Foundations of Artificial Intelligence

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Michela Milano

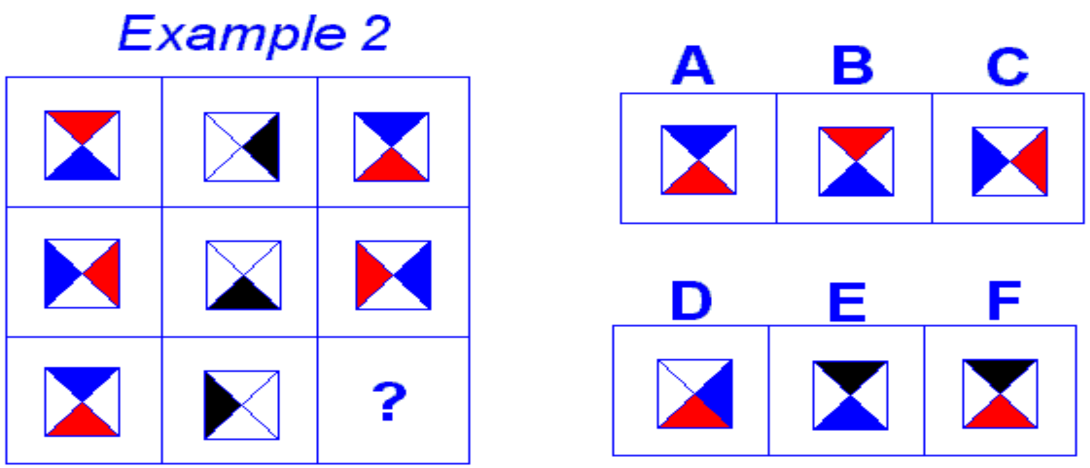
Dipartimento di Informatica – Scienza e Ingegneria
Università di Bologna

michela.milano@unibo.it

What is intelligence?

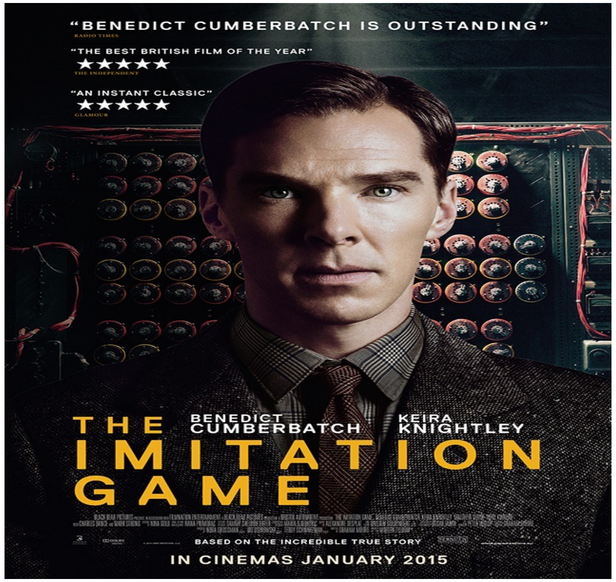
Intelligence has been defined in many ways, including: the capacity for logic, understanding, self-awareness, learning, emotional knowledge, reasoning, planning, creativity, critical thinking and problem solving. More generally, it can be described as the ability to perceive or infer information, and to retain it as knowledge to be applied towards adaptive behaviors within an environment or context.

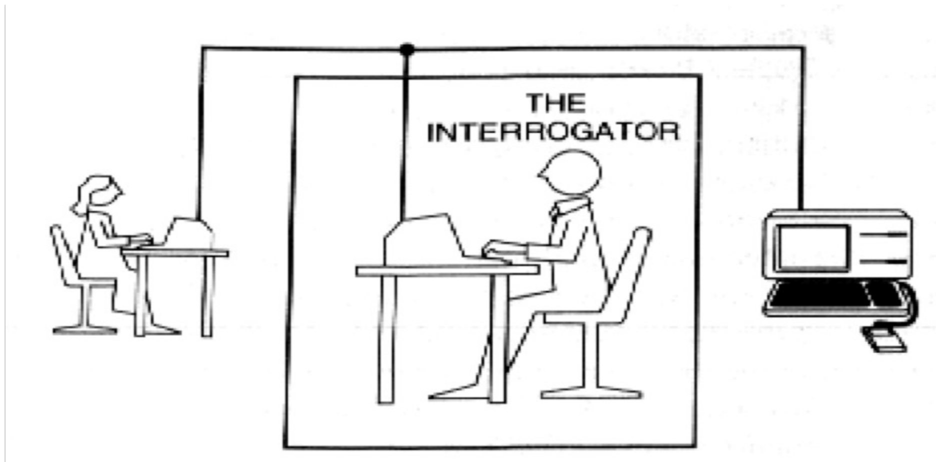
From Wikipedia



Turing: Can machine think?
Computing Machinery and Intelligence (1950)

- Problem of defining a universal machine and defining thinking (ambiguous)
- Imitation game
- Three actors: a human, a computer, a interrogator in a different room. The interrogator should classify the human and the machine.
- *Is it possible that a computer can mislead the interrogator and be classified as a human?*
- Various objections to this test





Turing test and AI

- Computers should have the following abilities
  - Natural language processing
  - Knowledge representation
  - Automatic reasoning
  - Machine learning

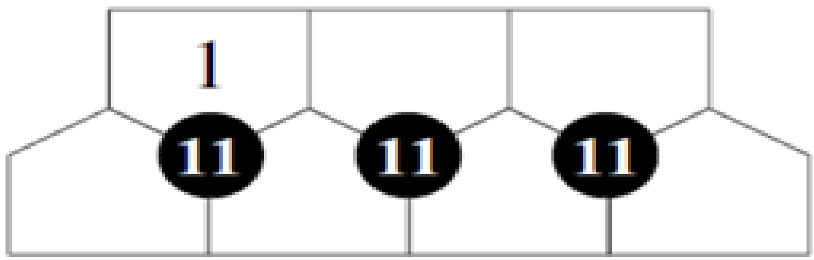
- Beyond Turing test – Physical interactions: Robotics, Artificial Vision, Speech, Movement, etc.
- In 2014, a chatbot (Eugene Goostman), mimiking the answer of a 13 years old boy, has succeeded the test.
- Cleverbot (Machine Intelligence Prize 2010), SIRI (Apple), Cortana (Microsoft), Alexa (Amazon) and ChatGPT
- Often built indexing previous conversations. What is missing is coherence, state of dialogue, semantics.
- Methodological perspective: engineering approach fostering emulation more than achievement of real intelligence in limited domains.

Beyond Turing test

Mathematical puzzles: Require deep language understanding, common-sense, reasoning capabilities, multi-modal analysis.

Geometrical problems solving - Allen Institute

Example: *Using integer numbers from 2 to 7, fill in the free tiles such that the sum of the three numbers around the black circle is 11.*



Turing forecast: true or false?

- *"I believe that in about fifty years' time it will be possible to programme computers, with a storage capacity of about 10^9, to make them play the imitation game so well that an average interrogator will not have more than 70% chance of making the right identification after five minutes of questioning. … I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted."*

From: A. Turing," A Computing machinery and intelligence", Mind, vol. 59, n. 236, pp. 433-460, 1950.

AI Systems Classification

Weak vs Strong AI

Weak AI: research question Is it possible to build sytems that act ***as if*** they were intelligent?

Strong AI: research question Is it possible to build sytems that are intelligent? That have conscious minds, wills and sentiments?

General AI vs Narrow AI

General AI refers to systems which are able to cope with any generalised task which is asked of it, much like a human.

Narrow AI refers to AI which is able to handle just one particular task. AI systems display a certain degree of intelligence in a particular field, but it remain computer systems that perform highly specialised tasks for humans, within that narrow field.

Artificial Intelligence

- Born in 1956. (Minsky, McCarthy, Shannon, Newell, Simon).
- *The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it.”* [McCarthy 1955].
- Which definition of intelligence? Which definition of Artificial Intelligence?

- Some definitions:
  - Study of how to make computers do things that humans do better.
    - Transitory definition (see chess)
  - **Study of how to build computers that pass the Turing test (reasoning, natural language understanding, learning). If situated in an environment also perception, vision, movement, robotics**
  - Other definitions of AI do not link directly to human intelligence but rather on the ability of interacting with and adapting to an environment.

Short history

- ***1943-1956*** *The birth of AI*
  - Neural networks, chess programs, theorem provers;
- **1952-1969** *Initial enthusiasm and big expectations*
  - General Problem Solver, LISP language, neural networks.
- ***1966-1974*** *Down to earth*
  - Some programs were not adequate (ELIZA, syntactic translations, neural networkks), other were too computationally expensive (combinatorial explosion).
- ***1969-1979*** *knowledge based systems*
  - Deep knowledge in a limited domain. Expert systems.
- **1980-1988** *AI enters in industry*
  - Commercial successful expert system. Fifth generation project in Japan. Companies working in AI, research funds
- **1988-2010** *Web and internet era*
  - Decision support systems, robotic agents, natural language
- **2010-today** *Machine learning and deep learning*
  - Big data and massive computing power have enabled deep networks to work properly. Augmented intelligence and perception. Industrial interest, industry 4.0
- **2020-today** *Generative AI and Conversational Agents*

Two main AI approaches

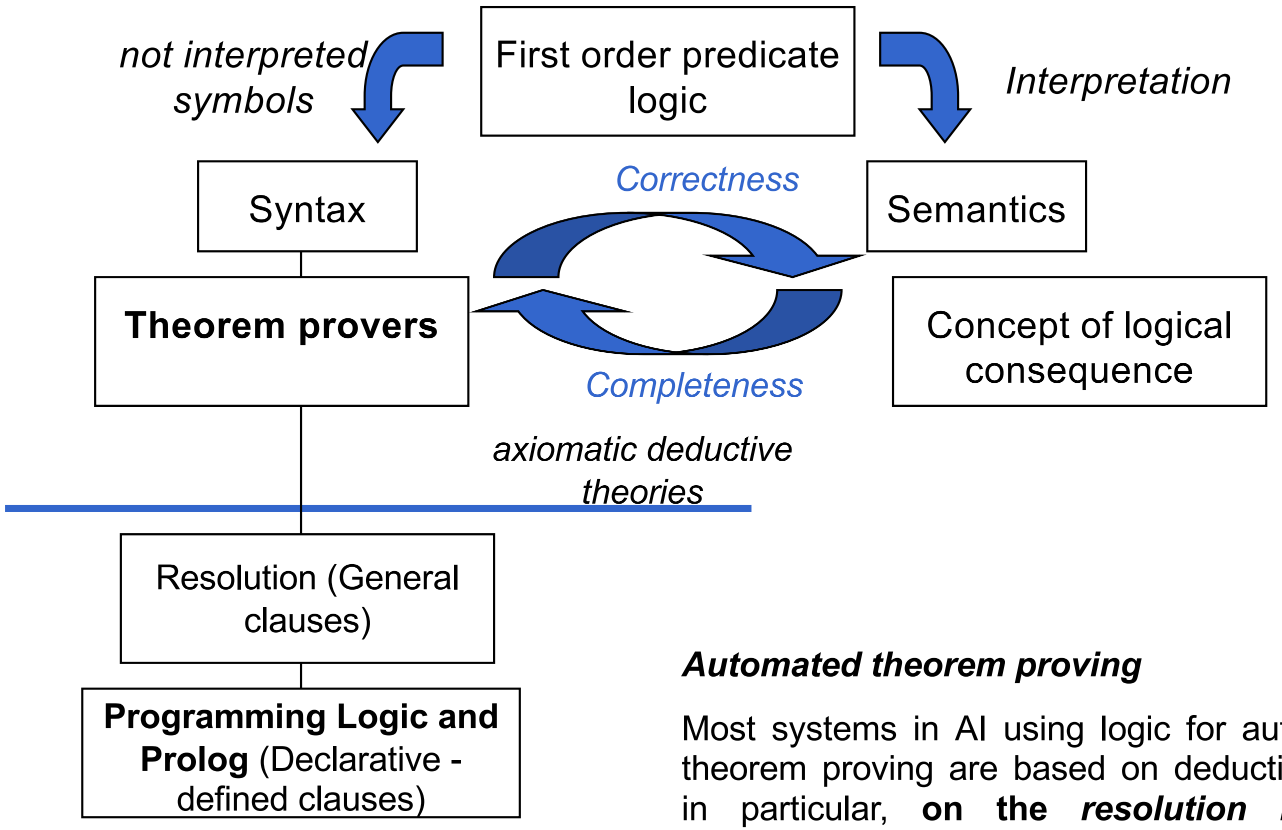
- **Top-down or symbolic AI**:
  - Symbolic representation of knowledge
  - Logics, ontologies, rule based systems, declarative architecture.
  - Human understandable models

