EE 421/521
Image Processing

Lecture 1
INTRODUCTION
IMAGE FORMATION AND REPRESENTATION
26.09.2013

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Instructor

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Recommended Books

Digital Image Processing (3rd edition)
Rafael C. Gonzalez and Richard E. Woods
Prentice Hall, 2007

Digital Image Processing Using MATLAB
Rafael C. Gonzalez, Richard E. Woods, and Steven L. Eddins
Prentice-Hall, 2003

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Weekly Program

- Thursdays
  - 15:40-18:30 (three hours)

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Course Organization

- Course content is divided in to **3 Levels**
  - **Level 1**: Core subjects (5 lectures)
  - **Levels 2 & 3**: Advanced subjects (4+3 lectures)
- Each **Level** ends with a **Midterm Exam**
  - Two hours long, closed books and notes
- Short **Projects** every week
  - Due in one week after assignment
- **No** Final Exam

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Points and Grades

	Level 1	Level 2	Level 3	Overall
Exams	20	16	12	48
Projects	25	20	15	60
Total	45	36	27	108

Points	90	80	70	60	55	50	45
Grade	A	A-	B+	B	B-	C+	C
Degree	**Expert**		**Competent**		**Novice**		

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Applications of Image Processing

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Enhancement

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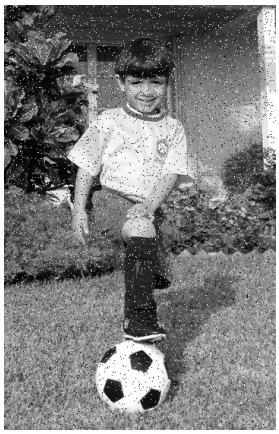
Noise Filtering



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Sampling conversion

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Segmentation

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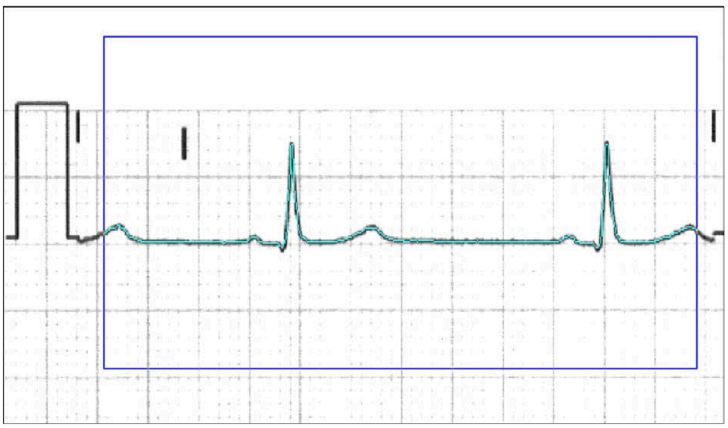
Line Detection



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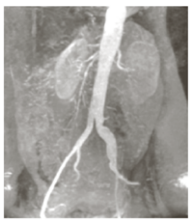
Restoration



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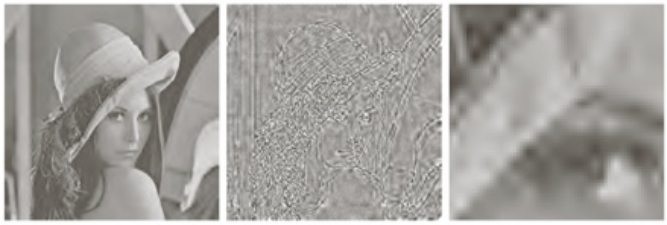
Compression



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Applications in Diverse Fields

- Medical applications
- Industrial applications
- Consumer applications
- Military applications
- Law enforcement and security
- Internet, particularly the Web.

Three Levels of Image Processing

- **Low-level**: primitive operations (e.g., noise reduction, contrast enhancement, etc.) where both the input and output are images.
- **Mid-level**: extraction of attributes (e.g., edges, contours, regions, etc.) from images.
- **High-level**: analysis and interpretation of the contents of a scene.

Relation to Other Fields

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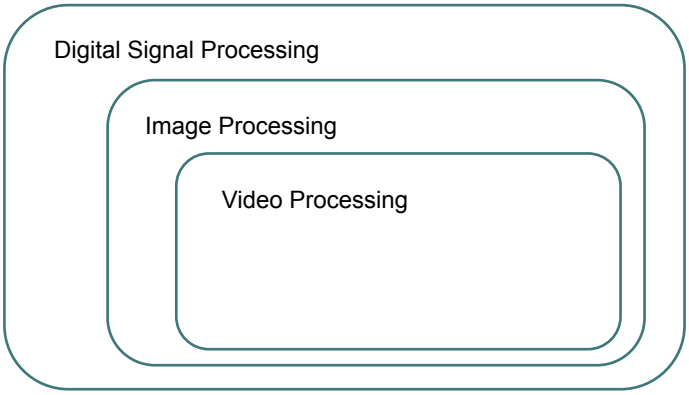
Video Processing



