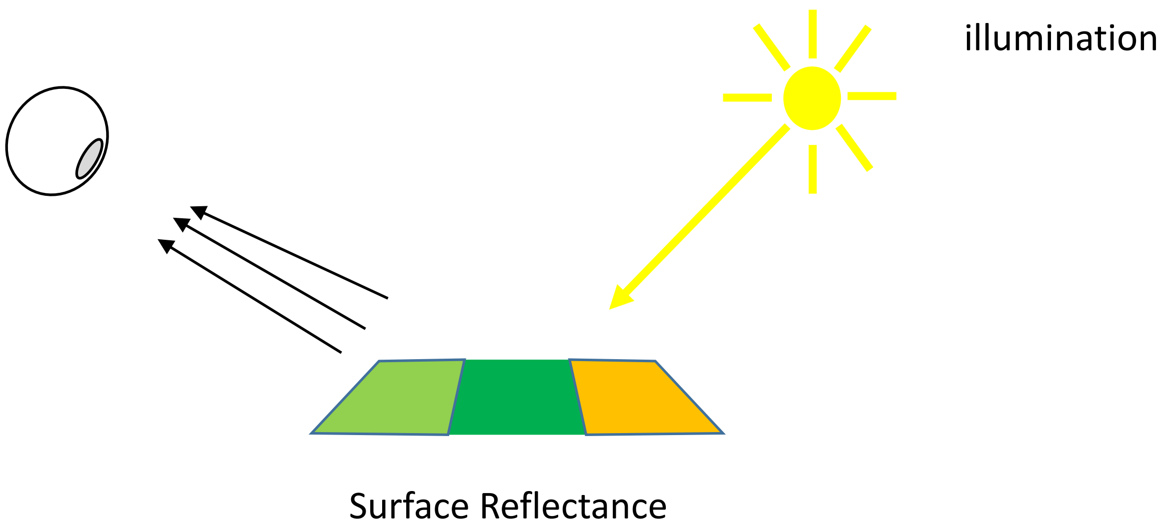
A:



Surface Color Perception

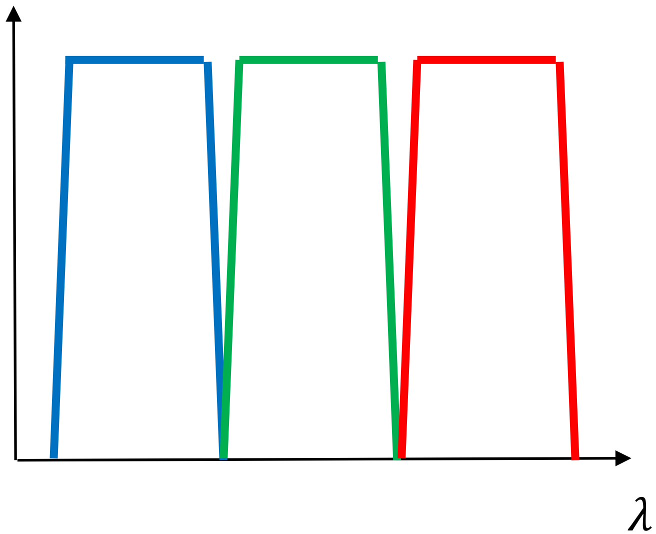
Q: What is the task? What is the problem to be solved?

A: Estimate the surface reflectance, by *discounting the illumination*.



$$I(x, y, \lambda) = \cancel{illumination(x, y, \lambda)} * reflectance(x, y, \lambda)$$

For simplicity, let's ignore the continuous wavelength λ and just consider RGB (*LMS*).



