UNIVERSITY OF
SOUTH CAROLINA

CSCE 590 INTRODUCTION TO IMAGE PROCESSING

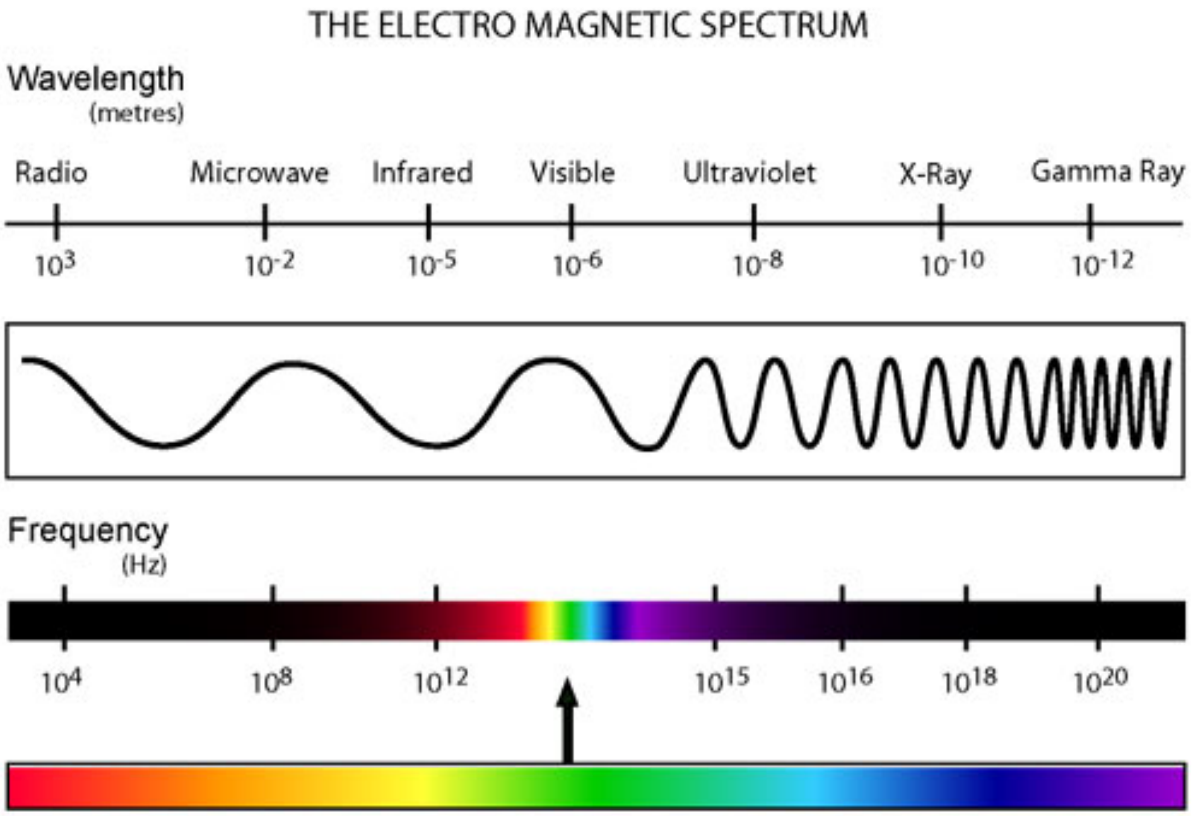
Image Generation

Perspective Transformation

Ioannis Rekleitis

Human Perception VS Machine Vision

- **Limited vs entire EM spectrum**



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

Slides courtesy of Prof. Yan Tong

Image Acquisition and Representation

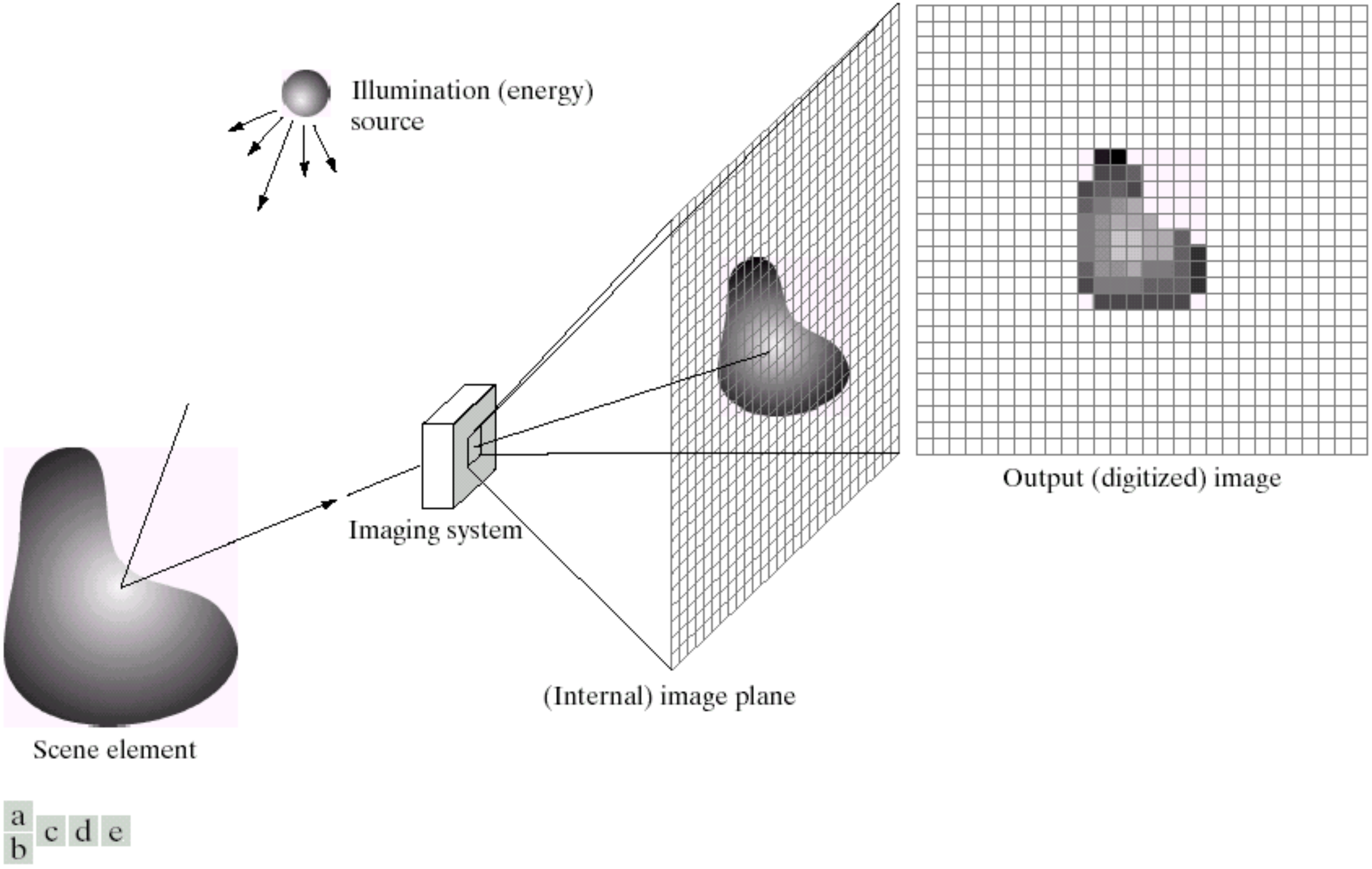
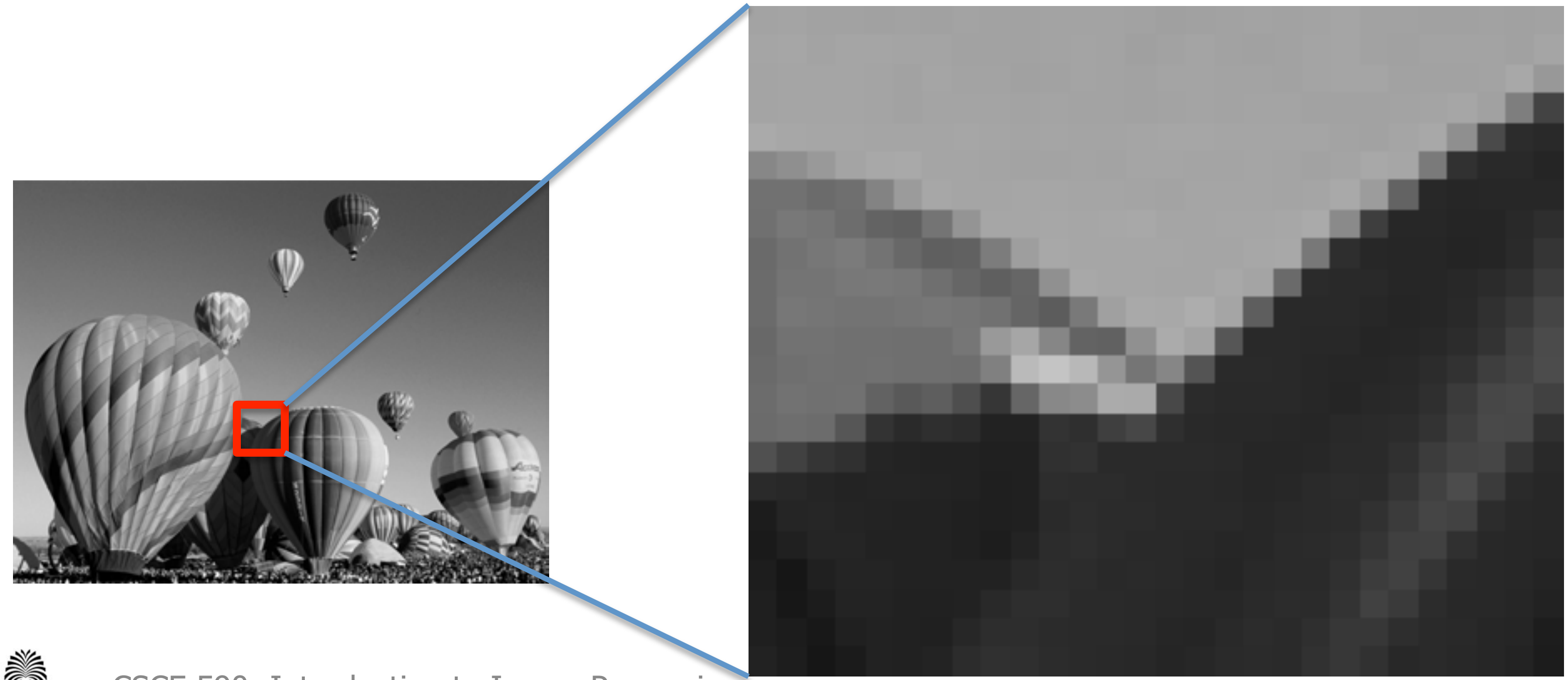


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Slides courtesy of Prof. Yan Tong

