Digital Image Processing

Introduction

Prof. Tiago Vieira

Universidade Federal de Alagoas

tvieira@ic.ufal.br

July 15, 2021

Contents

Introduction – What's DIP?

- Science mixed with art.
- Interdisciplinary territory.
- Stimulates scientific research, development and innovation.

Connected areas:

- Computer graphics.
- Computer vision.
- Robotics.
- Remote sensing.

Desired knowledges:

- Mathematics.
- Statistics.
- Algorithms.
- Signals and systems.

Contrast enhancement:

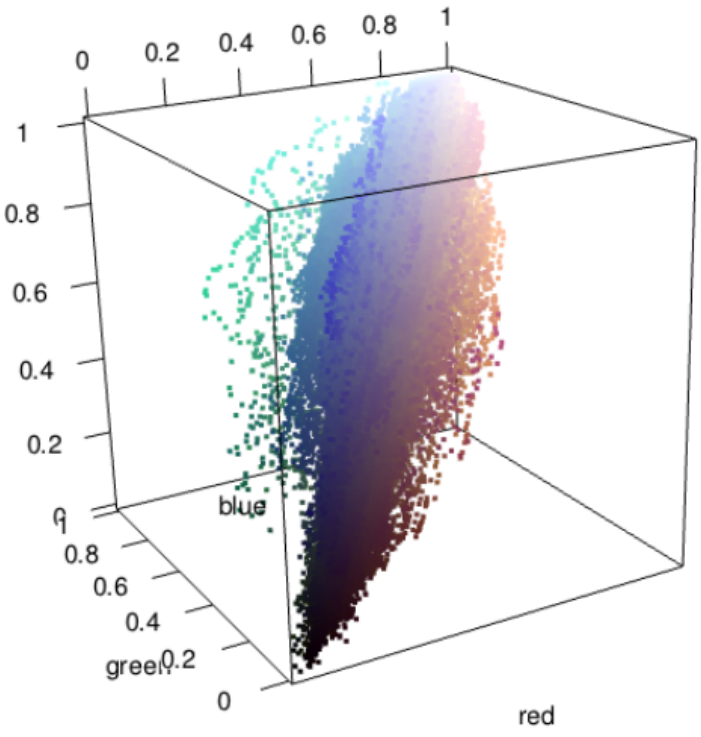
Contrast enhancement:

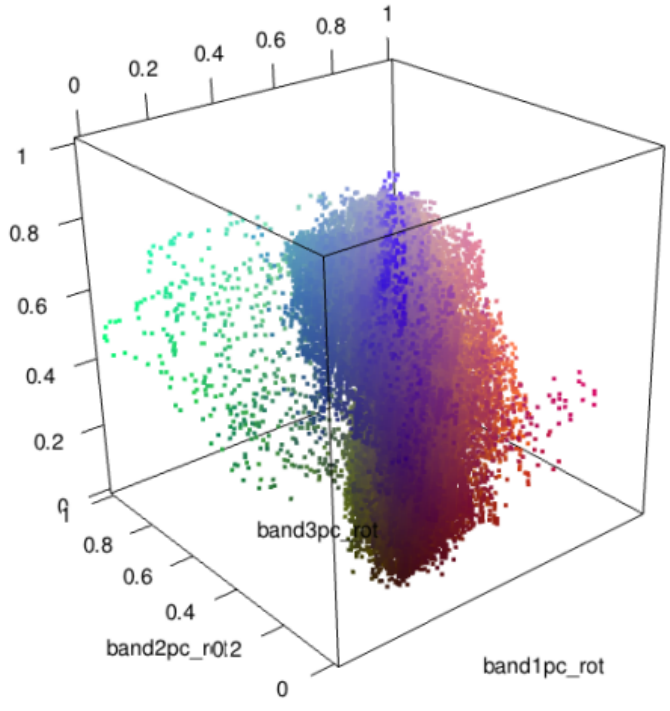
Contrast enhancement:

What is the magic?

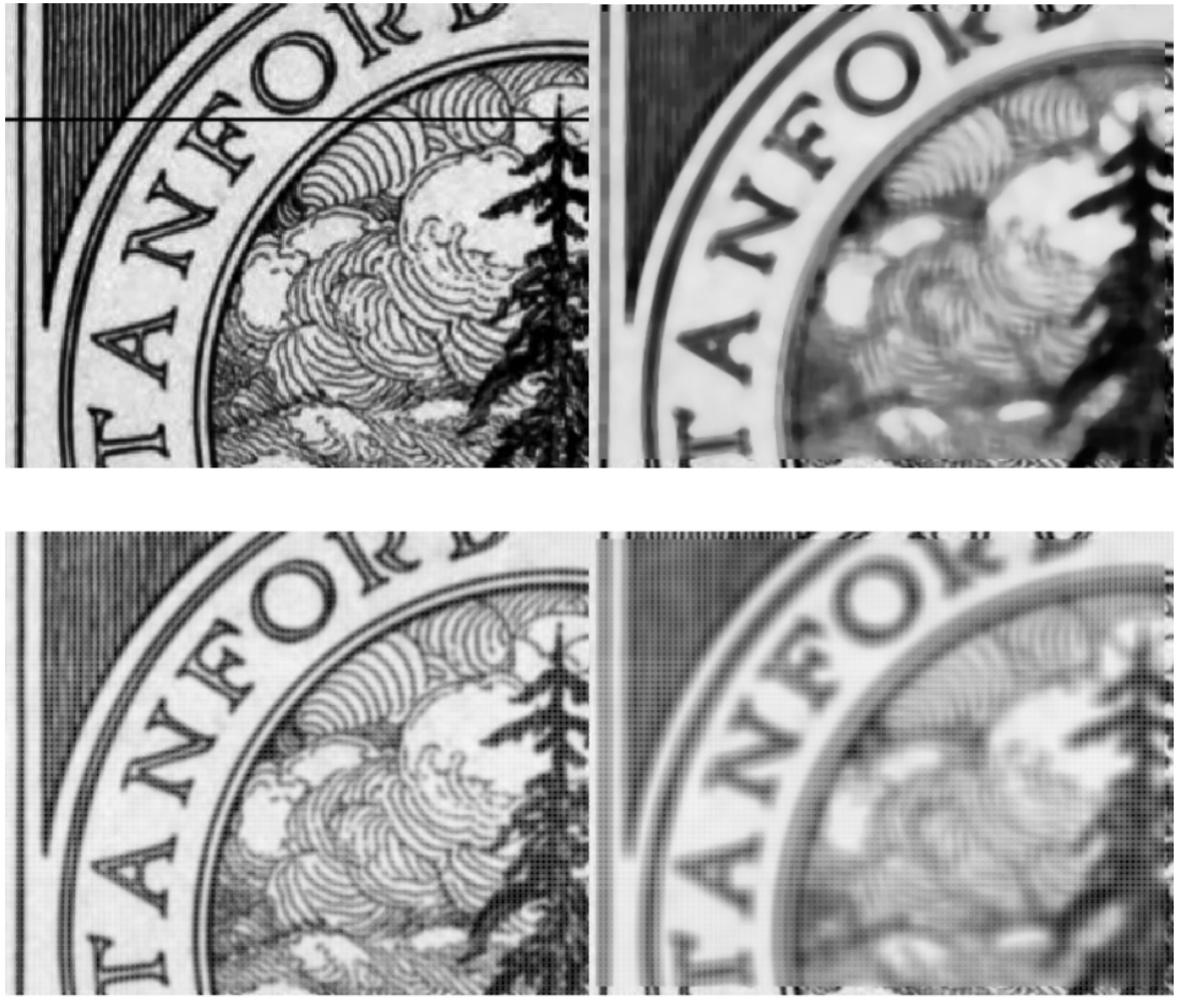
- Understand the relation between the data and what we observe.
- Model properly what we have and what we want.
- Possess a good set of tools allowing us to achieve the desired result with the least computational effort.

Selective contrast enhancement.

