

# 1. Introduction

## Visual Computing

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## What is Computer Vision?

# Human Visual System: What Do You See?



# Definition

Computer vision is about how to make computers  
work like human eyes

**(or beyond).**

# Input and Output

## Inputs:

- Visual Data (primarily: 2D images or videos)

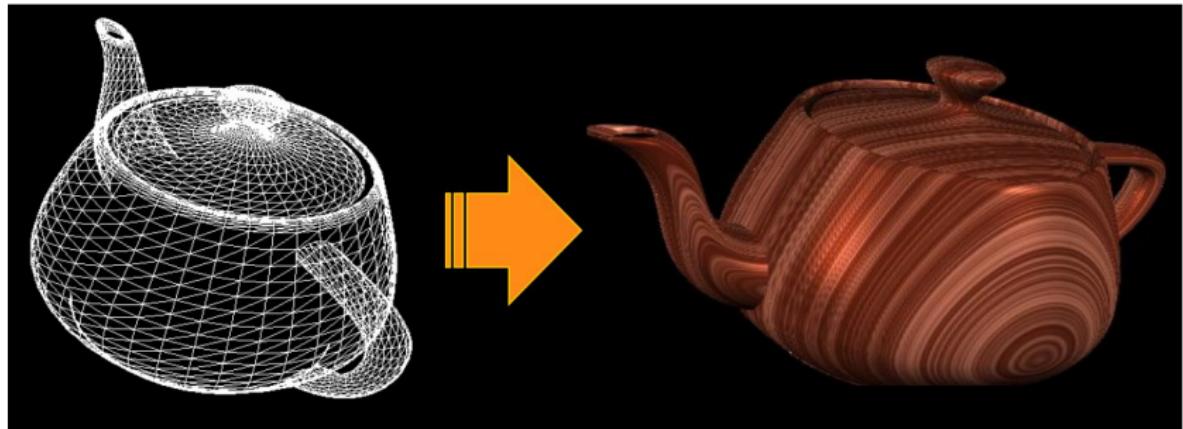
## Outputs:

- Information of the visual contents of the input

# Related Fields: Differences

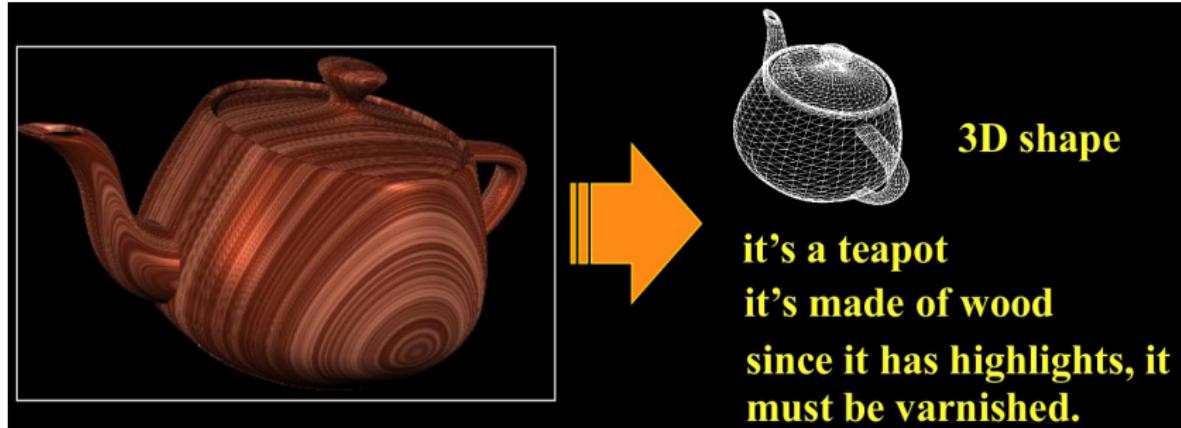
- ① Computer Graphics
- ② Image Processing
- ③ Artificial Intelligence

# Computer Graphics



Computer Graphics: from mathematical models of a 3D world  
to 2D images

# Computer Vision v.s. Computer Graphics



Computer Vision: from 2D images to the visual information

# Image Processing



Image Processing: from an image to another image (which is visually better to a human observer)

# Computer Vision and Image Processing



Image processing is part of low level computer vision.

- **Image processing:** given the left image, to produce the middle or the right image.
- **Computer vision:** given any image above, to identify the hand in the photograph.

# Artificial Intelligence

## **Artificial Intelligence:**

- A branch of computer science to extract information from all types of data (such as sound, text, visual, signal, etc.) through reasoning, deduction, planning, and learning.
- Machine learning is a set of learning techniques in AI.
- Deep learning is an approach in machine learning.

## **Computer Vision:**

- A branch of artificial intelligence focusing on visual data as the input.

## Why Computer Vision?

# Reasons of Studying Computer Vision

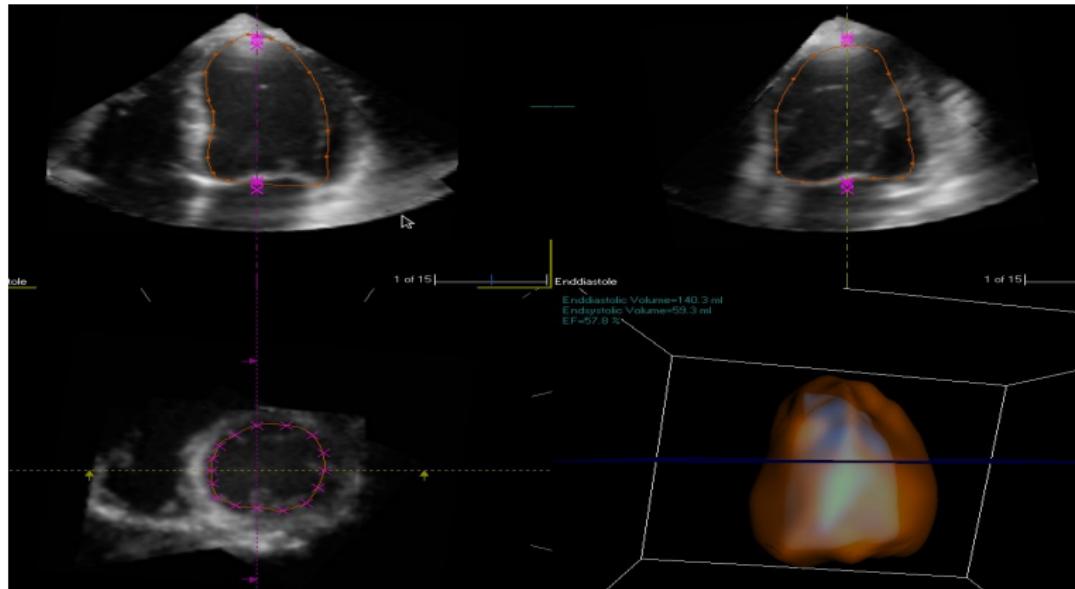
- ➊ If you think your eyes are important, so is computer vision.
- ➋ The potential applications are immense:
  - Game technology
  - Biomedical imaging
  - Robotics
  - Security/surveillance
  - Computer graphics
  - Human-computer interactions
  - Intelligent vehicle systems
  - Many more...
- ➌ Challenging, but FUN, really really fun ; )

# Tartan: CMU Driverless Racing Car (2007)



videos + detailed information:  
[www.darpa.mil/grandchallenge/index.asp](http://www.darpa.mil/grandchallenge/index.asp)

# Medical Imaging



Real-time 3D echocardiography (cardiac/heart ultrasound):  
[www.ibme.ox.ac.uk/biomedia](http://www.ibme.ox.ac.uk/biomedia)

# Surveillance



Tracking and activity recognition help surveillance systems.

