CMPE 362 / CS 563
Digital Image Processing

Introduction

Asst. Prof. Dr. Aslı Gençtav
Department of Computer Engineering
TED University

About this course

- Course objective:
  - to provide an introduction to students who wish to specialize in image processing, computer vision, and computational photography fields
- Skills to develop:
  - foundational understanding of image processing concepts & methods
  - ability to use these concepts & methods in practical problems
- Requirements:
  - Programming skills
  - Math background

Learning outcomes

Upon successful completion of this course, students will be able to:

- Describe the basic theory of image processing
- Examine binary and color images using image processing tools
- Analyze and apply image enhancement methods in spatial and frequency domain
- Analyze and apply image segmentation methods
- Analyze and apply algorithms to extract significant information from images
- Develop solution methods for image processing problems using the state of the art

- Digital Image Processing by R. C. Gonzalez, R. E. Woods, 4th Global Edition, Pearson Education Limited, 2018

- Computer Vision: Algorithms and Applications by R. Szeliski, 2nd Edition, Springer, 2021 (electronic draft available)

Communication via Moodle

- Announcements
- Lecture notes
- Assignments

Getting help

- Office hours
  - Online Zoom meetings (see Moodle for more info)
- Course Forum on Moodle

Course work and grading

- Midterm Exam 25%
- Final Exam 30%
- 4 Programming Assignments 40% (10% each)
- Class Participation & Weekly Activities 5%

Assignments

- All assignment works must be done individually or in pairs
  - The specific rule for an assignment will be explicitly stated in the assignment handout
- To be submitted electronically via Moodle
- Late submission policy:
  - Each late day imposes 20% penalty of the assignment grade.
  - Late submissions more than 2 late days will not be accepted
- Each assignment has a well-defined goal such as solving a specific problem
  - Coding (Python programming language, OpenCV software library)
  - Report

Class Participation & Weekly Activities

- To earn class participation & weekly activities grade (5%), you are expected to
  - attend classes and
  - submit your work for weekly hands on activities

- In each week, there will be a hands-on activity involving small programming question(s) about the topic of the week.

Academic Honesty

- https://student.tedu.edu.tr/en/principles-academic-integrity

Course Overview

- Introduction *(1 week)*
- Image Formation, Color *(1 week)*
- Point Operations, Spatial Filtering *(1 week)*
- Frequency Domain Techniques *(2 weeks)*
- Image Pyramids, Morphological Image Processing *(1 week)*
- Image Segmentation *(2 weeks)*
- Image Pattern Classification *(3 weeks)*
- Feature Extraction *(2 weeks)*

Tentative course outline

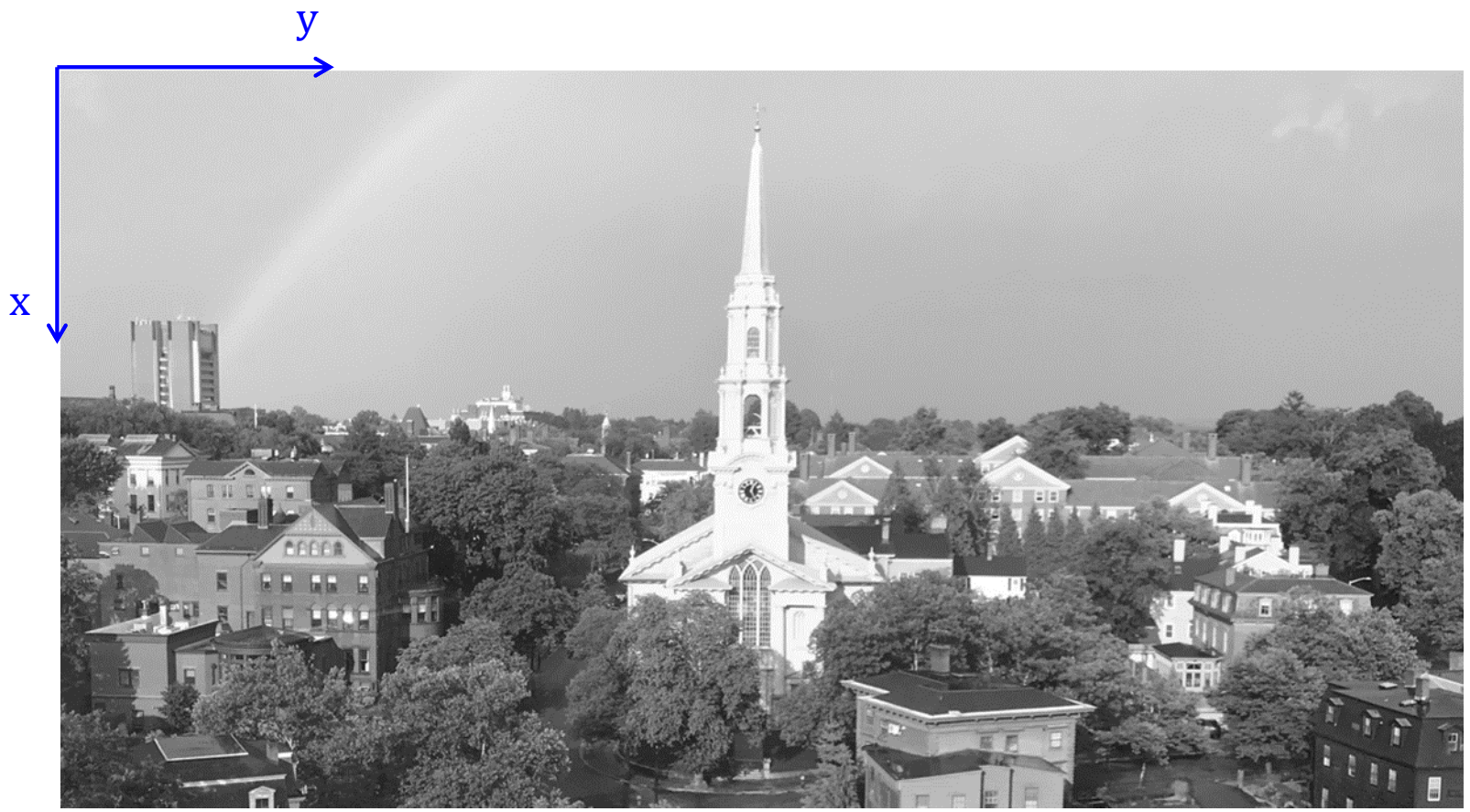
- TBD

Today

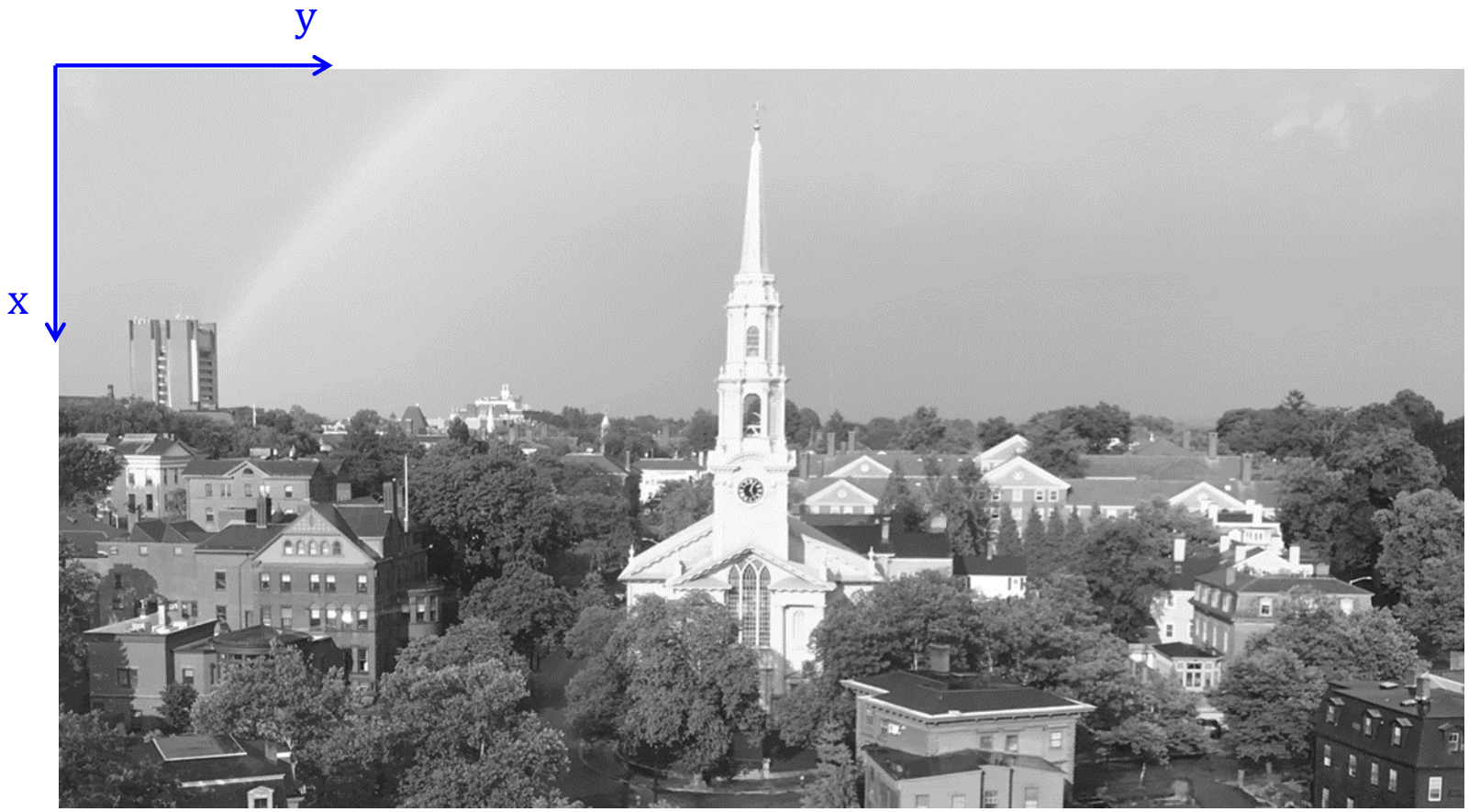
- What is a digital image?
- What is image processing?
  - Sample image processing problems
  - A medical application of image processing as an example
- Imaging in different parts of Electromagnetic Spectrum

