

Light, colour, & shadow

Semester 2, 2021 Kris Ehinger



https://www.youtube.com/watch?v=tBNHPk-Lnkk

Outline

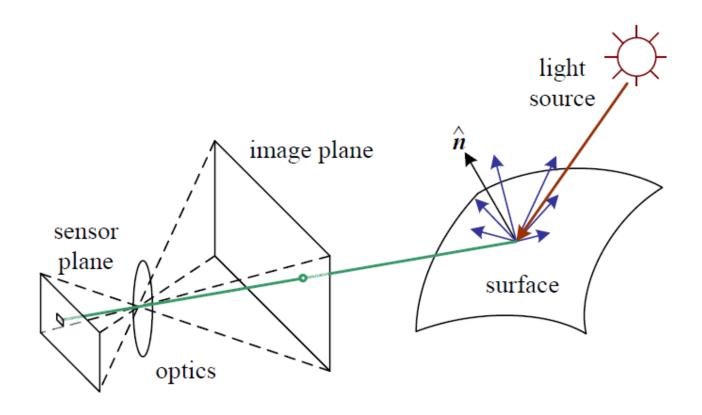
- Image formation, continued
- Colour
- Shading and surfaces

Learning outcomes

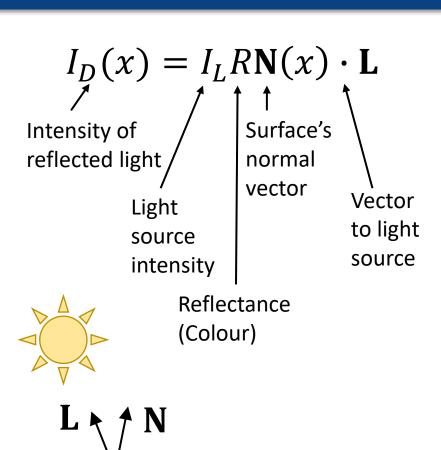
- Explain the diffuse reflectance model
- Explain how trichromatic colour values are computed and implement colour space transforms
- Implement a frequency-based model for separating illumination and reflectance
- Explain the problems involved in recreating surface properties from a single image

