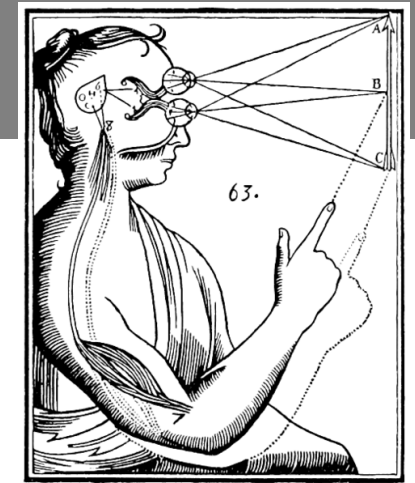


# *Artificial Intelligence*

## Introduction

Marco Piastra

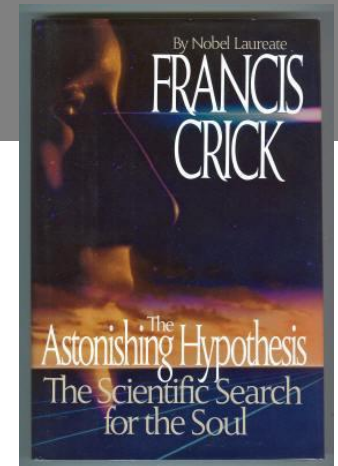
# *Artificial Mind?*



(from Wikipedia)

- [Descartes, R., *Discours de la méthode pour bien conduire sa raison, et chercher la vérité dans les sciences*, 1637]

“I had after this described the **reasonable soul**, and shown that *it could by no means be educed from the power of matter*, as the other things of which I had spoken, but that it must be expressly created; and that it is not sufficient that it be lodged in the human body exactly like a pilot in a ship, unless perhaps to move its members, but that it is necessary for it to be joined and united more closely to the body, in order to have sensations and appetites similar to ours, and thus constitute a real **man**” [English version from Project Gutenberg]

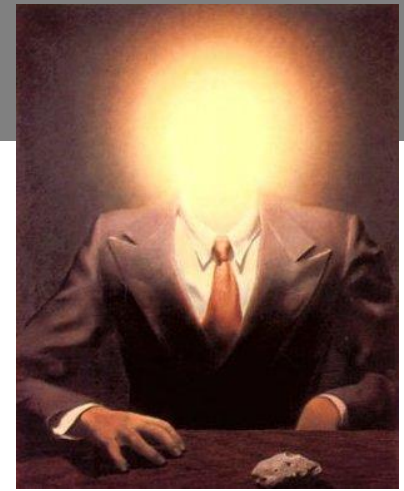


(from Wikipedia)

- [Crick, F., *The Astonishing Hypothesis*, 1994]

“You, your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cell and their associated molecules.”

*Artificial Brain:  
can machines think?*



(from Wikipedia)

- [Searle, J. R., *Minds, Brain and Science*, 1986]

“Because we do not understand the brain very well we are constantly tempted to use the latest technology as a model for trying to understand it.

In my childhood we were always assured that the brain was a telephone switchboard (*‘What else could it be?’*).

I was amused to see that Sherrington, the great British neuroscientist, thought that the brain worked like a telegraph system. Freud often compared the brain to hydraulic and electro-magnetic systems. Leibniz compared it to a mill, and I am told some of the ancient Greeks thought the brain functions like a catapult.

At present, obviously, the metaphor is the digital computer.”

# Turing Machine (A. Turing, 1937)

- An abstract model of effective computation

A **tape**, made up of individual **cells**

Each cell contains a **symbol**, from a finite **alphabet**

A **read/write head**, which can move in each direction - one cell at time

A **state register** that keeps the current **state**, from a finite set

A **transition table**, i.e. a set of *entries* like this:

$\{ \langle \text{current state}, \text{symbol read} \rangle \rightarrow \langle \text{next state}, \text{symbol written}, \text{move} \rangle \}$

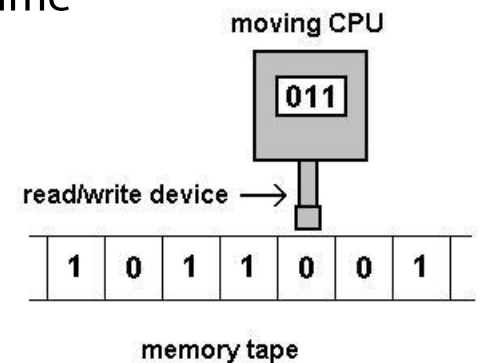
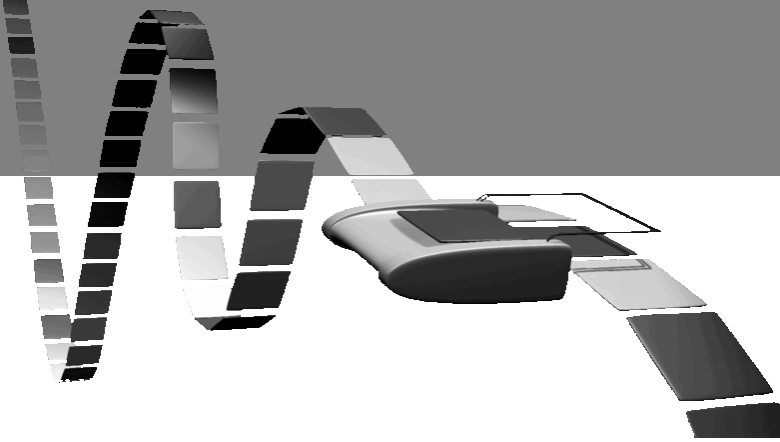
The **transition table** describes a *finite state machine*

