Artificial cognitive systems: from concept to the development of intelligent behaviors in autonomous robotics

Christophe SABOURIN
sabourin@u-pec.fr
Laboratoire Images, Signaux et Systèmes Intelligents (EA-3956)

UPEC UNIVERSITÉ PARIS-EST CRÉTEIL | IUT SENART FONTAINEBLEAU

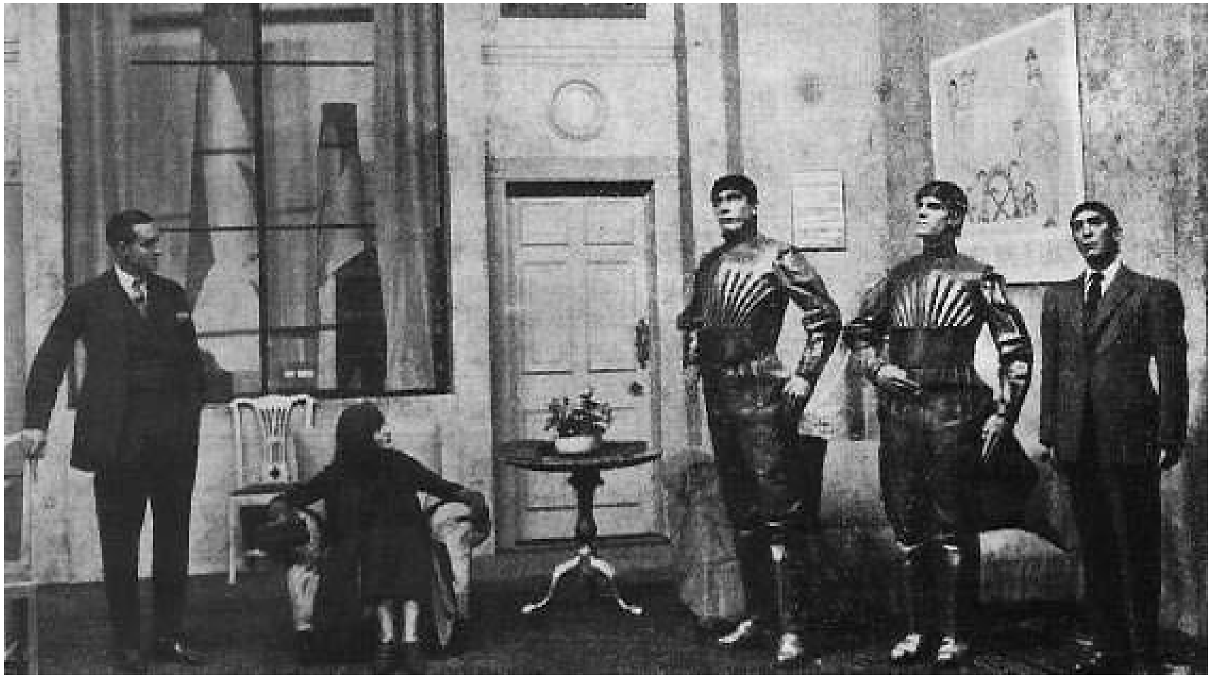
17/01/2023

A-Introduction : Brief history of AI and Autonomous Robotics

- literature book
- Cybernetics
- Brief history of IA
- Brief history of autonomous robotics
- Towards robots with cognitive abilities

Literature book

The word “robot” appears for the first time during a theatre play of Karel Capek in 1920: Rossum's Universal Robots. He comes from the Czech word 'robota' (servitude) and presents a vision of robots as docile and efficient servants to carry out the hard task . But they will rebel against their creators.



https://en.wikipedia.org/wiki/R.U.R .

Literature book

- Isaac Asimov (1920, 1992), Writer and Professor of biochemistry
- He writes science fiction books about robotics
- According to the Oxford English Dictionary, the word robotics was first used by Isaac Asimov, in his science fiction short story "Liar!", published in May 1941 in Astounding Science Fiction

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

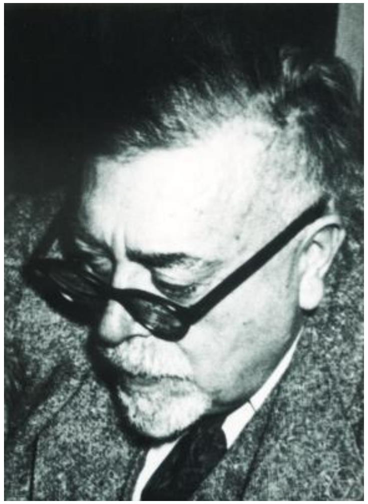
The Three Laws of Robotics (*The Robots (1950)*, Isaac Asimov) :

First law : «A robot may not injure a human being or, through inaction, allow a human being to come to harm . »

Second law : «A robot must obey the orders given it by human beings except where such orders would conflict with the First Law »

Third law Loi : «A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws »

Cybernetics



- **Norbert Wiener (1894 –1964), Mathematician and Philosopher.**
- **He was a professor of mathematics at the Massachusetts Institute of Technology (MIT)**
- **He is author of "Cybernetics or Control & Communication in the Animal & the Machine"**
- **Wiener is considered the originator of cybernetics**

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

- **William Grey Walter (1910 –1977), Neurophysiologist, Cybernetician and Robotician.**
- **Gray Walter built the "*first autonomous electronic robots*"**

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

The design of the "first" autonomous robot is based on the desire to understand and reproduce the behavior of animals or humans:

Book about "Cybernetics":

Cybernetics or Control and Communication in the Animal and the Machine,

(N. Wiener - 1948)

Turtle robots
(Grey Walter - 1950)

https://www.youtube.com/watch?v=lLULRlmXkKo

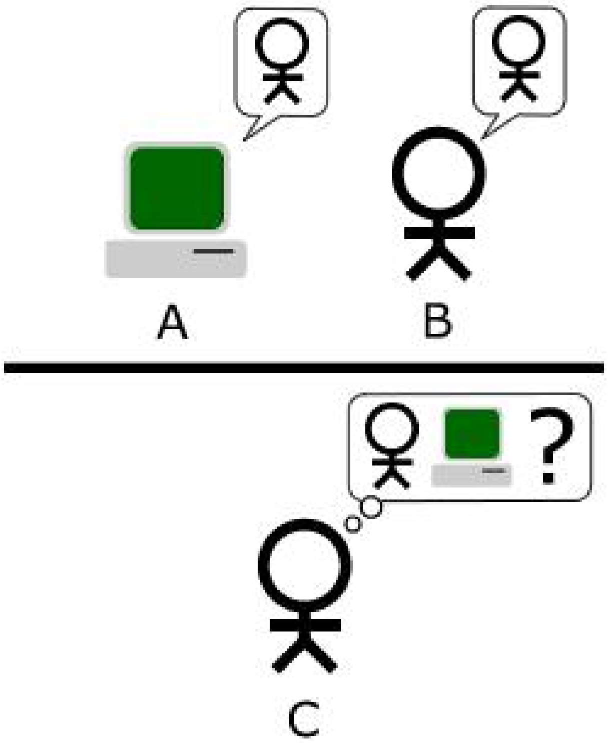
One definition of Cybernetics (N. Wiener 1950): the scientific study of control and communication in the animal and the machine

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

In 1950, in the paper « Computing Machinery and Intelligence », Alan Turing considers the question "Can machines think?“. And the paper introduces the “Turing test”

In the "standard interpretation" of the Turing Test, an interrogator is tasked with trying to determine which player is a computer and which is a human

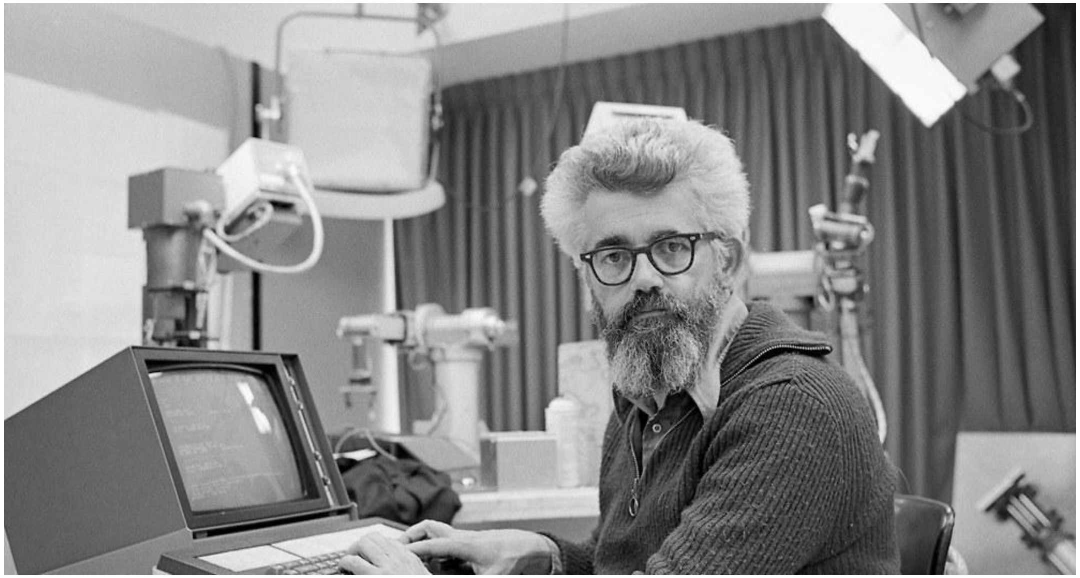
- Player A is a machine, player B is an human and player C (who plays the role of the interrogator) is an human.
- Player C is unable to see either player A or player B (and knows them only as X and Y), and can communicate with them only through written notes or any other form that does not give away any details about their gender.
- By asking questions of player A and player B, player C tries to determine which of the two is the man and which is the machine.



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

The Dartmouth Summer Research Project on Artificial Intelligence was the name of a 1956 summer workshop now considered by many (though not all) to be the seminal event for artificial intelligence as a field.

This conference was organized by Marvin Minsky, John McCarthy, Claude Shannon et Nathan Rochester (IBM).



McCarthy

1) Dr. Marvin Minsky
2) Dr. Julian Bigelow
3) Professor D.M. Mackay
4) Mr. Ray Solomonoff
5) Mr. John Holland
6) Mr. John McCarthy.

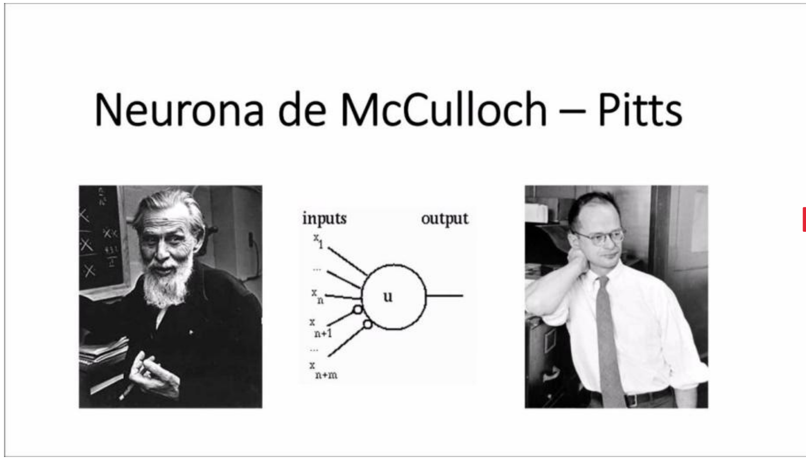
7) Dr. Claude Shannon
8) Mr. Nathanial Rochester
9) Mr. Oliver Selfridge

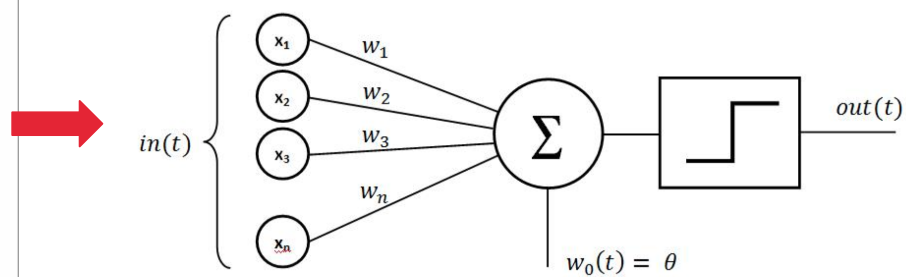
10) Mr. Allen Newell
11) Professor Herbert Simon.

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

Brief history of IA

The first mathematical and computer model of the biological neuron was proposed by Warren McCulloch and Walter Pitts in 1943.





1957 : Frank Rosenblatt invente le perceptron

1985 : Rétro propagation (Rumelhart, Parker, Le Cun) / Perceptron multicouche

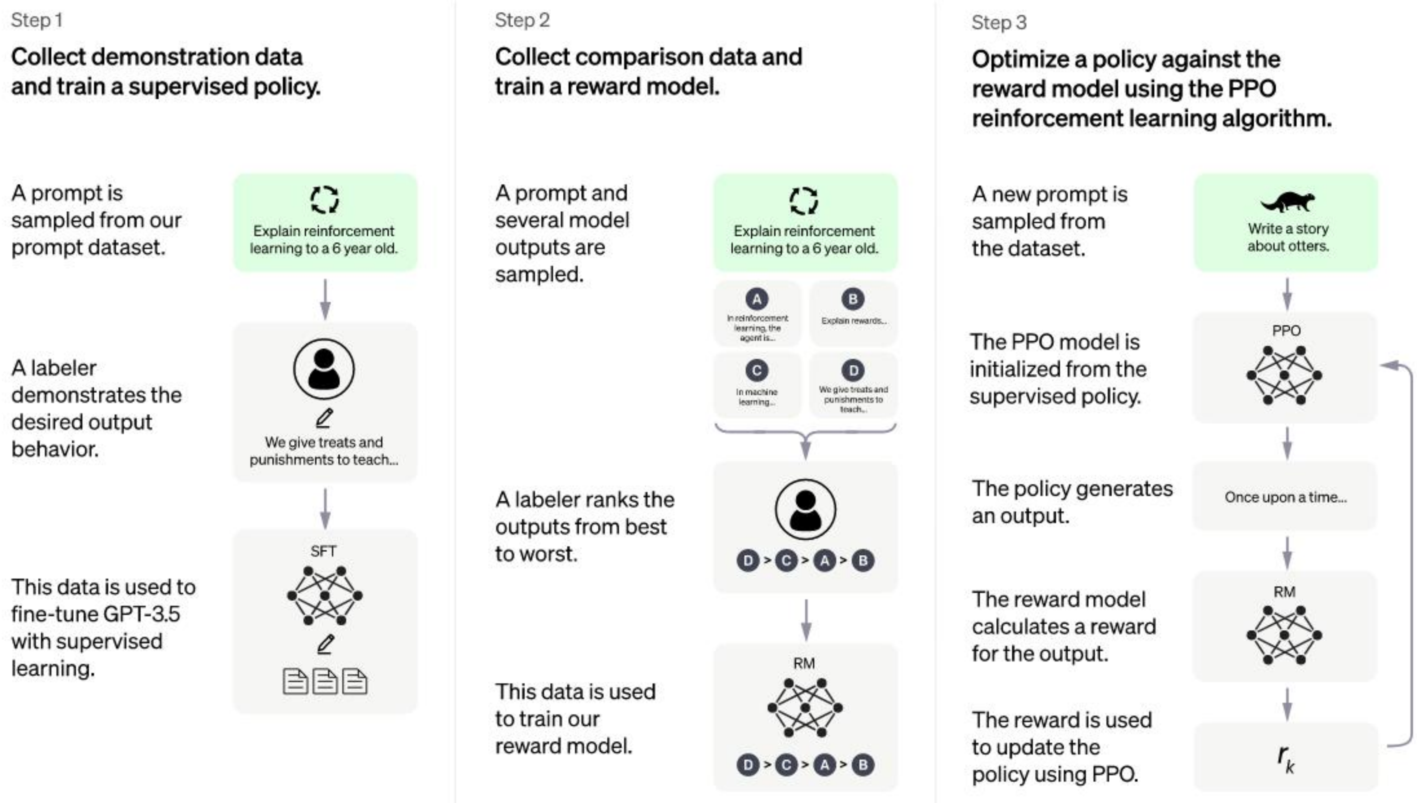
1989 : Le Cun utilise la “back-propagation “ pour l’apprentissage d’un CNN