Image formation

Image formation model

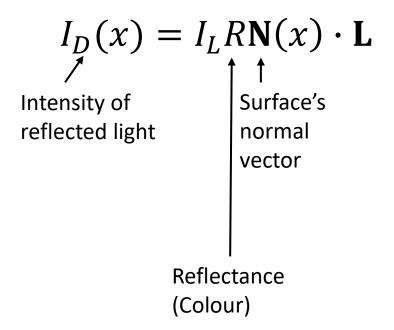


Diffuse (Lambertian) reflectance





Goal of vision

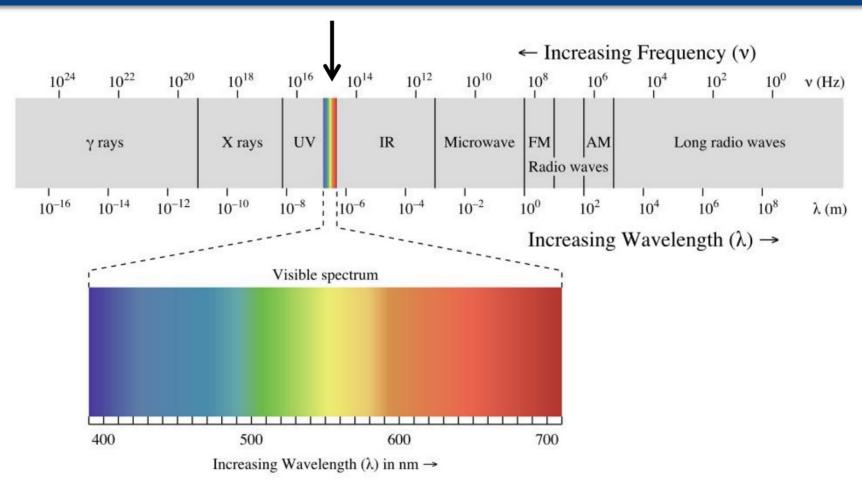


Recover surface colour and normal from reflected light



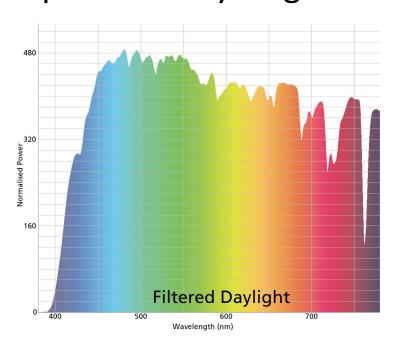
Colour

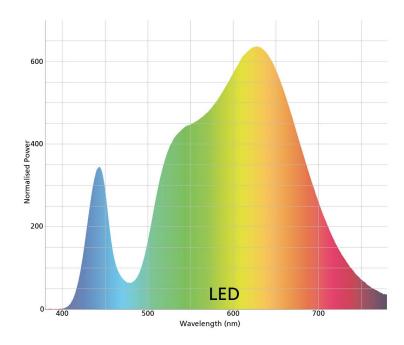
Visible light



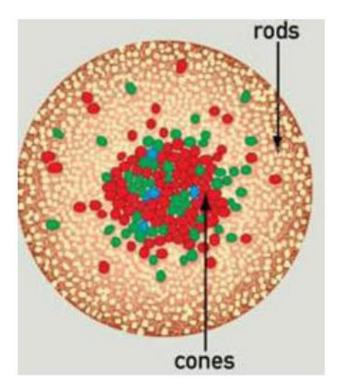
Visible light

 Spectral power distribution (SPD) = relative amount of each wavelength reflected by a surface (or produced by a light source)





 Human colour perception is based on 3 types of colour-sensitive cells (cones)



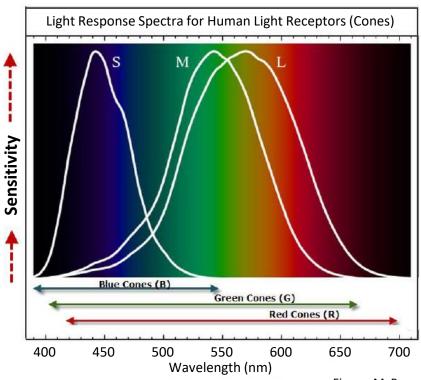
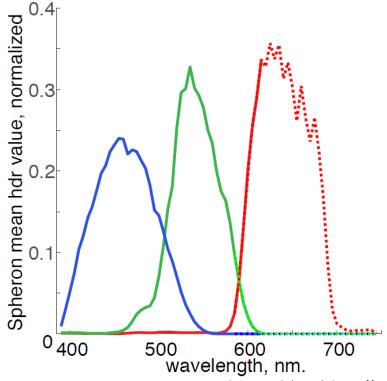


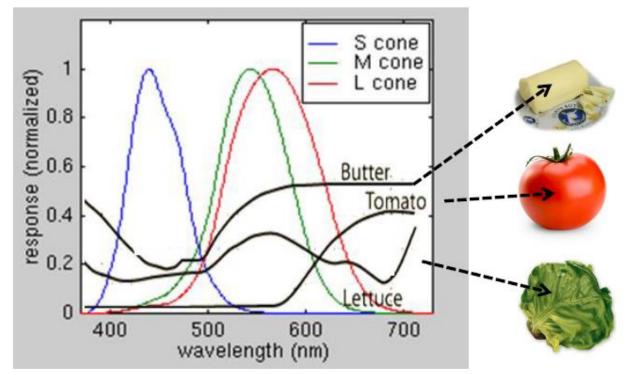
Figure: M. Brown

 Standard cameras also have 3 colour sensors, each with a different spectral sensitivity

