CSCE-5683
Digital Image Processing

Introduction

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EECS Department

University of Arkansas

Things to Do

- Register your team (groups of two)
  (Email me if you want but cannot find a teammate)
- Review background and programming languages
  (Materials on the website are being updated)
- Start reading textbooks and research papers.
- Define your goals to achieve in and after this course.

Overview

- Definition
- Motivation
- Applications

Review

- Matrices and Vectors
- Probability/Statistics
- Linear Systems

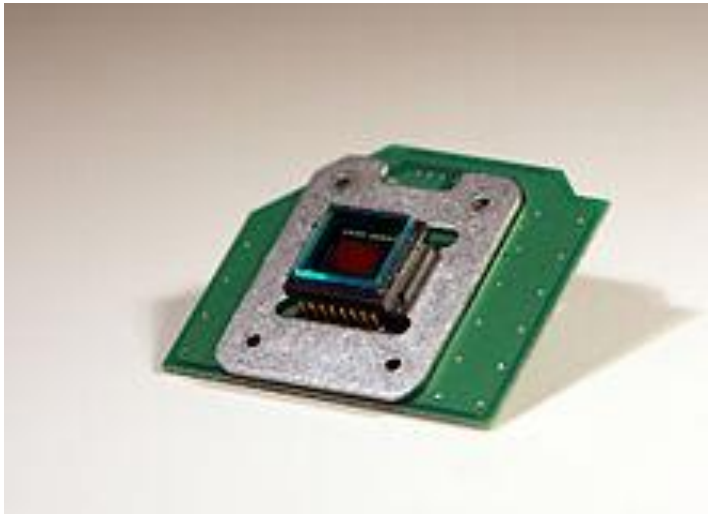
Adapted from Prof. Tien D. Bui's lectures

What is a digital image?

- Image on CCDs: a piece of silicon called Charge-Coupled Device
- Divided into array of light-sensitive cells called photosites or **pixels**
- Each pixel has a **Gray-level** or brightness (0-255)
- For **Color pixel**: needs three channels or bands (**RGB**)
- Resolution or size: number of rows and columns in the image

  3060 x 2036 for HR

  720 x 576 for standard video format

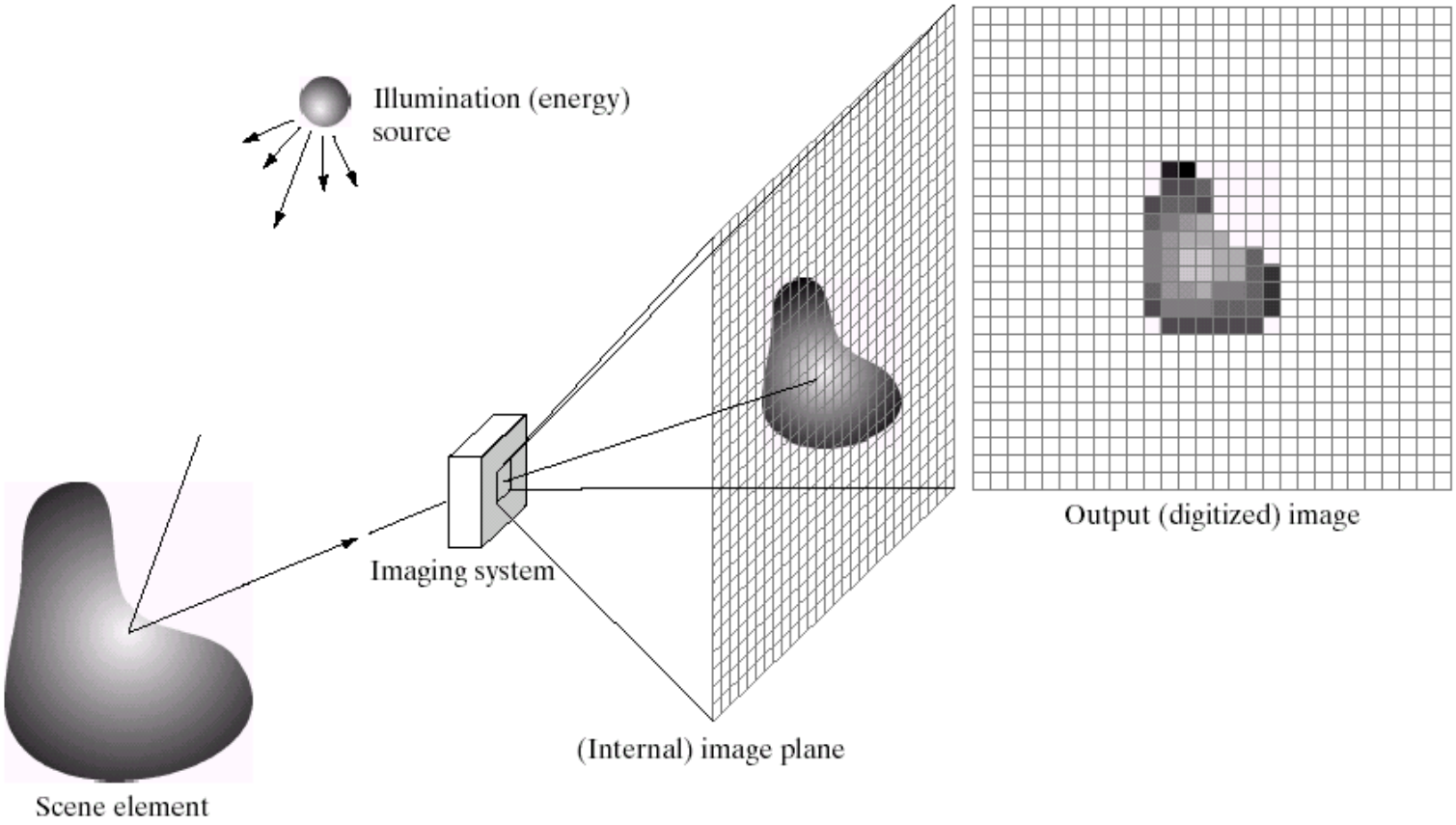


CCD from a 2.1 megapixel Argus digital camera

CCD from a 2.1 megapixel Hewlett-Packard digital camera

Souce: Wikipedia

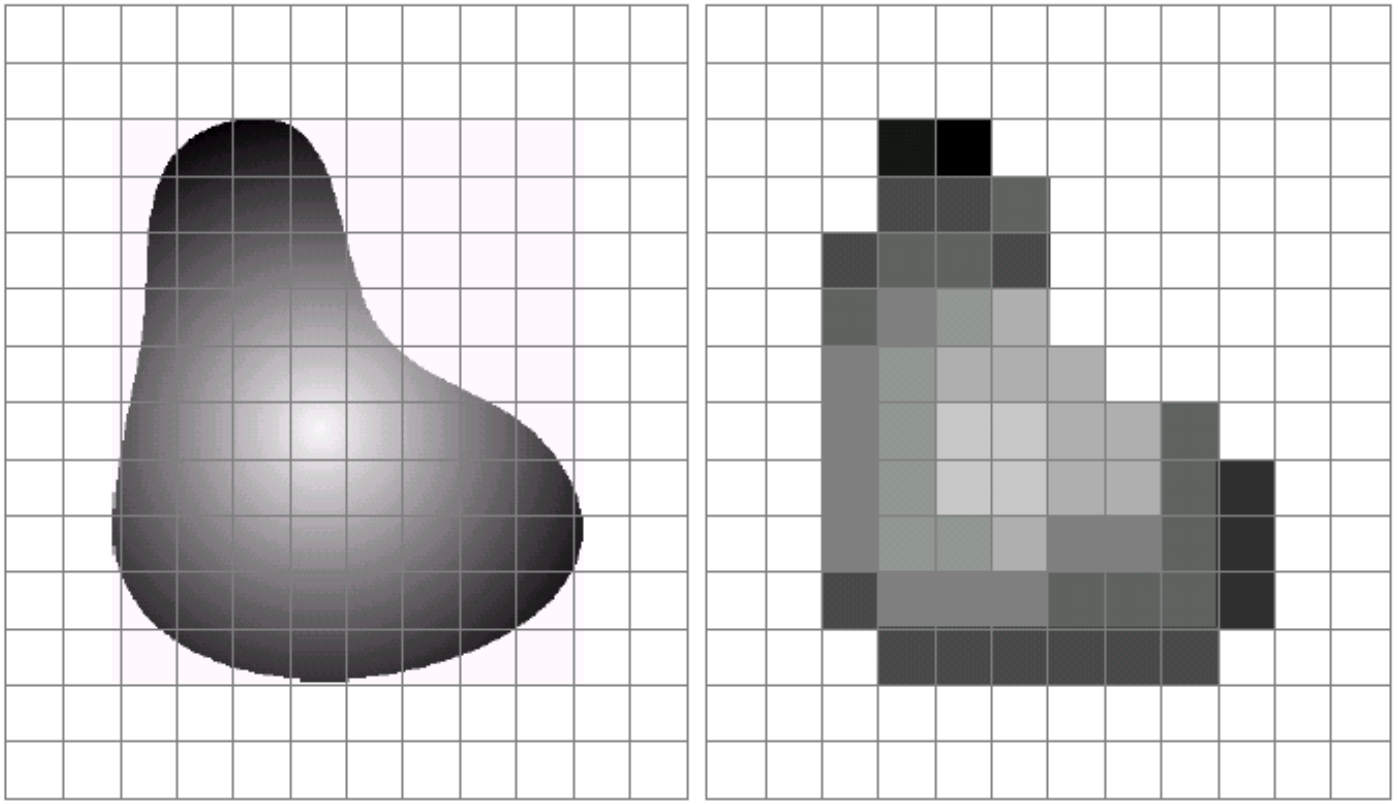
Image Acquisition



a
b c d e

FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image Sampling and Quantization

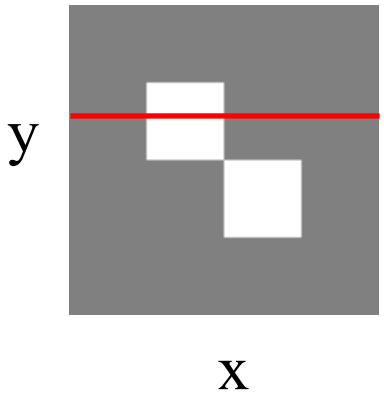


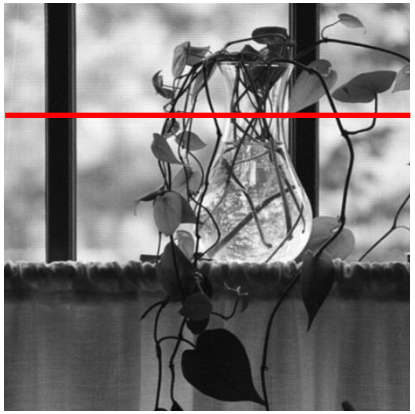
a b

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

What is Digital Image Processing?