- **2010 : Deep Learning**

Brief history of IA

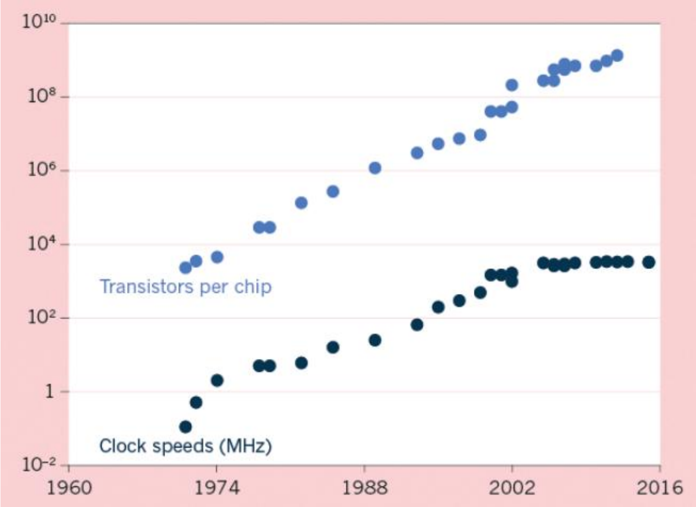
http://www.cea.fr/multimedia/Pages/videos/culture-scientifique/technologies/histoire-intelligence-artificielle.aspx

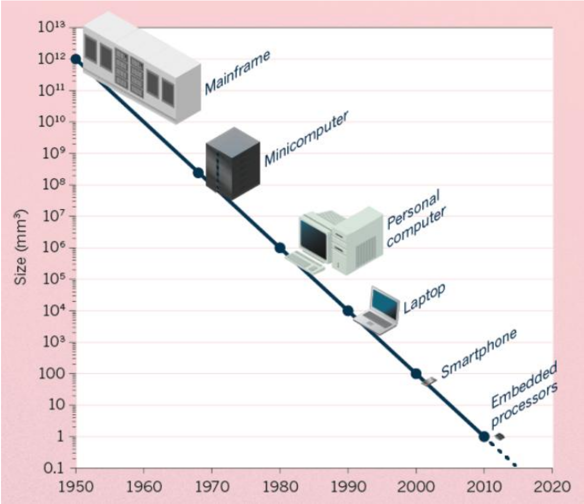
ChatGPT (Generative Pre-trained Transformer)



https://openai.com/blog/chatgpt/

But although during the last fifty years, a lot of progress have be done in algorithm and computing power, today, the AI is still far from equalizing all human abilities.



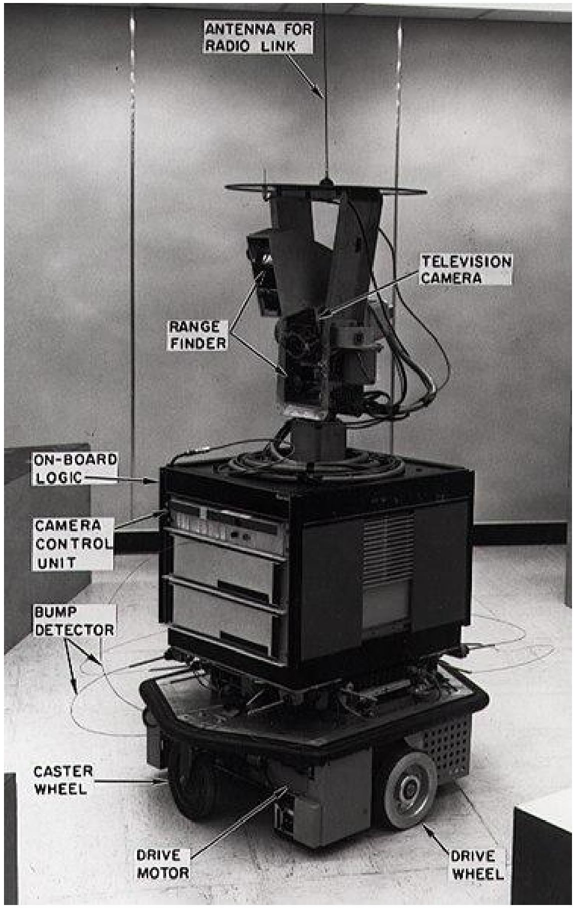


M. Waldrop, « The chips are down for Moore's law », Nature News, vol. 530, nº 7589, p. 144, févr. 2016.

85x10^9 neurons, 10^4 synapses/neuron
1.4 kg, 1.7 litres

« Our brain has a talent from birth that the best artificial intelligence software can't yet imitate: the ability to learn. »

Stanislas Dehaene. « Apprendre ! Les talents du cerveau, le défi des machines »



Shakey (1966 -1972) : The project combined research in robotics and artificial intelligence. Shakey was developed at the Artificial Intelligence Center of Stanford Research Institute (now called SRI International).

Hardware equipment:

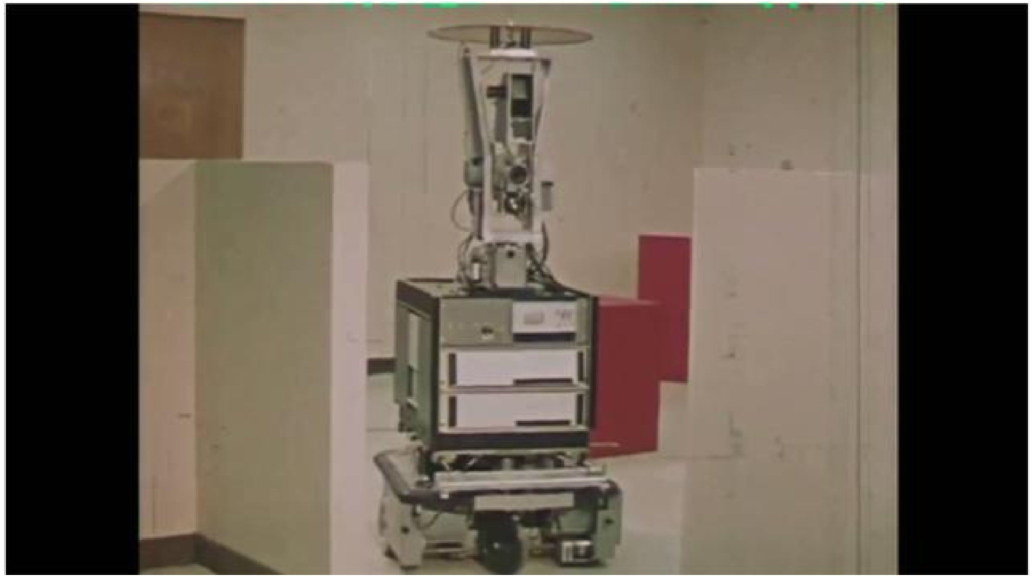
- antenna for a radio link,
- sonar range finders, camera,
- on-board processors,
- collision detection sensors

Abilities:

- perception,
- obstacle avoidance,
- path planning,
- moving to a desired position

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

Shakey (1966 -1972) : The project combined research in robotics and artificial intelligence. Shakey was developed at the Artificial Intelligence Center of Stanford Research Institute (now called SRI International).



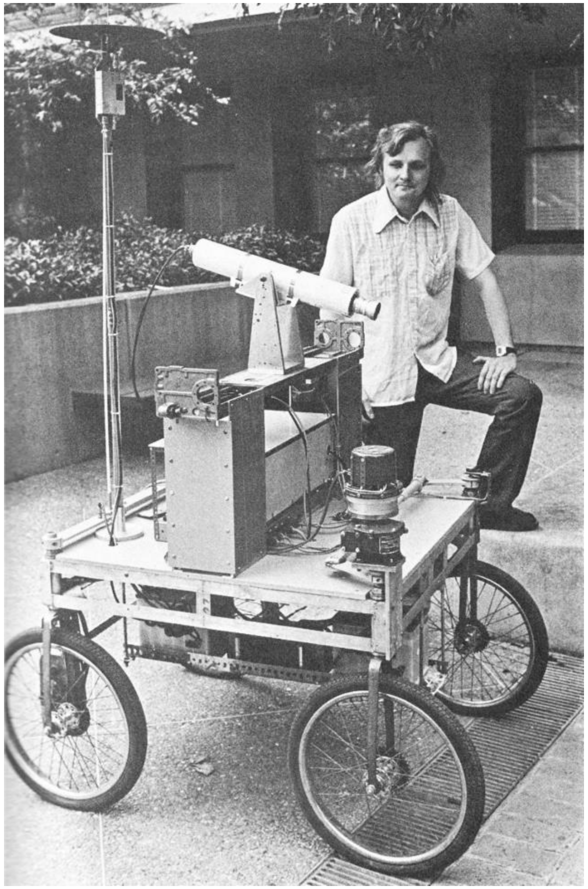
Hardware equipment:

- **antenna for a radio link,**
- **sonar range finders, camera,**
- **on-board processors,**
- **collision detection sensors**

Abilities:

- **perception,**
- **obstacle avoidance,**
- **path planning,**
- **moving to a desired position**

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



- Hans Peter Moravec (born in1948),
- Stanford Cart (1973-1979)
- techniques in computer vision for determining the region of interest (ROI) in a scene.

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

Moravec's paradox is the discovery by artificial intelligence and robotics researchers that, contrary to traditional assumptions, high-level reasoning requires very little computation, but low-level sensorimotor skills require enormous computational resources.

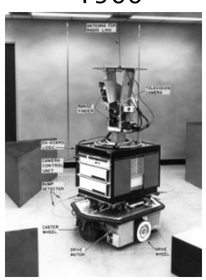
https://en.wikipedia.org/wiki/Moravec%27s_paradox

Brief history of autonomous robotics

The turtles Elmer and Elsie
(Birth of Cybernetics)

1950

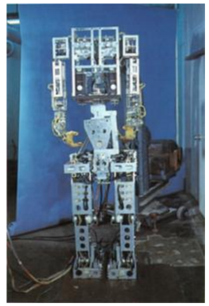
1966



Robot Shakey
(IA & Robotics)

1973

Robot Wabot
(1er humanoid robot)



2000

Robot Asimo
(One of the humanoid robot)

2010

Google car
(Autonomous car)

21st century

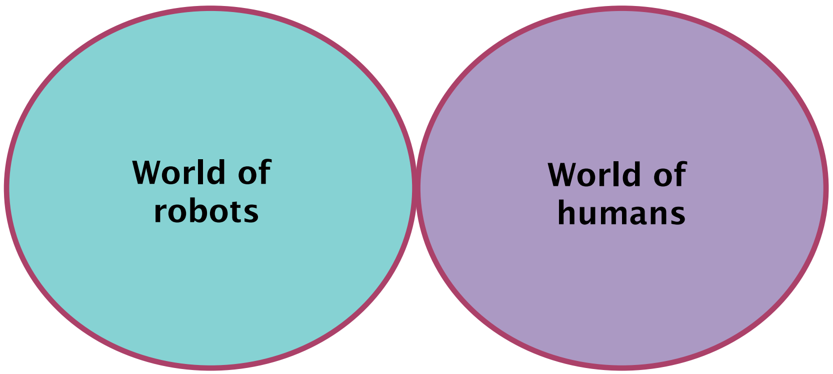
Personal Robotics – Cobotique
(At home, In manufactury)

Robots substitute humans — 20st century

Robots and humans live together — 21st century

Brief history of autonomous robotics

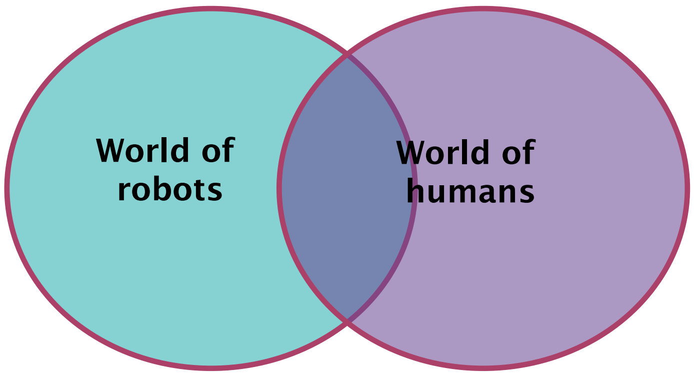
Robots substitute humans (In manufactory, in dangerous environment)



Robots and humans live in different environments

$20^{ème}$ siècle

Robots and humans work together



Robots and humans live in the same environment

$21^{ème}$ siècle

ROMEO project: new generation of personal assistant robots

The objective of the ROMEO project is to develop a new generation of personal assistant robots able to move in a real human environment and to interact with humans in order to help him during the daily tasks.

http://projetromeo.com/

- Although during the last century, a lot of progress have be done in the robotic field, today, the robot are still far from equalizing human abilities.

- The scientific and technological challenges in robotics during the of 21st century will focus on the design of robots able of cohabiting (assisting, collaborating) with human being.

These robotic systems will therefore have to demonstrate a great flexibility and adaptation by developing, during their "live", new cognitive abilities allowing them to learn to cohabit gradually with human beings.

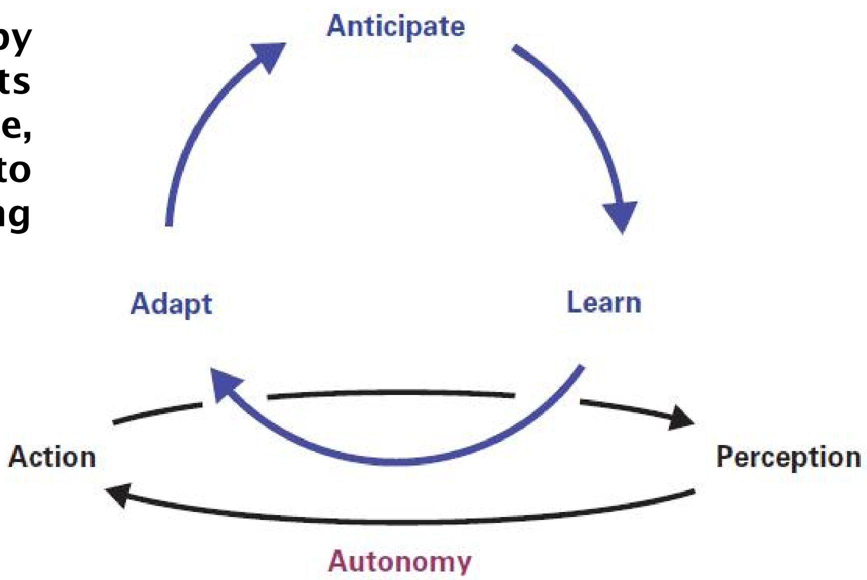
B. Cognitive Robotics & Cognitive Sciences

- **What Is Cognitive Robotics?**
- **Cognitive science**
- **Connectionism paradigm**
- **Cognitivism paradigm**
- **Embodied cognition**
- **Behavioral and Cognitive Capabilities**

Definition : Cognitive robotics is the field that combines insights and methods from AI, as well as cognitive and biological sciences, to robotics.