# Human Computer Interaction



Human interaction with mobile devices: the SixthSense (MIT)  
[www.pranavmistry.com/projects/sixthsense/index.htm](http://www.pranavmistry.com/projects/sixthsense/index.htm)

# Computer Graphics



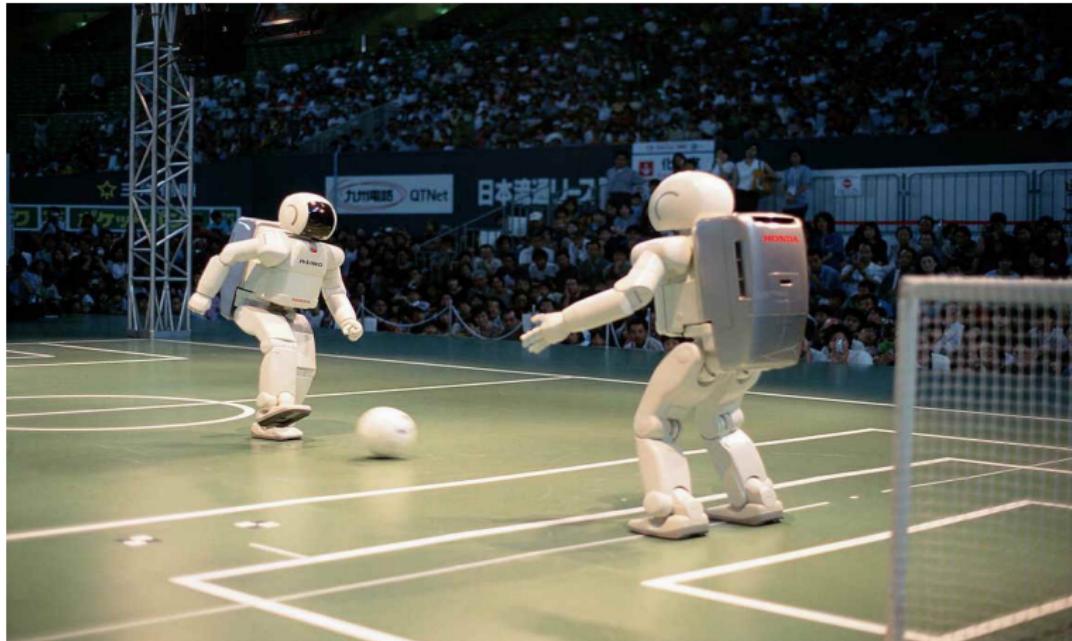
To realistically render a moving object from different angles requires the geometric (e.g. 3D data) and photometric properties (e.g. lighting).

# Game Technology



To recognize the human poses in real time.

# Robotics



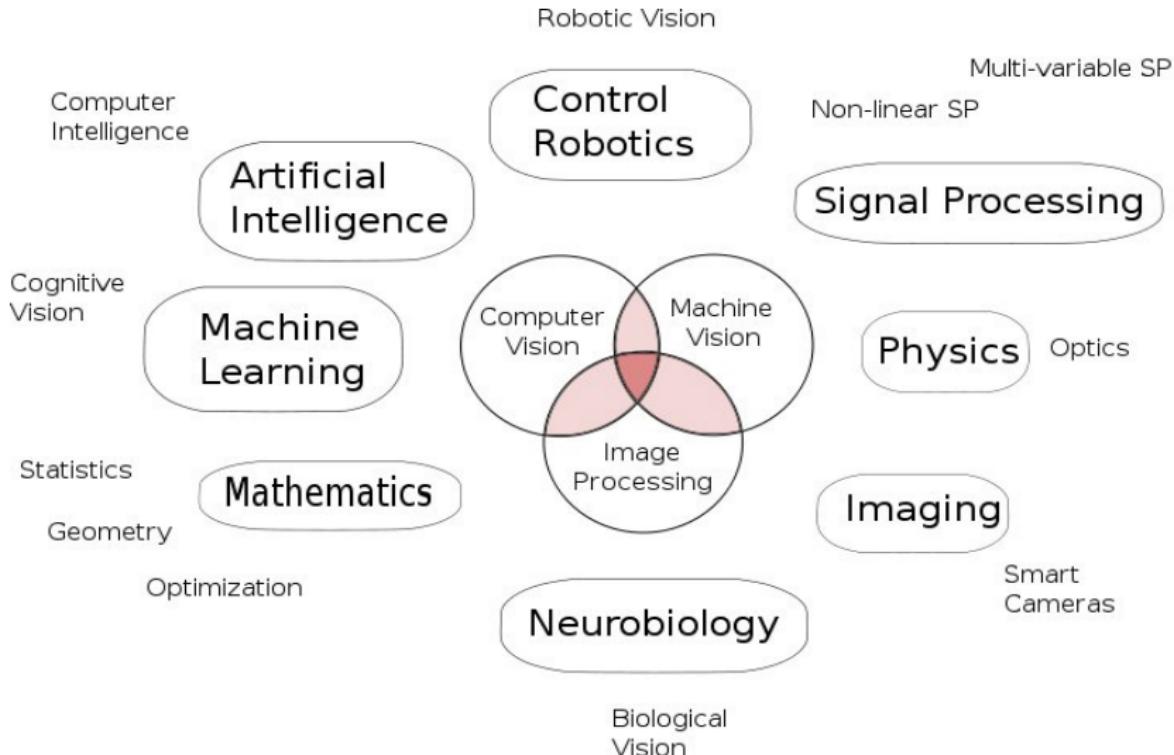
Robot vision is a direct application of computer vision.

## Many Other Applications

There are still many other applications of computer vision.

Computer vision technologies will soon be applied for a broad range of products.

# Related Fields



# Challenge: Variation and Definition

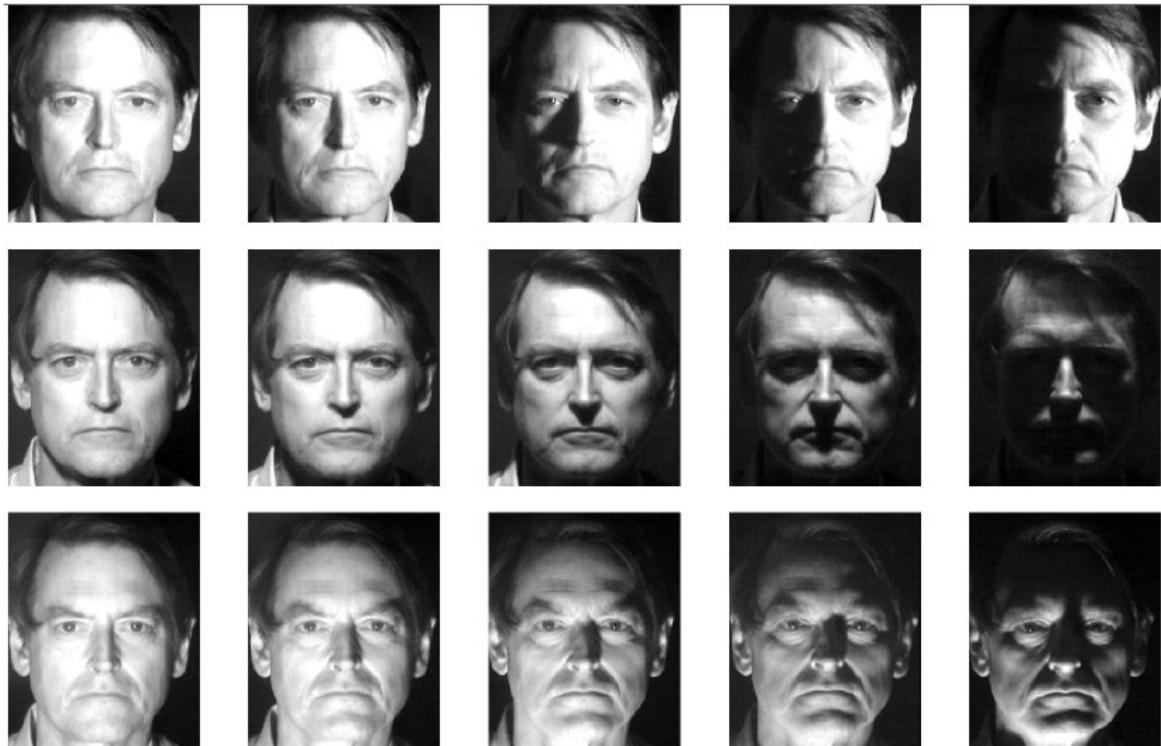
Het internet Afbeeldingen Video's Maps Nieuws Boeken Gmail meer ▾ Zoekinstellingen | Aanmelden