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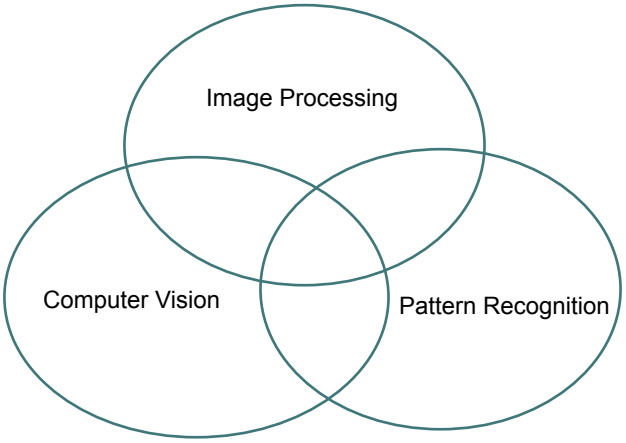
Computer Vision



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Computer Graphics

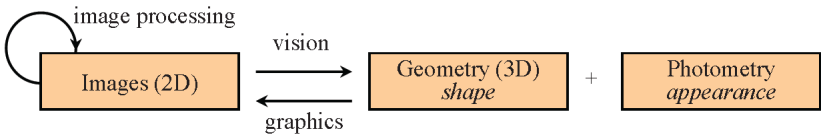

Figure from "Computer Vision: Algorithms and Applications," Richard Szeliski, Springer, 2010.

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Imaging Modalities

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2D Image

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Stereo image (2.5D)

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Image + Depth (2.5D)

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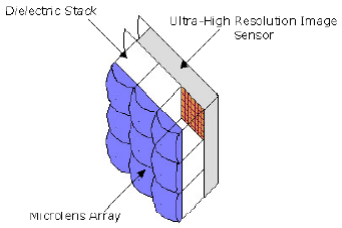
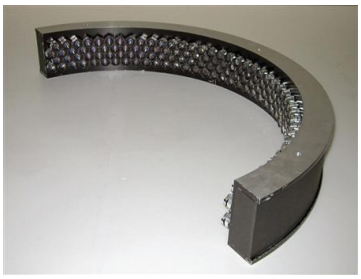
Holoscopic Imaging





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3D image
(Hologram)

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Image Sequence (Video)

Panoramic Image

Catadioptric (mirror + lens) Image

Course Outline

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Level 1
Fundamental Concepts

1. Image formation and representation
2. Color theory and HVS
3. Image enhancement
4. FIR filtering of images
5. Image transforms

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Level 2
Geometry Processing

1. Image resampling
2. Geometric transforms
3. Edge detection (line processing)
4. Segmentation (region processing)

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Level 3
Signal Processing

1. Noise filtering
2. Image restoration and reconstruction
3. Image compression

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Image Formation

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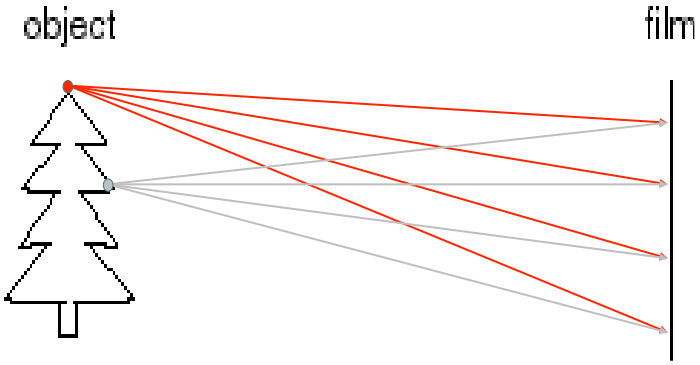
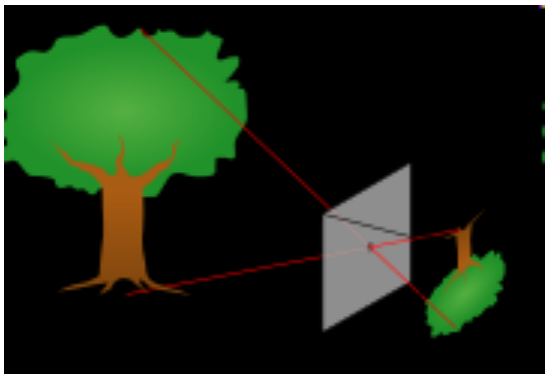
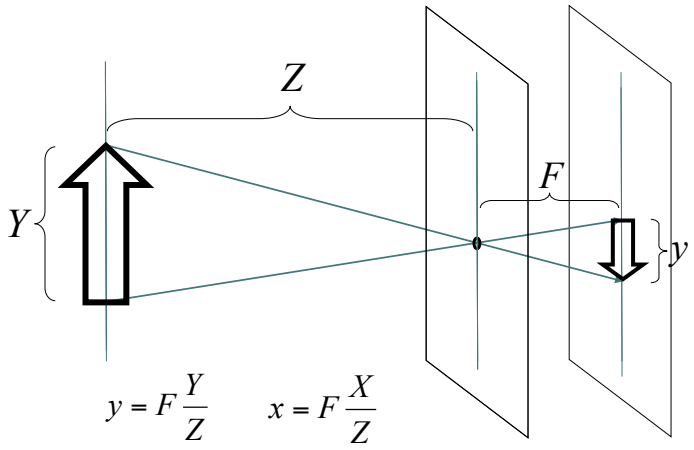
Image formation