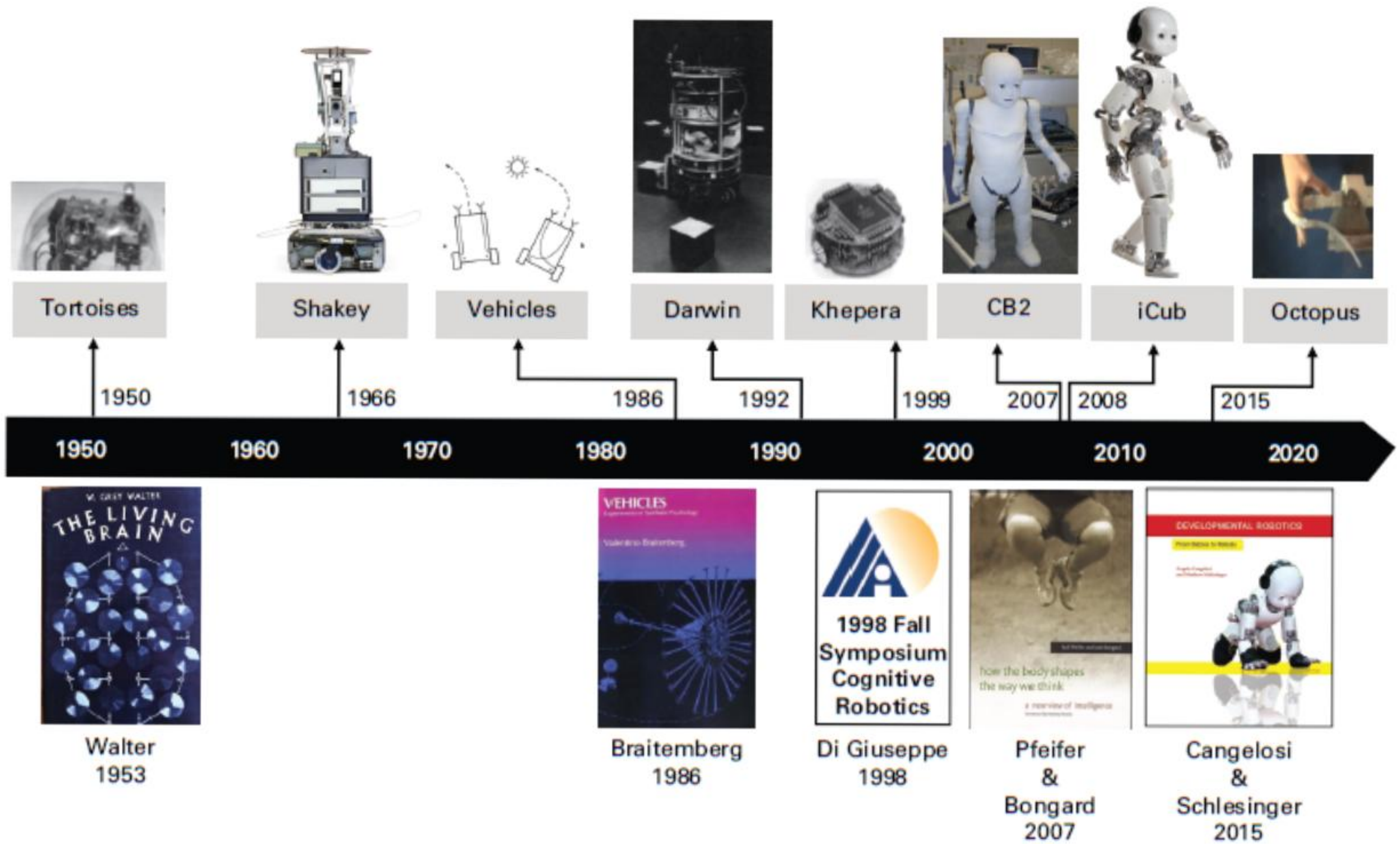
Cognition can be defined as “the process by which an autonomous system perceives its environment, learns from experience, anticipates the outcome of events, acts to pursue goals, and adapts to changing circumstances. (D. Vernon, 2014)

Cognition can be represented as a cycle of anticipation, assimilation, and adaptation, embedded within a continuous process of action and perception and dynamically adapting via learning



A. Cangelosi et M. Asada, « What Is Cognitive Robotics? », mai 2022, doi: 10.7551/mitpress/13780.003.0005.

History of Cognitive robotics



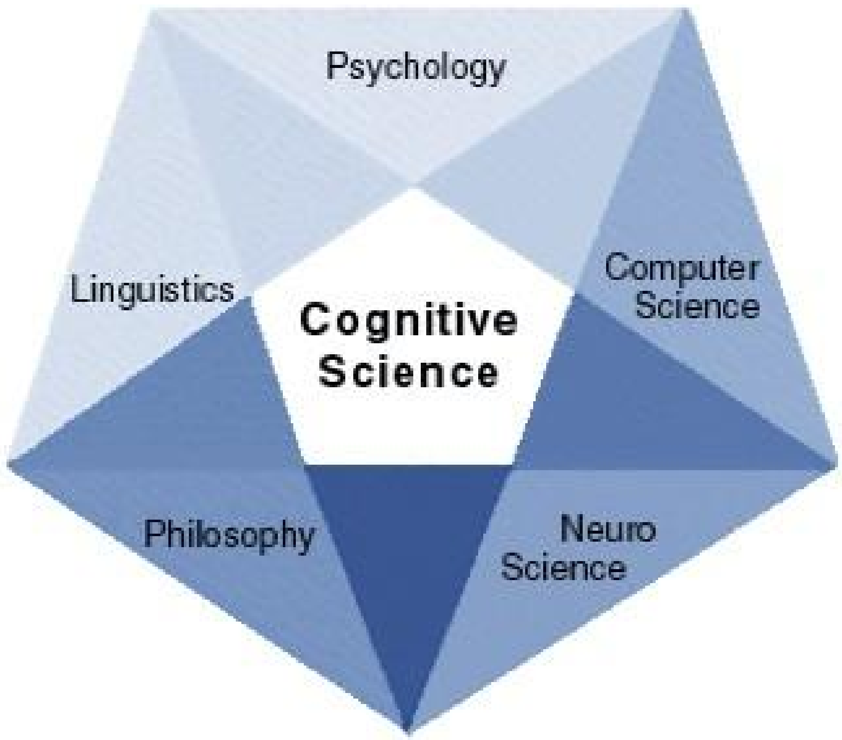
A. Cangelosi et M. Asada, « What Is Cognitive Robotics? », mai 2022, doi: 10.7551/mitpress/13780.003.0005.

Cognitive science

Cognitive science is the interdisciplinary, scientific study of the mind and its processes. It examines the nature, the tasks, and the functions of cognition.

Cognitive scientists study intelligence and behavior, with a focus on how nervous systems represent, process, and transform information.

Mental faculties of concern to cognitive scientists include language, perception, memory, attention, reasoning, and emotion; to understand these faculties, cognitive scientists borrow from fields such as linguistics, psychology, artificial intelligence, philosophy, neuroscience, and anthropology



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

Cognitive science offers a transversal theoretical framework suitable to the development of artificial cognitive systems for robotics.

Two main paradigms:

For the cognitivism paradigm, the brain converts the perception of the world into internal symbolic representations that it then manipulates using a set of predefined rules to compute outputs. We can therefore compare the brain to a computer that processes information via purely symbolic processes.

For the connectionism paradigm, the brain (the mind) is modelled by using interconnected networks (neural networks). The parallel operations of these networks must allow, from input stimuli, to reproduce cognitive activities such as perception, language, sensory-motor control.

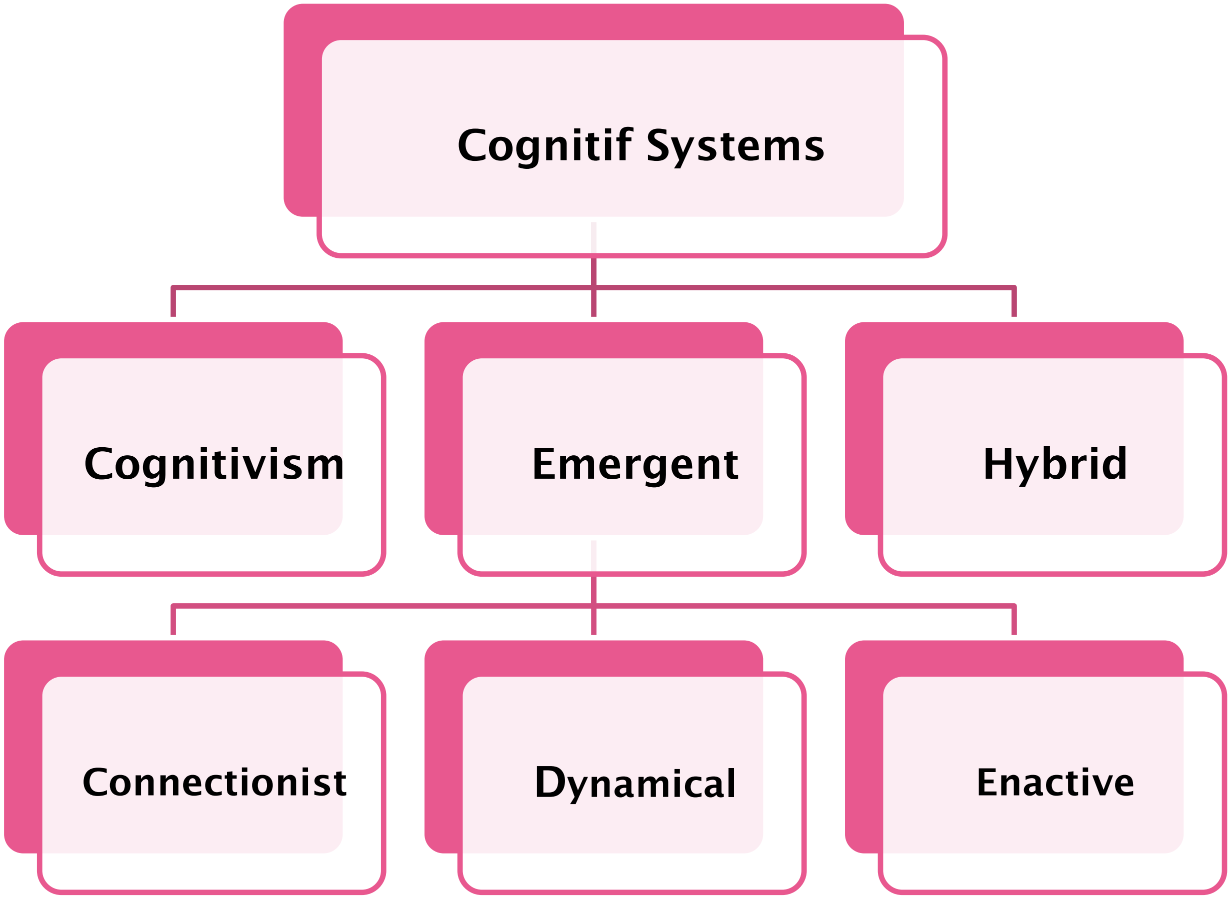
The two paradigms are complementary: the cognitivist makes it possible to model a reasoning, and the connectionist is well adapted for sensorimotor control.

But the more important point is to know whether cognition can be completely "disembodied" or, on the contrary, necessarily "embodied".

Embodied cognition (Enaction): The principal idea of enaction is that a cognitive system develops it own understanding of the world around it through its interactions with the environment:

- **« Autonomy »**
- **« Embodiment »**
- **« Emergence »**
- **« Experience »**
- **« Sense-making »**

Cognitive science



Cognitive science

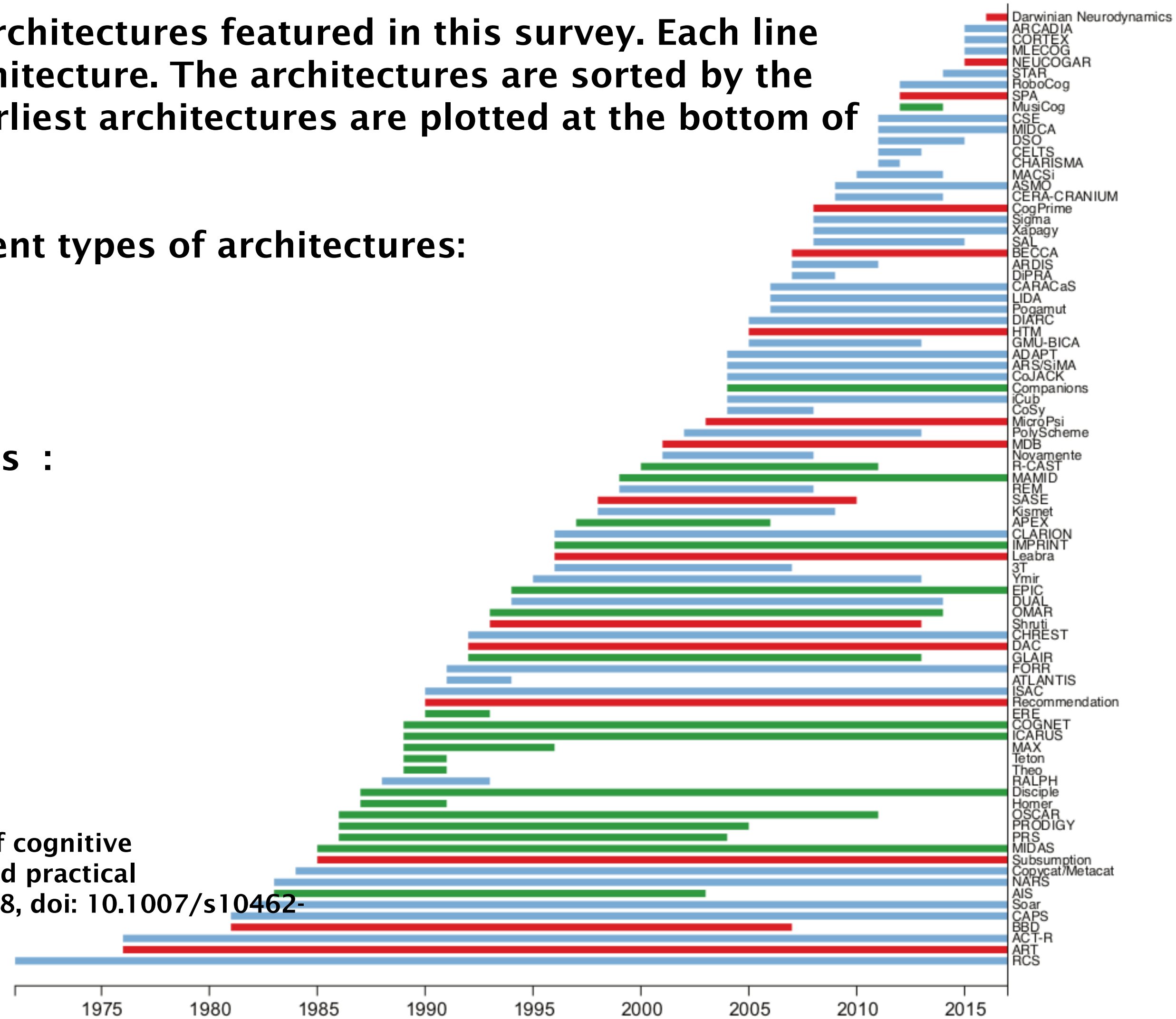
A timeline of 84 cognitive architectures featured in this survey. Each line corresponds to a single architecture. The architectures are sorted by the starting date, so that the earliest architectures are plotted at the bottom of the figure.

