CSCE 590 INTRODUCTION TO IMAGE PROCESSING

Image Acquisition

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Image Acquisition and Representation

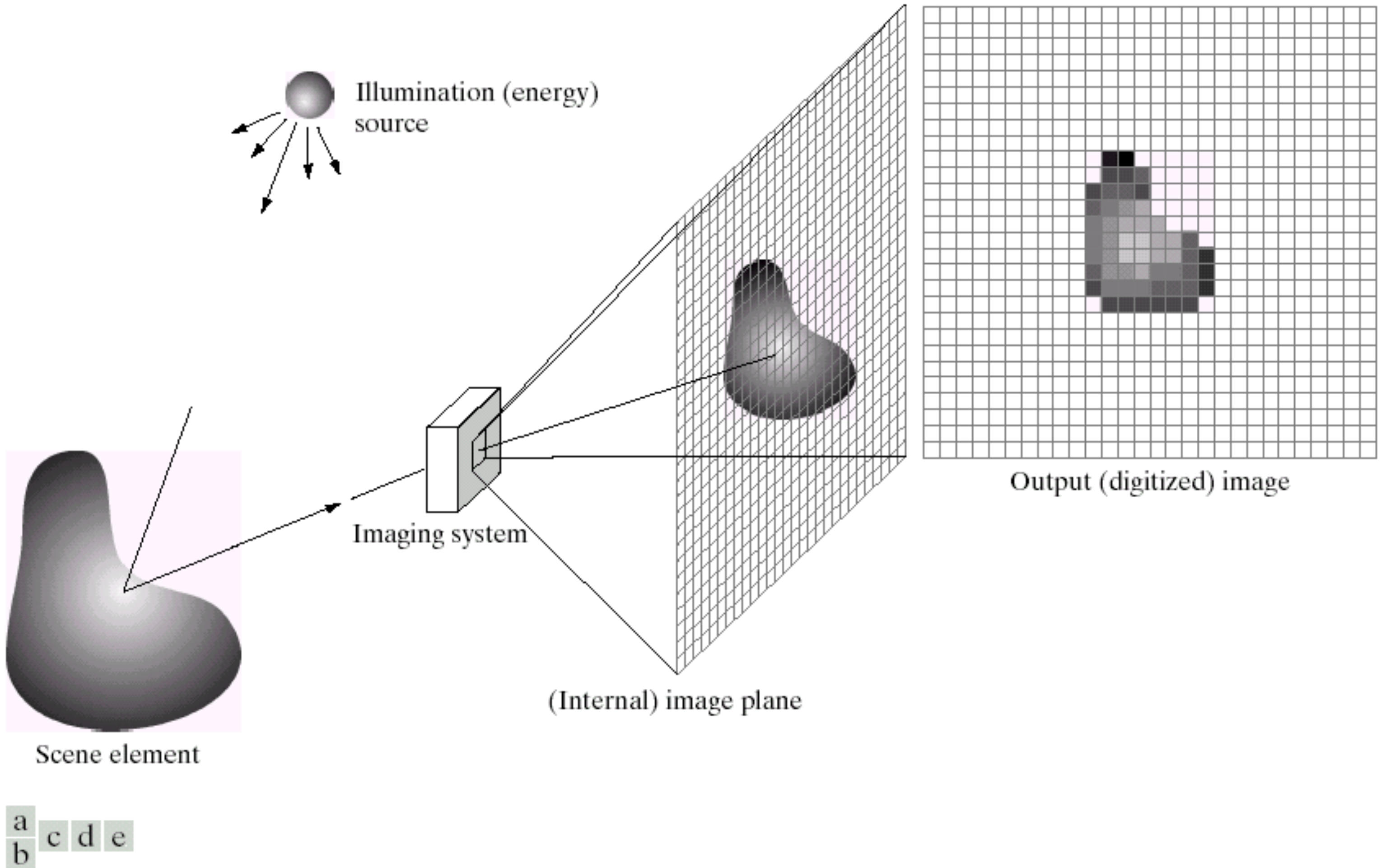
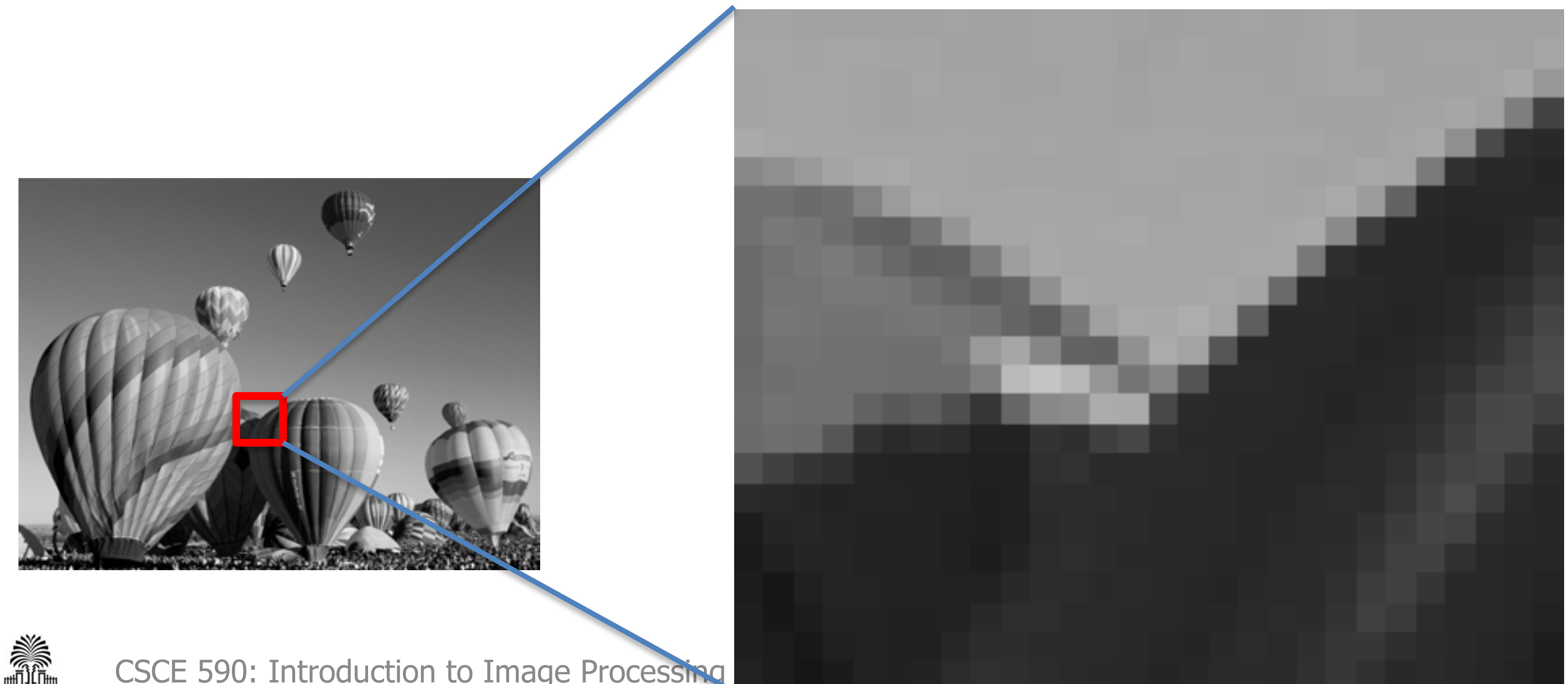


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image Representation

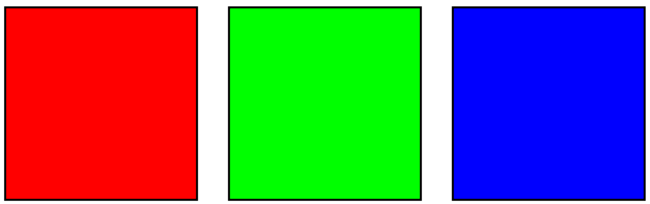
- **Discrete representation of images**
  - we'll carve up image into a rectangular grid of pixels $P[x,y]$
  - •each pixel p will store an intensity value in [0 1]
  - •0 →black; 1 →white; in-between →gray
  - •Image size m by n →(mn) pixels

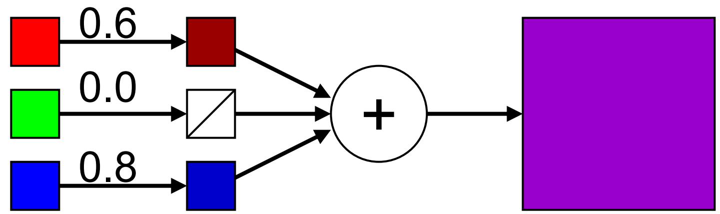


Slides courtesy of Prof. Yan Tong

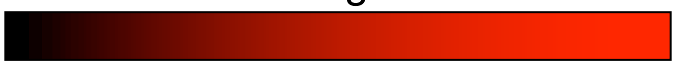
Color Image

Red (1,0,0) Green (0,1,0) Blue (0,0,1)





0 Colors along Red axis 1



RGB channels

Slides courtesy of Prof. Yan Tong

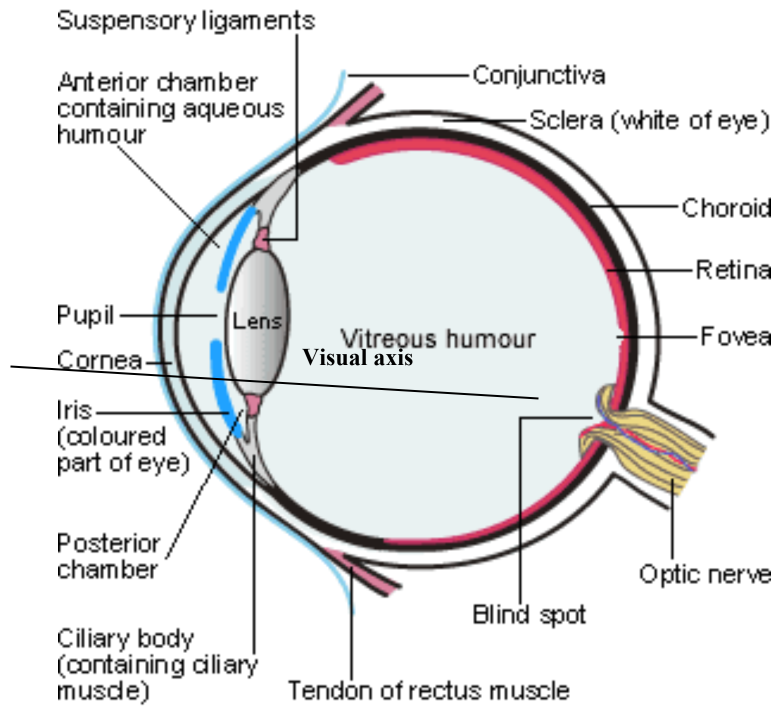
Elements of Human Visual Perception

Human visual perception plays a key role in selecting a technique

Lens and Cornea: focusing on the objects

Two receptors in the retina:

- Cones and rods
- Cones located in fovea and are highly sensitive to color
- Rods give a general overall picture of view, are insensitive to color and are sensitive to low level of illumination



http://www.mydr.com.au/eye-health/eye-anatomy

Distribution of Rods and Cones in the Retina

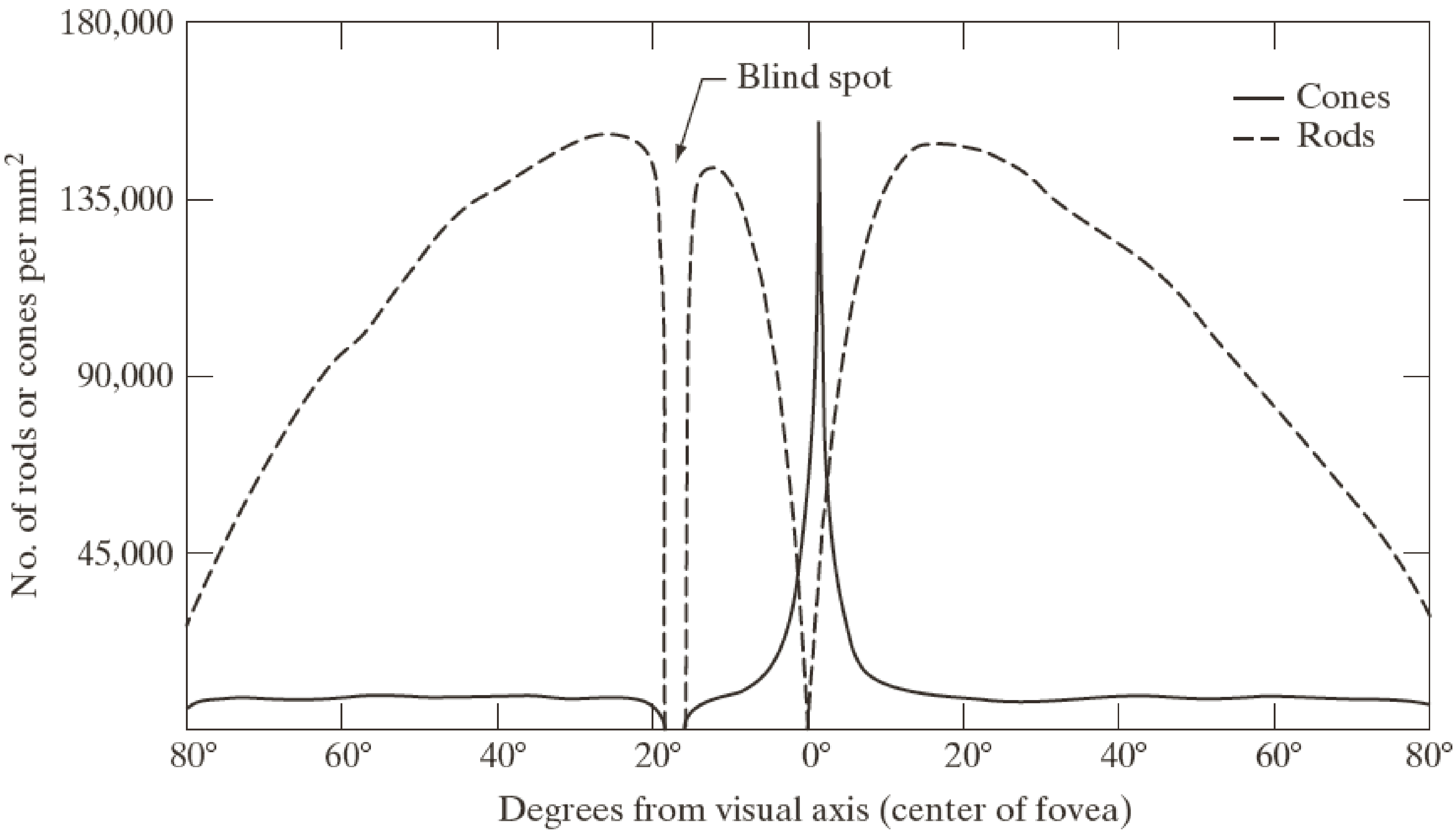


FIGURE 2.2 Distribution of rods and cones in the retina.

Slides courtesy of Prof. Yan Tong

Brightness Adaptation: Subjective Brightness

Scotopic:

- **Vision under low illumination**
- **rod cells are dominant**

Photopic:

- **Vision under good illumination**
- **cone cells are dominant**

The total range of distinct intensity levels the eye can discriminate *simultaneously* is rather small

Brightness adaptation level

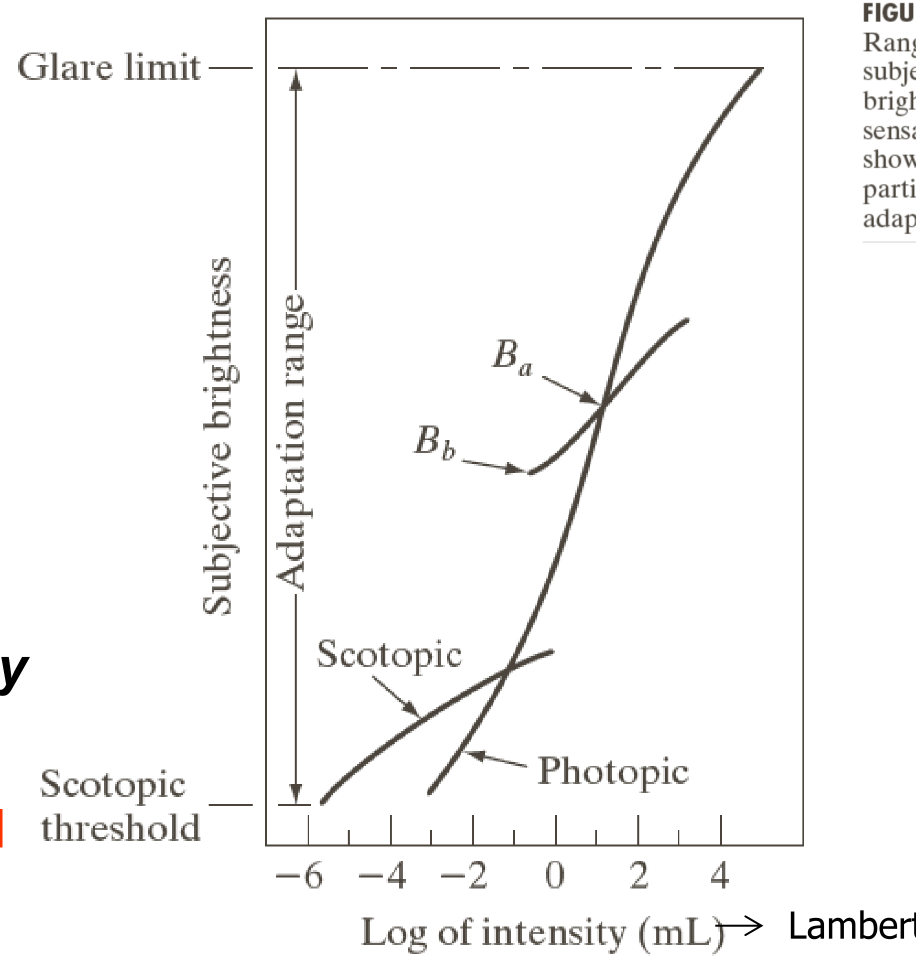


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

Brightness Discrimination

Weber Ratio/Fraction

$$\frac{\Delta I_c}{I}$$

$I + \Delta I_c$:

Short-duration flash

Small ratio: good brightness discrimination

Large ratio: poor brightness discrimination

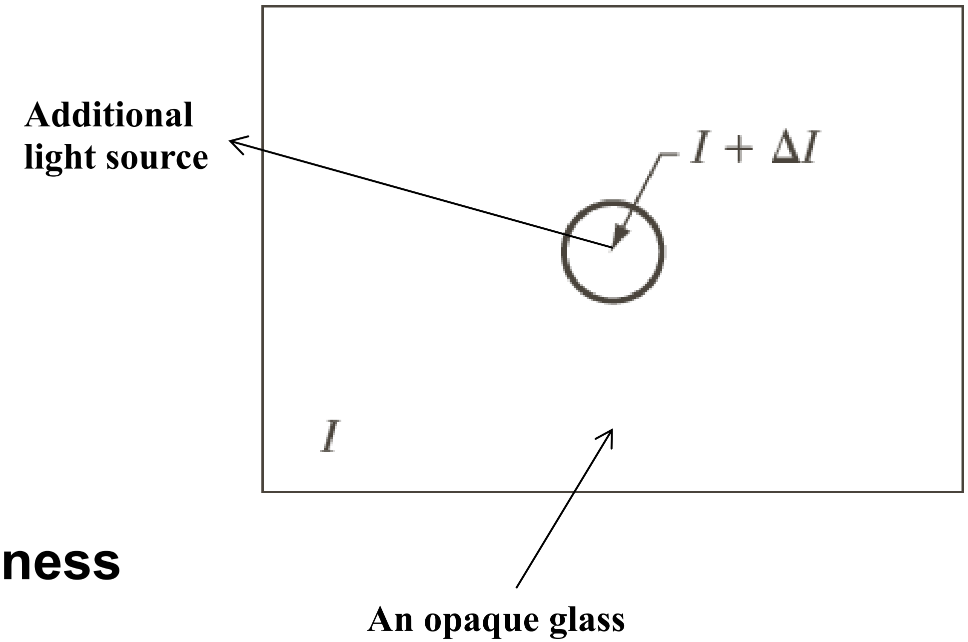


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Brightness Discrimination at Different Intensity Levels

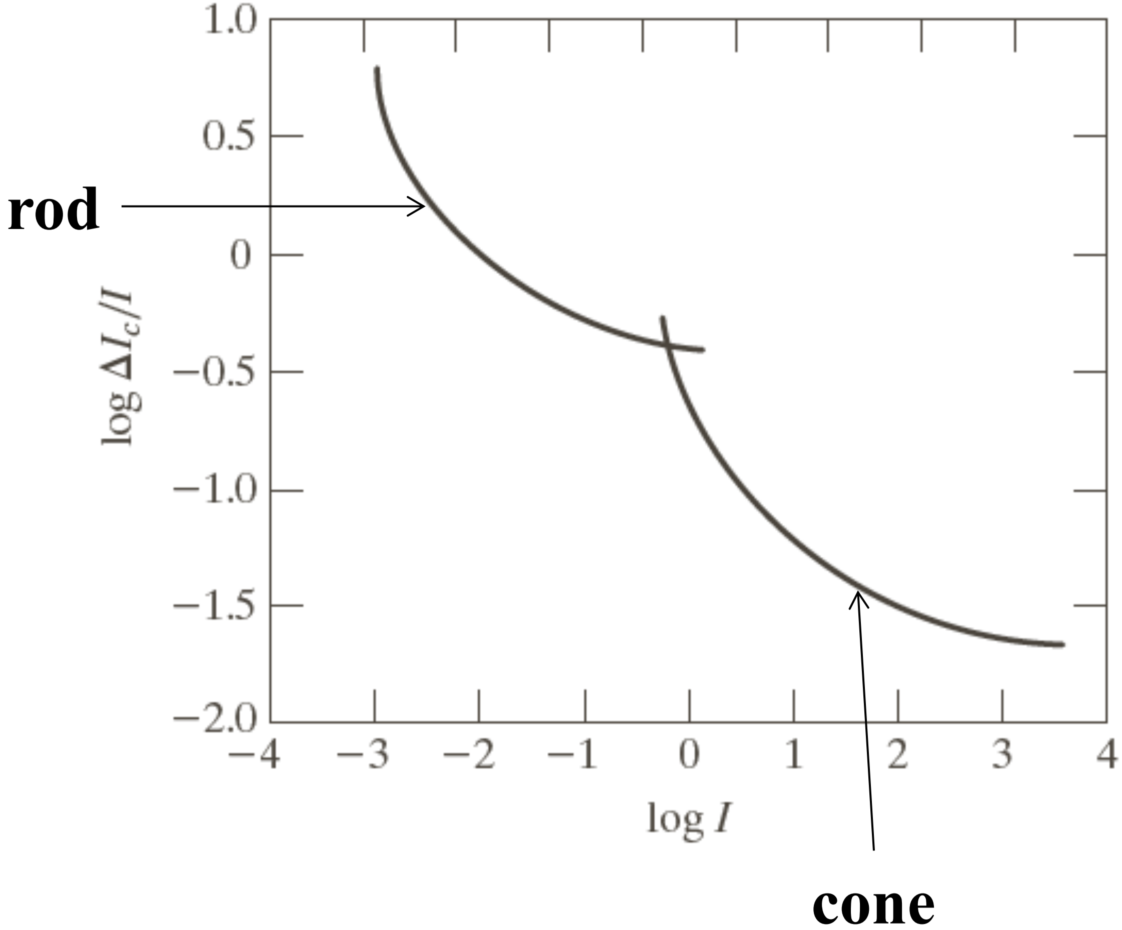
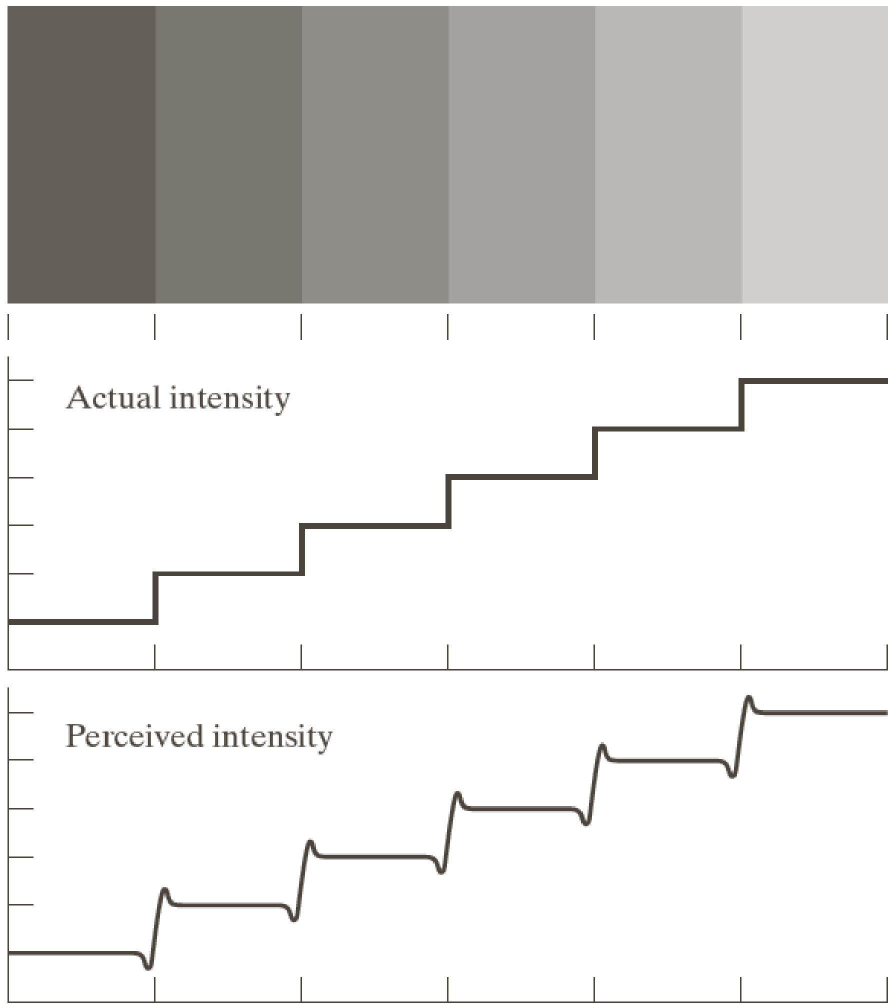


FIGURE 2.6 Typical Weber ratio as a function of intensity.