- **Bottom up, or connessionist approach**.
  - Neural networks. Knowledge is not symbolic and it is “encoded” into connections between neurons.
  - Concepts are learned by examples
  - Non understandable by humans

Reasoning and Logic

- **Deductive reasoning** (Aristotelian syllogism - deductive logic):
  - From: *All men are mortal* and *Socrates is a man* then: *Socrates is mortal*
  - Okay, but it does not allow us to "learn" new knowledge.
- **Inductive Reasoning** (Learning, reverse deduction)
  - From the observation that *several birds flying* then *All the birds fly* (And penguins?).
  - Production of new knowledge at the expense of correctness.
- **Hypothetical or abductive** reasoning (Dual of deductive):
  - From the observation of *Death of Socrates* and knowing that *All men are mortal* hypothesizes that *Socrates is a man*. (And if he were a cat?).
  - It dates back to the causes through observation of the effects at the expense of correctness.
- **Reasoning by analogy** (Metaphorical, case-based)
  - It does not require a model or a lot of data, but it uses the principle of similarity. *Socrates and John "resemble"* is *Socrates loves philosophy* then: *John loves philosophy*.
  - K-Nearest-Neighbor and Support Vector Machine (SVM).
- **Constraint reasoning and optimization** Using constraints, probability, statistics (Bayes theorem)

Logic, automatic proof and Prolog



Automated theorem proving

Most systems in AI using logic for automated theorem proving are based on deduction and, in particular, **on the *resolution method*** defined by A Robinson in 1965.

Different algorithm interpretations

- Algorithm = data structures and instructions
- Algorithm = logic (knowledge) + control (engine inference)
- Algorithm = examples (experience) + Machine learning

Level of generality and "intelligence” increases

Declarative languages and Prolog

Algorithm = Logic + CONTROL

- Problem knowledge is independent from its use
  - It expresses WHAT and not HOW
  - High modularity and flexibility
  - Design scheme at the base of most KNOLWEDGE BASED SYSTEMS (Expert Systems)
- LOGIC: knowledge about the problem determines correctness and efficiency
- CONTROL: solution strategy determines the efficiency

PROLOG: PROgramming in LOGic

- It is the best known Logic Programming language. It is built on the ideas by R. Kowalski and the first realization by A. Colmareur (1973).

Prolog Program

- A PROLOG PROGRAM is a set of Horn clauses representing:
  - FACTS about the object under examination and the relationships
  - RULES on objects and relationships (IF ... ..THEN)
  - GOAL (clauses with no head), on the basis of definite knowledge

- EXAMPLE: two individuals are colleagues if they work for the same company

Head Body

```
colleague(X,Y):- works(X,Z), works(Y,Z), different(X,Y).
```

RULE

```
works(emp1,ibm).
works(emp2,ibm).
works(emp3,txt).
works(emp4,olivetti).
works(emp5,txt).
```

FACTS

```
:- colleague(X,Y).
```

GOAL

Prolog Program

- Sum of two integer numbers. Declarative definition

```
sum(0,X,X).                    → FACT
sum(s(X),Y,s(Z)):- sum(X,Y,Z). → RULE
```

- **sum** is a non interpreted symbol
- Integer numbers defined with the successor structure **s(X)**
- Recursive definition
- Many possible queries (algorithms)

```
:- sum(s(0),s(s(0)),Y).
:- sum(s(0),Y,s(s(s(0)))).
:- sum(X,Y,s(s(s(0)))).
:- sum(X,Y,Z).
:- sum(X,Y,s(s(s(0)))), sum(X,s(0),Y).
```

Deduction and induction in logic programming

T		*B*		*E* (deduction)
parent(X,Y) :- mother(X,Y). parent(X,Y) :- father(X,Y).	$\cup$	mother(mary,vinni). mother(mary,andre). father(carrey,vinni). father(carry,andre).	$\rightarrow$	parent(mary,vinni). parent(mary,andre). parent(carrey,vinni). parent(carrey,andre).

E+ / *E-*		*B*		*T* (induction)
E+: parent(mary,vinni). parent(mary,andre). parent(carrey,vinni). parent(carrey,andre). parent(mary,carrey). *E-*	$\cup$	mother(mary,vinni). mother(mary,andre). father(carrey,vinni). father(carry,andre).	$\rightarrow$	parent(X,Y) :- mother(X,Y). parent(X,Y) :- father(X,Y).

$\forall e^+ \in E^+$: $B \cup T \models e^+$ (T is **complete**)

$\forall e^- \in E^-$: $B \cup T \not\models e^-$ (T is **consistent**)

Abduction in logic programming

T

parent(X,Y) :- mother(X,Y).
parent(X,Y) :- father(X,Y).

$\cup$

E

parent(mary,vinni).
parent(mary,andre).
parent(carrey,vinni).
parent(carrey,andre).

$\rightarrow$

B (abduction)

mother(mary,vinni) ∨ father(mary, vinni).
mother(mary,andre) ∨ father(mary,andre).
mother(carrey,vinni) ∨ father(carrey,vinni).
mother(carey,andre) ∨ father(carry,andre).

$$T \cup B \models E$$

Often we use integrity constraints to control hypothesis

T

parent(X,Y) :- mother(X,Y).
parent(X,Y) :- father(X,Y).

mother(X,Y) → female(X).
father(X,Y) → male(X).
female(mary).
male(carrey).

IC

$\cup$

E

parent(mary,vinni).
parent(mary,andre).
parent(carrey,vinni).
parent(carrey,andre).

$\rightarrow$

B (abduction)

mother(mary,vinni).
mother(mary,andre).
father(carrey,vinni).
father(carey,andre).

$$T \cup B \models E$$
$$T \cup B \models IC$$

Prolog

- Great revolutionary idea
- The language is not linked to Von Neumann architectures
- European versus American
- Japanese Fifth generation project in the 80 (failed)
- Technology has made gigantic steps in the meantime...
- Why Prolog has not spread as believed in the 80s?
- Many applications, ideas, research, extensions Prolog in AI, but not all.

Many Prolog implementations:

SWI Prolog: widely used and well integrated with Semantic Web: http://www.swi-prolog.org

tuProlog: Java based Prolog used for internet applications developed by Unibo.

http://apice.unibo.it/xwiki/bin/view/Tuprolog/

Machine learning

- Learning from experience, learning from one's mistakes, learning from teachers, learning by imitation, is a unique feature of intelligence.
- Empiricist approach (which opposes to the rationalist approach).

- Definition1:
  – Learning is constructing or modifying representations of what is being experienced [Michalski 1986]
- Definition 2:
  – Learning denotes changes in the system that are adaptive in the sense that they enable the system to do the same task or tasks drawn from the same population more efficiently and more effectively the next time [Simon 1984], pag. 28

Machine learning

- Machine learning is one of the **hot topics** of Artificial Intelligence
- All the most important ICT companies are investing money on ML and hire people with a background in ML: Google, Facebook, IBM, Baidu, Disney, . . .

WHY?

- They have many data. . .
  - . . . And want to extract value from data

The era of big data…..

Machine learning

- Supervised Learning:
  - It starts from a set of examples given by a teacher ("training set").
  - It solves problems of classification/regression (ex. patterns recognition).
- Unsupervised Learning:
  - Through observations and discovery.
  - From the outside it does not get any help, but the system that is in charge of analysing the information available, to classify and structure them and to discover patterns.
  - Clustering/data mining
- Reinforcement Learning:
  - Learning optimal behaviour from past experiences.
  - Observation of good and bad choices made (through rewards and punishments), and modify the behaviour accordingly.
  - Mainly learns from mistakes
  - Finds many applications in robotics.

What can we do with machine learning?

Classify incoming e-mails as spam or not

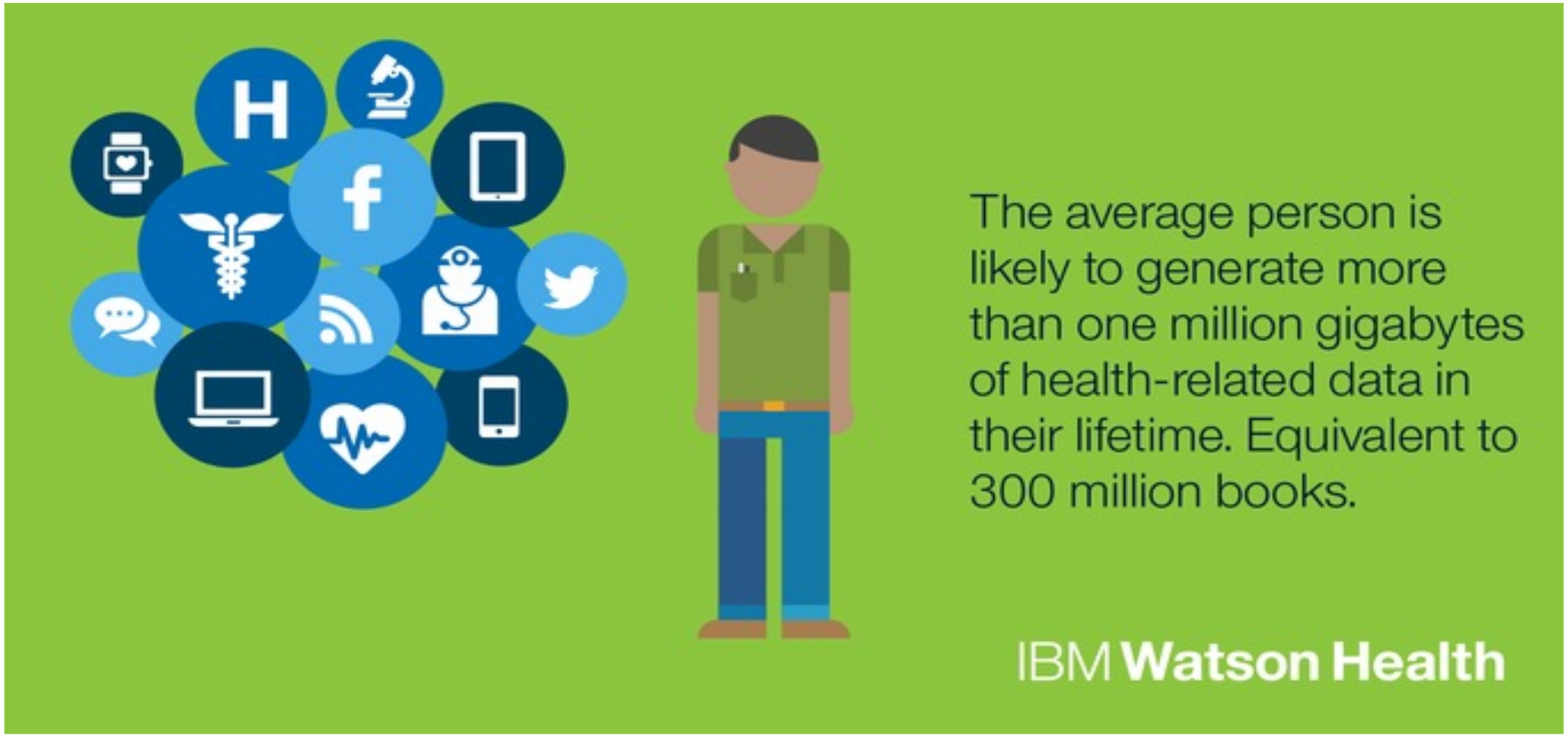
Figure source: http://www.resilientsystems.co.uk/

What can we do with machine learning?