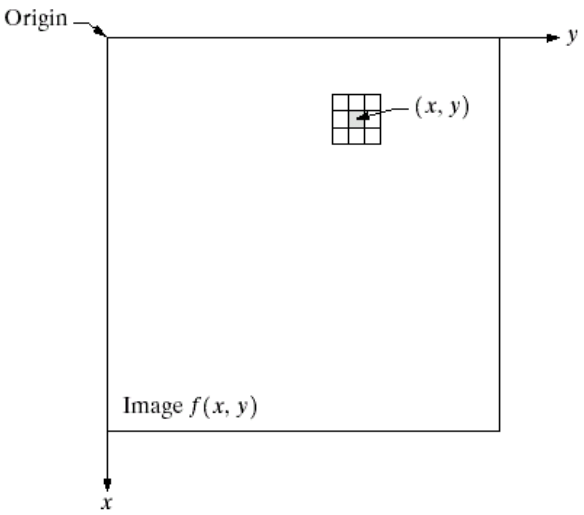
- An image is a function of two spatial variables f(x,y), where (x,y) denote the planar image coordinates, and f(.) is the amplitude of the image at the given location.

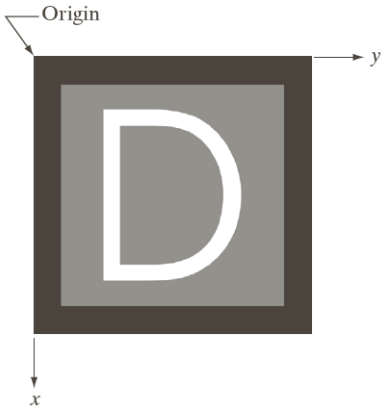




Digital Image Representation

FIGURE 3.1 A 3×3 neighborhood about a point (x, y) in an image.





a
b c

FIGURE 2.18
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array.
(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).

Digital Image Representation

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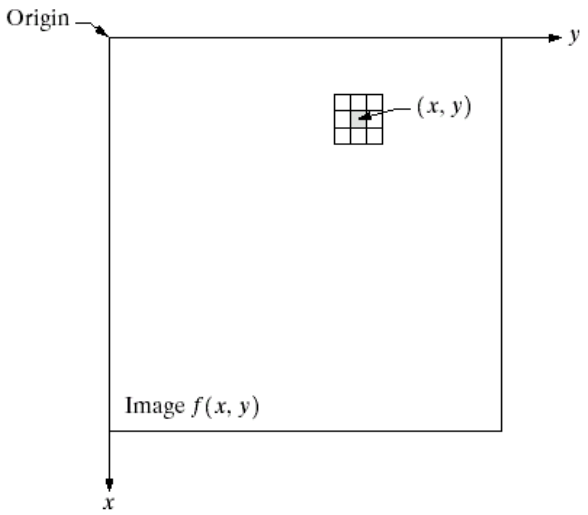
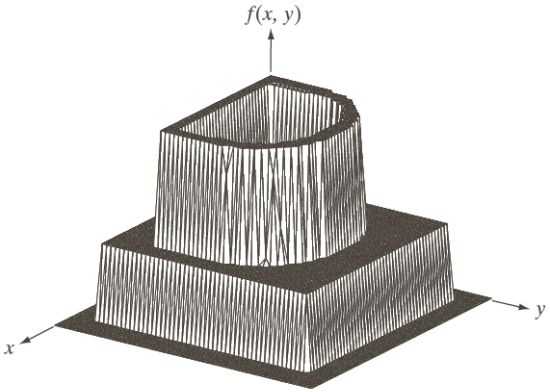
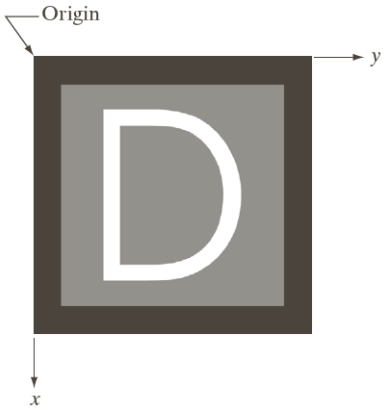






a
b c

FIGURE 2.18
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array.
(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).

Image representation

An image is represented by a two-dimensional function $f(x, y)$. The value of f at (x, y) is a +ve scalar quantity, i.e. $0 < f(x, y) < \infty$.

$f(x, y)$ is formed by 2 components:

(1) amount of source illumination incident on the scene.

(2) amount of illumination reflected by the objects in the scene.

(1) is called illumination $= i(x, y)$,

(2) is called reflectance $= r(x,y)$, and:

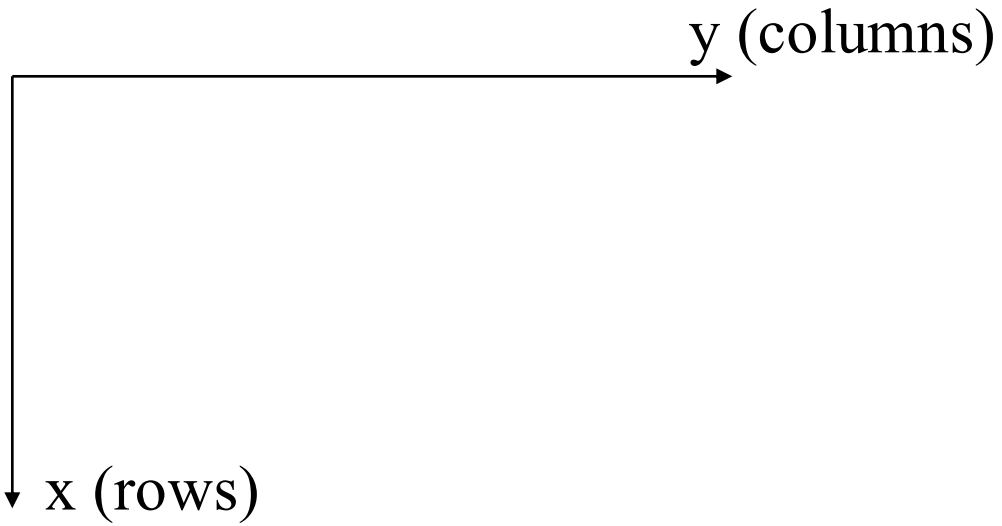
$$f(x, y) = i(x, y)r(x, y)$$

where $0 < i(x, y) < \infty$ and $0 < r(x, y) < 1$

• An MxN digital grayscale image: (for color f(x,y) would be 1 color component)

$$f(x,y)=\begin{bmatrix} f(0,0) & \cdots & f(0,N-1) \\ \vdots & \ddots & \vdots \\ f(M-1,0) & \cdots & f(M-1,N-1) \end{bmatrix}$$

• Book Convention: (Same as MATLAB, except MATLAB starts index at 1)



Chapter 2: Digital Image Fundamentals

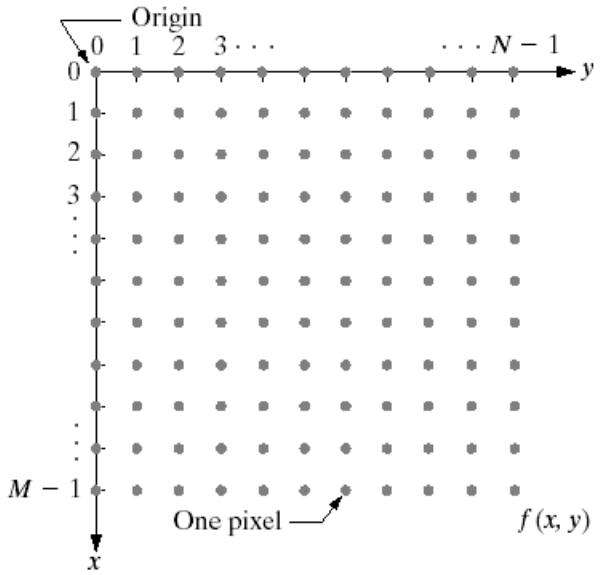


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

The Grayscale and Its Perception

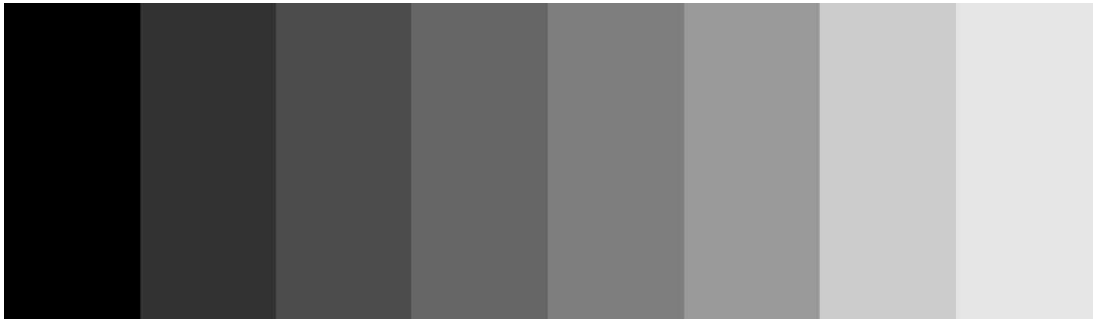
- We call the intensity L = f(x,y) the "gray level" value

- The range of values of Lmin < L < Lmax is called the grayscale.

- Commonly, we use the range [0 , L-1] for integer L that is a power of 2.

Black White

Example: 3 bits,
2^3 = 8 gray levels



Chapter 2: Digital Image Fundamentals

TABLE 2.1
Number of storage bits for various values of N and k.

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Pixel intensity is 2^k

Image size is NxN

Storage Needs for Images:

- Image MxN pixels, 2^B gray levels, *c* color components
  - *Size = M x N x B x c*
  - *Example: MxN=1024x1280, B=8, c=3 (24 bit RGB image)*
- *Size = 31,457,280 bits (or 3.75 MBytes)*

- Need to have (lossy) compression!