Today

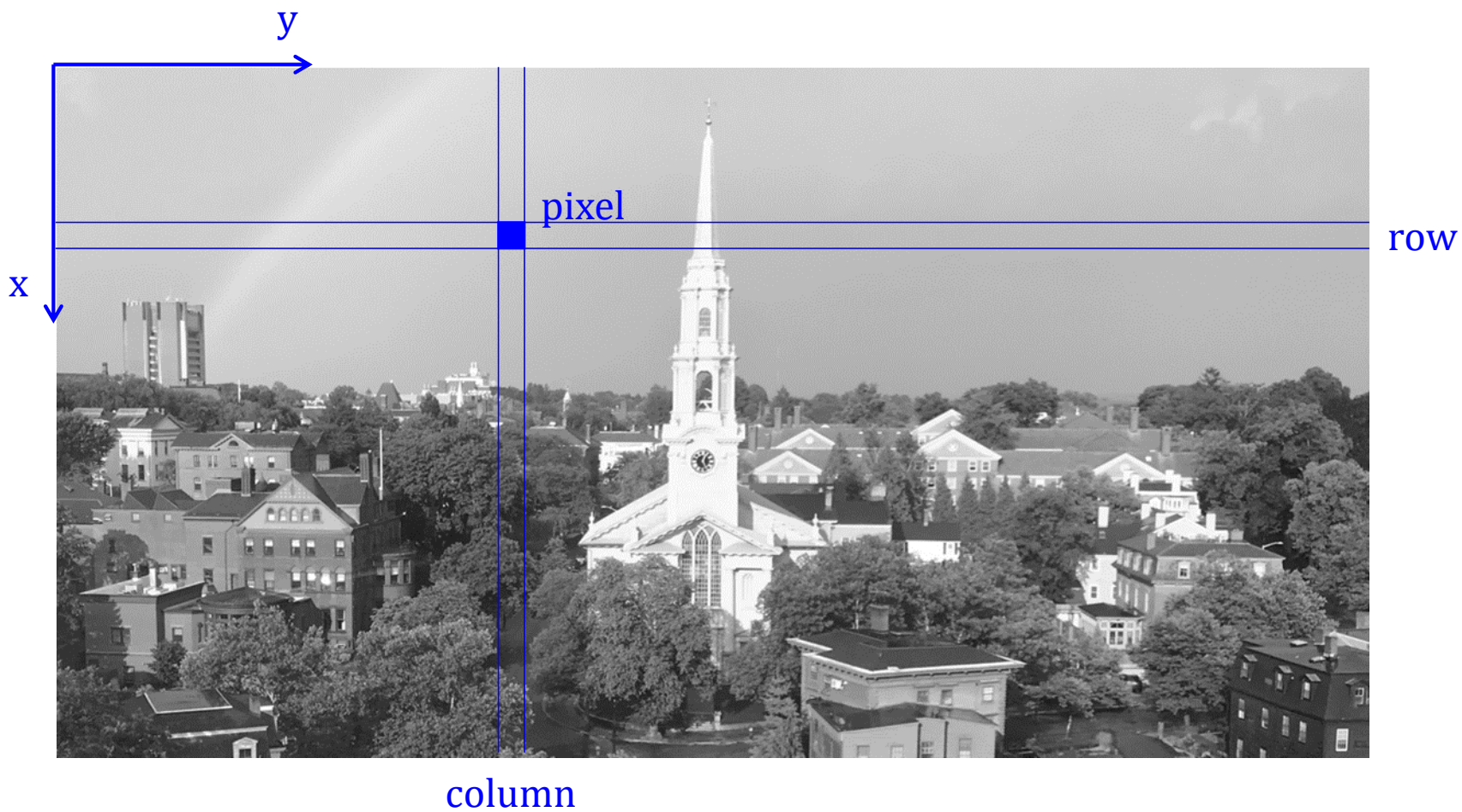
- What is a digital image?
- What is image processing?
  - Sample image processing problems
  - A medical application of image processing as an example
- Imaging in different parts of Electromagnetic Spectrum

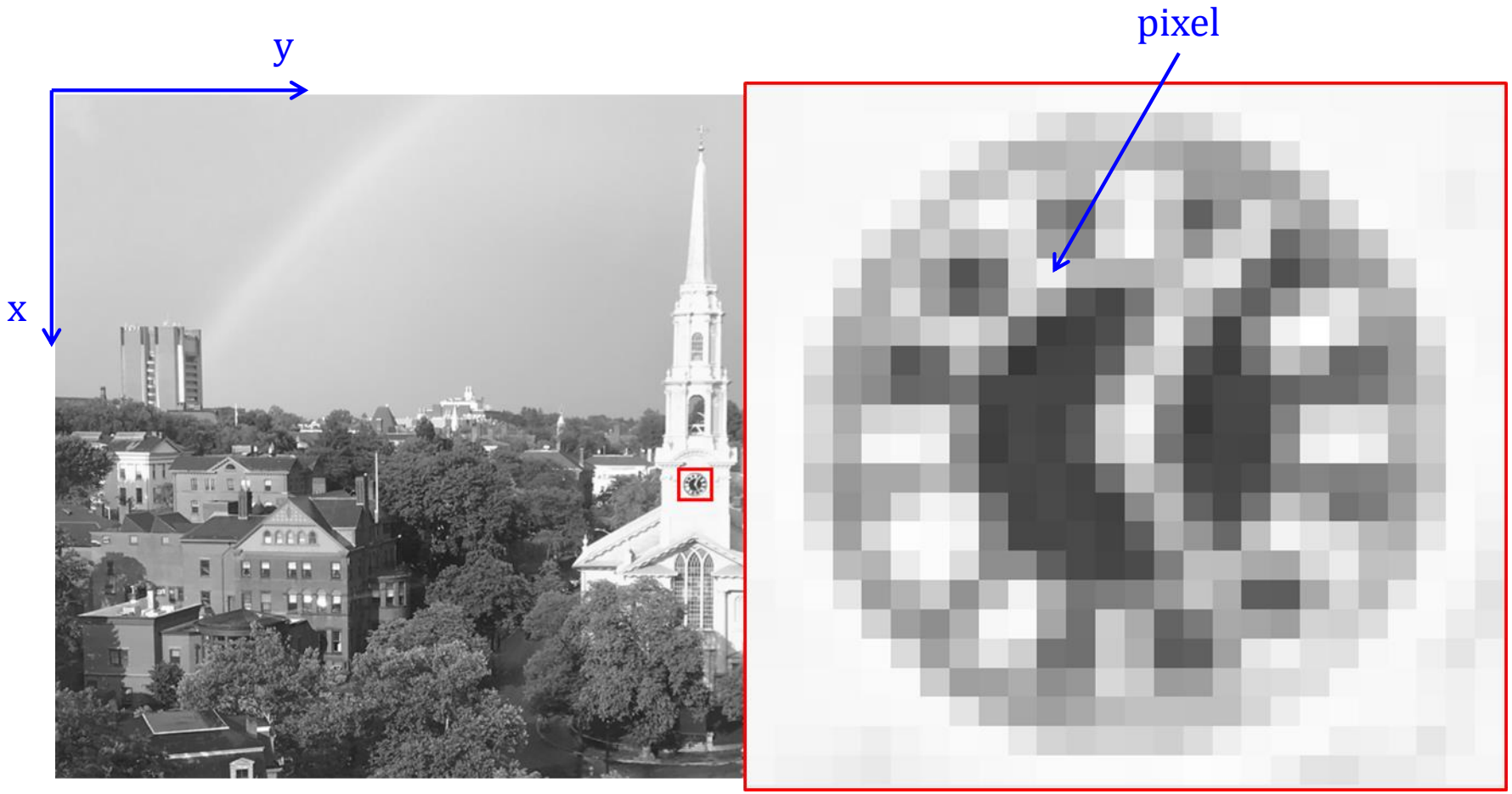


f(x,y)



A digital image is a two-dimensional function f(x,y) or matrix where x, y, f(x,y) are finite and discrete.


y
x
pixel
row
column


y
x
pixel

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249	251	215	181	245	249	239	138	62	74	70	90	199	228	115	65	69	68	144	239	247	236	177	205	250	249
249	251	196	152	168	168	186	150	73	71	73	68	109	191	163	74	70	78	124	133	127	131	148	196	250	248
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248	249	248	188	180	236	251	220	142	142	95	74	69	75	126	190	189	170	167	217	235	193	195	248	249	235
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246	242	241	237	233	241	243	246	248	249	251	251	251	250	251	253	252	249	241	228	226	235	235	239	246	246

What do computers see?

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From Selim Aksoy http://www.cs.bilkent.edu.tr/~saksoy/courses/cs484-Fall2019/index.html

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- Imaging in different parts of Electromagnetic Spectrum

Image processing	Image analysis & understanding	Computer vision

Low-level

- Primitive operations
  - Image preprocessing to reduce noise
  - Contrast enhancement
  - Image sharpening
- Both their inputs and outputs are images

Mid-level

- Tasks
  - Segmentation (partitioning an image into regions or objects)
  - Description of those objects for further computer processing
  - Classification (recognition) of individual objects
- Their inputs generally are images but their outputs are attributes extracted from those images
  - e.g. edges, contours, identity of individual objects

High-level

- Making sense of a group of recognized objects
- Performing cognitive functions associated with human vision

