CSEN1121-Computational Intelligence and Neural Networks

For junior graduate students

Academic Year 2023/2024, Winter Semester

Lecture 1: Course Info & Intro

14.09.2023

Prof. Dr. Mohammed A.-Megeed Salem

Media Engineering Technology,

German University in Cairo

Outline

- Course Information
  - People, Format, Objectives, Content, Resources, Grading Scheme
- Introduction
  - Definitions
    - Intelligence, Evolutionary Computing, Artificial Neural Network, Fuzziness, Paradigm vs Implementation, Heuristic, Optimization, Metaheuristic Algorithms, Soft Computing, Computational Intelligence.

Course Information - People

- Prof. Dr. Mohammed Abdel-Megeed Salem
  - Lectures: Tuesday: 10:00 am – 11:30 am
    Lecture Hall: D4.210
  - Tutorial: Thursday: 11:45 am – 1:15 pm
    Class room: D4.201
  - Office Hours: Sunday 2nd Slot or by appointment

Course Information - Format

- Weekly lectures of 2 Hours
  - Lecture Notes (ppt files) – Discussion and Board
- Weekly Tutorials 2 Hours
  - Practice Assignments
- Assignments and Course Projects
  - Executable Code, Assignment Report, Project Presentation and Report
- Scheduled short quizzes
- Scheduled Final Exam

Course Information - Objectives

- Under the term Computational Intelligence are the tools that facilitate solving problems in a different way than the traditional approaches of signal processing or pattern recognition. These new analytical tools include artificial neural networks, fuzzy systems, and evolutionary computation. This course addresses the concepts and the implementation of
  - 1) genetic algorithms, evolutionary programming, and particle swarm optimization;
  - 2) the most commonly used neural network paradigms; and
  - 3) systems based on fuzzy sets and fuzzy logic.

Course Information - Contents

1. Introduction
2. Foundations of CI
3. Evolutionary Computation
4. Neural Networks
5. Neural Networks Implementation
6. Fuzzy Logic
7. Performance Metrics
8. Analysis & Explanation

Course Information – Contents – Evolutionary Computing

- Machine learning optimization and classification paradigms roughly based on mechanisms of evolution such as natural selection and biological genetics.
- Evolutionary Computation compromise:
  - Genetic algorithms,
  - Evolutionary programming,
  - Particle swarm optimization
  - Evolution strategies, and
  - Genetic programming

Course Information – Contents – Neural Networks

- Neural network concepts, paradigms, and implementations.
- Neural Network Theory and Paradigms: terminology, biological bases, survey of architectures and topologies, review of learning paradigms and recall procedures.
- Neural Network Implementations: back-propagation, self-organizing feature maps, and learning vector quantization.

Course Information – Contents – Fuzzy Systems

- Theory, concepts and implementations of fuzzy logic and fuzzy systems.

- Fuzzy Systems Theory and Paradigms: Fuzzy logic terminology and symbology, fuzzy logic theorems, differences with probability, steps in applying fuzzy logic.

- Fuzzy Systems Implementation: fuzzy expert system.

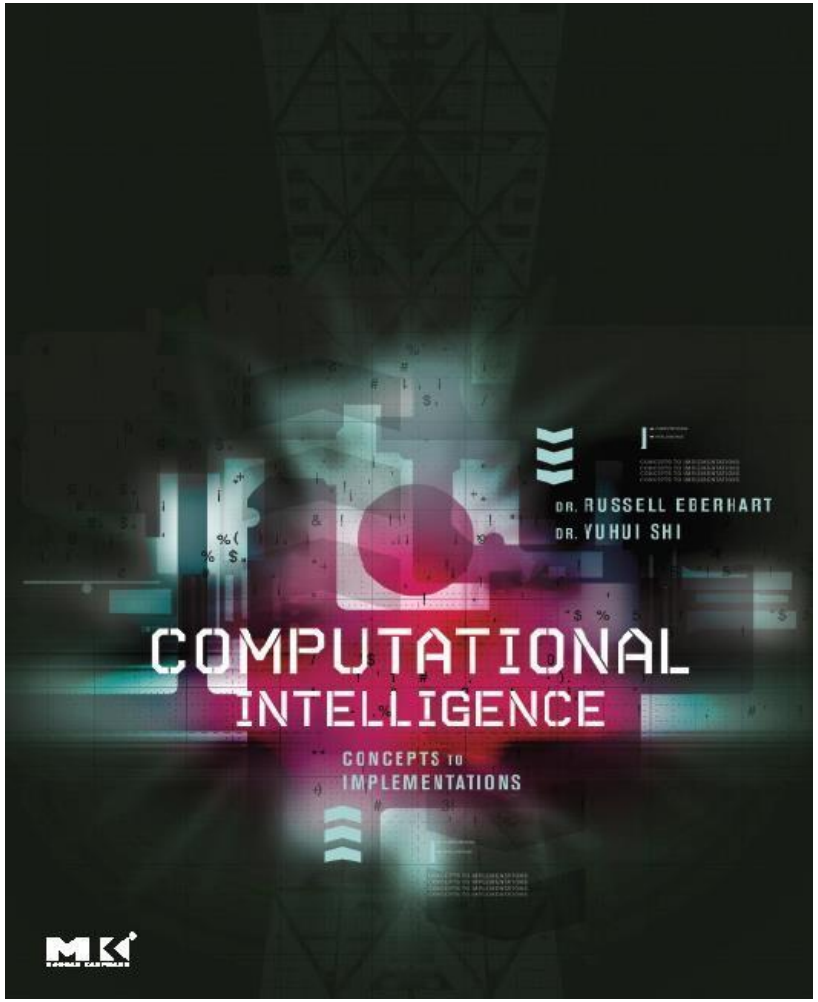
Course Information – Contents – Metrics and Analysis and Explanation

- Fitting functions needed for CI system development
- Performance Metrics: methods for measuring and representing the performance of computational intelligence tools.
- Analysis and Explanation Facilities: graphical representation of neural network weights, development of explanation facilities for CI systems, example of explanation facility for a neural network.

