Deep Learning for Computer Vision

Image Formation

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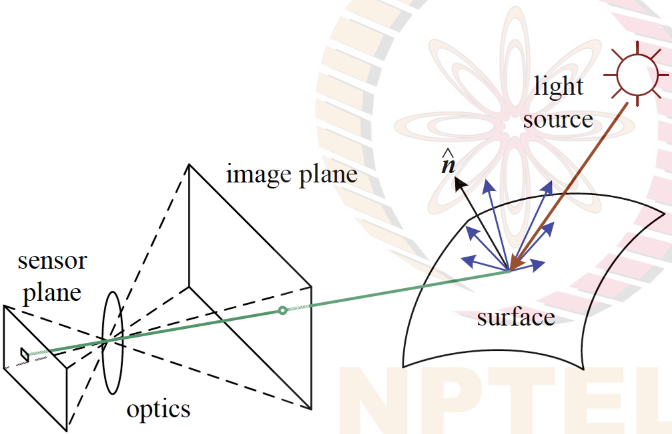
Image Formation: An Overview[1]



Factors

- Light source strength and direction
- Surface geometry, material and nearby surfaces
- Sensor capture properties
- Image representation and colour

[1]Credit: Szeliski, *Computer Vision: Algorithms and Applications*, 2010

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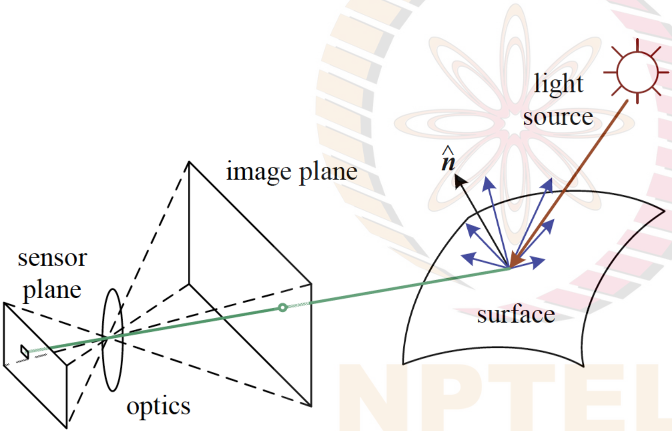

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Related Topics

- **Geometry**: 2D Transformations, 3D Transformations, Camera Calibration, Distortion
- **Photometry**: Lighting, Reflectance and Shading, Optics
- **Colour**: Physics of Colour, Human Colour, Colour Representation
- **Sensor**: Human Perception, Camera Design, Sampling and Aliasing, Compression

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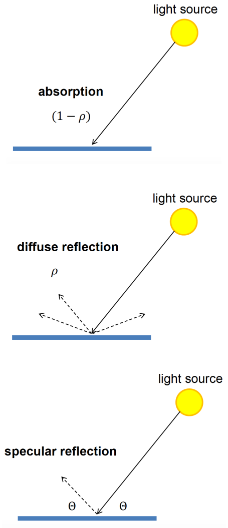
We will cover a few relevant topics from these

For a detailed understanding, read Chapters 1-5 of the book, *Computer Vision: A Modern Approach* by Forsyth and Ponce

Models of Reflection

When light hits a surface:

- Some light is absorbed ($1 - \rho$, $\rho =$ albedo);
  - More absorbed for low albedos
- Some light is reflected diffusively, independent of viewing direction
  - E.g.: Brick, cloth, rough wood
  - **Lambert's cosine law:** Amount of reflected light proportional to $\cos(\theta)$
- Some light is reflected specularly, depends on viewing direction
  - E.g.: Mirror



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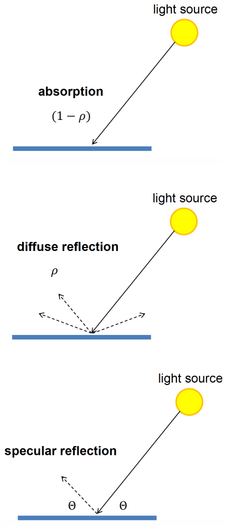

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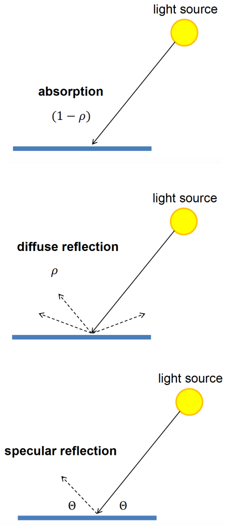


