Digital Image Processing summary

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Artificial Intelligence & Information Analysis Lab

Digital Image Processing

- **Histogram Equalization**
- BW Image Pseudocoloring
- BW Image Halftoning
- Image Mosaicing
- Image Watermarking
- Template Matching
- Background Subtraction
- DNN Image Denoising

Histogram Equalization

Image contrast is a very important image property.

- High image contrast is very desirable, since it is easier to identify an image's details.
- The higher the contrast, the wider the image intensity value range.
- Low contrast images can result from poor illumination, lack of dynamic range in the imaging sensor or wrong setting of the lens aperture during image acquisition.
- Image contrast and hence image quality can be enhanced by modifying image histogram using Histogram equalization/modification.

Histogram Equalization

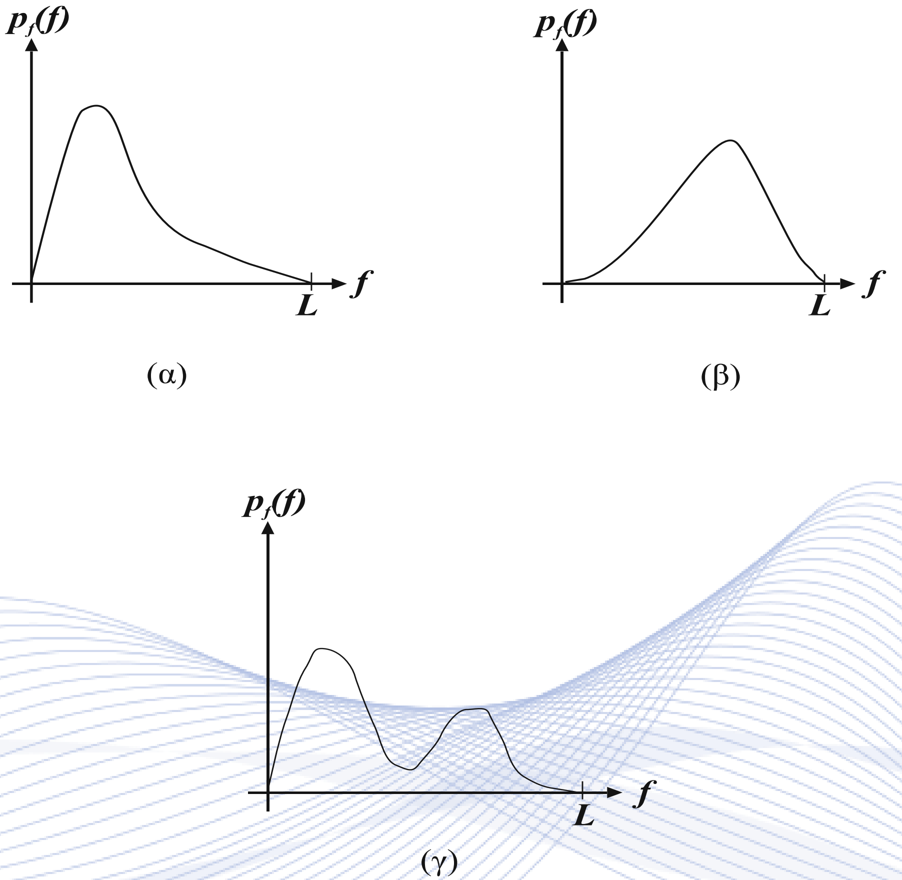
Image histogram $\hat{p}_f$ is an image probability distribution estimator.
It can be calculated by:

$$\hat{p}_f(f_k) = \frac{n_k}{n}, \quad k = 0,1,\ldots,L-1.$$

- n: total number of image pixels.
- n_k, $k = 0,1,\ldots,L-1$: number of image pixels having intensity.