Course Information - Resources

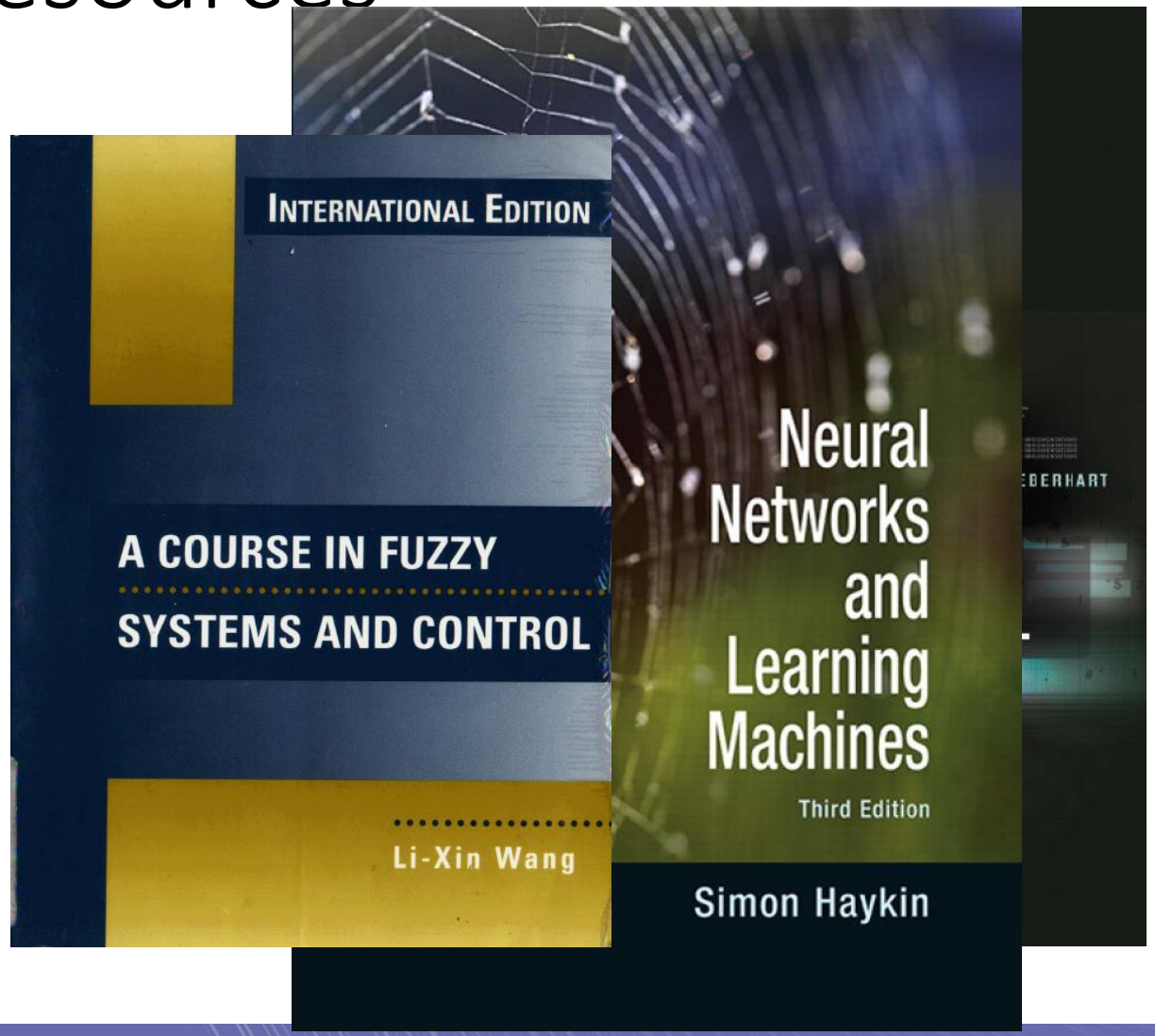
- Recommended Textbook
  - Russel C. Eberhart, Yuhui Shi: Computational Intelligence: Concepts to Implementation, Morgan Kaufmann Publishers, 2007

- Recommended Further Reading
  - Guil, N., Bregáins, J.C., Dapena, A. (2011). Computational Intelligence in Multimedia Processing. In: Cabestany, J., Rojas, I., Joya, G. (eds) Advances in Computational Intelligence. IWANN 2011. Lecture Notes in Computer Science, vol 6691. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-21501-8_65



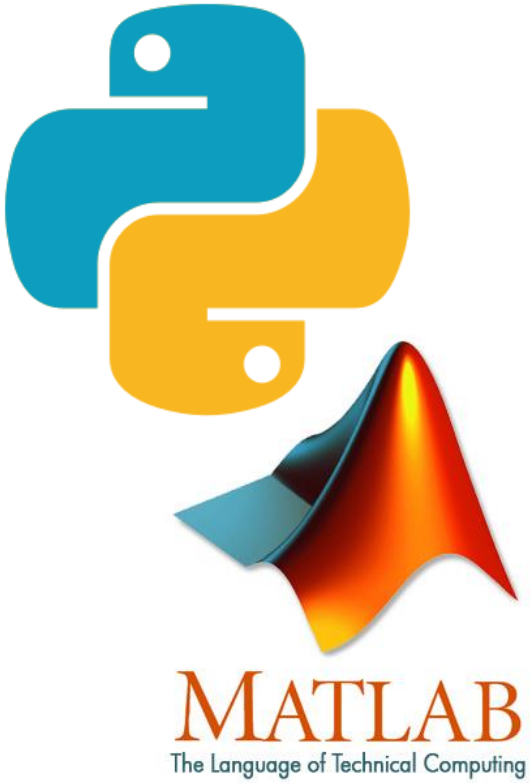
Course Information - Resources

- Recommended Textbooks
  - Simon Haykin, Neural Networks and Learning Machines, 3rd edition, Pearson, 2009
  - Li-Xin Wang, A Course in Fuzzy Systems and Control, Prentice-Hall International, 1997



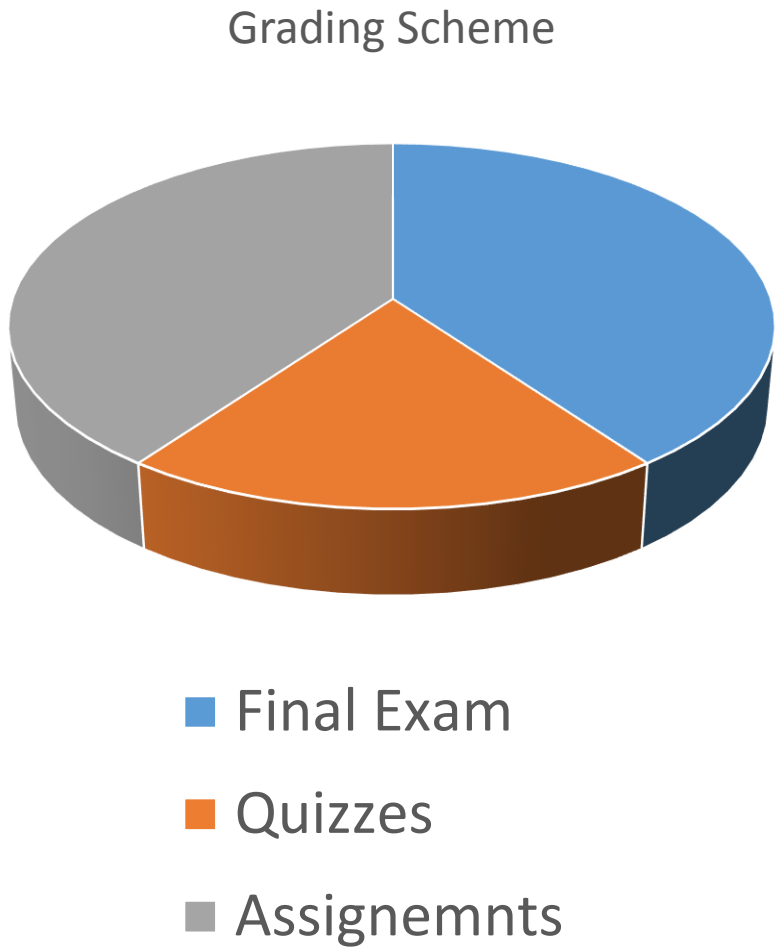
Course Information - Resources

- Tools for practical exercises, assignments, and project:
  - High programming skills
    - Recursive functions
    - Matrix Operations
    - Object Oriented Programming
  - Python with Jupyter notebooks.
  - Matlab is available as an alternative.



Course Info – Grading Scheme

- Final Exam 40%
- Quizzes best 2 out of 3 20%
- Assignments & Project 40%



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  - Adaptation and Self-Organization
  - Computational Intelligence

1. Introduction
1.1 Definitions

Intelligence

- Webster's New Collegiate Dictionary defines intelligence as
- "1a(1) : The ability to learn or understand or to deal with new or trying situations : REASON; also : the skilled use of reason
- (2) : the ability to apply knowledge to manipulate one's environment or to think abstractly as measured by objective criteria (as tests)."

Intelligence

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- The capability of a system to adapt its behavior* to meet its goals in a range of environments. It is a property of all purpose-driven decision makers.

David Fogel

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David B. Fogel

Engineer

davidfogel.com

David B. Fogel is a pioneer in evolutionary computation. Fogel received his Ph.D. in engineering from the University of California, San Diego in 1992. Wikipedia

Citations: 41,000

Education: University of California San Diego

Books View 2+ more

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Computational Intelligence Definition

- Computational intelligence comprises practical adaptation and self-organization concepts, paradigms, algorithms and implementations that enable or facilitate appropriate (re)actions (intelligent behavior) in complex and changing environments.