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

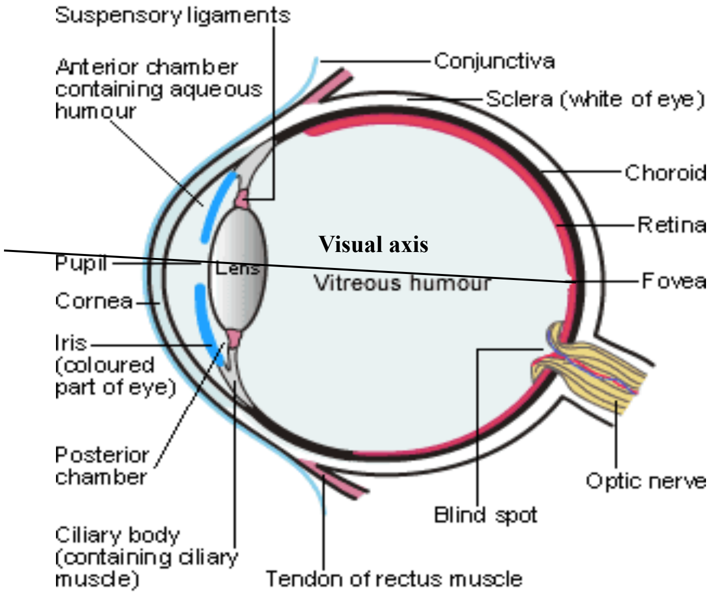
Elements of Human Visual Perception

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

Slides courtesy of Prof. Yan Tong

Distribution of Rods and Cones in the Retina

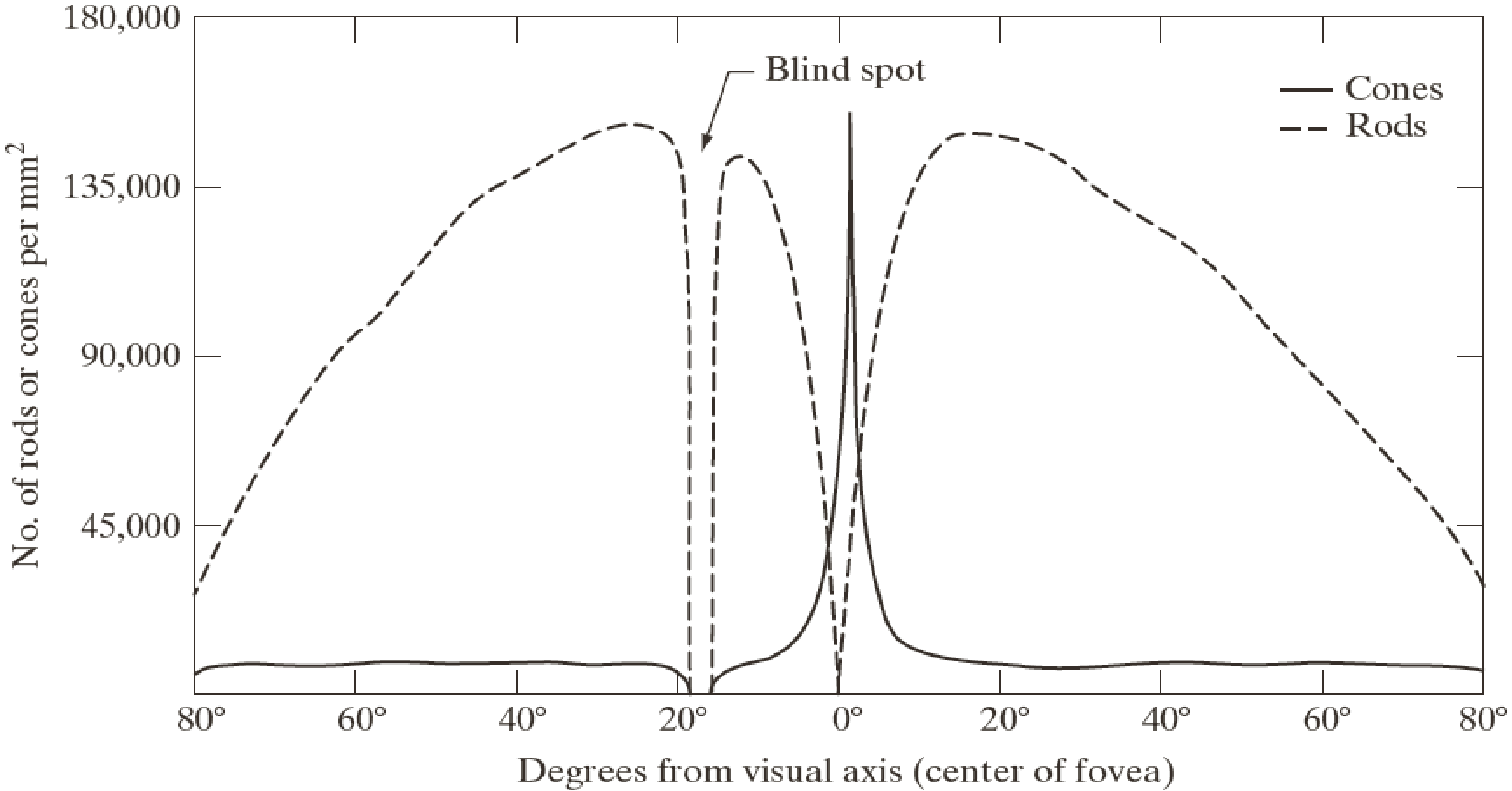


FIGURE 2.2 Distribution of rods and cones in the retina.

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

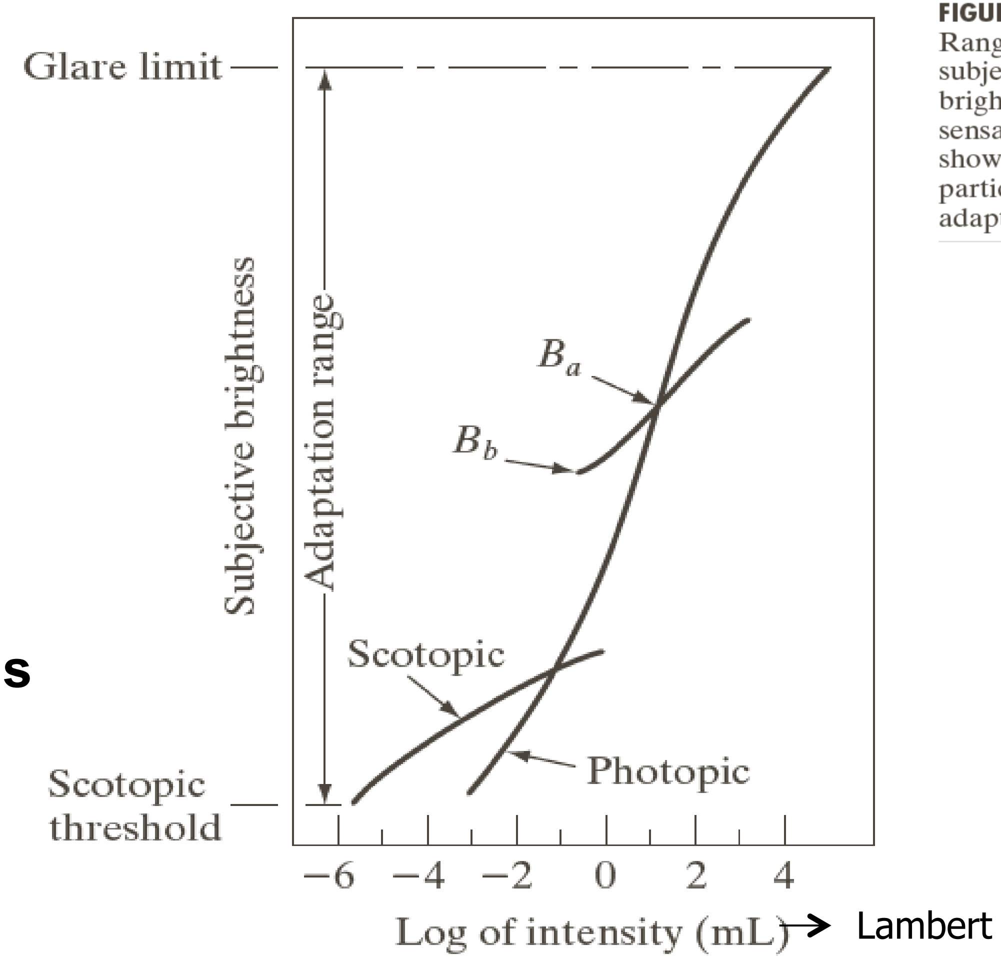


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

Slides courtesy of Prof. Yan Tong

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

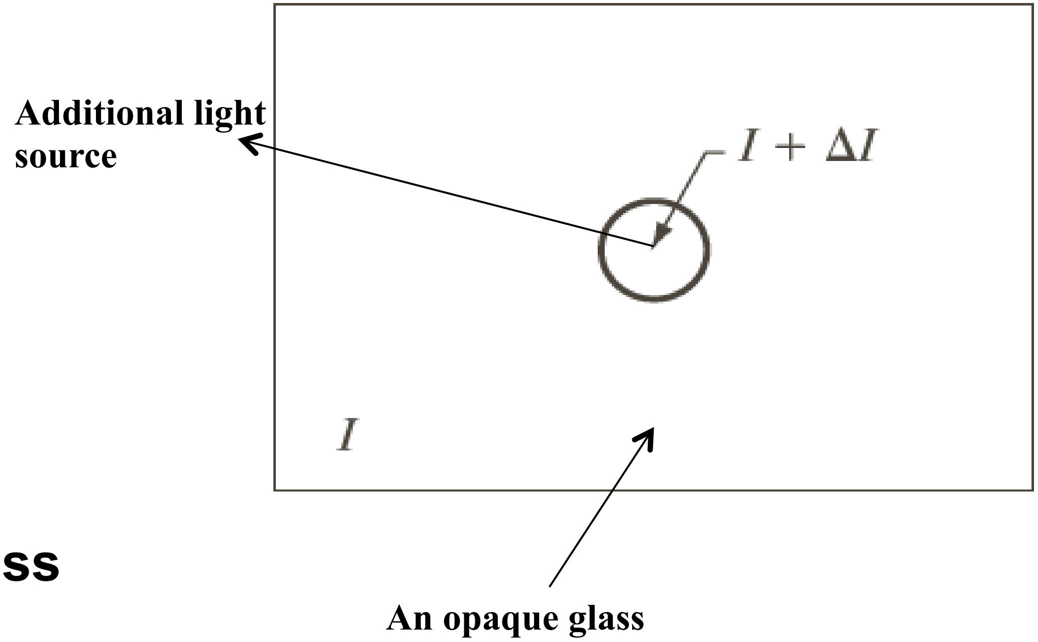


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Slides courtesy of Prof. Yan Tong

