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Universidade do Minho
Escola de Engenharia
Departamento de Informática

Natural Computation
Introduction

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Mestrado Integrado em Engenharia Informática
Mestrado em Engenharia Informática
Perfil SI :: Computação Natural

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Artificial Intelligence

It is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable.

John McCarthy, 2007

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Introduction

Image source: https://elmejorserviciotecnico.com/tecnologia-para-mejora-del-medio-ambiente/

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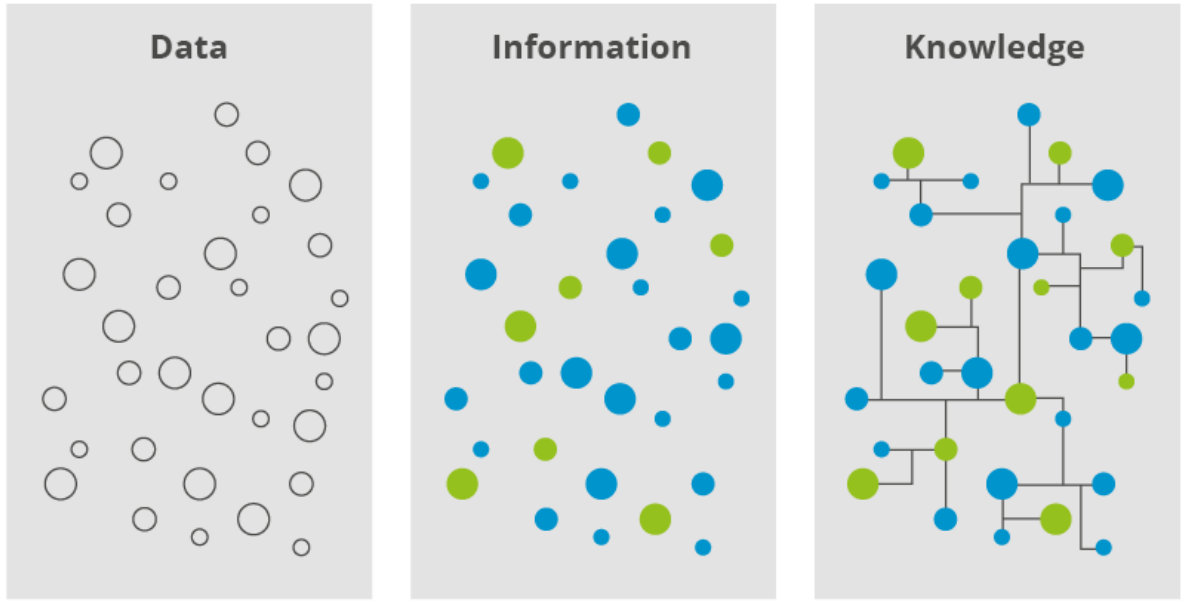
Data, Information and Knowledge



Source: https://www.unymira.com/en/knowledge-management/what-is-knowledge-management-for-customer-service/

Data - Simple facts, unprocessed, unorganized, raw.

Information - Structured, organized and processed data, presented with context, which makes it relevant and useful.

Knowledge - A map of information linked together through experience. Knowledge has the ability to predict and make decisions and generalizations.