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- It is about **Adaptation** and **Self-organization**
  - Evolutionary Computation
  - Neural Networks
  - Fuzzy logic and Systems

Artificial Neural Network

- An analysis paradigm very roughly modeled after the massively parallel structure of the brain.

- Simulates a highly interconnected, parallel computational structure with numerous relatively simple individual *processing elements (PE).*

Fuzzy Logic Behavioral Motivations

- FL analogous to uncertainty in human experiences ("Stop the car pretty soon.")
- Fuzziness is associated with nonstatistical uncertainty
- FL thus is reflected at the behavioral level of the organism
- Fuzziness is not resolved by observation or measurement

Fuzziness

- ***Fuzziness***: Non-statistical imprecision and vagueness in information and data.
- ***Fuzzy Sets*** model the properties of properties of imprecision, approximation or vagueness.
- ***Fuzzy Membership*** Values reflect the membership grades in a set.
- ***Fuzzy Logic*** is the logic of approximate reasoning. It is a generalization of conventional logic.

Paradigm vs Implementation

- ***Paradigm***: A particular choice of attributes for a concept.
- An example is the back-propagation paradigm that is included in the neural network concept. In other words, it is a specific example of a concept.

- Implementation: A computer program written and compiled for a specific computer or class of computers that implements a paradigm.

Heuristic

- A method of learning or solving problems that allows people to discover things themselves and learn from their own experiences:
  - *As a heuristic, it is a good test to ask the question: what might I do in this situation?* https://dictionary.cambridge.org/dictionary/english/heuristic
- A heuristic, or heuristic technique, is any approach to problem solving or self-discovery that employs a practical method that is not guaranteed to be optimal, perfect, or rational, but is nevertheless sufficient for reaching an immediate, short-term goal or approximation. https://en.wikipedia.org/wiki/Heuristic

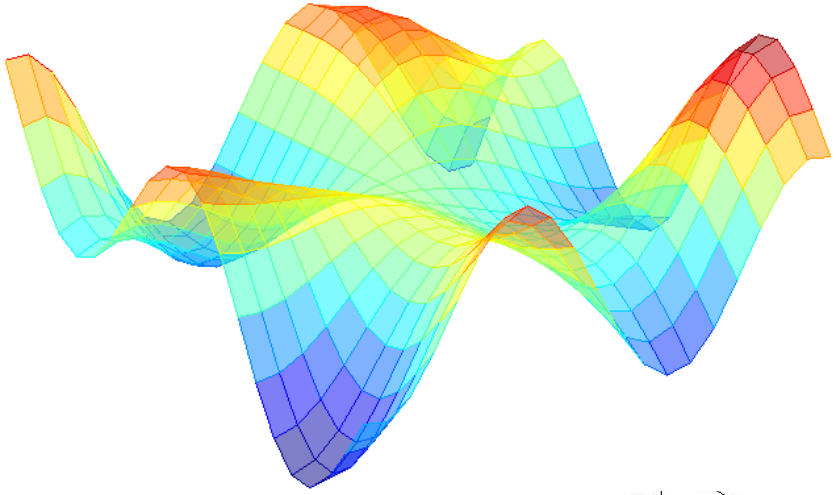
Optimization

- A key subject:
- Computer Science
- Artificial Intelligence
- Operations Research
- Engineering
- …
  - **To optimize is an imprecise term that essentially means "make better"**

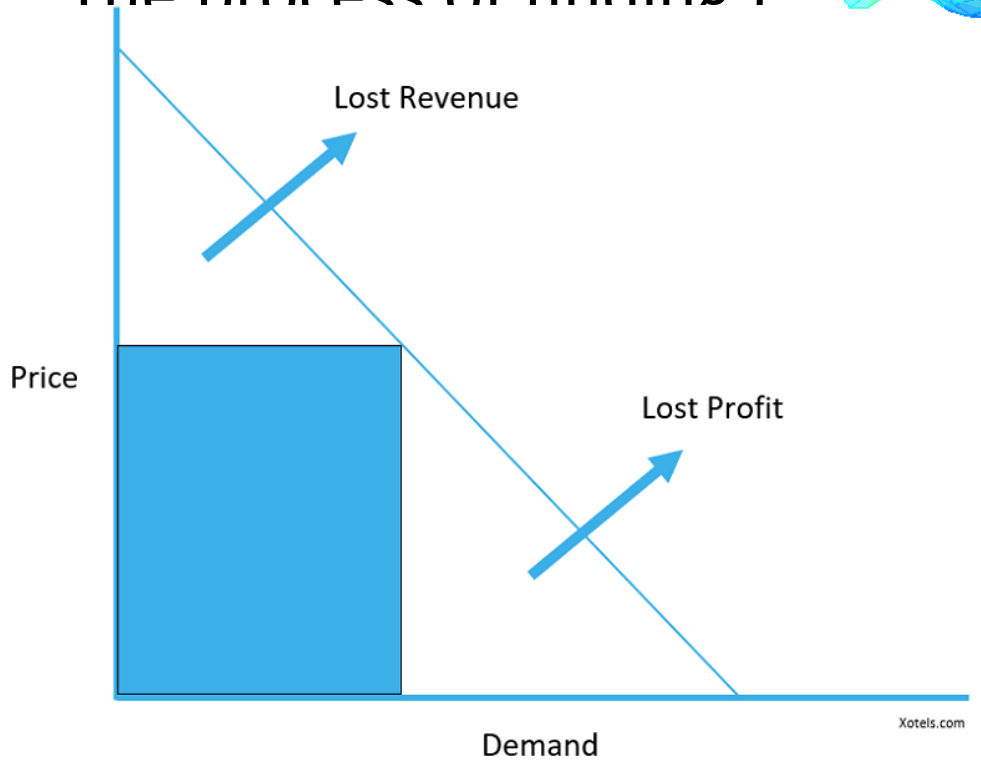
Optimization

- “The process of finding the best solution for a given problem with a given resource and temporal budget.”
- Optimization problem:
  - Has a number of feasible solutions.
  - There is a clear notion of quality of solutions.
  - The best solution: global optimum

Optimization



- “The process of finding t optimization ”



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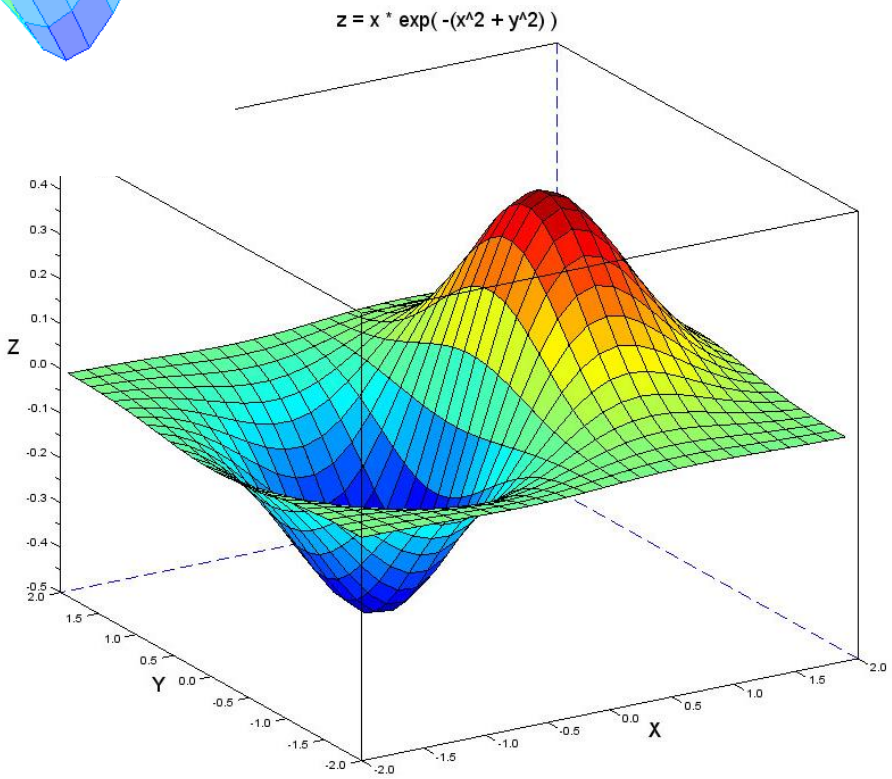


Optimization

- Problems can be classified as:
  - Tractable: if there is an algorithm that solves it polynomial time.
  - Intractable (hard): if there is no algorithm that solves the problem in polynomial time, NP problems.