Google chairs Zoeken SafeSearch gematigd ▾ Geavanceerd zoeken

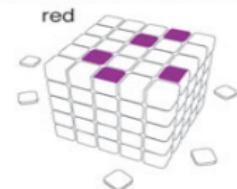
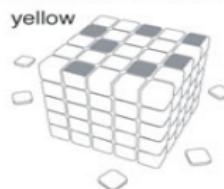
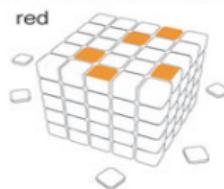
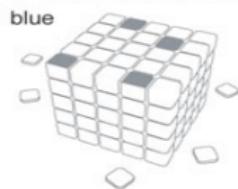
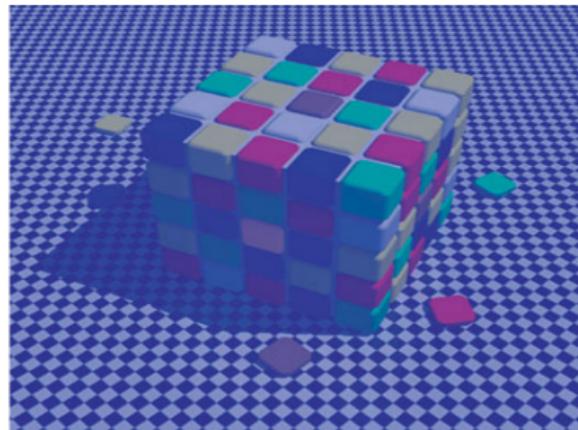
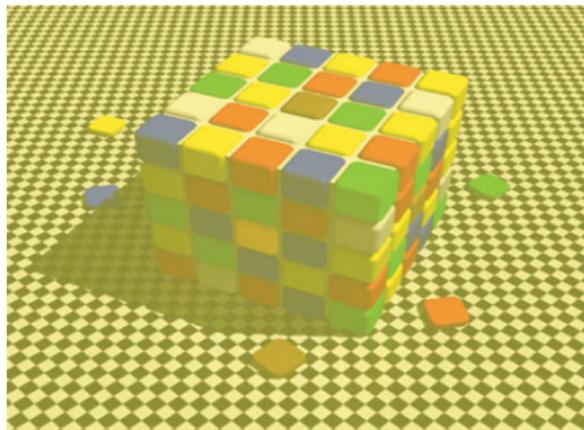
Ongeveer 37.100.000 resultaten (0,05 seconden)

Alles Afbeeldingen Meer Elk formaat Groot Gemiddeld Pictogram Grooter dan... Exact... Elk type Gezicht Foto Clipart Lijntekening Elk kleur Full colour Zwart-wit Standaardweergave Formaat weerg.

# Challenge: Lights

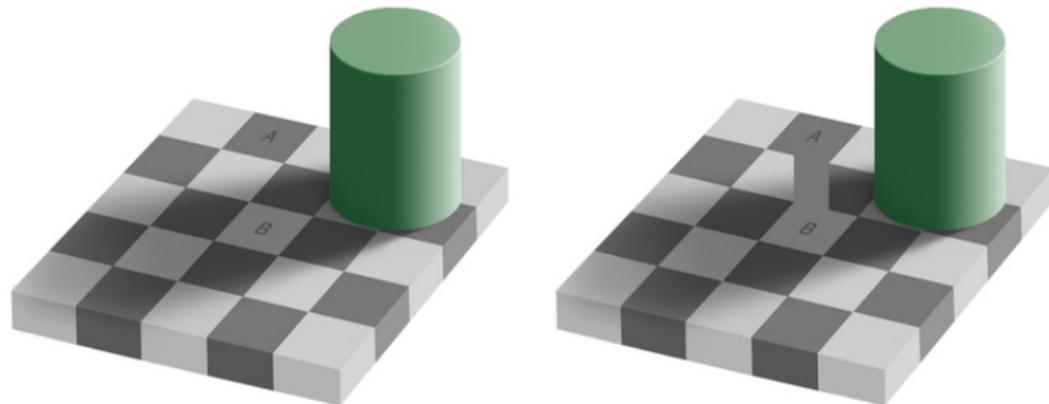


# Challenge: Colors



Don't believe it? Check them yourself using an image editor!

# Challenge: Intensities



# Challenge: Size

*Size  
constancy*

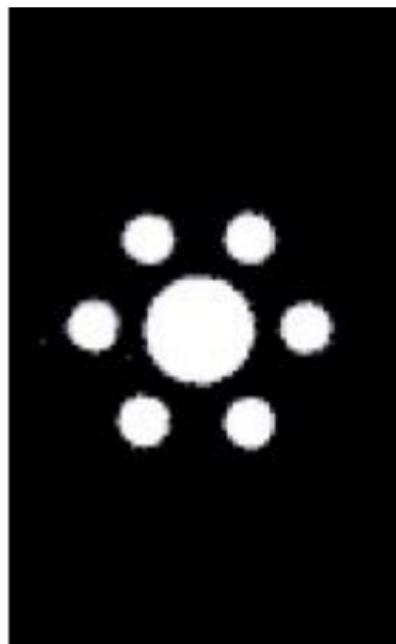


# Challenge: Size

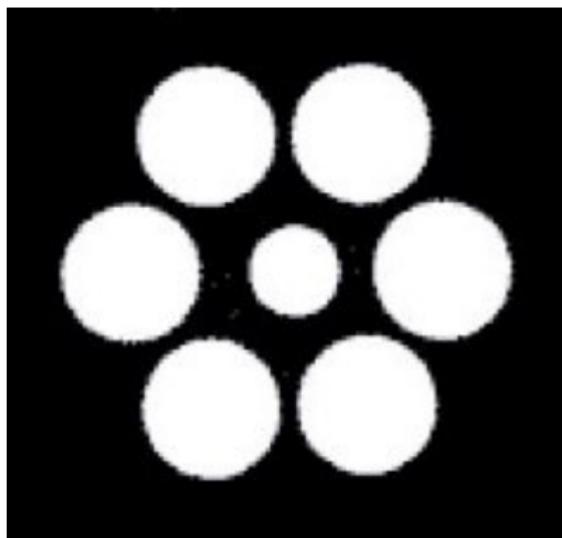
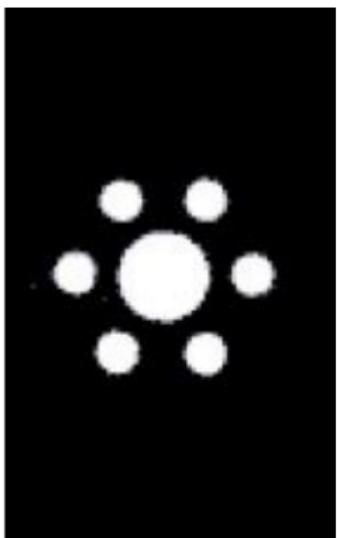
Size  
constancy



# Challenge: Relative Size



# Challenge: Relative Size



# Challenge: Patterns



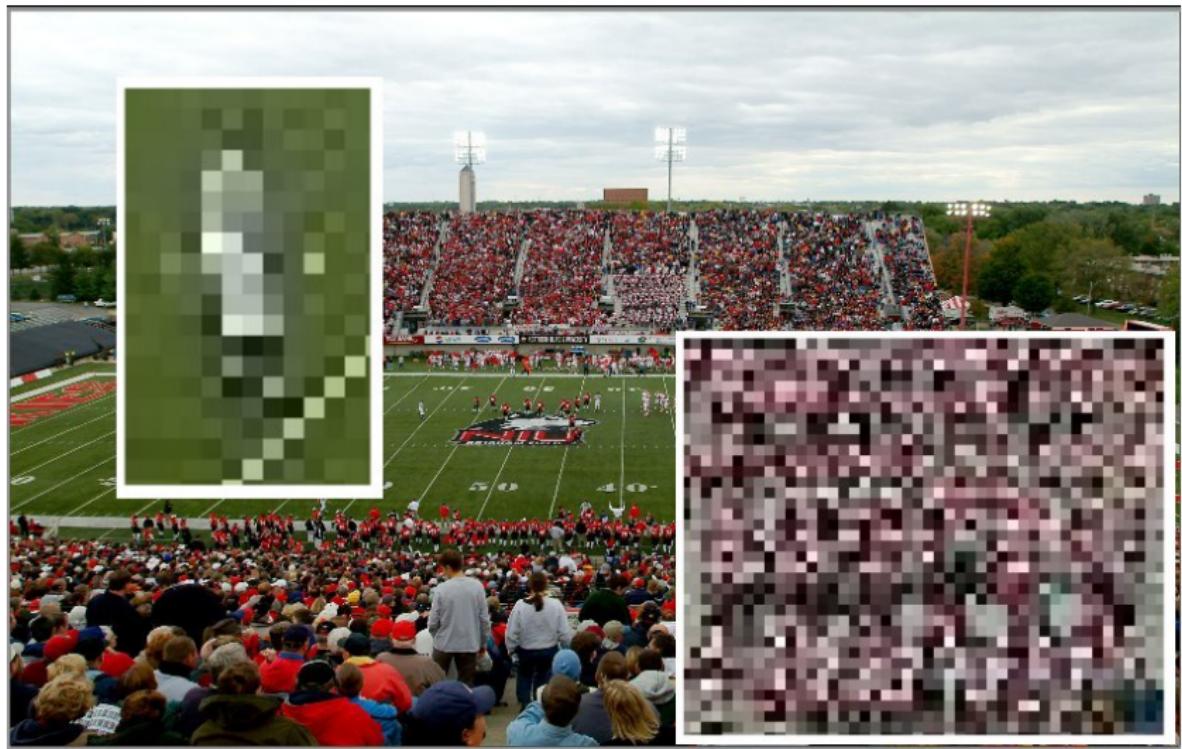
# Challenging, but FUN, really FUN!