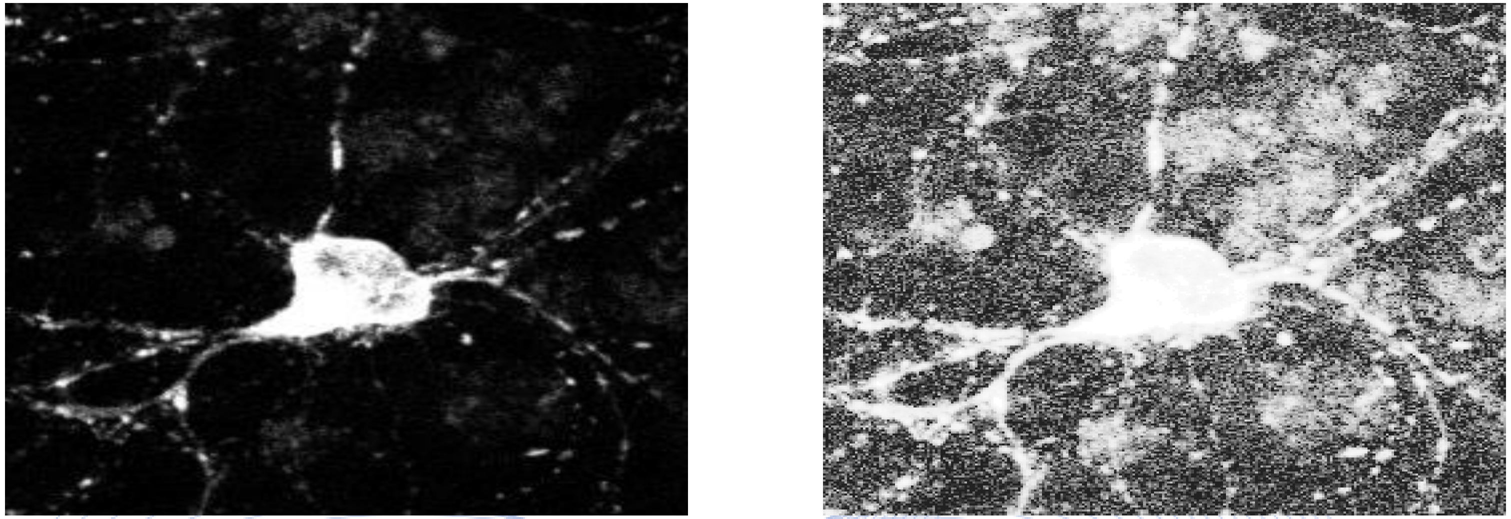
- Image quality can be enhanced by modifying its histogram:
  - Histogram equalization/modification.

Histogram Equalization



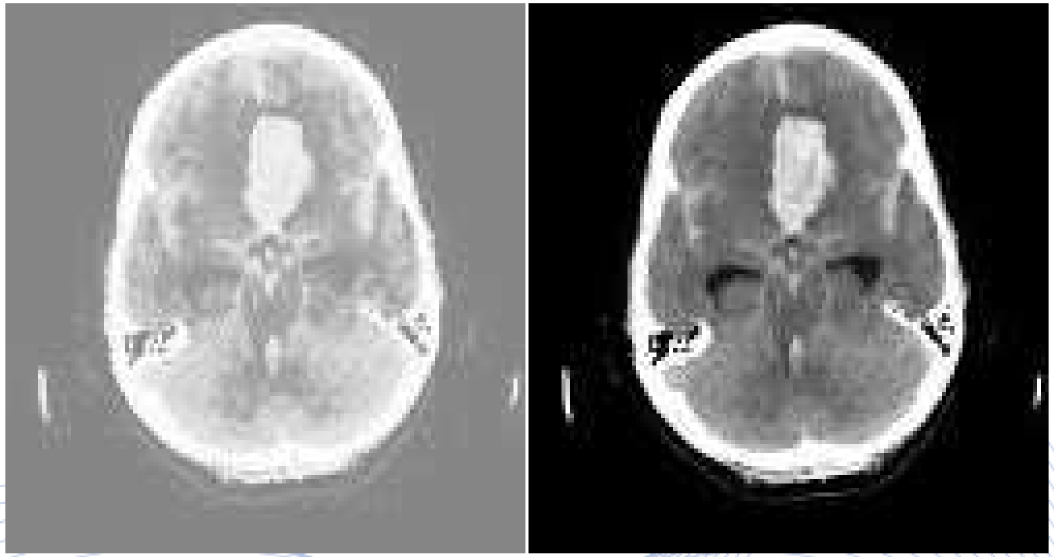
a) Histogram of a dark image; b) Histogram of a bright image; c) Histogram of an image with two intensity concentrating regions (PIT2000]).

