Overview (1):

- What is Digital Image Processing (DIP)?
  - What is an image?
  - Relationship to computer vision
- Origins of Digital Image Processing
  - Brief historical overview
- Fields that Use Digital Image Processing
  - Image categorization and the electromagnetic spectrum (EM)
    - Gamma ray, x-ray, ultraviolet, visible, infrared, microwave, radio wave

Overview (2):

- Fundamental Steps
  - Methodologies
  - Overview of what this course will cover
- Components of a Digital Image Processing System
  - Hardware
  - Software
- Conclusions
  - Summary
What is Digital Image Processing?

What is a Digital Image? (1):
- A **Discrete Two-Dimensional Function** \( f(x,y) \)
  - \( x,y \) denote the spatial coordinates
  - Consider a table (or **matrix** or **grid**) where \( x \) indicates the row and \( y \) the column
  - Example: matrix with 5 rows and 6 columns (5 \( \times \) 6)

<table>
<thead>
<tr>
<th>Row (x)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>4.2</td>
<td>4.3</td>
<td>4.4</td>
<td>4.5</td>
</tr>
</tbody>
</table>

What is a Digital Image? (2):
- **Intensity**
  - The value (or amplitude) of the function \( f \) at spatial coordinates \( (x,y) \)
  - Finite and discrete when considering digital images
  - Non-discrete and non-finite → not a digital image!

NOTE:
The digital image is obtained by **sampling** an analog 2D image but for now, let’s not be concerned with this. Sampling will be discussed next week!
What is a Digital Image? (3):

- **Intensity** (continued...)
  - The intensity of a digital image can vary from a wide range of values
    - Typical examples: 0 - 255, 0 - 32,767 etc...
  - Can also have more than one intensity value associated with each spatial location
    - Color images → one intensity value for each color (e.g., red, green, blue color channels - more of this in the future)...  
    - Single color → intensity also known as **gray level**

What is a Digital Image? (4):

- **Pixel**
  - Each element of a digital image e.g., each entry in the grid (matrix) with its distinct spatial location
  - Also known as
    - Picture element or pel
    - Image element

Digital Image Processing (1):

- **Definition**
  - Processing digital images with a digital computer
- **Two Principal Applications of Digital Image Processing**
  - Improvement of images for human interpretation
  - Processing of image data for storage, transmission and representation for **autonomous** machine perception
### Digital Image Processing (2):
- Covers a Large and Varied Field of Applications
  - Although the human visual system can only respond to the visual band of the electromagnetic spectrum, machines can be used to image (sample) the (almost) entire electromagnetic spectrum
  - More about this later

### Digital Image Processing (3):
- Relationship to Other Fields
  - Computer vision
    - Create real-world model from one or more images
    - Recovers useful information about a scene from a 2D projection of the 3D world
    - Ultimately emulate human visual system!
  - Where does image processing stop and image analysis/computer vision start?
    - No clear cut boundaries!
    - How about defining image processing such that both input and output are images?

### Digital Image Processing (4):
- Relationship to Other Fields (cont...)
  - Too restrictive! e.g., then the common operation of computing the average intensity of an image is not part of image processing!
  - A useful paradigm is to consider three types of computerized processes
    - Low level → primitive operations such as noise reduction, contrast enhancement, image sharpening
    - Mid Level → segmentation, classification,
    - High level → making sense of recognized objects, even performing cognitive functions
Digital Image Processing (5):
- Definition Used in this Course
  - Processes whose inputs and outputs are images but we also include processes which extract attributes from images including the recognition of individual objects.
- As an “Aside” - Computer Graphics
  - Computer used to recreate a “picture” given some description of a scene/environment
    - “Almost” like the opposite problem to image processing although there is some overlap!

