



# (Digital) Image processing

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The materials are based on the earlier lecturer prof. Árpád BARSI

- Part 1: (6/12/2022) „Theory” of image processing
- Part 2: (13/12/2022) Practice with software examples



# Main content

- Basic terms
- Image descriptions
- Image acquisition
- Resolutions
- Storage & software
- Manipulations: LUT, morphology, histogram operations
- Image filterings
- Color models
- Geometric manipulations
- Basic measurements
- Machine Learning Basics



# Content

- Photography
- Mathematics
- Physics, optics
- Signal processing, electronics
- IT
- ...
- Application fields



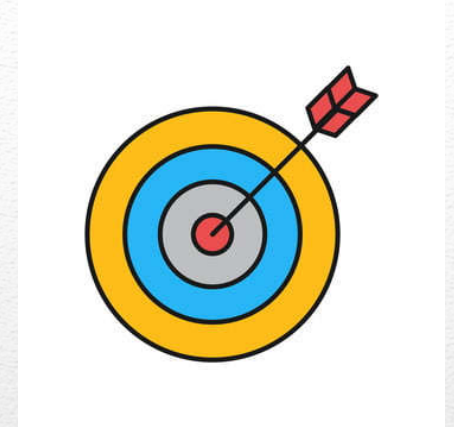
# Is it interdisciplinary?

- Photography, documentation (from holiday to events)
- Cinema
- Design, marketing, advertisements
- Medicine, biology
- Industrial applications: robots, QA/QC, transportation...
- Physics, astronomy, measurement technologies
- Military applications
- Remote sensing, GIS
- And many more...

# Application fields

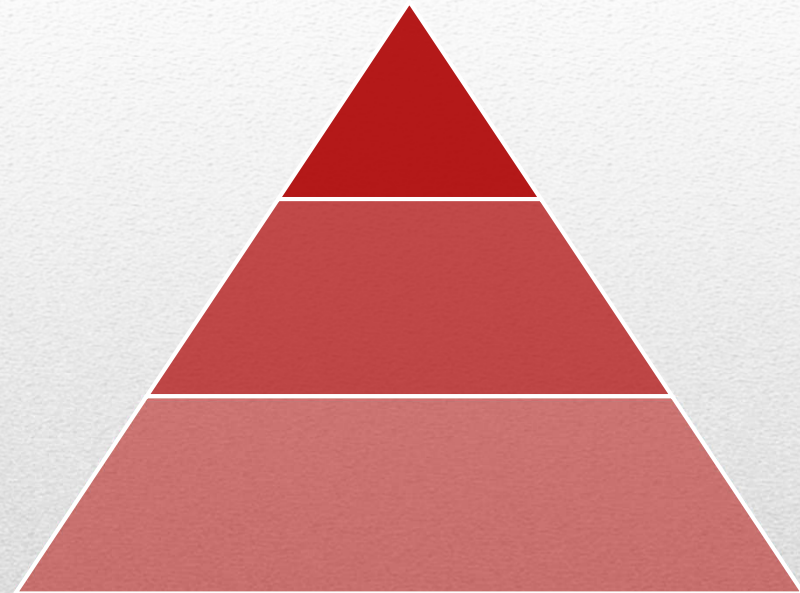
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- Detection and recognition of known objects
- Obtaining geometric models of unknown objects
- Computing position and orientation of objects
- Measurement of spatial properties of objects (distances, sizes, etc.)
- Measurement of object motion
- Measurement of surface texture and color

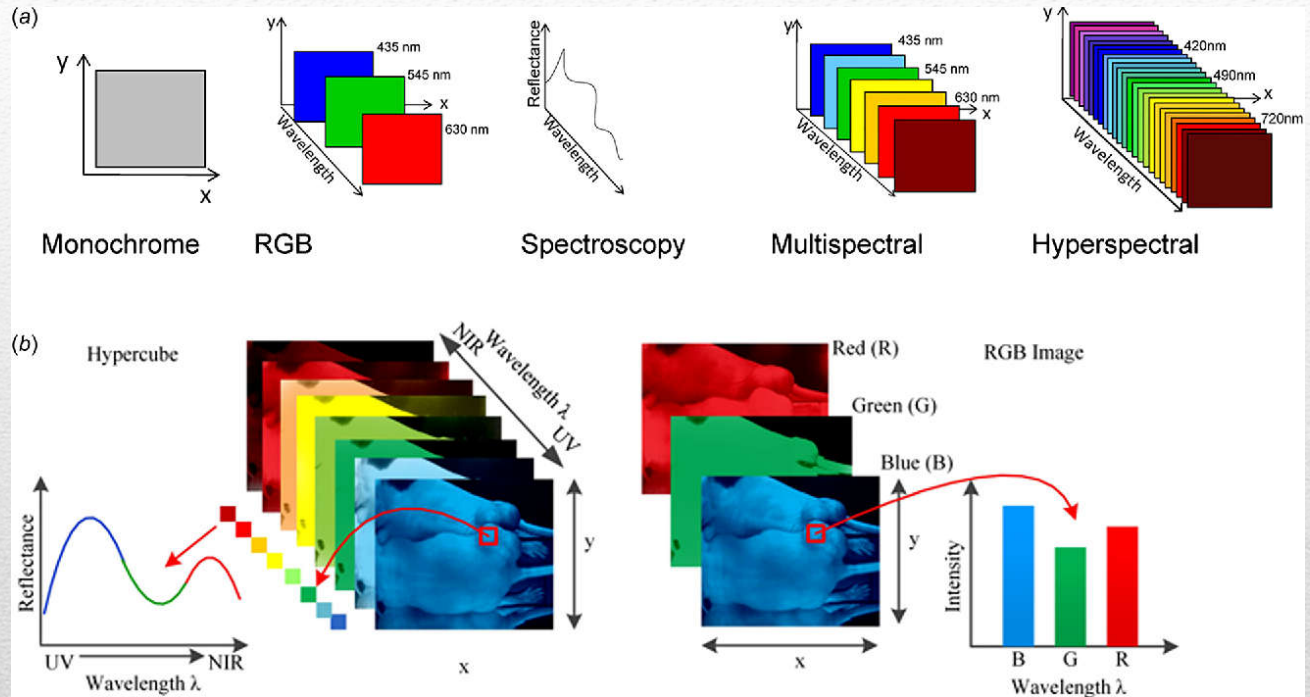
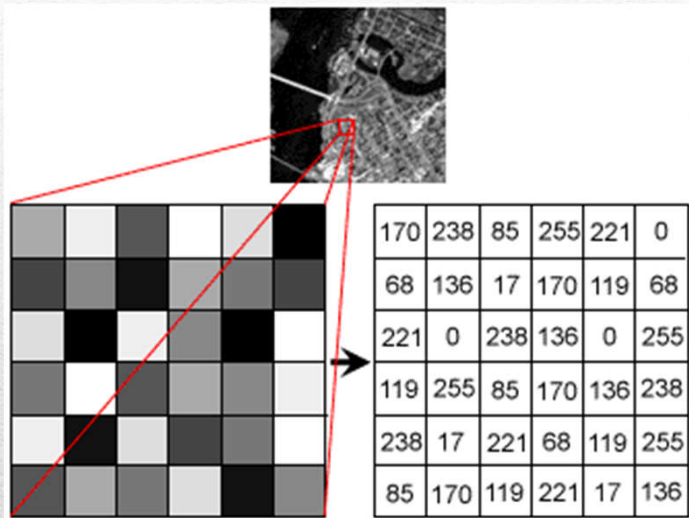


# Goals of image processing

- Image processing
  - E.g. image enhancement
- Image analysis
  - E.g. feature extraction
- Image understanding
  - E.g. semantics

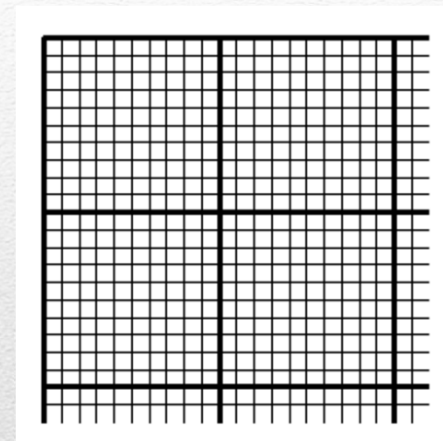
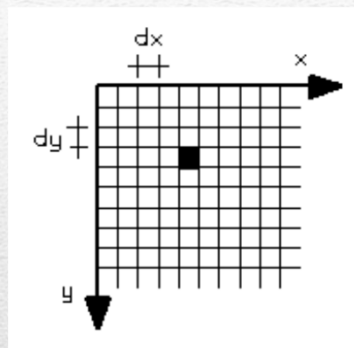


# Levels



# Image and pixel





# Image coordinate systems

```
graph TD; A[Reality] --> B[Projection (optics)]; B --> C[Sampling]; C --> D[Quantization]; D --> E[Digital image];
```

Reality

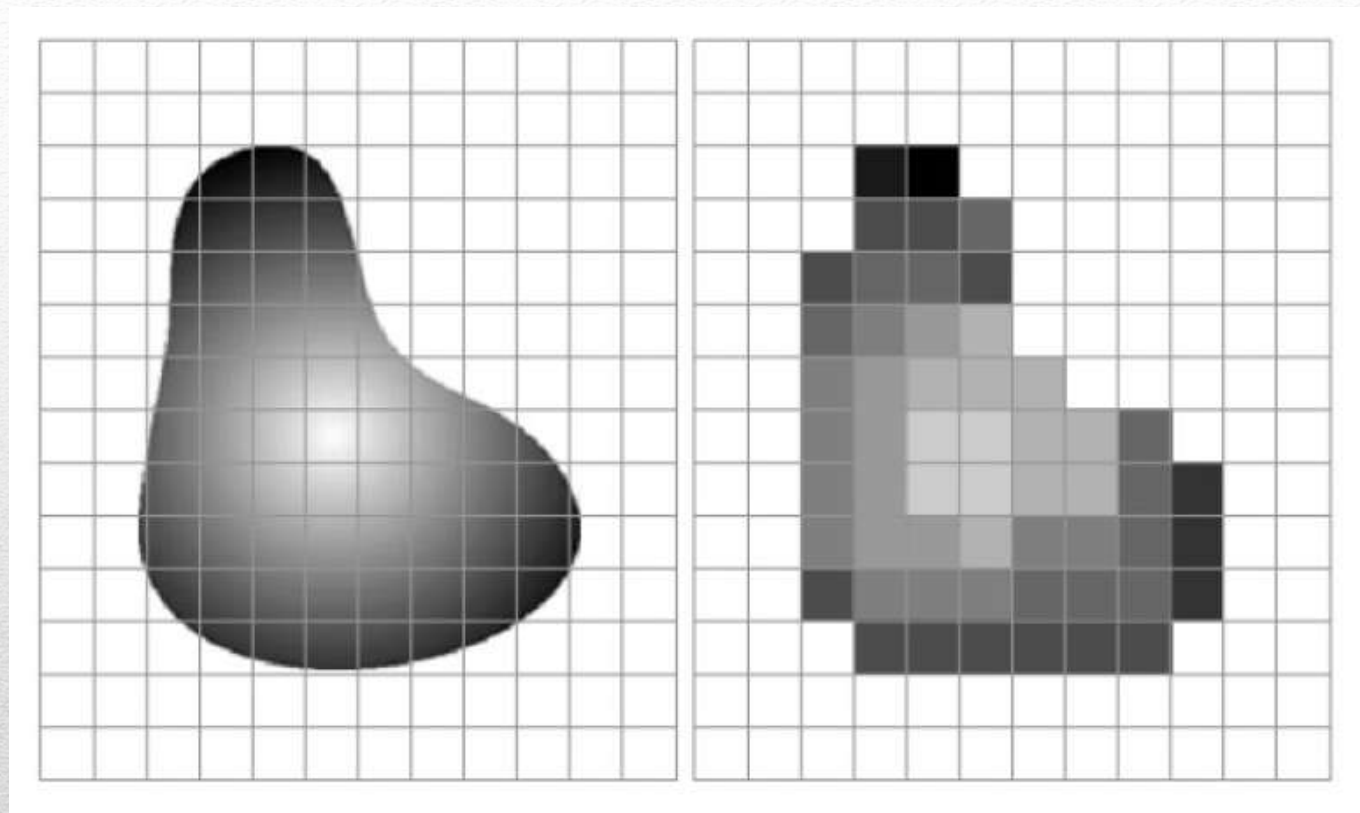
Projection (optics)

Sampling

Quantization

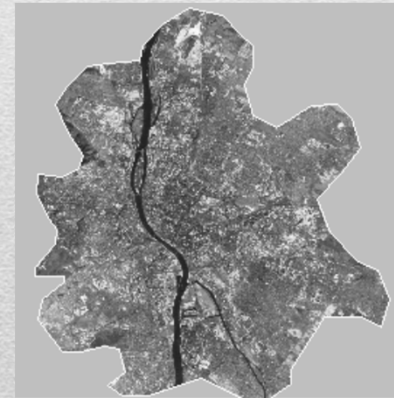
Digital image

# Image acquisition procedure



# Image acquisition procedure

- An image is a function  $f(x,y,b,t)$
- Resolution: geometric, radiometric, spectral, temporal
- Cut-off/mask: regular, arbitrary (ROI, AOI)
- Storage formats (color and BW; lossy and lossless)
- Features: descriptive data, statistics, histogram, sections



