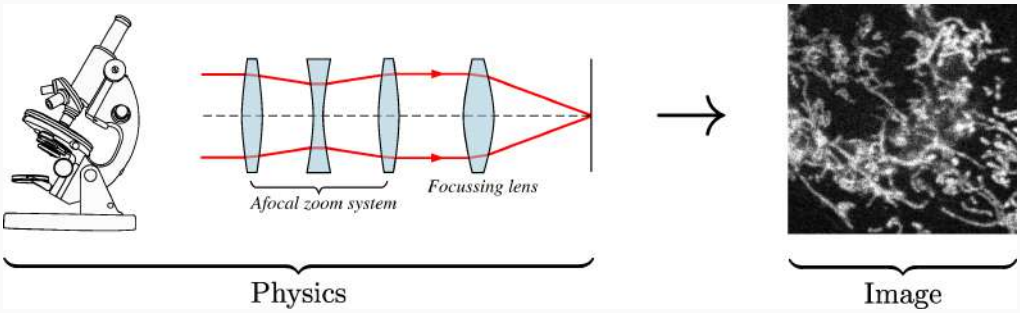
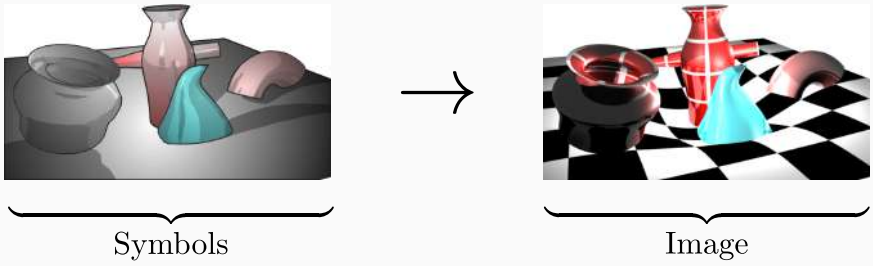
Imaging sciences – Overview

- Imaging:



Modeling the image formation process

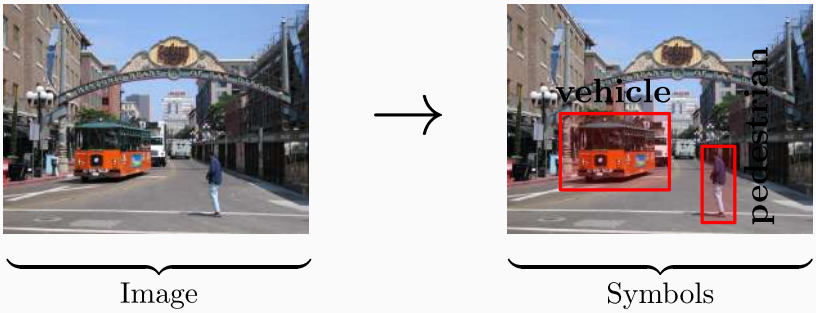
- Computer graphics:



Rendering images/videos from symbolic representation

Imaging sciences – Overview

- Computer vision:

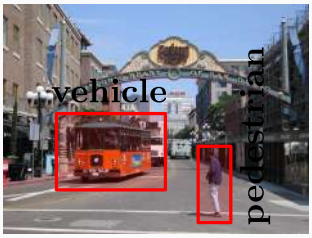


Extracting information from images/videos

Imaging sciences – Overview

- Computer vision:

Image



Symbols

Extracting information from images/videos

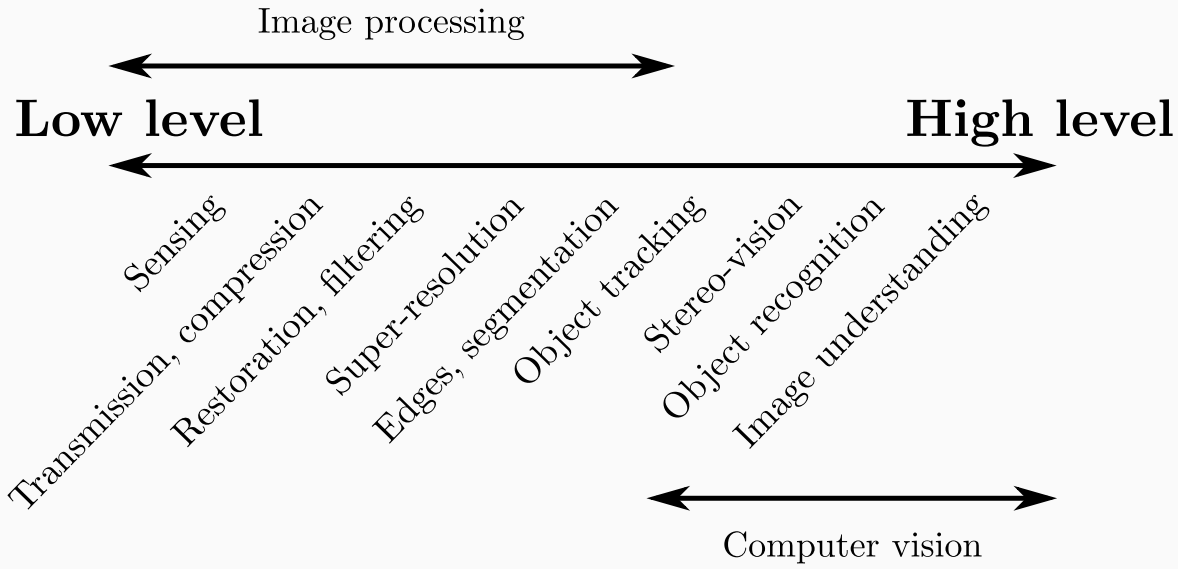
- Image/Video processing:

Image

Image

Producing new images/videos from input images/videos

Imaging sciences – Image processing



Imaging sciences – Image processing

Denoising

Enhancement

Compression

Feature detection

Inpainting

Super-resolution

Source: Iasonas Kokkinos

- Image processing: define a new image from an existing one
- Video processing: same problems + motion information

Imaging sciences – Image processing

Denoising

Enhancement

Compression

Feature detection

Inpainting

Super-resolution

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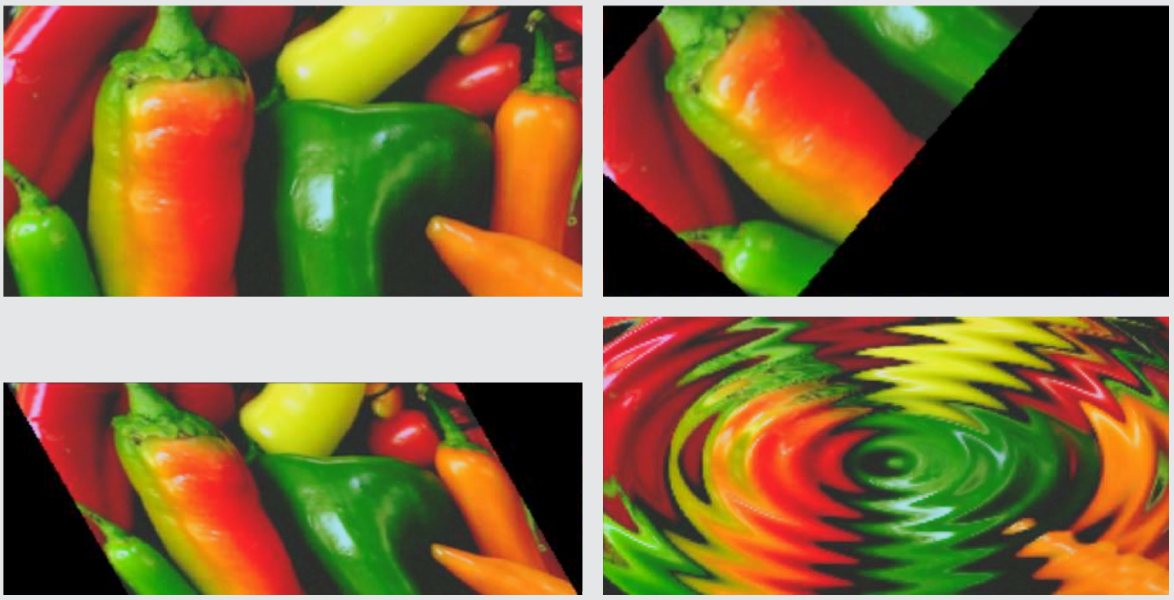
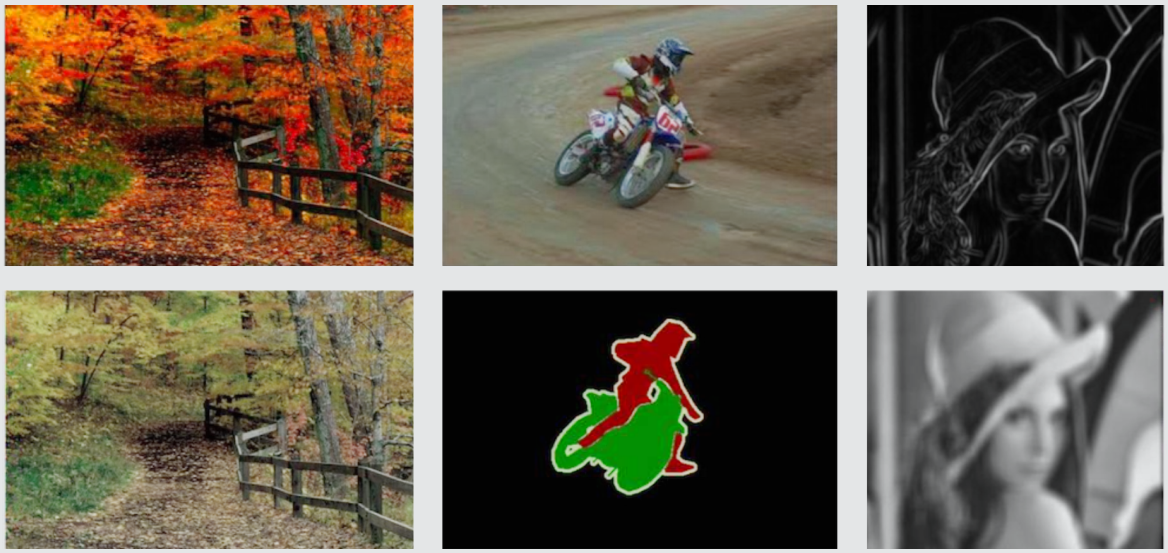
- Image processing: define a new image from an existing one
- Video processing: same problems + motion information

Geometric transform



Change pixel location

Colorimetric transform



- Filtering: change pixel values
- Segmentation: provide an attribute to each pixel

Imaging sciences – Photo manipulation

Photo manipulation – Applications & Techniques (sources Wikipedia)

