Introduction to Computer Vision

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What is a Digital Image?

- **Image as a Function**
  - An image can be represented as a 2D function $f(x,y)$.
  - x,y : spatial coordinates (location on the plane).
  - $f(x,y)$: intensity or gray level at point (x,y).
- **Digital Image**
  - When x,y and intensity values are finite and discrete, the image is called a digital image.
  - Digital images are processed by a computer.
- **Pixels**
  - A digital image consists of a finite number of elements.
  - Each element has a specific location and value.

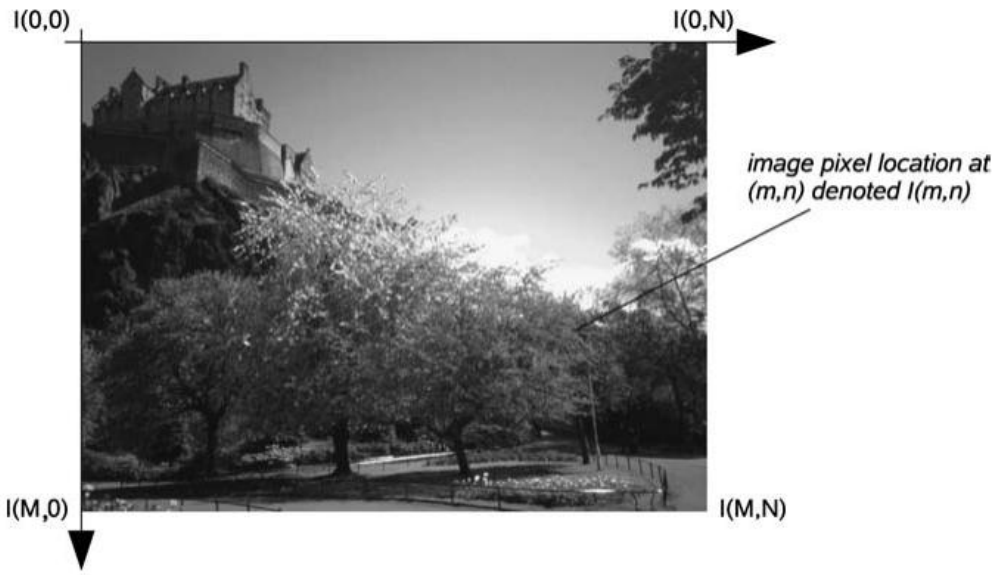


Figure 1.1 The 2-D Cartesian coordinate space of an M x N digital image

Types of Digital Image Representation

- **Binary Images**:
  - Binary images are black and white images that contain only two colors, black and white.
  - They are often used for object detection or segmentation.
- **Grayscale Images**:
  - Grayscale images contain shades of gray between black and white. They are often used for medical images.
- **Color Images**:
  - Color images contain multiple colors and are the most common type of digital image.
  - Color images can be represented using different color models, such as RGB (Red, Green, Blue), CMYK (Cyan, Magenta, Yellow, Black), or HSL (Hue, Saturation, Lightness).

Resolution vs. Color Depth

- **Resolution** :
  - The number of pixels in the image.
- **Color depth**
  - The number of bits that are used to represent each color component. Higher bit depths let more shades and colors be shown.

