AI in Medical Imaging

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Version 1.3

VML

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AI in Medical Imaging

- **What is AI?**
- Symbolic AI
- Data
- Machine Learning
  - Clustering
  - Classification
  - Neural Networks
- Computer Vision
- Natural Language Processing
- AI and Proteomics
- AI and Medical Imaging

What is AI?

- **AI Science and Engineering** (AISE) is the interdisciplinary, scientific study and engineering of **Artificial Systems** that mimic and/or surpass **human intelligence** in information analysis and **human interaction** with the world.

- Core AISE disciplines are:
  - Classical (Symbolic) **Artificial Intelligence** (AI),
 - **Machine Learning** (ML).

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Symbolic AI

Concepts and ideas (ιδέες).

- Concepts are specific mental constructs residing in our mind (brain?) that refine and abstract ideas.

- Examples: 'Triangle', 'Freedom', 'Love'.

- **Concept definition**: Triangle consists of three points connected by 3 straight line segments.
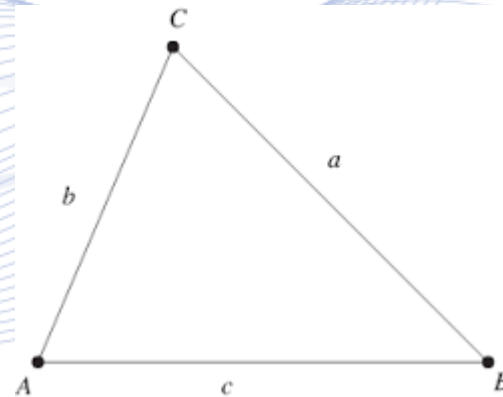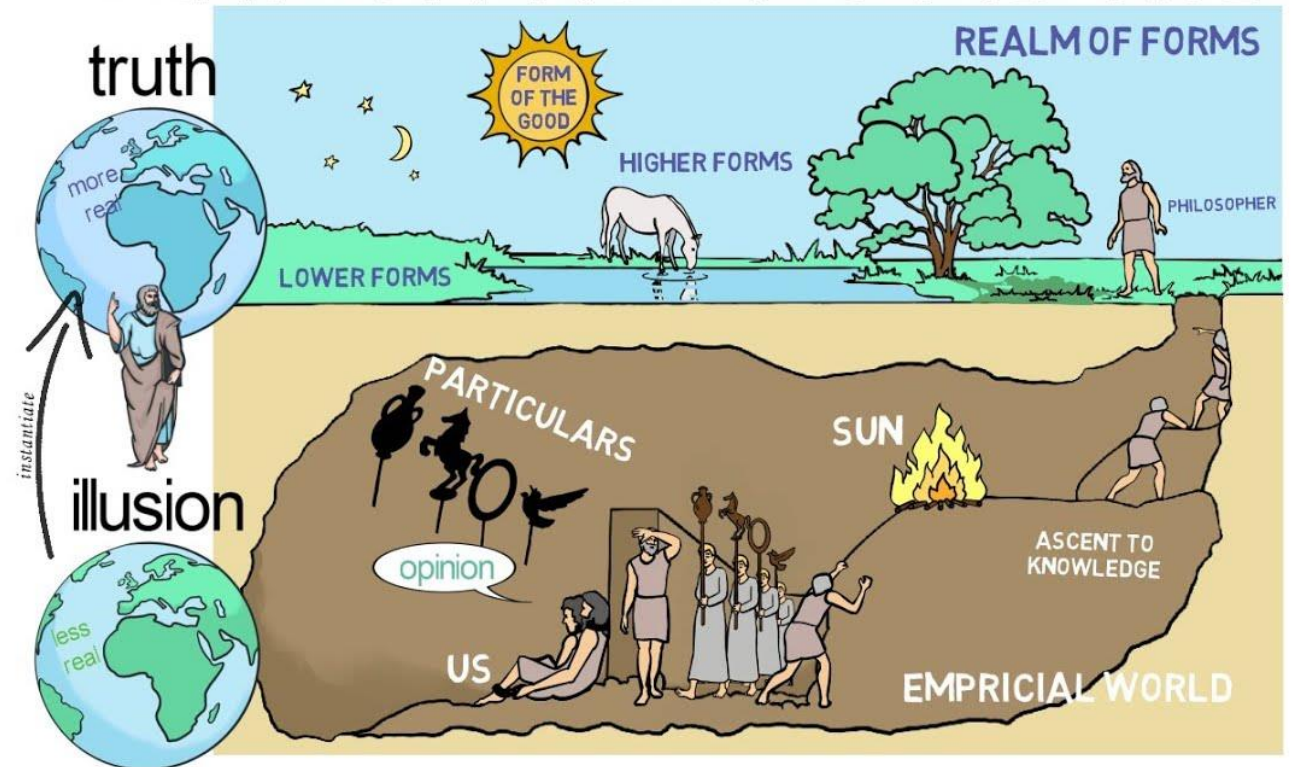
Triangle.

Symbolic AI

Ideas in Philosophy.

- Plato's cave.
- ***Idealism***: reality is a reflection of ideas.
- ***Materialism***: ideas are shadows of matter on itself (brain).

PLATO'S ANALOGY OF THE CAVE

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Symbolic AI

- ***Symbolic AI*** operates on concepts and their relations though ***logic*** and ***search***.

- It mimics and simulates high-level human intelligence and ***reasoning***.

- ***Reasoning*** is one of the most complex brain activities.

- ***Symbolic AI*** employs Mathematical Logic.

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Symbolic AI

Rule-based medical expert systems

- Examples:

  'If somebody has high fever and coughs, she/he has flu.'

- ***Symbolic AI failed to deliver!***

- Medical knowledge too complicated to be hard-coded in software.

- Human body too diverse (yet stable) to be coded by rules.

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Data

- ***Data***: measured quantities related to nature and/or human activities.

- ***Data are primarily numbers*** representing object characteristics (***features***).
- ***Measured in bits.***

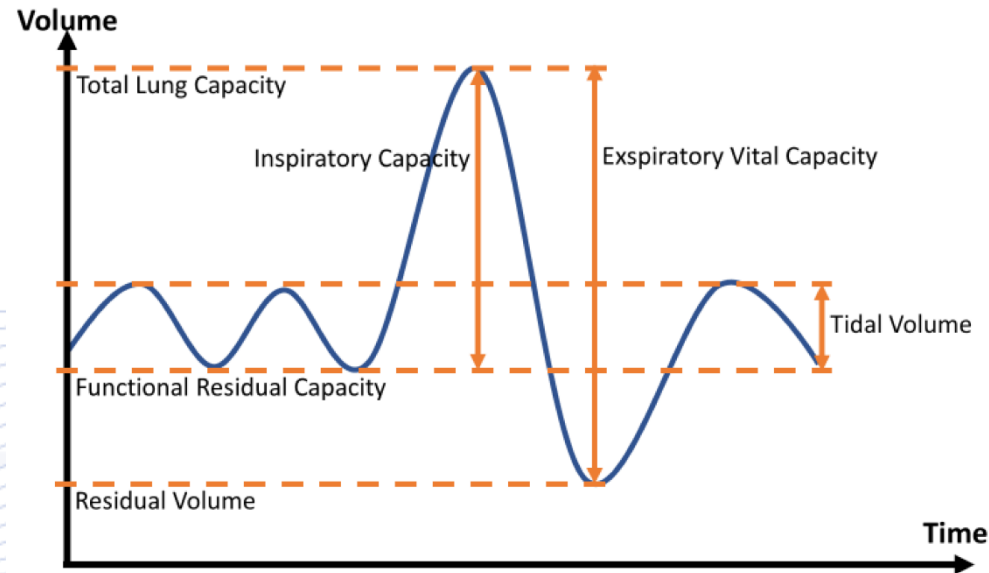- ***Data can be organized in vectors.***

Data

(a)

