Light and Shading

EECS 442 – David Fouhey
Winter 2023, University of Michigan

http://web.eecs.umich.edu/~fouhey/teaching/EECS442_W23/
Administrivia

- HW1 Due in a Week
- Please sign up for Piazza
- Piazza highlights:
  - student answers (please pay it forward!)
  - general tone of discussion!
- One request: please don’t post screenshots of code. In many companies, screenshots support requests / emails get ignored or explicitly rejected. Why?
Thoughts on Homework

• Some self-study will be required for:
  • Reinforcing concepts
  • Learning libraries (there’s great documentation!)
  • Often “self-study” parts won’t be indicated

• Try first aid tips for debugging
  • Print \texttt{X.shape}, X.dtype, X when you’re stuck
  • \texttt{plt.imsave(“debug.png”)}
  • Read documentation

• This is a skill you need
Recap: Projection

\[ P = K[R, t]X \]

Image → Intrinsic → World

Extrinsic

Photo. Material

P

X
Recap: Lenses

Pinhole Model

Mathematically correct
Not quite correct in practice
Reasonable approximation

Reality: Lenses

Necessary in practice
Introduce complications
Complications fixable
Today

• A little bit about light and how you represent it
• A little bit about lighting and how it works
Your Very Own Camera

- Iris: Controls pupil
- Pupil: Aperture letting in light
- Lens: ...

Slide Credit: NIH
Your Very Own Camera

Where’s the film/CCD?

Slide Credit: NIH
Demo Time
What is Retina/Film Made Of?

Cross-section of eye

- Ganglion cell layer
- Bipolar cell layer
- Receptor layer
- Pigmented epithelium

Cross section of retina

- Ganglion axons
- Bipolar cell layer
- Receptor layer


Slide Credit: J. Hays
Two Type of Photo Receptors

**Cones**
- cone-shaped
- less sensitive
- operate in high light
- color vision

**Rods**
- rod-shaped
- highly sensitive
- operate at night
- gray-scale vision

Slide Credit: J. Hays
Rod / Cone Sensitivity

Dazzling light; bright sun on snow
Outdoors in full sunlight
Outdoors under a tree on a sunny day
Comfortable indoor illumination; night sports events
Threshold for perception of color; bright moonlight
Threshold when dark-adapted
Rod/Cone Distribution

(a) Left eye

(b) Diagram showing distribution of rods and cones with peaks at various angles relative to the fovea. The blindspot is indicated.

Diagram Credit: B. A. Wandell, *Foundations of Vision*
Electromagnetic Spectrum

Why do we see light in these wavelengths?

Slide Credit: J. Hays
The Physics of Light

A. Ruby Laser

B. Gallium Phospshide Crystal

C. Tungsten Lightbulb

D. Normal Daylight

Slide Credit and Copyright: S. Palmer
The Physics of Light

Red
Yellow
Blue
Purple

Slide Credit and Copyright: S. Palmer
The Physics of Light

Slide Credit and Copyright: S. Palmer
Red-Green Color Blindness

“Peaks” of these red/green cones shifted, making it hard to distinguish red and green

Four possibilities:
- **Deuteranomaly**: Green cone shifted toward red
- **Protanomaly**: Red cone shifted toward green
- **Deutanopia**: Green cone missing
- **Protanopia**: Red cone missing
Color Vision in Animals

Birds have 4 cone types: can see ultraviolet light

Some flowers have “Nectar Guides” in UV


Color Vision in Animals

Mantis Shrimp: Up to 16 types of photoreceptors! Can also detect polarization of light!

How Do We Get Light?
Artificial Cones

Estimate RGB at ‘G’ cells from neighboring values

Slide Credit: S. Seitz
Color Image

Combined

Red

Green

Blue

Slide Credit: J. Hays
Images in Python
Images in Python

Images are matrix / tensor `im`

`im[0,0,0]`
  top, left, red

`im[y,x,c]`
  row y, column x, channel c

`im[H-1,W-1,2]`
  bottom right blue

Slide inspired by James Hays
Images in Python

Images are matrix / tensor im
im[0,0,0]  
  top, left, red
im[y, x, c]  
  row y, column x, channel c
im[H-1, W-1, 2]  
  bottom right blue

Slide inspired by James Hays
5 Things To Always Remember

1. Origin is top left
2. Rows are first index (what’s the fastest direction for accessing?)
3. Usually referred to as Height x Width
4. Typically stored as uint8 [0,255]
5. for y in range(H): for x in range(W): will run 1 million times for a 1000x1000 image. A 4GHz processor can do only 4K clock cycles per pixel per second.
Representing Colored Light

Discussion time: how many numbers do you actually need for colored light? Assume all tuples (R,G,B) are legitimate colors (they are).

