AI, System Complexity, Life, Intelligence and Environment

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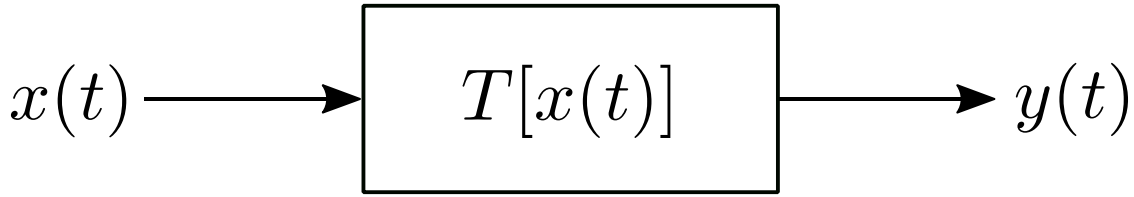
Version 1.0

Artificial Intelligence & Information Analysis Lab

AI, System Complexity, Life, Intelligence and Environment

- **Systems, Networks**
- Life
- Biological Neural Networks
- What is AI?
- Artificial Neural Networks
- Society
- Environment
- System and Matter Complexity
- Evolution by Design.

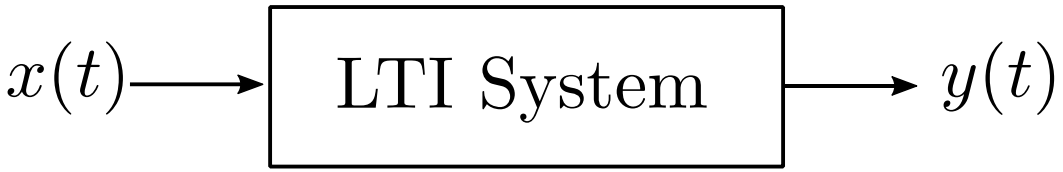
Systems



System definition: a transformation of input signal $x(t)$ into output signal $y(t)$:

$$y(t) = T[x(t)].$$

Systems



Linear Time Invariant (LTI) system output is a ***convolution*** of input signal $x(t)$ and impulse response $h(t)$:

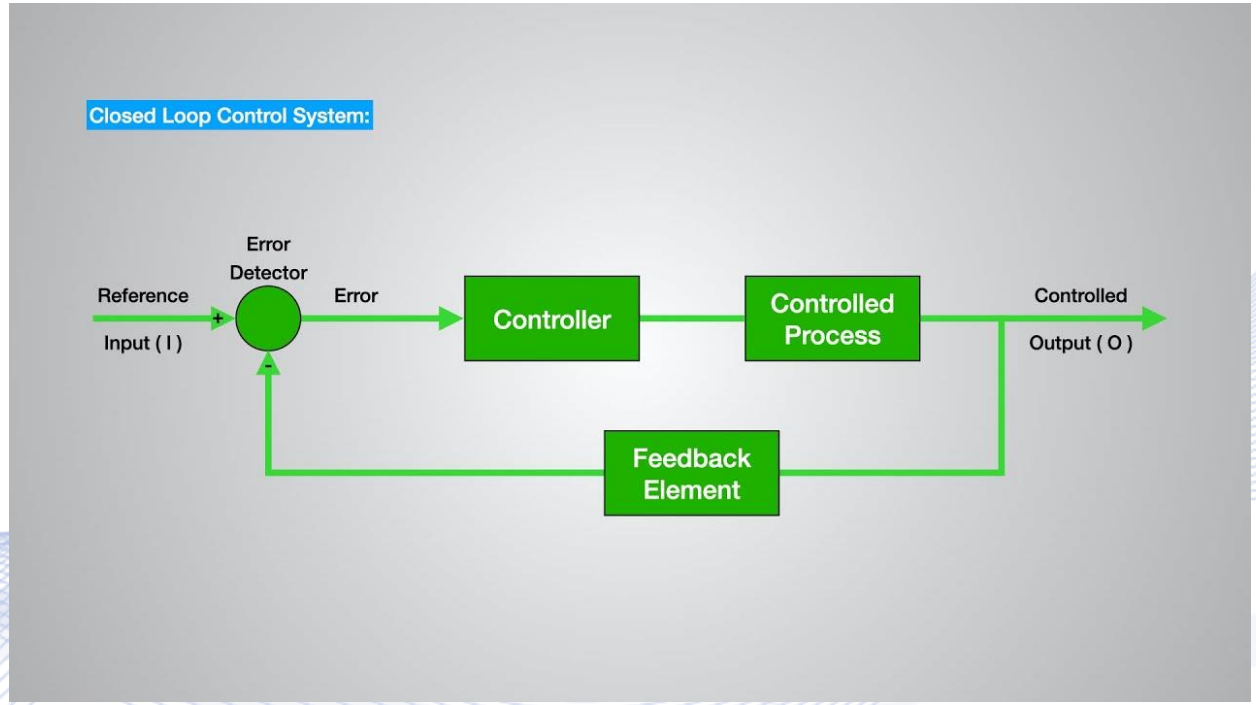
$$y(t) \stackrel{\Delta}{=} x(t) * h(t).$$

- They are the backbone of current ***world modeling***.
- Very well coupled with Linear Algebra, Analysis, Gaussian probabilities.

Systems

Feedback for system control.

- Principal mechanism for ***life homeostasis.***
- Basis of ***automatic control systems.***

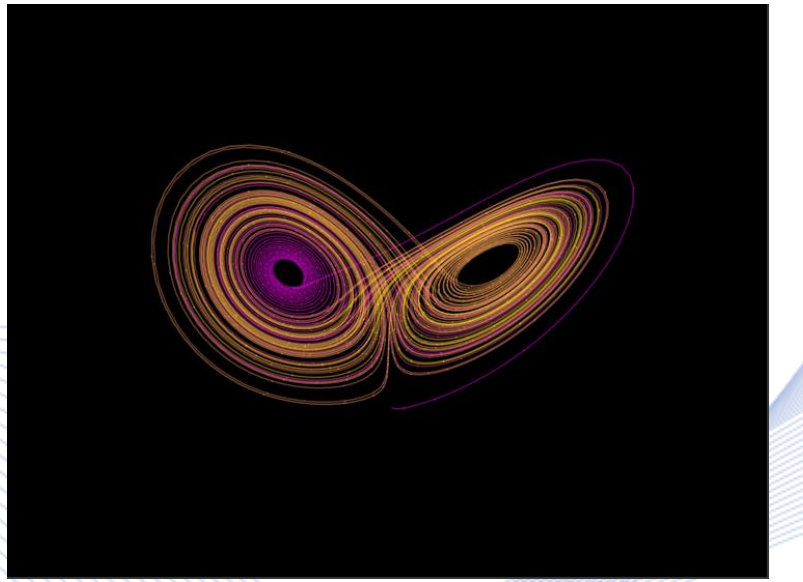


Systems

Nonlinear dynamic systems are typically defined by nonlinear differential equations.

- They can have chaotic behaviour.
- Difficult to analyse.

- ***Our world is dynamic and highly nonlinear.***



Lorenz attractors.

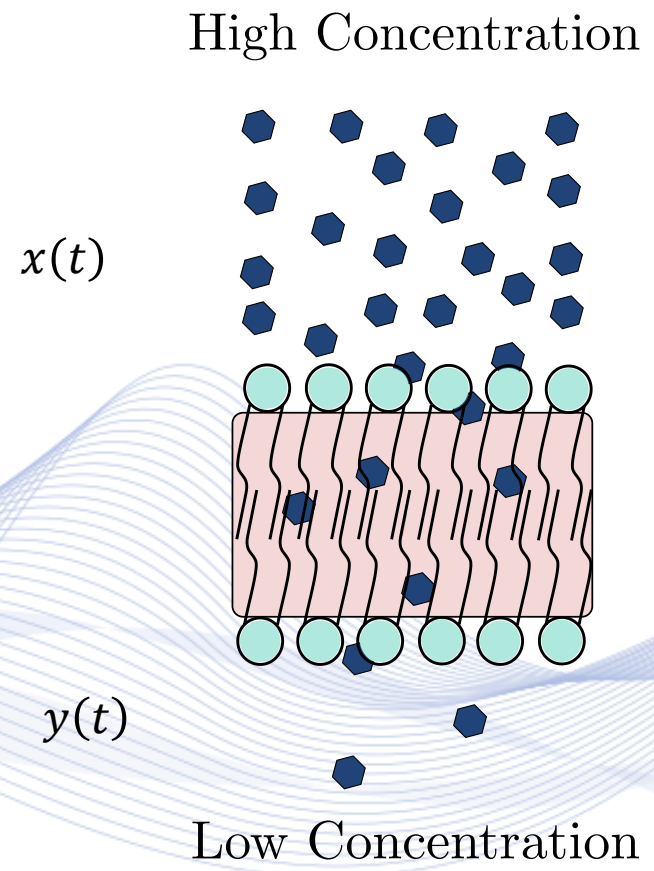
Systems

Dynamic continuous world modeling.

- Differential Equations for systems models.
- ***Diffusion equation.***

$$\frac{dy(t)}{dt} = c\big(x(t) - y(t)\big).$$

- c: diffusion coefficient.
- Pharmacokinetic modeling



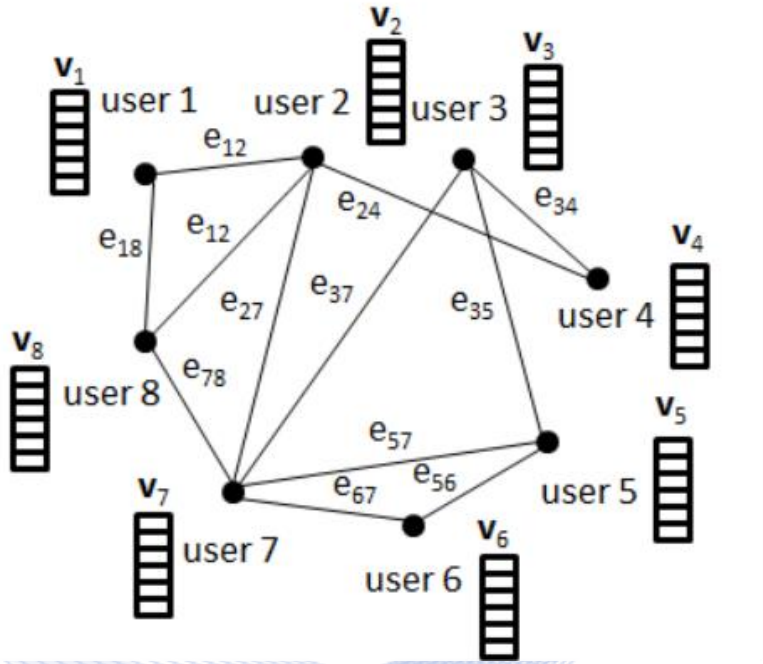
Pharmacokinetic modeling.

Networks

Networks describing interacting entities.

- They are described by ***graphs*** G(V,E).
- Graph nodes are connected by edges.

- Discrete and static description of the world.

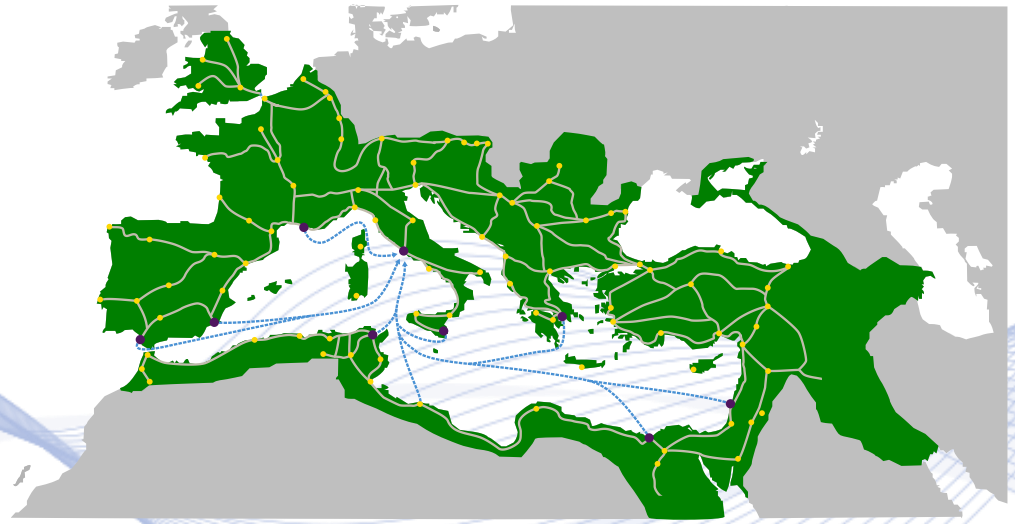


Social network graph.

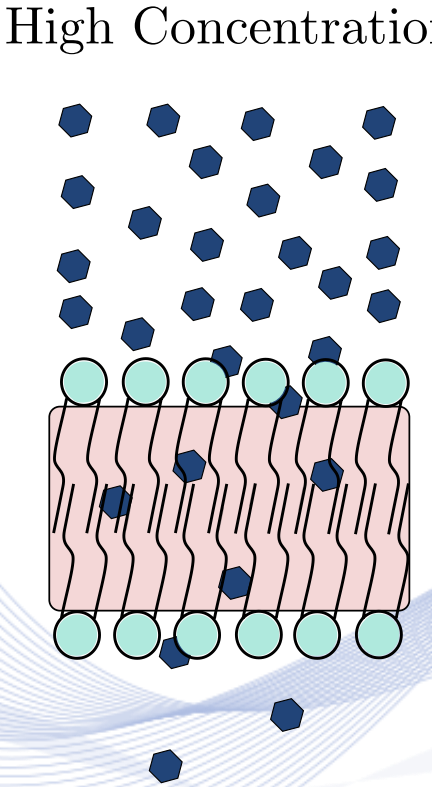
Networks

Reconciling continuous and discrete world models.

- Diffusion processes.



Information diffusion: Christianity along Roman routes.

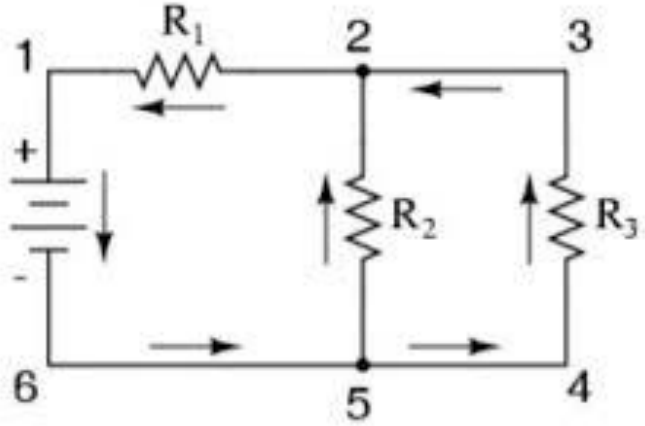


Continuous diffusion models.