Slides courtesy of Prof. Yan Tong

Perceived Intensity is Not a Simple Function of the Actual Intensity (1)



a
b
c

FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

Perceived Intensity is Not a Simple Function of the Actual Intensity (2) – Simultaneous Contrast

a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Optical Illusions: Complexity of Human Vision

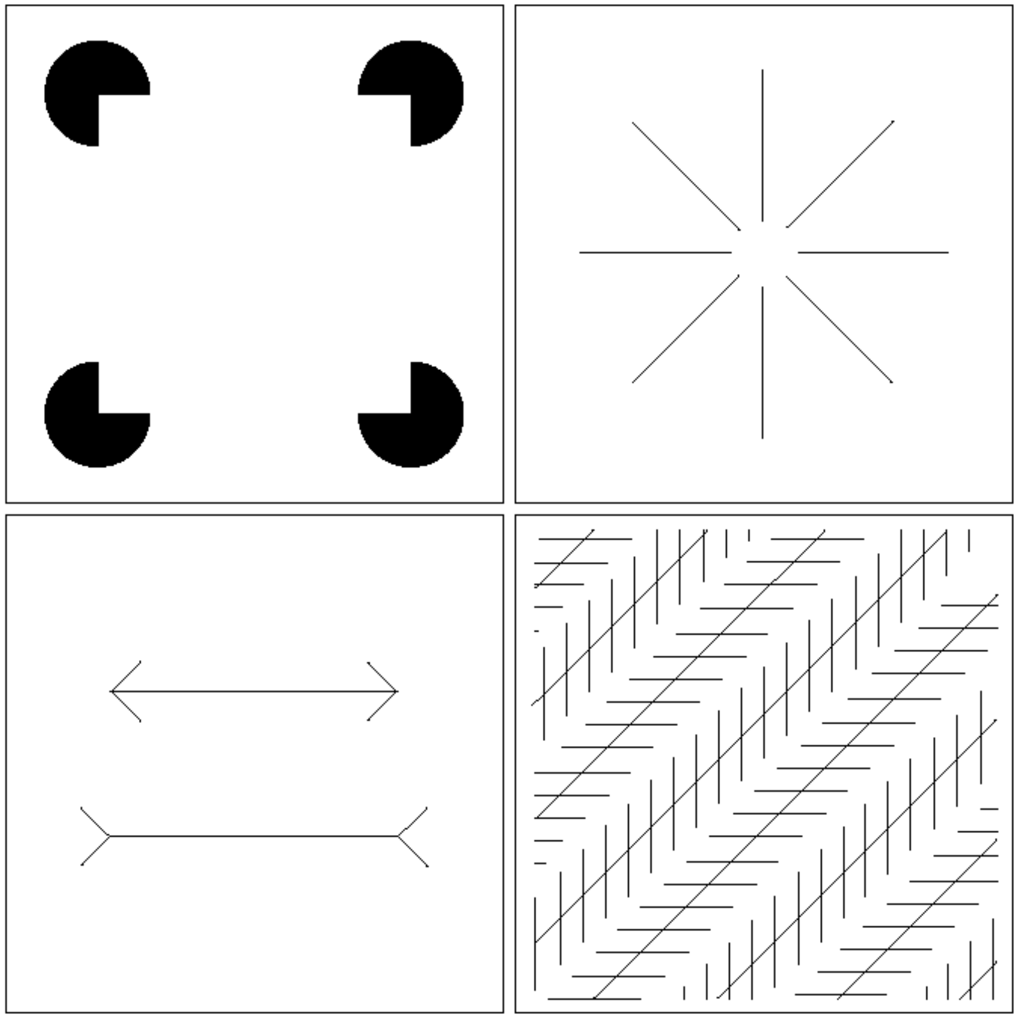
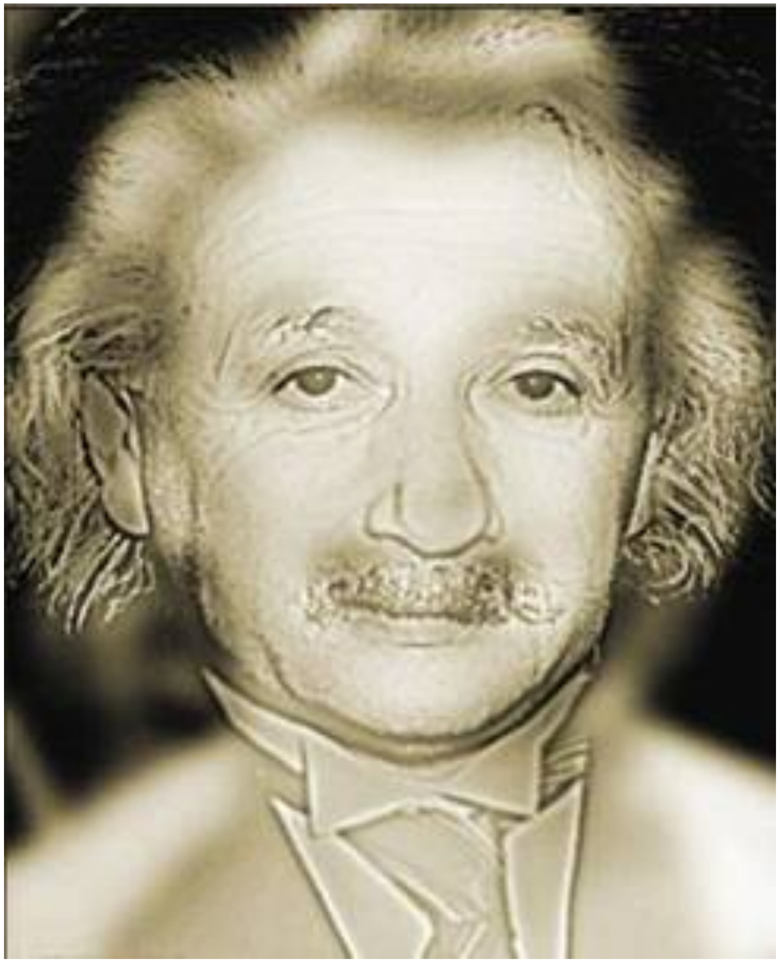


FIGURE 2.9 Some well-known optical illusions.

More Optical Illusions



http://www.123opticalillusions.com/

http://brainden.com/optical-illusions.htm

Slides courtesy of Prof. Yan Tong

More Optical Illusions

http://www.newopticalillusions.com/ambiguous-optical-illusions/can-you-see-the-dalmation/

Image Formation in the Eye

Image is upside down in the retina/imaging plane!

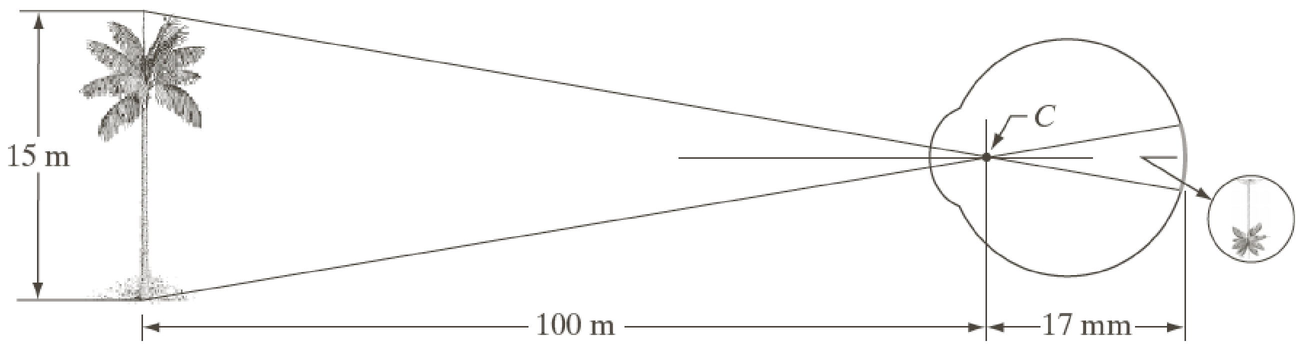
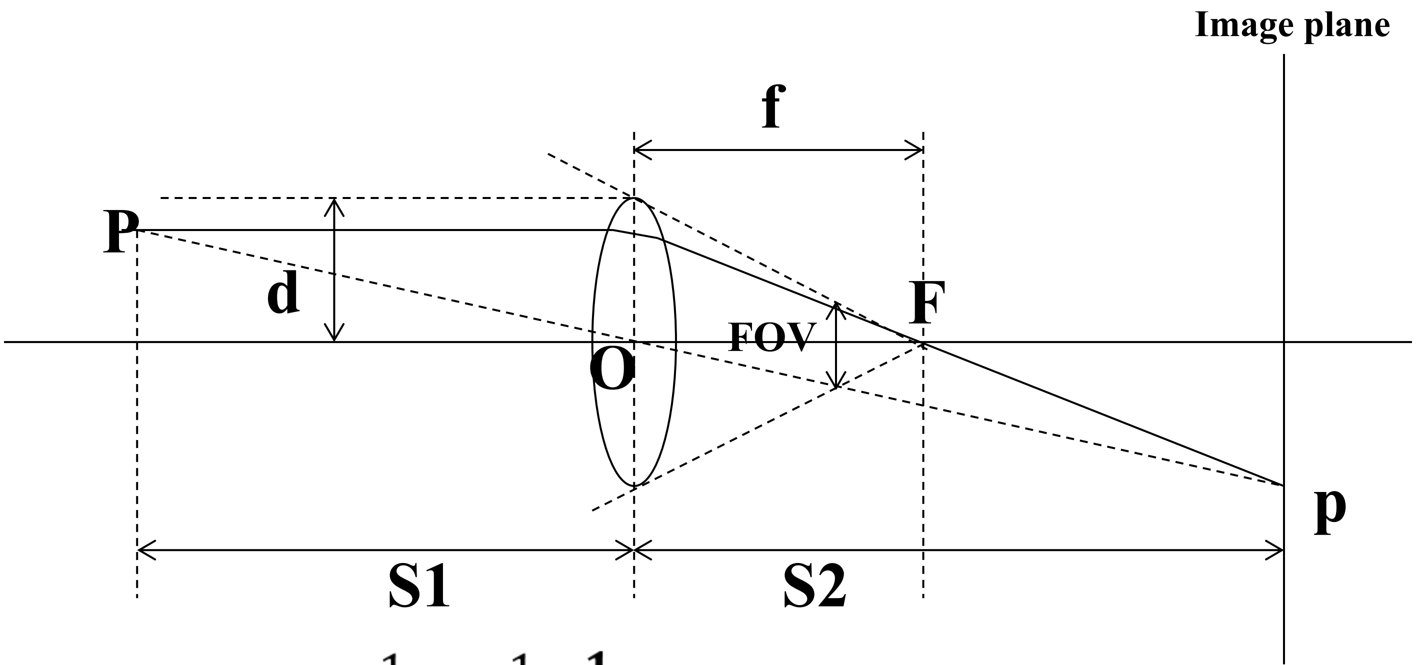