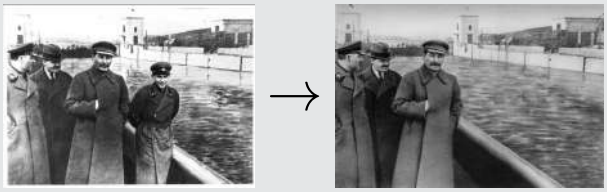
Media industry

Skin flaw removal (Minnie Driver by Justin Hoch)

Art

Editing (by Achraf Baznani)

Propaganda



Joseph Stalin with Nikolai Yezhov entirely removed after retouching

- Media / Journalism / Advertising
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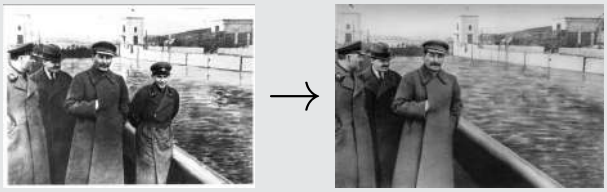

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- Color & contrast enhancement
- Image sharpening (reduce blur)
- Removing elements (inpainting)
- Removing flaws (skin, scratches)
- Image compositing/fusion
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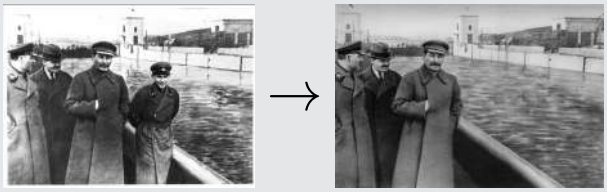

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Often handmade by graphic designers/artists/confirmed amateurs
or aided with raster images/graphics editor

Classical editors: Adobe Photoshop (commercial), GIMP (free and open-source)

Imaging sciences – Is image processing = Photo manipulation?

Photo manipulation

- Manual/Computer aided
- Performed image per image
- Users: artists, graphic designers
- Target: general public
- Input: photography
- Goal: visual aspects

v.s

Main image processing purposes

- Automatic/Semi-supervised
- Applied to image datasets
- Users: industry, scientists
- Target: industry, sciences
- Input: any kind of $\geqslant$ 2d signals
- Goal: measures, post analysis

Photo

v.s

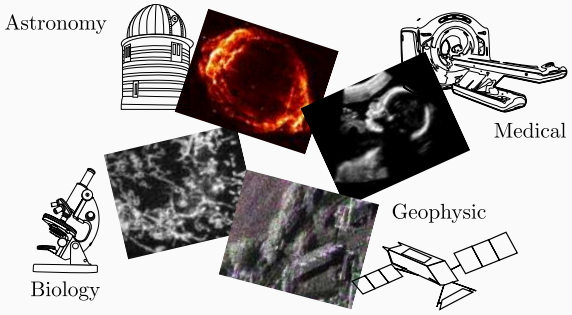

Photo manipulation uses some image processing tools

Scope of image processing is much wider than photography

Imaging sciences – Related fields

Multidisciplinary of Image processing

Intersection of several covering fields

- **Physics and biology:** link between phenomena and measures
- **Mathematics:** analyze observations and make predictions
- **Computer science:** algorithms to extract information
- **Statistics:** account for uncertainties in data

Imaging sciences – Related fields

Multidisciplinary of Image processing

Intersection of several covering fields

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Differences with signal processing

- Image processing: subset of signal processing
- Inputs and outputs: images, series of images or videos
- Content: sound waves, stock prices behave differently
- Signals are usually causal: $f(t_0)$ depends only on $f(t)$ for any time $t \leqslant t_0$
- Images are non-causal: $f(s_0)$ may depend on $f(s)$ for any position s

Imaging sciences – What is image restoration?

What is image restoration?

- Subset of image processing
- Input: corrupt image
- Output: estimate of the clean/original image
- Goal: reverse the degradation process

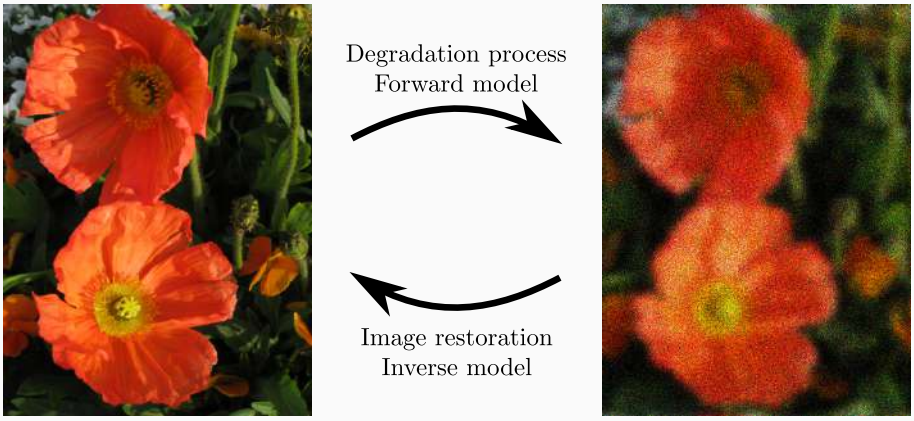

Image restoration requires **accurate models** for the degradation process.
Knowing and modeling the sources of corruptions is essential.

Imaging sciences – Why image restoration?

Why image restoration?

