Introduction and Overview

Image Processing

CSE 166

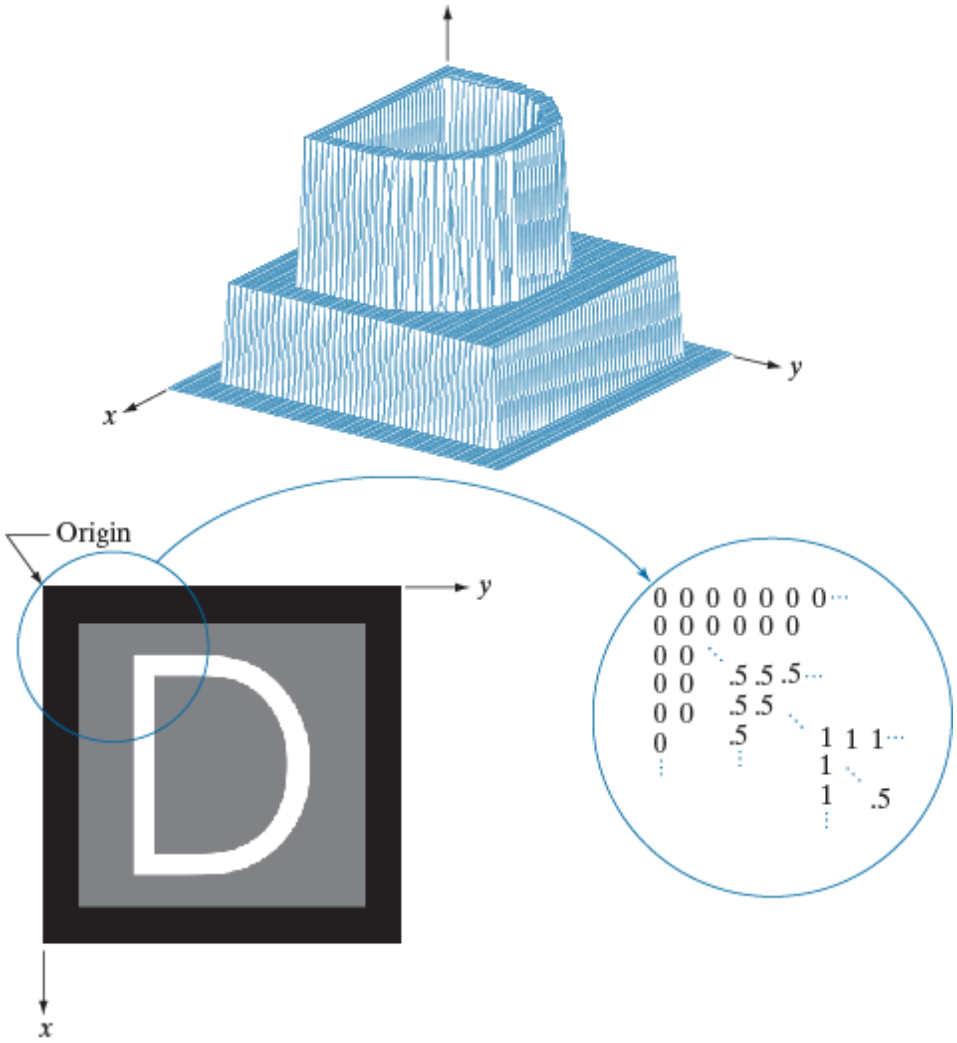
CSE 166: Image Processing

- Today
  - Course overview
  - Logistics
  - Review of vectors and matrices

What is an image?

- A two-dimensional function $f(x,y)$, where x and y are spatial coordinates
- The amplitude of f at the coordinates (x,y) is called the intensity or gray level at that point
- A *digital* image is composed of a finite number of elements at discrete points
  - The elements are called picture elements (pixels, pels) or image elements

Representing an image

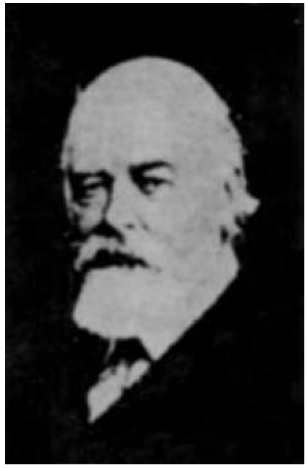


What is image processing?

- A discipline in which both the input and output of a process are images
  - Some believe this to be limiting, including the authors of the textbook
  - There are usually other input parameters to the process
- Related disciplines
  - Image analysis, machine vision, computer vision

History

- In the early 1920s, newspapers transmitted and received digital pictures by cable across the Atlantic (without computers)
  - Reduced transport time from over a week to less than three hours

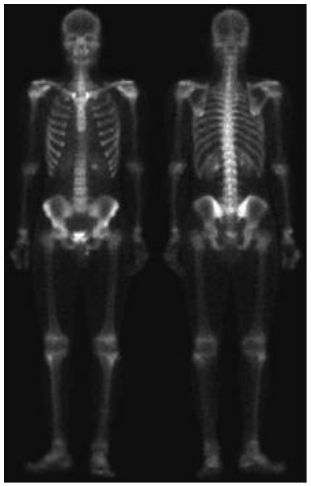



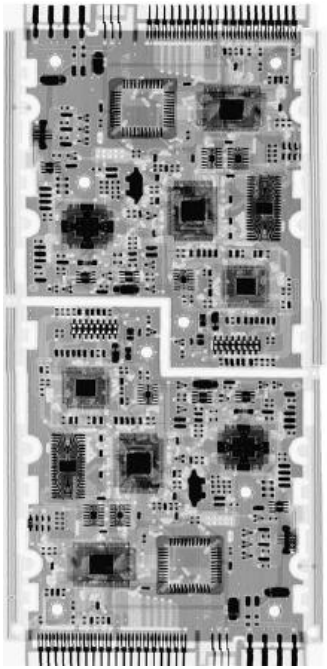

History

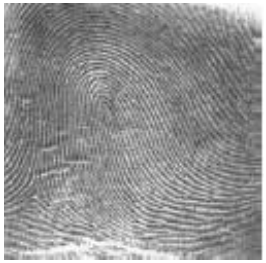
- 1940s: Modern digital computers
- 1950s: High-level programming languages and the integrated circuit
- 1960s: Operating systems
- 1964: Computer-based digital image processing
- 1970s: Microprocessor
- 1980s: Personal computers (PCs)