NP Complexity

In computational complexity theory, NP (nondeterministic polynomial time) is a complexity class used to classify decision problems.
https://en.wikipedia.org/wiki/NP_(complexity)

Optimization

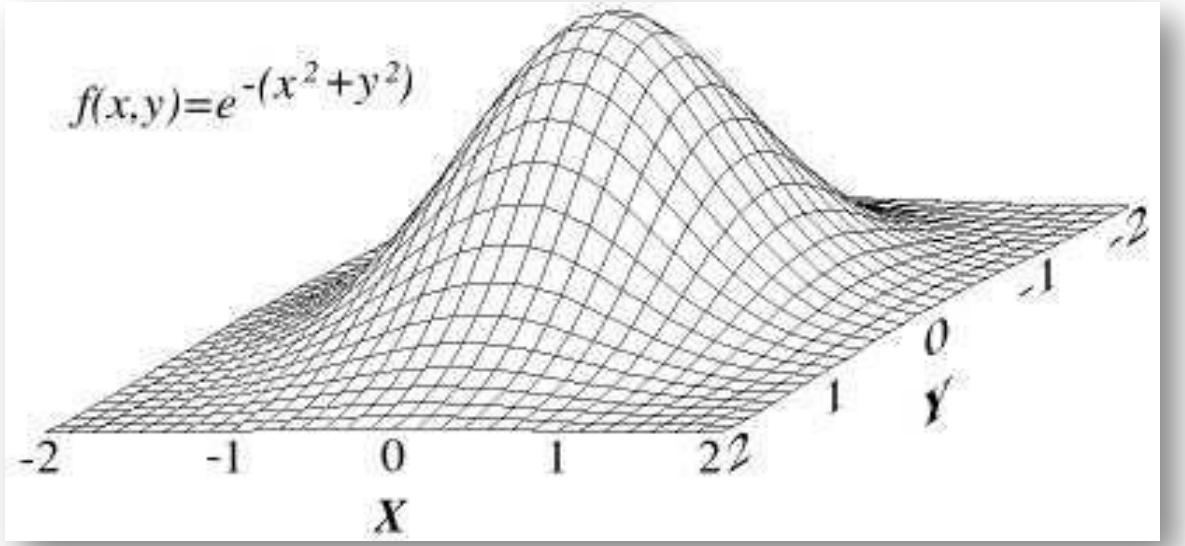
- We are interested in "hard problems"
- Not warrantied that the solution can be found.
- Properties of the problem is unknown.
- We need metaheuristics:
  - "Reduced" computational complexity.
  - Do not ensure convergence to the global optimum.

Metaheuristic Algorithms

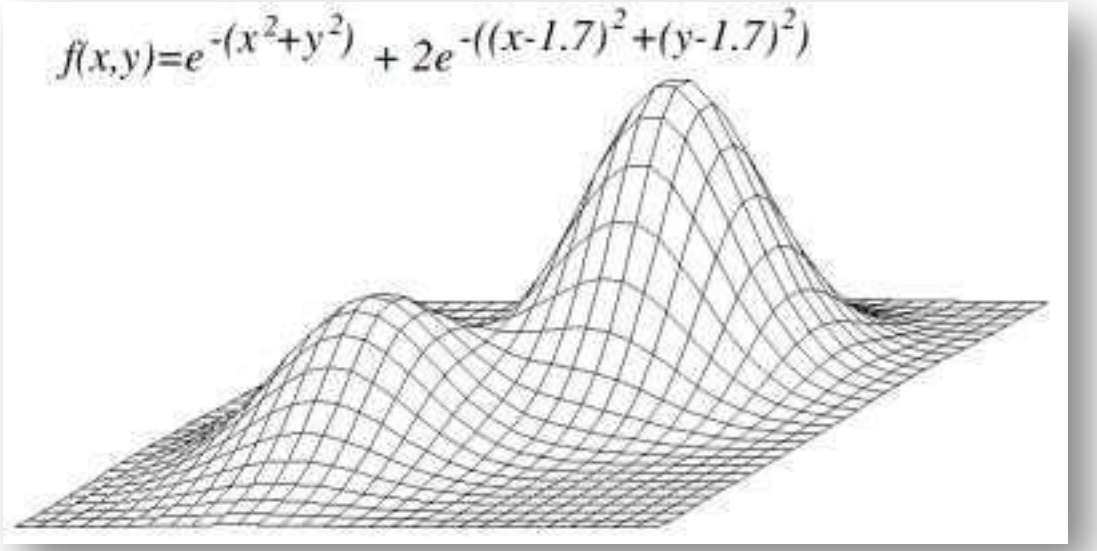
- In computer science and mathematical optimization, a metaheuristic is a higher-level procedure or heuristic designed to find, generate, or select a heuristic (partial search algorithm) that may provide a sufficiently good solution to an optimization problem, especially with incomplete or imperfect information or limited computation capacity.
- Compared to optimization algorithms and iterative methods, metaheuristics do not guarantee that a globally optimal solution can be found on some class of problems.[3] Many metaheuristics implement some form of stochastic optimization, so that the solution found is dependent on the set of random variables generated.

https://en.wikipedia.org/wiki/Metaheuristic

Optimization



Only one (global) optimum.



Local Optima: Repeat the algorithm with different initializations.

Soft Computing

- Soft computing is not a single methodology. Rather, it is a consortium of computing methodologies which collectively provide a foundation for the conception, design and deployment of intelligent systems.
  - At this juncture, the principal members of soft computing are fuzzy logic, neurocomputing, genetic computing, and probabilistic computing, with the last subsuming evidential reasoning, belief networks, chaotic systems, and parts of machine learning theory.
- In contrast to traditional hard computing, soft computing is tolerant of imprecision, uncertainty and partial truth.The guiding principle of soft computing is: exploit the tolerance for imprecision, uncertainty and partial truth to achieve tractibility, robustness, low solution cost and better rapport with reality.