- Artistic value?
- or, Automatic image analysis?
  - Object recognition
  - Image indexation
  - Image classification
  - ...
- Usually one of the first steps in computer vision (CV) pipelines.

Pointillism (Georges Seurat, 1884-1886)

- A source of inspiration to perform higher level tasks.

What is an image?

La Trahison des images, René Magritte, 1928
(Los Angeles County Museum of Art)

Imaging sciences – What is an image for the general public?

Definition (Collins dictionary)

image, *noun*: the visual impression of something produced by reflection from a mirror, refraction through a lens, etc.

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- Something you can visualize on a display
- A representation/impression of something

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- Obtained/Produced form a device — How has it been acquired?
- Something you can visualize on a display — What is the format?
- A representation/impression of something — What is the content?

Imaging sciences – What is an image for a mathematician?

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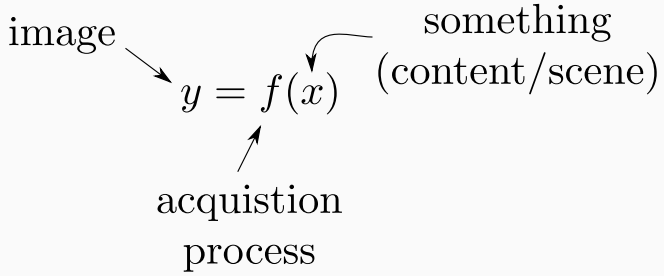
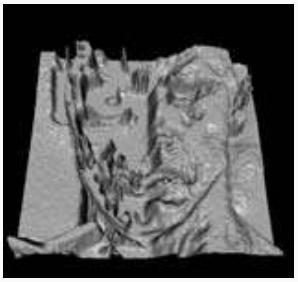
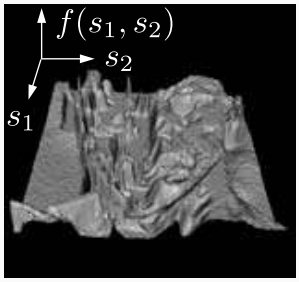


Imaging sciences – What is an image for us?

A function?

- Think of an image as a function f from $\mathbb{R}^2$ (2d space) to $\mathbb{R}$ (values).
- $f(s_1, s_2)$ gives the intensity at location $(s_1, s_2) \in \mathbb{R}^2$.
- In practice, usually limited to: $f : [0, 1]^2 \to \mathbb{R}$.





Source: Steven Seitz

Convention: larger values correspond to brighter colors.

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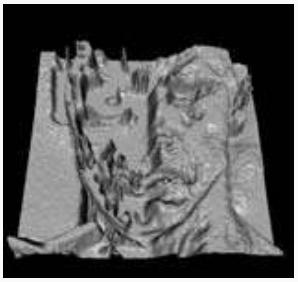

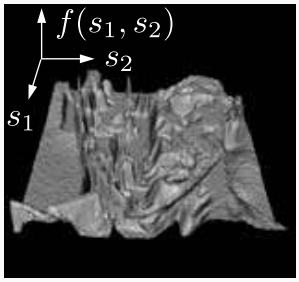

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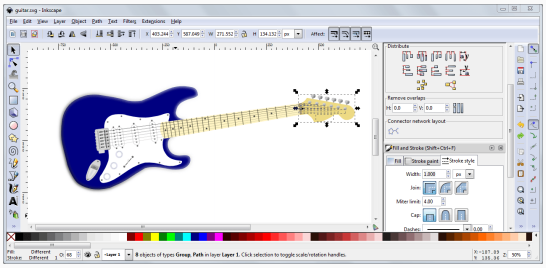
Convention: larger values correspond to brighter colors.

A color image is defined similarly as a 3 component vector-valued function:

$$f(s_1, s_2) = \begin{pmatrix} r(s_1, s_2) \\ g(s_1, s_2) \\ b(s_1, s_2) \end{pmatrix} .$$

Imaging sciences – Types of images

- Continuous images:
  - Analog images/videos,
  - Vector graphics editor, or (Adobe Illustrator, Inkscape, ...)
  - 2d/3d+time graphics editors. (Blender, 3d Studio Max, ...)
  - Format: `svg`, `pdf`, `eps`, `3ds`...
- Discrete images:
  - Digital images/videos,
  - Raster graphics editor. (Adobe Photoshop, GIMP, ...)
  - Format: `jpeg`, `png`, `ppm`...
- All are displayed on a digital screen as a digital image/video (rendering).

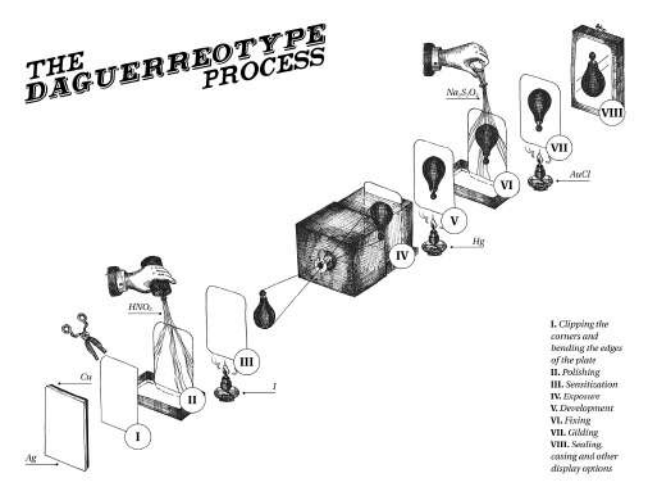


(a) Inkscape

(b) Gimp

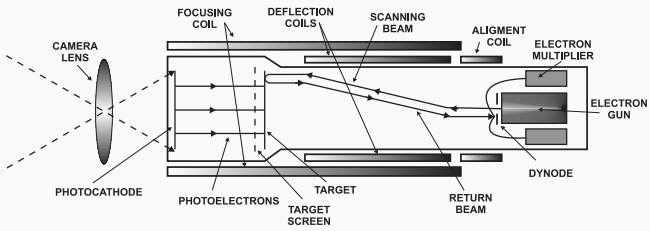
Imaging sciences – Types of images – Analog photography