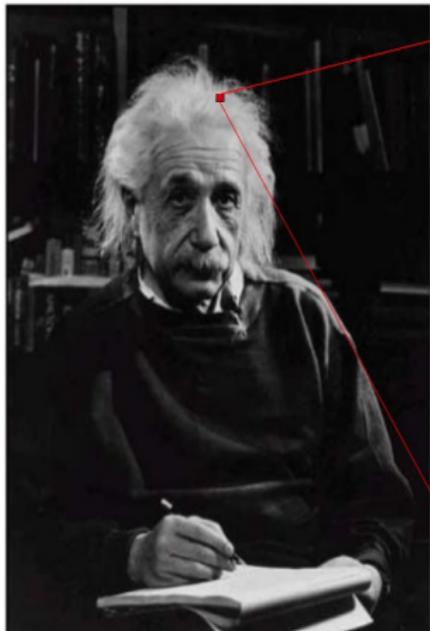
# Challenging, but FUN, really FUN!



# Challenging, but FUN, really FUN!



# Our Input Data are Numbers!



123	121	119	127	116	114	118	116	154	201	134	133	99	123	123	131
143	157	123	255	111	116	114	112	99	128	131	125	137	137	129	116
137	116	198	122	152	127	203	117	155	161	167	149	143	159	116	93
143	157	123	255	111	116	114	112	99	128	131	125	137	137	129	116
149	103	111	238	172	154	110	108	134	162	129	119	137	141	109	125
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143	157	123	255	111	116	114	112	99	128	131	125	137	137	129	116
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119	127	116	114	118	116	123	121	154	201	134	133	99	123	123	131
159	116	93	137	116	198	122	152	127	203	117	155	161	167	149	143

# Topics in Visual Computing Course

- ① Recognition
- ② Geometry (3D Reconstruction)
- ③ Motion Analysis
- ④ Low Level Vision

Deep Learning is excluded in the discussion.

# Logistics

# Assessment

- ① Assignments
- ② Final Exam

# Academic Honesty

Academic honesty is compulsory in finishing the assignments and the exams:

- ① Exchanging codes is not allowed.
- ② Using codes from the previous years or from the internet is prohibited, unless stated otherwise in the lectures.
- ③ Copying texts of the reports from other groups is strictly prohibited.
- ④ Generally, cheating, academic misconduct, plagiarism, and fabrication of any submitted material (including code and text) are not tolerated.

Any violation to the academic honesty will imply failure to pass the course.

# References

- Textbooks:
  - ① S. Prince, “Computer Vision: Models, Learning and Inference”
  - ② R. Hartley and A. Zisserman, “Multiple View Geometry”
- Academic Papers: available on the course website.

# Others

- Programming Language: Matlab
- Course website: [https://tanroddy.github.io/  
teaching/ece\\_visual/index.html](https://tanroddy.github.io/teaching/ece_visual/index.html)

# Image Formation

## Visual Computing

Robby T. Tan

# Image Formation

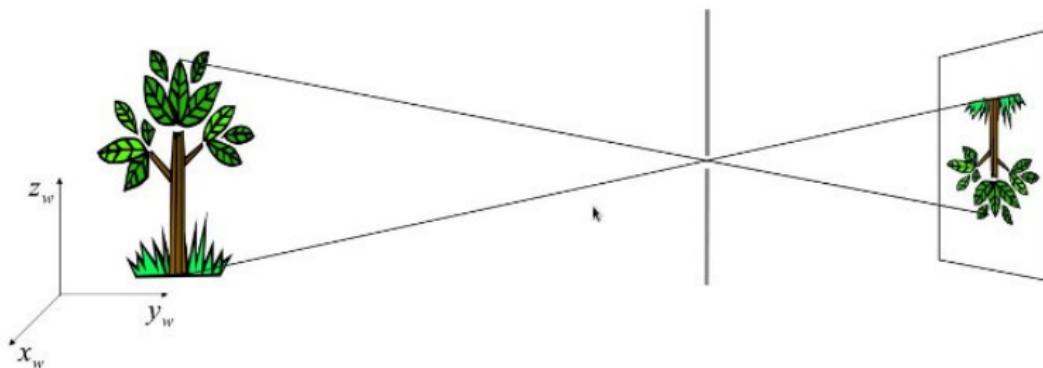


Two fundamental aspects of image formation:

- Geometric Aspects
- Radiometric Aspects

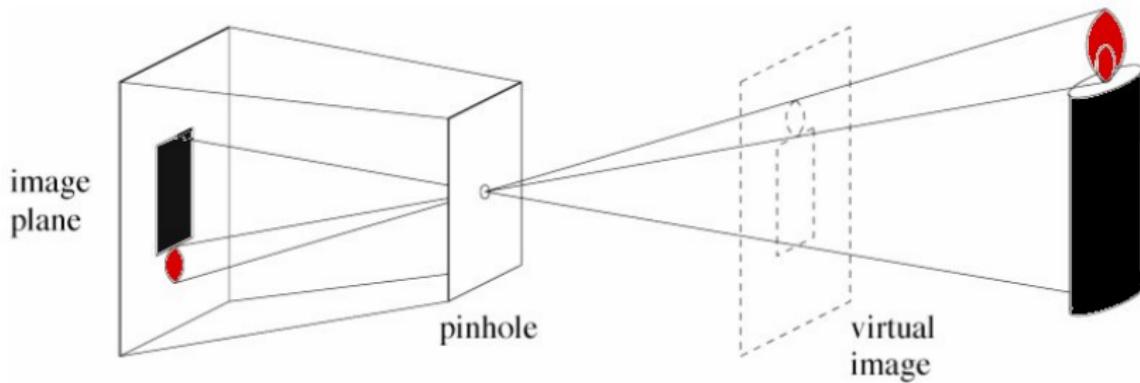
# Geometric Aspect

# Pinhole Camera Model: 3D to 2D



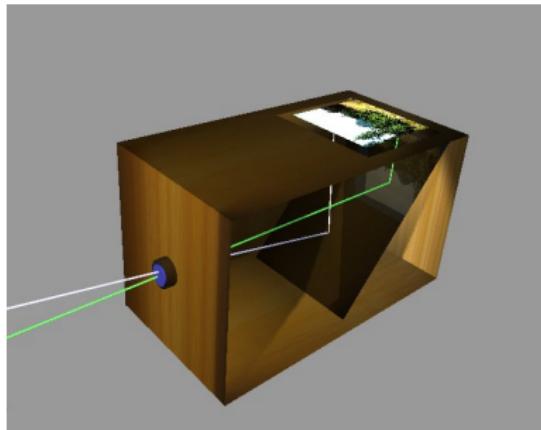
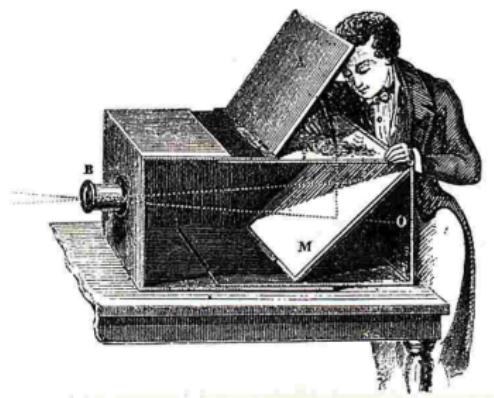
In the geometric perspective: an image is the projection of 3D structures onto a 2D image plane.