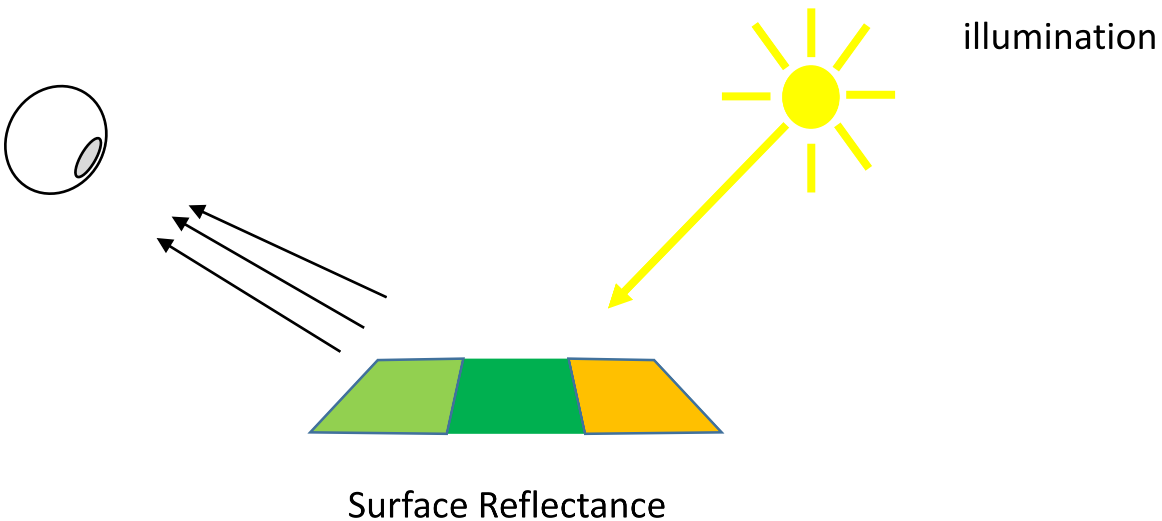
Cone response

$$\int I(x, y, \lambda)\, C_{LMS}(\lambda)\, d\lambda$$

$$I_{RGB}(x, y) = illumination_{RGB}(x, y) * reflectance_{RGB}(x, y)$$

“Color Constancy”