- Progressively changing recording medium,
- Often chemical or electronic,
- Modeled as a continuous signal, *e.g.*:
  - Gray level images: $[0,1]^2 \to \mathbb{R}$ position to gray level,
  - Color images: $[0,1]^2 \to \mathbb{R}^3$ position to RGB levels.



(a) Daguerrotype

(b) Roll film



(c) Orthicon tube

Example (Analog photography/video)

- First type of photography was analog.

(a) Daguerrotype

(b) Carbon print

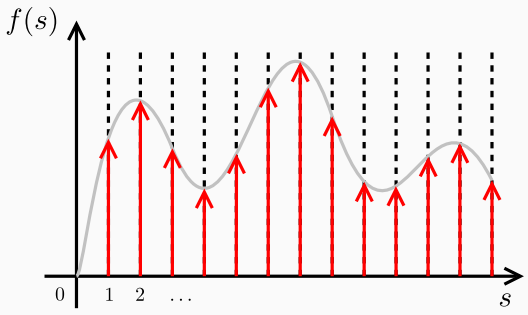
(c) Silver halide

- Still in used by photographs and the movie industry for its artistic value.

(d) Carol (2015, Super 16mm)

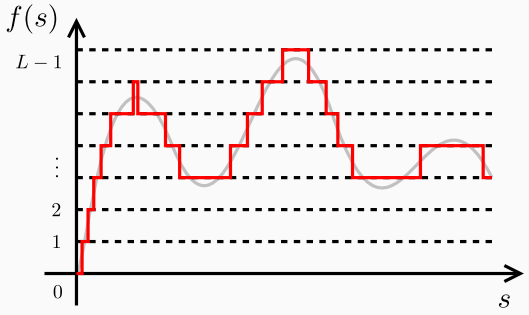
(e) Hateful Eight (2015, 70mm)

(f) Grand Budapest Hotel (2014, 35mm)



Raster images

- Sampling: reduce the 2d continuous space to a discrete grid $\Omega \subseteq \mathbb{Z}^2$
- Gray level image: $\Omega \to \mathbb{R}$ (discrete position to gray level)
- Color image: $\Omega \to \mathbb{R}^3$ (discrete position to RGB)

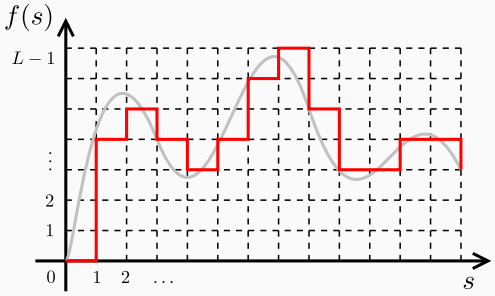


Bitmap image

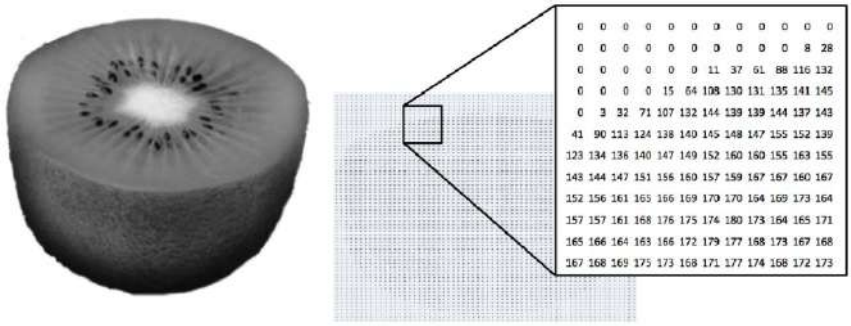
- Quantization: map each value to a discrete set $[0, L-1]$ of L values
  (*e.g.*, round to nearest integer)
- Often $L = 2^8 = 256$ (8bits images $\equiv$ `unsigned char`)
  - Gray level image: $\Omega \to [0, 255]$ $(255 = 2^8 - 1)$
  - Color image: $\Omega \to [0, 255]^3$
- Optional: assign instead an index to each pixel pointing to a color palette
  (format: `.png`, `.bmp`)

Imaging sciences – Types of images – Digital imagery

- Digital images: sampling + quantization



$\longrightarrow$ 8bits images can be seen as a matrix of integer values



Imaging sciences – Types of images – Digital imagery

Definition (Collins dictionary)

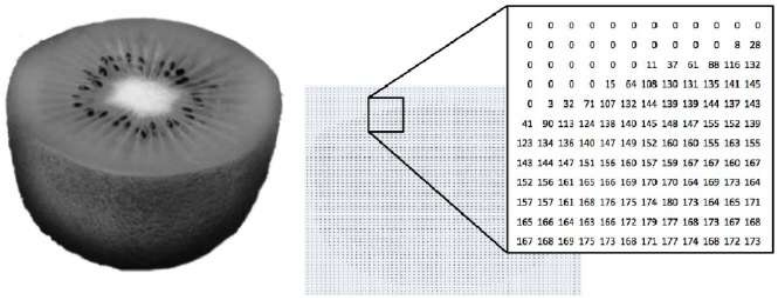
pixel, *noun*: any of a number of very small "picture elements" that make up a picture, as on a visual display unit.

pixel, *noun*: smallest area on a computer screen which can be given a separate color by the computer.