Colors correspond to different types of architectures:

- **symbolic (green)**
- **emergent (red)**
- **hybrid (blue).**

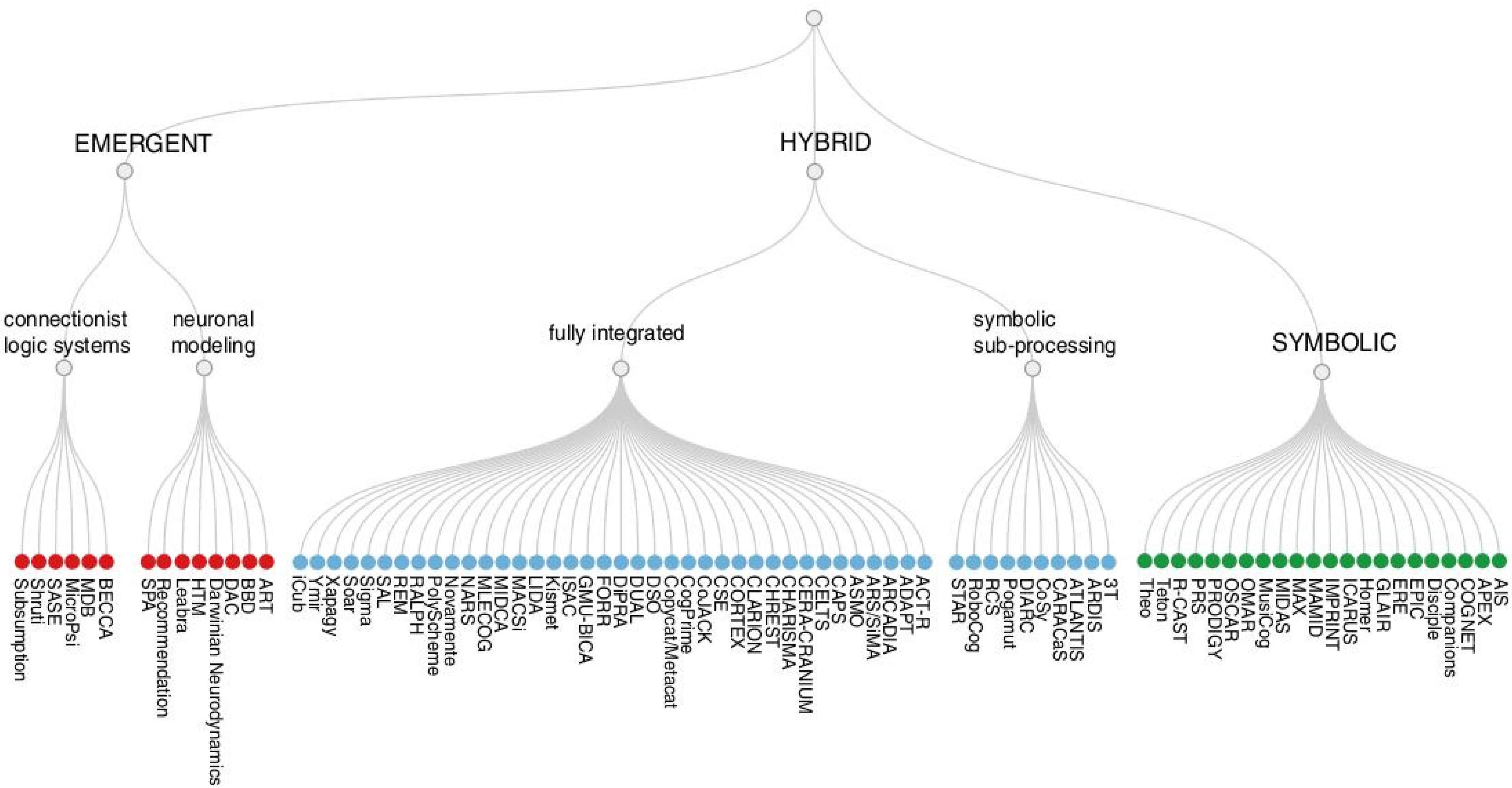
Seven core cognitive abilities :

- **perception,**
- **attention mechanisms,**
- **action selection,**
- **memory,**
- **Learning,**
- **reasoning,**
- **and metareasoning**



Kotseruba et J. K. Tsotsos, « 40 years of cognitive architectures: core cognitive abilities and practical applications », Artif Intell Rev, juill. 2018, doi: 10.1007/s10462-018-9646-y.

Cognitive science

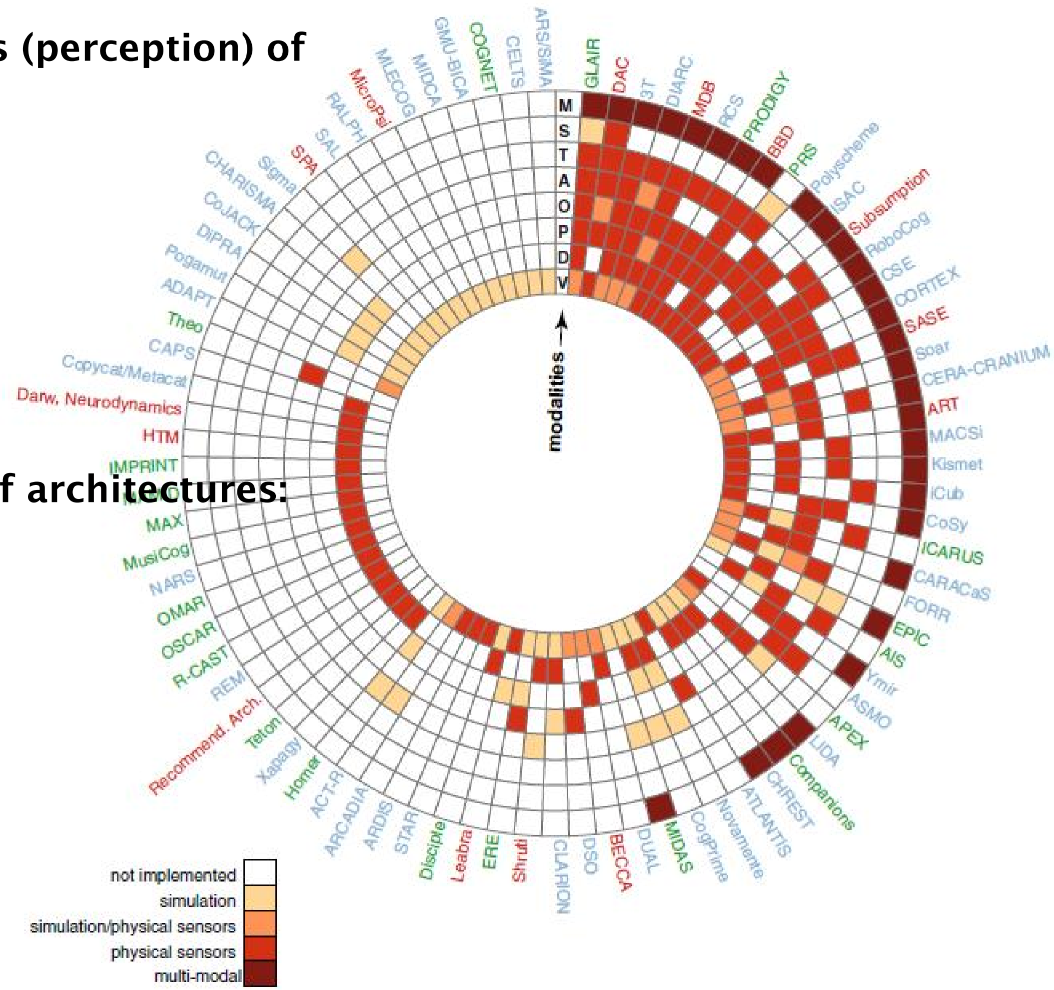


Kotseruba et J. K. Tsotsos, « 40 years of cognitive architectures: core cognitive abilities and practical applications », Artif Intell Rev, juill. 2018, doi: 10.1007/s10462-018-9646-y.

Cognitive science

A diagram showing sensory modalities (perception) of cognitive architectures :

- **vision (V),**
- **symbolic input (D),**
- **proprioception (P),**
- **other sensors (O),**
- **audition (A), touch (T),**
- **smell (S)**
- **and multi-modal (M).**



Colors correspond to different types of architectures:

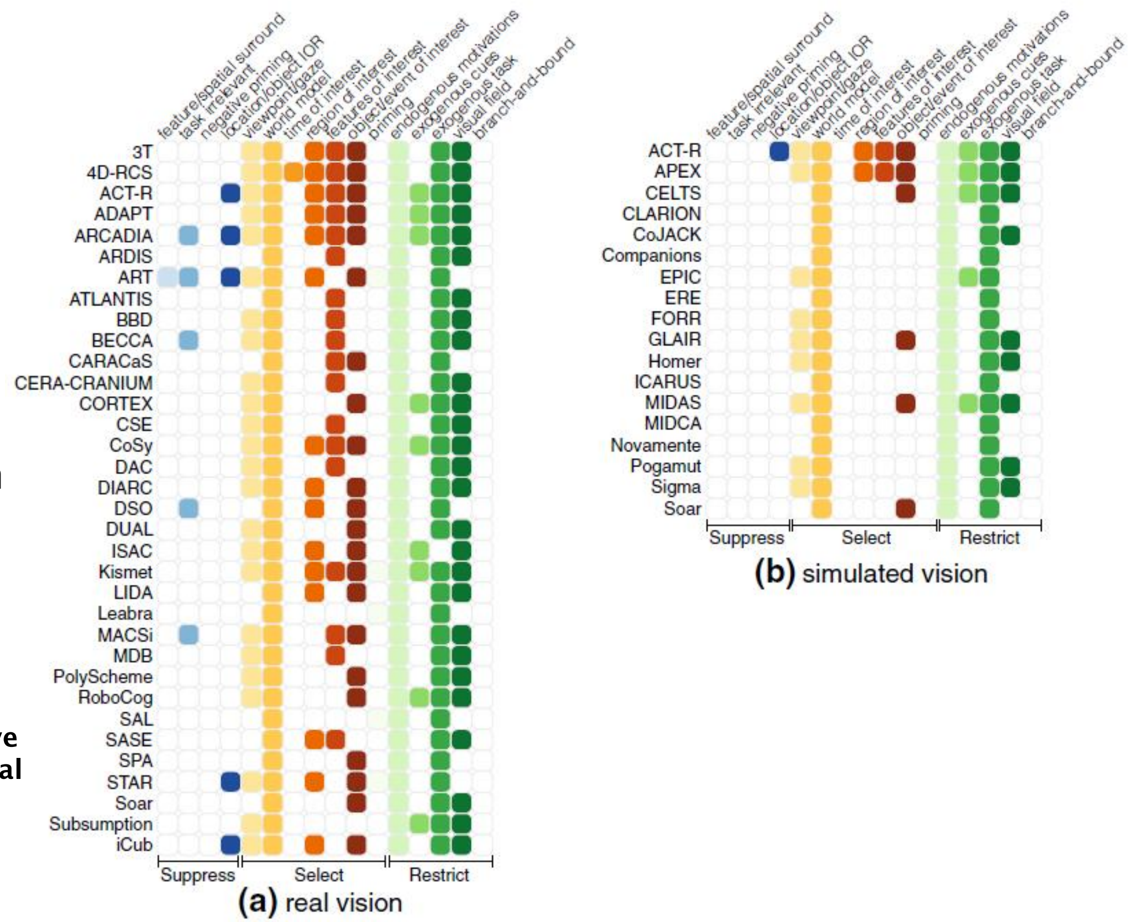
- **symbolic (green)**
- **emergent (red)**
- **hybrid (blue)**

Kotseruba et J. K. Tsotsos, « 40 years of cognitive architectures: core cognitive abilities and practical applications », Artif Intell Rev, juill. 2018, doi: 10.1007/s10462-018-9646-y.

A diagram showing visual attention mechanisms implemented in cognitive architectures for suppressing, selecting and restricting visual information

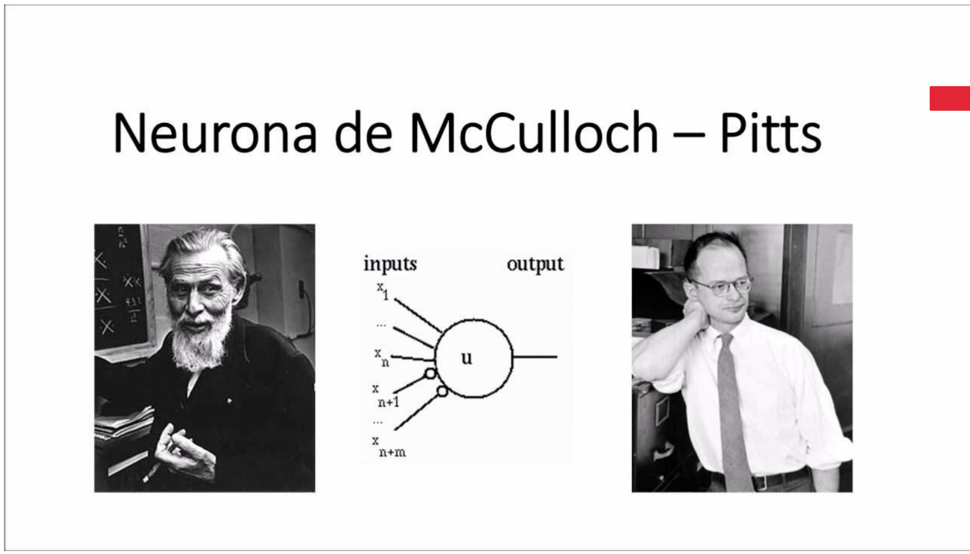
Three classes of information reduction mechanisms:

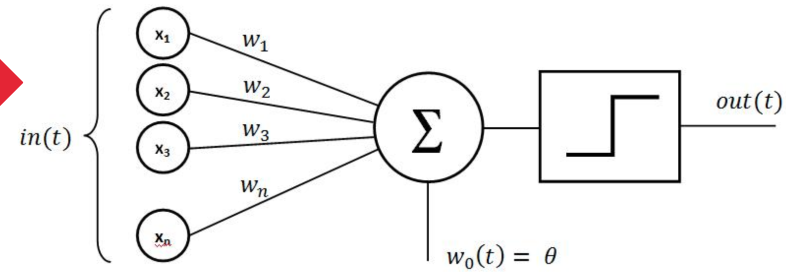
- selection (choose one from many),
- restriction (choose some from many)
- suppression (suppress some from many)



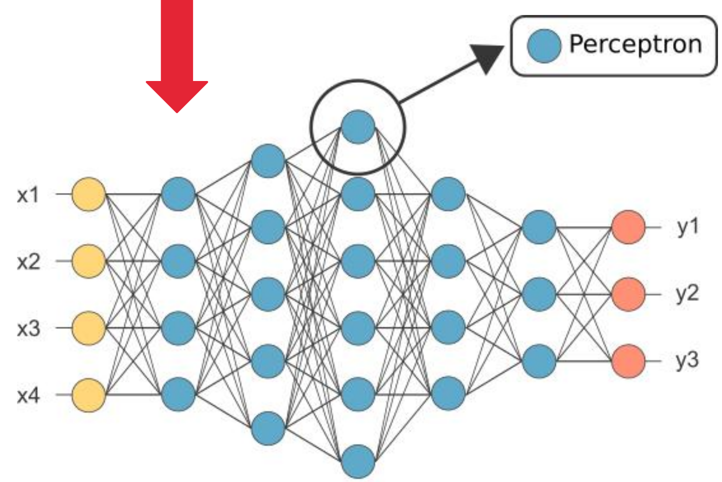
Kotseruba et J. K. Tsotsos, « 40 years of cognitive architectures: core cognitive abilities and practical applications », Artif Intell Rev, juill. 2018, doi: 10.1007/s10462-018-9646-y.

