COMP 478/6771

Image Processing

Introduction

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Slides modified from materials provided by Dr. Tien D Bui

COMP 478/6771

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- Office hours: Wednesday: 16:00 - 17:00 ET (virtual)
- Classroom: H429 SGW
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- Tutorials/Labs:

Sobhan Goudarzi (sobhan.goudarzi@yahoo.com) - Tutorial
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Faezeh Sohrabi (faezeh.sohrabi96@gmail.com) - Marker
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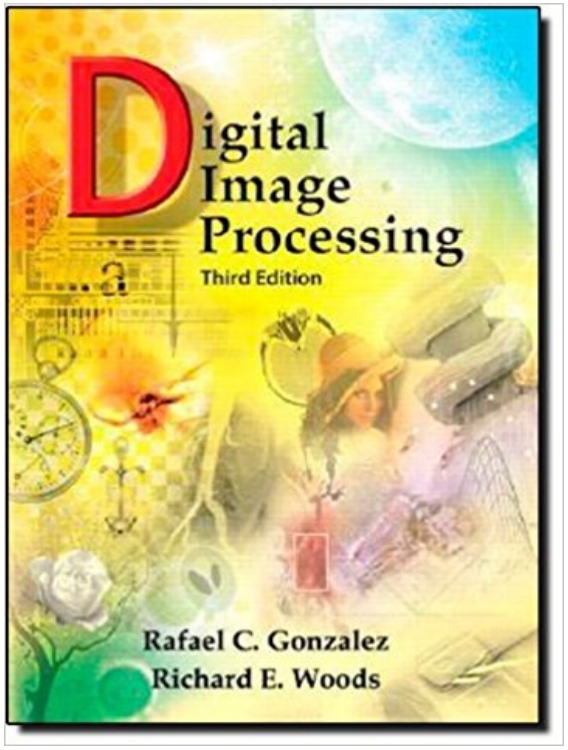
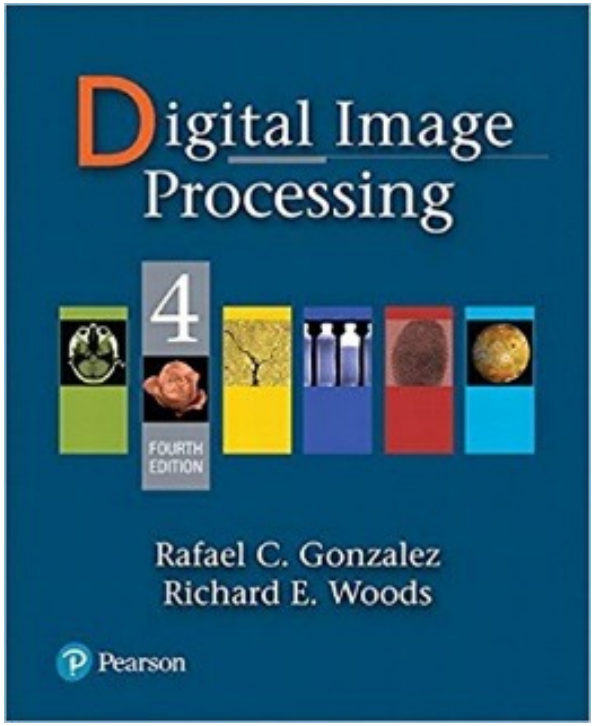
Bahar Jahani (baharjahani98@gmail.com) - Marker

✓ LabDDDI1-T——20:30~22:00 ET TBA
✓ LabDDDJ1-T——20:30~22:00 ET TBA

- **Textbook:** *Digital Image Processing, 4th Edition, R. C. Gonzalez and R. E. Woods, Prentice Hall.*





- **Textbook:** *Digital Image Processing, 4th Edition, R. C. Gonzalez and R. E. Woods, Prentice Hall.*

- **Reference book:** *Digital Image Processing using Matlab, 2nd Edition, R. C. Gonzalez, R. E. Woods, S. L. Eddins, Prentice Hall.*

- **Assignments:** *There will be four assignments. Assignments must be done individually. Assignments are due strictly on the due date. No submissions will be accepted three days after the due date, and in that period, there is a penalty of 30% for each day late. Assignments are worth 20% of the final mark.*

- **Mid-term test:** *There will be one mid-term test worth 20% of the final mark.*

- **Project:** *There will be a project worth 30% of the final mark. The project for COMP 478 is different from the project for COMP 6771. Students taking the course as COMP 478 are required to submit only a final written report. Students taking the course as COMP 6771 must submit a final written report and may have to make a presentation at the end of the term and before the final exam period. Students must submit the final written report before the final exam. Final written report should not be more than 10 pages long and contain details of the implementation as well as all computer codes in MATLAB. Details will be announced later.*
- *You can propose your own project, but the proposal (<1page) will needs to be handed in one week after the project announcement.* ***Students may complete the project in a team with at most 2 members.***

- **Final exam:** *<3-hr final exam at the end of term, worth 30% of the final mark.*

- **Note:** *There is no relationship between the total numerical marks and the final letter grades.*

- **Supporting software:** *MATLAB, Image Processing toolbox, Signal Processing toolbox, Wavelet toolbox .*

Faculty of Engineering and Computer Science
Expectations of Originality

This form sets out the requirements for originality for work submitted by students in the Faculty of Engineering and Computer Science. Submissions such as assignments, lab reports, project reports, computer programs and take-home exams must conform to the requirements stated on this form and to the Academic Code of Conduct. The course outline may stipulate additional requirements for the course.

1. Your submissions must be your own original work. Group submissions must be the original work of the students in the group.
2. Direct quotations must not exceed 5% of the content of a report, must be enclosed in quotation marks, and must be attributed to the source by a numerical reference citation[1]. Note that engineering reports rarely contain direct quotations.
3. Material paraphrased or taken from a source must be attributed to the source by a numerical reference citation.
4. Text that is inserted from a web site must be enclosed in quotation marks and attributed to the web site by numerical reference citation.
5. Drawings, diagrams, photos, maps or other visual material taken from a source must be attributed to that source by a numerical reference citation.

Overview

- Definitions
- Motivations
- Applications

Review

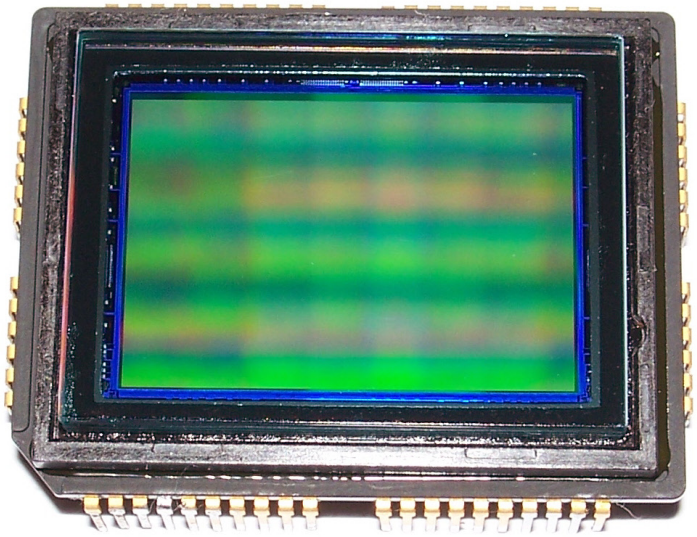
- Matrices and Vectors
- Probability/Statistics
- Linear Systems

What is a digital image?

- Sensors: CCD (Charge-Coupled Device) & CMOS (Complementary Metal-Oxide Semiconductor)
  - ✓ Photon -> electron -> voltage
- Divided into array of light-sensitive cells called photosites or **pixels**
- Each pixel has a **gray-level** or brightness (e.g, 0-255)
- For color pixel: needs three **channels** or bands (RGB)
- **Resolution** or size: number of rows and columns in the image

  1280 x 720 (720p) for HD video

  For brain MRI images: ~256x256x120 (~1x1x1 mm^3)



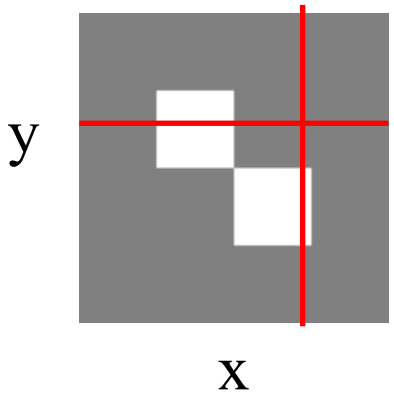
CCD from a Sony alpha DSLR-A300 (10.14 Megapixel)

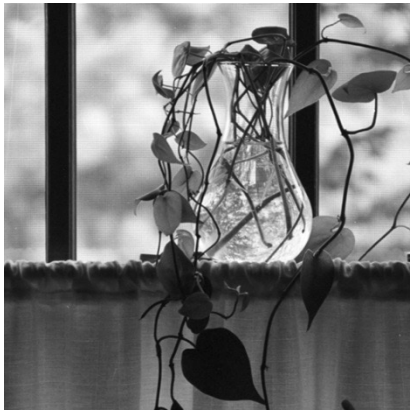
CMOS sensor from Canon 5D Mark II

Bulk processing vs. element-wise processing

What is Digital Image Processing?

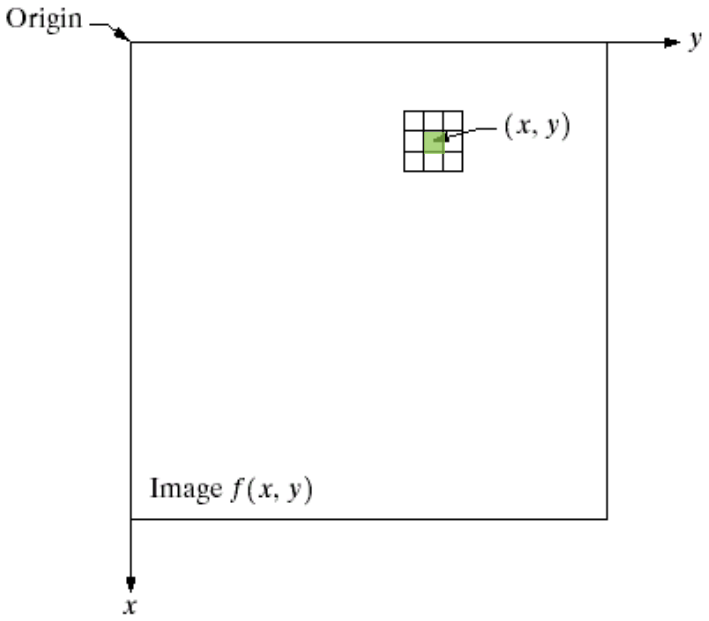
- An image is a function of two spatial variables f(x,y), where (x,y) denote the planar image coordinates, and f(.) is the amplitude of the image at the given location.