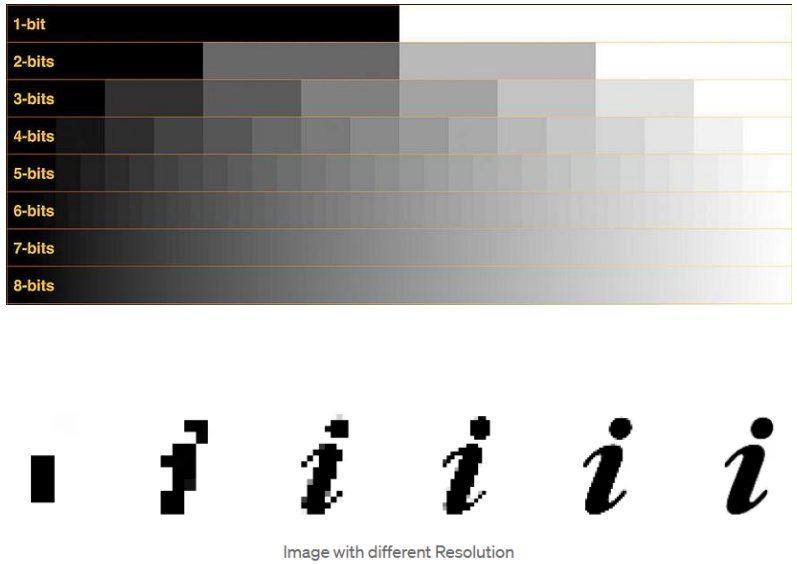
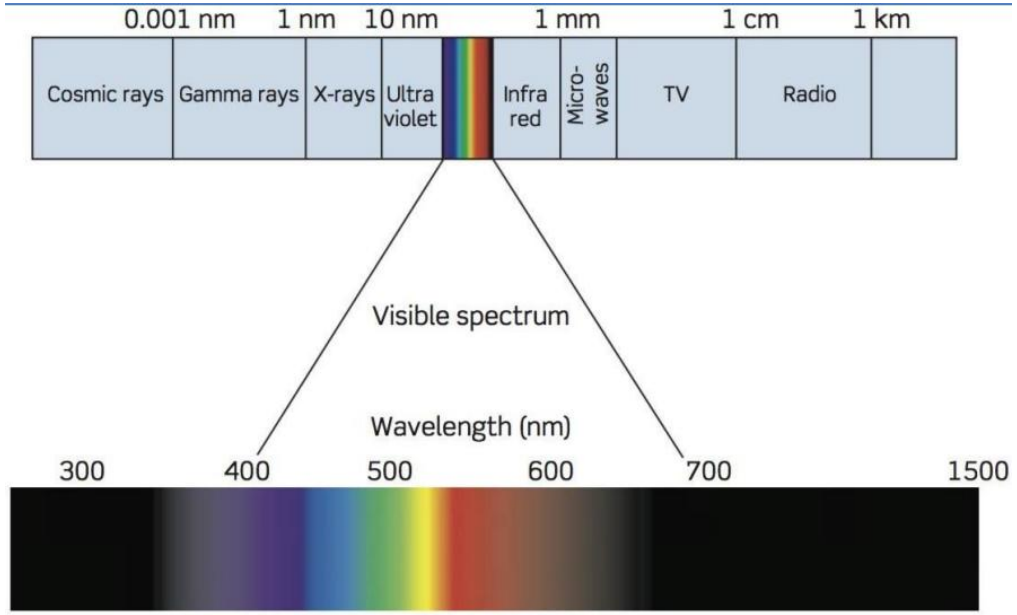


Image with different Resolution

Images in Human and Machine Perception

- **Human Vision**
  - Vision is the most advanced human sense.
  - Images play a central role in human perception.
  - Humans are limited to the visible band of the electromagnetic (EM) spectrum.
- **Machine Vision**
  - Imaging machines can capture data across almost the entire EM spectrum: From gamma rays to radio waves.
- Digital Image Processing covers a wide range of applications in science, medicine, and technology.



Relationship Between Image Processing and Computer Vision

Digital Image Processing

- Often defined as operations where input and output are images.

Computer Vision

- Enable computers to emulate human vision.
- Includes learning, inference, and decision-making from visual data.
- A branch of Artificial Intelligence (AI).

Early Application of Digital Images

- **1920s – Newspaper Industry**
- **1921 – Bartlane Cable Picture Transmission System**
  - Cut transfer time from **>1 week** (by ship) to **<3 hours** (by cable).

A digital picture produced in 1921 from a coded tape by a **telegraph printer** with special typefaces.

Early Application of Digital Images

- Poor distribution of intensity (gray) levels.
- Improved Printing (1921)
  - Early printing method abandoned.
  - Replaced by photographic reproduction from perforated tapes at telegraph terminals.
  - Better tonal quality and resolution.

Unretouched cable picture of Generals Pershing (right) and Foch, transmitted in 1929 from London to New York by 15-tone equipment.

Origins of Digital Image Processing

- 1960s: First powerful computers capable of meaningful image processing.
- Digital image processing emerged with the space program.
- 1964 – Ranger 7 (NASA/JPL):Captured first U.S. spacecraft image of the Moon.
- Computers corrected distortions from the onboard TV camera.

The first picture of the moon by a U.S. spacecraft. Ranger 7 took this image on July 31, 1964, at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface.