Apple shares price prediction

What can we do with machine learning?

Diagnosis based on exams of a patient



What can we do with machine learning?

Understand VAT numbers

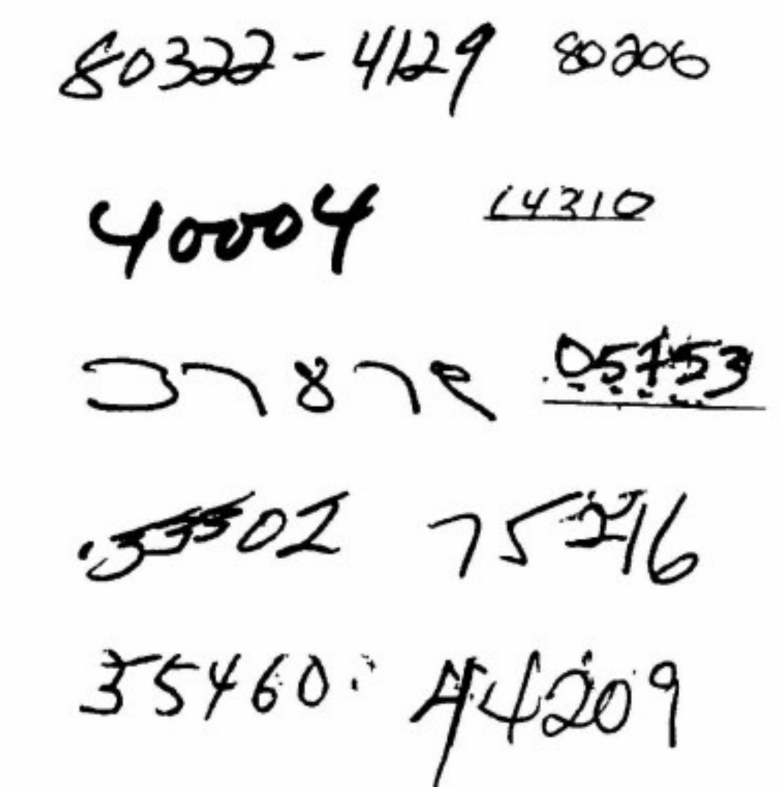


Figure source: [LeCun et al., 1989]

What can we do with machine learning?

Teach a robot to grab a cup

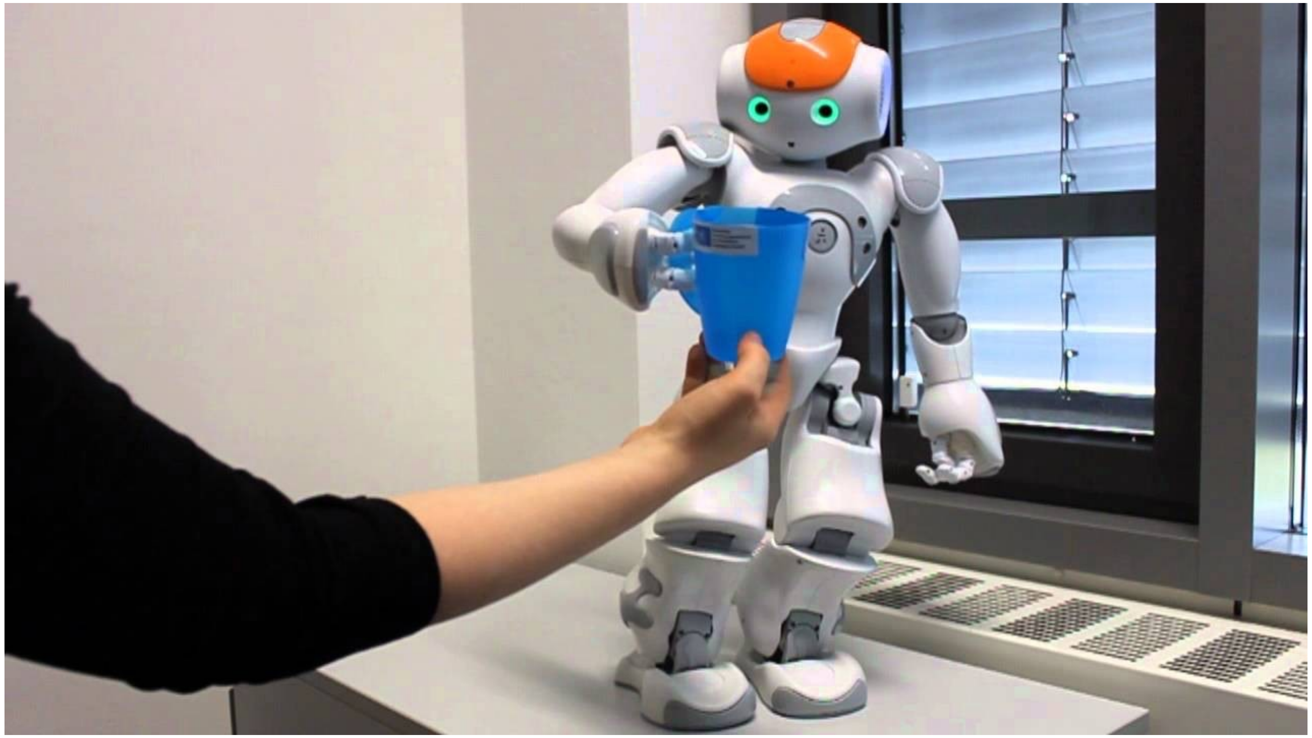


Figure source: http://www.informatik.uni-bremen.de/

What can we do with machine learning?

Design a molecule with specific properties

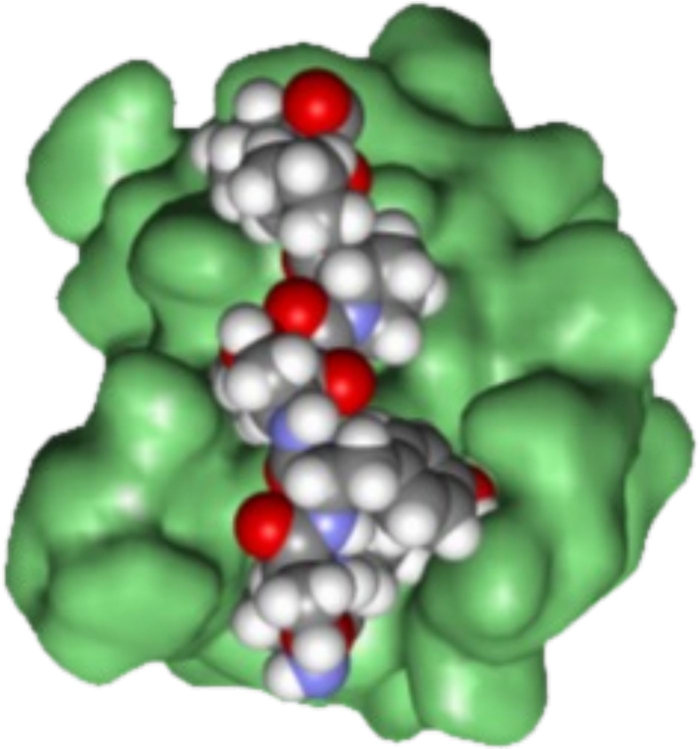


Figure source: http://pande.stanford.edu/

What can we do with machine learning?

Text translation

What can we do with machine learning?

Convert a voice in text

What can we do with machine learning?

Automatically write the caption to a figure

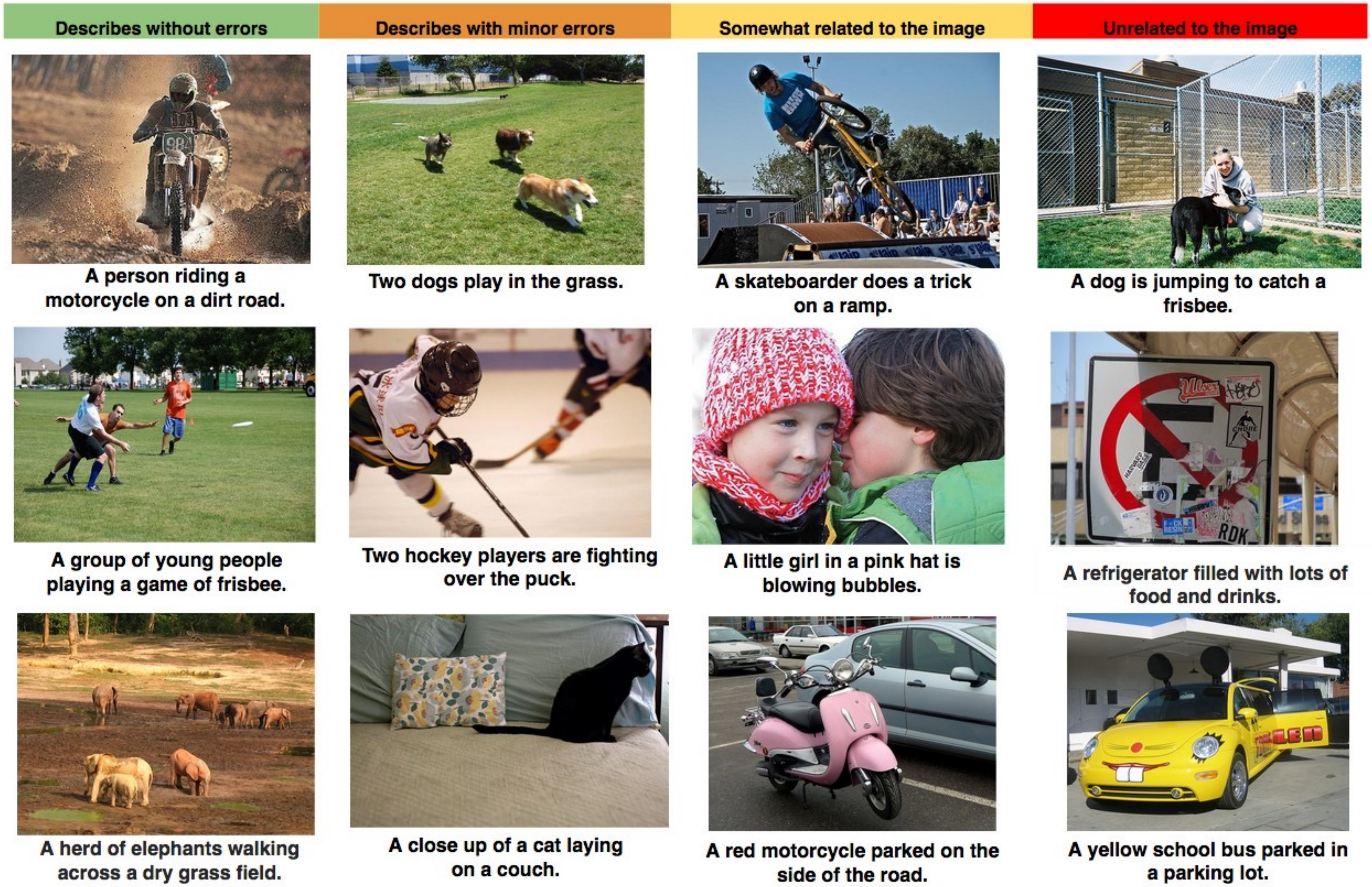


Figure source: Google Research

What can we do with machine learning?