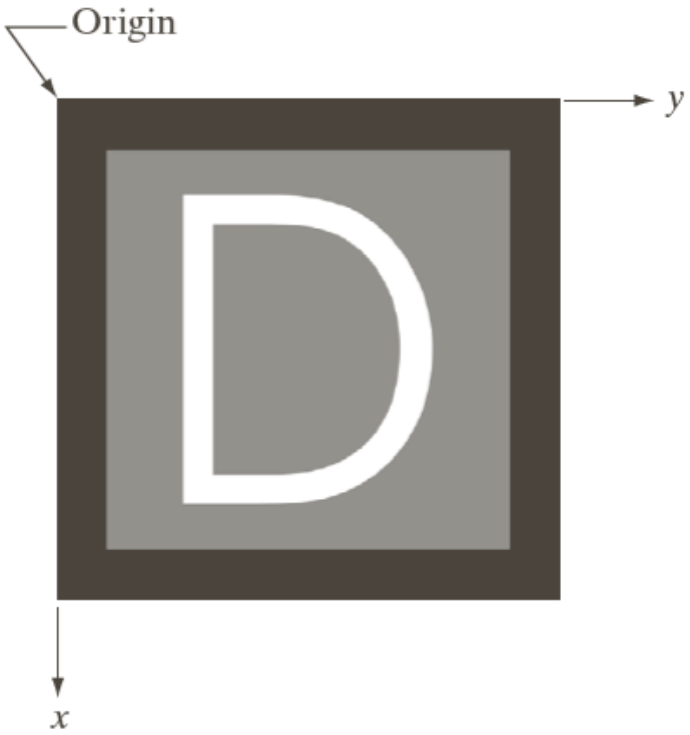




Digital Image Representation

A pixel in 3x3 neighborhood,
at location (x,y)

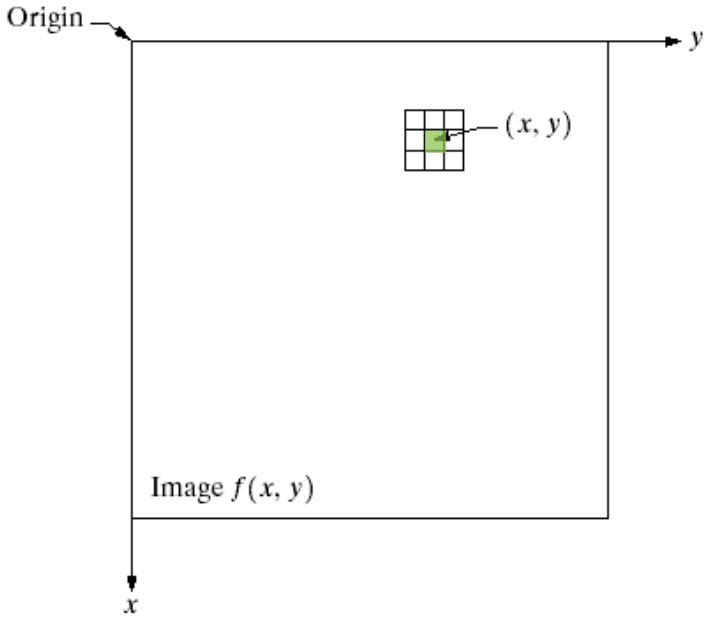




Intensity values: {0, 0.5, 1}

Digital Image Representation

A **pixel** in 3x3 neighborhood, at location (x,y) with intensity f(x,y)



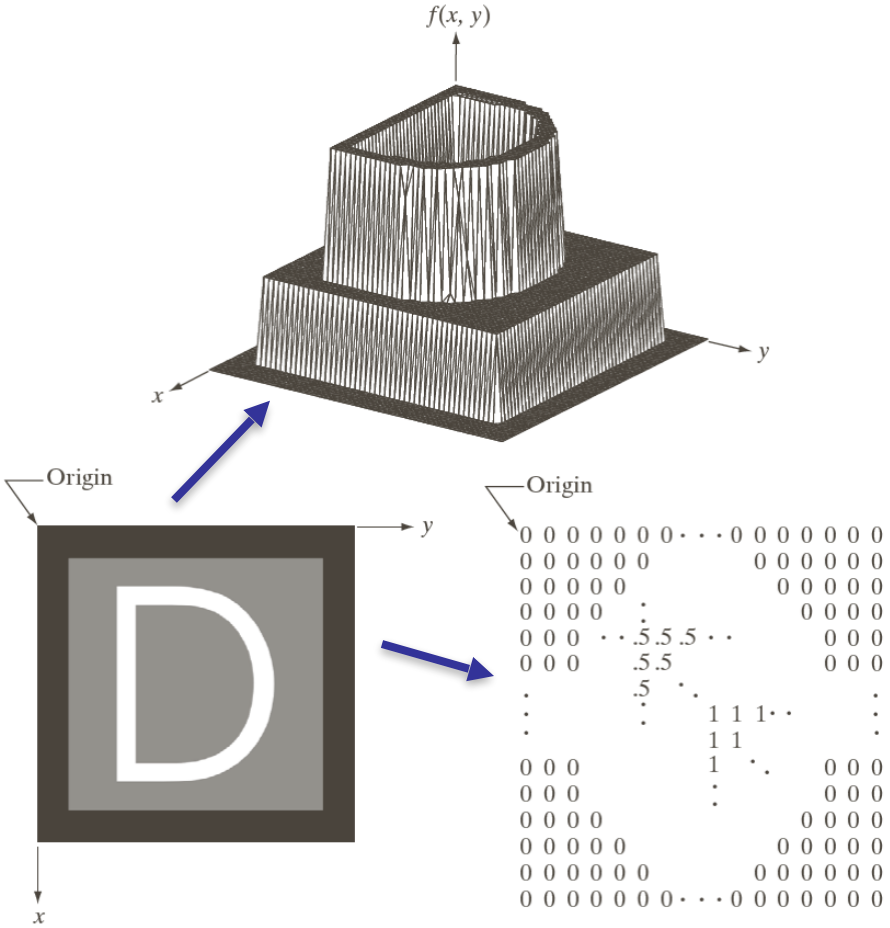
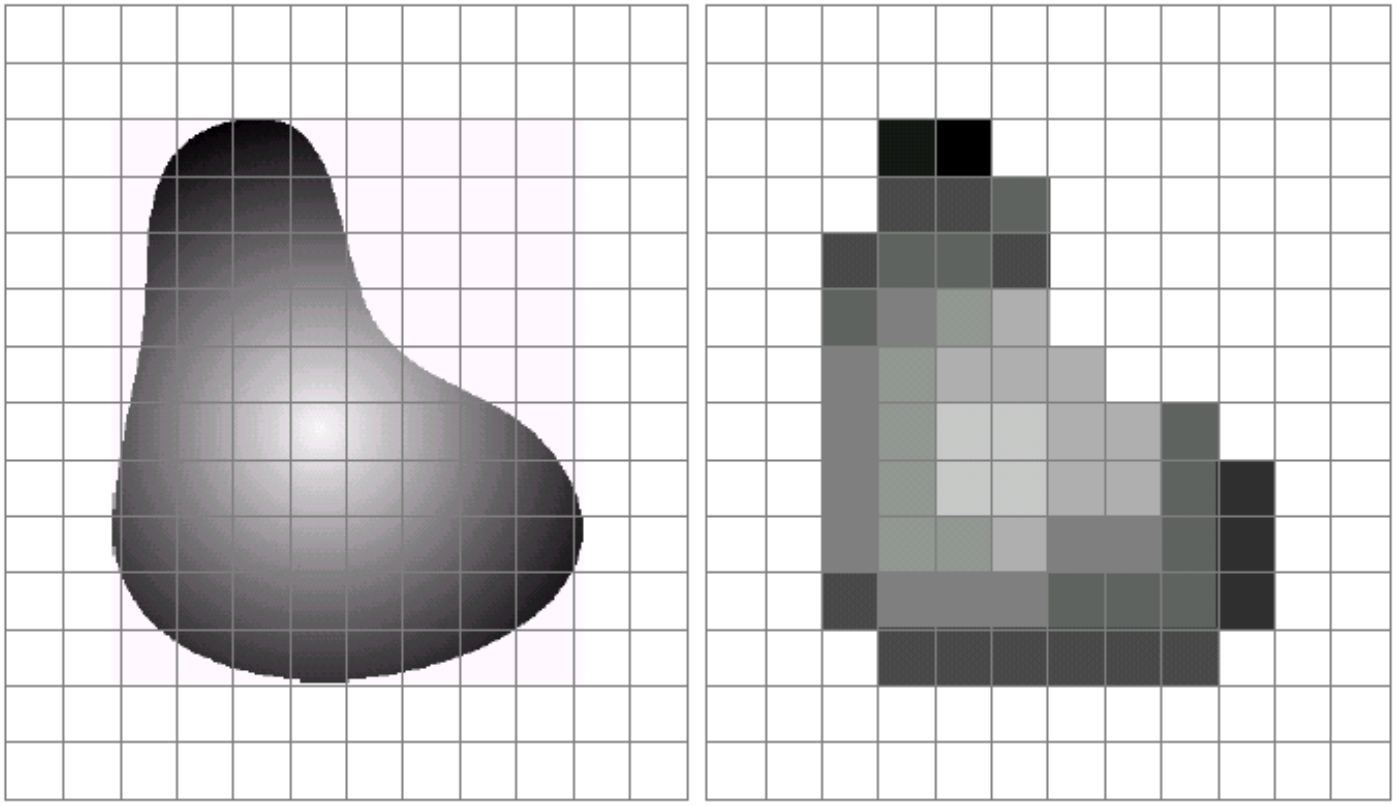