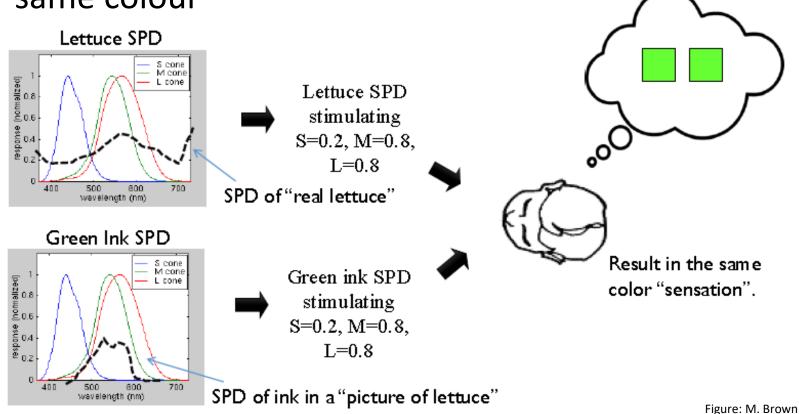




 Most surfaces reflect a range of wavelengths, but perceived colour is a function of cone response



Result: many different spectra appear to be the same colour



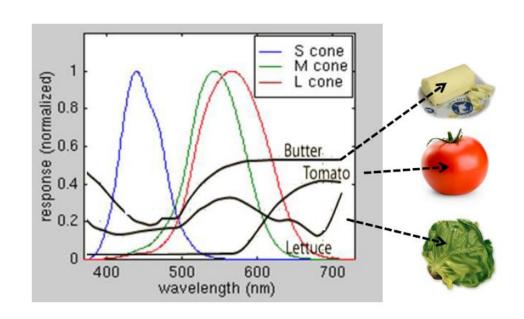
Trichromatic colour response

 Sensor response = sensitivity x spectrum, integrated over all wavelengths

$$I_R = \int_{400}^{700} I(\lambda) S_R(\lambda) \partial \lambda$$

$$I_G = \int_{400}^{700} I(\lambda) S_G(\lambda) \partial \lambda$$

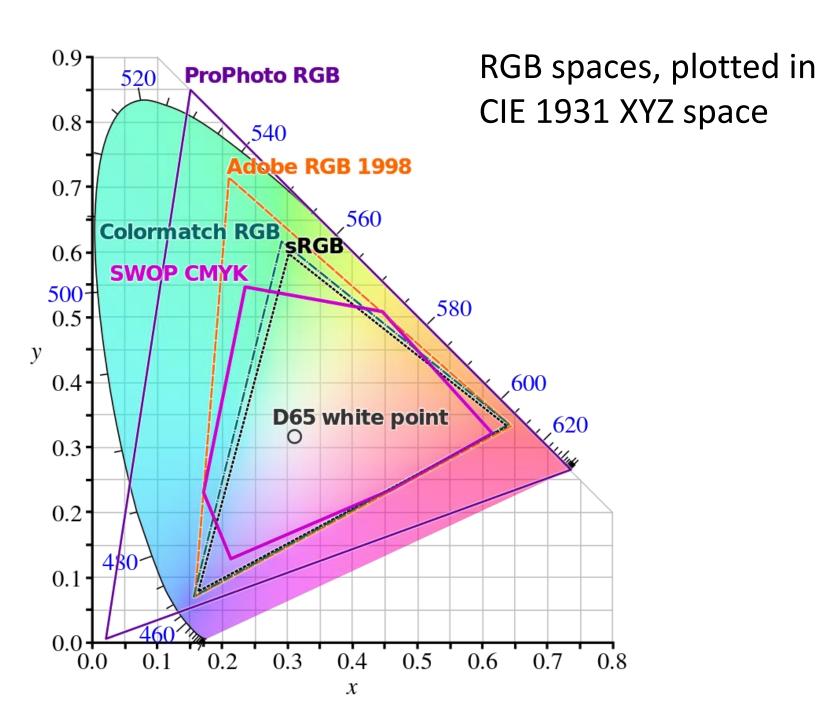
$$I_B = \int_{400}^{700} I(\lambda) S_B(\lambda) \partial \lambda$$



https://csci1230.graphics/demos/metamers/index.html

Colour representation

- Common colour spaces:
- RGB (red, green, blue)
 - Most common spaces for digital images
- HSL/HSV (hue, saturation, lightness/value)
 - Attempt to match human understanding of colour
- CIE 1931 XYZ
 - Based on human cone sensitivity, basis for other spaces
- LAB (luminance, a*=red/green, b*=blue/yellow)
 - Approximately perceptually uniform space

