Light, colour, & shadow

Semester 2, 2021

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

Outline

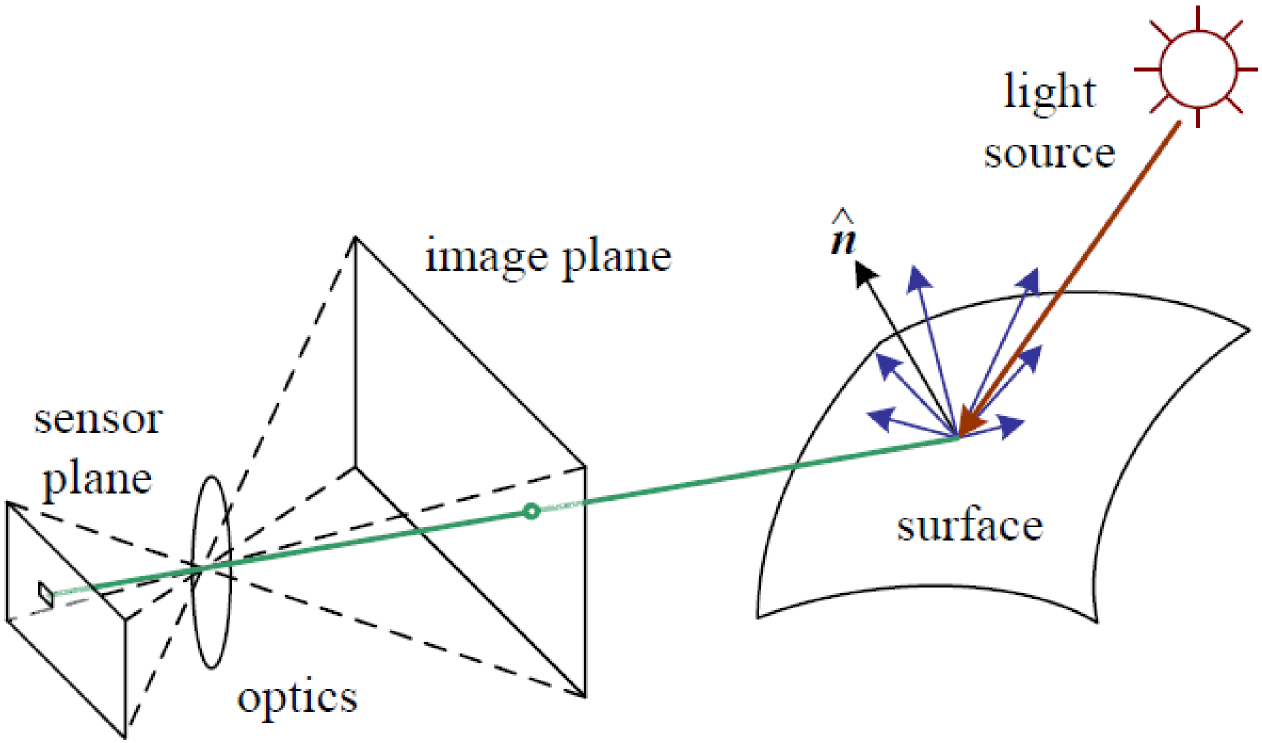
- Image formation, continued
- Colour
- Shading and surfaces

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



Computer Vision, Richard Szeliski (2021)

Diffuse (Lambertian) reflectance

$$I_D(x) = I_L R \mathbf{N}(x) \cdot \mathbf{L}$$

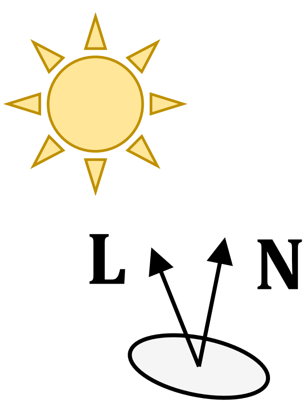
Intensity of reflected light

Light source intensity

Reflectance (Colour)

Surface's normal vector

Vector to light source



Goal of vision

$$I_D(x) = I_L R \mathbf{N}(x) \cdot \mathbf{L}$$

Intensity of reflected light

Surface's normal vector

Reflectance (Colour)

Recover surface colour and normal from reflected light

Colour

Visible light

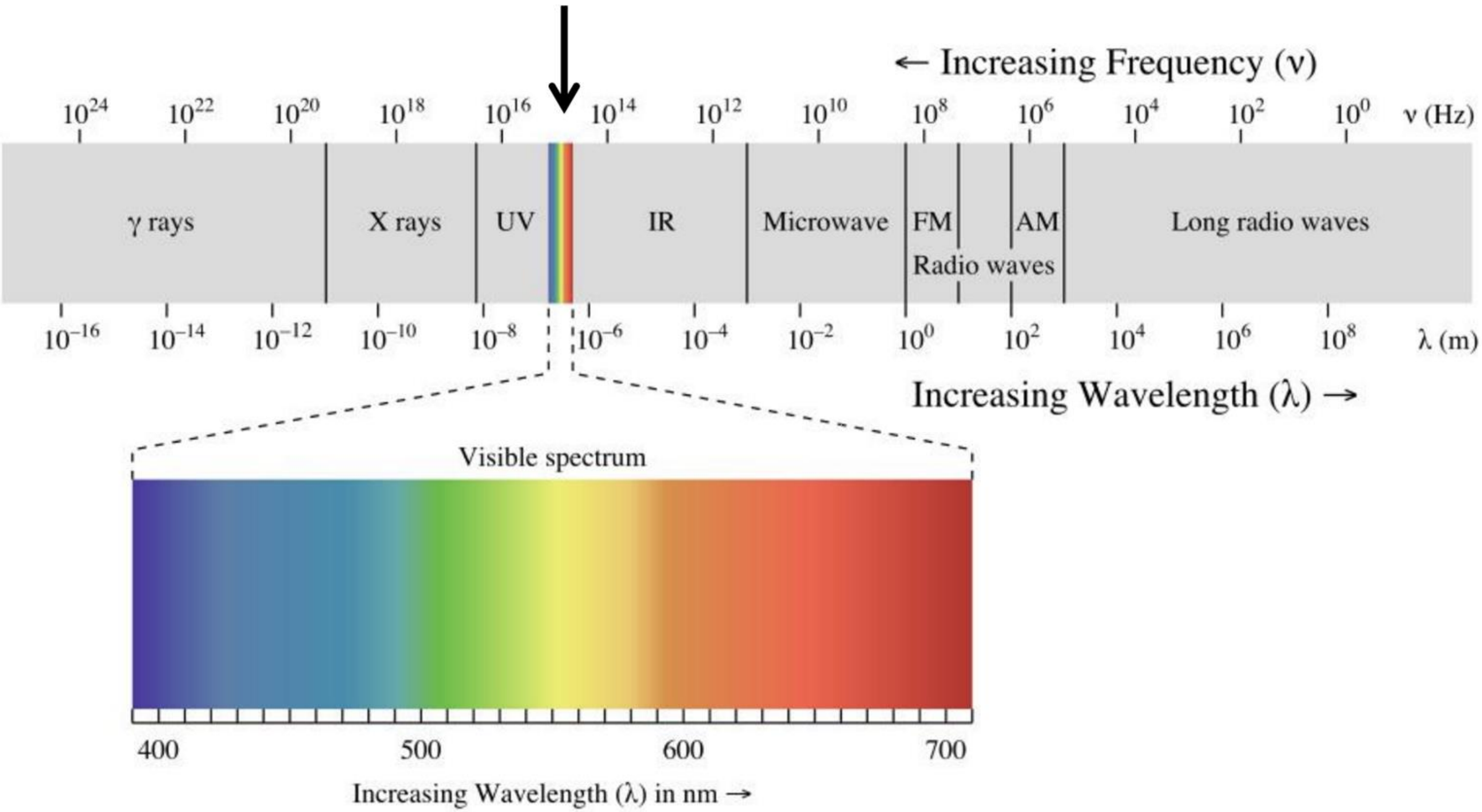
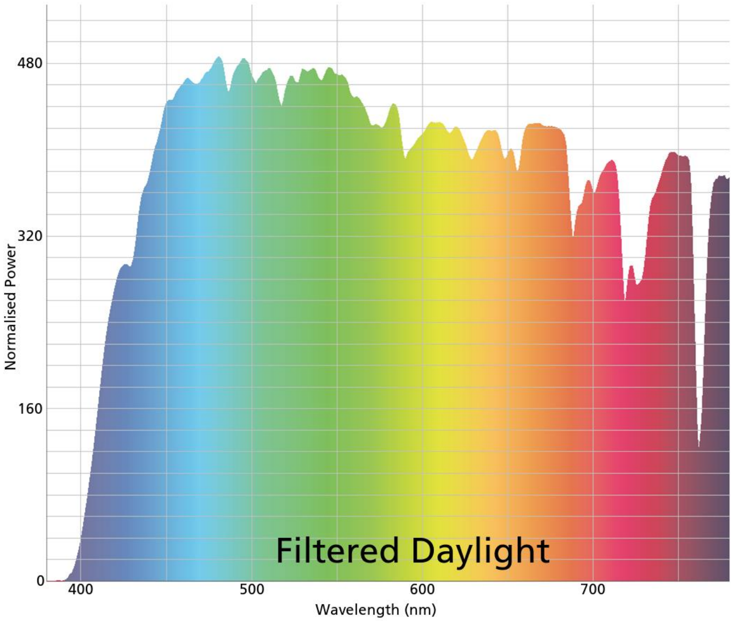