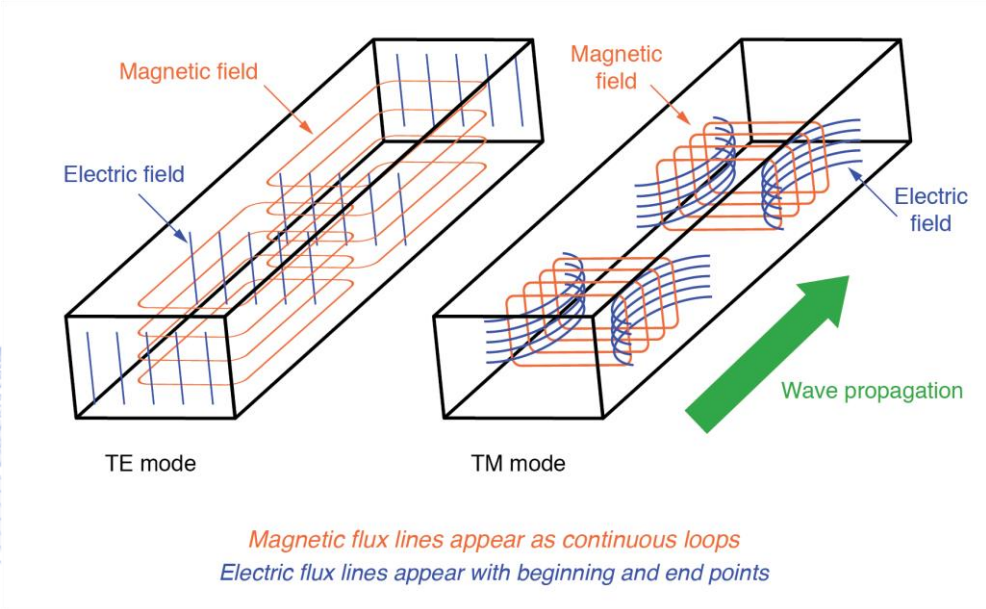
Networks

Reconciling continuous and discrete world models.

- Electric networks and wave equation.



Electric circuits (graphs).



Electromagnetic waveguides.

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Life

Life properties:

- Organization.
- ***Homeostasis***
- ***Response to stimuli and adaptation.***
- Metabolism
- Growth
- Reproduction
- Death.

Life is based on matter!

Life

- Life is organized along ***matter interactions of increasing complexity.***

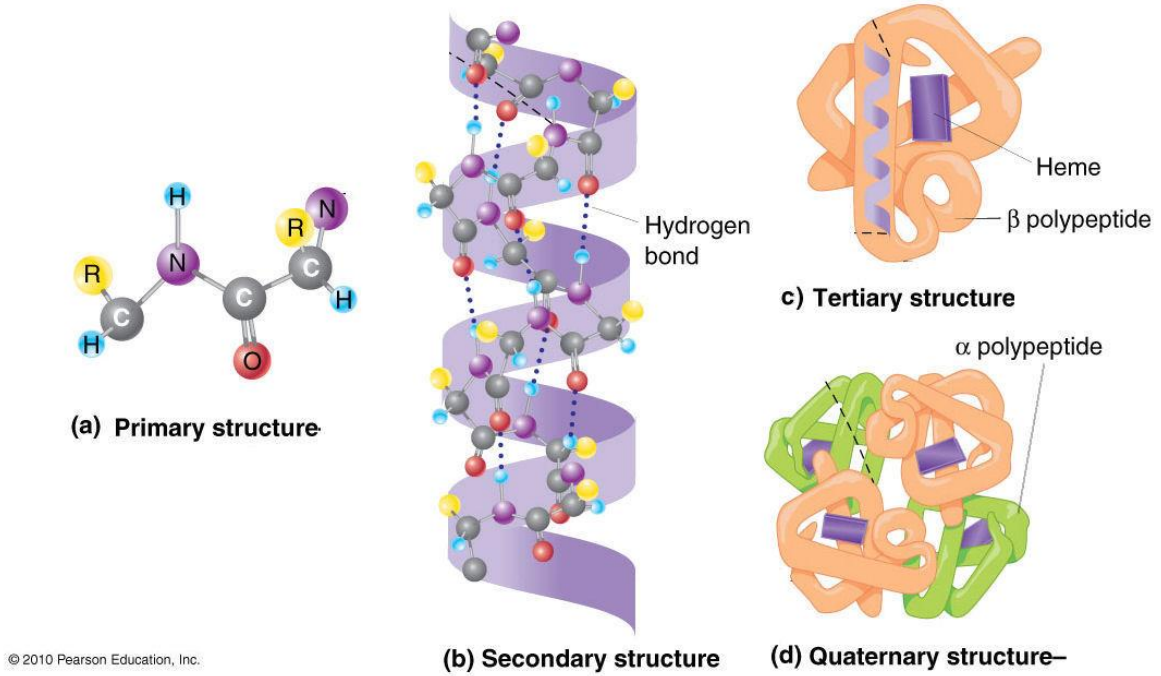
$$Atoms > nucleotides > DNA - RNA - proteins > subcellular\ structures > cells\ (neurons) > organisms > multicelular\ organism > colonies, swarms, networks.$$

- Can life be described by interaction graphs?
- ***Can we envisage other complex matter forms?***

Life

- Does life consist of ***'thin' interacting structures*** floating in a sea of water and smaller molecules?
- Can life be described by interaction graphs?

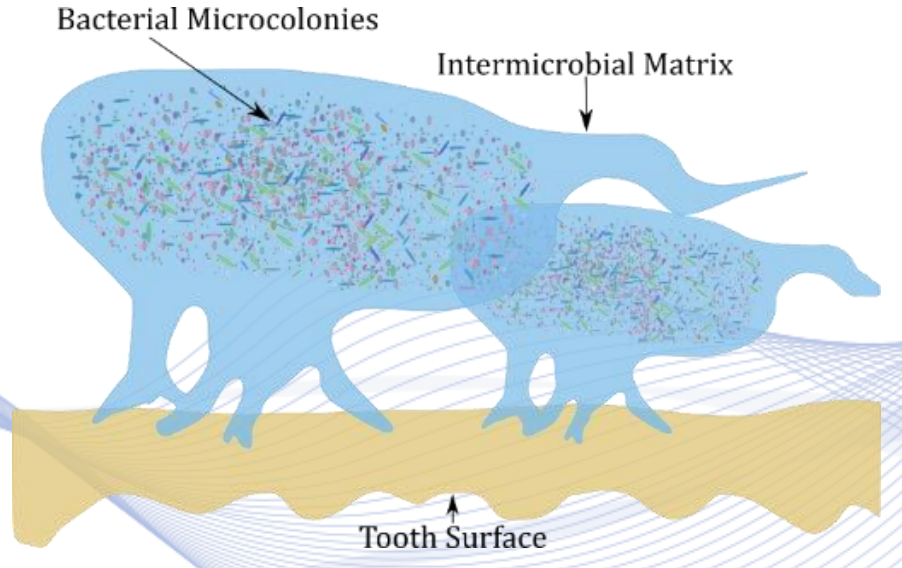
- ***Can we envisage other complex matter forms of life?***



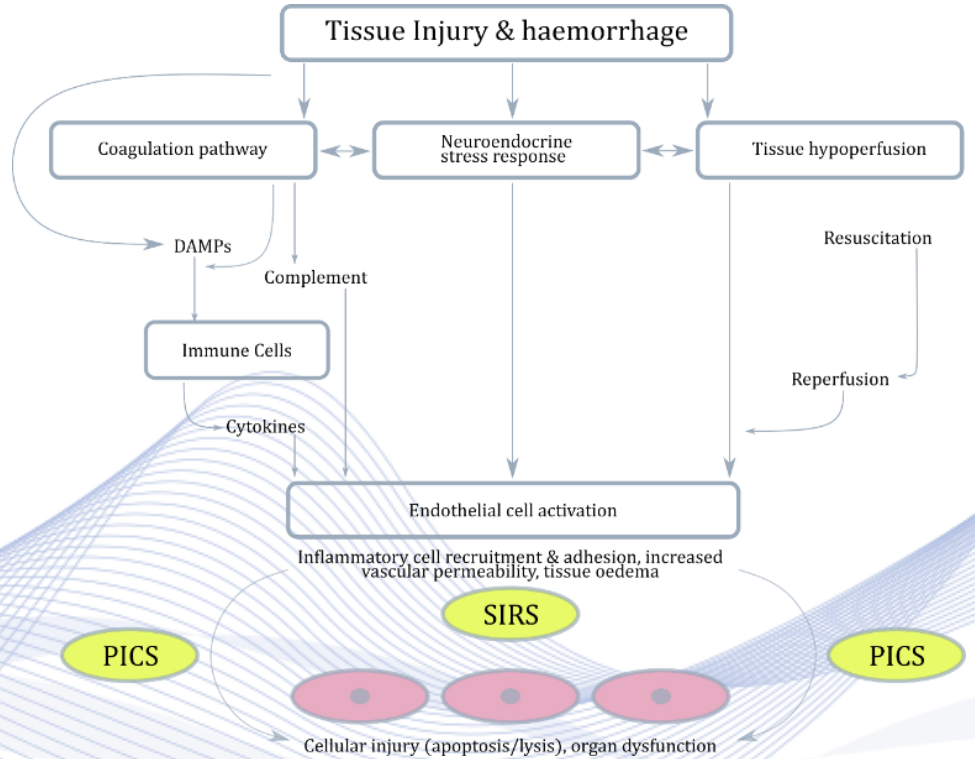
Life

Systems Biology.

- Interacting biological systems.



Dental biofilm.

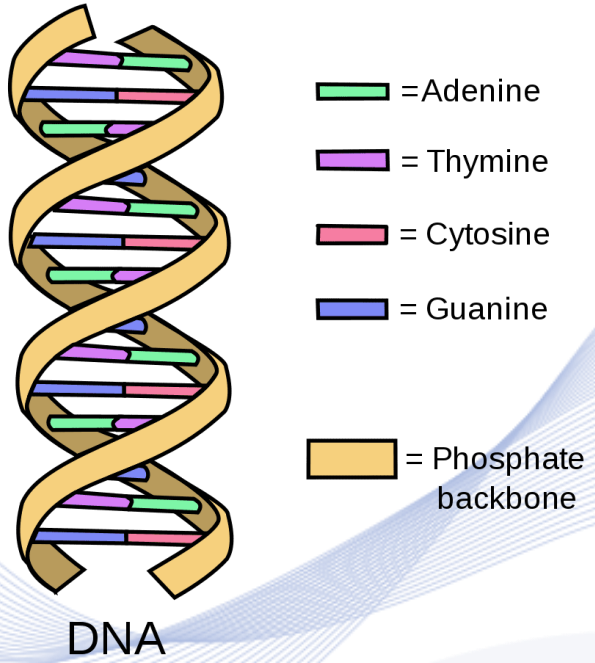


Tissue and organ damage pathways after trauma.

Life

Robustness and stability [WAG2014] ***.***

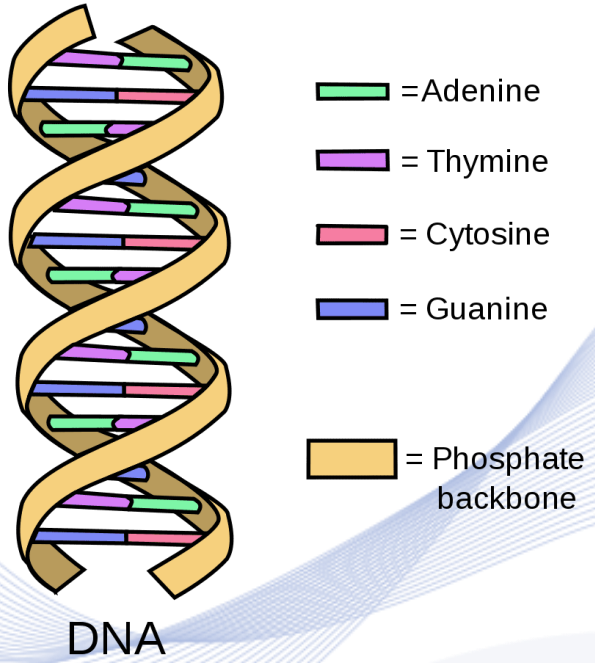
- Life duplicates information to achieve robustness (***diploidy***).
- Biological feedback mechanisms can ensure stability vs perturbations.



Life

Evolution

- Perturbations, e.g., ***DNA mutations***, are essential for life evolution.
- Are perturbations random?
- ***Does life solve an optimization problem to find the fittest perturbation?***
- Perturbations may produce various ***desirable side-effects*** that create unintended fitness to multiple environments:
  - E.g., multiple drug resistance.



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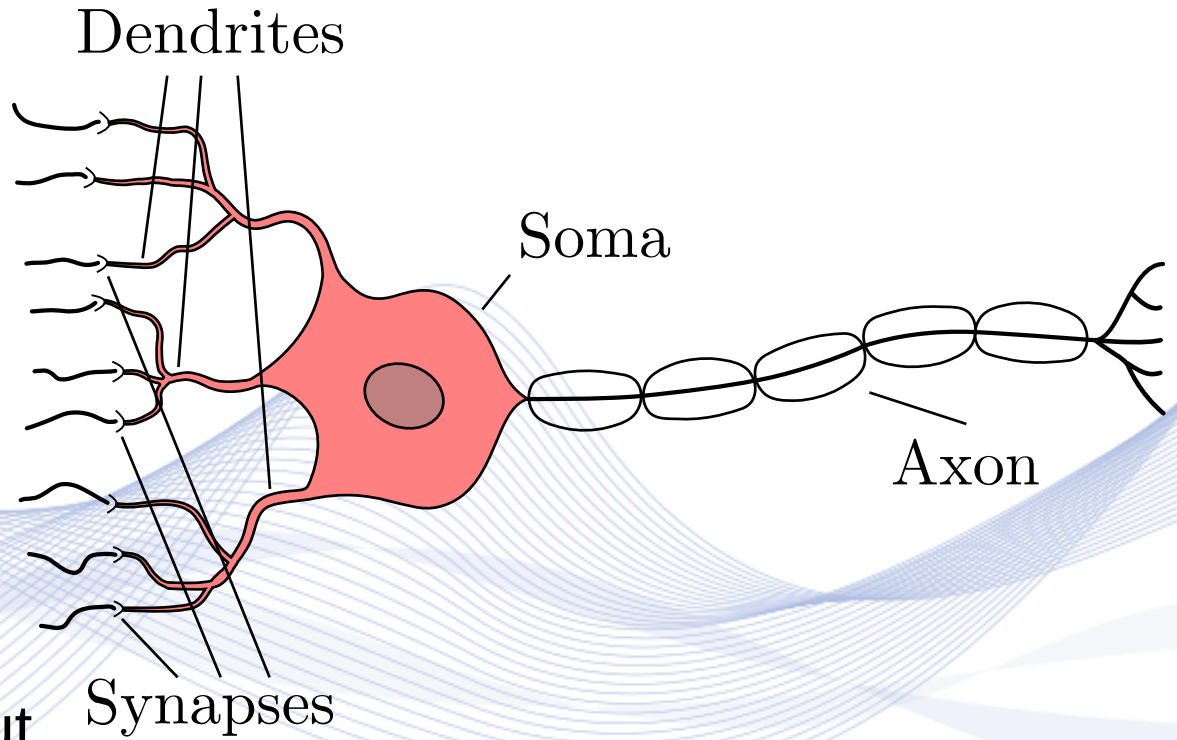
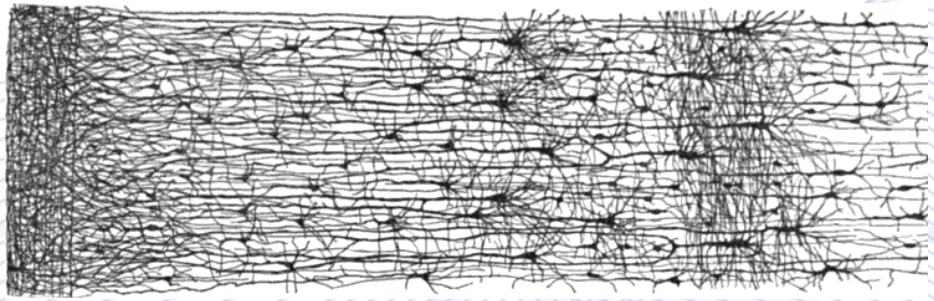
Biological Neural Networks

- Basic computational unit of the brain.
- Main parts:
  - ***Dendrites***
    - They act as inputs.
  - ***Soma***
    - Main body of neuron.
  - ***Axon***
    - It acts as neuron output.