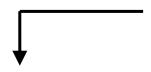


Colour transforms

- Converting between colour spaces is straightforward:
 - Linearize R, G, B values
 - Linear transform, e.g. $\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M \begin{bmatrix} R \\ G \\ B \end{bmatrix}$
 - Values of M can be looked up for various colour spaces and white points (= the value defined to be "white" for a given colour space)
- Built-in functions in OpenCV, scikit-image

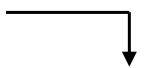
Example: colour swap

Swap R,G channels in RGB





Invert red-green axis in LAB





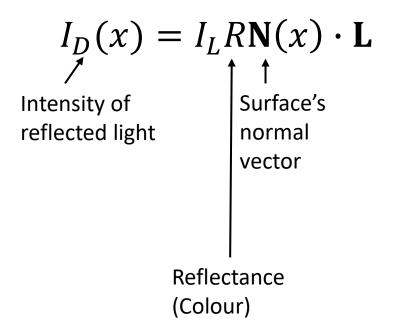


Summary

- Colour is not just three values, but human eye (and standard camera) depends on just three sensors
- Many trichromatic colour spaces
- RGB most common for image storage, other spaces may be more useful for colour manipulations

Shading and surfaces

Goal of vision



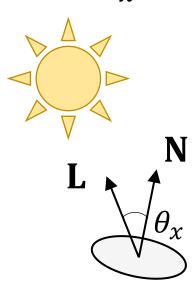
Recover surface colour and normal from reflected light



Recovering surface normal

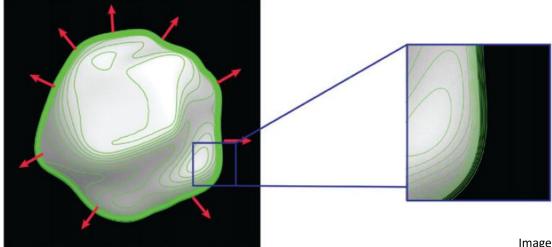
- Assume no changes in surface colour/reflectance (constant albedo)
- Can you recover surface normal from image?

•
$$I_D(x) = \mathbf{N}(x) \cdot \mathbf{L} = \cos \theta_x$$



Recovering surface normal

- Can recover angle between surface normal and light source, but not normal
- However, can add additional assumptions:
 - Normals along boundary of object are known
 - Neighbouring normal are similar



"Shape from shading"