(b)
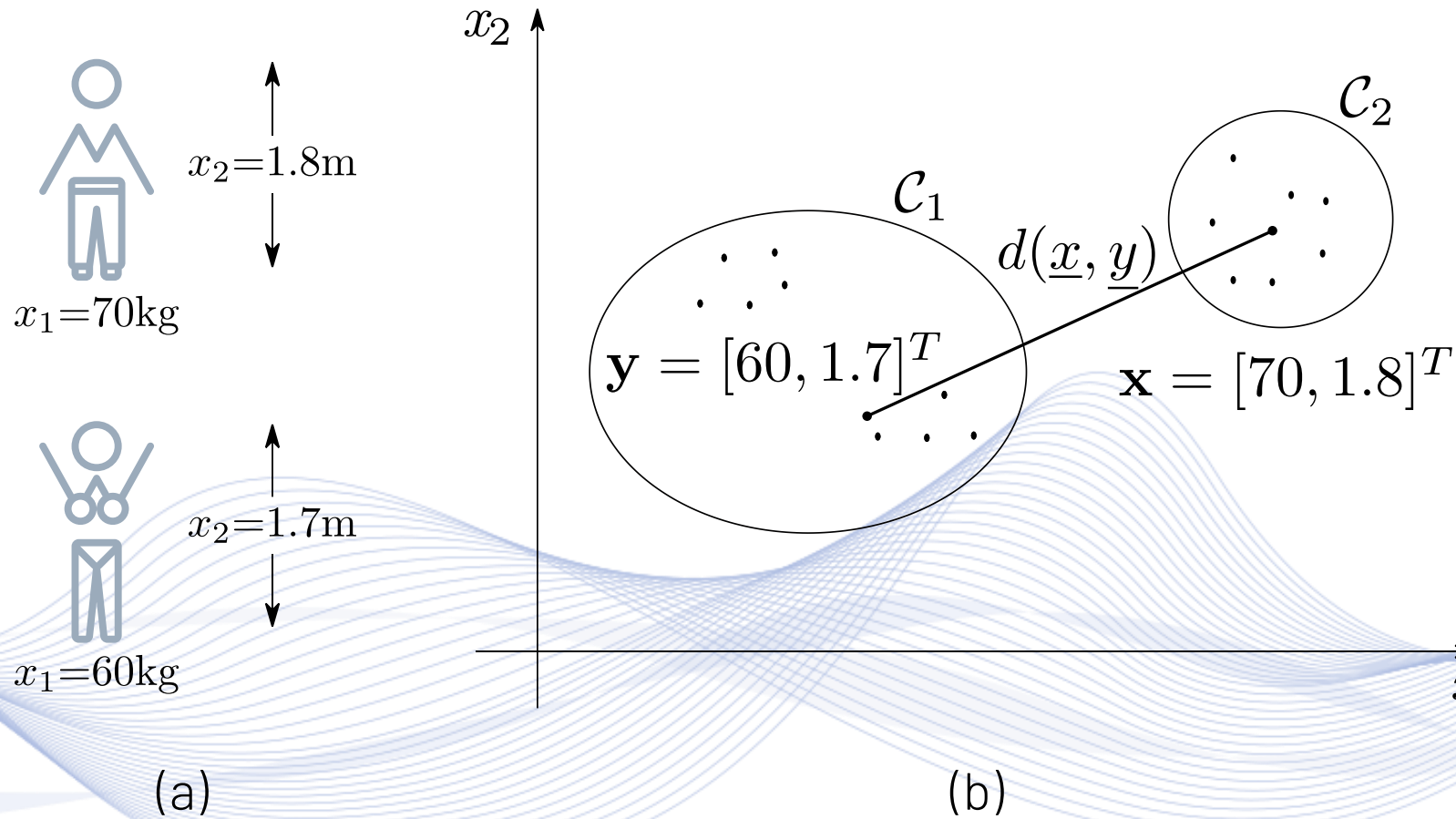
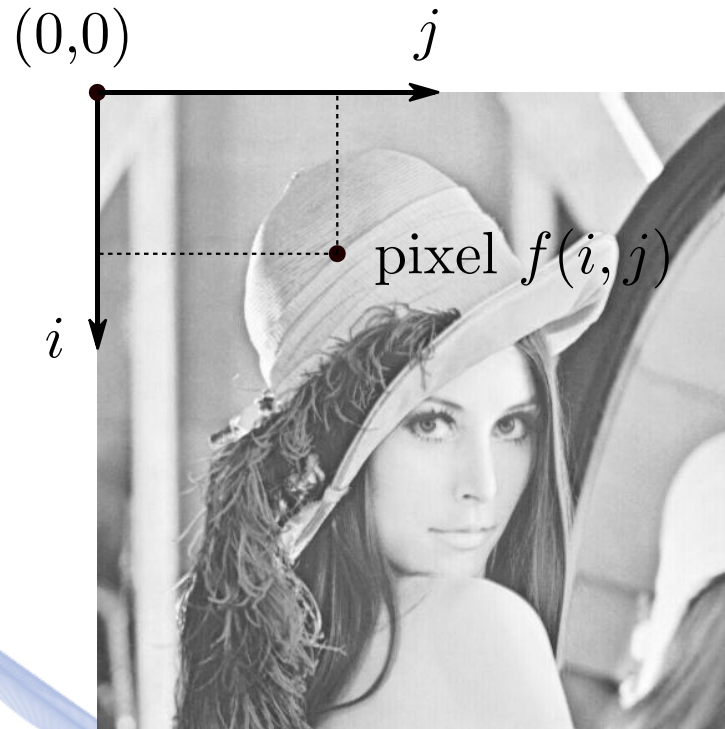Measuring humans and producing their weight and height vectors.

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Data

Signals $y = f(t)$: voice, medical **time series** etc.

- Also called **functions.**

Respiratory volume measurements.

Data

$(0,0)$

j

i

pixel $f(i,j)$

Lung X-ray image.

Digital Images: Matrix of image dots (pixels).
Each image can have up to 48 Mpixels or more!

Data

Once we extract the object/image/signal features (data):

- Data analysis can be performed.

- Mathematics and Computer Science are needed.

- Machine Learning is applied Statistics, Calculus and Programming.

- We can concentrate on data and forget the real world.
- ***All sciences are increasingly mathematized.***
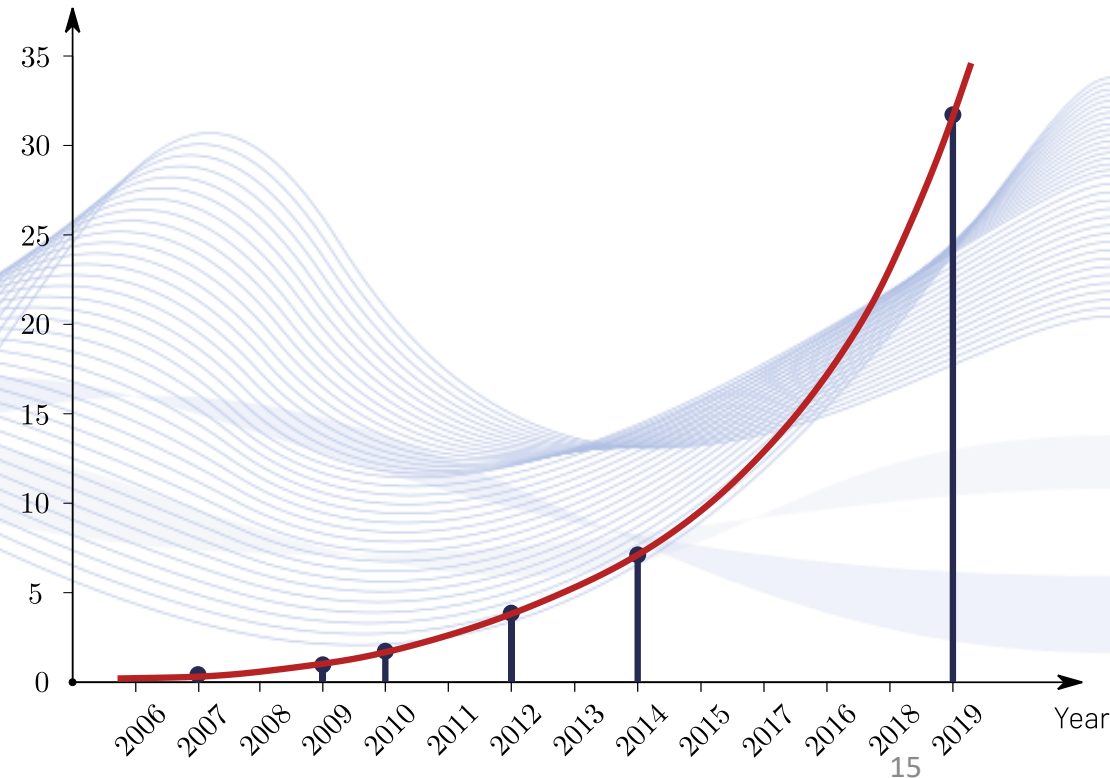- High impact on Liberal sciences and Medicine.