# Pinhole Camera Model: Virtual Image

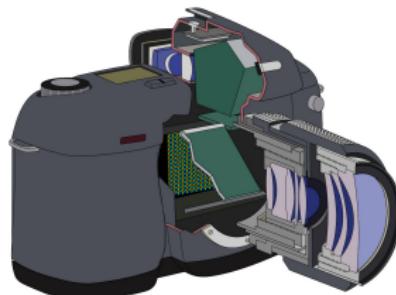
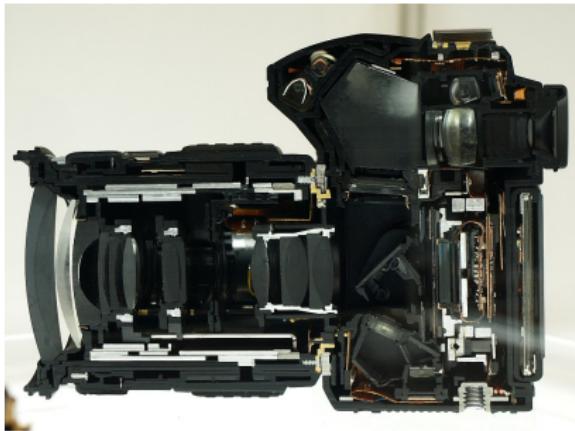


In a pinhole camera model, we can assume the presence of the virtual image.

# Pinhole Camera: Camera Obscura

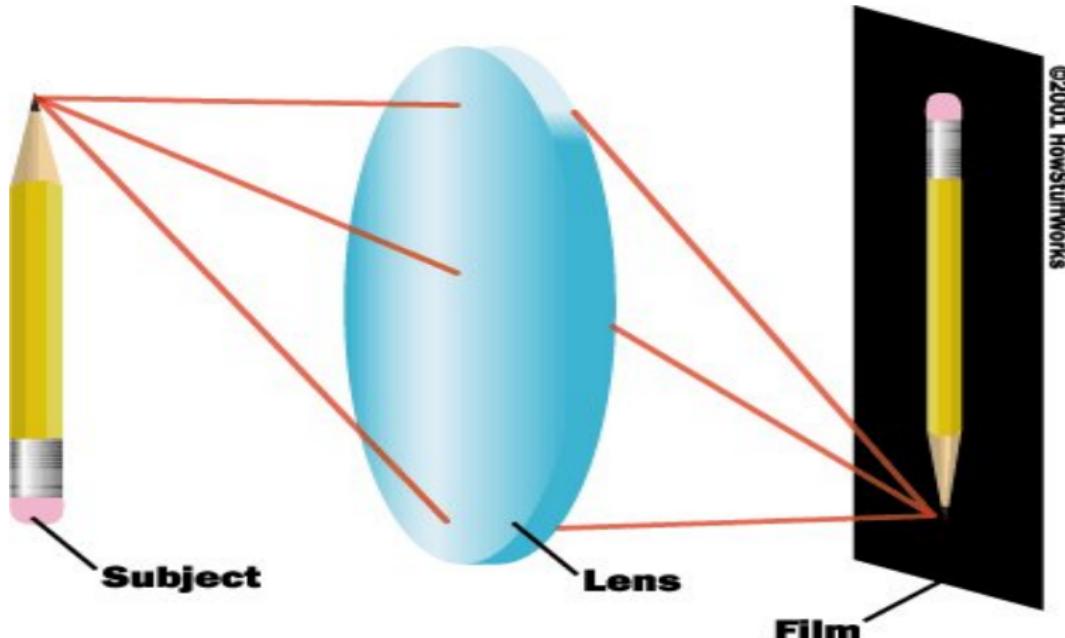


# Digital Camera



Instead of using a pinhole, modern cameras use lenses to have greater accumulated lights (and other functionalities).

# Digital Cameras



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# Light as a Ray



What are the geometric correlations between: a point in the 3D world, a pixel in the 2D image, and the camera?

# Radiometric Aspects

# Light to Image



- What is light?
- What is a digital image?
- How does a camera transform light into an image?

# Electromagnetic Radiation

Light is electromagnetic radiation.

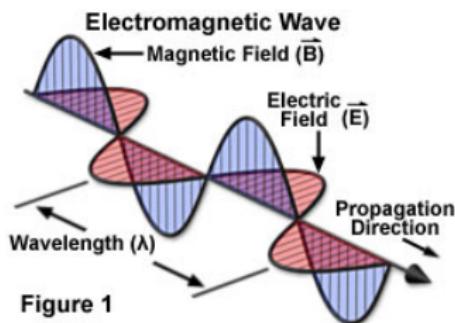
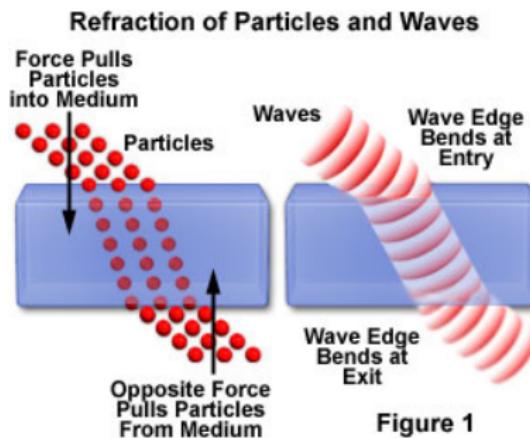


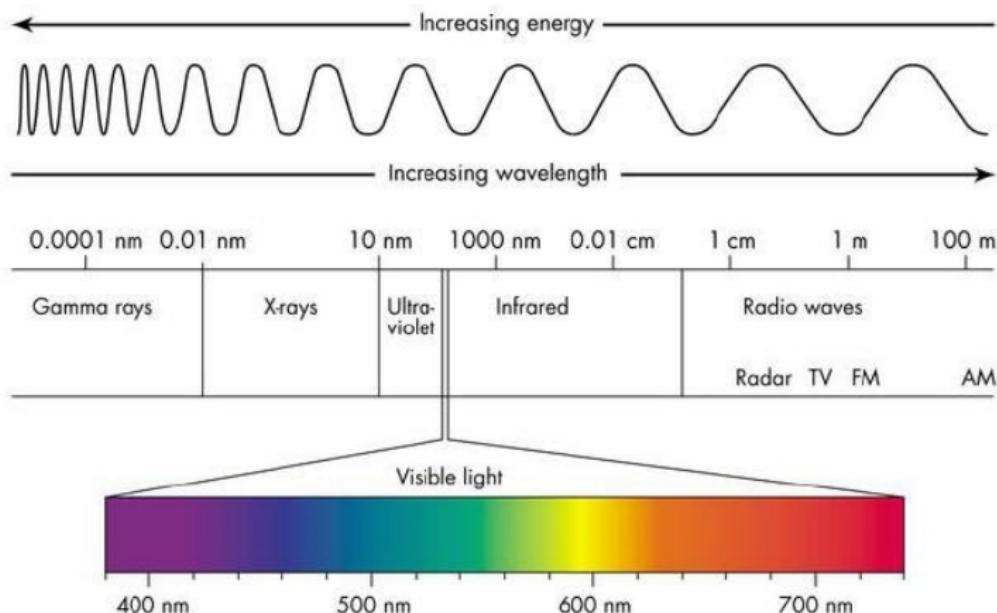
Figure 1

# Wave-Particle Duality

Light is both wave and particle (wave-particle duality).



