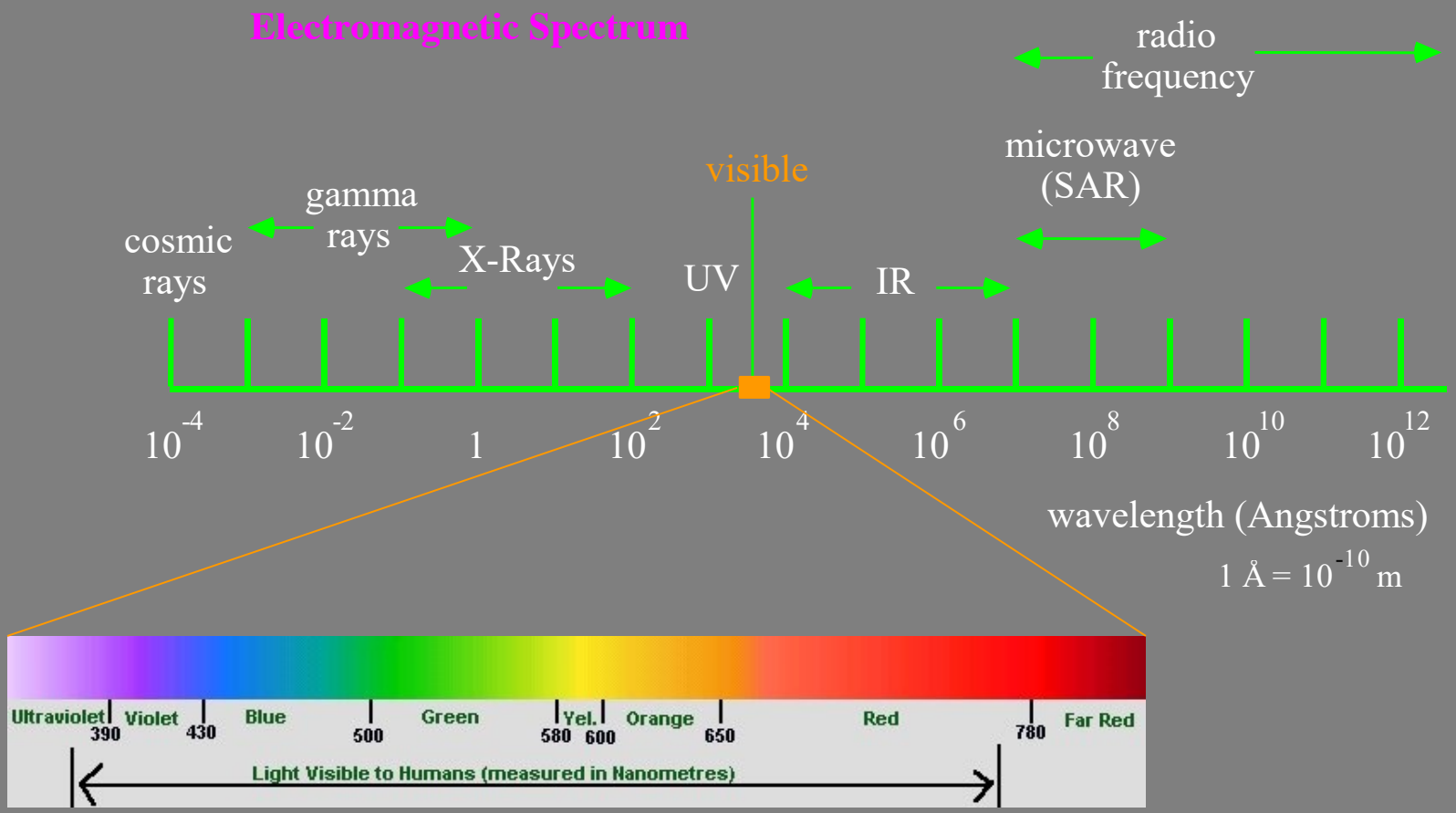
IMAGE PROCE SING

“One picture is worth more than ten thousand words”

Anonymous

Imaging

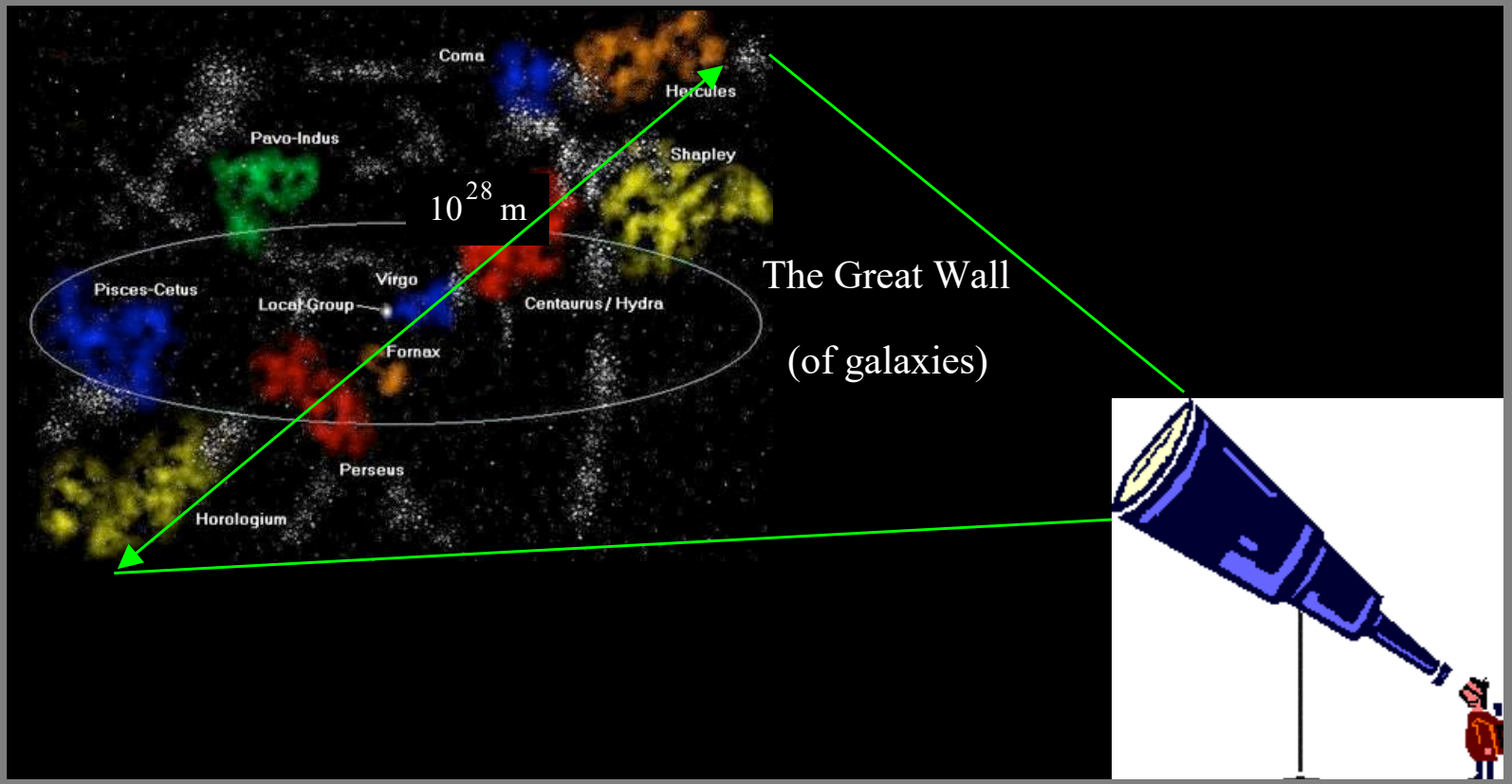
The whole electromagnetic spectrum is used by "imagers"



From Prof. Alan C. Bovik

Scales of Imaging

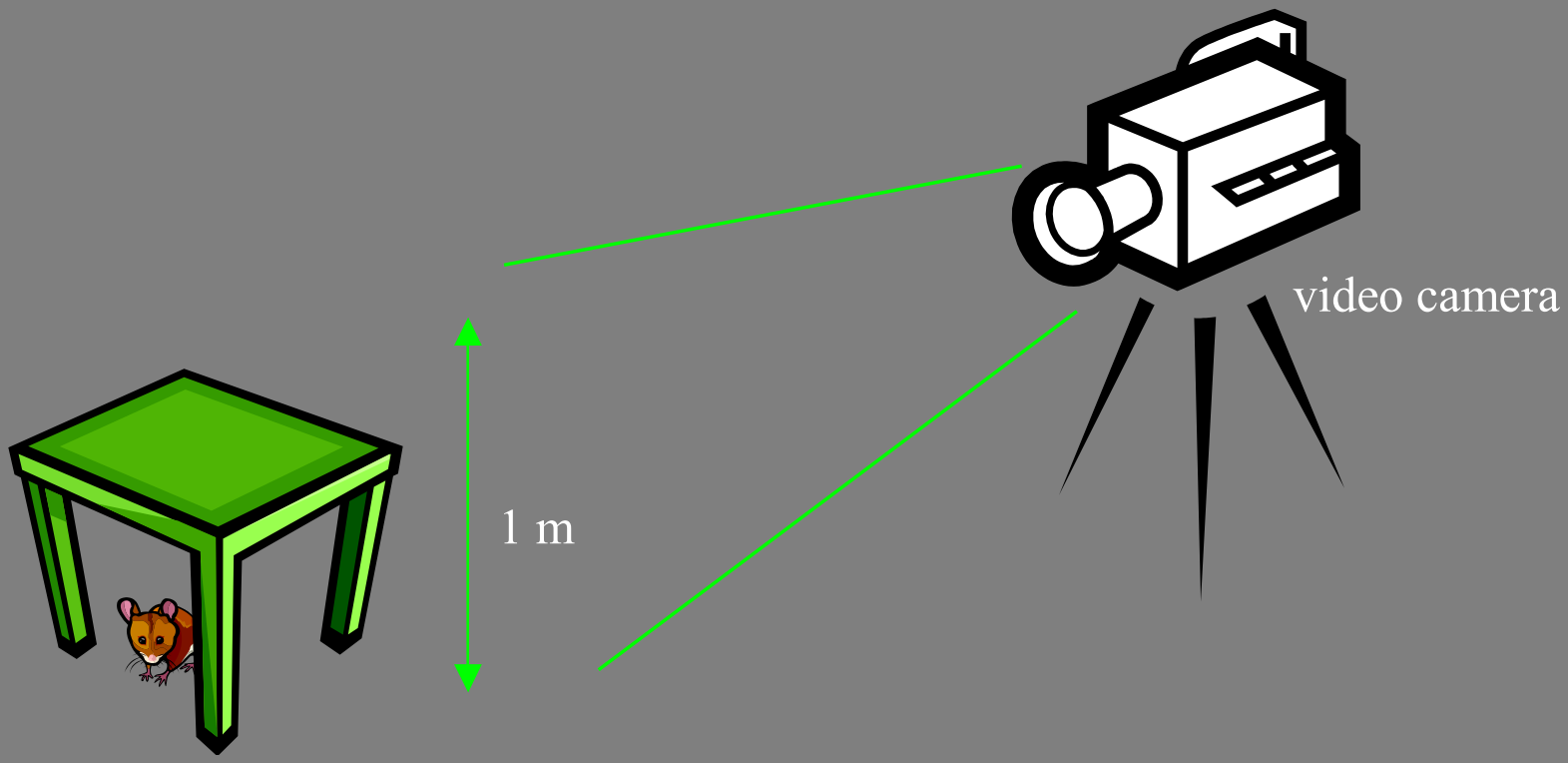
From the **gigantic**…



From Prof. Alan C. Bovik

Scales of Imaging

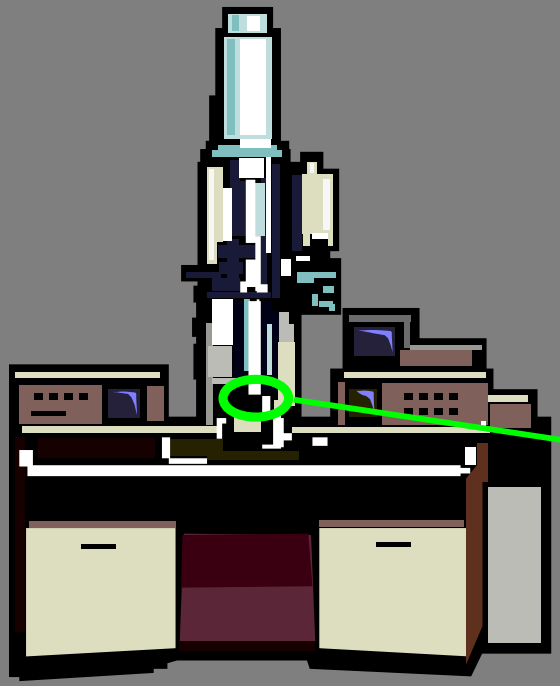
… to the **everyday** …



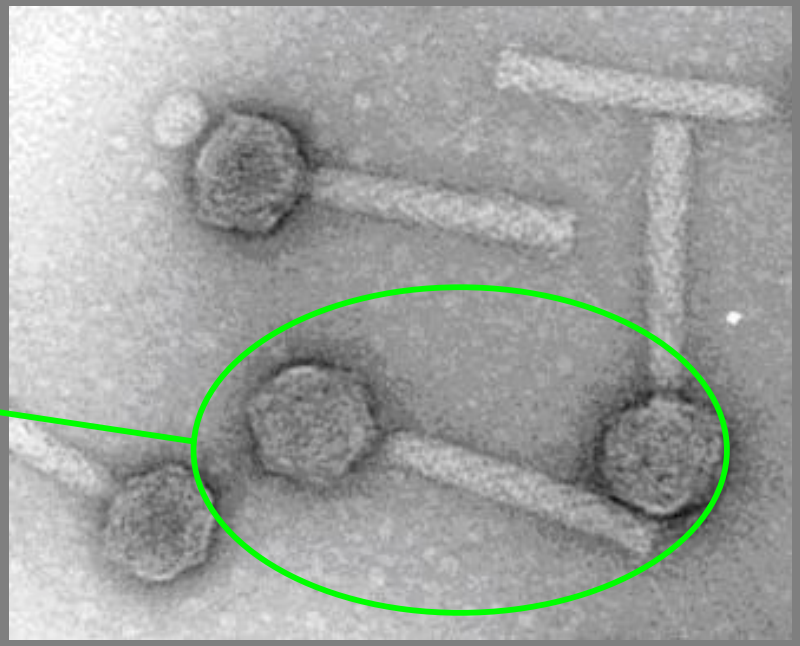
From Prof. Alan C. Bovik

Scales of Imaging

… to the **tiny**.



electron microscope



10^{-6} m

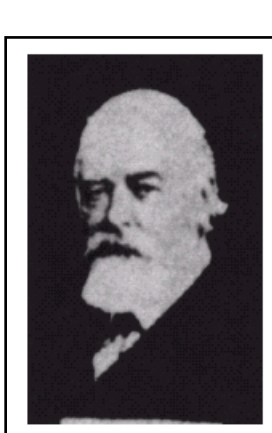
From Prof. Alan C. Bovik

Early 1920s: One of the first applications of digital imaging was in the news-paper industry

Early digital image

- The Bartlane cable picture transmission service
- Images were transferred by submarine cable between London and New York
- Pictures were coded for cable transfer and reconstructed at the receiving end on a telegraph printer

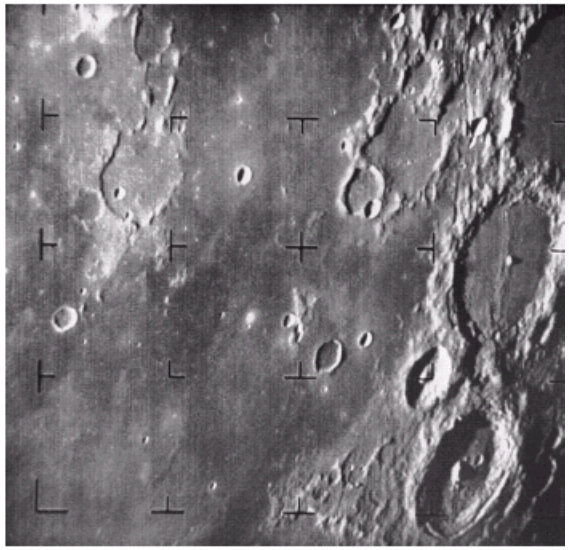
- **Mid to late 1920s:** Improvements to the Bartlane system resulted in higher quality images
  - New reproduction processes based on photographic techniques
  - Increased number of tones in reproduced images



Improved digital image

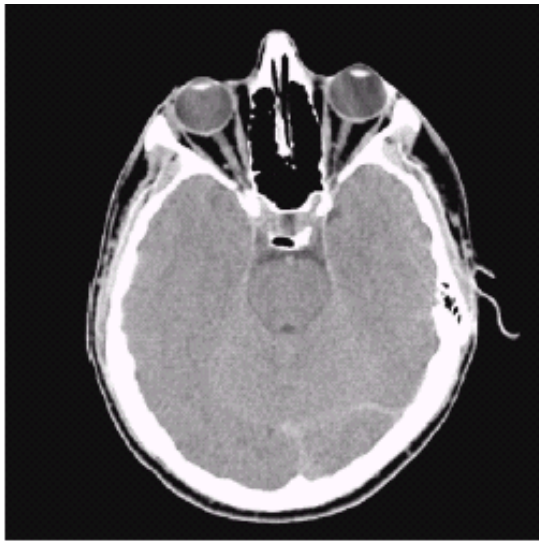
Early 15 tone digital image

- **1960s:** Improvements in computing technology and the onset of the space race led to a surge of work in digital image processing
  - **1964:** Computers used to improve the quality of images of the moon taken by the *Ranger 7* probe
  - Such techniques were used in other space missions including the Apollo landings



A picture of the moon taken by the Ranger 7 probe minutes before landing

- **1970s:** Digital image processing begins to be used in medical applications
  - **1979:** Sir Godfrey N. Hounsfield & Prof. Allan M. Cormack share the Nobel Prize in medicine for the invention of tomography, the technology behind Computerised Axial Tomography (CAT) scans