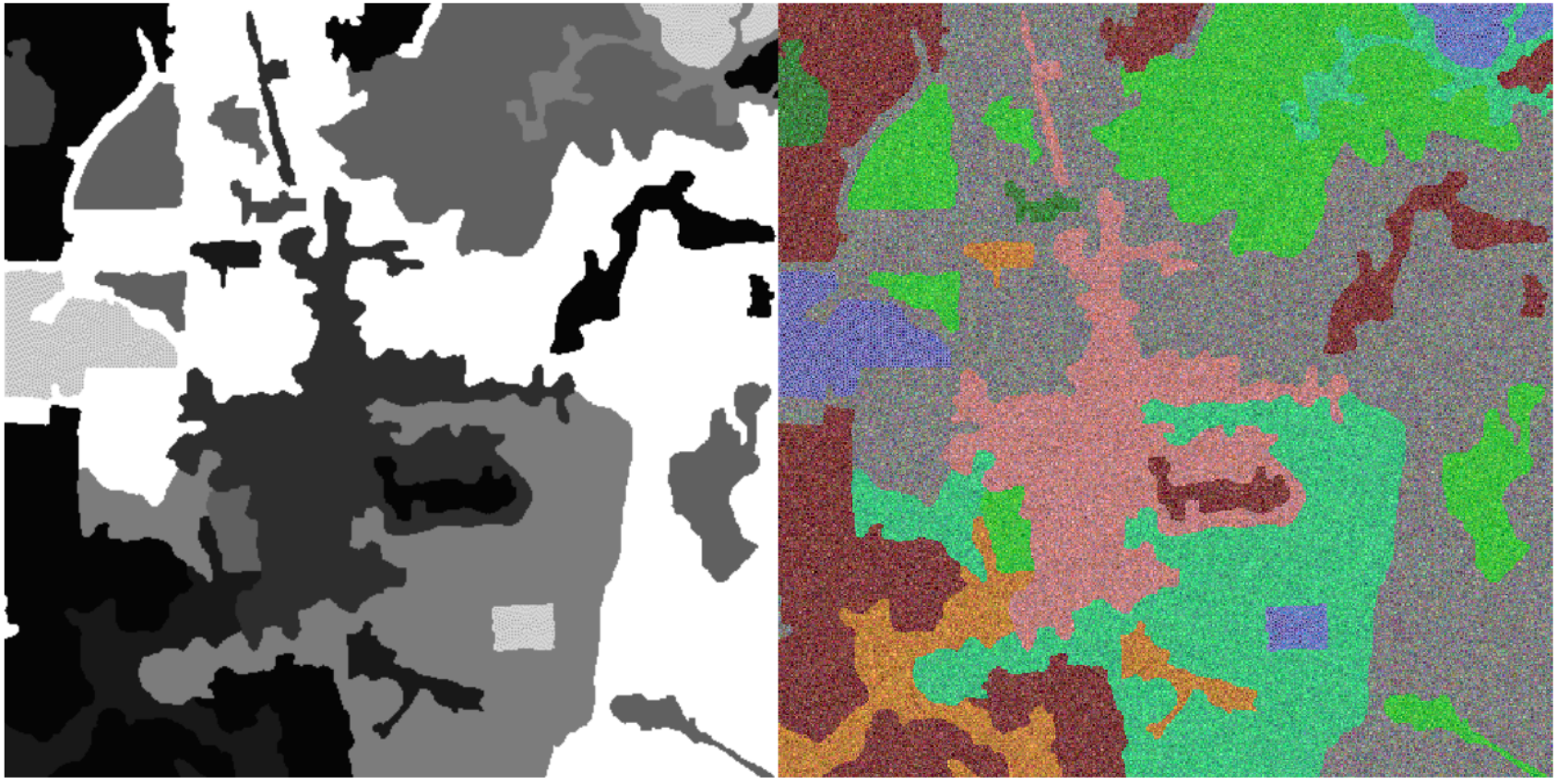

0
0.2
0.4
0.6
0.8
1
blue
green
red


band3pc_rot
band2pc_rot
band1pc_rot

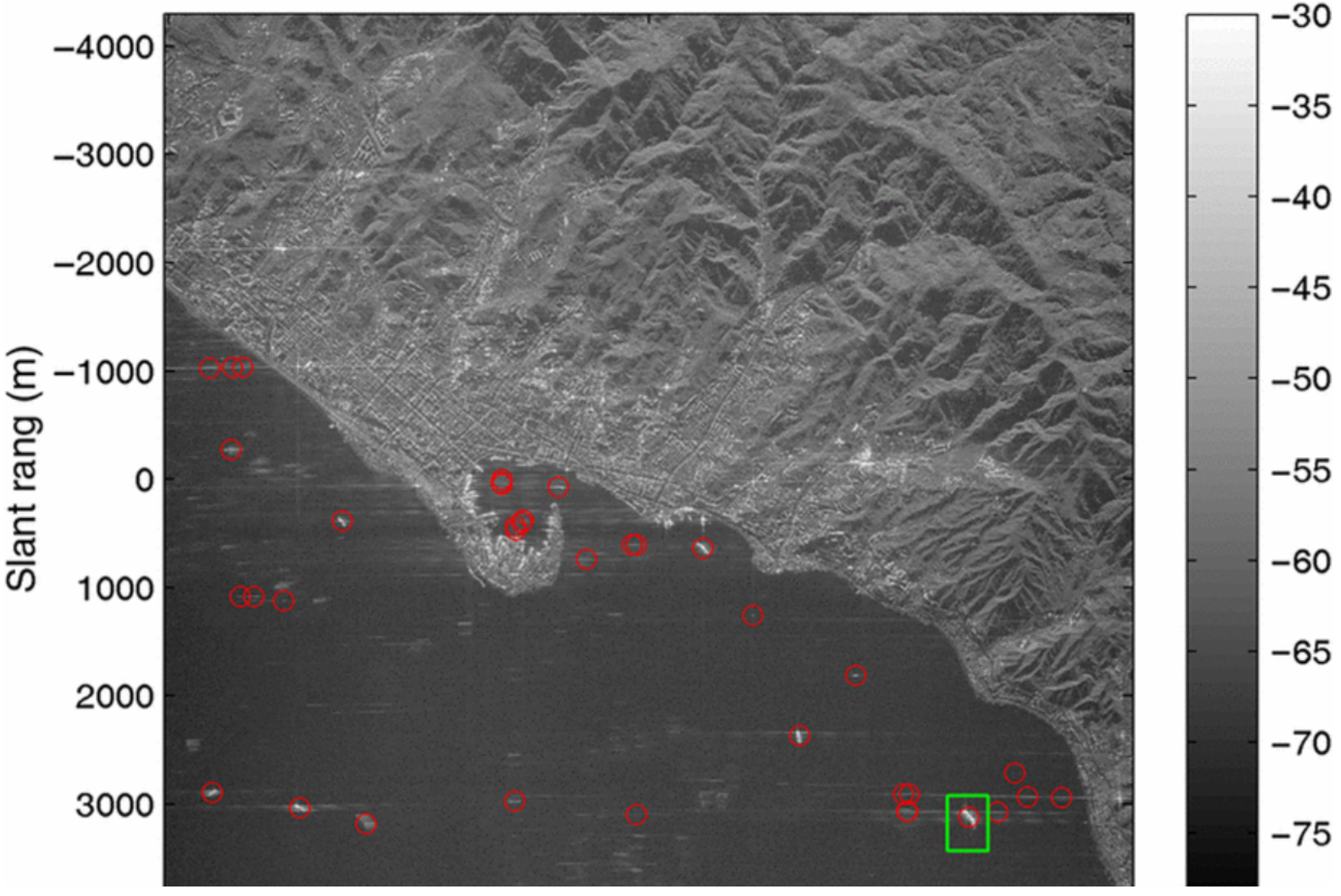
Blurring.



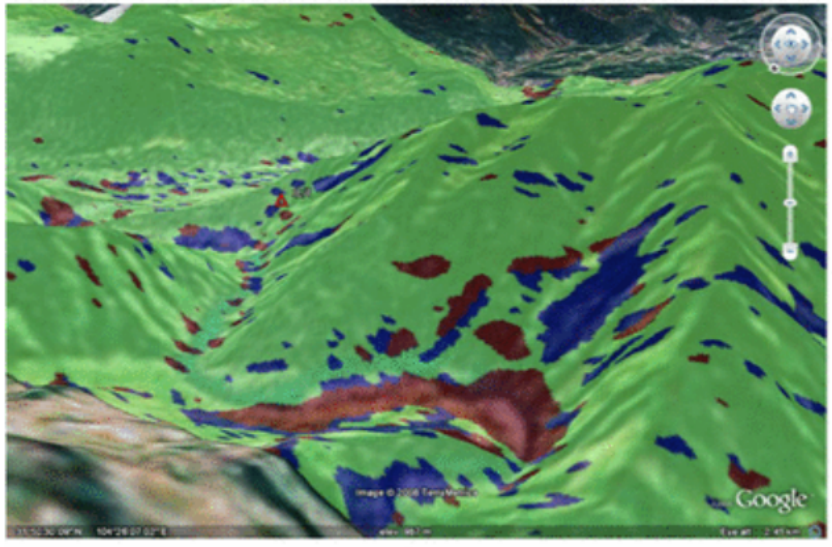
Terrain labelling.



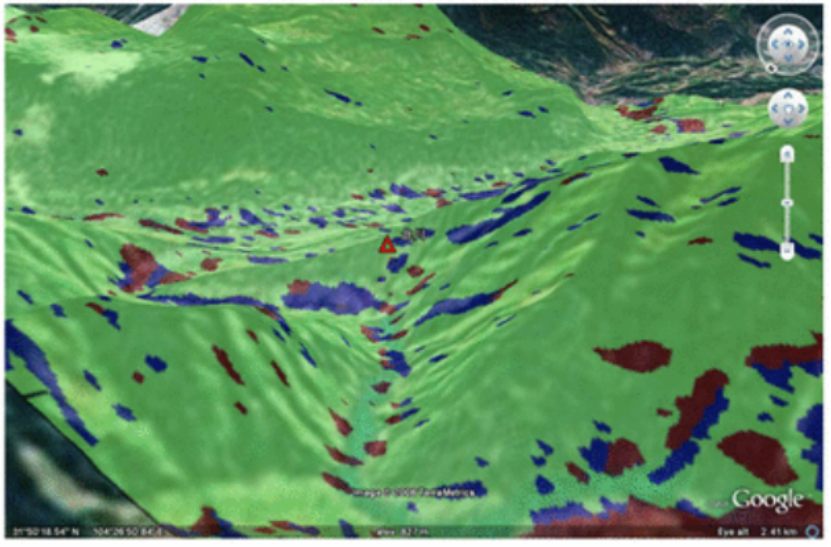
Boat detection.



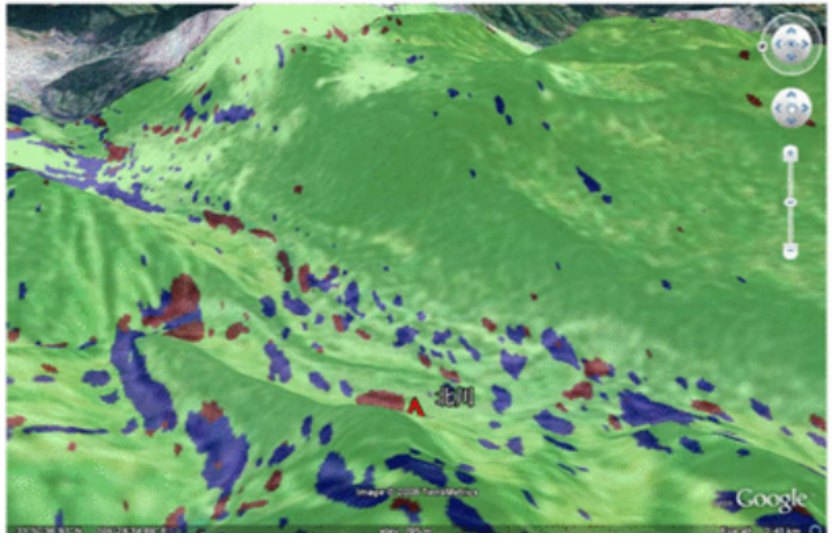
Terrain deformation analysis.