One Option: RGB

**Pros**
1. Simple
2. Common

**Cons**
1. Distances don’t make sense
2. Correlated

Another Option: HSV

**Pros**
1. Intuitive for picking colors
2. Sort of common
3. Fast to convert

**Cons**
1. Not as good as other better spaces

Slide Credit: J. Hays, HSV cylinder: https://en.wikipedia.org/wiki/HSL_and_HSV
HSV

Photo credit: J. Hays
Another Option: YCbCr/YUV

**Pros**
1. Great for transmission / compression

**Cons**
1. Not as good as other better smart color spaces

YCbCr

Photo credit: J. Hays
Another Option: Lab

Pro **s**
1. Distances correspond with human judgment
2. Safe

Con **s**
1. Complex to calculate (don’t write it yourself, lots of fp calculations)

Slide Credit: J. Hays, Lab diagram cube: https://en.wikipedia.org/wiki/CIELAB_color_space
Lab

Photo credit: J. Hays
Why Are There So Many?

• Each serves different functions
  • RGB: sort of intuitive, standard, everywhere
  • HSV: good for picking, fast to compute
  • YCbCr/YUV: fast to compute, compresses well
  • Lab: the right(?) thing to do, but “slow” to compute

• Pick based on what you need and don’t sweat it: color really isn’t crucial
Only Images

• Almost all of this class is about ordinary RGB images because this has driven a lot of applications
• However, there are lots of other images
Depthmap

2.3m
Surface Normals

Legend

- [0.06, 0.99, 0.12]

Room
Science Data

Magnetic Field in:
    \( x, \quad y, \quad z \)
via polarized light

Light at 9 \( \sim \) wavelengths:
9.4nm, 13.1nm, 17.1nm
19.3nm, 21.1nm, 30.4nm
33.5nm, 160nm, 170nm

NASA Solar Dynamics Observatory observing solar flare
Volumes

Volumes: images with more dimensions.

Emerge in 3D reconstruction, medical imaging, temporal data

From: Girdhar et al., *Learning a predictable and generative vector representation for objects*. ECCV 2016
Other Images

• A small part of computer vision in this class is really only for ordinary images
• The rest is easily generalized to other images
• Really transformative stuff will happen when good vision techniques get traction in other areas
So Far

How do we represent light and its storage on film?
Now

How does the scene cause that light?
Light and Surfaces

What happens when light hits a surface?
Light and Surfaces

What happens when light hits a surface?

1. Absorbed
   It’s absorbed and converted into some other form of energy (e.g., a black shirt getting hot in the sun)
Light and Surfaces

What happens when light hits a surface?

2. Transmitted
Possibly bouncing around before going through or out (e.g. lenses bend and go through, milk bounces around)
Light and Surfaces

What happens when light hits a surface?

3. Reflected
It’s reflected back, in one or more directions with varying amounts (e.g., mirror, or a white surface)
What happens when light hits a surface?

4. Everything
All of the above! Real surfaces often have combinations of all of these options.
Opaque Reflections
Bi-directional reflectance function: % reflected given incident angle to light reflected angle to the viewer.

Note: have not specified form of function.
Specular and Diffuse Reflection

Same lighting, as close as possible camera settings, but different location
Specular and Diffuse Reflection

Diffuse

Specular

Totally different

Basically same
Diffuse Reflection

Lambertian Surface

Light depends *only* on orientation of surface $\phi_i, \theta_i$ to light. Result of random small facets. Looks identical at all views.
Diffuse Reflection

Lambert’s Law

N: surface normal
S: source direction and strength
ρ: how much is reflected

\[ B = \rho N \cdot S \]

\[ B = \rho \|S\| \cos(\theta) \]
Specular Reflection

Specular Surface
Light reflected like a mirror, but spreads out in a “lobe” around the reflection ray
Specular Reflection

Phong Model

V: vector to viewer
R: reflection ray
α: shininess constant

\[ B = (V^T R)^\alpha \]
BRDFs can be incredibly complicated…

Slide Credit: L. Lazebnik
What Can This Be Used For

Shape from Shading

Lambert’s Law: for each $i$ of $K$ pixels,

$$B_i = \rho N_i \cdot S$$

- Reflected Light (1 dim)
- Surface Orientation (3? dim)
- Illumination Global (3 dim)

Given: illumination and light, recover normals

Potential problems?
Shape From Shading

\[ B_i = \rho N_i \cdot S \]

- System of K equations that’s underdetermined (K equations, 2K unknowns)
- \textbf{Solution}: Add more equations that enforce smoothness or finding a single surface.
Realistic Shape From Shading

\[ B_i = \rho N_i \cdot S \]

- System of equations that’s underdetermined (K equations, 2K+3 unknowns)
- **Solution**: need prior beliefs to disambiguate.
Ambiguity
Ambiguity

Humans assume light from above (and the blueness also tells you distance)
Shape from Shading in Practice

https://www.youtube.com/watch?v=4GiLAOtjHNo