Lotfi Zadeh

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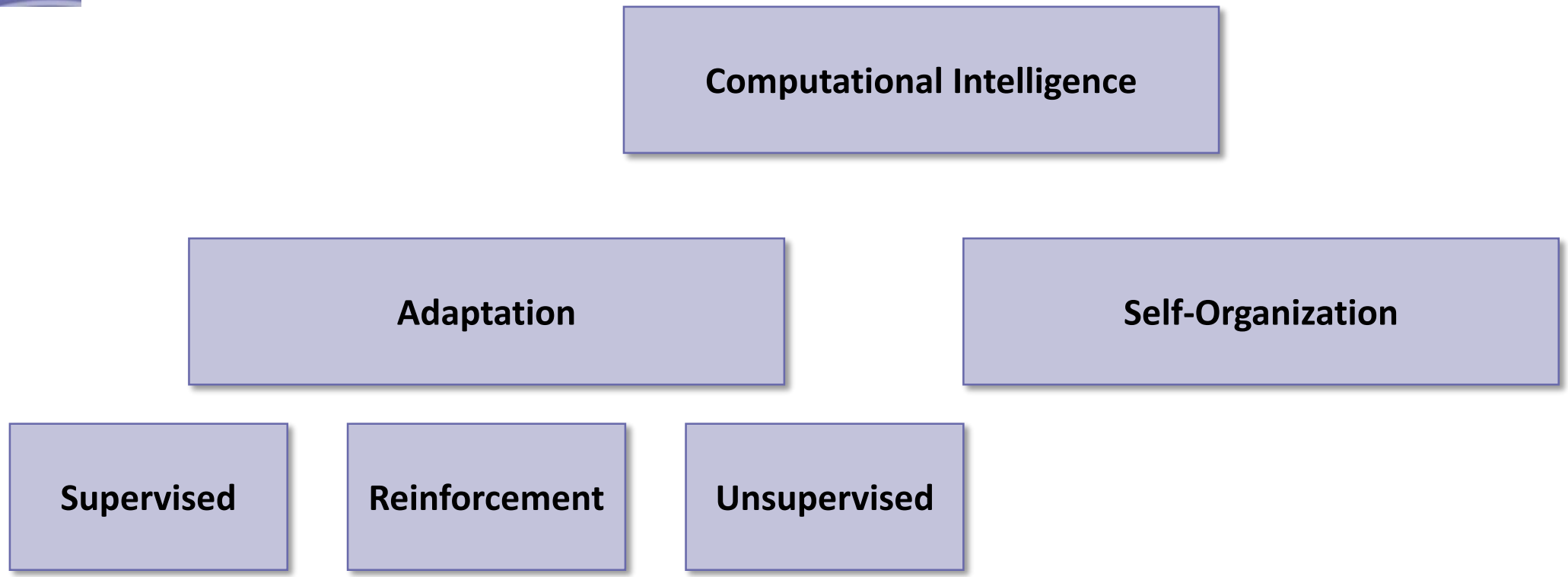
1.2 Adaptation and Self-Organization

Computational Intelligence



Adaptation versus Learning

- **Adaptation 1:**the act or process of adapting : the state of being adapted **2:** adjustment to environmental conditions: as **a:** adjustment of a sense organ to the intensity or quality of stimulation **b:**modification of an organism or its parts that makes it more fit for existence under the conditions of its environment.
- **Adapt:** to make fit (as for a specific or new use or situation) often by modification
- **Fit:** suitable, adapted so as to be capable of surviving, acceptable from a particular viewpoint

Adaptation

- Adaptation is any process whereby a structure is progressively modified to give better performance in its environment.

Holland 1992

- Adaptive processes are **improvement** (amelioration) processes. They are usually not really optimization processes.
- Adaptation overcomes the **barriers** of nonlinearity and **local optima**.
- It involves a **progressive modification** of some structure or structures, and uses a set of operators acting on the structure(s) that **evolve over time**.

Barriers to Adaptation

- Large problem spaces
- Large numbers of variables
- Complex and nonlinear fitness functions
- Fitness functions that change over time and over the problem space
- Complex and changing environments

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The Law of Sufficiency

If a solution to a problem is:
Good enough (it meets specs), Fast enough, Cheap enough … Then it is Sufficient.

Adaptation versus Learning

- **Learning:** knowledge or skill acquired by instruction or study
  - syn: knowledge
- **To Learn:** to gain knowledge or understanding of or skill in by study, instruction or experience
  - syn: discover
- Learning is what an entire intelligent system does.

System Adaptation Methodologies

- An adaptive system (or a complex adaptive system, CAS) is a system that **changes its behavior in response to its environment**. The adaptive change that occurs is often relevant to achieving a goal or objective. We tend to associate adaptive behavior with individual plants, animals, human beings, or social groups.

https://necsi.edu/adaptive#:~:text=An%20adaptive%20system%20(or%20a,human%20beings%2C%20or%20social%20groups.

- Supervised adaptation
- Unsupervised adaptation
- Reinforcement adaptation

Supervised Adaptation

- "The process of adjusting (adapting) a system so it produces specified outputs in response to specified inputs."
- "Supervised" means that the output is known for all inputs and the system training algorithm uses the error to guide the training.

[Reed and Marks 1999]

Reed, R. D. and Robert J. Marks. "Neural Smithing: Supervised Learning in Feedforward Artificial Neural Networks." (1999).

Supervised Adaptation

- A “teacher” provides input-output examples (the “gold standard”)
- Adaptation is carried out one iteration at a time
- Fitness is often inversely proportional to a function of the sum of errors
- Good for function approximation: mapping input vectors to output vectors
- Example: Back-propagation algorithm used to train neural networks

Reinforcement Adaptation

- A "sparse reinforcement signal" grades the system response as good or bad. A “critic” provides heuristic reinforcement information.

- Example: game playing.

Reinforcement Adaptation

- Most closely related to biological systems
- Has roots in dynamic programming
- Often waits until the time series of inputs is complete to judge the fitness
- The system “critic” only looks at outcomes, not individual error measures

- Example: Particle swarm optimization

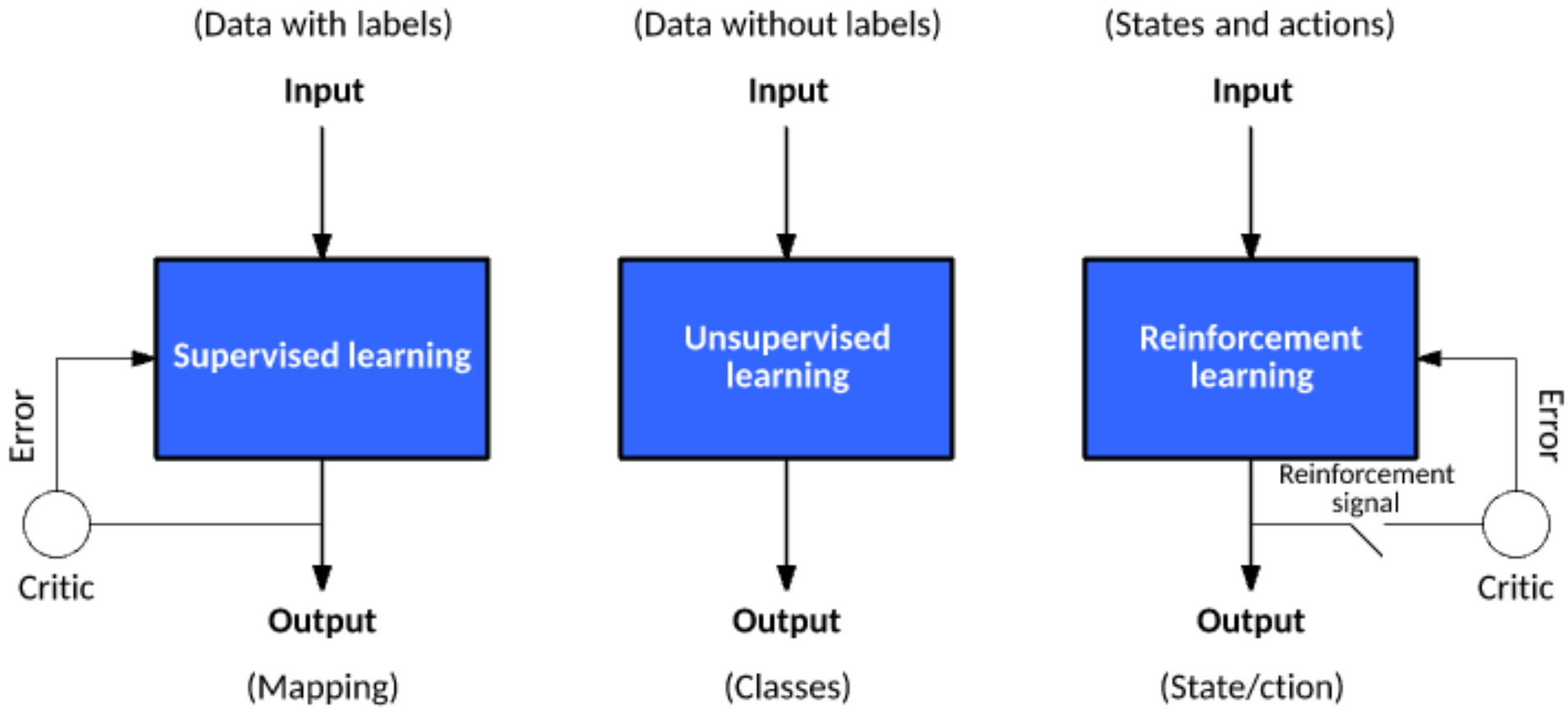
Unsupervised Adaptation

- The system adapts to regularities in the data according to rules implicit in its design. The 'design' is a substitute teacher. Targets don't exist. (Reed and Marks 1999)