Task: estimate the surface reflectance, by *discounting the illumination*

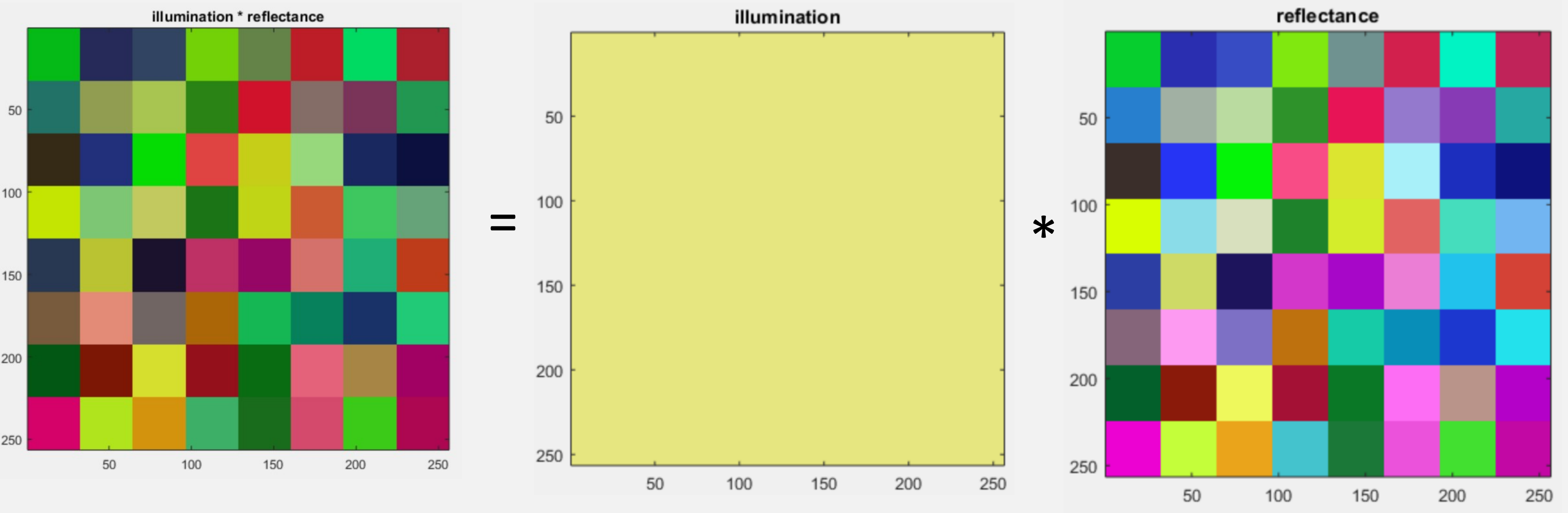


$$I_{RGB}(x,y) = illumination_{RGB}(x,y) \ * \ reflectance_{RGB}\,(x,y)$$

Why we need color constancy

- object recognition
- skin evaluation (health, emotion, …)
- food quality
- …

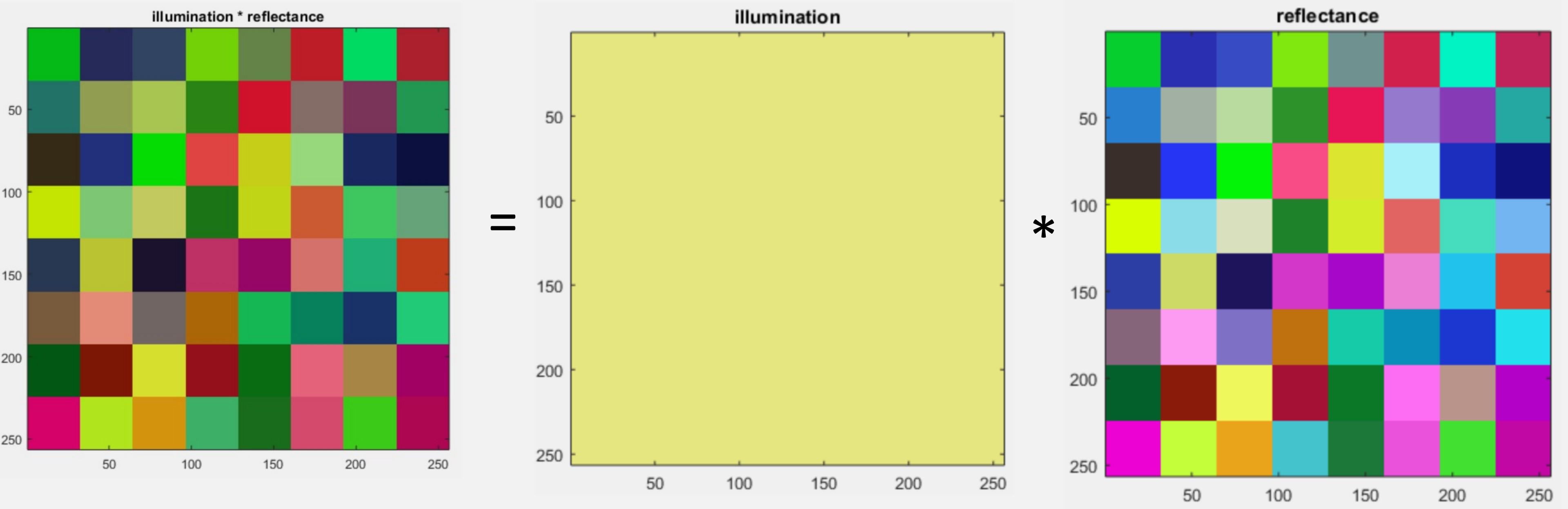
Example 1: spatially uniform illumination



$$I_{RGB}(x,y) = illumination_{RGB}(x,y) \ * \ reflectance_{RGB}\ (x,y)$$

Given this, how to estimate this?