Biological Neural Networks

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



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

Biological Neural Networks

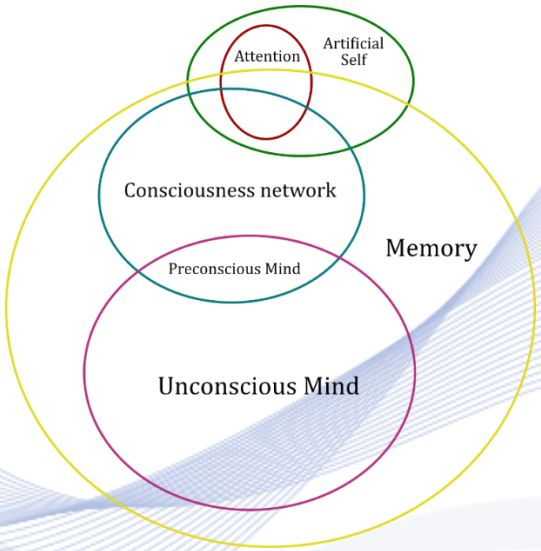
Interoception and Physical Intelligence

- ***Interoception*** is the perception of stimuli from inside our body.
- It supports ***homeostasis*** (maintenance of functional body equilibrium).
- ***It is essential for human (self)consciousness.***
- Current robots do not have interoception.
- Closest approximation: ***Physical Intelligence*** uses distributed sensors to allow robots to live in unstructured environments.
  - Multimodal machine perception: tactile, smell, taste sensors.

AI and Human Mind

Brain-Inspired Computing

- ***Computational Neuroscience*** creates mathematical models of the brain and nervous systems.
- Despite advances, no breakthroughs compared to AI revolution.
- Modeling memory, consciousness, affect etc.



- Major advances expected by Neuroscience and AI/ML fusion.

AI and Human Mind

Intelligent Self-aware systems

- Memory (easy)
- Affect (easy?)
- Consciousness(doable?)
- Real intelligence (difficult?)

- Swarm/social intelligence (doable).

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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:
  - ***Machine Learning*** (ML),
  - Classical (Symbolic) ***Artificial Intelligence*** (AI)

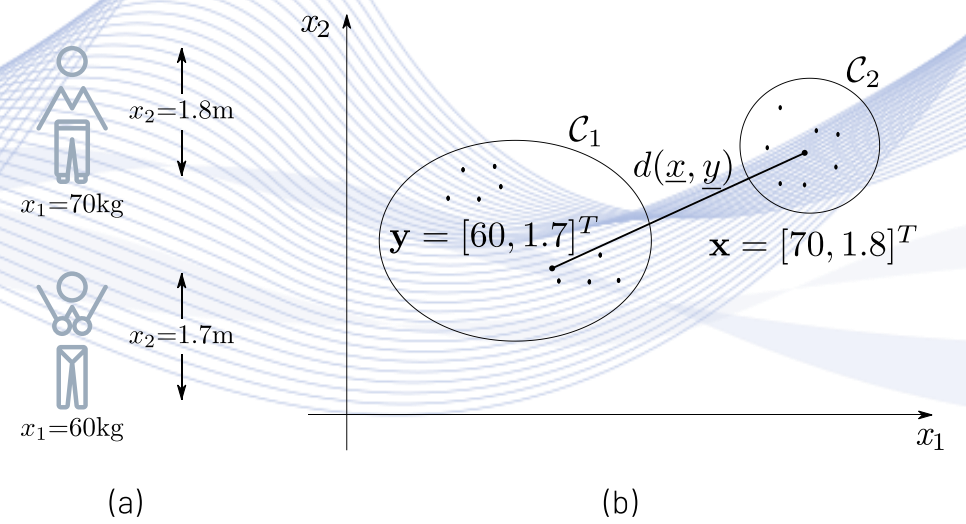
What is AI?

Data/information/knowledge definitions

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

- ***Data are primarily numbers*** representing object characteristics (features).
- Passive/active data acquisition.
- Data sampling.

- ***Measured in bits.***



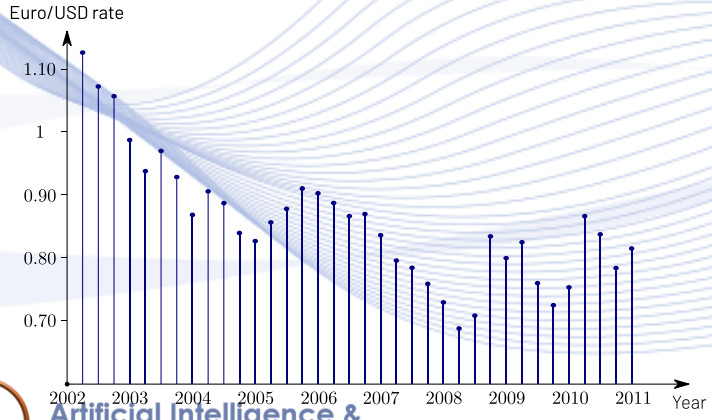
What is AI?

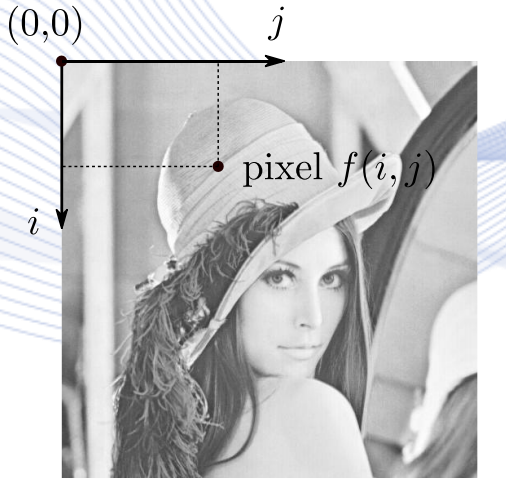
Data can have ***spatiotemporal structure***:

- 1D temporal signals, e.g., music
- 2D spatial signals: images

- Signals and object features can be represented by ***vectors***:

$$\mathbf{x}^T = [x_1, x_2, \ldots, x_n].$$

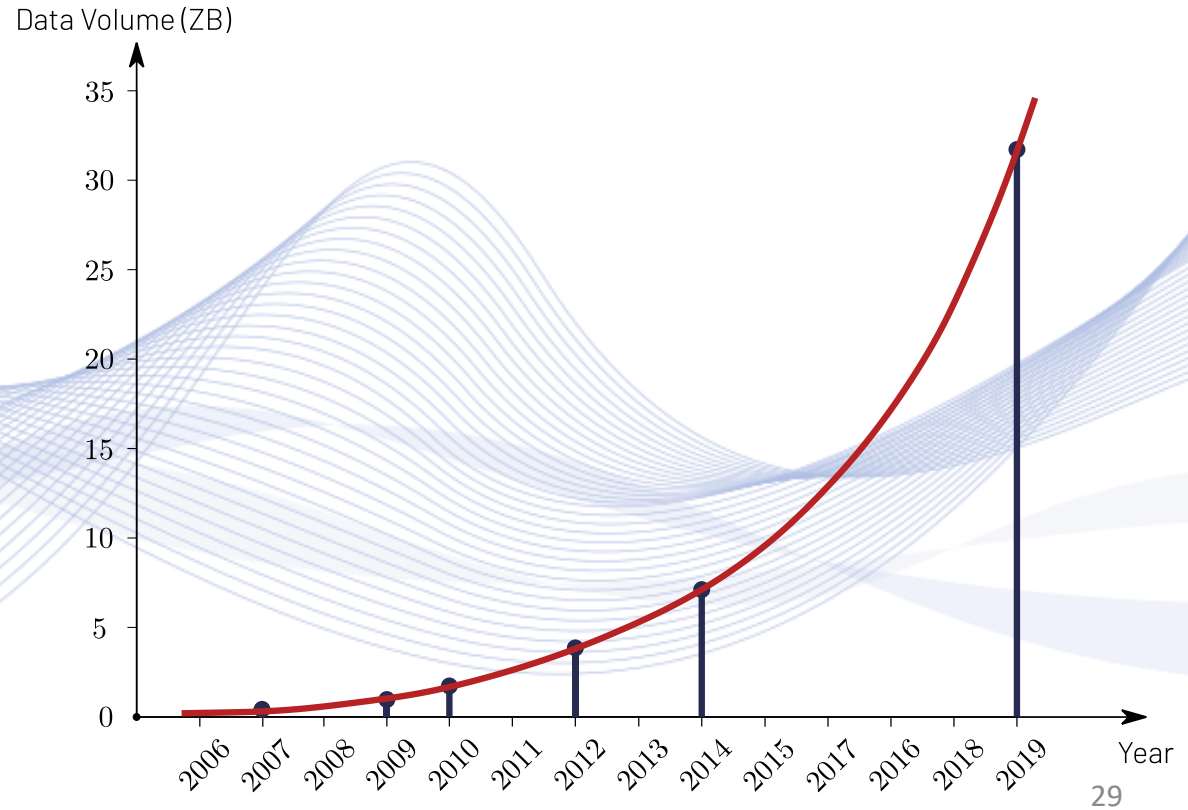




What is AI?

Exponential data increase:

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



Data volume increase in past decade.

What is AI?

Why we need ever more data?

- To navigate in an ever more complex world.
  - ***Why do we need a more complex world?***

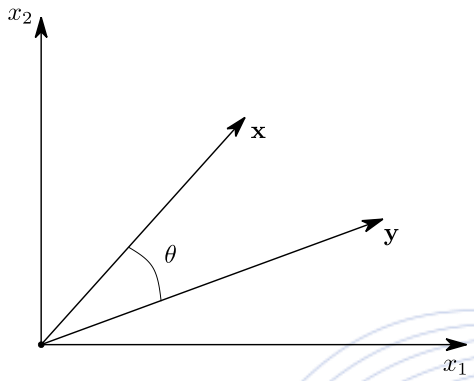
Data sustainability:

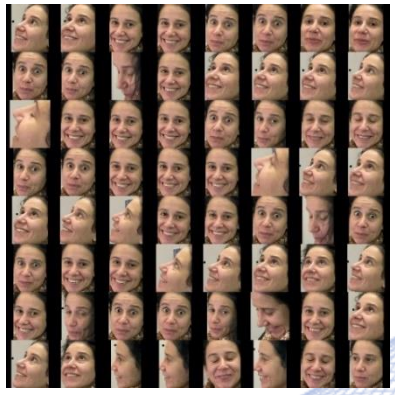
- HW enabled
- ***Moore's law***
- Data storage constraints
- Data communication constraints.

What is AI?

Unsupervised Machine Learning

- Data clustering:



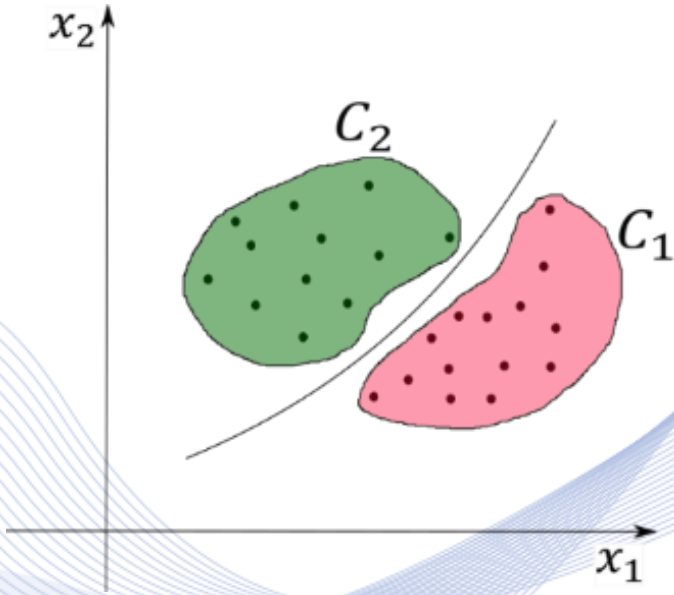


- Data geometry
- ***Abstraction***
- ***Data compression.***

What is AI?

Supervised Machine Learning

- Learning functions $\mathbf{y} = \boldsymbol{f}(\mathbf{x}; \boldsymbol{\theta})$ from labeled training data $\{(\mathbf{x}_i, \mathbf{y}_i), i = 1, \ldots, N\}$.
- ***Classification***
- ***Regression.***



- Learning data probability distributions $p(\mathbf{x})$.
  - ***Generative neural networks.***
    - ***Fake data creation.***

What is AI?

Information

- Notoriously vague definitions
- My definition: ***Information is the result of the manual or automatic Data Analysis***.

Taxonomy: Data → Information → Knowledge.

Machine Learning/inference produces ***information*** (including metadata).

- ***Information theory/entropy: bits (once more)!***

What is AI?

Concepts and ideas (ιδέες).