The image of a thin line is not a thin line

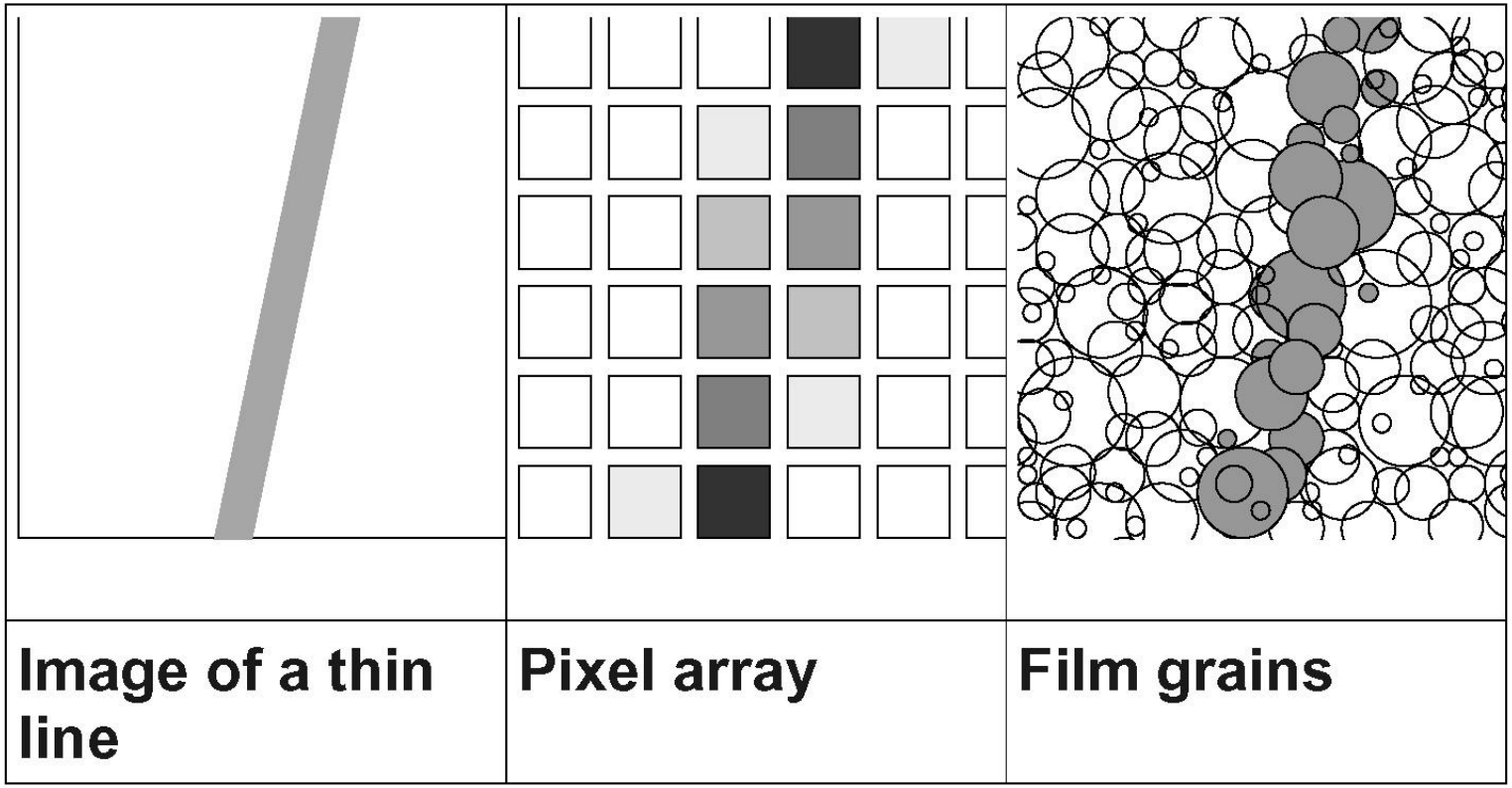
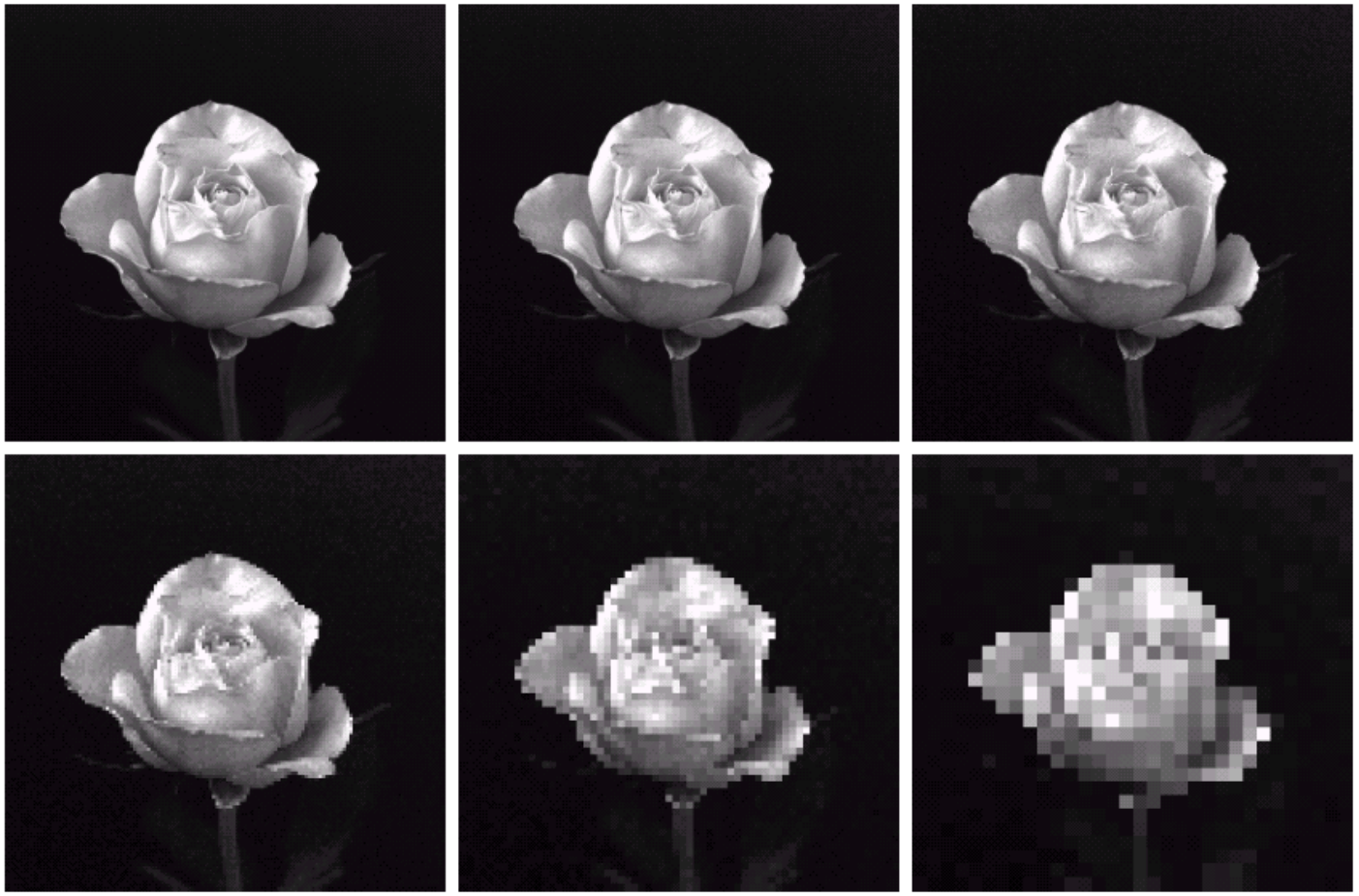


Image of a thin line	Pixel array	Film grains

Number of Pixels and Resolution

FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

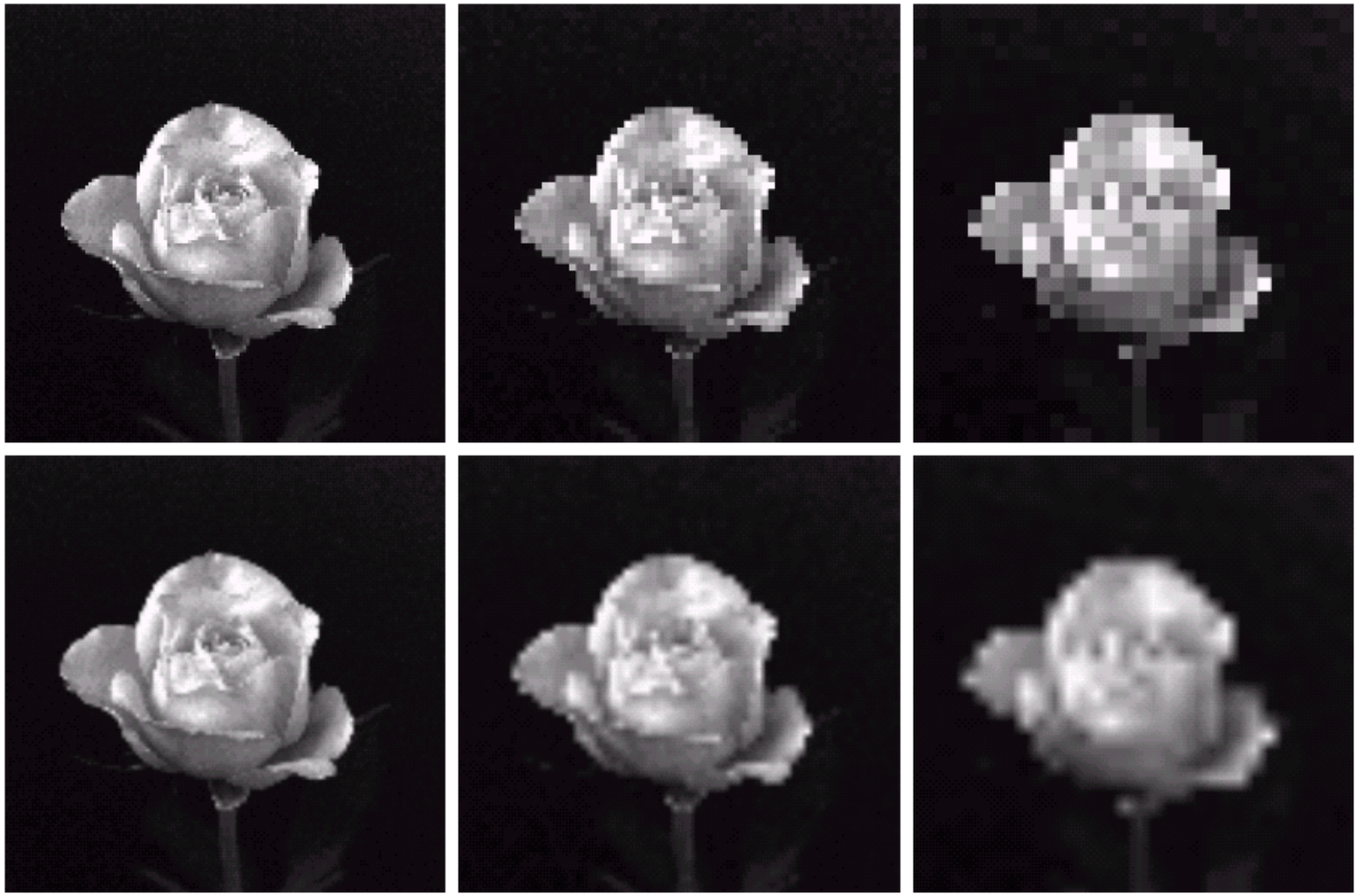
Number of Pixels ≠Resolution



a b c
d e f

FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

Number of Pixels ≠Resolution



a b c
d e f

FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

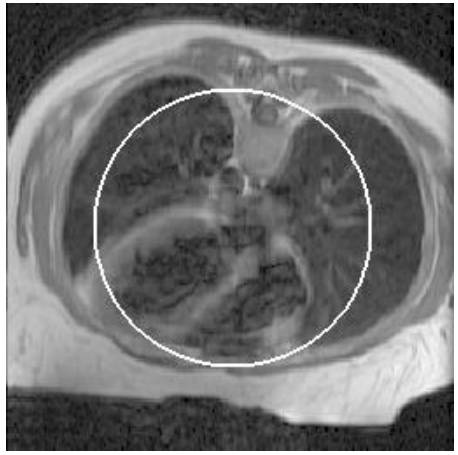
What Is An Image?