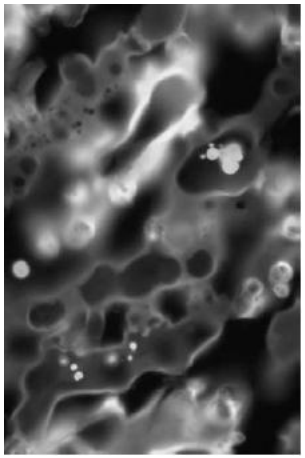
Examples

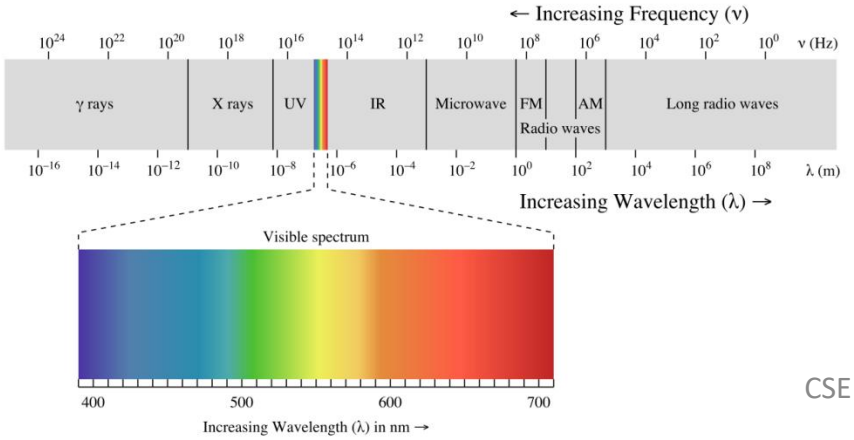
- Gamma-ray imaging
- X-ray imaging
- Ultraviolet imaging
- Visible light imaging
- Infrared imaging
- Microwave imaging
- Radio imaging

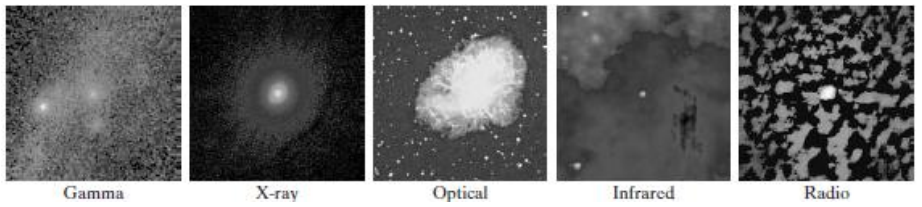








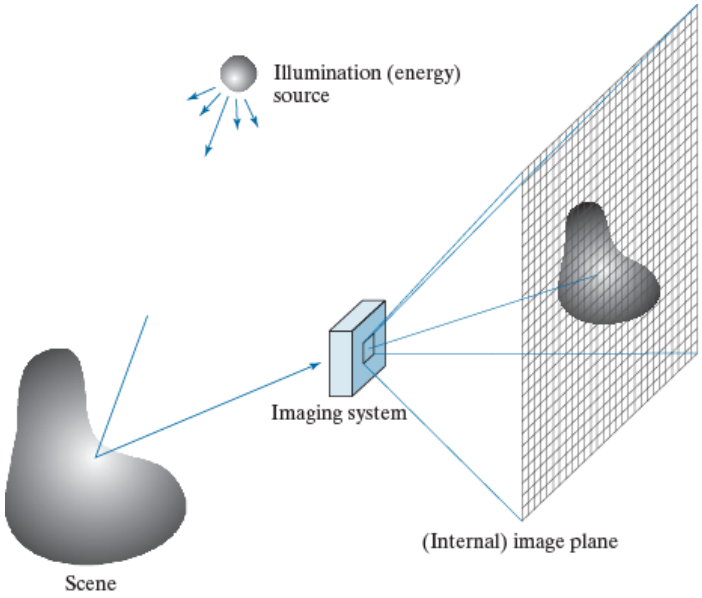


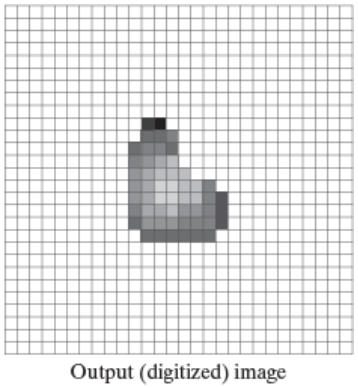


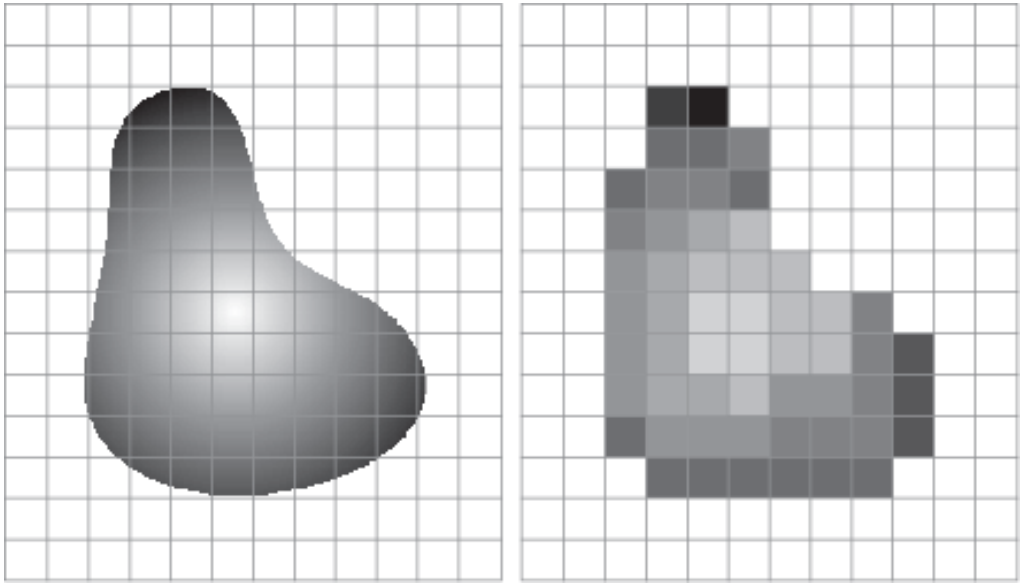
CSE 166 topics

- Image acquisition
- Geometric transformations
- Image filtering and enhancement
- Image restoration
- Color image processing
- Wavelets and other image transforms
- Image compression and watermarking
- Morphological image processing
- Image segmentation
- Feature extraction