- One of the First Applications was in the Newspaper Industry
  - Pictures sent by submarine cable between Europe and North America
    - Bartlane transmission system → transfer picture in a couple of hours instead of more than one week
    - Code picture at the transmitting end, send coded data over cable, receive and decode at the receiving end
    - Five discrete levels of gray and later up to 15

Origins of Digital Image processing (2):
- Bartlane Transmitter

Sample Image
Origins of Digital Image Processing (3):

- Early Examples did not Include Computer!
  - Technically, do not fall into our definition of image processing since we require the use of a computer!
    - Although the notion of a computer can be traced back more than 5000 years, the modern digital computer dates back to the 1940s and the two key concepts introduced by John von Neumann:
      1. Memory to hold stored programs and data
      2. Conditional branching


- Image Processing VERY Computationally Expensive!
  - Early computers were very restrictive until the intro. of the transistor, high level programming languages, VLSI etc.
  - Not until the 1960s that the field of digital image processing, as we know it today was born!
  - Many motivations
    - Space/arms race of the cold war era
    - Medicine - medical imaging
    - Satellites etc.


- From 1960s Until Presently, Digital Image Processing has Grown Vigorously!
  - In addition, to space exploration and medicine, many more applications have arisen
    - Geographical
    - Industrial
    - Archeology
    - Satellite technology
    - Law enforcement
    - Biology, astronomy

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- Digital Image Processing no Longer Restricted to Professionals

  - With the (affordable) computing power currently available and the internet, image processing has found its way into most peoples homes
    - PhotoShop™
    - Microsoft™ imaging utilities standard on Windows operating system
    - etc...
  - How many times have you modified an image on your PC?

Fields that Use Digital Image Processing

Introduction (1):

- Digital Image Processing is All Around Us
  - Every area of technical endeavor impacted by it
    - Immense breadth and importance
  - Given this large breadth, images are typically categorized according to their source
    - Principle (and most familiar) source for images today is the electromagnetic spectrum
    - This is not the only source → acoustic, ultrasonic, electronic

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Electromagnetic Spectrum (1):

- Electromagnetic Waves
  - Conceptualized as:
    - Wave theory → propagating sinusoidal waves of varying wavelength or
    - Particle theory → stream of mass-less particles containing a certain amount of energy, moving at the speed of light (known as a photon)
  - There is also the dual theory in which both forms are present! We won’t worry about this!!!

Electromagnetic Spectrum (2):

- Grouping of Spectral Bands of EM Spectrum
  - According to Energy per Photon we Obtain:
    - Highest energy → gamma rays
    - Lowest energy → radio waves
    - No “smooth transition” between bands of the EM spectrum

Gamma Ray Imaging (1):

- Primary Uses:
  - Nuclear medicine (detect tumors etc.) - Idea:
    - Patient injected with radioactive isotope that emits gamma rays as it decays
    - Emission of gamma rays are collected by gamma ray detectors and image is constructed
  - Positron-Emission-Tomography (PET)
    - Patient given radioactive isotope that emits positrons as it decays
    - When positron meets electron, both destroyed and two gamma rays given off
    - Gamma rays are detected and using special detectors an image is constructed
Gamma Ray Imaging (2):

- Nuclear Medicine Example:
  - Complete bone scan

Gamma Ray Imaging (3):

- Primary Uses (cont...)
  - Astronomical observations
    - Many "objects" in space (e.g., stars, galaxies etc.)
      naturally emit gamma ray radiation
      special sensors can detect and record this

X-Ray Imaging (1):

- Oldest Sources of EM Radiation for Imaging
  - Best known for medical diagnostics
    - Patient placed between "X-ray tube" and special
      film sensitive to X-ray radiation
    - Electrons are emitted from X-ray tube and go
      through patient
    - Intensity of X-rays is modified by absorption as
      they go through patient
    - Intensity collected at film and image is then
      created

Star in Cygnus constellation exploded 15,000 years ago and created a gas cloud which emits gamma radiation.
X-Ray Imaging (2):

- Other Applications of X-ray Imaging
  - Angiography
    - Obtain images of blood vessels (angiograms)
    - X-ray contrast medium injected via catheter at appropriate location
    - X-ray image obtained and blood vessels highlighted

X-Ray Imaging (3):

- Other Applications of X-ray Imaging (cont...)
  - Computerized axial tomography (CAT scan)
    - The process of using computers to generate a three-dimensional image from flat (e.g., two-dimensional) X-ray pictures, one slice at a time...
    - CAT image is a "slice" taken perpendicularly through the patient
    - Patient is moved in the longitudinal direction
    - Has revolutionized medical medicine due to their high resolution and 3D capabilities

X-Ray Imaging (4):

Example CAT of Head

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**X-Ray Imaging (5):**
- Other Applications in Addition to Medicine
  - Industrial processes
    - Imaging of parts/components to detect cracks and flaws
  
  Commonly used to examine circuit boards to detect missing parts, cracks etc.