The first mathematical and computer model of the biological neuron is proposed by Warren McCulloch and Walter Pitts in 1943.



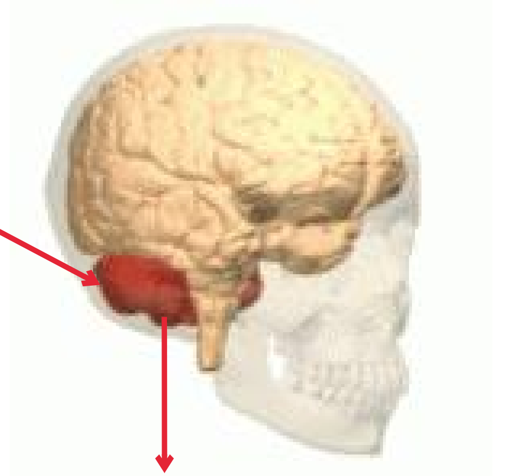


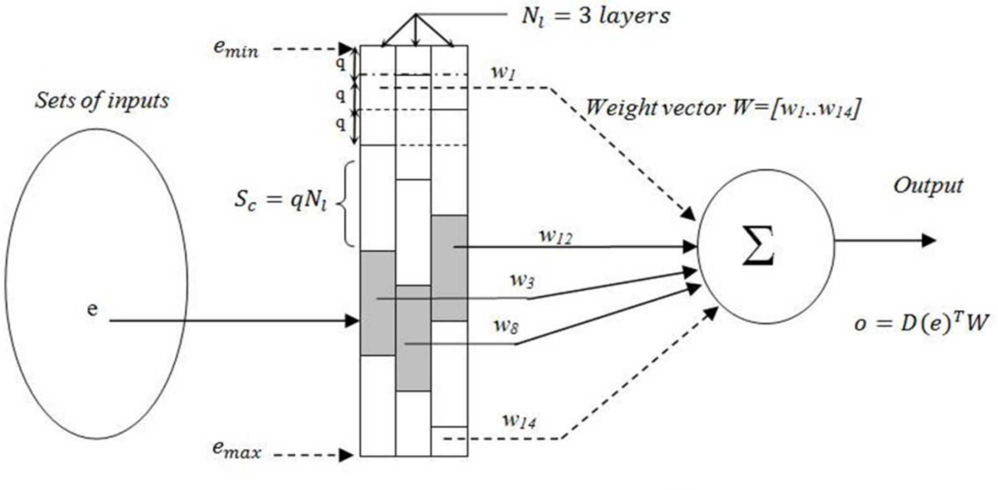
In 1957, Frank Rosenblatt invents the perceptron



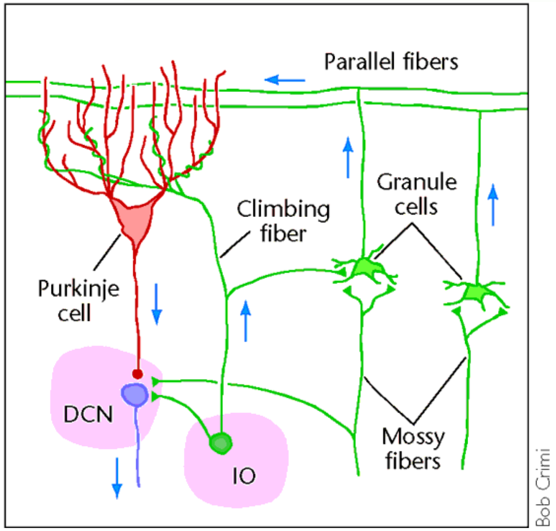
The cerebellar model arithmetic computer (CMAC) is a type of neural network based on a model of the mammalian <u>cerebellum</u>. It is also known as the cerebellar model articulation controller. It is a type of associative memory

The CMAC was first proposed as a function modeler for robotic controllers by James Albus in 1975





Association vector of receptive field (N_c=14, N_l=3)
D=[0,0,1,0,0,0,0,1,0,0,0,1,0,0]

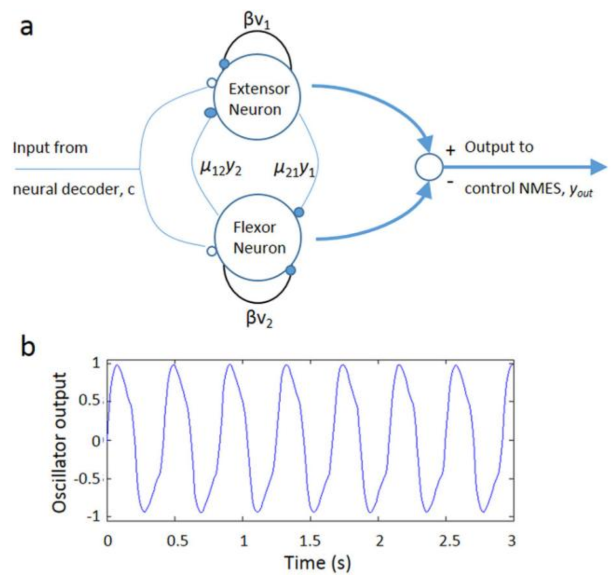


Connectionist system example: The Central Pattern Generator (CPG)

Central pattern generators (CPGs) are biological neural networks that produce rhythmic patterned outputs without sensory feedback (https://en.wikipedia.org/wiki/Central_pattern_generator)

CPGs have been clearly identified in some animals as the lamprey. In humans, CPG can be assimilated to local circuits and motoneurons of the spinal cord and brainstem

Central pattern generators based on Matsuoka oscillators



$$\tau_1 \frac{dx_1}{dt} = -x_1 - \beta v_1 - u_{21} y_2 + c$$

$$\tau_2 \frac{dv_1}{dt} = -v_1 + y_1 \qquad (2)$$

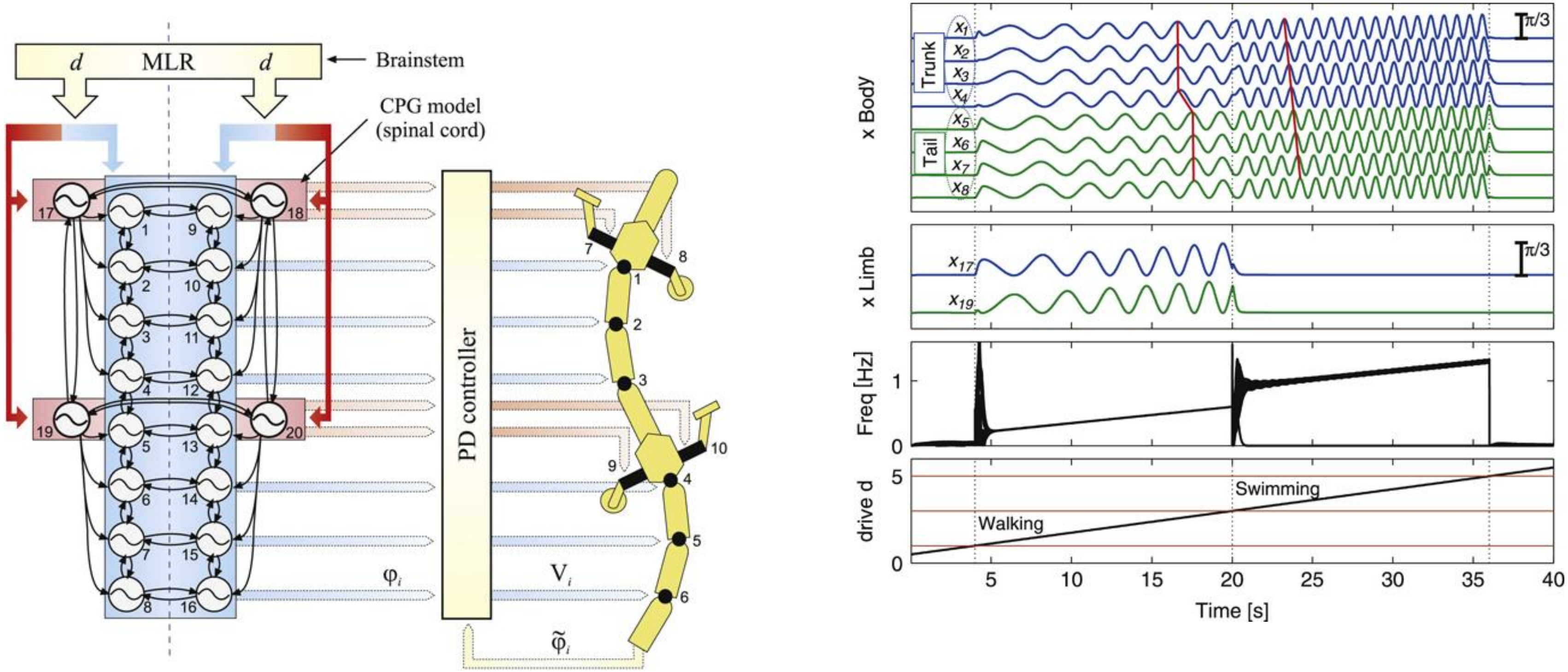
$$\tau_1 \frac{dx_2}{dt} = -x_2 - \beta v_2 - u_{12} y_1 + c$$

$$\tau_2 \frac{dv_2}{dt} = -v_2 + y_2 \qquad (4)$$

$$y_i = \max(0, x_i) \qquad (5)$$

$$y_{out} = y_1 - y_2 \qquad (6)$$

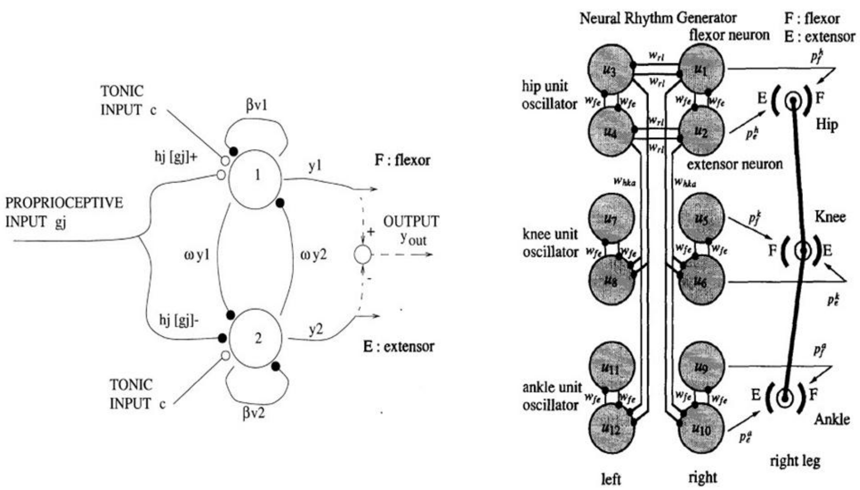
Salamander robot driven by a spinal cord model
(https://biorob.epfl.ch/salamandra)



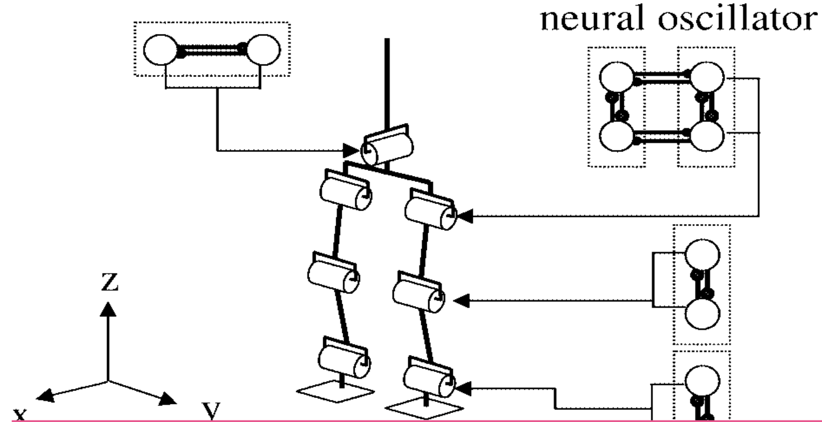
A. J. Ijspeert. Central pattern generators for locomotion control in animals and robots : A review. Neural Networks, vol. 21, no. 4, pages 642 – 653, 2008.