Brightness Discrimination at Different Intensity Levels

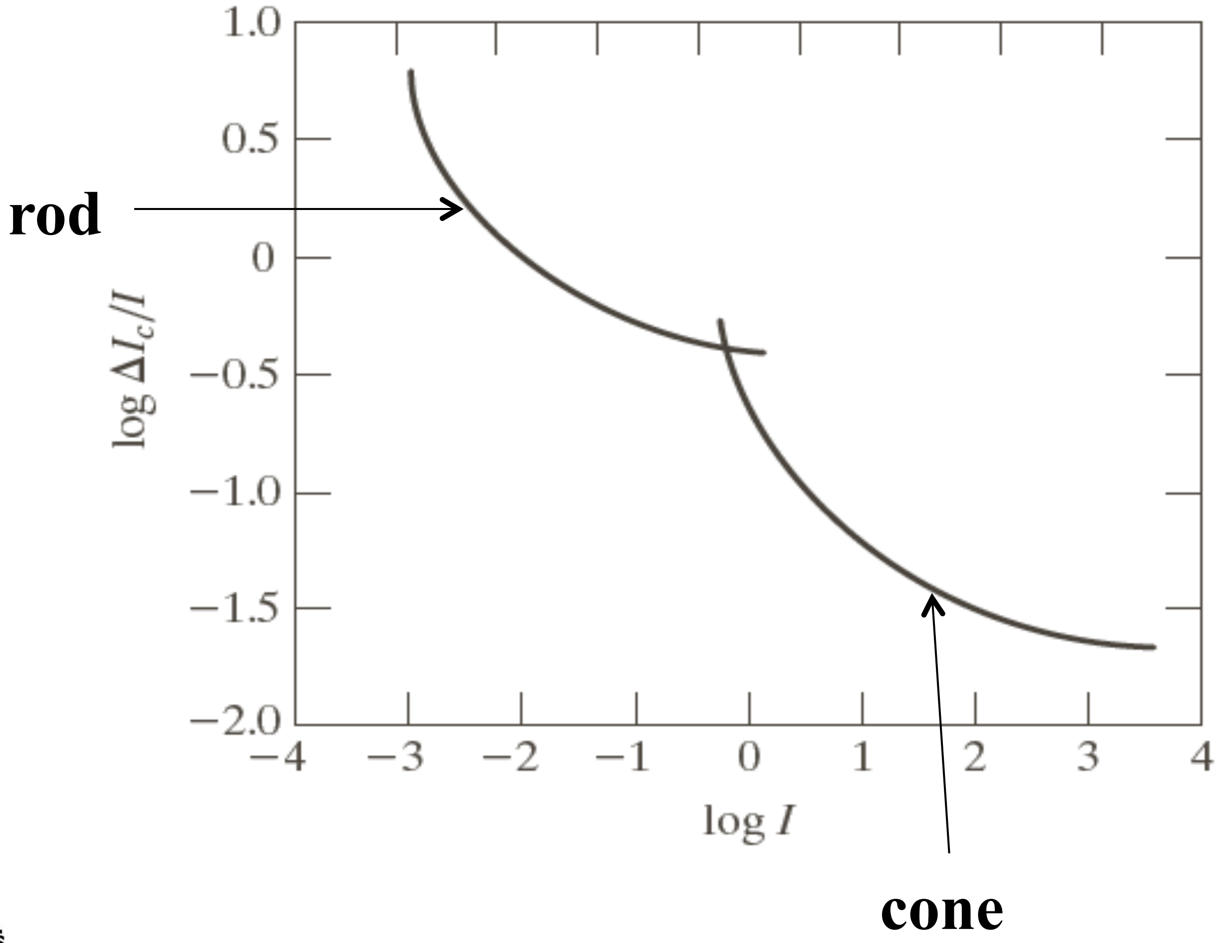


FIGURE 2.6 Typical Weber ratio as a function of intensity.

Slides courtesy of Prof. Yan Tong

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

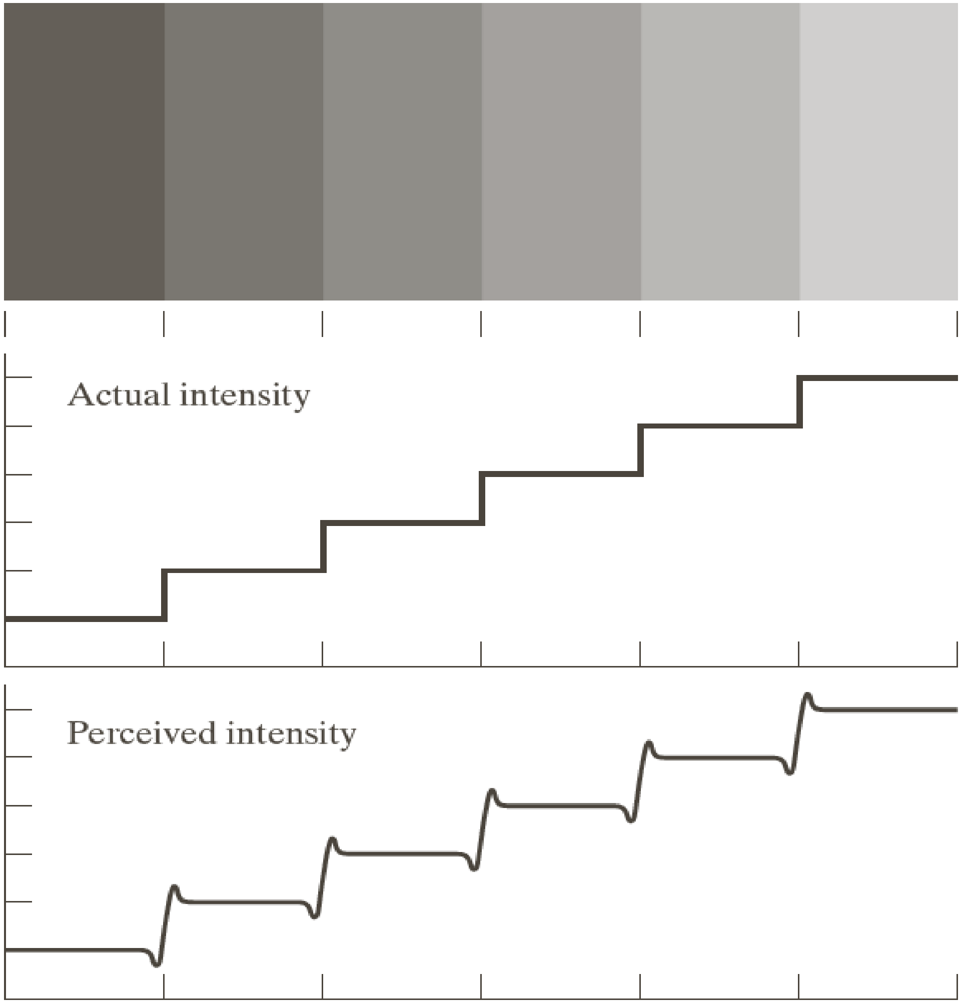


FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

Slides courtesy of Prof. Yan Tong

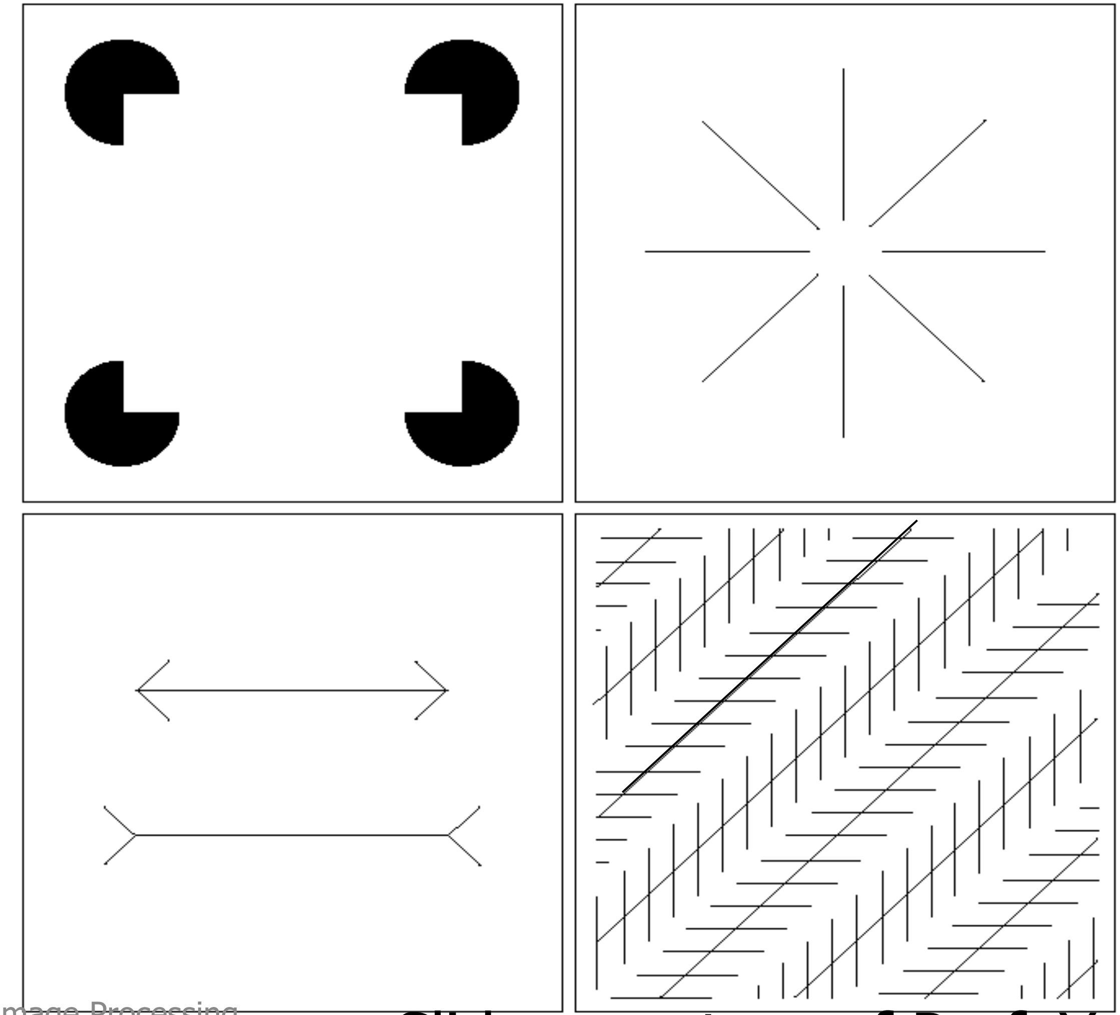
Perceived Intensity is Not a Simple Function of the Actual Intensity – Simultaneous Contrast

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.