Each *transition* is governed by the input symbol, the current state and the corresponding entry in the transition table

The next state is written into the state register

The output is written to the cell

Then the head moves (i.e. *left, right, none*)



# Turing Machine (A. Turing, 1937)

- An abstract model of effective computation

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- What is the meaning of this?

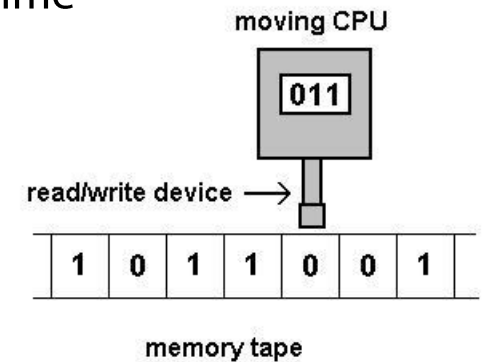
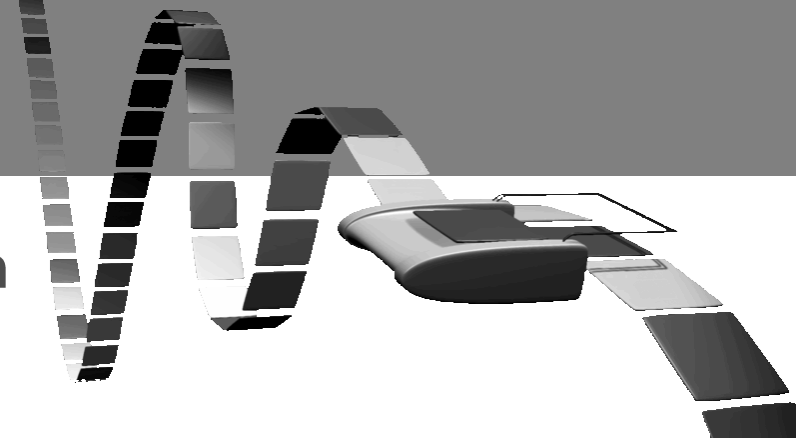
The Turing Machine is a mathematical model of a physical computing device

*(It is very simple)*

Any given problem for which there is a Turing Machine that computes the solution is clearly computable by a physical machine

***Is the vice-versa also true?***

*(If a problem is computable by a physical machine, does it exist a Turing Machine for it?)*





# Church-Turing Thesis



*Caution: there is no such a thesis in the original writings of either author. Its formulation can be extrapolated from both. Hence the attribution (made by others)*

- A possible formulation (from Wikipedia):

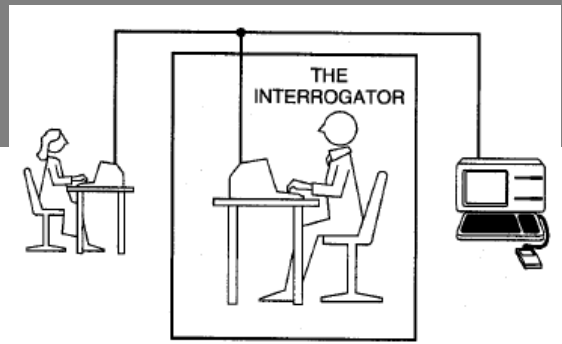
*“Every 'function which would naturally be regarded as computable' can be computed by a Turing machine.”*

*The vagueness in the above sentence gives raise to different interpretations. One of these (though not entirely equivalent) is (from Wikipedia):*

*“Every 'function that could be physically computed' can be computed by a Turing machine.”*

Searle: “... At present, obviously, the metaphor is the digital computer.”

# Can machines think? (the Turing Test)



(from Wikipedia)

- Turing, A., *Computing Machinery and Intelligence*, 1950

“[The ‘imitation game’] is played with three people, a man (A), a woman (B), and an interrogator (C) who may be of either sex.

The interrogator stays in a room apart from the other two.

The object of the game for the interrogator is to determine which of the other two is the man and which is the woman.

He knows them by labels X and Y, and at the end of the game he says either ‘X is A and Y is B’ or ‘X is B and Y is A’

The interrogator is allowed to put **questions** to A and B. [...]

We now ask the question,

‘What will happen when a machine takes the part of A in this game?’

Will the interrogator decide wrongly as often when the game is played like this as he does when the game is played between a man and a woman?