Figure: M. Brown

Visible light

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



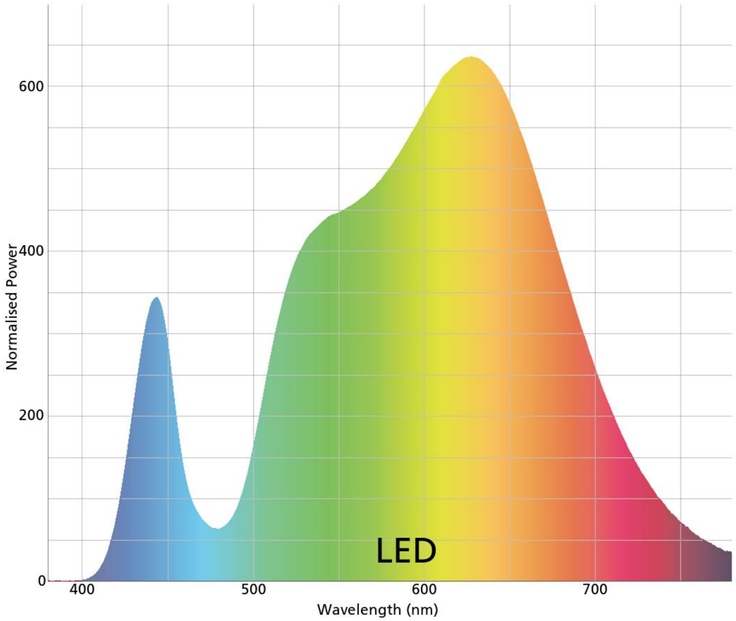
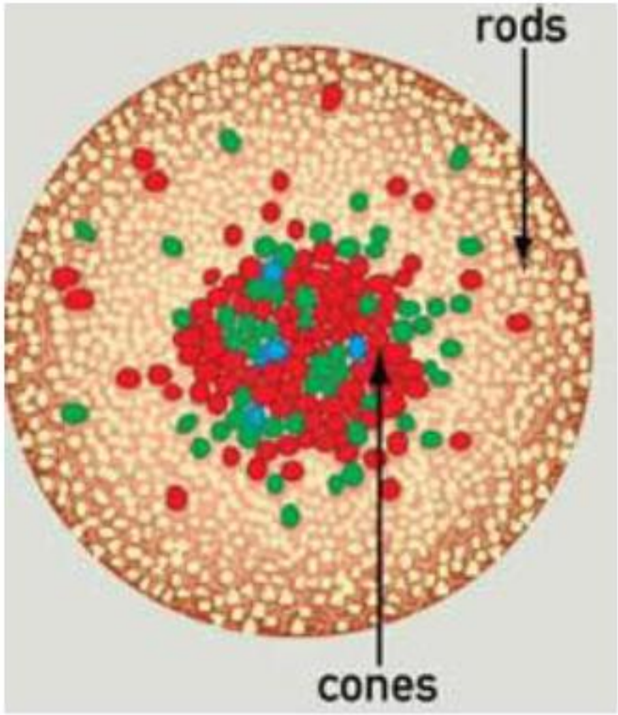


Figure: https://research.ng-london.org.uk/scientific/spd/

Perceived colour

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



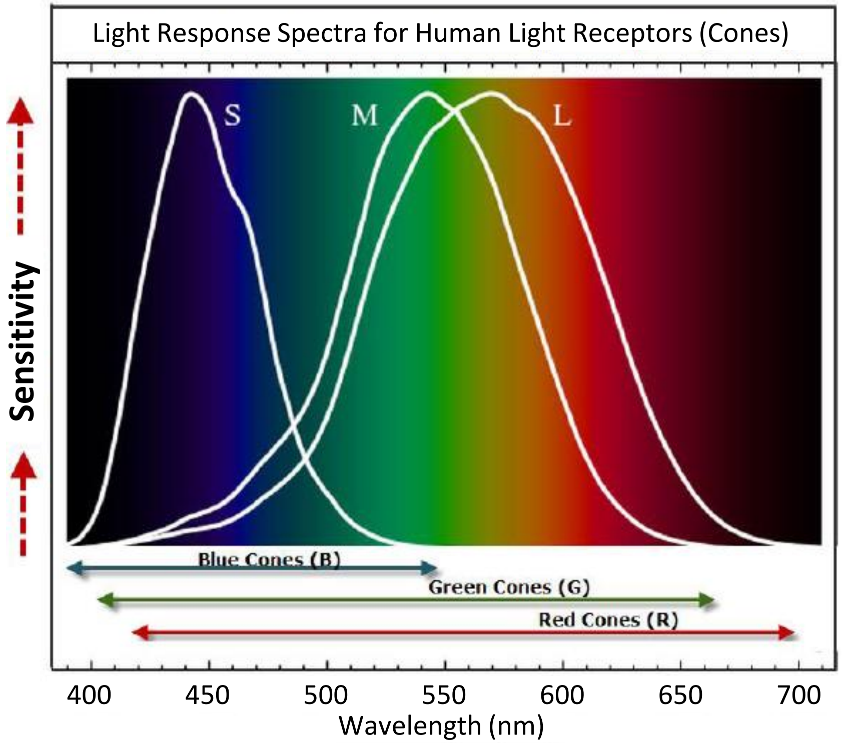
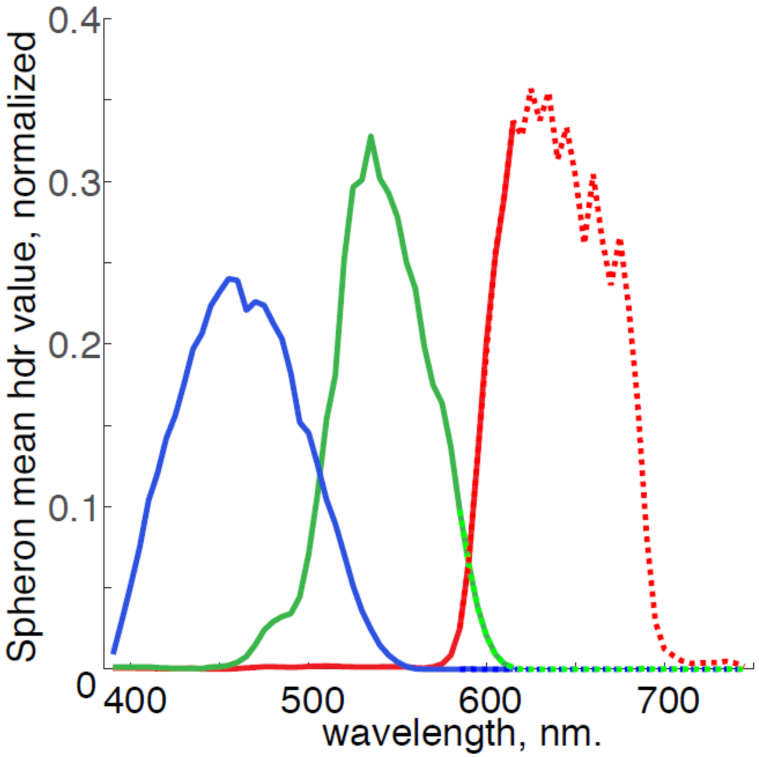