- No indication of fitness exists whatsoever
- Offline evaluation occurs after the algorithm stops running

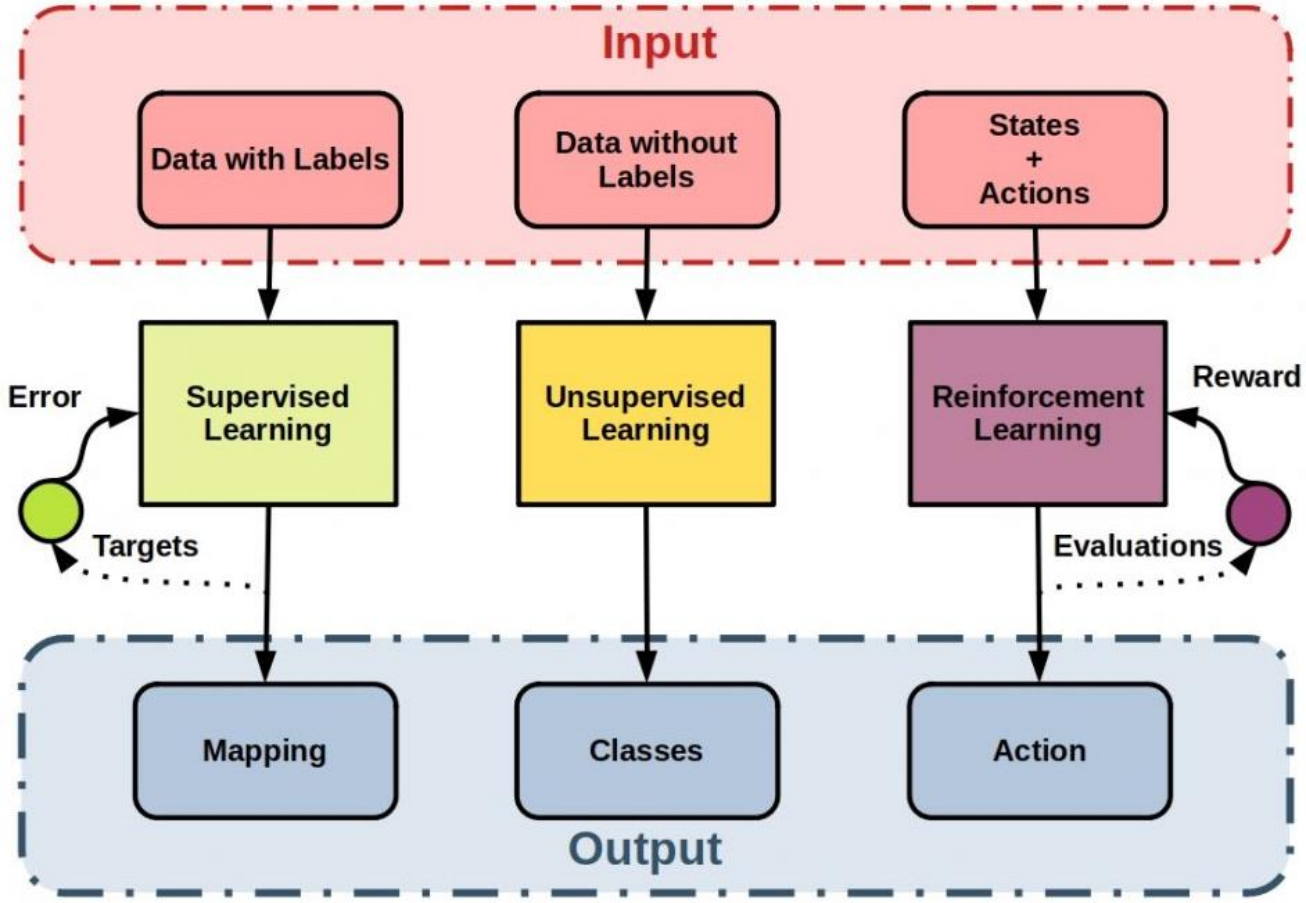
- Examples: SOFM and LVQ networks (clustering)

System Adaptation Methodologies



https://machine-learning.paperspace.com/wiki/supervised-unsupervised-and-reinforcement-learning

System Adaptation Methodologies



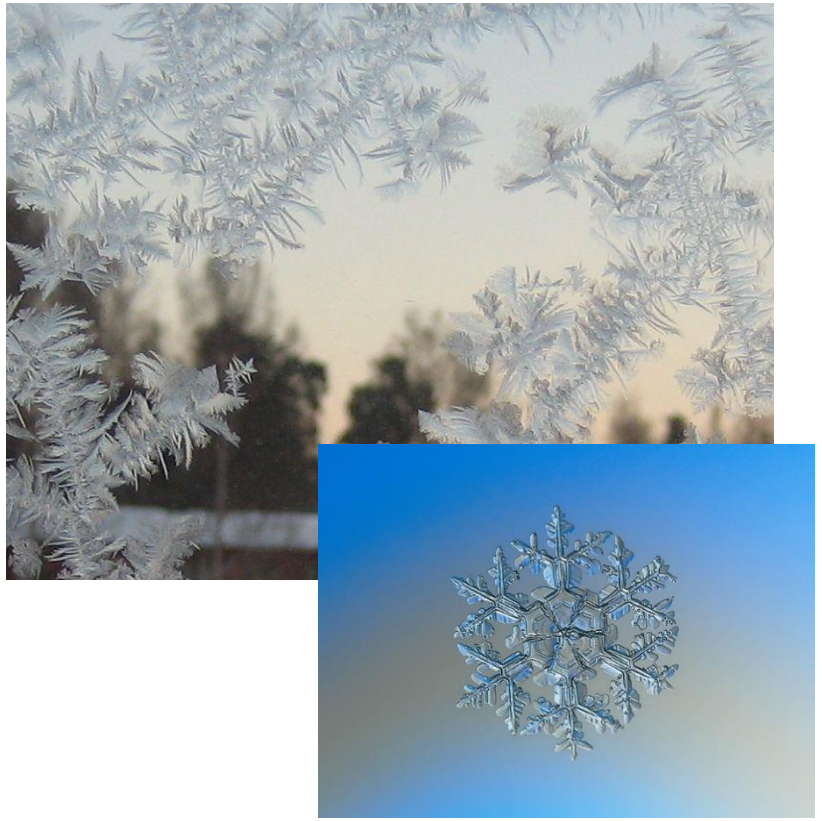
https://starship-knowledge.com/supervised-vs-unsupervised-vs-reinforcement

Self-Organization

- Overall system state is emergent property of the system interconnected system components become organized in a productive or meaningful way based on local information
- Complex systems can self-organize
- The self-organization process works near the "edge of chaos"

Self-Organization

- “A set of dynamical mechanisms whereby structures appear at the global level of a system from interactions among its lower-level components.
- The rules specifying the interactions among the system’s constituent units are executed on the basis of purely local information, without reference to the global pattern.”
- Examples: Formation of ice crystals, salt crystals. Cellular automata. The human brain.