These questions replace our original, ‘Can machines think?’ ”

*Artificial Brain:  
can machines think?*

*Do answers, however partial,  
change the original question?*

# Deep Blue

In 1945 A. Turing mentions playing chess as an example of intelligent human activity that some days machines could perform

In 1946 A. Turing defines the first *algorithm* for playing chess

In 1997 the *Deep Blue* system, made by IBM, beats the world chess champion Gary Kasparov



(from Wikipedia)

- **Deep Blue, 1997** [Campbell, M., Hoane, A. J., Hsu, F., 2001]
  - 30 standard CPUs (120Mhz) + 480 special-purpose CPUs ('chess search engines', each evaluating 2.5M moves per second)
  - Three-layered hardware architecture, 30 GB of RAM
  - Software written in C
  - Wide usage of a large database of recorded games played by grand masters
- Questions:
  - Is Deep Blue *intelligent*?
  - Does Deep Blue *perform* an intelligent human activity?

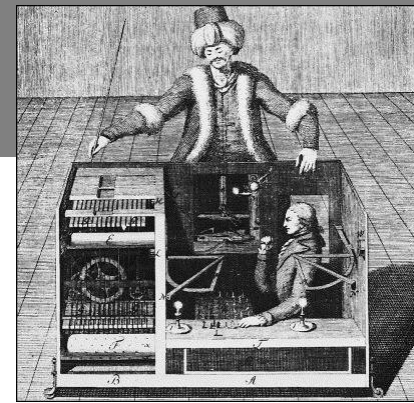
# Can machines play chess?

## ■ Programming a Computer for Playing Chess [Shannon, 1948]

Chess game statistics

More than  $10^{43}$  different legitimate chessboard configurations

More than  $10^{120}$  possible games



(from Wikipedia)

## Strategy A

It is based on an *evaluation function*  $f(P)$  defined for all possible, **final** positions:

+1 if the first player (i.e. the computer) wins, regardless;

0 if it is a draw, regardless;

-1 if the second player wins, regardless;

The machine computes backwards the values of  $f(P)$  of all possible, **non-final** positions starting from all possible **final** positions

The value assigned to each **non-final** position  $P$  is equal to the sum of  $f$  values of the **final** position which  $P$  may lead to

At each move, the computer chooses the move that leads to the position with the maximum value of  $f$

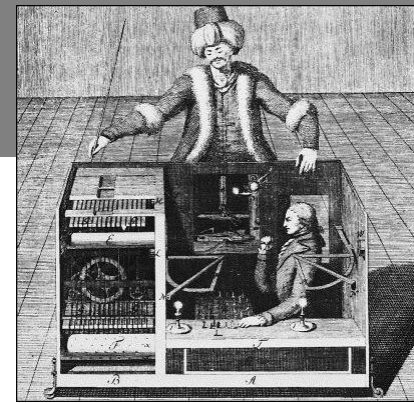
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***This strategy is unfeasible, even with modern computers, as it entails exploring all possible games***

Current supercomputer:  $\sim 10^{16}$  FLOPS,  
i.e.  $\sim 10^{23}$  FLO per year

At one FLO per game (irrealistic)  
this would require  $\sim 10^{97}$  years

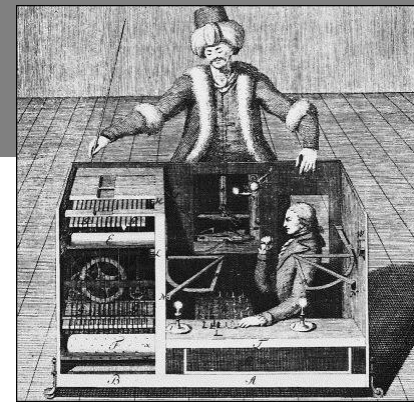
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(from Wikipedia)

### Strategy A (***revised***)

Use an approximate evaluation function  $f^*(P)$  on all possible positions

Given the current position in the game, the machine *looks forward* by exploring all possible positions not farther away than  $k$  moves

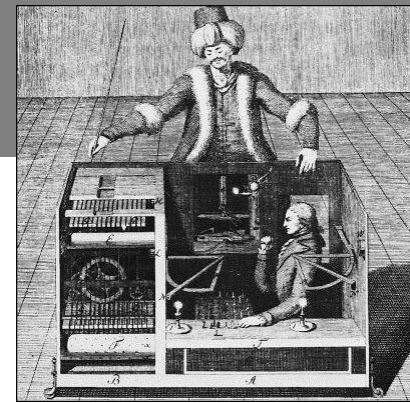
The computer chooses the move with the MINIMAX method

# Can machines play chess?

- Programming a Computer for Playing Chess [Shannon, 1948]