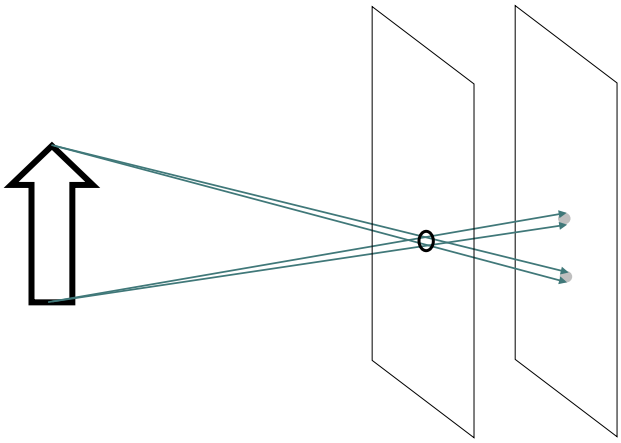
Pin-Hole Camera (Camera Obscura)



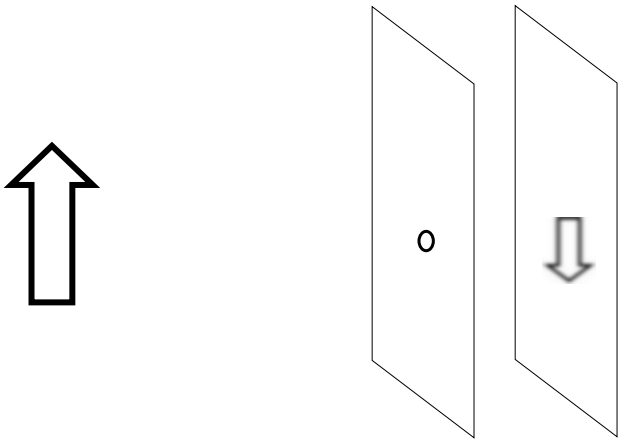
Perspective (Central) Projection



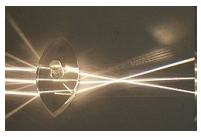
Point Spread Effect

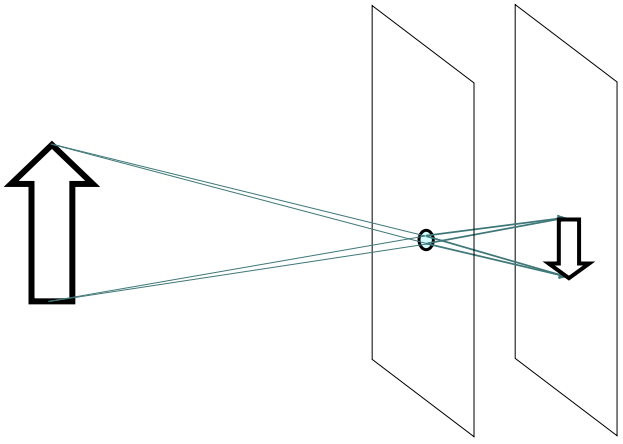


Out-of-Focus Blur

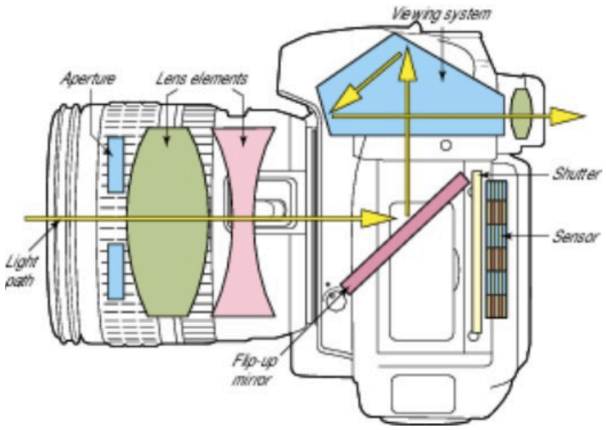


Correction with a Converging Lens





Inside a Camera



Focal Length

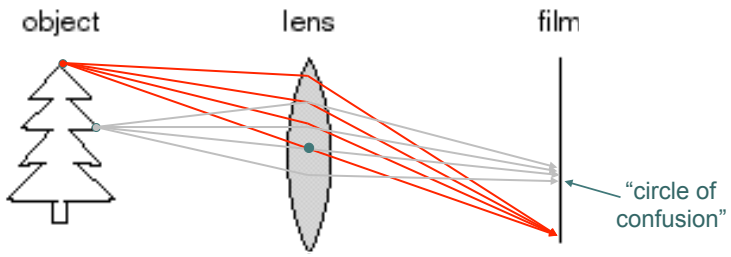
- A program like "jhead" can be used to extract the EXIF (*exchangeable image file format*) tags from a JPEG image

```
File name : foo.jpg
File size : 463023 bytes
File date : 2001:08:12 21:02:04
Camera make : Canon
Camera model : Canon PowerShot S100
Date/Time : 2001:08:05 15:39:33
Resolution : 1600 x 1200
Flash used : No
Focal length : 5.4mm
CCD Width : 5.23mm
Exposure time: 0.100 s (1/10)
Aperture : f/2.8
Focus Dist. : 1.18m
Metering Mode: center weight
Jpeg process : Baseline
```