# Lights as Waves: Wavelength



# Lights as Waves: Light Sources

Spectra From Common Sources of Visible Light

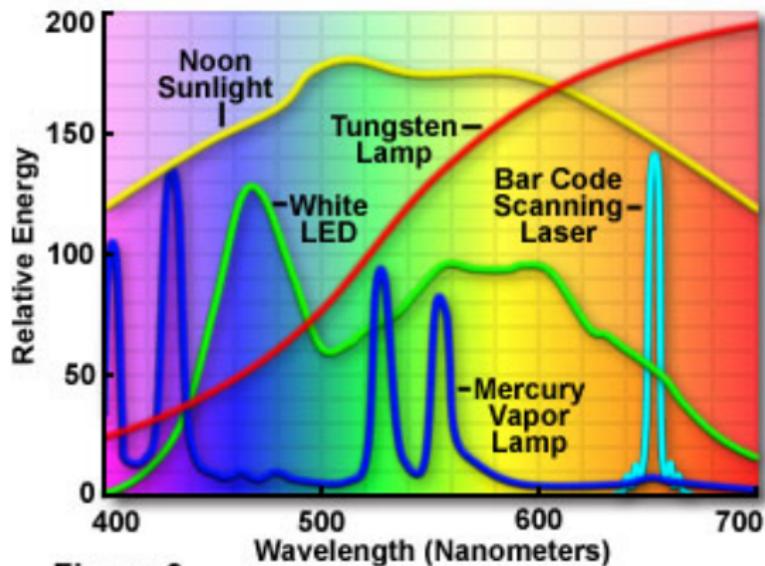
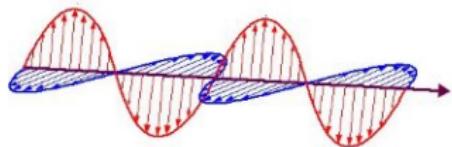


Figure 3

# Digital Camera



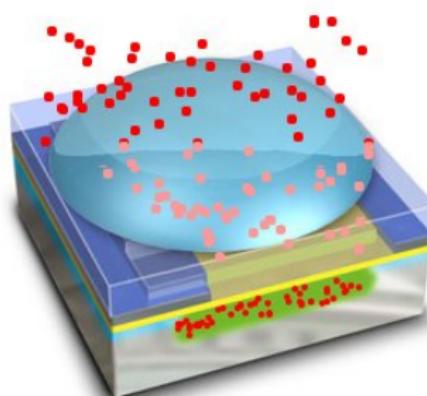
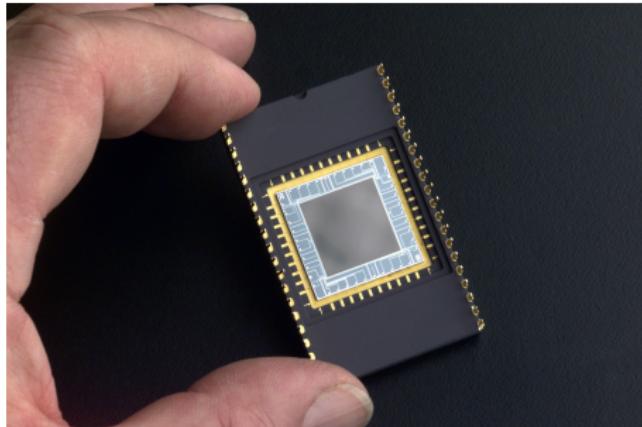
**Digital camera:** to convert light into electrical charges  
(then, to digital pixel intensities: 0 – 255)

**Basic components:**

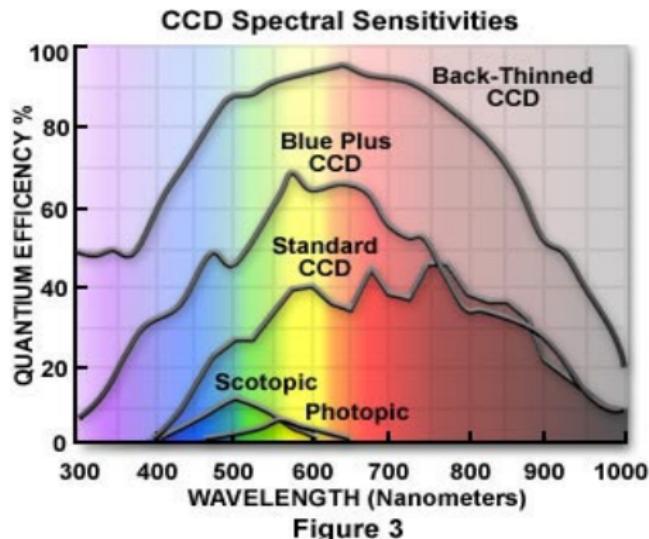
- Image sensors: CMOS or CCD
- Color Filters

142	231	139	237	124	124	124	120	250	251	120	125	96	127	122	123	123	123	123
143	237	123	225	111	118	120	260	257	127	89	251	120	125	126	126	126	126	126
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182	262	134	238	122	124	120	280	129	128	127	126	127	149	140	145	146	146	146

# Charge Couple Devices (CCDs)



# Spectral Sensitivity

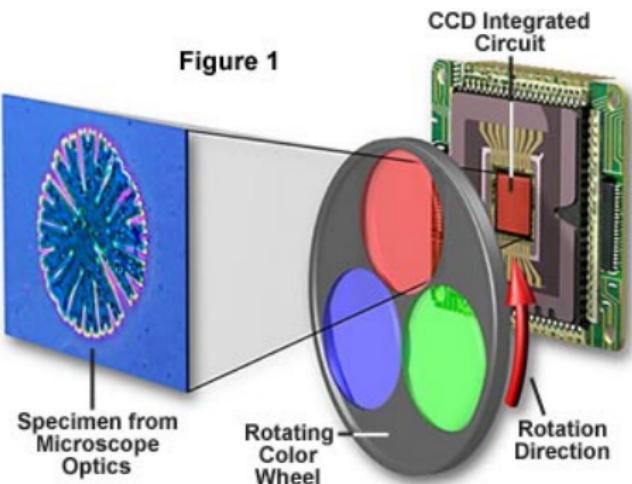


$$I(\mathbf{x}) = \int_{\Omega} E(\mathbf{x}, \lambda) q(\lambda) d\lambda \quad (1)$$

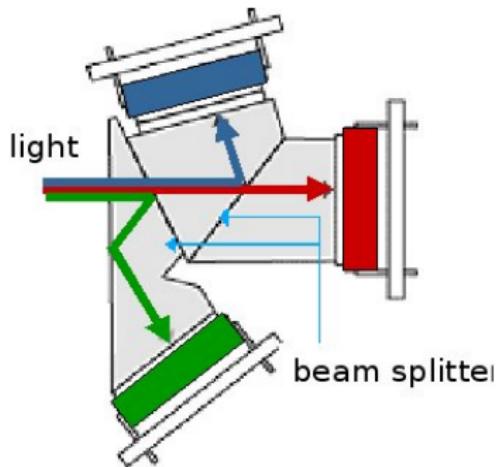
# Color Filters: Color Wheel

Sequential Color Three-Pass CCD Imaging System

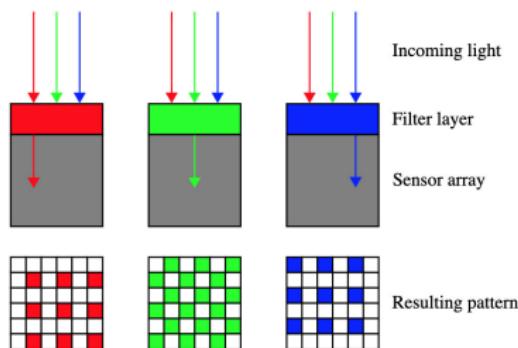
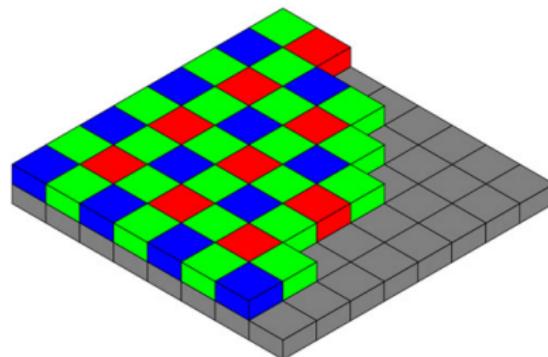
Figure 1



# Color Filters: Beam Splitter

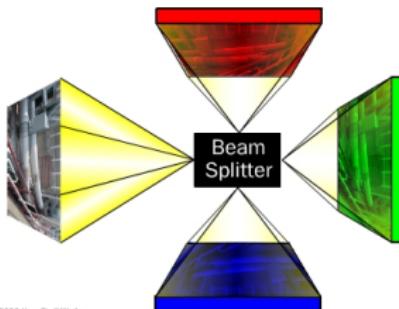
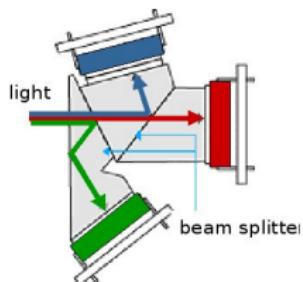