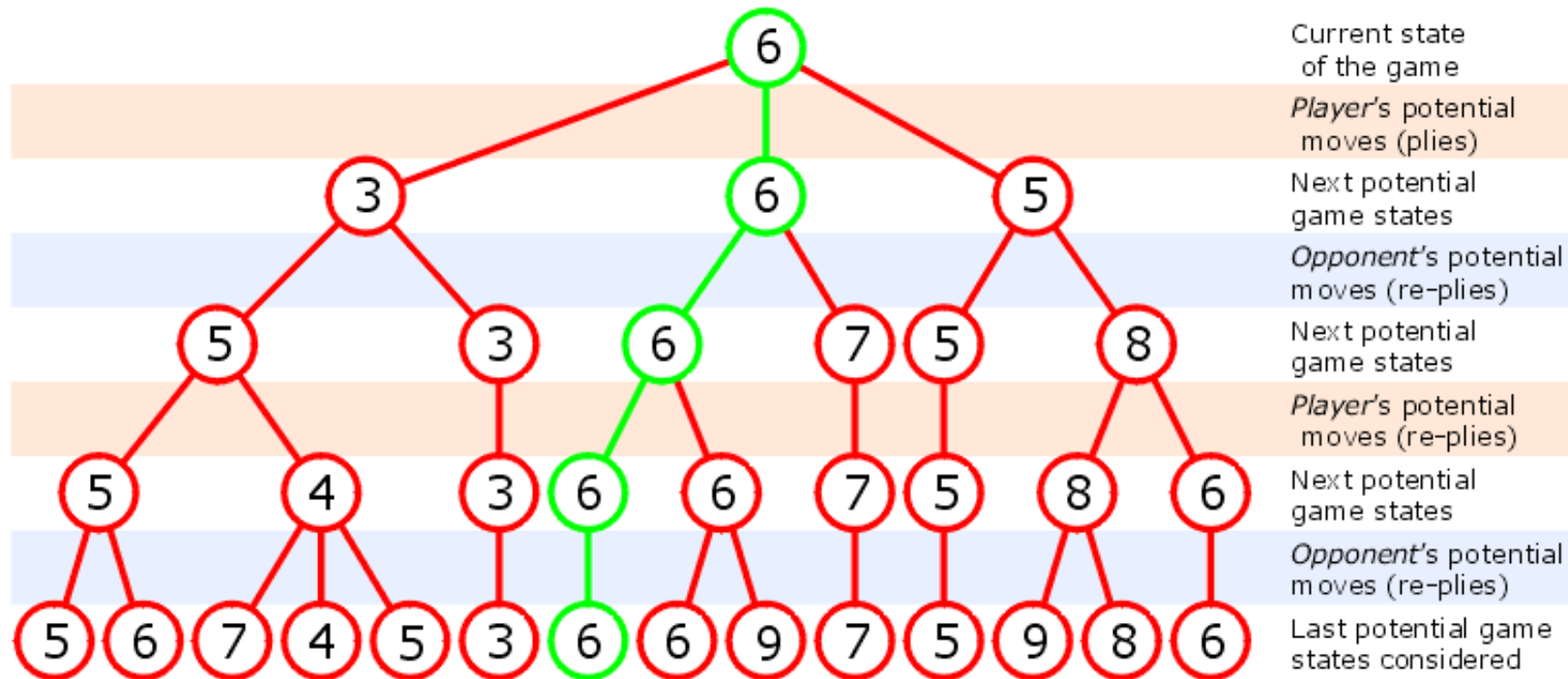
## Strategy A (*revised*)

The computer chooses the move with the MINIMAX method



(from Wikipedia)

Minimax on a two-person game tree of 4 plies



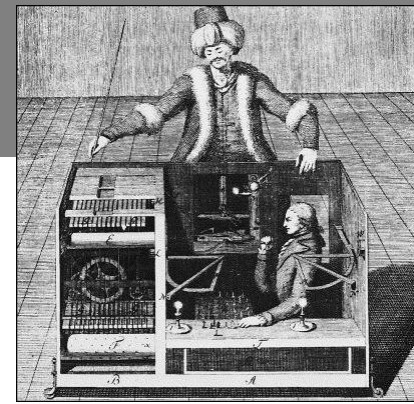
(from Wikipedia)



# Can machines play chess?

## ■ Programming a Computer for Playing Chess [Shannon, 1948]

### Strategy A (*revised*)



(from Wikipedia)

In the game tree for chess, each node has an average *branching factor* of 30

The number of nodes in the game tree is  $O(b^d)$

$b$  is the average *branching factor*

$d$  is the *depth* (i.e. how far the exploration goes)

The complete game tree for ply 2 contains  $30^2$  (i.e. around  $10^3$ ) nodes

The complete game tree for ply 6 around  $10^9$  nodes

A computer that can evaluate  $10^6$  positions per second would take more than 16 minutes

A typical chess game has ply 80-90

Human master players are believed to have an implicit *lookahead* of ply 30-40 and more (but without an explicit computation...)