- Definition: An **image** is a 2-dimensional light intensity function, *f(x,y),* where *x* and *y* are spatial coordinates, and *f* at *(x,y)* is related to the brightness of the image at that point.
- Definition: A **digital image** is the representation of a continuous image *f(x,y)* by a 2-D array of discrete samples.
- The amplitude of each sample is quantized to be represented by a finite number of bits.
- Definition: Each element of the 2-D array of samples is called a **pixel** (Picture Element)

What is Digital Image Processing?

Processing images generally results in one of several kinds of outputs:

- Another image: g(x,y) = P (f(x,y)) (low-level processing)
- A set of attributes: edges, segments, objects (mid-level)
- An algorithmic “understanding” (high-level)



Why do we process images?

- Facilitate storage and transmission of pictures
  - Compression of digital images
  - Transmission of images
- Prepare an image for display
  - Resizing images
  - Halftoning
- Enhance and restore images
  - Restoring old movies
  - Better medical images
- Information extraction from images
  - Reading zip codes, bar codes
  - Measuring pollution from aerial images

- Image MxN pixels, 2^B gray levels, *c* color components
  - *Size = M x N x B x c*
  - *Example: MxN=1024x1280, B=8, c=3 (24 bit RGB image)*
- *Size = 31,457,280 bits (or 3.75 MBytes)*

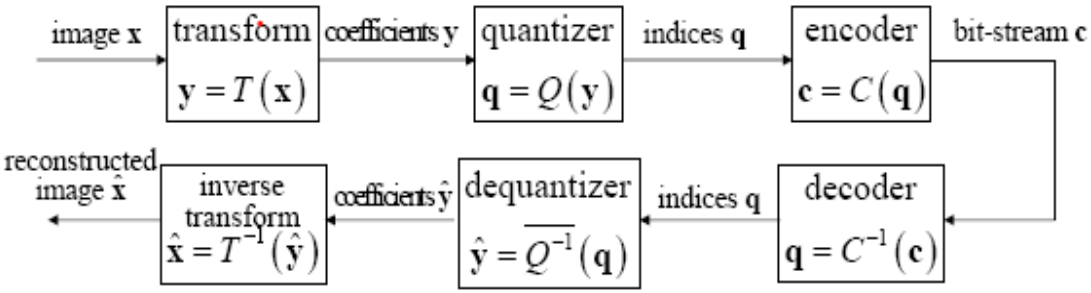
- 8.5x11 document scanned at 7.7 lines/mm, ~1600 pixels per line, 1 bit per pixel = 3.25 Megabits per page, or 5.65 minutes per page over 9600 baud line

Areas of Image Processing

- Compression
- Recognition/classification
- Denoising
- Enhancement
- Restoration
- Segmentation
- Inpainting
- Super-resolution
- Watermarking
- Others

Areas of Image Processing

Compression



- Transform $T(\mathbf{x})$ usually invertible
- Quantization $Q(\mathbf{y})$ not invertible, introduces distortion
- Combination of encoder $C(\mathbf{q})$ and decoder $C^{-1}(\mathbf{c})$ lossless

Image compression standard:

- JPEG (1992): Joint Photographic Expert Group: works with color and grayscale images.
- *Compression ratio* of lossless methods is not high enough.
- JPEG uses *transform coding* (DCT)
- JPEG 2000 uses wavelet transforms

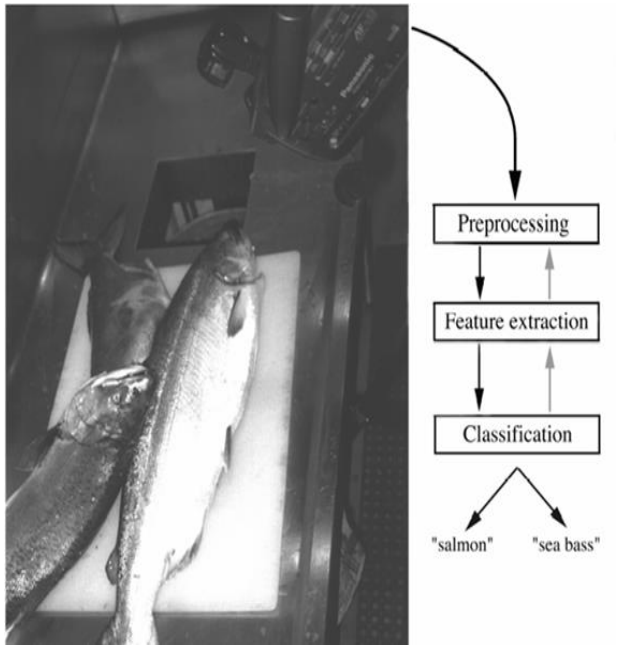
Image Compression

At 158:1 compression ratio

Courtesy of Minh Do

Areas of Image Processing

Recognition and classification

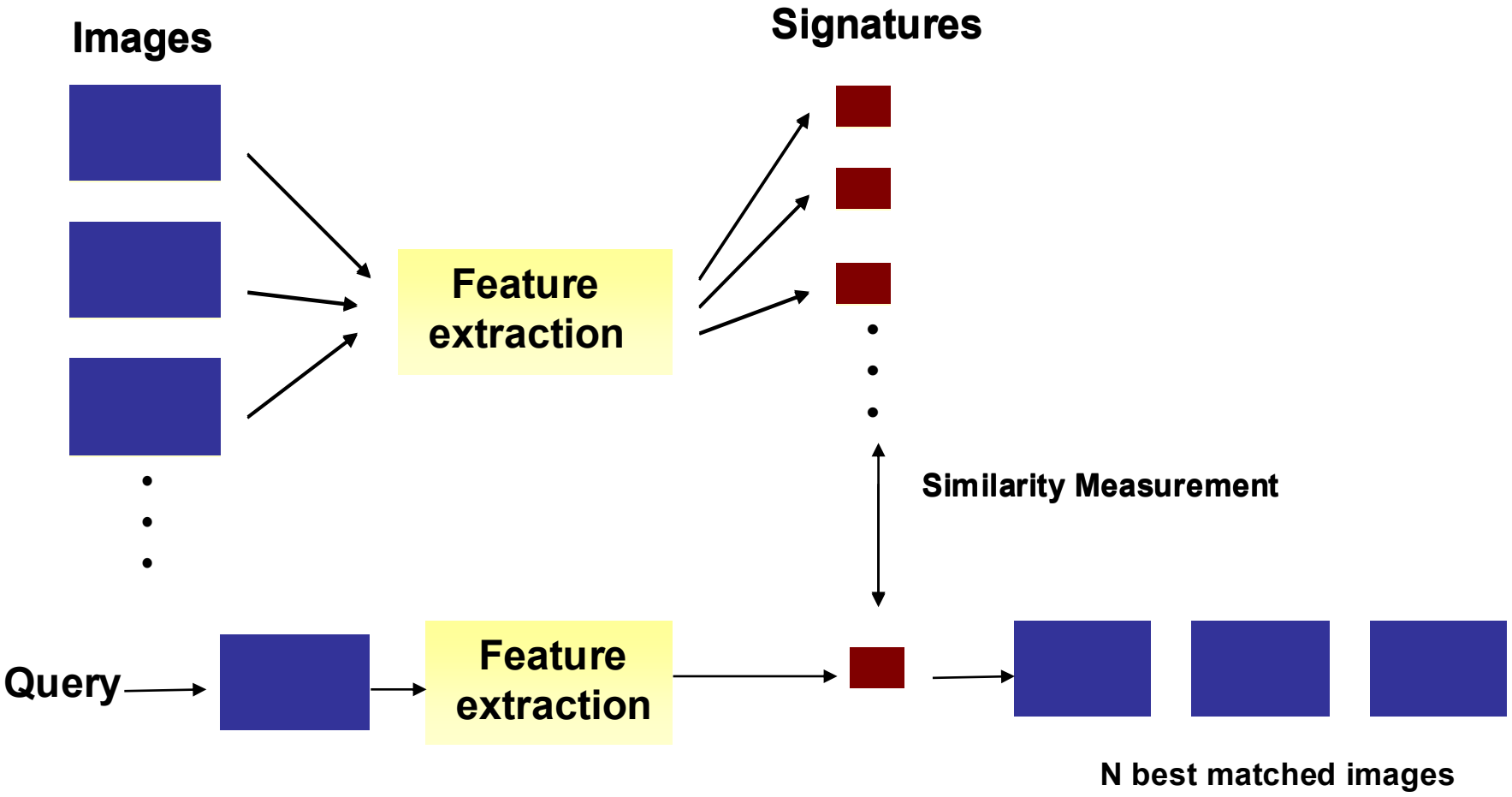


Some important steps:

- Preprocessing (denoise, deblurr, contrast equalization,…)
- Segmentation (edge detection)
- Feature extraction (scale space, multiresolution, invariant features, occlusion)
- Recognition (feature matching, distance measure,…)
- Classification (decision theory, training, machine learning,…)
- Applications: medical imaging, pattern recognition, video processing, document processing, industrial applications

Recognition-Classification

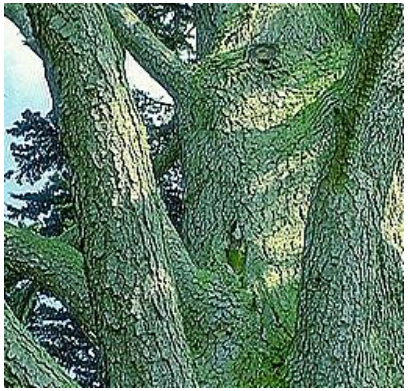
Feature extraction (e.g. for content-based image retrieval)



Areas of Image Processing

Denoising






- To give an image a softer effects ⇨ *smoothing or blurring*
- Removal of small details (aesthetic effects)
- Bridging of small gaps in lines or curves
- Image smoothing using Gaussian mean filter

Areas of Image Processing

Denoising

"Many important data images contain noise that is signal dependent and obeys a Poisson distribution. A familiar example is that of radiography. The signal in a radiograph is determined by photon counting statistics and is often described as particle-limited, emphasizing the quantized and non-Gaussian nature of the signal. Removing noise of this type is a more difficult problem."