Eric Bonabeau, Guy Theraulaz, Jean-Louls Deneubourg, Serge Aron, Scott Camazine, Self-organization in social insects, Trends in Ecology & Evolution, Volume 12, Issue 5, 1997, Pages 188-193, ISSN 0169-5347, https://doi.org/10.1016/S0169-5347(97)01048-3.

The Three Spaces of Adaptation

- Input parameter (problem) space: Defined by dynamic ranges of input variables
- System output (function) space: Defined by dynamic ranges of output variables
- Fitness space: Defines the “goodness” of solutions; often scaled from 0 to 1
  - *In general, system output and fitness values aren’t the same.*

Fitness Space

- Auxiliary information such as derivatives used to minimize sum-squared error in neural nets is not used
- The fitness value optimized is directly proportional to the function value being optimized
- If fitness is proportional to profit, for example, then the fitness rises as the profit rises
- Provides environmental influence on individuals

Behavior of Adapted System

- **Converges** to stable point
- Exhibits **cyclical** behavior
- Exhibits **chaotic** behavior
- Exhibits **complex** behavior (the edge of chaos)

- *Note: These behaviors are also exhibited by system adaptation processes!*

Readings

- https://machine-learning.paperspace.com/wiki/supervised-unsupervised-and-reinforcement-learning
- https://starship-knowledge.com/supervised-vs-unsupervised-vs-reinforcement
- Eric Bonabeau, Guy Theraulaz, Jean-Louls Deneubourg, Serge Aron, Scott Camazine, Self-organization in social insects, Trends in Ecology & Evolution, Volume 12, Issue 5, 1997, Pages 188-193, ISSN 0169-5347, https://doi.org/10.1016/S0169-5347(97)01048-3.

Readings

- Russell C. Eberhart, Yuhui Shi Computational Intelligence Concepts to Implementations, Morgan Kaufmann Publishers, 2007 [Chapter 2]

1.3 Computational Intelligence

Computational Intelligence

- A methodology involving computing that exhibits an ability to learn and/or to deal with new situations, such that the system is perceived to possess one or more attributes of reason, such as generalization, discovery, association and abstraction.
- Silicon-based computational intelligence systems usually comprise hybrids of paradigms such as artificial neural networks, fuzzy systems, and evolutionary algorithms, augmented with knowledge elements, and are often designed to mimic one or more aspects of carbon-based biological intelligence.

Computational Intelligence

- Computational intelligence comprises practical adaptation and self-organization concepts, paradigms, algorithms, and implementations that enable or facilitate appropriate actions (intelligent behavior) in complex and changing environments.

Computational Intelligence

- A system is *computationally intelligent* when it: deals only with numerical (low-level) data, has a pattern recognition component, does not use knowledge in the AI sense; and additionally, when it (begins to) exhibit (i) computational adaptivity; (ii) computational fault tolerance; (iii) speed approaching human-like turnaround, and (iv) error rates that approximate human performance.

Bezdek's 1994

Pattern Recognition

- Definition:The identification of objects and images by their shapes, forms, outlines, color, surface texture, temperature, or other attribute, usually by automatic means. [Weik ’89, ATIS Committee T1A1]
- Pattern recognition, like intuition, has a vague definition. We know what it means to recognize a face, but we cannot explain how we do it.

Computational intelligence

- Computational intelligence (CI) is a recently emerging area of fundamental and applied research exploiting a number of advanced information processing technologies. The main components of CI encompass neural networks, fuzzy set technology and evolutionary computation. In this triumvirate, each of them plays an important, well-defined, and unique role.

Pedrycz 1998

Computational intelligence

- **Computational intelligence** comprises practical **adaptation and self-organization** concepts, paradigms, algorithms and implementations that enable or facilitate **appropriate actions** (intelligent behavior) in complex and **changing environments**.

Simplified View of Computational Intelligence

Biological Basis

- Biological evolution (according to Charles Darwin) as a process is characterized by three elementary principles:
  - **Inheritance:** Many properties of parents are inherited by their offspring.
  - **Variation:** Offspring are not exact copies of their parents. Instead they are subject to random variations.
  - **Selection:** The probability of a parent having the opportunity to hand its properties on to the next generation depends on exactly these properties.

- These three principles are characteristic for each evolutionary process. The details can vary widely. In particular they can deviate from the biological process.

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  - **Selection:** The probability of a parent having the opportunity to hand its properties on to the next generation depends on exactly these properties.
- the theory of evolution explains the biological diversity (On planet Earth there exists a huge number of species) and the adaptation to the environment.
- A consequence of a single principle: “survival of the fittest”.

Biological Basis

- On Earth there exist creatures that are capable of reproduction. These creatures require certain resources for survival, e.g., space, sunlight, and food.
- With increasing population size some resources become scarce.
- Individuals that obtain too few resources die or fail to reproduce (**selection**).
- By means of reproduction individuals pass properties that are helpful for obtaining resources on to their offspring (**inheritance**).
- This reproduction process introduces small variations. These can have a positive or a negative impact (**variation**).

Biological Basis

The result:

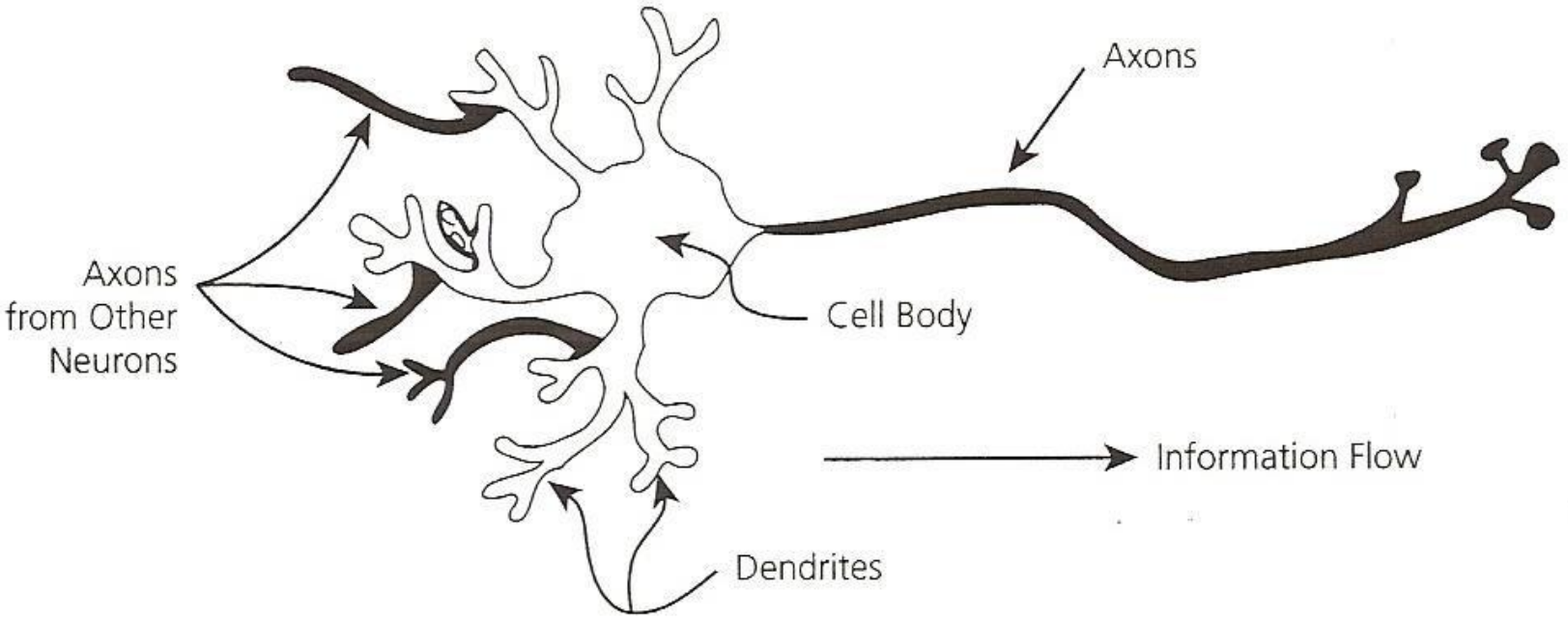
- Creatures are rewarded for the use of less competitive resources. This is a drive for diversification of species.
- Over the generations the ability to compete for resources improves. (“quality” is relative, it depends on the context on the biological bodies, and on the strength of competitors).
- Creatures develop towards efficient use of resources.