Data

Exponential data increase:

- Proliferation of sensors
- Detailed recording of nature and humans
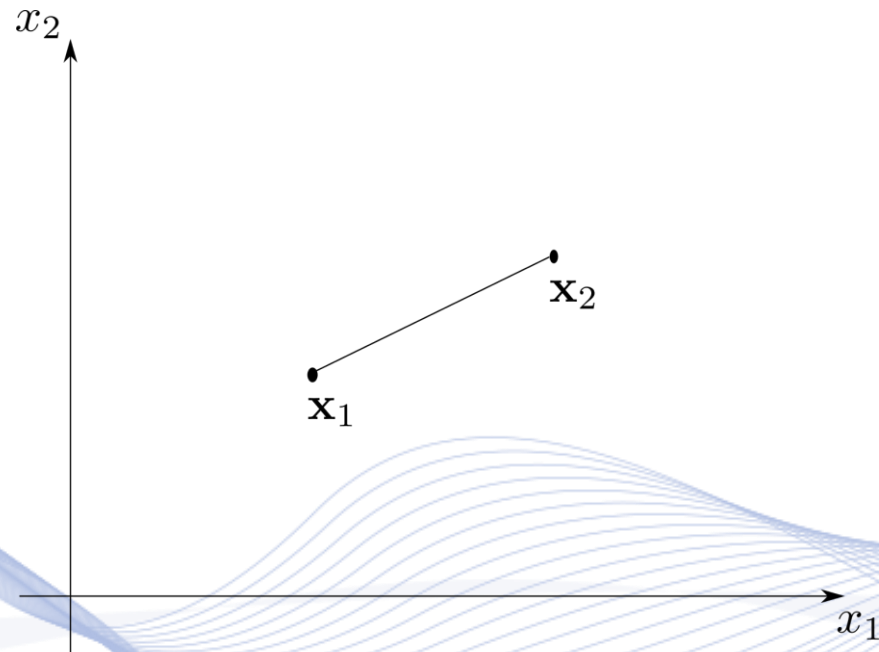- Sensing automation.

Big data analytics is only possible through Machine Learning.

Data volume increase in past decade.

Data Volume (ZB)

Data

Distance between two lung X-ray images.

(a) Normal (b) Bacterial Pneumonia (c) Viral Pneumonia (d) COVID-19 Pneumonia

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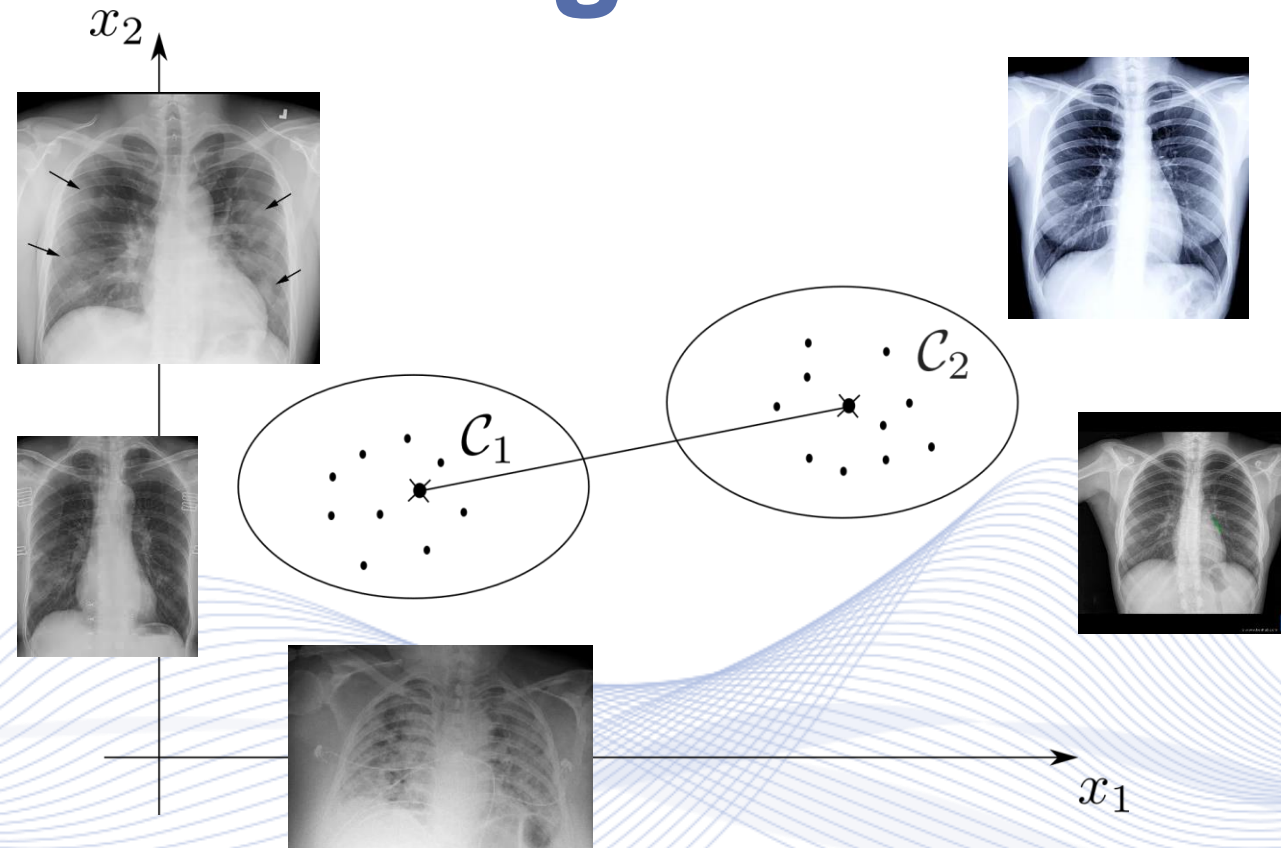- AI and Proteomics
- AI and Medical Imaging

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Data clustering

Medical image clustering:
- **Input**: many X-ray image ROIs
- **Output**: X-ray image clusters.

- **Unsupervised learning.**

- Applications:
  - Medical research
  - Medical education.

X-ray cluster 1

Xray cluster 2
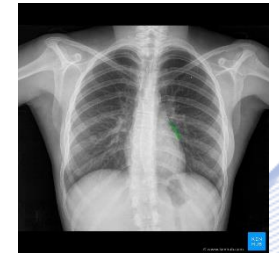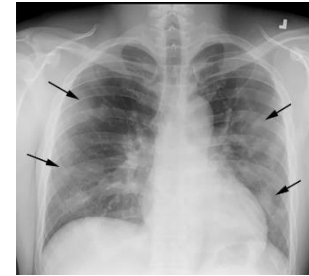
18
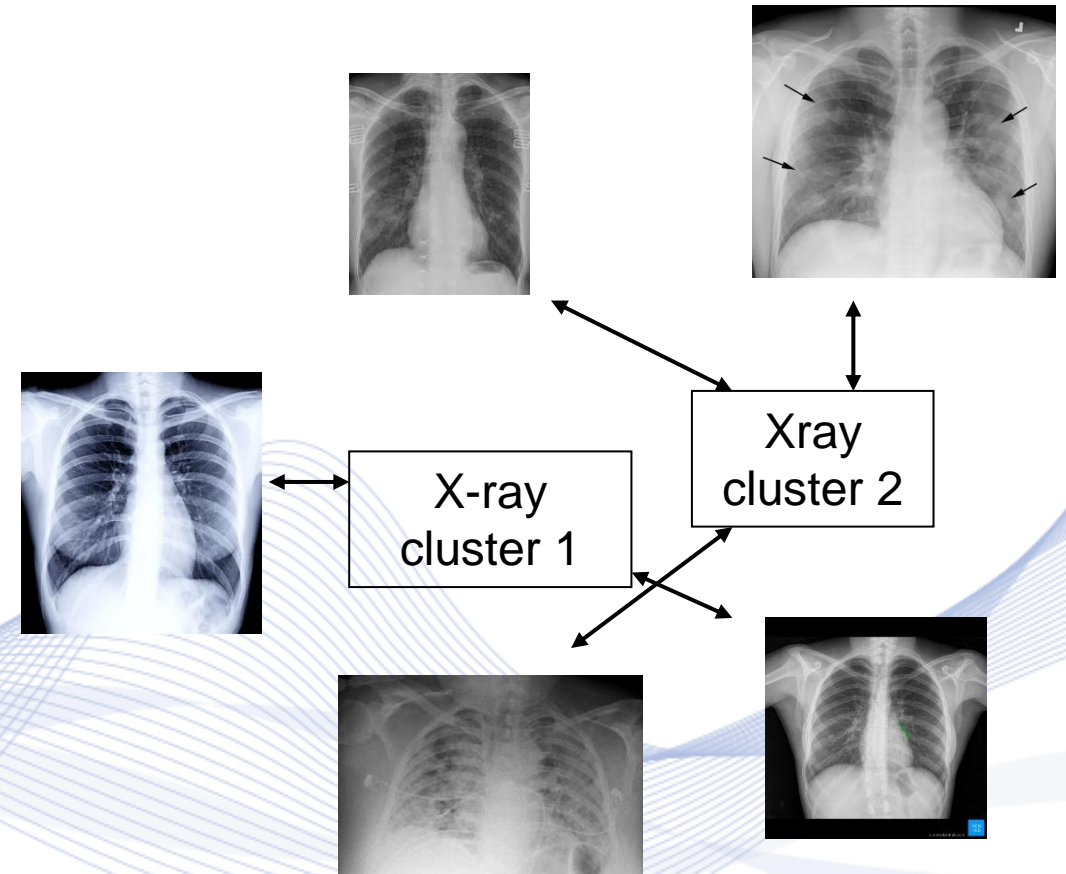
Data clustering

Set partitioning. Data clusters should: a) be homogeneous; b) distant from each other.