# Color Filters: Bayer Filter



The green channel has more information about the scene

# Color Filters: Summary



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Full-Frame CCD Architecture

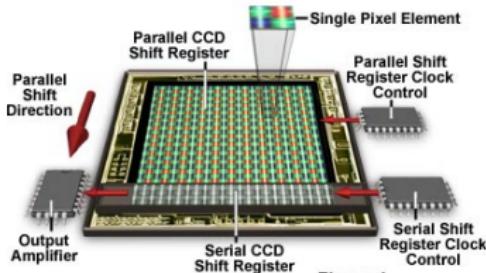
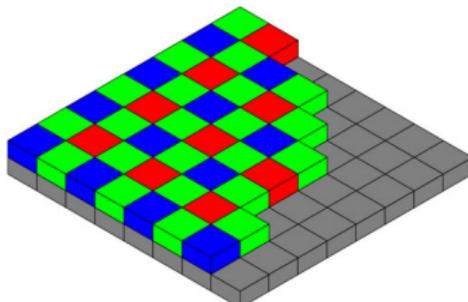
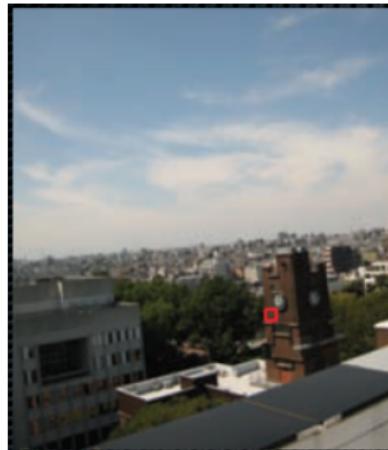
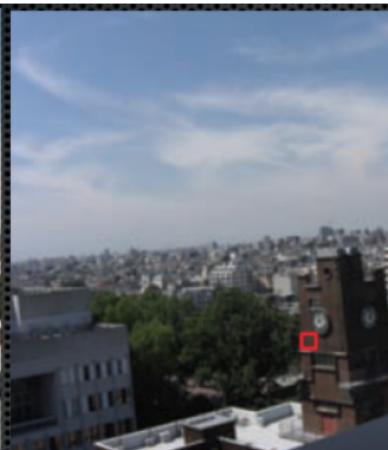


Figure 1

# Color Profile



Casio IXY

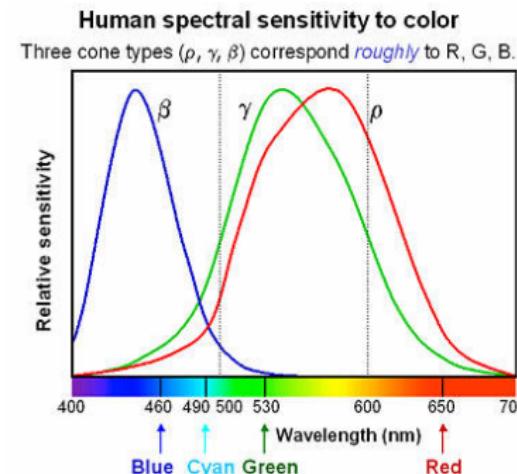
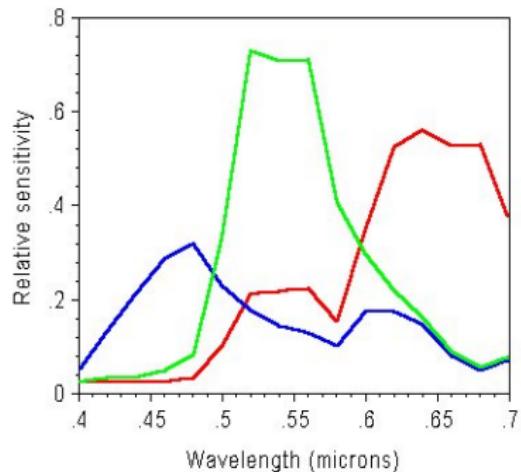


Canon EXZ



Panasonic DMC

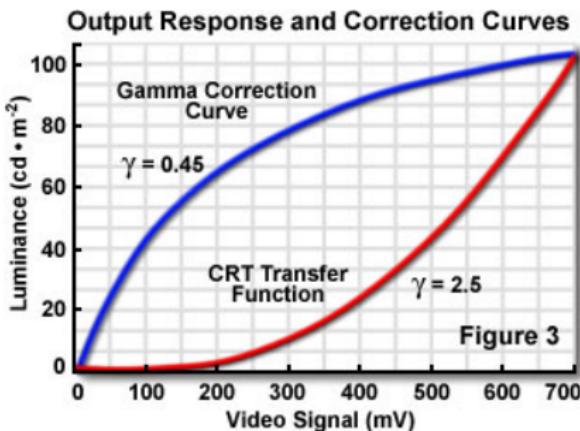
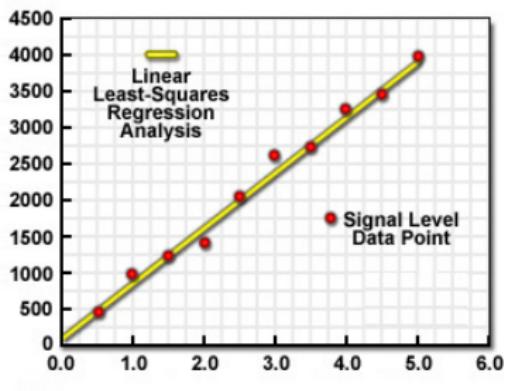
# Spectral Sensitivity



$$I_c(\mathbf{x}) = \int_{\Omega} E(\mathbf{x}, \lambda) q_c(\lambda) d\lambda \quad (2)$$

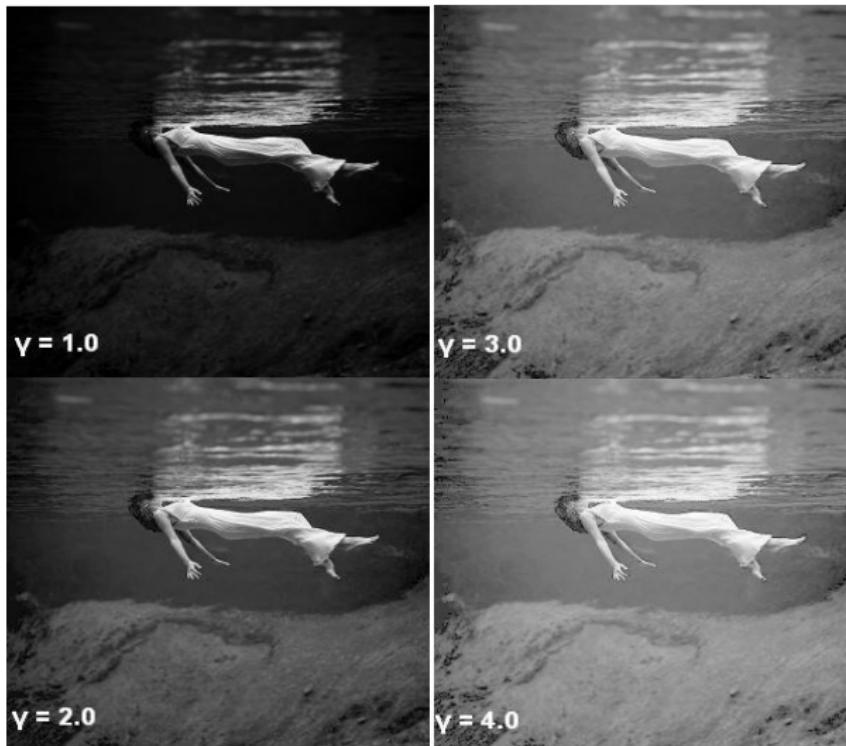
where index  $c = \{R, G, B\}$

# Camera Response Function: Gamma Correction



- The response function is determined by the camera manufacturers
- Radiometric calibration is to find the function and to linearize the response.

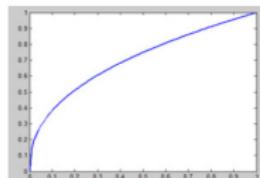
# Why Non-linear?