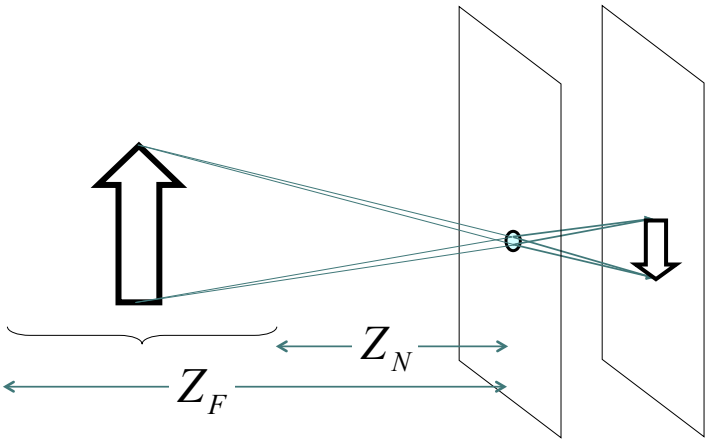
focal length in pixels = 1600 pixels * 5.4mm / 5.23mm = 1652 pixels

http://www.cs.washington.edu/education/courses/cse455/08wi/projects/project2/web/focal.html

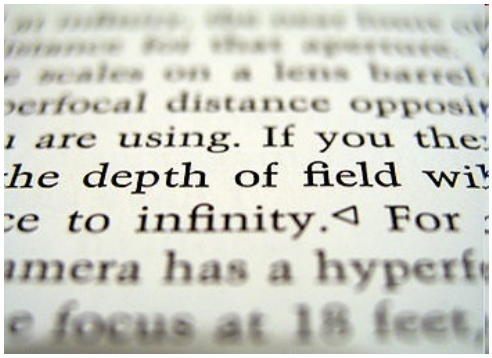
Perfectly In-Focus for a Certain Distance Only



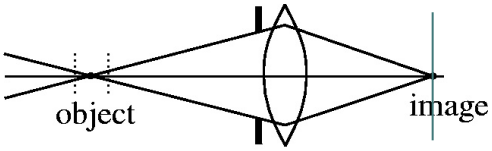
Depth-of-Field

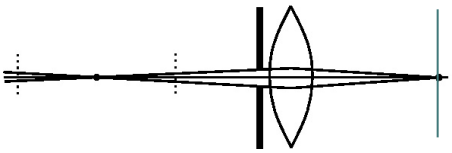


Depth-of-Field



Aperture Size Affects Depth-Of-Field

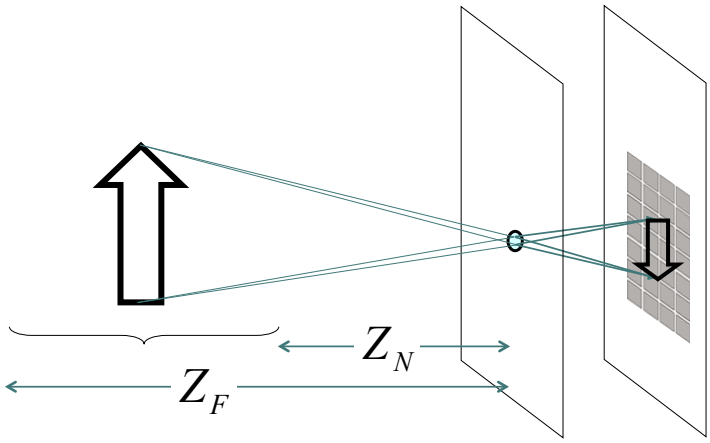




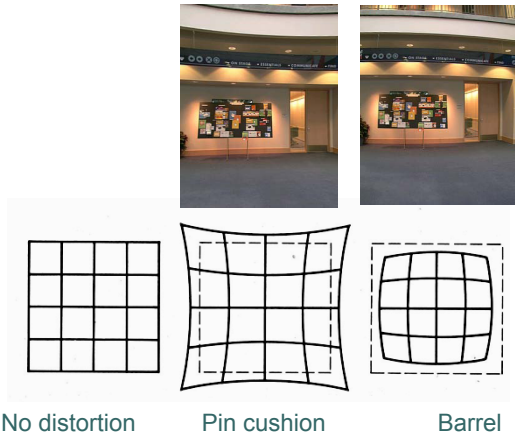
f / 5.6

f / 32

"Sharp Image" within Depth-of-Field due to Finite Sensor Size



Radial Distortion

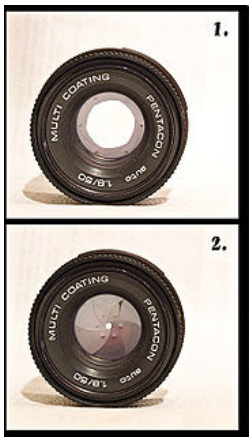


- Caused by imperfect lenses
- Deviations are most noticeable at the edges of the lens