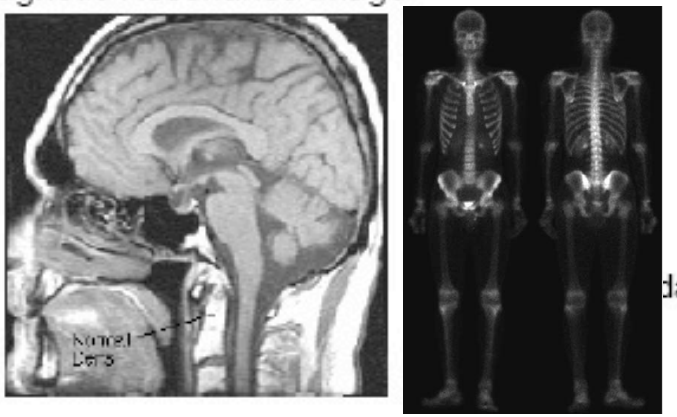


Typical head slice CAT image

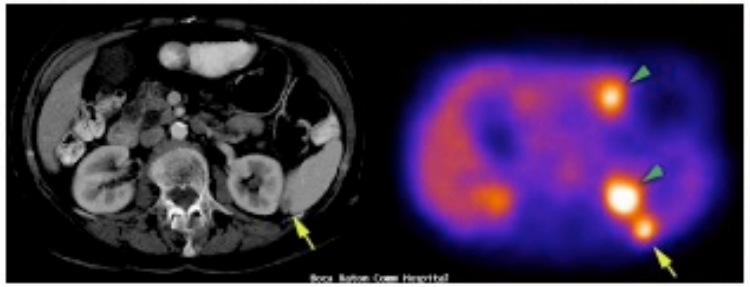
- **1980s - Today:** The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas
  - Image enhancement/restoration
  - Artistic effects
  - Medical visualisation
  - Industrial inspection
  - Law enforcement
  - Human computer interfaces

Imaging in Medicine (images are created in computers)

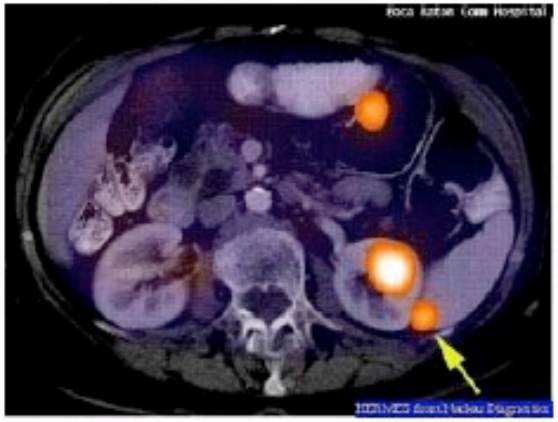
Magnetic Resonance Image



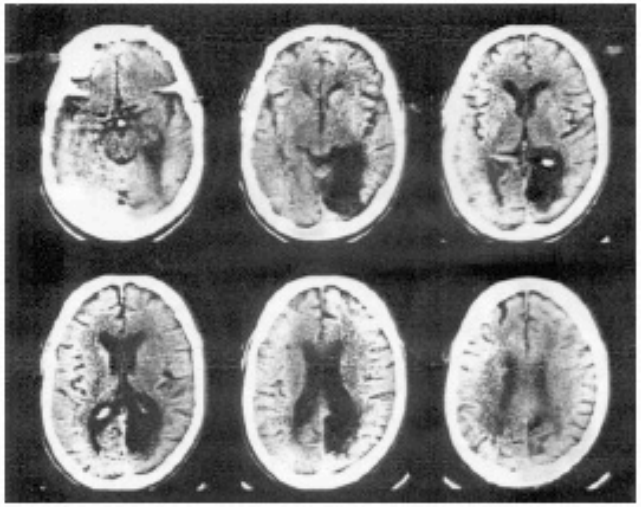
Positron Emission Tomography (PET scan)



data fusion



Computerized Axial Tomography (CAT scan)



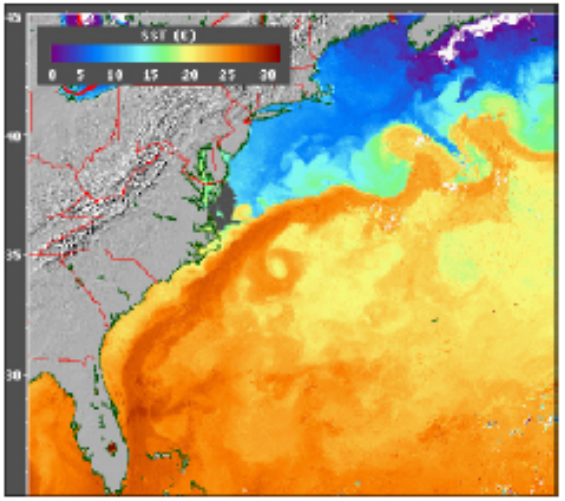
Ultrasound

Imaging Applications

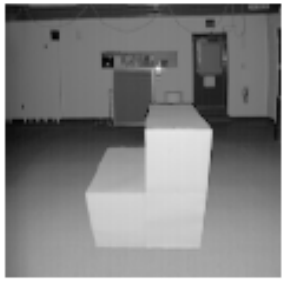
Aerial images

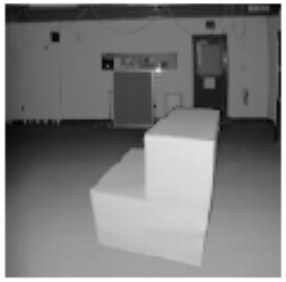
Satellite images

(sea surface temperature)
Advanced Very High Resolution Radiometer



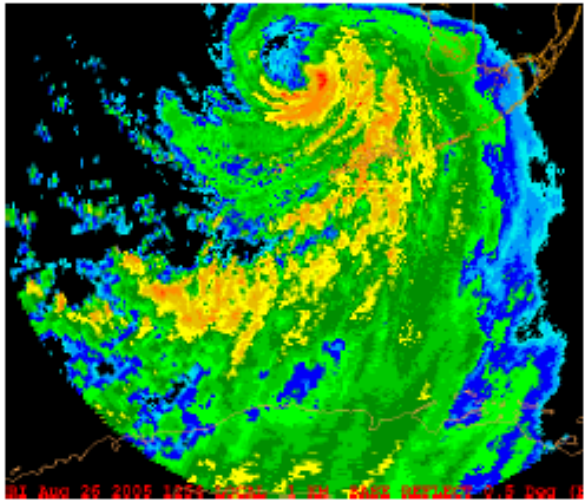
Laser range images





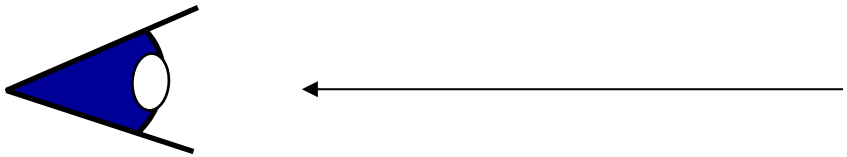
GLORIA side scan sonar images

Athmospheric radar images

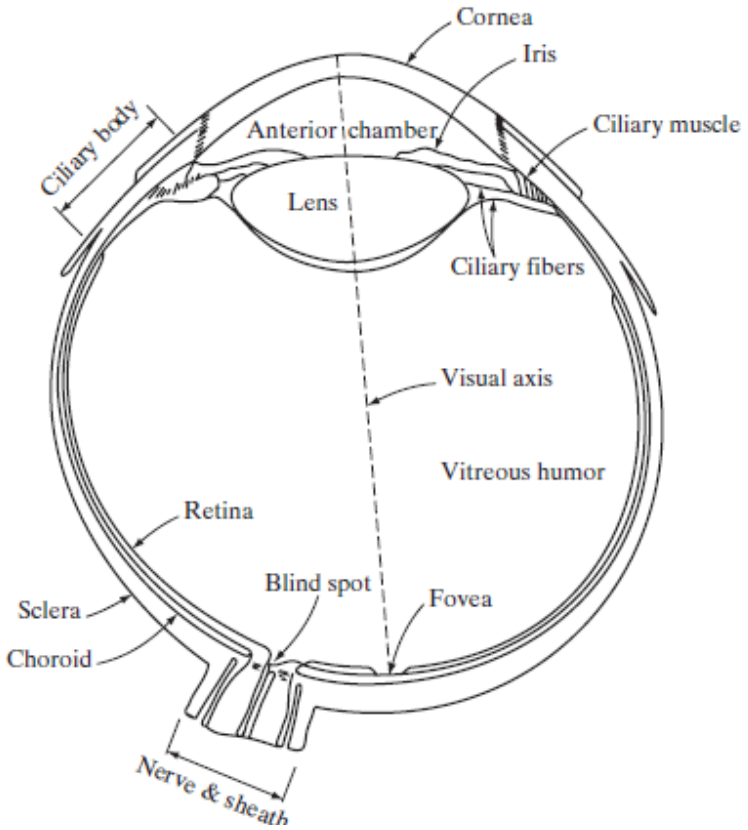


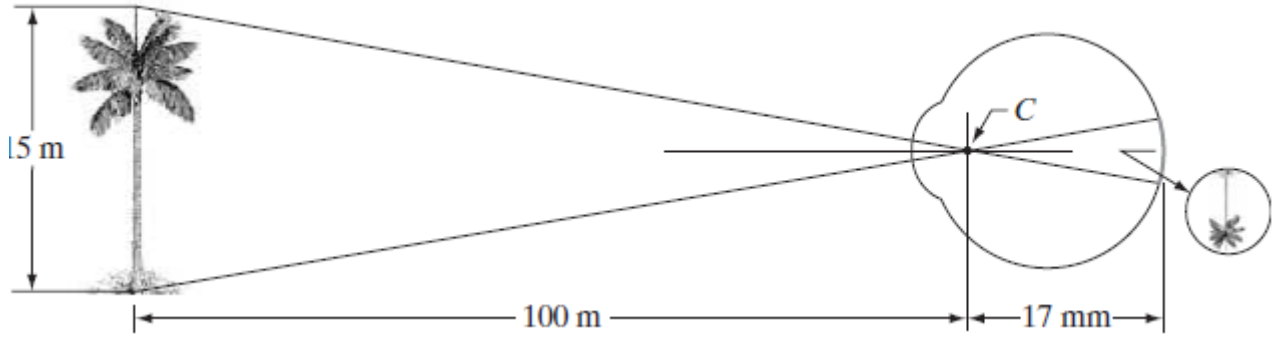
What is light?

- Electromagnetic radiation (EMR) moving along rays in space
  - $R(\lambda)$ is EMR, measured in units of power (watts)
    - λ is wavelength

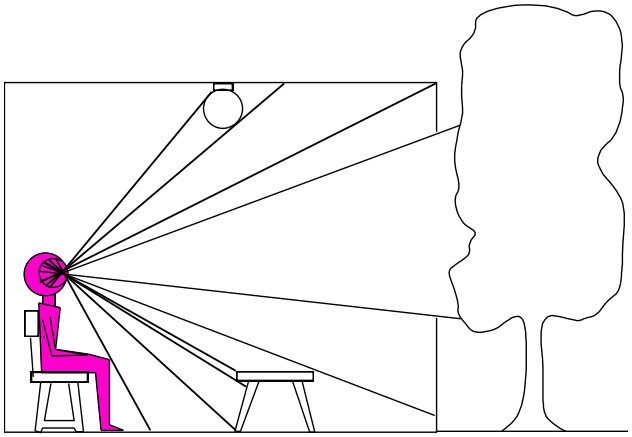


- Useful things:
- Light travels in straight lines
- In vacuum, radiance emitted = radiance arriving
  - i.e. there is no transmission loss

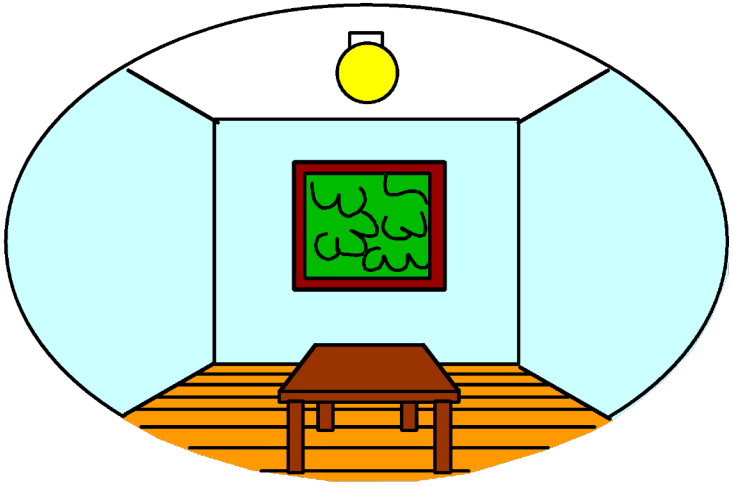




What do we see?

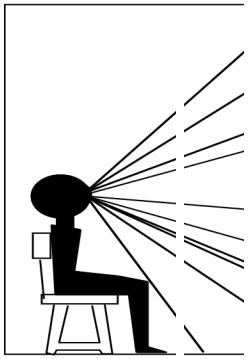


Point of observation



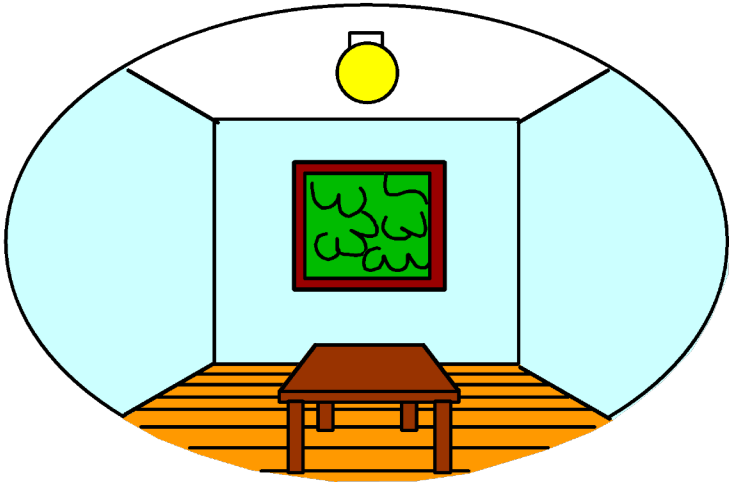
What do we see?

3D world



Painted
backdrop

2D image



Grayscale snapshot

P(x,y)

- is intensity of light
  - Seen from a single view point
  - At a single time
  - Averaged over the wavelengths of the visible spectrum

Color snapshot

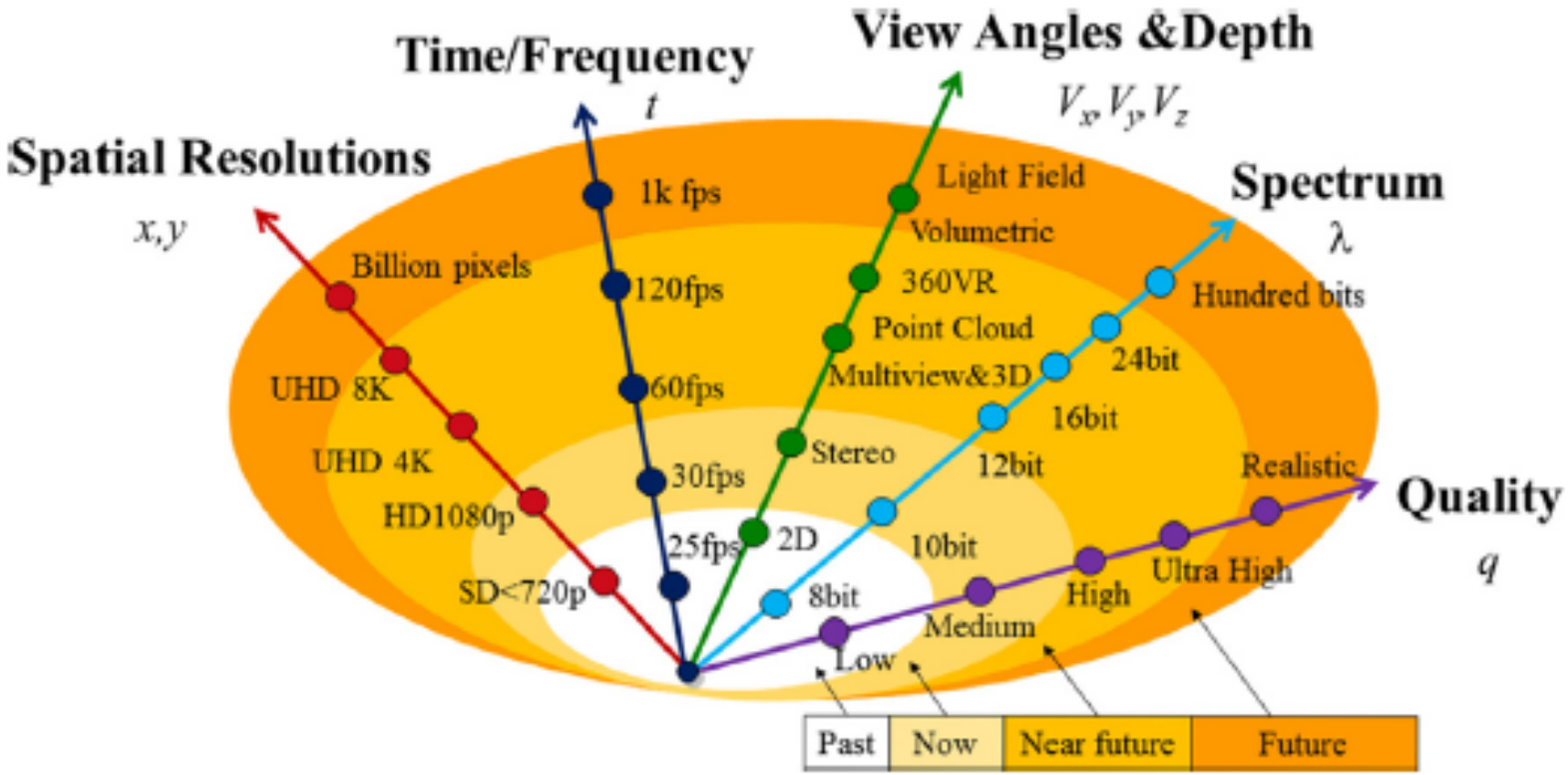
$$P(x,y,\lambda)$$

- is intensity of light
  - Seen from a single view point
  - At a single time
  - As a function of wavelength

A movie

$$P(x,y,\lambda,t)$$

- is intensity of light
  - Seen from a single view point
  - Over time
  - As a function of wavelength



3D world scene

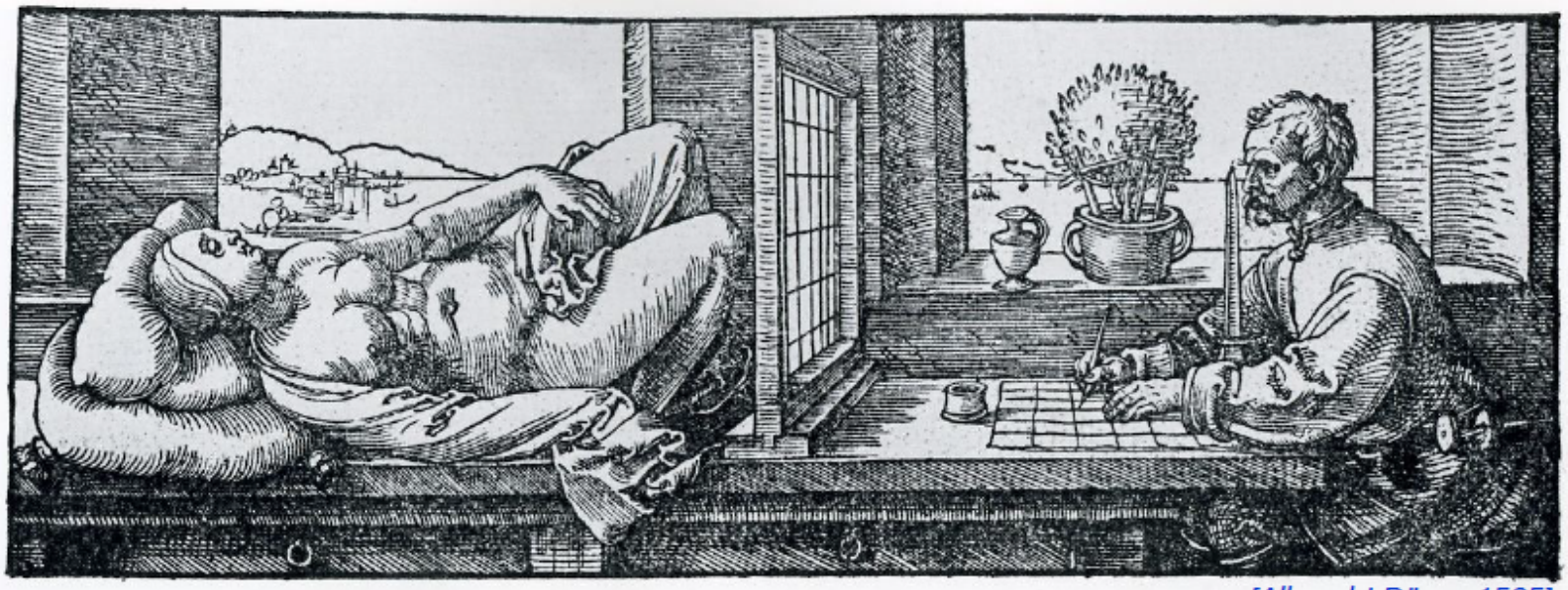
$$\mathbf{P} = F_7(\varphi,\ \theta,\ \lambda,\ t,\ V_x,\ V_y,\ V_z),$$

Cartesian coordinates

$$\mathbf{P} = G\,(\,x, y, \lambda, t, V x\,, V y\,, V z\,)$$

Q. Dai , J. Wu , J. Fan , F. Xu , X. Cao , Recent advances in computational photography, Chin. J. Electron. 28 (1) (2019) 1–5 .