Le Triet et al. J. Math Imaging Vision

Areas of Image Processing

Restoration

$$f(x,y) \longrightarrow \text{Degraded} \longrightarrow \oplus \longrightarrow g(x,y)$$

$h(x,y)$ $\quad$ $noise$

$$g(x,y) = h(x,y) * f(x,y) + \eta(x,y)$$

Restoration : $g(x,y) \longrightarrow$ Restoration box $\longrightarrow \hat{f}(x,y)$

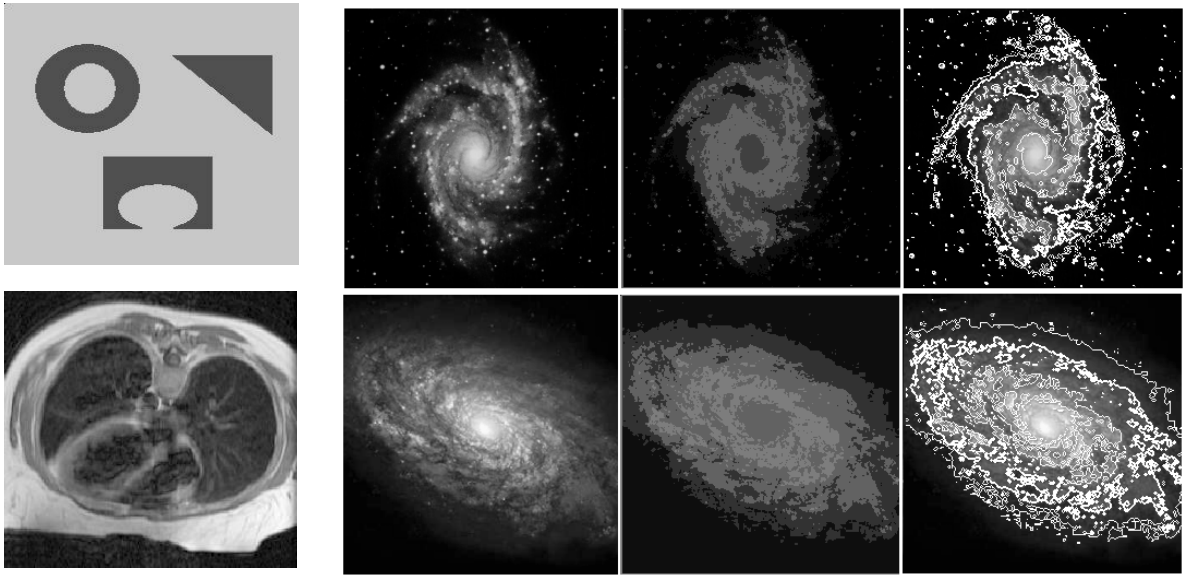
Criteria : Minimize $E[(f(x,y) - \hat{f}(x,y))^2]$

Given image *g*, related to true image *f* through blur *h* and noise η

Inverse Problem: restore *f*, given *h* and statistics for η . Keeping edges sharp and in the correct location is a key problem !

Areas of Image Processing

Segmentation



Objective: Partition an image Ω into *n* sub-regions

$\Omega_i : \Omega = \Omega_1 \cup \ldots \cup \Omega_n$ such that:

1. image data $u(x, y)$ vary smoothly and/or slowly within each Ω_i

2. image $u(x, y)$ varies discontinuously and/or rapidly across the boundary C between different Ω_i

Areas of Image Processing

Inpainting

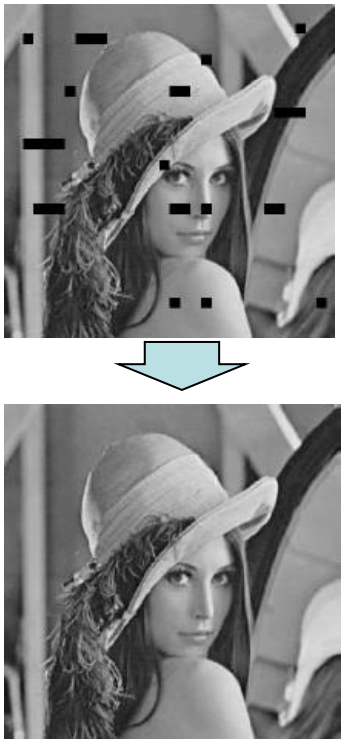


Real inpainting example
from http://www.topcstudio.com/inpainting.htm

- How to estimate some missing or damaged regions in an image?
- Inpainting (retouching, repairing): originated from art conservation or restoration
- A manual procedure to restore a damaged artwork (e.g. mediaeval painting)

Related Subjects to Inpainting

- Disocclusion (object removal, image completion)
  - Fundamentally the same problem as image inpainting



Block recovery [Rane03]

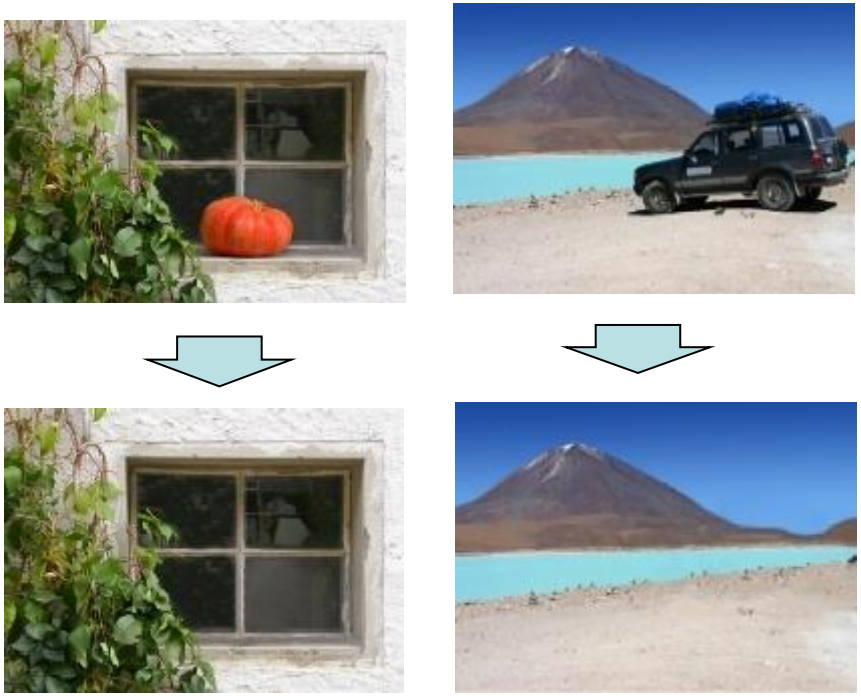
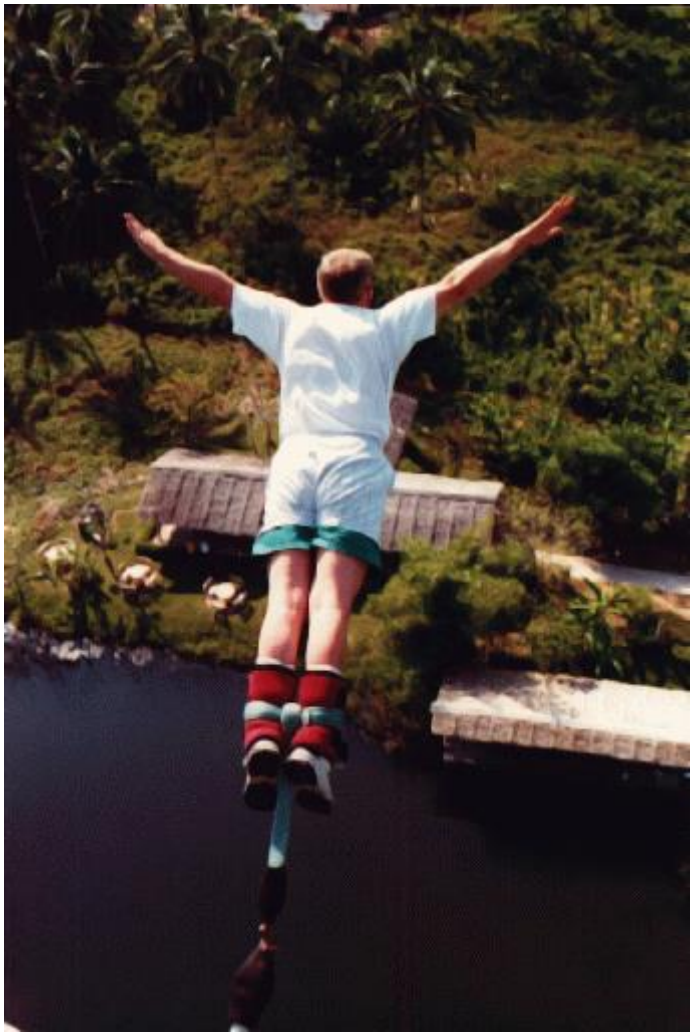


Image completion (object removal) [Sun05]

Automatic Image Inpainting Examples



Courtesy of Beretalmio et al. [Bertalmio2000]
Also see http://www.iua.upf.es/~mbertalmio/restoration1.html

Areas of Image Processing

Super-resolution

Super-resolution (SR) reconstruction is able to produce high-resolution (**HR**) image(s) from a set of low-resolution (**LR**) images. **Color video resolution enhancement using 30 input frames** (courtesy of Dr. Milanfar at UCSC)

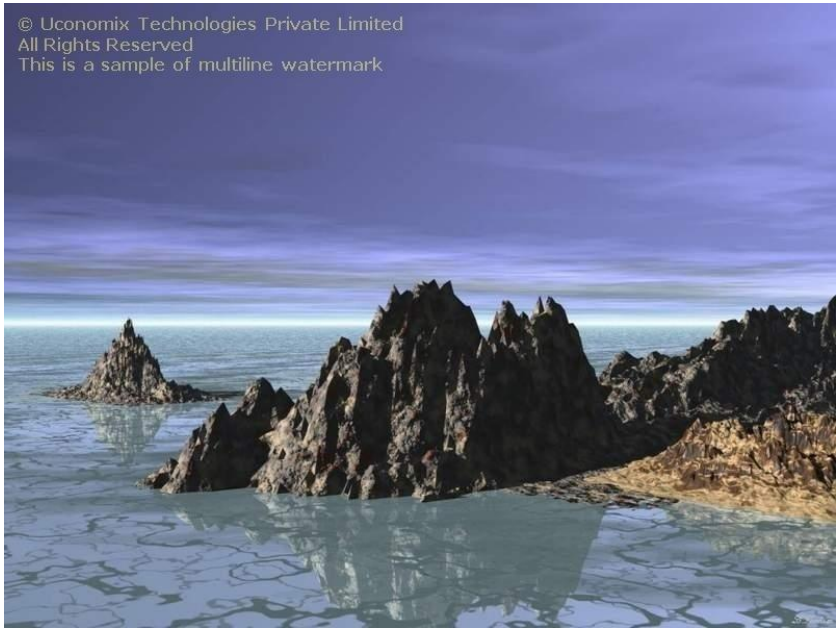
Video-video resolution enhancement using 325 input frames

Areas of Image Processing

Watermarking

What is watermarking?

Watermarking means protecting the image with a copyright notice or a logo that denotes the origin of the image/photo. Such watermark prevents people from using your images and photos without your consent. If they use it they must use it with the your mark.