# Image basics



Original resolution



1/4 of original



1/8 of original



1/16 of original

# Geometric resolution



64 gray levels



16 gray levels



8 gray levels



4 gray levels

# Radiometric resolution



R

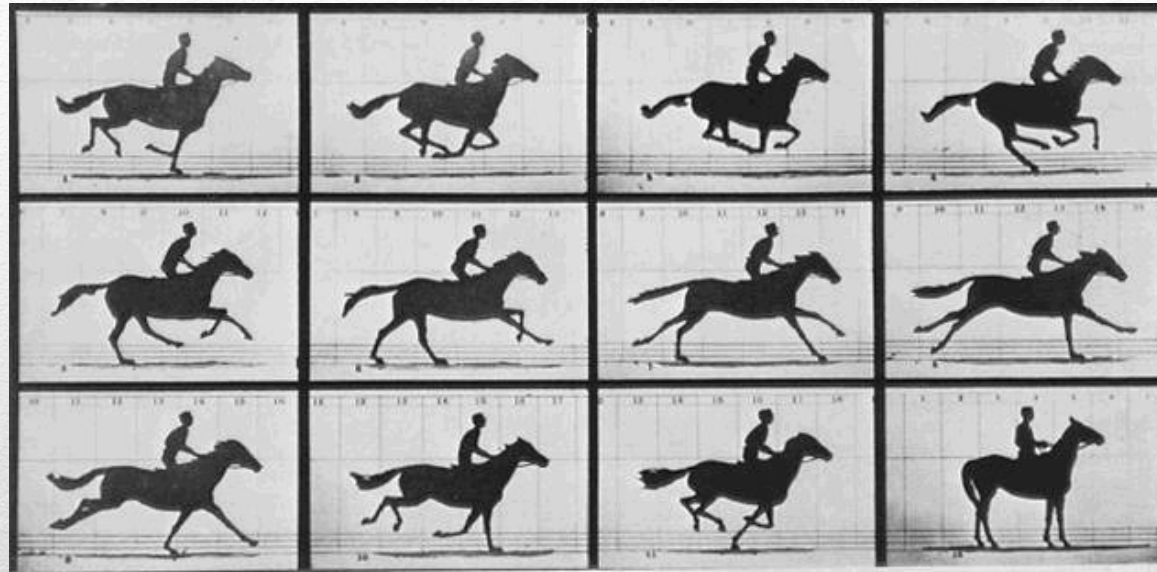


G



B

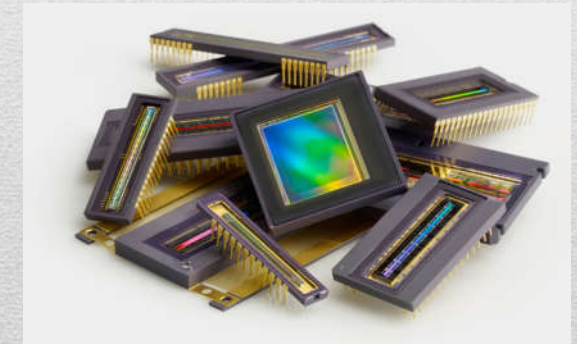
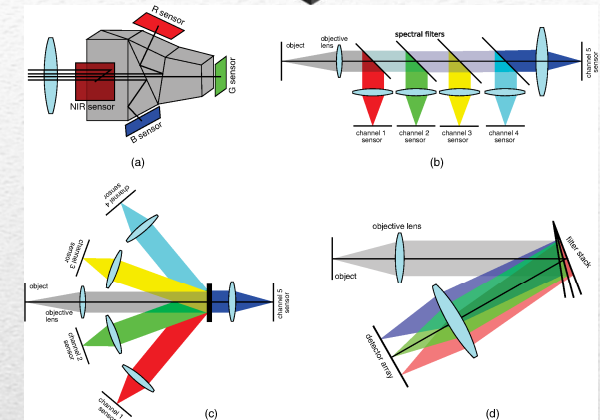
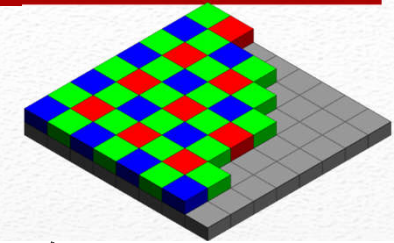
# Spectral resolution



# Temporal resolution

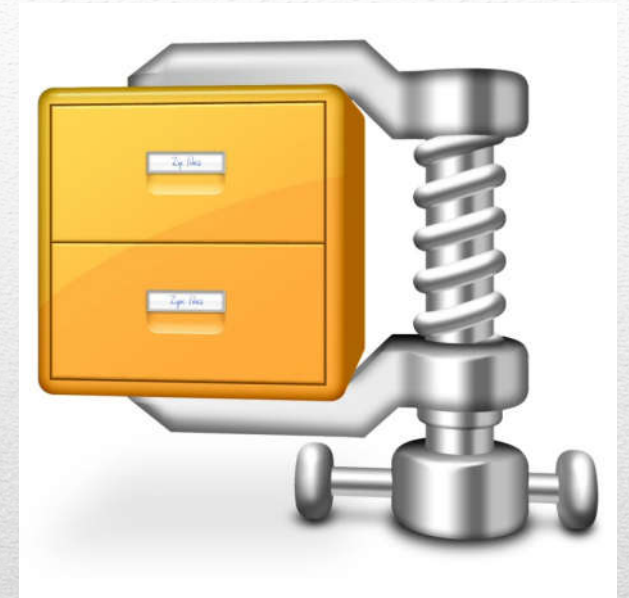


- Trigger (to have a single image not a video)
- Detector:
  - Single point – really fast
  - Small area (APD arrays)
  - Camera (CCD, CMOS)
- Photons  $\rightarrow$  Electrons  $\rightarrow$  Voltage  $\rightarrow$  Dig. Number
- Parameters: Noise / Range / TimeFrame



# Image acquisition

- Paper of A4 with 600 dpi
  - $210 \times 297$  mm
  - $4961 \times 7016$  pixel = 34 806 376 pixel
  - à 24 bit (1 byte) = 99.6 MB !
- Aerial image with  $7 \mu\text{m}$  pixel size
  - $230 \times 230$  mm
  - $32\,857 \times 32\,857$  pixel = 1 079 582 449 pixel
  - à 24 bit = 3.02 GB !!!
- Efficient algorithms to store information
  - Lossy or lossless methods



# Image storage

- Graphics software:
  - PhotoShop, PhotoPaint, PaintShopPro, Kai, Photo DeLuxe, Gimp...
- General purpose development environments:
  - Khoros, **Matlab Image Processing Toolbox**, AVS, Image Vision Library, Halcon, ImageMagick, Rapidminer...
- Special application software:
  - ImageStation Imager, Erdas Imagine, GRASS, ImagePro Plus, Ilwis, **ImageJ**, **Fiji**, SNAP...

# Image processing software

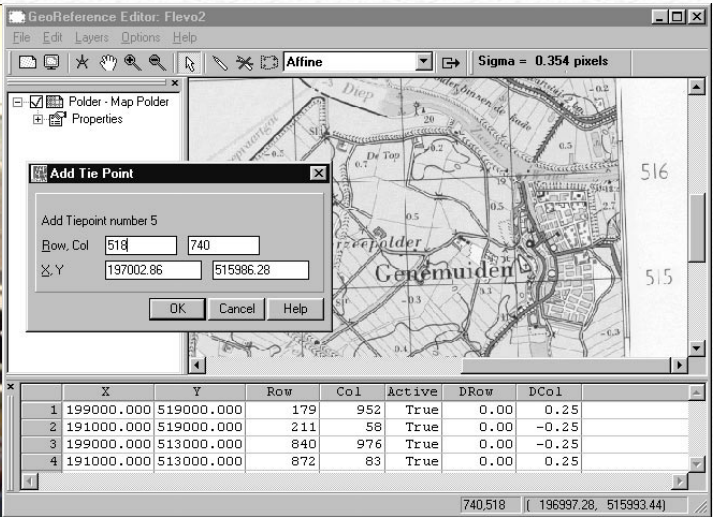
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PhotoShop



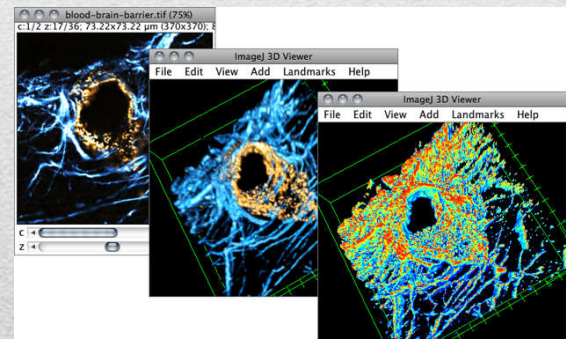
Kai's Power Tools



ILWIS



GIMP



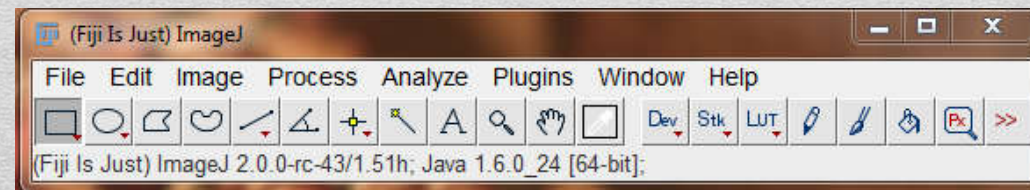
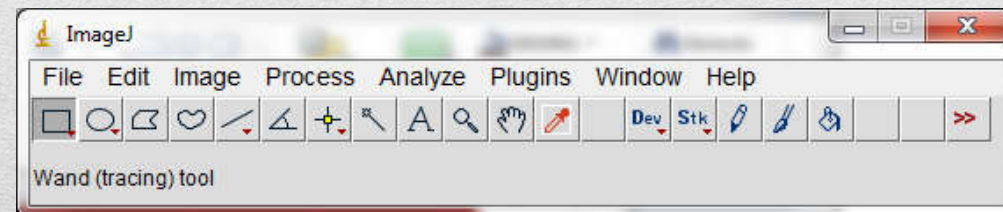
ImageJ

# Software examples

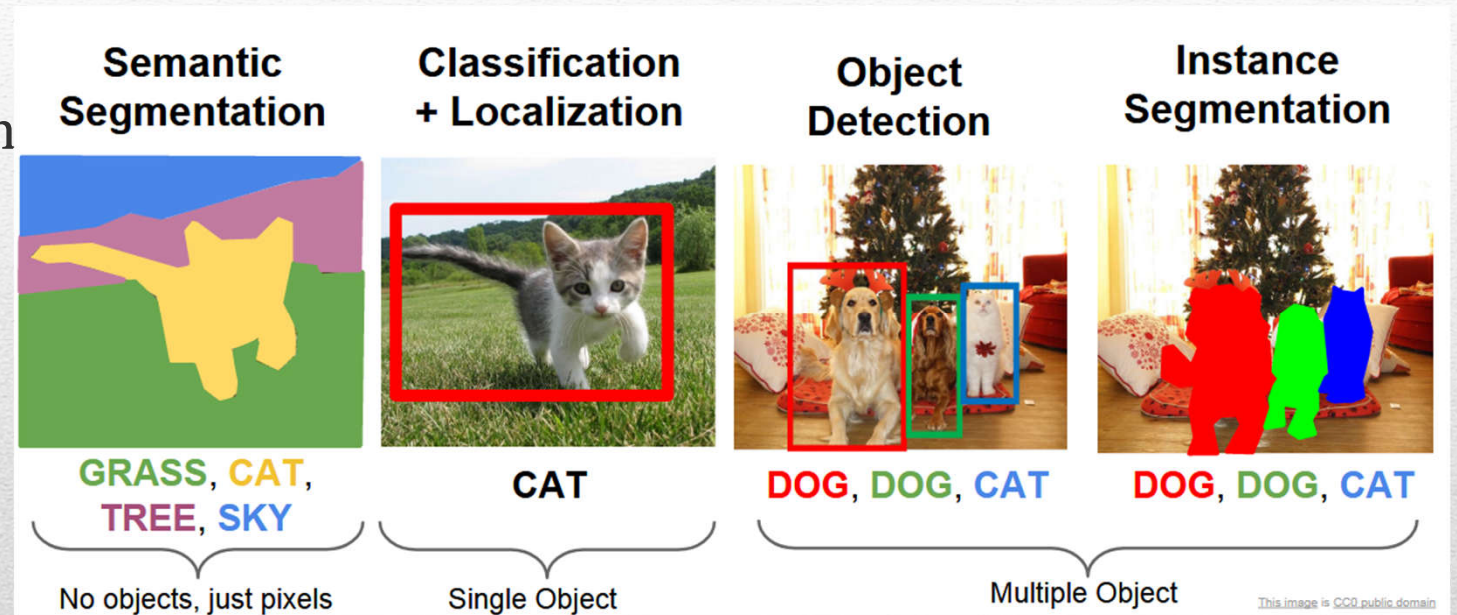
- Free Java based image processing software
- Download from: <http://imagej.nih.gov/ij/>
- Clear menu structure
- Numerous medical/biologic function
- Add-on possibility (plug-in)
- Well-documented (help, tutorials, videos)



# ImageJ and FIJI



- Classification
- Semantic segmentation
- Object detection
- Object localization