Histogram Equalization



a) Original neuron image;
b) Image after histogram equalization.

Histogram Equalization



a) Original image;
b) Image after histogram equalization.

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Image Pseudocoloring

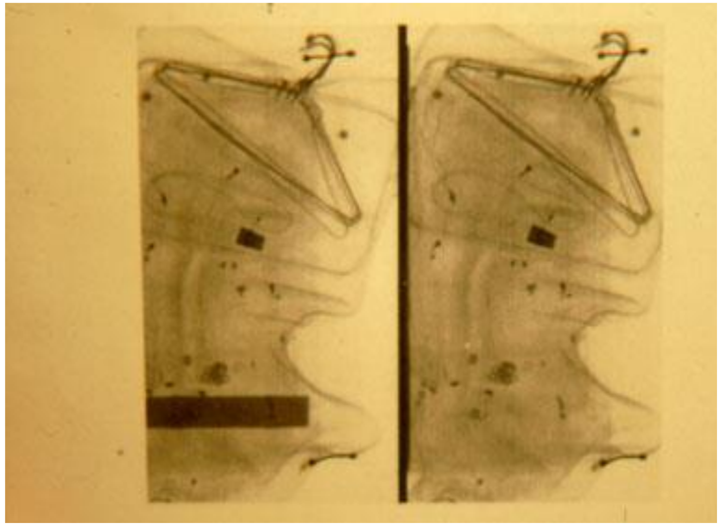
In many applications, acquired images are BW only:

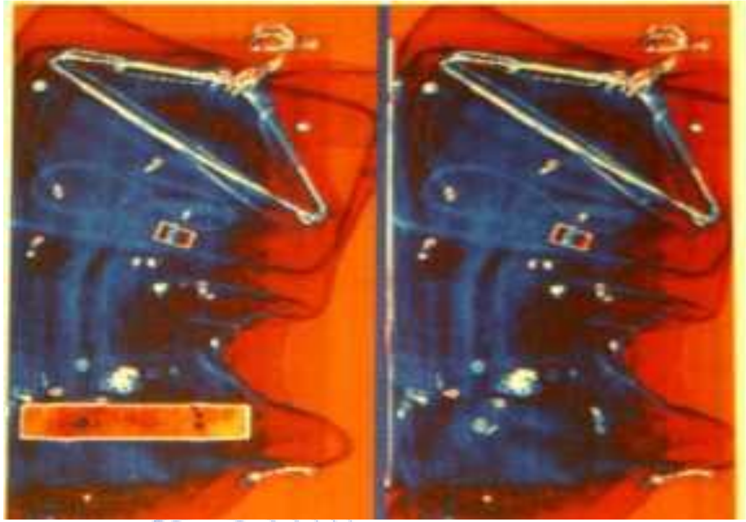
- Medical imaging (e.g., Xray images, CT/MRI images).
- Ultrasound images.
- Seismic images for oil exploration.
- Infrared images.