Face Detection In Images

Other applications: Medical Imaging

Standard x-ray

Functional x-ray

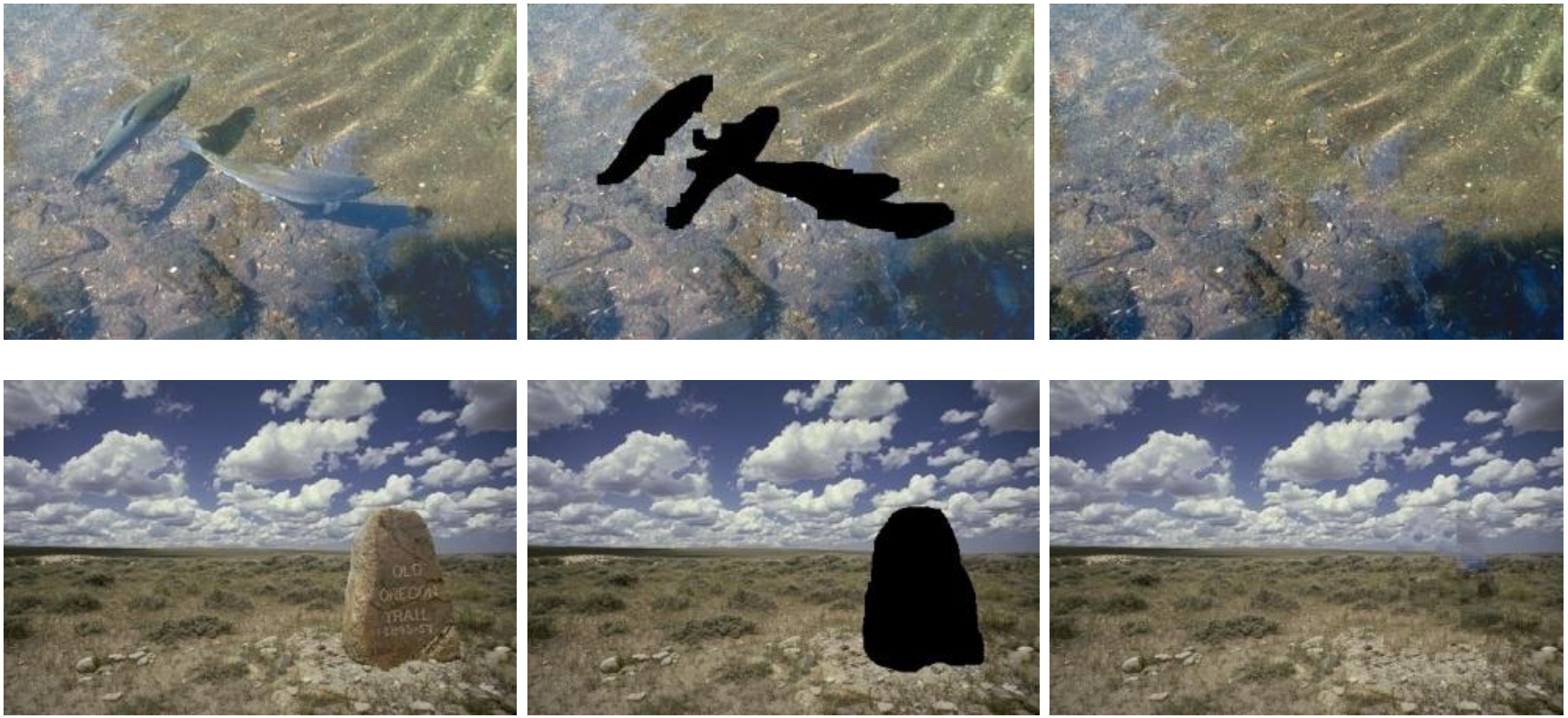
CAT Scan

Our Computer Vision and Image Understanding Center

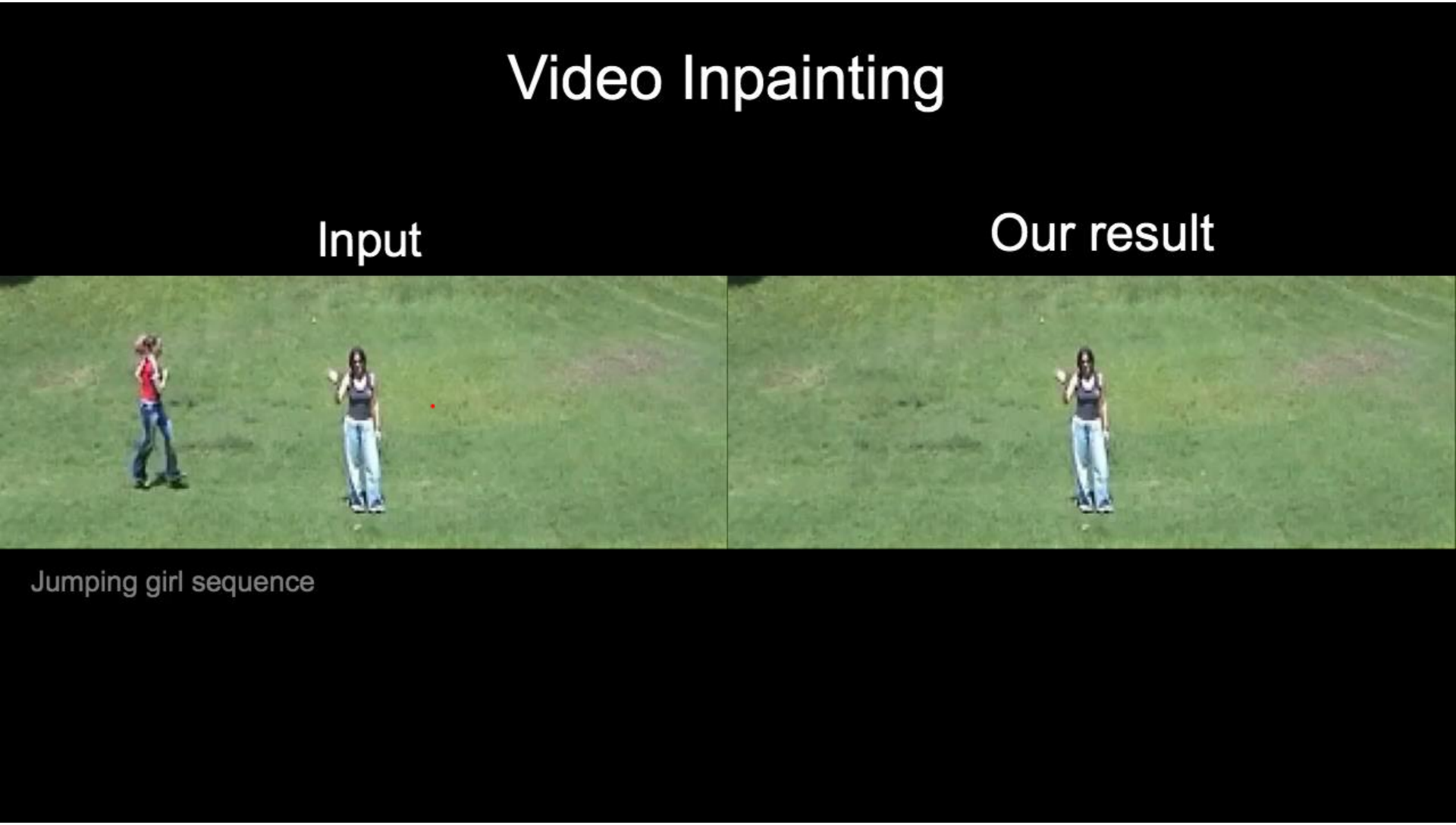
Scene Text Detection

Scene Text Recognition

Image Inpainting

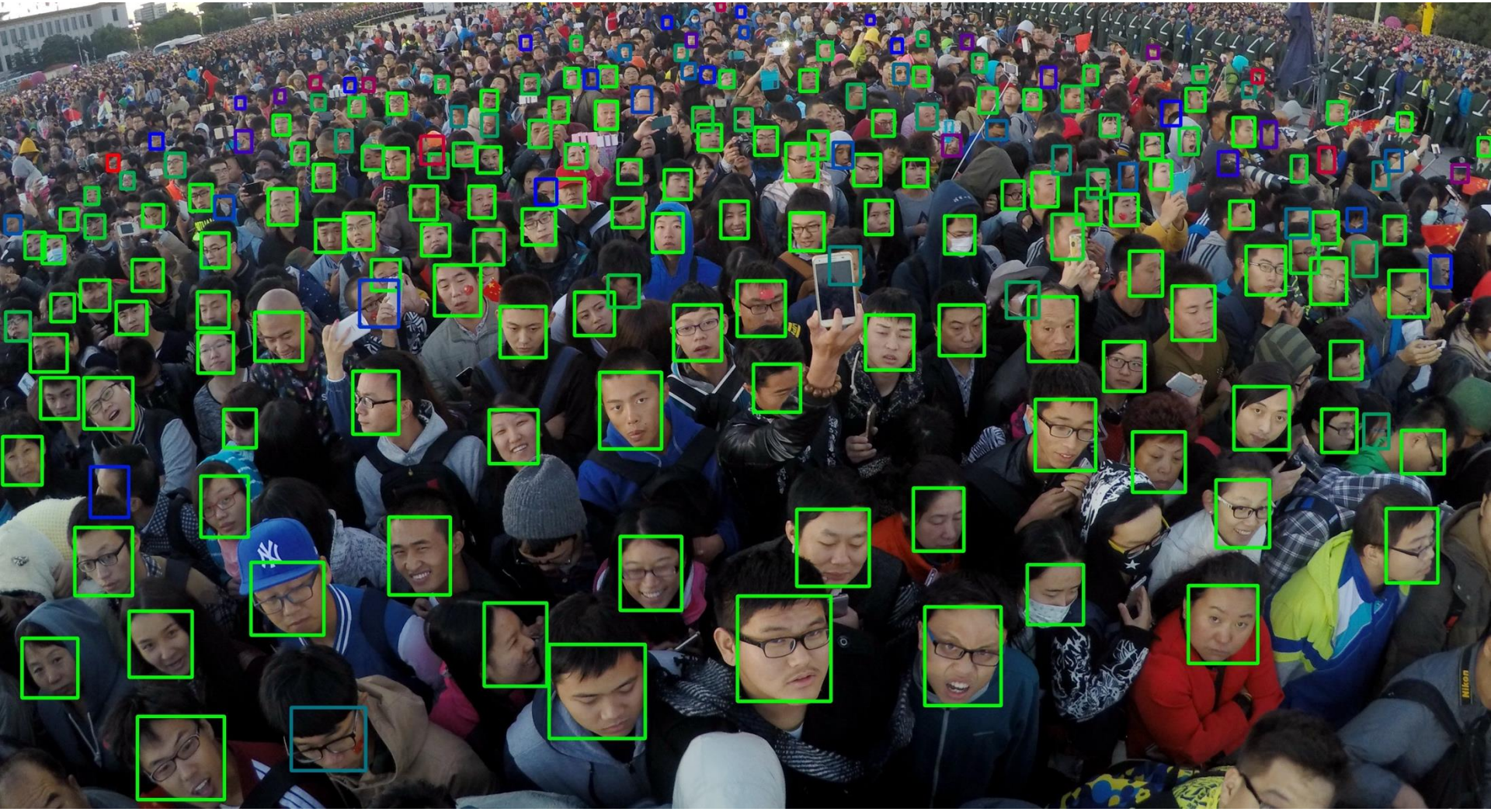