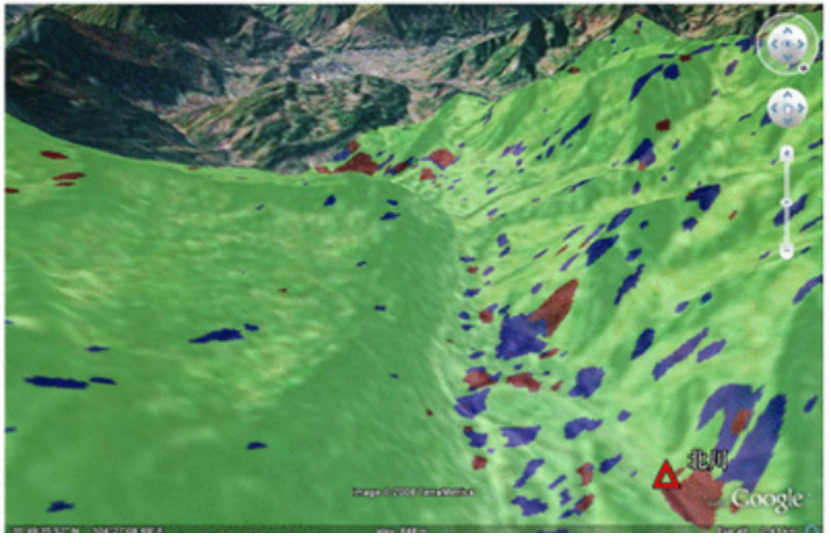


(a)

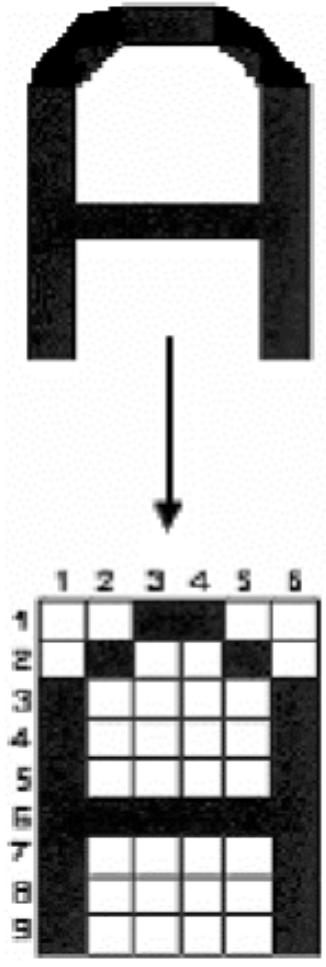


(b)





- An image:
  - Bi-dimensional function $f(x, y)$.
  - Amplitude of $f(x, y)$ at any pair of coordinates (x, y) is called *intensity* or *gray level*.
- When x, y and $f(x, y)$ are finite the image is *digital*.
- Digital image processing = process digital images using a digital computer.



A digital image is composed by a finite number of elements, AKA:

- Picture elements.
- Image elements.
- Pels.
- Pixels.

Paradigm:

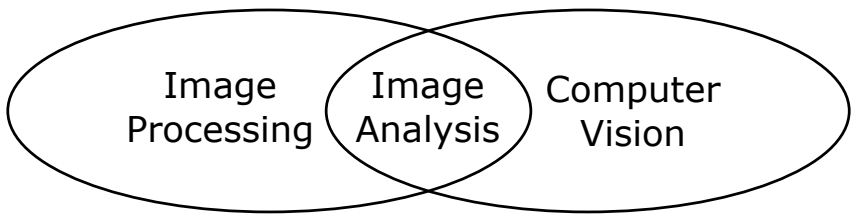
- Where does IP beggins and where does it end?
- (*Narrow definition*) In IP, both input and output are images.

Another paradigm, according to processing level:

- Low-level:
  - Primitive operations.
  - Noise-reduction, pre-processing steps.
  - Content enhancement.
  - Sharpening.
- Mid-level:
  - Segmentation.
  - Classification.

- High-level:
  - Understanding.
  - Cognitive functions.

Processing level	Input	Output
Low	Image	Image
Mid	Generally image	Attribute
High	Attribute	Significance



Origins - Newspaper industry

- Pictures sent by submarine cable.
  - (1920) Bartlane cable (London $\rightarrow$ NY): Transmission time (1 week $\rightarrow$ 3 h).

Figure: A digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces.

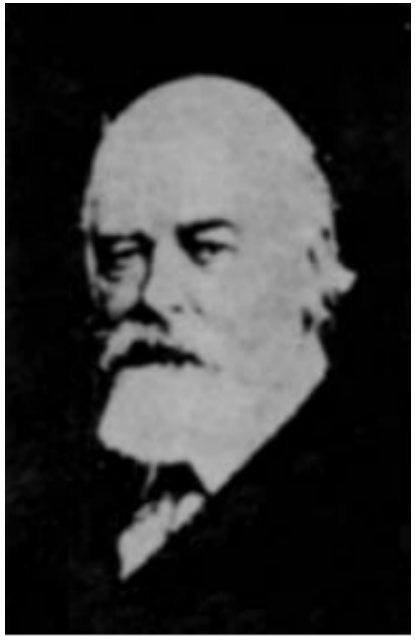
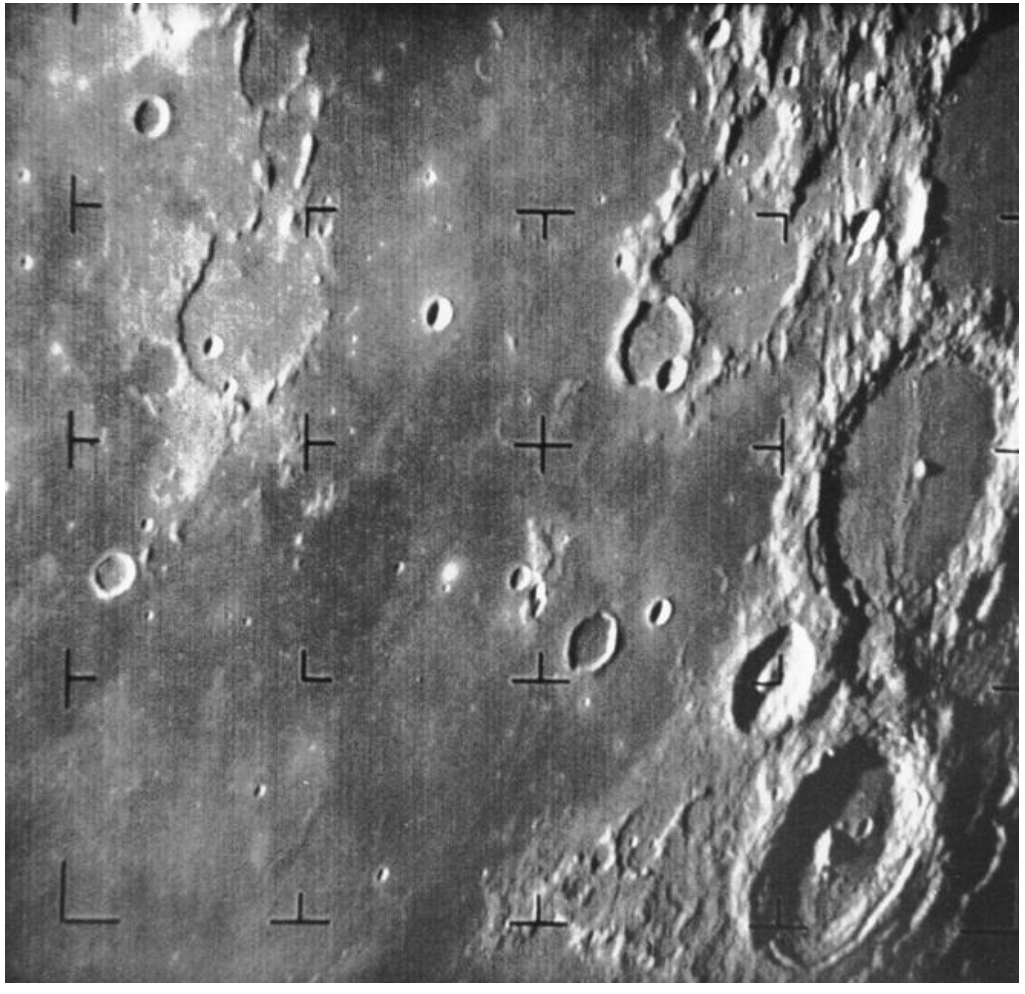


Figure: (1922) A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice.

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

- However, image transmission is different from image processing.
- Image processing can be traced back to 1960s:
  - Computer powerful enough.
  - Space program.

- (1964) *Ranger 7* transmitted the first pictures of the moon.
  - Lens distortions were corrected.



- Late 1960s, early 1970s.
  - Medical (Computerized Tomography - CT).
    - Tomography in converting sensed data into a "slice".
    - Tomography was invented independently by Sir G. N. Hounsfield and A. M. Cormack, who shared the 1979 Nobel Prize in Medicine for their invention.
    - X-rays were discovered in 1895 by Wilhelm Conrad Roentgen (1901 Nobel Prize for Physics).
    - Nearly 100 years between inventions.
  - Remote earth resources.
  - Astronomy.

How much is IP growing so far? Enormously!

- Space.
- Medicine.
- Pseudo-color generation (contrast enhancement) in.
  - X-rays.
  - Industry.
  - Medicine.
  - Biological sciences.

- Geography.
  - Analysis of aerial or satellite imagery.
  - Pollution, crop evolution, drug plantation detection, disaster assessment, event prediction.
- Enhancement/ Restoration.
  - Recover information of partially lost evidence.
- Physics.
  - Image enhancement of experiments related to high-energy plasmas, and;
  - electron microscopy.

- Astronomy.
- Biology.
- Medicine.
- Defense.
- Industry.