Beat the world champion in a game

Figure source: Google Research

Machine learning task: classification

Classification is the task of approximating a mapping function (f) from input variables (X) to discrete/categorical output variables (y).

The output variables are often called labels or categories or classes.

The mapping function predicts the class or category for a given observation.

Supervised learning task

Machine learning task: classification

- **A classification problem requires that examples be classified into one of two or more classes.**
- A classification can have real-valued or discrete input variables.
- A problem with two classes is often called a two-class or **binary classification** problem. A problem with more than two classes is often called a **multi-class classification** problem.
- A problem where an example is assigned multiple classes is called a **multi-label classification** problem.
- The **classification accuracy** is the percentage of correctly classified examples out of all predictions made.

Machine learning task: regression

Regression is the task of approximating a mapping function (f) from input variables (X) to a continuous output variable (y).

A continuous output variable is a real-value, such as an integer or floating point value. These are often quantities, such as amounts and sizes.

Supervised learning task

Machine learning task: regression

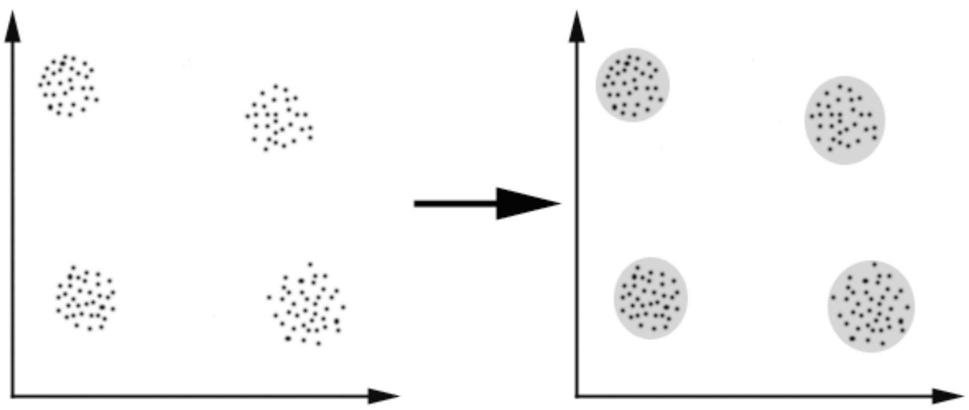
- A regression problem requires the prediction of a quantity.
- A regression can have real valued or discrete input variables.
- A problem with multiple input variables is often called a **multivariate regression** problem.
- A regression problem where input variables are ordered by time is called a **time series forecasting** problem.
- Because a regression predictive model predicts a quantity, the skill of the model must be reported as an error in those predictions, like the RMSE

Machine learning task: clustering

Clustering is the problem of organizing objects into groups whose members are similar in some way.

Clustering determines the intrinsic grouping in a set of **unlabeled data**

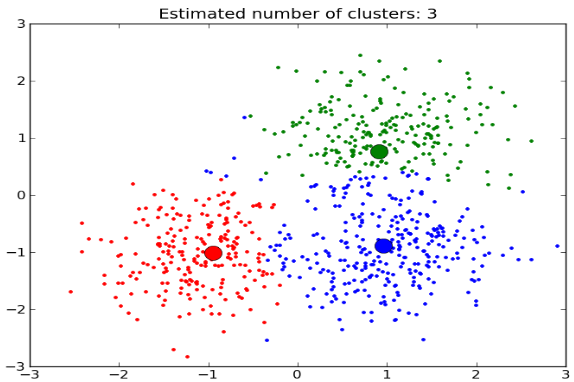
Clustering is the main **unsupervised learning task**



Machine learning task: clustering

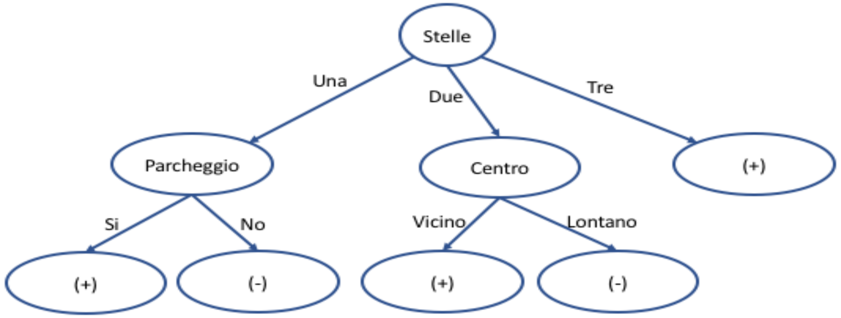
Clustering types
Hard clustering: each element can be assigned to one and only one group
Soft* or *fuzzy clustering: each element can belong to more than one group

Most widely used algorithm for hard clustering
k-means MacQueen 1967

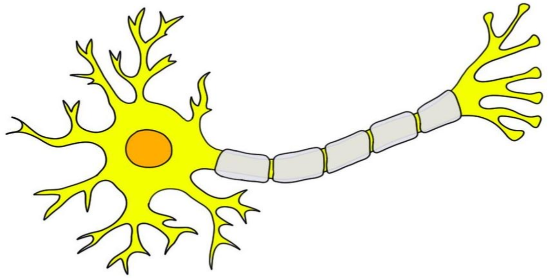


Symbolic and sub-symbolic learning

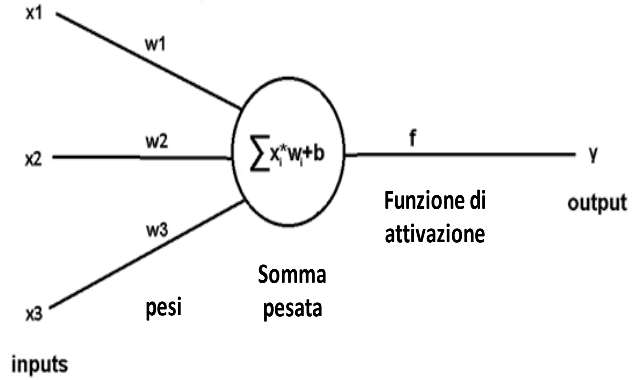
Decision tree



Neuron



Artificial Neuron



Prolog

```
suggest(H) :- stelle(H,***).
suggest(H):- stelle(H,**),
          centro(H,vicino).
```

Rules

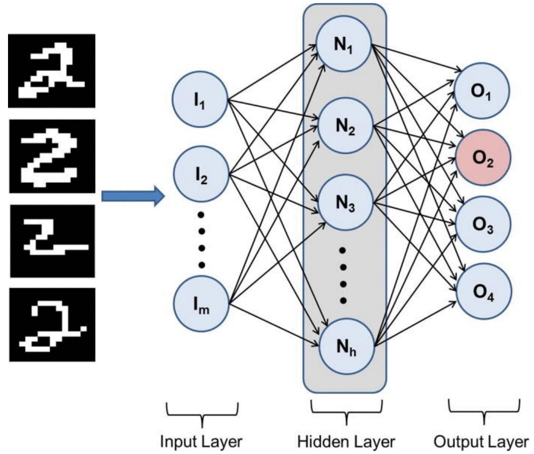
If the hotel is three star **then** suggest it.

if the hotel is two star AND close to the city center **then** suggest it.

………

Stelle	Costo	Centro	Parcheggio	Classe
**	Medio	Vicino	f	+
**	Alto	Lontano	f	-
**	Alto	Lontano	v	-
**	Medio	Lontano	v	-
**	Basso	Vicino	v	+
***	Medio	Lontano	f	+
***	Alto	Lontano	v	+
***	Basso	Vicino	f	+
***	Alto	Lontano	v	+
*	Medio	Lontano	f	-
*	Basso	Vicino	f	-
*	Medio	Lontano	v	+
*	Basso	Lontano	v	+
*	Medio	Lontano	v	+

Multi-layer networks

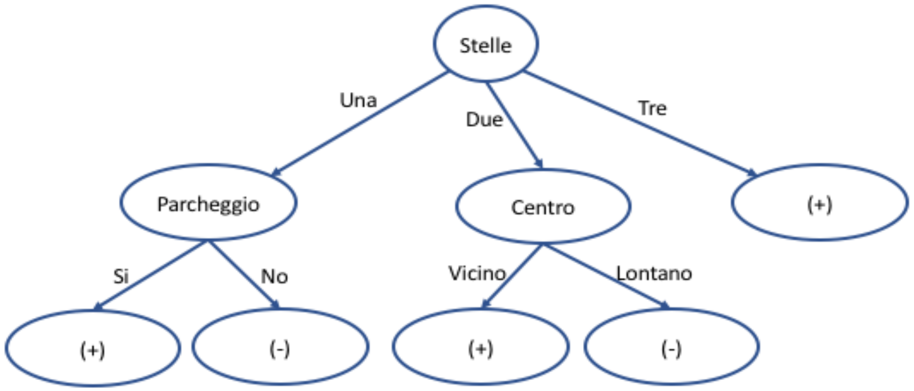


Symbolic learning: decision trees (ID3, C4.5)

Possible training set of hotels:

Stelle	Costo	Centro	Parcheggio	Classe
**	Medio	Vicino	f	+
**	Alto	Lontano	f	-
**	Alto	Lontano	v	-
**	Medio	Lontano	v	-
**	Basso	Vicino	v	+
***	Medio	Lontano	f	+
***	Alto	Lontano	v	+
***	Basso	Vicino	f	+
***	Alto	Lontano	v	+
*	Medio	Lontano	f	-
*	Basso	Vicino	f	-
*	Medio	Lontano	v	+
*	Basso	Lontano	v	+
*	Medio	Lontano	v	+

Corresponding decision tree



Rules

If the hotel is three star **then** suggest it.

if the hotel is two star AND close to the city center **then** suggest it.