Video Inpainting



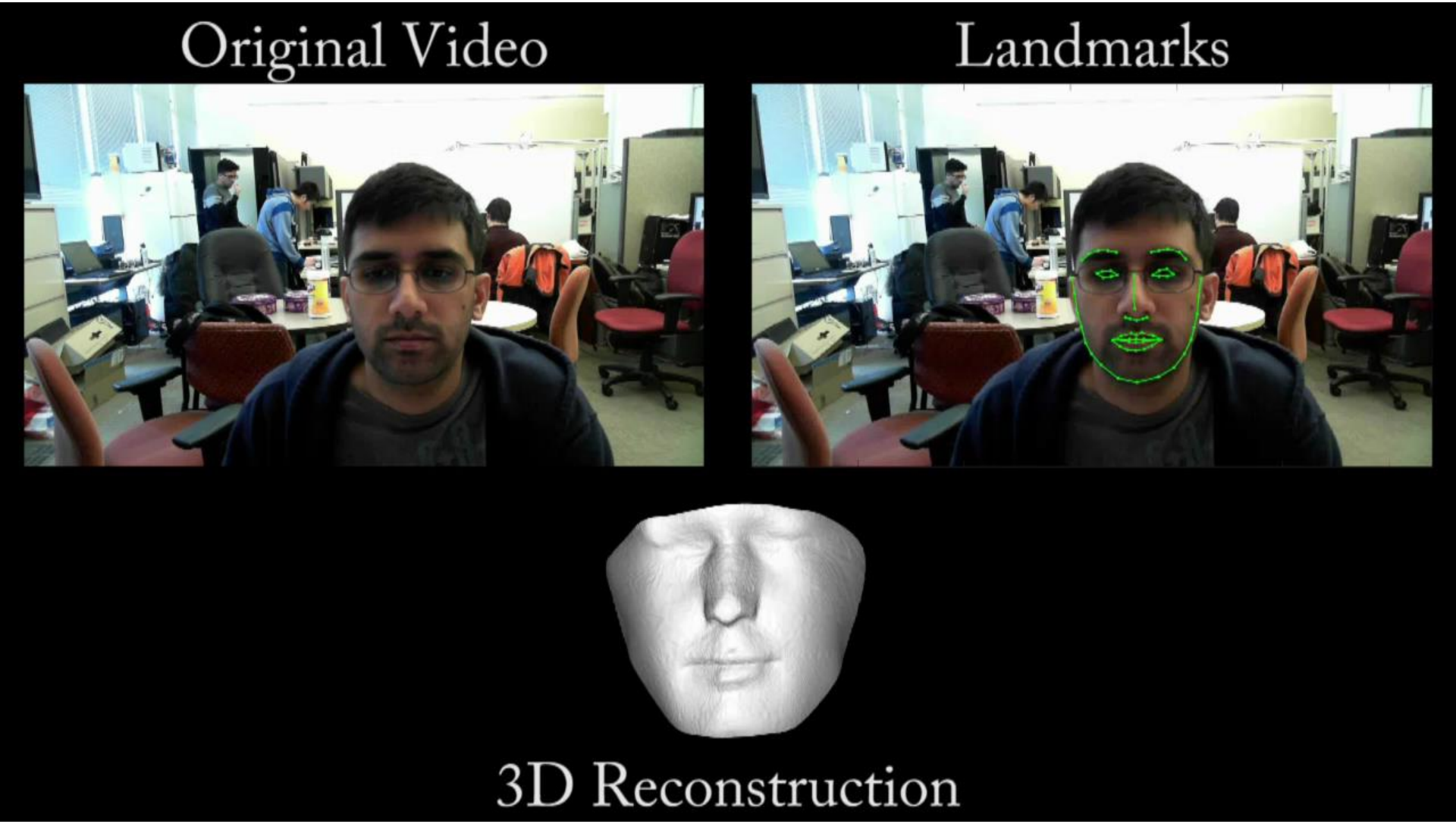
Scene Parsing

Face Detection



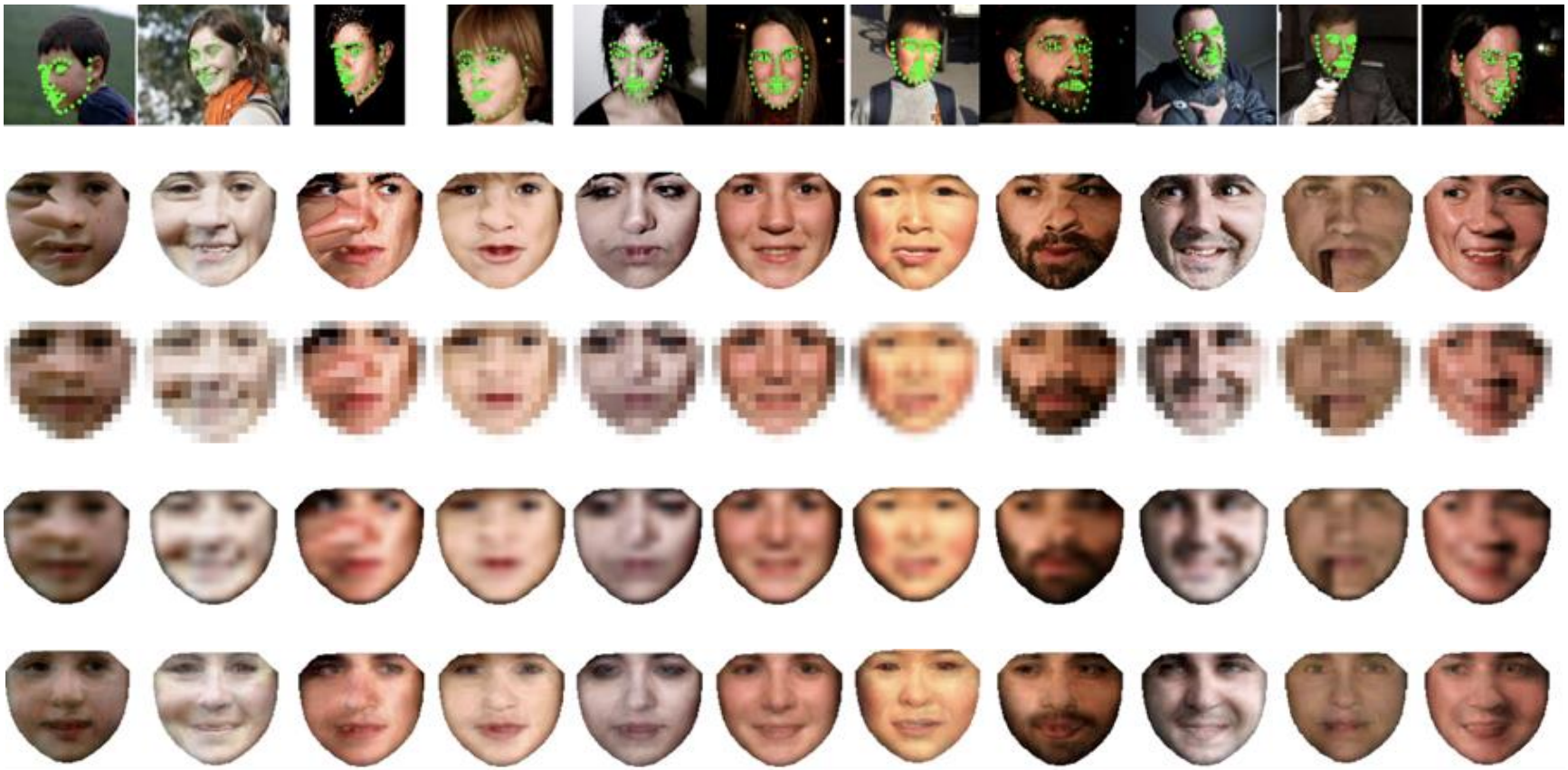
Face Detection

3D Face Modeling



Automatic Face Aging

Face Super-Resolution



Driver Safety Analysis

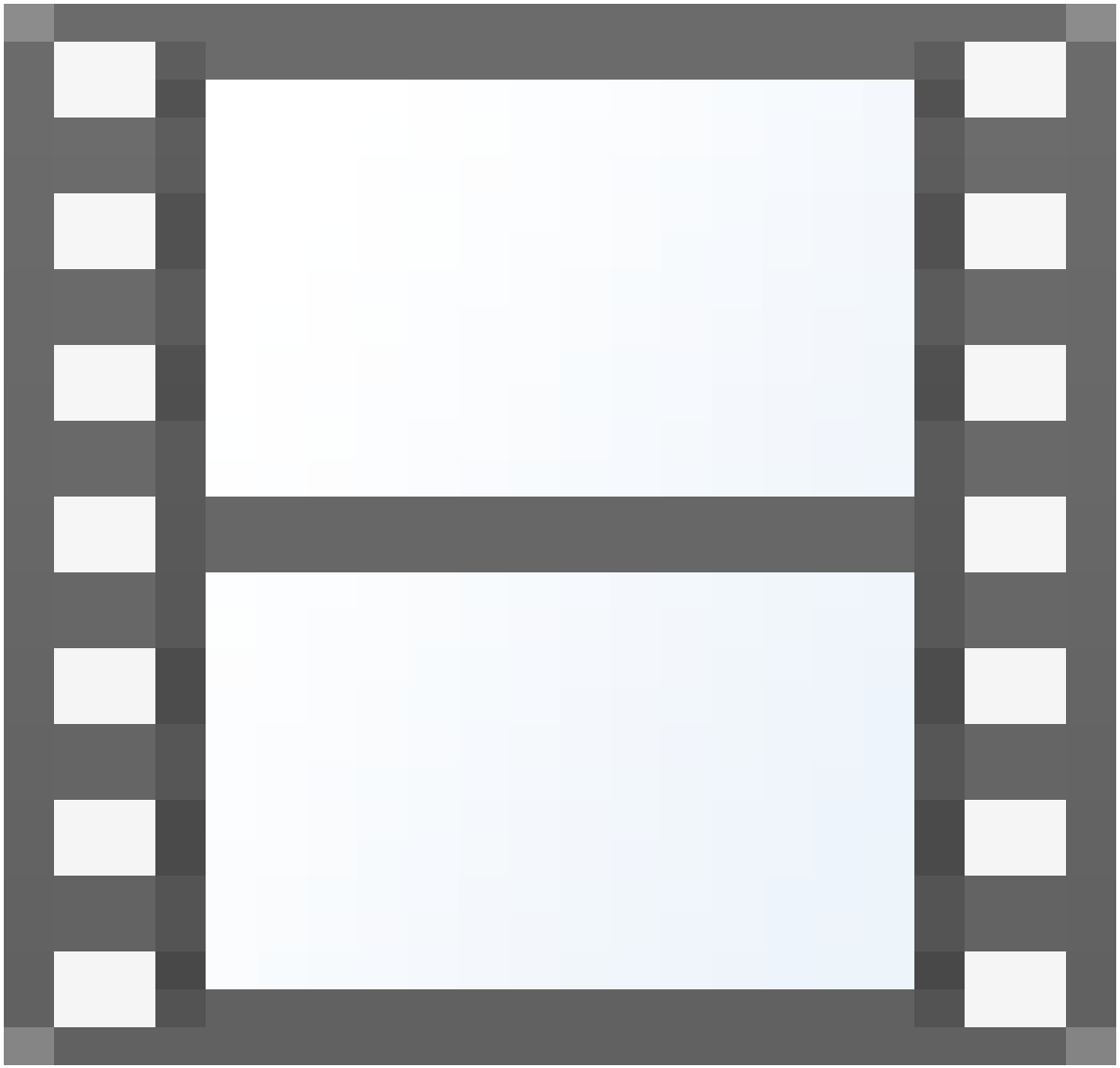
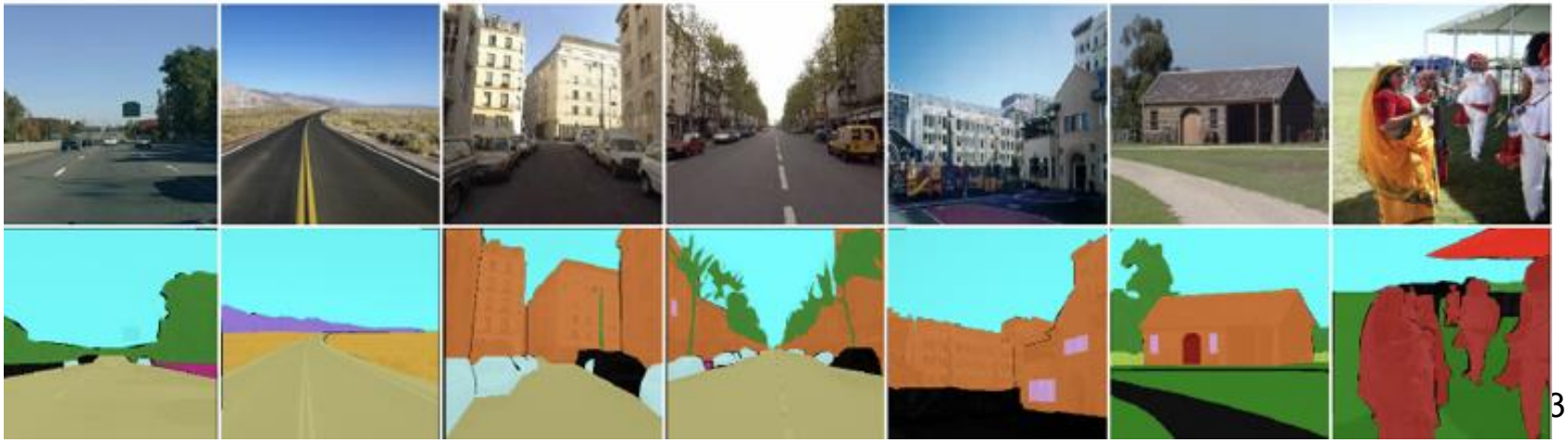