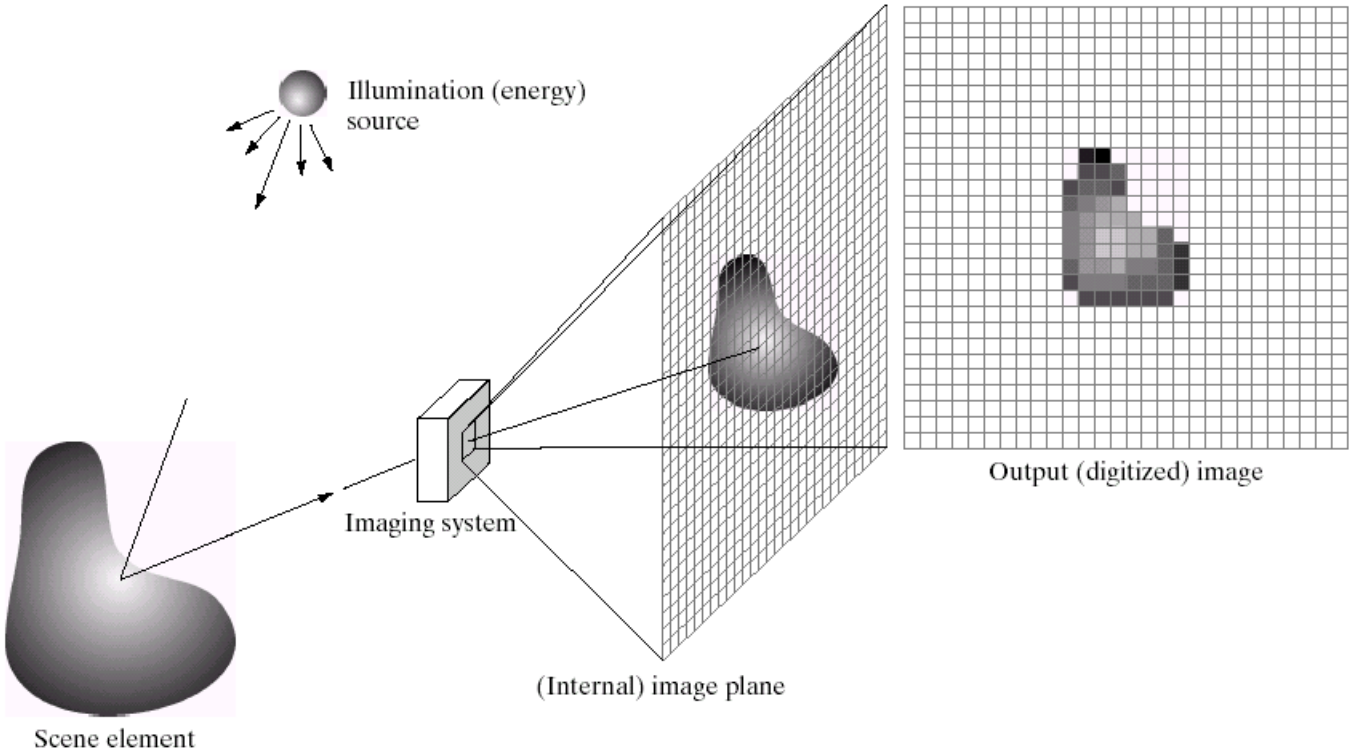
Imaging



[Albrecht Dürer, 1525]

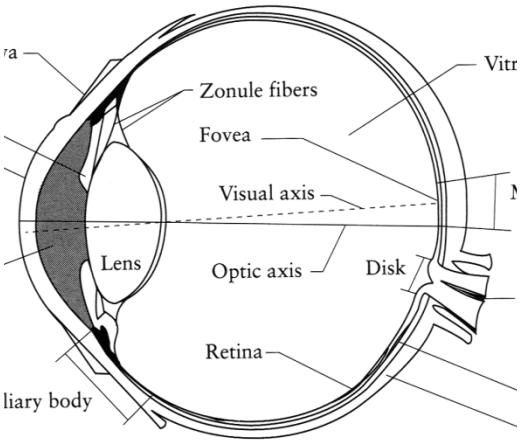
- **Image**: a visual representation in form of a function $f(x,y)$ where f is related to the brightness (or color) at point (x,y)
- Most images are defined over a rectangle
- Continuous in amplitude and space

Image Formation



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.



The Eye

*f(x,y) = reflectance(x,y) * illumination(x,y)*

Reflectance in [0,1], illumination in [0,inf]

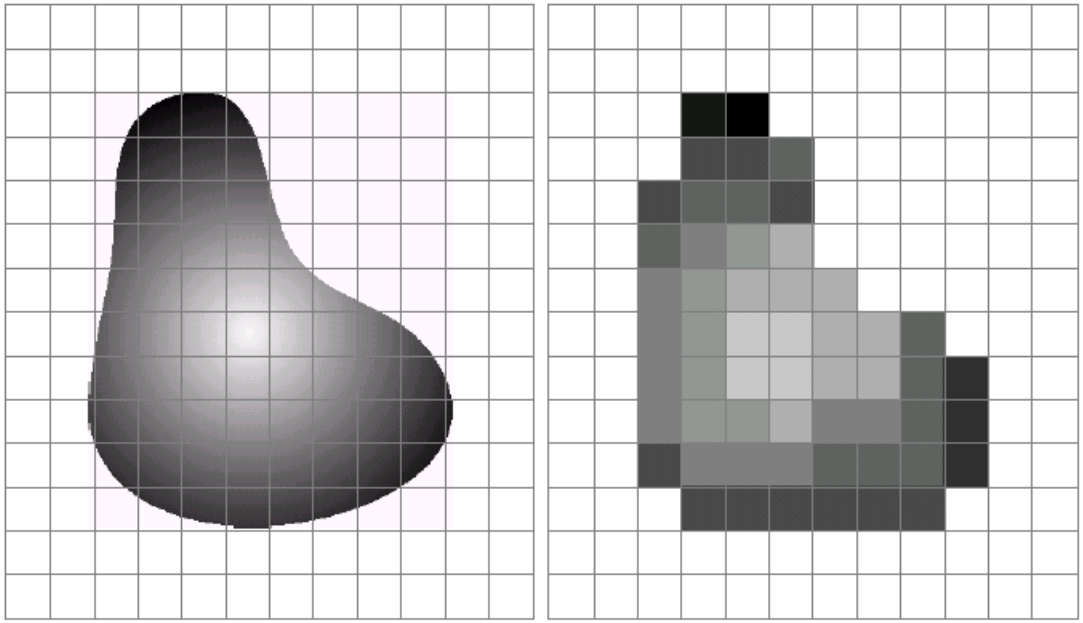
Digital camera

A digital camera replaces film with a sensor array

- Each cell in the array is light-sensitive diode that converts photons to electrons
- Two common types: Charge Coupled Device (CCD) and CMOS
- http://electronics.howstuffworks.com/digital-camera.htm

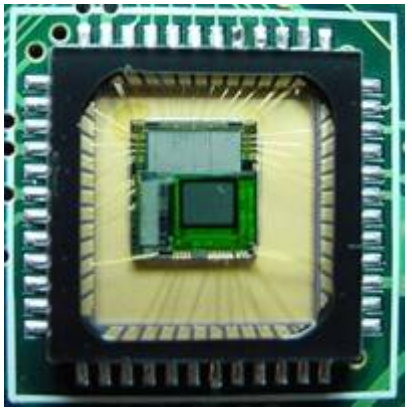
Slide by Steve Seitz

Sensor Array



a b

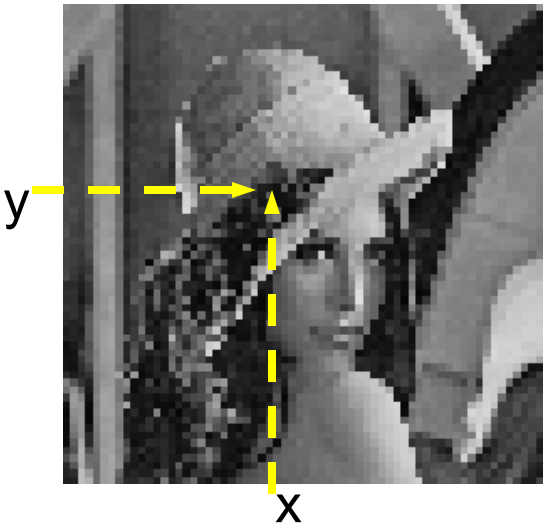
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



CMOS sensor

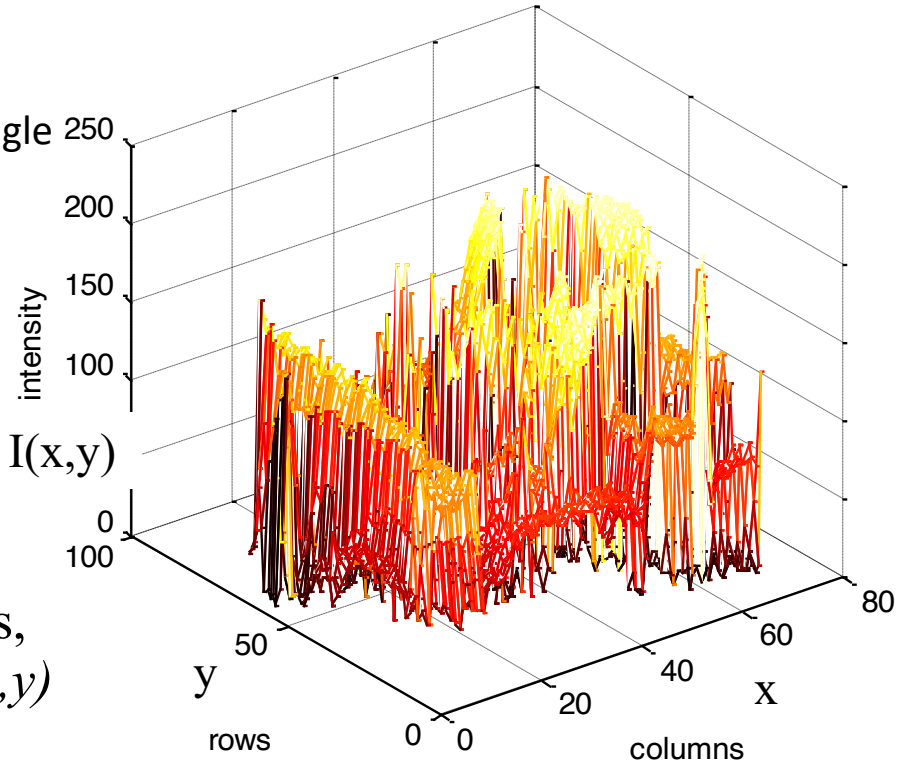
Each sensor cell records amount of light coming in at a small range of orientations

What is An Image?



- Grayscale image
  - A grayscale image is a function *I(x,y)* of the two spatial coordinates of the image plane.
  - *I(x,y)* is the intensity of the image at the point *(x,y)* on the image plane.
    - *I(x,y)* takes non-negative values
    - assume the image is bounded by a rectangle *[0,a]×[0,b]*

I: [0, a] × [0, b] → [0, inf)

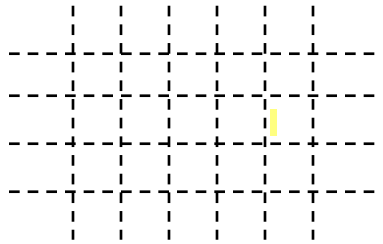


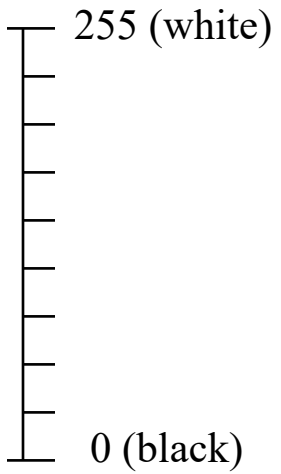
- Color image
  - Can be represented by three functions, *R(x,y)* for red, *G(x,y)* for green, and *B(x,y)* for blue.

Sampling and Quantization

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

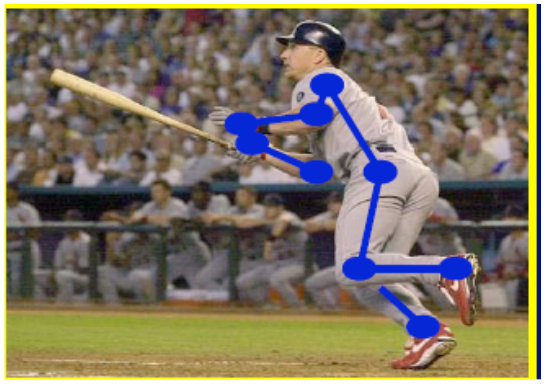
- Computer handles “discrete” data.
- Sampling
  - Sample the value of the image at the nodes of a regular grid on the image plane.
  - A pixel (picture element) at (i, j) is the image intensity value at grid point indexed by the integer coordinate (i, j).
- Quantization
  - Is a process of transforming a real valued sampled image to one taking only a finite number of distinct values.
  - Each sampled value in a 256-level grayscale image is represented by 8 bits.



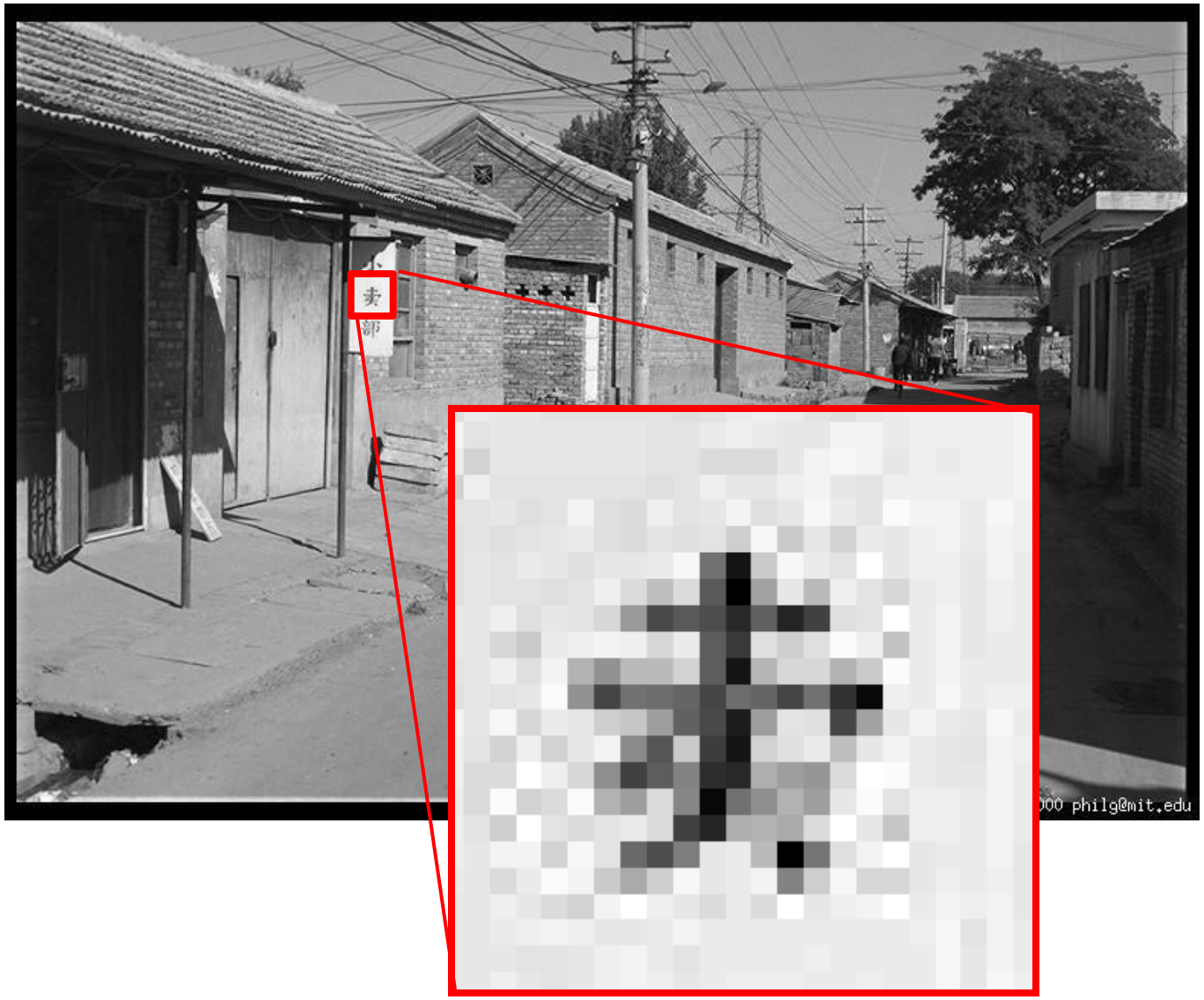


Resolution

- Sensor: size of real world scene element a that images to a single pixel
- Image: number of pixels
- Influences what analysis is feasible, affects best representation choice