Data clustering

Data clustering offers:
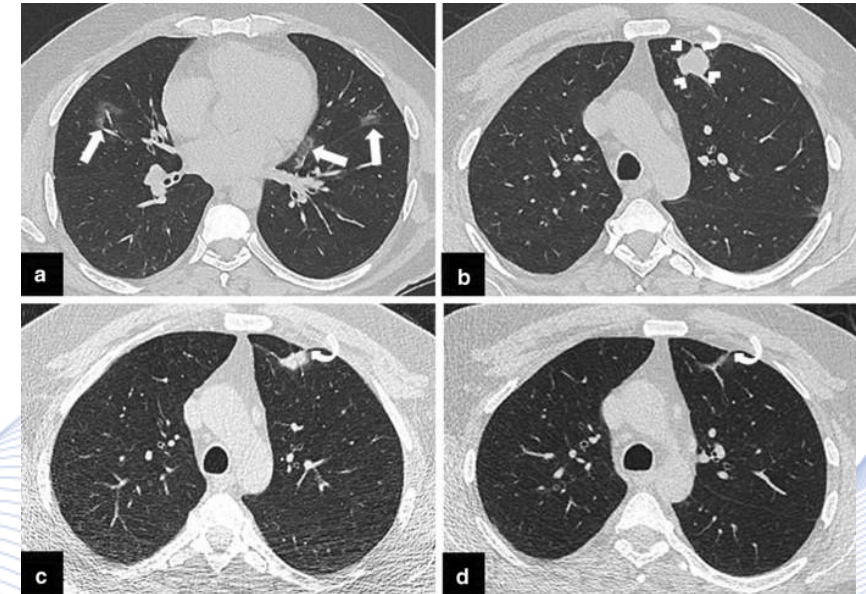
- Description of data geometry.
- Data visualization.

- **Abstraction.**
- **Data compression.**

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Abstraction

Medical Concepts

- Medical diagnosis concepts, e.g.,
"irregularly shaped pulmonary nodule"

- **Abstraction and generalization**:
  - Difficult to describe medical concepts.
  - Abundance of concept instances.
  - Useful in diagnosis and education.

COVID-19 lung CT images.
https://insightsimaging.springeropen.com/articles/10.1186/s13244-021-00987-7

Classification

Supervised Machine Learning

Decision-making theory:

- Does X-ray $\mathbf{x}$ belong to class $\mathcal{C}_1$ or class $\mathcal{C}_2$?
- E.g., 'normal' or 'COVID-19'?

Examples:

- Medical diagnosis.
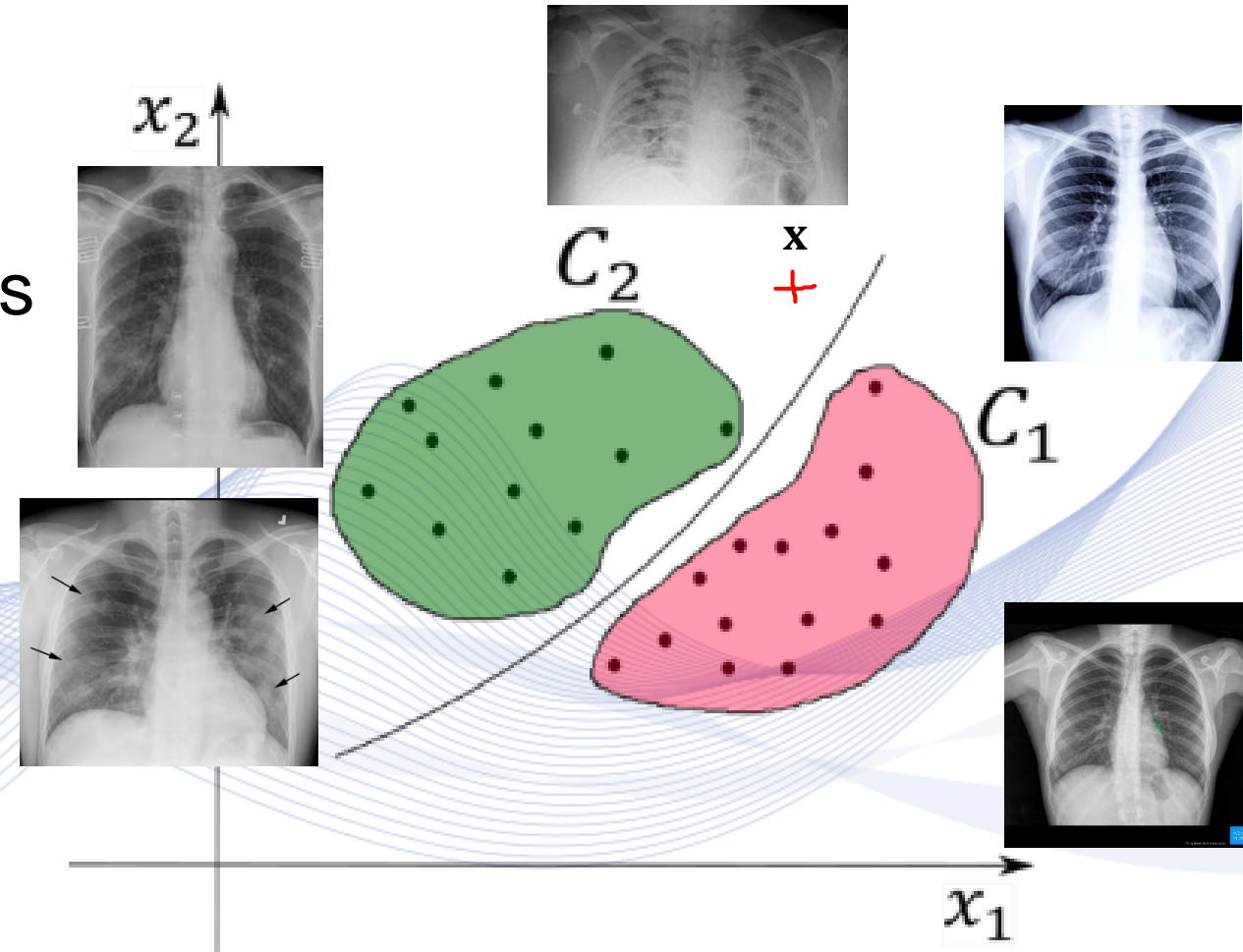
Introduction to AI Science

- Symbolic AI
- Data
- **Machine Learning**
  - Clustering
  - Classification
  - **Neural Networks**
- Computer Vision
- Natural Language Processing
- Generative AI
- Knowledge
- AI and Society
- AI, Life and the Environment

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Neural Networks

- Basic computational unit of the brain.

- Main parts:

  - *Dendrites*

    - They act as inputs.

  - *Soma*

    - Main body of neuron.

  - *Axon*

    - It acts as neuron output.