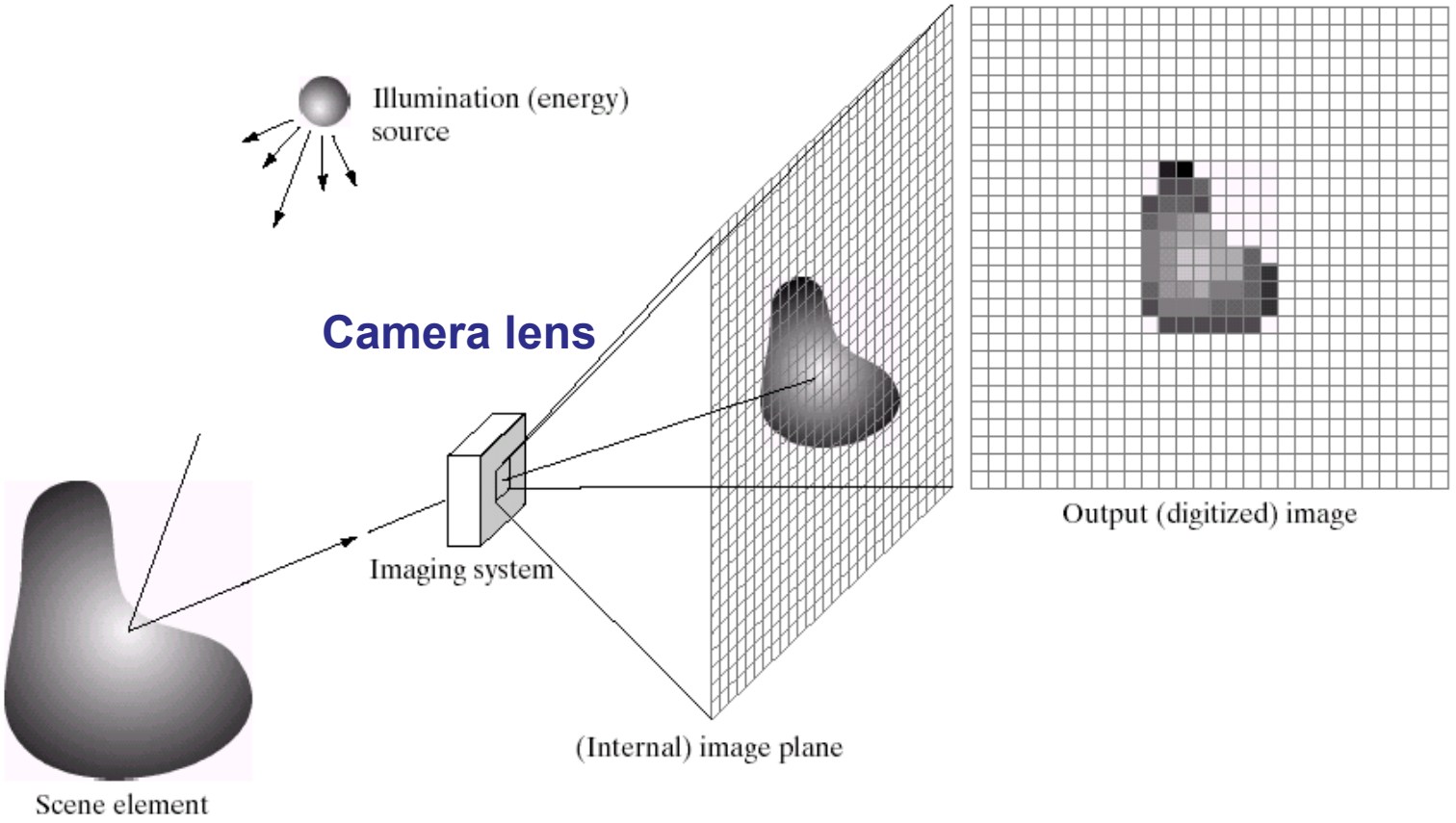
Image Sampling and Quantization



a b

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

Image Acquisition



a
b c d e

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

An image is represented by a two-dimensional function $f(x, y)$. The value of f at (x, y) is a +ve scalar quantity, i.e. $0 < f(x, y) < \infty$.

$f(x, y)$ is formed by 2 components:

(1) amount of source illumination incident on the scene.

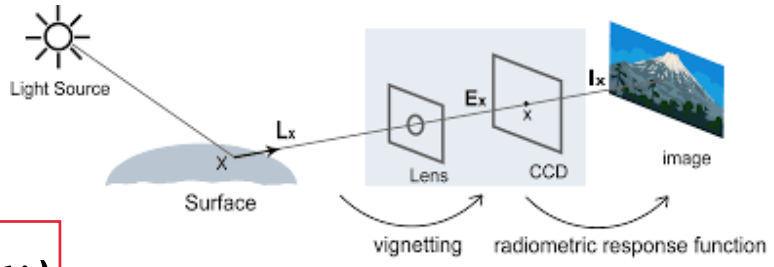
(2) amount of illumination reflected by the objects in the scene.

(1) is called illumination $= i(x, y)$,

(2) is called reflectance $= r(x,y)$, and :

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

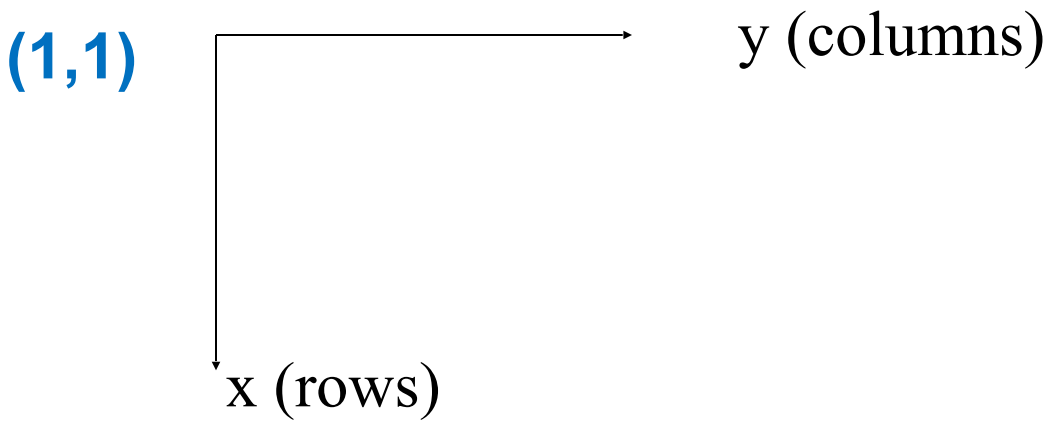
where $0 < i(x, y)$ and $0 < r(x, y) < 1$



• An MxN digital grayscale image: (for color f(x,y) would be 1 colour component)

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

• Book Convention: (Same as MATLAB, except MATLAB starts index at 1)



Chapter 2: Digital Image Fundamentals

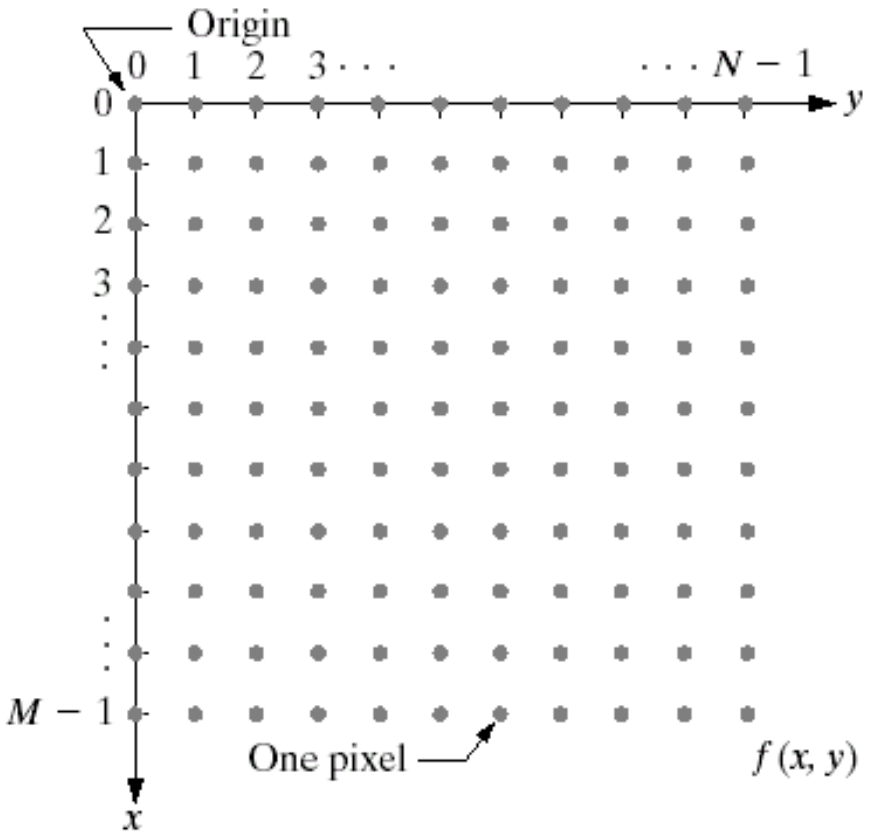


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

The Grayscale and Its Perception

- We call the intensity L = f(x,y) the "gray level" value
- The range of values of $L_{min} < L < L_{max}$ is called the grayscale.
- Commonly, we use the range [0 , L-1] for integer L that is a power of 2.

Black White

Example: 3 bits,
2^3 = 8 gray levels

Chapter 2: Digital Image Fundamentals

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

Pixel intensity is 2^k
Image size is NxN

Storage Needs for Images:

- Image MxN pixels, 2^B gray levels, *c* color components
  - *Size = M x N x B x c*
  - *Example: MxN=1024x1280, B=8, c=3 (24 bit RGB image)*
- *Size = 31,457,280 bits (or 3.75 MBytes)*

- Need to have (lossy) compression!