The raster image (pixel matrix)



The raster image (pixel matrix)

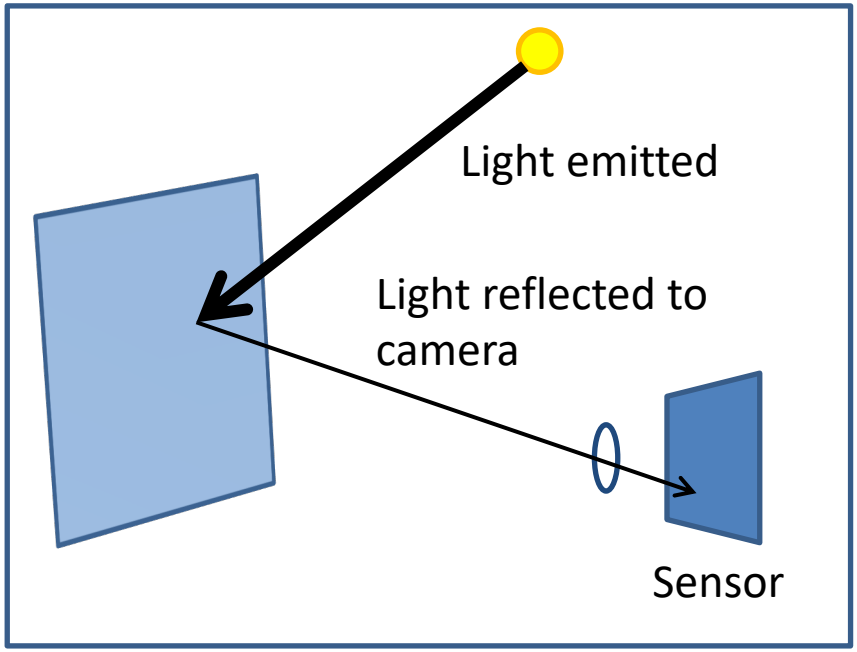
0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

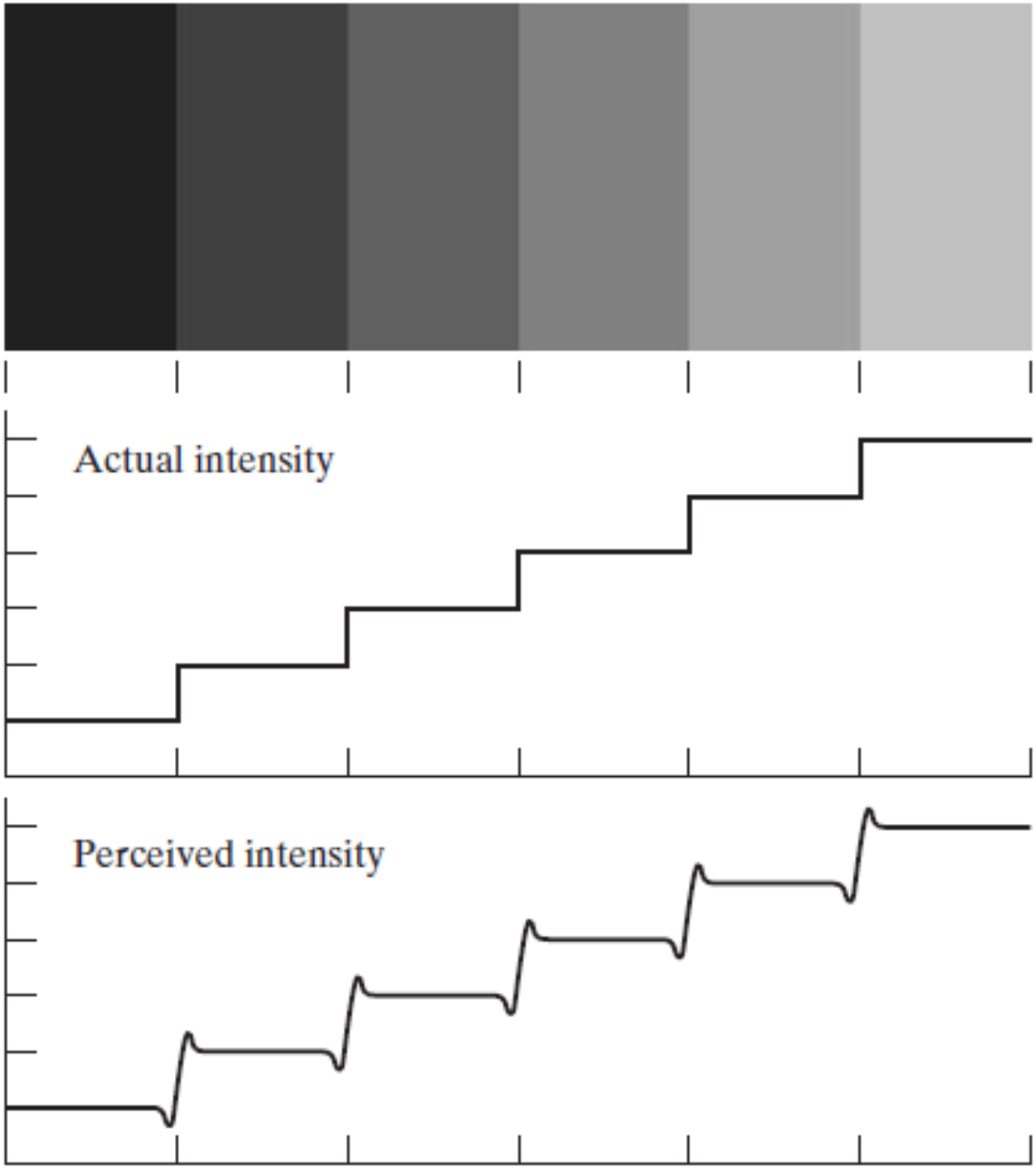
Light and Shading

- What determines a pixel's intensity?
- What can we infer about the scene from pixel intensities?

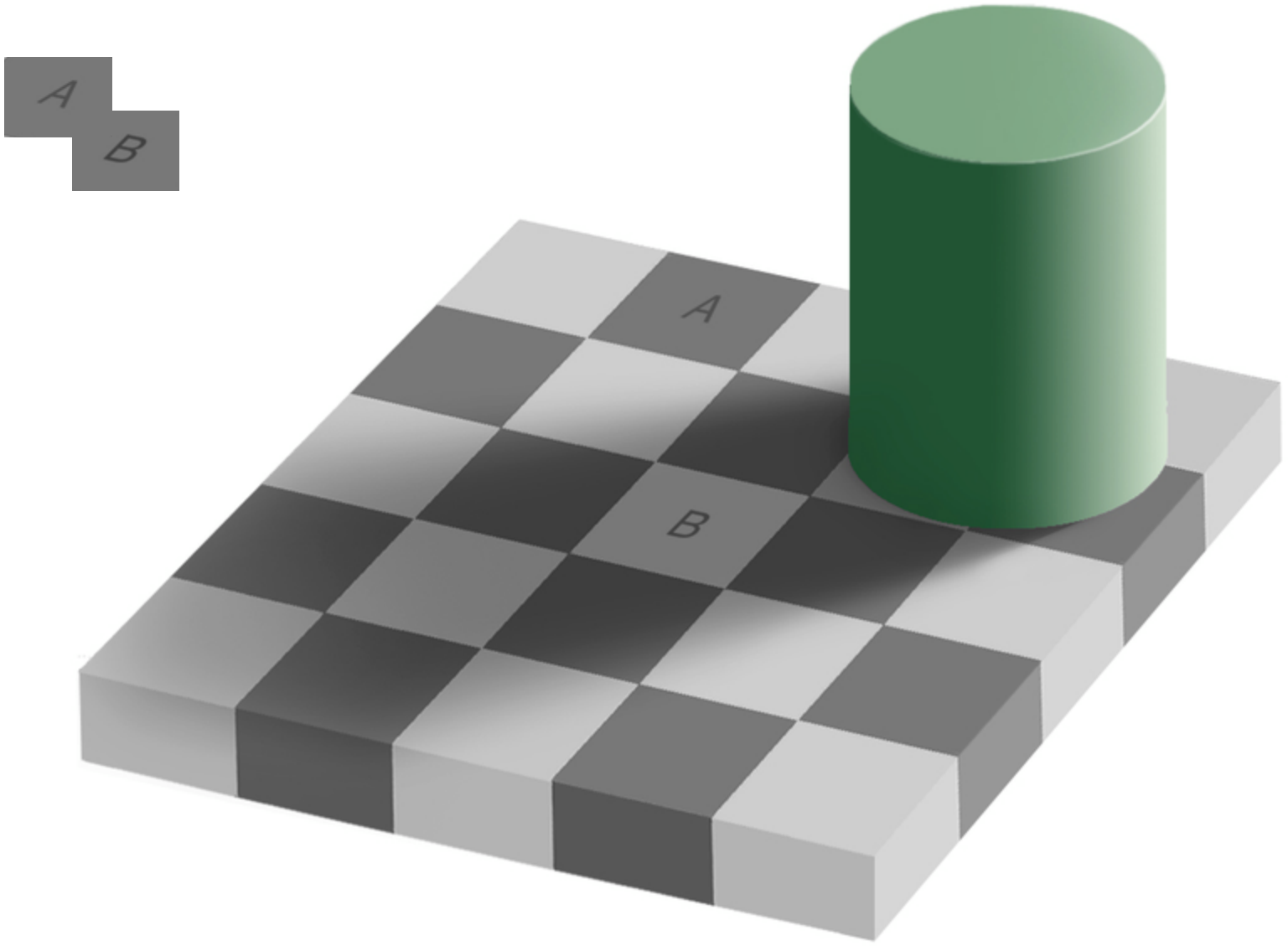
How does a pixel get its value?

- Major factors
  - Illumination strength and direction
  - Surface geometry
  - Surface material
  - Nearby surfaces
  - Camera gain/exposure