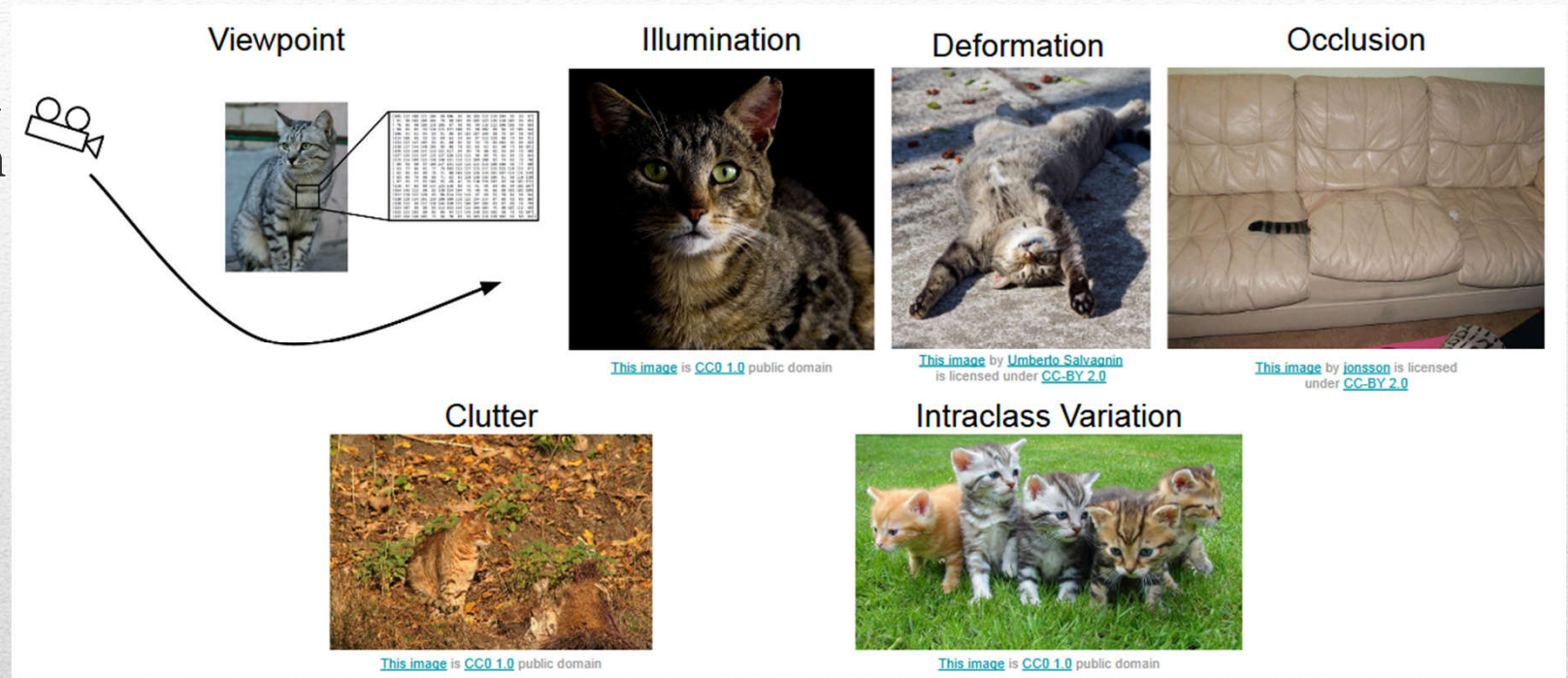


Source: [http://cs231n.stanford.edu/slides/2017/cs231n\\_2017\\_lecture11.pdf](http://cs231n.stanford.edu/slides/2017/cs231n_2017_lecture11.pdf)

# Image processing tasks


Wide variety of:

- Viewpoint
- Illumination
- Deformation
- Occlusion
- Clutter
- Intraclass Variation



Source: [http://cs231n.stanford.edu/slides/2022/lecture\\_3\\_ruohan.pdf](http://cs231n.stanford.edu/slides/2022/lecture_3_ruohan.pdf)

# Recognition challenges

- 
- Transformation (Translation, Rotation, Cut, Resize, Denoise, Contrast enhancement, morphological transformations)
  - Segmentation
  - Registration (e.g. to fuse multiple images to the same CS)

# Image processing elements

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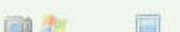



















- DICOM – Digital Imaging and Communication in Medicine
- Copyright at NEMA – National Electrical Manufacturers Association
- First standard: NEMA + American College of Radiology (1985)
- DICOM Standard Committee
- Providers: e.g. Agfa, Philips, Siemens, Zeiss...
- Users: e.g. American Academy of Ophthalmology, European Society of Cardiology, Deutsche Roentgengesellschaft...
- Other members: e.g. IT companies, health industry companies...

# DICOM



## Quick Links To Popular Programs

	Windows Full List of 96 79 Screen Captures	Macintosh Full List of 61 47 Screen Captures	Linux Full List of 61 47 Screen Captures
<b>Display DICOM</b>	<ol style="list-style-type: none"> <li>Mango </li> <li>MIPAV - Medical... </li> <li>Synedra View Pe... </li> </ol>	<ol style="list-style-type: none"> <li>OsiriX </li> <li>Mango </li> <li>MIPAV - Medical... </li> </ol>	<ol style="list-style-type: none"> <li>Mango </li> <li>MIPAV - Medical... </li> <li>Aeskulap - DICO... </li> </ol>
<b>Convert Files</b>	<b>Full List of 40 19 Screen Captures</b> <ol style="list-style-type: none"> <li>Mango </li> <li>MIPAV - Medical... </li> <li>XMedCon </li> </ol>	<b>Full List of 23 11 Screen Captures</b> <ol style="list-style-type: none"> <li>Mango </li> <li>MIPAV - Medical... </li> <li>XMedCon </li> </ol>	<b>Full List of 34 14 Screen Captures</b> <ol style="list-style-type: none"> <li>Mango </li> <li>MIPAV - Medical... </li> <li>XMedCon </li> </ol>
<b>PACS Client</b>	<b>Full List of 39 29 Screen Captures</b> <ol style="list-style-type: none"> <li>MIPAV - Medical... </li> <li>Synedra View Pe... </li> <li>ConQuest </li> </ol>	<b>Full List of 25 20 Screen Captures</b> <ol style="list-style-type: none"> <li>OsiriX </li> <li>MIPAV - Medical... </li> <li>CDMEDIC PACS </li> </ol>	<b>Full List of 27 21 Screen Captures</b> <ol style="list-style-type: none"> <li>MIPAV - Medical... </li> <li>Aeskulap - DICO... </li> <li>ConQuest </li> </ol>

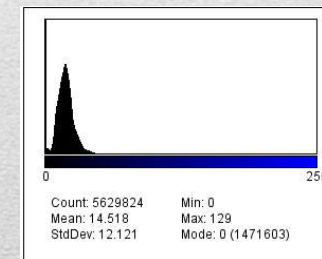
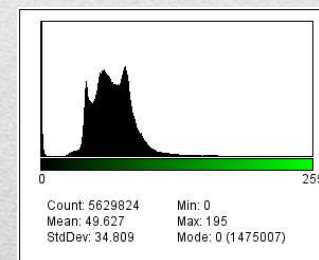
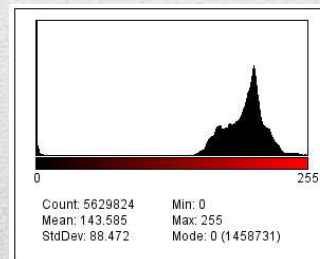
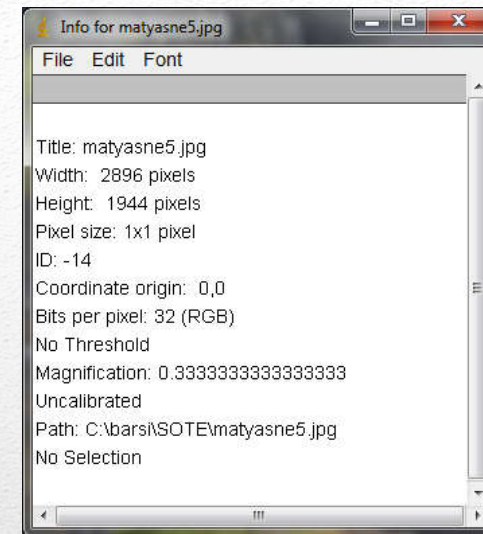
# DICOM support



```
Info for 476287A0.DCM
File Edit Font
0020,0012 Acquisition Number: 7
0020,0013 Image Number: 4
0020,0032 Image Position (Patient): -121.91341535875~-109.93346959850~-32.537737485952
0020,0037 Image Orientation (Patient): 0.99996411800384~-6.167521496E-05~0.00847145821899~
0020,0052 Frame of Reference UID: 1.3.46.670589.11.17162.5.0.5772.2007121414034121028
0020,0100 Temporal Position Identifier: 1
0020,0105 Number of Temporal Positions: 1
0020,1040 Position Reference Indicator:
0020,1041 Slice Location: 0
0028,0002 Samples per Pixel: 1
0028,0004 Photometric Interpretation: MONOCHROME2
0028,0010 Rows: 256
0028,0011 Columns: 256
0028,0030 Pixel Spacing: 0.8984375~0.8984375
0028,0034 Pixel Aspect Ratio: 1~1
0028,0100 Bits Allocated: 16
0028,0101 Bits Stored: 12
0028,0102 High Bit: 11
0028,0103 Pixel Representation: 0
0028,1050 Window Center: 4116.68686868686
0028,1051 Window Width: 8233.37373737373
0028,2110 Lossy Image Compression: 00
0032,000A Study Status ID: COMPLETED
0040,0241 Performed Station AE Title: INTERA
0040,0244 Performed Procedure Step Start Date: 20071214
0040,0245 Performed Procedure Step Start Time: 140213
0040,0250 Performed Procedure Step End Date: 20071214
0040,0251 Performed Procedure Step End Time: 140213
0040,0253 Performed Procedure Step ID: 250869242
0040,0254 Performed Procedure Step Description: Koponya Orbita
0040,0321 Film Consumption Sequence:
0040,9224 >---:
0040,9225 >---: 01?
2001,0010 ---: Philips Imaging DD 001
2001,100B ---: TRANSVERSAL
2005,0010 ---: Philips MR Imaging DD 001
```

# DICOM example

- Descriptive data
  - #rows, #columns, capture date, exposition time...
- Statistics
  - Max, min, mean, median...
- Histogram
- Sections