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

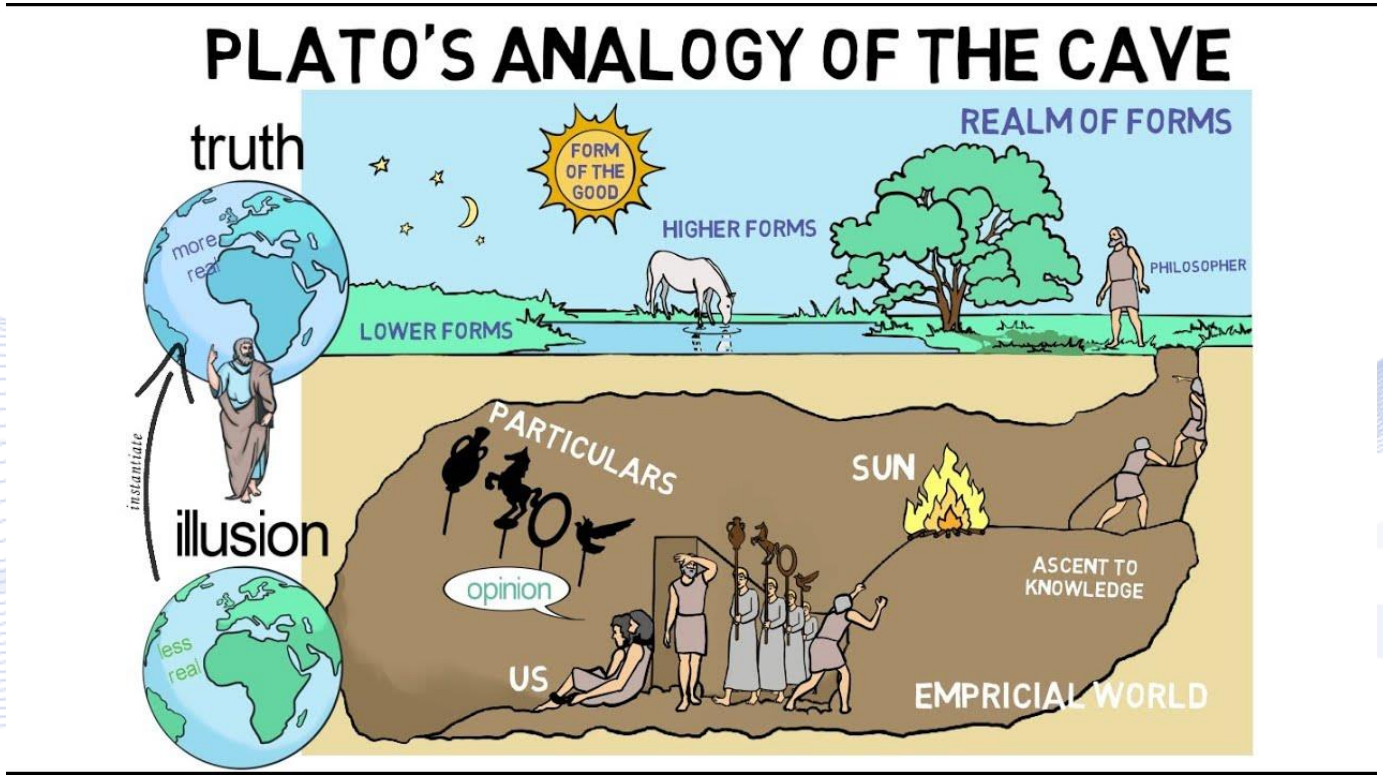
Instances of a triangle.

- ***Abstraction and generalization***:
  - Simplification and data compression.

What is AI?

Ideas in Philosophy.

- Idealism, materialism, dualism.
- Plato's cave.



What is AI?

Symbolic AI

- A ***symbol*** (‘Σύμβολο’) is a ***comprehensible representation*** of an object, idea, concept, action, status, or relationship.
- Symbolic AI mimics and simulates high-level human intelligence and ***reasoning***.
- It represents and operates on concepts and their relations though ***logic*** and ***search***.

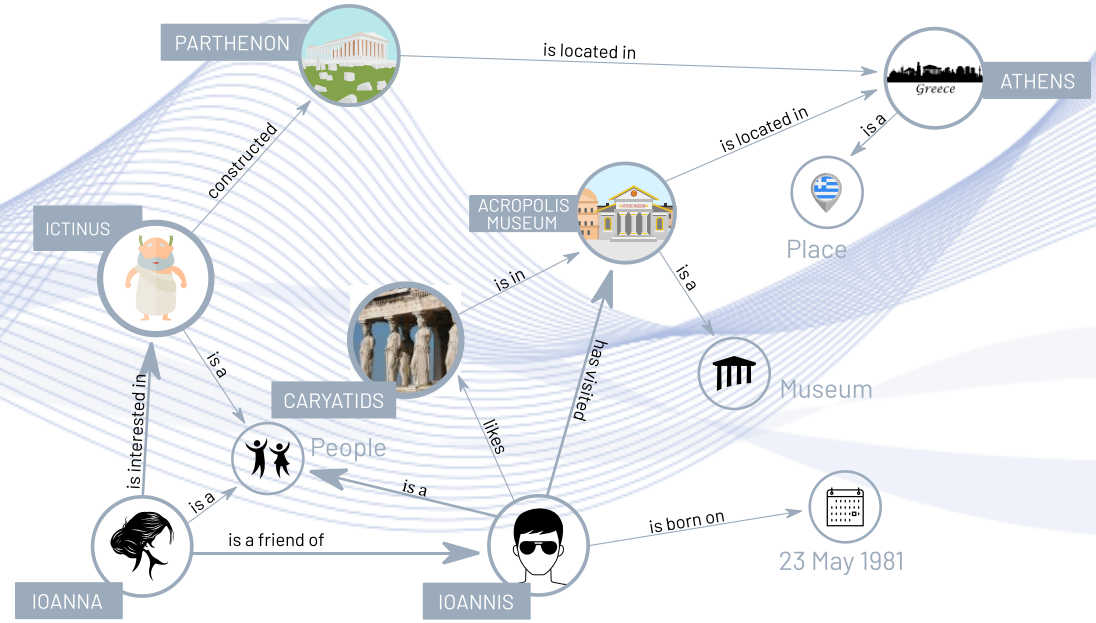
- ***Reasoning*** is one of the most complex brain activities.

What is AI?

Knowledge

- It is a familiarity, awareness, or ***understanding of someone or something***:
  - Facts (propositional knowledge),
  - Skills (procedural knowledge),
  - Objects relations (relational knowledge).

- Various knowledge descriptions.

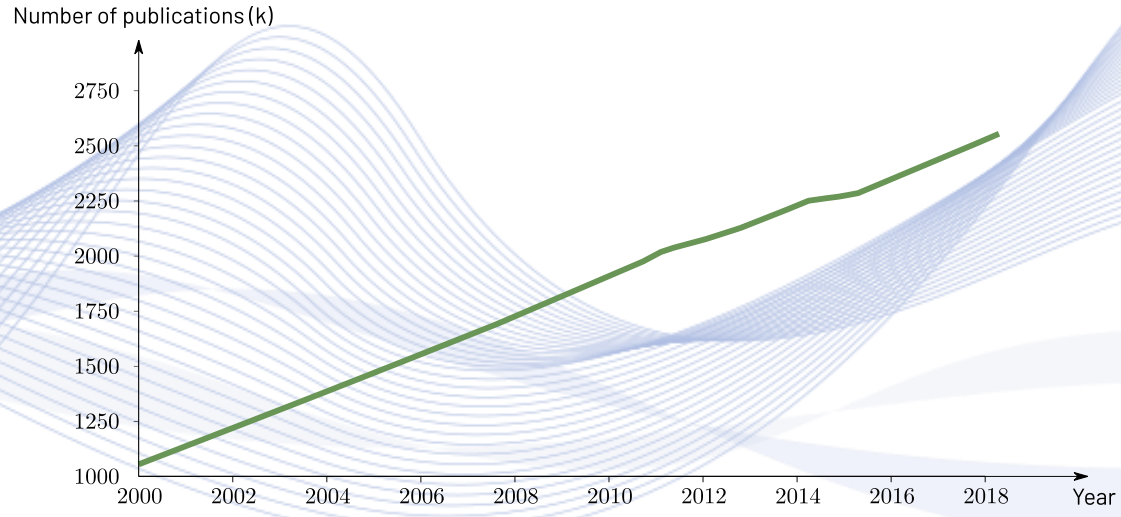


What is AI?

Knowledge is primarily a product of reasoning.

- Is knowledge finite?
- ***Can we measure knowledge?***
- Knowledge increase is linear.

- ***Encyclopedias***
- ***Research publications.***



Global research output (publication) growth.

What is AI?

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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Artificial Neural Networks

Artificial neurons are mathematical models loosely inspired by their biological counterparts.

- Previous dendrites fetch the input vector:

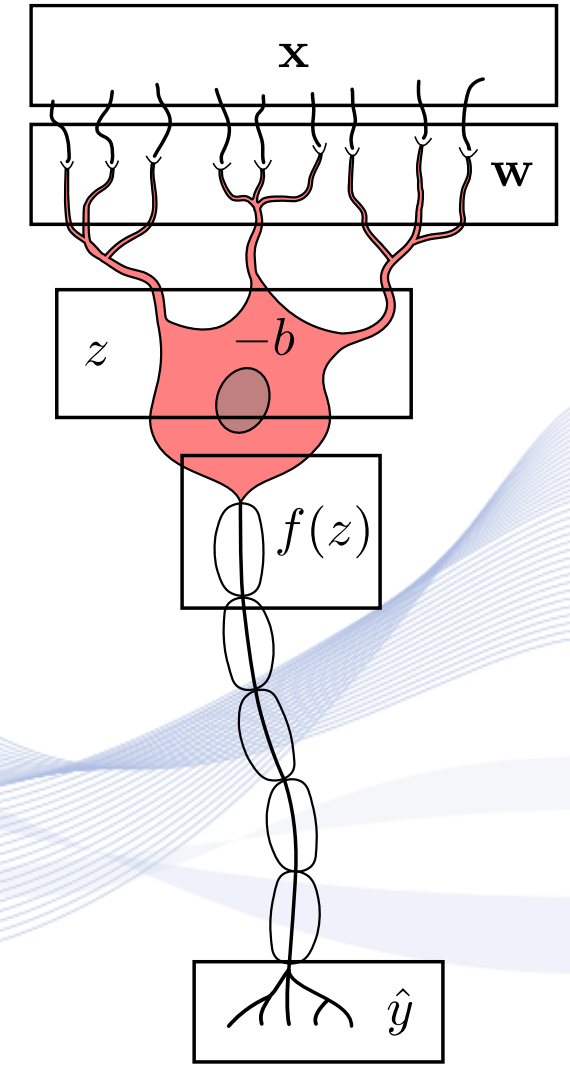
$$\mathbf{x} = [x_1, x_2, \dots, x_n]^T, \qquad x_i \in \mathbb{R}.$$

- The synaptic weights are grouped in a weight vector:

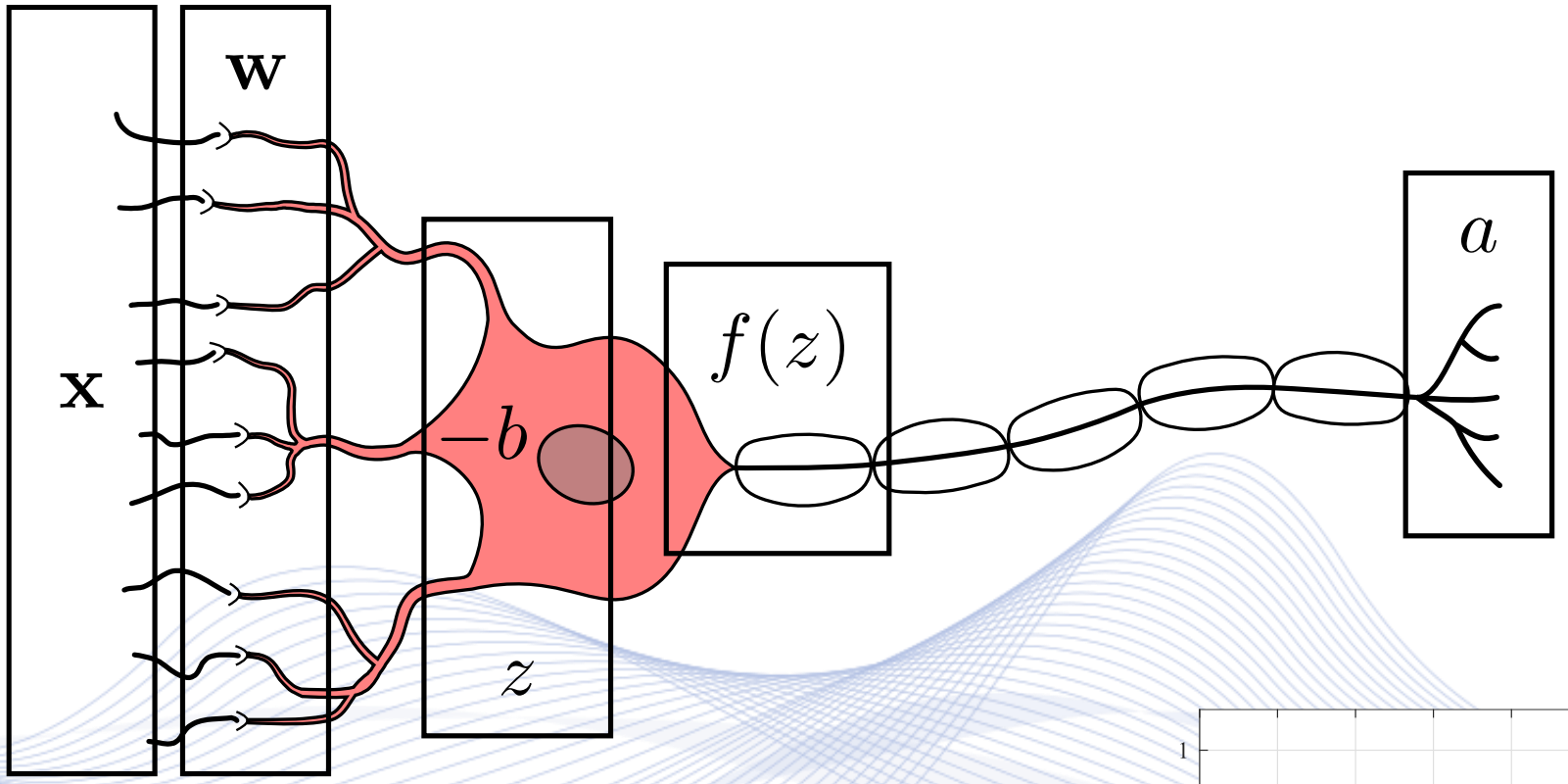
$$\mathbf{w} = [w_1, w_2, \dots, w_n]^T, \quad w_i \in \mathbb{R}.$$