Image acquisition




Output (digitized) image



Sampling and quantization

Geometric transformations

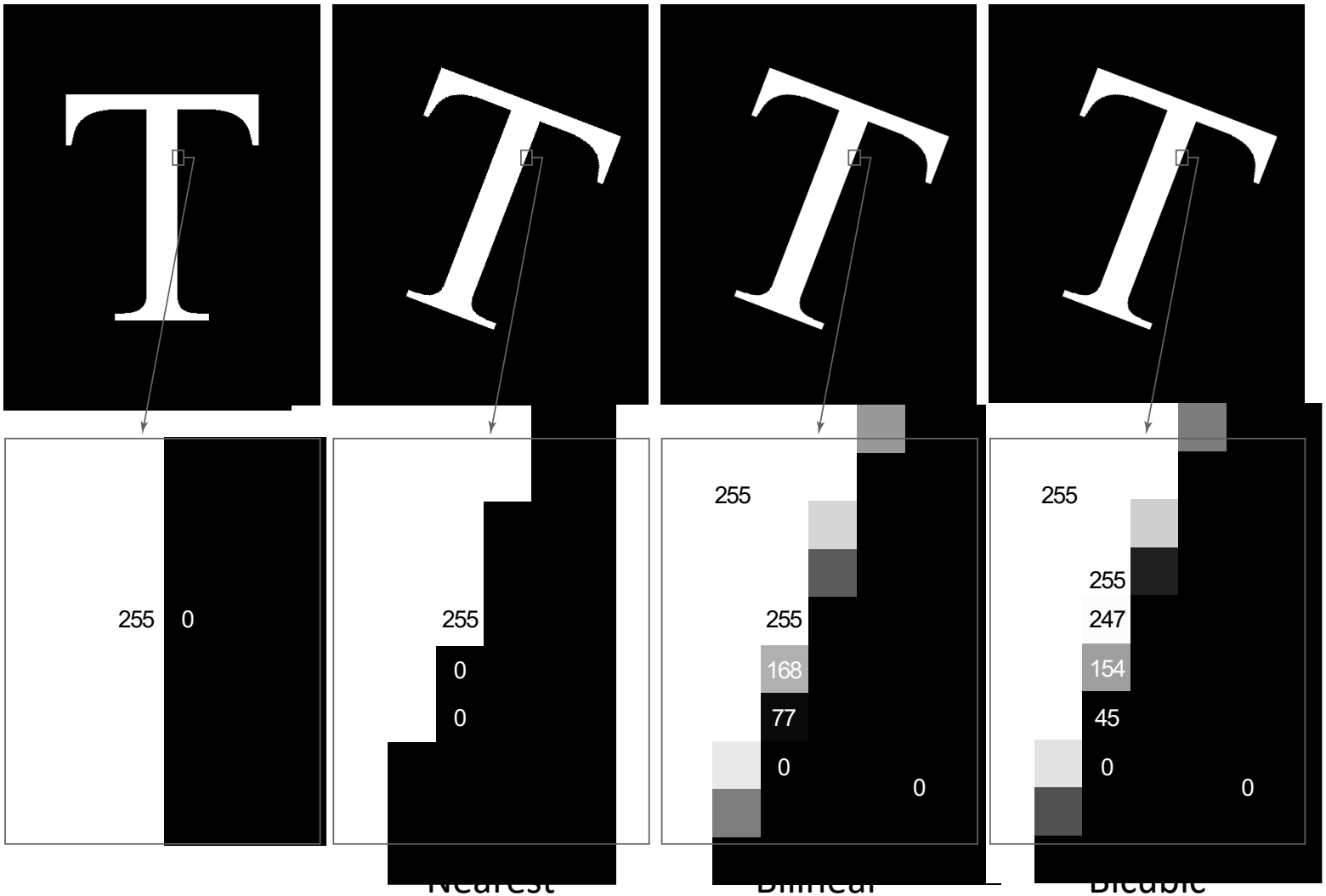


Image filtering and enhancement

- Intensity transformations