Slides courtesy of Prof. Yan Tong

Optical Illusions: Complexity of Human Vision

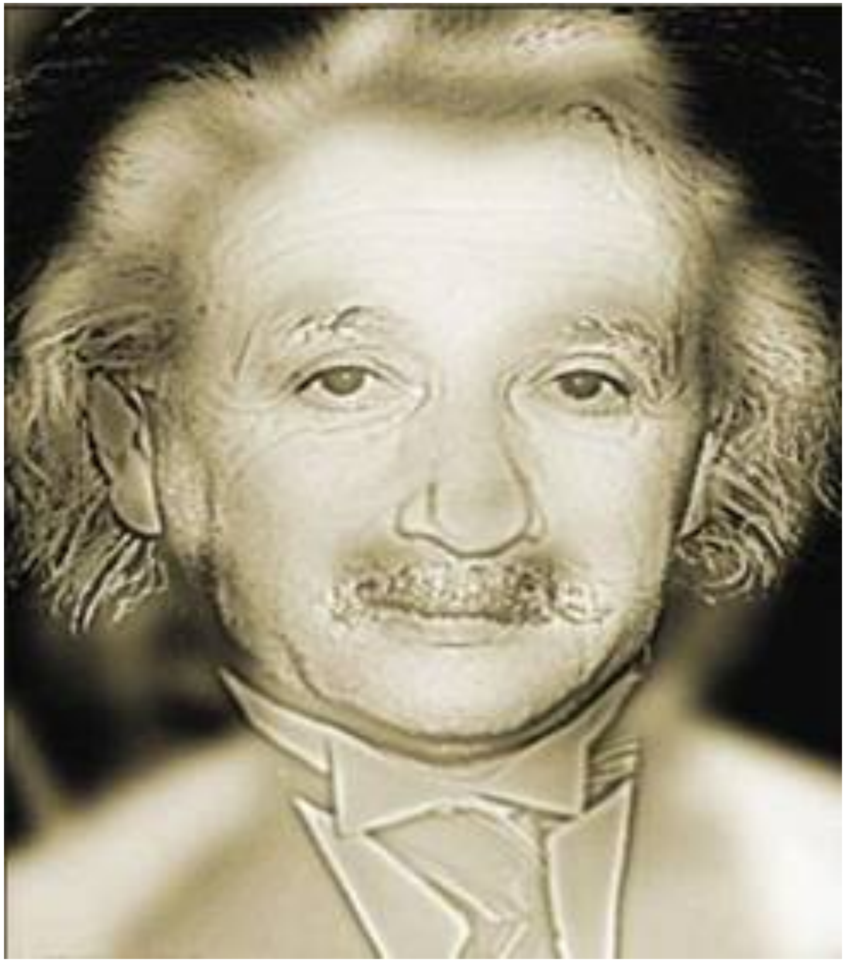


a b
c d

FIGURE 2.9 Some well-known optical illusions.

Slides courtesy of Prof. Yan Tong

More Optical Illusions



http://www.123opticalillusions.com/

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

Slides courtesy of Prof. Yan Tong

Image Formation in the Eye

Image is upside down in the retina/imaging plane!

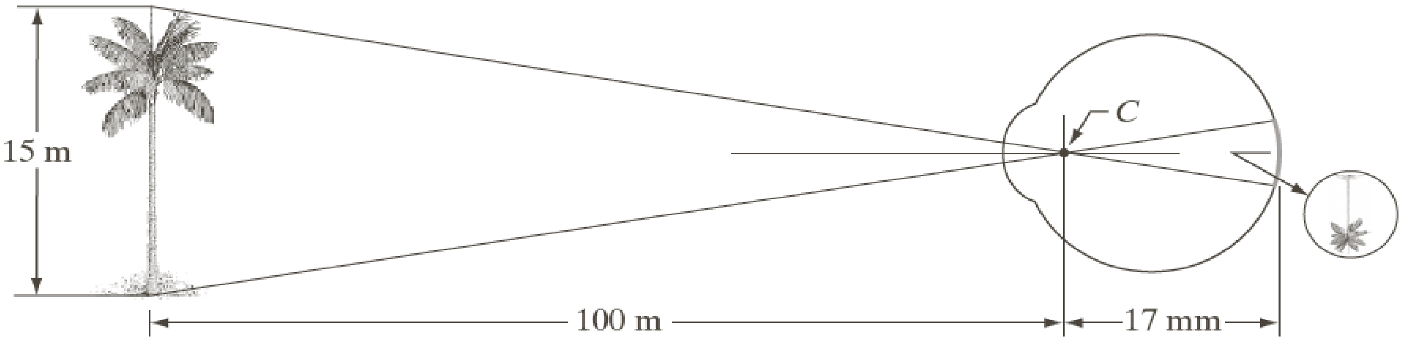


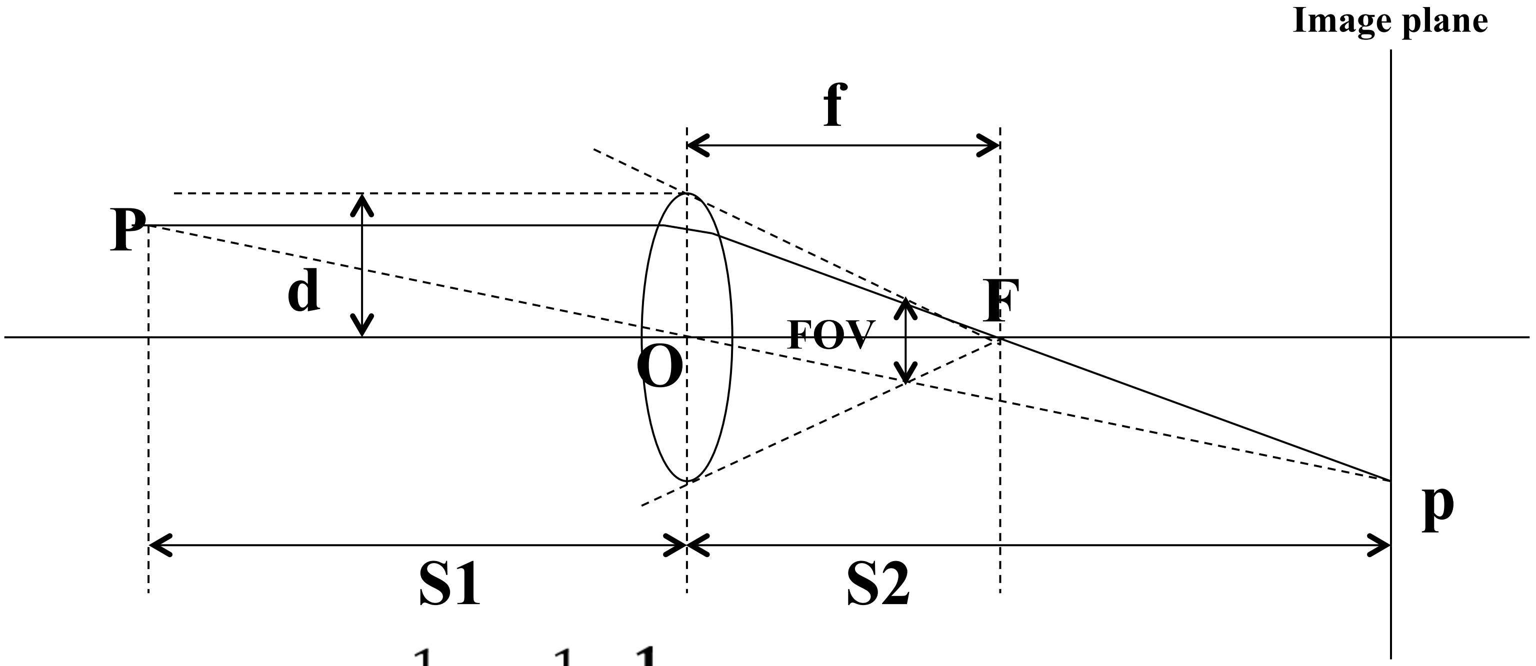
FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Adjust focus length

- Camera
- Human eye

Slides courtesy of Prof. Yan Tong

Lens Parameters



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

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

FOV

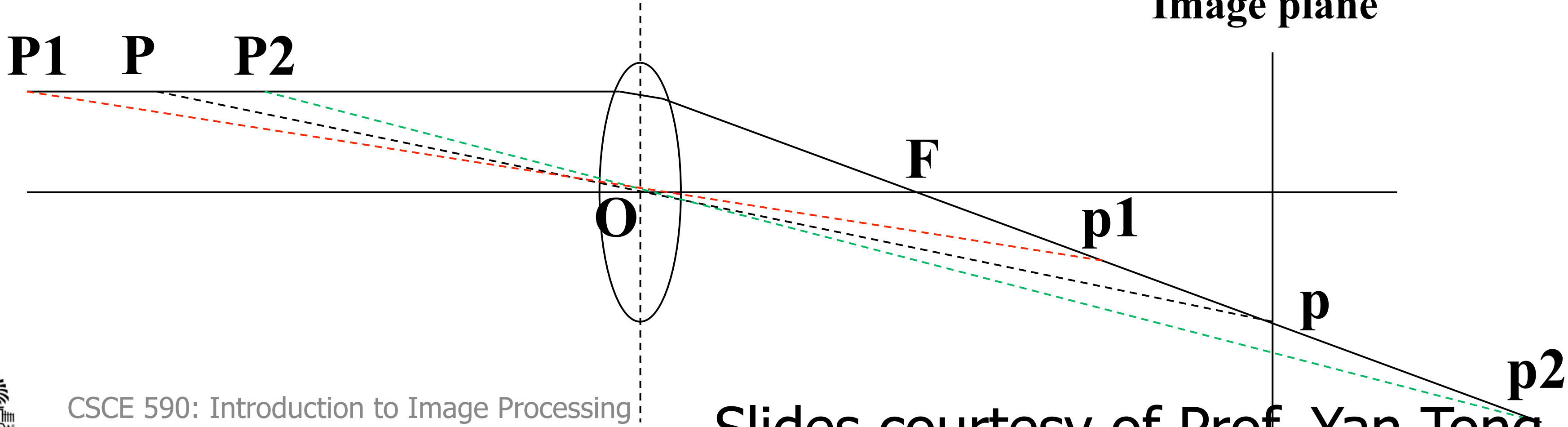
- **Increasing the distance from the object to the lens will reduce the size of image**
- **Large focus length will give a small FOV**