Note: the MINIMAX method can be optimized (i.e. with *alpha-beta pruning*, see Wikipedia) so that it is possible to double the *depth* that can be explored in the same time

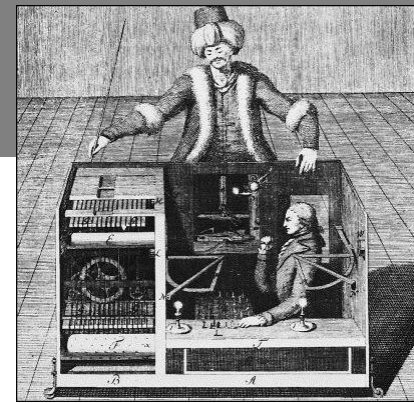
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Use an approximate evaluation function  $f^*(P)$  on all possible positions

Given the current position in the game, the machine *looks forward* by exploring all possible positions not farther away than  $k$  moves

The computer chooses the move with the MINIMAX method (see after)

### Strategy B

“A good human player examines only **a few selected variations** and carries these out to a reasonable stopping point”

Use two functions that evaluate the stability of a position  $P$  and to what extent a move  $M$  in a position  $P$  *is worth being examined* at all

In short: find higher level patterns

# Strategy A or Strategy B?

[Shannon, 1948]

Due to the high computational complexity of Strategy A,  
he foresees a progressive development of Strategy B

(i.e. something like “Computer can improve by emulating humans”)

How did it go, in reality?

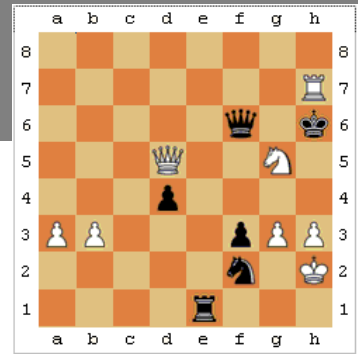
- At the early stages of computer chess technology, Strategy B was preferred
- During the period 1959-1962 a first ‘credible’ player was developed (Kotok-McCarthy)  
(at the *beginner* level)
- In 1973 the developers of the soon-to-be world champion in computer chess players abandoned Strategy B in favor of Strategy A
- Since then, Strategy A – with significant improvements – dominates the scene  
This includes *Deep Blue* and all current top-ranking computers  
Excellent computer chess players (i.e. *grandmaster level*) are now available for smartphones

# Deep Blue

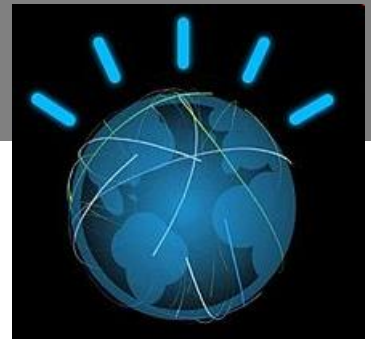
- **Deep Blue, 1997** [Campbell, M., Hoane, A. J., Hsu, F., 2001]
  - Great *lookahead* power
    - On the average, it could search ply 12.2 ply in three minutes
  - Dedicated hardware
    - Special evaluation primitives implemented in silicon
  - Hybrid dedicated machine: hardware + software
    - Software algorithms in C for standard CPUs, easily modified
    - Specialized processors for exploring the game tree
  - Massive parallelism
    - More than 500 processors for parallel exploration
  - Huge database of games by grand masters (humans)

(A *supercomputer* for those times - It was turned off at the end of the match)

- Same questions:
  - Is Deep Blue *intelligent*?
  - Does Deep Blue *perform* an intelligent human activity?



# DeepQA (a.k.a. "Watson")



(from Wikipedia)

- *Jeopardy!*: a quiz game

*Category: General Science*

**Clue:** When hit by electrons, a phosphor gives off electromagnetic energy in this form.

**Answer:** Light (or Photons)

*Category: Diplomatic Relations*

**Clue:** Of the four countries in the world that the United States does not have diplomatic relations with, the one that's farthest north.

**Answer:** North Korea

*Category: Rhyme Time*

**Clue:** It's where Pele stores his ball.

**Answer:** soccer locker

*Category: Lincoln Blogs*

**Clue:** Secretary Chase just submitted this to me for the third time; guess what, pal. This time I'm accepting it.

**Answer:** his resignation

# DeepQA (a.k.a. "Watson")

## ■ DeepQA, 2010 [Ferrucci, D., et al. 2010]

The Event (14-18/02/2011)

In a sequence of three "*Jeopardy!*" games, Watson beats in a very convincing way the all-times human champions

- Brad Rutter, winner of the highest amount of money
- Ken Jennings, winner of the longest string of games

*Jeopardy!*: a quiz game

In the real game, questions can also be about images, audio or video displays

DeepQA can only accept spoken text as input

Autonomous search, local memory

The rules of the challenge forbid connecting to Internet during the game:

DeepQA must use its local memory only

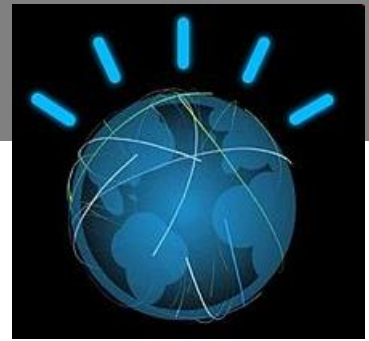
It does use Internet during training

Conventional hardware, massive parallelism

High Performance system, with 2880 standard CPUs (no specialized hardware required)