- Spatial filtering



Low-pass filter



Gamma correction

Image filtering and enhancement

- Filtering in the frequency domain

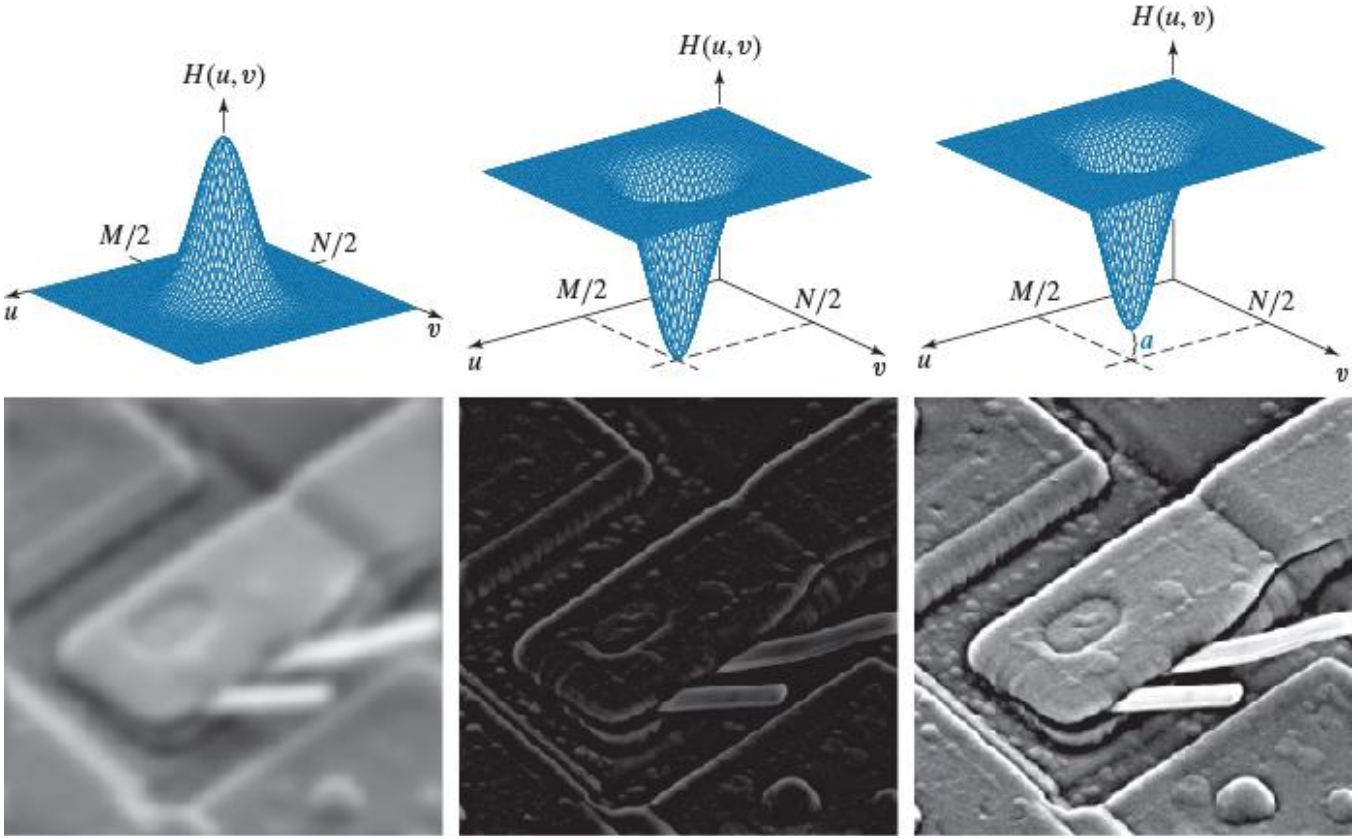
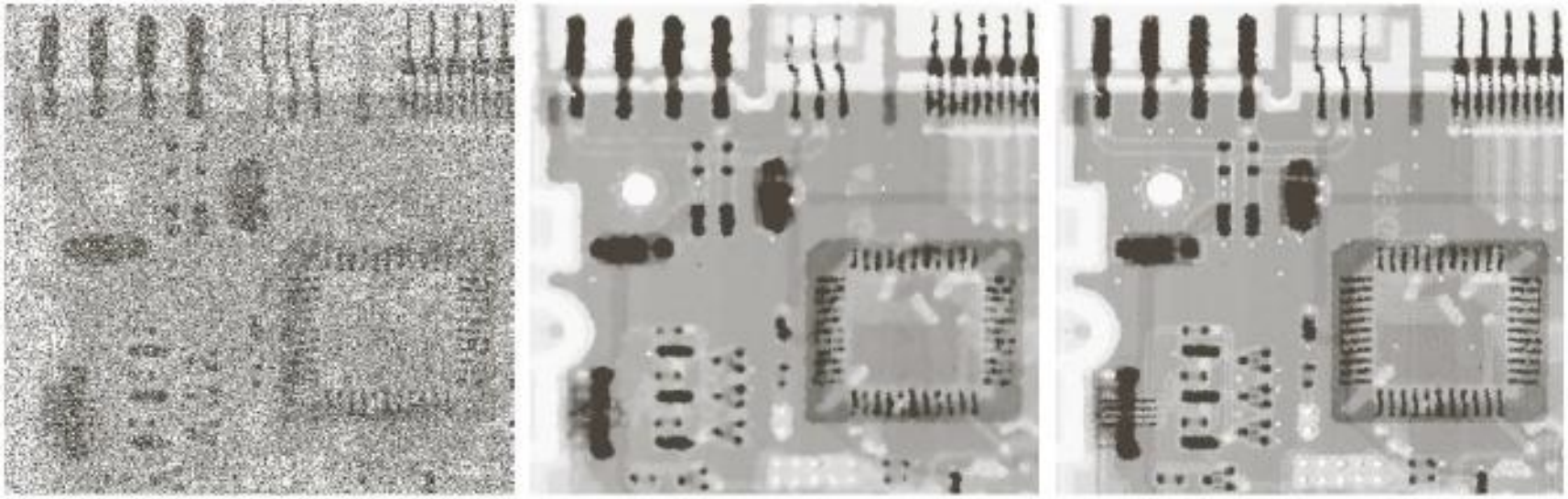