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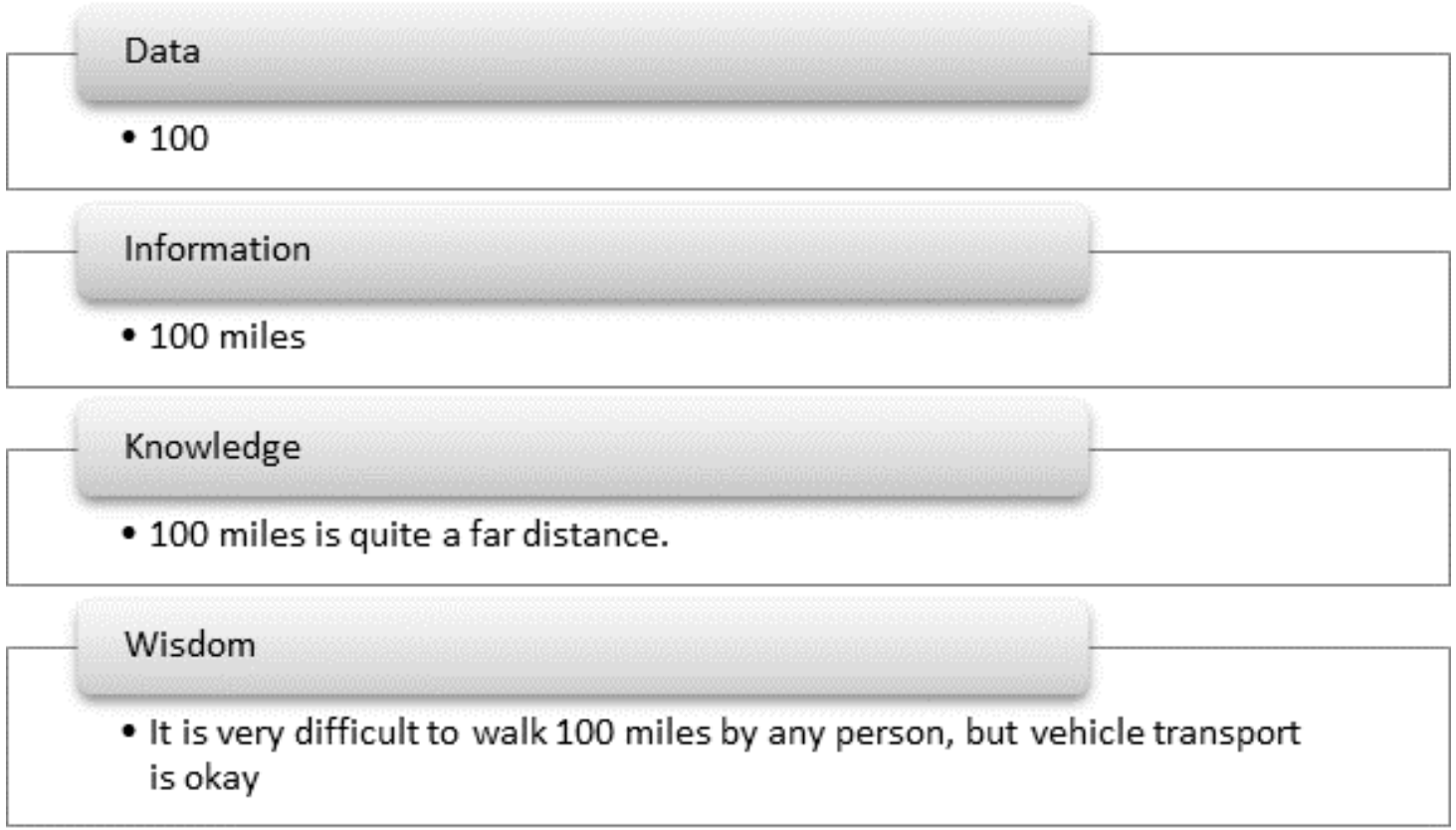
Examples



Source: https://www.guru99.com/information-vs-knowledge-difference.html

Introduction

What is knowledge?

knowledge can be defined as **information** (which can be expressed in the form of propositions) **from the environmen**t.

What is knowledge representation?

I can be defined as **symbols used to represent** the propositions.

What is knowledge representation and reasoning?

One way to define it is as the **manipulation of symbols** encoding propositions **to produce representations** of new propositions.

Source: Grosan C., Abraham A. (2011) Knowledge Representation and Reasoning. In: Intelligent Systems. Intelligent Systems Reference Library, vol 17. Springer, Berlin, Heidelberg

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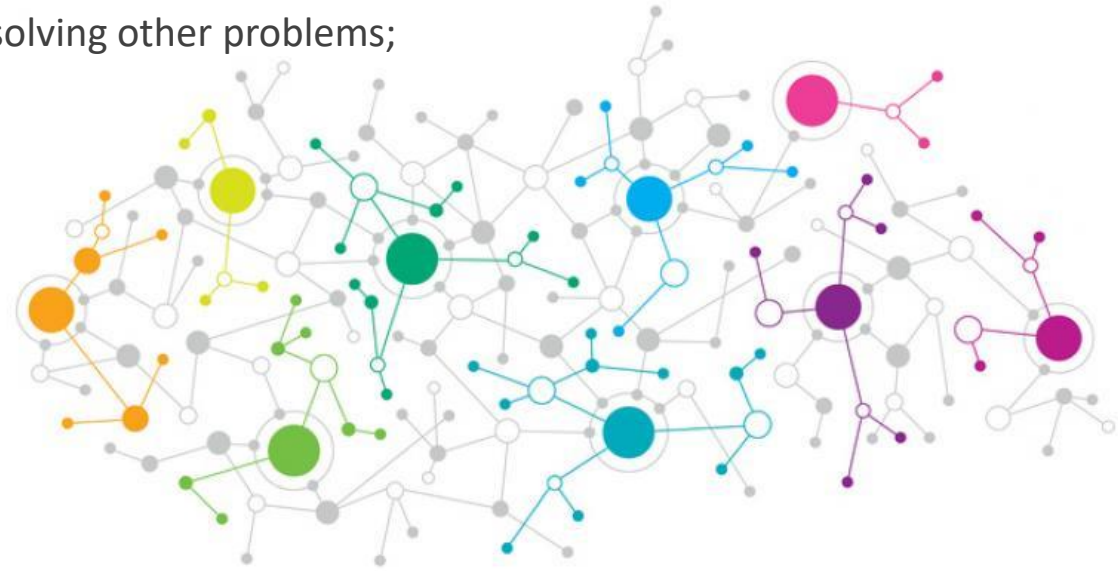
Artificial Intelligence Contextualization

The AI approach to knowledge representation is exposed (normally) through two paradigms:

- Symbolic
  - It is based on logic to represent knowledge;
  - It bases the reasoning in the construction of inference systems;

- Non-symbolic, or connectionist
  - It bases the functioning of the system on the ability to learn, generalizing;
  - Solves problems based on past knowledge or data on solving other problems;



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Artificial Intelligence Contextualization

Advantages of the symbolic approach:

- The problem of knowledge representation is simple;
- Great expressive power of representation languages;
- Solidified inference mechanisms.