………

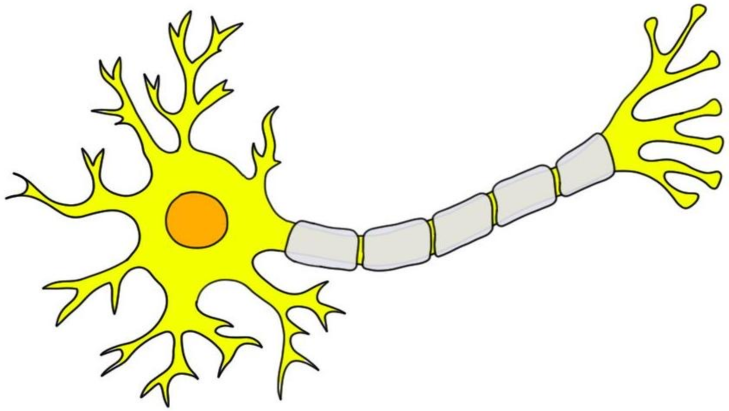
Artificial Neuron

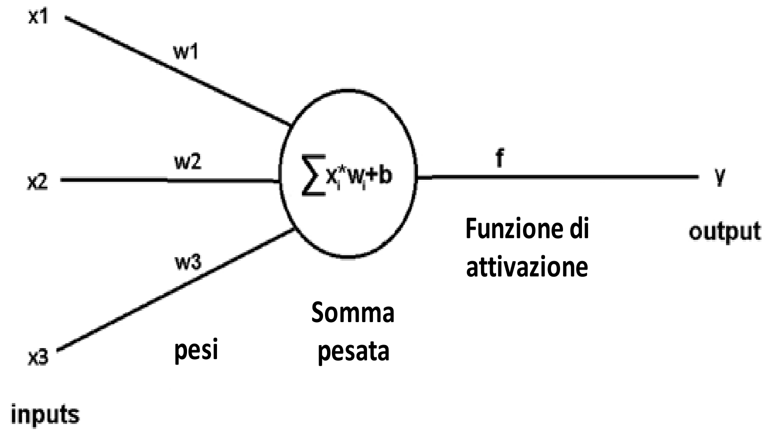
Idea: directly simulate brain functioning in a computer, and build an intelligent machine from artificial neurons.

First mathematical model of an artificial neuron has been inspired by the biological neurons proposed in 1943 by McCulloch and Pitts.

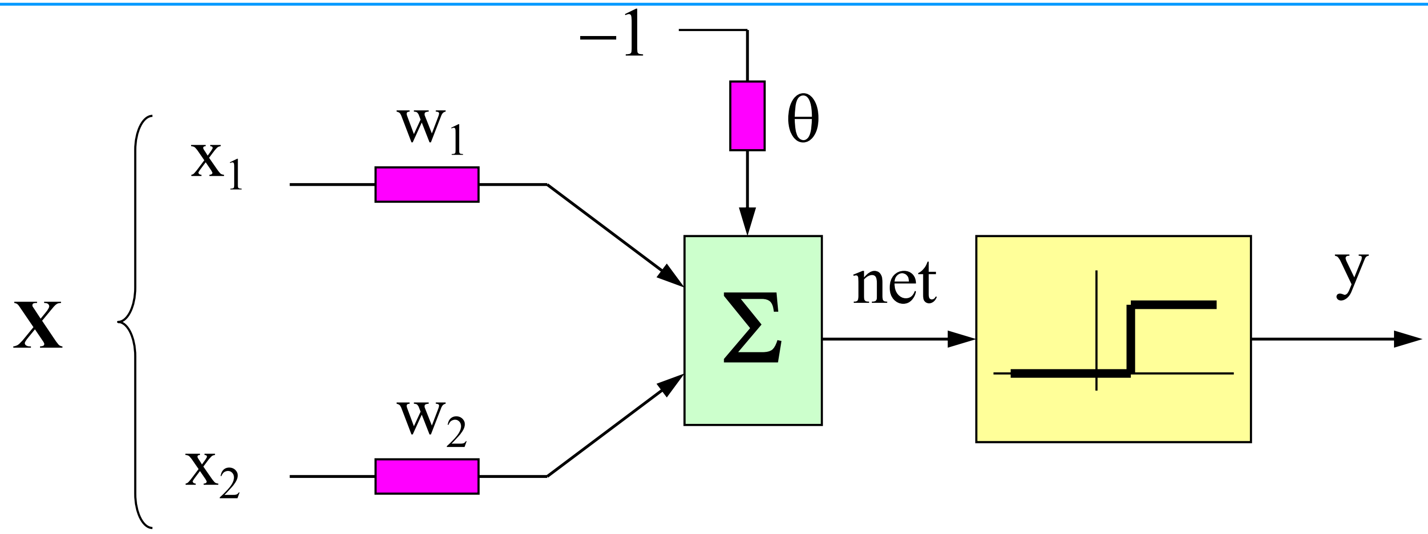
A neuron receives a set of inputs, makes a weighted sum and then applies an activation function to calculate the output.

The output is controlled by an activation function: each neuron is active only in case its input exceeds a certain threshold.





Two input perceptron



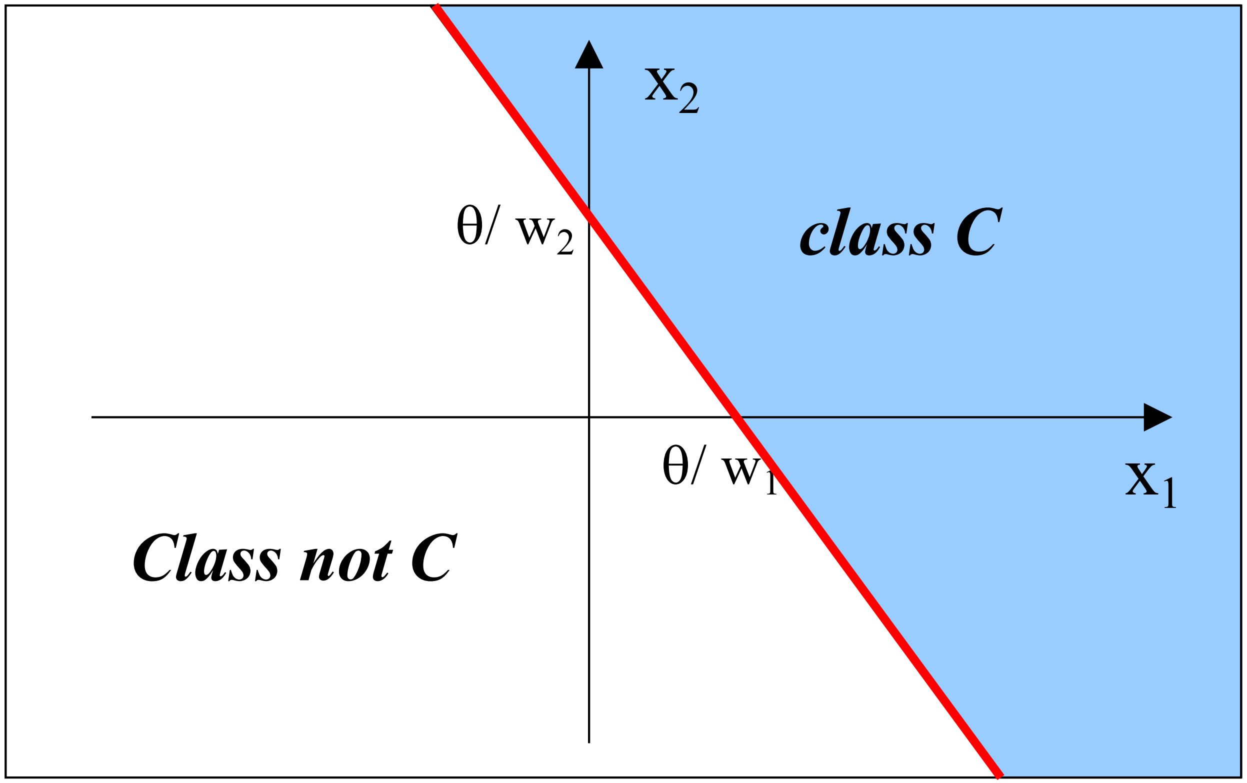
$$y = HS\,(w_1\,x_1 + w_2\,x_2 - \theta)$$

The patterns belonging to the class will be those such that:

$$w_1\,x_1 + w_2\,x_2 - \theta\; > 0$$

Linear separation of the input space

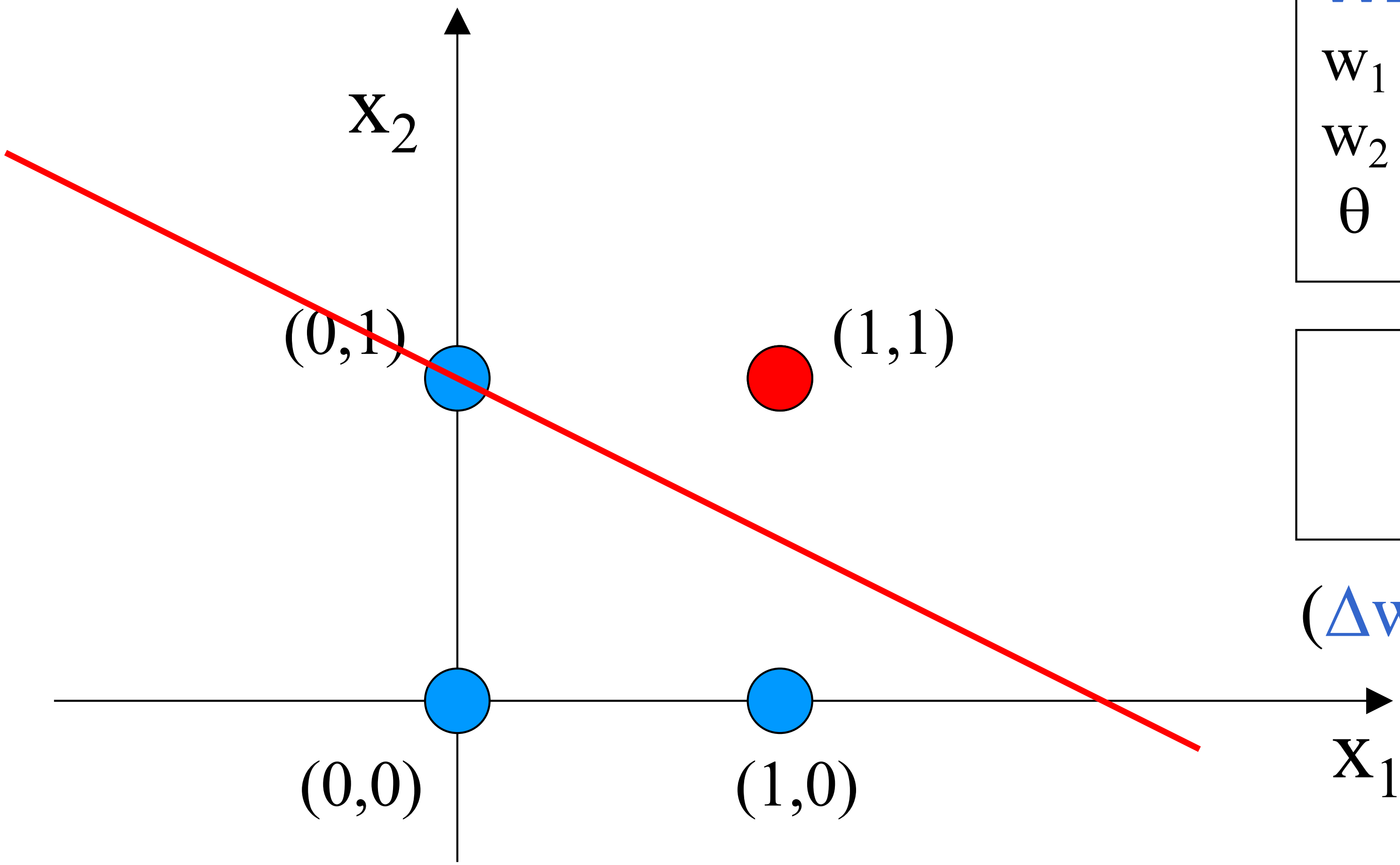
$$x_2 > -(w_1 / w_2)\, x_1 + \theta / w_2$$