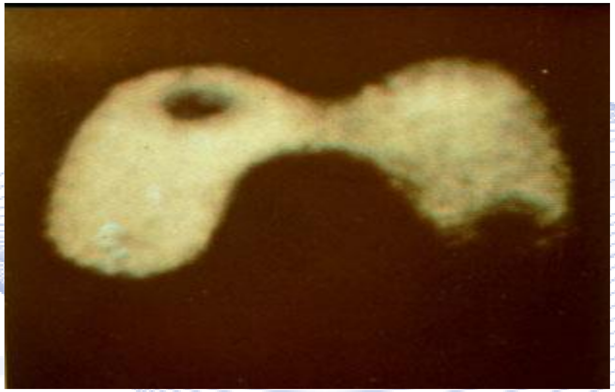
Pseudocoloring transforms BW images to color (RGB) ones, in order to:

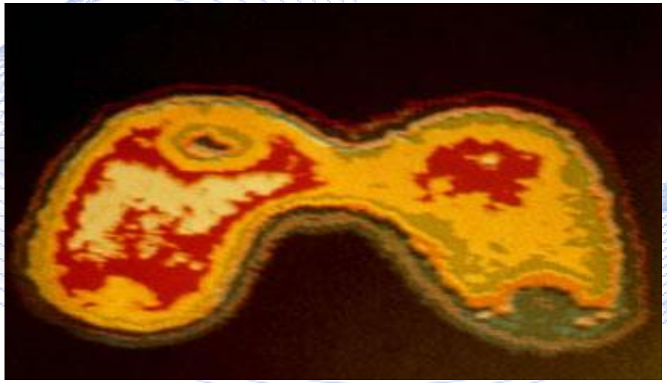
- facilitate inspection operators, doctors, etc.
- Produce aesthetically pleasant BW image visualizations.

Image Pseudocoloring









Original BW images. Pseudocoloured Images.

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Digital Image Halftoning

Digital BW image printing uses only black ink:

- Varying black dot density can create the illusion of printed image greyscales.
- It exploits a Human Visual System (HVS) deficiency:
    - HVS has bandpass characteristics and cannot discern individual black dots.
    - HVS tends to get an overall impression of a local image region.

Digital Image Halftoning

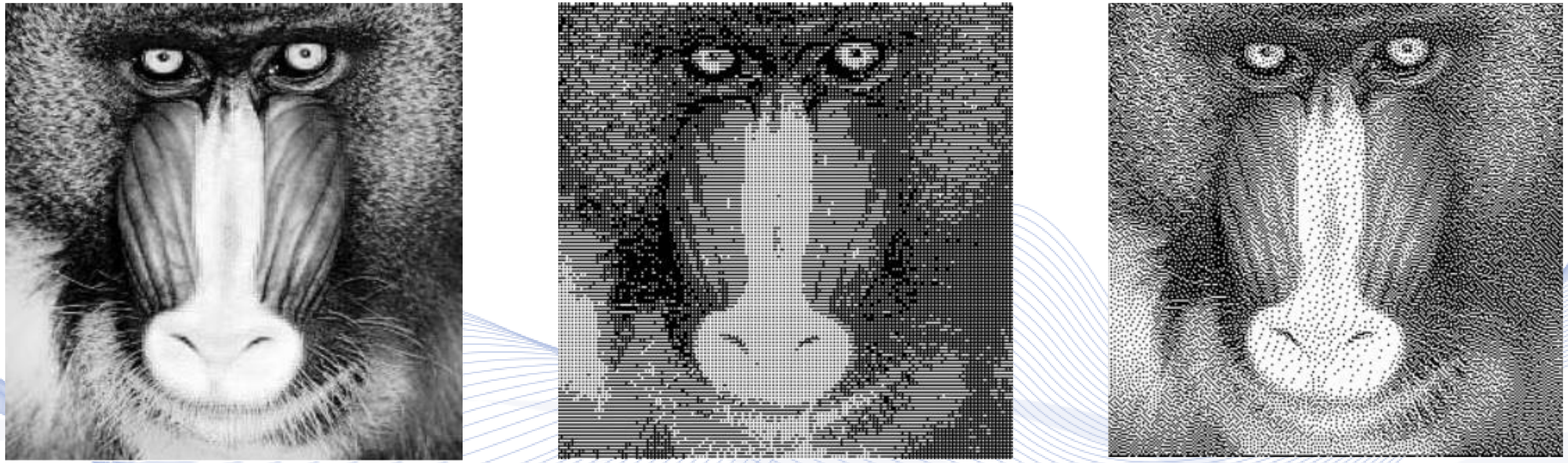
a) Original Image; b) Thresholded image with $T = 100$;
c) Thresholded image with $T = 200$.