Advantages of the non-symbolic approach:

- Ability to learn to solve problems;
- Ability to generalize problem solving;
- Fault-tolerant.

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Some methods

Symbolic methods

- Declarative Languages (Logic)
- Prolog
- Rules
- Frames
- Semantic Networks
- Others

Non – symbolic methods

- Neural Networks
- Genetic Algorithms
- Swarm Computing
- Others

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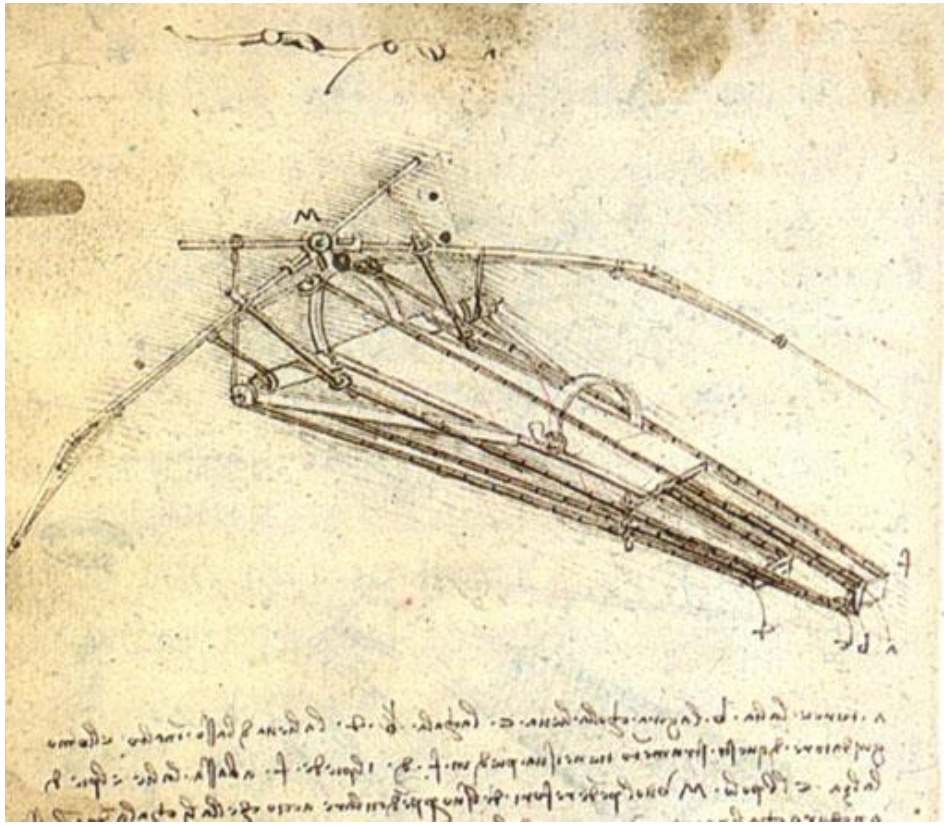

Image source: Ornitóptero - Leonardo da Vinci
https://pt.wikipedia.org/wiki/Ornit%C3%B3ptero

Image source: https://www.roboticshell.com/Tutorial/NeuralNetwork

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Classical vs Natural

Classical computing is good at:

- Numerical manipulation and Scientific Calculation
- Thought support
- Rules-based reasoning
- Repetition of well-defined actions.

But Classical computing isn't good at:

- Pattern Recognition
- Robustness to failure and error
- Dealing with imprecise and incomplete information;
- Adapting and improving based on experience