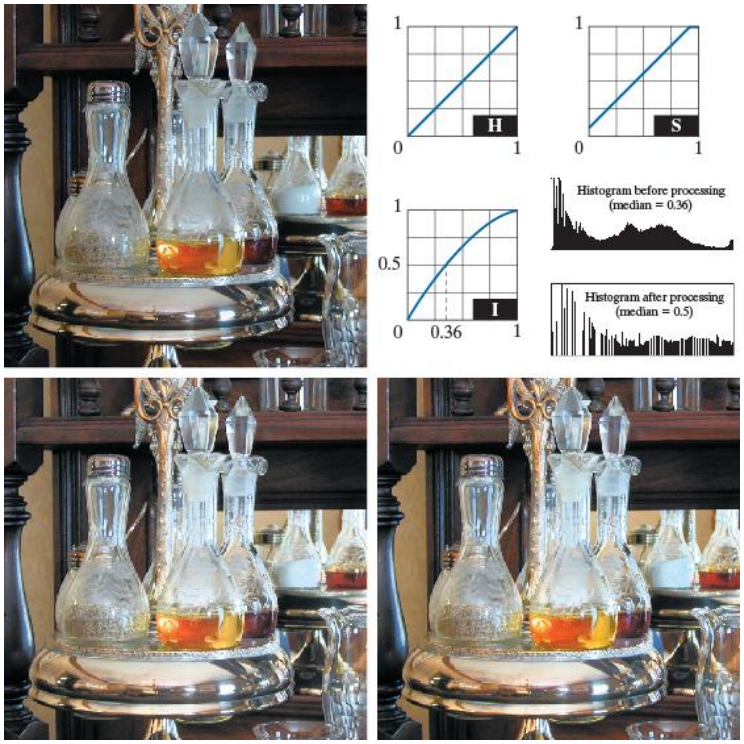
Image restoration

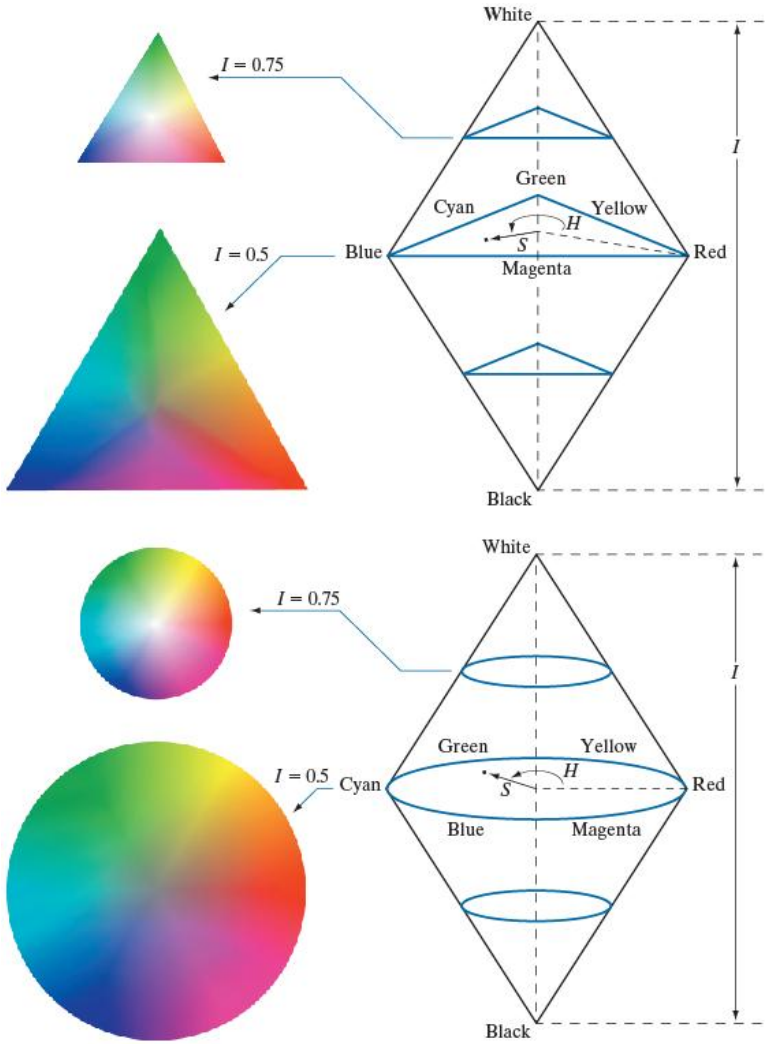
- Noise models
- Noise reduction



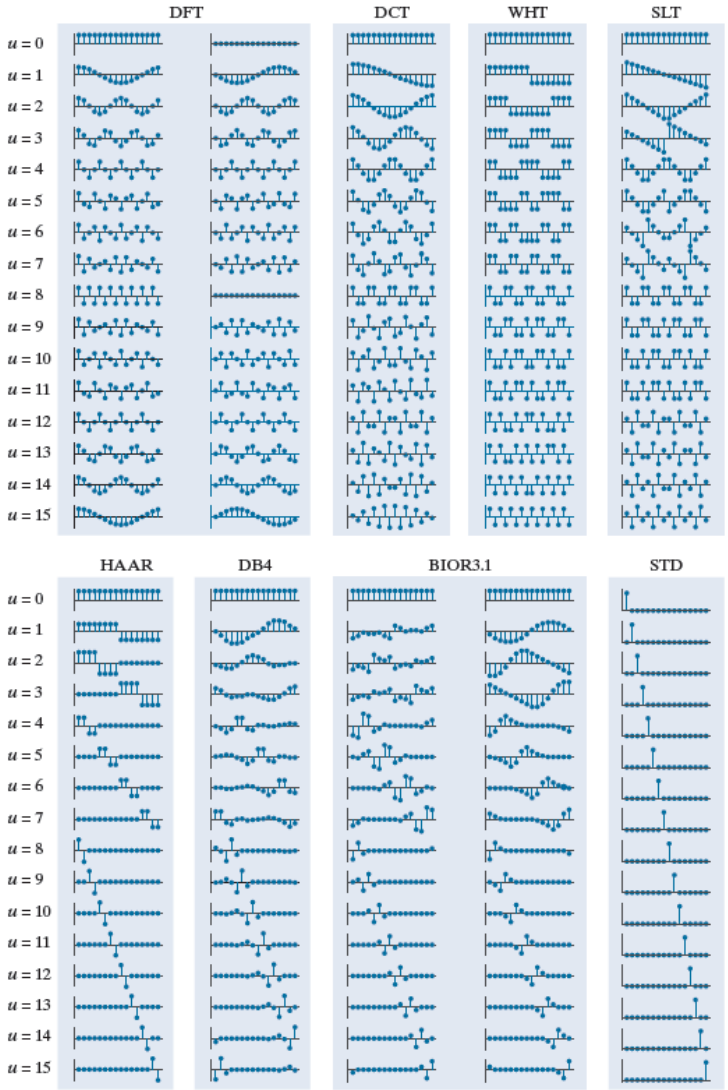
Color image processing

- Color models
- Color transformations

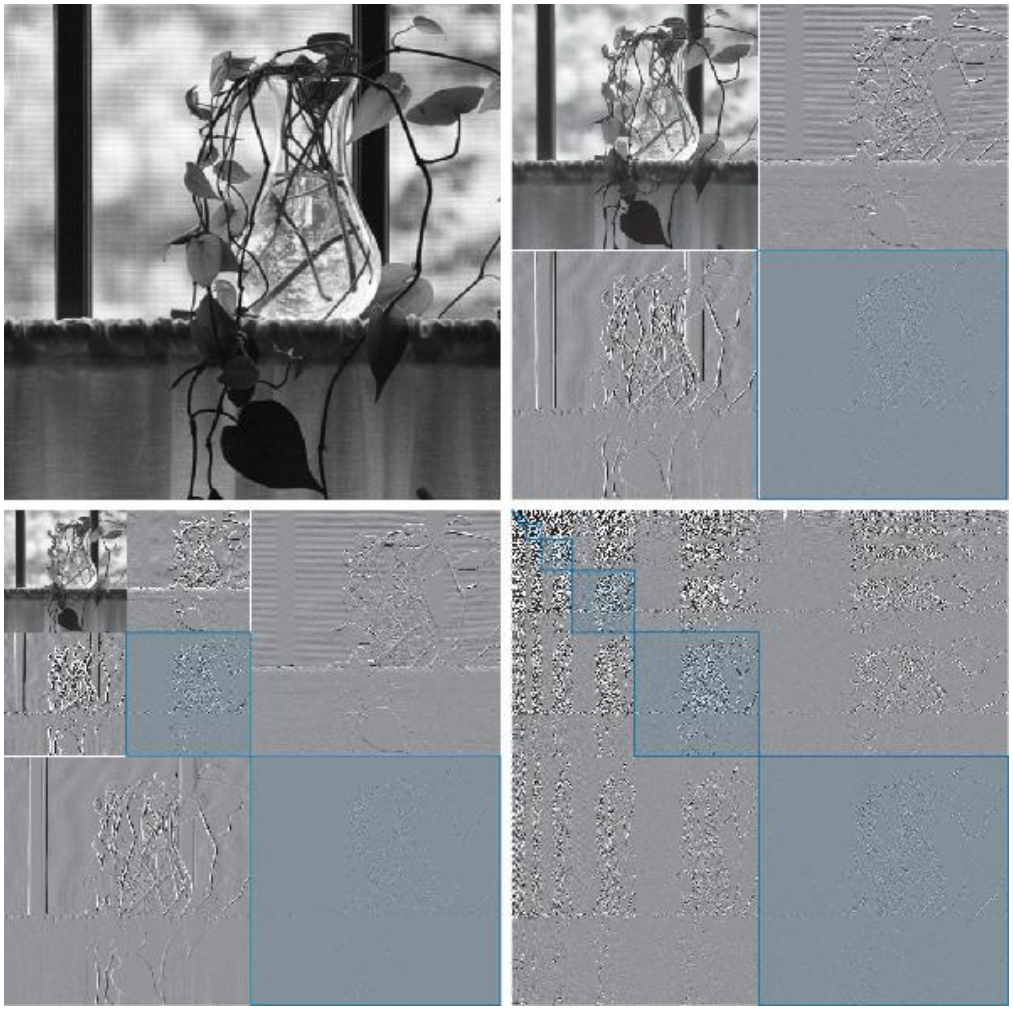




Wavelets and other transforms



Basis vectors

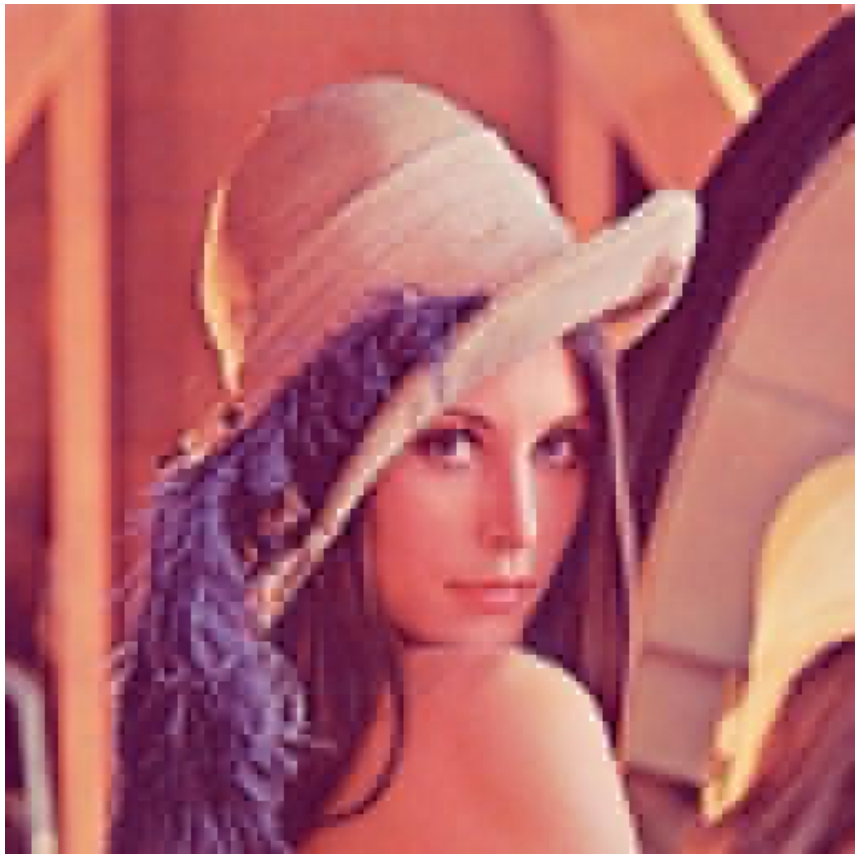


Wavelet and Haar transform

Image compression and watermarking

- Lossless vs lossy compression





Morphological image processing

- Dilation and erosion
- Opening and closing

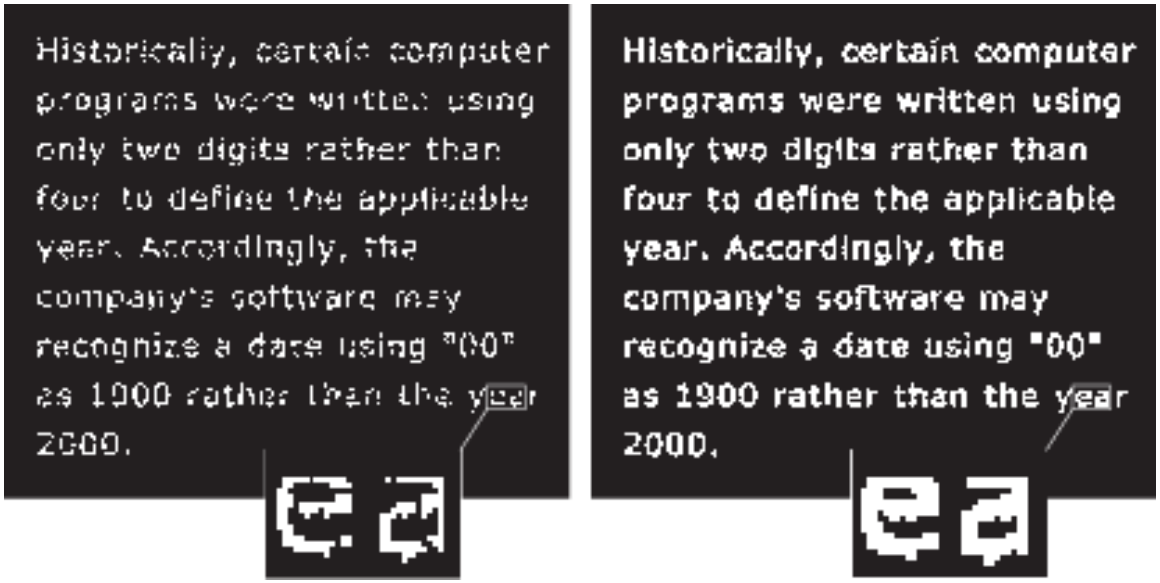
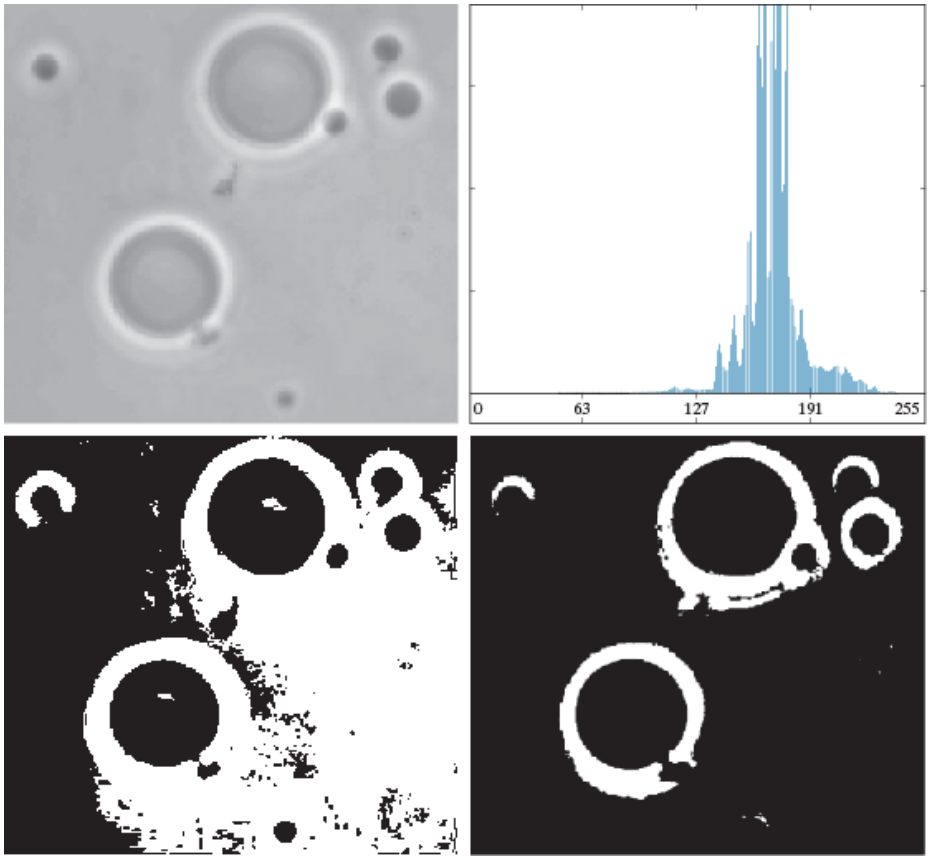


Image segmentation

- Thresholding



Feature extraction

- Feature detection



Syllabus

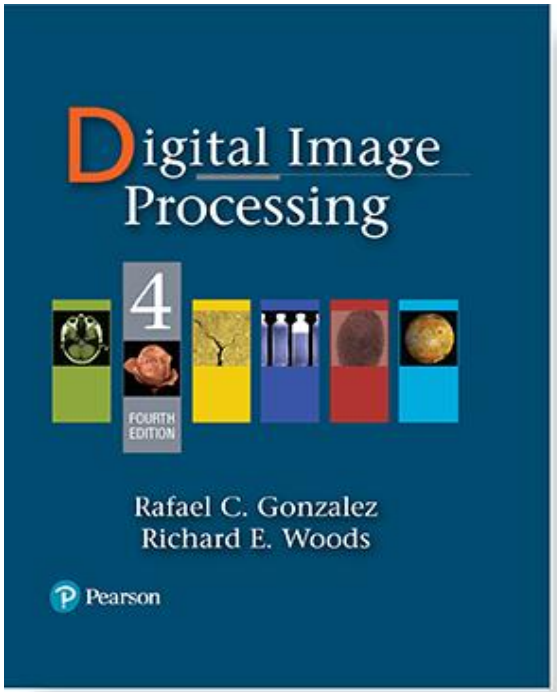
- Instructor: Ben Ochoa
- TA: Mustafa Yaldiz
- TritonGPT Student AI Assistant (pilot program)
  - https://tritongpt.ucsd.edu/chat?assistantId=473
- Public course website
  - https://cseweb.ucsd.edu/classes/sp26/cse166-a/
- Course is on Canvas
  - **Piazza** for discussion
  - **Gradescope** for submitting assignments
  - **Media gallery** for recorded lecture meetings
- 19 lecture meetings
  - No lecture meeting on Memorial Day observance (Mon, May 25)