Digital Image Halftoning

a) Original image; b) Original image subsampled by
a factor of 2; c) Halftoned image using greyscale binary fonts.

Digital Image Halftoning

Pseudorandom Thresholding:



a) Original image; b) Halftoned image using 10 binary fonts;
c) Dithering output of $n = 8$.

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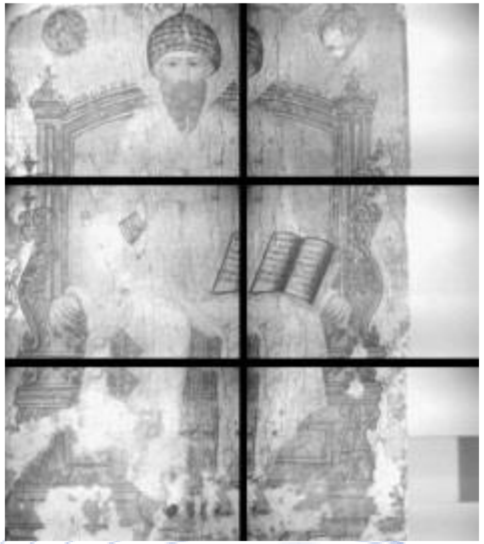
Image Mosaicing

- Detailed reconstruction of large images, by successively acquiring and mosaicking image patches.
- Image assembly is achieved by finding similarities in the overlapping image patch regions.

- For smooth image intensity transition between regions with different illumination, the contributions of pixels coming from different areas are weighted based on the distance of each pixel from the respective image patch border.
- This ensures a smooth luminance transition between the mosaiced image patches.

Image Mosaicing



a) Original set of Byzantine painting image patches; b) Resulting mosaiced image.

Image Mosaicing

- 2D affine transformation for image registration.
- Overlapping image regions are registered and mosaiced.

Image Mosaicing

Final image after mosaicing.

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Image Watermarking

- ***Data hiding*** or ***steganography***: Invisible data (***watermark***) are embedded in an image,
  - It can act as proof of IP ownership.
- ***Authentication or tamper-proofing***: Signals an authentication violation, when the visual content is significantly modified and pinpoints the altered image regions.

Watermarks should be:

- undeletable, easily and securely detectable by the owner and resistant to standard image processing operations.
- Modified (if inserted for authentication purposes), when the image is manipulated.

Image Watermarking

- A typical watermarking technique generates a 2D watermark pattern $w(n_1, n_2)$ for embedding in a host image $x(n_1, n_2)$ of same dimensions, e.g., in an additive way:

$$x'(n_1, n_2) = x(n_1, n_2) + w(n_1, n_2).$$

- Simple watermark detection is performed using zero-lag correlation:

$$r_{x'w}(0,0) = \sum_{n_1, n_2} w(n_1, n_2) x'(n_1, n_2).$$

Image Watermarking

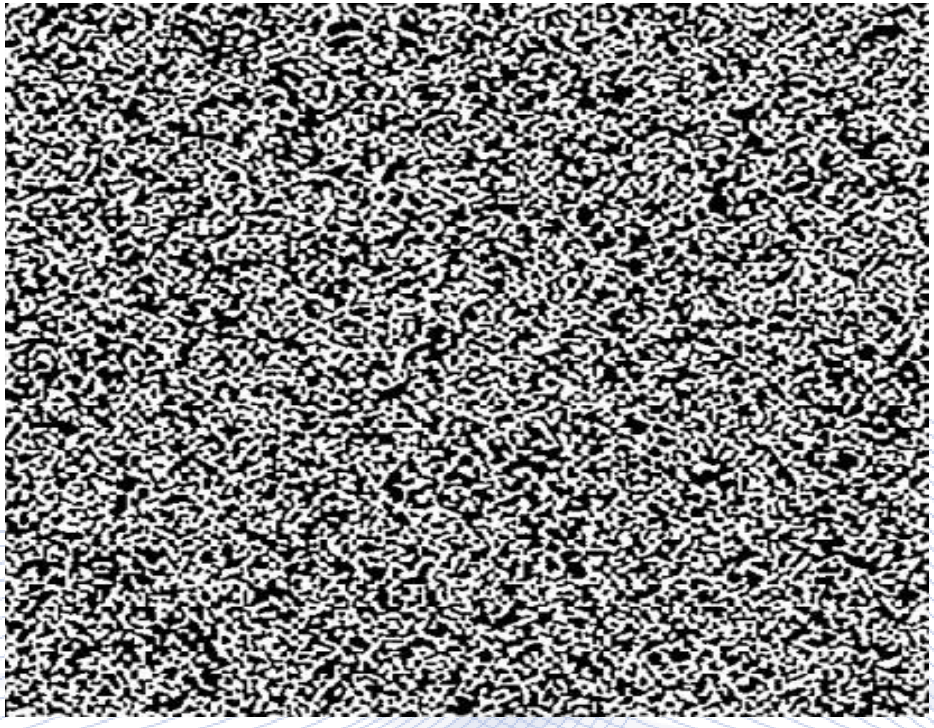

Image watermark.

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Template Matching

Template matching can be used to detect a particular feature (e.g., an object) in an image by using a subimage identical to that of the object (***object template***).

- It computes a similarity measure, e.g., ***template-image cross-correlation*** which reflects how well the image data match the template for each possible location. The point of maximal match is the location of the feature.

- Mostly used to identify printed characters, numbers, and other small, simple objects.

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Background Subtraction

Background subtraction removes background image variations, by first approximating them with a background image $f_b(x)$ which is then subtracted from the original one.

Background image $f_b(x,y)$ can be modeled as:

- a constant c.
- A linear plane: $f_b(x,y) = mx + c$.
- A low pass version of the original image:

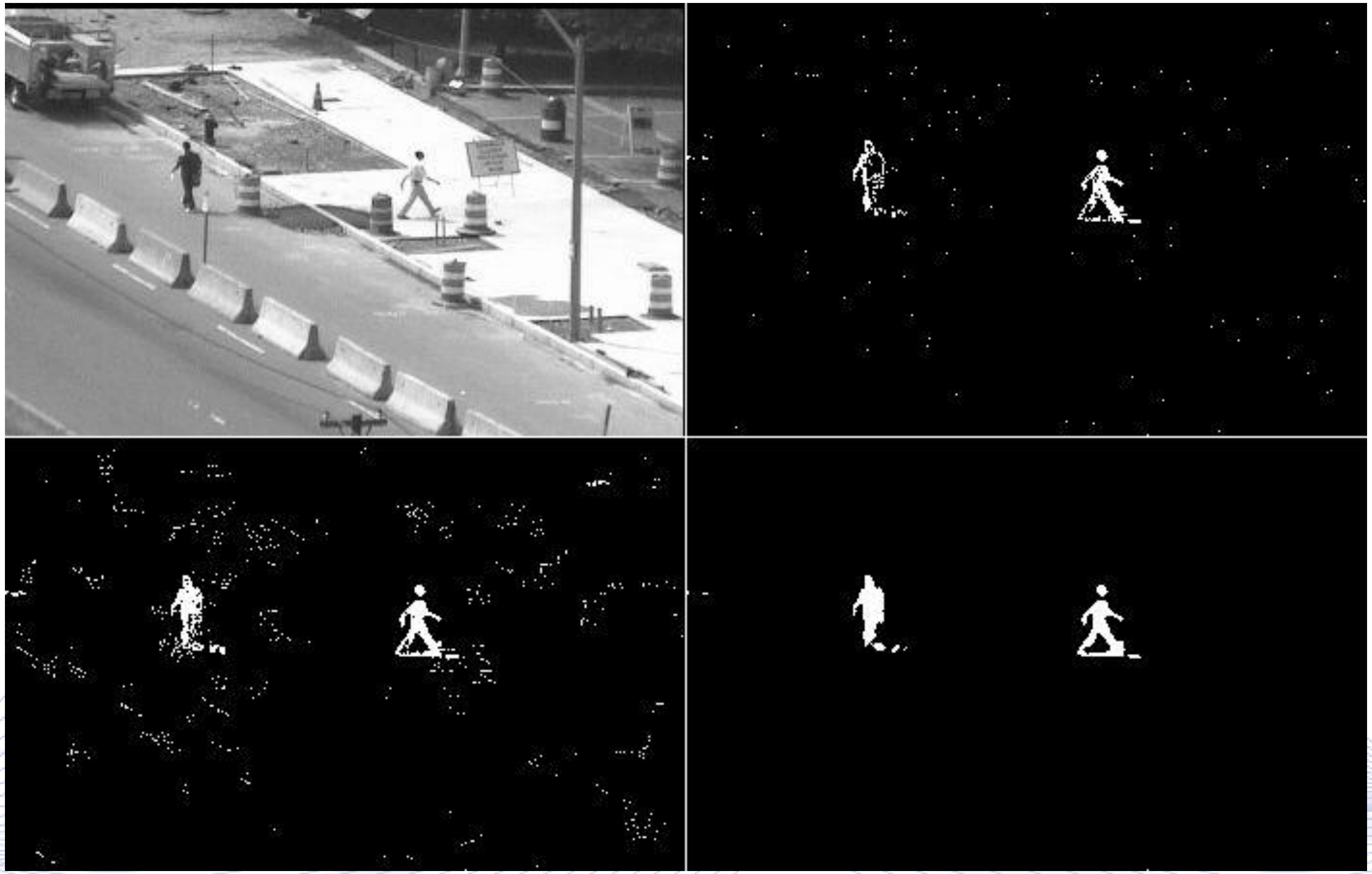
$$f_b(x,y) = f(x,y) ** h(x,y),$$

where $h(x,y)$ is a low-pass filter.

- The image after background removal is given by:

$$f_n(x) = f(x) - f_b(x).$$

Background Subtraction



Background subtraction [HUG2009].

Background Subtraction

SVD background subtraction: *Singular Value Decomposition* is the generalization of the *Eigen* decomposition of a square matrix into any $d \times n$ matrix.

It is used to decompose a matrix **A** into:

$$\boldsymbol{A} = \boldsymbol{U}\boldsymbol{\Sigma}\boldsymbol{V}^T.$$

$\boldsymbol{U}, \boldsymbol{V}$: orthogonal matrices of dxd and nxn size, respectively.

$\boldsymbol{\Sigma}$: diagonal $d \times n$ matrix:

$$\boldsymbol{\Sigma} = \begin{bmatrix} \boldsymbol{\Sigma}' & 0 \\ 0 & 0 \end{bmatrix},$$

where $\boldsymbol{\Sigma}'$ has strictly positive diagonal values.