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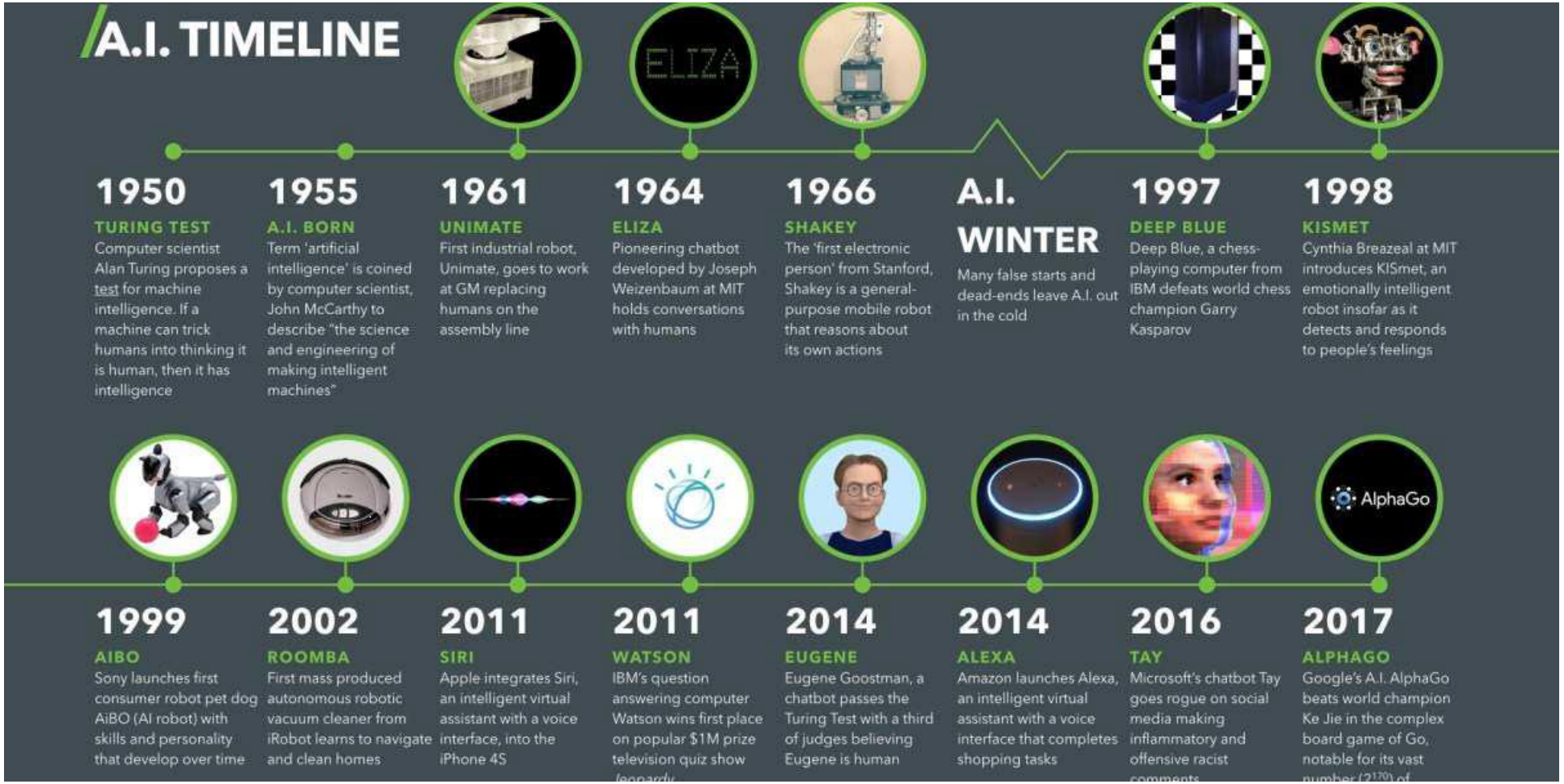
AI Timeline



Source: Paul Marsden
https://digitalwellbeing.org/artificial-intelligence-timeline-infographic-from-eliza-to-tay-and-beyond/

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Natural Computing

"**Natural Computing refers to computational processes observed in nature, and human-designed computing inspired by nature**. When complex natural phenomena are analyzed in terms of computational processes, our understanding of both nature and the essence of computation is enhanced.

Characteristic for human-designed computing inspired by nature is the metaphorical use of concepts, principles and mechanisms underlying natural systems. Natural computing includes evolutionary algorithms, neural networks, molecular computing and quantum computing."

In Natural Computing journal, Springer

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Natural computing

"Natural computing is the computational version of the process of extracting ideas from nature to develop computational systems, or using natural materials to perform computation."

Encompass three classes of methods:

1) those that take **inspiration from nature** for the **development of novel problem-solving techniques**;
2) those that are based on the **use of computers to synthesize natural phenomena**;
3) those that **employ natural materials** (e.g., molecules) to compute.

Source: Castro, L. (2007). Fundamentals of natural computing: an overview. Physics of Life Reviews, 4, 1-36.

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Research Areas

Two different fields of research:

- **Computing paradigms inspired by nature**;

"The main idea of this branch is to develop computational tools by taking inspiration from nature for the solution of complex problems."

- **Computing occurring in nature**;

"The simulation and emulation of nature by means of computing"

But, the first can be subdivided into two areas:

- Creating algorithms inspired by observations of nature

"use of nature as inspiration for the development of problem solving techniques (e.g., algorithms)"

- **Computing with natural materials**.

"use of novel natural materials to perform computation."

Source: Castro, L. (2007). Fundamentals of natural computing: an overview. Physics of Life Reviews, 4, 1-36.