Slides courtesy of Prof. Yan Tong

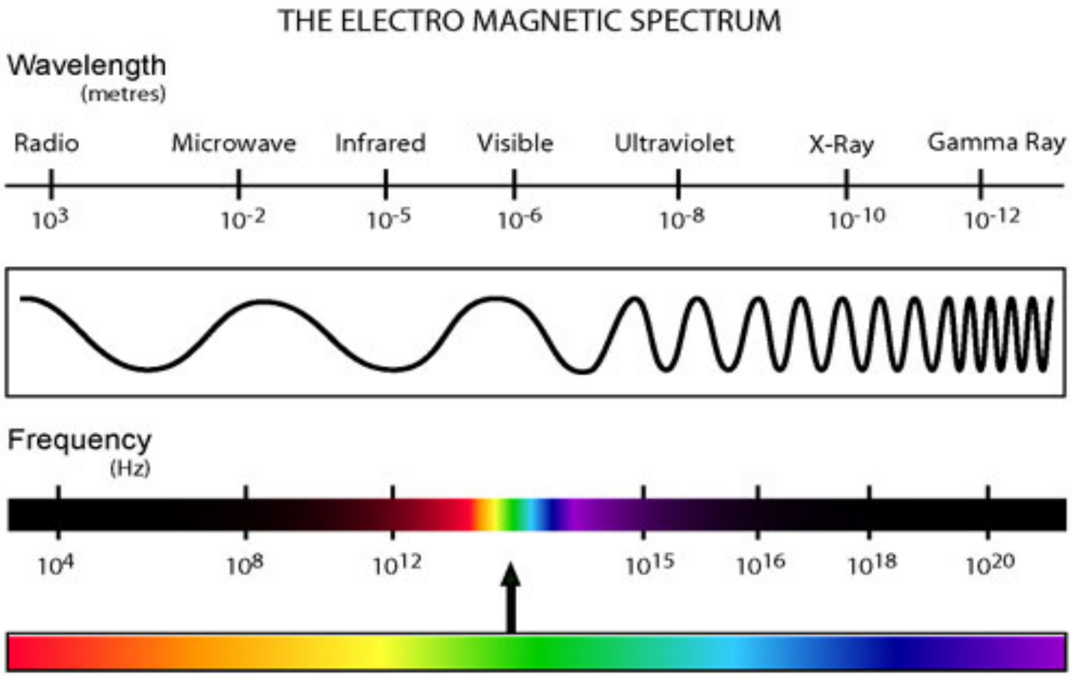
Depth of Field & Out of Focus

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

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



Light and EM Spectrum

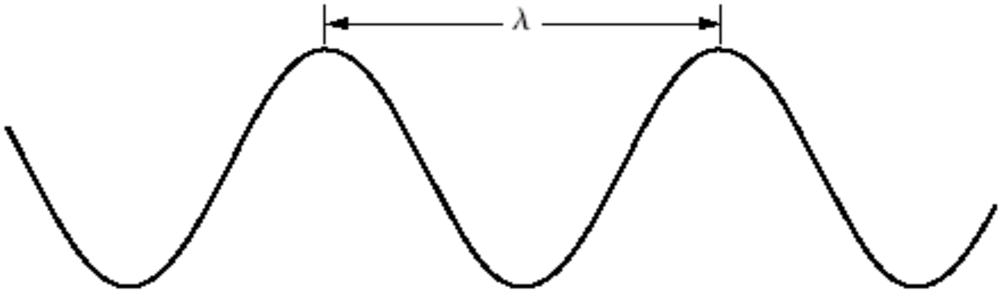


http://www.kollewin.com/blog/electromagnetic-spectrum/

Slides courtesy of Prof. Yan Tong

Relation Among Wavelength, Frequency and Energy

FIGURE 2.11
Graphical representation of one wavelength.



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

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

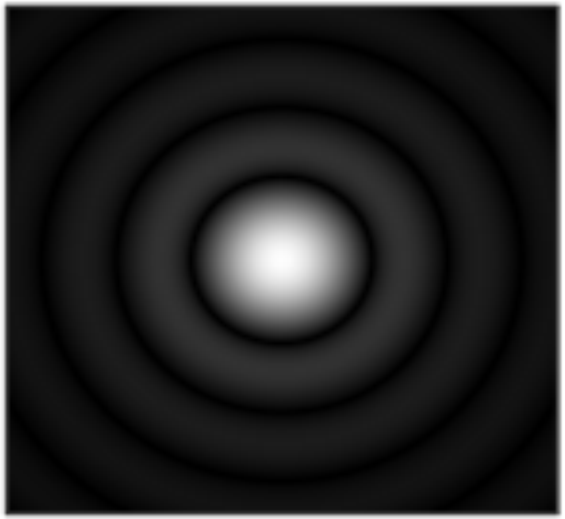
$$E = hv, \quad h \text{ is the Planck's constant, } 6.626068 \times 10^{-34} \text{ m}^2 \text{ kg / s}$$

Slides courtesy of Prof. Yan Tong

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)

$$\sim \lambda f / d$$

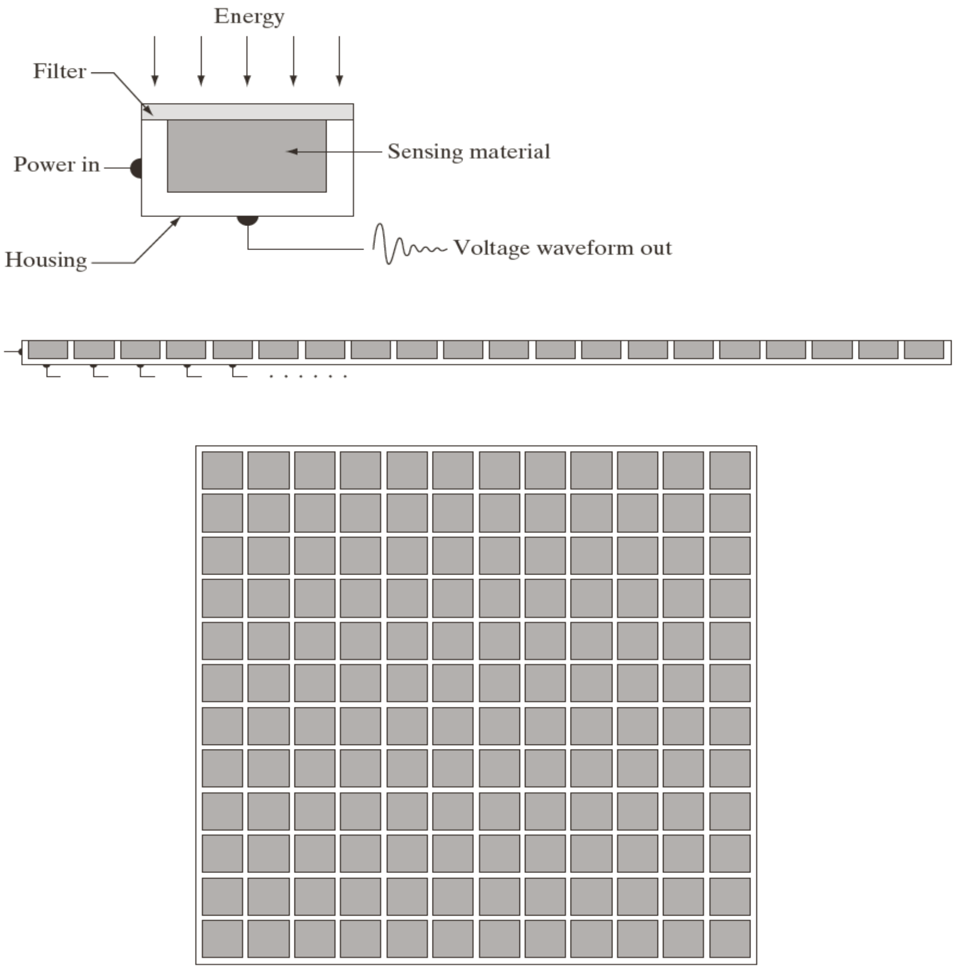
Slides courtesy of Prof. Yan Tong

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

- An 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**

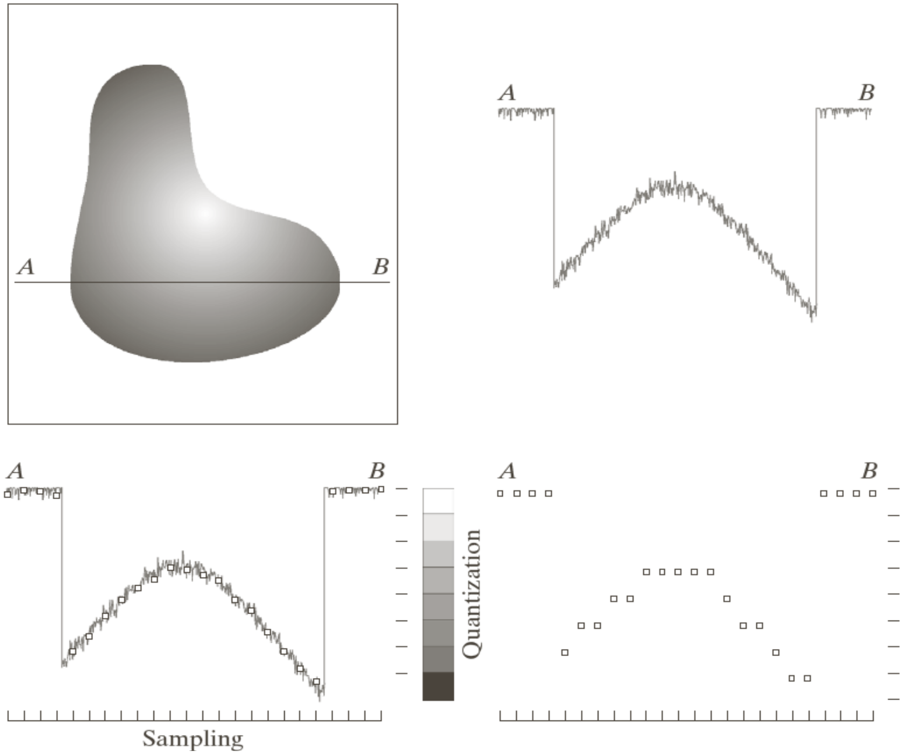
where $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