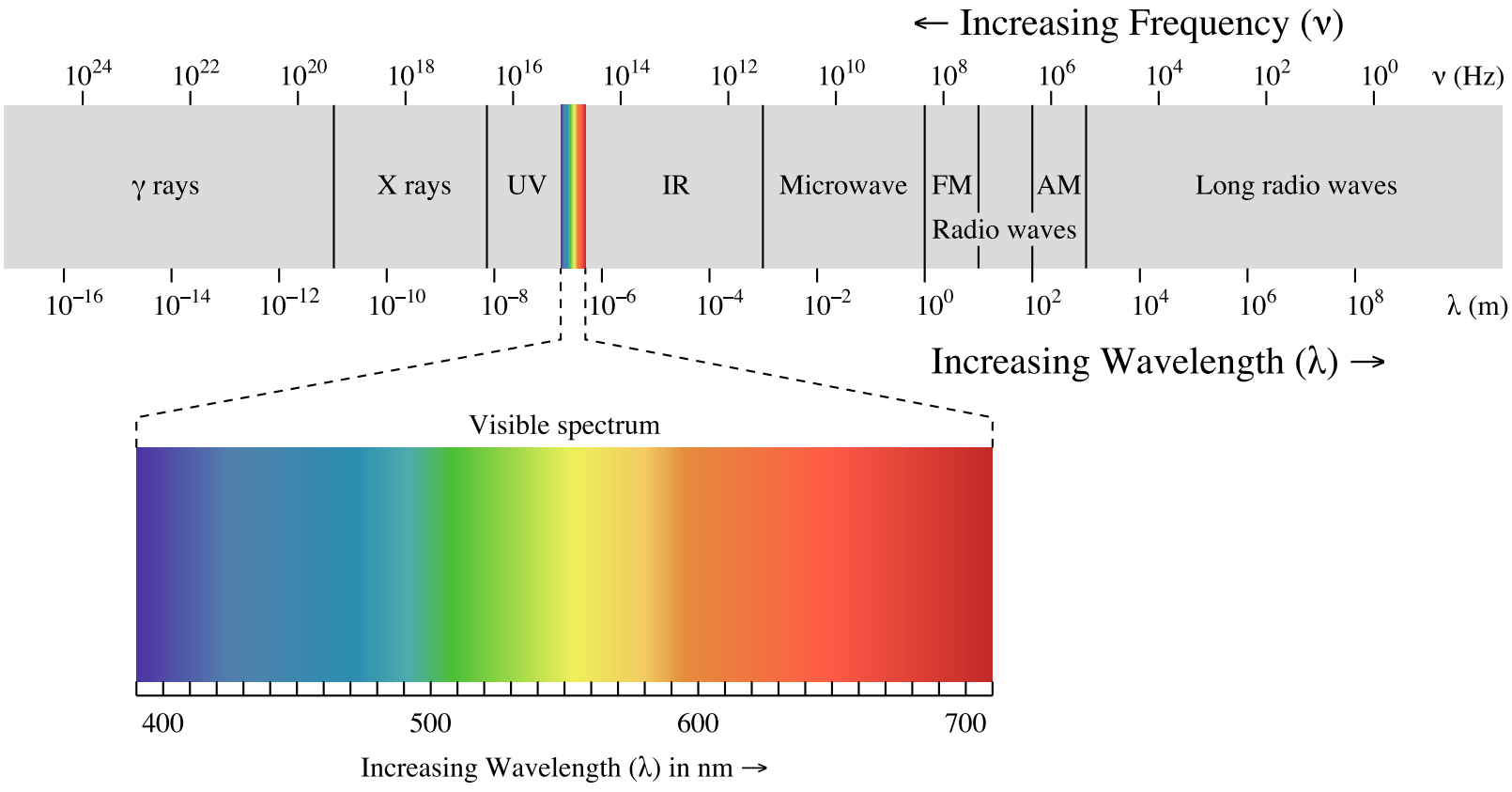
Machine interpretation.

- Human *vs* Machine.
  - Statistical moments.
  - Fourier transforms.
  - Multidimensional feature distance measures.

Examples:

- Industry:
  - Inspection.
  - Assembly.
- Military recognizance.
  - Fingerprints.
  - Terrain evaluation.
- Aerial and satellite imagery for;
  - Geographical Information System (GIS) assessment.
  - Weather forecast.

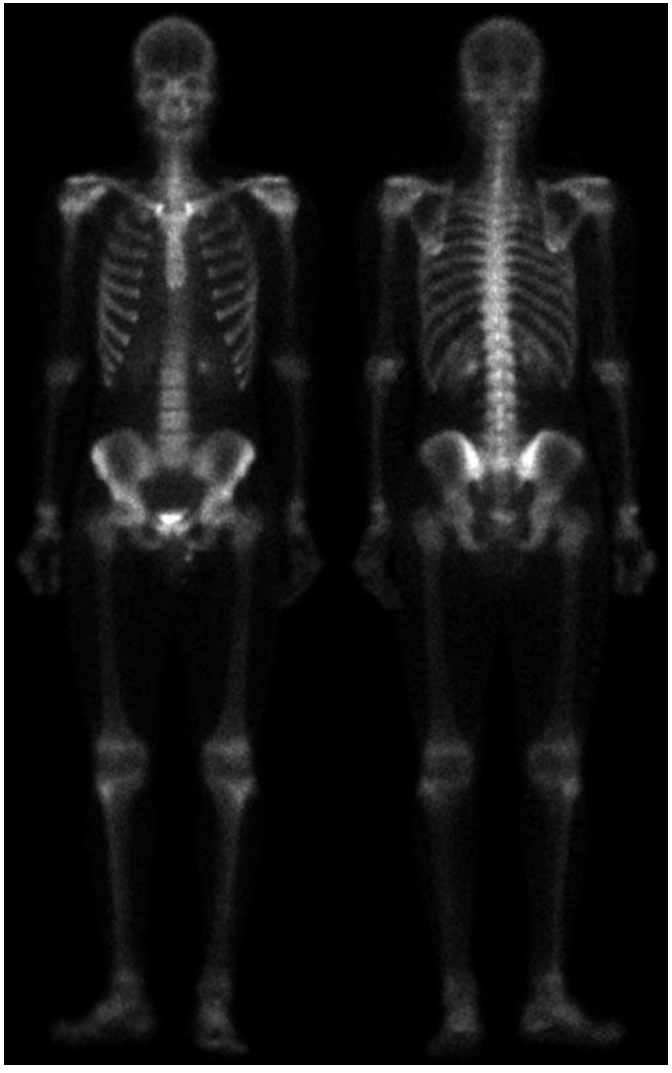
- Vision is the most advanced human sense.
- Although, we can only see a tiny part of the electromagnetic (EM) spectrum:



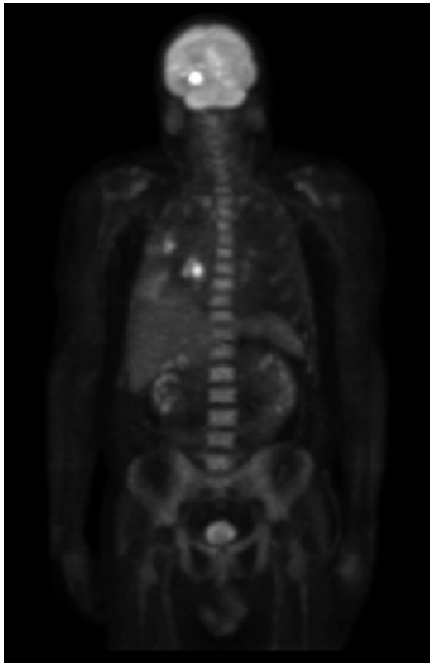
Examples of gamma-ray imaging:

- Nuclear medicine. Patient take radioactive isotopes.
- Astronomy.

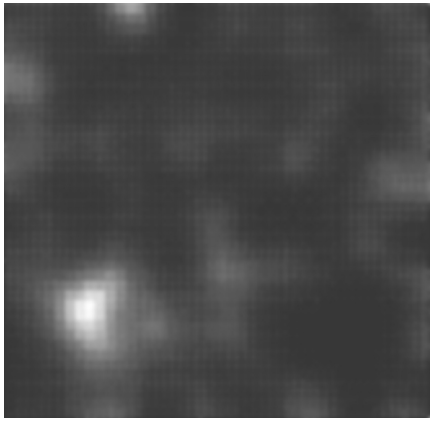
Bone scan using gamma ray



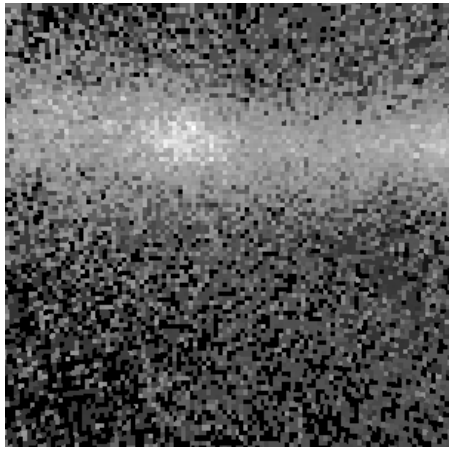
Positron Emission Tomography (PET) scanET image