44

Learning an AND gate

$$y = 1 \text{ if } x_2 > -(w_1/w_2)\,x_1 + \theta / w_2$$



WEIGHTS

$w_1 = 0.5$

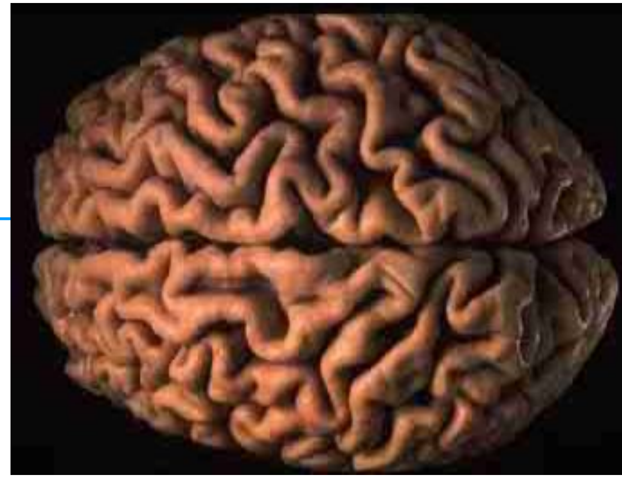
$w_2 = 1$

$\theta = 1$

($\Delta w = \eta\delta x$)

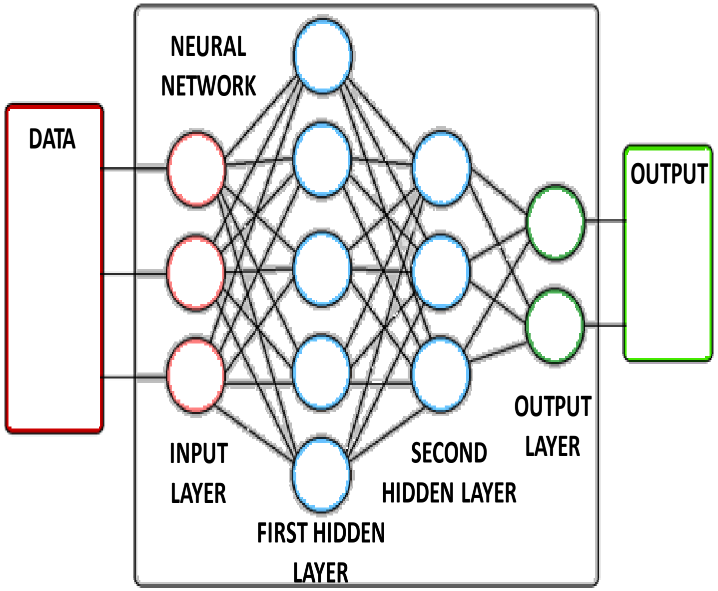
45

Neural Networks



- To represent more complex concepts networks of neurons should be built: multi-layer architectures (forward or feed-forward networks), and new learning algorithms.

- Significantly different approach from the symbolic one. The knowledge is not explicit but inherent in the network structure and connection weights.

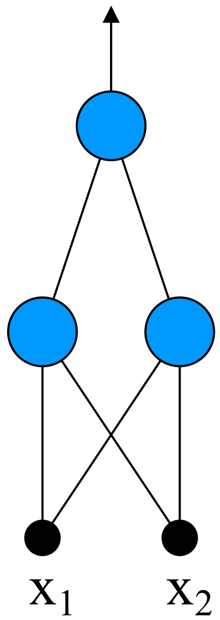


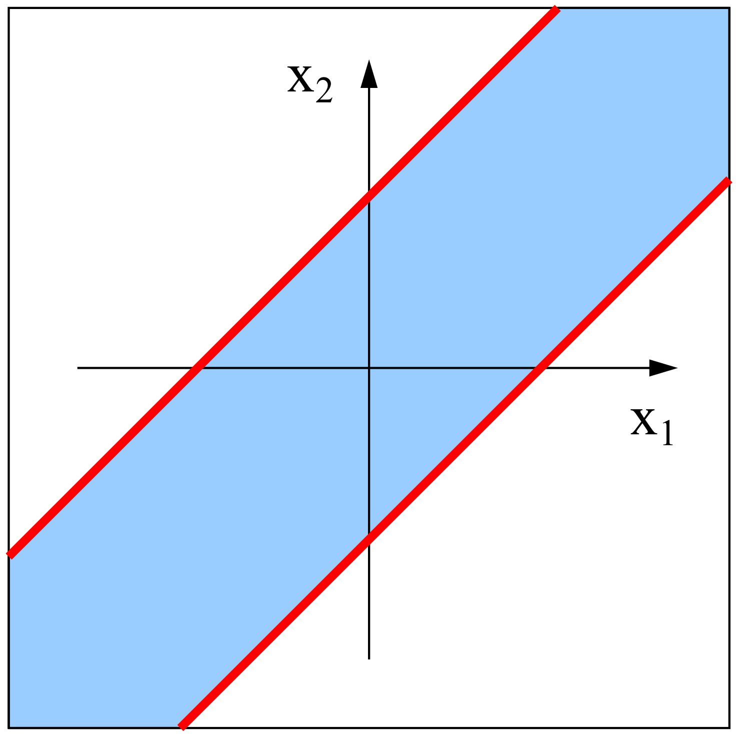
feed-forward network with two hidden layers