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**Ultraviolet Imaging (1):**
- Varied Applications
  - Lithography
  - Industrial inspection
  - Microscopy → fluorescence microscopy one of the fastest growing fields of microscopy
  - Lasers
  - Biological imaging
  - Astronomical observation

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**Ultraviolet Imaging (2):**
- Example Ultraviolet Images
  - Corn → detect diseased corn

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Visible and Infrared Imaging (1):
- Obviously the Most Widely Used Given our Sensitivity to the Visual Spectrum
  - Low frequency (red) $\rightarrow 4.3 \times 10^{14}$ Hz
  - High frequency (violet) $\rightarrow 7.5 \times 10^{14}$ Hz
- Often used in conjunction with infrared imaging
- Various applications
  - Light microscopy
  - Law enforcement
  - Astronomy
  - Industrial applications
  - Remote sensing

Visible and Infrared Imaging (2):
- Remote Sensing
  - Definition:
    - The process of obtaining data or images from a distance, as from satellites or aircraft
  - Major area of visual/infrared imaging
  - Usually covers several bands of the visual/infrared spectrum
  - NASA’s LANDSAT satellite
    - Primary purpose $\rightarrow$ Obtain and transmit images of earth from space for environmental monitoring purposes

Visible and Infrared Imaging (3):
- Thermatic Bands of LANDSAT
  - Bands of interest

<table>
<thead>
<tr>
<th>Band No.</th>
<th>Name</th>
<th>Wavelength (μm)</th>
<th>Characteristics and Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visible Blue</td>
<td>0.43-0.52</td>
<td>Measurement of water</td>
</tr>
<tr>
<td>2</td>
<td>Visible green</td>
<td>0.52-0.60</td>
<td>Good for measuring plant height</td>
</tr>
<tr>
<td>3</td>
<td>Visible red</td>
<td>0.63-0.70</td>
<td>Vegetation discrimination</td>
</tr>
<tr>
<td>4</td>
<td>Near Infrared</td>
<td>0.765-0.898</td>
<td>Vegetation and mineral mapping</td>
</tr>
<tr>
<td>5</td>
<td>Middle infrared</td>
<td>1.25-2.75</td>
<td>Monitoring of soil and vegetation, fire detection</td>
</tr>
<tr>
<td>6</td>
<td>Shortwave infrared</td>
<td>3.04-3.22</td>
<td>Monitoring of vegetation</td>
</tr>
<tr>
<td>7</td>
<td>Middle infrared</td>
<td>2.08-2.35</td>
<td>Mineral mapping</td>
</tr>
</tbody>
</table>
Visible and Infrared Imaging (4):
- Example Images Obtained from LANDSAT
  - Washington D.C. area
  - Detect vegetation, roads, rivers, buildings etc.

Visible and Infrared Imaging (5):
- Further Examples of Visual Satellite Images
  - Hurricane Andrew

Visible and Infrared Imaging (6):
- Infrared Image Example
  - North America from Space

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**Microwave Imaging (1):**
- **Dominant Use is Radar**
  - Ability to collect data over virtually any region, at any time, regardless of weather conditions or ambient light conditions
  - Penetrate clouds
  - At times, can see through vegetation, ice, sand...
  - Operates similar to flash camera
  - Provides its own illumination (microwave pulses) to illuminate area of interest and then "snaps" image
  - Instead of camera lens, antenna is used

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**Microwave Imaging (2):**
- **Example Microwave Image**
  - Image of mountainous region of Tibet obtained from space satellite