Gamma radiation from a reactor valve

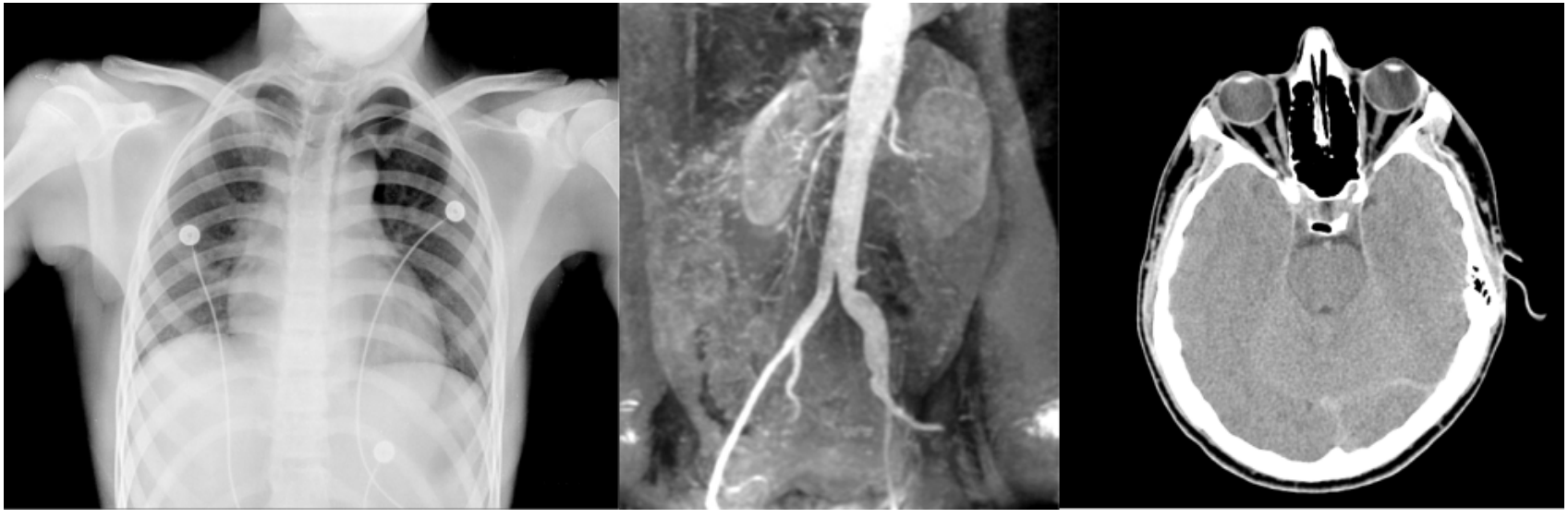


Cygnus loop



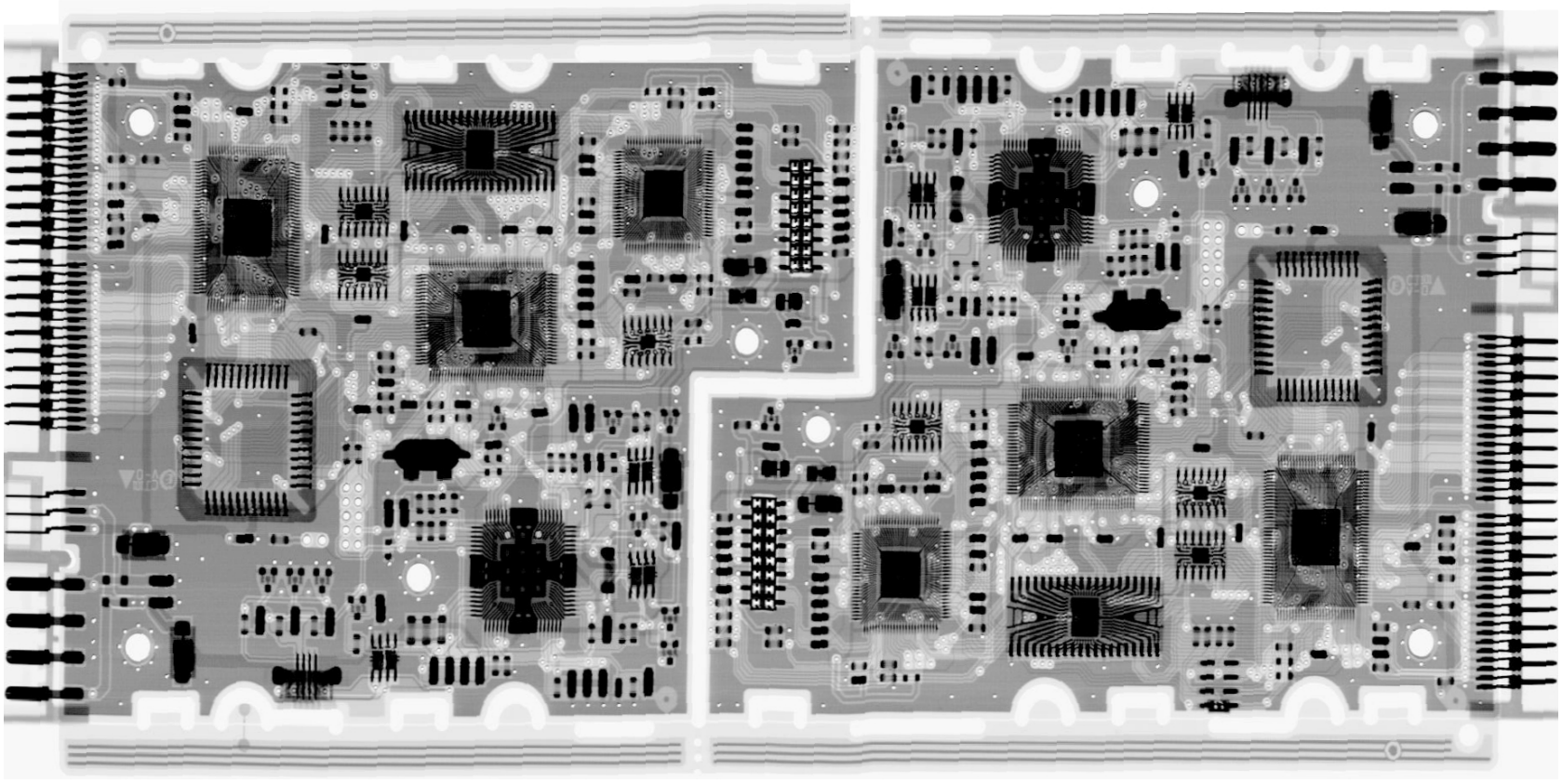
X-ray imaging:

- Medicine.
  - Radiography.
  - Angiography (Contrast Enhancement Radiography).
  - Computerized Axial Tomography (CAT).



X-ray imaging:

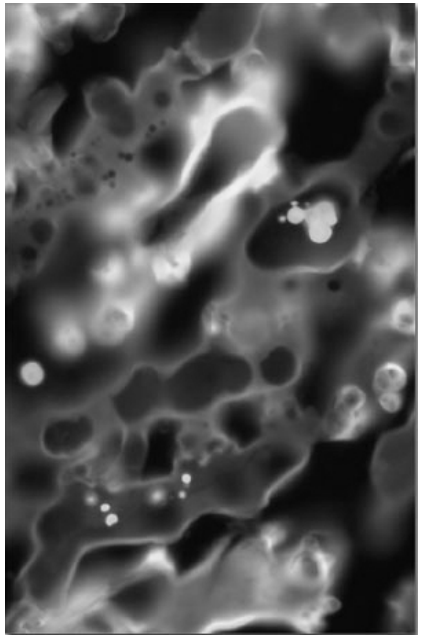
- Industry:
  - Flaw detection.



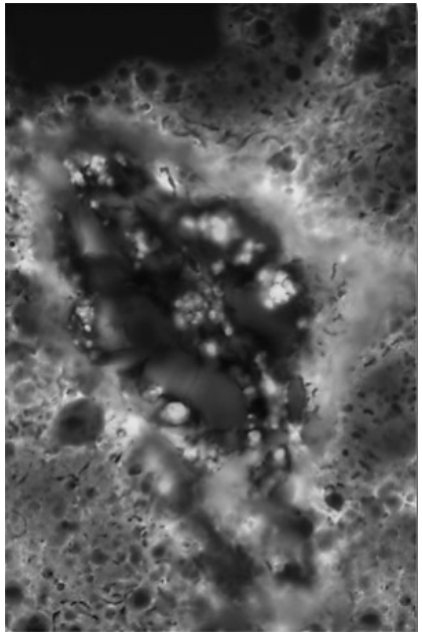
Ultra-violet (UV) imaging:

- Fluorescence microscopy.

Normal corn



Smut corn

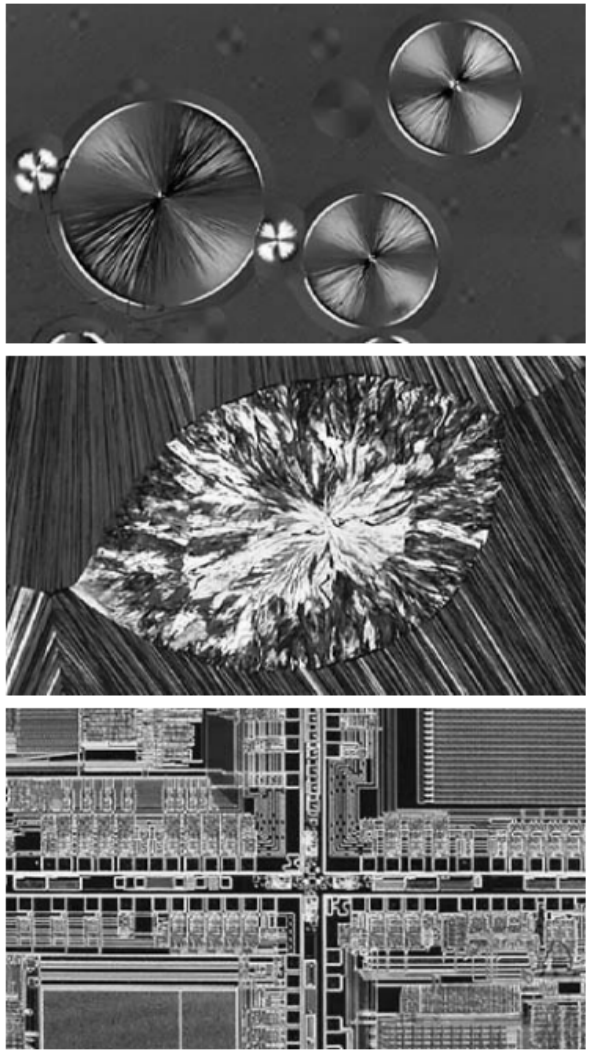


Visible and infrared imaging.

- Light microscopy.
- Astronomy.
- Remote sensing.
- Industry.
- Law enforcement.

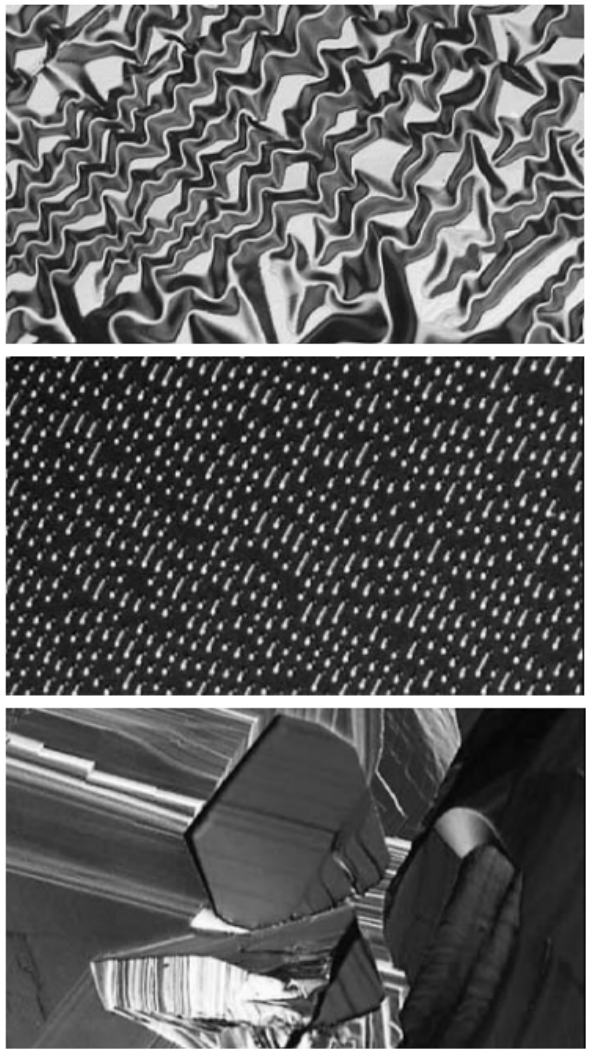
Light microscopy imaging:

- Anti-cancer agent – 250×.
- Cholesterol – 40×.
- Microprocessor – 60×.



Light microscopy imaging:

- Nikel-oxide thin film – 600×.
- Audio CD surface – 1750×.
- Organic superconductor – 450×.