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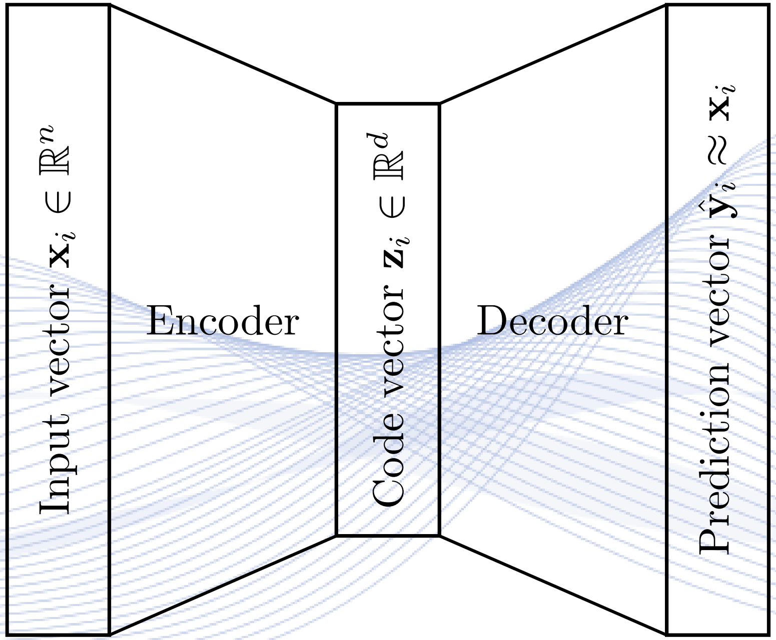
DNN Image Denoising

Autoencoders

Given a sample $\mathbf{x} \in \mathbb{R}^n$ and a DNN function $\hat{\mathbf{y}} = \boldsymbol{f}(\mathbf{x}; \boldsymbol{\theta})$, the model output $\hat{\mathbf{y}}$ should be equal to the model input $\mathbf{x}$.



Autoencoder structure ([PIT200]).

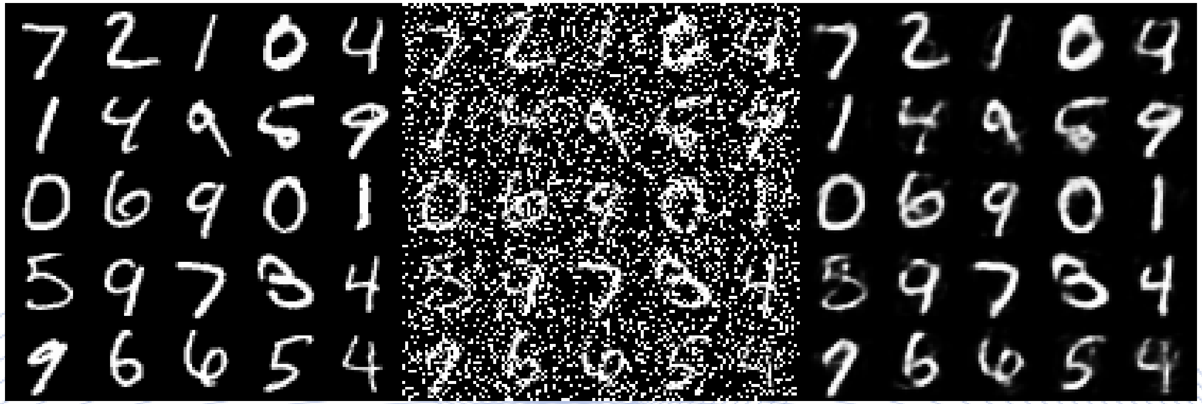
DNN Image Denoising

Autoencoder Training:

- Given N pairs of training examples $\mathcal{D} = \{(\mathbf{x}_i, \mathbf{y}_i), i = 1, \dots, N\}$, where $\hat{\mathbf{y}}_i = \mathbf{x}_i,\ \mathbf{x}_i \in \mathbb{R}^n$.
- Autoencoder estimates θ by minimizing the loss function:

$$\boldsymbol{\theta}^* = \underset{\boldsymbol{\theta}}{\operatorname{argmin}}\, J(\mathbf{x}, \hat{\mathbf{y}}).$$

DNN Image Denoising



Denoising Autoencoder [MON2021].

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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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