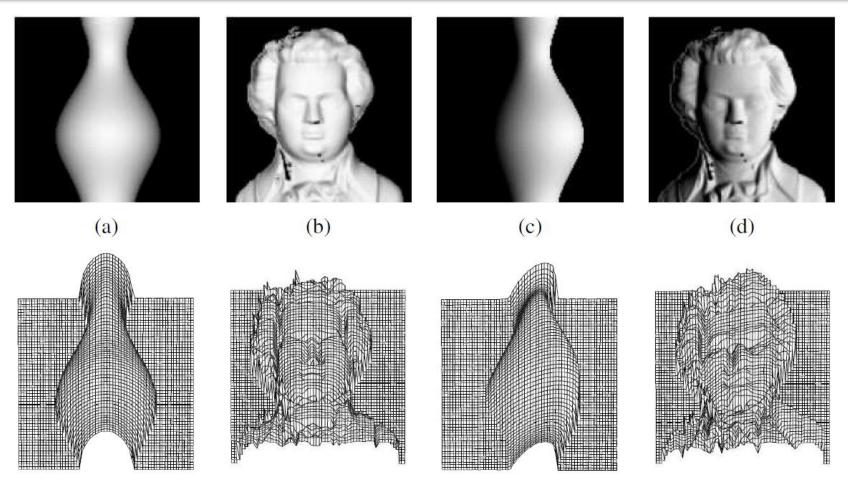


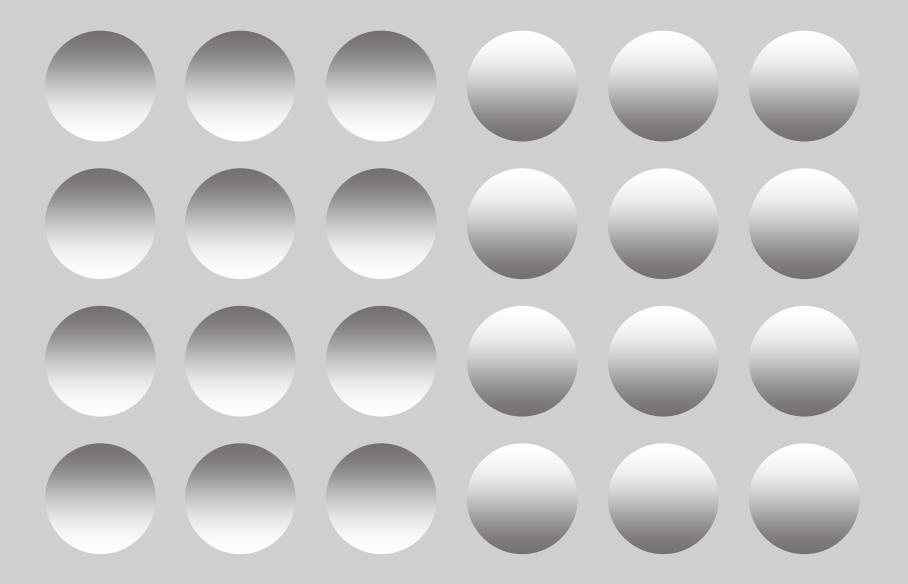
Image: R. Szeliski, Computer Vision, Figure 13.2

"Shape from shading"

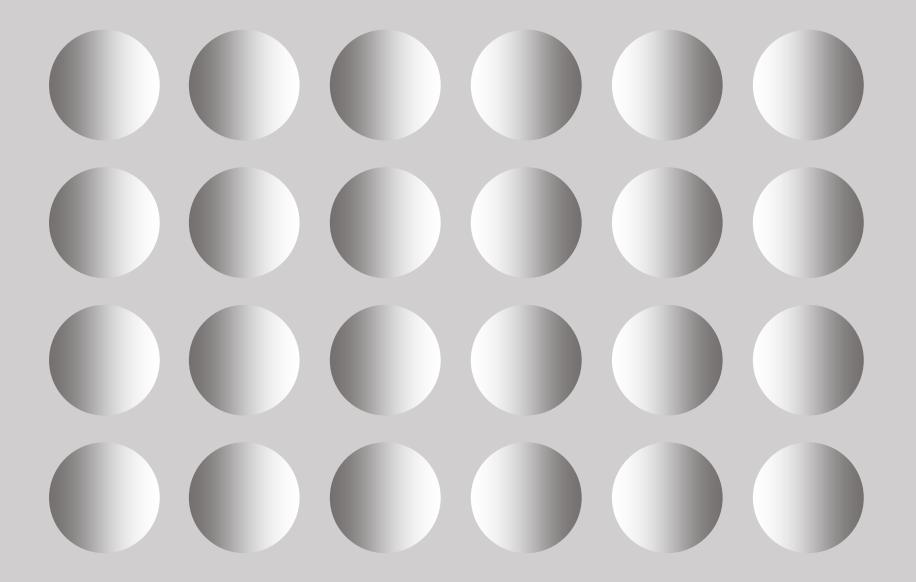
- Recover 3D shape from 2D image based only on surface brightness (shading)
- Requires additional assumptions, no algorithm works for all cases

How does the human visual system do it?