Radial Distortion Correction

Camera Capture Parameters

Aperture



$$A \propto d^2$$

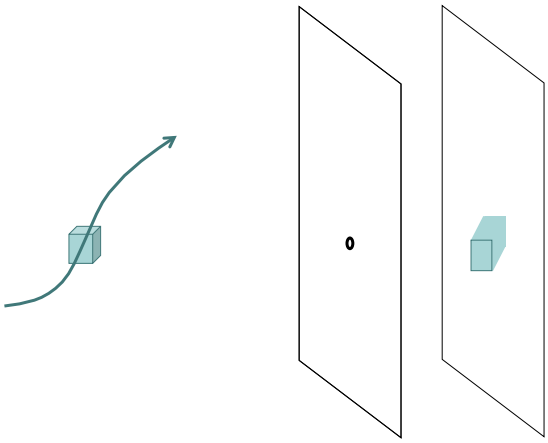
Camera *f*-number

$$f = \frac{F}{d}$$

$$A \propto \left(\frac{F}{f}\right)^2$$

Exposure Time

Motion Blur Effect due to Finite Exposure Time



Observation: Decrease in aperture implies…

- Increase in depth-of-field
- Decrease in motion blur
- Decrease in exposure

Source of Images

- Light
  - Visual (what the eye sees)
  - X-ray (absorption by matter)
  - Infrared (heat)
  - Radar (range)
- Ultrasound (tissue boundary)
- Synthetic (computer graphics)

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Scene Illumination

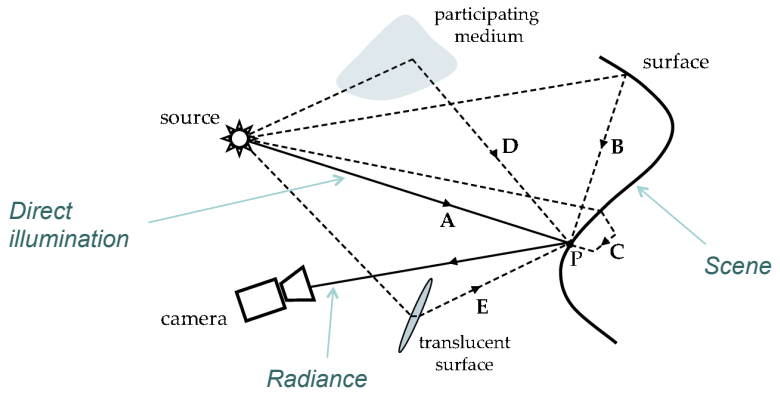

Figure from "Fast Separation of Direct and Global Components of a Scene using High Frequency Illumination," S.K. Nayar, G. Krishnan, M. D. Grossberg, R. Raskar, ACM Trans. on Graphics (also Proc. of ACM SIGGRAPH), Jul, 2006.

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Types of Images

- **Reflection images**: result of radiation that has been reflected from the surfaces of objects. Most images are reflection images
- **Emission images:** self-luminuous objects (stars)
- **Absorption images:** radiation that passes through an object (X-ray)

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Digital Image Capture

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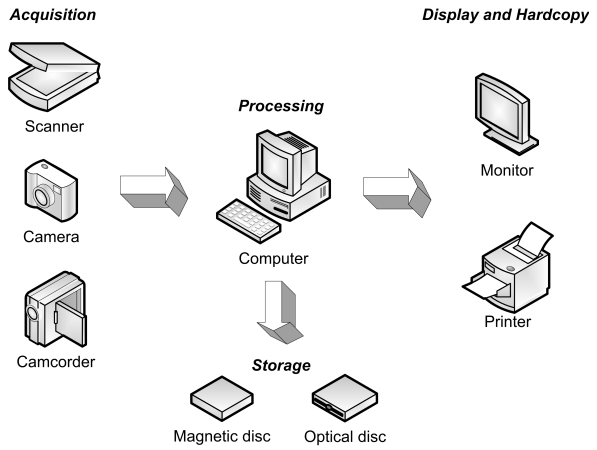
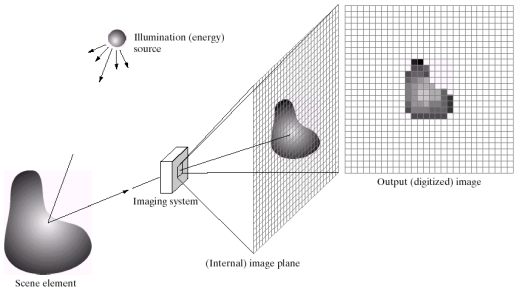
Four Stages in Image Processing



Digital Image Capture



(Courtesy Gonzalez & Woods)

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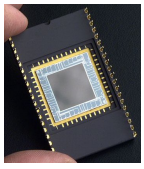
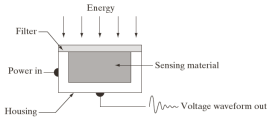
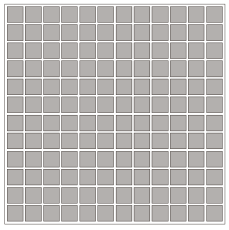
Digital Image Capture



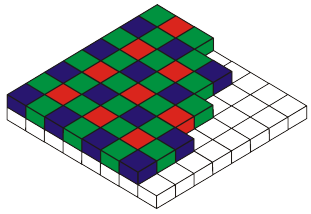


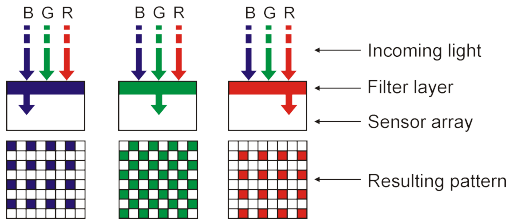
An imaging sensor is made up of an array of light-sensitive cells, each of which produces a voltage proportional to the intensity of light falling on them.