Actual intensity
Perceived intensity

Perception of Intensity

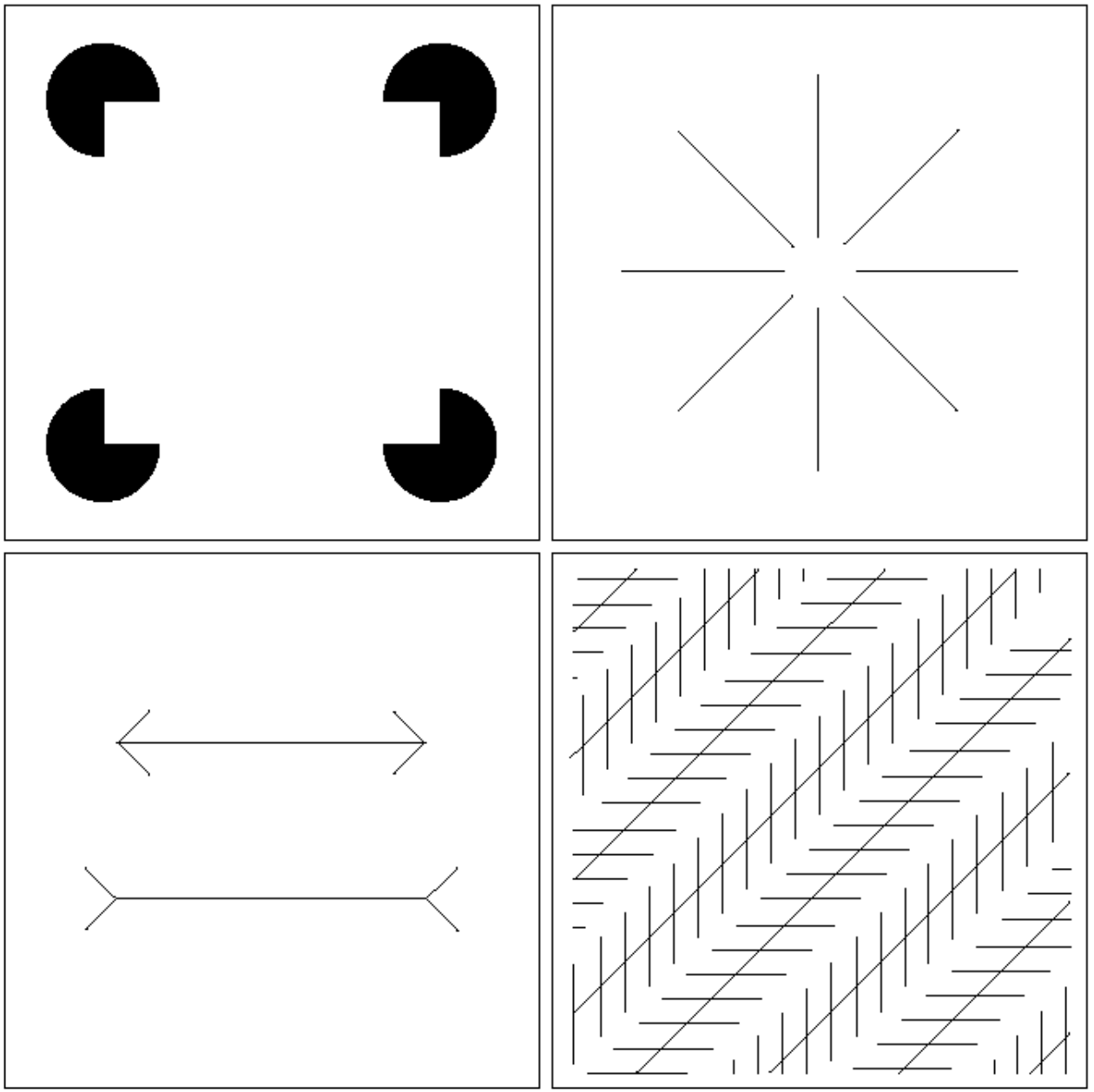


from Ted Adelson

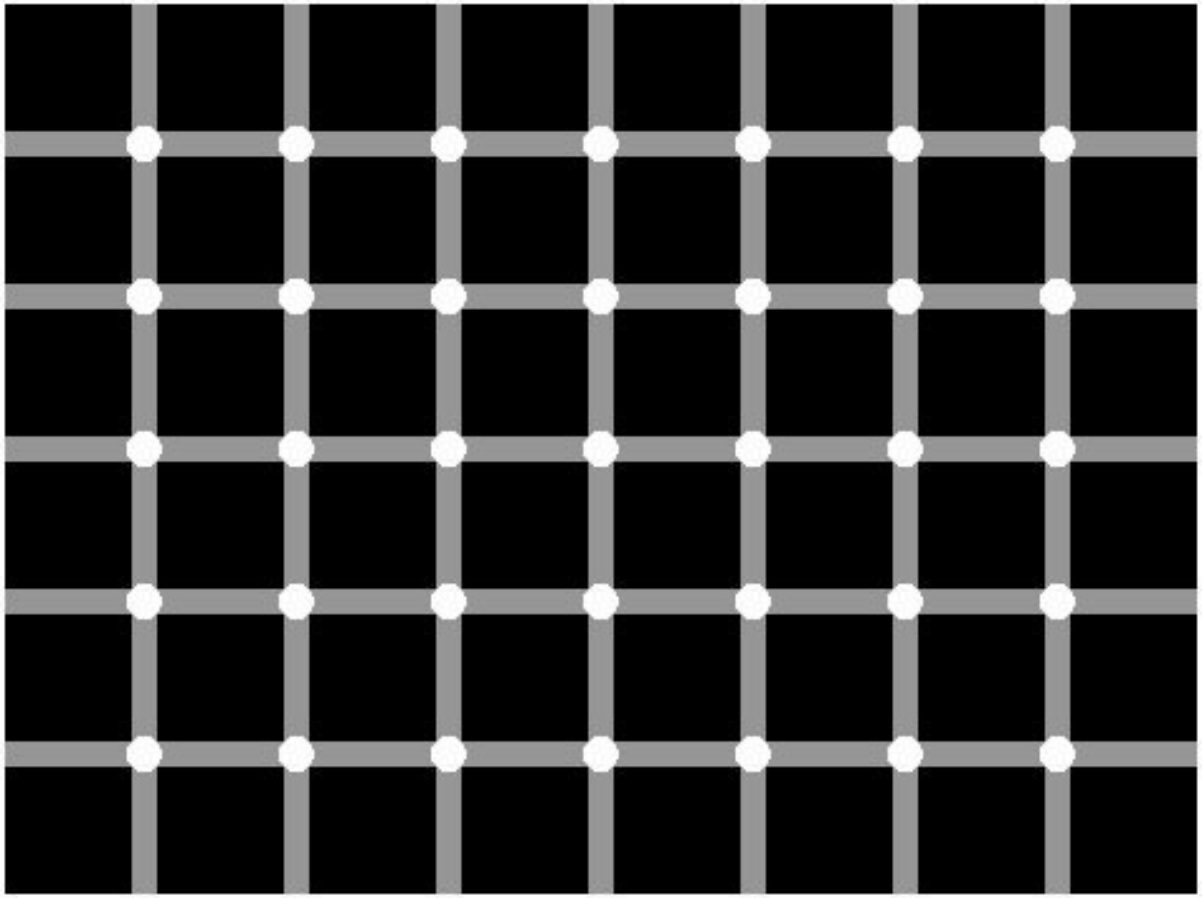
HVS: Visual Illusion

a b
c d

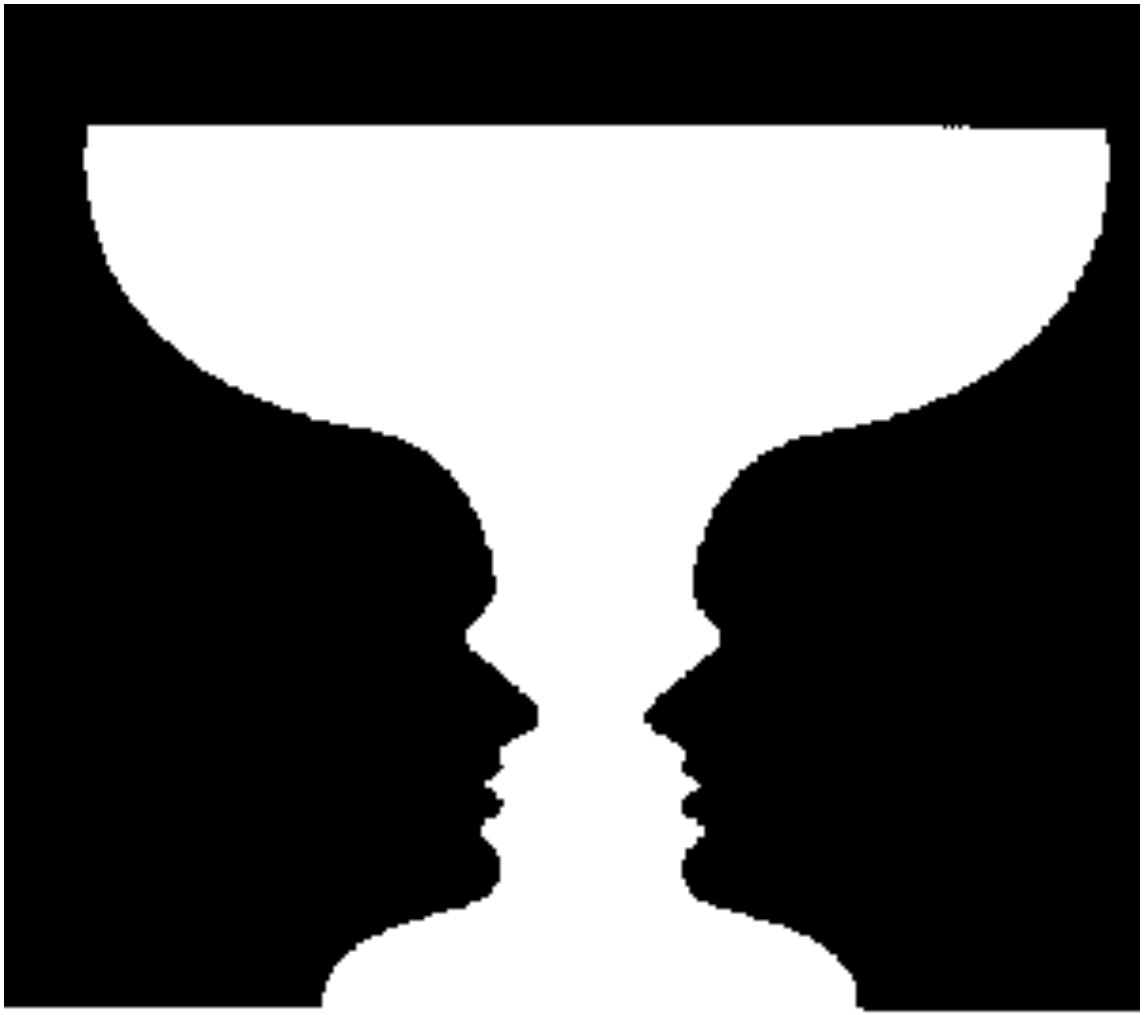
FIGURE 2.9 Some well-known optical illusions.



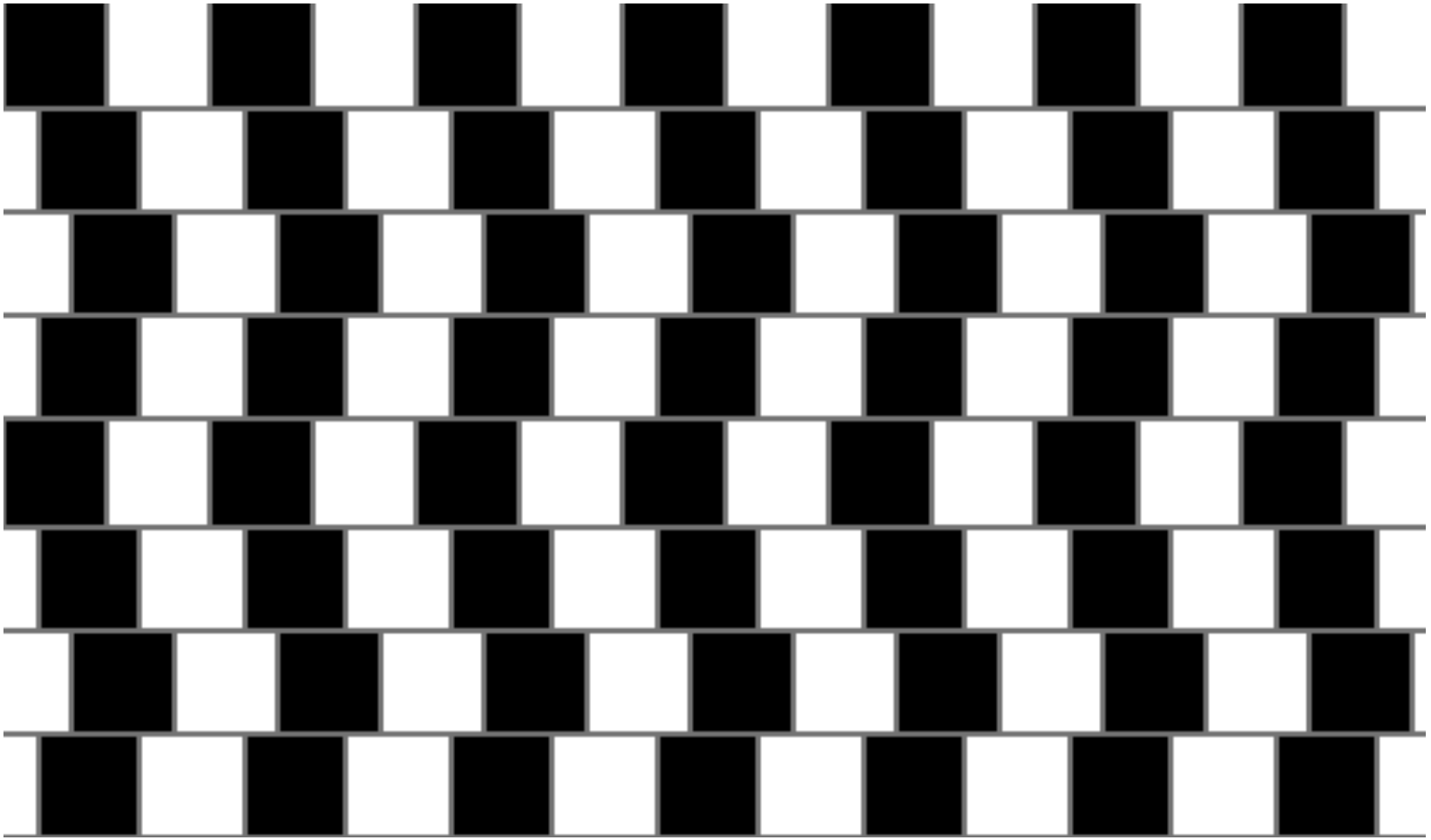
HVS: Visual Illusion

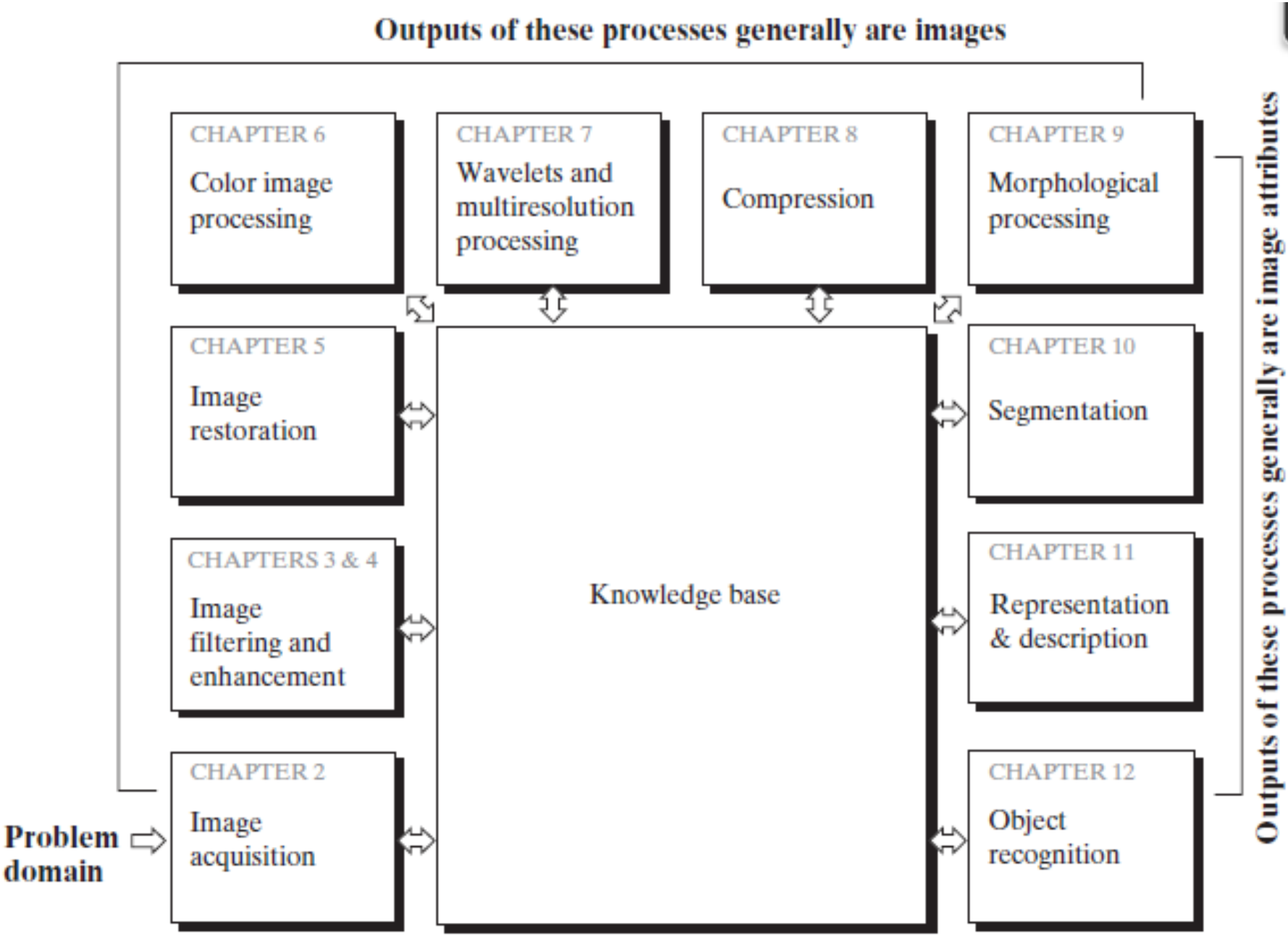


HVS: Visual Illusion

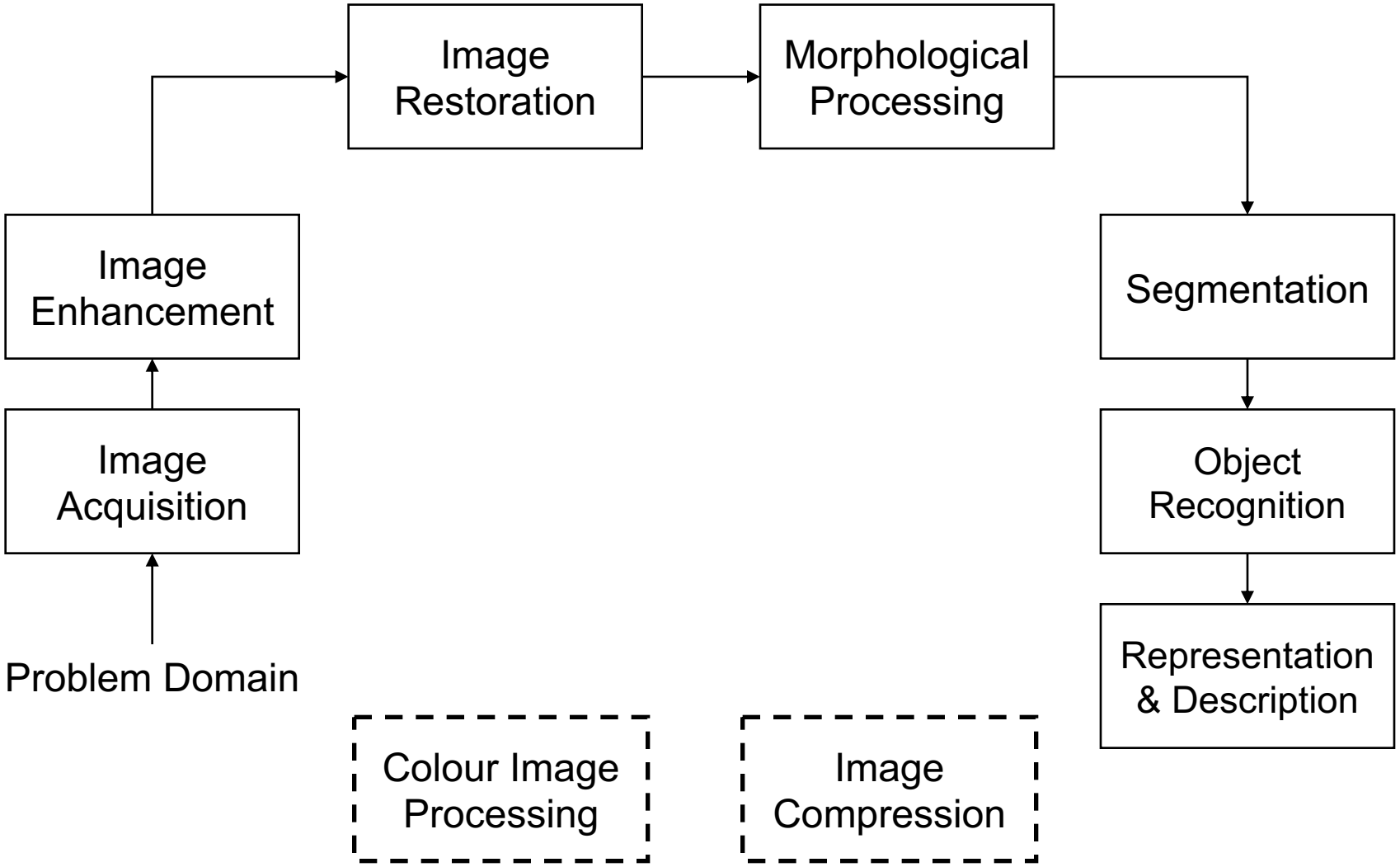


HVS: Visual Illusion

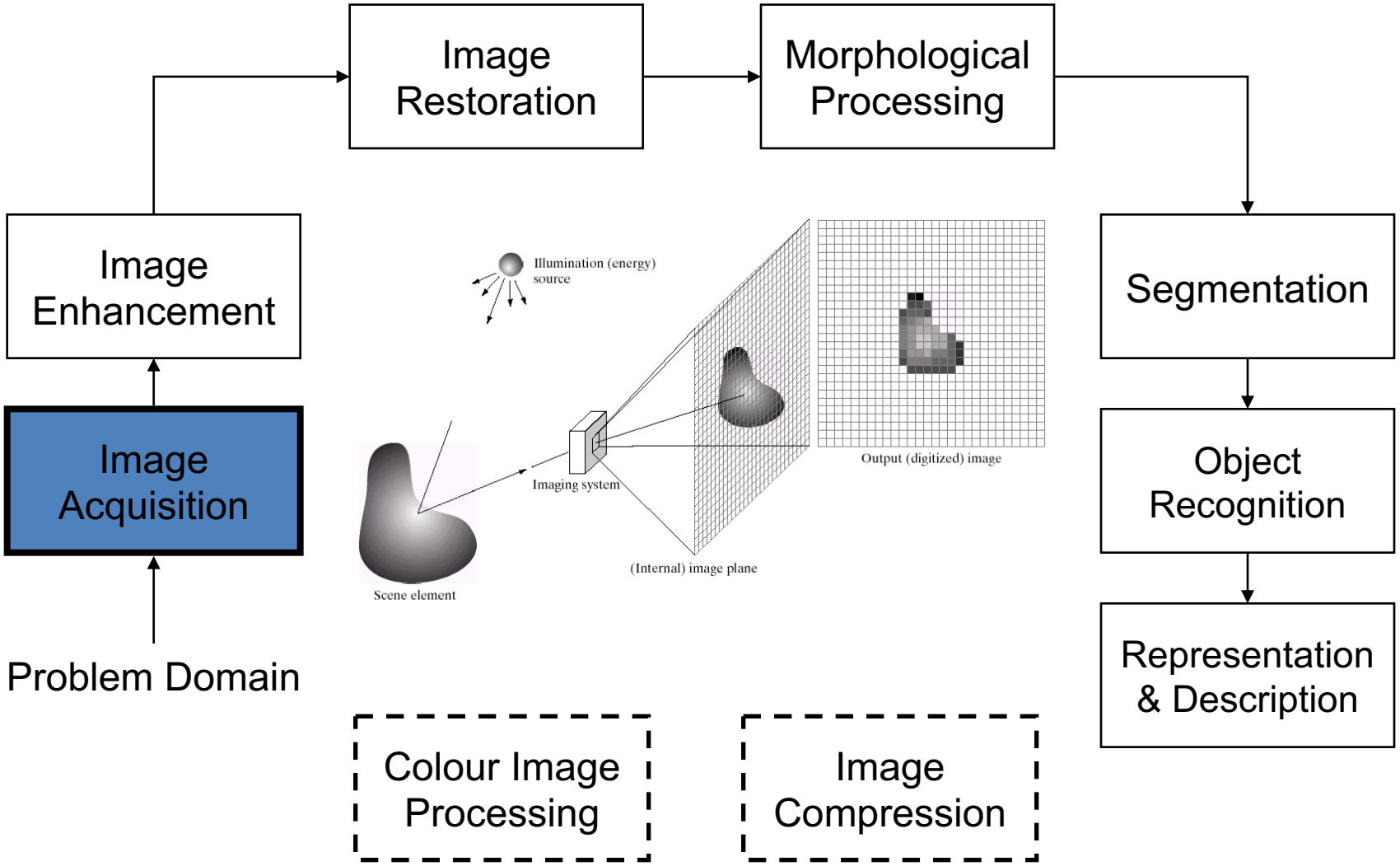



Outputs of these processes generally are images
CHAPTER 6
Color image processing
CHAPTER 7
Wavelets and multiresolution processing
CHAPTER 8
Compression
CHAPTER 9
Morphological processing
CHAPTER 5
Image restoration
Knowledge base
CHAPTER 10
Segmentation
CHAPTERS 3 & 4
Image filtering and enhancement
CHAPTER 11
Representation & description
CHAPTER 2
Image acquisition
CHAPTER 12
Object recognition
Problem domain
Outputs of these processes generally are image attributes