We will refer to an element $s \in \Omega$ as a pixel location,

$f(s)$ as a pixel value,

and a pixel is a pair $(s, f(s))$.



Imaging sciences – Types of images – Digital imagery

Functional representation: $f : \Omega \subseteq \mathbb{Z}^d \to \mathbb{R}^K$

- d: dimension ($d = 2$ for pictures, $d = 3$ for videos, ...)
- K: number of channels ($K = 1$ monochrome, 3 color, ...)
- $s = (i, j)$: pixel position in Ω
- $f(s) = f(i, j)$: pixel value(s) in $\mathbb{R}^K$

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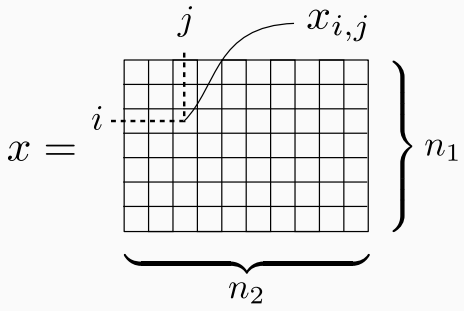
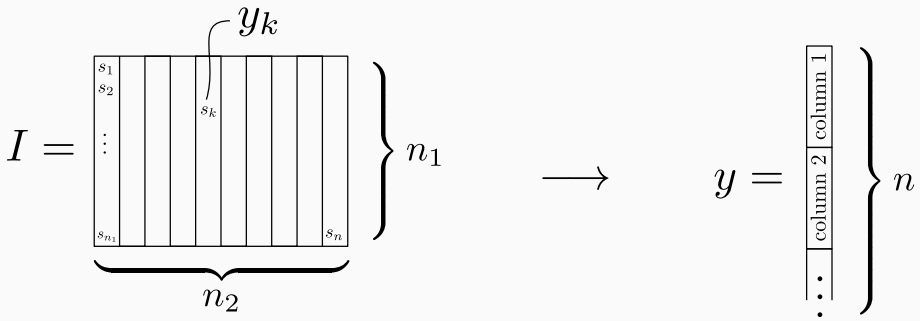
Array representation ($d = 2$): $x \in (\mathbb{R}^K)^{n_1 \times n_2}$

- $n_1 \times n_2$: n_1: image height, and n_2: width
- $x_{i,j} \in \mathbb{R}^K$: pixel value(s) at position $s = (i, j)$: $x_{i,j} = f(i, j)$

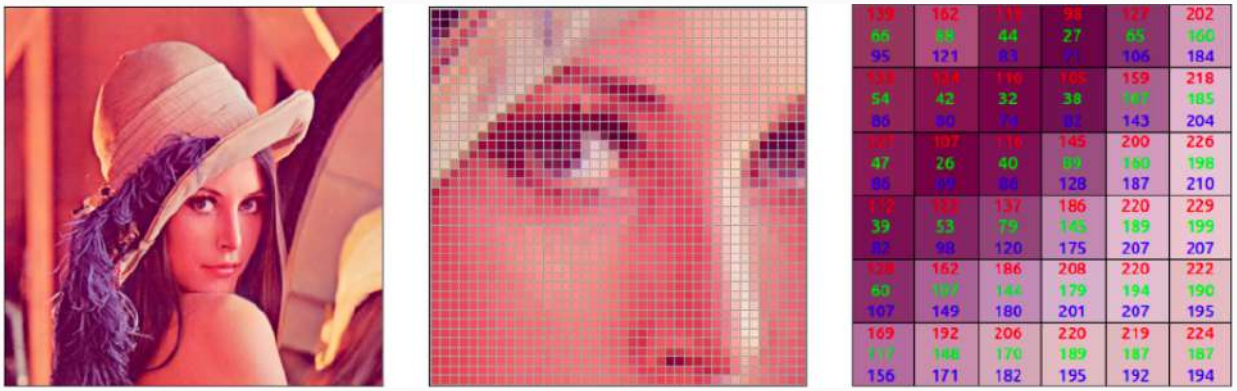


Vector representation: $y \in (\mathbb{R}^K)^n$

- $n = n_1 \times n_2$: image size (number of pixels)
- $y_k \in \mathbb{R}^K$: value(s) of the k-th pixel at position s_k: $y_k = f(s_k)$