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Adjust focus length

- Camera
- Human eye

Lens Parameters



Thin lens theory: $\frac{1}{S1} + \frac{1}{S2} = \frac{1}{f}$

Field of View: $\omega = 2arctan\frac{d}{f}$

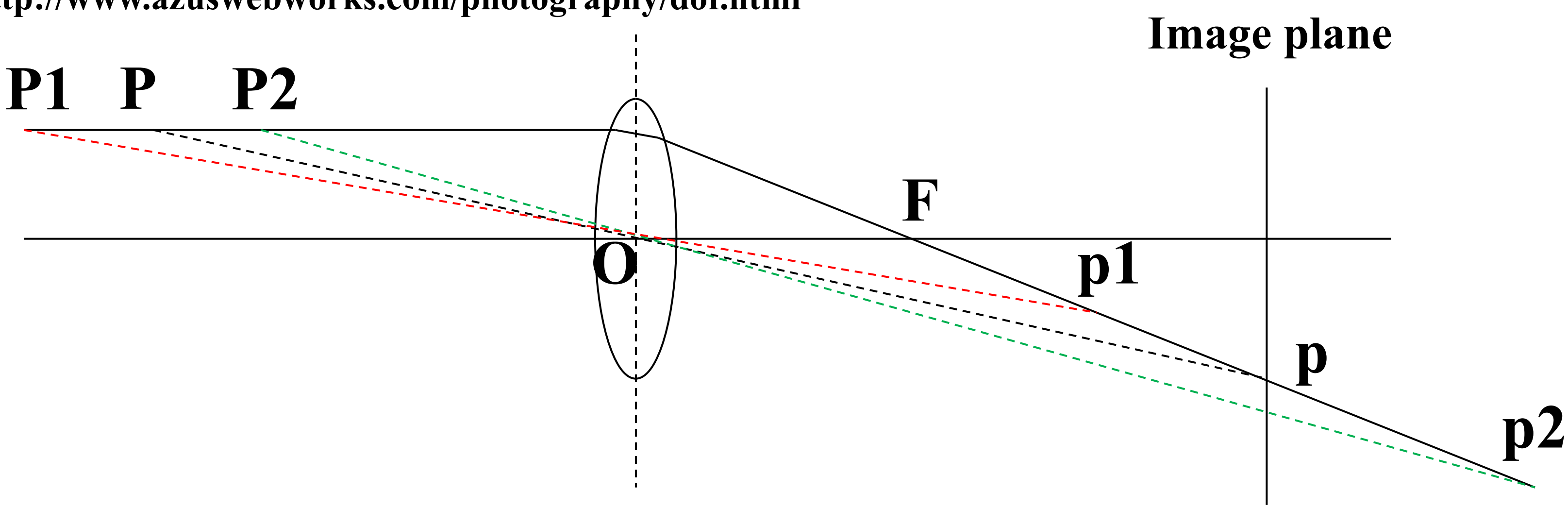
FOV

- **Increasing the distance from the object to the lens will reduce the size of image**
- **Large focus length will give a small FOV**

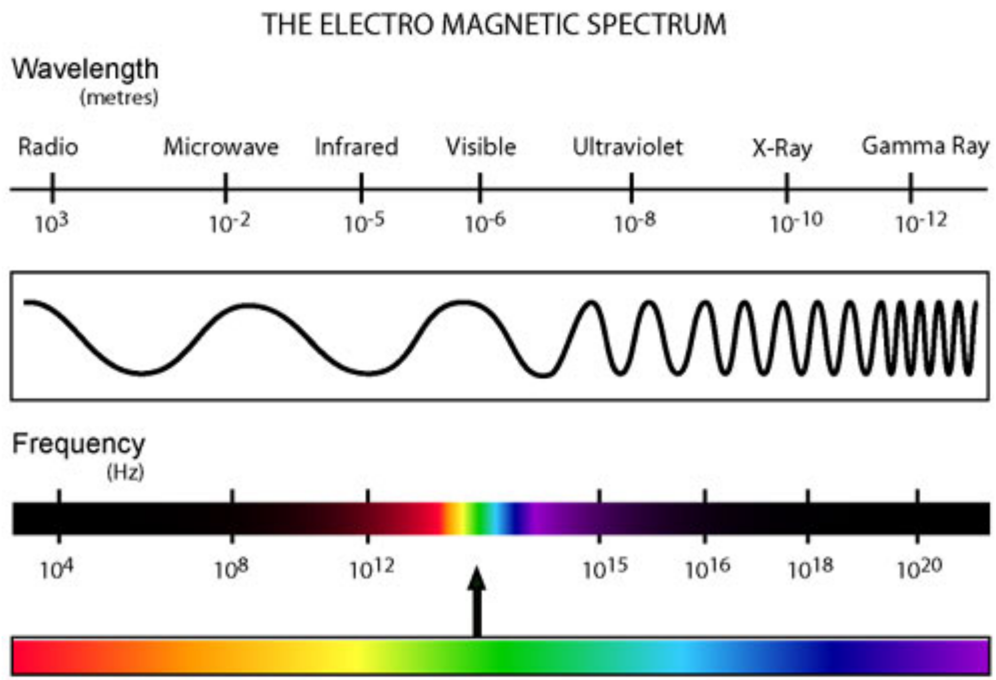
Depth of Field & Out of Focus

http://www.azuswebworks.com/photography/dof.html

- **DOF is inversely proportional to the focus length**
- **DOF is proportional to S1**



Light and EM Spectrum



http://www.kollewin.com/blog/electromagnetic-spectrum/

Relation Among Wavelength, Frequency and Energy

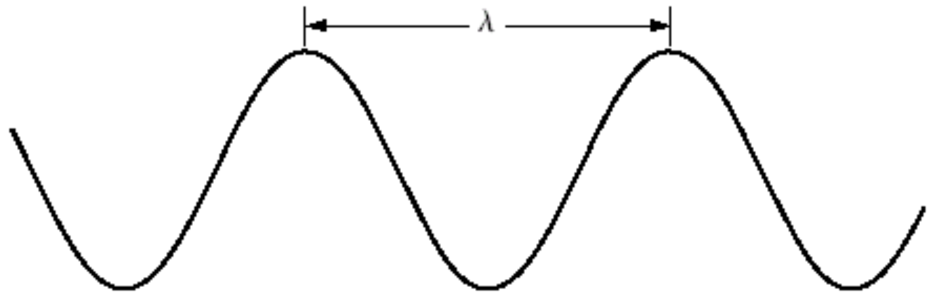


FIGURE 2.11 Graphical representation of one wavelength.

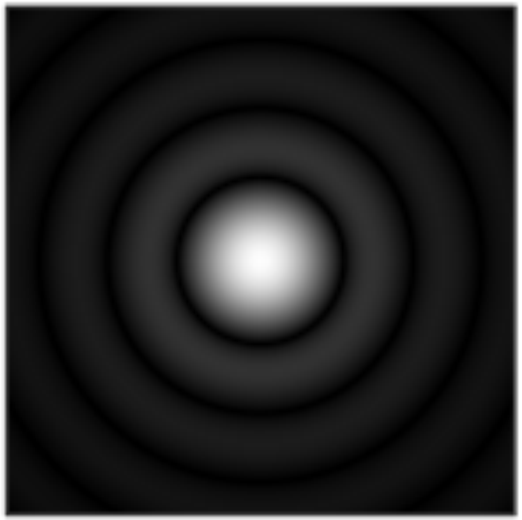
wavelength (λ), frequency (v), and energy (E)

$$\lambda = \frac{c}{v}, \quad c = 2.998 \times 10^{8}\, m/s \text{ is the speed of light}$$

$$E = hv, \ \ h \text{ is the Planck's constant, } 6.626068 \times 10^{-34} \text{ m}^2 \text{ kg / s}$$

Light and EM Spectrum

What size of the object you can "see"? Diffraction-limit.



http://en.wikipedia.org/wiki/Airy_disc

Airy disk: the size is proportional to wavelength and f-number (focal length/lens dimension)

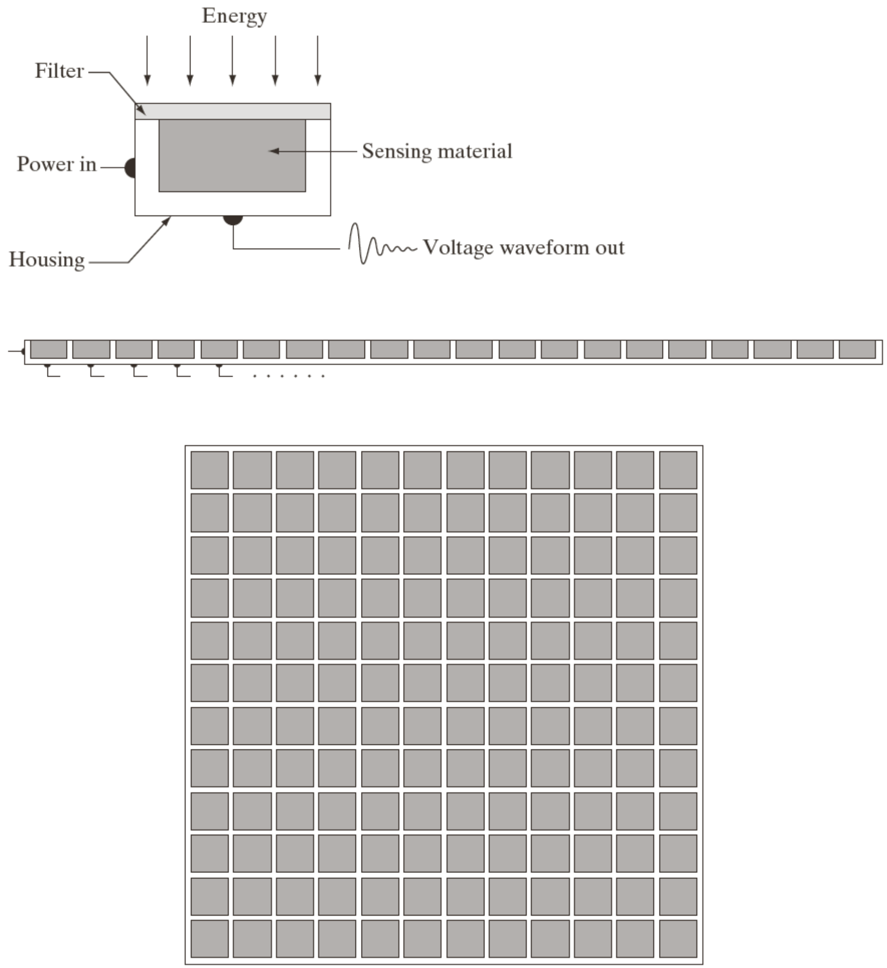
$$\sim \lambda \frac{f}{d}$$

Image Sensing and Acquisition

Illumination energy → digital images

Incoming energy is transformed into a voltage

Digitizing the response



a
b
c

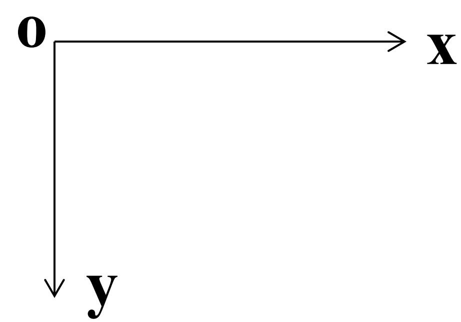
FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Slides courtesy of Prof. Yan Tong

A (2D) Image

An image = a 2D function *f*(*x*,*y*) where

- *x* and *y* are spatial coordinates
- *f*(*x*,*y*) is the intensity or gray level



A digital image:

- *x*, *y*, and *f*(*x*,*y*) are all finite
- For example $x \in \{1, 2, \ldots, M\}$, $y \in \{1, 2, \ldots, N\}$

$$f(x, y) \in \{0, 1, 2, \ldots, 255\}$$

Digital image processing → processing digital images by means of a digital computer

Each element (*x*,*y*) in a digital image is called a pixel (picture element)