Salamander robot driven by a spinal cord model (https://biorob.epfl.ch/salamandra)

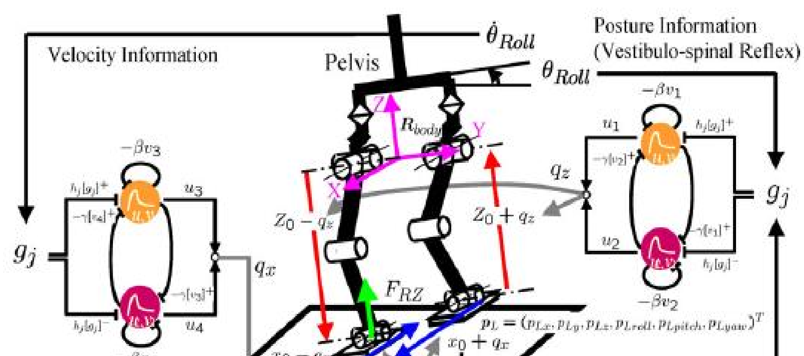
Control architecture for biped locomotion based on using neural oscillator (CPG)



(a) (b)



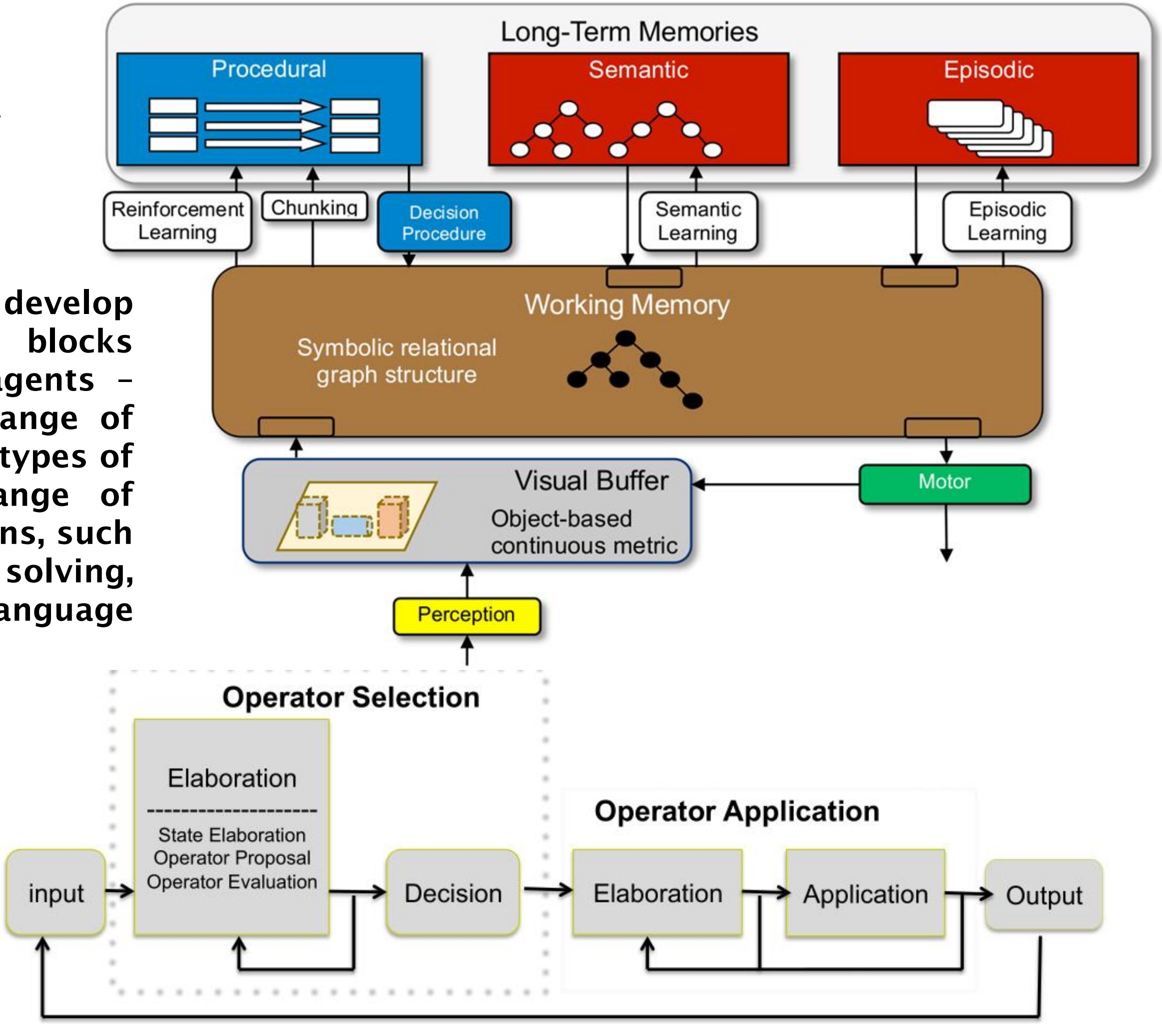
Structure based on one oscillator per articulation (dof)



Structure based on two oscillators to control the two legs

Cognitivism system example:
SOAR

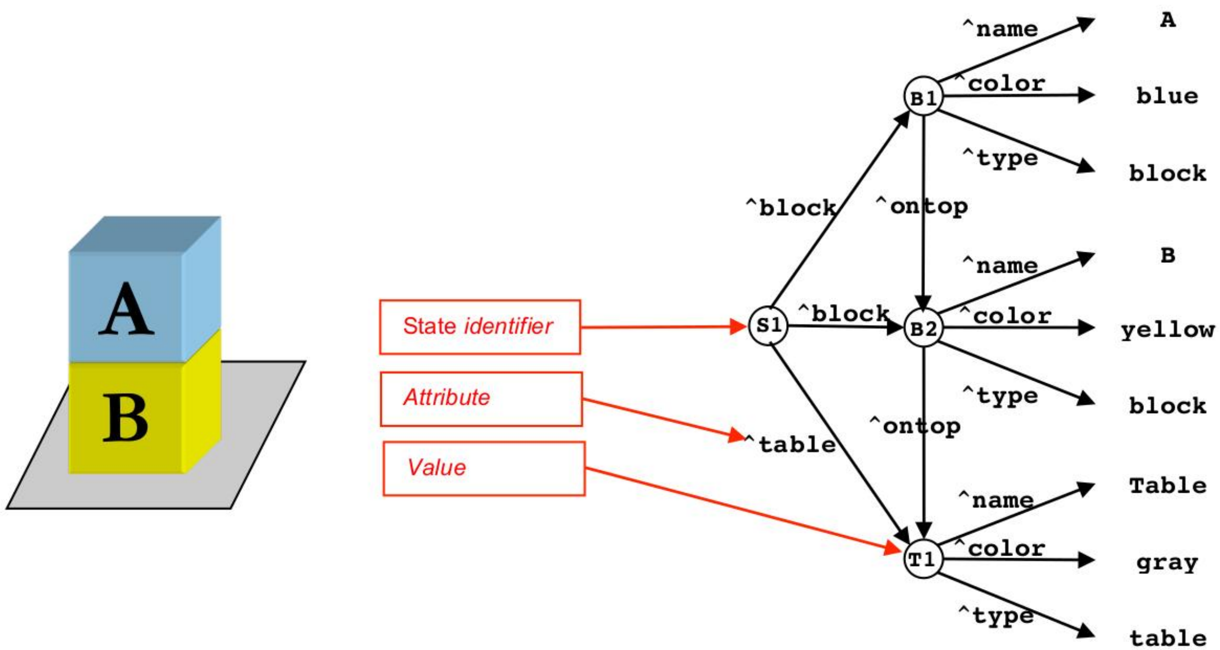
The goal of the Soar project is to develop the fixed computational building blocks necessary for general intelligent agents – agents that can perform a wide range of tasks and encode, use, and learn all types of knowledge to realize the full range of cognitive capabilities found in humans, such as decision making, problem solving, planning, and natural language understanding



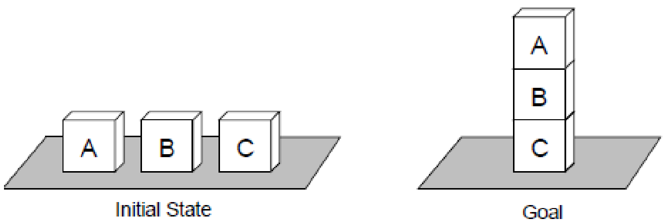
Laird, J. E., & Mohan, S. (2018). Learning Fast and Slow: Levels of Learning in General Autonomous Intelligent Agents .

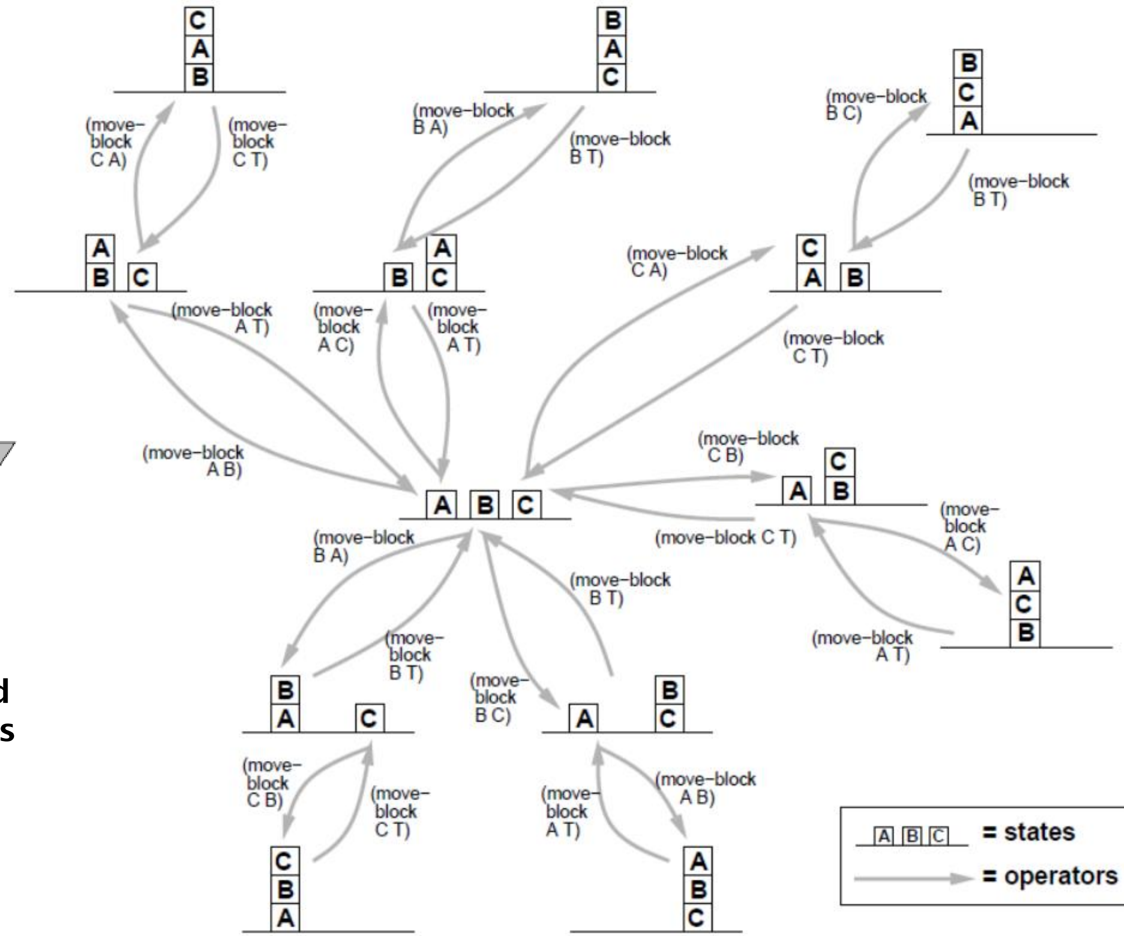
http://soar.eecs.umich.edu/

Cognitivism paradigm



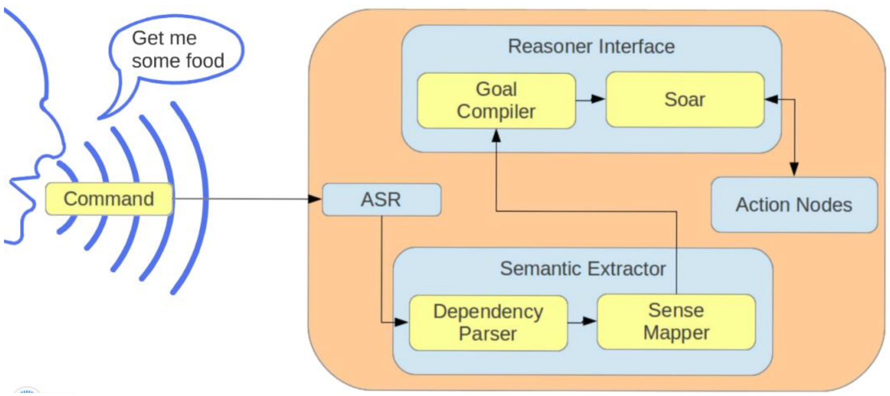
Example of problem-Solving Functions in Soar





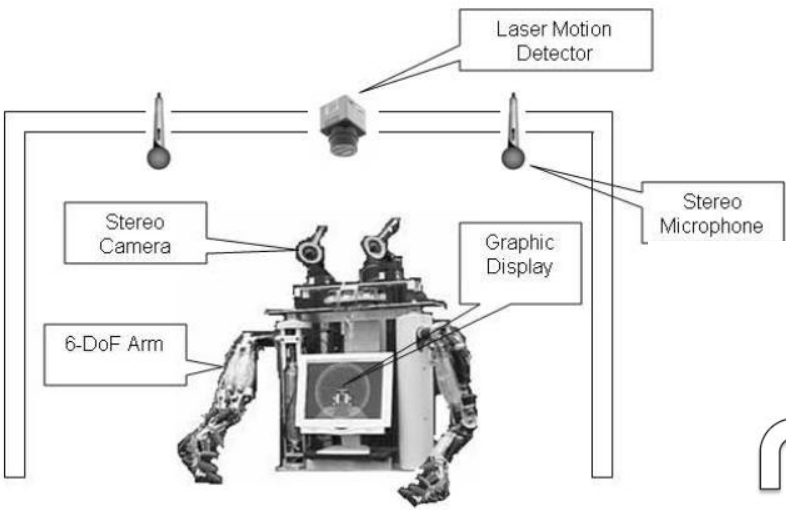
The problem space in the blocks-world includes all operators that move blocks from one location to another and all possible configurations of the three blocks.

Hybrid architecture (based on SOAR)

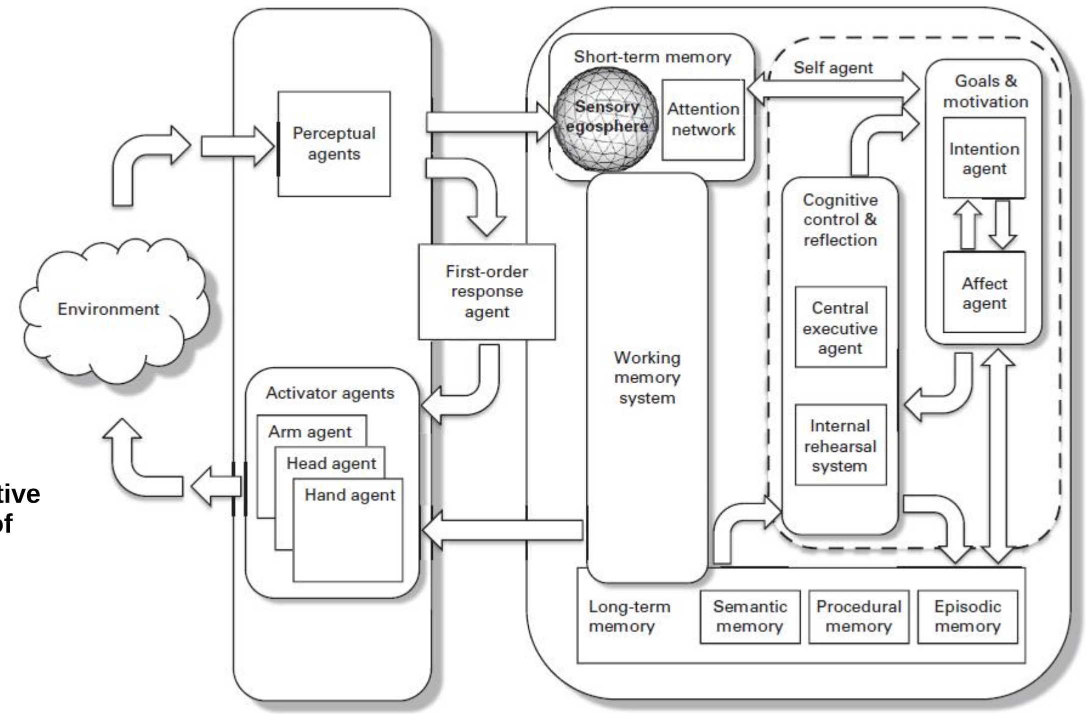


Skill	Action
Go to	Navigate to a location
Introduce himself	Talk about himself
Follow person	Follow a specific person in front of him
Search objects	Look for objects in front of him
Search person	Look for someone in the area
Grasp object	Grasp a specific object
Deliver object	Deliver an object to the person or place in front
Memorize person	Learn a person's face and store his name
Exit apartment	Look for the nearest exit and exit the area
Recognize person	Check the person in front as already known and retrieve its name
Point at an object	Point the location of a specific object

Hybrid architecture (ISAC humanoid robot)



ISAC (intelligent soft arm control) is a hybrid cognitive architecture for an upper-torso humanoid robot also called ISAC



Kawamura, Kazuhiko, et al. "Implementation of cognitive control for a humanoid robot." International Journal of Humanoid Robotics 5.04 (2008): 547-586.