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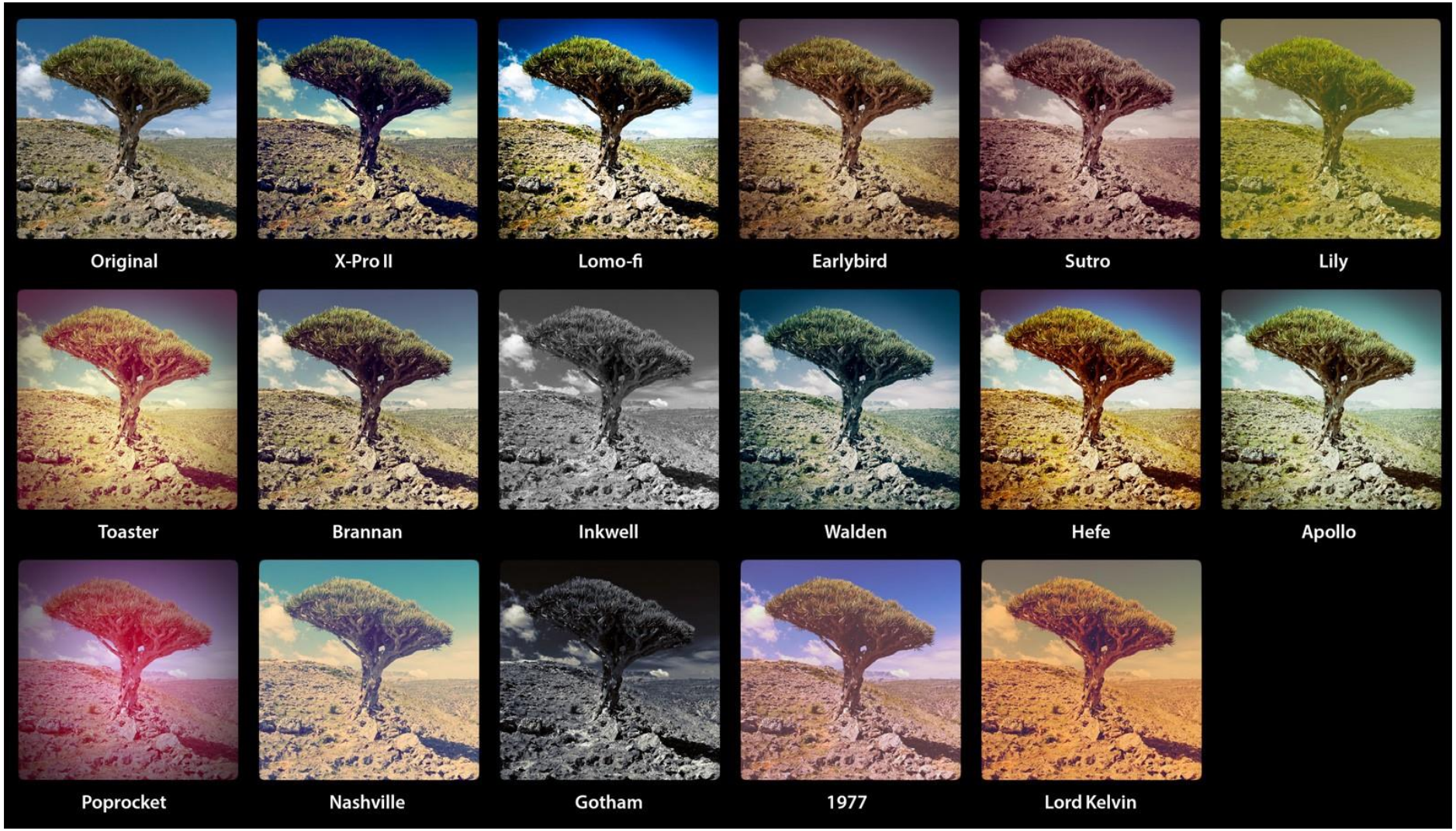
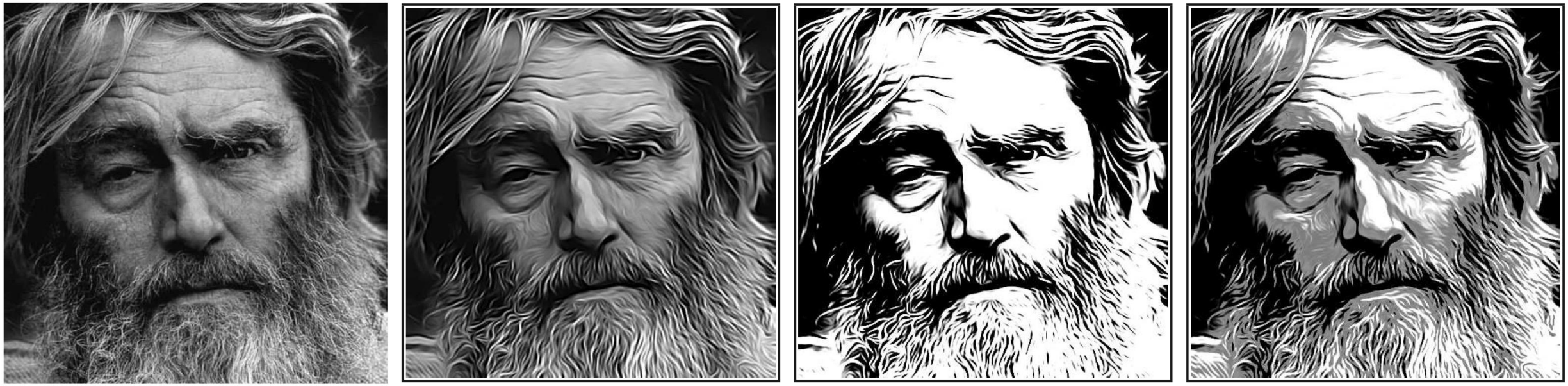
Image Enhancement

- Instagram



Artistic Image Stylization



H. Winnemöller, J. E. Kyprianidis, S. C. Olsen, XDoG: An eXtended difference-of-Gaussians compendium including advanced image stylization, Computers & Graphics, 2012

Image Denoising

$$f(x,y) = u(x,y) + n(x,y)$$

observed image | original image | noise

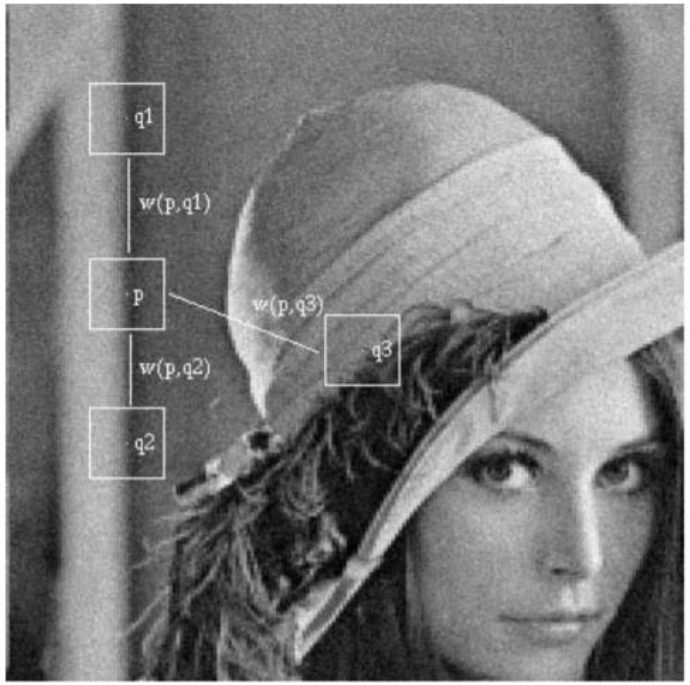
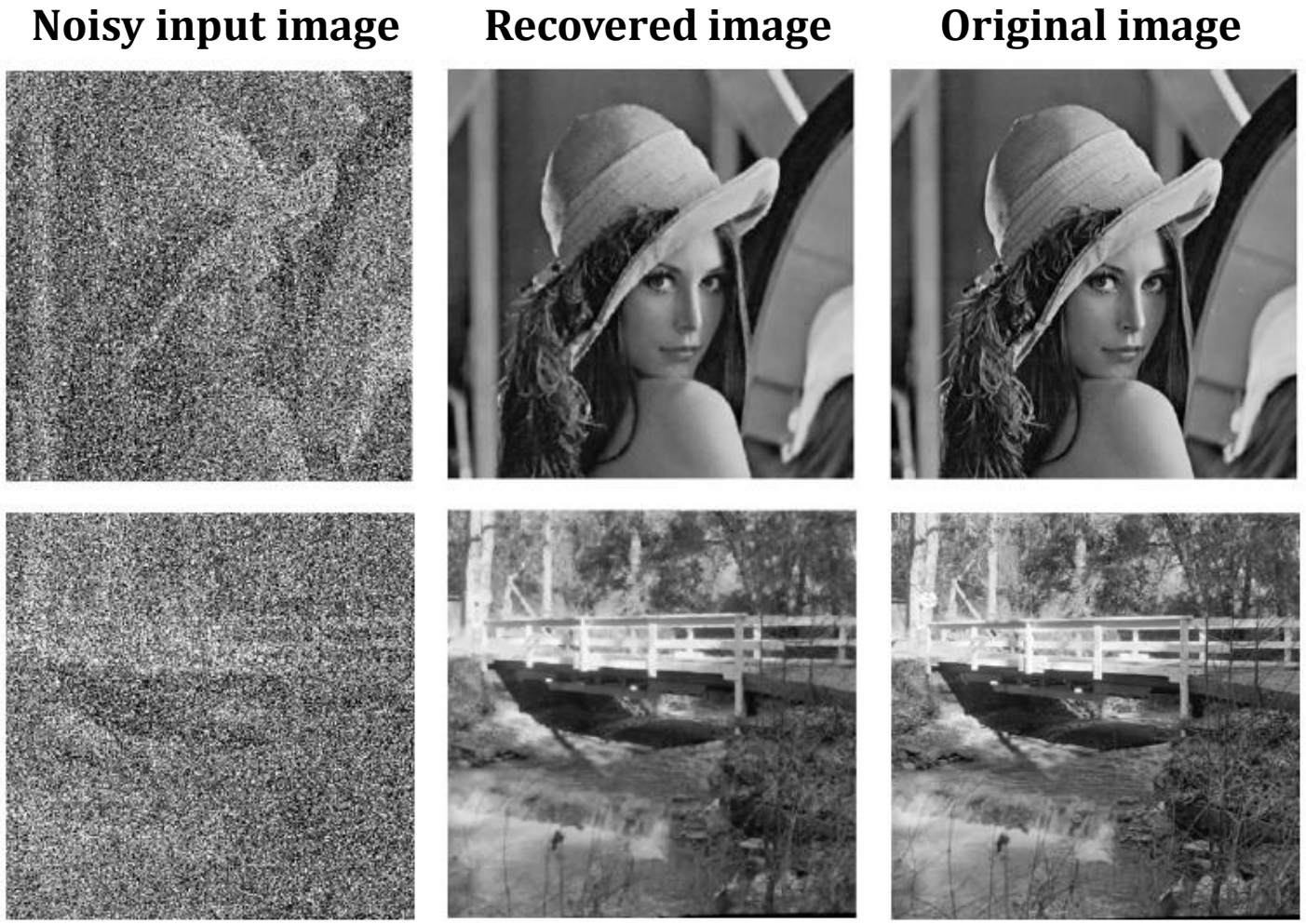


Figure 1. Scheme of NL-means strategy. Similar pixel neighborhoods give a large weight, w(p,q1) and w(p,q2), while much different neighborhoods give a small weight w(p,q3).

A. Buades, B. Coll, and J.-M. Morel, A non-local algorithm for image denoising, CVPR, 2005

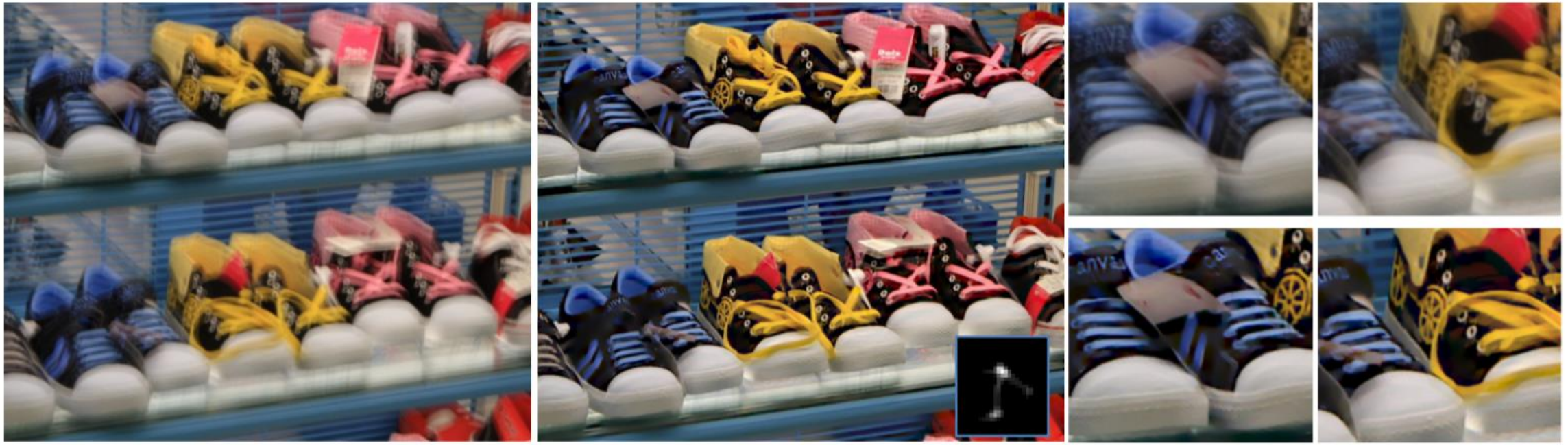
Image Denoising

- Noisy input images are corrupted with 70% salt-and-pepper noise.