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**

Slides courtesy of Prof. Yan Tong

Image Sampling and Quantization



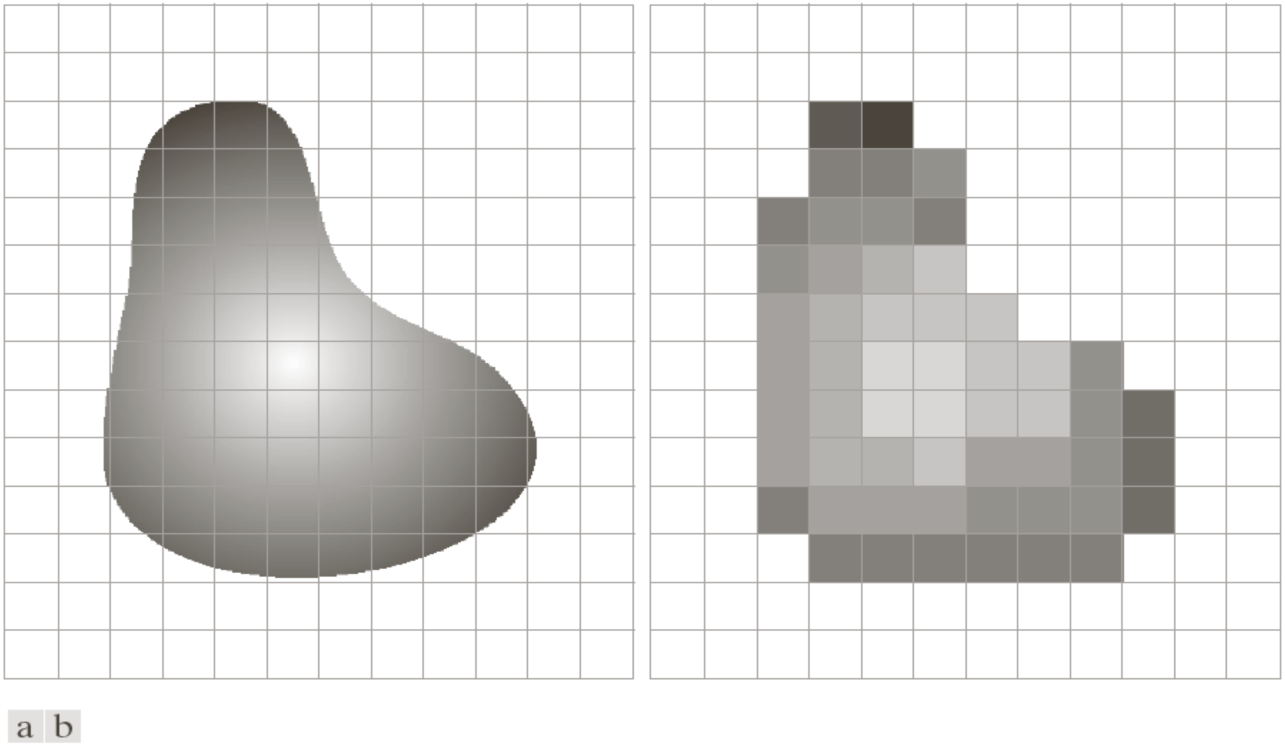
a b
c d

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



CCD array

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

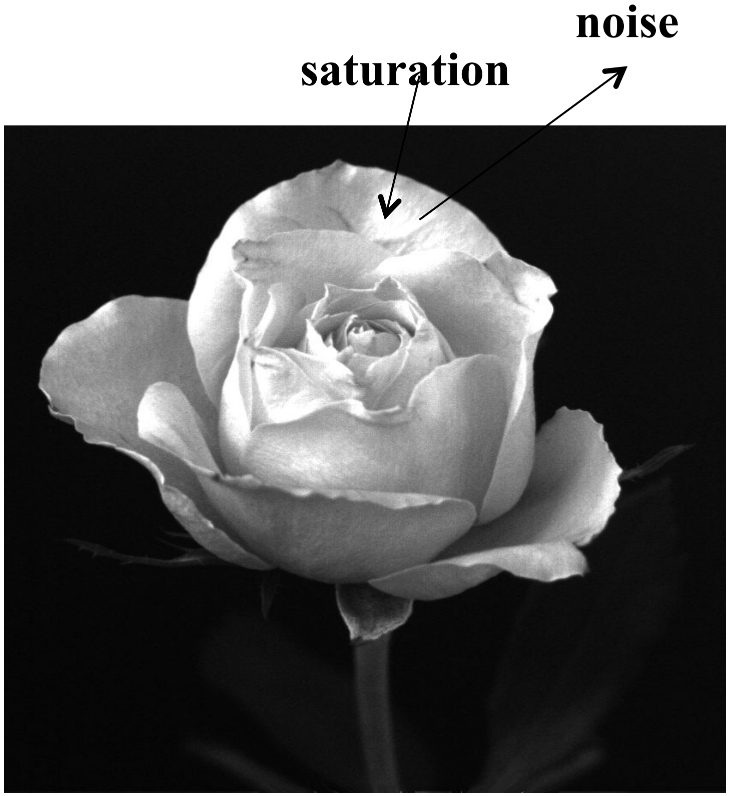
Slides courtesy of Prof. Yan Tong

Dynamic Range

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

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

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



Dynamic range/contrast ratio:

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

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

Slides courtesy of Prof. Yan Tong

Representing Digital Images

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

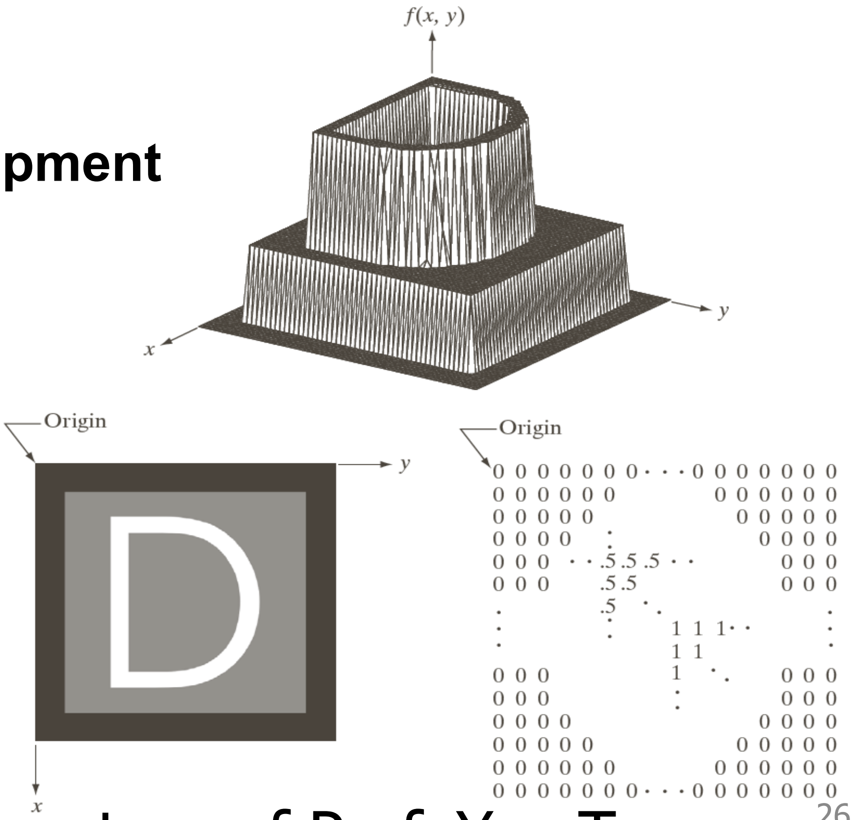
***x*, *y*: spatial coordinates → spatial domain**

(b): suitable for visualization

(c): processing and algorithm development

***x*: extend downward (rows)**

***y*: extend to the right (columns)**



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).

Number of bits storing the image

$$\underset{\uparrow}{}$$

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

Slides courtesy of Prof. Yan Tong

Store an Image

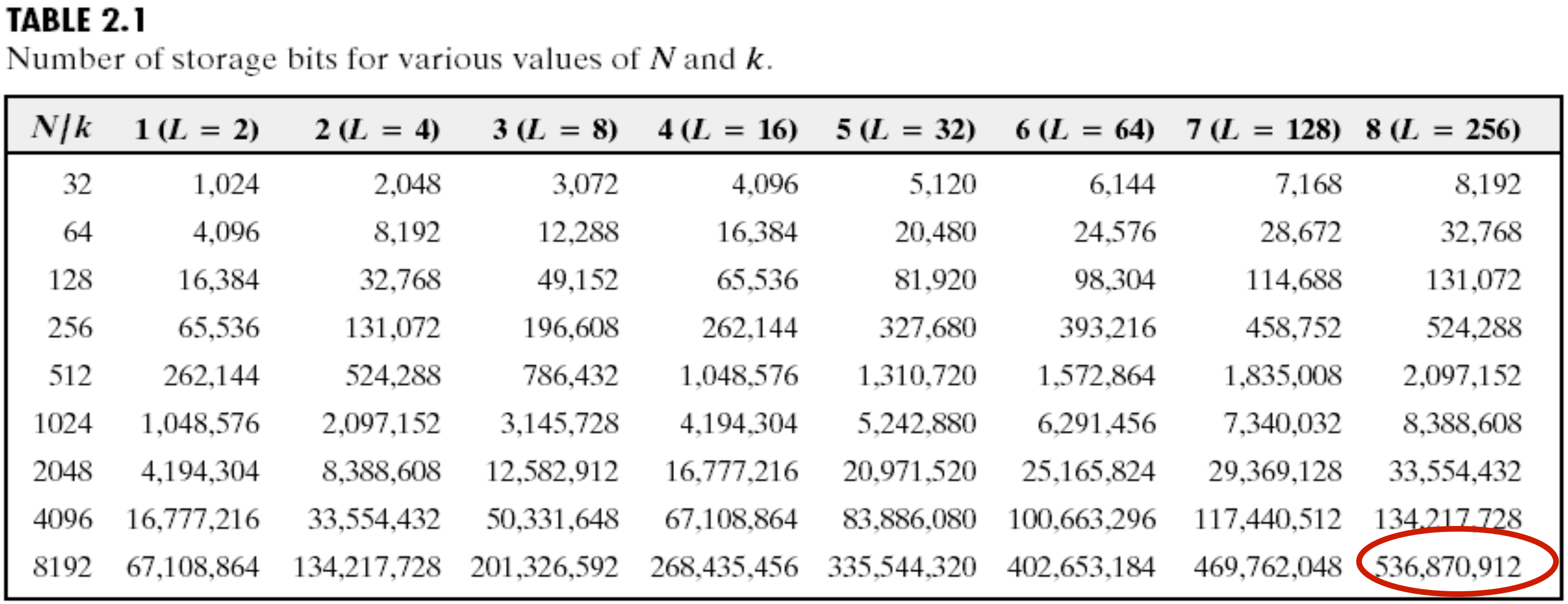


TABLE 2.1
Number of storage bits for various values of N and k.

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Slides courtesy of Prof. Yan Tong

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

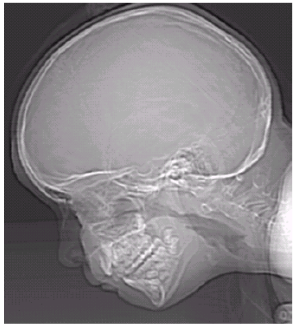
https://www.shimanodealer.com/fishing_reports.htm

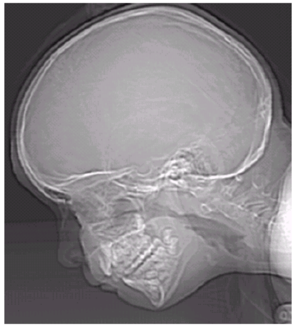
FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Intensity Resolution

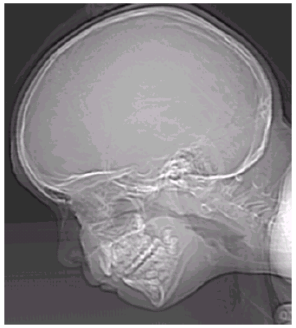
Intensity resolution

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

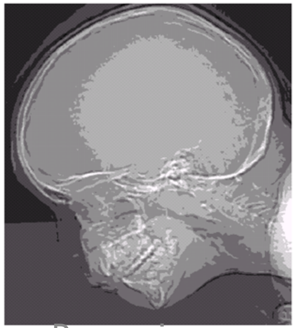

256

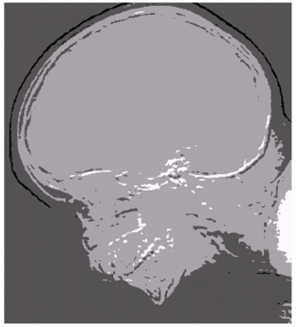

128


64


32


16


8


4


2

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:

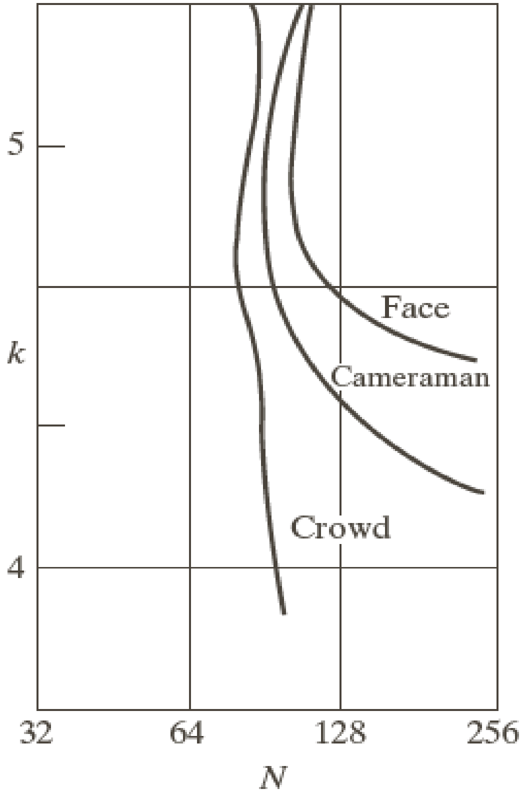


FIGURE 2.23 Typical isopreference curves for the three types of images in Fig. 2.22.