Dendrites

Soma

Axon

Synapses

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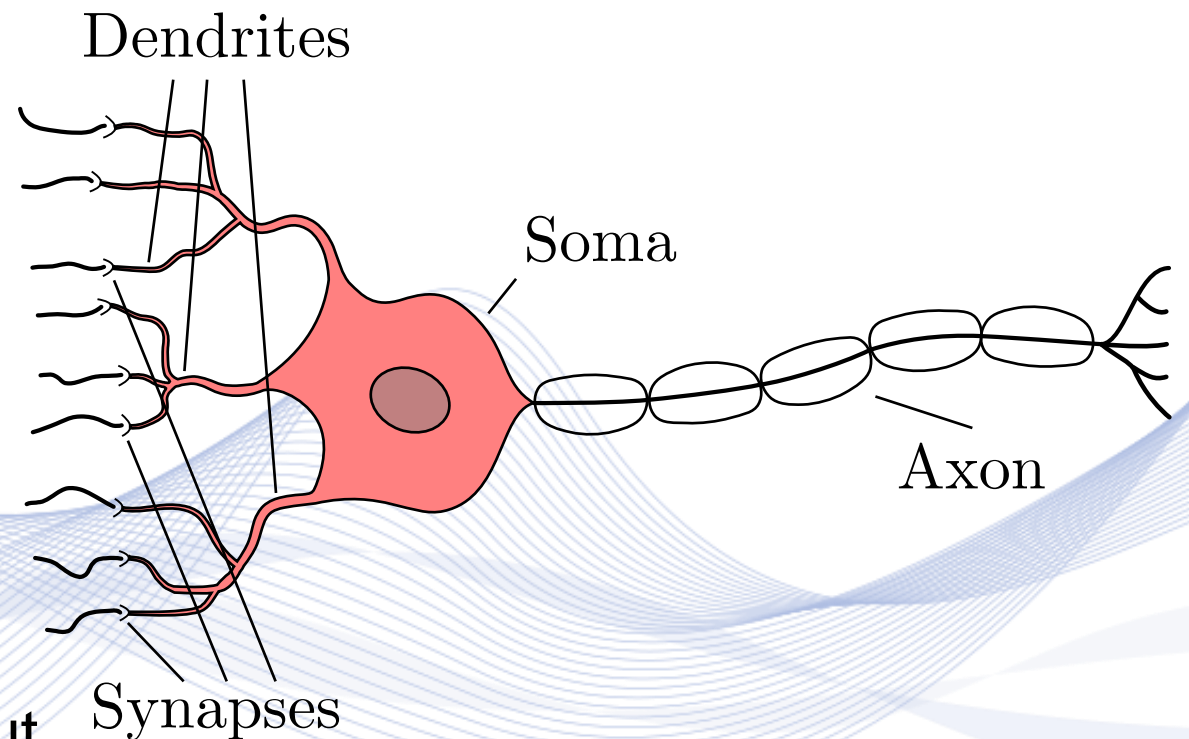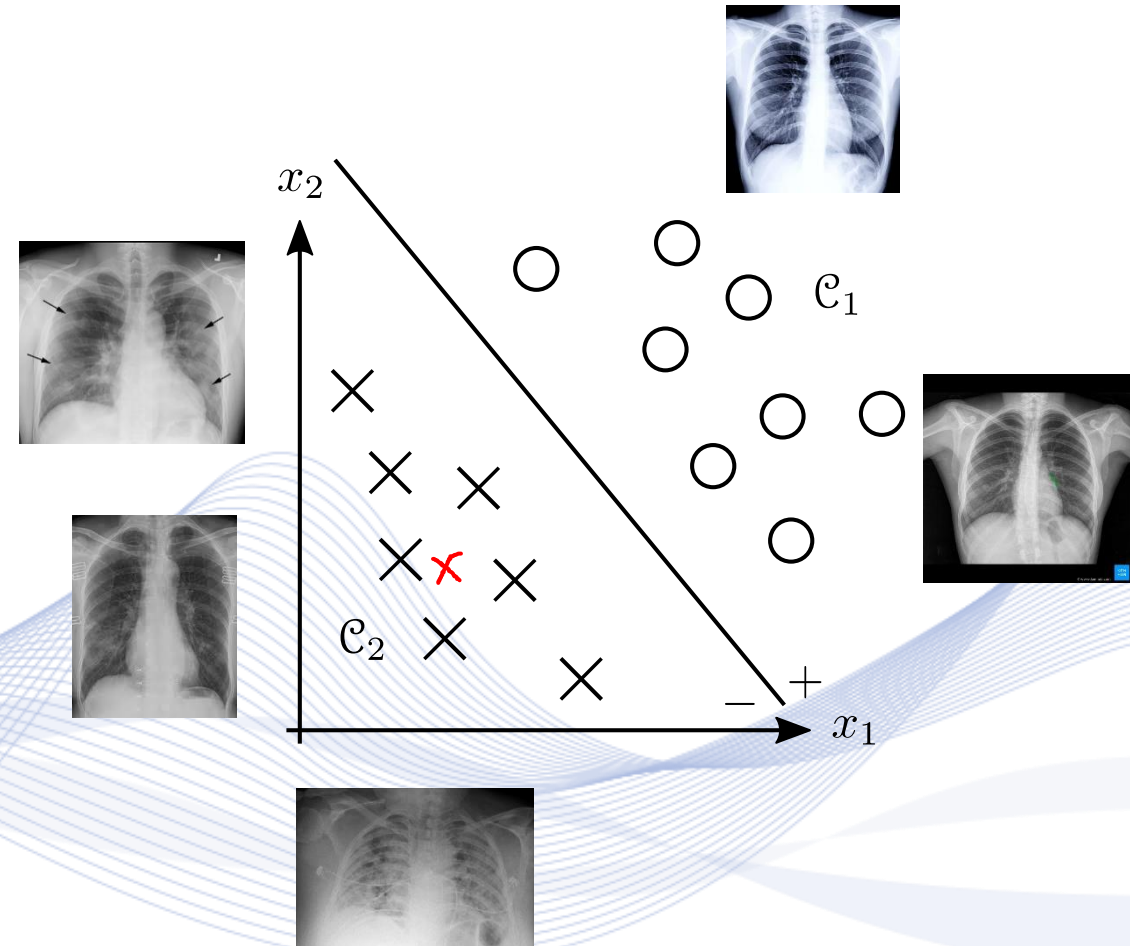
Neural Networks

Artificial Neural Networks
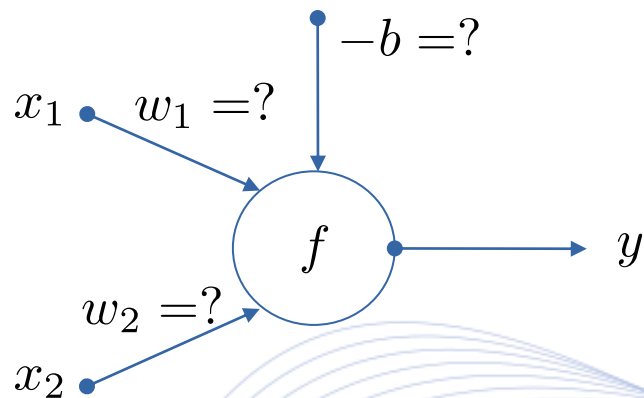
2D perceptron for normal/COVID-19 recognition

- x_1, x_2: X-ray image features.
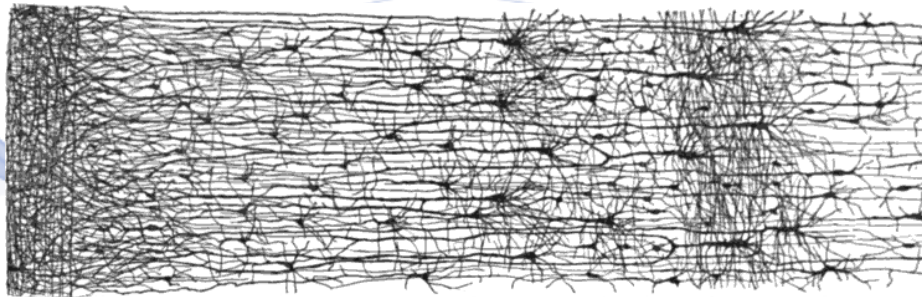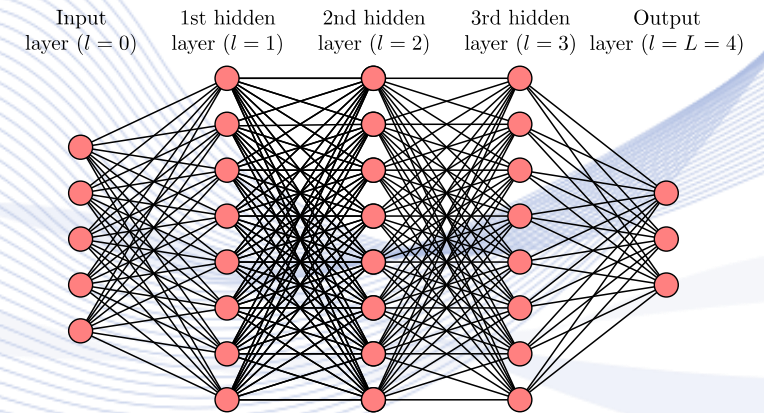
Separating line: $w_1 x_1 + w_2 x_2 + c > 0$.

Neural Networks

Artificial and Biological Neural Networks

- Neurons can form *Artificial Neural Networks* (*ANNs*).

- *Deep NNs* (DNNs) have many neuron layers.

- Is *network complexity* the basis of both the biological and artificial intelligence?

Biological NN (https://en.wikipedia.org/wiki/Cerebral_cortex).

Deep neural Network.

Neural Networks

Neural regression provides an approximation of a function

$$y = f(t).$$

- t**: input** (time).

- $\hat{y}$: **output** (approximated function values).

- Very useful in **time series prediction.**

- **Applications**: financial prediction, weather forecasting.