R.H. Chan, C.-W. Ho, and M. Nikolova, Salt-and-pepper noise removal by median-type noise detectors and detail-preserving regularization, IEEE Transactions on Image Processing, 2005

Image Deblurring



Input blurred image | Deblurring result | Magnified views

S. Cho, and S. Lee, Fast motion deblurring, ACM Transactions on Graphics, 2009

Image Inpainting

M. Bertalmio, G. Sapiro, V. Caselles, and C. Ballester, Image inpainting, SIGGRAPH 2000.

Image Superresolution

input

4x output

W.-S. Lai, J.-B. Huang, N. Ahuja and M.-H. Yang, Deep Laplacian Pyramid Networks for Fast and Accurate Super-Resolution, CVPR 2017

Image Superresolution

input

4x original

W.-S. Lai, J.-B. Huang, N. Ahuja and M.-H. Yang, Deep Laplacian Pyramid Networks for Fast and Accurate Super-Resolution, CVPR 2017

Image Style Transfer

L. A. Gatys, A. S. Ecker, M. Bethge, Image Style Transfer Using Convolutional Neural Networks, CVPR 2016

Image Segmentation

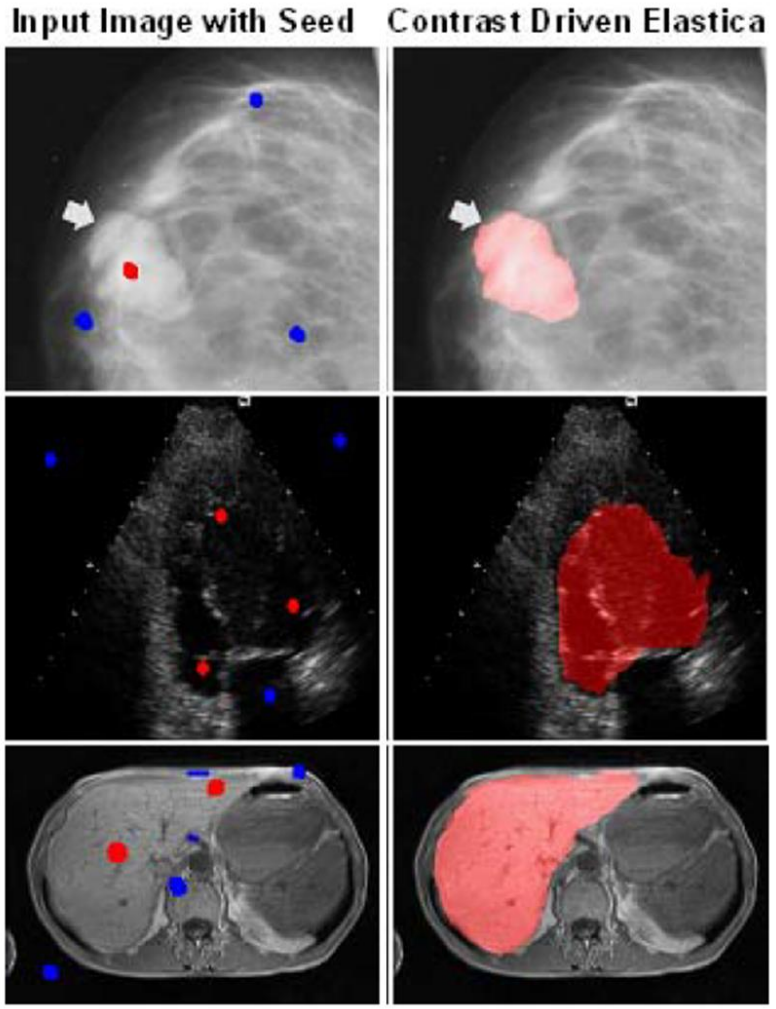
J.-G. Yu, Y. Li, C. Gao, H. Gao, G.-S. Xia, Z. L. Yu, and Y. Li, Exemplar-Based Recursive Instance Segmentation With Application to Plant Image Analysis, IEEE Transactions on Image Processing, 2020

Image Segmentation

Circumscribed mass in a mammogram

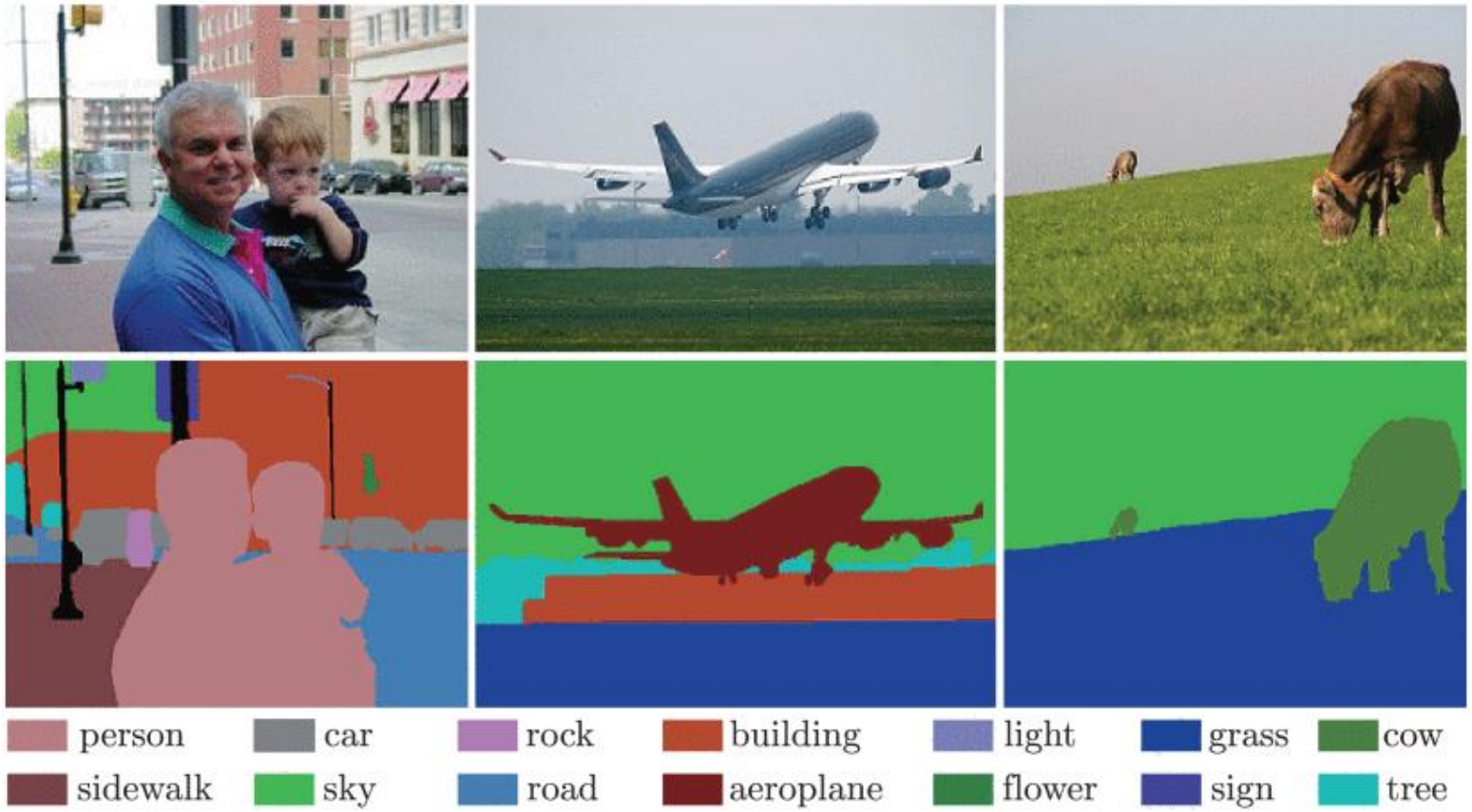
Left ventricle in ultrasound

Liver in MRI



N. Y. El-Zehiry, and L. Grady, Contrast Driven Elastica for Image Segmentation, IEEE Transactions on Image Processing, 2016

Image Segmentation



H. Ding, X. Jiang, B. Shuai, A. Q. Liu, and G. Wang, Semantic Segmentation With Context Encoding and Multi-Path Decoding, IEEE Transactions on Image Processing, 2020

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A medical application of image processing

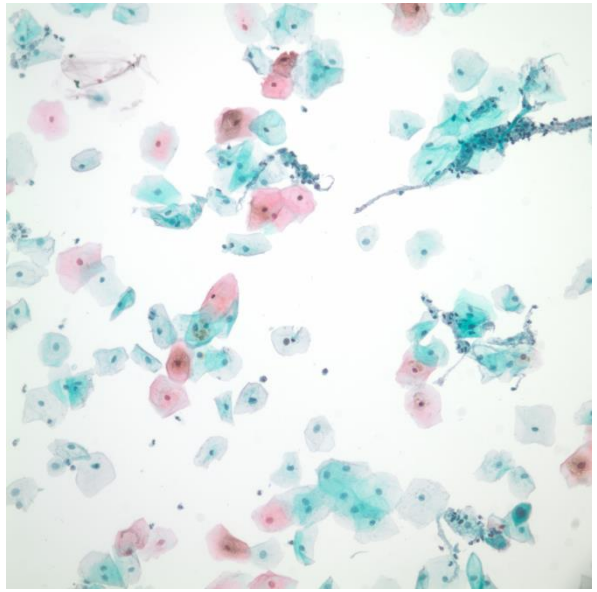
- Cervical cancer is the fourth most frequent cancer among women globally.

- Cervical cancer is a preventable disease
  - Develops during a long duration
  - When early detected, can be treated

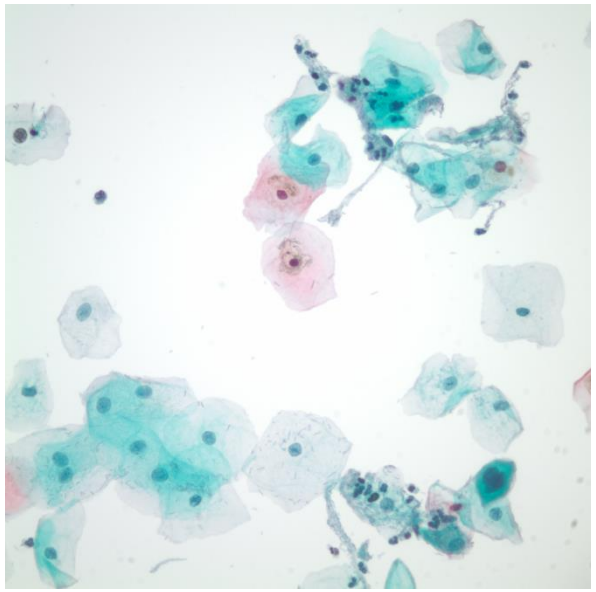
Pap Smear Test

- Specimen taken from cervix are smeared onto a thin glass slide.
- In the laboratory, they are colored and examined under the microscope.
- Cells containing dysplasia or cancer are determined by experts.