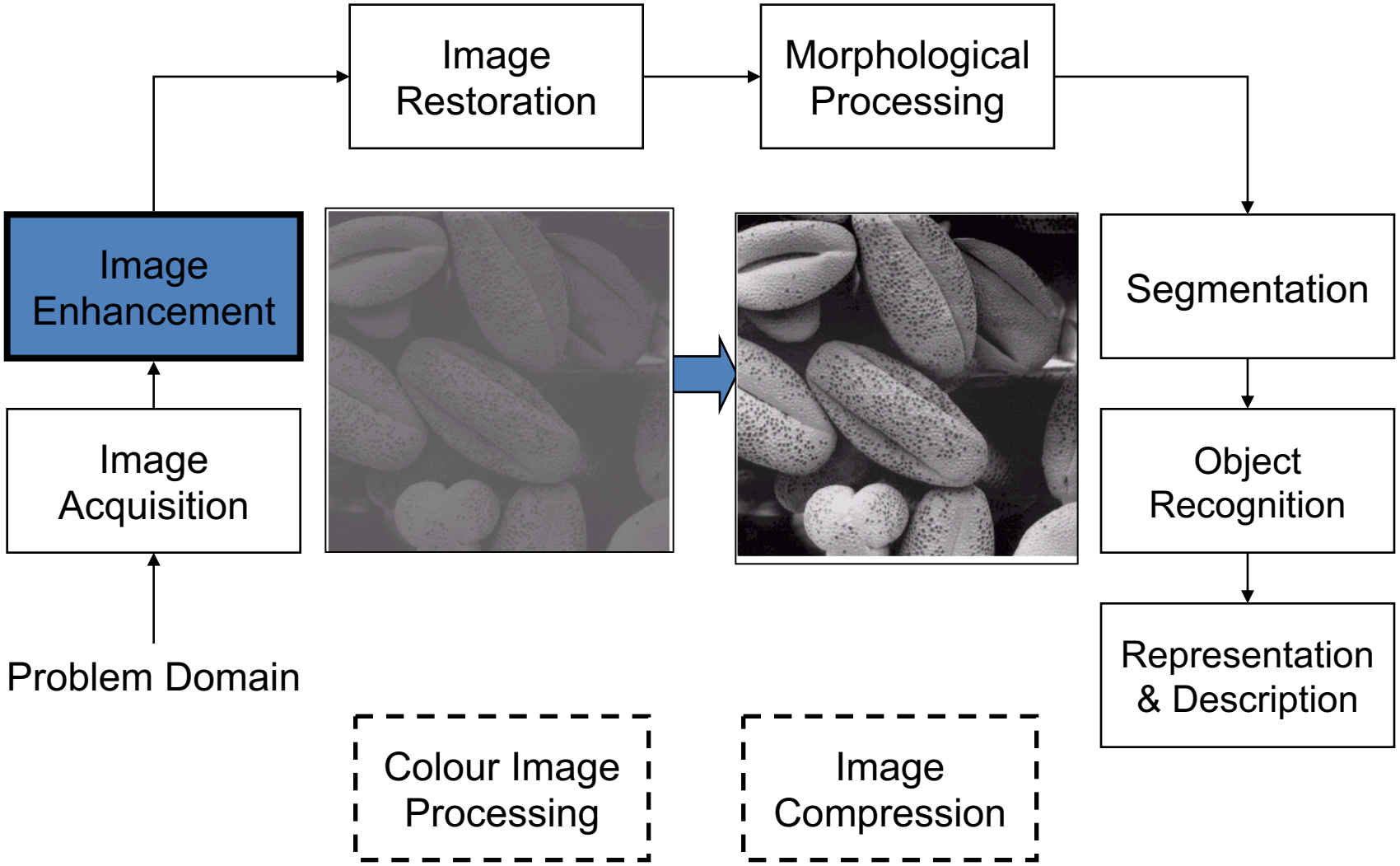
Key Stages in Digital Image Processing



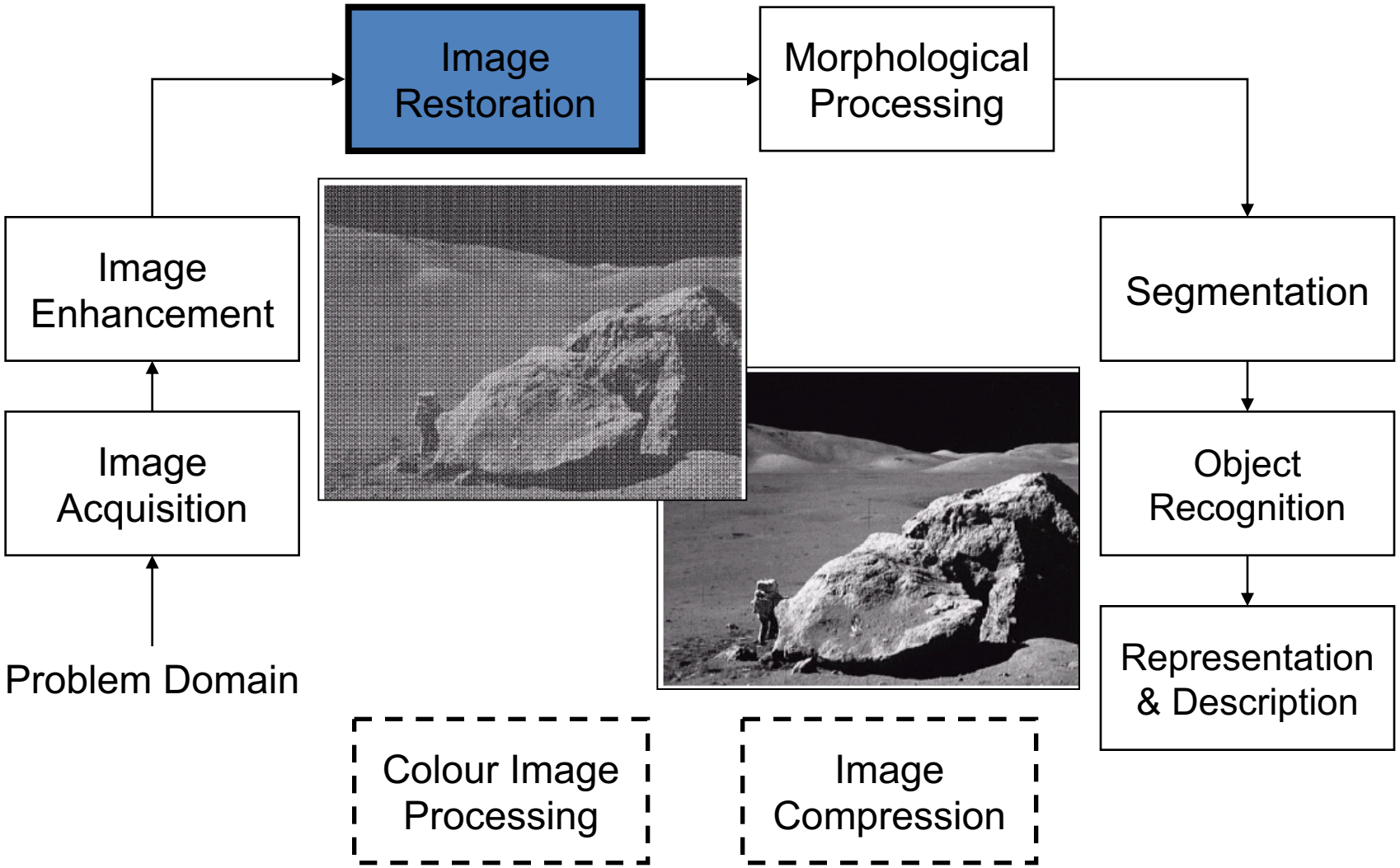
Key Stages in Digital Image Processing: Image Aquisition



Key Stages in Digital Image Processing: Image Enhancement

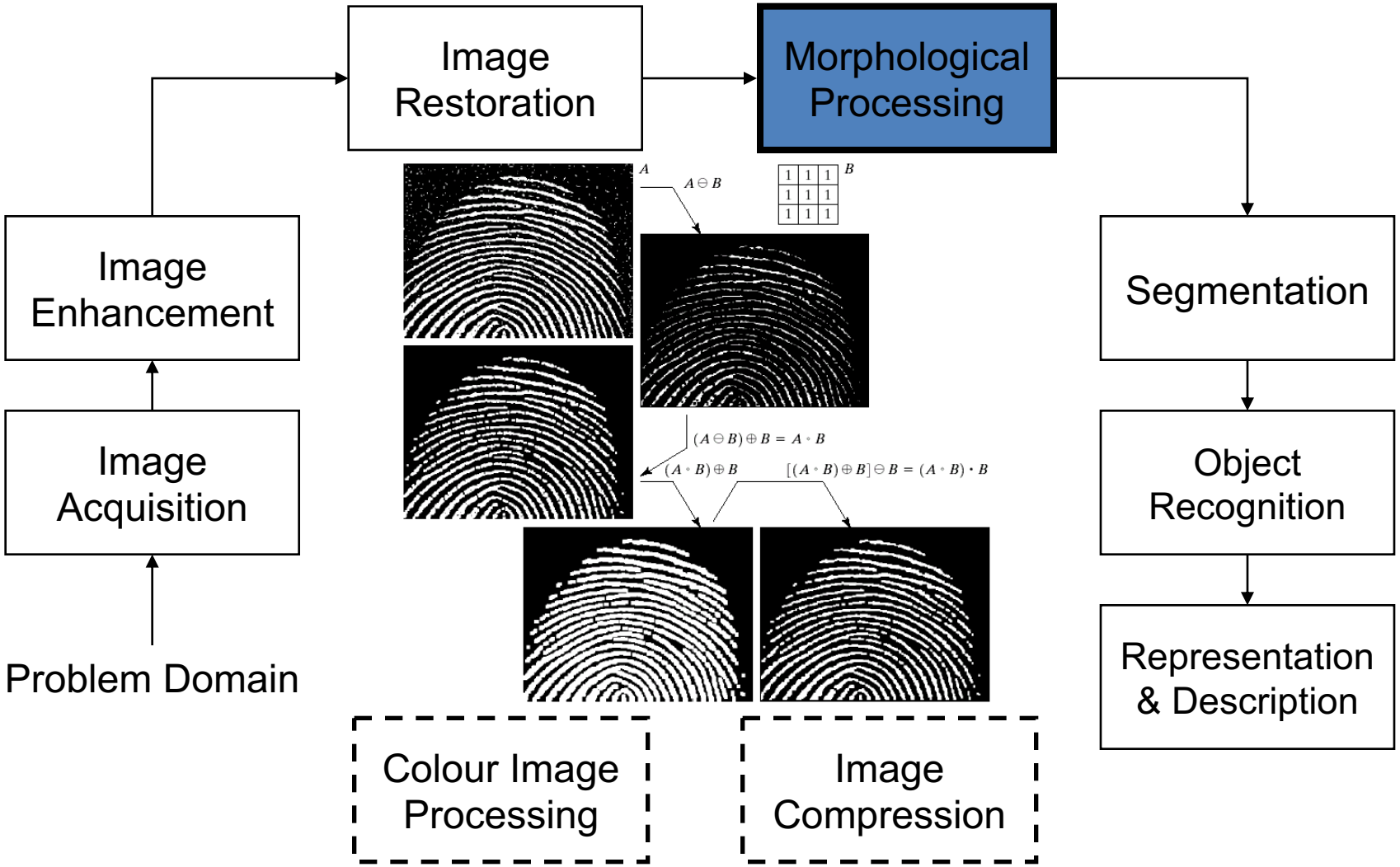


Key Stages in Digital Image Processing: Image Restoration



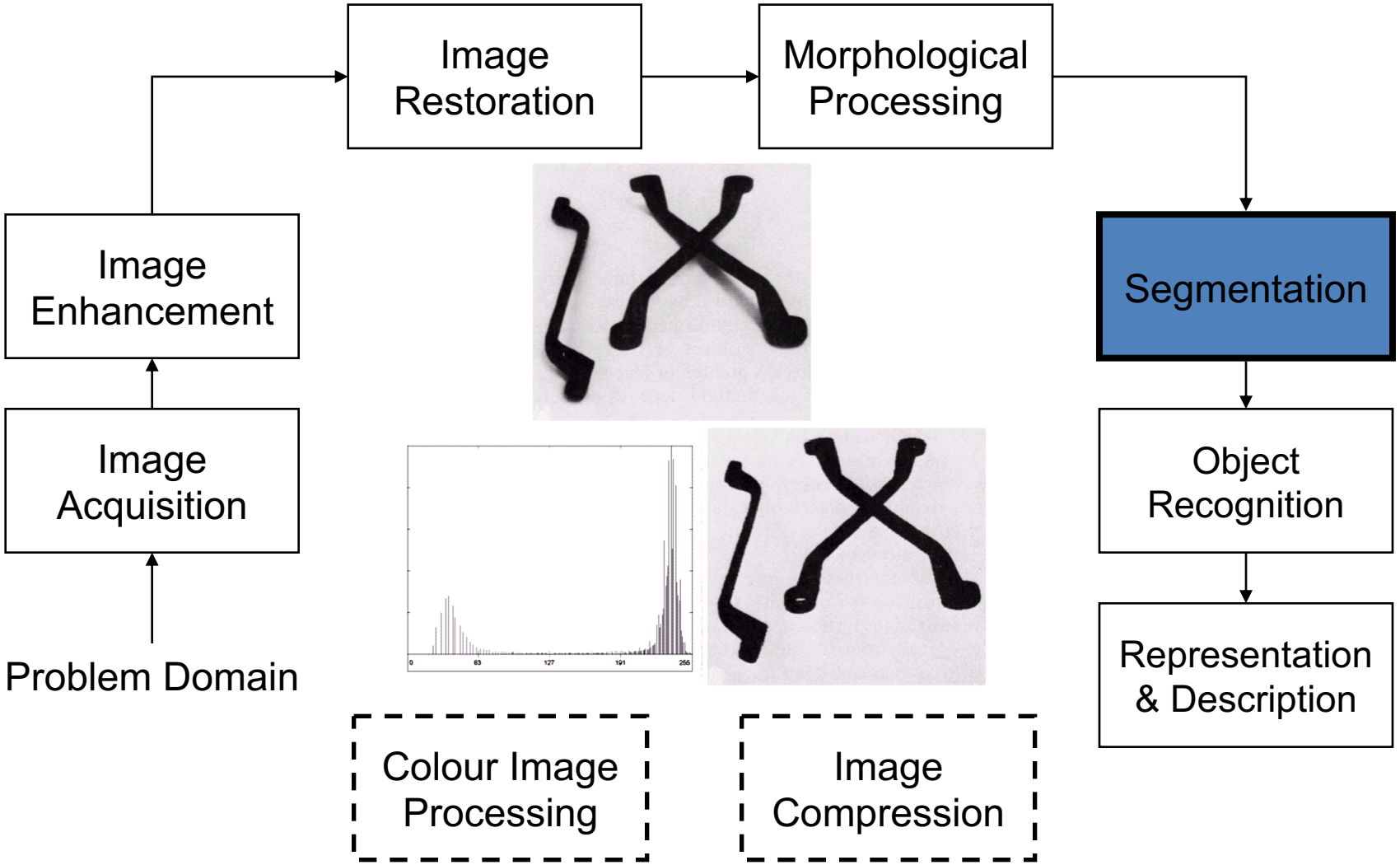
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Morphological Processing



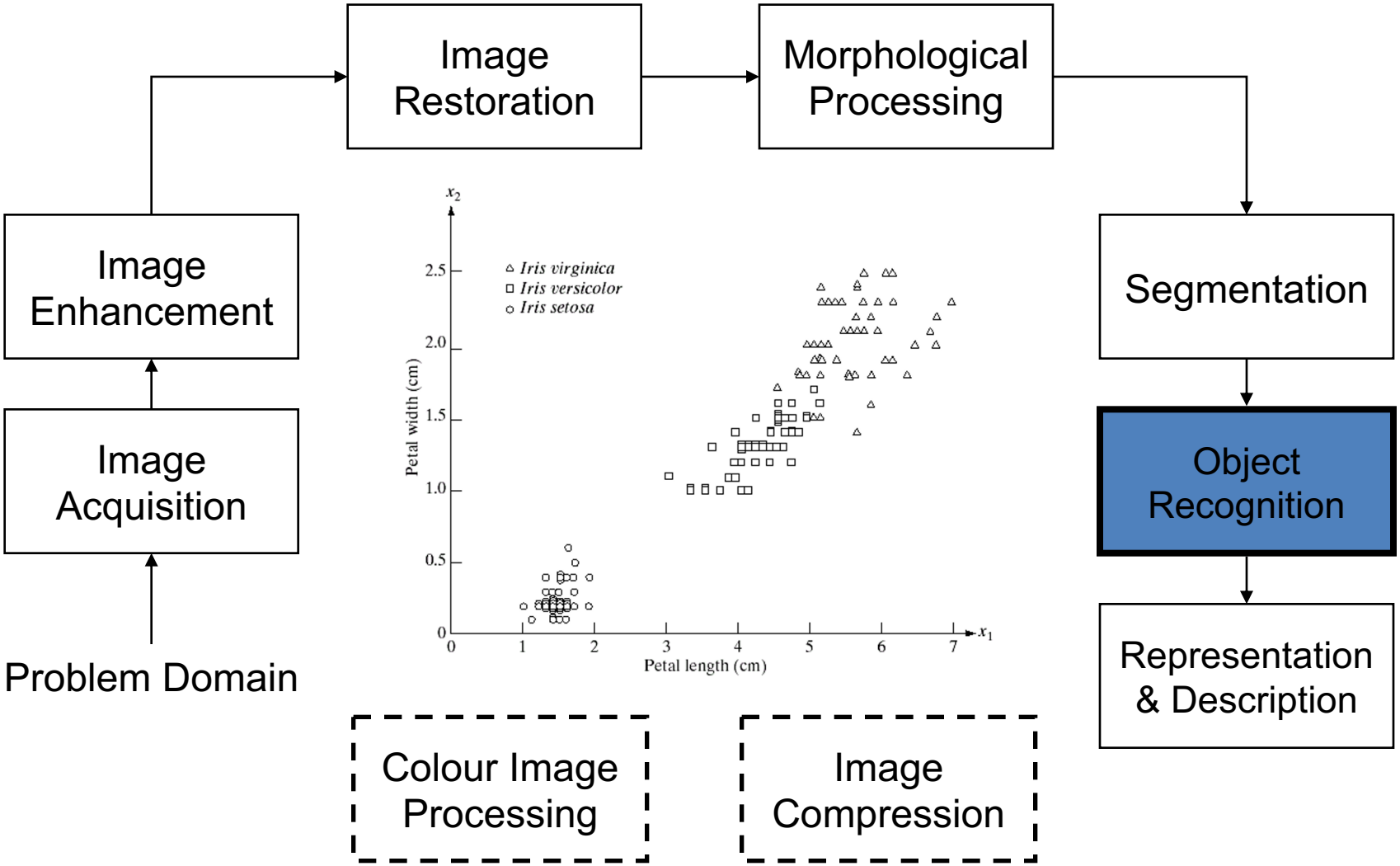
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Segmentation