Hybrid architecture (CRAM)

CRAM (Cognitive Robot Abstract Machine) is a toolbox for designing, implementing and deploying software on autonomous robots.

https://www.cram-system.org/home

CRAM comprises five core elements:

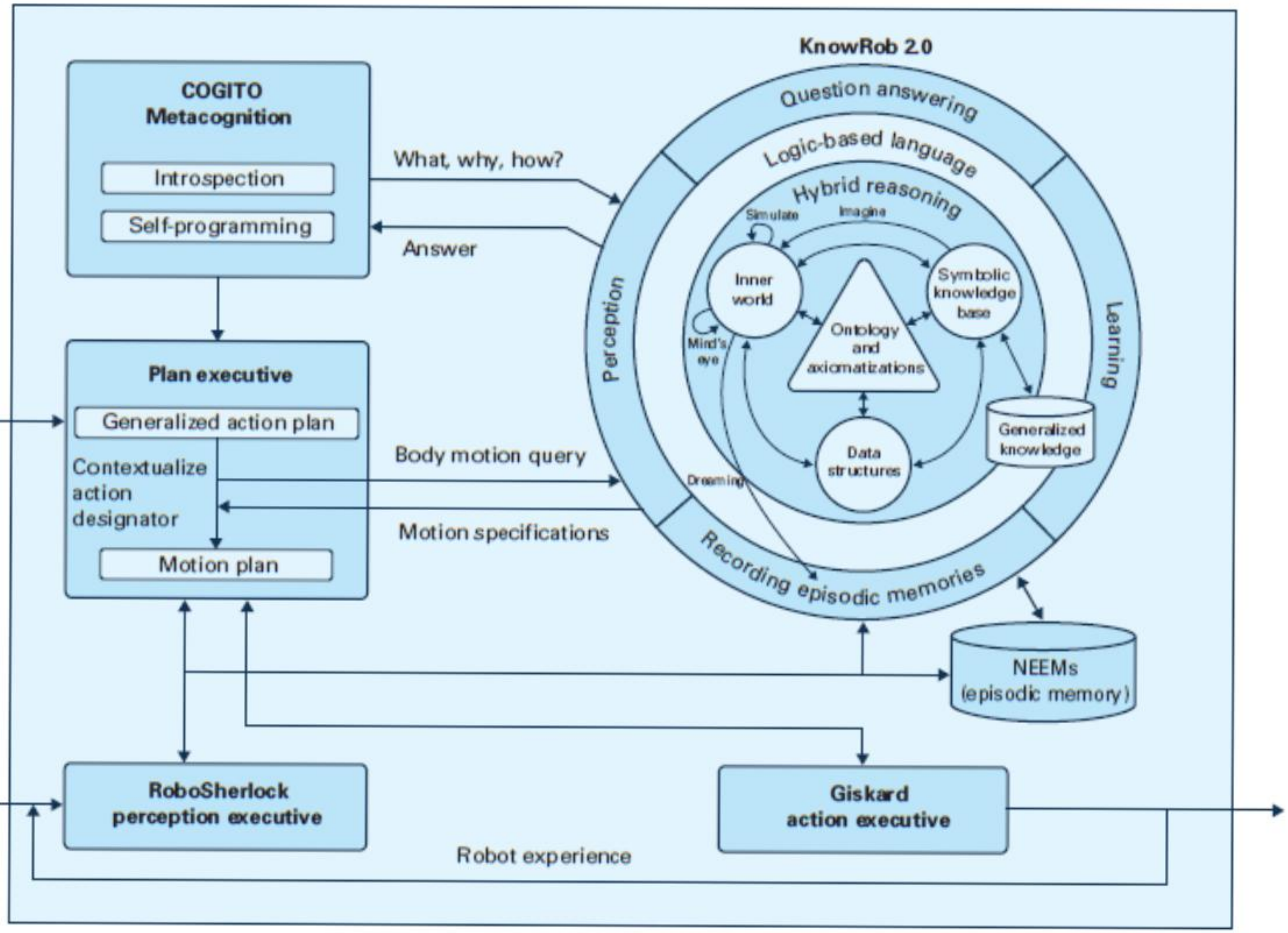
- **the CRAM Plan Language (CPL) executive;**
- **a suite of knowledge bases and associated reasoning mechanisms, collectively referred to as KnowRob2 (Beetz et al. 2018);**
- **a perception executive;**
- **an action executive;**
- **a metacognitive reasoning system**

A PR2 robot setting a table during a demonstration of cognition-enabled robot manipulation using the CRAM

https://www.youtube.com/watch?v=pv_n9FQRoZQ&t=60s

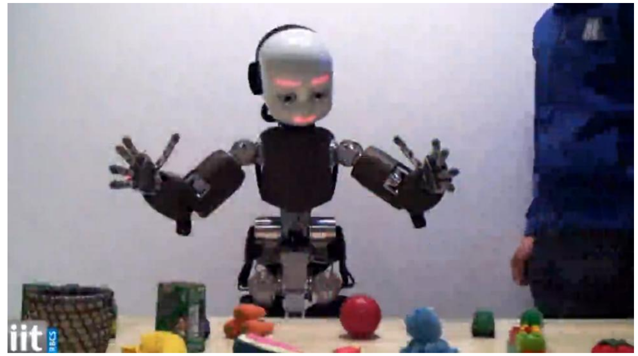
Hybrid architecture (CRAM)

The CRAM cognitive architecture. *Source:* Courtesy of the EASE interdisciplinary research center at the University of Bremen, Germany

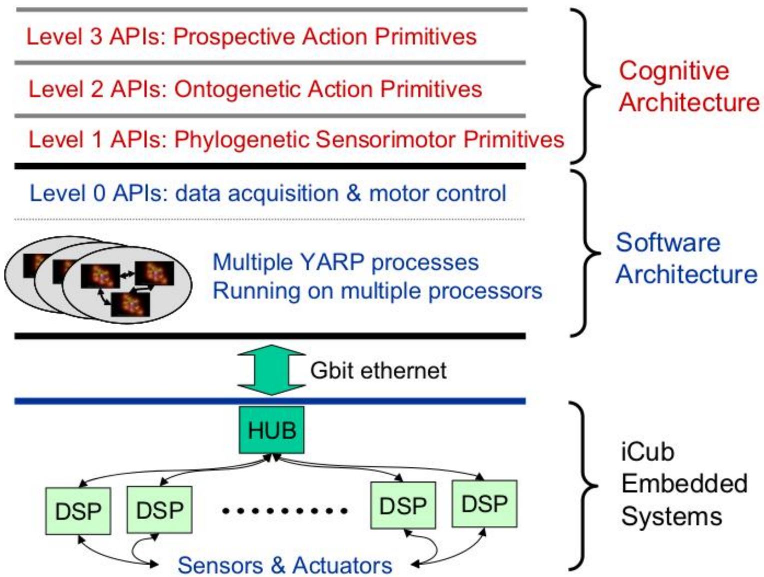


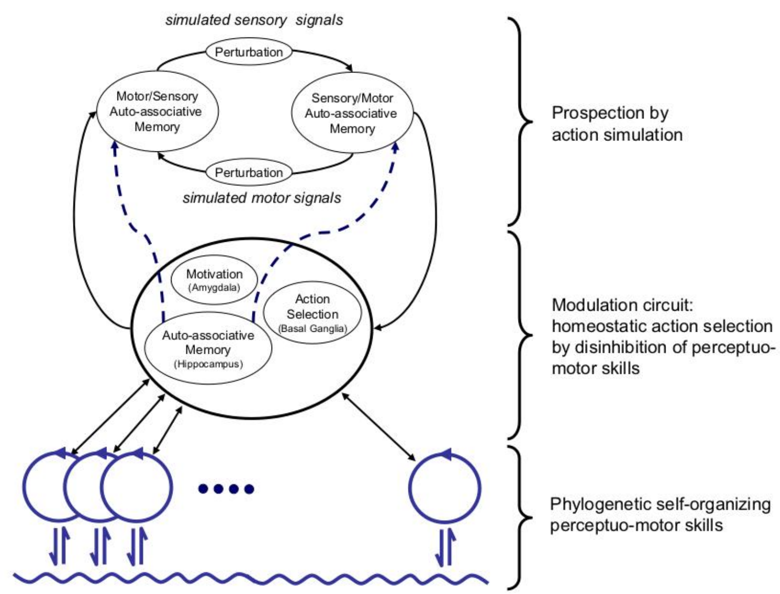
Embodied cognition

Humanoid robot platform for the study of cognitive robotics (104 cm, 22 kg, 53 dof)



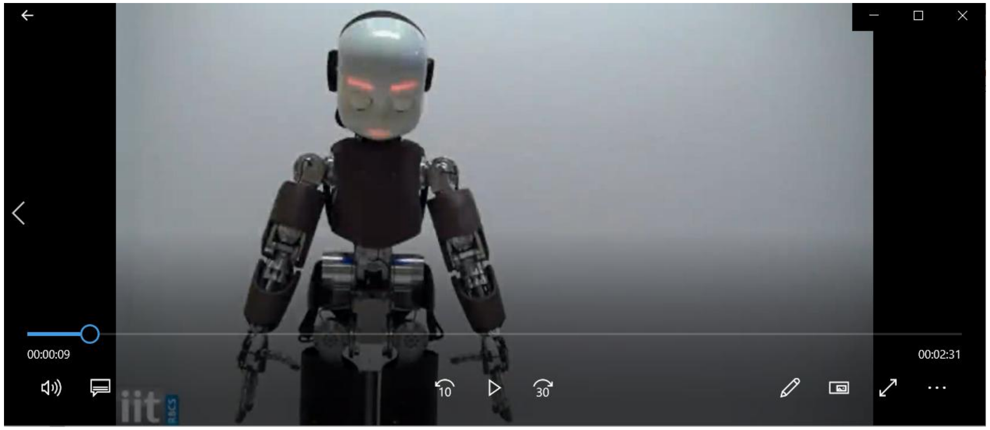
http://www.icub.org/





Embodied cognition

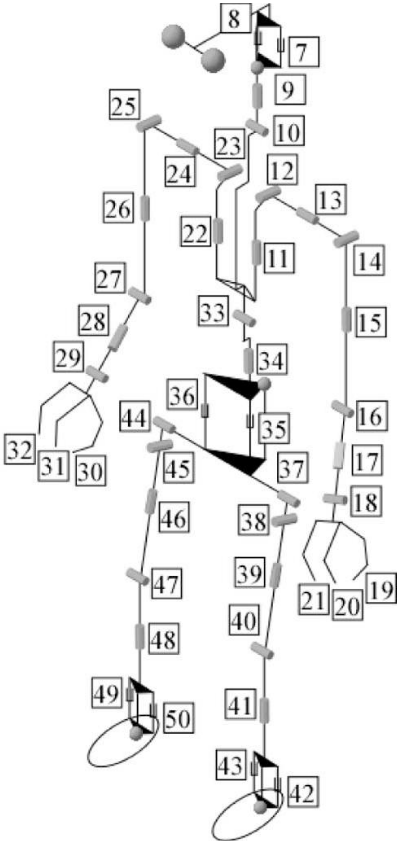
Scenario Capabilities: cognitive perception/action behaviours
Object tracking through occlusion (smooth pursuit & saccades)
Learn to coordinate vestibulo-ocular reflex (VOR) & tracking
Learn to reach towards a fixation point
Attention and action selection by modulation of capabilities
Condition modulation based on anticipation
Construct sensorimotor maps & cross-modal maps
Learn by demonstration (crawling & constrained reaching)
Exploratory, curiousity-driven, action
Experience-based action selection based on interaction histories
Navigate based on local landmarks and ego-centric representations
Quasi-independent Phylogenetic Capabilities
Saccadic re-direction of gaze towards salient multi-modal events
Focus attention and direct gaze on human faces
Ocular modulation of head pose to centre eye gaze
Move the hand(s) towards the centre of the visual field
Stabilize & integrate of saccadic percepts
Stabilize gaze with respect to self-motion (VOR)
Create attention-grabbing stimuli
Gait control
Component Capabilities
Compute optical flow
Compute visual motion with ego-motion compensation
Segmentation of the flow-field based on similarity of flow parameters
Segmentation based on the presence of a temporally-persistent boundary
Fixation and vergence
Gaze control: smooth pursuit with prediction; possibly tuned by learning
Classification of groups of entities based on low numbers
Classification of groups of entities based on gross quantity
Detection of mutual gaze
Detection of biological motion



https://www.youtube.com/watch?v=ZcTwO2dpX8A

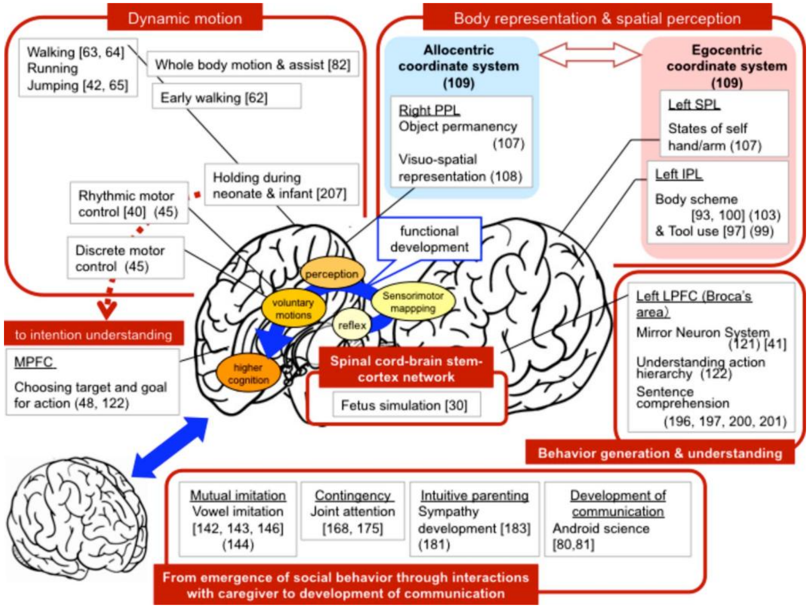
Embodied cognition

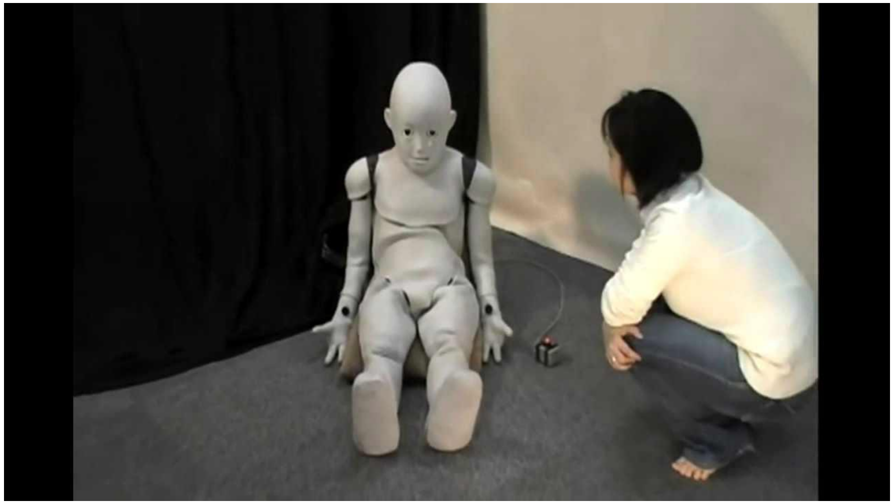
CB2 (Child Robot With Biomimetic Body) is a Japanese humanoid robot that aims to reproduce the behavior of a 2-year-old child as well as his cognitive development



Embodied cognition

The model of cognitive development that starts from the fetal sensorimotor mapping in the womb to the social behavior learning through body representation, motor skill development, and spatial perception.