# Why Non-linear?



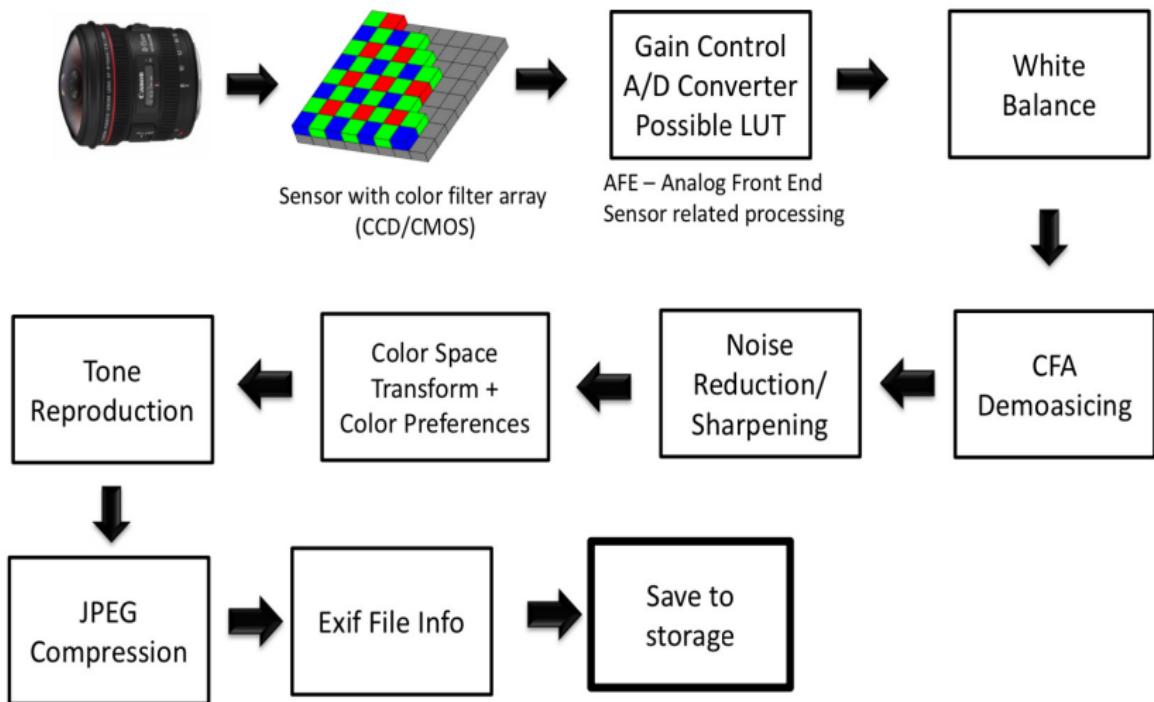
Final sRGB



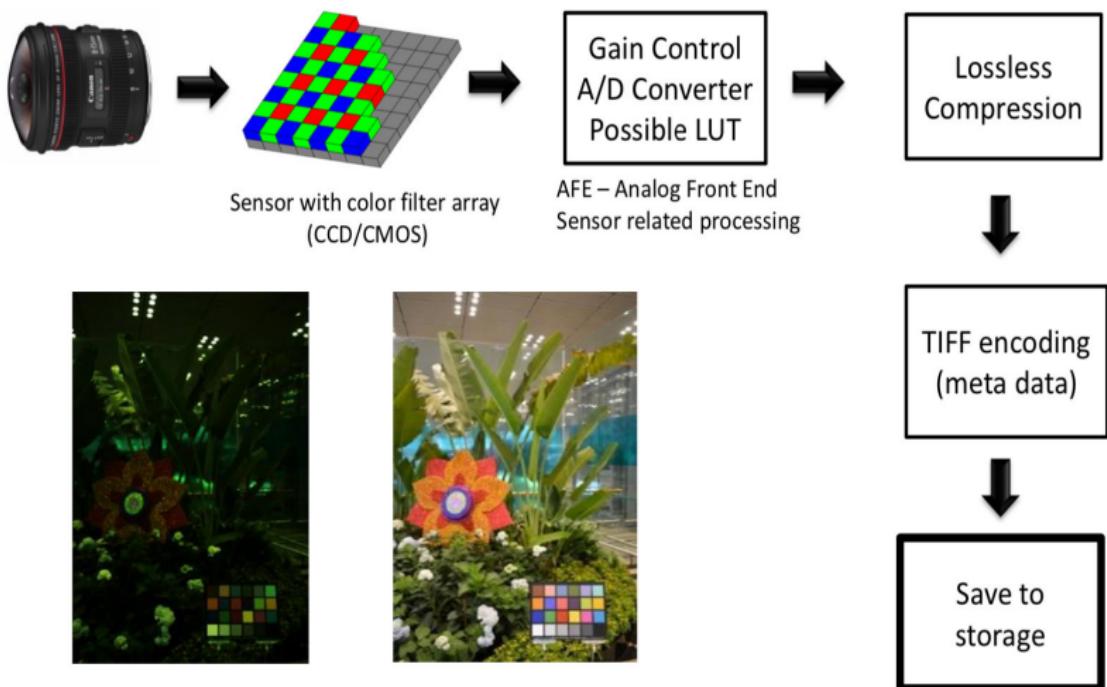
Linear sRGB

Final sRGB

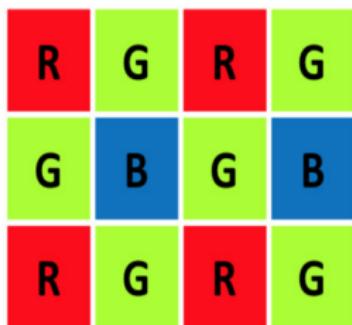
# Camera Pipeline: JPEG



# Camera Pipeline: RAW



# CFA (Color Filter Array) Demosaicing

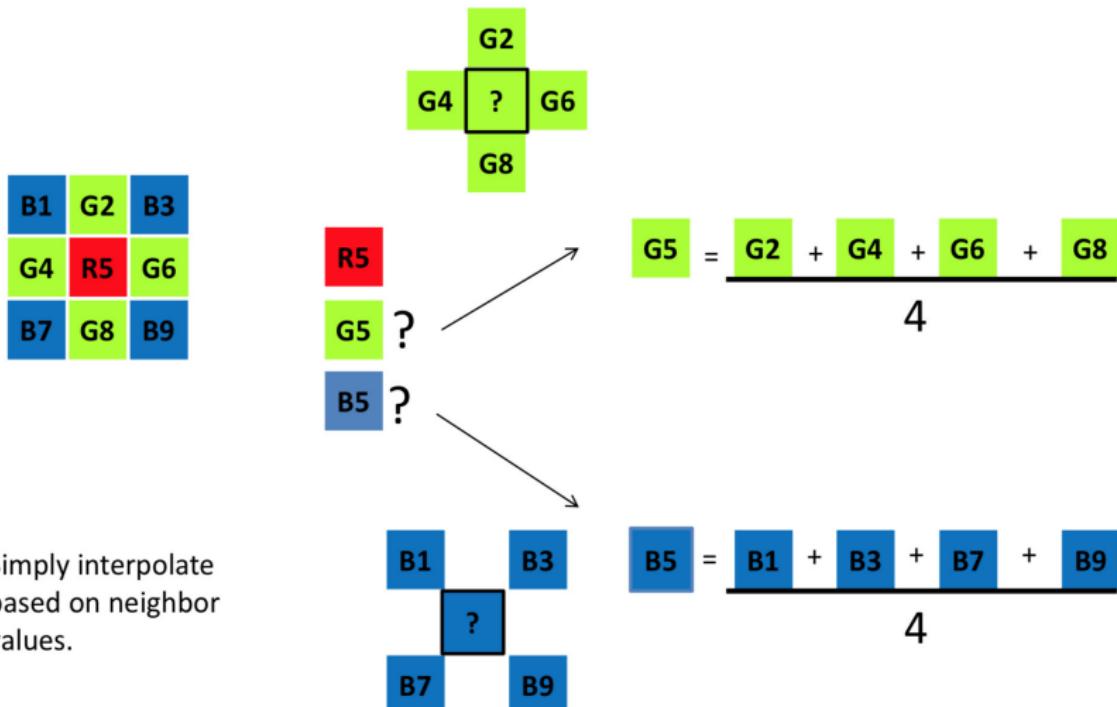


Sensor RGB layout



Desired output with RGB per pixel.

## Demosaicing: Simple Interpolation



# Summary

- ① A camera is not a light-measuring device
- ② Radiometry: Quantitative measurements of radiant energy
- ③ Photometry: Quantitative measurements of **perceived** radiant energy