- ***Synaptic integration***:

$$z = w_1 x_1 + w_2 x_2 + \cdots + w_n x_n > b.$$

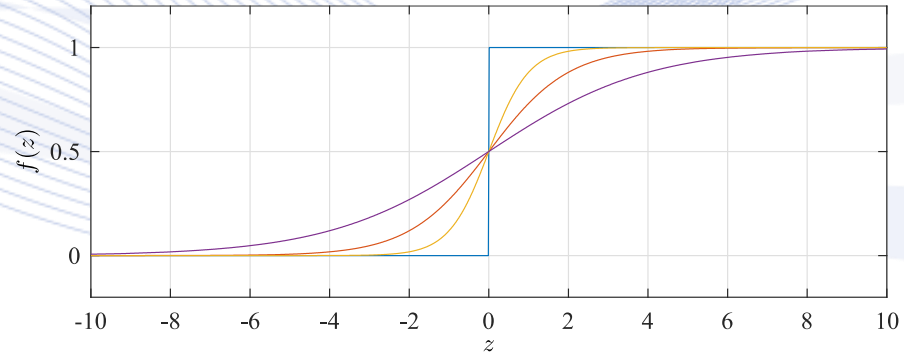


Artificial Neural Networks



Perceptron:

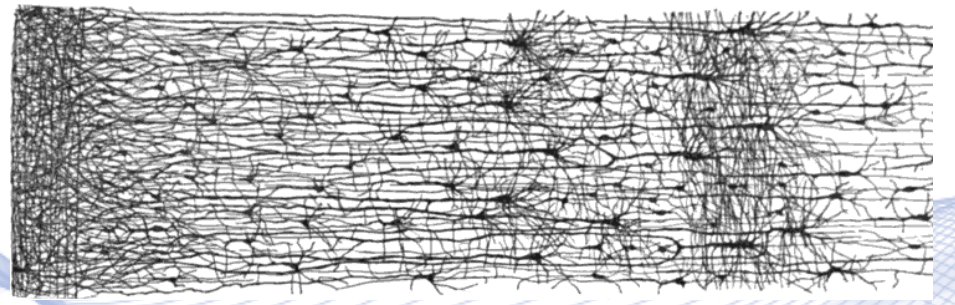
$$a = f(z) = f(w_1 x_1 + w_2 x_2 + \cdots + w_n x_n).$$



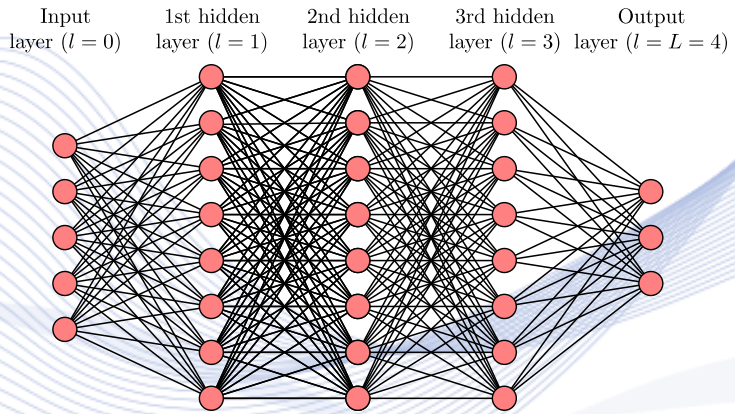
Artificial Neural Networks

Artificial and Biological neural networks

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



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



Multilayer perceptron.

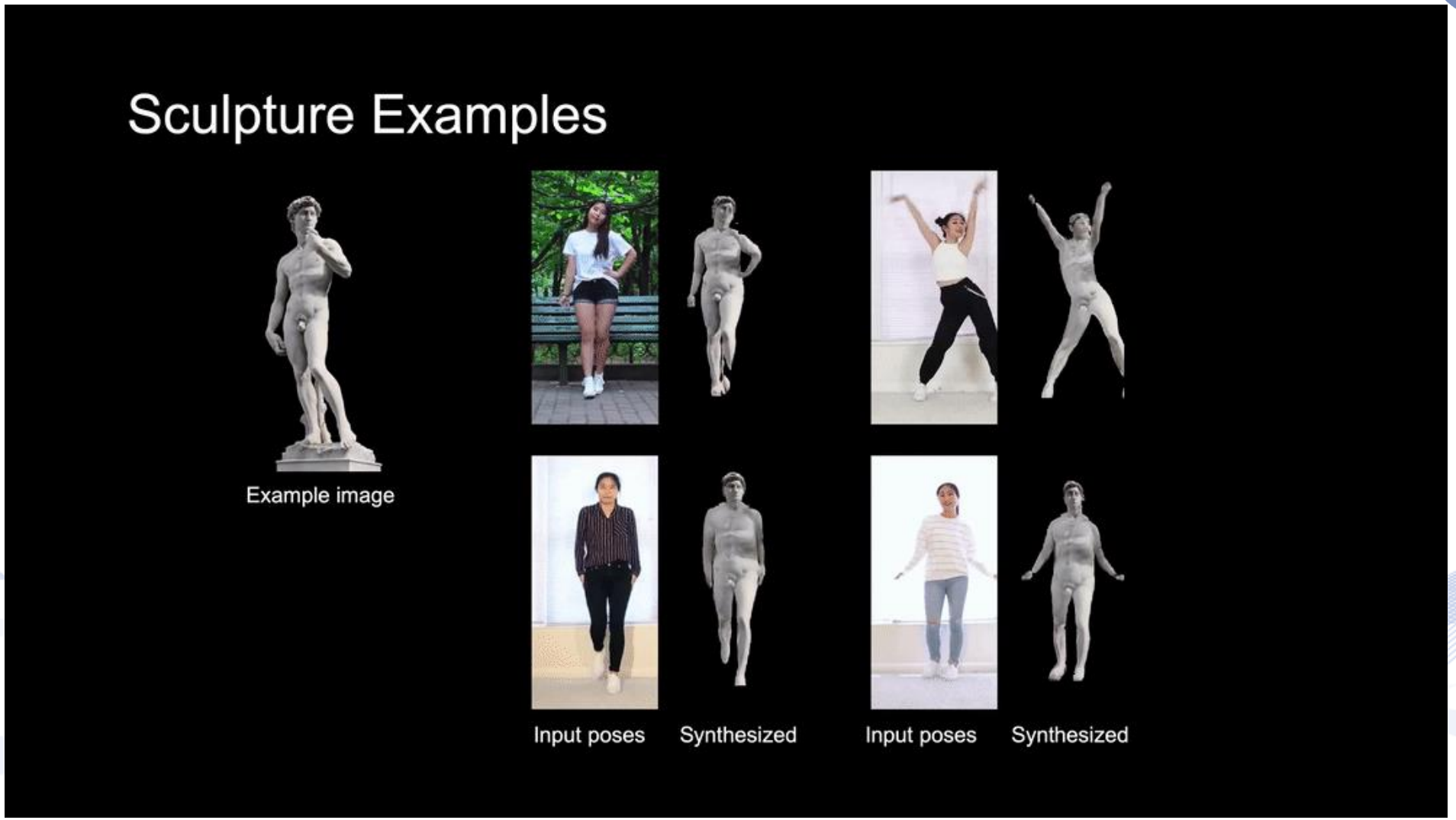
Artificial Neural Networks

Classification is a binary function ***prediction*** (estimation):

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

- ***Input***: $\mathbf{x} = [x_1, x_2, \dots, x_n]^T$, e.g., facial 100×80 pixel image.
- ***Trainable parameters*** (NN weights): $\mathbf{w} = [w_1, w_2, \dots, w_n]^T$.
- ***Output***: $\mathbf{y} = [0, 1, 0, \dots, 0]^T$.
  - Only the correct facial (person) class label is 1.

Generative AI

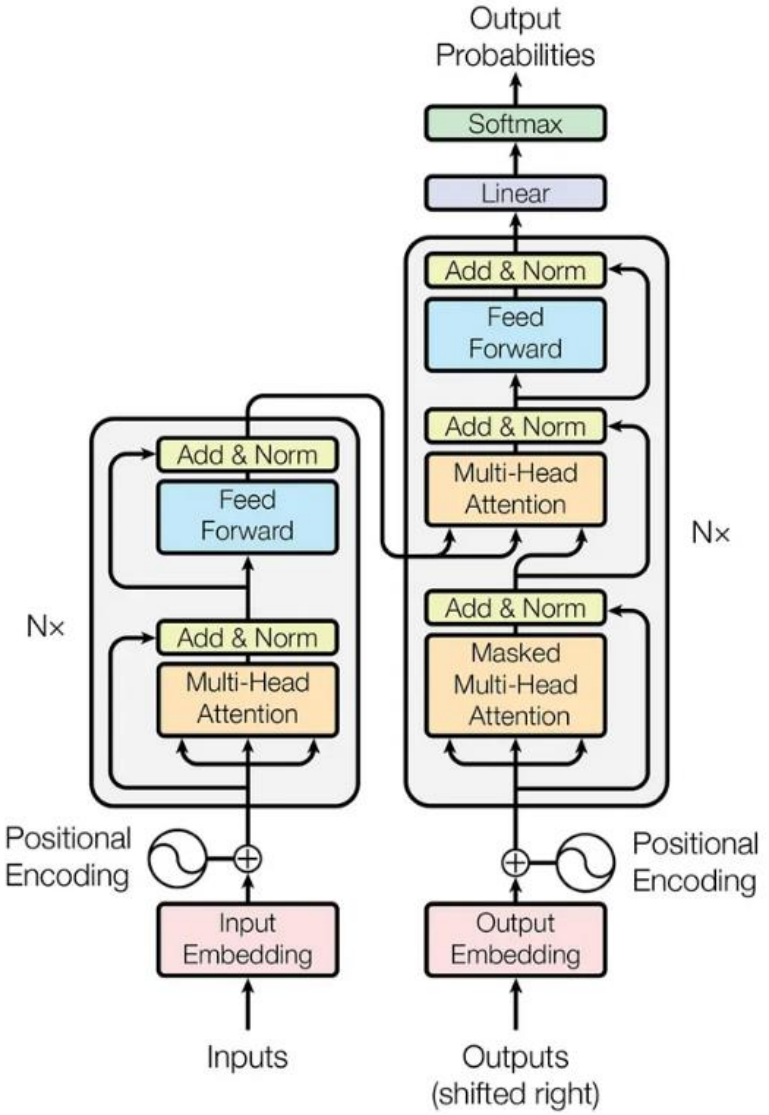


GANs in video synthesis.

Large Language Models

Transformers

- ***Transformers*** comprise of the encoder and decoder and use the self-attention mechanism to weigh the importance of input elements [VAS2017] .
- GPT-3.5 is a fine-tuned model of the GPT-3, which is a Transformer DNN.



Transformer architecture [VAS2017].

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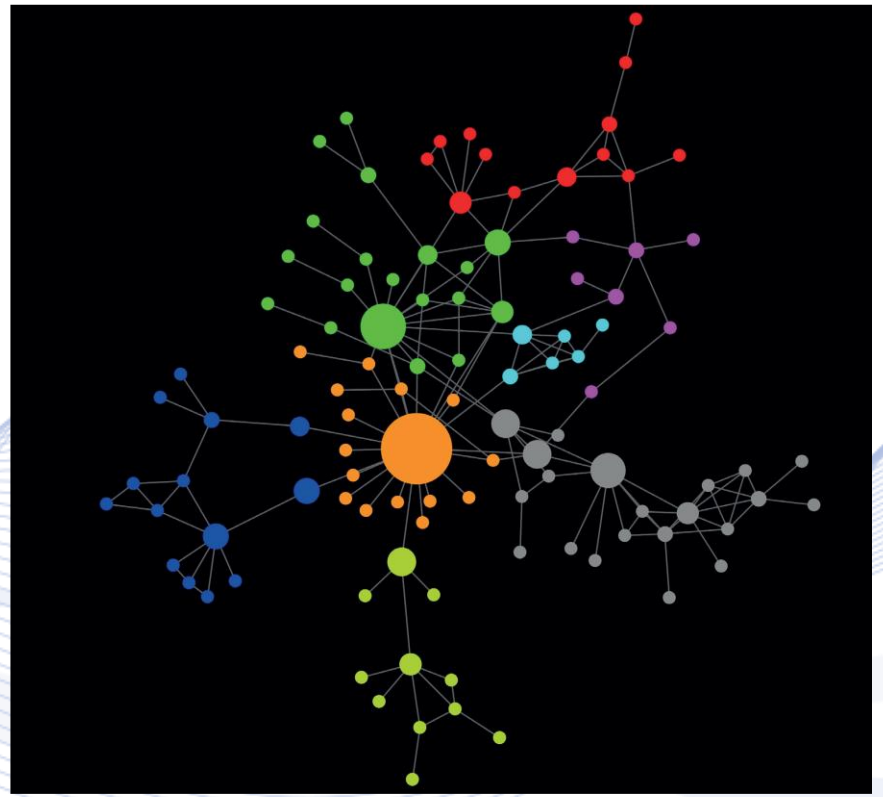
Society

Graphs of social interactions.

- Increasing social structure complexity over the ages.
- Social structure stability.

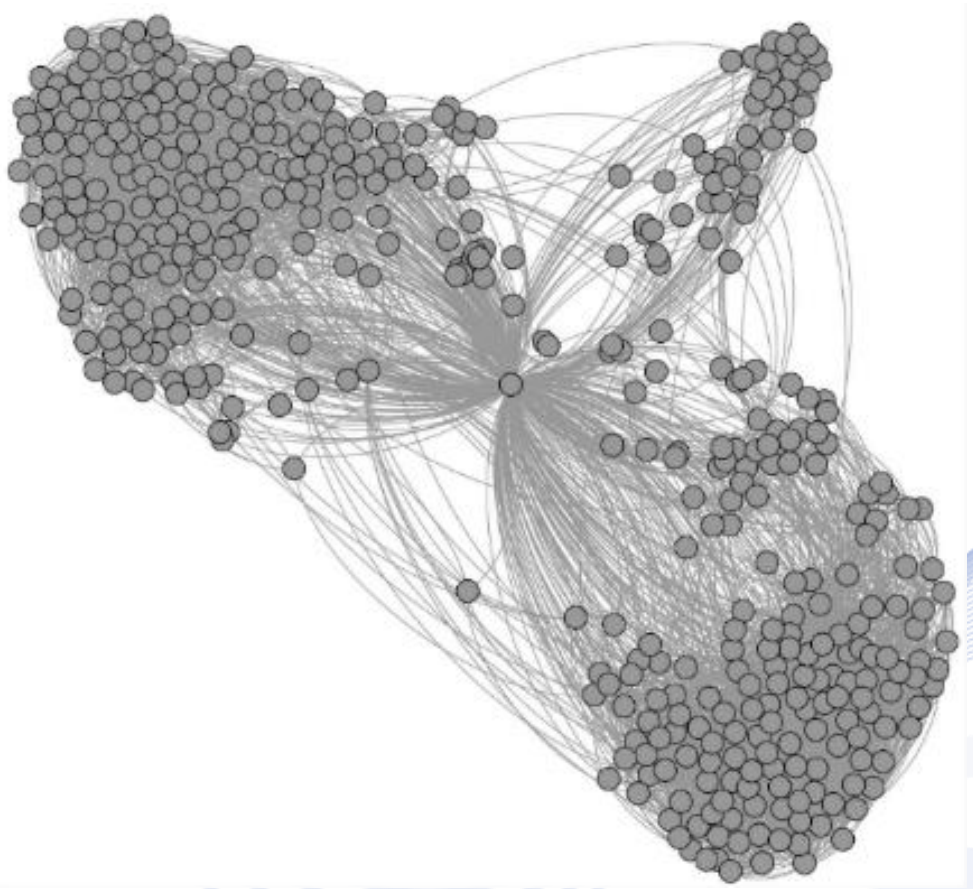


Clusters of the Byzantine nobility in the period 1321-1328 AD.

