CS4501: Introduction to Computer Vision

Human Vision and Image Processing

Various slides from previous courses by:
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Last Class

• Practical Advice on Photography
• Camera Parameters
• Brief Introduction to Projective Geometry (Computer Graphics)
• Introduction to Light (BRDF)
Phong Reflection Model

\( \hat{L}_m \), which is the direction vector from the point on the surface toward each light source (\( m \) specifies the light source),

\( \hat{N} \), which is the normal at this point on the surface,

\( \hat{R}_m \), which is the direction that a perfectly reflected ray of light would take from this point on the surface, and

\( \hat{V} \), which is the direction pointing towards the viewer (such as a virtual camera).

\[
I_p = k_a i_a + \sum_{m \in \text{lights}} (k_d (\hat{L}_m \cdot \hat{N}) i_{m,d} + k_s (\hat{R}_m \cdot \hat{V})^\alpha i_{m,s}).
\]
Phong Reflection Model

- The BRDF of many surfaces can be approximated by the Lambertian + Specular Model.
Our own Camera as a species:
The Human Eye
Vicente’s eye
• The human eye is sort of a camera!
  • **Iris** - colored annulus with radial muscles
  • **Pupil** - the hole (aperture) whose size is controlled by the iris
  • What’s the “film”?
    – photoreceptor cells (rods and cones) in the **retina**
Retina

ganglion cell

bipolar cell

retinal artery

cone

rod

retinal pigment epithelium (RPE)

https://www.findlight.net/blog/2018/03/16/artificial-photoreceptors/
More about the eye

https://www.youtube.com/watch?v=L_W-IXqoxHA
Two types of light-sensitive receptors

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

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

Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm
The human eye is sort of a camera!

- **Iris** - colored annulus with radial muscles
- **Pupil** - the hole (aperture) whose size is controlled by the iris
- What’s the “film”?
  - photoreceptor cells (rods and cones) in the **retina**
Eye Evolution

pigment spot (limpet, *Patella*)
- photoreceptor layer (pigment cells and nerve cells)
- nerve fibres
- epithelium

pigment cup (slit-shell mollusk, *Pleurotomaria*)
- photoreceptor layer
- nerve fibres
- epithelium

simple optic cup ("pinhole-lens" eye; *Nautilus*)
- epithelium
- water-filled cavity
- photoreceptor layer (retina)
- optic nerve

eye with primitive lens (Murex, a marine snail)
- epithelium
- refractive lens
- retina
- optic nerve
- cornea

Complex eye (octopus)
- refractive lens
- iris
- cornea
- retina
- optic nerve
- vitreous body

What the Frog’s Eye Tells the Frog’s Brain*

J. Y. LETTVIN†, H. R. MATURANA‡, W. S. McCulloch‖, Senior Member, IRE, and W. H. Pitts‖
Hubel and Wiesel

https://www.youtube.com/watch?v=I0Hayh06LJ4

Image Processing & Image Filtering
Reminder of what is an image for a computer.
Images as Functions

\[ z = f(x, y) \]
Images as Functions

\[ z = f(x, y) \]

- The domain of \( x \) and \( y \) is \([0, \text{img-width})\) and \([0, \text{img-height})\).
- \( x \) and \( y \) are discretized into integer values.
Images as Matrices

```
0 3 2 5 4 7 6 9 8
3 0 1 2 3 4 5 6 7
2 1 0 3 2 5 4 7 6
5 2 3 0 1 2 3 4 5
4 3 2 1 0 3 2 5 4
7 4 5 2 3 0 1 2 3
6 5 4 3 2 1 0 3 2
9 6 7 4 5 2 3 0 1
8 7 6 5 4 3 2 1 0
```
Color Images as Tensors

channel x height x width
Basic Image Processing

\[ I \quad \alpha I \]

\( \alpha > 1 \)
Basic Image Processing

I

\[ \alpha I \]

0 < \alpha < 1
Color Images as Tensors

channels x height x width

Channels are usually RGB: Red, Green, and Blue

Other color spaces: HSV, HSL, LUV, XYZ, Lab, CMYK, etc
Some drawbacks

- Strongly correlated channels
- Non-perceptual

Default color space
Color spaces: HSV

Intuitive color space

H
(S=1,V=1)

S
(H=1,V=1)

V
(H=1,S=0)
Color spaces: L*a*b*

“Perceptually uniform”* color space

Slide by James Hays
Most information in intensity

Only color shown – constant intensity
Most information in intensity

Only intensity shown – constant color
Most information in intensity
Image filtering
Image filtering

Image filtering

Image filtering: e.g. Mean Filter
Image filtering: e.g. Mean Filter
Image filtering: e.g. Median Filter

Image filtering: Convolution operator

\[ g(x, y) = \sum_{v} \sum_{u} k(u, v)f(x - u, y - v) \]

(filter, kernel)

Input image * Weights \rightarrow Output image

```
4 5 7 6 6
3 2 8 0 7
6 7 7 1 5
3 0 1 1 1
4 3 2 1 7
```

```
0 0 0
1 0 1
0 0 0
```

```
11 2 15
13 8 12
```

```
4
```

http://www.cs.virginia.edu/~vicente/recognitionanimation.gif
Image filtering: Convolution operator

e.g. mean filter

\[ k(x, y) = \begin{bmatrix} 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \end{bmatrix} \]

Image filtering: Convolution operator e.g. mean filter

\[ k(x, y) = \begin{bmatrix} 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \end{bmatrix} \]

Image filtering: e.g. Mean Filter
Image filtering: Convolution operator
e.g. gaussian filter (gaussian blur)

\[ k(x, y) = \begin{bmatrix}
\frac{1}{16} & \frac{1}{8} & \frac{1}{16} \\
\frac{1}{8} & \frac{1}{4} & \frac{1}{8} \\
\frac{1}{16} & \frac{1}{8} & \frac{1}{16}
\end{bmatrix} \]

Image filtering: Convolution operator e.g. gaussian filter (gaussian blur)

Image filtering: Convolution operator
e.g. sobel operator

Next Class: More on Image Filters
Questions?