Early Applications Beyond Space

- Medical Imaging and CT Scans
  - Late 1960s – early 1970s: Digital image processing expanded to:
    - Medical imaging
    - Remote Earth observation
- Computerized Tomography (CT / CAT) – early 1970s
  - Detectors arranged in a ring around patient
  - Rotating X-ray source passes through the body
  - Algorithms reconstruct cross-sectional “slices”
  - Multiple slices form a 3D view of the interior
  - Inventors Awarded 1979 Nobel Prize in Medicine

Photo from the Nobel Foundation archive.

Allan M. Cormack

Prize share: 1/2

Photo from the Nobel Foundation archive.

Godfrey N. Hounsfield

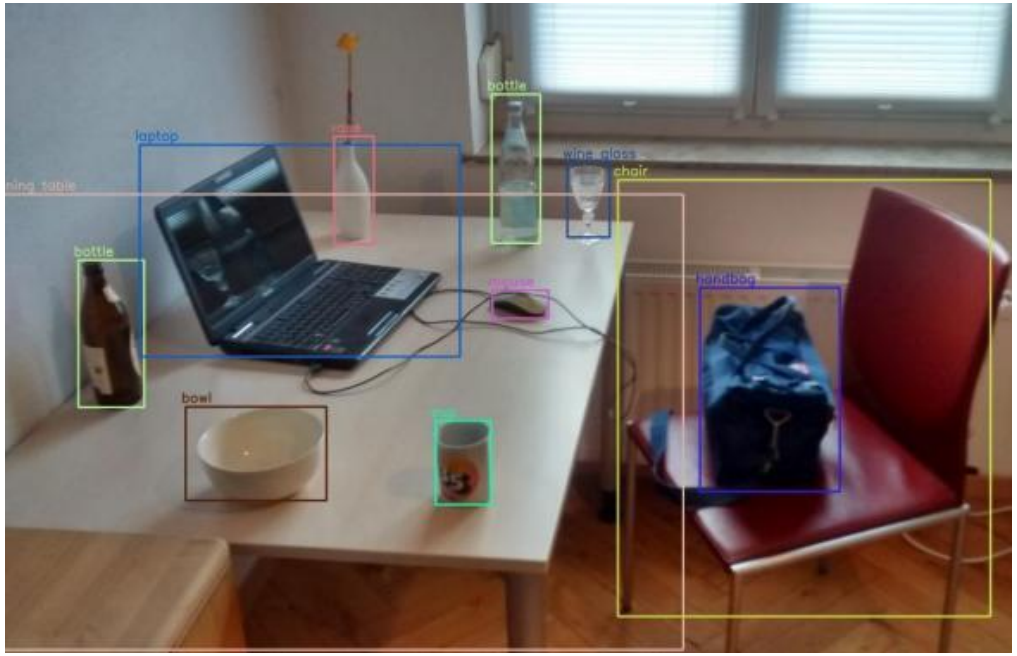
Prize share: 1/2

Growth of Digital Image Processing (1960s – Present)

- Expanded beyond medicine and space program
- Medical & biological sciences → enhance X-rays, color coding for interpretation
- Geography → study pollution patterns via aerial & satellite images
- Restoration → recover degraded or unique experimental images
- Physics → enhance images in plasma studies, electron microscopy
- Law enforcement, defense, industry

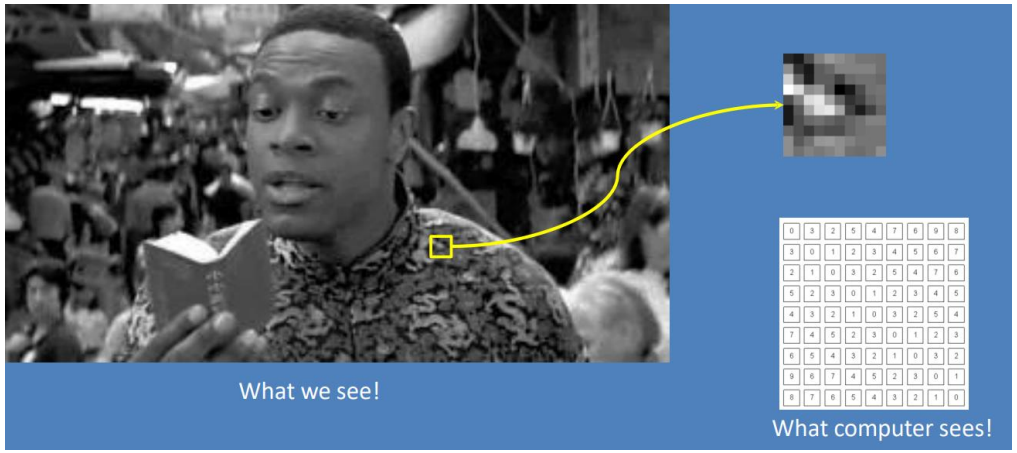
What is Computer Vision?