Figure: M. Brown

Perceived colour

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

Spheron SpheroCam HDR



Adams, et al. (2016), https://syns.soton.ac.uk/

Perceived colour

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

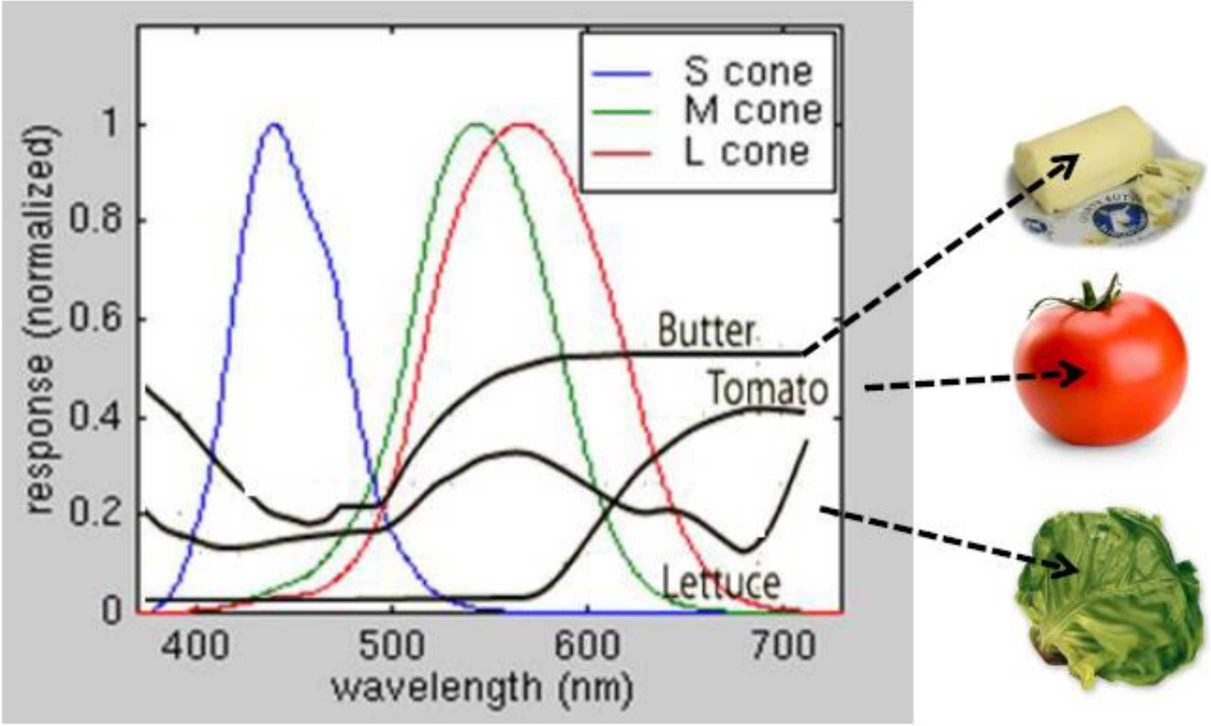


Figure: M. Brown

Perceived colour

- Result: many different spectra appear to be the same colour

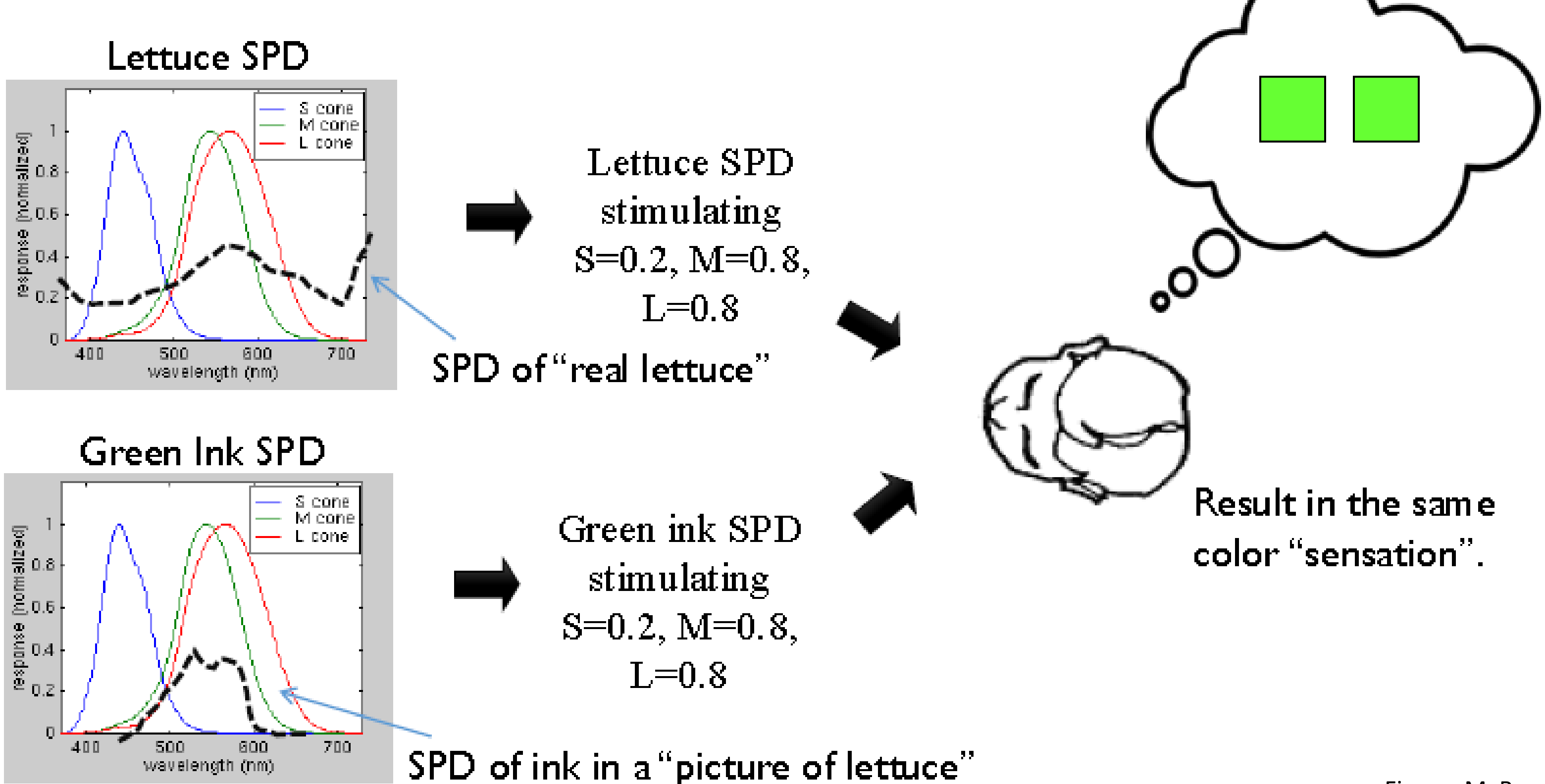


Figure: M. Brown

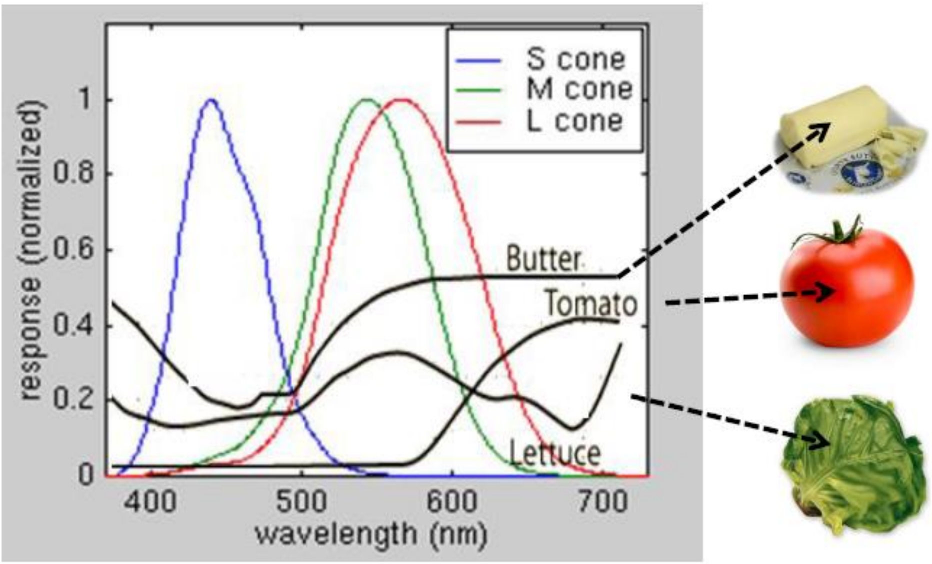
Trichromatic colour response

- Sensor response = sensitivity x spectrum, integrated over all wavelengths

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