The image of a thin line is not a thin line

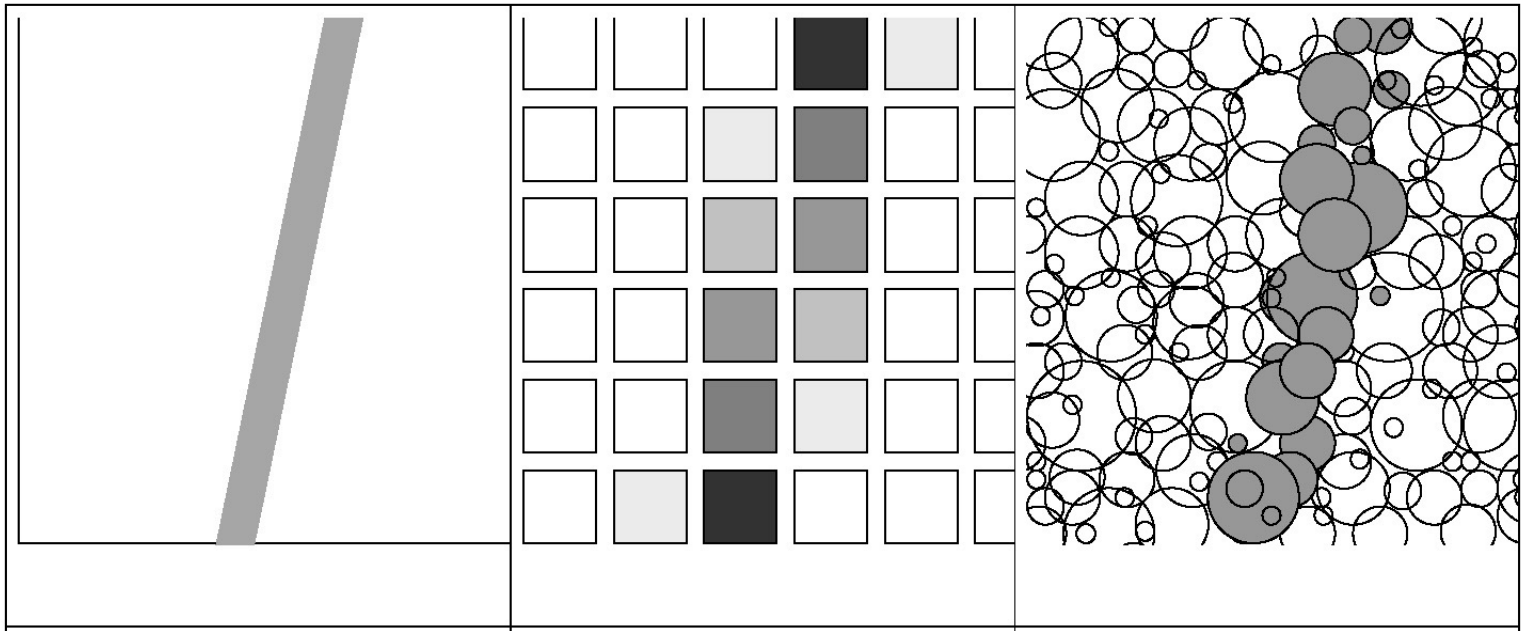
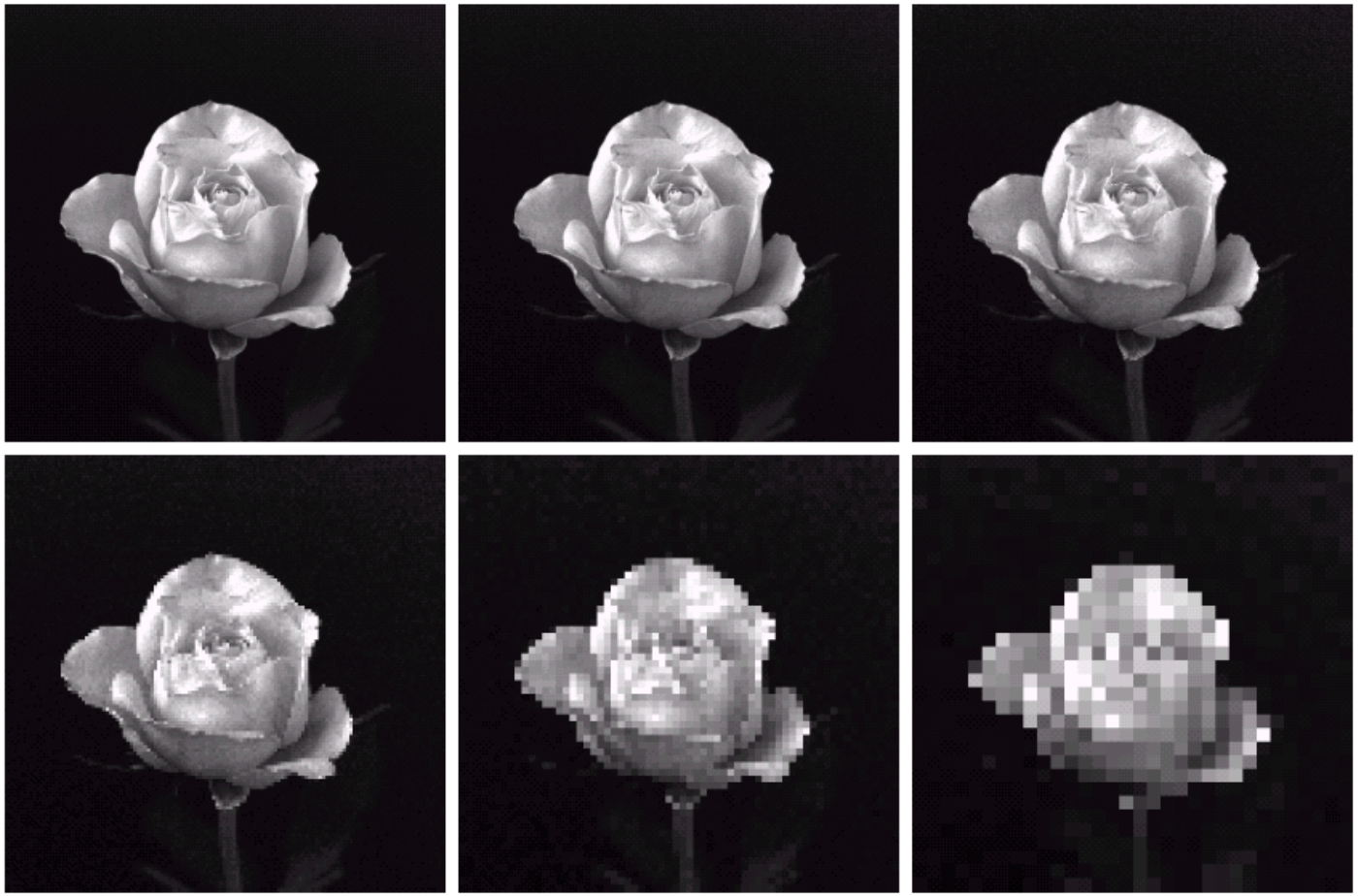


Image of a thin line	Pixel array	Film grains

Number of Pixels and Resolution

FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

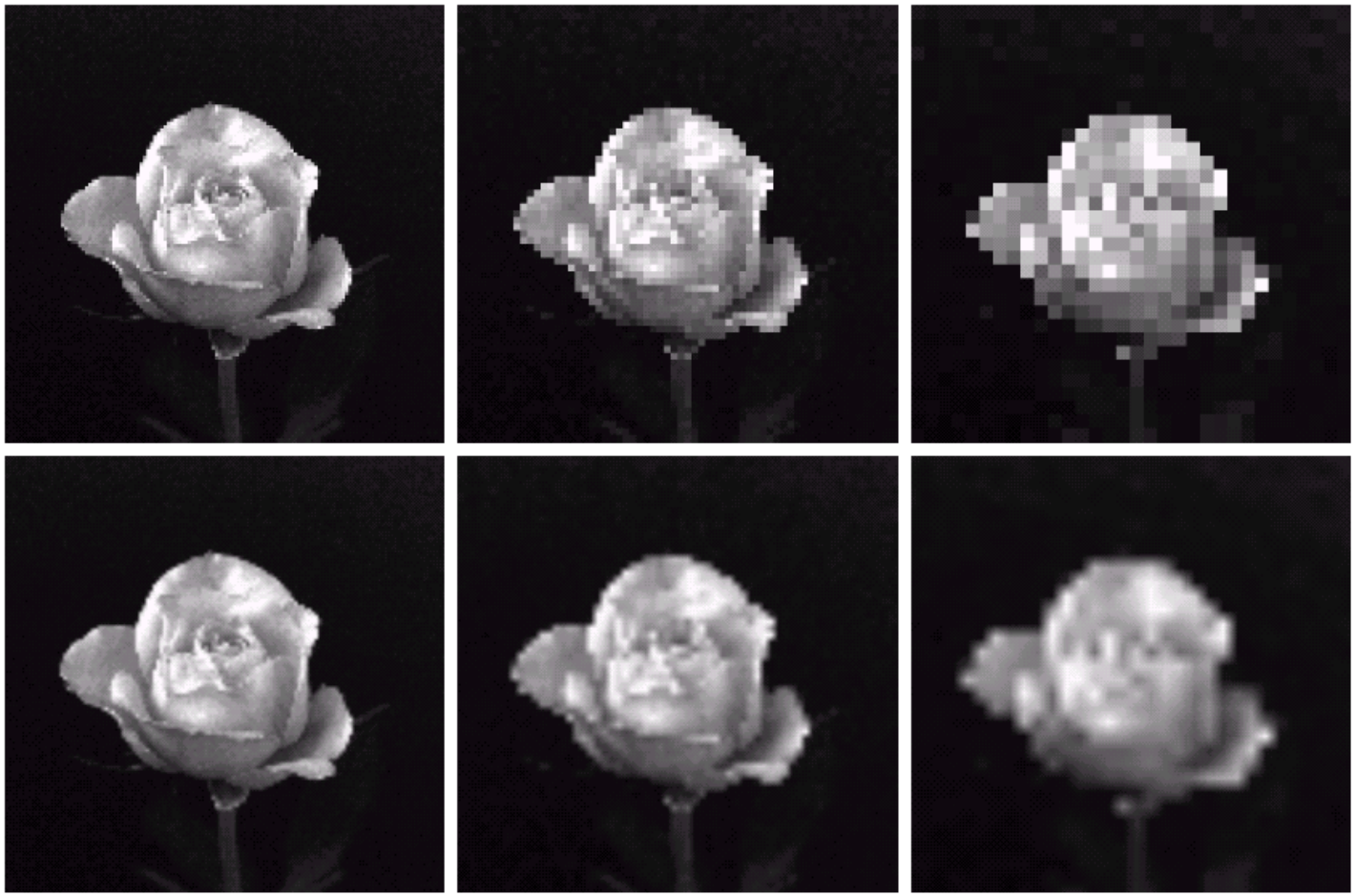
Number of Pixels ≠Resolution



a b c
d e f

FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

Number of Pixels ≠Resolution



a b c
d e f

FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

What Is An Image?

- Definition: An **image** is a 2-dimensional light intensity function, *f(x,y),* where *x* and *y* are spatial coordinates, and *f* at *(x,y)* is related to the brightness of the image at that point.
- Definition: A **digital image** is the representation of a continuous image *f(x,y)* by a 2-D array of discrete samples.
- The amplitude of each sample is quantized to be represented by a finite number of bits.
- Definition: Each element of the 2-D array of samples is called a **pixel** (Picture Element)

What is Digital Image Processing?

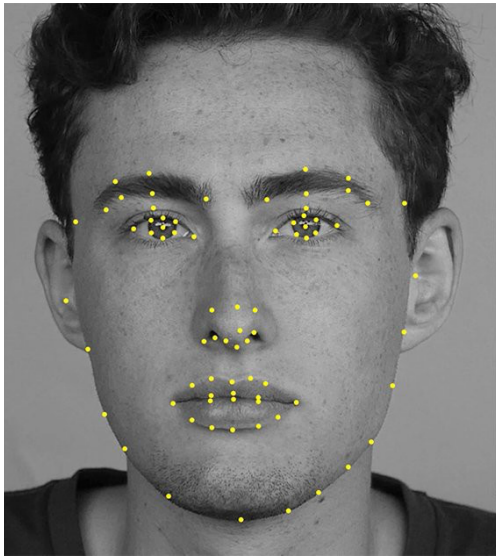
Processing images generally results in one of several kinds of outputs:

- Another image: g(x,y) = G (f(x,y)) (low-level processing)
- A set of attributes: edges, segments, objects (mid-level)
- An algorithmic "understanding" (high-level)

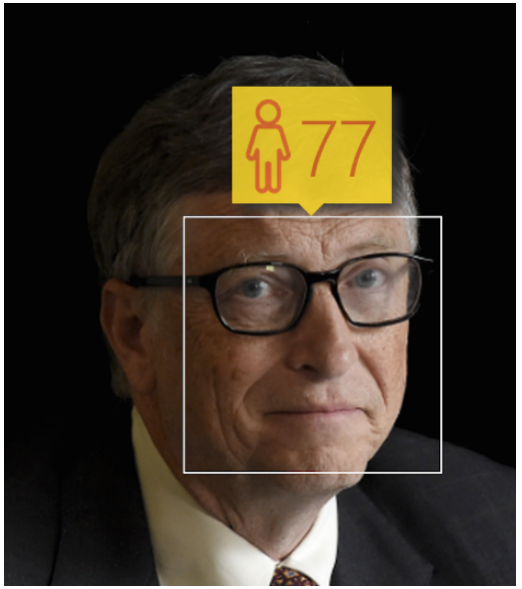
Processing **Vision**

Low-level	Mid-level	High-level
Denoising **Contrast enhancement** **Image sharpening**	Segmentation Contours	Image recognition