Three-layer networks

They are able to separate convex regions

number of edges ≤ number hidden neurons



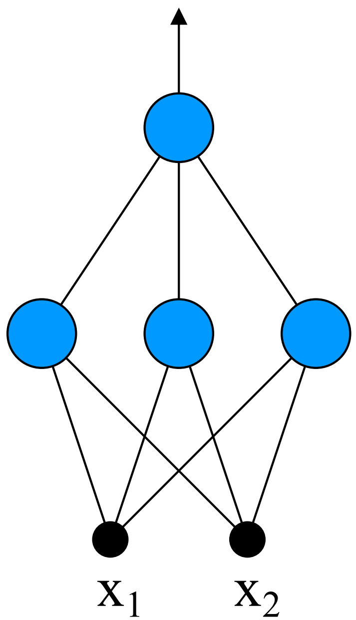


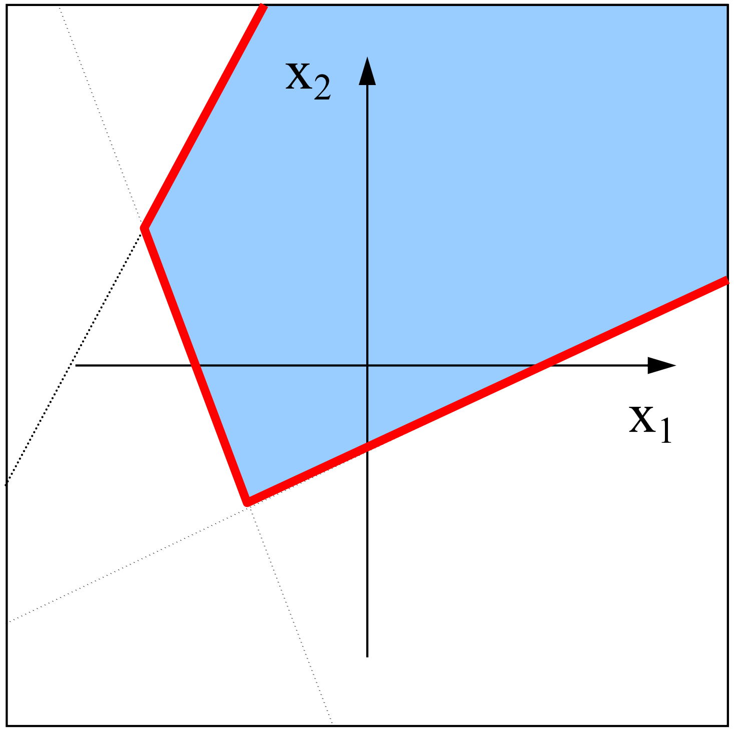
47

Three-layer networks

They are able to separate convex regions

number of edges $\leq$ number hidden neurons



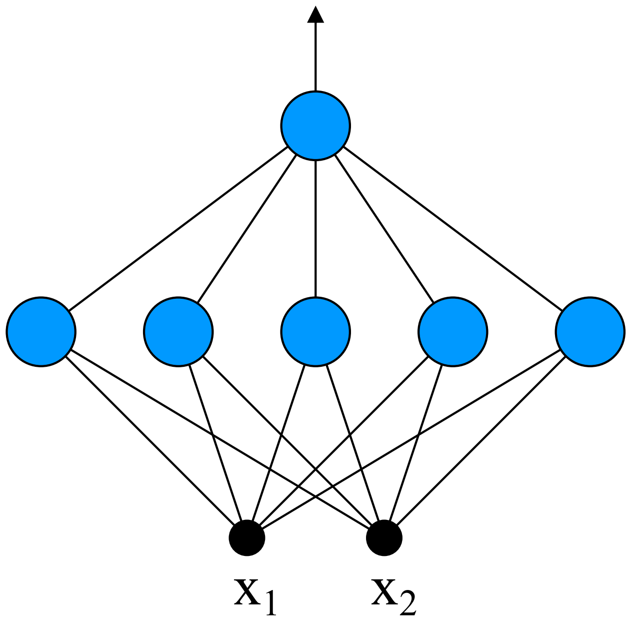


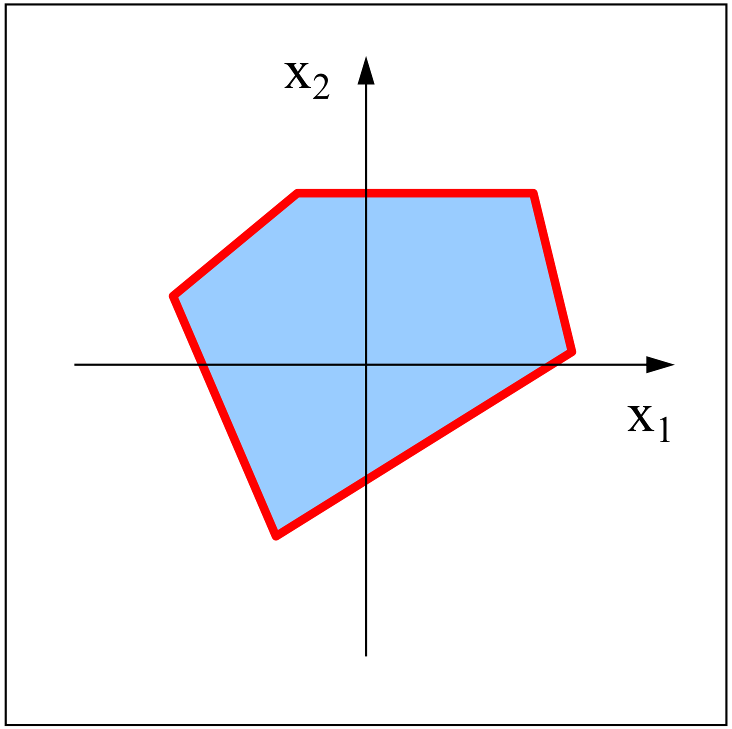
48

Three-layer networks

They are able to separate convex regions

number of edges ≤ number hidden neurons

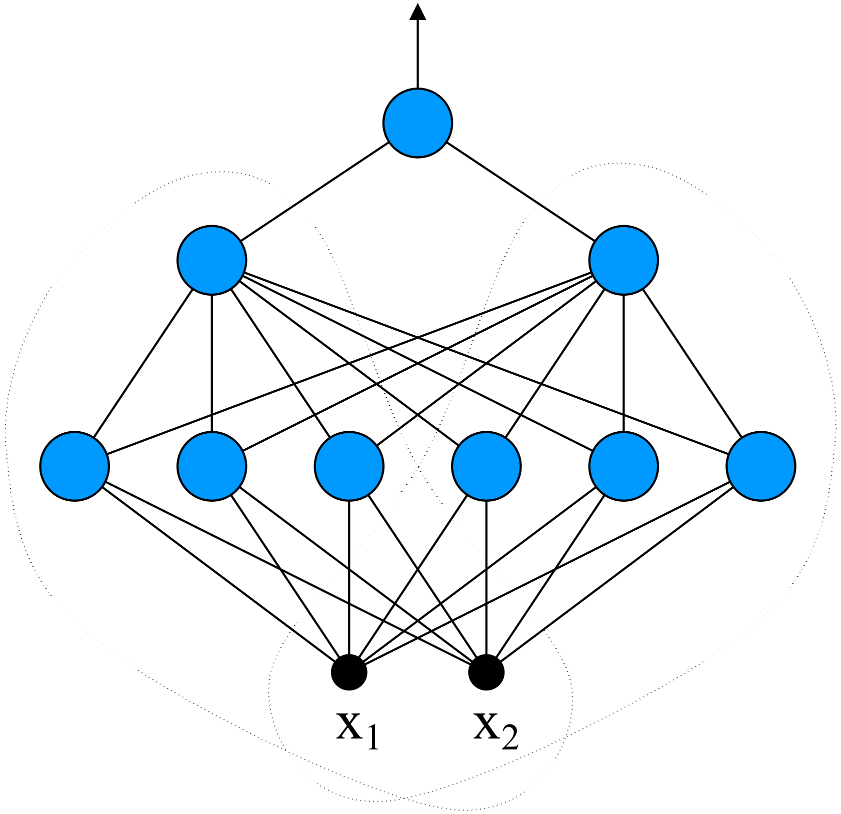


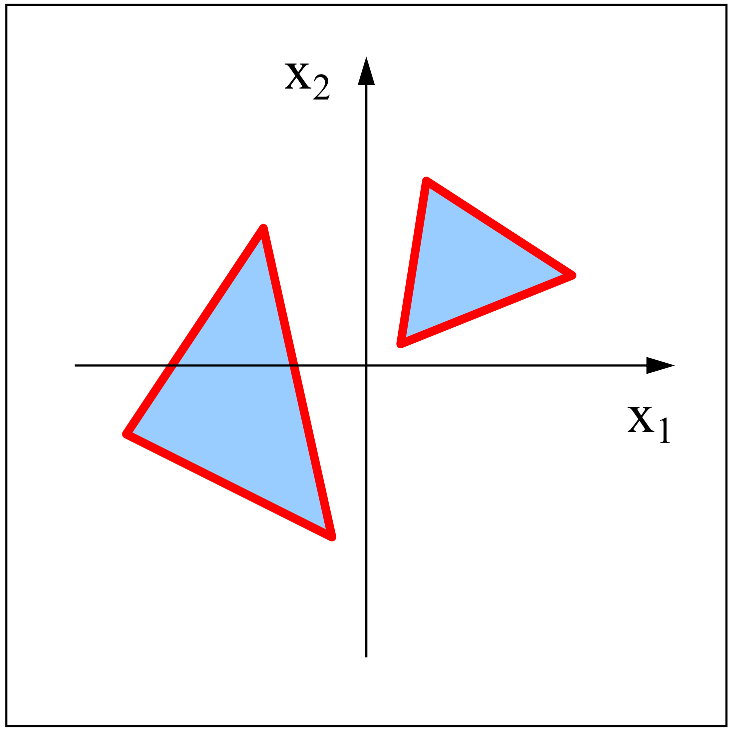


49

Four-layer networks

- They are able to separate regions of every shape





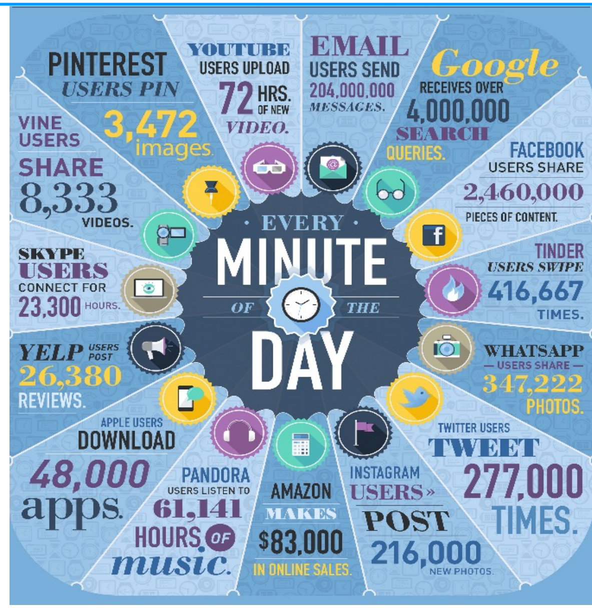
Neural networks: power and limitations

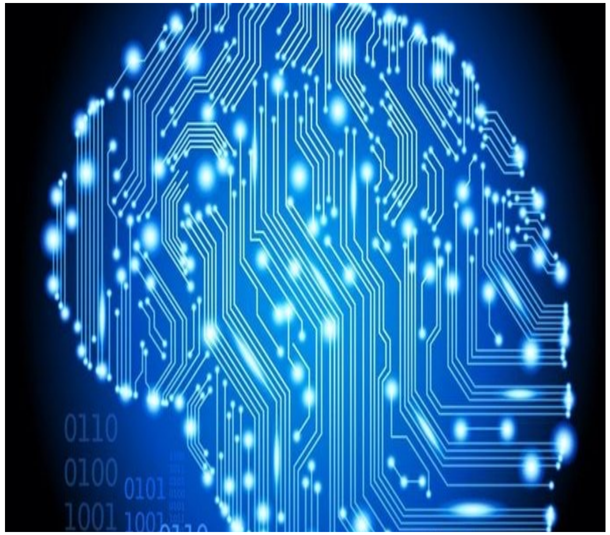
- The perceptron can represent only linear functions. If, however, we use multi-layer networks, the expressive power increases substantially.
- Universal approximation theorem: *A feed-forward network with one hidden layer and a finite number of neurons can approximate any continuous function with desired accuracy.*
- Interesting theory, but it says nothing about how to configure the neural network and how to apply the learning algorithms to get a good approximation. What output functions? How many neurons? How many layers?

- From the 80s more complex and detailed models have been designed for artificial neurons, with different non-linear functions (for example the sigmoid).
- Also various architectures have been identified, and more sophisticated learning algorithms have been developed

Deep Neural Networks and Deep learning

- **Deep Learning:** models and algorithms that use neural networks with many neurons and many **layers.** They can learn complex **functions**, trying to identify most relevant data (rough).
- The most commonly used DNNs consist of a very number of levels (even some hundreds)
- Computational expensive training process
- The supervised algorithms currently get good performance with around 5,000 examples for each category and surpass humans with 10 million examples.
- It is not a "simulation" of the brain that has more neurons and a much more complex structure. With a further development of computing power, we will have a comparable number of neurons with human in 2050.

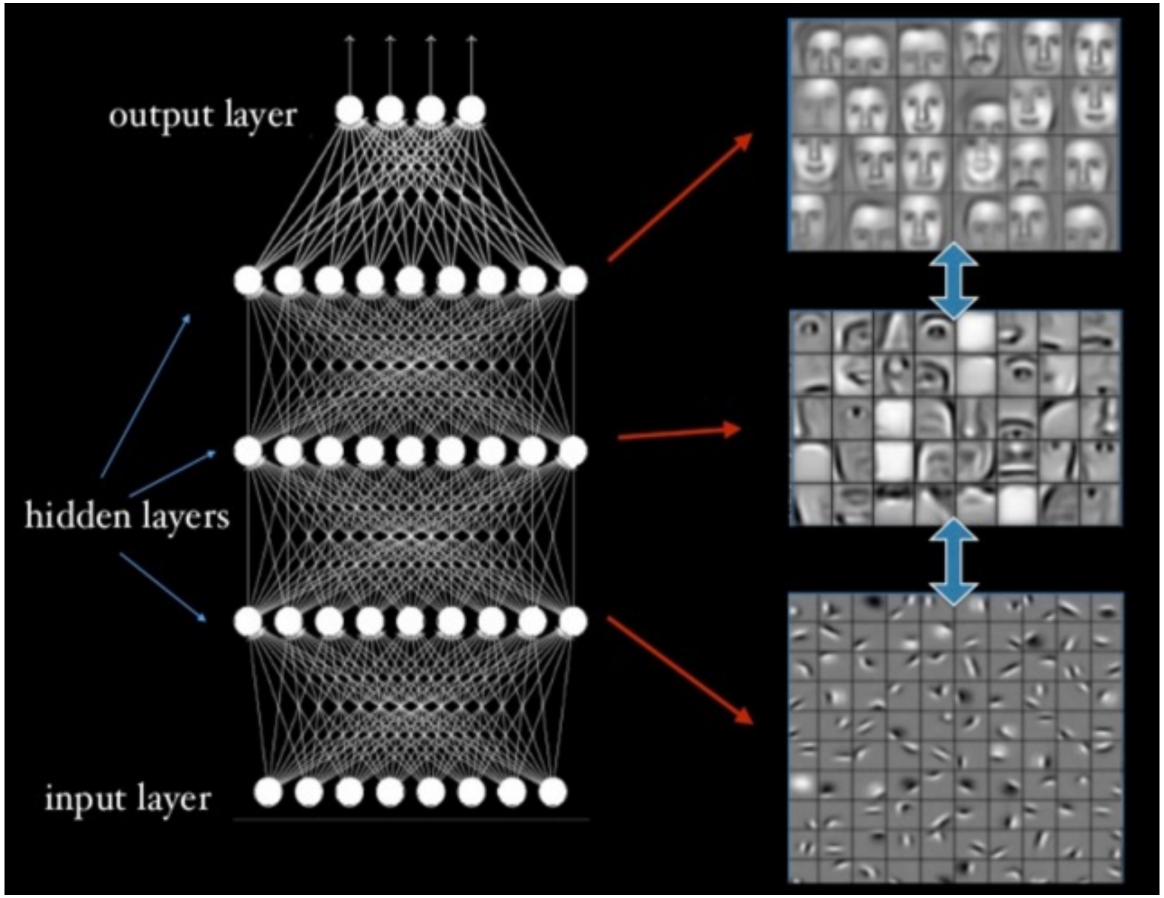




Da: I. Goodfellow, Y. Bengio, A. Courville: “Deep Learning”, MIT Press, http://www.deeplearningbook.org, 2016

Deep Neural Networks and Deep learning

In Deep Learning concepts are learnt through a hierarchy of features, from the simplest to more abstract and complex. Representation is implicitly distributed in different layers



https://leonardoaraujosantos.gitbooks.io/artificial-inteligence/content/deep_learning.html

Automated Planning

Automated Planning is an important problem solving activity which consists in synthesizing a **sequence of actions** performed by an agent that leads from an initial state of the world to a given target state (**goal**)

Given:

- an initial state
- a set of actions you can perform
- a state to achieve (**goal**)

Find:

a plan: a partially or totally ordered set of actions needed to achieve the goal from the initial state

Automated Planning

An **automated planner** is an intelligent agent that operates in a certain domain described by:

1. a representation of the initial state
2. a representation of a goal
3. a formal description of the executable actions (also called operators) in terms of precondition and effects

It dynamically defines the plan of actions needed to reach the goal from the initial state.