Color CCD cameras

- Tricolor imager with different sensors for Red, Green and Blue.
- Bayer pattern (single-CCD cameras)
- Each pixel records one of three primary colors.
- A demosaicing algorithm interpolates the color for each pixel before recording .

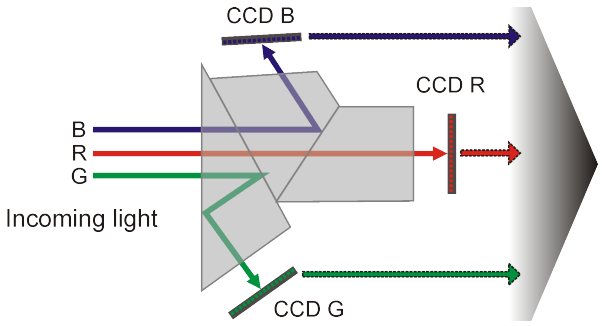




By Oge Marques

Color CCD cameras

- More expensive cameras use 3 CCDs and a beam splitter.
- Beam splitter (three-CCD cameras)

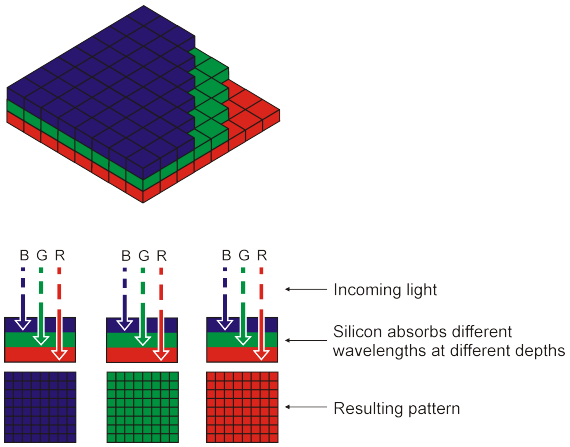


By Oge Marques

Color CMOS cameras

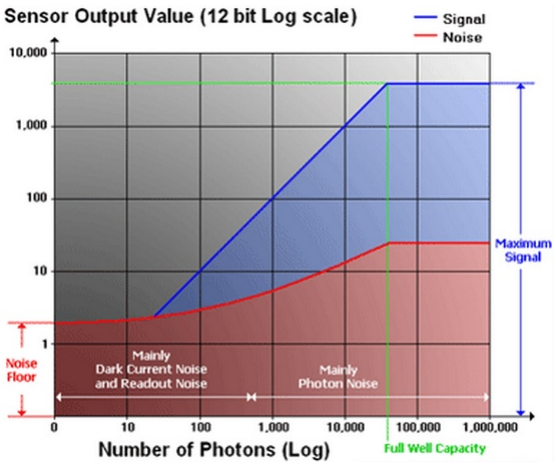
CMOS sensors are an alternative to CCDs

- Cheaper
- Less power
- Susceptible to noise



By Oge Marques

Sensor Dynamic Range

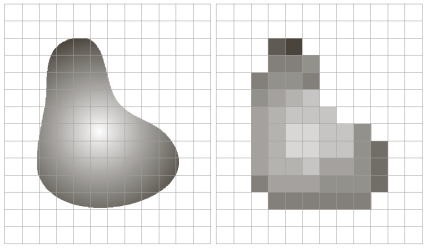


Digital Camera Issues

- Noise
  - caused by low light
- Color
  - color fringing (chromatic aberration) artifacts from Bayer patterns
- Blooming
  - charge overflowing into neighboring pixels

- In-camera processing
  - over-sharpening can produce halos
- Interlaced vs. progressive scan video
  - even/odd rows from different exposures
- More megapixels
  - noise issues
- Stabilization
  - compensate for camera shake
- Compression
  - creates blocking artefacts

Digitization: Sampling and Quantization

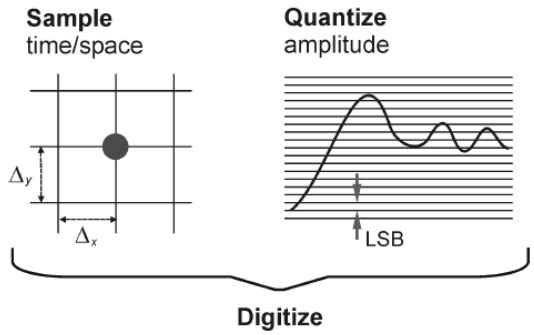


a b

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

Digitization = Sampling + Quantization

- Sampling selects a finite number of points within an interval.
- Quantization assigns an amplitude to one of finite values.