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

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

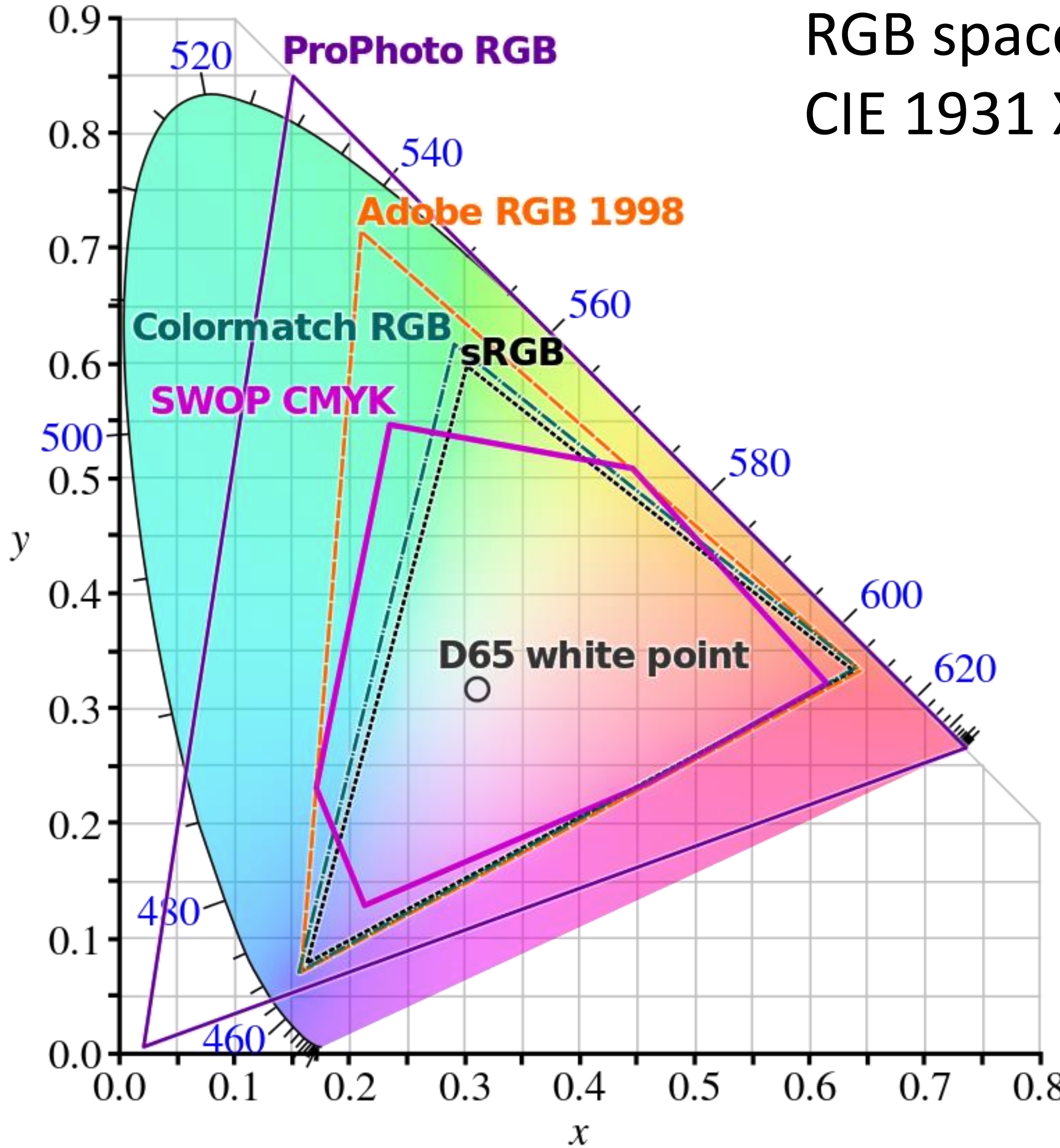


https://csci1230.graphics/demos/metamers/index.html

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

RGB spaces, plotted in CIE 1931 XYZ 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

$$I_D(x) = I_L R \mathbf{N}(x) \cdot \mathbf{L}$$

Intensity of reflected light

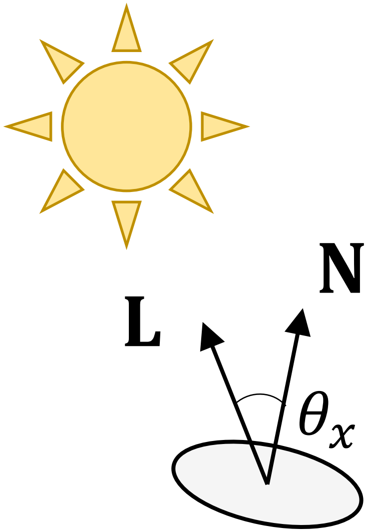
Surface's normal vector

Reflectance (Colour)

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

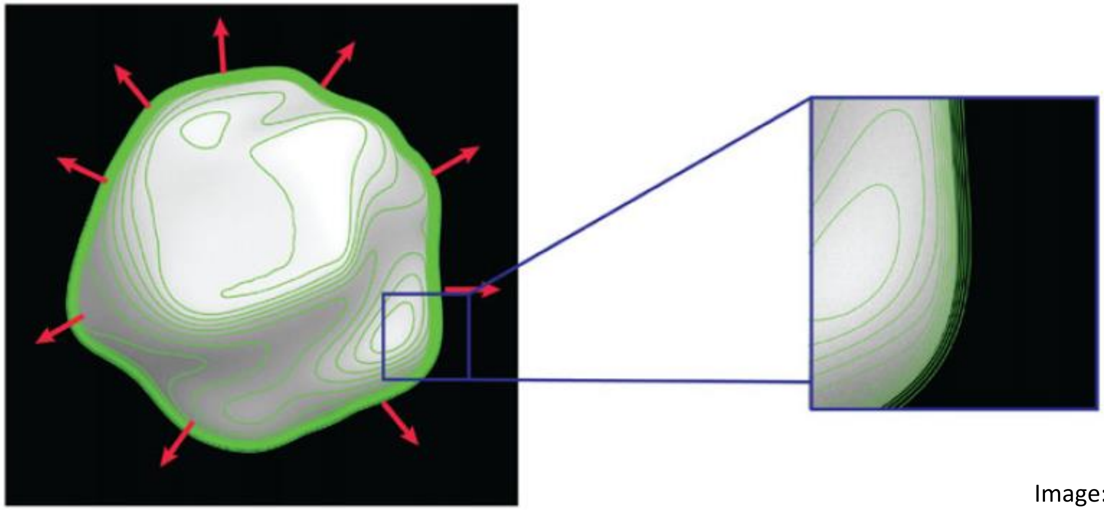


Image: Kunsberg, et al. (2018)

“Shape from shading”