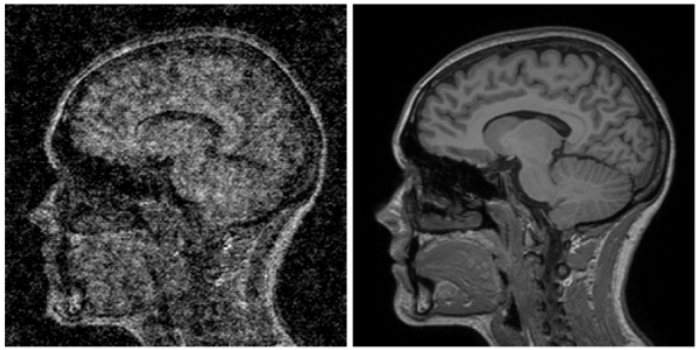
Denoising



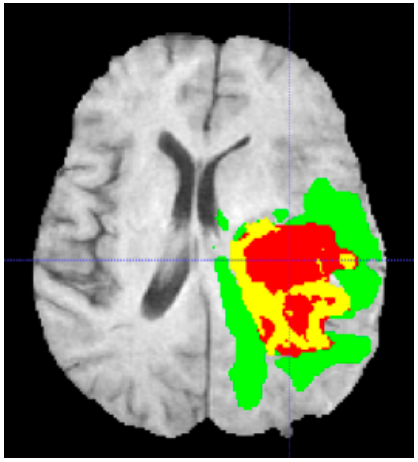
Landmark labels



Face recognition



Denoising



Segmentation

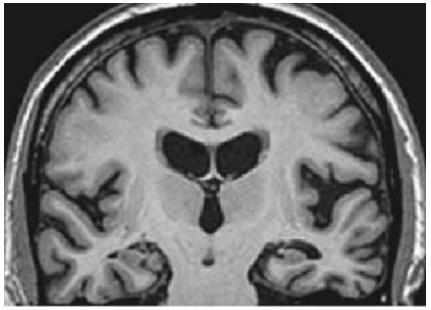
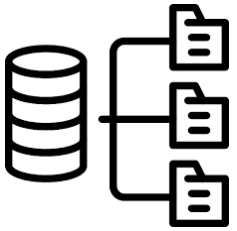


Image classification

Take a break!

Why do we process images?

- Facilitate storage and transmission of pictures
  - Compression of digital images
  - Transmission of images
- Prepare an image for display
  - Resizing images
  - High-dynamic range (HDR) display
- Enhance and restore images
  - Restoring old movies
  - Better medical scans
- Information extraction from images
  - Reading zip codes, bar codes
  - Robotics: e.g., Self-driving cars

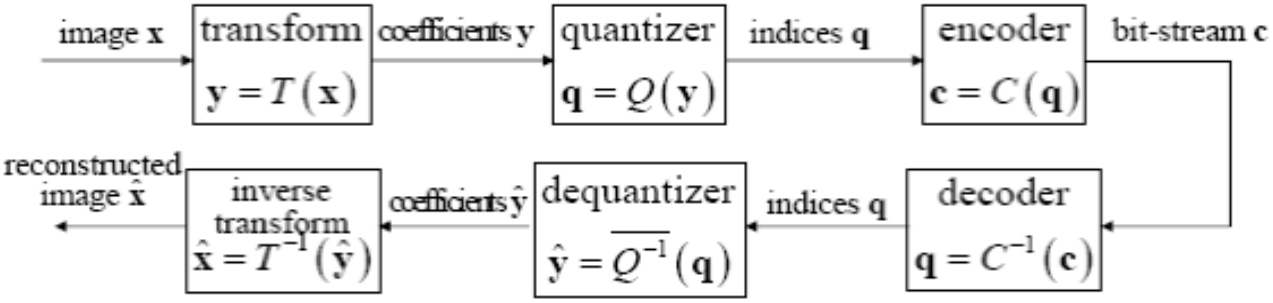


General Areas/Techniques of Image Processing

- Compression
- Recognition/classification
- Denoising
- Enhancement
- Restoration
- Segmentation
- Inpainting
- Super-resolution
- Watermarking
- Others

Areas of Image Processing

Compression



- Transform $T(\mathbf{x})$ usually invertible
- Quantization $Q(\mathbf{y})$ not invertible, introduces distortion
- Combination of encoder $C(\mathbf{q})$ and decoder $C^{-1}(\mathbf{c})$ lossless

Image compression standard:

- JPEG (1992): Joint Photographic Expert Group: works with color and grayscale images.
- *Compression ratio* of lossless methods is not high enough.
- JPEG uses *transform coding* (DCT = discrete cosine transform)
- JPEG 2000 uses wavelet transforms

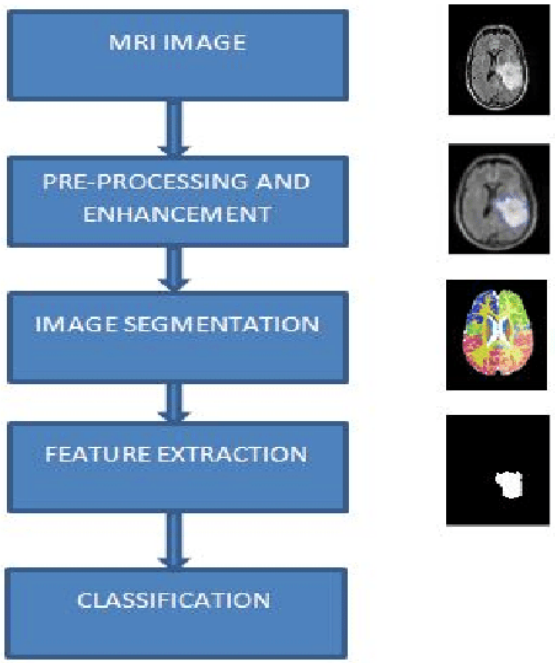
Image Compression

At 158:1 compression ratio

Courtesy of Minh Do

Areas of Image Processing

Recognition and classification



Some important steps:

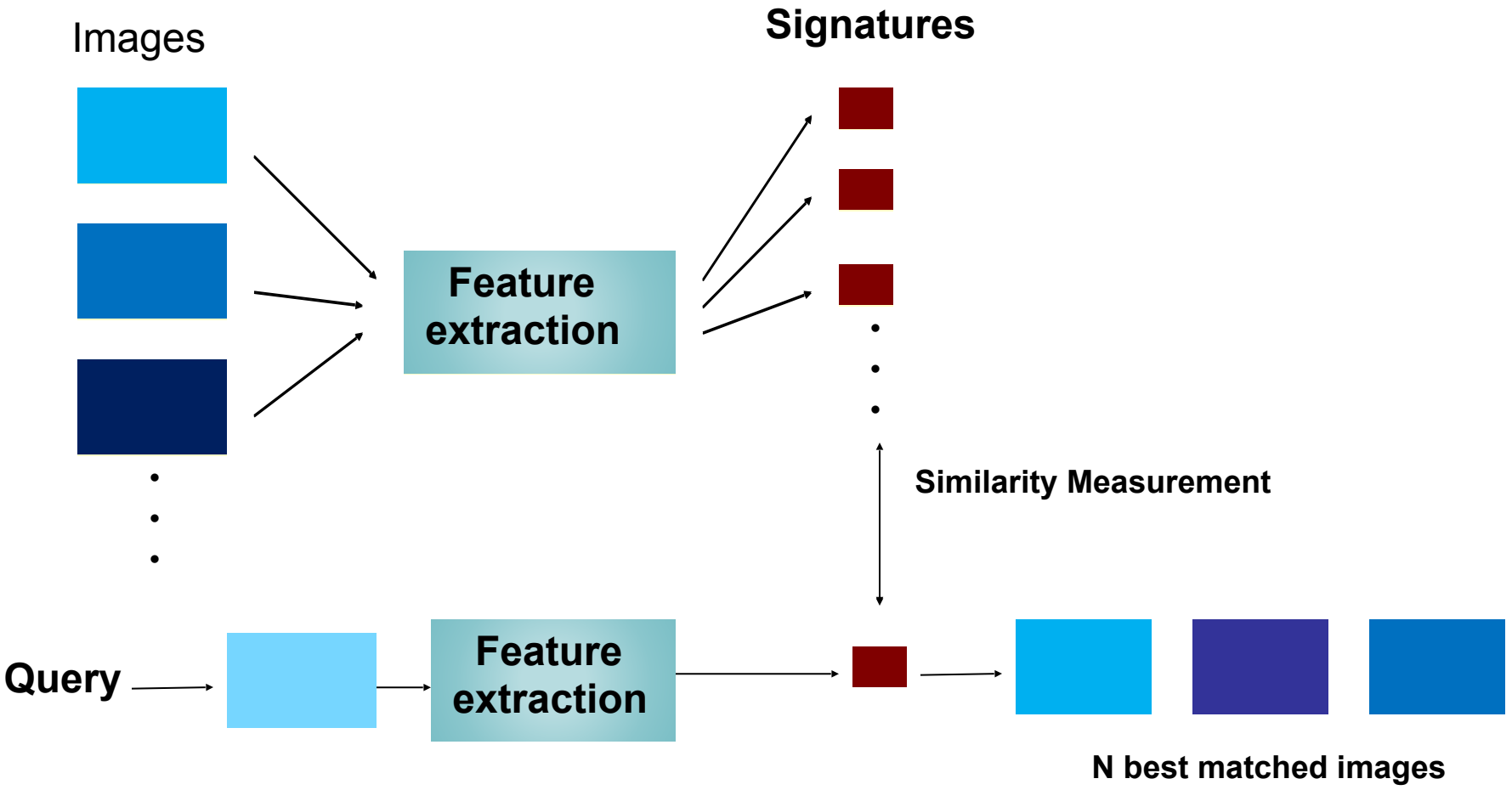
- Preprocessing (denoise, deblurr, contrast enhancement,…)
- Segmentation
- Feature extraction (scale space, multiresolution, invariant features, occlusion)
- Recognition (feature matching, distance measure,…)
- Classification (machine learning)

Applications:

medical imaging, pattern recognition, video processing, document processing, industrial applications

Recognition-Classification

Feature extraction (e.g. content-based image retrieval)



Areas of Image Processing

Denoising




- To give an image a softer effects ⇨ *smoothing or blurring*
- Removal of small details (aesthetic effects)Bridging of small gaps in lines or curves
- image smoothing using Gaussian mean filter

Areas of Image Processing

Denoising

"Many important images contain noise that is signal dependent, and obeys a Poisson distribution. A familiar example is that of radiography. The signal in a radiograph is determined by photon counting statistics and is often described as particle-limited, emphasizing the quantized and non-Gaussian nature of the signal.
Removing noise of this type is a more difficult problem."