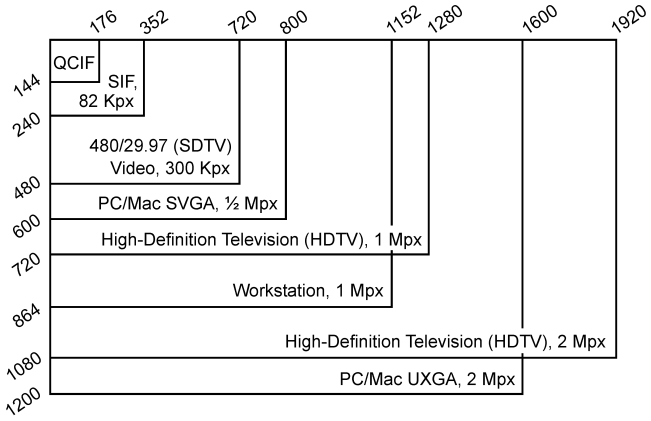


By Oge Marques

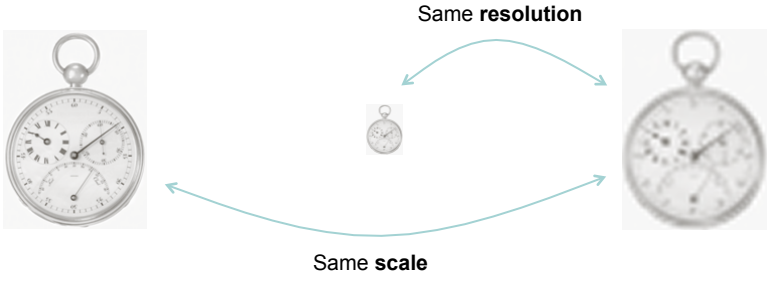
Spatial resolution

- A way of expressing the density of pixels in an image using units such as dots per inch (dpi).
- The greater the spatial resolution, the more pixels are used to display the image within a certain fixed physical size.

Sampling Examples



Scale vs. Resolution



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Gray Level Resolution

- Gray-level resolution is the smallest change in intensity level that the HVS can discern.
- Adoption of 8 bits per pixel is a good compromise between subjective quality and practical implementation.
- Higher end imaging applications may require 12 or 16 bits per pixel.

Quantization Examples

- Bi-level (black & white) image (fax)
  - *s = 0 or 1*
- 8-bit color image (photograph)
  - *0 ≤ r,g,b ≤ 255*
- 10-bit color image (movie)
  - *0 ≤ r,g,b ≤ 1023*
- 12-bit intensity image (X-ray)
  - *0 ≤ s ≤ 4095*
- Multi-spectral image (satellite)
  - *0 ≤ c1,c2,…,c7 ≤ 255*

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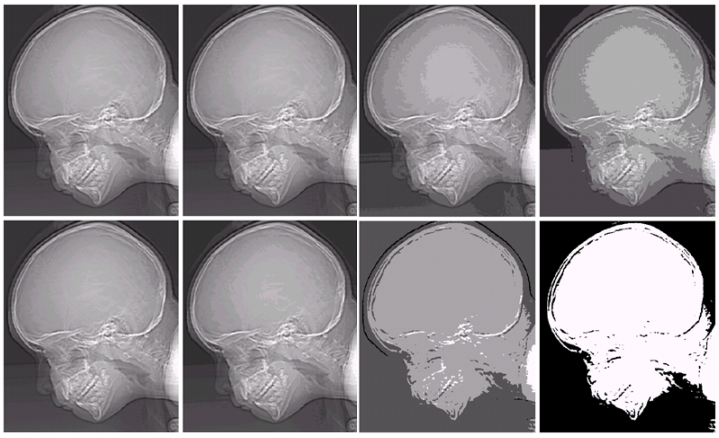
Quantization (8 bit ⇨ 1 bit)



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2D Image Representation

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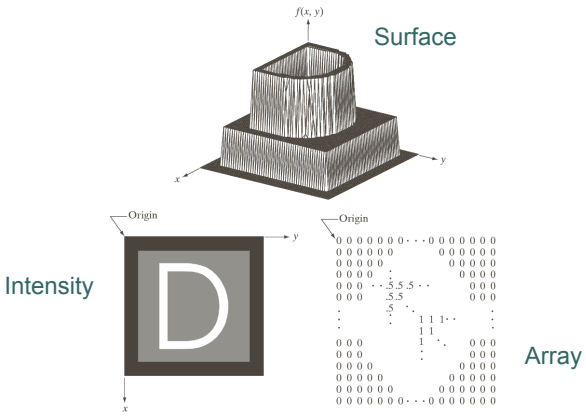
Images as Functions

- We can think of an **image** as a function, *f*, from $\mathbb{R}^2$ to $\mathbb{R}$:
  - $f(x, y)$ gives the **intensity** at position (x, y)
  - Realistically, we expect the image only to be defined over a rectangle, with a finite range:
    - f: $[a,b]$x$[c,d]$ → $[0,1]$

- A color image is just three functions pasted together. We can write this as a "vector-valued" function:

$$f(x,y) = \begin{bmatrix} r(x,y) \\ g(x,y) \\ b(x,y) \end{bmatrix}$$

Image Representation



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Intensity Representation

NB: There is no universally accepted convention or notation. Always check carefully!