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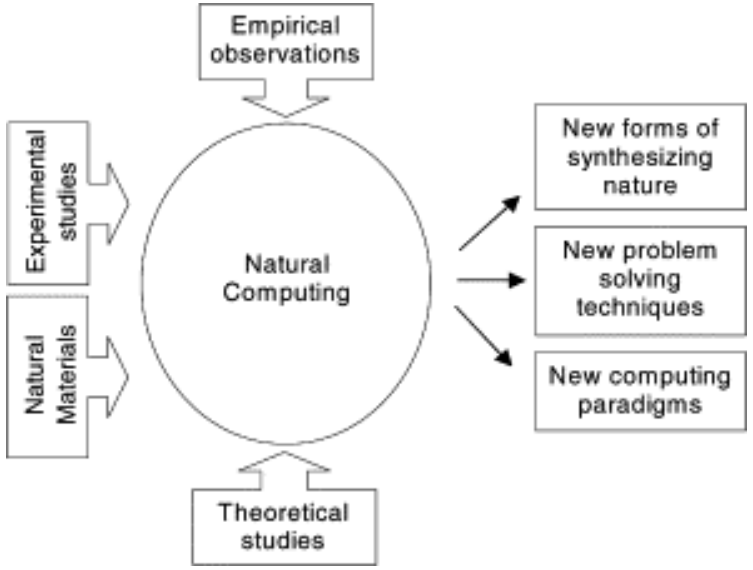
Fundamental

"Natural computing can be defined as the field of research that, based on or inspired by nature, allows the development of new computational tools (in software, hardware or 'wetware') for problem-solving, leads to the synthesis of natural patterns, behaviors, and organisms, and may result in the design of novel computing systems that use natural media to compute."



Source: Castro, L. (2007). Fundamentals of natural computing: an overview. Physics of Life Reviews, 4, 1-36.

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When natural computing should be used

- **The problem to be solved is complex**

  large number of variables or potential solutions, highly dynamic, nonlinear, multiple objectives, …

- **Not possible to guarantee that a potential solution found is optimal**

  but it is possible to find a quality measure that allows the comparison of solutions among themselves.

- **Problem to be solved cannot be (suitably) modeled**

  pattern recognition and classification, the system is somehow capable of 'learning from examples'.

- **Single solution is not good enough or when diversity is important**

  Standard techniques are deterministic and natural computing is (majority) composed of stochastic methods.

Source: Castro, L. (2007). Fundamentals of natural computing: an overview. Physics of Life Reviews, 4, 1-36.

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When natural computing should be used

- **Realistic Simulation of Biological, Physical and Chemical Phenomena**
  - Fractal geometry as an alternative to Euclidean geometry to model Nature
- **Artificial synthesis of living behaviors or natural phenomena**
- **Computing with Natural Materials**

Source: Castro, L. (2007). Fundamentals of natural computing: an overview. Physics of Life Reviews, 4, 1-36.

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Computational Intelligence

Computational intelligence refers to the ability of a computer to learn a specific task from data or experimental observation;

Set of nature-inspired computational methodologies and approaches to address complex real-world problems to which mathematical or traditional modeling can be useless for a few reasons: the processes might be too complex for mathematical reasoning, it might contain some uncertainties during the process, or the process might simply be stochastic in nature.

Optimization

Many real-world problems involve maximizing or minimizing a value:

- How can a car manufacturer get the most parts out of a piece of sheet metal?
- How can a moving company fit / transport the maximum majority of furniture in a truck of a given size?
- How can a telephone company route calls to get the best use of its lines and connections?
- How can a university schedule its classes to make the best use of classrooms without conflict?

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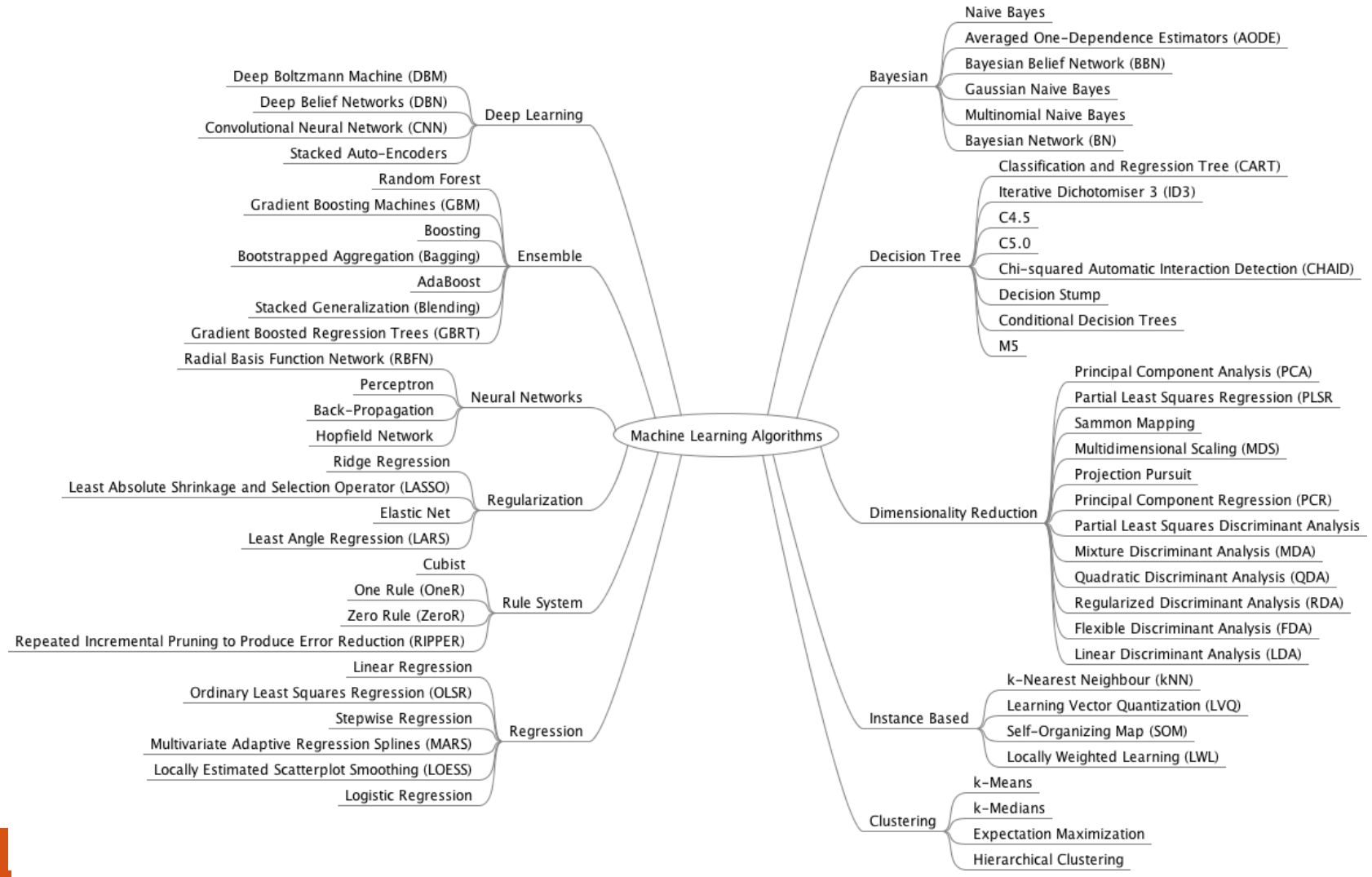
Machine Learning Pattern Recognition