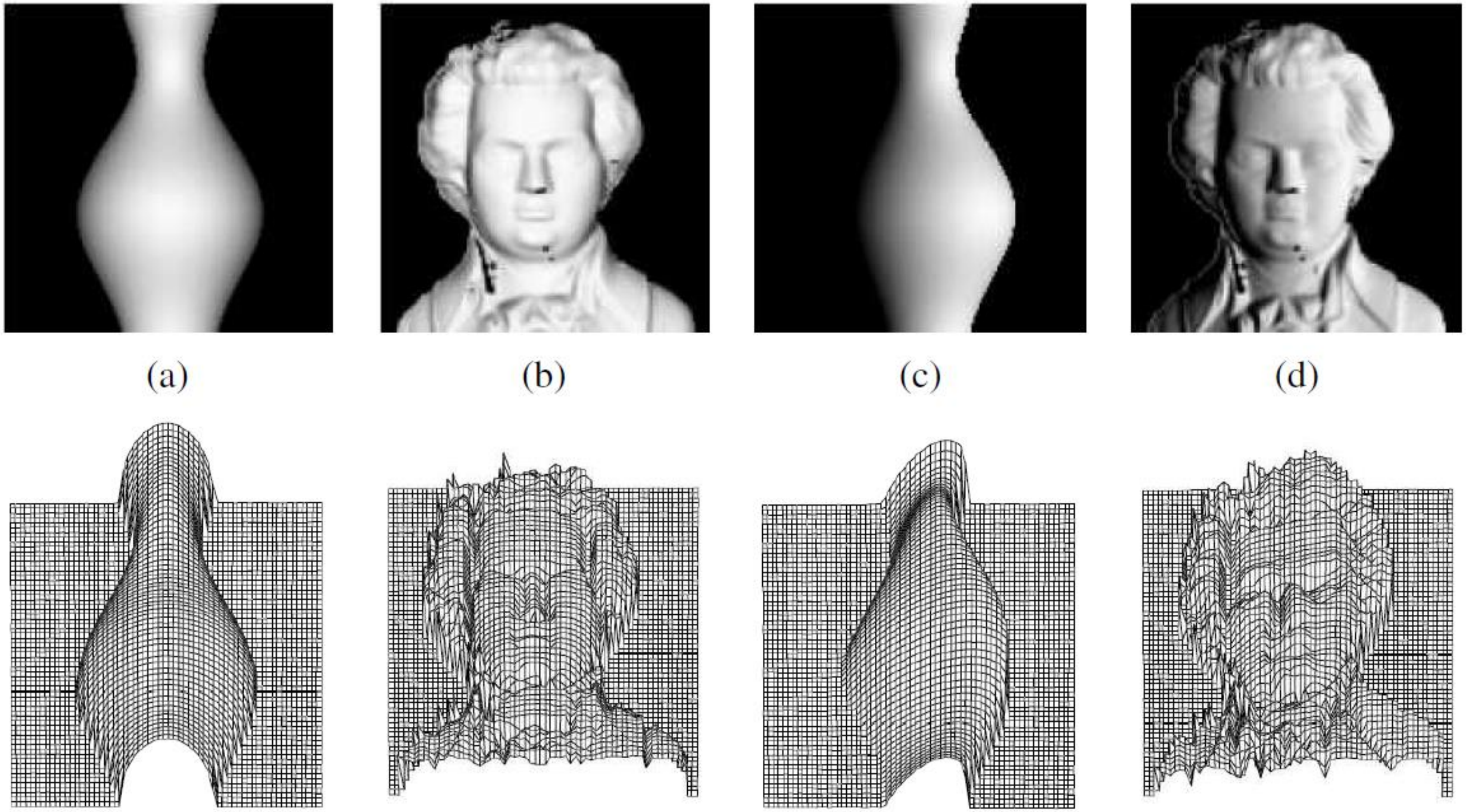


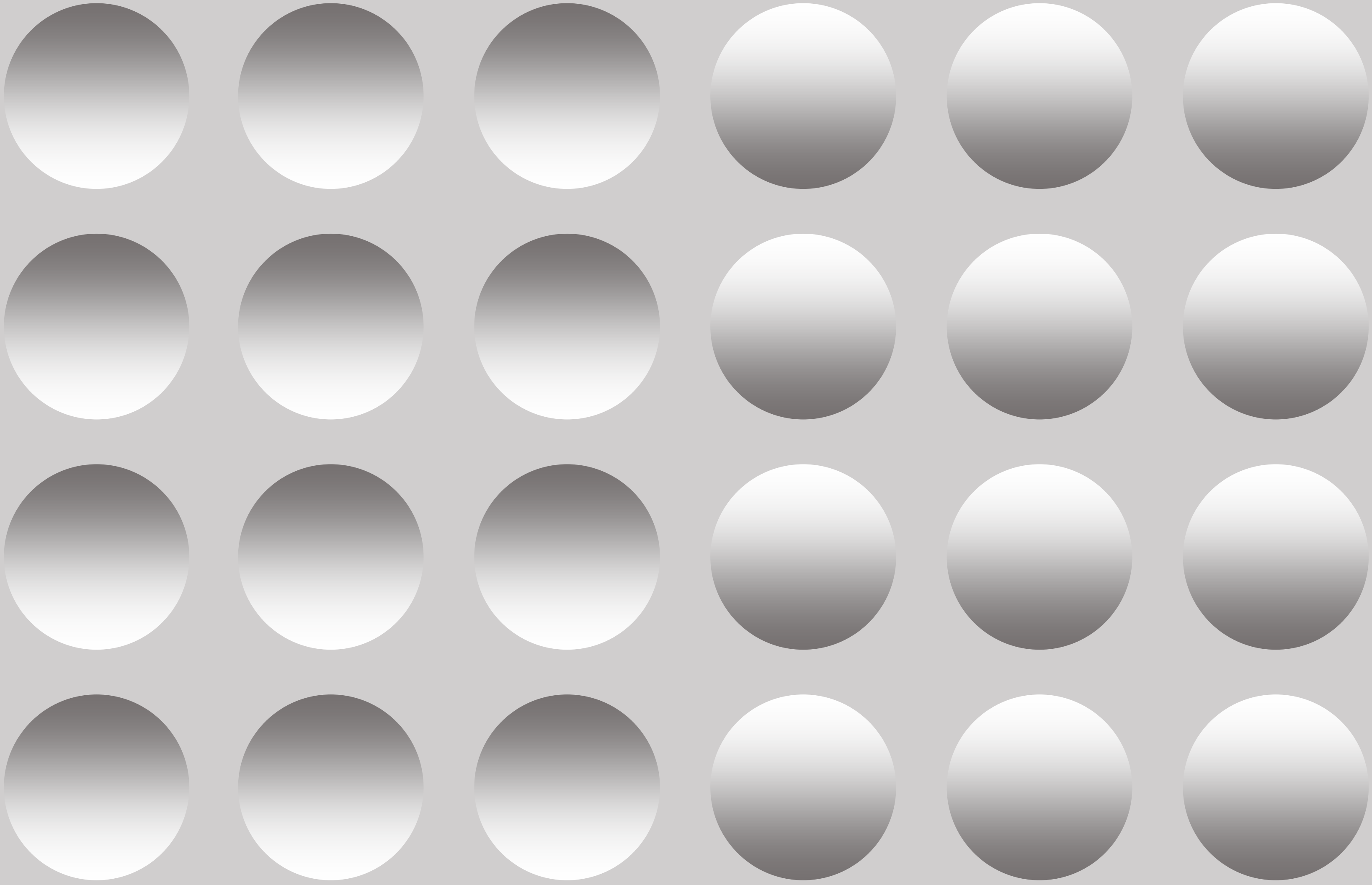
Image: R. Szeliski, *Computer Vision*, Figure 13.2

“Shape from shading”

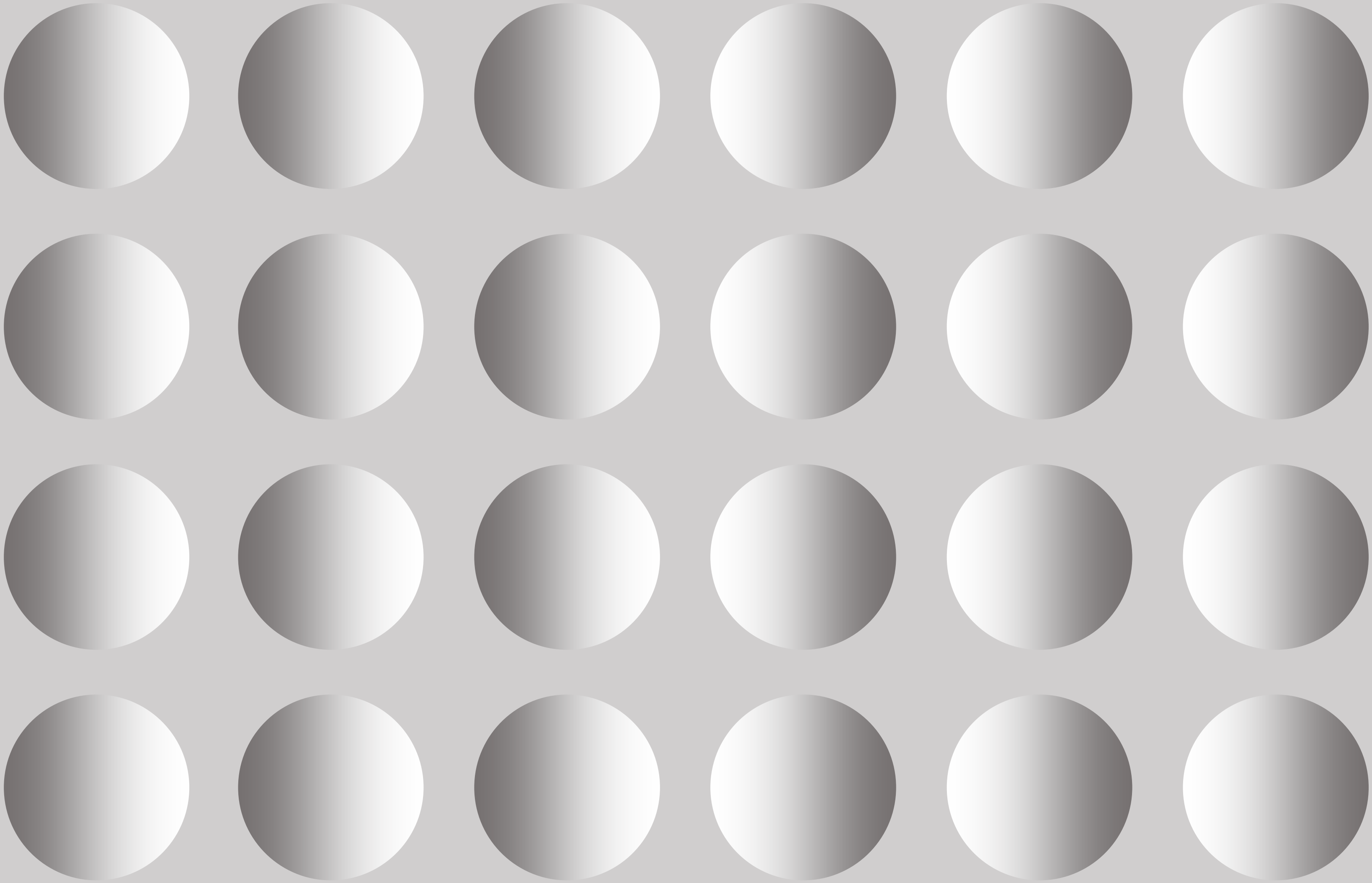
- Recover 3D shape from 2D image based only on surface brightness (shading)
- Requires additional assumptions, no algorithm works for all cases

- How does the human visual system do it?