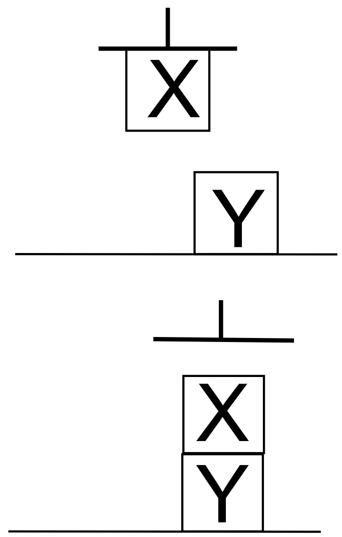
Example: block world

Actions:

STACK (X, Y)

IF: holding (X) and clear (Y)

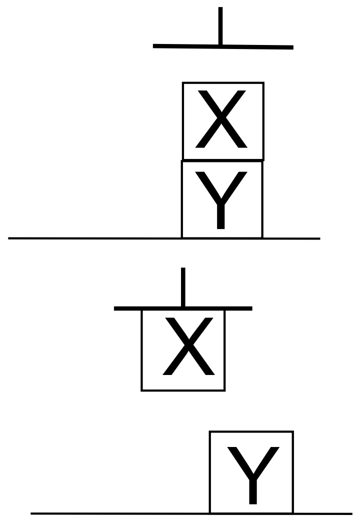
THEN: handempty and clear (X) and on (X, Y);



UNSTACK (X, Y)

IF: handempty and clear (X) and on (X, Y)

THEN: holding (X) and clear (Y);

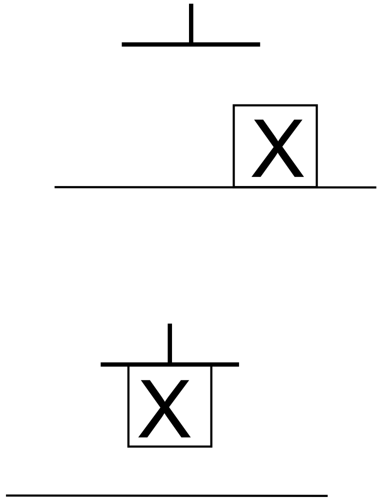


Example: block world

PICKUP (X)

IF: ontable (X) and clear (X) and handempty

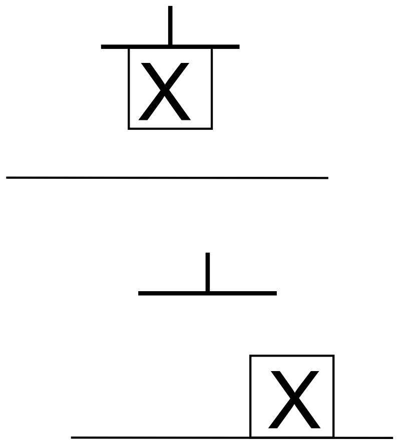
THEN: holding (X);



PUTDOWN (X)

IF: holding (X)

THEN: ontable (X) and clear (X) and handempty.



Planning Techniques

- Deductive planning / planning as search/ linear planning in **Foundations of AI**
- Nonlinear planning
  - Partial Order Planning (POP)
- Hierarchical planning
- Conditional planning
- Graph-based planning
- Planning for robotics paths
- Planning as emergent behavior: swarm intelligence
- Reinforcement learning (to learn a policy)

Swarm intelligence

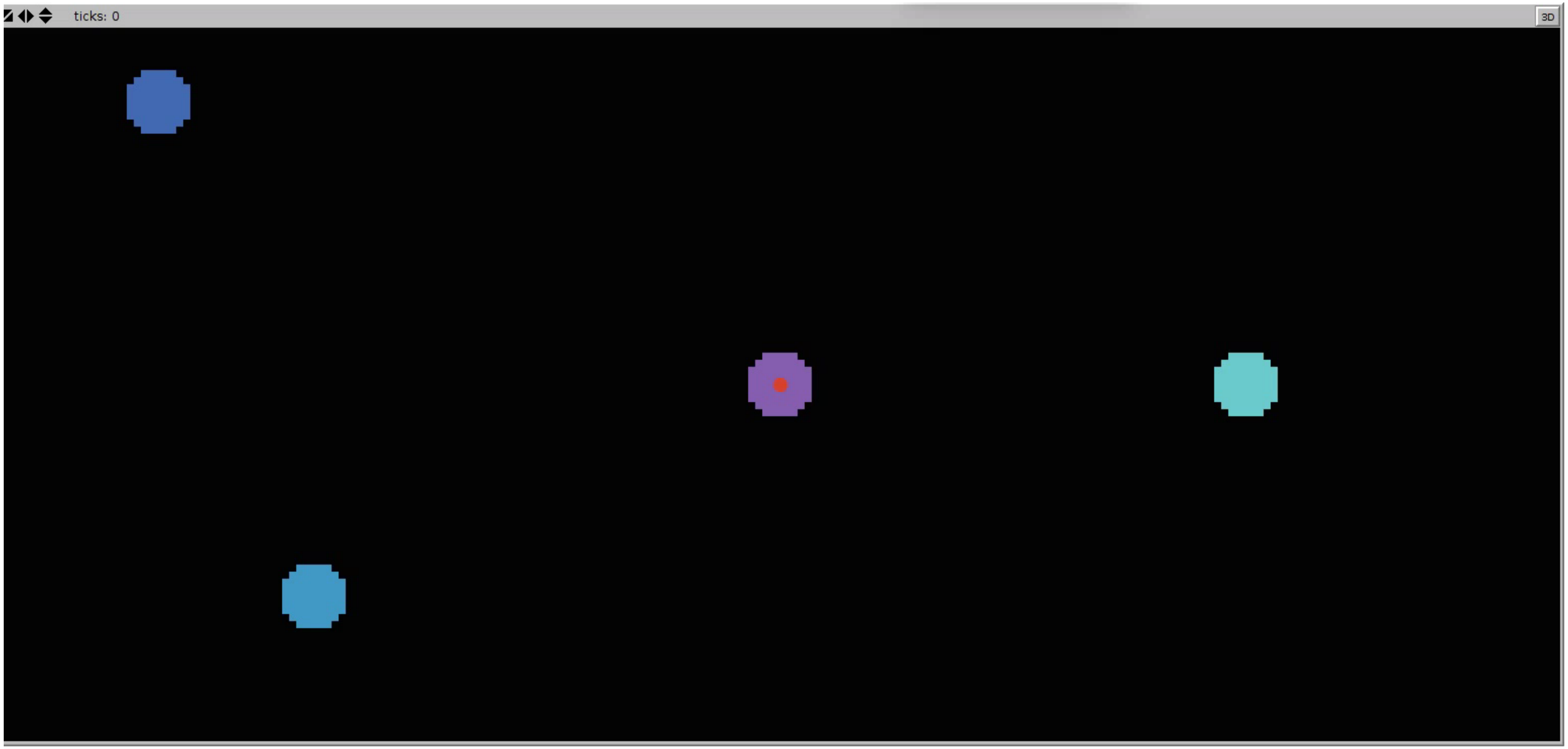
Nature has developed verious forms of distributed intelligence

- our organism, spieces selections for adapting to environmental changes (**Genetic algos**)
- Coordination among animals (ants building huge nests or moving heavy objects without any central coordination) (**Swarm Intelligence**)

Who is governing all this? Who is giving instructions, predict future dynamics, produce plans and maintain equilibrium?

- These smart behaviour emerge autonomously with no central coordination nor supervision.
- Development of intelligent systems based on natural metaphores, that are robust and adaptive.
- Swarm intelligence and swarm robotics

Ants and food search

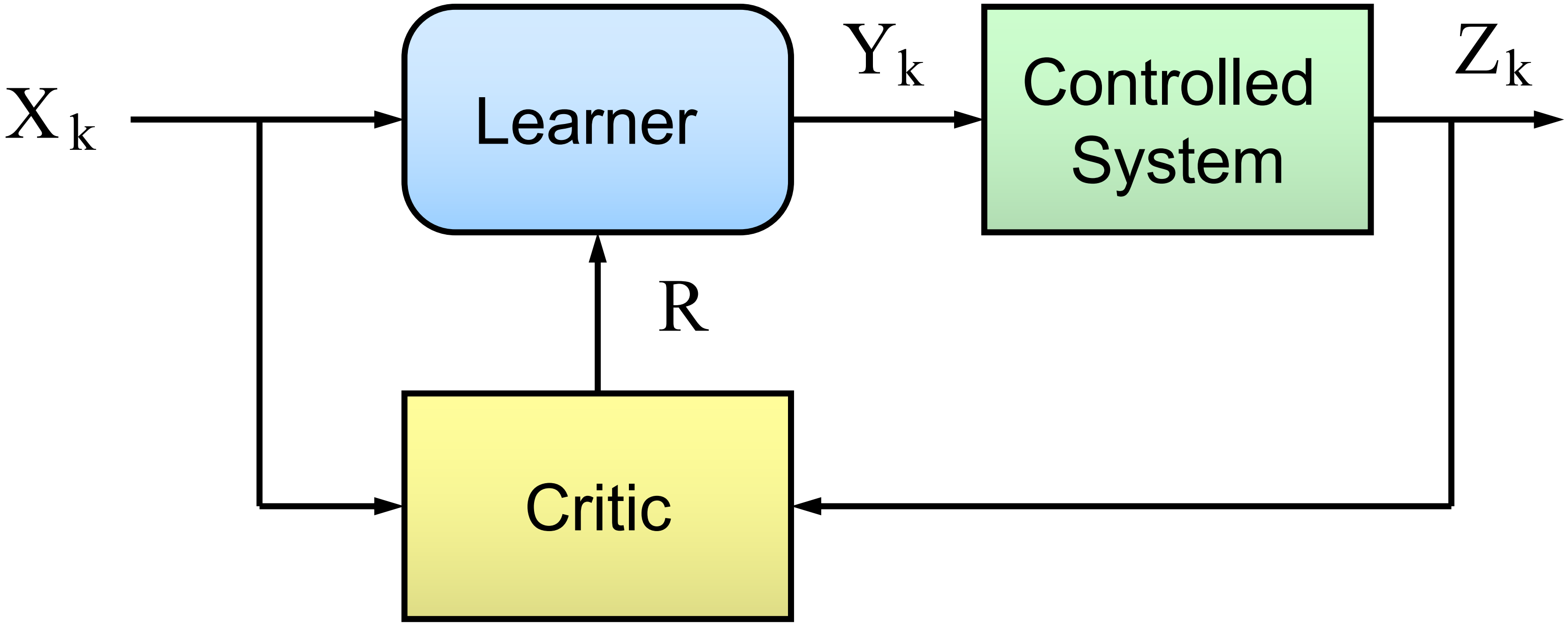


Genetic and evolutionary algorithms

- Genetic algorithms (and evolutionary algorithms in general) are inspired by the natural evolution and have been developed in the 70s by John Holland.
- We start from an initial ramdom population of individuals, that create new individuals through specific laws (cross-over - mutation).
- Fitness: ensures that only the best individuals are kept.
- Mutation: new elements introduced randomly
- Cross-over combines good parent solutions.
- Fitness is not always easy to define. Can be asked to the user in some cases.
- These algorithms are useful when a model of the problem is hard to be defined.

Reinforcement learning

- Learning policies: how to act given a system state



Reinforcement: punishment or reward