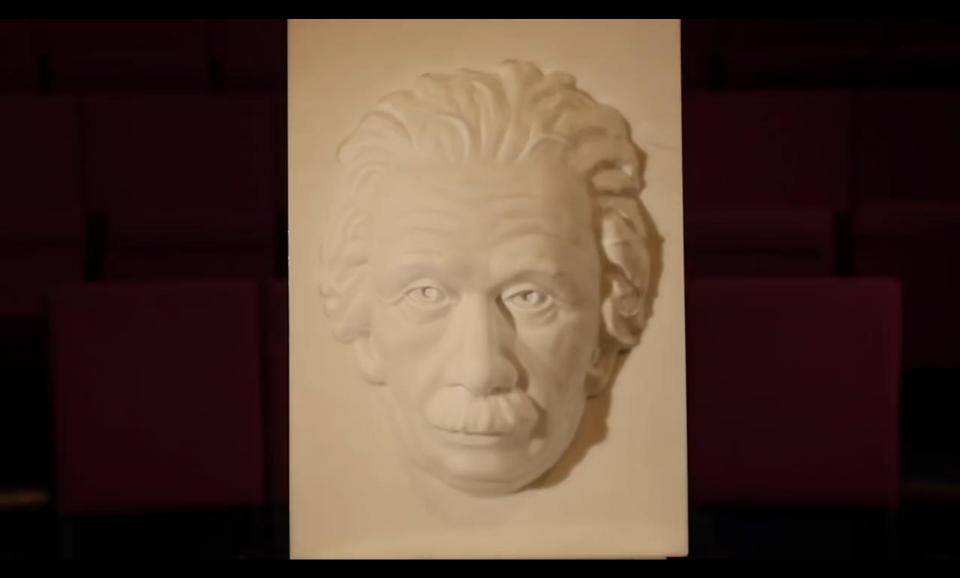
Lighting priors



Lighting priors



Shape priors

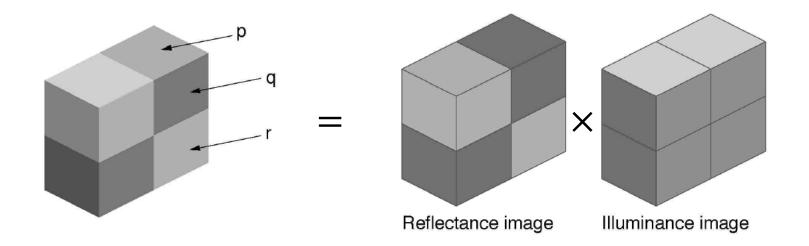


"Shape from shading"

- Recover 3D shape from 2D image based only on surface brightness (shading)
- Requires additional assumptions, no algorithm works for all cases

What if surface isn't constant albedo?

Recovering surface reflectance



 $Luminance = Reflectance \times Illumination$

Recovering surface reflectance

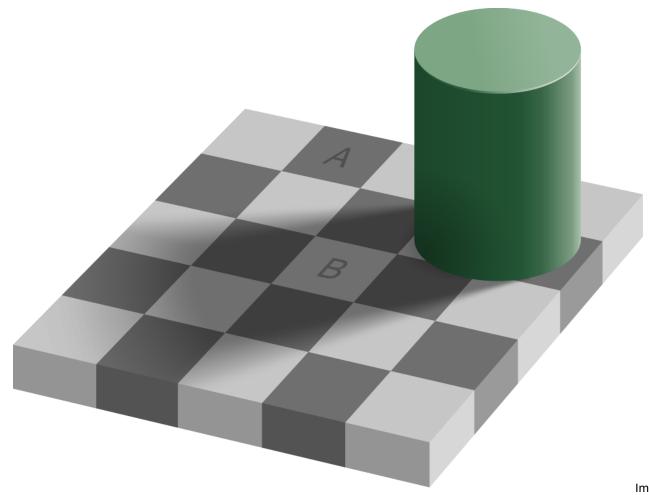
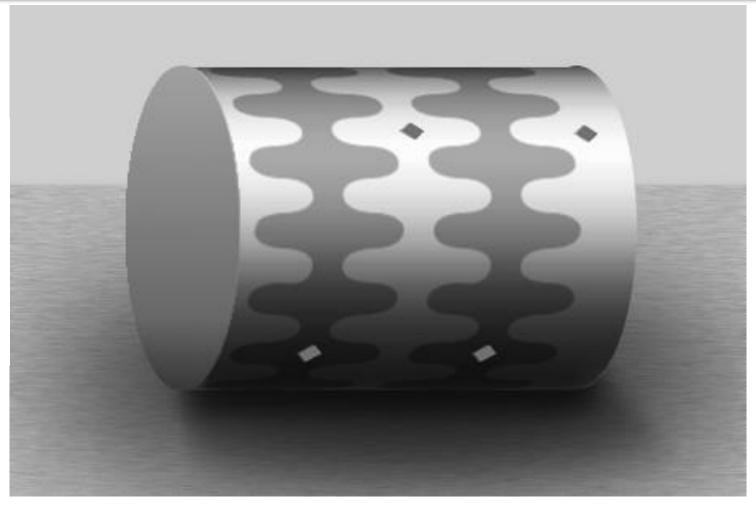