Society

Social networks.

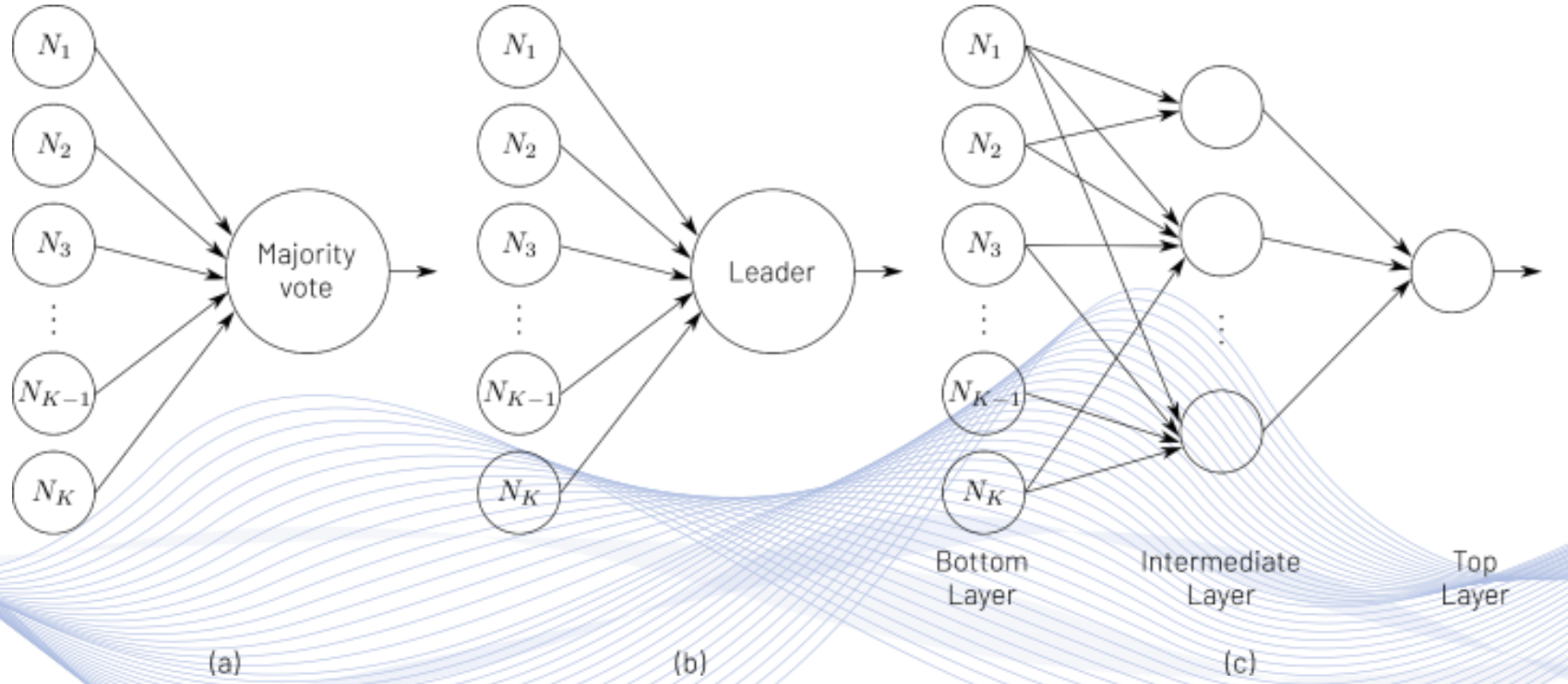
- Small-world phenomenon.
- Rich-get-richer phenomenon.



Facebook friendship relation graph.

Society

Political decision making.



Direct democracy. Dictatorship. Representative Democracy.

Society

AI and IT enable ***Social Engineering***:

- Understanding and analyzing social processes
- Influencing individual humans, social strata and structure.

- Marx's famous eleventh thesis on Feuerbach: "***Philosophers have hitherto only interpreted the world in various ways; the point is to change it.***"

Society

AI-powered Social Engineering examples

On-line marketing and recommendation systems

- New gold-rush: personal data
- Massive personal data collection (Surveillance Capitalism).
- ***User profiling*** and recommendations (turn data into profit):
  - On-line marketing.
- Using ***Cognitive Psychology*** to hook users in the system.

- Solution: Protect and ***valorize*** personal data.
  - Blockchain technologies.

Society

AI-powered Social Engineering examples

Social match-making systems

- Essentially, recommendation and user profiling systems
- Great influence on personal relations and sexual life.
- ***Can we allow agents decide our mates?***
  - Matchmaking is an age-old social tradition, e.g., in India.

- Coupling with mobile communications and VR:
  - Cybersex and beyond.

Society

AI-powered Social Engineering paradigm gone bad:

- ***Social media changed the way we interact with humans***
- The world became too small: 5 hops to reach anybody.
- Constant 24/7 connectivity and information flooding.
- ***Great communication facilitators.***
- Downside:
  - ***Generalized OnLine Affect and Cognition*** (GOLAC) ***disorder***.
    - ***Anti-intellectualism and Disinformation.***

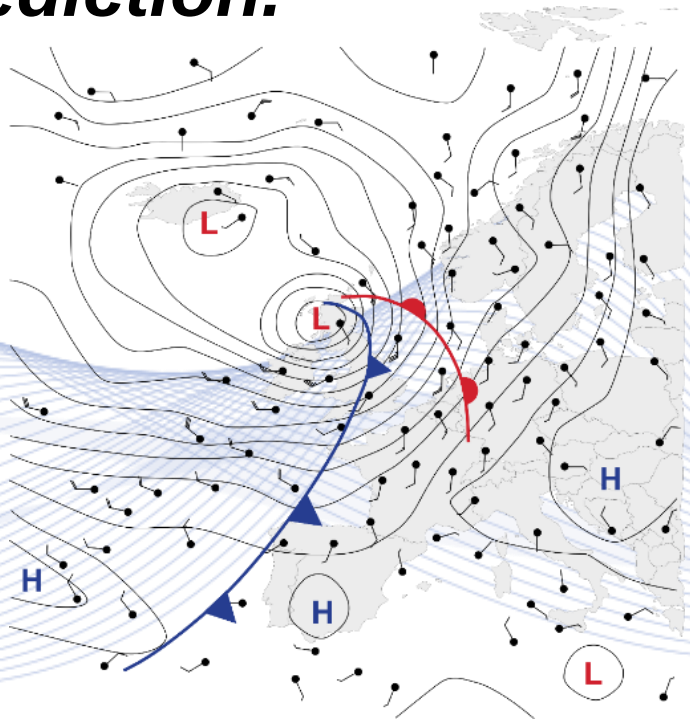
AI, System Complexity, Life, Intelligence and Environment

- Systems, Networks
- Life
- Biological Neural Networks
- What is AI?
- Artificial Neural Networks
- Society
- **Environment**
- System and Matter Complexity
- Evolution by Design.

Environment

Dynamic weather and climate phenomena.

- Described by nonlinear partial differential equations.
- ***Neural modeling for prediction.***



Weather prediction.

Environment

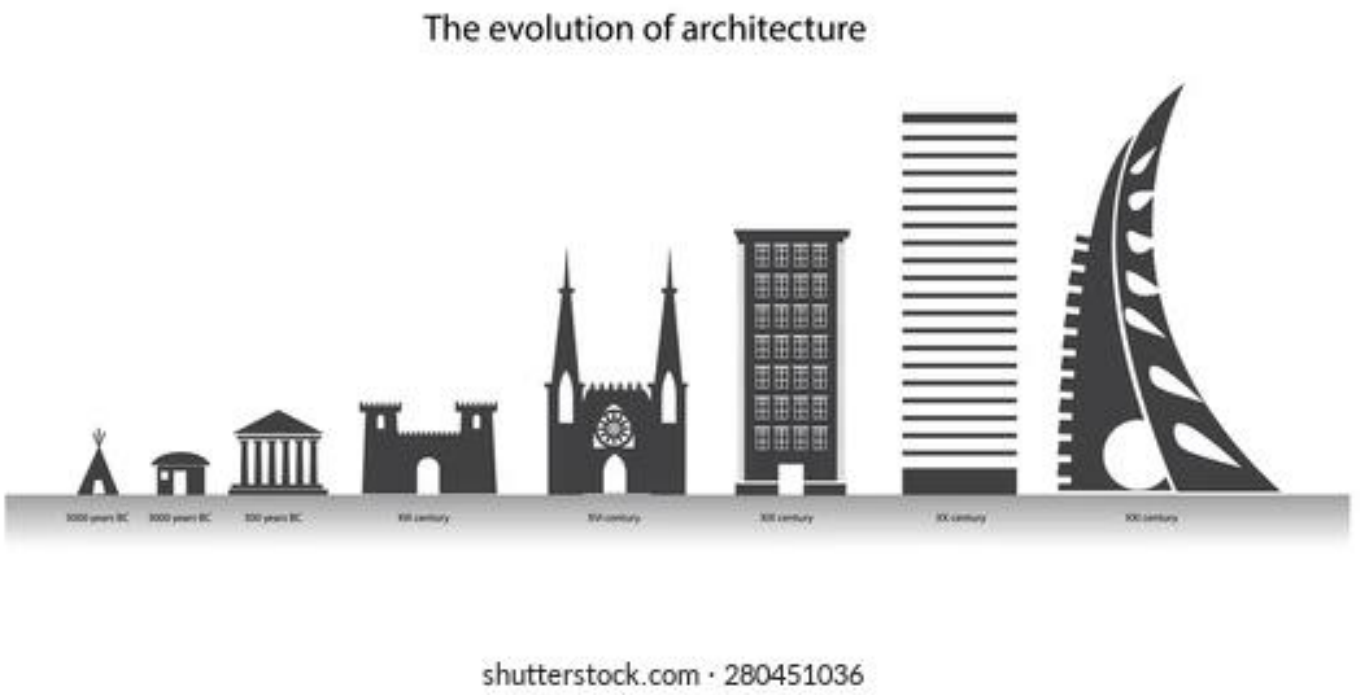
Ecological interactions.

Forest network graph.

Wildflower habitat patch graph.

Environment

Man-made Environment complexity ever increases.



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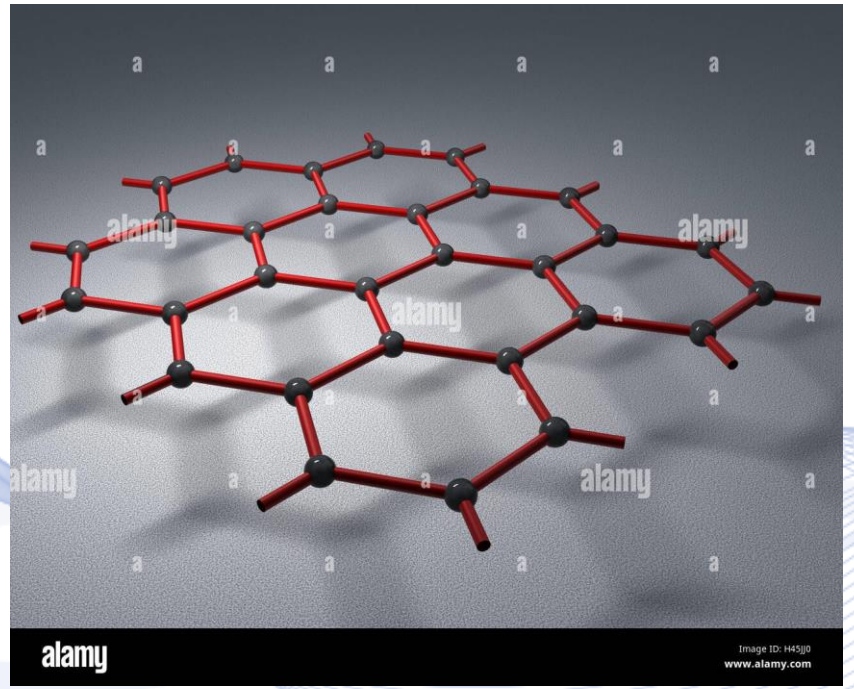
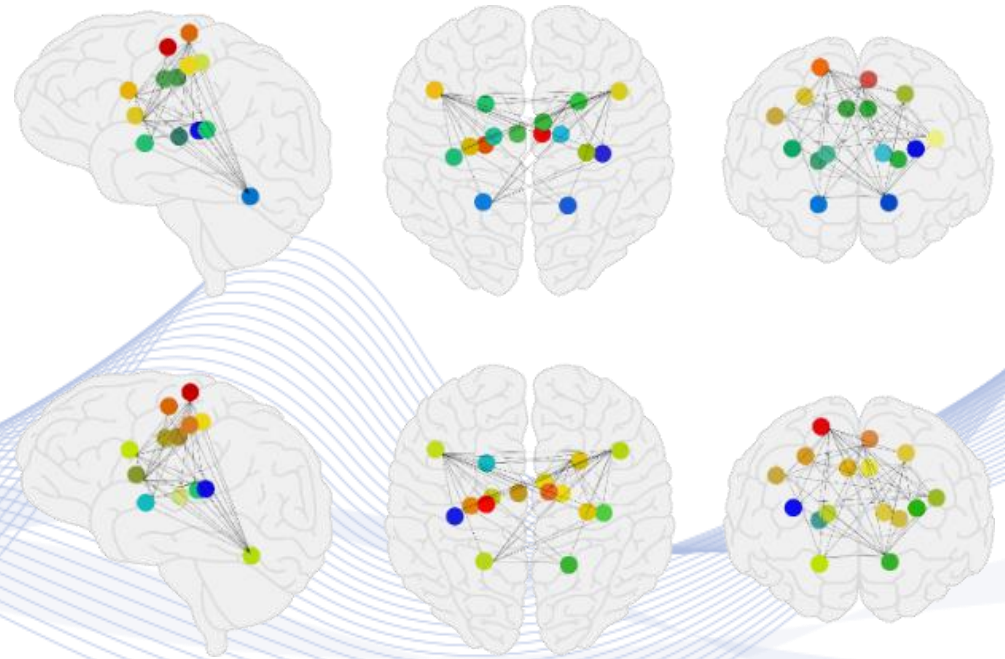
System and Matter Complexity

How can we define system complexity?