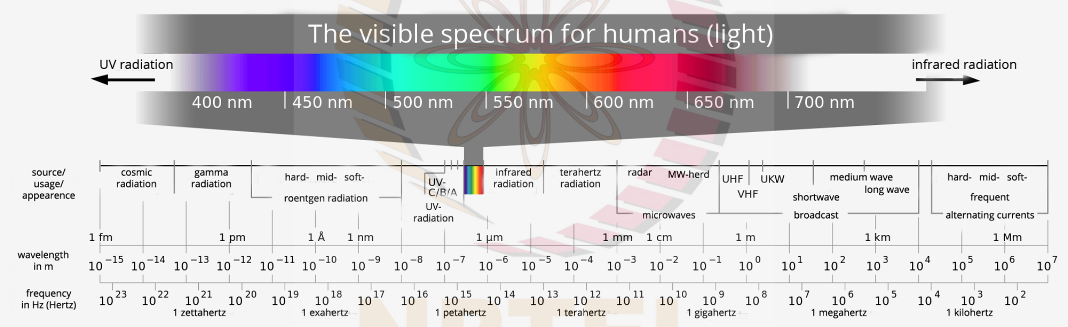
Credit: Derek Hoiem, UIUC

Models of Reflection

- Most surfaces have both specular and diffuse components
- Intensity depends on illumination angle because less light comes in at oblique angles
- Other possible effects:
  - Transparency
  - Refraction
  - Subsurface scattering
  - Fluorescence, phosphorescence
- BRDF - Bidirectional Reflectance Distribution Function: Model of local reflection that tells how bright a surface appears when viewed from one direction when light falls on it from another

Credit: Derek Hoiem, UIUC

Light is composed of a spectrum of wavelengths

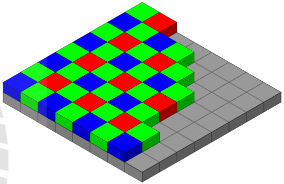


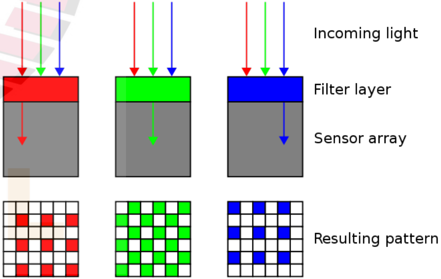
Coloured light arriving at sensor involves: (i) Colour of light source; (ii) Colour of surface

Credit: Electromagnetic spectrum by Horst Frank, Jailbird and Phrood. Under CC 3.0 License

Bayer Grid/Filter

- Bayer arrangement of color filters on a camera sensor
- Filter pattern is 50% green, 25% red and 25% blue
- To obtain full-colour image, **demosaicing** algorithms used - surrounding pixels used to estimate values for a particular pixel.





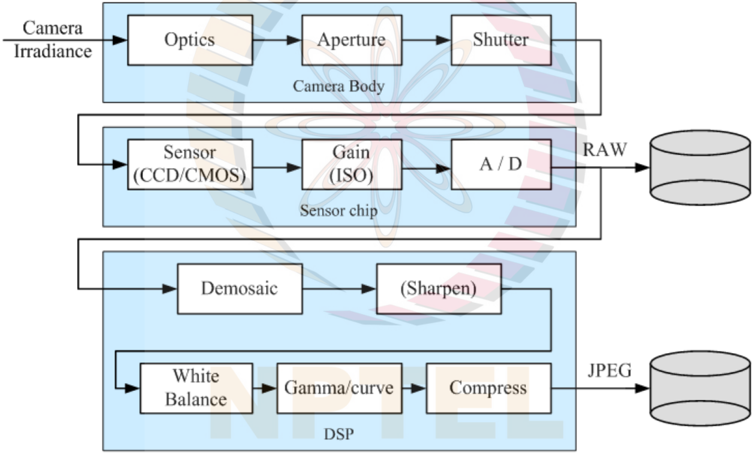
Credit: https://en.wikipedia.org/wiki/Bayer_filter

Question

On Colour

If visible light spectrum is VIBGYOR, why RGB colour representation?

Image Sensing Pipeline[2]



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Digital Image Sensing

CCD vs CMOS: What's the difference?

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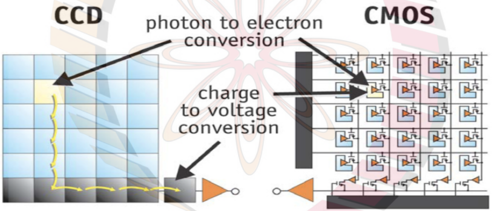
CCD vs CMOS: What's the difference?