Image: E. Adelson

Global shape and context

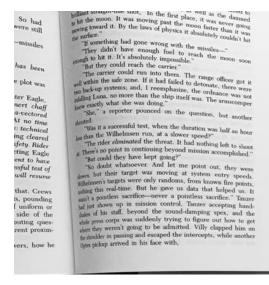


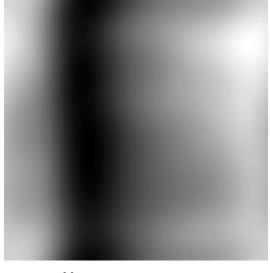
Reflectance from frequency

- Simple approach: assume illumination variation produces low-spatial-frequency changes in image, remove illumination in frequency domain
- $L = R \times I$
- ln(L) = ln(R) + ln(I)
- $FT(\ln(L)) = FT(\ln(R)) + FT(\ln(I))$
- ullet Apply a high-pass filter g in the frequency domain
- $Image = e^{FT^{-1}(g \times FT(\ln(L)))}$

Reflectance from frequency

Separating reflectance and illumination in the frequency domain:





at stranger-time shot. In the first place, it was never going billiant stranger. In the first place, it was never not up bit the moon. It was moving past the moon faster than going going toward it. By the laws of physics it absolutely couldn't has a second to the second stranger. If something had gone wrong with the missiles missiles They didn't have enough fuel to reach the moon soon googh to hit it. It's absolutely impossible "But they could reach the carrier." has been The carrier could run into them. The range officer got it and within the safe zone. If it had failed to detonate, there were plot was and wenning used to be a systems; and, I reemphasize, the ordnance was not so backup 7 ter Eagle brew exactly what she was doing." nert chaff "She," a reporter pounced on the question, but another a-vectored At no time "Was it a successful test, when the duration was half an hour technical is than the Wilhelmsen run, at a slower speed? ing cleared The rider eliminated the threat. It had nothing left to shoot fety. Rider a There's no point in continuing beyond mission accomplished cting Eagle "But could they have kept going?" ent to have "No doubt whatsoever. And let me point out, they were ssful test of down but their target was moving at system entry speeds. will resume undelmsen's targets were only randoms, from known fire points. ushing this real-time. But he gave us data that helped us. It that Crews esalt a pointless sacrifice—never a pointless sacrifice." Tanzer ts, pounding had just shown up in mission control. Tanzer accepting handuniform or takes of his staff, beyond the sound-damping spex, and the side of the shole press corps was suddenly trying to figure out how to get outing quesabee they weren't going to be admitted. Villy clapped him on rent proximthe shoulder in passing and escaped the intercepts, while another Ostes pickup arrived in his face with, ers, how he