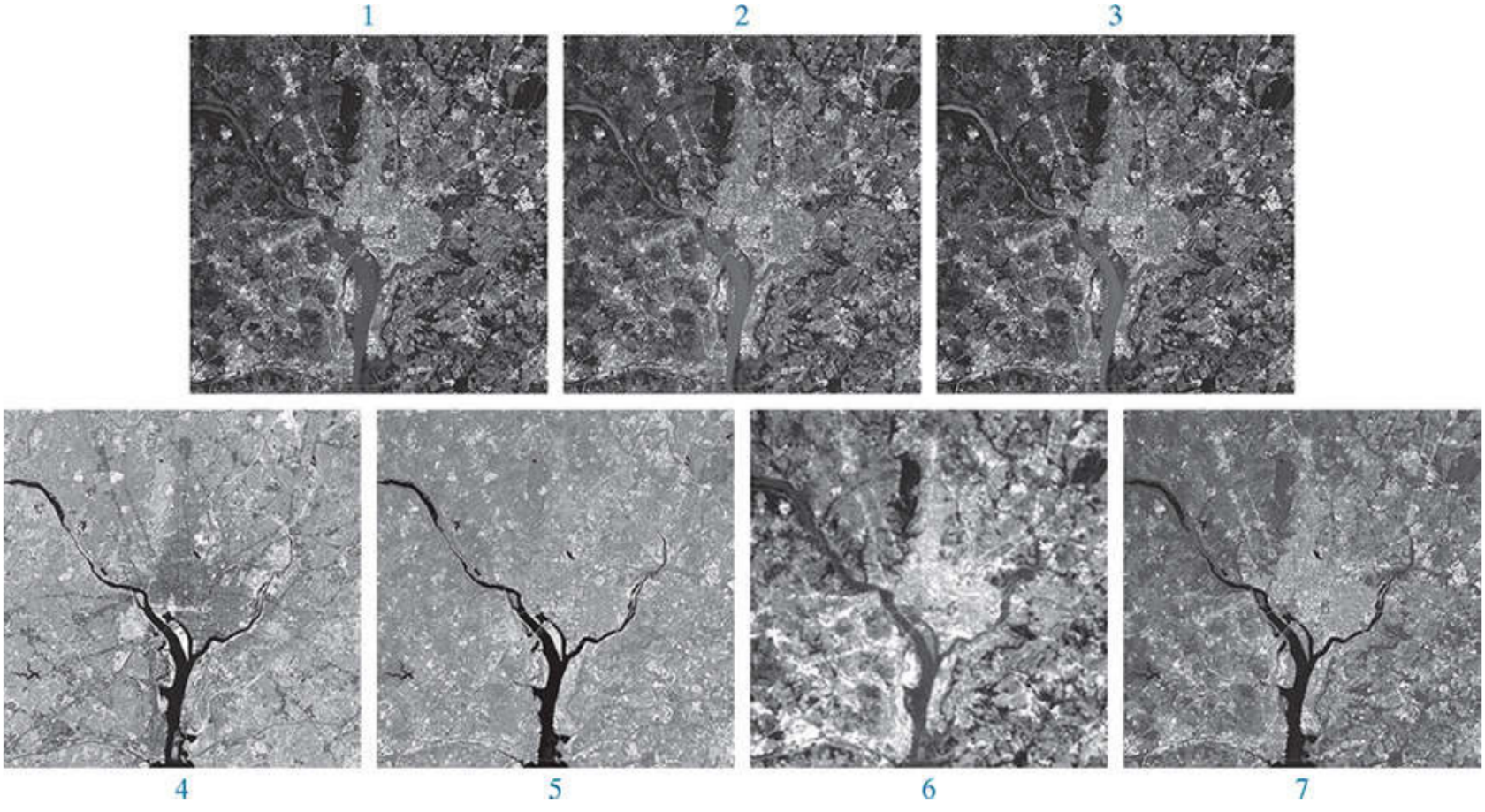
Remote sensing.

- Environmental monitoring.
- Population growth assessment, land occupation.
- Hazard prediction.

Remote sensing.

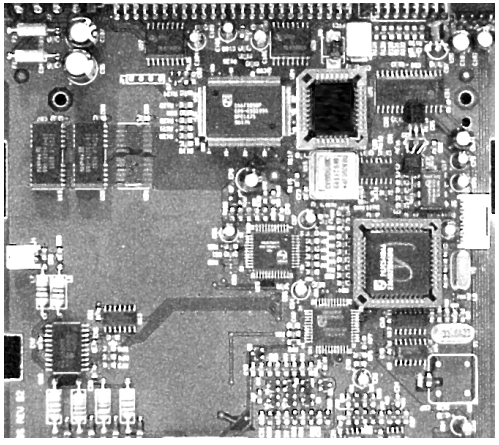
Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45– 0.52	Maximum water penetration
2	Visible green	0.53– 0.61	Measures plant vigor
3	Visible red	0.63– 0.69	Vegetation discrimination
4	Near infrared	0.78– 0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content: soil/vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Short-wave infrared	2.09–2.35	Mineral mapping

Remote sensing.

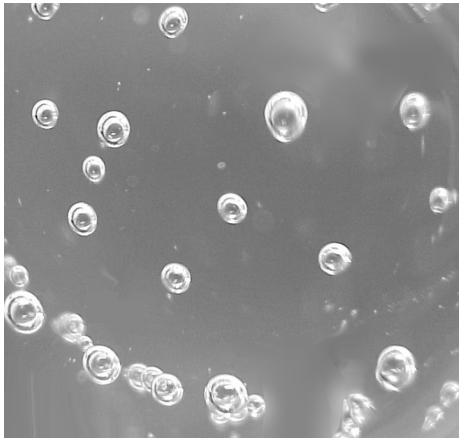


Industry.