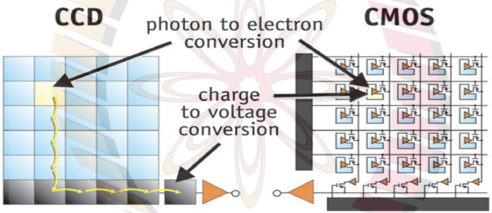
CCD

- Move photogenerated charge from pixel to pixel, and convert it to voltage at output node
- An analog-to-digital converter (ADC) then turns each pixel's value into a digital value

Photo Credit: Litwiller, *CMOS vs. CCD: Maturing Technologies, Maturing Markets*, 2005

Digital Image Sensing

CCD vs CMOS: What's the difference?



CMOS

- CMOS convert charge to voltage inside each element
- Uses several transistors at each pixel to amplify and move the charge using more traditional wires
- CMOS signal is digital, so it needs no ADC

Digital Image Sensor Properties

Shutter speed:	Controls the amount of light reaching the sensor (also called *exposure time*)
Sampling pitch:	Physical spacing between adjacent sensor cells on the imaging chip
Fill factor:	Active sensing area size as a fraction of the theoretically available sensing area (product of horizontal and vertical sampling pitches)
Chip size:	Size/area of the chip
Analog gain:	Amplification of the sensed signal using automatic gain control (AGC) logic (controlled using ISO setting on cameras)
Sensor noise:	Noise from various sources in the sensing process
Resolution:	How many bits for each pixel, decided by analog-to-digital conversion module
Post-processing:	Digital image enhancement methods often used before compression and storage of captured image

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Popular Question: *"With smartphones, do you need DSLR cameras?"*[3]

[3]Source: VSBytes.com

Popular Question: *"With smartphones, do you need DSLR cameras?"*[3]

- **DSLR - Digital Single Lens Reflex camera:** Uses a mirror mechanism to reflect light from lens to a viewfinder, or let light fully pass onto image sensor by moving the mirror out of the way
- Essentially a comparison between mirror and mirrorless cameras
- *Pros of mirrorless cameras:* Accessibility, portability, Low cost
- *Pros of DSLRs:* Picture quality, Versatility and functionality, Physical shutter, Variable focal length/aperture

Credit: http://www.pixelrajeev.com/

[3]Source: VSBytes.com

Sampling and Aliasing

Credit: Wikimedia Commons

- **Shannon's Sampling Theorem:** $f_s \geq 2f_{\text{max}}$, where f_s is sampling rate, and f_{max} is maximum frequency in signal, also called **Nyquist frequency**
- Frequencies above Nyquist frequency or when Shannon's sampling rate is not met $\implies$ *aliasing* happens

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- Why is aliasing bad?

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- Frequencies above Nyquist frequency or when Shannon's sampling rate is not met $\implies$ *aliasing* happens
- Why is aliasing bad? Creates issues while downsampling and upsampling an image
- More coming in later lectures

Colour Space Representations

- Popular colour spaces: RGB, CMYK
- Additive colours: R, G, B
- Subtractive colours: C, M, Y
- Other colour spaces: XYZ, YUV, Lab, YCbCr, HSV
- Standards established by Commission Internationale d'Eclairage (CIE)
- Understanding of colour spaces important in printing industry


Credit: Szeliski, Computer Vision: Algorithms and Applications, 2010

For more information:

- https://www.tutorialspoint.com/dip/introduction_to_color_spaces.htm
- https://ciechanow.ski/color-spaces/

Image Compression

- Last stage in a camera's processing pipeline
- Convert signal into YCbCr (or variant), compress luminance with higher fidelity than chrominance
- Most common compression technique: Discrete Cosine Transform (DCT), used in MPEG and JPEG
- DCT, a variant of Discrete Fourier Transform - a reasonable approximation of eigendecomposition of image patches
- Videos also use block-level motion compensation
- Compression quality measured using Peak Signal-to-Noise Ratio (PSNR):

$$PSNR = 10 \log_{10} \frac{I_{max}^2}{MSE}$$

$$\text{where } MSE = \frac{1}{n} \sum_x \left[I(x) - \hat{I}(x) \right]^2$$

where $\hat{I}$ is compressed version of I

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Homework

Readings

- Chapter 2, Szeliski, *Computer Vision: Algorithms and Applications*
- Other links provided on respective slides
- (Optional, if you want to know about geometric formation of images) Chapters 1-5, Forsyth and Ponce, *Computer Vision: A Modern Approach*

References

- Dave Litwiller. "CMOS vs. CCD: Maturing Technologies, Maturing Markets-The factors determining which type of imager delivers better cost performance are becoming more refined.". In: *Photonics Spectra* 39.8 (2005), pp. 54–61.
- Richard Szeliski. *Computer Vision: Algorithms and Applications*. Texts in Computer Science. London: Springer-Verlag, 2011.
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- VSBytes Team. *DSLR Cameras vs Smartphone - Which of the two cameras is better?* May 2019. URL: https://vsbytes.com/dslr-vs-smartphone-camera/ (visited on 04/14/2020).