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**Radio Band Imaging (1):**
- **Dominant Use is Medicine and Astronomy**
  - In medicine, popular technique is magnetic resonance imagine (MRI)
  - Patient placed in powerful magnet
  - Radio waves are passed through patient's body in short pulses
  - Each pulse causes another pulse to be emitted by the patient's tissues
  - Location and strength of the pulses is determined by computer and 2D image is created based on this information
Radio Band Imaging (2):
- Example MRI Image
  - Human knee and spine → common uses of MRI
  - MRI images of any plane can be made

Other (Non-EM) Imaging Modalities (1):
- Acoustical Imaging
  - Sound waves (typically low frequency, e.g., < 100Hz) are emitted from transmitter
  - Reflections of transmitted sound recorded by receiver
    - Image constructed based on time of arrival and intensity of echoes
  - Many applications
    - Geological exploration (oil and mineral exploration)
    - Industry
    - Medicine (ultrasound)

Other (Non-EM) Imaging Modalities (2):
- Acoustical Imaging (cont...)
  - Popular use of acoustical imaging is ultrasound
    - Viewing of unborn babies
    - Viewing other body tissues/bones
    - Can detect certain cancers
  - To construct typical ultrasound image, millions of pulses and echoes are emitted and received respectively each second
    - Pulses typically 1 - 5 MHz
Other (Non-EM) Imaging Modalities (3):
- Example Ultrasound Images

Un-born baby
Thyroids
Muscle

Fundamental Steps in Digital Image Processing

Two Broad Categories (1):
- Methods Whose Input and Output are Images
- Methods Whose Inputs are Images but Outputs are Attributes Extracted from these Images
Two Broad Categories (2):
- Outline for Remainder of Course!

Image Enhancement (1):
- Bring out Details that are Obscured or Highlight Certain Areas of an Image
  - Simplest/most appealing areas of image processing
  - Subjective \rightarrow highly dependent on the human observer
    - My idea of a “good” image may differ from yours!
  - Examples include adjusting image
    - Brightness
    - Contrast
    - Color etc.

Image Enhancement (2):
- Example
  - Removing “red-eye”
Image Restoration (1):

- Improving Image Appearance
  - Real-life images typically contain noise which can arise from many aspects of the imaging process
    - Sensor itself
    - Environmental noise
    - Sampling
  - Objective
    - Typically based on mathematical or probabilistic models of image degradation

Image Restoration (2):

- Example
  - Old family photos
    - Cracks, wrinkles, tears, can disappear!
    - Faces can be made to look sharp and clear!

Before

After

Color Image Processing (1):

- Most “Modern-day” Images are not Gray-Scale
  - Consider the internet!
  - Typically three color channels
    - Red, green, blue (r,g,b)
    - Many times, each color is treated separately
Compression (1):

- Techniques for Reducing Image Storage Requirements or bandwidth Required to Transmit Images
  - Images can be very large in terms of memory especially when considering color images and potentially, image sequences over time
  - Storage capacity has increased tremendously over the last 10 years but transmission capacity has not been keeping up!

Morphological Processing (1):

- Extraction of Image Components
  - These components may be useful in the representation of and description of shape

- Segmentation
  - Partition an image into its constituent parts or objects
    - Background vs. foreground
    - Finding a specific object in an image
    - Typically not an easy task!

Description and Representation (1):

- Extraction of Image Components
  - Converting image data to a form suitable to computer processing
  - Typically follows the output of the segmentation stage which outputs ray pixel data representing either a boundary or a region
  - Decide whether data be represented as a boundary or a complete region

- Recognition
  - Assign labels to objects based on its descriptors
Knowledge Base (1):

- Prior Knowledge
  - Knowledge about a problem can be incorporated into a image processing modules via the knowledge base
  - Knowledge may include
    - Knowing regions in an image were an object may reside
    - Can reduce total processing e.g., no need to search the entire image!

Components of a Digital Image Processing System

Component Summary (1):
Component Summary (2):

- **Large Scale vs. Small Scale**
  - Until recently (e.g., late 1980s) image processing systems were fairly large and substantial.
  - Recently, shifting towards single peripheral boards designed to be compatible with standard buses.
    - Can be used with specialized equipment, workstations and even standard PCs.
  - Recent trends also focus on image processing software and given the advances in computing power and storage.
    - Many tasks can now be performed in software.