# Image features

Grayscale Histograms and Contrast Levels in Digital Images

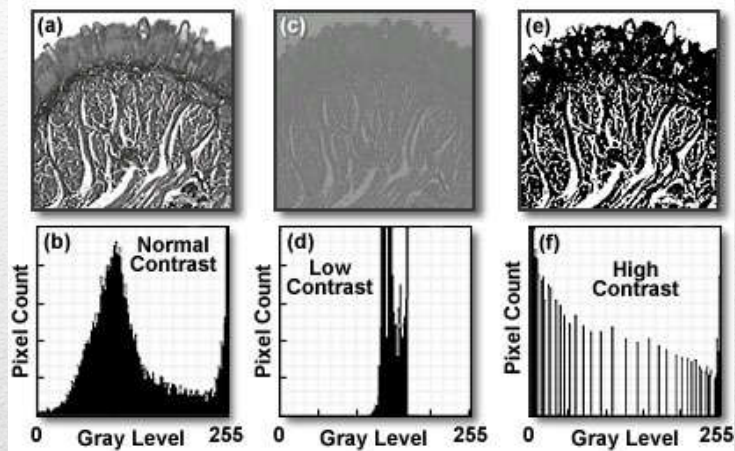


Figure 7

Color Digital Images and RGB Histograms

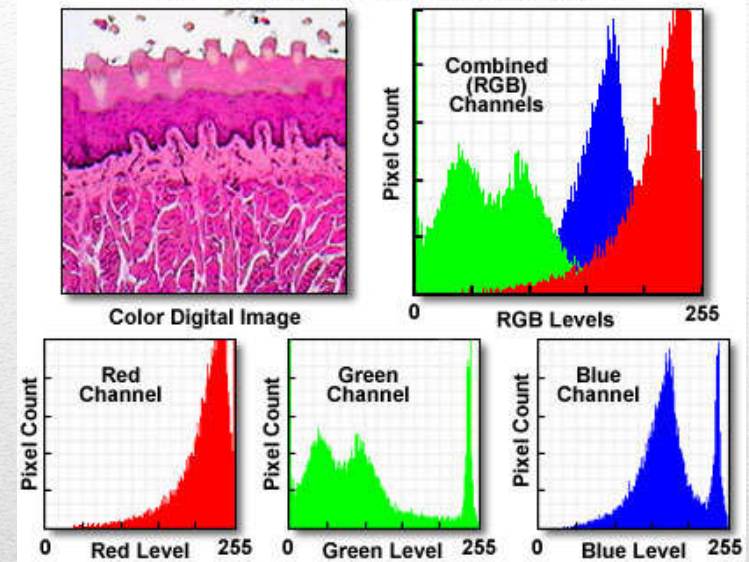
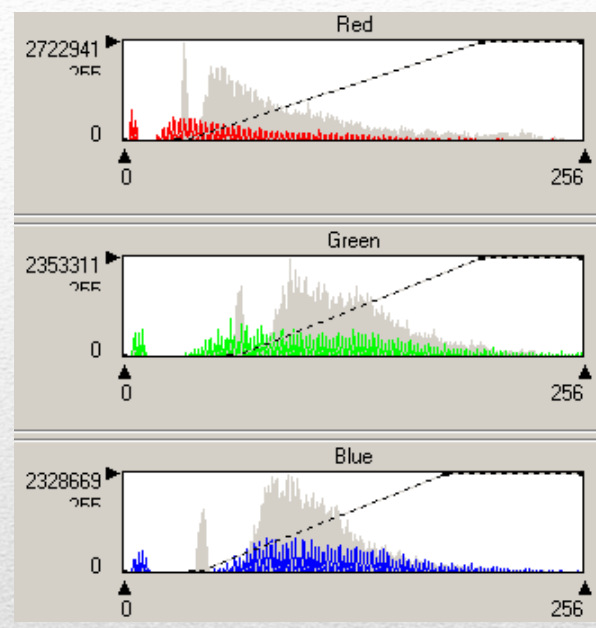
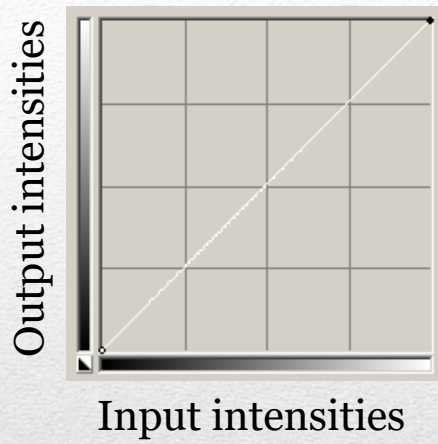
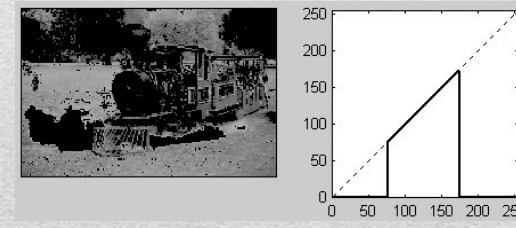
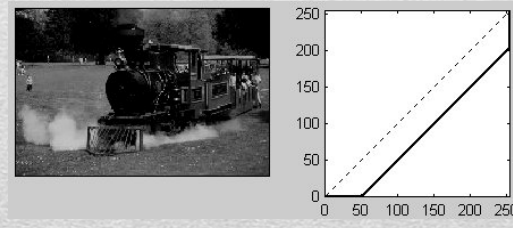
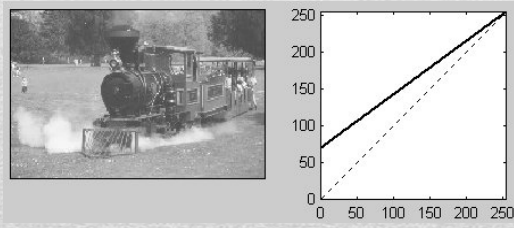
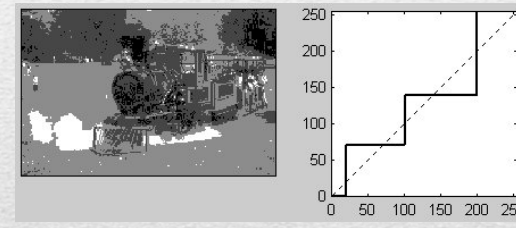
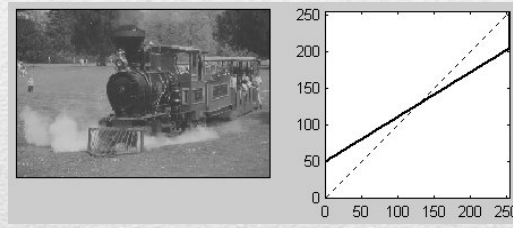
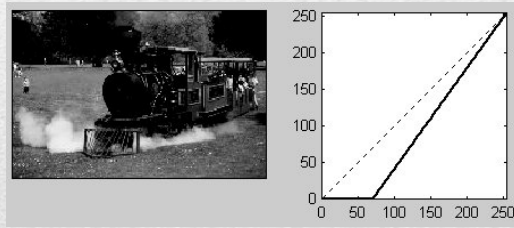
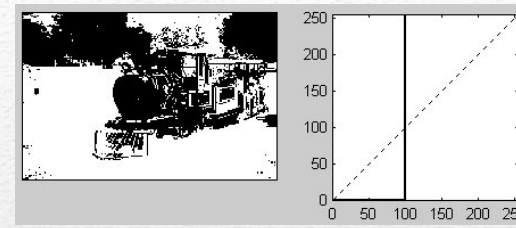
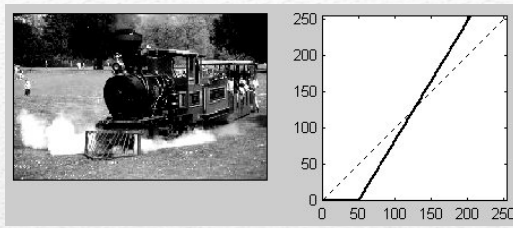
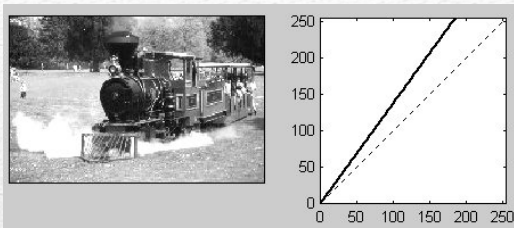
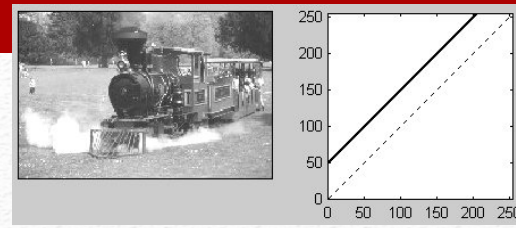
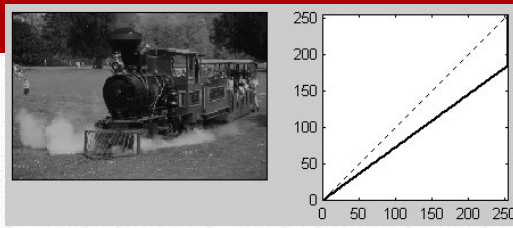
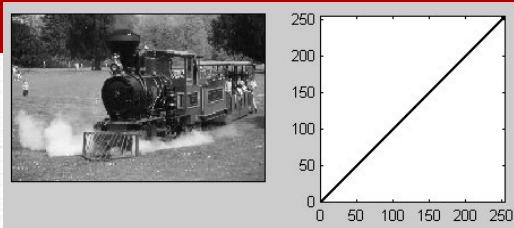


Figure 8

# Once more about histograms



# Look-Up Table (LUT)



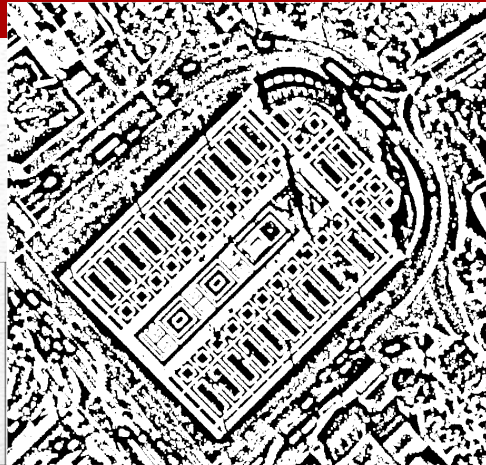
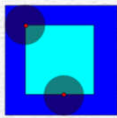
# LUT cases



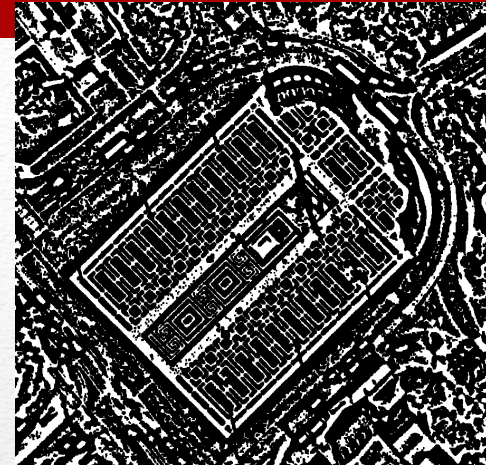
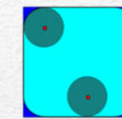
# Binarization



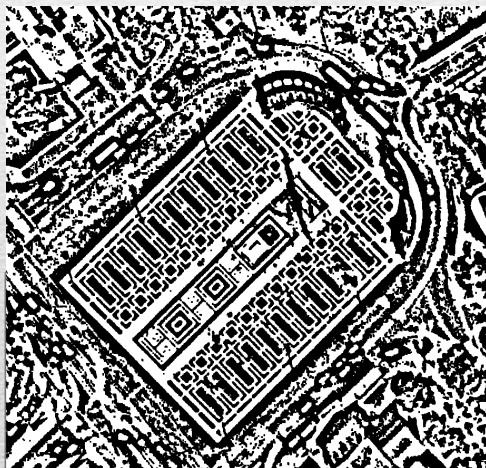
Erosion



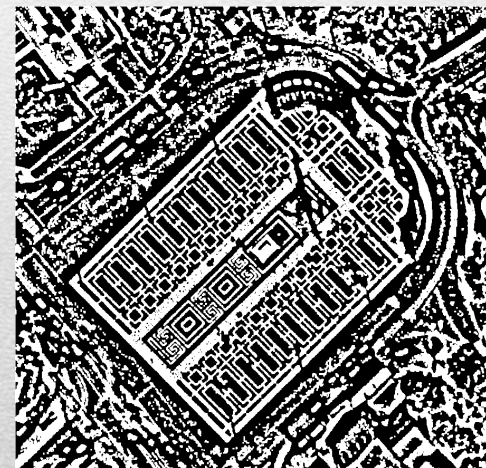
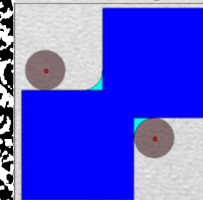
Dilatation



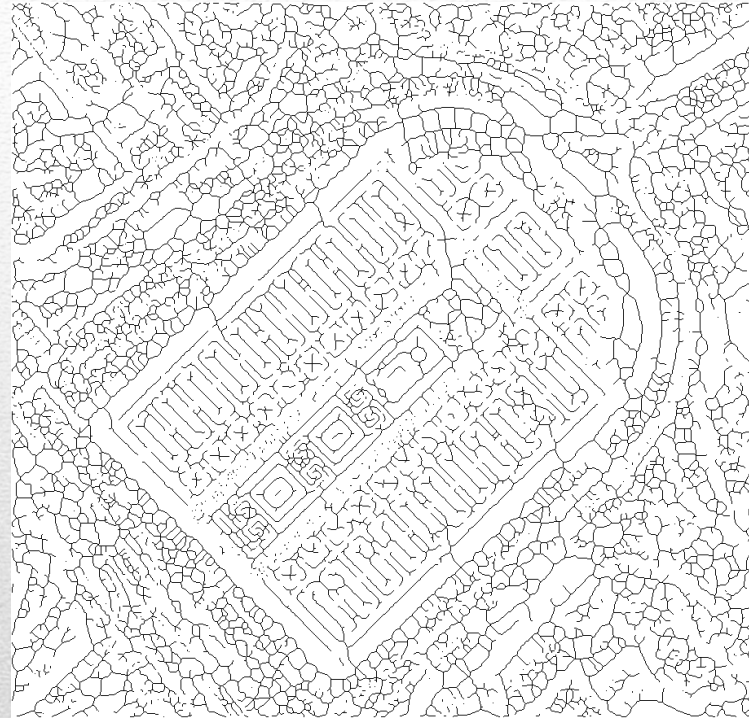
Opening



Closing



# Morphology

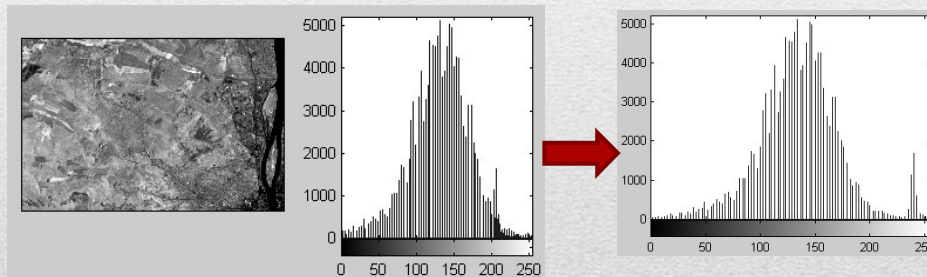
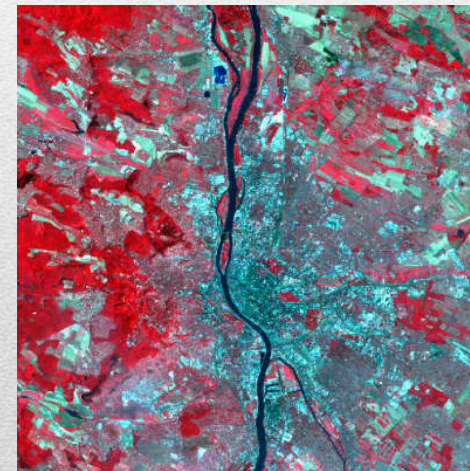
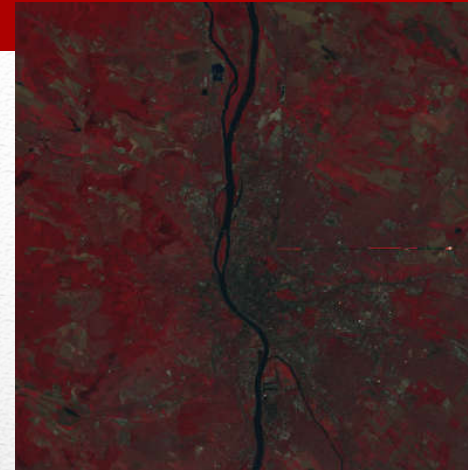
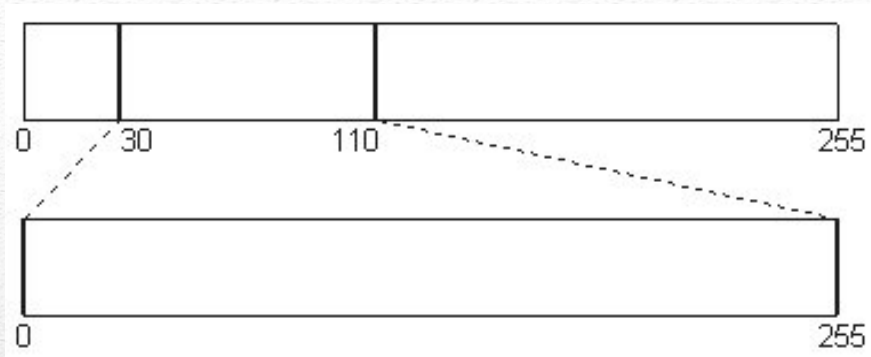