Linux SUSE ES 11, Software in Java and C++, with Apache Hadoop and Apache UIMA

(IBM expects a commercial return from Watson)

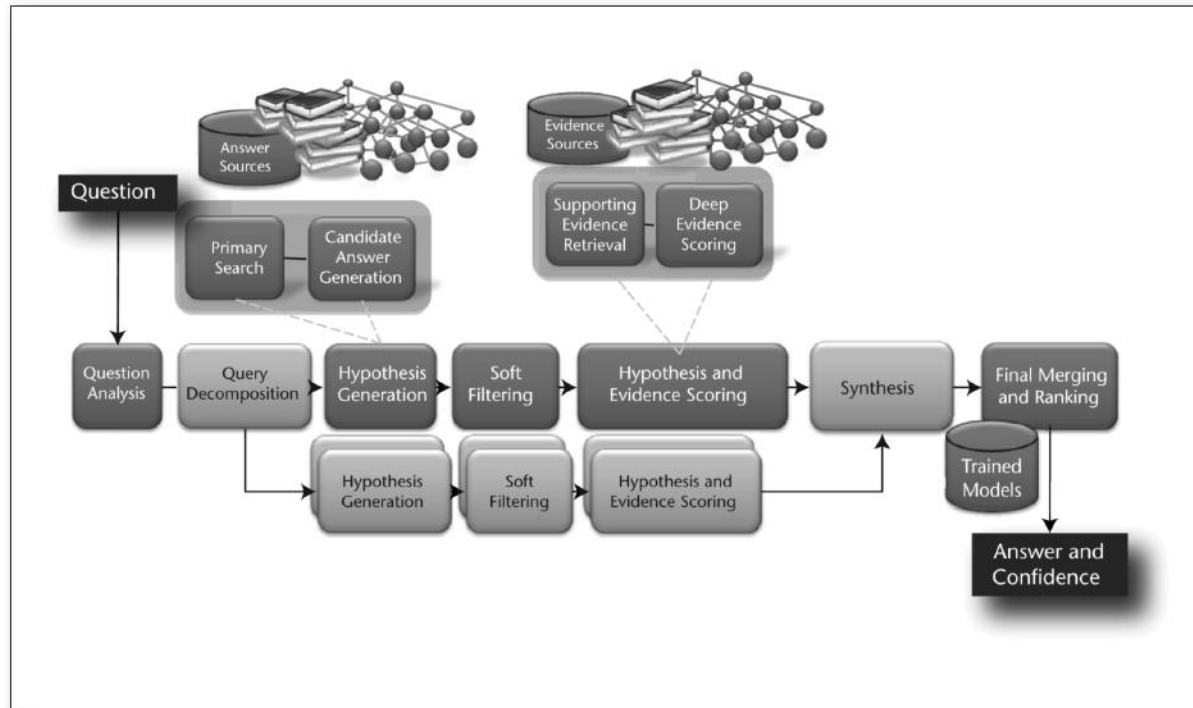


(from Wikipedia)

# DeepQA (a.k.a. "Watson")

- How does it work?

*Very little is known...*



(from [Ferrucci, D, et al. 2010])

## Processing stream

"They used nearly every trick in the book.." (from a video on YouTube)

## Several competing streams in parallel

Each stream scores a 'degree of confidence': the best answer is chosen, at the end