A Simple Image Formation Model

$$f(x,y) = i(x,y) \cdot r(x,y)$$

$0 < f(x,y) < \infty$: **Image (positive and finite)**

Source: $0 < i(x,y) < \infty$: **Illumination component**

Object: $0 < r(x,y) < 1$: **Reflectance/transmission component**

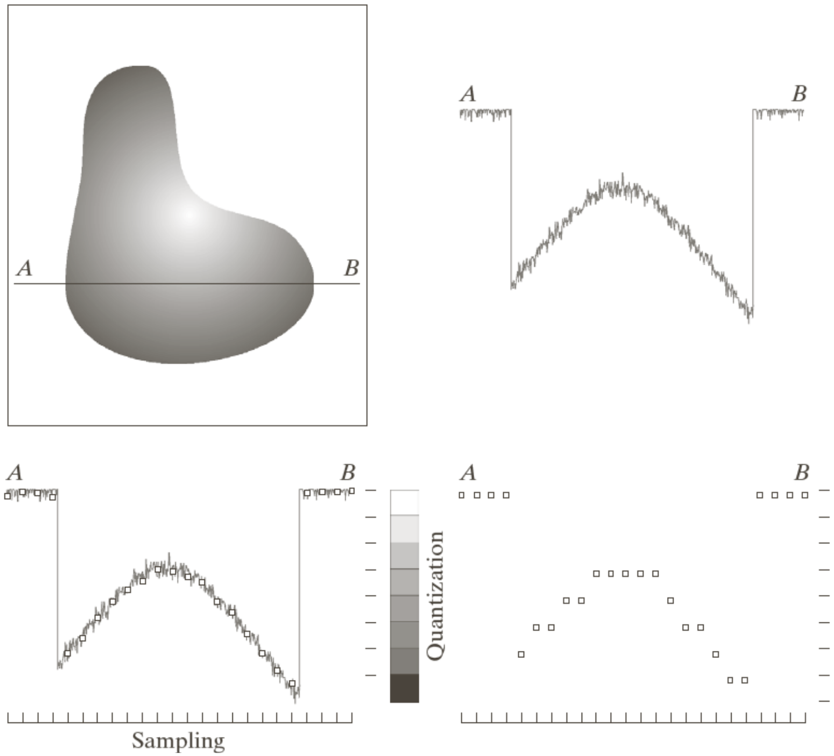
$L_{\min} < f(x,y) < L_{\max}$ **in practice**

where $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

i(x,y): **Sunlight: 10,000 lm/m^2 (cloudy), 90,000lm/m^2 clear day**
Office: 1000 lm/m^2

r(x,y): **Black velvet 0.01; white pall 0.8; 0.93 snow**

Image Sampling and Quantization



a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling: Digitizing the coordinate values (usually determined by sensors)

Quantization: Digitizing the amplitude values

Image Sampling and Quantization in a Sensor Array

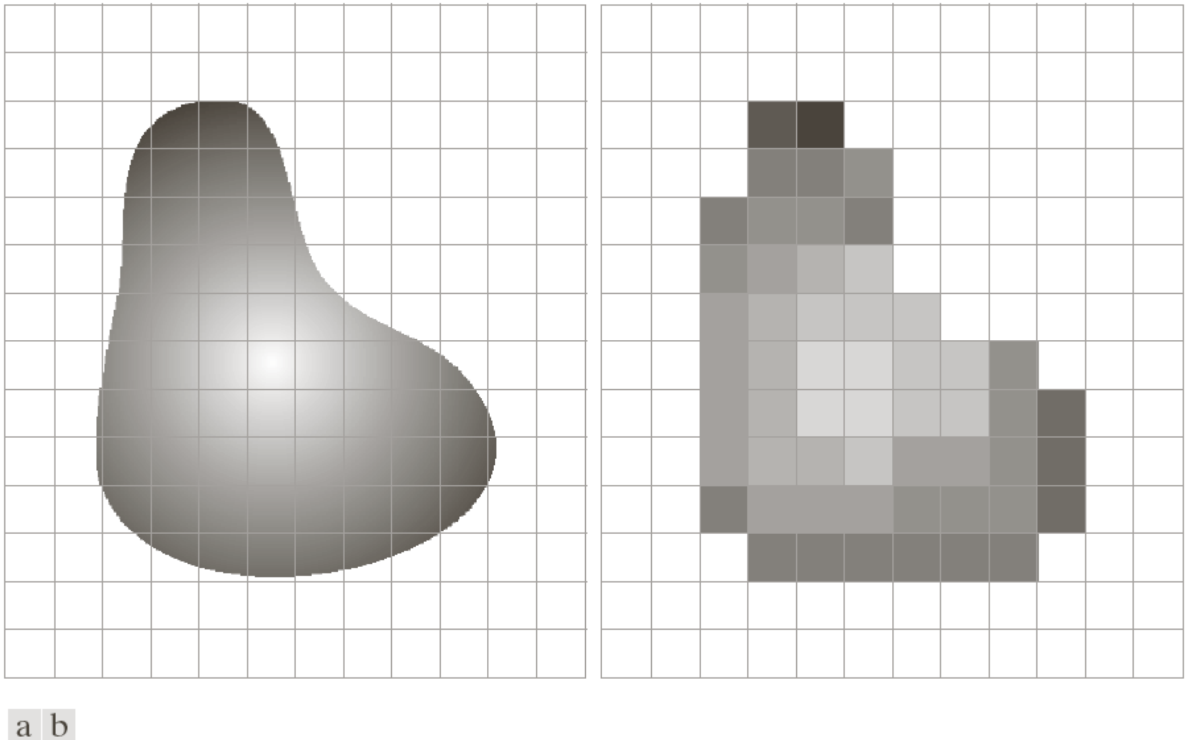


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

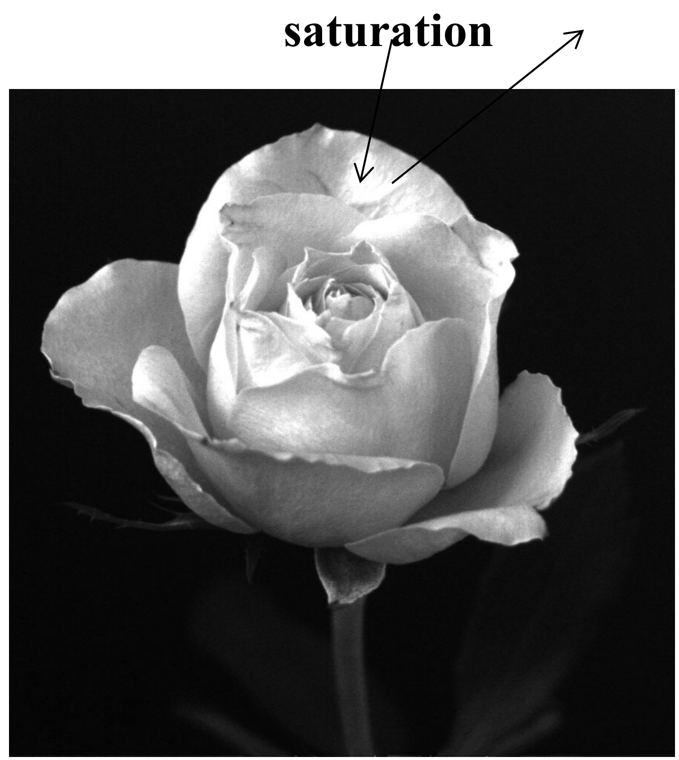
CCD array

Dynamic Range

$L_{\min} < f(x,y) < L_{\max}$ **in practice**

where $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

$0 \le f(x,y) \le L-1$ **and** $L = 2^k$



Dynamic range/contrast ratio:

the ratio of the maximum detectable intensity level (saturation) to the minimum detectable intensity level (noise)

$$\frac{I_{max}}{I_{min}}$$

High Dynamic Range

https://en.wikipedia.org/wiki/High-dynamic-range_imaging

High Dynamic Range

High Dynamic Range

High Dynamic Range

High Dynamic Range

Representing Digital Images

(a): $f(x,y)$, x=0, 1, …, M-1, y=0,1, …, N-1

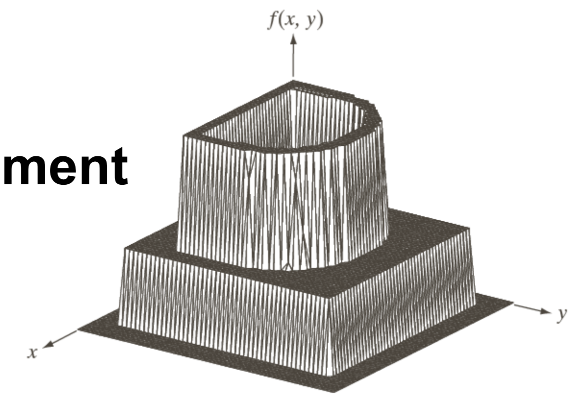
x, y: spatial coordinates → spatial domain

(b): suitable for visualization

(c): processing and algorithm development

x: extend downward (rows)

y: extend to the right (columns)



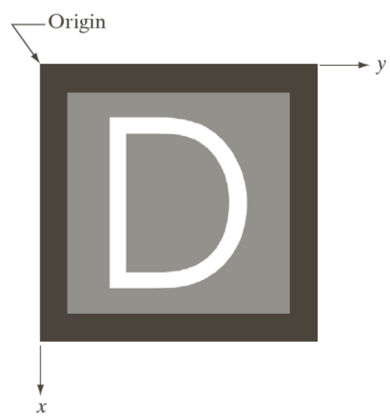
Number of bits storing the image

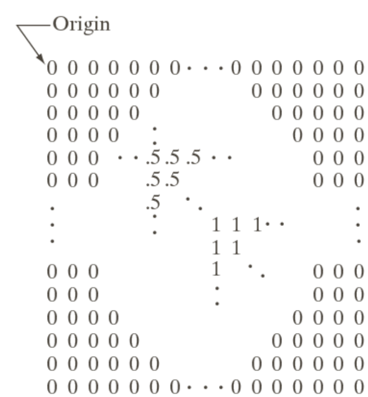
↑

$$b = M \times N \times k$$

a
b c

FIGURE 2.18 (a) Image plotted as a surface. (b) Image displayed as a visual intensity array. (c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).





Spatial Resolution

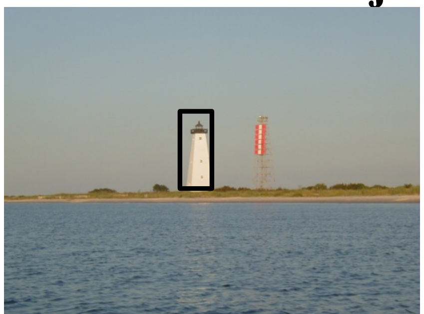
Spatial resolution: smallest discernible details

- # of line pairs per unit distance
- # of dots (pixels) per unit distance
  - Printing and publishing
  - In US, dots per inch (dpi)

Newspaper → magazines → book

Large image size itself does not mean high spatial resolution!

→ **Scene/object size in the image**



1280*960

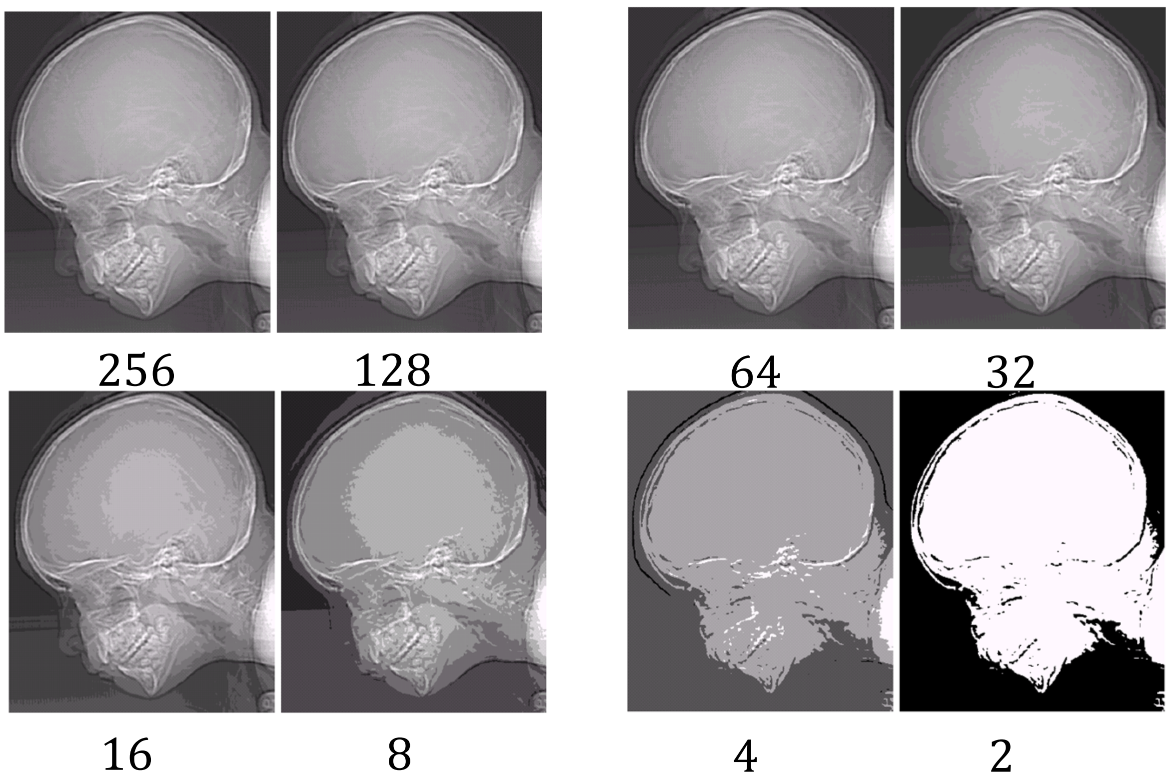
http://www.shimanodealer.com/fishing_reports.htm