Natural Computation Program

- Neurocomputing
  - Inspired by the biological neural networks that constitute human brains.
- Evolutionary Computing
  - Family of algorithms for global optimization inspired by biological process of evolution
  - , solving problems based on population-based trial and error.
- Social Computing
  - Algorithms whose mechanisms are inspired by principles of biology and nature phenomena.
- Reinforcement Learning
  - Inspired by behavioral psychology, interested in seeing how software agents act in an environment in order to maximize some notion of cumulative reward.

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Natural Computing: The Course

Learning expectations include:

- Knowledge of the terminology and concepts of natural computing;
- Insight into the possibilities and fundamental limitations of natural computing;
- Insight into the relative advantages and disadvantages of the major approaches to natural computing (Evolutionary computing, neural networks, Particle Swarm and so on);
- Understanding of the basic methods and techniques used in natural computing;
- Skills in applying the basic methods and techniques to concrete problems in natural computing.

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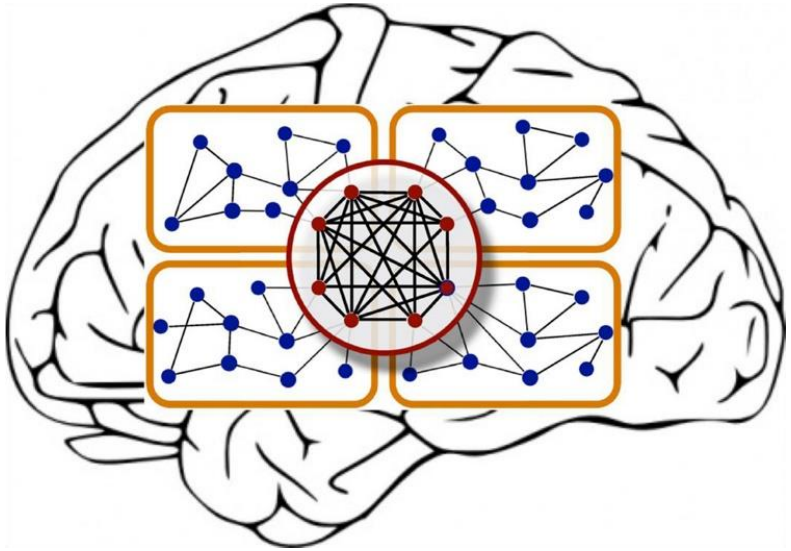
Neurocomputing: Artificial Neuronal Network

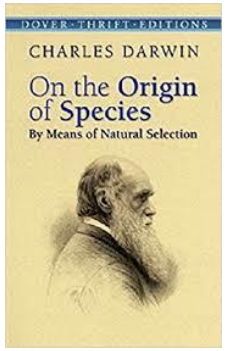
ANN is a connection-based computational system for problem-solving:

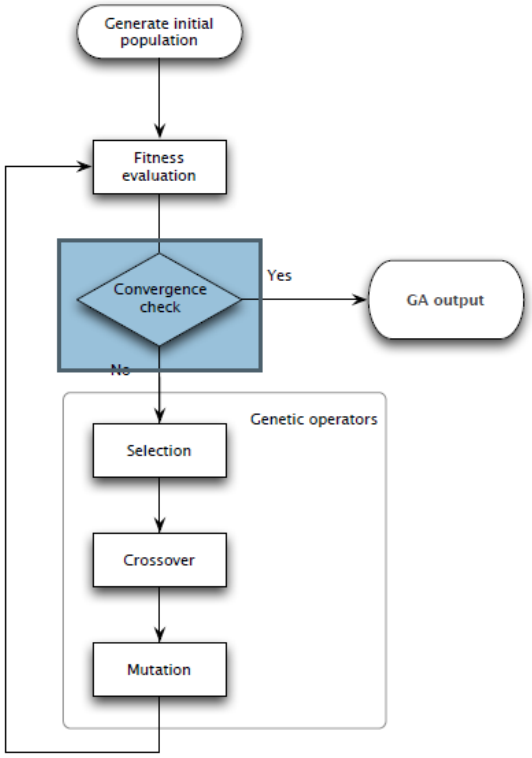
- designed based on a simplified model of the human central nervous system.
- defined by an interconnected structure of computational units, called neurons, with learning capacity.



Evolutionary Computing: Genetic Algorithms

- Iterative procedure that maintains a population of structures that are candidates for solutions, for specific domains.
- With each increment of time (generation), the structures of the current population are evaluated on their ability to be valid solutions for the problem domain, forming a new population of candidate solutions, based on their evaluation, developed by the application of genetic operators (selection, crossing, mutation, purification, among others).





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Social Computing: Ant Colony Optimization

- Method of population survey based on the behavior of an ant colony;
- Simulates the behavior of a set of agents (ants) that cooperate to solve an optimization problem through simple communications.

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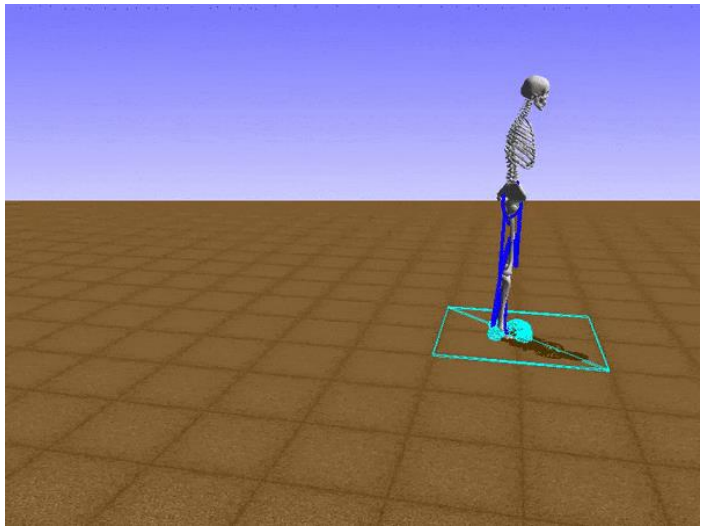
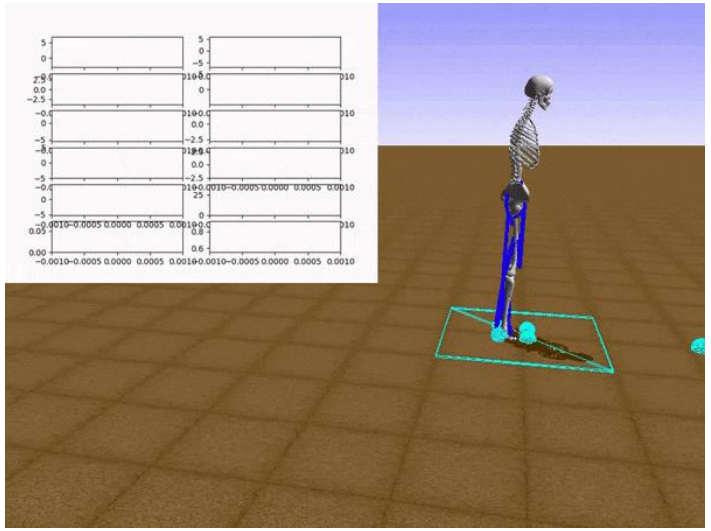
Reinforcement Learning

Source: Machine Learning for Everyone
https://vas3k.com/blog/machine_learning/





Source: Learning to run – an example of reinforcement learning
https://deepsense.ai/learning-to-run-an-example-of-reinforcement-learning/

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General Characteristics

Flexible - different problems

Robust - deal with uncertainty and noise

Adaptive - deal with dynamic environments

Autonomous - without human intervention

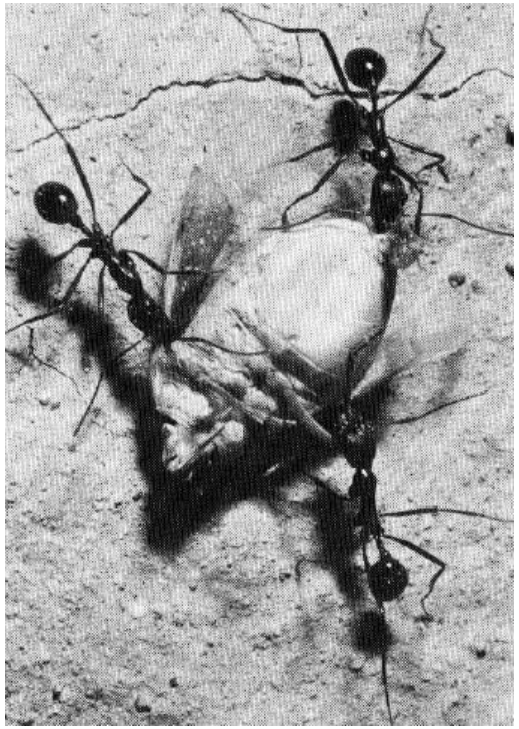
Decentralized - without a central authority