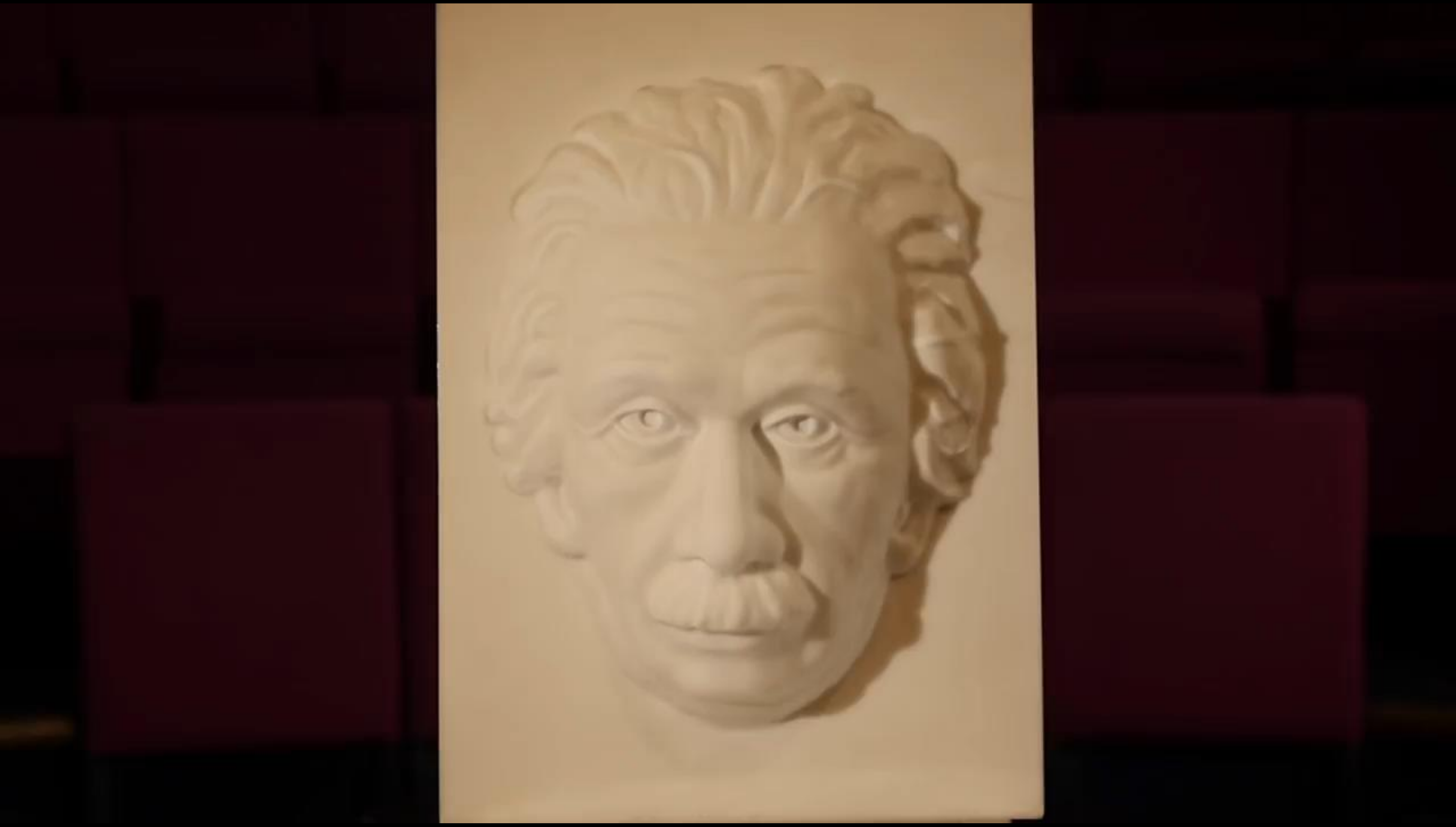
Lighting priors



Lighting priors



Shape priors



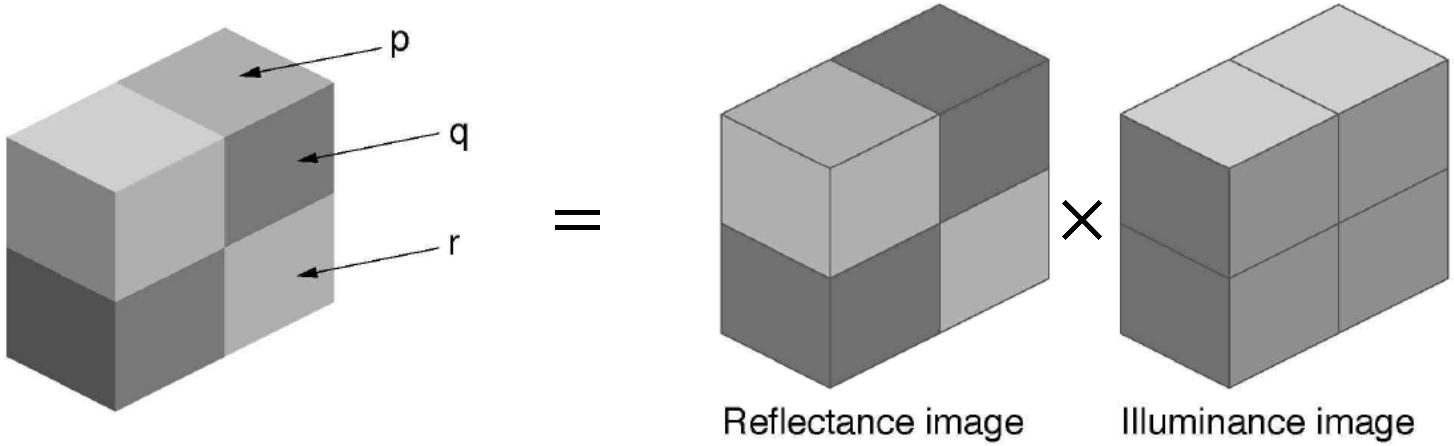
https://www.youtube.com/watch?v=pH9dAbPOR6M

"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



$$Luminance = Reflectance \times Illumination$$

Image: E. Adelson (2000)