Solution 1: 'max-RGB' Adaptation



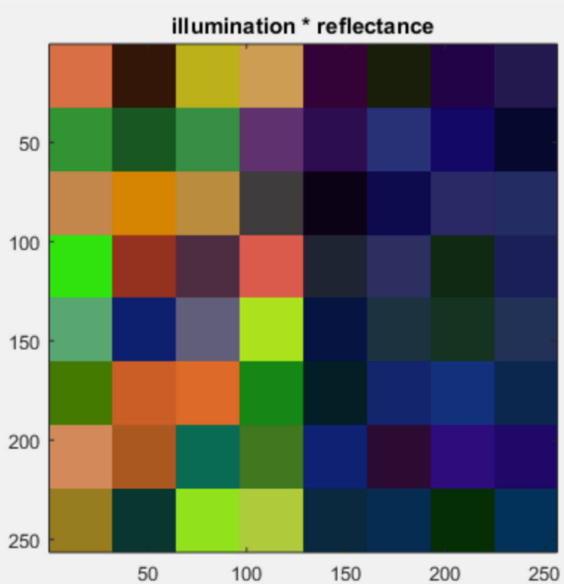
$$I_{RGB}(x,y) = illumination_{RGB}(x,y) * reflectance_{RGB}(x,y)$$

Divide each I_{RGB} channel by the max value of I_{RGB} in each channel.

When does this give the correct answer?

Example 2: non-uniform illumination

sun + blue sky | only blue sky



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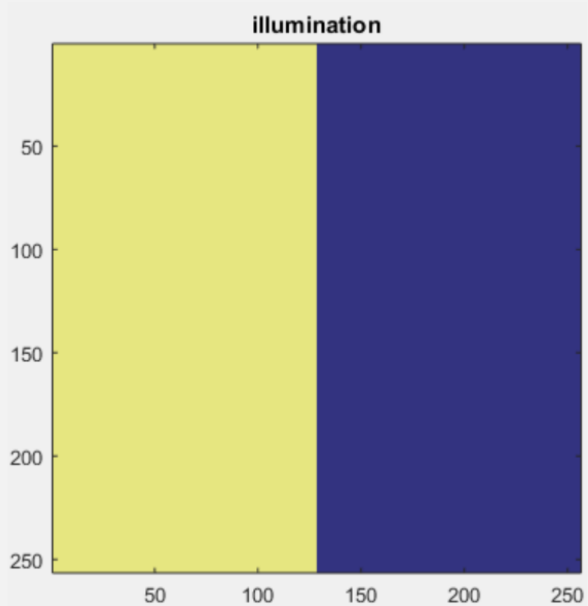

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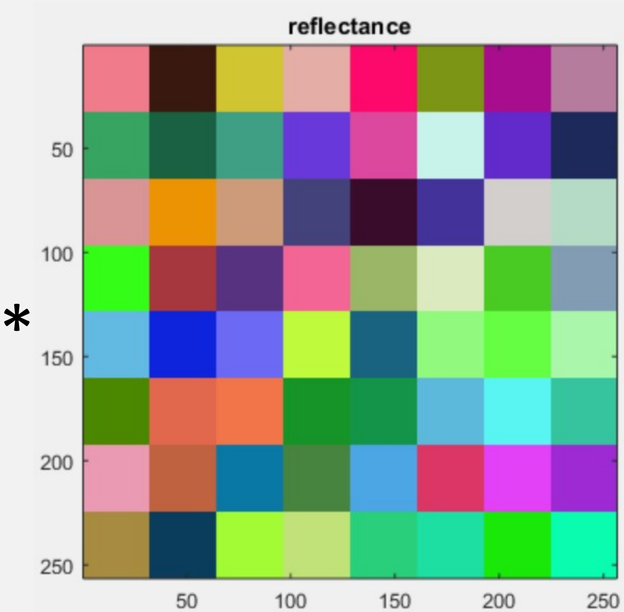

$$I_{RGB}(x,y) = illumination_{RGB}(x,y) \, * \, reflectance_{RGB}\,(x,y)$$

Solution: See Exercises.

Illumination and Reflectance

- Shape from Shading
- Brightness versus Lightness
- Color constancy

Different solutions require different underlying assumptions. This is separate issue from how we can code up a solution using neural circuits.