Biological Basis: Neural Networks

- Neurons: nerve cells; consist of dendrites, body and an axon; signals flow through synapses.

- Some differences between biological and artificial neurons (processing elements):
  - Signs of weights (+ or -)
  - Signals are AC in neurons, DC in PEs
  - Many types of neurons in a system; usually only a few at most in neural networks
  - Basic cycle time for PC (~100 ns) faster than brain (10-100ms) {as far as we know!}

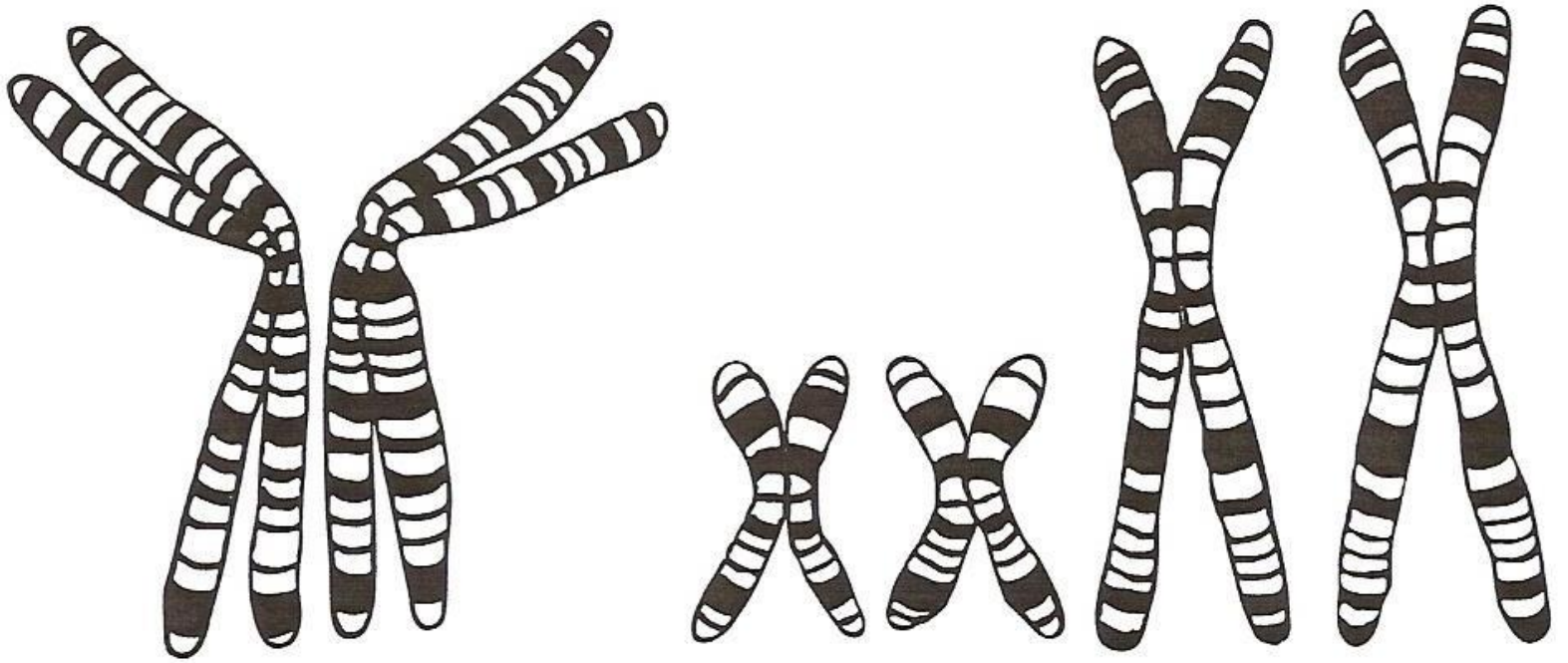
Biological Neuron



Biological Basis: Evolutionary Computation

- Ties with genetics, “a branch of biology that deals with the heredity and variation of organisms”
- Chromosomes: structures in cell bodies that transmit genetic information; humans have 46, in 23 pairs
- Individual patterns in EC correspond to chromosomes in biological systems
- The genotype completely specifies an organism; in EC a structure specifies a system; in most EC tools, one string specifies a structure, so structure is interchangeable with chromosome. A solution.

Chromosomes



Drawing by Mark Eberhart

Chromosomes

- Biological chromosomes: have different length and made of DNA
- In reproduction, biological cells divide
- Synthesis of new chromosomes: 50 percent from each biological parent.
- Artificial (EC) chromosomes all same length
- EC: Binary or real numbers
- EC cells copy them selves, synthesis using any percentage from EC parents.
- Mutation not intrinsic to biological system as it is in EC.

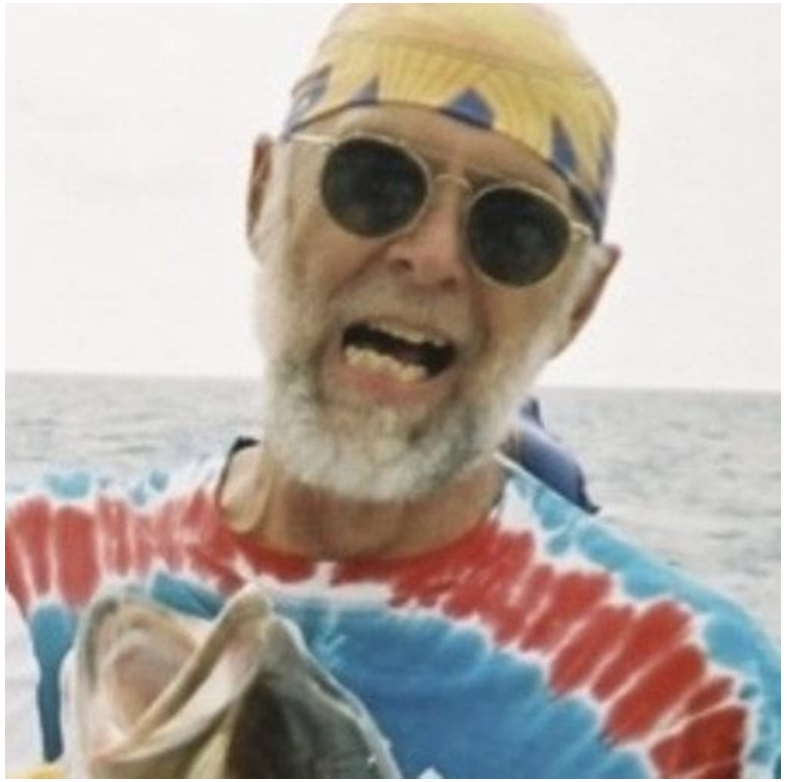
Readings

- Russell C. Eberhart, Yuhui Shi Computational Intelligence Concepts to Implementations, Morgan Kaufmann Publishers, 2007 [Chapter 1]

Conclusion

- Computational Intelligence provides success stories that are often hard to justify with formal mathematical models (which are but a subset of all computational models, some of which are based on mathematics, and some of which are not).

Jim Bezdek



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CSEN1121-Computational Intelligence and Neural Networks, Winter Semester 2023/2024

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