CS4501: Introduction to Computer Vision
Light and Image Processing

Various slides from previous courses by:
D.A. Forsyth (Berkeley / UIUC), I. Kokkinos (Ecole Centrale / UCL), S. Lazebnik (UNC / UIUC), S. Seitz (MSR / Facebook), J. Hays (Brown / Georgia Tech), A. Berg (Stony Brook / UNC), D. Samaras (Stony Brook). J. M. Frahm (UNC), V. Ordonez (UVA).
Last Class

• Practical Advice on Photography
• Camera Parameters
• Brief Introduction to Projective Geometry (Computer Graphics)
• Intro to Light (BRDF)
About the Course

CS4501-008: Introduction to Computer Vision

• Instructor: Vicente Ordonez
• Email: vicente@virginia.edu
• Website: http://vicenteordonez.com/vision/
• Class Location: Thornton Hall E316
• Class Times: Monday-Wednesday 2pm - 3:15pm
• Piazza: http://piazza.com/virginia/spring2018/cs4501008/home
Teaching Assistants + Office Hours

**Fengyang Zhang**
Tuesday 3pm to 4pm (Rice 340)
Thursday 3pm to 4pm (Rice 340)

**Gautam Somappa**
Monday 4pm to 5pm (Rice 436)
Tuesday 2pm to 3pm (Rice 436)

**Siva Sivaraman**
Wednesday 3:30 to 4:30pm (Rice 436)
Thursday 2pm to 3pm (Rice 340)
Things to Remember for Quiz

- Pinhole camera model
- Focal length in the pinhole camera model
- Shutter Time / Aperture / ISO
- Homogeneous Coordinates
- Extrinsic Camera Properties and Intrinsic Camera Properties
- Describe mathematically (and intuitively) the conversion process from World Coordinates to Image Coordinates (Should be easy after completing the first programming assignment)
Light

- What determines the color of a pixel?
BRDF (Bidirectional reflectance distribution function)

\[ E_{\text{surface}}(\theta_i, \phi_i) \]  Irradiance at Surface in direction \((\theta_i, \phi_i)\)

\[ L_{\text{surface}}(\theta_r, \phi_r) \]  Radiance of Surface in direction \((\theta_r, \phi_r)\)

\[ E_{\text{surface}}(\theta_i, \phi_i) \sim \cos \theta_i \ L_{\text{surface}}(\theta_i, \phi_i) \]
BRDF (Bidirectional reflectance distribution function)

E_{surface}^{\theta_i, \phi_i} \quad \text{Irradiance at Surface in direction } \left( \theta_i, \phi_i \right)

L_{surface}^{\theta_r, \phi_r} \quad \text{Radiance of Surface in direction } \left( \theta_r, \phi_r \right)

\text{BRDF} : f(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{L_{surface}^{\theta_r, \phi_r}}{E_{surface}^{\theta_i, \phi_i}}
Reflection

- **Body Reflection:**
  - Diffuse Reflection
  - Matte Appearance
  - Non-Homogeneous Medium
  - Clay, paper, etc.

- **Surface Reflection:**
  - Specular Reflection
  - Glossy Appearance
  - Highlights
  - Dominant for Metals

Image Intensity = Body Reflection + Surface Reflection
Reflection

Body Reflection:

**Diffuse Reflection**
Matte Appearance
Non-Homogeneous Medium
Clay, paper, etc

Surface Reflection:

**Specular Reflection**
Glossy Appearance
Highlights
Dominant for Metals

Many materials exhibit both Reflections:
Diffuse Reflection – Lambertian Surface / BRDF

- Only body reflection, and no specular reflection
- BRDF is independent of outgoing direction
- BRDF depends on indent direction (foreshortening)

- Light intensity does not depend on the outgoing direction. Only incoming.
- It is independent of where the viewer stands.
- Smooth surface, not glossy. Can think of any examples?

Slide by Aaron Bobick
CAN'T perceive the shape of the snow covered terrain!

CAN perceive shape in regions lit by the street lamp!!

WHY?
The other extreme – Only Specular Reflection

How about a mirror?

Reflection ONLY at mirror angle

https://wonderopolis.org/wonder/how-do-mirrors-work
Problem in Computer Vision: Intrinsic Image Decomposition

Given this

Extract this

Images by Marc Serra
Problem in Computer Vision: Shape from Shading
Same ideas used in Computer Graphics

• Ray Tracing
• Radiosity
• Photon Mapping
Phong Reflection Model

- The BRDF of many surfaces can be approximated by the Lambertian + Specular Model.
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 - Recap

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

Phong Reflection Model - Recap

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Phong’s Shading / Illumination Model

• Originally from Vietnam / PhD from Utah, Professor at Utah, and later Stanford.

• Died at age 32 from leukemia

• Phong’s professor Ivan Sutherland went on to win the Turing Award (Nobel Prize in CS) for lifelong contributions to Computer Graphics
A photon’s life choices

• Absorption
• Diffusion
• Reflection
• Transparency
• Refraction
• Fluorescence
• Subsurface scattering
• Phosphorescence
• Interreflection
A photon’s life choices

- **Absorption**
- Diffusion
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• **Diffuse Reflection**
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Slide by James Hays
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- **Interreflection**
Our own Camera as a species:  
The Human Eye
Vicente’s eye
The human eye is 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**
The Retina

Cross-section of eye

Ganglion axons
Ganglion cell layer
Bipolar cell layer
Receptor layer

Cross section of retina

Pigmented epithelium

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
More about the eye

https://www.youtube.com/watch?v=L_W-lXqoxHA
What you need to know for a Quiz

- Describe the various factors that modify object’s lighting
  - Camera position (viewer position)
  - Light positions
  - Object shape (surface normals) and material properties (BRDF)

- Understanding the effect of the following:
  - Ambient Light
  - Diffuse Light
  - Specular Light
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 \([0 \text{ and } \text{img-height})\).
- \( x \), and \( y \) are discretized into integer values.
Images as Matrices

La Gare Montparnasse, 1895

\[
\begin{bmatrix}
0 & 3 & 2 & 5 & 4 & 7 & 6 & 9 & 8 \\
3 & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
2 & 1 & 0 & 3 & 2 & 5 & 4 & 7 & 6 \\
5 & 2 & 3 & 0 & 1 & 2 & 3 & 4 & 5 \\
4 & 3 & 2 & 1 & 0 & 3 & 2 & 5 & 4 \\
7 & 4 & 5 & 2 & 3 & 0 & 1 & 2 & 3 \\
6 & 5 & 4 & 3 & 2 & 1 & 0 & 3 & 2 \\
9 & 6 & 7 & 4 & 5 & 2 & 3 & 0 & 1 \\
8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\end{bmatrix}
\]
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 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)

Slide by James Hays
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

Original image
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

\[ g(x, y) = \sum_u \sum_v k(u, v) f(x - u, y - v) \]

(filter, kernel)

Input image * Weights → Output image

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

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

Image filtering: 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: 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

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

A color picture of a steam engine

The Sobel operator applied to that image
Next Class: More on Image Filters
Questions?