- Weekly discussion section (optional)

Syllabus

- Grading
  - 6 homework assignments (50% of grade)
    - By hand and programming using Python
    - Late policy: 15% grade reduction for each 12 hours late
      - Will not be accepted 72 hours after the due date
  - Midterm exam (20% of grade)
  - Final exam (30% of grade)
  - Piazza
    - Extensive, nontrivial participation could raise your grade (e.g., raise a B+ to an A-)

Textbook

- Digital Image Processing, 4th edition
  - Rafael C. Gonzalez and Richard E. Woods
- See book website
  - Corrections and clarifications
  - Review material
    - Linear systems
    - Matrices and vectors
    - Probability



Jupyter Notebook

- Used for all homework assignments
- Unless specified in the assignment, you may not use any function or method contained in any package
  - If you are unsure about using a specific function or method, then ask the instructor and instructional assistants for clarification



Collaboration Policy

- Ask and answer questions on Piazza, not email
- Post **publicly** (optionally anonymously)
  - Conceptual questions and high-level questions about assignments
- All other posts must be **private** to "All Instructors" (includes instructor and instructional assistants)
  - Low-level, detailed assignment questions (e.g., implementation details)
  - Assignment-specific code
  - Results (intermediate or final; e.g., numerical values, images, figures)
  - **Posting such items publicly is an academic integrity violation**
- If you are unsure, then post privately to "All Instructors"
  - If suitable, then it will be changed to a public post
- Piazza is the official, University-sanctioned discussion forum
  - **Do not use Piazza to solicit others to an alternative forum**

Collaboration Policy

It is expected that you complete your academic assignments on your own and in your own words and code. The assignments have been developed by the instructor to facilitate your learning and to provide a method for fairly evaluating your knowledge and abilities (not the knowledge and abilities of others). So, to facilitate learning, you are authorized to discuss assignments with others; however, to ensure fair evaluations, you are not authorized to use the answers developed by another, copy the work completed by others in the past or present, or write your academic assignments in collaboration with another person.