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Intensity Resolution

Intensity resolution

- Smallest discernible change in intensity levels
- Using the number of levels of intensities
- False contouring (banding) when *k* is small - undersampling



Isopreference Curves

FIGURE 2.22 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

Vary the spatial and intensity sampling simultaneously:

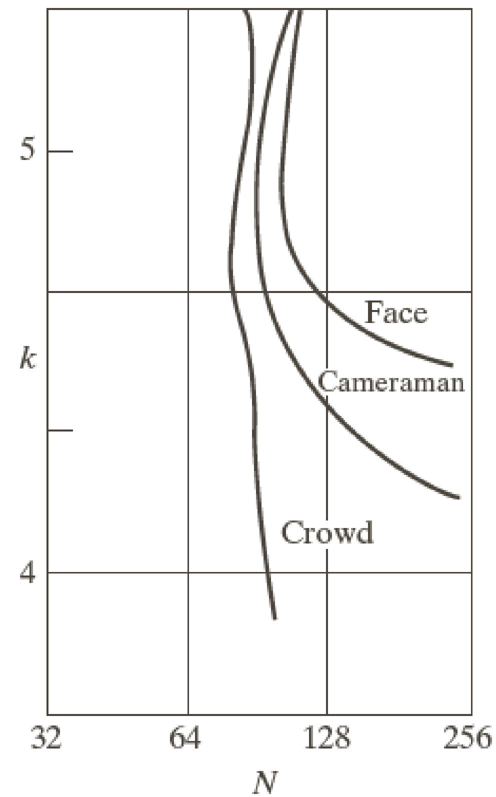


FIGURE 2.23 Typical isopreference curves for the three types of images in Fig. 2.22.

Data heavy

From GoPro HERO3+ at Barbados 2015 Field Trials

1920

$$1080 \quad \begin{bmatrix} 43 & 43 & 42 & 40 & 39 & \cdots & 29 & 29 & 31 & 33 \\ 42 & 41 & 40 & 39 & 38 & \cdots & 31 & 32 & 35 & 37 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ 54 & 57 & 60 & 62 & 66 & \cdots & 42 & 43 & 56 & 46 \end{bmatrix} \quad R$$

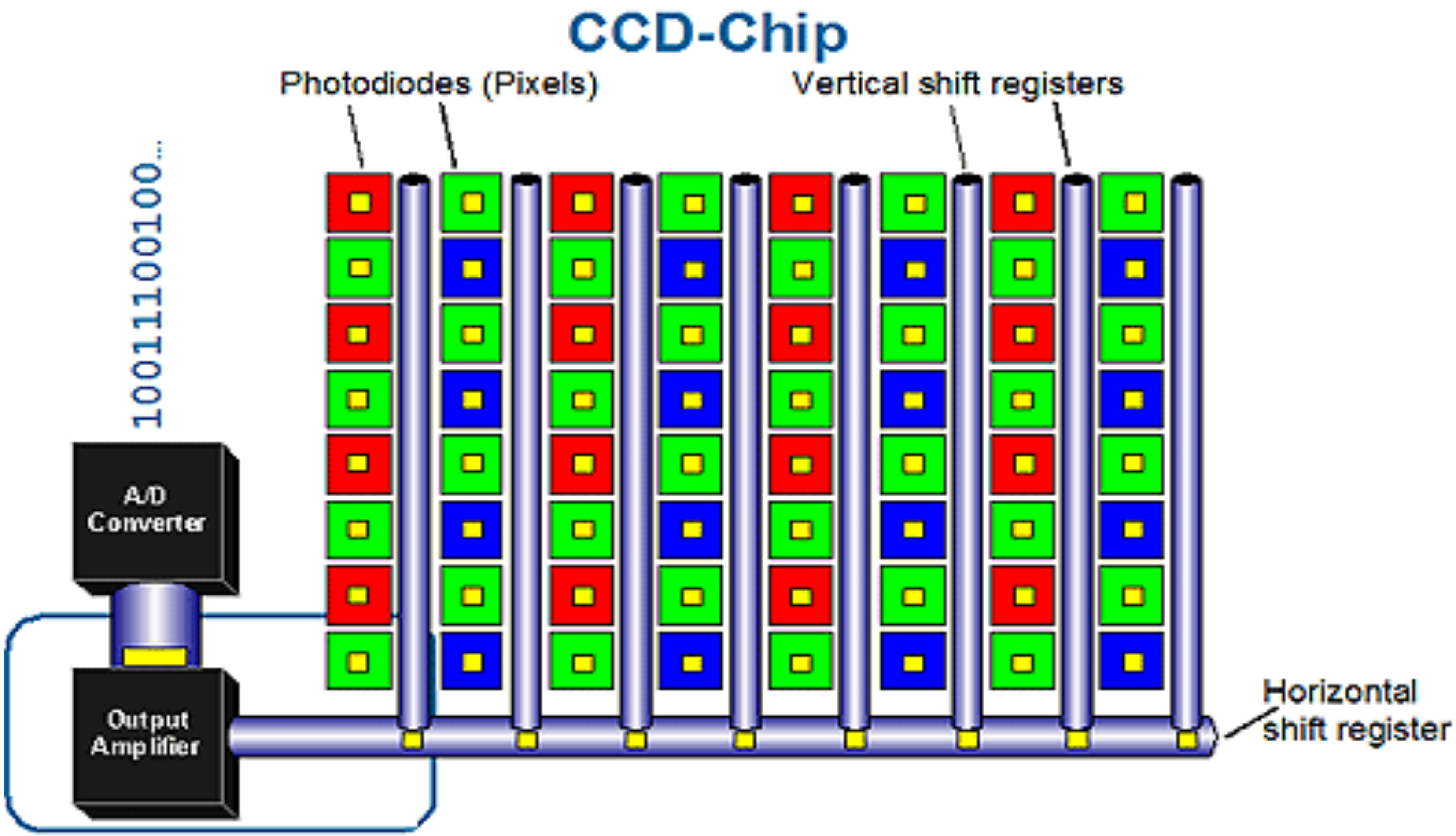
$$1080 \quad \begin{bmatrix} 129 & 129 & 129 & 129 & 128 & \cdots & 149 & 149 & 151 & 153 \\ 128 & 128 & 127 & 128 & 127 & \cdots & 151 & 152 & 155 & 157 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ 146 & 146 & 148 & 148 & 148 & \cdots & 149 & 150 & 151 & 152 \end{bmatrix} \quad G$$

$$1080 \quad \begin{bmatrix} 146 & 146 & 146 & 145 & 146 & \cdots & 166 & 166 & 168 & 170 \\ 145 & 145 & 144 & 144 & 145 & \cdots & 168 & 169 & 172 & 174 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ 159 & 160 & 160 & 161 & 162 & \cdots & 165 & 166 & 165 & 166 \end{bmatrix} \quad B$$

Aliasing

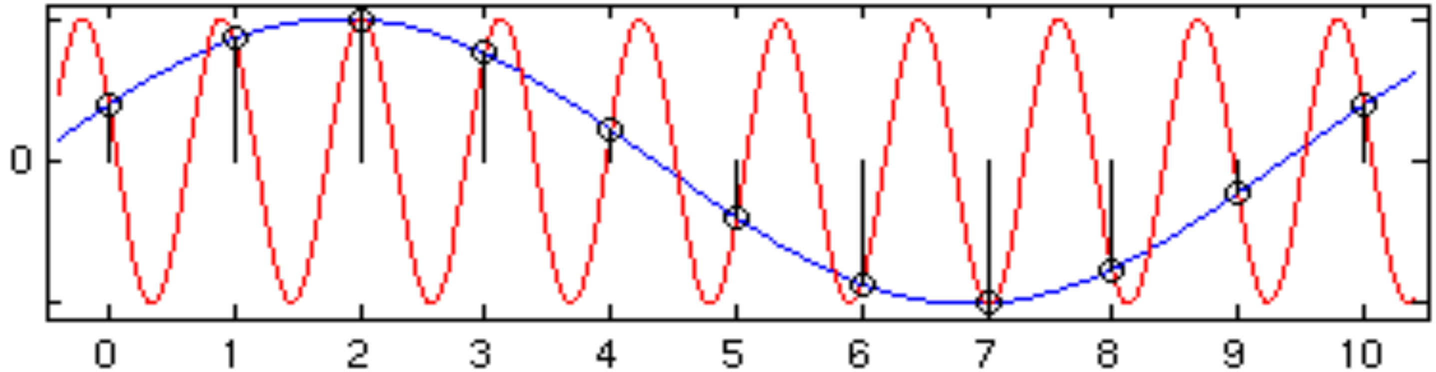
- Images are not actually continuous.
- The sampling (and hardware) issues lead to a few other minor problems.

Aliasing



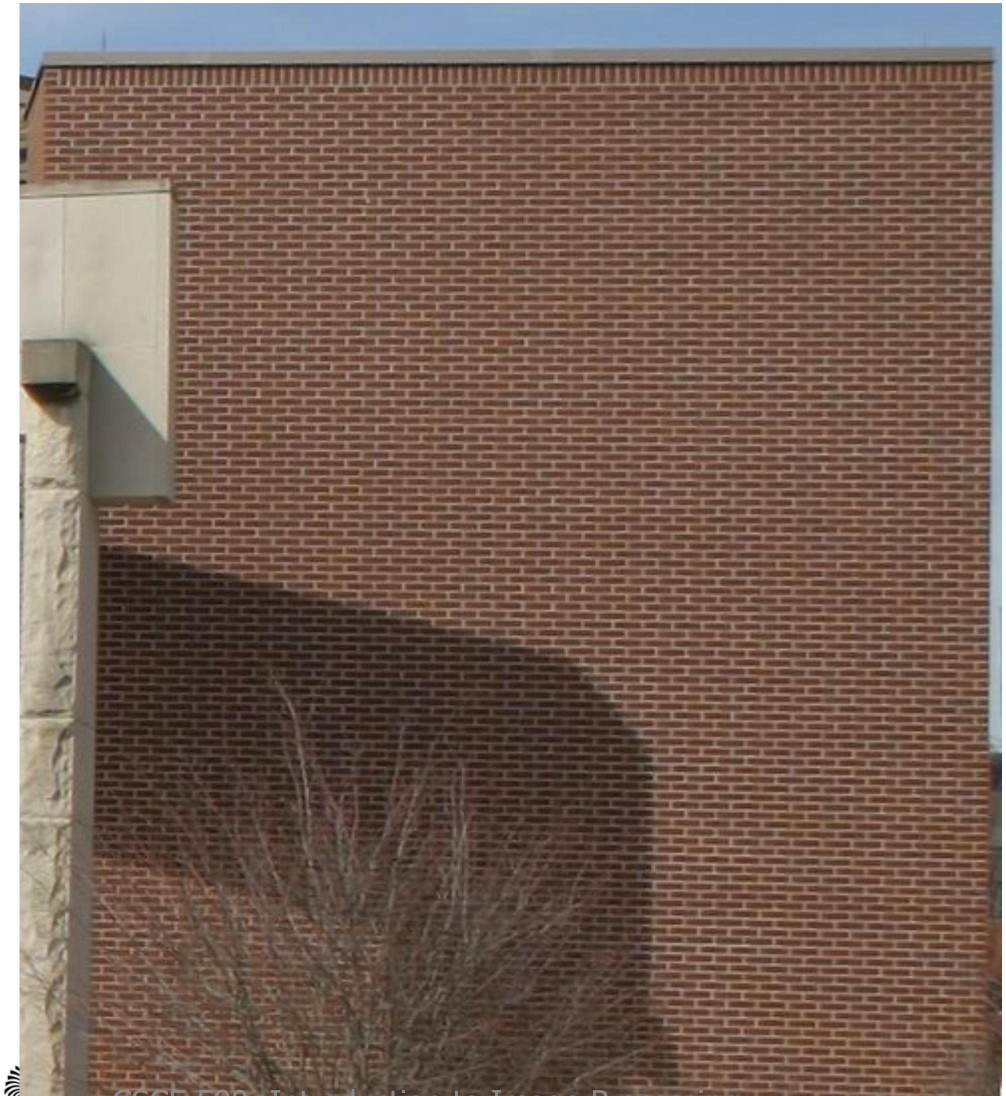
CCD-Chip
Photodiodes (Pixels)
Vertical shift registers
10011100100...
A/D Converter
Output Amplifier
Horizontal shift register