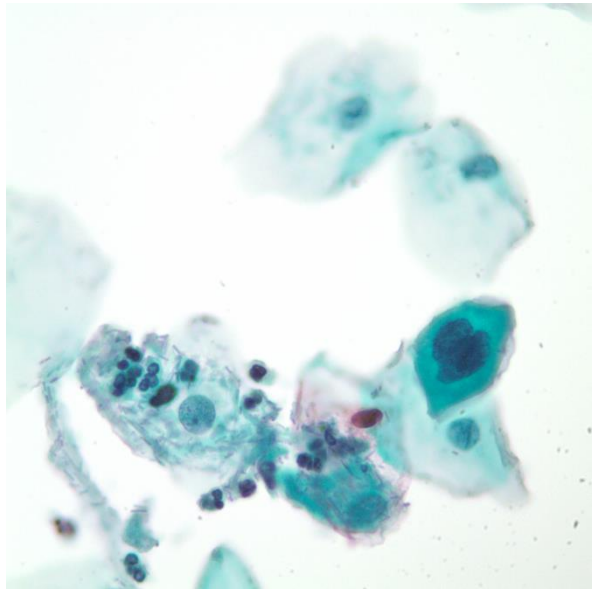
Example Pap Smear Test Images



20x

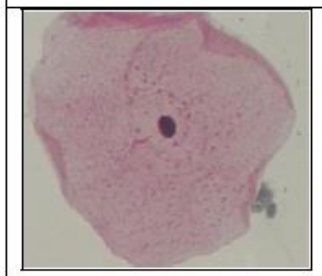
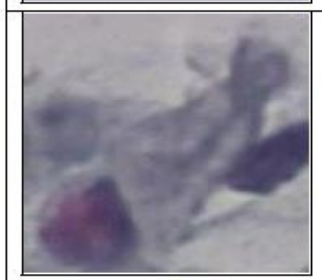


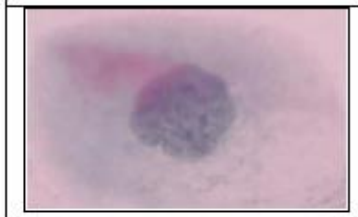
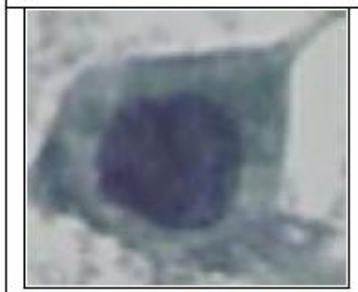
40x



100x

Types of Cervical Cells

Normal cells	
	**Superficial squamous** • Shape flat/oval • Nucleus very small • Nucleus/cytoplasm ratio very small
	**Intermediate squamous** • Shape round • Nucleus large • Nucleus/cytoplasm ratio small
	**Columnar** • Shape column-like • Nucleus large • Nucleus/cytoplasm ratio medium

Abnormal cells	
	**Mild dysplasia** • Nucleus light/large • Nucleus/cytoplasm ratio medium
	**Moderate dysplasia** • Nucleus large/dark • Cytoplasm dark • Nucleus/cytoplasm ratio large
	**Severe dysplasia** • Nucleus large/dark/deform • Cytoplasm dark • Nucleus/cytoplasm ratio very large
	**Carcinoma in situ** • Nucleus large/dark/deform • Nucleus/cytoplasm ratio very large

Pap Smear Test

- Costly
- Inaccurate diagnoses
  - Intra- and inter-observer variablity

Pattern Recognition
Volume 45, Issue 12, December 2012, Pages 4151-4168

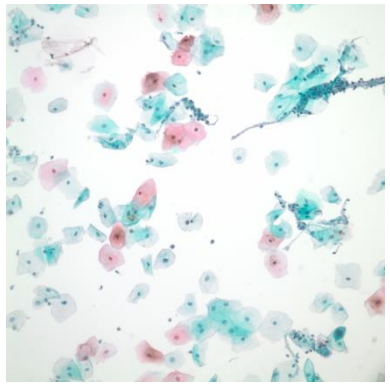
Unsupervised segmentation and classification of cervical cell images

Aslı Gençtav [a, 1] ✉, Selim Aksoy [a] ✉, Sevgen Önder [b] ✉

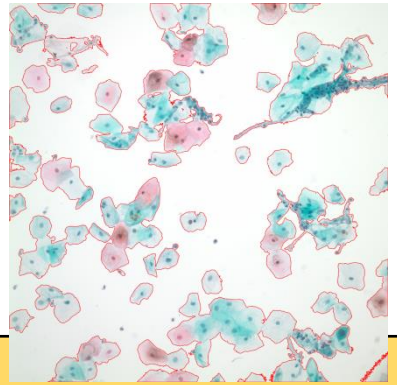
[a] Department of Computer Engineering, Bilkent University, Ankara 06800, Turkey
[b] Department of Pathology, Hacettepe University, Ankara 06100, Turkey

Received 1 August 2011, Revised 18 April 2012, Accepted 2 May 2012, Available online 18 May 2012.

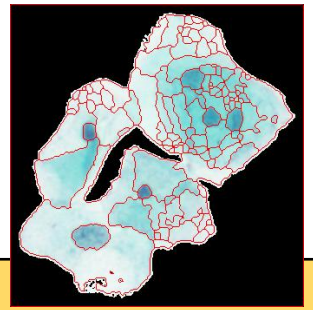
- Computer-assisted screening system
- Sort cells according to their abnormality degree



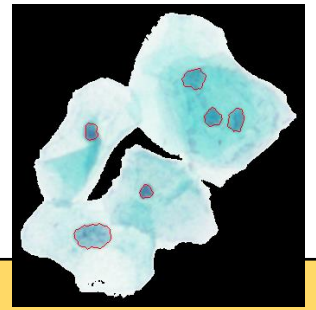
Input image



Background Extraction



Nucleus and Cytoplasm Segmentation

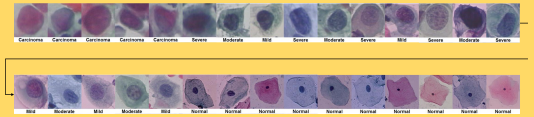


Nucleus and Cytoplasm Classification

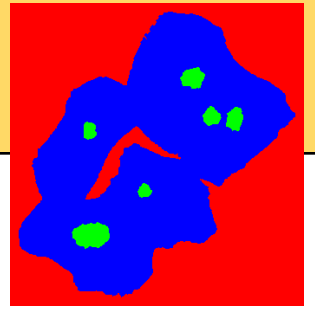
Segmentation of Cervical Cells

Classification of Cervical Cells

Ranking of Cells

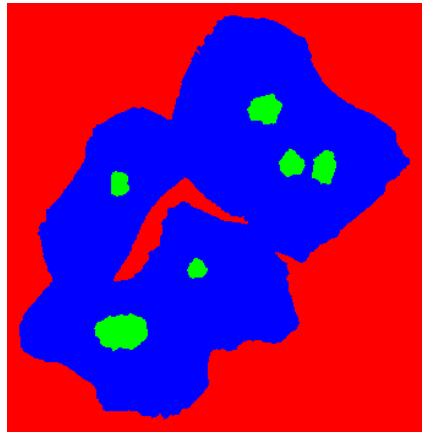


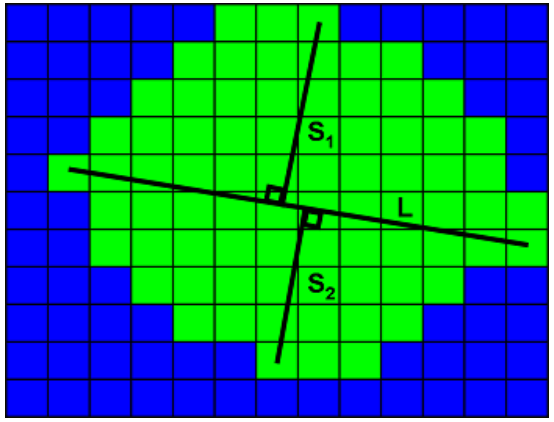
Feature Extraction



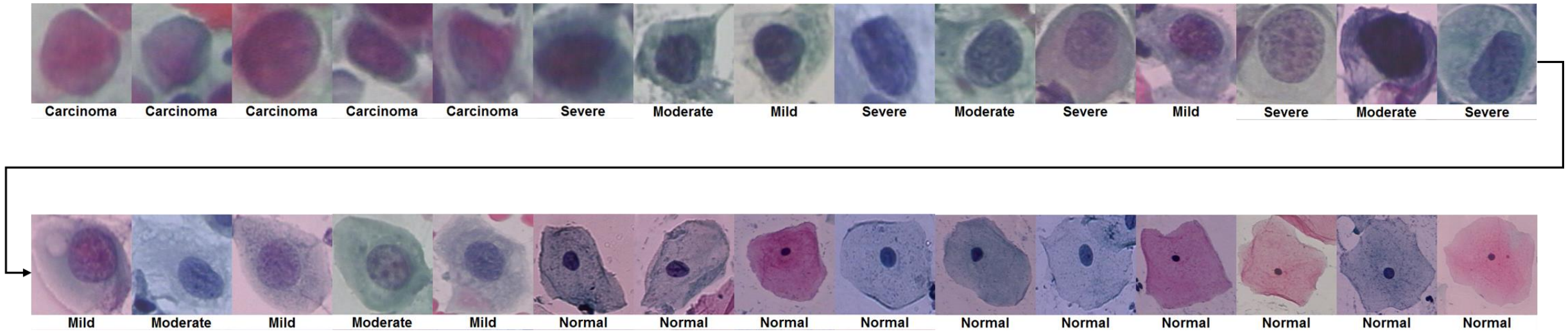
Feature Extraction

- Nucleus area
- Nucleus brightness
- Nucleus longest diameter
- Nucleus shortest diameter
- Nucleus elongation
- Nucleus roundness
- Nucleus perimeter
- Nucleus maxima
- Nucleus minima
- Cytoplasm area
- Nucleus/Cytoplasm ratio
- Cytoplasm brightness
- Cytoplasm maxima
- Cytoplasm minima





Ranking of Cervical Cells



Today

- What is a digital image?
- What is image processing?
  - Sample image processing problems
  - A medical application of image processing as an example
- Imaging in different parts of Electromagnetic Spectrum