Le Triet et al. J. Math Imaging Vision

Areas of Image Processing

Restoration

$$f(x,y) \longrightarrow \text{Degraded} \longrightarrow \oplus \longrightarrow g(x,y)$$

$$h(x,y) \qquad \text{noise}$$

$$g(x,y) = h(x,y) * f(x,y) + \eta(x,y)$$

$$\text{Restoration}: \quad g(x,y) \longrightarrow \text{Restoration box} \longrightarrow \hat{f}(x,y)$$

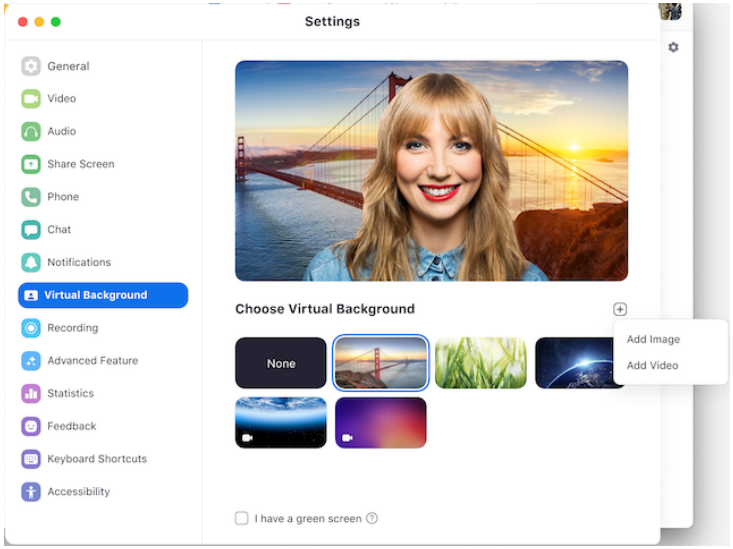
$$\text{Criteria}: \quad \text{Minimize} \quad E\left[(f(x,y) - \hat{f}(x,y))^2\right]$$

Given image *g*, related to true image *f* through blur *h* and noise

Inverse Problem: restore *f*, given *h* and statistics for the noise. Keeping edges sharp and in the correct location is a key problem !

Areas of Image Processing

Segmentation



support.zoom.us

Objective: Partition an image Ω into *n* sub-regions, such that:

1. image data $u(x, y)$ vary smoothly and/or slowly within each Ω_i

2. image $u(x, y)$ varies discontinuously and/or rapidly across the boundary C between different Ω_i

Areas of Image Processing

Inpainting

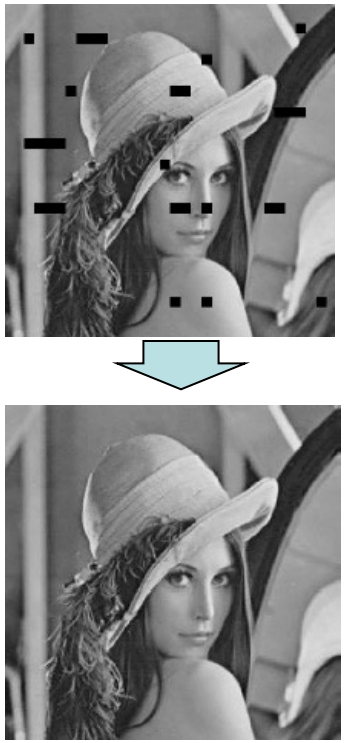


Real inpainting example
from http://www.topcstudio.com/inpainting.htm

- How to estimate some missing or damaged regions in an image?
- Inpainting (retouching, repairing): originated from art conservation or restoration
- A manual procedure to restore a damaged artwork (e.g., mediaeval painting)

Related Subjects to Inpainting

- Disocclusion (object removal, image completion)
  - Fundamentally the same problem as image inpainting



Block recovery [Rane03]

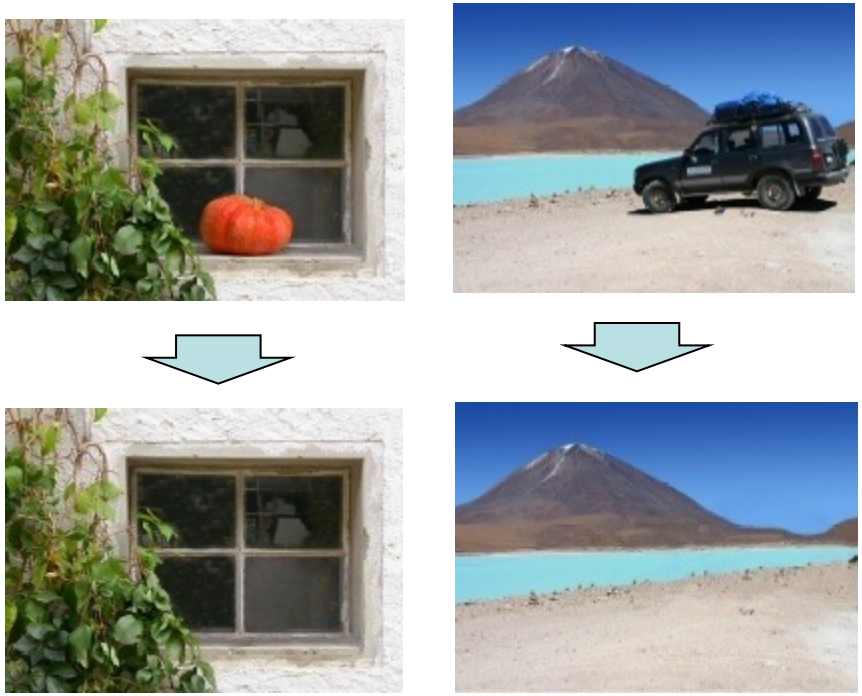


Image completion (object removal) [Sun05]

Areas of Image Processing

Super-resolution

Super-resolution (SR) reconstruction is able to produce high-resolution (**HR**) image(s) from a set of low-resolution (**LR**) images. **Color video resolution enhancement using 30 input frames** (courtesy of Dr. Milanfar at UCSC)

Your source of training data are important!

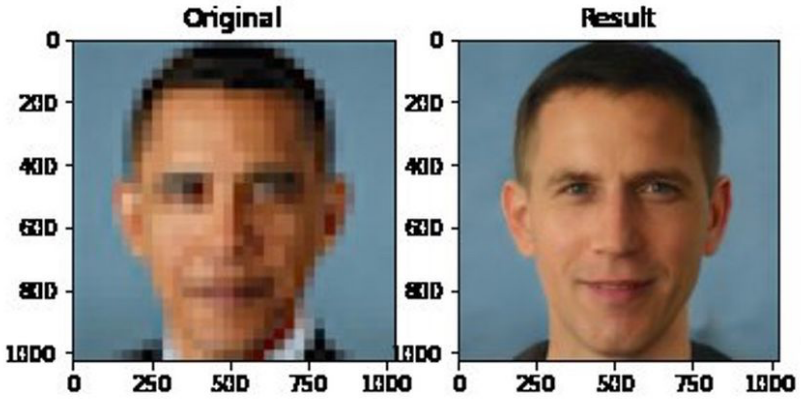


Image: Twitter / @Chicken3gg

Areas of Image Processing

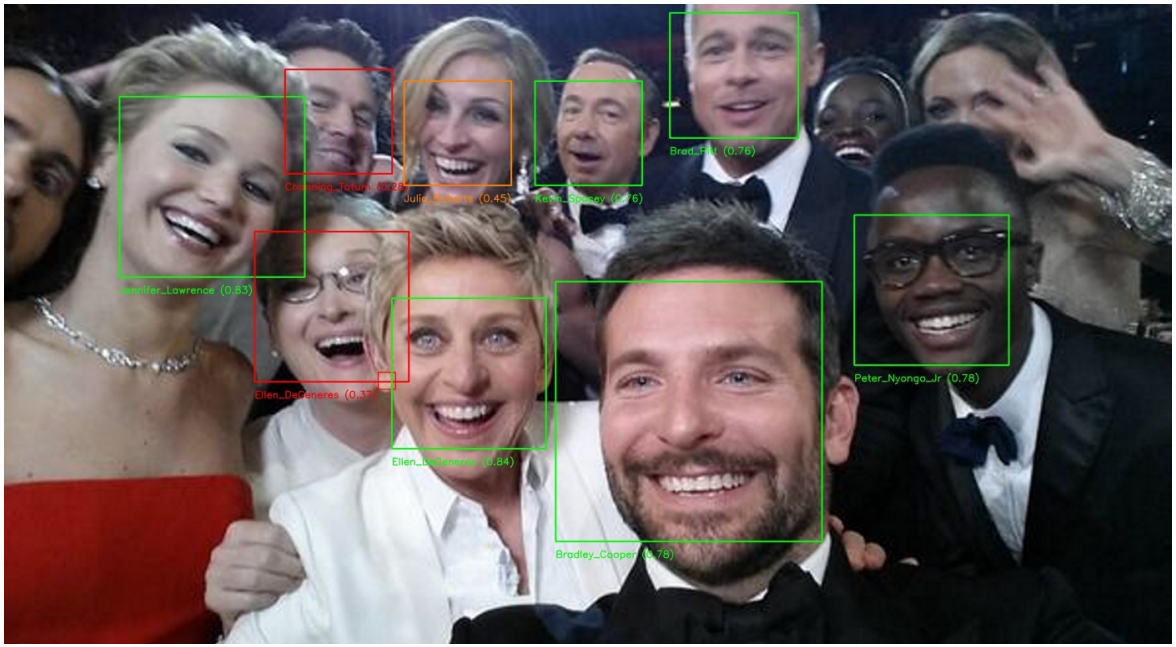
Watermarking

What is watermarking?

Watermarking means protecting the image with a copyright notice or a logo that denotes the origin of the image/ photo. Such watermark prevents people from using your images and photos without your consent. If they use it they must use it with the your mark.

What are the applications?