Array Representation

- Mathematical notation

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}$$

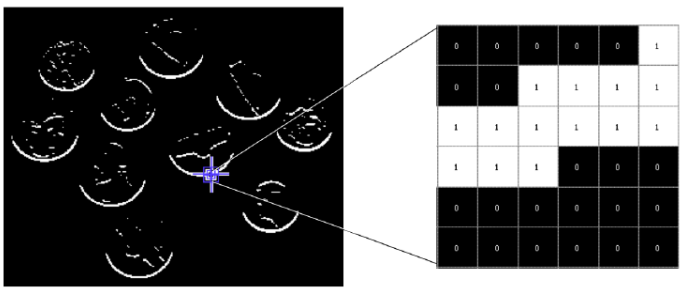
Array Representation

- MATLAB notation

$$f(p,q) = \begin{bmatrix} f(1,1) & f(1,2) & \cdots & f(1,N) \\ f(2,1) & f(2,2) & \cdots & f(2,N) \\ \vdots & \vdots & & \vdots \\ f(M,1) & f(M,2) & \cdots & f(M,N) \end{bmatrix}$$

Digital image representation

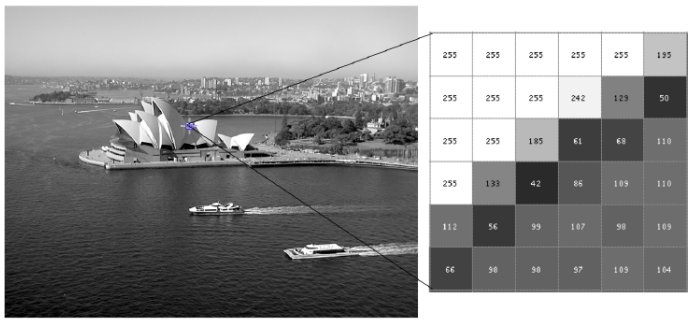
- Binary (1-bit) images
  - 2D array, one bit per pixel, a 0 *usually* means "black" and a 1 means "white".
  - In MATLAB: binary images are represented using a **`logical`** array of 0s and 1s.



By Oge Marques

Digital image representation

- Gray-level (8-bit) images
  - 2D array, 8 bits per pixel, a 0 usually means "black" and a 255 means "white".
  - In MATLAB: intensity images can be represented using different data types (or classes): **`uint8`**, **`uint16`**, or



Digital image representation

- Color images
  - **RGB representation**: each pixel is usually represented by a 24-bit number containing the amount of its Red (R), Green (G), and Blue (B) components (8 bits per component)
  - **Indexed representation**: a 2D array contains indices to a color palette (or look-up table, LUT).

Digital image representation

(a) 24-bit (true color) RGB image

(b) R

(c) G

(d) B

2^24= 16M colors

Digital image representation

- Indexed color images: old hardware can not display 16M colors. Use a pointer to a color palette (color map) . Typically 256 colors.

Compression

- Most image file formats employ some type of compression.
- Compression methods can be:
  - **Lossy**: a tolerable degree of deterioration is introduced in visual quality.
  - **Lossless**: image is encoded in its full quality.
- As a general guideline:
  - **Lossy** compression should be used for general purpose photographic images
  - **Lossless** compression should be used for images in which no loss of detail may be tolerable (e.g., space images and medical images).

Image file formats

- Image file contents:
  - File header
  - Pixel data (often compressed)
- Most common file types:
  - BIN, PPM (color images), PBM (binary images), PGM (gray-scale images), PNM, BMP, JPEG, GIF, TIFF, PNG
- imread and imwrite functions of MATLAB handle most formats

Image Aspect Ratio

Height in cm (H)

Width in cm (W)

Image Aspect Ratio = image width/image height = W/H

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Aspect Ratio Examples

- VGA: 640x480 (4:3)
- SVGA: 800x600 (4:3)
- CD: 360x288 (5:4)
- DVD: 720x576 (5:4)
- HD: 1920x1080 (16:9)

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Pixel Aspect Ratio

Number of lines (N)

Number of pixels per line (M)

Pixel Aspect Ratio = pixel width/pixel height = WN/HM

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Pixel Aspect Ratio Example

- SDTV video on HDTV monitor:

Pixel Aspect Ratio = 16x4/9x5 = 1.42

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Project 1.1

Image Quantization

Due 03.10.2013

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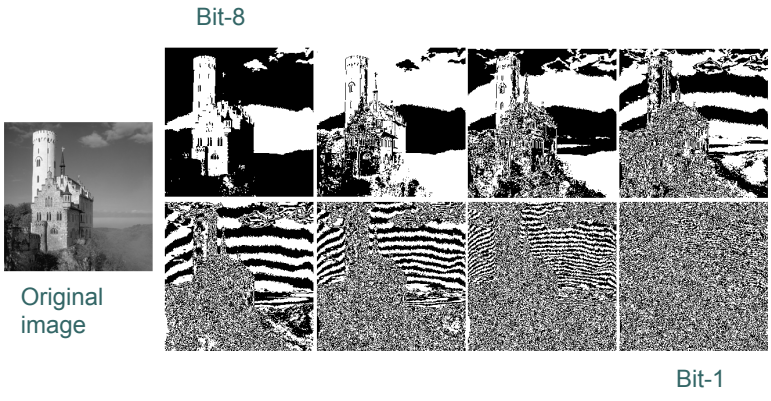
Image Quantization: Bit Planes



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Project 1.1

1. Select an arbitrary image.
2. Display the individual bit planes of the image.
3. Display the image obtained by combining Bit-8 and Bit-7 only.
4. Display the image obtained by combining Bits 8,7,6, and 5 only.
5. Compare the original image with the images obtained in Steps 3 and 4, and comment on the results.

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Next Lecture

- COLOR THEORY
- IMAGE ENHANCEMENT