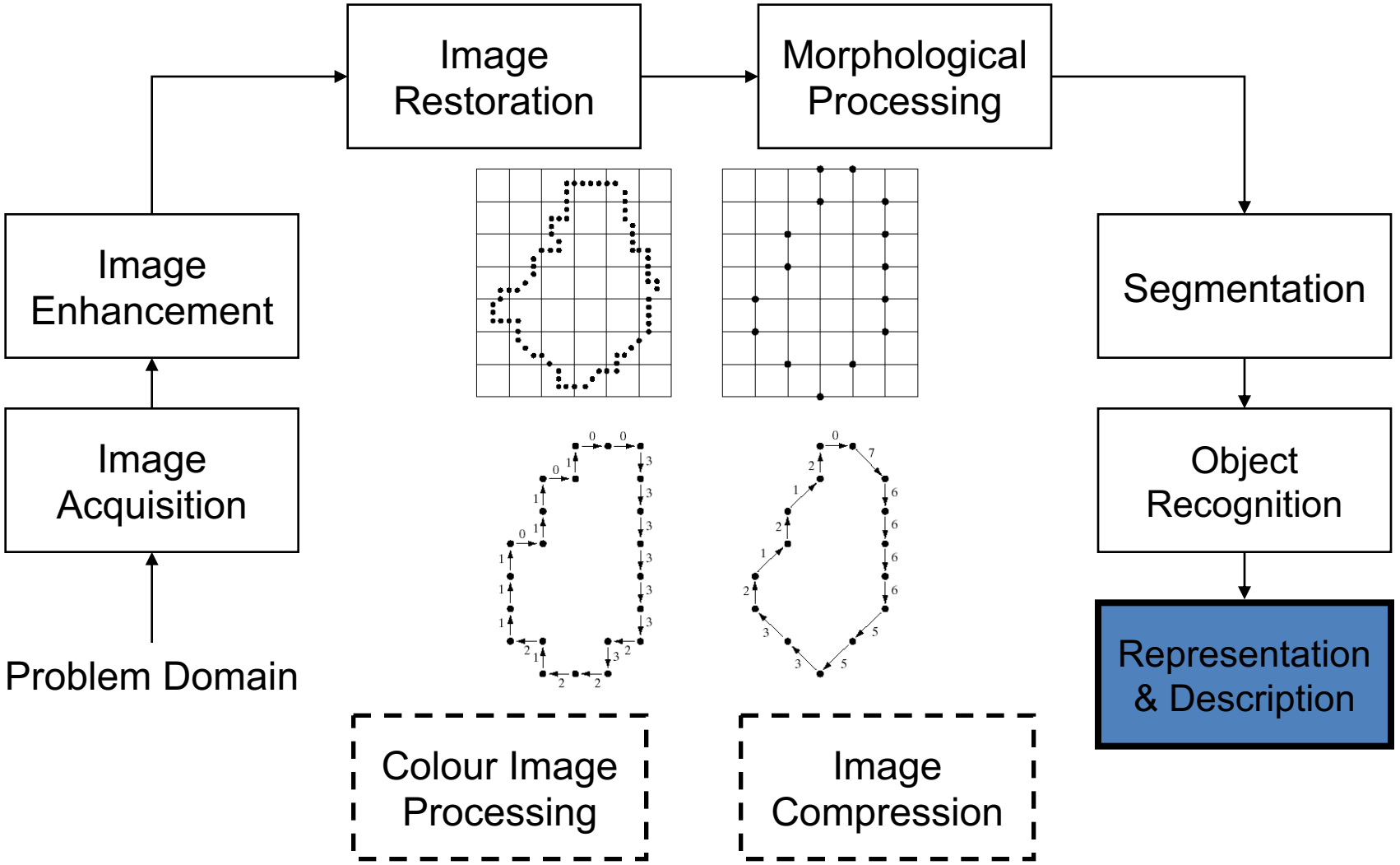


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Object Recognition

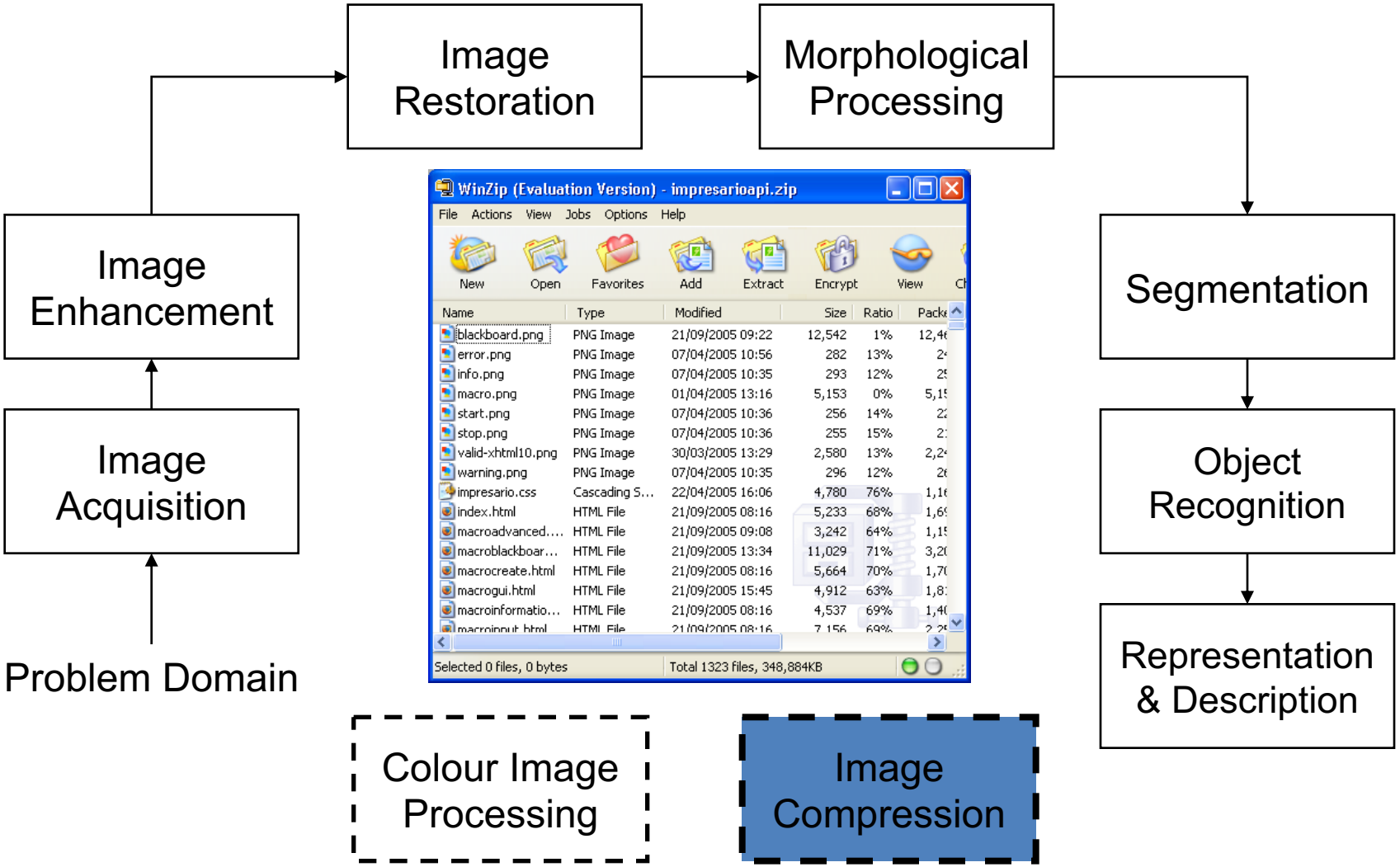


Key Stages in Digital Image Processing: Representation & Description

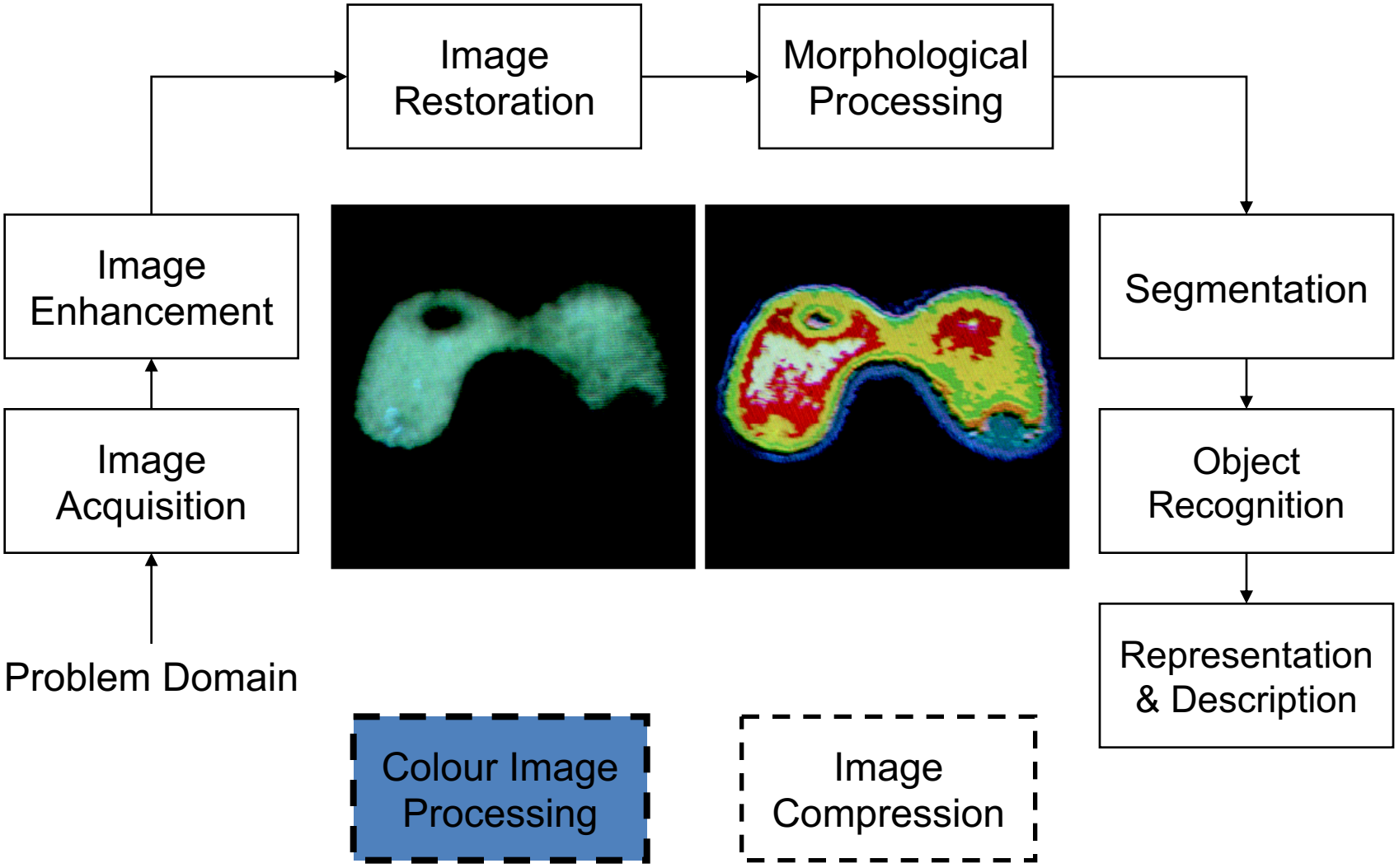


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Image Compression



Key Stages in Digital Image Processing: Colour Image Processing




Video Applications

Examples of state-of-the-art

Earth viewers (3D modeling)

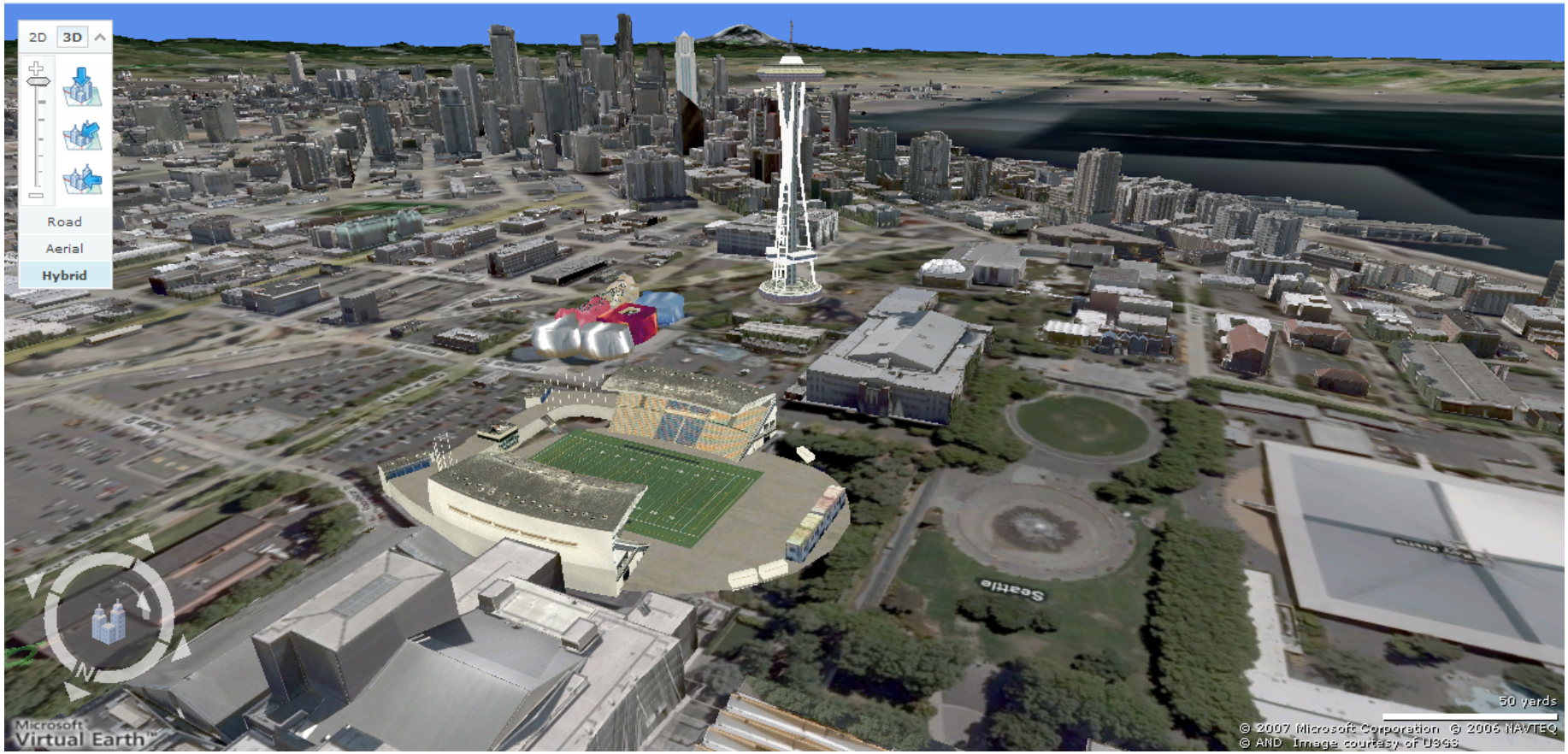
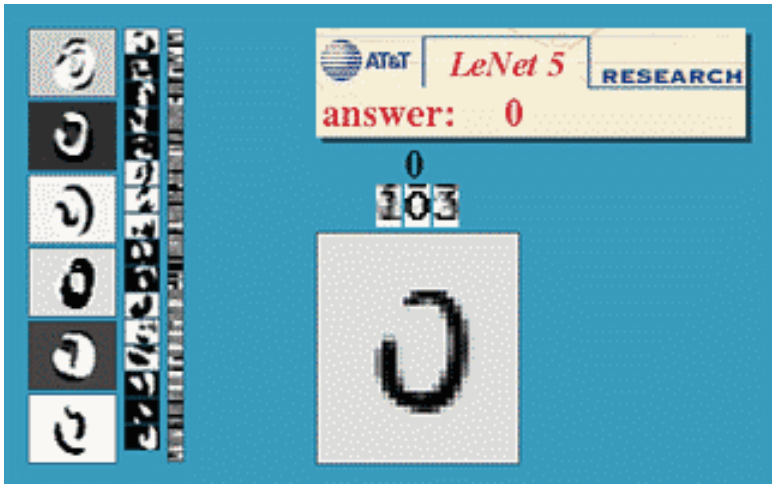


Image from Microsoft's Virtual Earth
(see also: Google Earth)

Optical character recognition (OCR)

Technology to convert scanned docs to text

- If you have a scanner, it probably came with OCR software



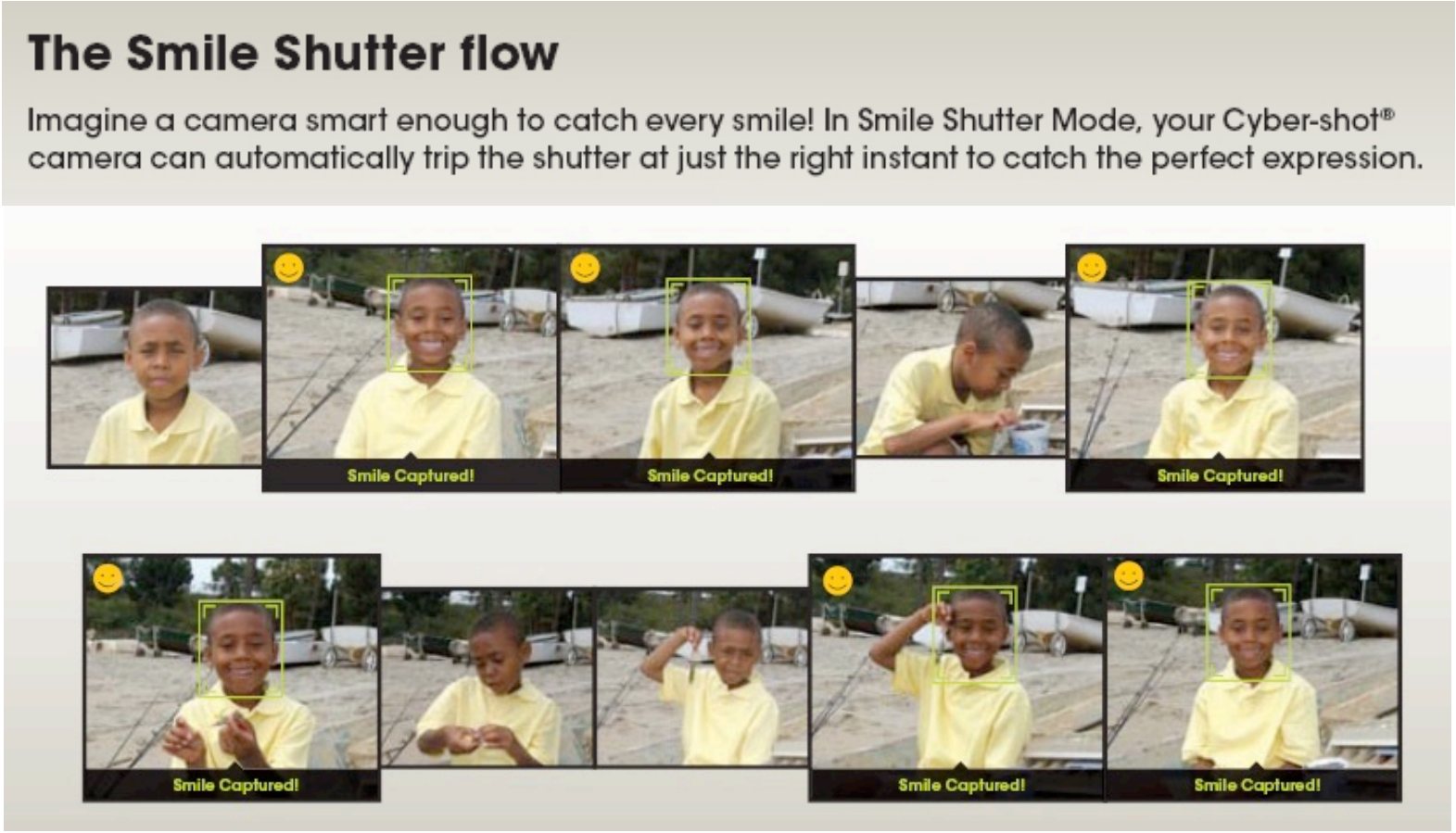
Digit recognition, AT&T labs
http://www.research.att.com/~yann/

License plate readers
http://en.wikipedia.org/wiki/Automatic_number_plate_recognition

Face detection

- Many new digital cameras now detect faces
  - Canon, Sony, Fuji, …

Smile detection?