Face Detection (identity, sex, age, etc)

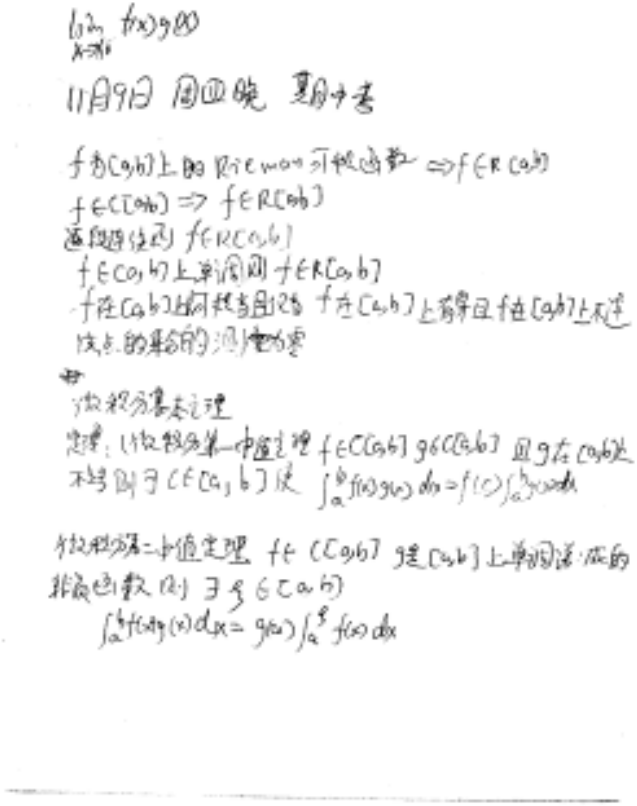


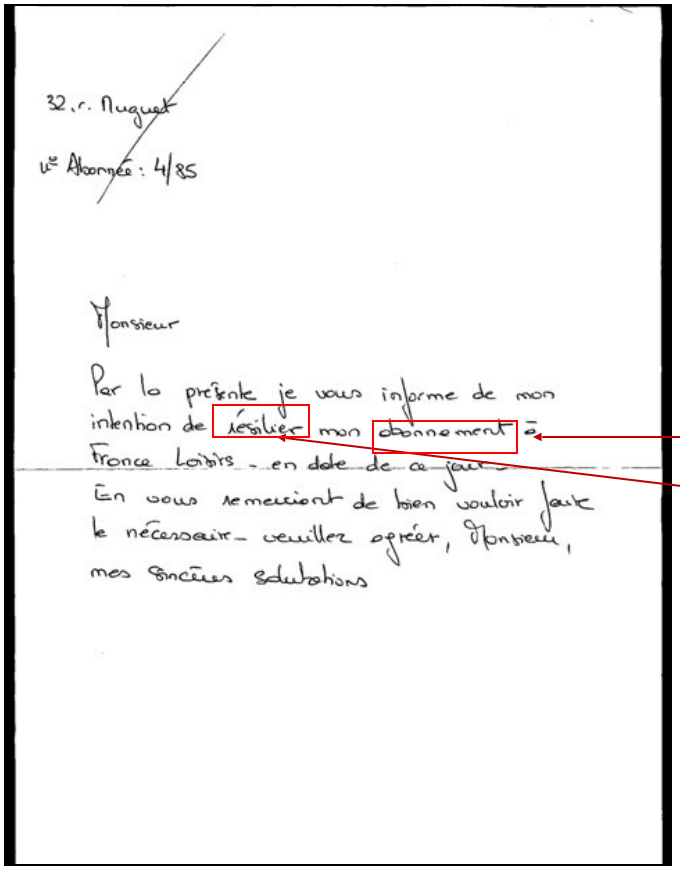
towardsdatascience.com/an-intro-to-deep-learning-for-face-recognition-aa8dfbbc51fb

www.youtube.com/watch?v=Pc2aJxnmzh0&feature=emb_title

Digital Document Processing

- Textlines and keywords detection in handwritten documents
- Classification of handwritten documents





User-entered search keywords:

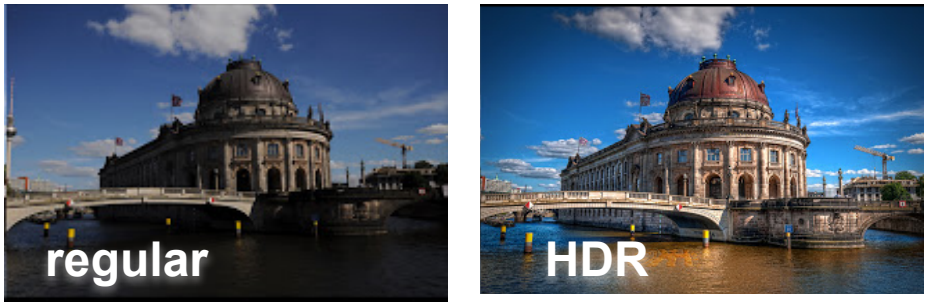
abonnement

résilier

Scene Text Detection

Digital photography

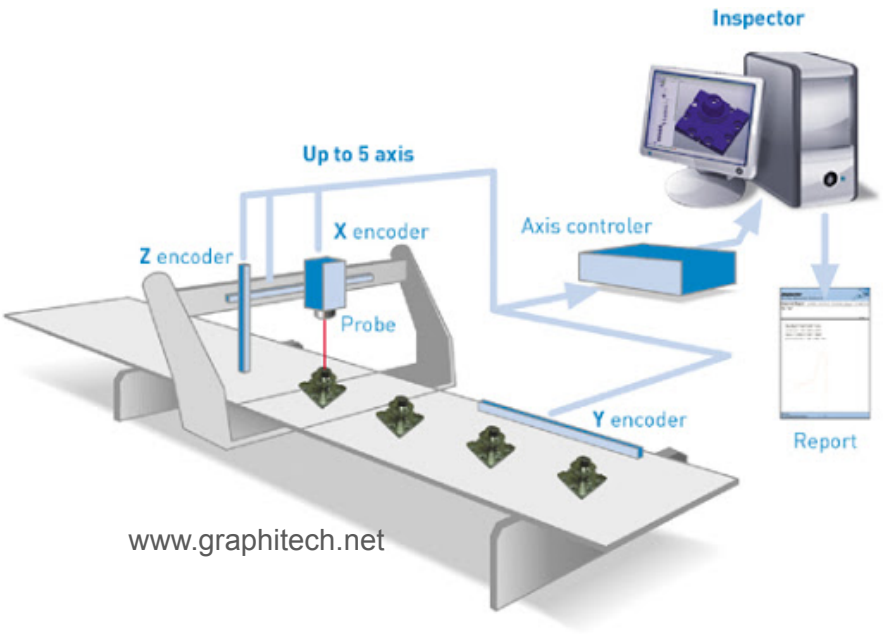
Content-aware image scaling (https://helpx.adobe.com)



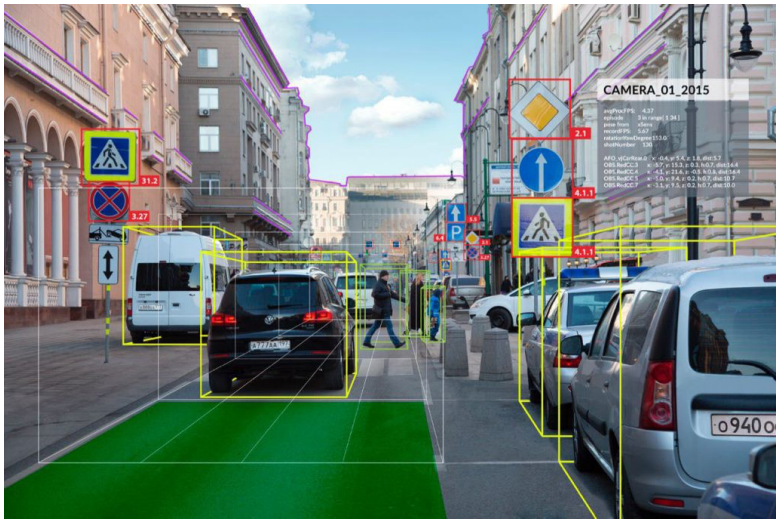
High-dynamic-range (HDR) photography

(http://pristinekk.blogspot.com)

Automated decisions / robotics



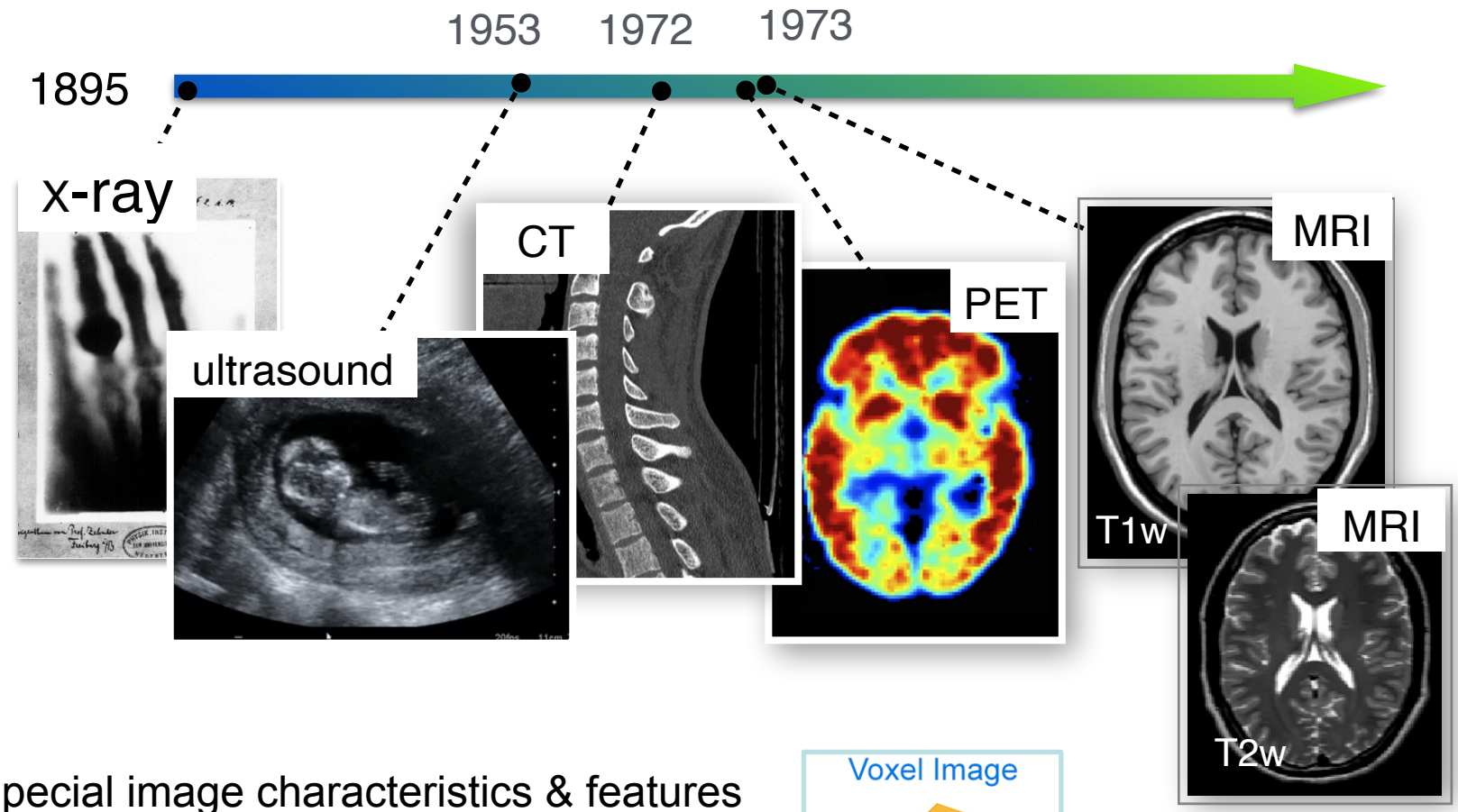
Product quality control



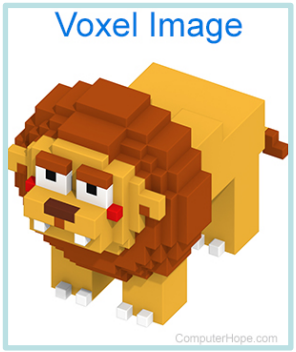
https://becominghuman.ai/computer-vision-applications-in-self-driving-cars-610561e14118