Approximation $\hat{y} = \hat{f}(x, w)$ of the function $y = f(x)$

$$\hat{\mathbf{y}} = \hat{f}(\mathbf{x}, \mathbf{w})$$
$$\mathbf{y} = f(\mathbf{x})$$

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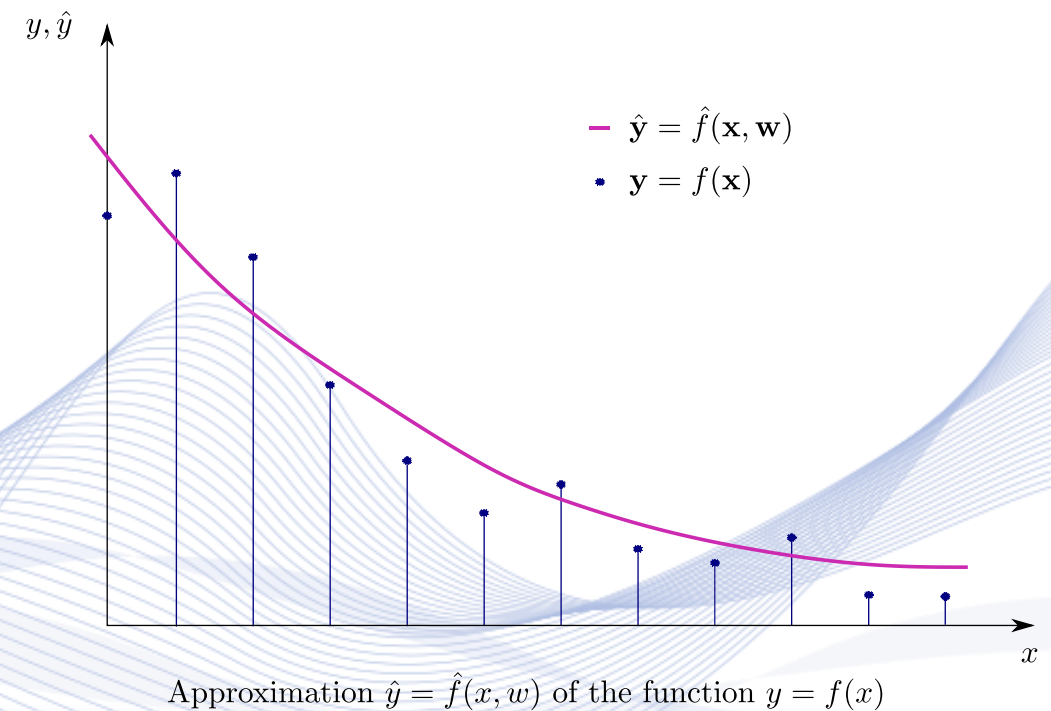
Neural Networks

Advantages

- Very good decision accuracy
  - (frequently above human performance).
- Wide range of applications.
- New generative (creative) arts.

Pitfalls

- Too many data/energy needed for their training.
- Poor explainability.
- Possible decision bias.
- Creation of fake data/news.

Neural Networks

VML

Current AI revolution:

- ***AI means ML, which means Deep Neural Networks***
- Stagnation of symbolic AI
- Resurrection of a dead term: AI

Major breakthrough needed:

- Advancement of symbolic AI
- ***Fusion of Machine Learning and symbolic AI.***

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Computer Vision

Digital images consist of **pixels**.
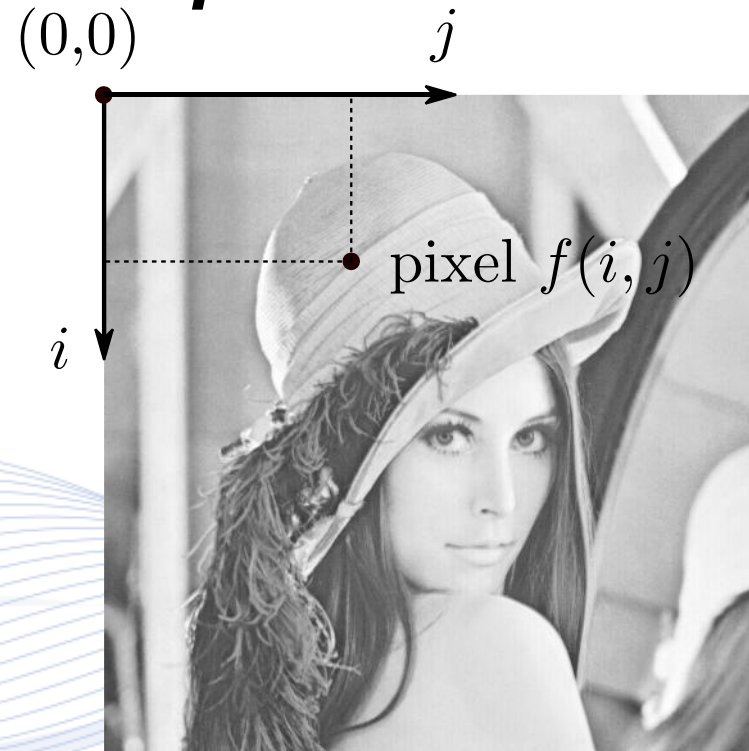
Example: 256×256 pixel image.

Computer Vision

Image processing and analysis.

Input image.   Vertical image edges.
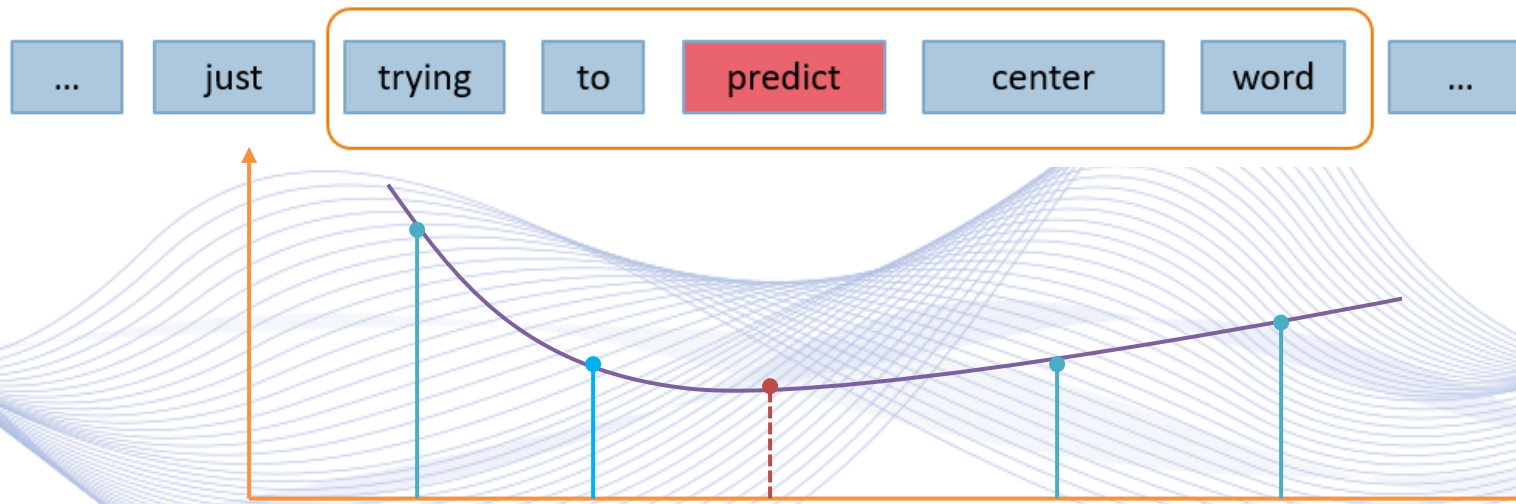
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Natural Language Processing

Word embeddings

- Transforming words in series of numbers (vectors).
- Predicting word order.

Vectors representing words 'to' and 'center' can best interpolate the 'predict' vector.

Natural Language Processing

ChatGPT text production

- Question: What do you know about Mt. Olympus and Greece?
- Answer using word order prediction:

  - Mt Olympus is the highest mountain in Greece.
  - Mt Olympus is the loveliest mountain in Greece. (sentimental).
  - Mt Olympus is a tropical mountain in Greece. (LLM hallucination).
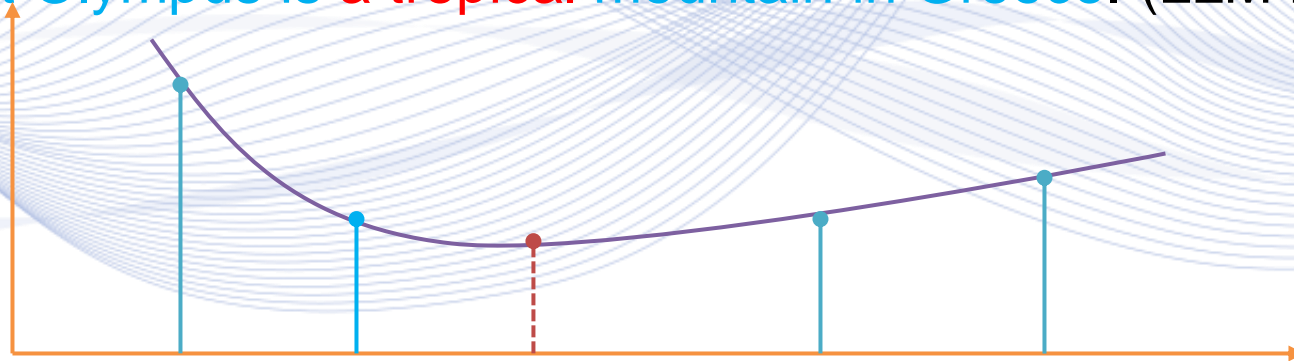
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AI and Proteomics

Protein folding.

- AlphaFold is an AI (Deep Learning) program developed by DeepMind that predicts of protein structure.

- It has been used to predict structures of proteins of SARS-CoV-2.