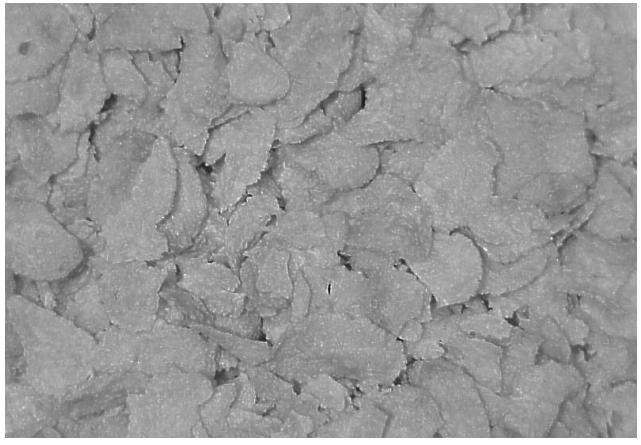
Circuit board



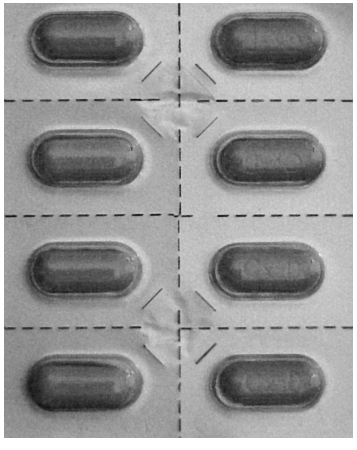
Bubbles



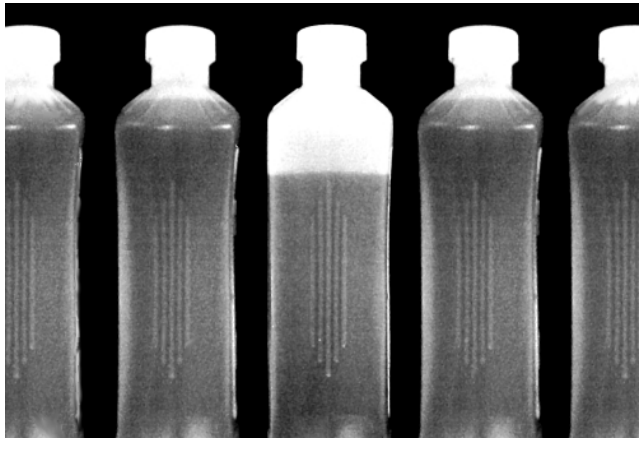
Cereal



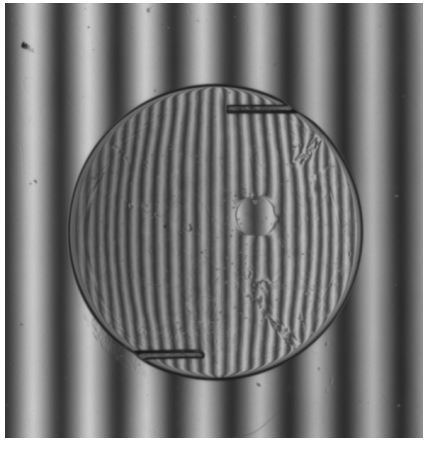
Pills



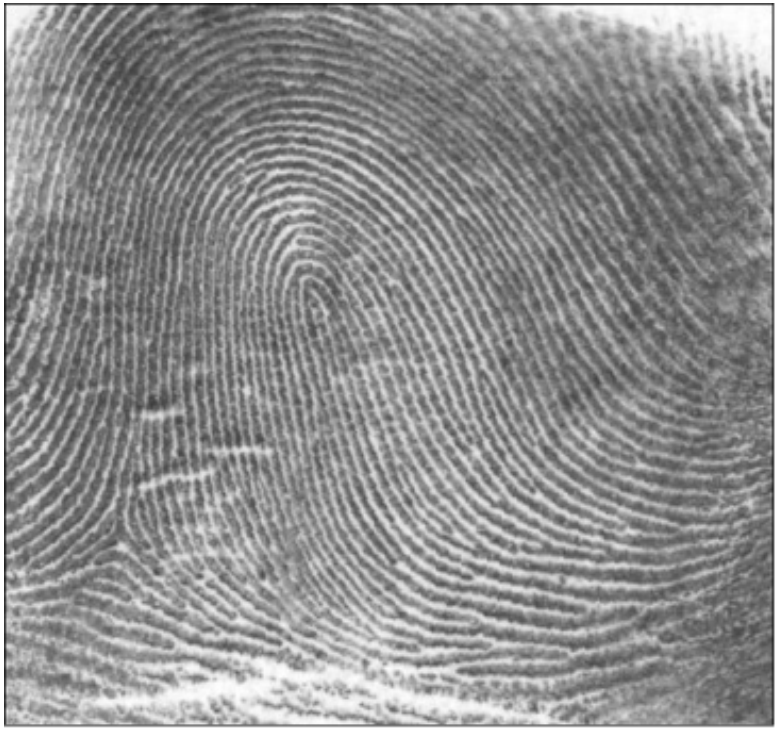
Bottles



Intraocular implant

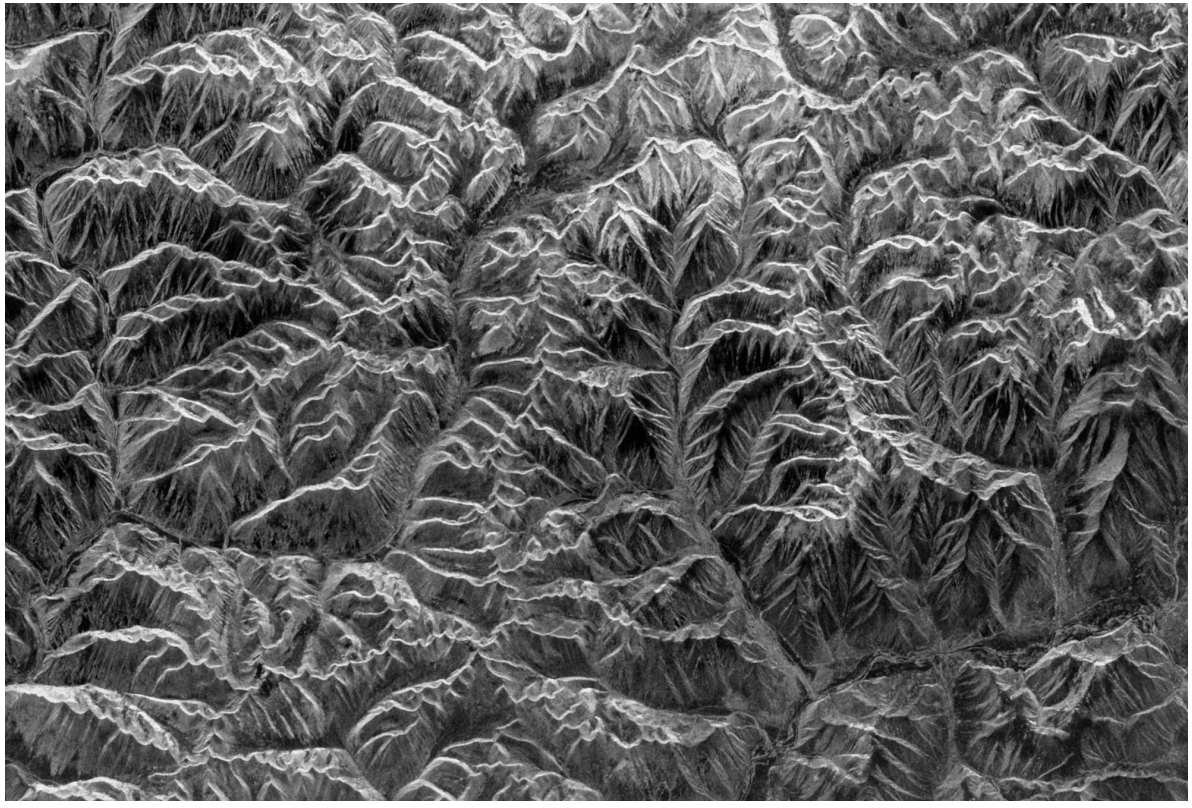


Law-enforcement.



Radar.

- Insensitive to weather conditions.
- Microwave energy reflected back is registered as image.
- Example: south Tibet mountains:



Medicine.

- Magnetic Resonance Imaging (MRI).
- Radio waves stimulates responses from the tissues.

Knee.

Spine.

Acoustic imaging.

- Geological (mineral and oil) exploration.
  - Low end (hundreds of Hz).
  - Ultrasound (millions of Hz).
- Industry.
- Medicine.
  - Imaging unborn babies.

Acoustic imaging.

1. The ultrasound system (a computer, ultrsound probe consisting of a source, a receive, and a display) transmits high-frequency (1 to 5 MHz) sound pulses into the body.
2. The sound waves travel into the body and hit a boundary between tissues (e.g., between fluid and soft tissue, soft tissue and bone). Some of the sound waves are reflected back to the probe, while some travel on further until they reach another boundary and are reflected.
3. The reflected waves are picke up by the probe and relayed to the computer.
4. The machine calculates the distance from the probe to the tissue or organ boundaries using the speed of sound in tissue (1540 m/s) and the time of each echo's return.
5. The system displays the distances and intensities of the echoes on the screen, forming a two-dimensional image.

Acoustic imaging.

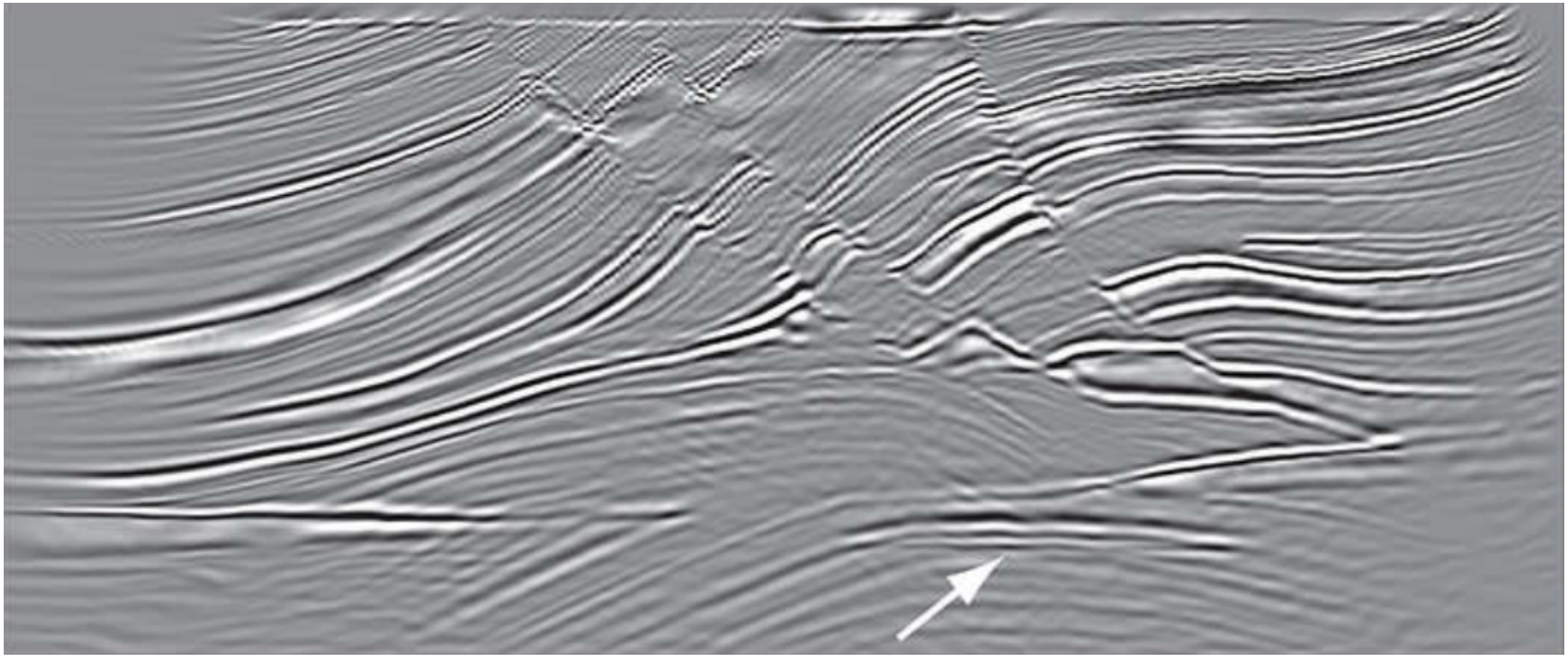


Figure: Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories).

- Electron microscopy
  - Can achieve 10.000× magnification or more (Optical = up to 1000×).
  - Uses a focused beam of electrons instead of light.
  - Scanning Electron Microscope (SEM):

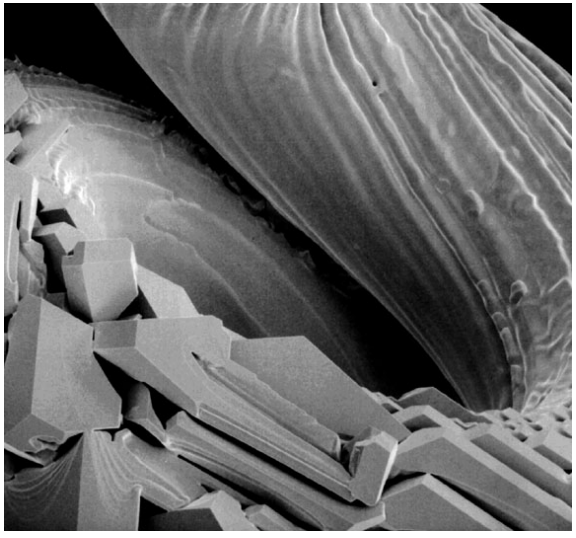


Figure: 250× image of tungsten filament with thermal failure.