# Skeletonize

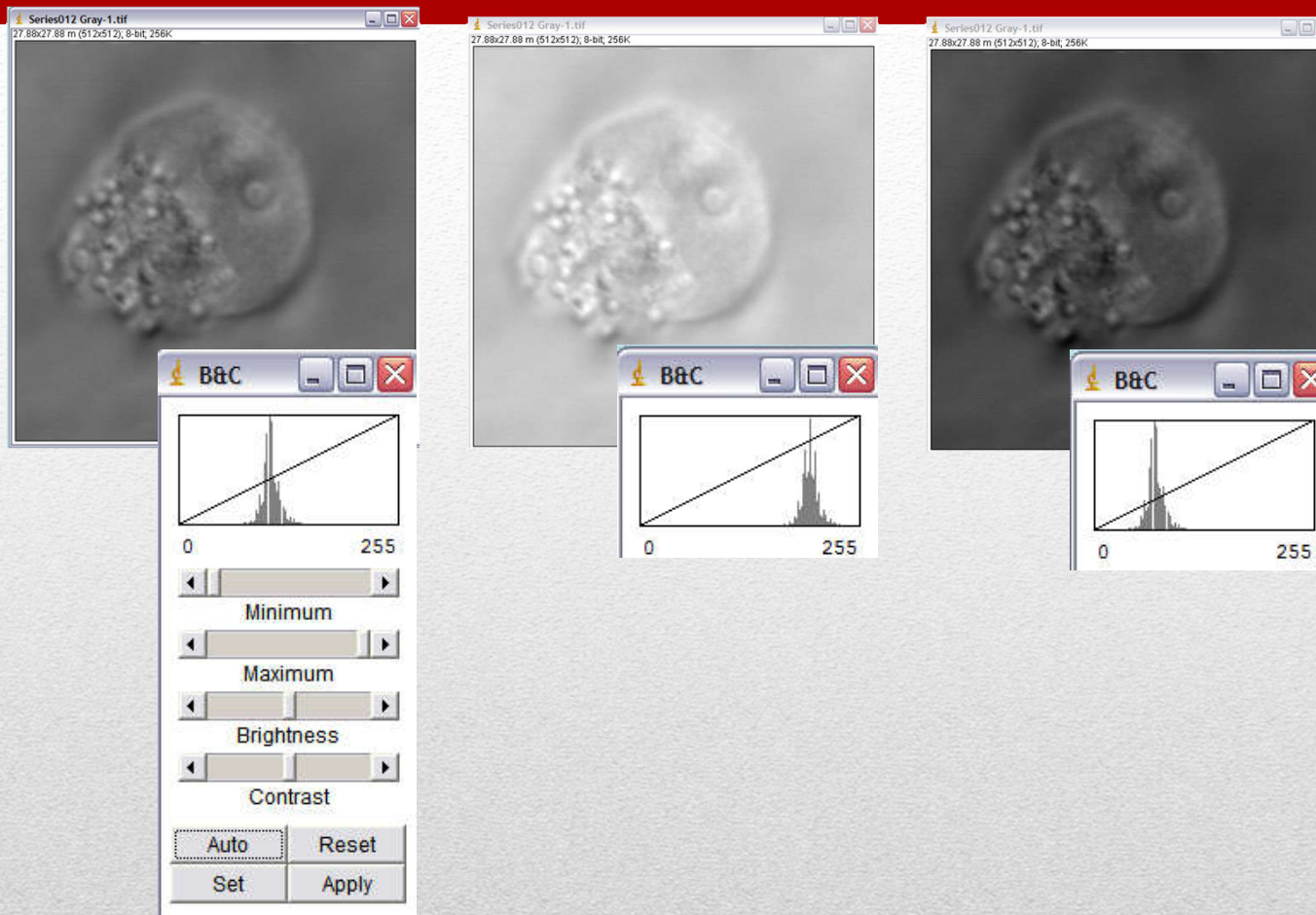


Opening & closing with 5 pixel radius STREL

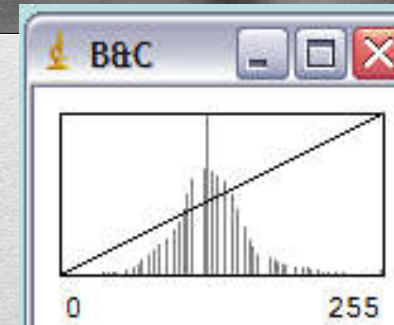
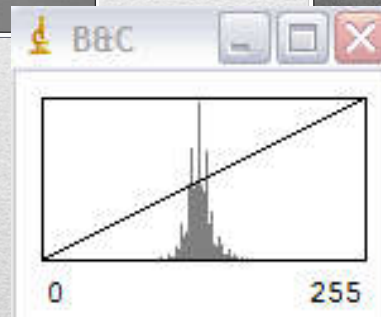
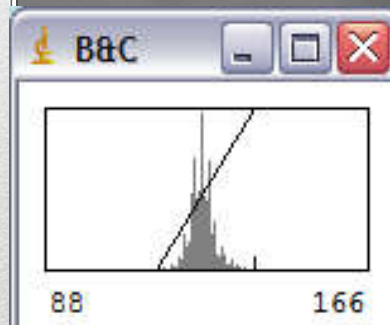
# Grayscale morphology



# Histogram stretch

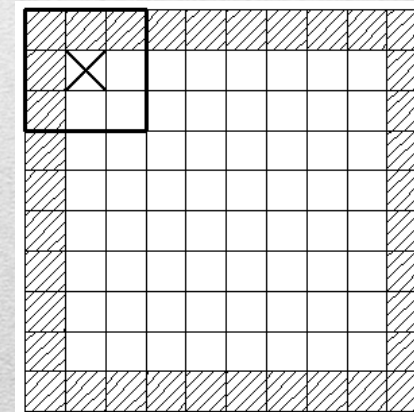
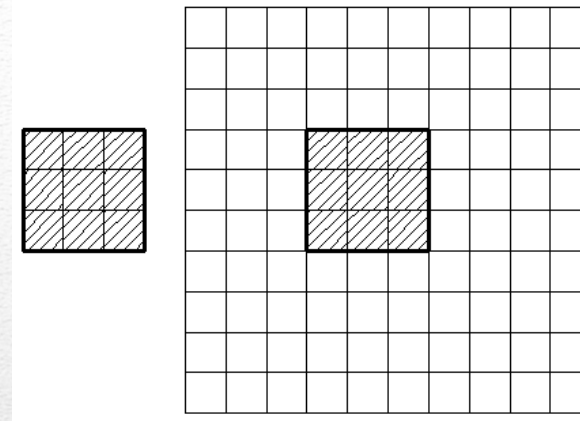


# Brightness functions

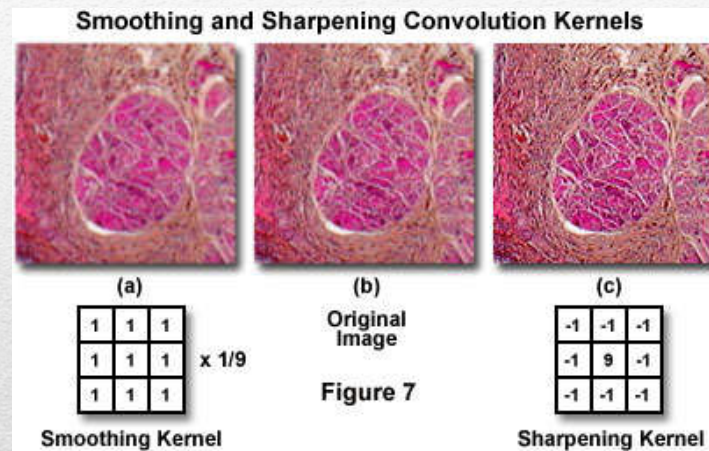
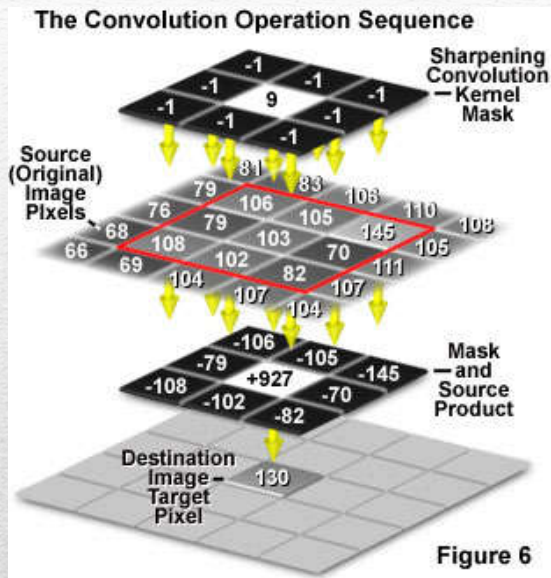


# Contrast function

- Convolution
  - Smoothing
  - Edge detection
- Non-convolution
  - Special effects
- Filtering in frequency domain
  - Periodic noise removal

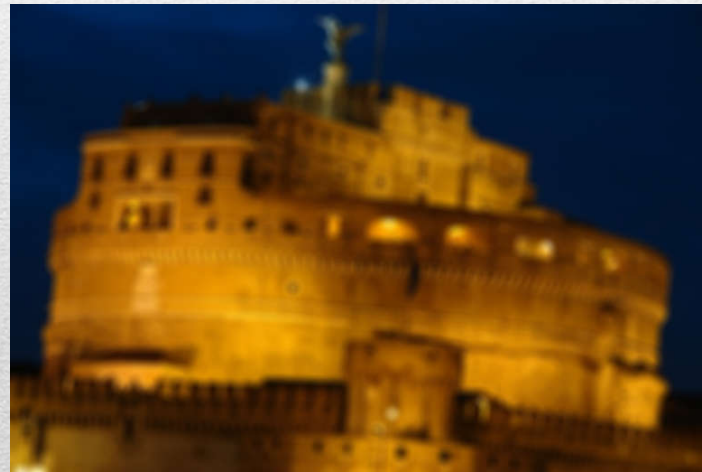


# Image filtering



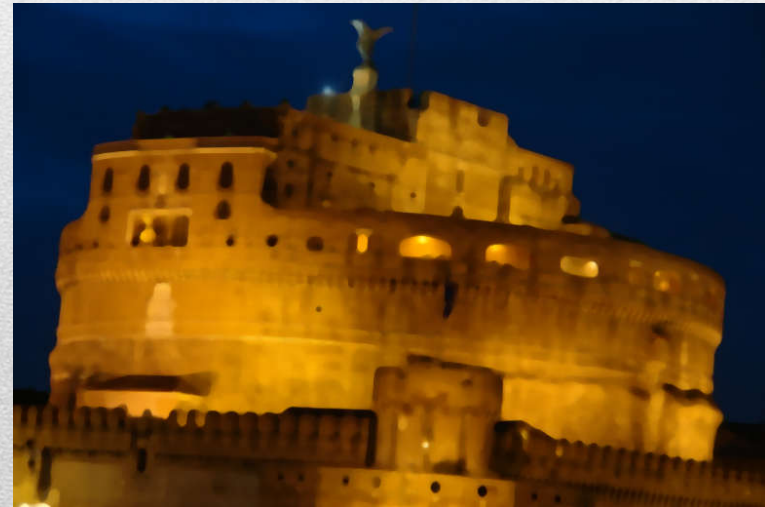
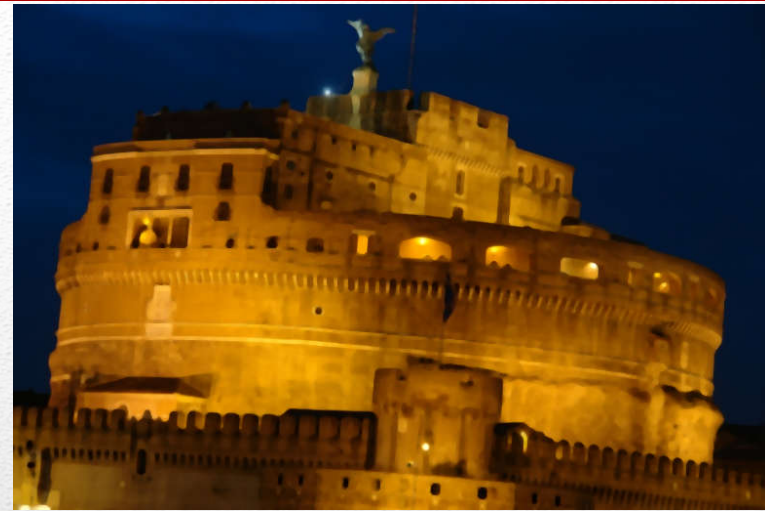
# Convolution





Smoothing filter (mean)