- It predicted correctly of the structure of the ORF3a protein that assist the virus in breaking out of the host cell once it replicates.

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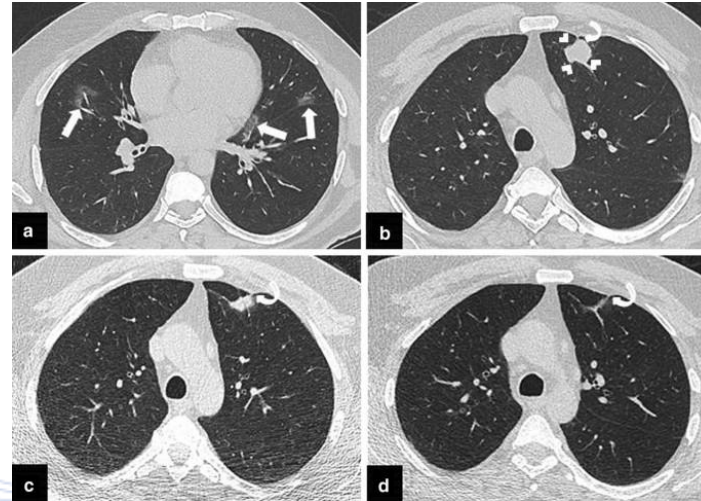- AI and Proteomics
- **AI and Medical Imaging**

AI and Medical Imaging

Medical imaging modalities

Lung X-ray image.

Lung CT scan.

Lung MRI scan.
https://insightsimaging.springeropen.com/articles/10.1007/s13244-012-0176-x
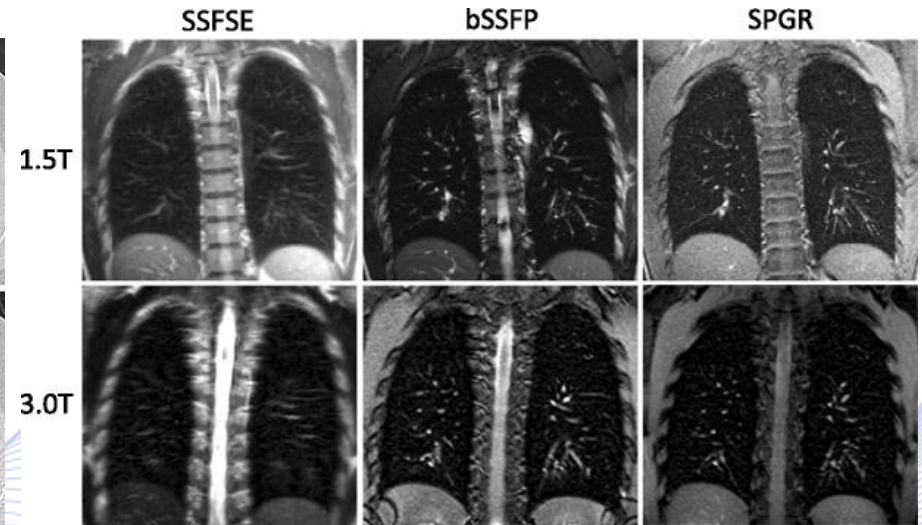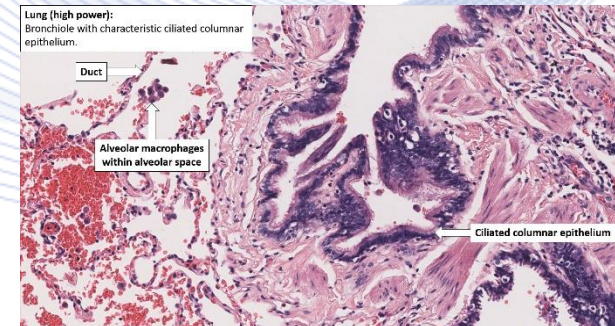
Lung histology.

AI and Medical Imaging

DNN-based medical image segmentation

Lung X-ray image segmentation.
https://www.researchgate.net/figure/Example-lung-segmentations-for-MC-CXRs-Note-the-over-segmentation-in-the-apices-The-CXR_fig6_257599582

AI and Medical Imaging

DNN-based medical image depth estimation
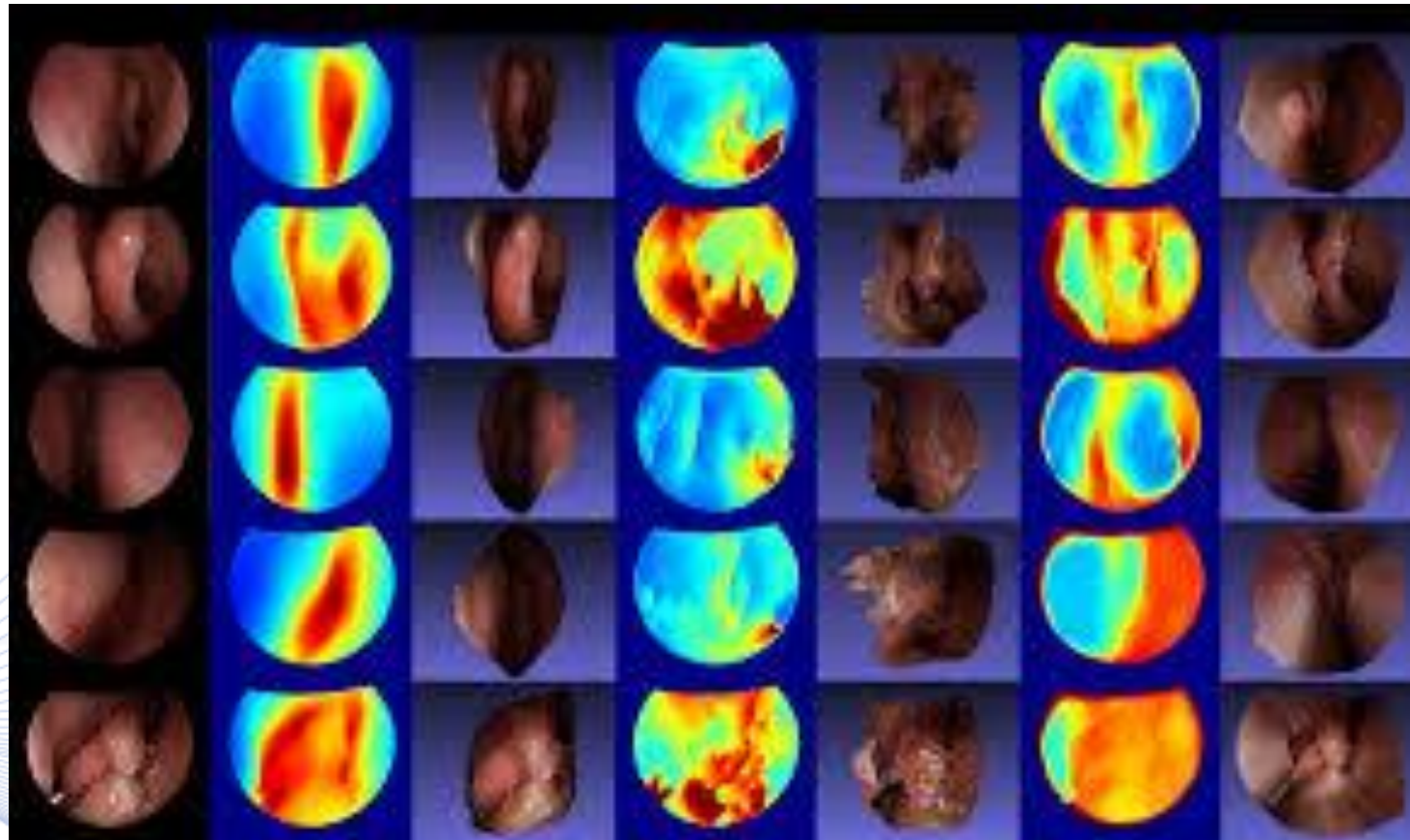
Dense Depth Estimation in Monocular Endoscopy
with Self-supervised Learning Methods, X. Li et al, 2019.

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DNN-based medical image registration.

A. Hammoudeh, S. Dupont, Deep Learning in Medical Image Registration: Introduction and Survey, 2023.

AI and Medical Imaging

AI-assisted medical image analysis

- Use of trainable Deep Neural Networks (DNNs).

- Thousands of training images are needed.