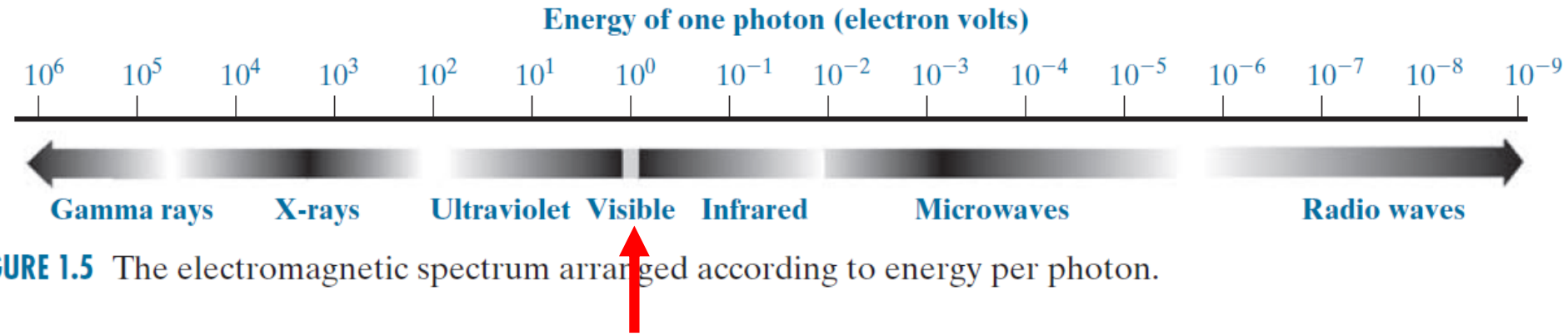


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

Figure from Digital Image Processing, Gonzalez, Woods, 4th Global Edition, Pearson, 2018

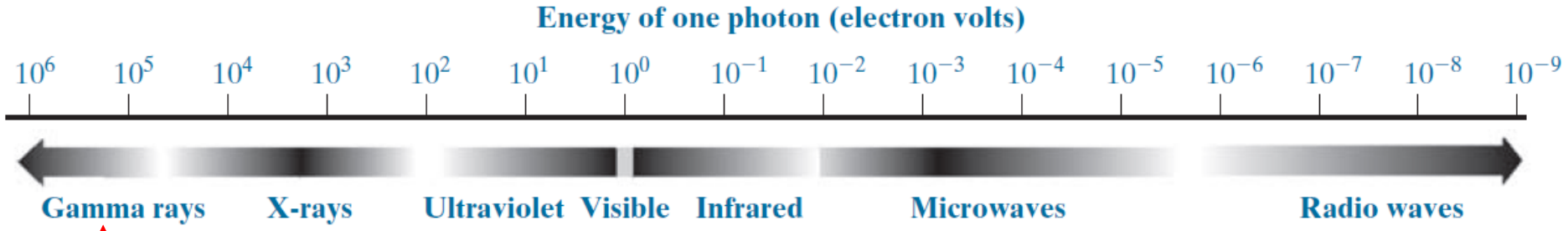
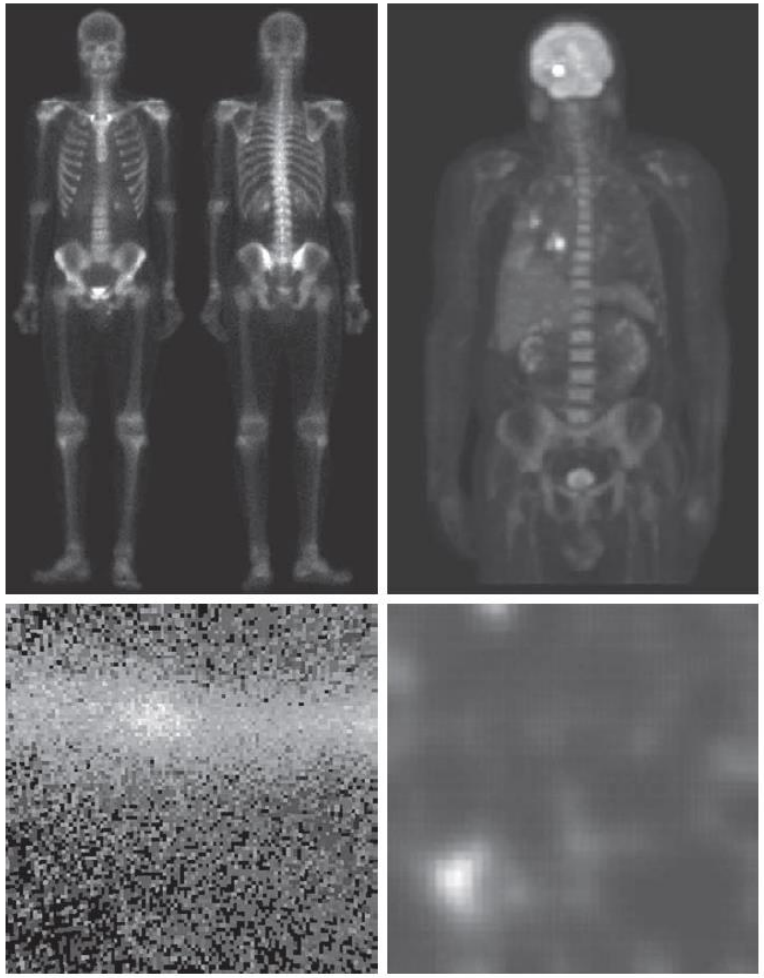


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.



a b
c d

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems; (b) Dr. Michael E. Casey, CTI PET Systems; (c) NASA; (d) Professors Zhong He and David K. Wehe, University of Michigan.)

Figures from Digital Image Processing, Gonzalez, Woods, 4th Global Edition, Pearson, 2018

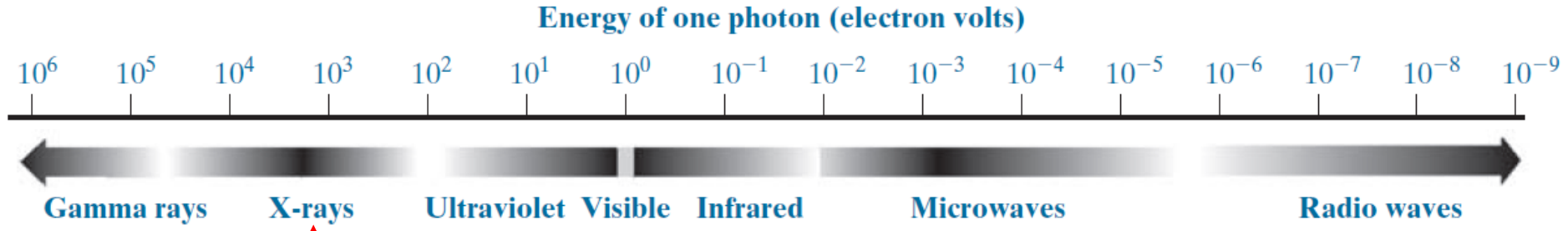
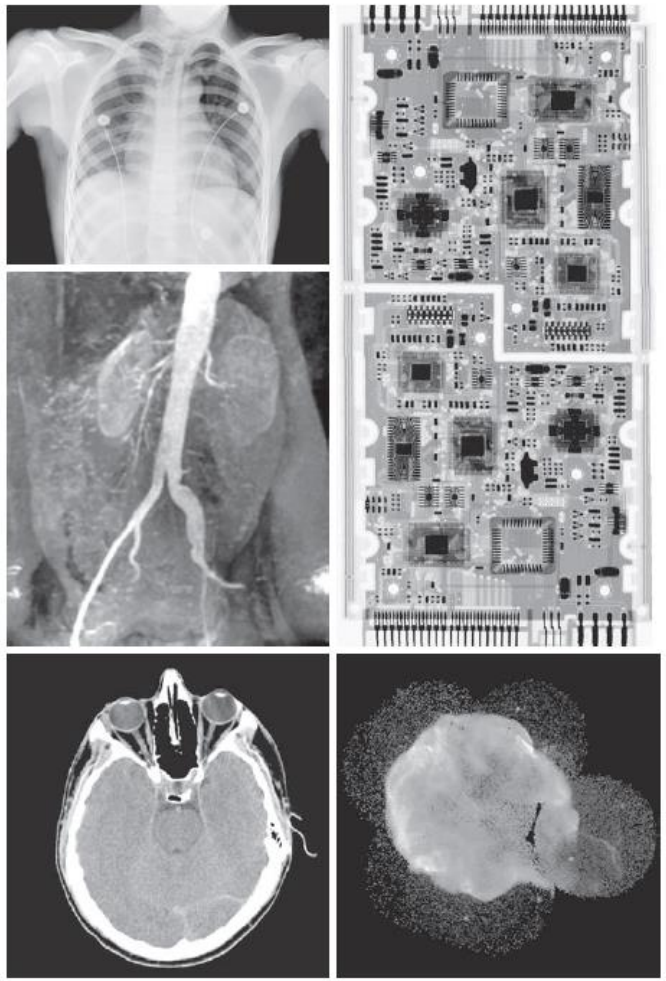


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.



a c d
b e

FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center; (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, Univ. of Michigan Medical School; (d) Mr. Joseph E. Pascente, Lixi, Inc.; and (e) NASA.)

Figures from Digital Image Processing, Gonzalez, Woods, 4th Global Edition, Pearson, 2018

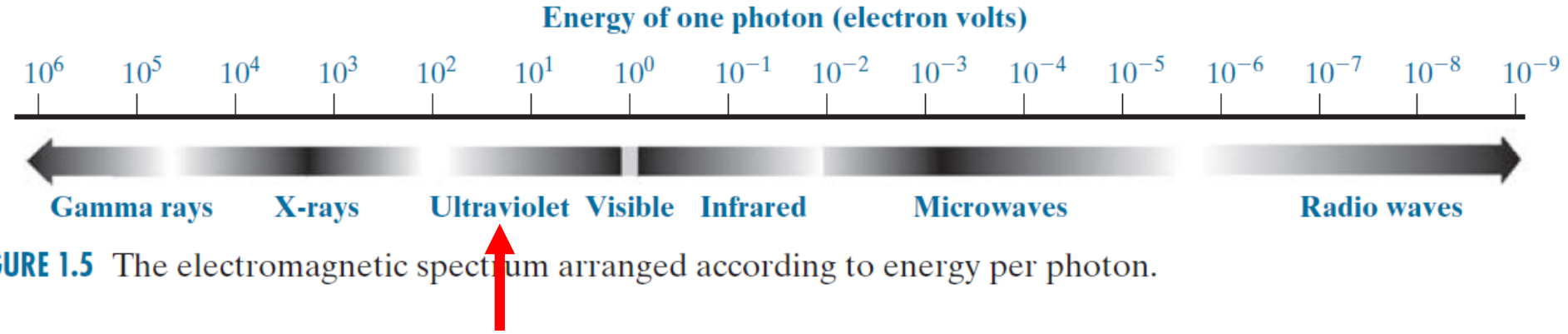
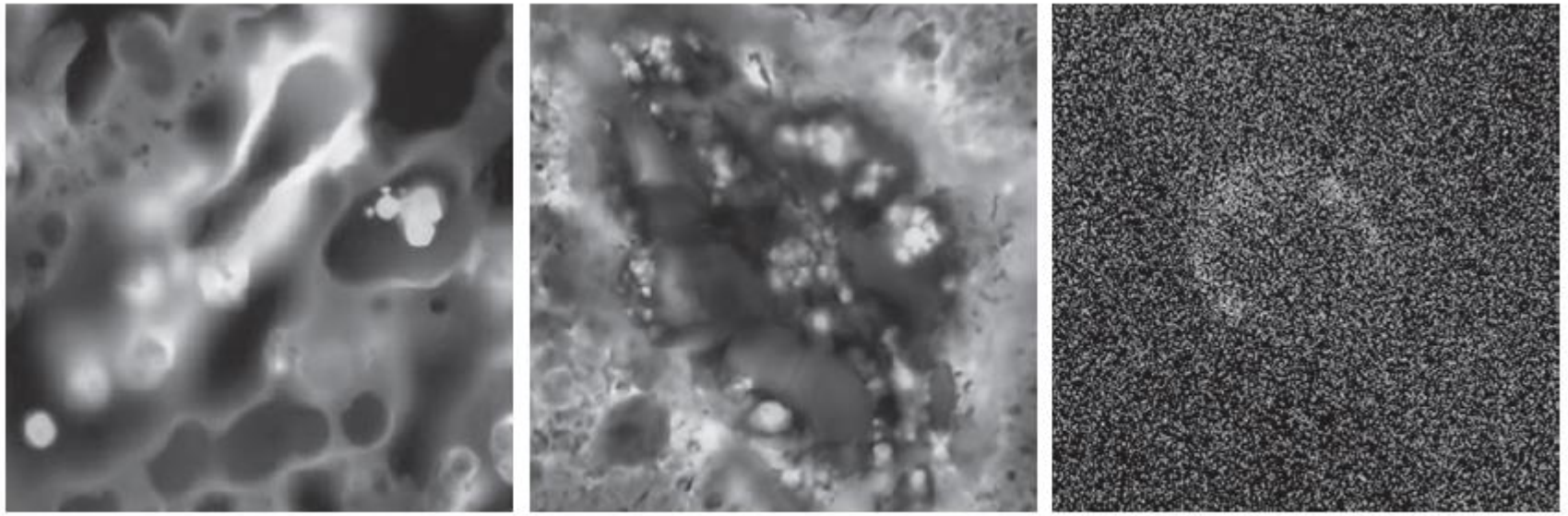