People, Entities and Agents

Agent can be defined as an entity with:

- A representation (of the environment in which it is inserted
- Able to act on himself and his environment
- Able to communicate with other agents

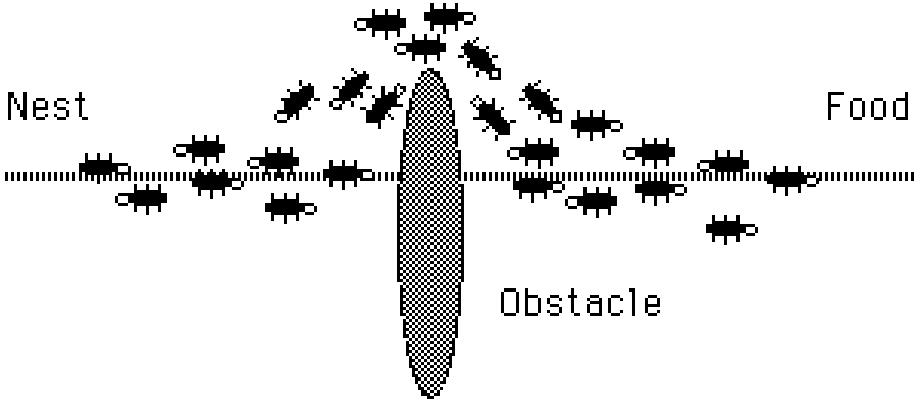
Observations – Knowledge - Interactions



Introductory Concepts

Parallelism and Distributivity

- Ability to process more than one item at a time;
- Operations and tasks distributed by several entities.



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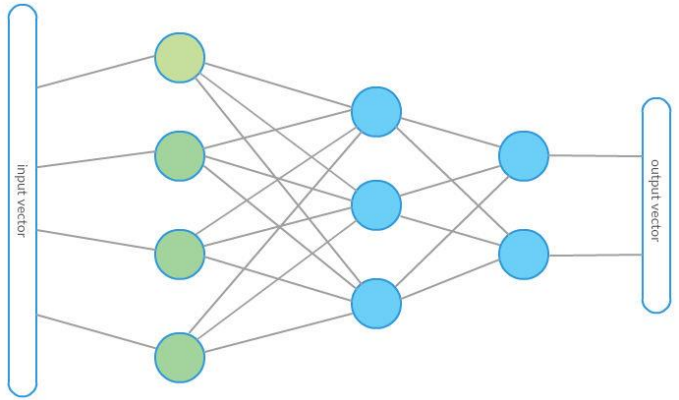
Introductory Concepts

- **Interactivity** ability to interact with each other and their environment.

- **Connectivity** is a term widely used in terms of networks that has meaning in terms of the passage of information between the various nodes and neural network.

- **Stigmergy** is a concept that arose referring to the way the termites communicate indirectly in the construction of the nest. Use of a chemical known as pheromones is deposited on the materials (self-reinforcement).



Introductory Concepts: Others

Adaptation

A system's ability to adapt to its environment in response to incoming stimuli.

Learning

Evolution (e.g., natural selection)

Feedback

Consists in making the response obtained at the system output as a result of a stimulus applied at its input, influencing the stimulus to be applied (positive or negative).

Self-Organization

In this context refers to the process of creating patterns in biological, physical and chemical systems.

Computação Natural: Sistema de Avaliação

SISTEMA DE AVALIAÇÃO a discutir com os alunos na primeira aula)

Em virtude da Crise Pandêmica, o Sistema de Avaliação foi adequado ao contexto de ensino a distância.

A avaliação é composta por três instrumentos de avaliação: um (1) Instrumentos de Avaliação em Grupo e um (1) Instrumento de Avaliação Individual.

Instrumento de Avaliação Individual

O primeiro envolverá o estudo de Redes Neuronais e Algoritmos Genéticos.

Instrumento de Avaliação em Grupo

O segundo consistirá no estudo de Deep Reinforcing Learning.

A classificação final é dada na forma:

- 50% da classificação provém dos Instrumentos de Avaliação em Grupo;

- 50% da classificação provém dos Instrumentos de Avaliação Individual.

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References

Castro, L. (2007). Fundamentals of natural computing: an overview. Physics of Life Reviews, 4, 1-36.

Krishnaveni, A. (2019). A Survey on Natural Inspired Computing (NIC): Algorithms and Challenges. Global journal of computer science and technology.

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