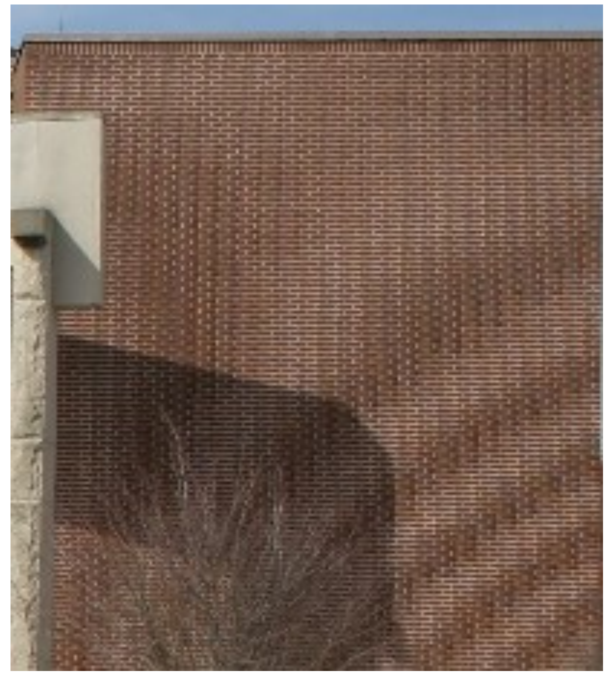
Aliasing



- To avoid: $f_{sampling} > 2F_{max}$
  - Nyquist Rate

Aliasing: Moiré Patterns





Ill-posed

- What a camera does to the 3d world...

Shigeo Fukuda

squeezes away one dimension

http://www.psychologie.tu-dresden.de/i1/kaw/diverses Material/www.illusionworks.com/html/art_of_shigeo_fukuda.html

Ill-posed

- What a camera does to the 3d world…

Shigeo Fukuda

http://www.psychologie.tu-dresden.de/i1/kaw/diverses Material/www.illusionworks.com/html/art_of_shigeo_fukuda.html

Ill-posed

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.

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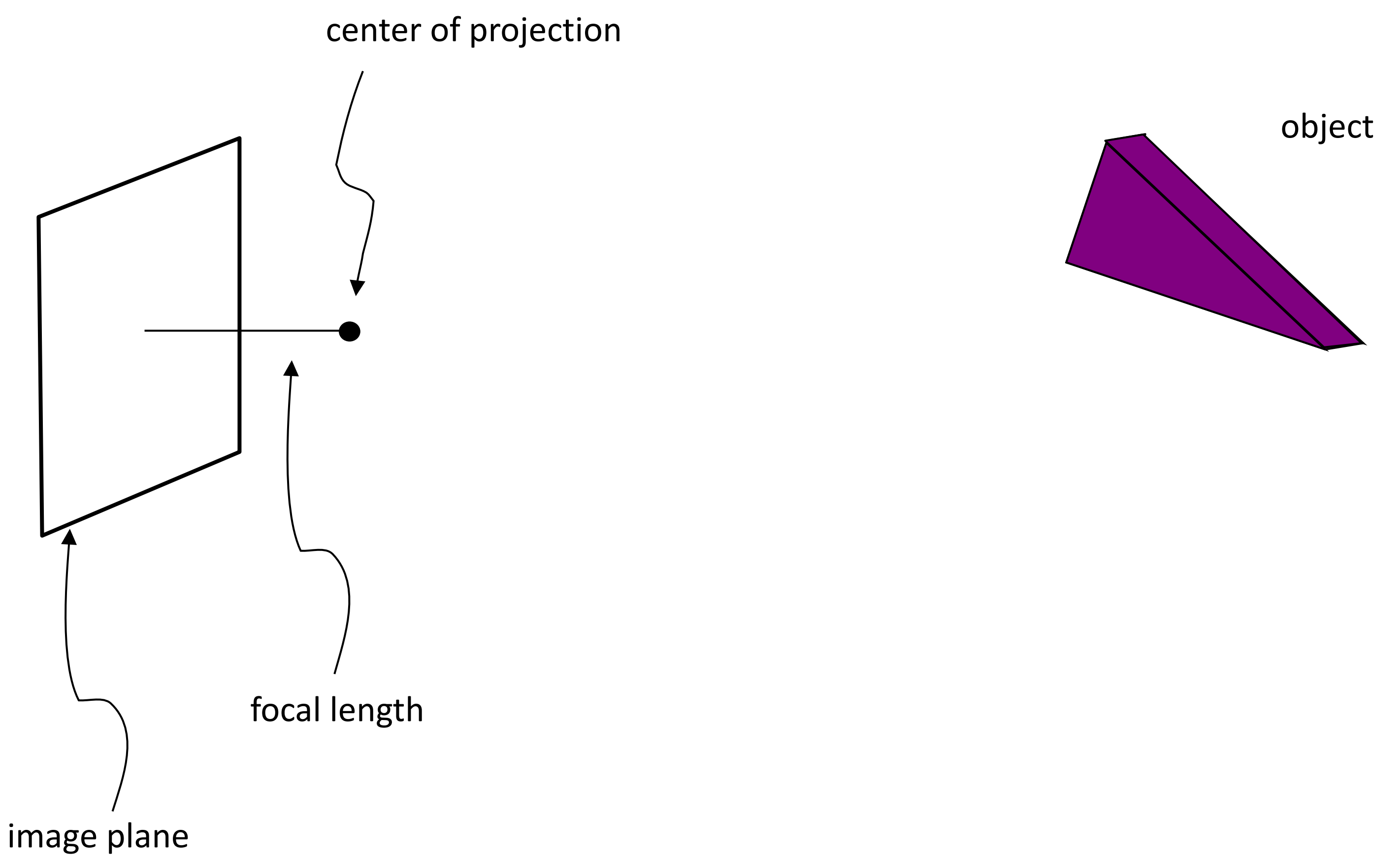
Ill-posed

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.

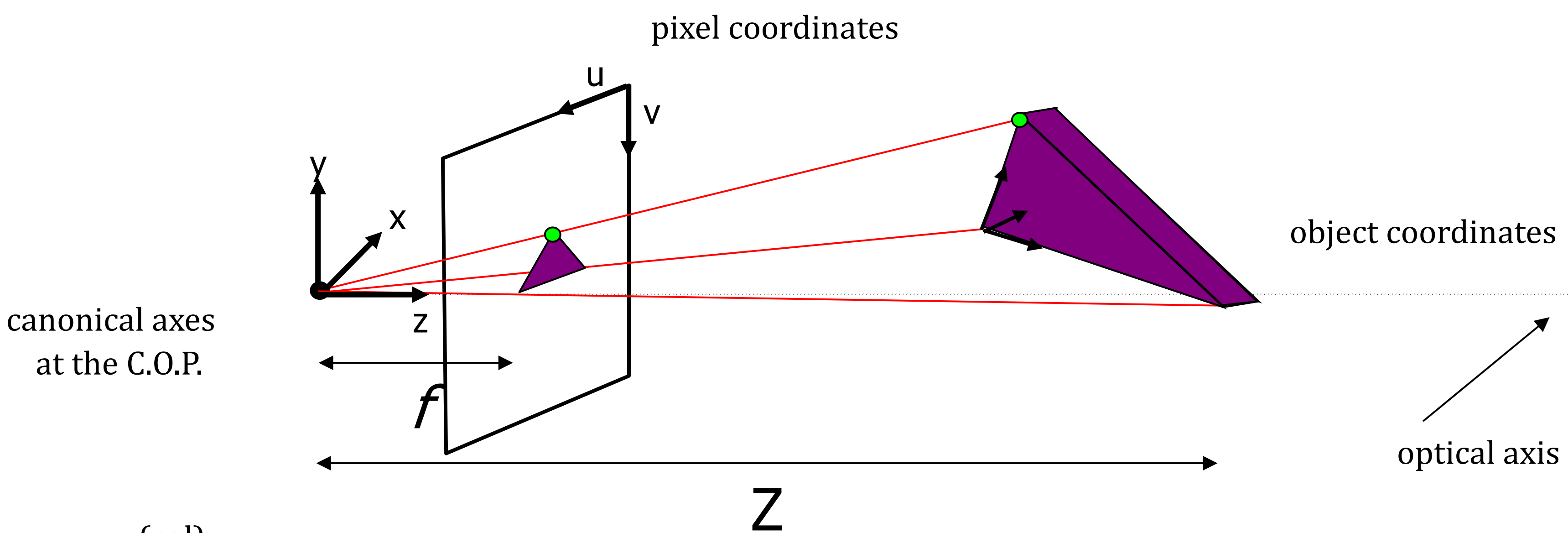
  – An image isn't enough to disambiguate the many possible 3d worlds that could have produced it.