Imaging sciences – Types of images – Digital imagery



Color 2d image: $\Omega \subseteq \mathbb{Z}^2 \to [0, 255]^3$

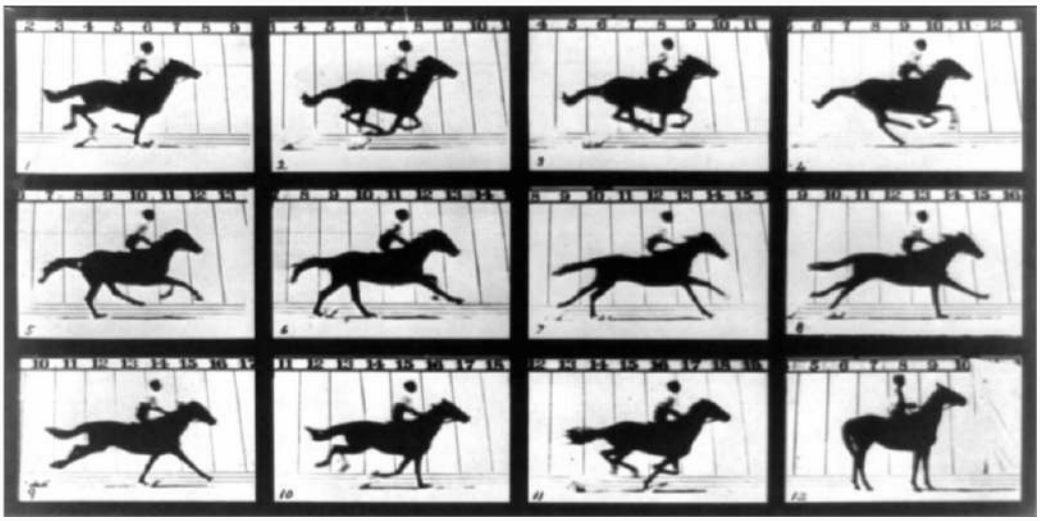
- Red, Green, Blue (RGB), $K = 3$
- RGB: Usual colorspace for acquisition and display
- Exist other colorspaces for different purposes:
  HSV (Hue, Saturation, Value), YUV, YCbCr...

Imaging sciences – Types of images – Digital imagery

Spectral image: $\Omega \subseteq \mathbb{Z}^2 \to \mathbb{R}^K$

- Each of the K channels is a wavelength band
- For $K \approx 10$: multi-spectral imagery
- For $K \approx 200$: hyper-spectral imagery
- Used in astronomy, surveillance, mineralogy, agriculture, chemistry

Imaging sciences – Types of images – Digital imagery

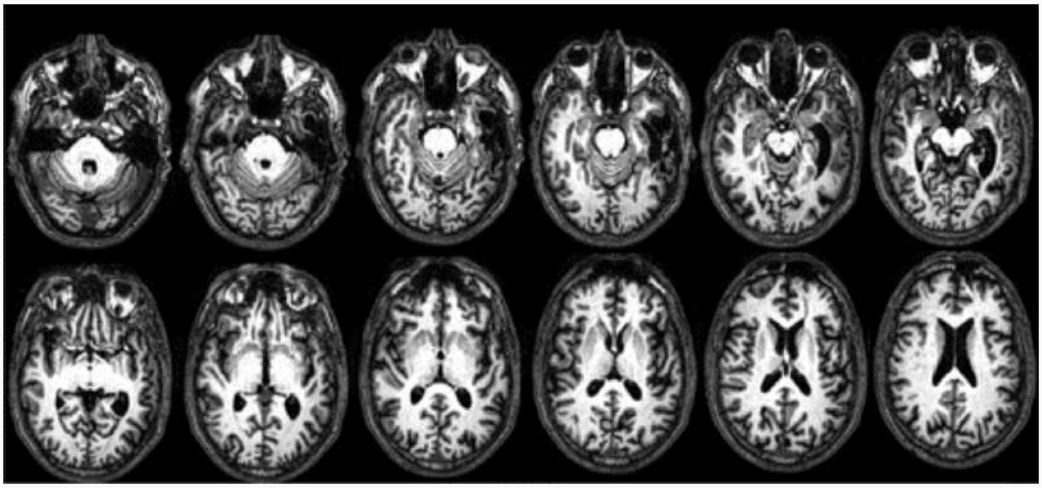


The Horse in Motion (1878, Eadweard Muybridge)

Gray level video: $\Omega \subseteq \mathbb{Z}^3 \to \mathbb{R}$

- 2 dimensions for space
- 1 dimension for time

Imaging sciences – Types of images – Digital imagery

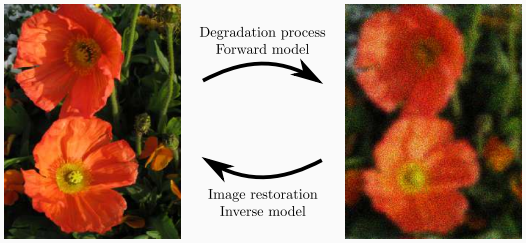


MRI slices at different depths

3d brain scan: $\Omega \subseteq \mathbb{Z}^3 \to \mathbb{R}$

- 3 dimensions for space
- 3d pixels are called voxels ("volume elements")

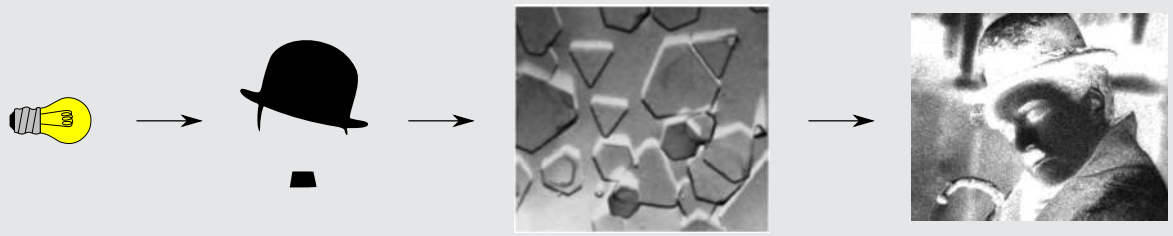
What is noise?