- Graph complexity.



Graphene atom grid.



Brain speech graphs.

System and Matter Complexity

How can we define system complexity?

- Graph complexity measures.

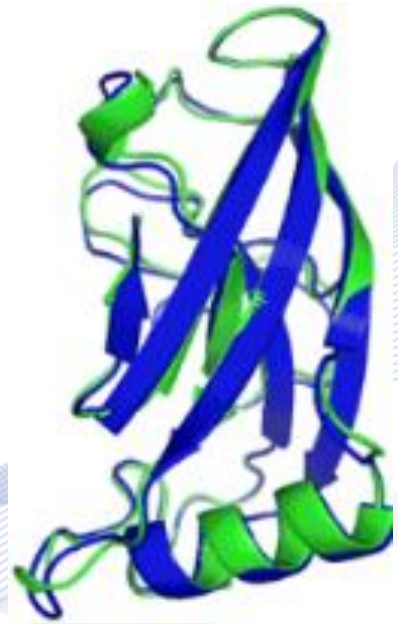
- What about dynamic system complexity?
  - Recursive/feedback systems.
  - Chaotic systems.

- Measuring ***functionality complexity***.
- Correlation between system and functionality complexity.

System and Matter Complexity

Entropy

- Can information entropy serve as a measure of complexity?
- Can we measure matter entropy [VOP2021]?
  - Matter can be encoded using 6×10^{80} bits?
  - Information encoded in each elementary matter particle:1.509 bits?
- Relation between information entropy and thermodynamic entropy?
- ***Do we live in a Matrix-like simulated Universe?***



System and Matter Complexity

Law of Complexity

- Is ***matter/system complexity*** the basis of life and intelligence?
- Necessary and sufficient condition?
- Complexity measures?
- ***Why live matter and social complexity ever increases?***
- Contrast to the 2nd thermodynamic law (***thermal death***).
- Does non-living matter have complexity?

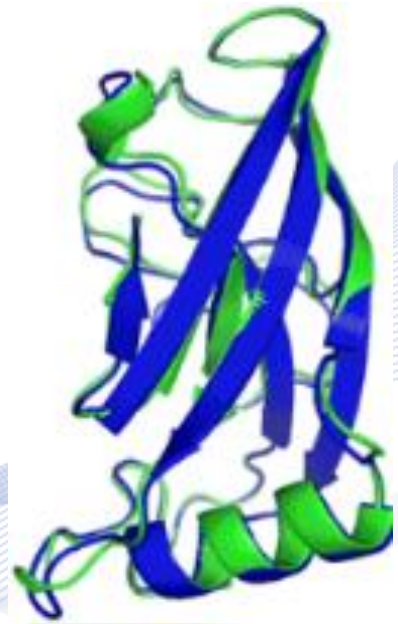
System and Matter Complexity

Complex system theory

- A complex system, e.g., life, intelligence, society, man-made environment can be modelled as function:

$$\mathbf{y} = f(\mathbf{x}, \mathbf{W}).$$

- ***In Biology***, $\mathbf{x}$: trigger (input), $\mathbf{W}$: genotype, $\mathbf{y}$: phenotype.
- ***In Neuroscience***, $\mathbf{x}$: stimulus, $\mathbf{W}$: brain structure, $\mathbf{y}$: perceived output.
- ***In Machine Learning***, $\mathbf{x}$: input,$\mathbf{W}$: DNN structure and parameters, $\mathbf{y}$: output.



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- **Evolution by Design.**

Evolution

System evolution is performed perturbations $\mathbf{N}$, e.g., ***DNA mutations***:

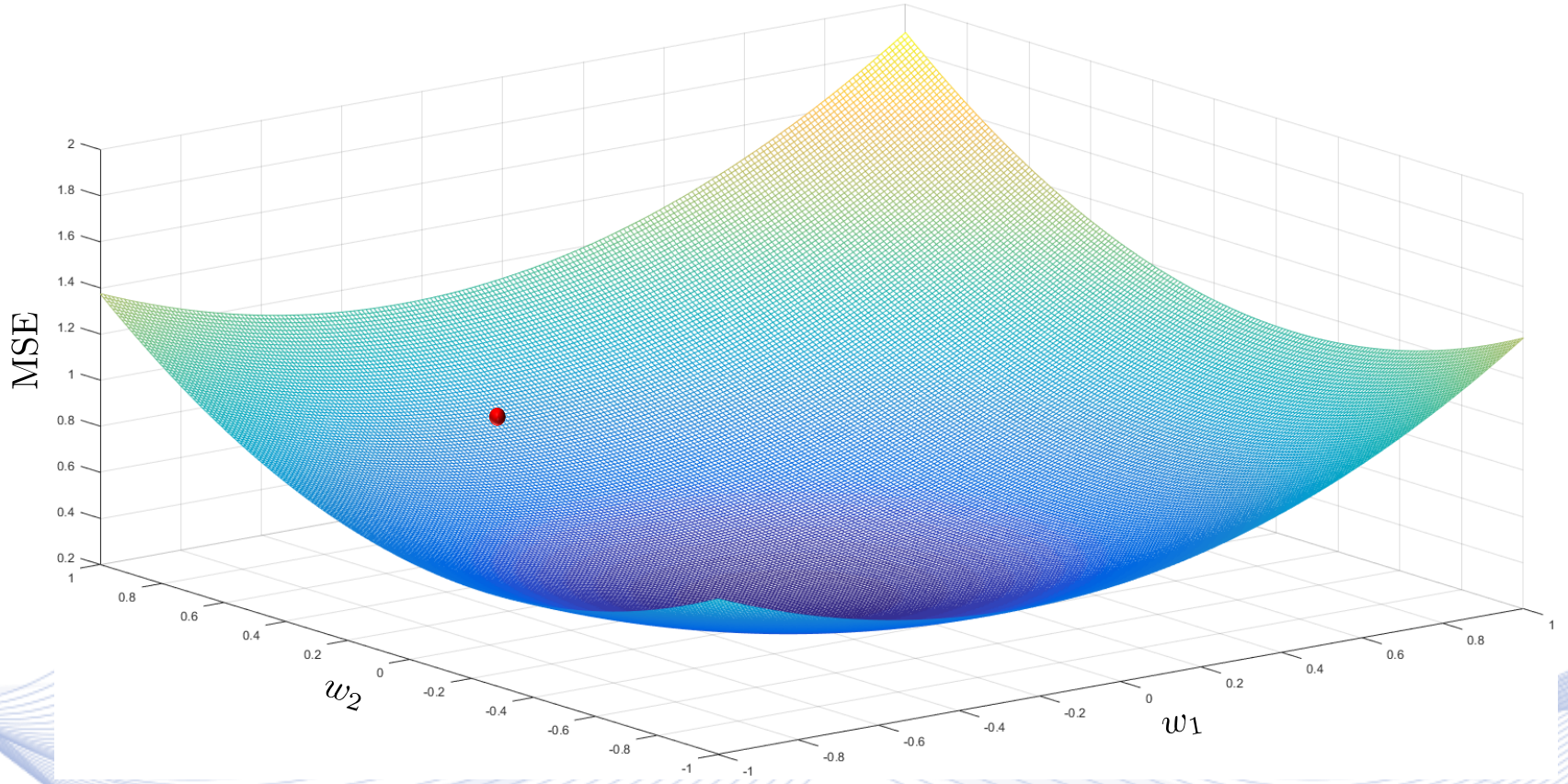
$$\mathbf{y}' = f(\mathbf{x}, \mathbf{W} + \mathbf{N}).$$

- They are essential for system (e.g., life) adaptation.
- If they fit are permanent, we have system evolution.

Optimization function (in Biology, ***Fitness Landscape***): $\mathrm{J}(\mathbf{y}, \mathbf{y}')$.

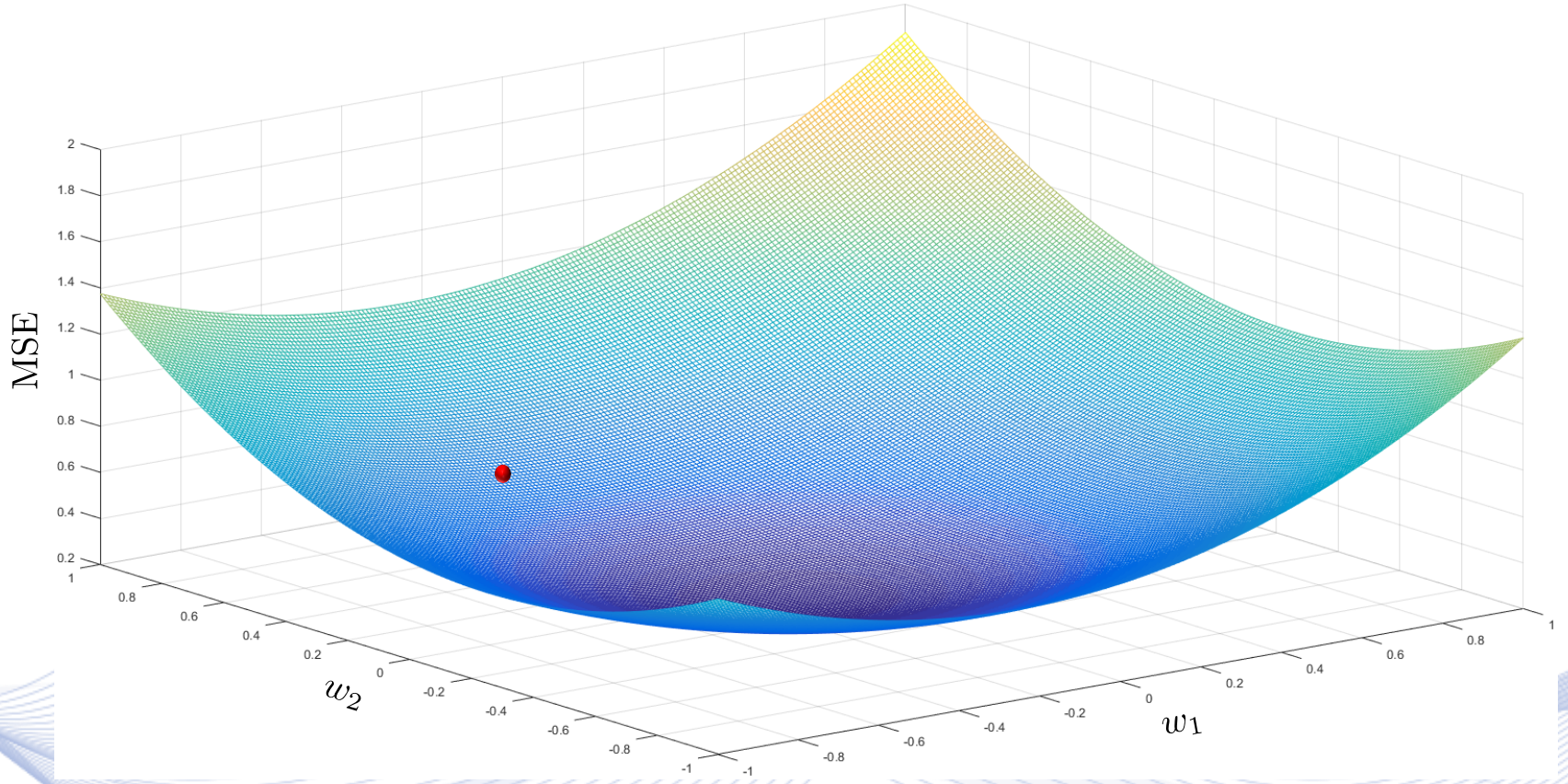
- Does it have simple or complex shape?
- Are perturbations $\mathbf{N}$ random?
- Does life/intelligence/society solve optimization through more elaborate algorithms?

Evolution



Steepest descent on a fitness landscape surface.

Evolution



Steepest descent on a fitness landscape function surface.

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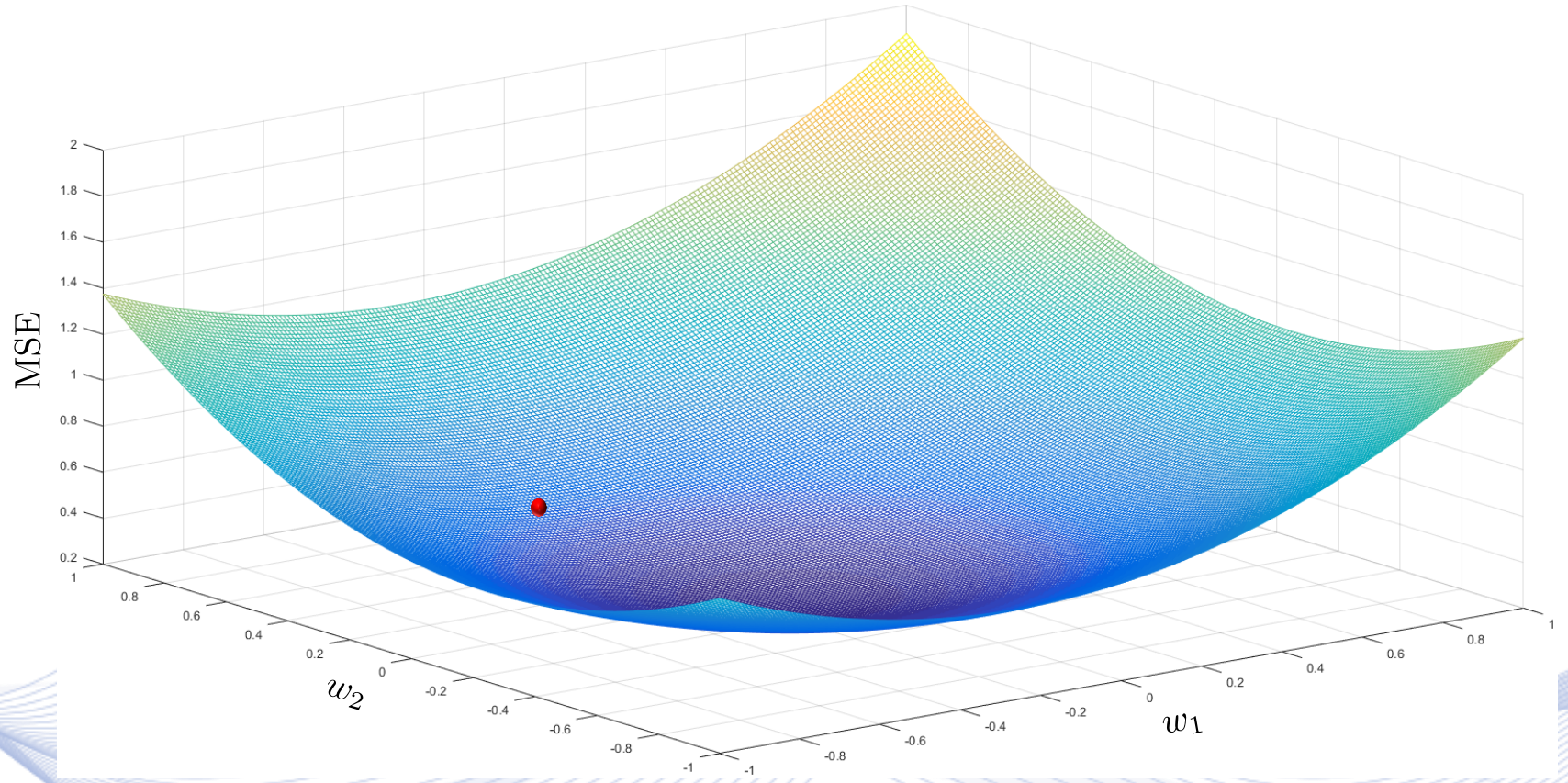