Recovering surface reflectance

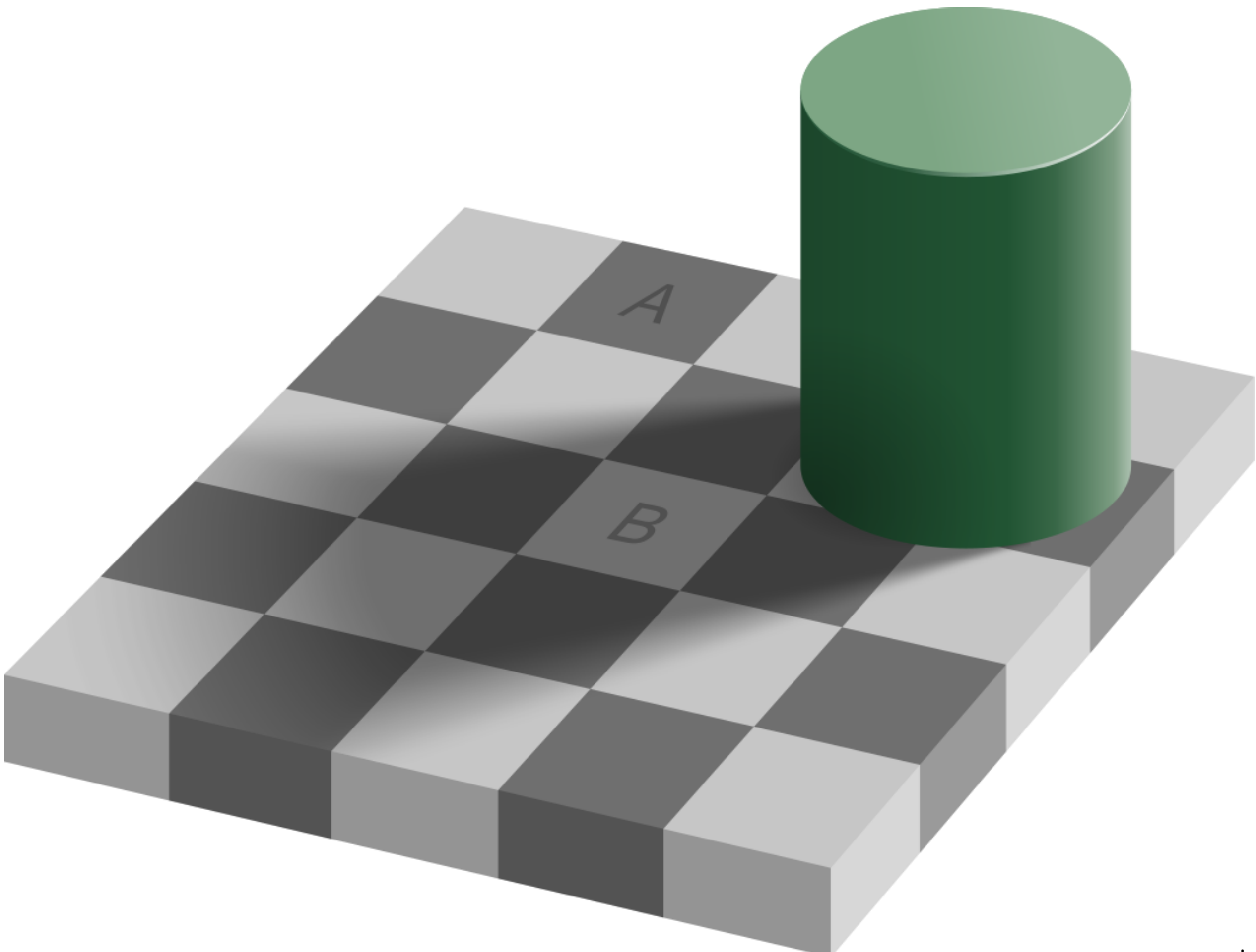


Image: E. Adelson

Global shape and context

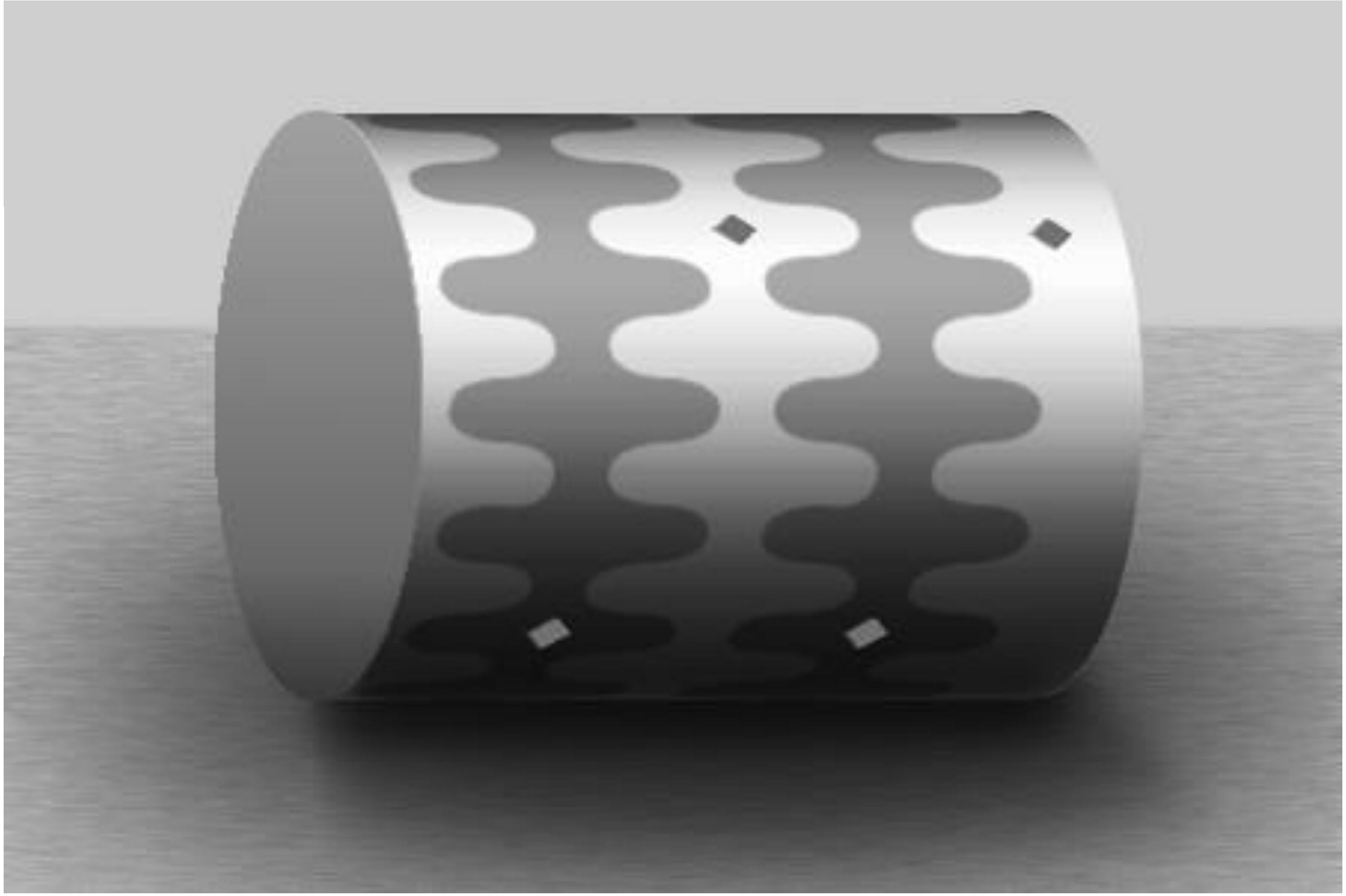


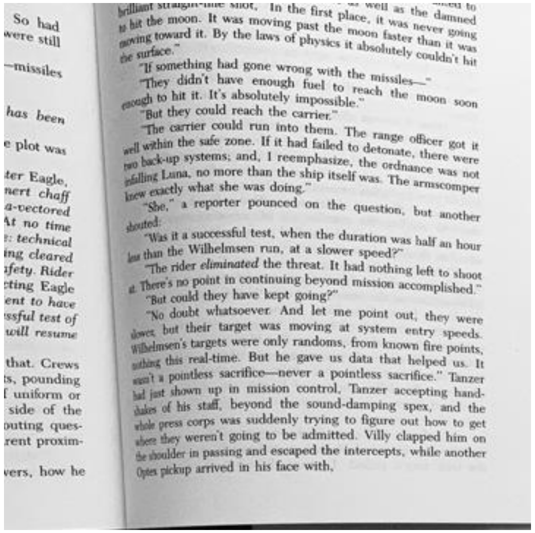
Image: E. Adelson

Reflectance from frequency

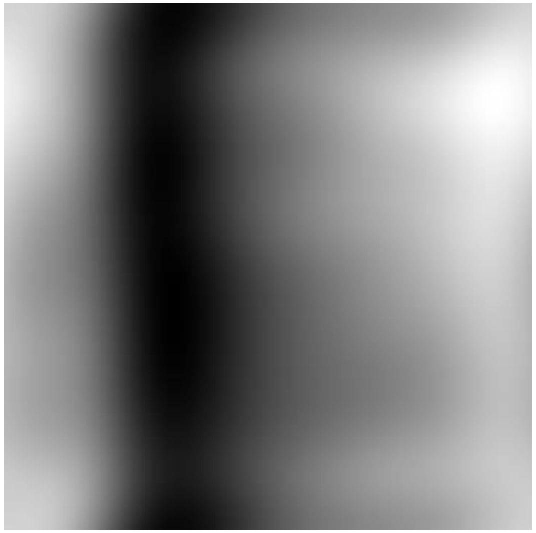
- Simple approach: assume illumination variation produces low-spatial-frequency changes in image, remove illumination in frequency domain
- $L = R \times I$
- $\ln(L) = \ln(R) + \ln(I)$
- $FT(\ln(L)) = FT(\ln(R)) + FT(\ln(I))$
- Apply a high-pass filter g in the frequency domain
- $Image = \ e^{FT^{-1}(g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

Reflectance from frequency

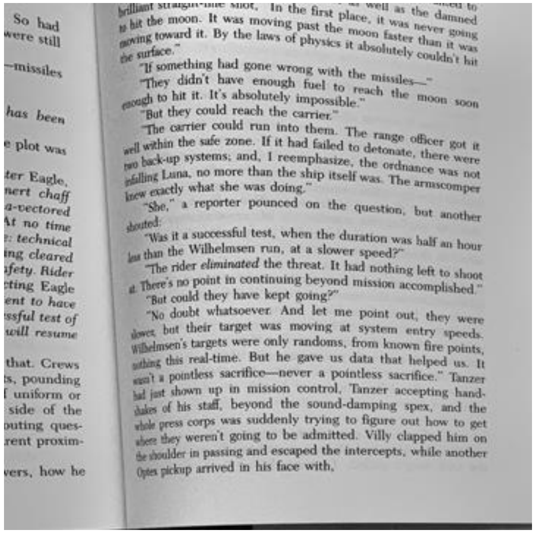
- Separating reflectance and illumination in the frequency domain:



Image



Illumination

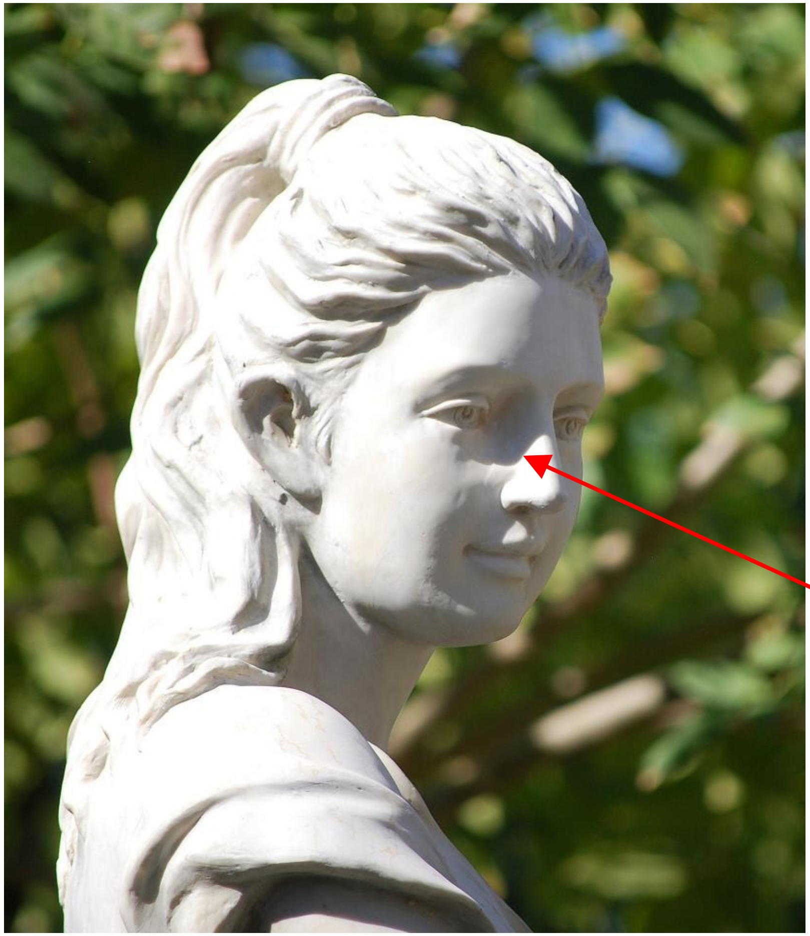


Reflectance

Recovering surface properties

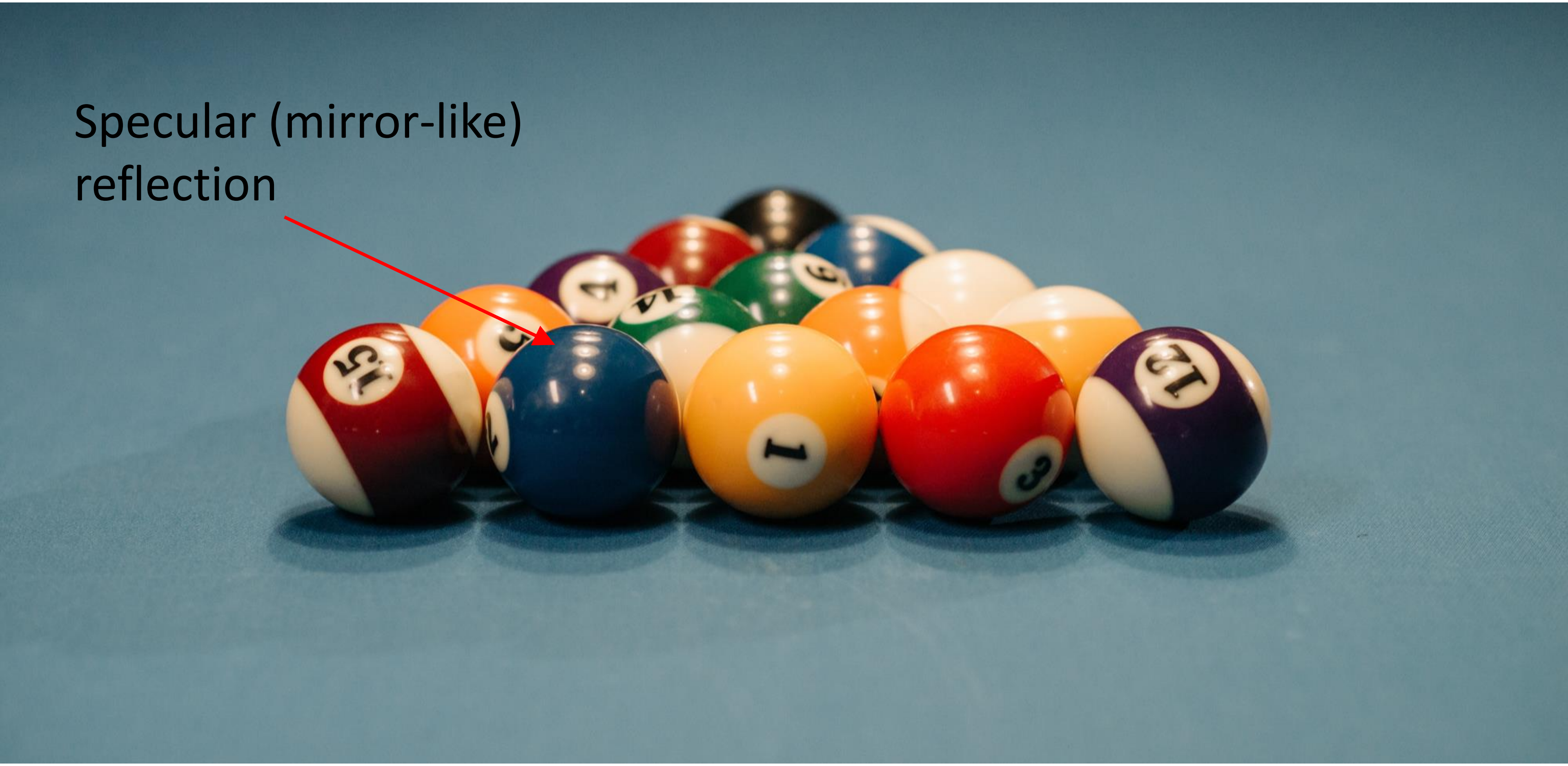
- Problems with the simple approach?
  - Some reflectance edges are smooth
  - Some lighting edges are not smooth (textures, corners)
- More sophisticated approaches (e.g., based on partial differential equations) can give better results but have similar problems
- Even more complicated in practice!
  - 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

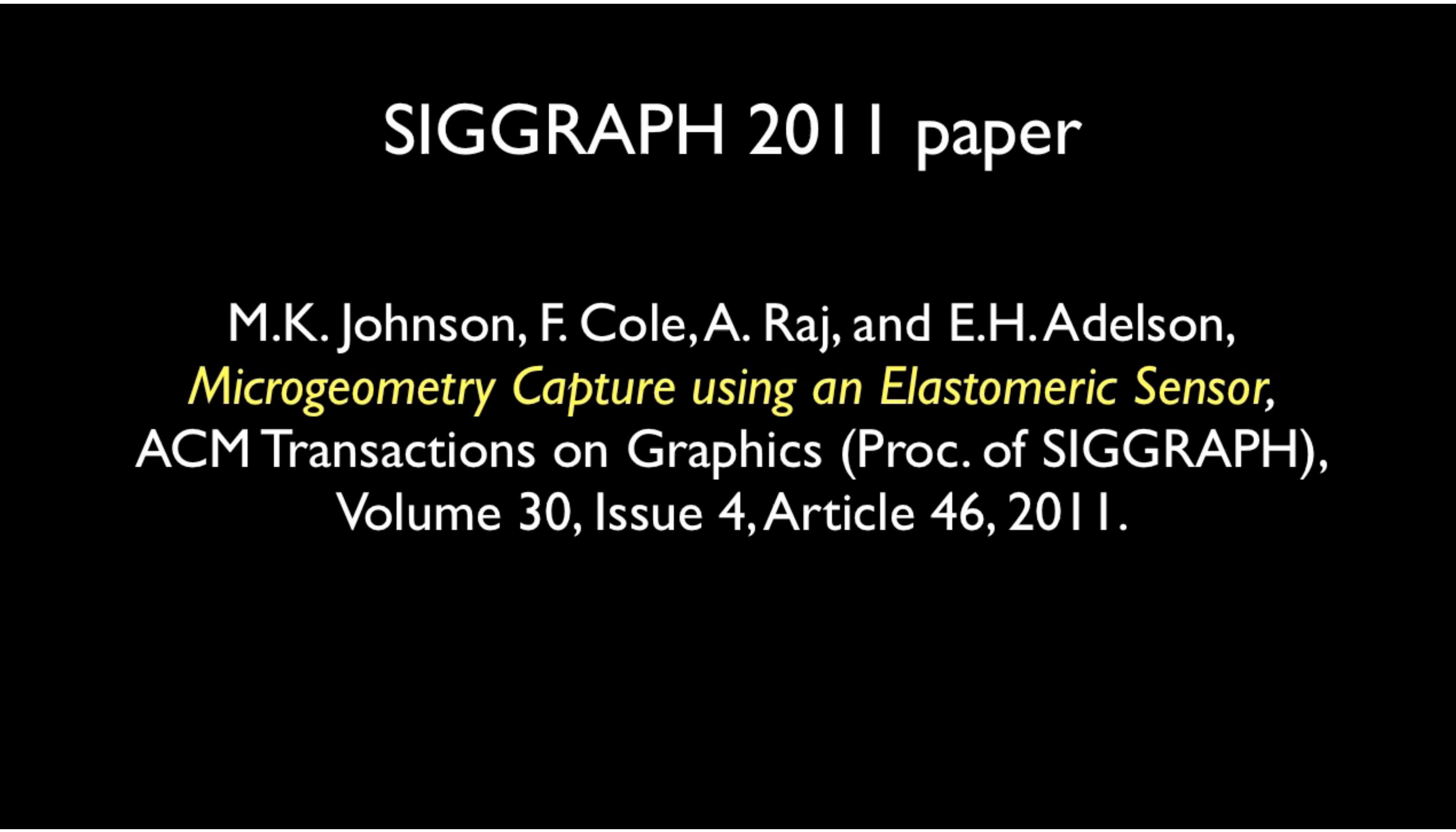
Transparent – light passes through surface

Translucent – light passes through but is scattered

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



Object

Camera view

Johnson & Adelson (2009)

https://www.youtube.com/watch?v=ste7l2OvVHs

Application: Using reflections

https://www.youtube.com/watch?v=bzsfREU2dDM

Summary

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