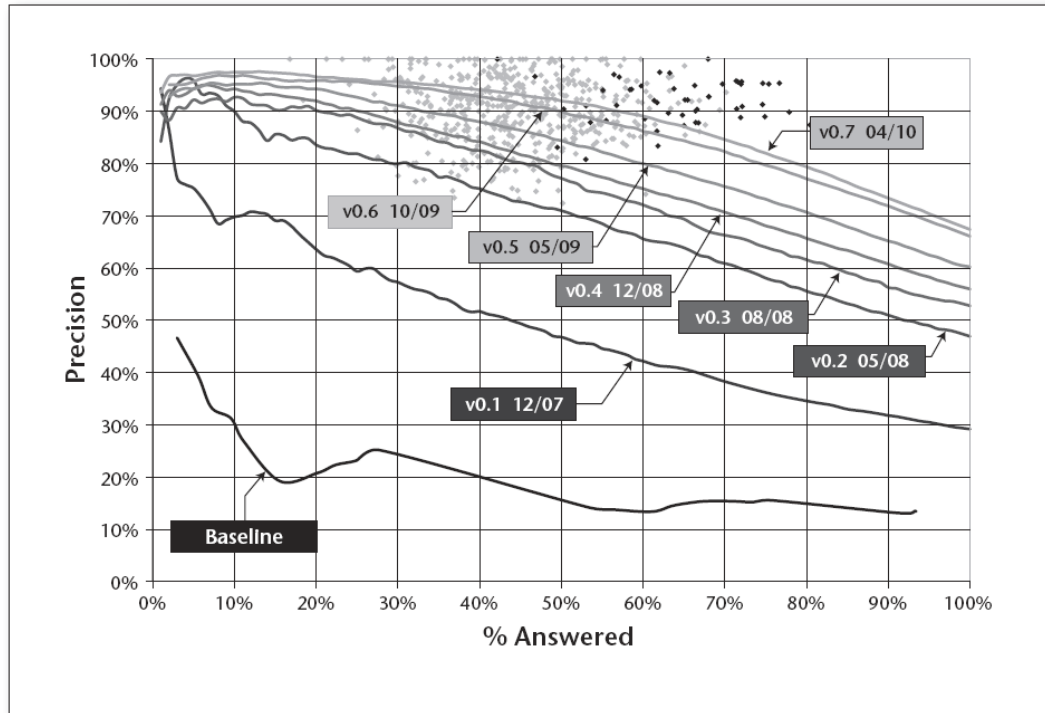


(from Wikipedia)

# DeepQA (a.k.a. "Watson")

- How does it work?

*Very little is known...*



Progressive, incremental training

Vast usage of *machine learning* techniques



(from Wikipedia)

(from [Ferrucci, D, et al. 2010])



# Is Watson intelligent?

## ■ “Does Watson Think?”

[D. Ferrucci, transcript from video  
<http://www.ted.com/webcast/archive/event/ibmwatson>]

“Huh, hmm, what’s my favorite response on that?  
(Do submarines swim?)

[...]

I’d like to look at it as a sort of task-based view:

when you think of Watson playing Jeopardy!  
it is acting like an intelligent Jeopardy! player,  
if you deconstruct its intelligence

you’re gonna find lots of different algorithms  
no one of them you would look at and say

“Wow! That’s really intelligent! It really understands the question!”

[...]

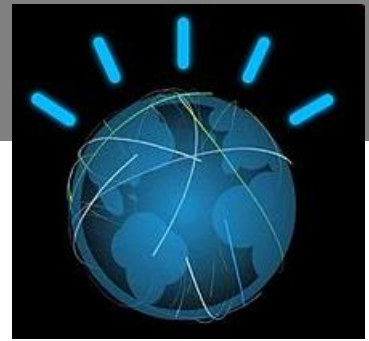
You have this holistic effect,

where it’s solving a problem that you formally think  
that takes you *think*, to solve that problem, ...

Watson is doing it in a perhaps different way.

[...]

And I think ultimately of it as a tool, that helps humans solving problems... “



(from Wikipedia)

# Generalization: Deep Mind

## ■ Playing Atari with Deep Reinforcement Learning, 2013

[V. Mnih, K. Kavukcuoglu, D. Silver, A. Graves, I. Antonoglou, D. Wierstra, M. Riedmiller,  
<http://arxiv.org/abs/1312.5602>,

see also <http://www.nature.com/nature/journal/v518/n7540/full/nature14236.html> ]

A software system only

Runs on virtually any Linux-based system, it contains optional provisions for GPU

*It's open source*

<https://github.com/kuz/DeepMind-Atari-Deep-Q-Learner>

Sophisticated machine-learning techniques

Uses reinforcement learning (RL - *see later in this course*)  
in combination with convolutional neural networks (CNN)

Same configuration, multiple games

Same configuration applied to arcade games

It learned to play 7 (2013) or 49 (2015) different games

*It is autonomous*

*It learns by itself*, it receives no human expertise as input

In many cases, it outperforms human players

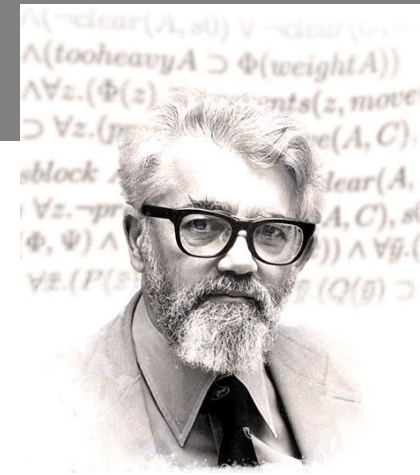
## ■ Same question: Is DeepMind *intelligent*?



(from GitHub)

# *Artificial* Intelligence (a cautious approach)

# "Artificial Intelligence" (first appearance of the term)



(from Wikipedia)

- [John McCarthy et al., 1955]

"We propose that a two-month, ten man study of **artificial intelligence** carried out during the summer of 1956 [...]

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. [...]

It may be speculated that a large part of human thought consists of manipulating **words** according to **rules of reasoning** and **rules of conjecture.**"

# The Physical Symbol System Hypothesis (PSSH)

[Newell, A., Simon, H., *Computer Science as Empirical Inquiry Symbols and Search*, 1976]

“A **physical symbol system** consists of a set of entities, called **symbols**, which are physical patterns that can occur as components of another type of entity called an **expression** (or symbol structure).