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Median-filter

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# Mean vs median filter

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$N=4, n=4$

$N=4, n=5$

$N=8, n=8$

$N=8, n=9$

# Laplace filtering

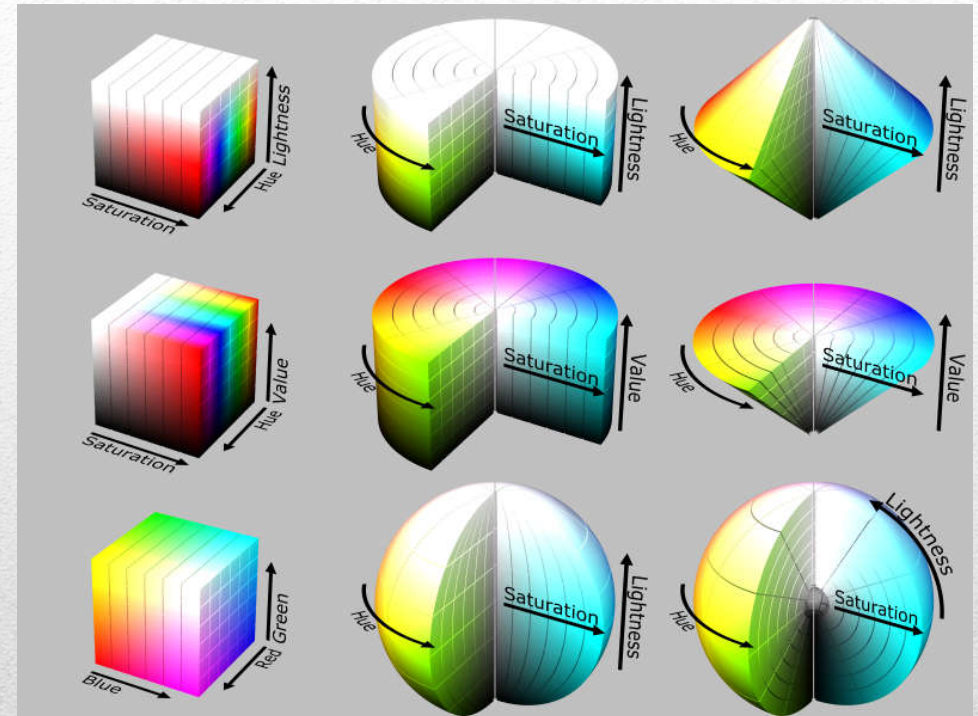
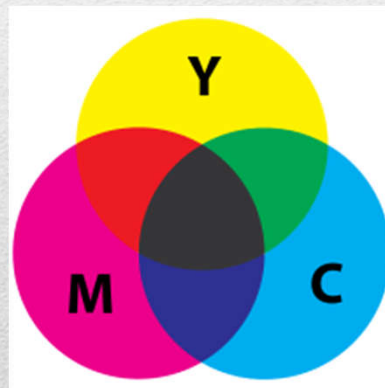
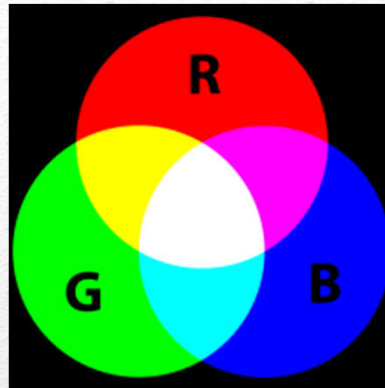
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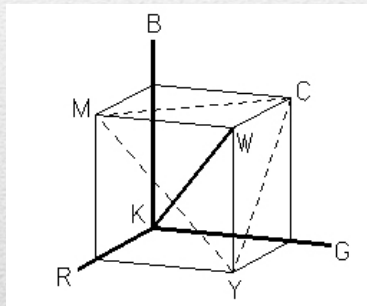
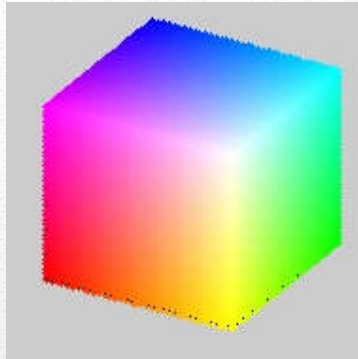
Find edges = Sobel filtering

---

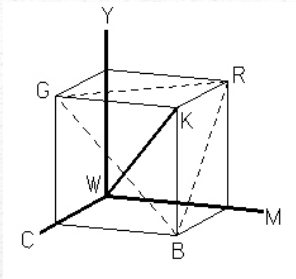
- Additive models
  - E.g. RGB
- Subtractive models
  - E.g. CMY



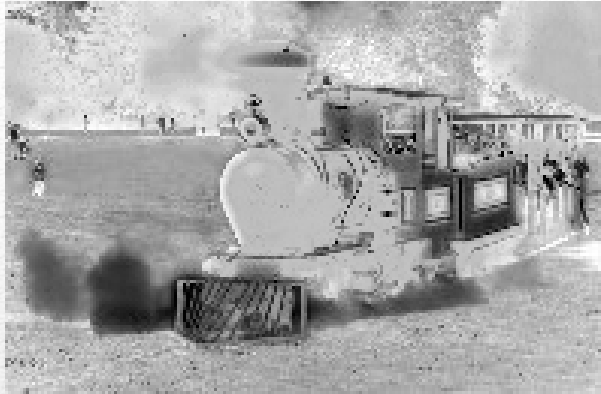
# Color models



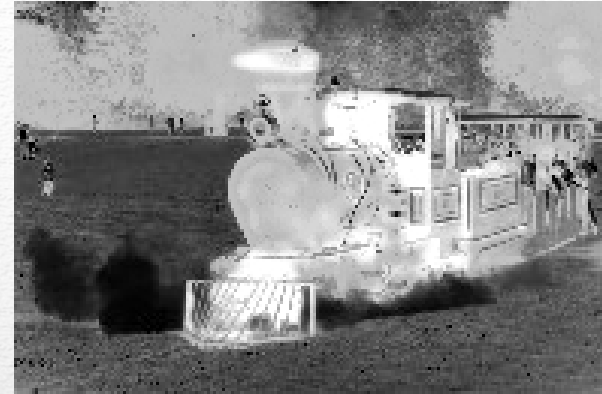
# RGB model



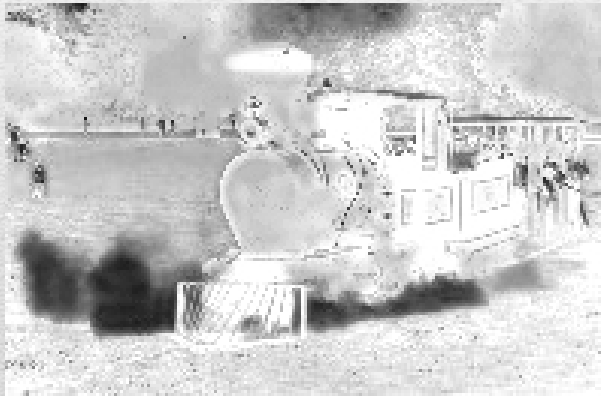
C



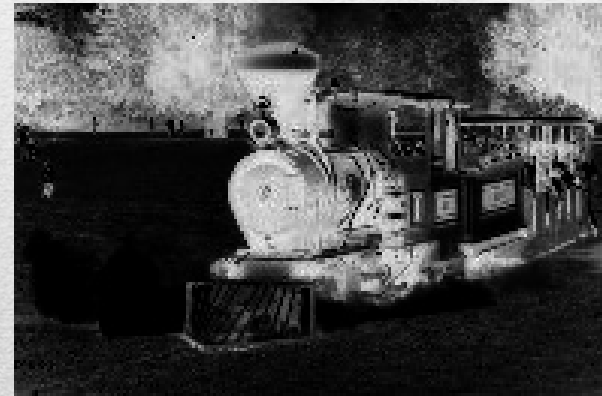
M



Y

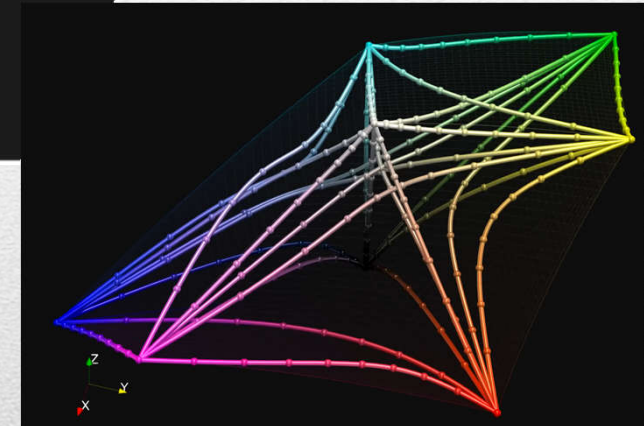
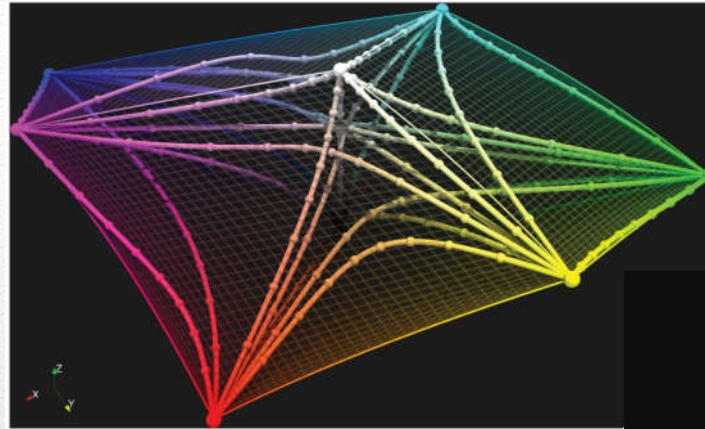
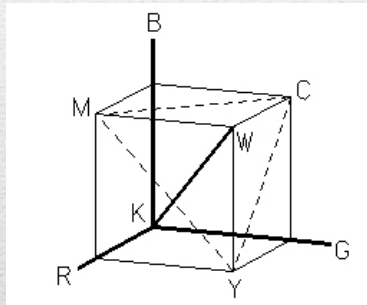
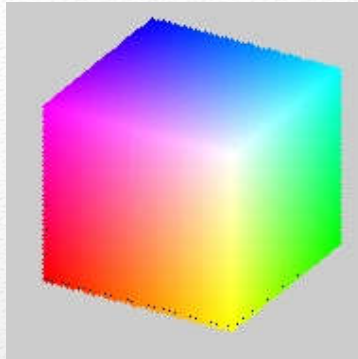


