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

Sampling and quantization
Geometric transformations

Nearest neighbor

Bilinear

Bicubic
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

<table>
<thead>
<tr>
<th>Basis vectors</th>
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<tbody>
<tr>
<td>DFT</td>
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<tr>
<td>DB4</td>
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<td>HAAR</td>
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<td>BiOr3.1</td>
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<td>STD</td>
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<td>WHT</td>
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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
• TAs: Harish Rithish Sethuram and Saqib Azim
• Public course website
  – https://cseweb.ucsd.edu/classes/wi23/cse166-a/
• Course is on Canvas
  – Piazza for discussion
  – Gradescope for submitting assignments
• 18 lecture meetings
  – 2 university holidays (Jan 16 and Feb 20)
• Weekly discussion section (optional)
Syllabus

• Grading
  – 7 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-)
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 “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 “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.
Academic Integrity Violation

If you commit a violation, then you will be reported to the Academic Integrity Office for violating UCSD'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.
Wait list

• Number of enrolled students is limited by
  – 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
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
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
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.

$$
A = \begin{bmatrix}
  a_{11} & a_{12} & \cdots & a_{1n} \\
  a_{21} & a_{22} & \cdots & a_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
  a_{m1} & a_{m2} & \cdots & a_{mn}
\end{bmatrix}
$$
• **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* (\( \mathbf{I} \)) if it is diagonal and all diagonal elements are 1.
• **A** is the *zero* or *null matrix* (\( \mathbf{0} \)) if all its elements are 0.
• The *trace* of \( \mathbf{A} \) equals the sum of the elements along its main diagonal.
• Two matrices \( \mathbf{A} \) and \( \mathbf{B} \) are *equal* iff the have the same number of rows and columns, and \( a_{ij} = b_{ij} \).
• The **transpose** $A^T$ of an $m \times n$ matrix $A$ is an $n \times m$ matrix obtained by interchanging the rows and columns of $A$.

• A square matrix for which $A^T = A$ is said to be **symmetric**.

• Any matrix $X$ for which $XA = I$ and $AX = I$ is called the **inverse** of $A$.

• Let $c$ be a real or complex number (called a **scalar**). The **scalar multiple** of $c$ and matrix $A$, denoted $cA$, is obtained by multiplying every elements of $A$ by $c$. If $c = -1$, the scalar multiple is called the **negative** of $A$. 
A **column vector** is an $m \times 1$ matrix:

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

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

$$b = [b_1, b_2, \cdots b_n]$$

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

$$a^T = [a_1, a_2, \cdots, a_m]$$
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 \(i\)th row of \(A\) times the entries down the \(j\)th column of \(B\); that is,

\[
c_{ij} = a_{i1}b_{1j} + a_{i2}b_{2j} + \cdots + a_{in}b_{pj}
\]
The inner product (also called dot product) of two vectors is defined as

\[
\begin{bmatrix}
  a_1 \\
  a_2 \\
  \vdots \\
  a_m
\end{bmatrix}
\begin{bmatrix}
  b_1 \\
  b_2 \\
  \vdots \\
  b_m
\end{bmatrix}
\]

\[
\begin{align*}
a^T b &= b^T a = a_1 b_1 + a_2 b_2 + \cdots + a_m b_m \\
&= \sum_{i=1}^{m} a_i b_i.
\end{align*}
\]

Note that the inner product is a scalar.
Elementwise vs matrix operations

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

Hadamard product (i.e., elementwise product)

\[
\begin{bmatrix}
  a_{11} & a_{12} \\
  a_{21} & a_{22}
\end{bmatrix}
\begin{bmatrix}
  b_{11} & b_{12} \\
  b_{21} & b_{22}
\end{bmatrix} =
\begin{bmatrix}
  a_{11}b_{11} & a_{12}b_{12} \\
  a_{21}b_{21} & a_{22}b_{22}
\end{bmatrix}
\]

Matrix product

\[
\begin{bmatrix}
  a_{11} & a_{12} \\
  a_{21} & a_{22}
\end{bmatrix}
\begin{bmatrix}
  b_{11} & b_{12} \\
  b_{21} & b_{22}
\end{bmatrix} =
\begin{bmatrix}
  a_{11}b_{11} + a_{12}b_{21} & a_{11}b_{12} + a_{12}b_{22} \\
  a_{21}b_{11} + a_{22}b_{21} & a_{21}b_{12} + a_{22}b_{22}
\end{bmatrix}
\]
Next Lecture

• Image acquisition, geometric transformations, and image interpolation

• Reading
  – Chapter 2: Digital Image Fundamentals
    • Sections 2.3, 2.4, and 2.5