Slides courtesy of Prof. Yan Tong

Data heavy

From GoPro HERO3+ at Barbados 2015 Field Trials

$$\begin{array}{ccc} & 1920 & \\ 1080 & \begin{bmatrix} 43 & 43 & 42 & 40 & 39 & \cdots & 29 & 29 & 31 & 33 \\ 42 & 41 & 40 & 39 & 38 & \cdots & 31 & 32 & 35 & 37 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 54 & 57 & 60 & 62 & 66 & \cdots & 42 & 43 & 56 & 46 \end{bmatrix} & R \end{array}$$

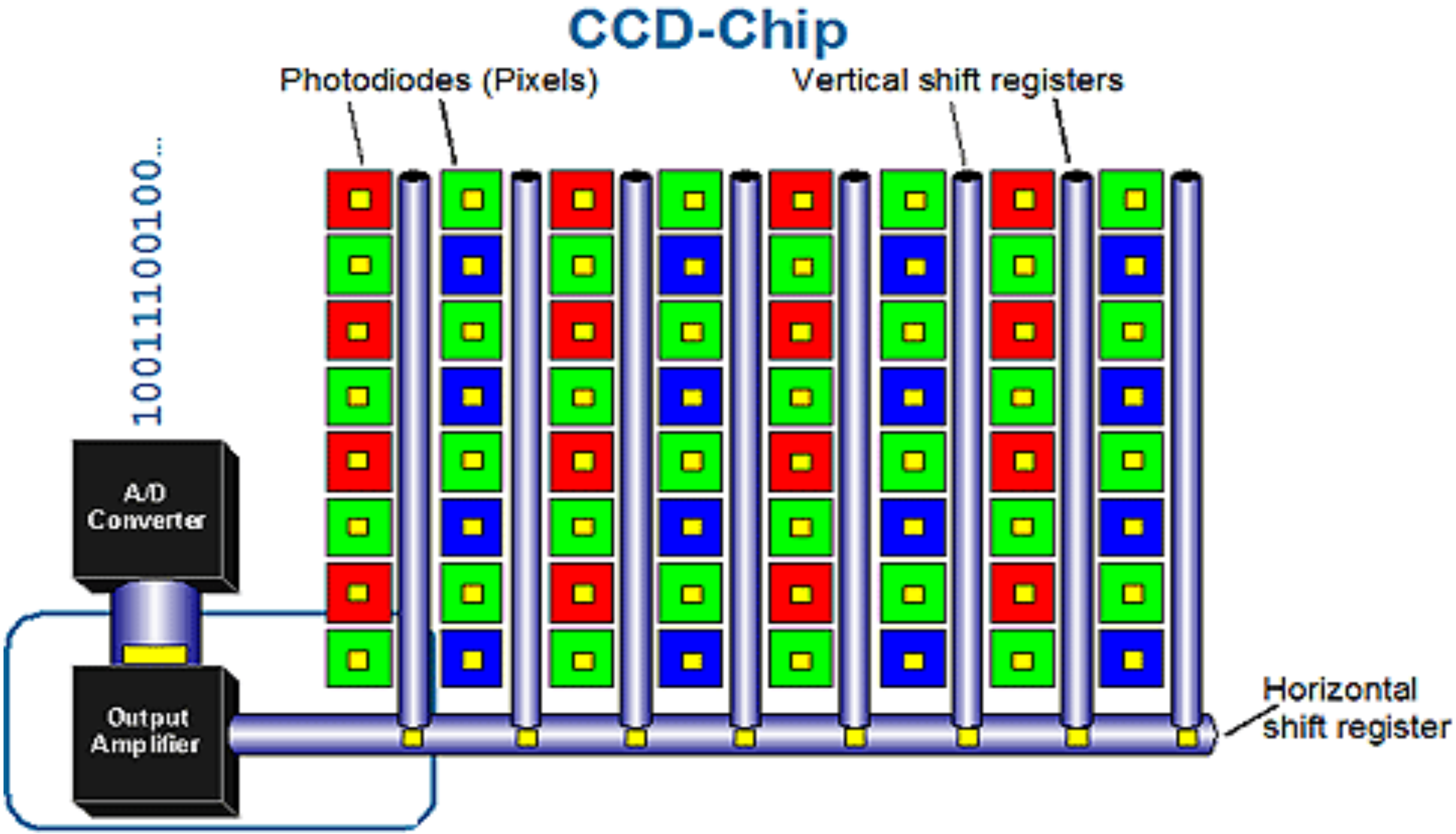
$$\begin{array}{ccc} 1080 & \begin{bmatrix} 129 & 129 & 129 & 129 & 128 & \cdots & 149 & 149 & 151 & 153 \\ 128 & 128 & 127 & 128 & 127 & \cdots & 151 & 152 & 155 & 157 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 146 & 146 & 148 & 148 & 148 & \cdots &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

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

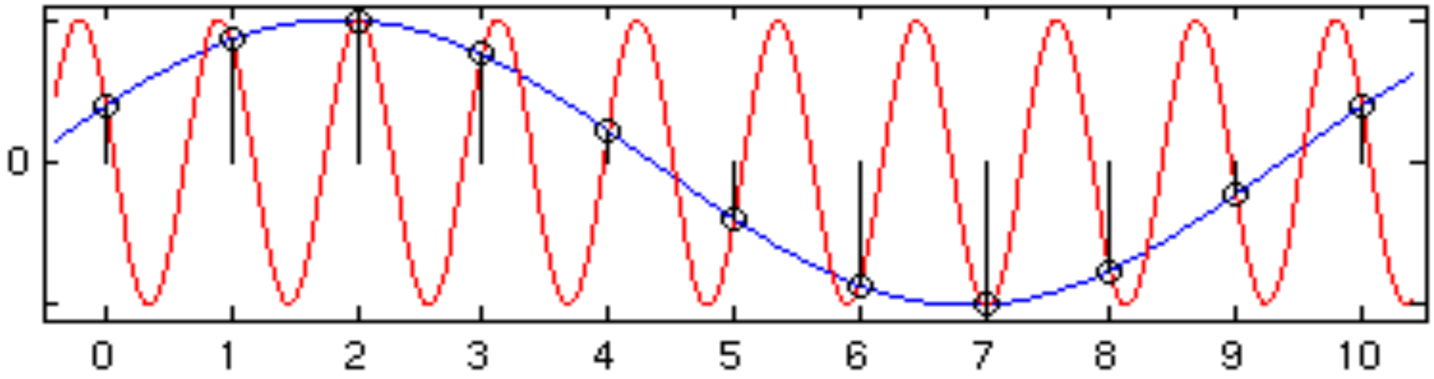
Aliasing

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

Aliasing

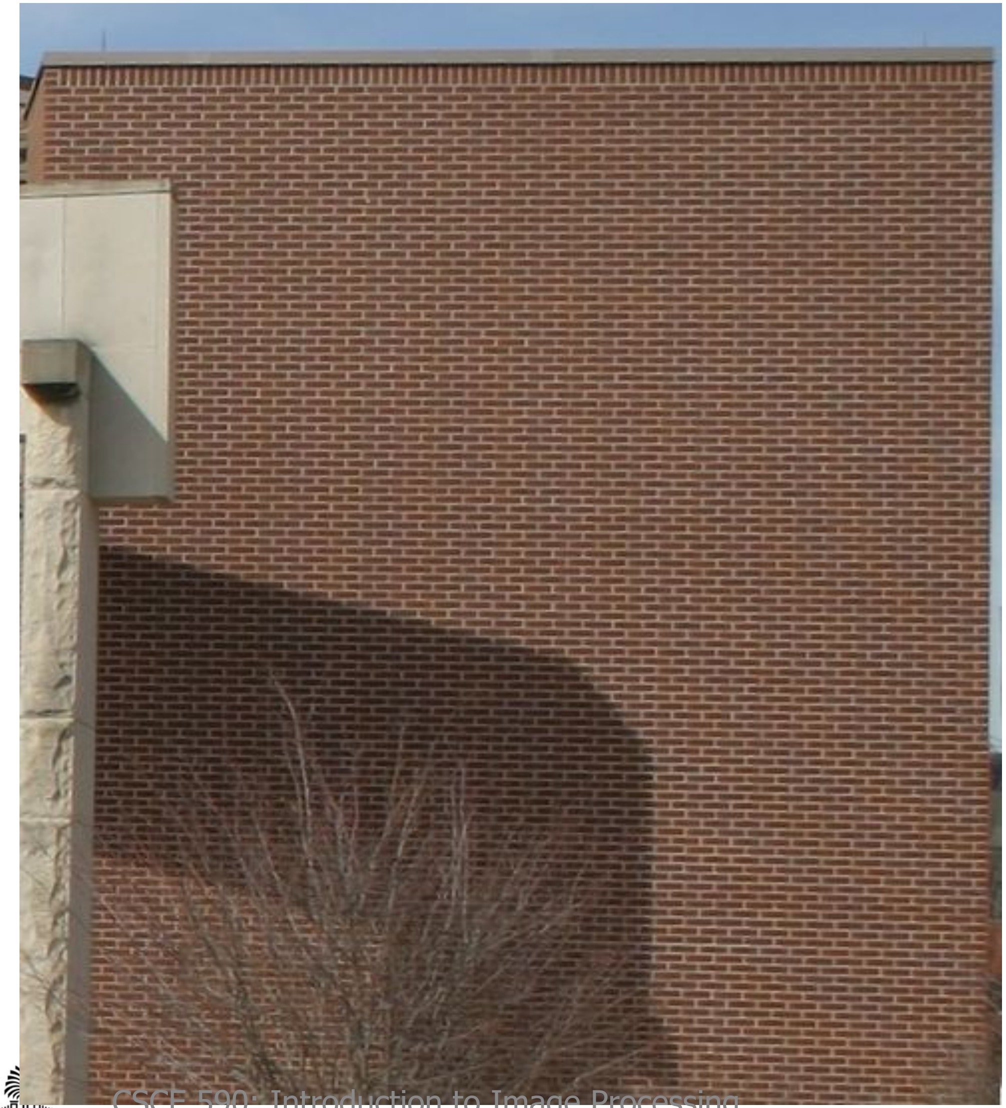

CCD-Chip
Photodiodes (Pixels)
Vertical shift registers
100111100100...
A/D Converter
Output Amplifier
Horizontal shift register

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.