Thus, a **symbol structure** is composed of a number of **instances** (or tokens) of symbols related in some physical way (such as one token being next to another).

At any instant of time the system will contain a collection of these symbol structures.

Besides these structures, the system also contains a collection of **processes** that operate on *expressions* to produce other *expressions*: processes of creation, modification, reproduction and destruction.”

# *Do elephants play chess?*

[Brooks, R., *Elephants Don't Play Chess*, 1990]

- Criticism of *intelligence* intended as the manipulation of *symbols*

- A unique and synchronous control system

- Studies on cerebral lesions suggest otherwise

- A unique, *general purpose* and neutral computational device

- Studies about human visual perception show clear preferences towards some interpretations over others

- A unique language for the internal representation of reality

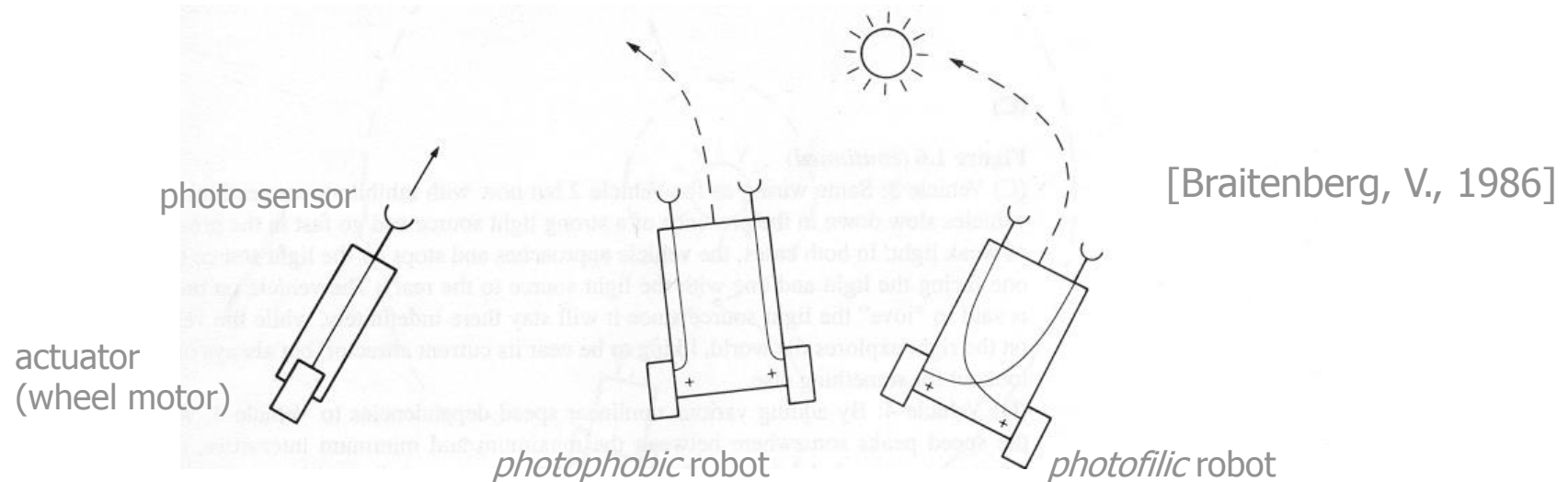
- Human beings do it differently – e.g. *change blindness*  
[O'Reagan, J. K., Rensink, R. A., Clark, J. J., 1999]

- Total separation between the thinker and its hardware (*disembodiment*)

- Hence excluding all forms of non-symbolical intelligence

- (Besides, how could it possibly *evolve* such a form of intelligence?)

# Does this behavior look intelligent?



## ■ Direct connection

These robots by V. Braitenberg have just a *reactive* behavior, i.e. no 'thought in between': since sensors are directly connected to actuators

The resulting behavior is remarkable anyway ... ("*intelligence is in the eye of the beholder*")

# Artificial Intelligence

- A modern (*and cautious*) approach
  - “The study of computer-based tools that help humans solving problems which *they* think require intelligence”



# Artificial Intelligence

- A modern (*and cautious*) approach
  - “The study of computer-based tools that help humans solving problems which *they* think require intelligence”
  - “And which, from time to time, helps them understanding how *their own* intelligence actually works.”

# Artificial Intelligence: *short plan of this course*

# Artificial Intelligence: *part 1*

- *Reasoning with symbols*

**Propositional logic then first-order logic, logic programming** (hints)

*Representation*: language and semantics

*Inference*: entailment

*Automation*: machines that computing entailment

*Plausible reasoning*: beyond the scope of entailment

# Artificial Intelligence: *part 2*

- *Reasoning with numbers*

  - Probability and machine learning**

    - Representation*: probability, graphical models

    - Inference*: answers from joint probabilities

    - Supervised learning*: learning from complete and well-formed datasets

    - Unsupervised learning*: when some of the data are either missing or hidden

    - Reinforcement learning*: learning while experiencing (even *online*)

    - Self-organization*:

      - the system changes its configuration in reaction to inputs (even *online*)