K

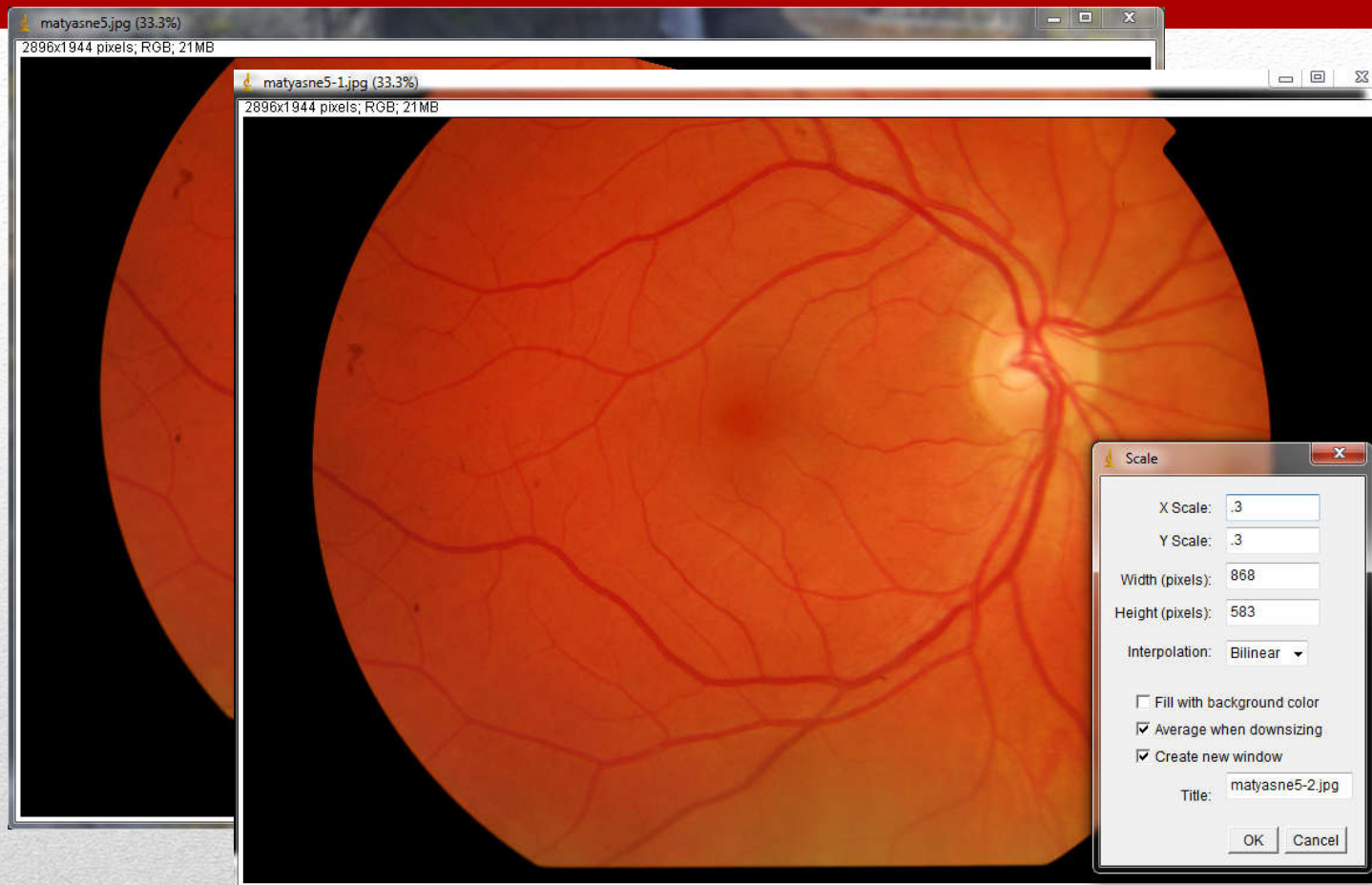


# CMYK model

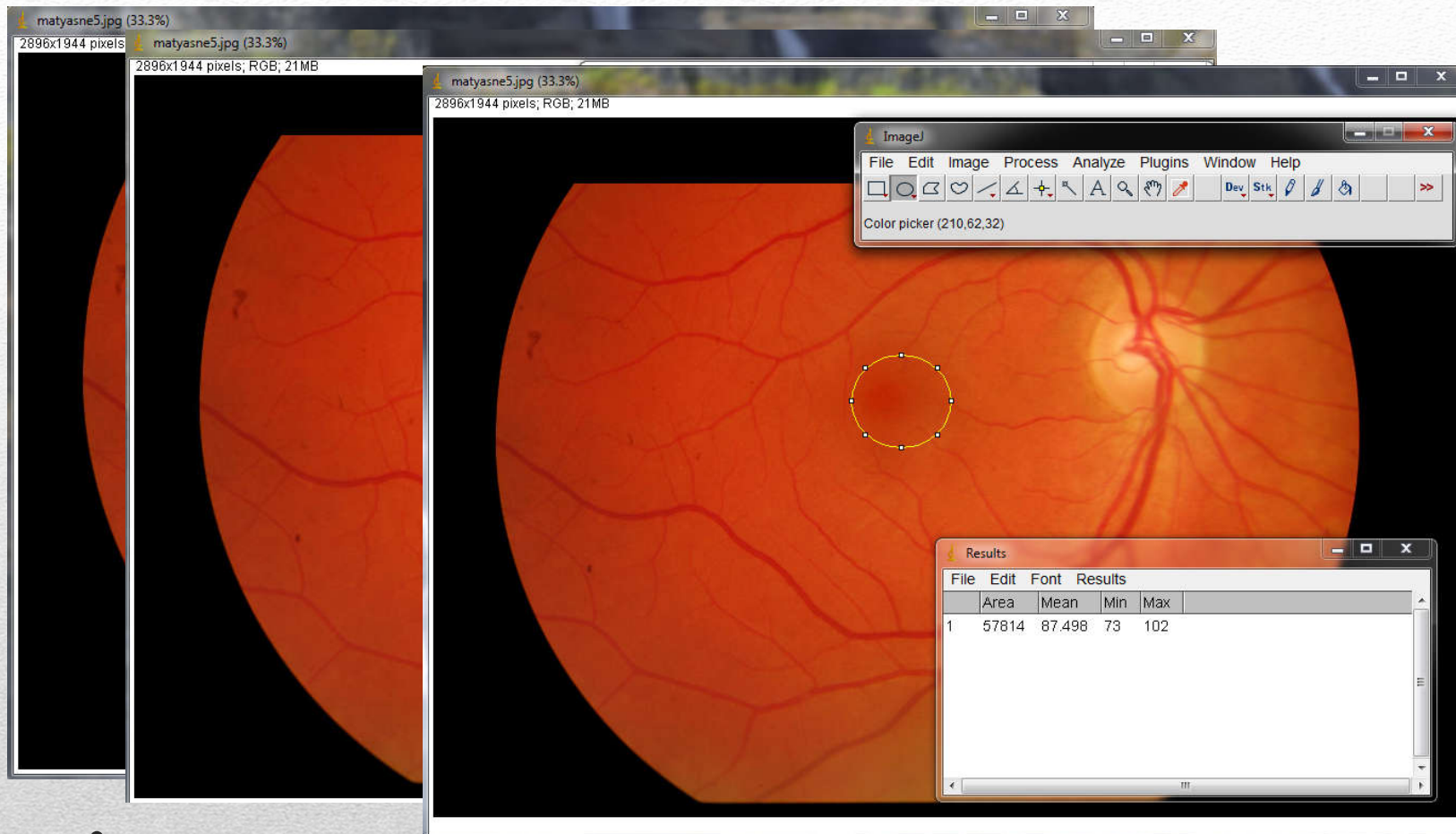




# RGB model vs. Perceptual color model



# Geometric manipulations

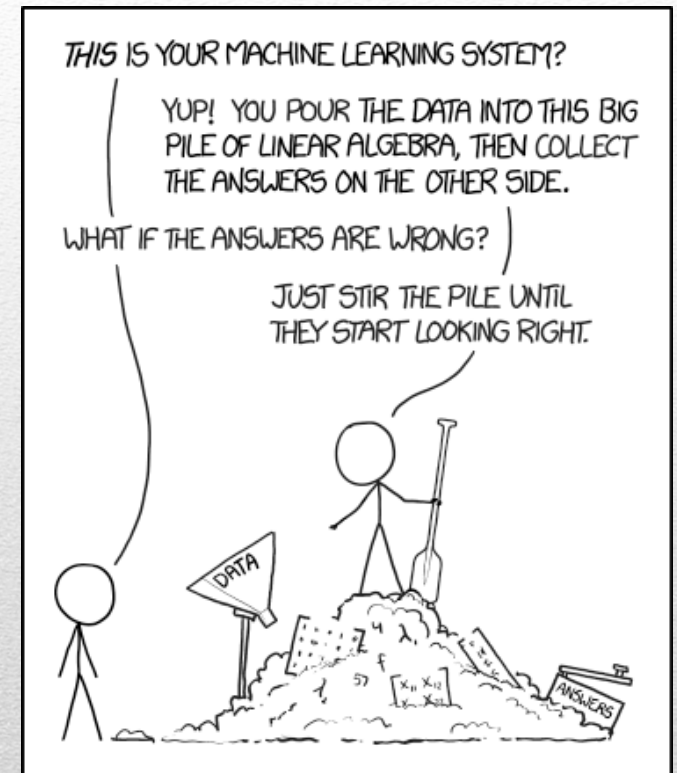
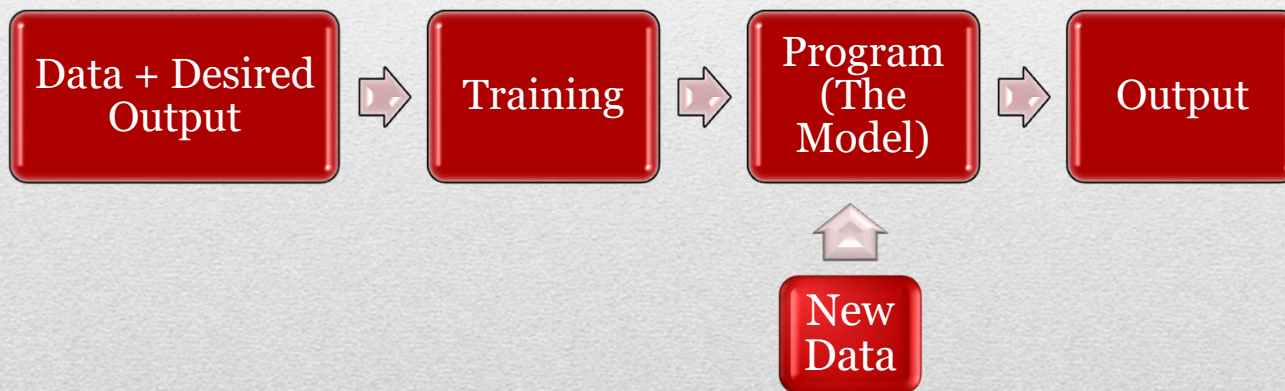


# Basic measurements

- Traditional processing:



- ML driven processing:



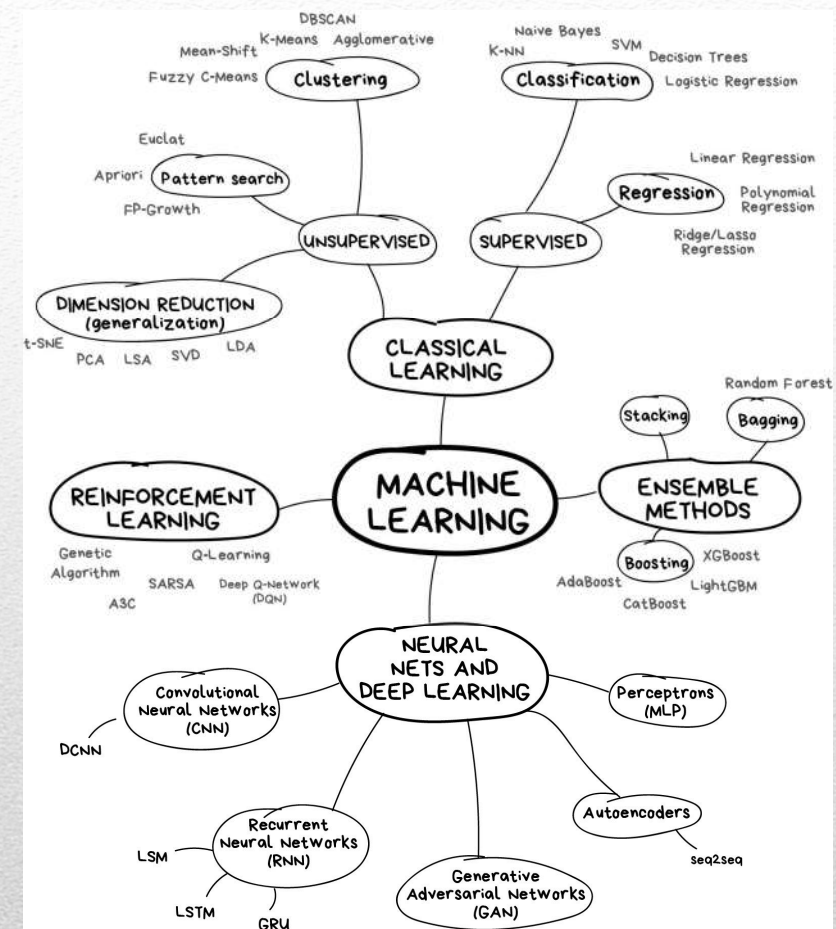
<https://xkcd.com/1838/>

# Machine Learning

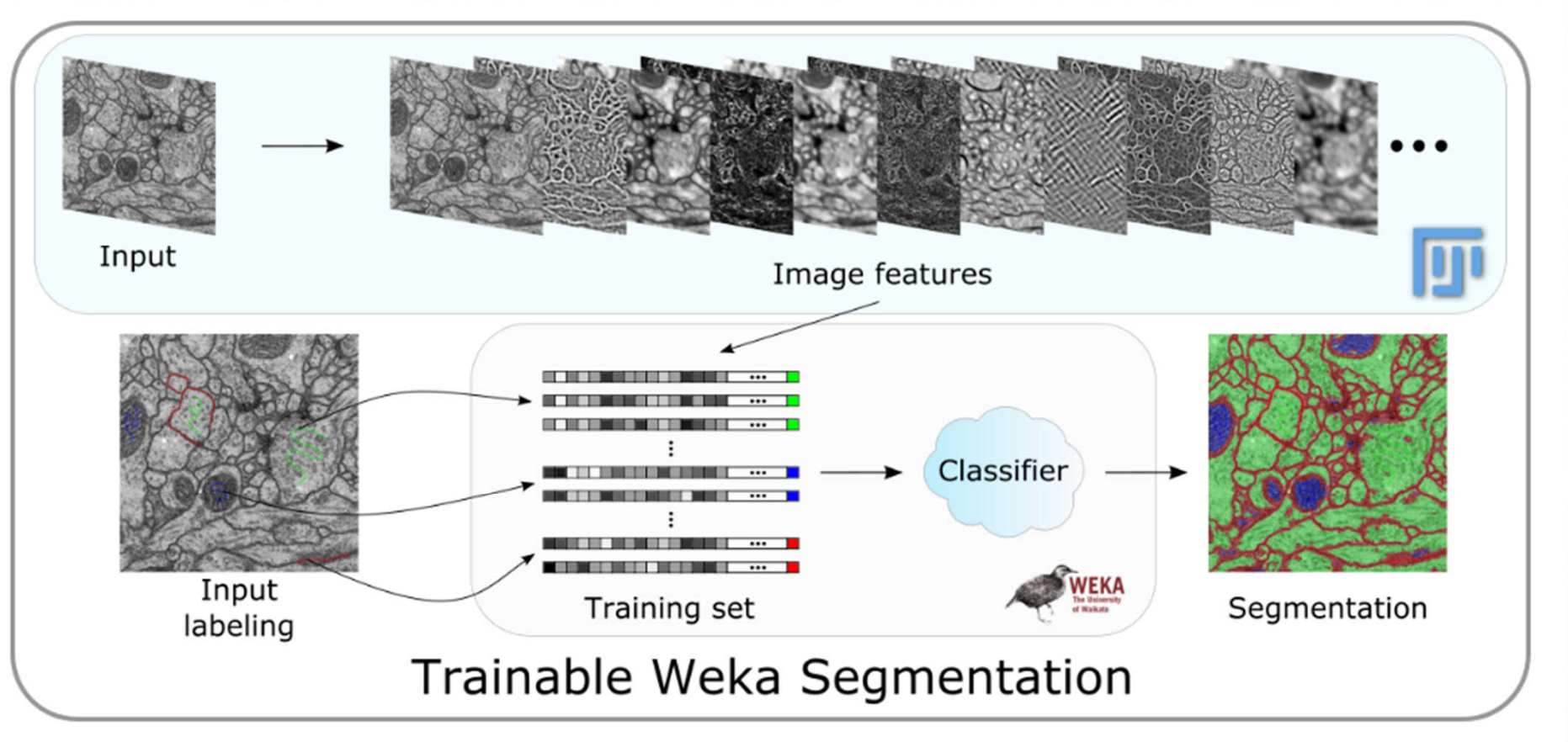
AI - Artificial Intelligence: Anytime we use the Computer for something more than just processing the prewritten code

ML - Machine Learning: Adapting to a task, based on previous information, looking for patterns in a massive amount of data.