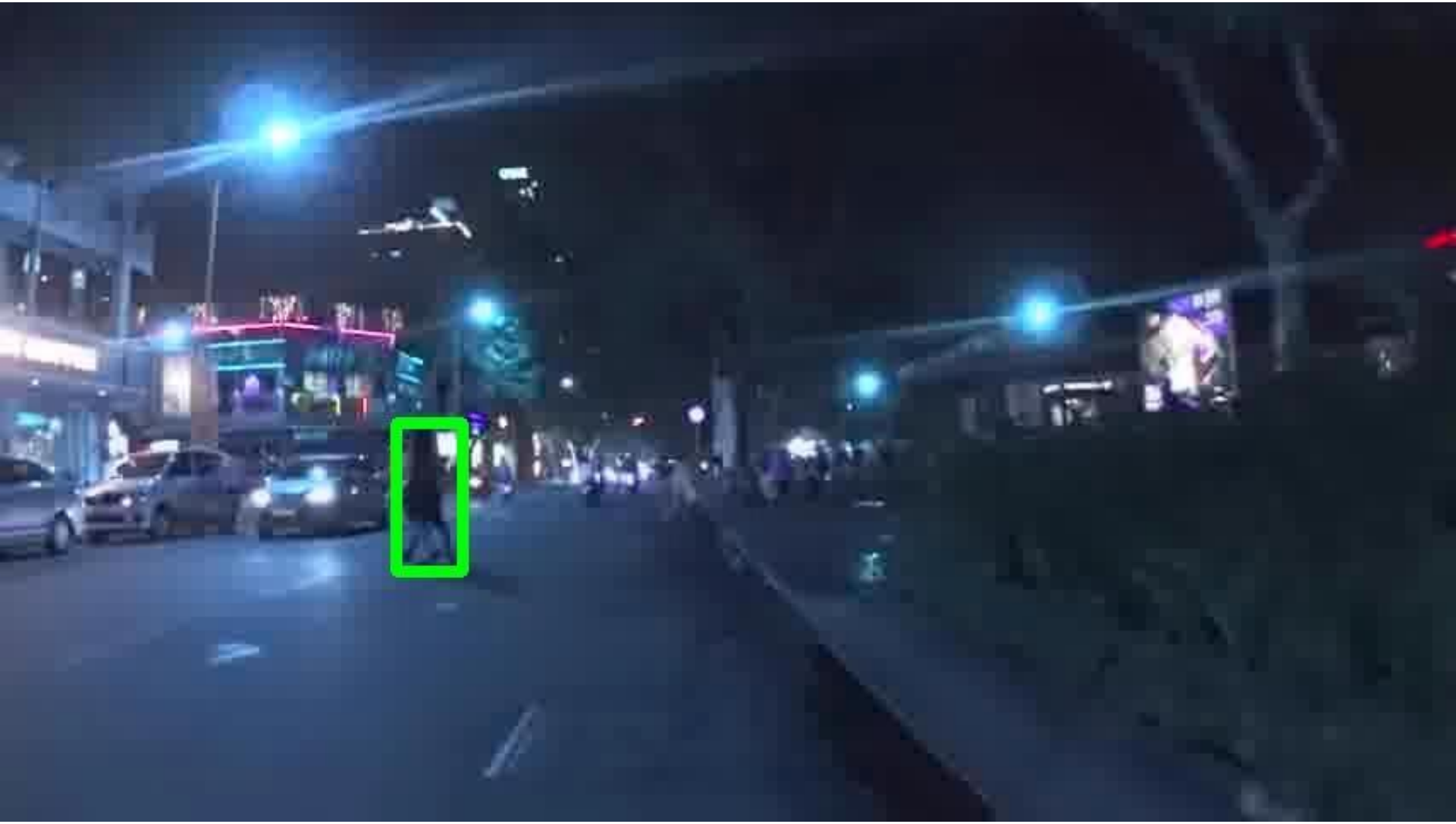
Image Segmentation



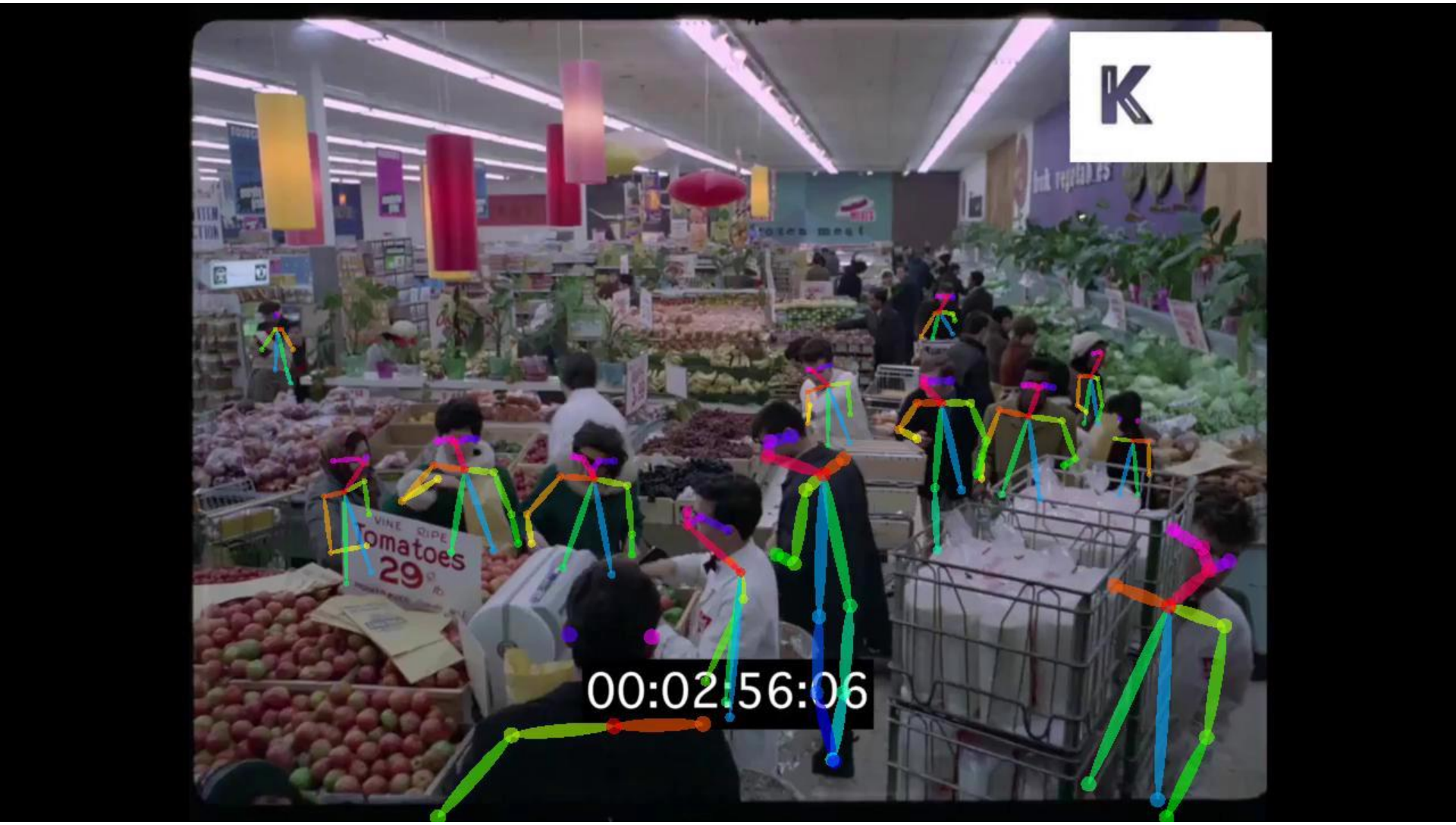
Object Recognition

Human Detection

Human Detection



Human Behavior Understanding



Human Behavior Understanding

Image Enhancement: improving the quality of images (make it better) Or modifying image to bring out hidden features. Two kinds: *spatial domain* and *frequency domain*.

Image Restoration: correcting images subjected to noise, blurs, distortions, atmospheric effects, ...