Academic Integrity Policy

Integrity of scholarship is essential for an academic community. The University expects that both faculty and students will honor this principle and in so doing protect the validity of University intellectual work. For students, this means that all academic work will be done by the individual to whom it is assigned, without unauthorized aid of any kind. ***Generative AI tools are allowed for out-of-class or un-proctored assessments. Generative AI tools are not allowed for in-class or proctored assessments.***

Academic Integrity Violation

If the work you submit is determined to be other than your own, you will be reported to the Academic Integrity Office for violating UC San Diego's Policy on Integrity of Scholarship. In accordance with the CSE department academic integrity guidelines, ***students found committing an academic integrity violation will receive an F in the course***.

Student Conduct Policy

UC San Diego strives to maintain a climate of fairness, cooperation, and professionalism. It is expected that you practice basic principles, including, but not limited to, mutual respect, civility, and decency, towards maintaining an atmosphere free of abusive or demeaning treatment. Non-academic student misconduct will be reported to the Center for Student Accountability, Growth, and Education for violating UC San Diego's Principles of Community.

Wait list

- Number of enrolled students is limited by
  - Size of room
  - Number of instructional assistants
- General advice
  - Wait for as long as you can
- UCSD policy: Extension (e.g., concurrent enrollment, UPS) students have lowest priority

Certification of Commencement of Academic Activity

- Every course at UC San Diego, per the US Department of Education, is required to certify whether students have commenced academic activity for a class to be counted towards eligibility for Title IV federal financial aid. This certification must be completed during the first two weeks of instruction.
- For this course, the requirement will be fulfilled via an ungraded prior knowledge quiz, which will assist the instructional team by providing information about your background coming into the course
  - In Canvas (https://canvas.ucsd.edu), go to the course and navigate to Quizzes, then click on **First Day Survey: Prior Knowledge #FinAid**

Review of vectors and matrices

- Vectors and matrices
- Vector transpose and matrix transpose
- Vector-vector inner (or dot) product
- Matrix-vector multiplication
- Matrix-matrix multiplication

Some Definitions

An $m \times n$ (read "m by n") ***matrix***, denoted by **A**, is a rectangular array of entries or elements (numbers, or symbols representing numbers) enclosed typically by square brackets, where m is the number of rows and n the number of columns.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

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Definitions (Con't)

- **A** is ***square*** if $m = n$.
- **A** is ***diagonal*** if all off-diagonal elements are 0, and not all diagonal elements are 0.
- **A** is the ***identity matrix*** (**I**) if it is diagonal and all diagonal elements are 1.
- **A** is the ***zero*** or ***null matrix*** (**0**) if all its elements are 0.
- The ***trace*** of **A** equals the sum of the elements along its main diagonal.
- Two matrices **A** and **B** are ***equal*** iff the have the same number of rows and columns, and $a_{ij} = b_{ij}$.

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Definitions (Con't)

- The ***transpose*** $\mathbf{A}^T$ of an $m \times n$ matrix $\mathbf{A}$ is an $n \times m$ matrix obtained by interchanging the rows and columns of $\mathbf{A}$.
- A square matrix for which $\mathbf{A}^T = \mathbf{A}$ is said to be ***symmetric***.
- Any matrix $\mathbf{X}$ for which $\mathbf{XA} = \mathbf{I}$ and $\mathbf{AX} = \mathbf{I}$ is called the ***inverse*** of $\mathbf{A}$.
- Let c be a real or complex number (called a ***scalar***). The ***scalar multiple*** of c and matrix $\mathbf{A}$, denoted $c\mathbf{A}$, is obtained by multiplying every elements of $\mathbf{A}$ by c. If $c = -1$, the scalar multiple is called the ***negative*** of $\mathbf{A}$.

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Definitions (Con't)

A ***column vector*** is an $m \times 1$ matrix:

$$\mathbf{a} = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{bmatrix}$$

A ***row vector*** is a $1 \times n$ matrix:

$$\mathbf{b} = [b_1, b_2, \cdots b_n]$$

A column vector can be expressed as a row vector by using the transpose:

$$\mathbf{a}^T = [a_1, a_2, \cdots, a_m]$$

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Some Basic Matrix Operations

- The ***sum*** of two matrices **A** and **B** (of equal dimension), denoted **A** + **B**, is the matrix with elements $a_{ij} + b_{ij}$.
- The ***difference*** of two matrices, **A**– **B**, has elements $a_{ij} - b_{ij}$.
- The ***product***, **AB**, of $m \times n$ matrix **A** and $p \times q$ matrix **B**, is an $m \times q$ matrix **C** whose (i,j)-th element is formed by multiplying the entries across the ith row of **A** times the entries down the jth column of **B**; that is,

$$c_{ij} = a_{i1}b_{1j} + a_{i2}b_{2j} + \cdots + a_{in}b_{pj}$$

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Some Basic Matrix Operations (Con't)

The ***inner product*** (also called ***dot product***) of two vectors

$$\mathbf{a} = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{bmatrix} \qquad \mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{bmatrix}$$

is defined as

$$\mathbf{a}^T\mathbf{b} = \mathbf{b}^T\mathbf{a} = a_1b_1 + a_2b_2 + \cdots + a_mb_m = \sum_{i=1}^{m} a_ib_i.$$

Note that the inner product is a scalar.

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Elementwise vs matrix operations

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

Matrix product

$$\mathbf{AB} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} a_{11}b_{11} + a_{12}b_{21} & a_{11}b_{12} + a_{12}b_{22} \\ a_{21}b_{11} + a_{22}b_{21} & a_{21}b_{12} + a_{22}b_{22} \end{bmatrix}$$

Hadamard product (i.e., elementwise product)

$$\mathbf{A} \circ \mathbf{B} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} a_{11}b_{11} & a_{12}b_{12} \\ a_{21}b_{21} & a_{22}b_{22} \end{bmatrix}$$

Next Lecture

- Image acquisition, geometric transformations, and image interpolation
- Reading
  - Chapter 2: Digital Image Fundamentals
    - Sections 2.3, 2.4, and 2.5