Self-driving cars

Medical Imaging



Special image characteristics & features
3D image: voxel instead of pixel
4D image: 3D image in time series



Medical Imaging

Blood vessel enhancement

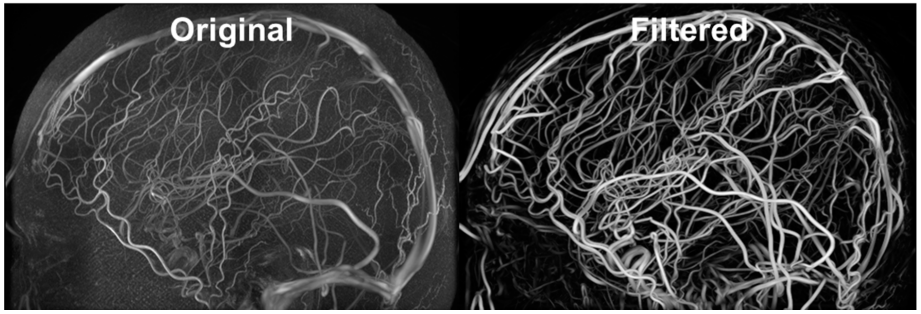


Image Enhancement

Generate CT from MRI

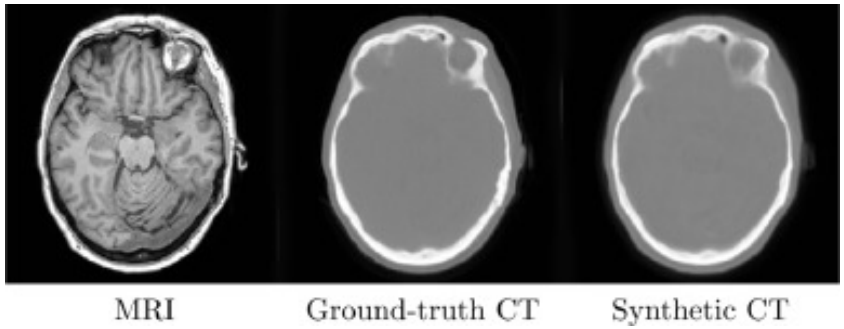


Image synthesis

Brain tissue classification

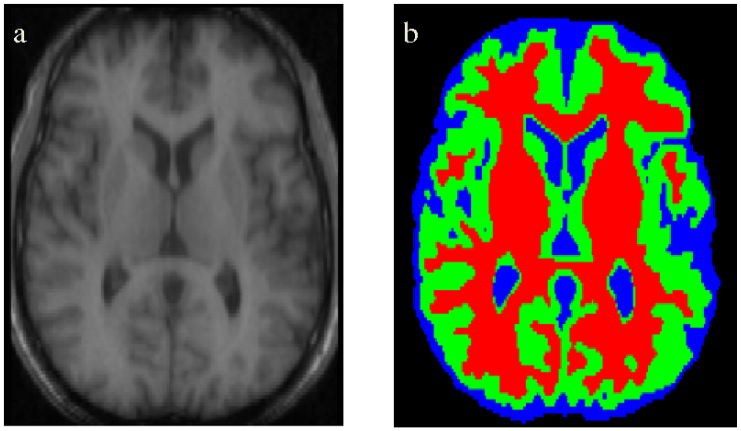
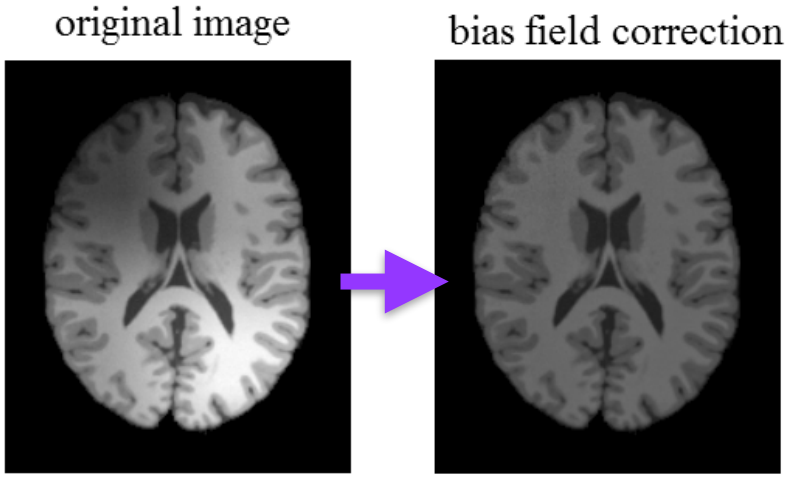
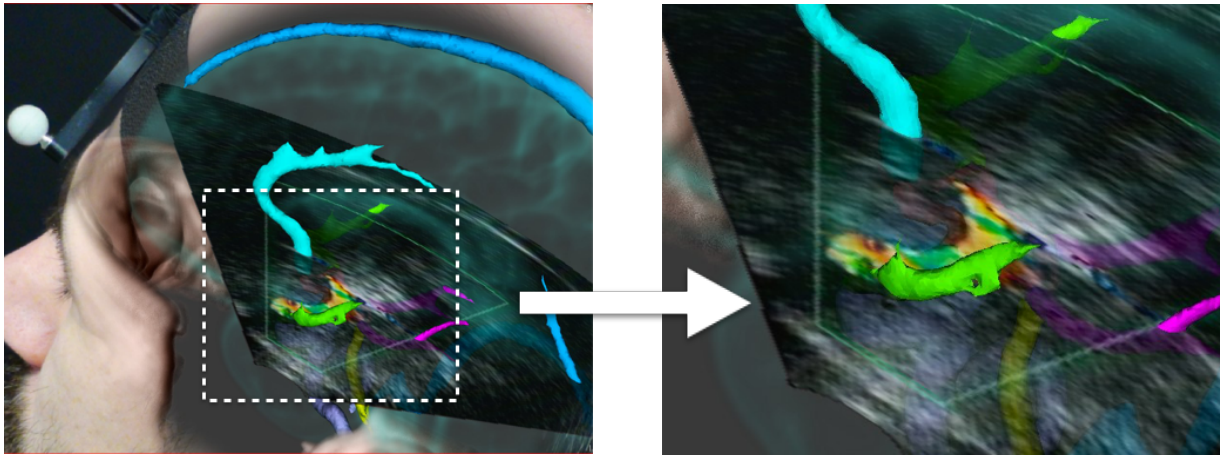


Image segmentation



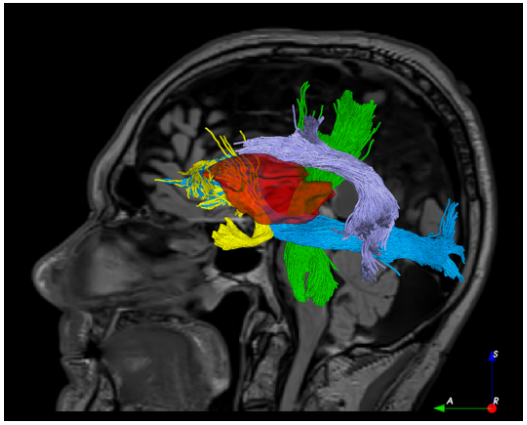
Contrast correction

Medical Imaging



(Xiao et al., Multimed Tools Appl, 2018)

Medical augmented-reality (AR)



Surgical planning

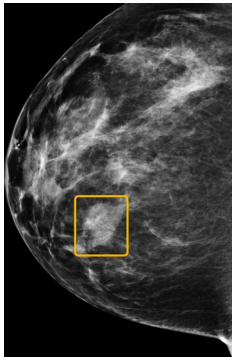
HEALTH AND SCIENCE

Google's DeepMind A.I. beats doctors in breast cancer screening trial

PUBLISHED THU, JAN 2 2020•8:13 AM EST

David Reid
@DAVYREID73

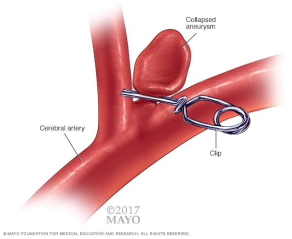
SHARE



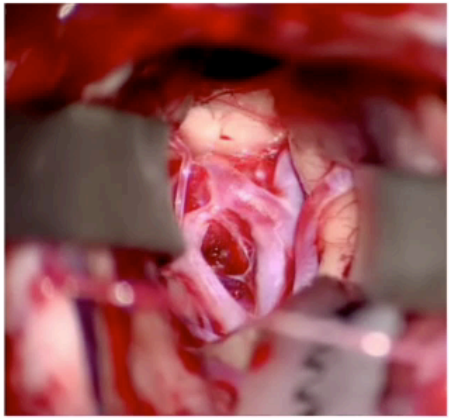
(McKinney et al., 2020)

Computer-assisted diagnosis

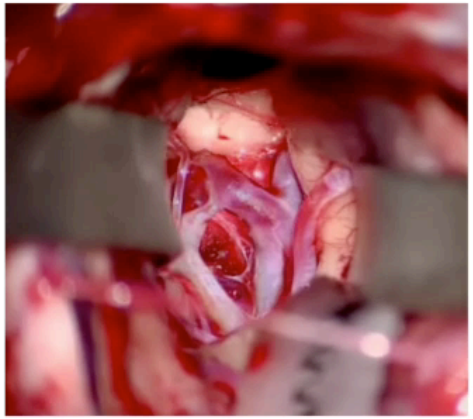
Medical Imaging



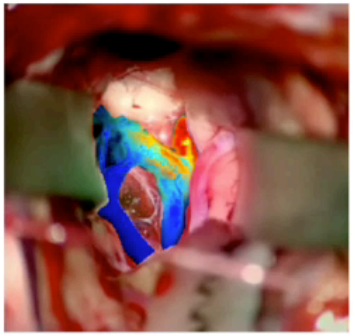
(Vassallo et al., Healthc. Tchnol. Lett., 2018)



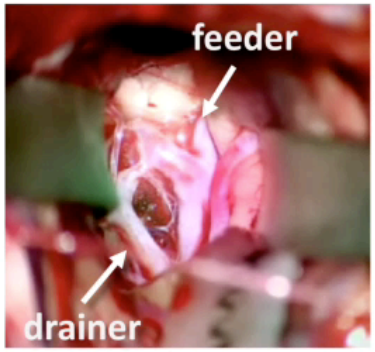
Original video footage



Enhanced video



AR view of pulsation power



Summary

- Introduction of key concepts and definitions
- General areas/techniques in image processing
- Applications in various domains