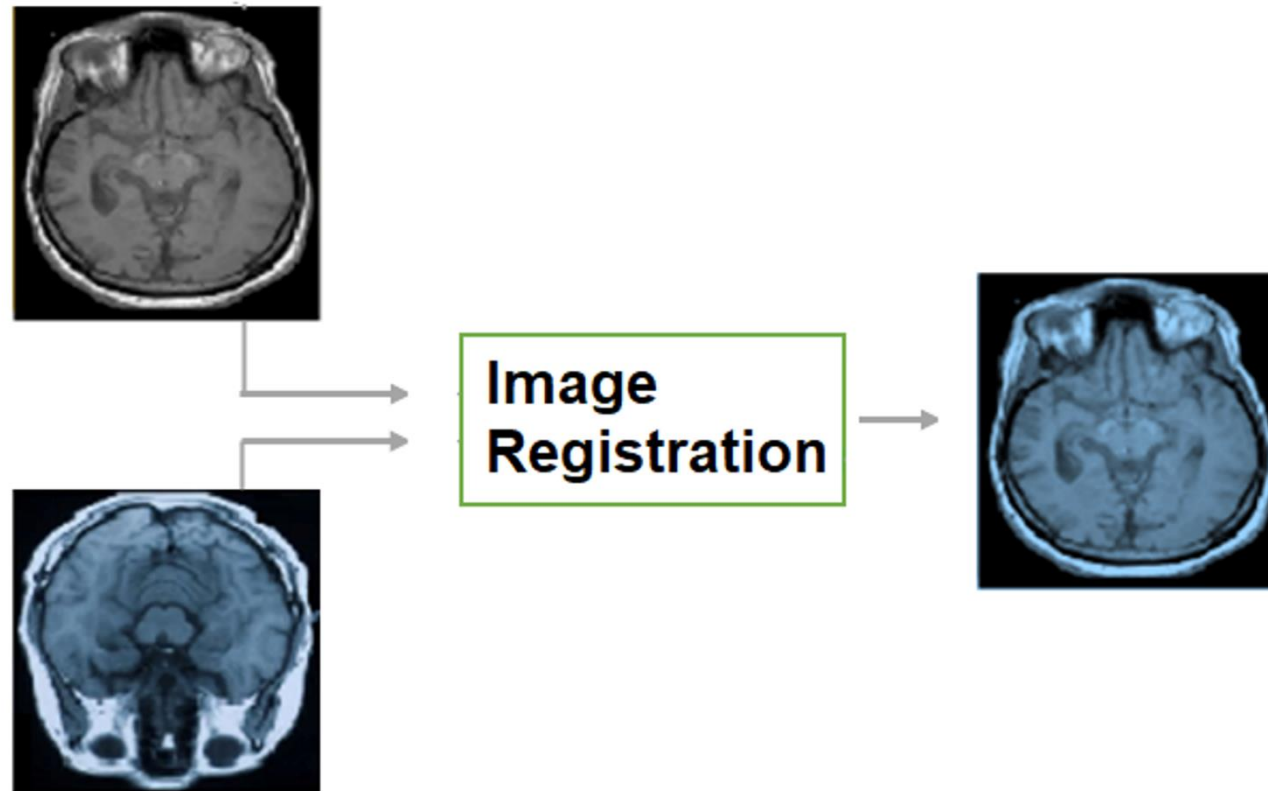- Time consuming ground-truth creation.

- High computational power needed for DNN training.

- No explicit medical reasoning needed.

- **High DNN inference accuracy.**

- Black-box (**non-explainable**) DNN inference.

- **Need to develop explainable AI methods.**

DNN lung X-ray image segmentation.
https://link.springer.com/article/10.1007/s42600-022-00242-y

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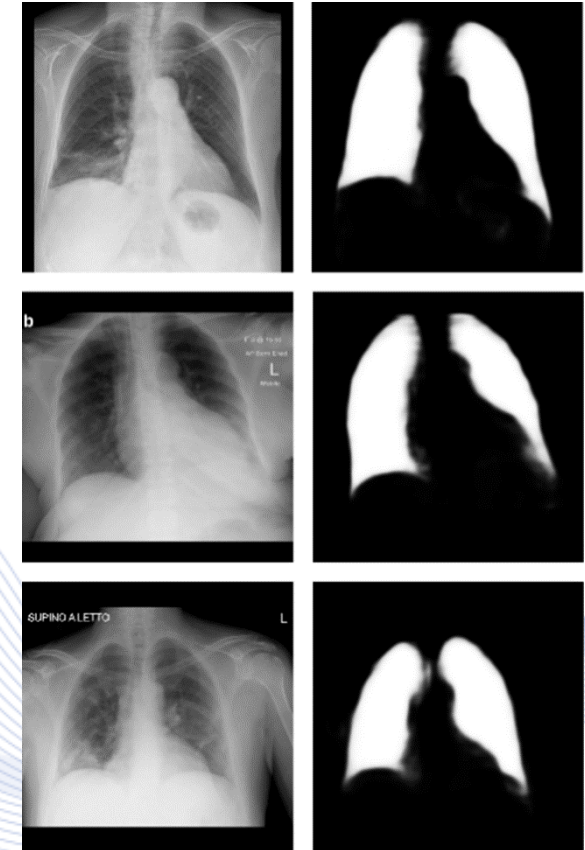
AI and Medical Imaging

AI-assisted medical diagnosis

- DNNs trained in millions of medical images.
- **Multimodal data** (images, medical exams and existing diagnosis text) can be used for training.
- Good diagnosis accuracy (to become better).
- **Essential in case of emergencies and high patient numbers.**
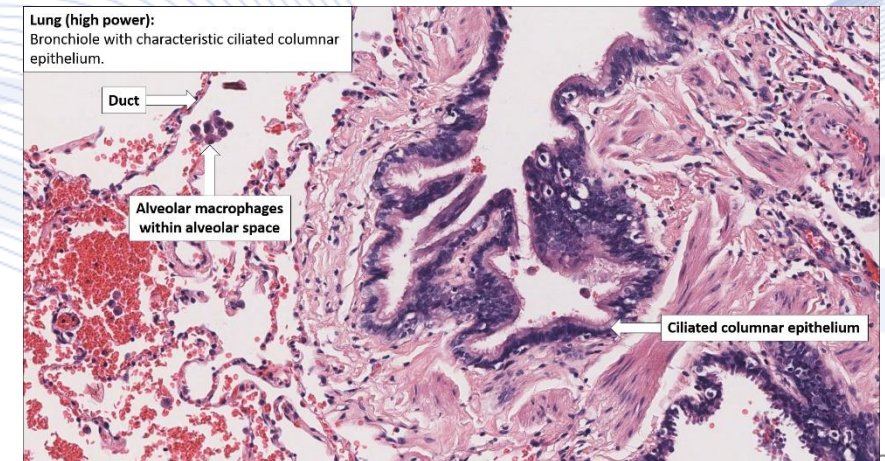- The doctor has always the final responsibility.

AI-assisted medical training

- Huge medical corpora can provide abundant information for student training.
- Case similarities and differences can be highlighted.

AI and Medical Imaging

AI-assisted medical diagnosis

- Useful in telemedicine environments.

- It can save lives in the case of disasters and medical emergencies.

- Unavoidable in super-high resolution medical imaging:

  - *Multiresolution imaging from organ/body level to sub-cellular level.*

  - *4D moving volume imaging, e.g., of heart, lungs.*

Lung (high power):
Bronchiole with characteristic ciliated columnar epithelium.

Duct

Alveolar macrophages within alveolar space

Ciliated columnar epithelium

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https://medicine.nus.edu.sg/pathweb/normal-histology/lung/

AI and Medical Imaging

VML

Medical data availability

- Huge data bases exist in developed countries.

- Limited use even in research.

- Interoperability issues.

Medical data privacy

- Medical data protection-by-design methods

- Data anonymization is not enough!

  - Example: Forensic DNA Phenotyping (FDP)

- Political correctness leading to privacy paranoia.

- *Reversible privacy protection mehods.*

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AI and Medical Imaging

Medical data availability

- Huge data bases exist in developed countries.

- Limited use even in research.

- Serious privacy issues.

Medical data market

- Medical data value should be measured.

$$Cost\_per\_MB = Medical\_data\_volume/Medical\_treatment\_cost.$$

- **People should be given financial or other incentives to sell/donate their medical data.**

- AI and biomedical companies should pay for the data they use for drug and equipment development.

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I. Pitas, 'AI Science and Society'

4-volume book, 1070+ pages, Amazon 2023.

Bibliography

[1] I. Pitas, "Artificial Intelligence Science and Society Part A: Introduction to AI Science and Information Technology", Amazon/Kindle Direct Publishing, 2022,

https://www.amazon.com/dp/9609156460?ref_=pe_3052080_397514860

[2]   I. Pitas, "Artificial Intelligence Science and Society Part B: AI Science, Mind and Humans", Amazon/Kindle Direct Publishing, 2022,
https://www.amazon.com/dp/9609156479?ref_=pe_3052080_397514860

[3]   I. Pitas, "Artificial Intelligence Science and Society Part C: AI Science and Society", Amazon/Kindle Direct Publishing, 2022,
https://www.amazon.com/dp/9609156487?ref_=pe_3052080_397514860

[4] I. Pitas, "Artificial Intelligence Science and Society Part D: AI Science and the Environment", Amazon/Kindle Direct Publishing, 2022,

https://www.amazon.com/dp/9609156495?ref_=pe_3052080_397514860

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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pitas@csd.auth.gr

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