- Computers understanding visual data (images, videos, etc.)
  - Different image types (RGB, grayscale, …)
  - Different sensors
- Develop algorithms/ representation that will enable a computer to autonomously analyze/ interpret the visual information.



What is Computer Vision?

- Automate human visual tasks
  - Humans easily distinguish and localize objects, can machines do the same?
- Extracting meaning from pixels
  - Images = just numbers for computers
  - Variations (scale, viewpoint, illumination, …) make recognition harder



What is Computer Vision?

- Make computers understand images and video or any visual data.
- What kind of scene? Where are the cars? How many cars ? How far is the building?

Why Study Computer Vision?

- Engineering / Business point of view:
  - Solves practical problems (e.g., analyzing long videos)
- Scientific point of view:
  - Simulates the human visual system
- Data-driven Need:
  - Massive visual data on the internet:
    - Facebook: 250+ billion photos, 300 million images a day
    - YouTube: 100 hours uploaded every minute
  - Enables modern CV systems (deep learning methods)
- Adoption:
  - From academia → industry (Google, Facebook, Apple, …)
- Applications:
  - Safety, healthcare, security, and more

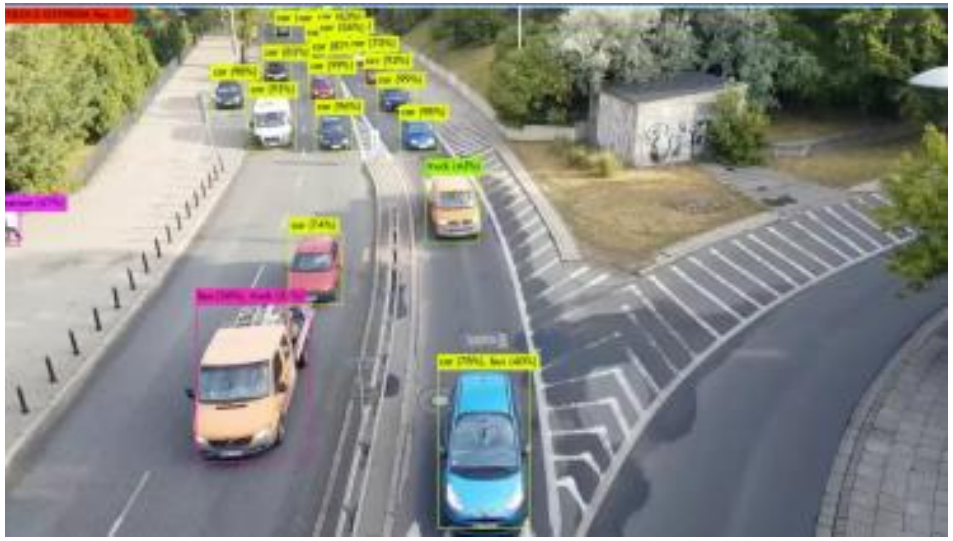
Computer Vision Discipline

Face Detection

Face Recognition

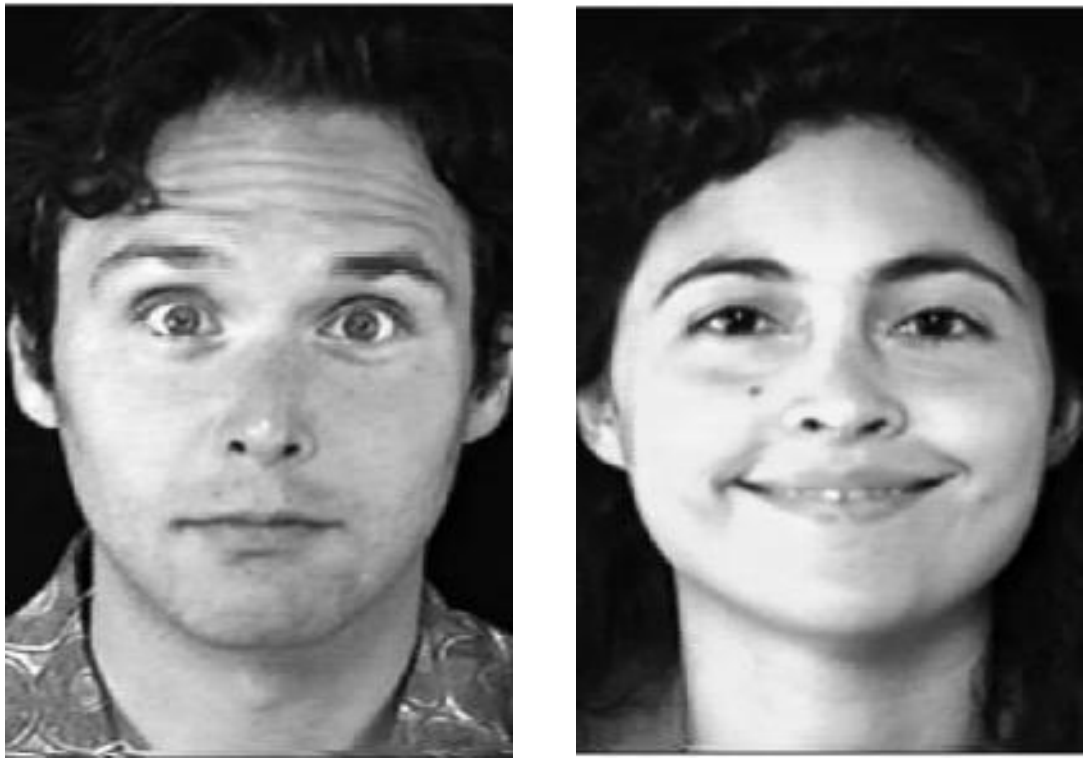
Computer Vision Discipline

Vision-based Biometrics



Generic object Recognition and Detection

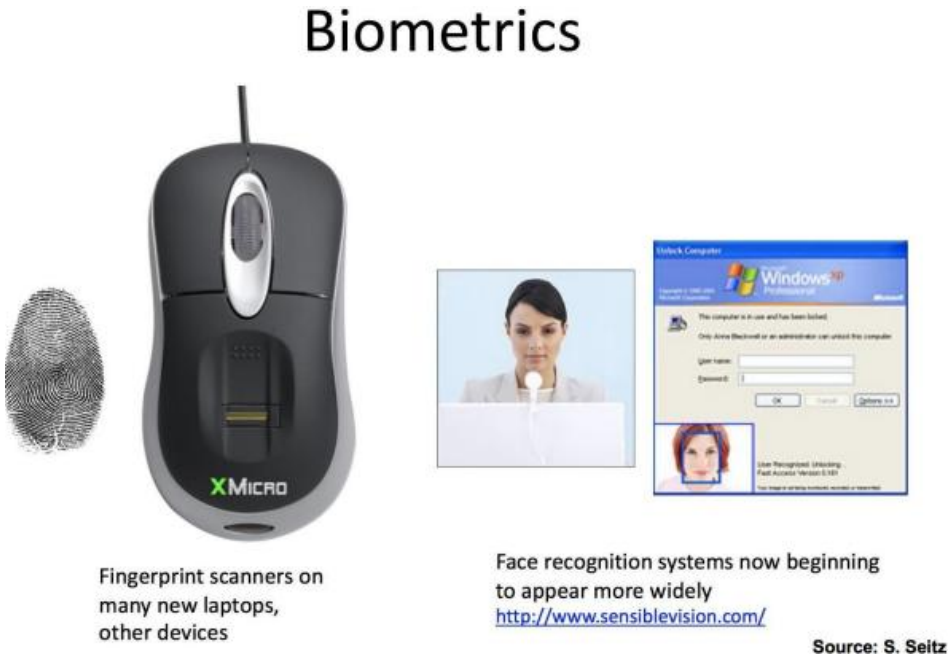
Computer Vision Discipline



Face Expression

Object recognition

Computer Vision Discipline



Biometrics

High Density Crowded Scenes