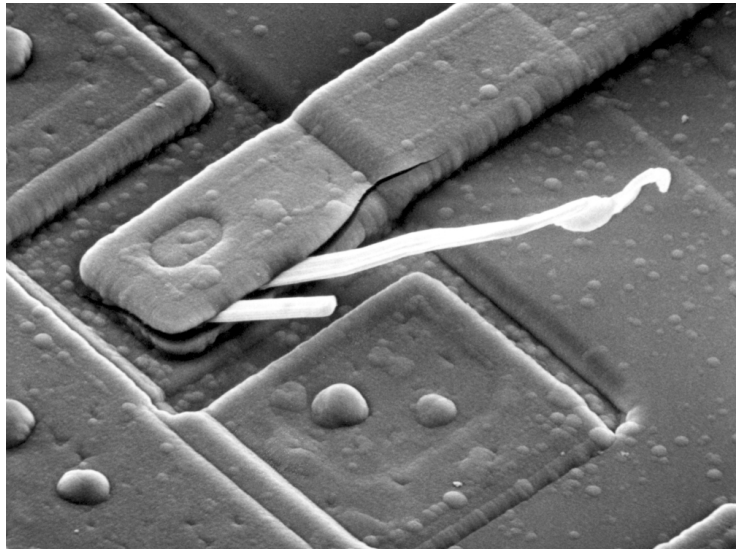
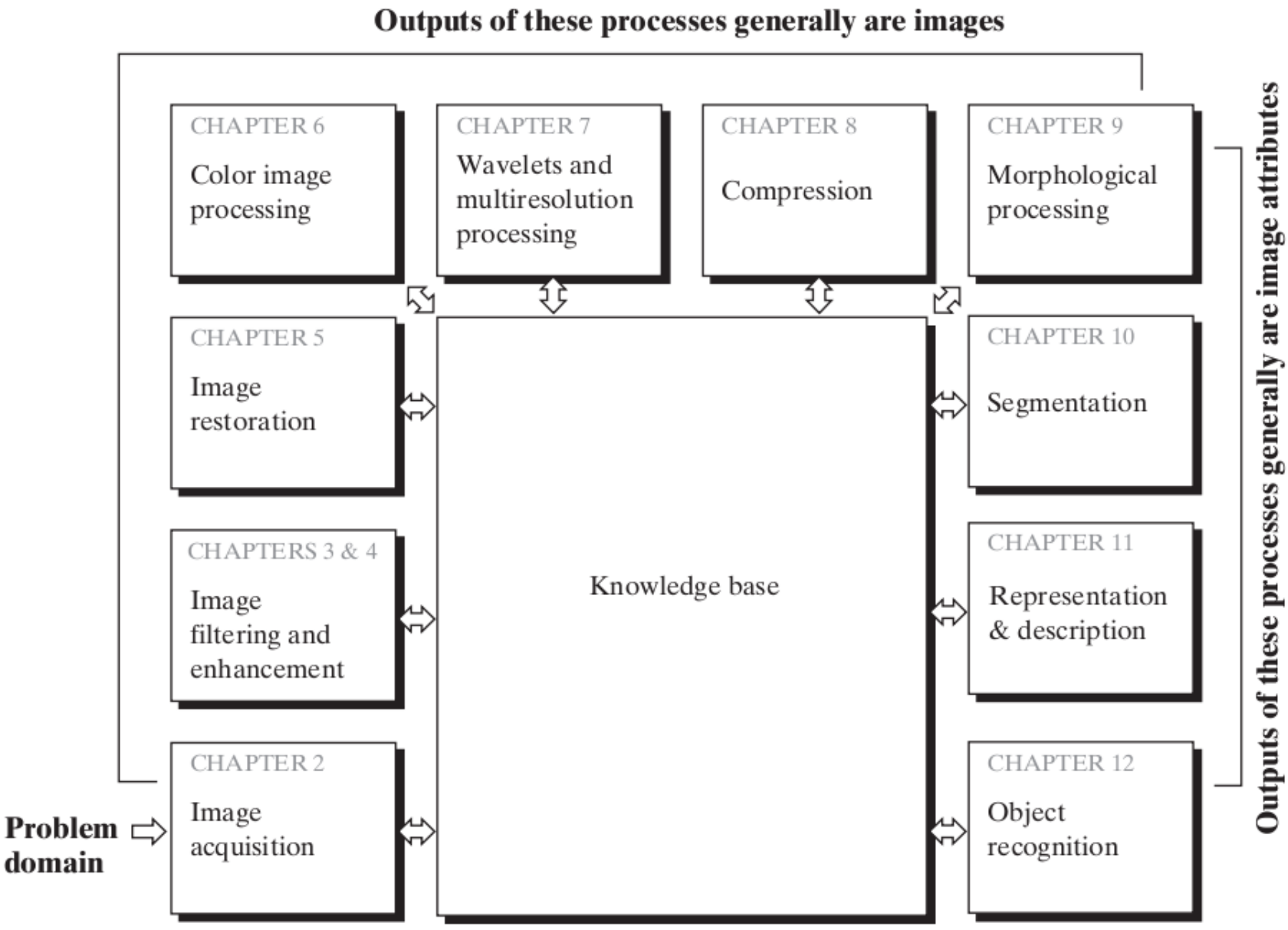
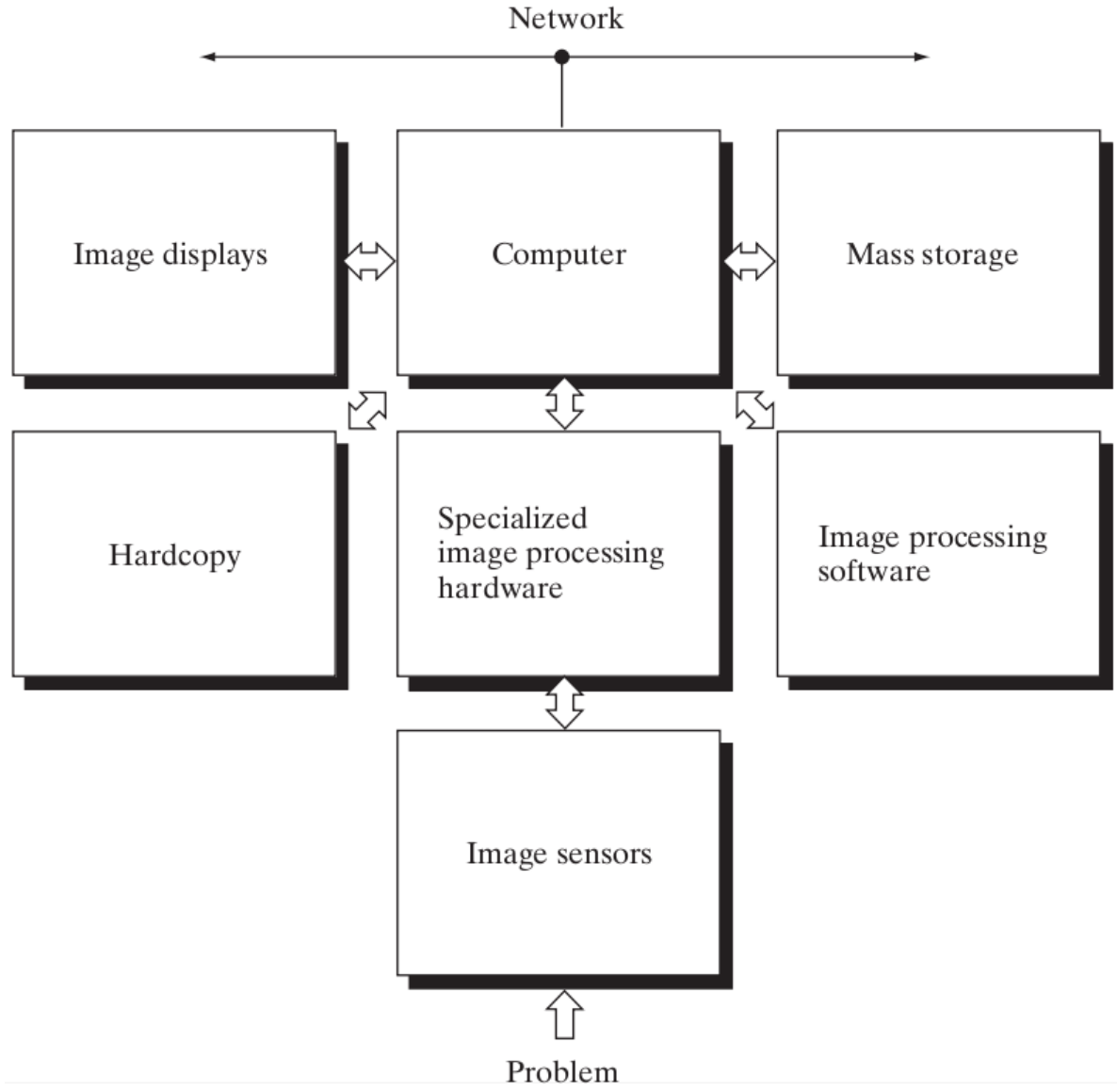


Figure: 2500× image of damaged integrated circuit.

Synthetic (computer-generated) images.

- Fractals.
  - Iterative reproduction of a basic pattern according to some mathematical rules.
  - Useful sometimes as random textures.
- 3-D modeling.
  - 3-D model projects a synthetic image.
  - Flight simulation.
  - Medical training.
  - Criminal forensics.
  - Special effects.


Outputs of these processes generally are images
CHAPTER 6
Color image processing
CHAPTER 7
Wavelets and multiresolution processing
CHAPTER 8
Compression
CHAPTER 9
Morphological processing
CHAPTER 5
Image restoration
Knowledge base
CHAPTER 10
Segmentation
CHAPTERS 3 & 4
Image filtering and enhancement
CHAPTER 11
Representation & description
CHAPTER 2
Image acquisition
CHAPTER 12
Object recognition
Problem domain
Outputs of these processes generally are image attributes


Network
Image displays
Computer
Mass storage
Hardcopy
Specialized
image processing
hardware
Image processing
software
Image sensors
Problem

Development tools:

- Matlab (octave - GNU).
- OpenCV.
- ImageJ.
- Photoshop.
- Gimp.
- Inkscape.
- Anaconda-navigator

What is MATLAB?

- High-performance language for technical computing.
- Matrix Laboratory.
- Integrates:
  - Computation.
  - Visualization.
  - Programming.
- Easy to use environment.

Typical uses:

- Math and computation.
- Algorithm development.
- Data acquisition.
- Scientific and engineering graphics.
- Application development (GUI).

MATLAB is widely used in Universities:

- Math, engineering, science.

Industries:

- Research, development and analysis.

Toolboxes:

- Collection of application-specific functions (*M-functions* or *M-files*).
- Extend the core capabilities of MATLAB.

Examples:

- Image Processing Toolbox (IPT).
- Signal Processing Toolbox.
- Neural Network.
- Fuzzy Logic.
- Wavelet.

OpenCV (Open Source Computer Vision Library).

- Initially developed by Intel.
- Free for both academic and commercial use.
- C++, C, Python and Java interfaces.
- Multi-core processing.
- OpenCL – hardware acceleration of the underlying compute platform.

Applications:

- Street view image stitching.
- Automated inspection and surveillance.
- Robot and driver-less car navigation and control.
- Medical image analysis.
- Video/image search and retrieval.
- Movies - 3D structure from motion.
- Interactive art installations.

Functionality:

1. Image/video I/O (core).
2. Processing (imgproc).
3. Display (highgui).
4. Object/feature detection (objdetect, features2d, nonfree).

Functionality:

5. Geometry-based monocular or stereo computer vision (calib3d, stitching, videostab).
6. Computational photography (photo, video, superres).
7. Machine learning & clustering (ml, flann)
8. CUDA acceleration (gpu).

Useful tools for prototyping.

- ImageJ.
- GIMP.
- Photoshop.

References

Gonzalez, Rafael C.; Woods, Richard E. (2018)

Digital Image Processing

Pearson 4^{th} Ed..

Gonzalez, Rafael C.; Woods, Richard E. (2009)

Digital Image Processing Using Matlab

Pearson 2^{nd} Ed..

Thank you!

tvieira@ic.ufal.br