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.



a b c

FIGURE 1.8 Examples of ultraviolet imaging. (a) Normal corn. (b) Corn infected by smut. (c) Cygnus Loop. (Images (a) and (b) courtesy of Dr. Michael W. Davidson, Florida State University, (c) NASA.)

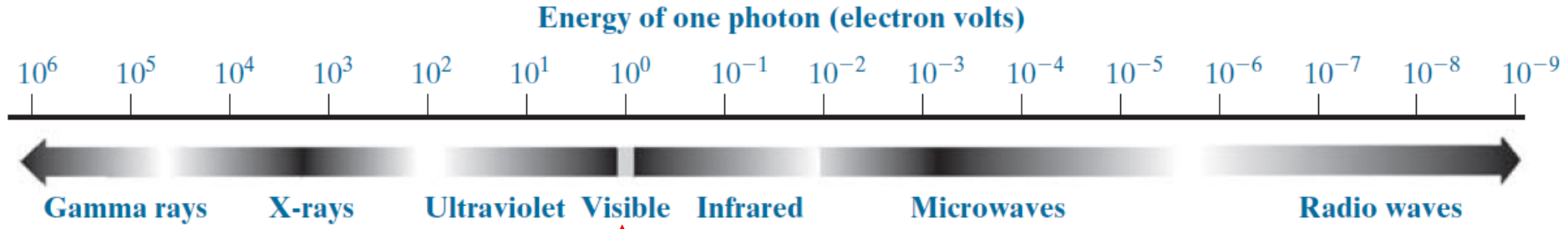


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

H. Ding, X. Jiang, B. Shuai, A. Q. Liu, and G. Wang, Semantic Segmentation With Context Encoding and Multi-Path Decoding, IEEE Transactions on Image Processing, 2020

Figures from Digital Image Processing, Gonzalez, Woods, 4th Global Edition, Pearson, 2018

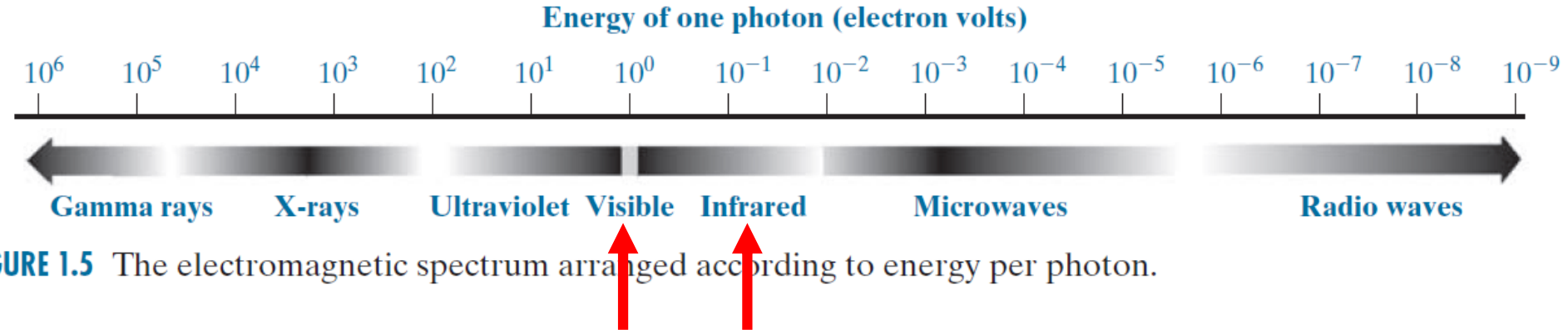


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

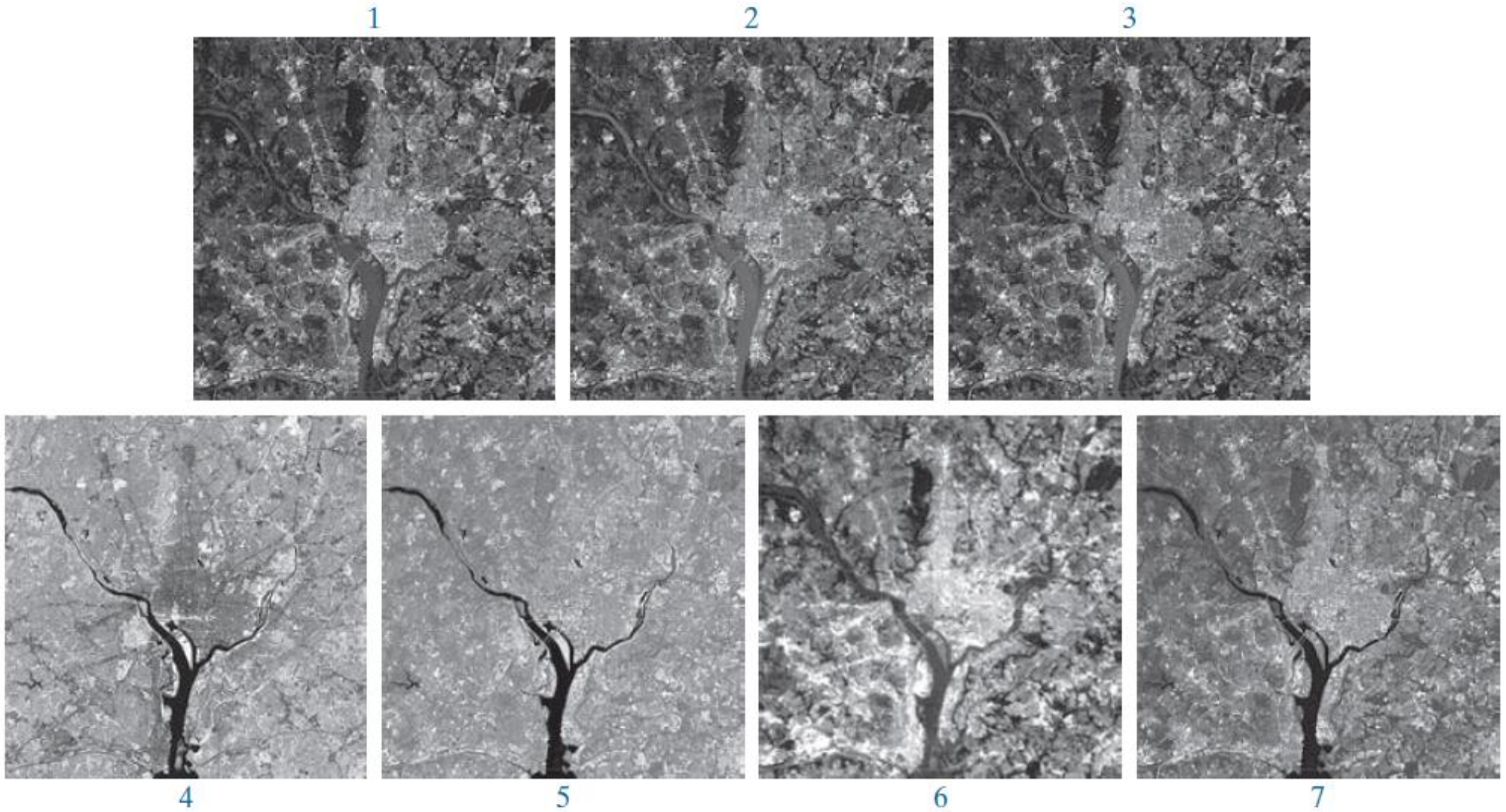


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Figures from Digital Image Processing, Gonzalez, Woods, 4th Global Edition, Pearson, 2018

TABLE 1.1
Thematic bands of NASA's LANDSAT satellite.