[Sony Cyber-shot® T70 Digital Still Camera]

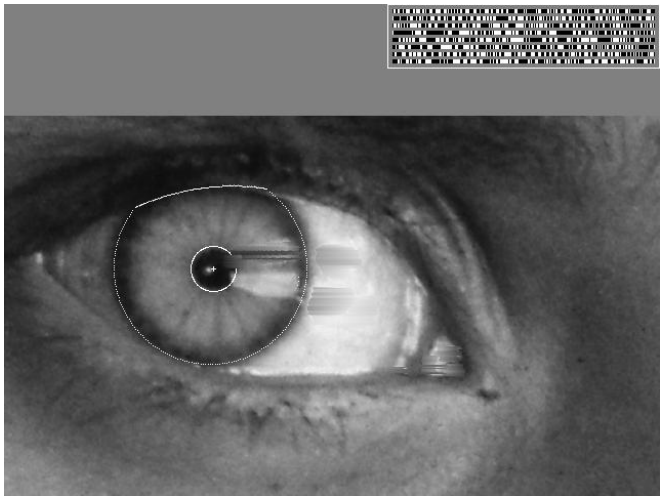
Object recognition (in supermarkets)

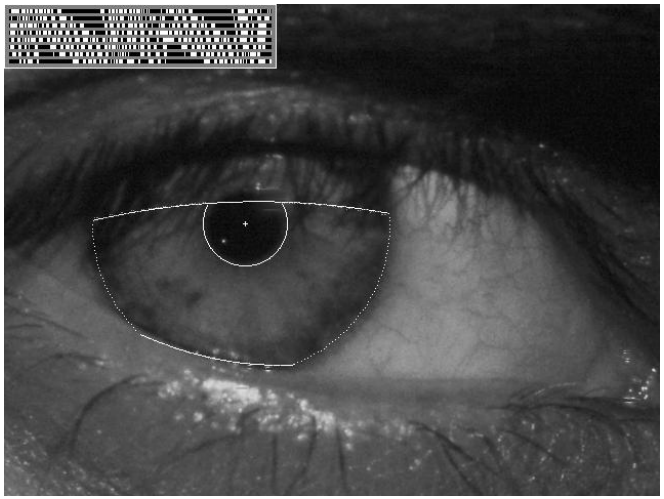
LaneHawk by EvolutionRobotics

“A smart camera is flush-mounted in the checkout lane, continuously watching for items. When an item is detected and recognized, the cashier verifies the quantity of items that were found under the basket, and continues to close the transaction. The item can remain under the basket, and with LaneHawk,you are assured to get paid for it… “

Vision-based biometrics

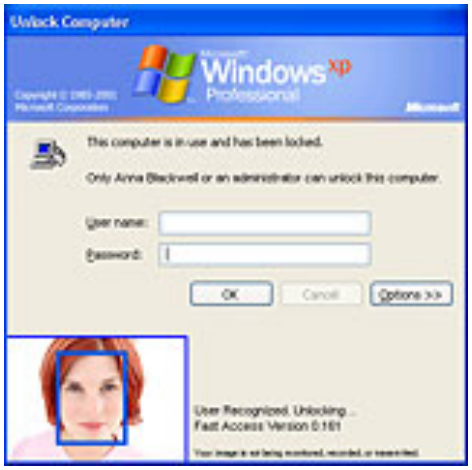
"*How the Afghan Girl was Identified by Her Iris Patterns*" Read the story wikipedia





Login without a password…

Fingerprint scanners on many new laptops, other devices



Face recognition systems now beginning to appear more widely
http://www.sensiblevision.com/

Object recognition (in mobile phones)

[Point & Find](), [Nokia]()

[Google Goggles]()

Special effects: shape capture

The Matrix movies, ESC Entertainment, XYZRGB, NRC

Special effects: motion capture

Pirates of the Carribean, Industrial Light and Magic

Sports

Sportvision first down line
Nice explanation on www.howstuffworks.com

http://www.sportvision.com/video.html

Smart cars

- Mobileye
  - Vision systems currently in many high-end models

http://mobileye.com/technology/applications/vehicle-detection/forward-colision-warning/
http://mobileye.com/technology/applications/pedestrian-detection/pedestrian-collision-warning/

Google cars

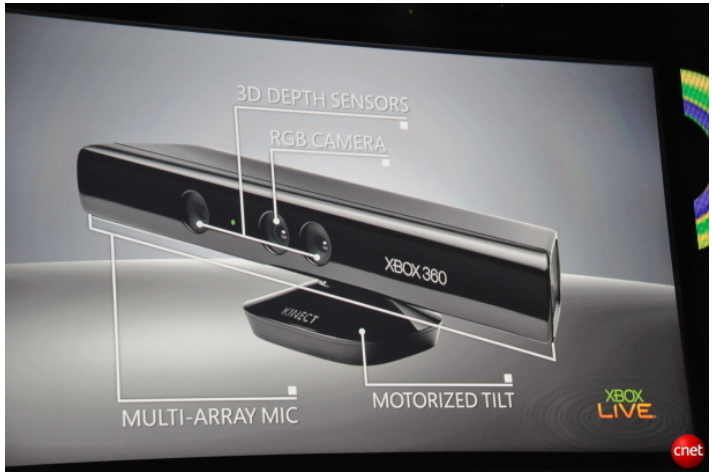
Oct 9, 2010. "Google Cars Drive Themselves, in Traffic". *The New York Times*. John Markoff

June 24, 2011. "Nevada state law paves the way for driverless cars". *Financial Post*. Christine Dobby

Aug 9, 2011, "Human error blamed after Google's driverless car sparks five-vehicle crash". *The Star* (Toronto)

Interactive Games: Kinect

- Object Recognition: http://www.youtube.com/watch?feature=iv&v=fQ59dXOo63o
- Mario: http://www.youtube.com/watch?v=8CTJL5lUjHg
- 3D: http://www.youtube.com/watch?v=7QrnwoO1-8A
- Robot: http://www.youtube.com/watch?v=w8BmgtMKFbY



Vision in space

NASA'S Mars Exploration Rover Spirit captured this westward view from atop a low plateau where Spirit spent the closing months of 2007.

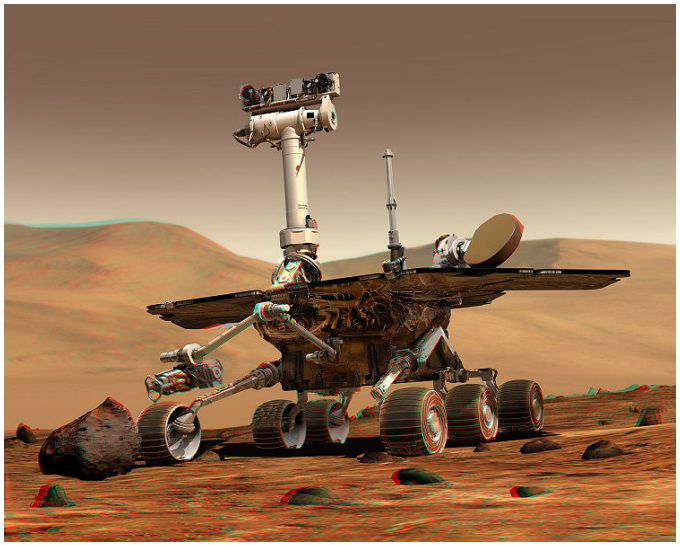
Vision systems (JPL) used for several tasks

- Panorama stitching
- 3D terrain modeling
- Obstacle detection, position tracking
- For more, read "Computer Vision on Mars" by Matthies et al.

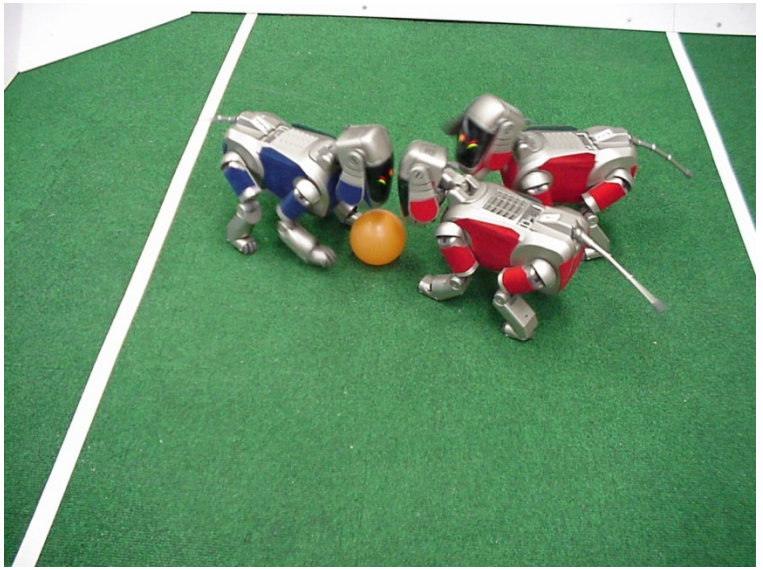
Industrial robots

Vision-guided robots position nut runners on wheels

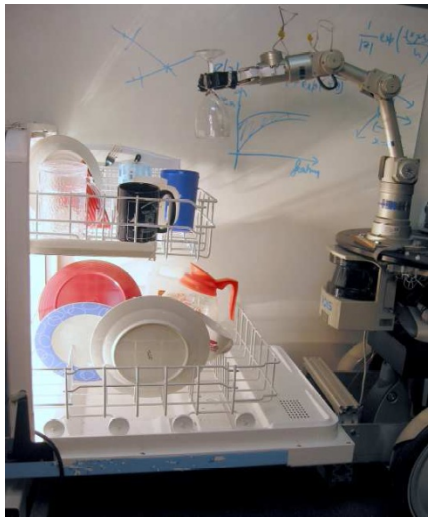
Mobile robots



NASA's Mars Spirit Rover
http://en.wikipedia.org/wiki/Spirit_rover



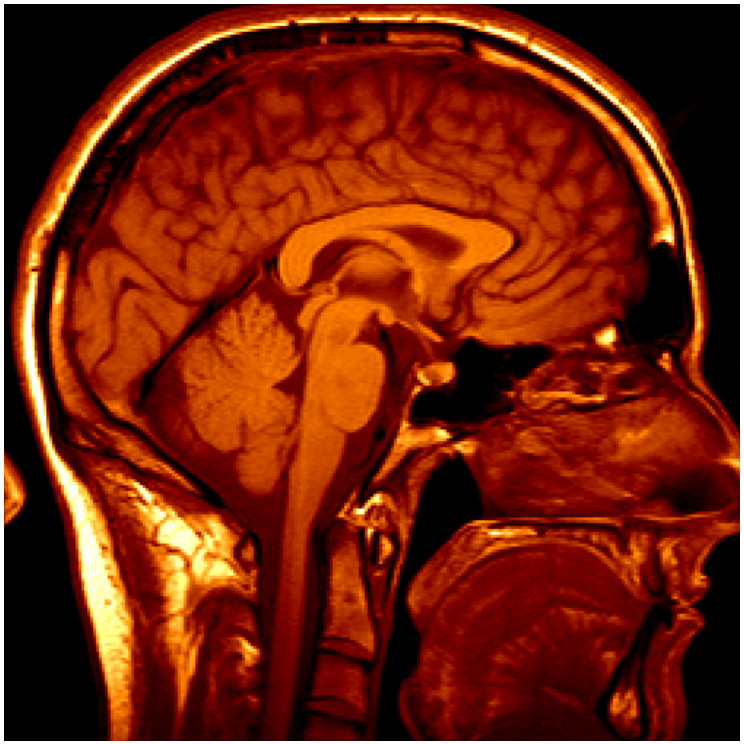
http://www.robocup.org/



Saxena et al. 2008
STAIR at Stanford

http://www.youtube.com/watch?v=DF39Ygp53mQ

Medical imaging



3D imaging
MRI, CT

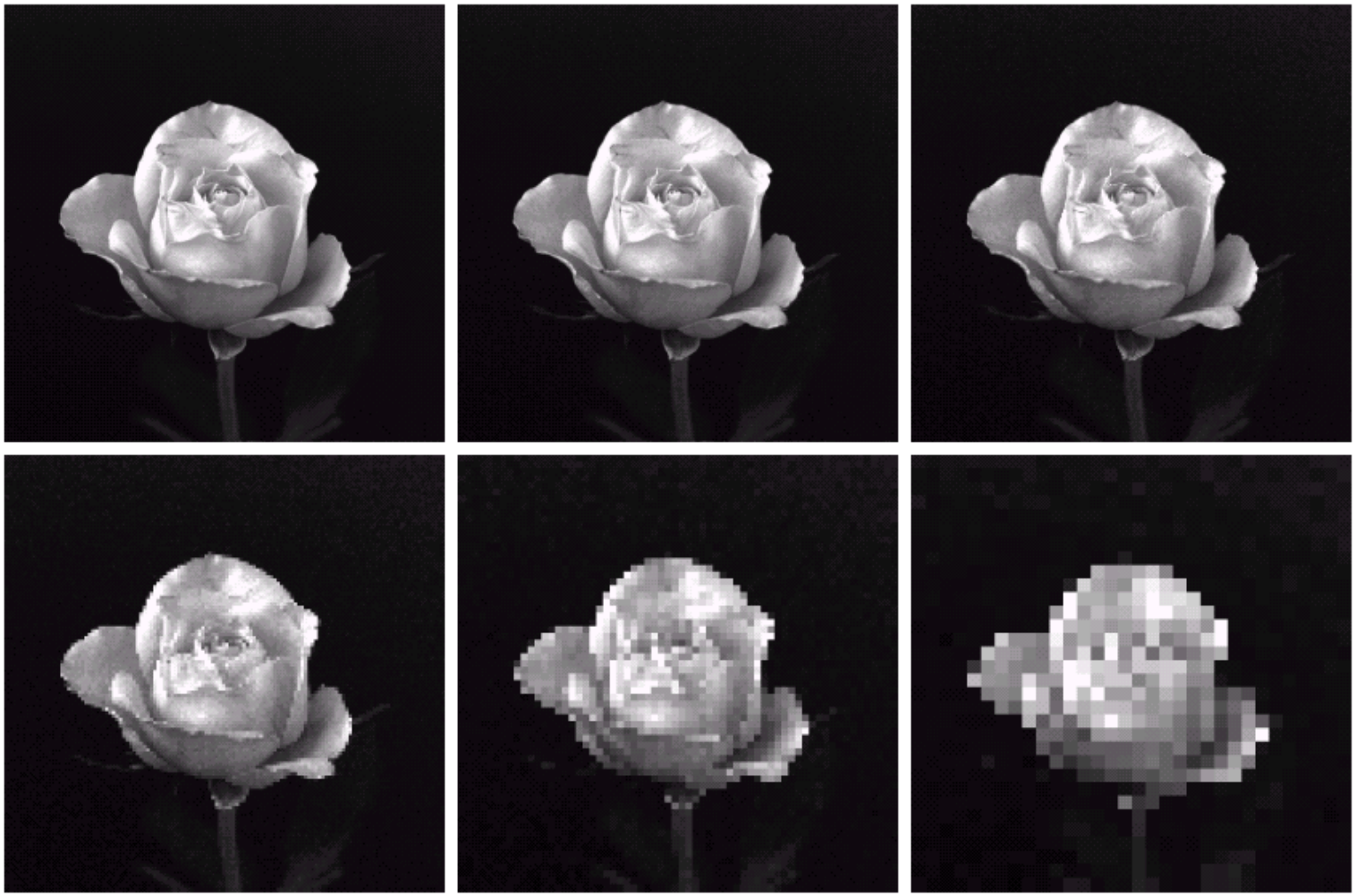
Image guided surgery
Grimson et al., MIT

Prerequisites

- **Linear algebra**, basic calculus, and probability
- Experience with image processing or Matlab will help but is not necessary

- Popular text books
  - William K. Pratt, „Introduction to Digital Image Processing," CRC Press, 2013.
  - R. C. Gonzalez, R. E. Woods, „Digital Image Processing," 3rd edition, Prentice-Hall, 2008.
  - A. K. Jain, „Fundamentals of Digital Image Processing," Prentice-Hall, Addison-Wesley, 1989.
- Software-centric books
  - R. C. Gonzalez, R. E. Woods, S. L. Eddins, „Digital Image Processing using Matlab," 2nd edition, Pearson-Prentice-Hall, 2009.
  - G. Bradski, A. Kaehler, „Learning OpenCV," O'Reilly Media, 2008.
- Comprehensive state-of-the-art
  - Al Bovik (ed.), „The Essential Guide to Image Processing," Academic Press, 2009.
- Journals/Conference Proceedings
  - IEEE Transactions on Image Processing
  - IEEE International Conference on Image Processing (ICIP)
  - IEEE Computer Vision and Pattern Recognition (CVPR)
  - ....

Next course: Spatial Resolution and application



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.