Knowing and modeling the sources of corruptions is essential.

Analog optical imagery

Basic principle of silver-halide photography



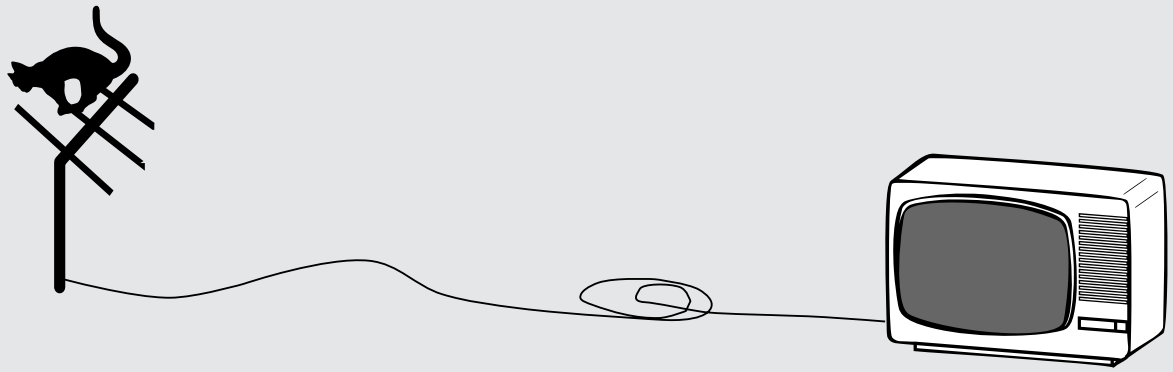
Crystals are sensitive to light
(chemical reaction during exposure and development)

Film grain:

- Depends on the amount of crystals (quality/type of film roll)
- Depends on the scale it is observed (noticeable in an over-enlarged picture)

Analog optical imagery

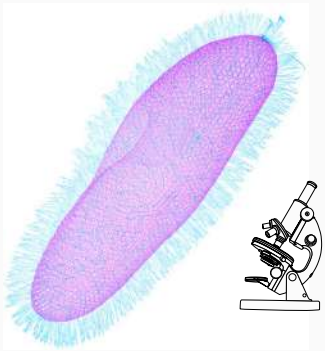
Analog television



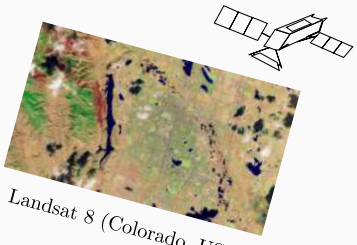
Noise due to bad transmission and/or interference

Digital optical imagery / CCD

Include:
- digital photography
- optical microscopy
- optical telescopes (e.g., Hubble, Planck, . . .)
- optical earth observation satellite (e.g., Landsat, Quickbird, . . .)

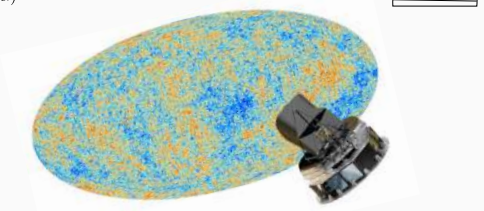


Leica microscope (paramecium aurelia)



Landsat 8 (Colorado, USA)

Hubble (Messier 4 globular cluster)



Planck (cosmic microwave background)

Digital optical imagery / CCD

Charge Coupled Device – Simplified description


Some photons,


captured during the exposure time (shutter speed),


are converted to electrons,


leading to a charge converted to voltage,

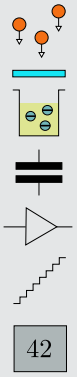

next amplified,


quantized and digitized,

providing a grey level.

Digital optical imagery / CCD

Charge Coupled Device – Simplified description



Some photons,

captured during the exposure time (shutter speed), ... Shot noise

are converted to electrons, ... Thermal noise

leading to a charge converted to voltage, ... Readout noise

next amplified, ...

quantized and digitized, ... ISO sensitivity

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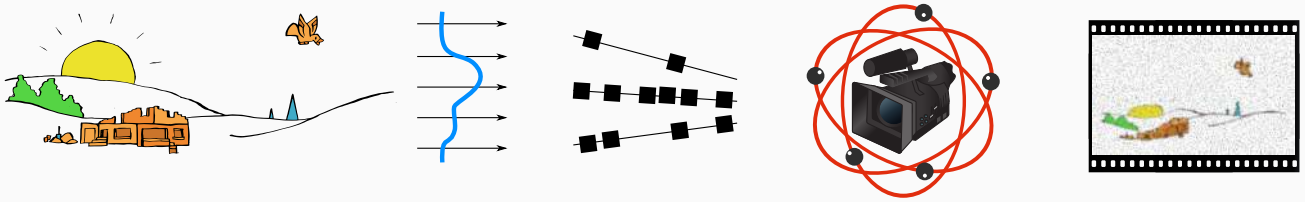
providing a grey level. (Often followed by non-linear post-processing and lossy compression)



Scene | Light intensity | Photon emission | Electronic fluctuations | Digital Image

Random fluctuations lead to noise