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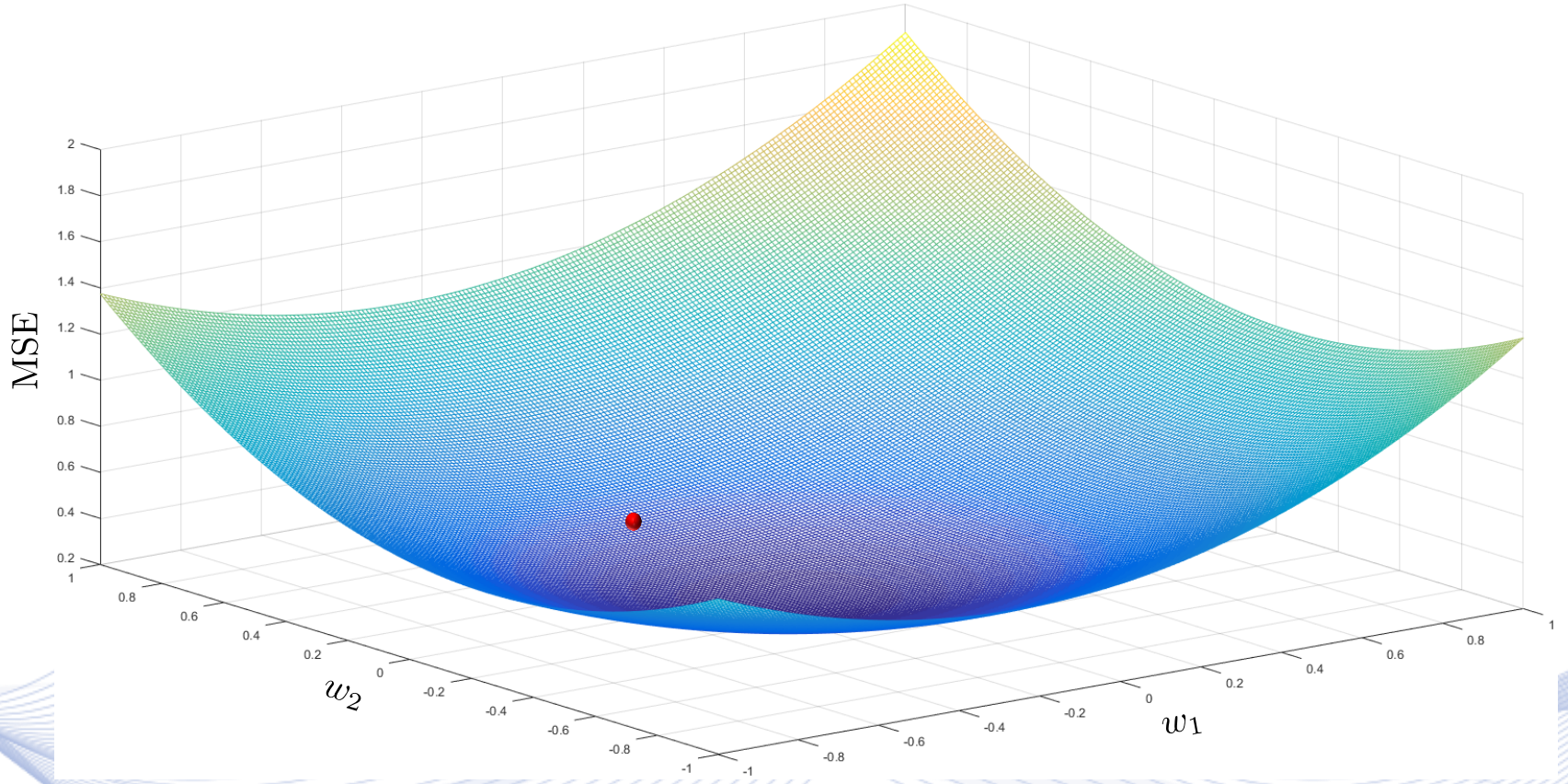
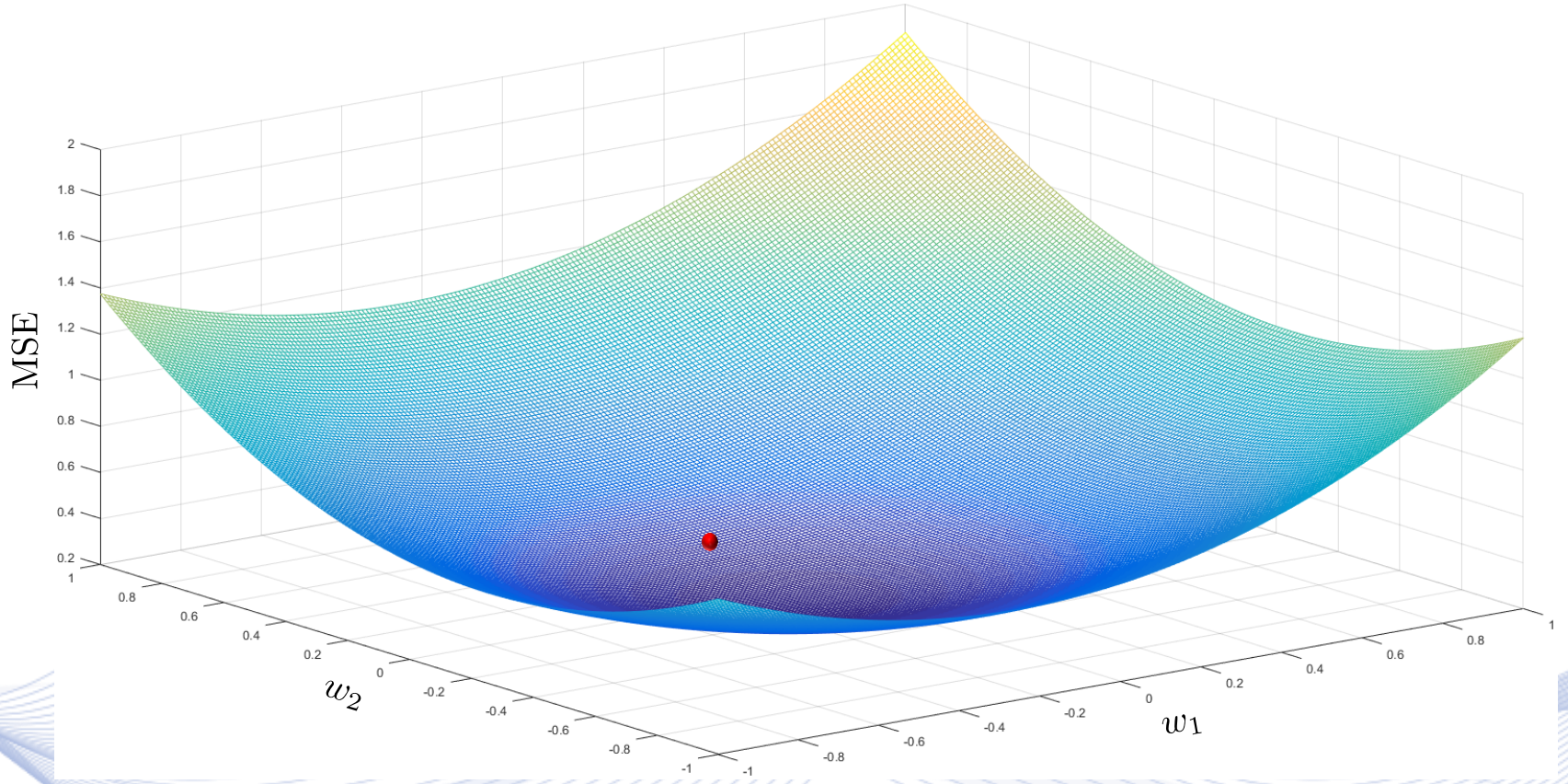


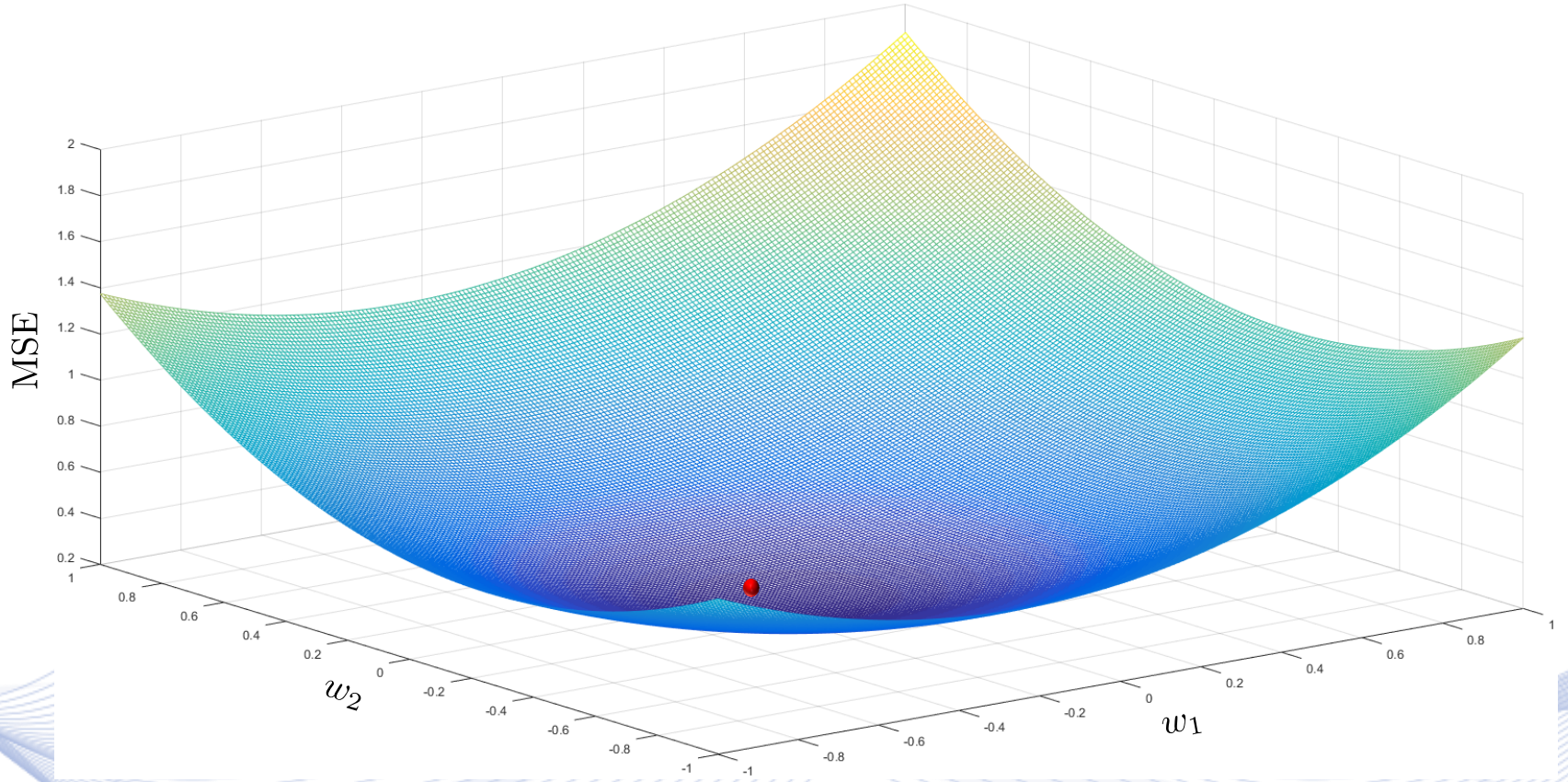
Steepest descent on a fitness landscape surface.

Evolution



Steepest descent on a function surface.

MLP Training



Steepest descent on a function surface.

Evolution by Design

- Darwinian theory of evolution.
- ***Life evolution increasingly relies on design:***
  - Genetics, Medicine, Engineering.
- Even Darwinian evolution has design elements
  - Example: Mating preferences/strategies for humans and animals.
- ***Evolution-by-design can move much faster then Darwinian evolution.***
- ***Elaborated optimization algorithms can be used.***
- Evolution-by-design can enjoy big leaps forward.
  - Big medical/genetic/engineering discoveries.

Evolution by Design

- Darwinian theory of evolution.
- ***Life evolution increasingly relies on design:***
  - Genetics, Medicine, Engineering.
- ***Human-machine symbiosis***.
- Cyber-human life?
  - Impact on philosophy/religion.
  - Materialism vs idealism/dualism.
- New/other forms of life?
- Should we be afraid of new forms of life?
  - ***They can be our human-friendly brainchildren.***

Evolution by Design

- Materialism has no problem with new forms of life.
  - ***Intelligence/mind is just a reflection of matter onto its-self.***
  - Open issues remain: reconciling matter and subjective experiences.
  - Feeling love is different than watching the related neural activity.

- Dualism (brain/mind, body/soul) seems to be on the defensive.
  - ***Why should dualism and many religions insist on anthrocentricity?***
  - Can mind/soul reside on other forms of complex matter/life?

Evolution by Design

- Religions need not corner themselves by denying scientific developments.
  - Dogma issues.
  - At times, poor understanding of scientific developments vs open-mindedness.
  - Current controversies remind the Galileo-Inquisition conflict.

- Materialism/dualism rivalry is too old to die soon.
  - Most probably it will just be elevated at a new level.

Evolution by Design

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Evolution by Design

Mellontology

- Is Homo Sapiens the ultimate end of evolution?
- If not, will there be ***meta-humans***?
- Should we be afraid of the future to come?

- Was fear of any help to ***Neanderthals***, when they faced extinction?

Evolution by Design

- ***Human-centric action approaches already reached their limits:***
  - Human impact on the environment.
- If other forms of life are possible, what is the meaning of humanism?

Paraphrasing Protagoras:

- ***Is man the measure of all things? ("Πάντων μέτρον εστίν άνθρωπος?)"***
- If not, is there any other measure?

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Q & A

Thank you very much for your attention!

This lecture can be found in the AIoD platform:

https://www.ai4europe.eu/education/education-catalog/ai-system-complexity-life-intelligence-and-environment-0

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

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