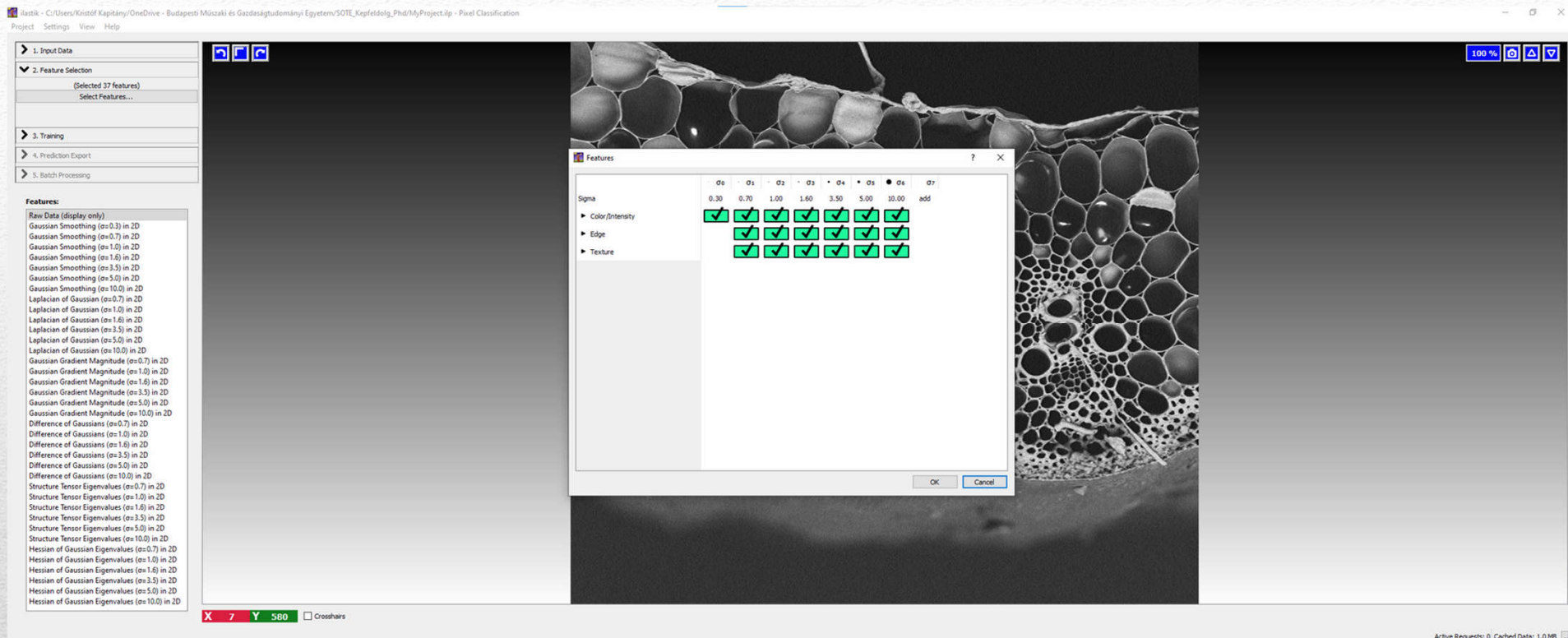
DL = ML + NN (Deep Neural Network)



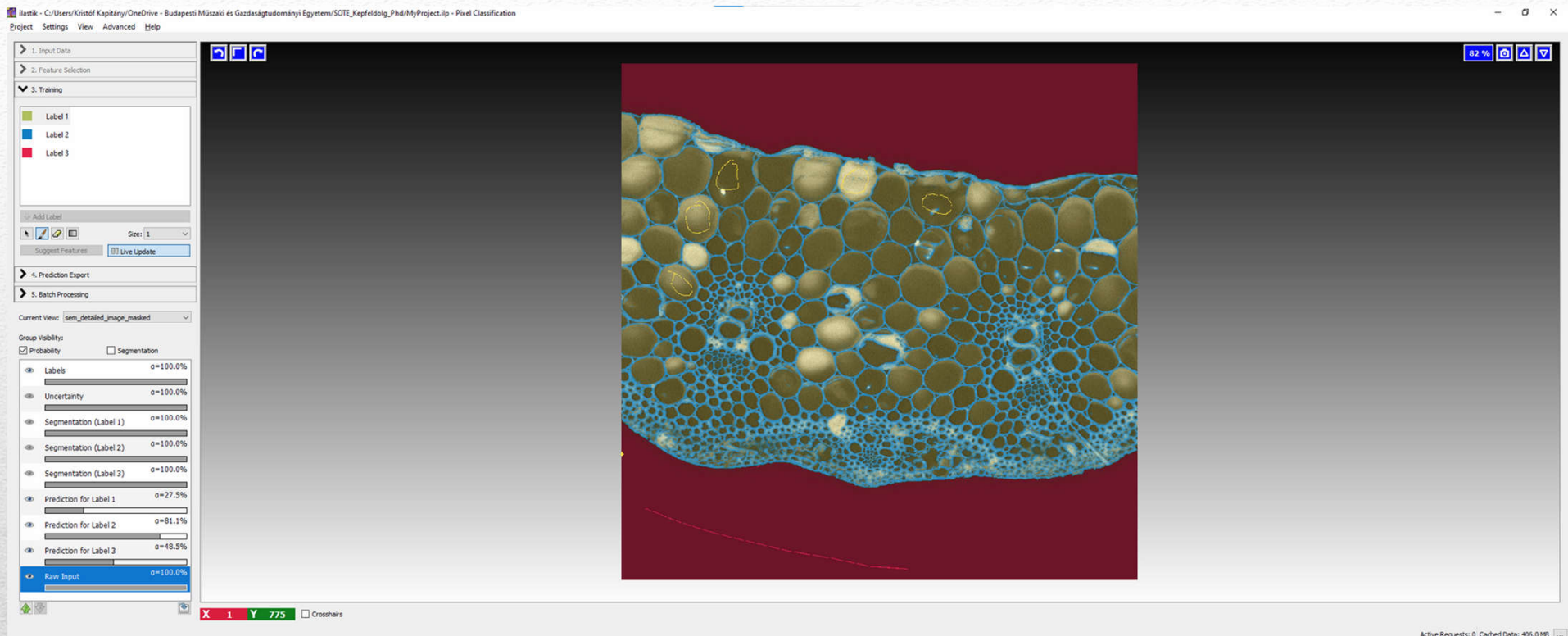
# Deep Learning vs Machine learning



# Machine learning in ImageJ

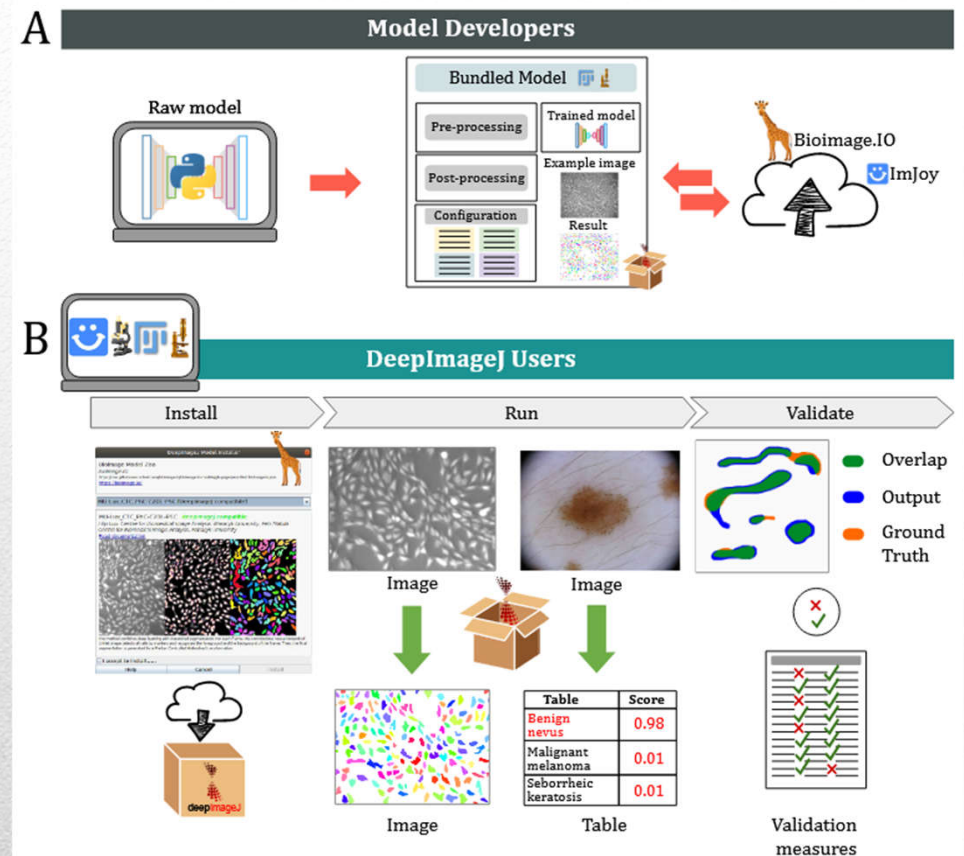
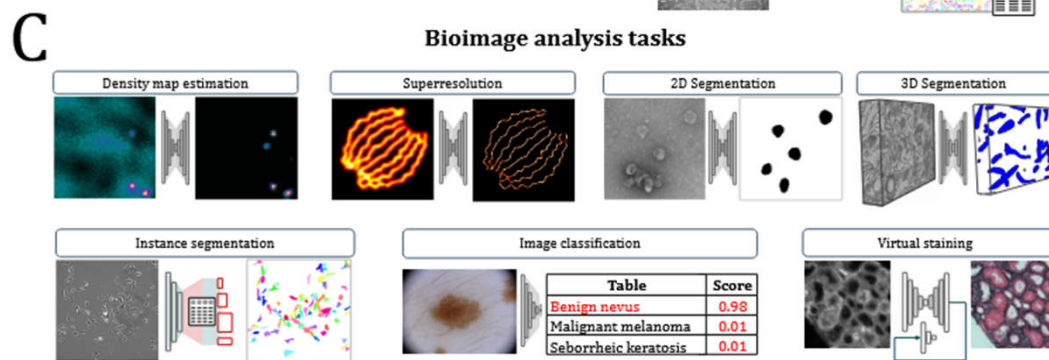
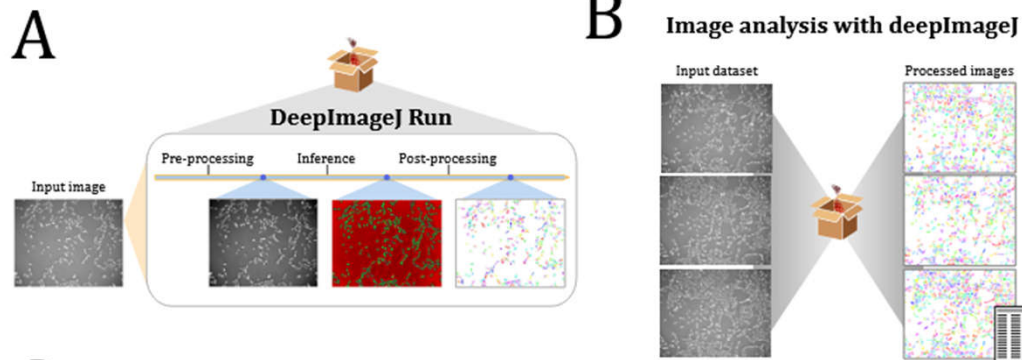


# Machine learning in Ilastik



# Machine learning in Ilastik





Source: <https://www.biorxiv.org/content/10.1101/799270v3.full.pdf>

# Deep learning in ImageJ



Thanks for your attention!

To be continued...

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The materials are based on the earlier lecturer prof. Árpád BARSÍ, the references for his materials:

- Gonzalez, R.C. – Woods, R.E.: Digital Image Processing
- Jähne, B.: Digital Image Processing
- Russ, J.C.: The Image Processing Handbook
- Epstein, L.C.: Introduction to the Mathematics of Medical Imaging
- Suetens, P.: Fundamentals of Medical Imaging
- dicom.nema.org
- <http://www.olympusmicro.com/>

References for the extensions:

- <https://commons.wikimedia.org/wiki/User:Datumizer>
- <https://www.pnas.org/doi/full/10.1073/pnas.2119753119>
- [https://vas3k.com/blog/machine\\_learning/](https://vas3k.com/blog/machine_learning/)
- <https://imagej.net/plugins/tws/>
- <https://www.biorxiv.org/content/10.1101/799270v3.full.pdf>

# References