Ill-posed

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

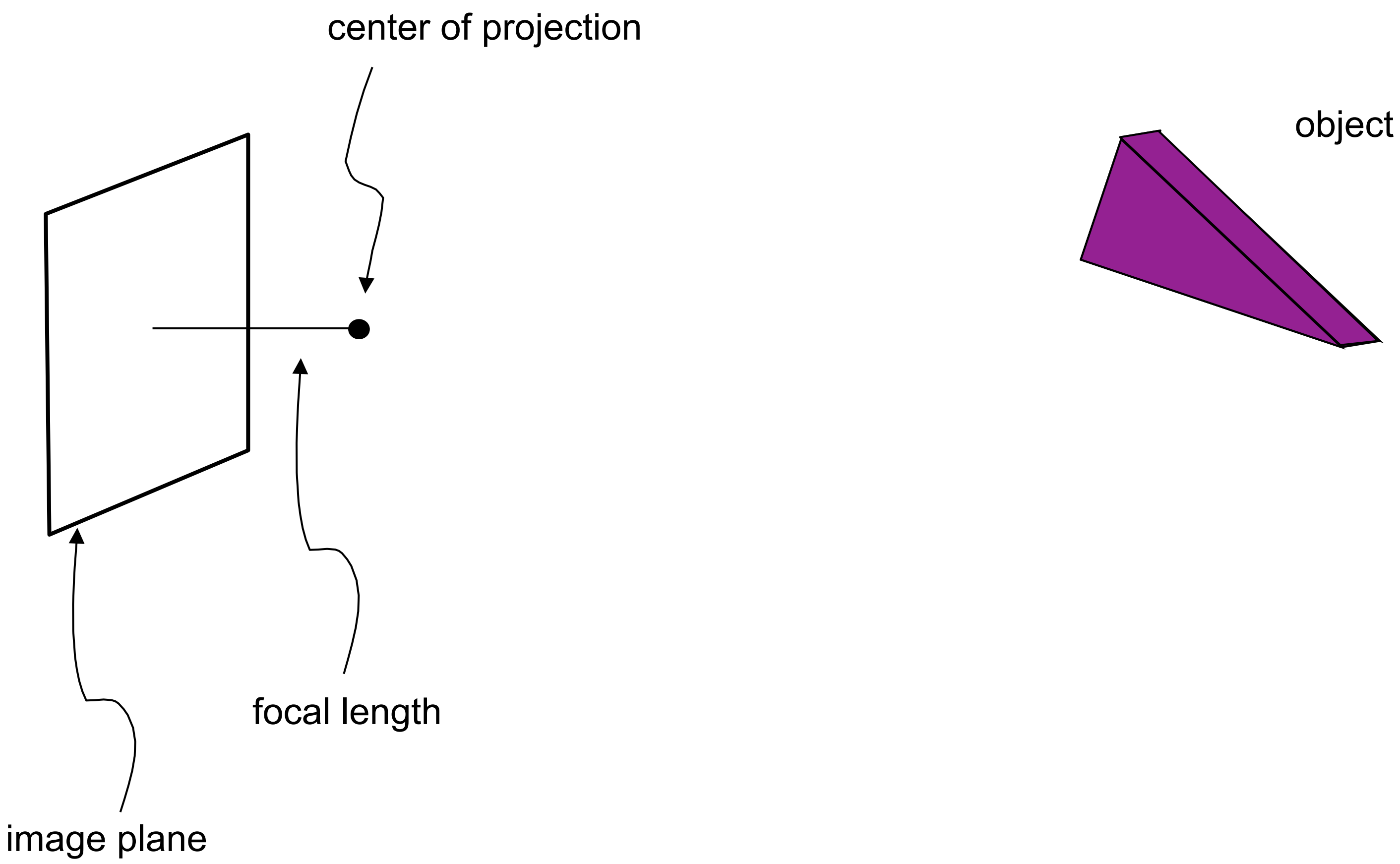
Ill-posed

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

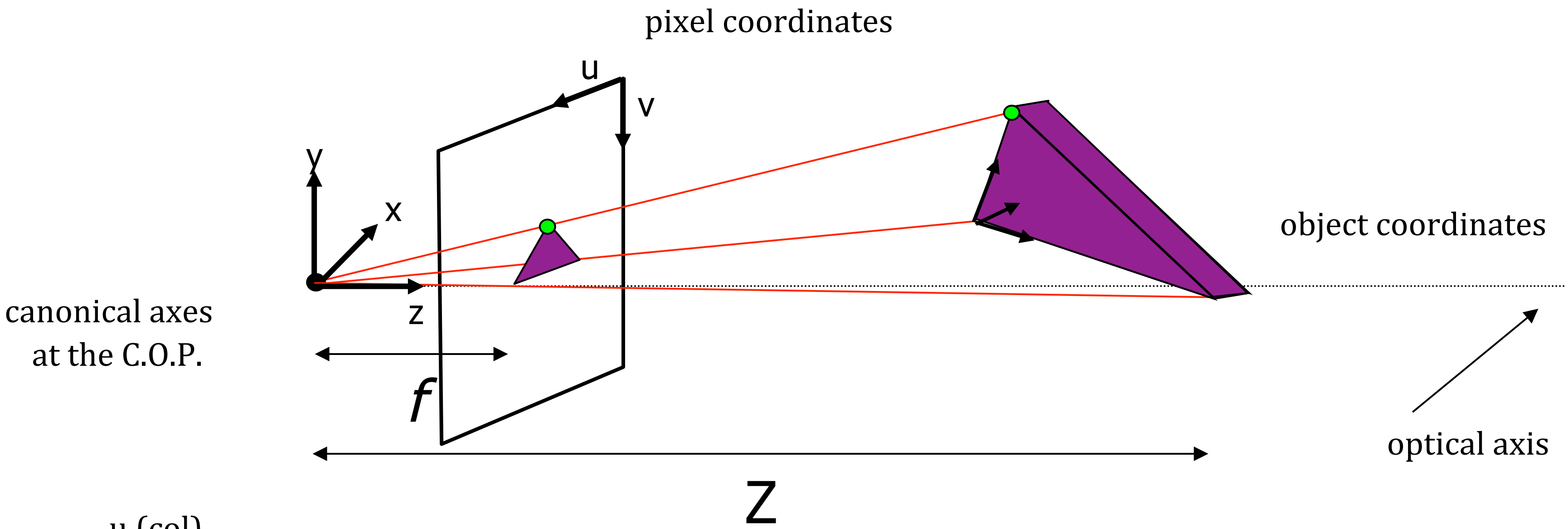
  - An image isn't enough to disambiguate the many possible 3d worlds that could have produced it.

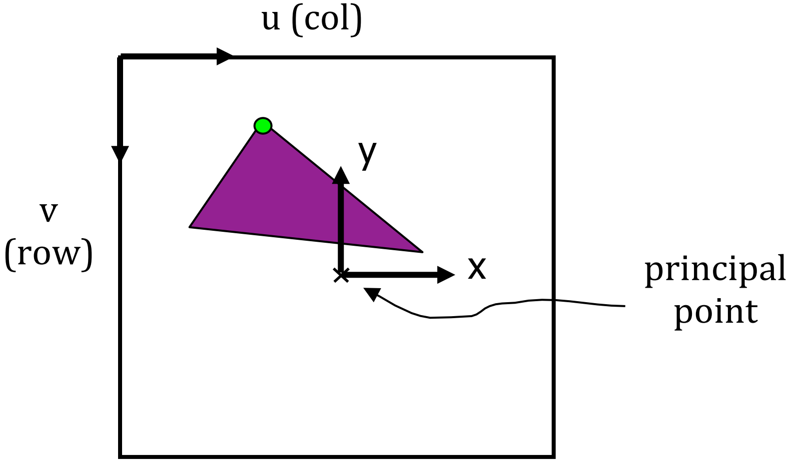
Camera Geometry

3D→2D transformation: perspective projection



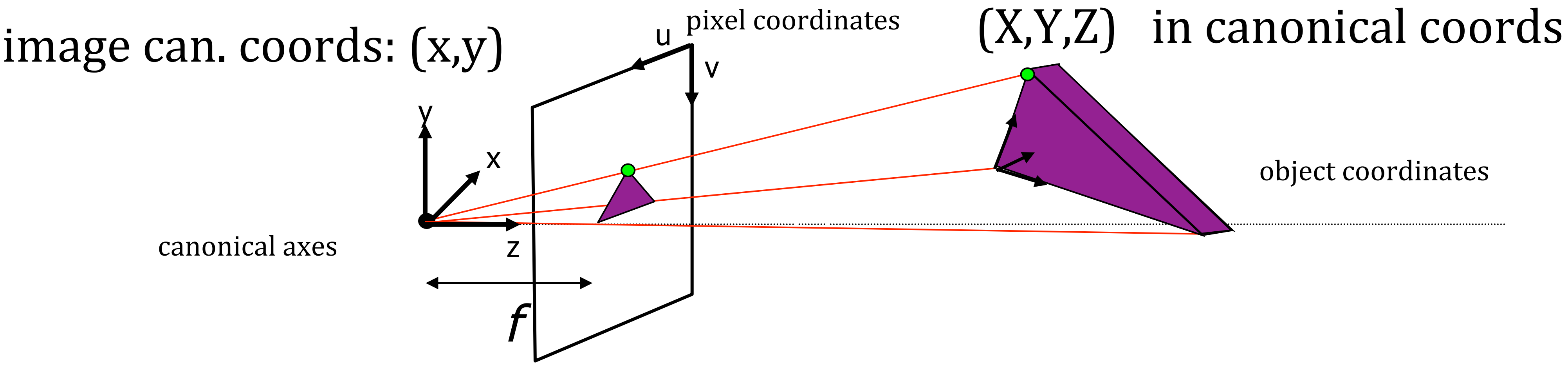
Coordinate Systems



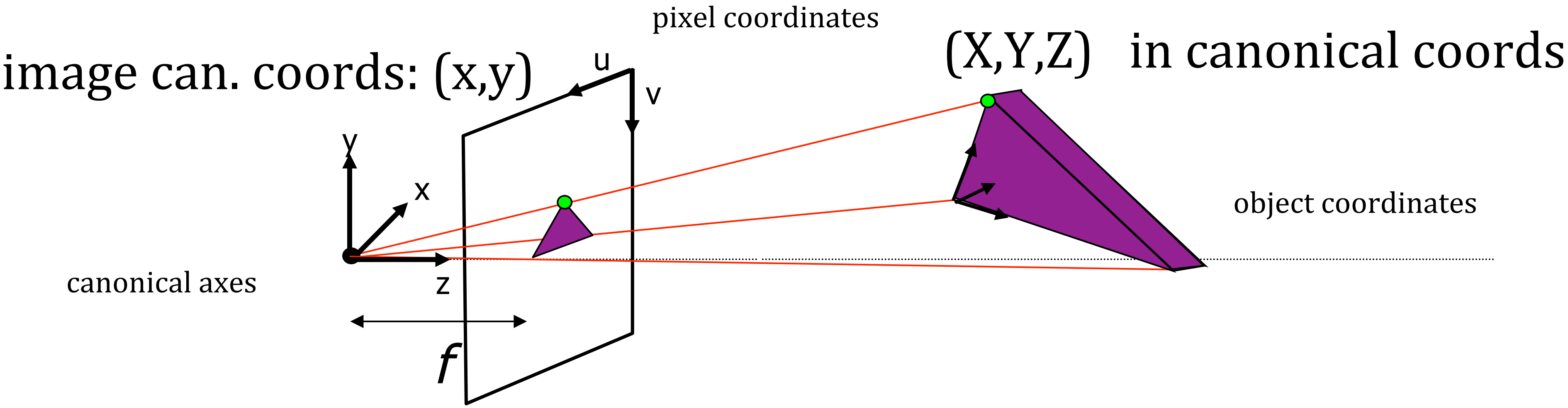


Add coordinate systems in order to describe feature points...

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)