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
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 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**
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

La Gare Montparnasse, 1895

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Color Images as Tensors

channel x height x width
Basic Image Processing

$I$

$\alpha I$

$\alpha > 1$
Basic Image Processing

\[ I \quad \alpha I \]

\[ 0 < \alpha < 1 \]
Color Images as Tensors

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
- R (G=0, B=0)
- G (R=0, B=0)
- B (R=0, G=0)

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

$L (a=0, b=0)$

$-a$ (L=65, b=0)

$b$ (L=65, a=0)

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

Original image
Image filtering
Image filtering

Image filtering

Input image \( f(x,y) \)

Output image \( g(x,y) \)

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 → Output image

http://www.cs.virginia.edu/~vicente/recognition/animation.gif
Image filtering: Convolution operator
e.g. mean filter

\[ k(x, y) = \begin{bmatrix}
\frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\
\frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\
\frac{1}{9} & \frac{1}{9} & \frac{1}{9}
\end{bmatrix} \]
Image filtering: Convolution operator
e.g. mean filter

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

Image filtering: e.g. Mean Filter
Image filtering: Convolution operator

e.g. gaussian filter (gaussian blur)

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

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

Image filtering: Convolution operator
e.g. sobel operator

\[ k(x, y) = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} \]

Next Class: More on Image Filters
Questions?