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.53–0.61	Measures plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.78–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content: soil/vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Short-wave infrared	2.09–2.35	Mineral mapping

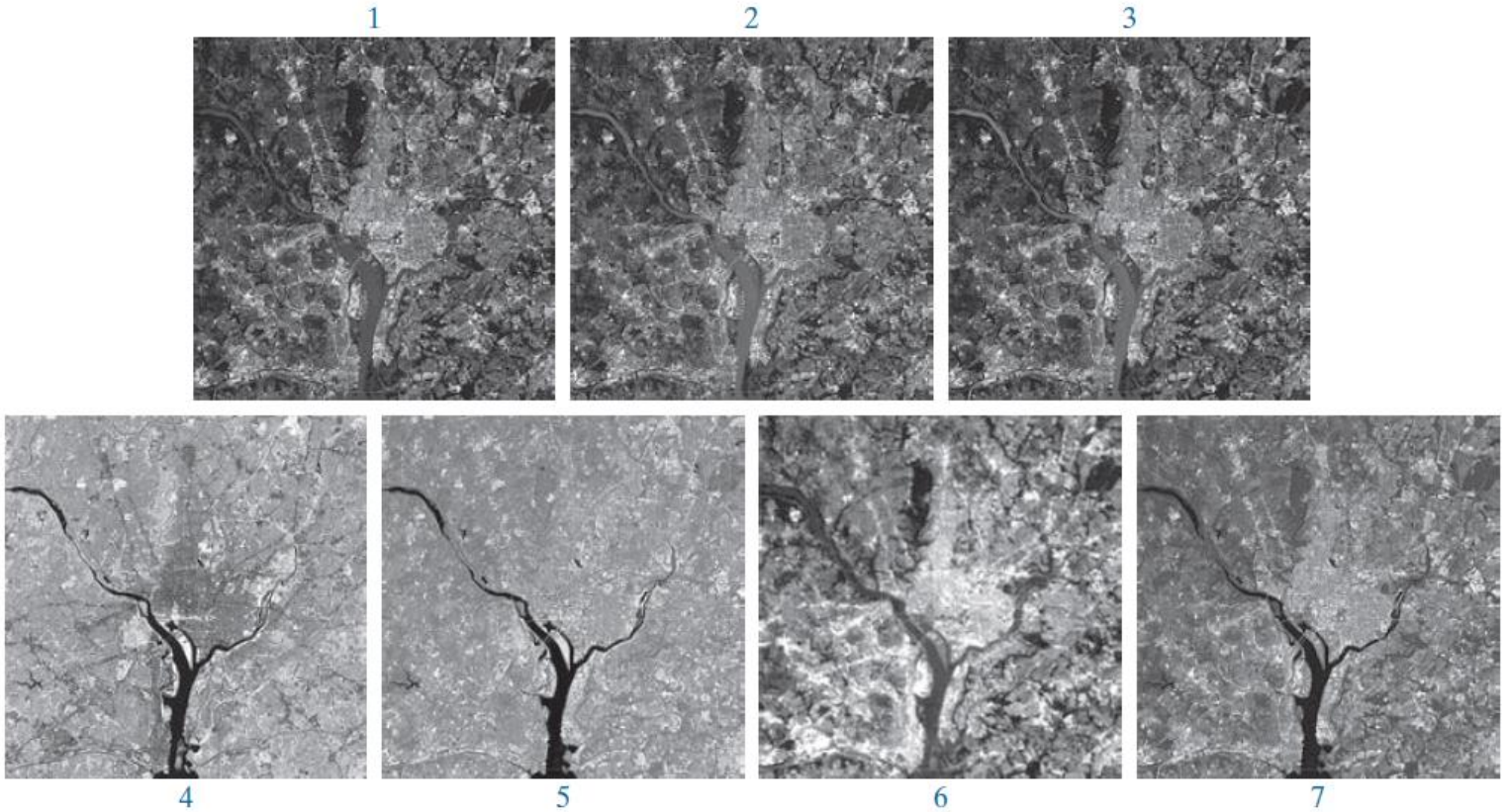


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

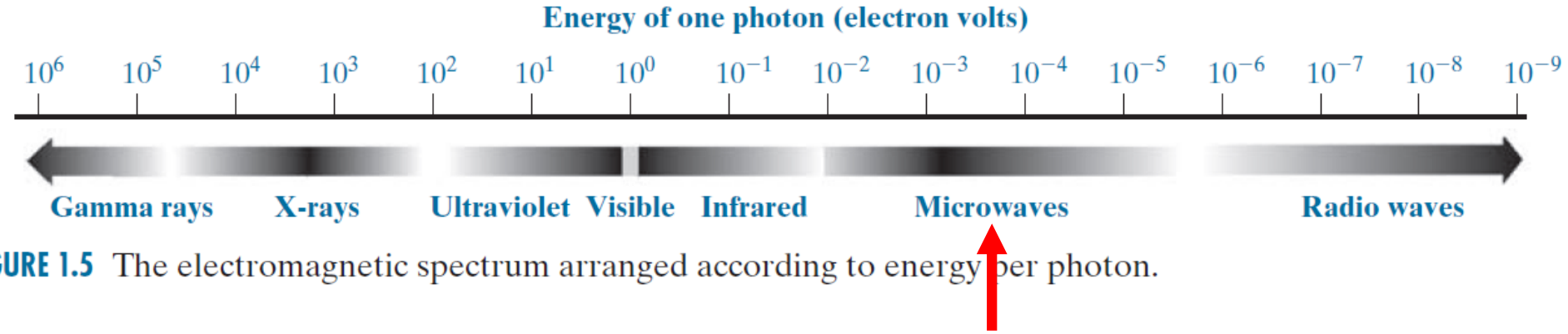
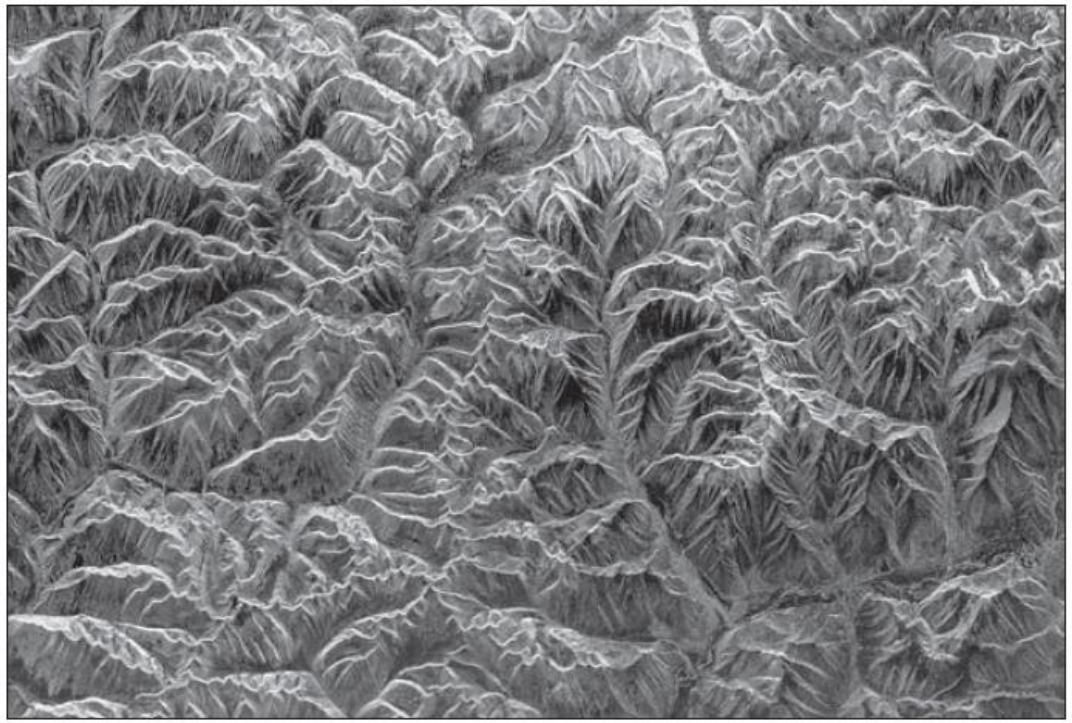


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

FIGURE 1.16 Spaceborne radar image of mountainous region in southeast Tibet. (Courtesy of NASA.)



Figures from Digital Image Processing, Gonzalez, Woods, 4th Global Edition, Pearson, 2018

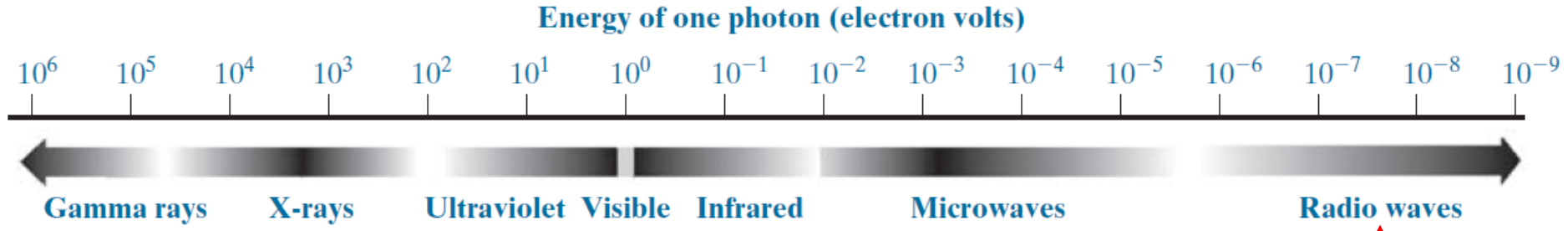
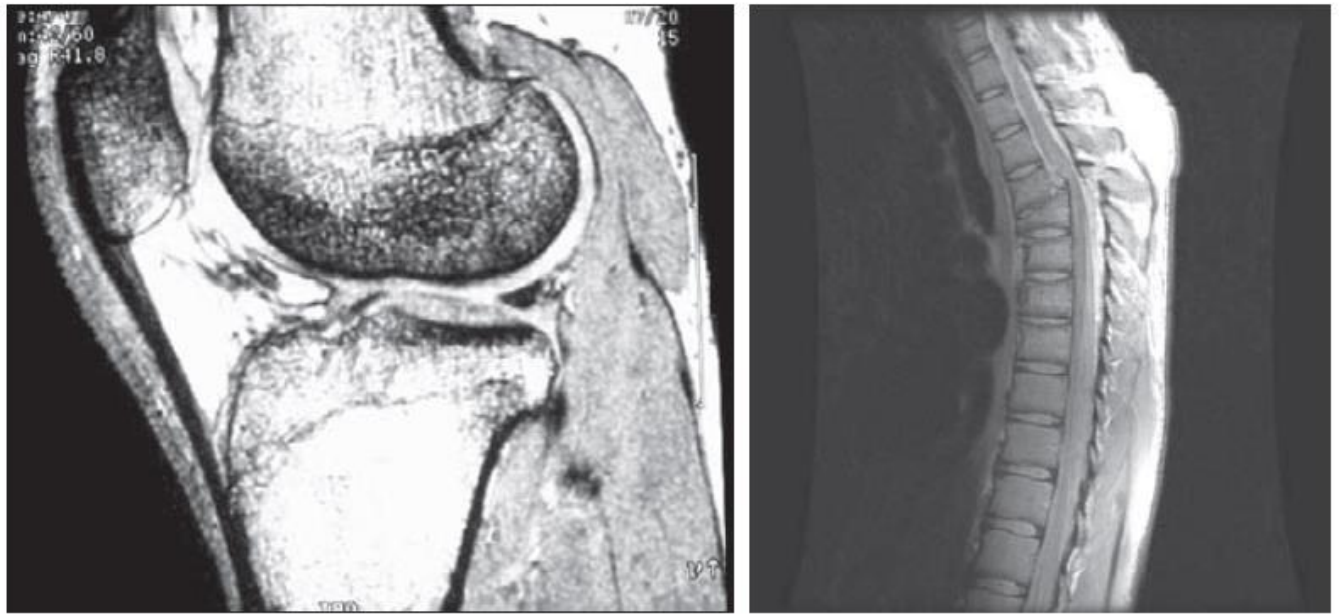


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.



a b

FIGURE 1.17 MRI images of a human (a) knee, and (b) spine. (Figure (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) courtesy of Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Next week

- Image Formation
- Color

Week 01 – Hands on activitiy

- Install
  - Python 3 with Miniconda
  - Jupyter Notebook
  - OpenCV
  - matplotlib

- Prepare and submit a Jupyter Notebook containing the code and the result for reading and displaying an image that you choose