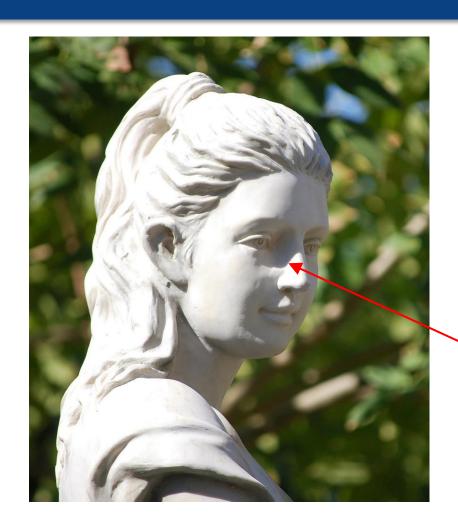
Image Illumination

Reflectance

Recovering surface properties

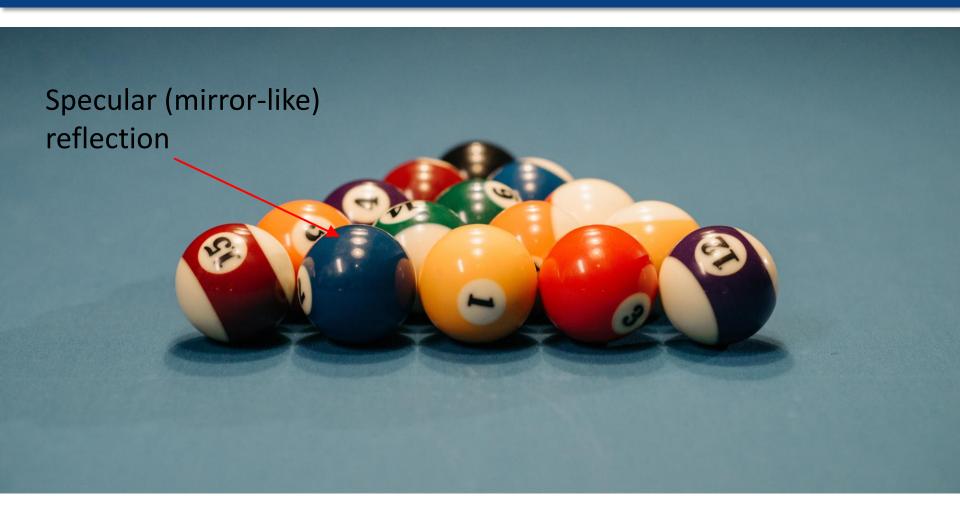
- Problems with the simple approach?
 - Some reflectance edges are smooth
 - Some lighting edges are not smooth (textures, corners)
- More sophisticated approaches (e.g., based on partial differential equations) can give better results but have similar problems
- Even more complicated in practice!
 - Lighting usually isn't uniform
 - Most surfaces aren't matte/Lambertian

Cast shadows



Cast shadow – change in illumination, not change in surface

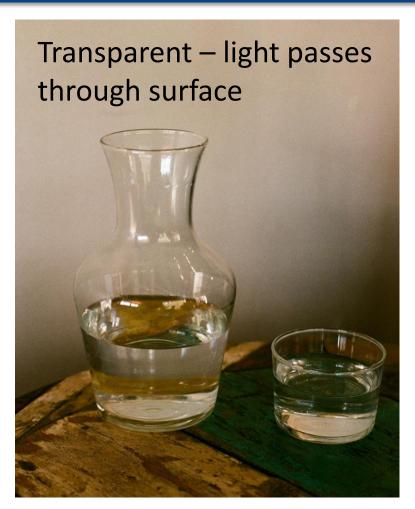
Specularity



Anisotropy



Transparency / translucency





Summary

- Recovering surface shape and reflectance from a single image is difficult
- Generally requires additional assumptions or constraints:
 - Assumptions about surface (e.g., matte, smooth)
 - Shape and/or lighting priors
- Images contain a lot of information, and it's not easy to separate out sources

Application: Photometric stereo

SIGGRAPH 2011 paper

M.K. Johnson, F. Cole, A. Raj, and E.H. Adelson, Microgeometry Capture using an Elastomeric Sensor, ACM Transactions on Graphics (Proc. of SIGGRAPH), Volume 30, Issue 4, Article 46, 2011.

Object



Camera view



Johnson & Adelson (2009)

Application: Using reflections

Computational Mirrors: Blind Inverse Light Transport by Deep Matrix Factorization

Miika Aittala Prafull Sharma Lukas Murmann Adam B. Yedidia Gregory W. Wornell William T. Freeman¹ Frédo Durand

Massachusetts Institute of Technology
¹ Google Research



NeurIPS 2019

Summary

 Images contain a lot of information, and if you understand the principles of image formation, you can find ways to extract it!