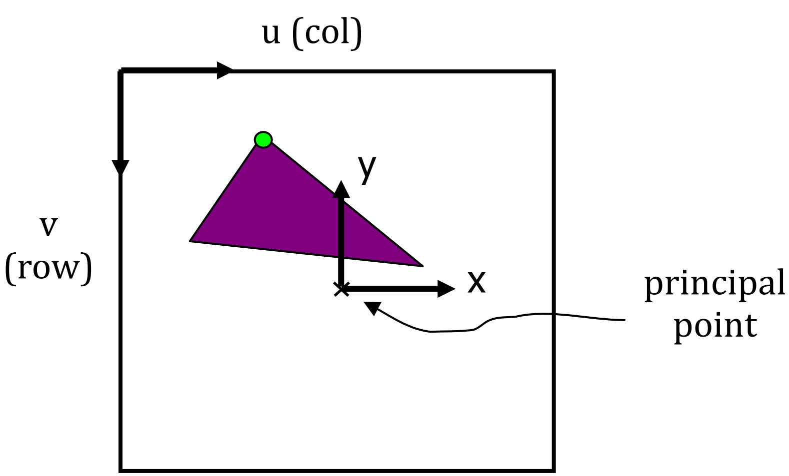
Camera Geometry

3D→2D transformation: perspective projection



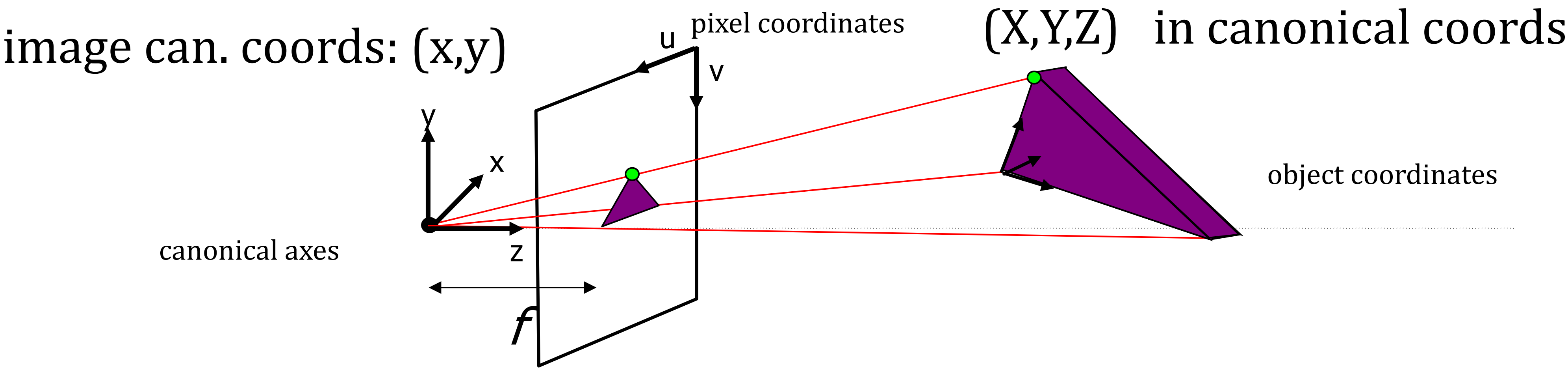
Coordinate Systems



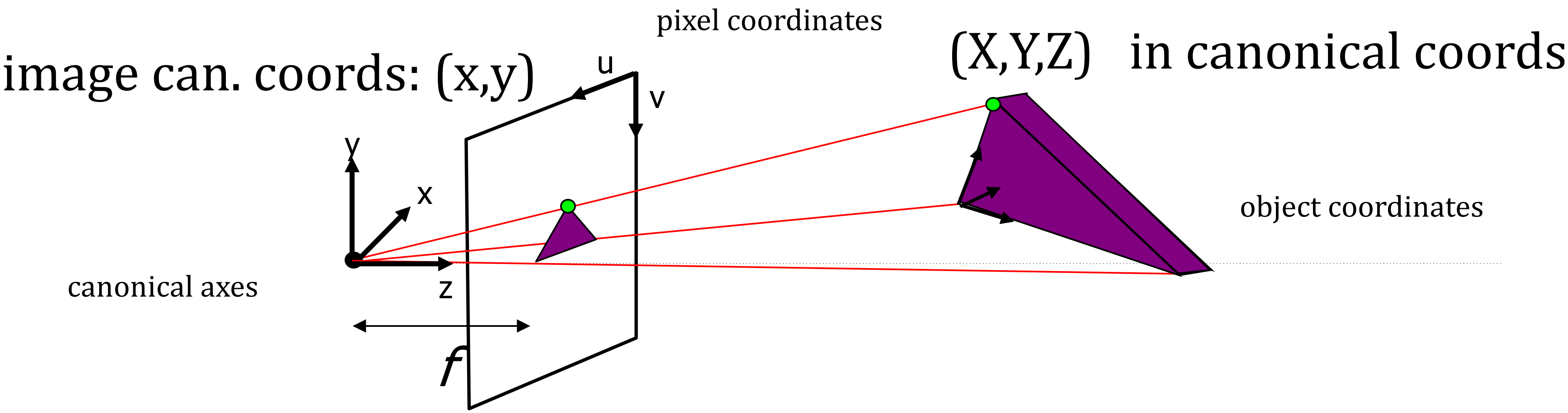


Add coordinate systems in order to describe feature points...

Coordinate Systems



From 3d to 2d



$$x = \frac{fX}{Z} \qquad y = \frac{fY}{Z}$$

a <u>nonlinear</u> transformation

goal: to recover information about (X,Y,Z) from (x,y)

Camera Calibration

- Camera Model
  - [*u v 1*] Pixel coords
  - $[x_w \quad y_w \quad z_w \quad 1]^T$ World coords

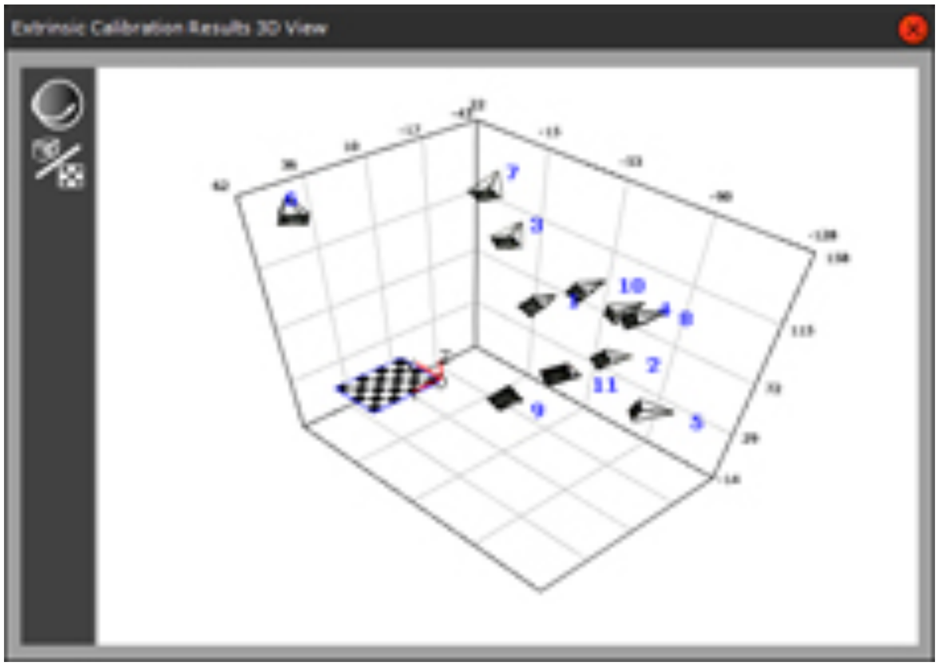
$$z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A[R \quad T] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

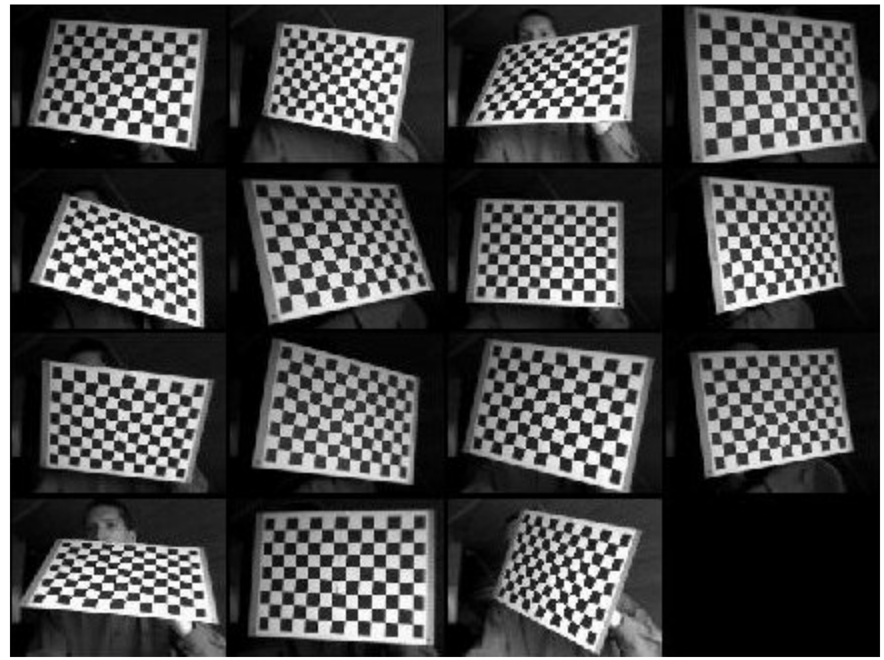
- Intrinsic Parameters
  - $\alpha_x = f \cdot m_x, \alpha_y = f \cdot m_y$ focal lengths in pixels
  - γ skew coefficient
  - u_0, v_o focal point

$$A = \begin{bmatrix} \alpha_x & \gamma & u_0 \\ 0 & \alpha_y & v_o \\ 0 & 0 & 1 \end{bmatrix}$$

- Extrinsic Parameters
  - $[R \quad T]$ Rotation and Translation

Camera Calibration





Existing packages in MATLAB, OpenCV, etc

Rectified Image Sample

Unrectified

Rectified

From Clearpath Husky Axis M1013 camera

Rectified Image Sample

Unrectified

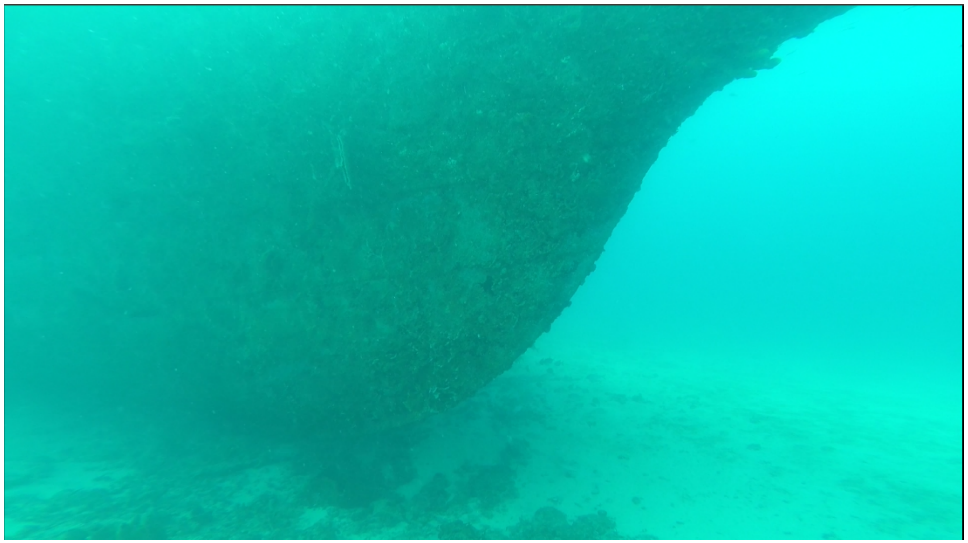
From Parrot ARDrone 2.0 front camera

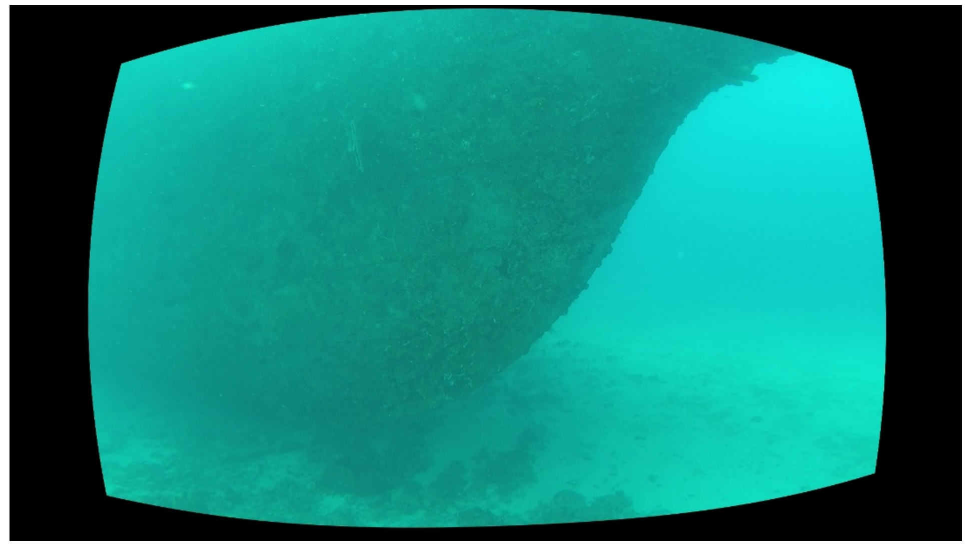
Rectified

Rectified Image Sample

Unrectified

Rectified



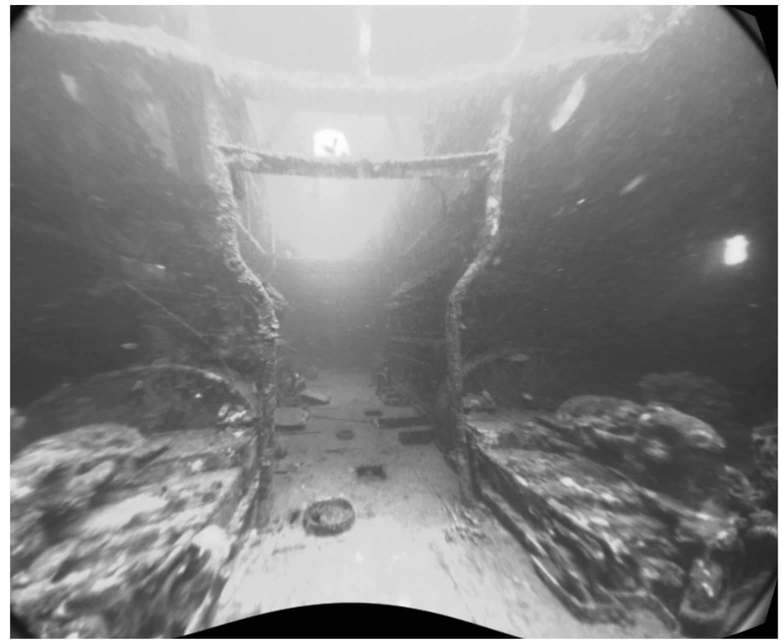


From GoPro HERO3+ at Barbados 2015 Field Trials

ReRectified Image Sample

Rectified

ReRectified



From Aqua front camera at Barbados 2013 Field Trials