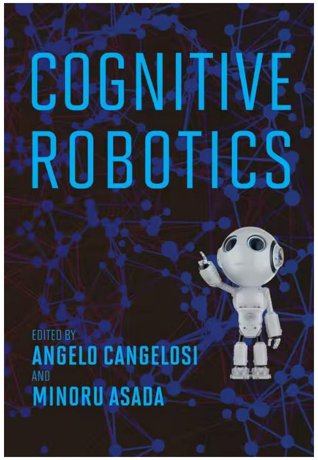


https://www.youtube.com/watch?v=rYLm8iMY5io

Asada, M., Hosoda, K., Kuniyoshi, Y., Ishiguro, H., Inui, T., Yoshikawa, Y., ... & Yoshida, C. (2009). Cognitive developmental robotics: A survey. IEEE Transactions on Autonomous Mental Development, 1(1), 12-34.

Behavioral and Cognitive Capabilities

- Intrinsic Motivations
-
- Cognitive Vision
-
- Cognitive Robot Navigation
-
- Cognitive Robot Manipulation
-
- Cognitive Control for Decision and Human-Robot Collaboration
-
- Social Cognition
-
- Human Robot Navigation
-
- Langage Comunication
-
- Knowledge Representation and Reasoning
-
- Abstract Concepts
-
- Robots and Machine Consciousness



https://mitpress.mit.edu/9780262046831/cognitive-robotics/

C. Cognitive System based on Conscious and Unconscious Cognitive Functions

- **Conscious and Unconscious Cognitive Functions**
- **Example N°1: Perception and Knowledge Conceptualization**
- **Example N°2: Acquisition and development of complex motor skills**

The 3 main paradigms

Cognitivism:

- The brain converts the perception of the world into an internal symbolic representation
- The brain computes output by applying predefined rules on the symbolic representation

Connectionism:

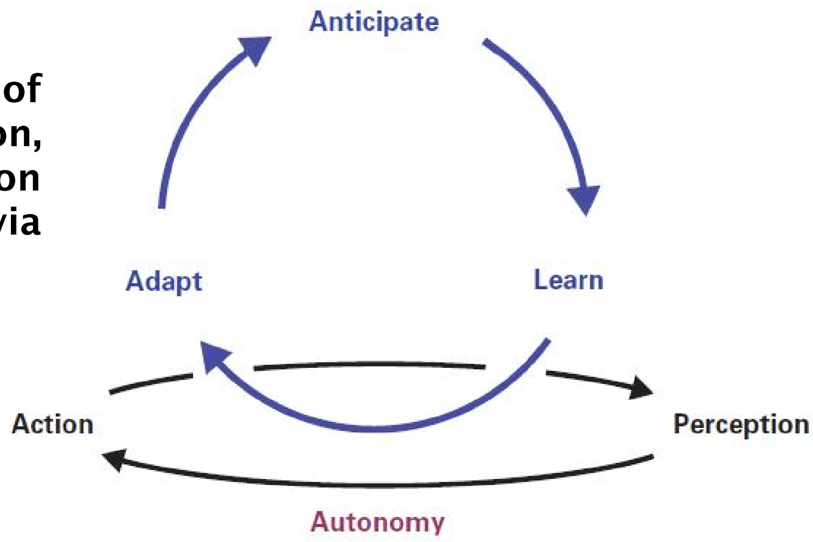
- The brain works is modeled by using neural networks
- The simultaneous running these networks makes it possible to reproduce cognitive activities such as perception, language, sensorimotor control, etc.

Embodied cognition (Enaction):

- The cognition is the result of a succession of sensorimotor experiments

Conscious and Unconscious Cognitive Functions

Cognition can be represented as a cycle of anticipation, assimilation, and adaptation, embedded within a continuous process of action and perception and dynamically adapting via learning



Two questions about cognitive functions (abilities)

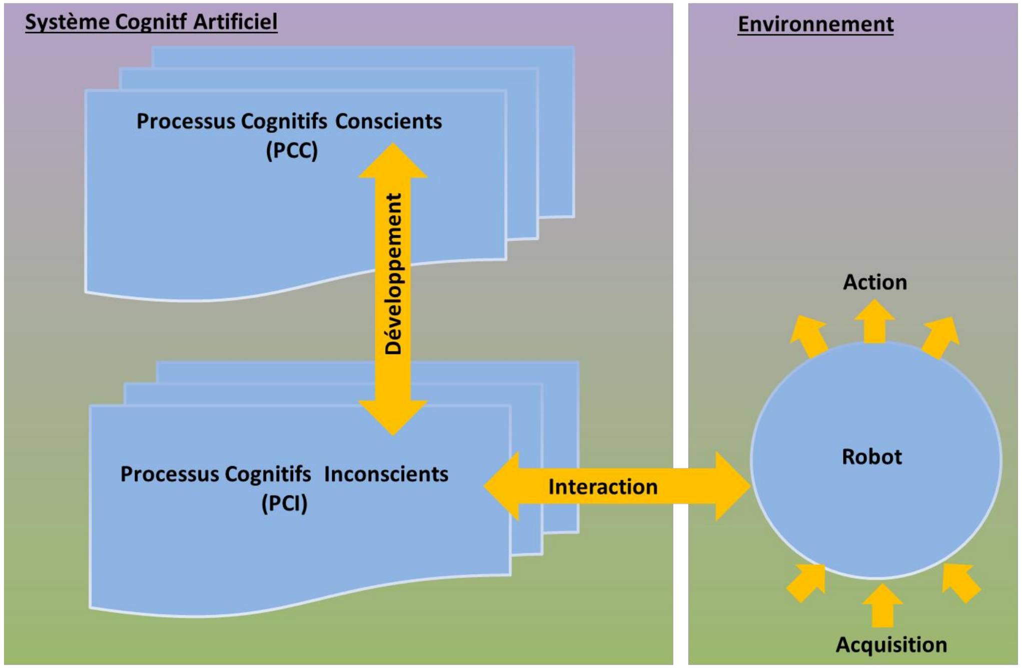
- innate knowledge/abilities versus learning knowledge/abilities?
- unconscious cognitive functions versus conscious cognitive functions in data processing?

Conscious and Unconscious Cognitive Functions

Conception of an artificial cognitive system based on the three main cognitive paradigms: embodiment, cognitivism, connectionism

Conscious Cognitive Functions contribute to the development of new skills / knowledge.

Unconscious Cognitive Functions are equivalent to learned and pre-programmed skills and knowledge.



Two examples

- **Acquisition and development of complex motor skills**
- **Perception and Knowledge Conceptualization**

Perception and Knowledge Conceptualization

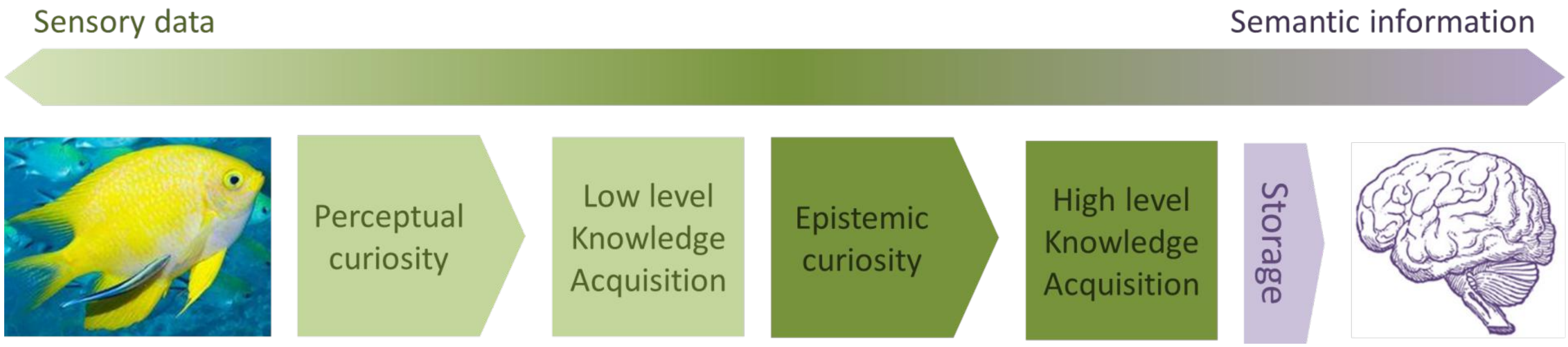
<u>Example N°1</u>: Perception and Knowledge Conceptualization

A basic skill of human beings is classify properties, objects or events. These categories can be perceptual, taxonomic, thematic, etc.

This categorization process reduces the diversity and complexity of the real world that is perceived through the sensory pathways.

Social interactions and language acquisition contribute to the emergence of categories

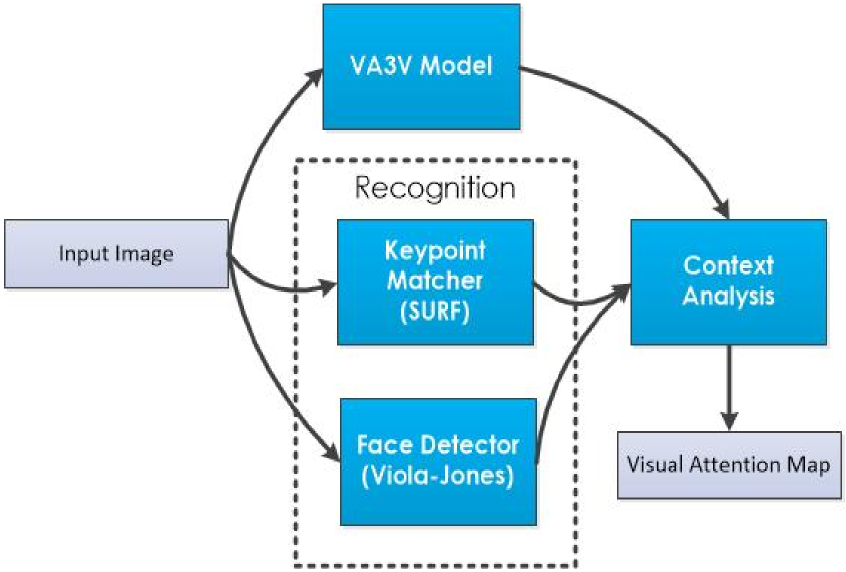
<u>D. Poulin-Dubois</u>. Le développement cognitif de 0 à 2 ans : Les fondements du développement ultérieur (Blaye, A., & Lemaire, P. Psychologie du développement cognitif de l'enfant)
<u>A. BLAYE</u>, « Développement De La Catégorisation (psychologie) », Encyclopædia Universalis
F. Bonthoux, C. Berger & A. Blaye. Naissance et développement des concepts chez l'enfant. Catégoriser et comprendre, Dunod, Paris, 2004.

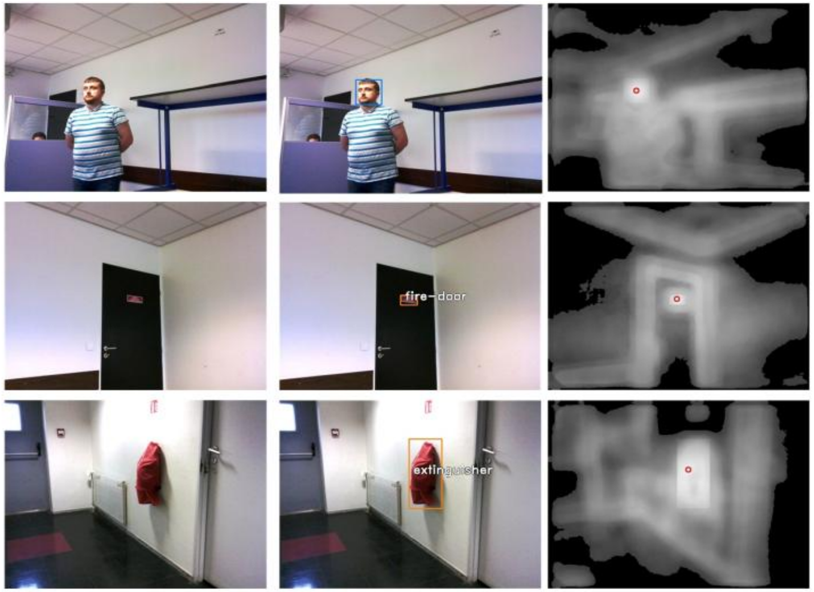


Cognitive and Visual Saliency Map :

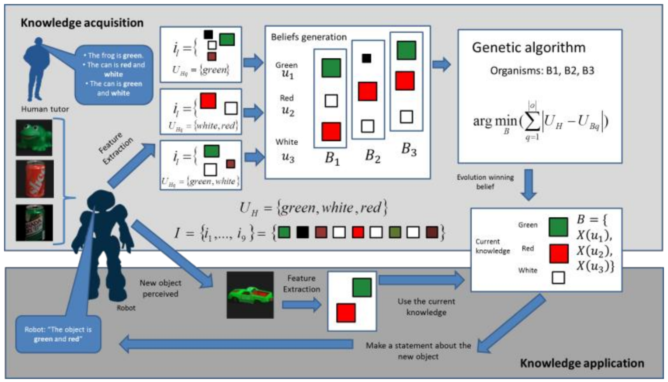
For evolving with humans, "attention" is an important cognitive skill. The goal of this research is to build an visual artificial attention system for autonomous robots:

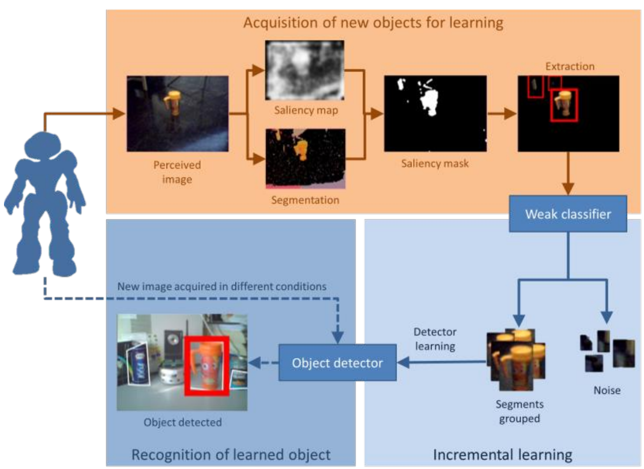
- **Visual Attention-based Autonomous Artificial Vision (VA3V)**
- **The recognition and contextual decision modules proffer the VA3V-based system a contextual Artificial Visual Attention**



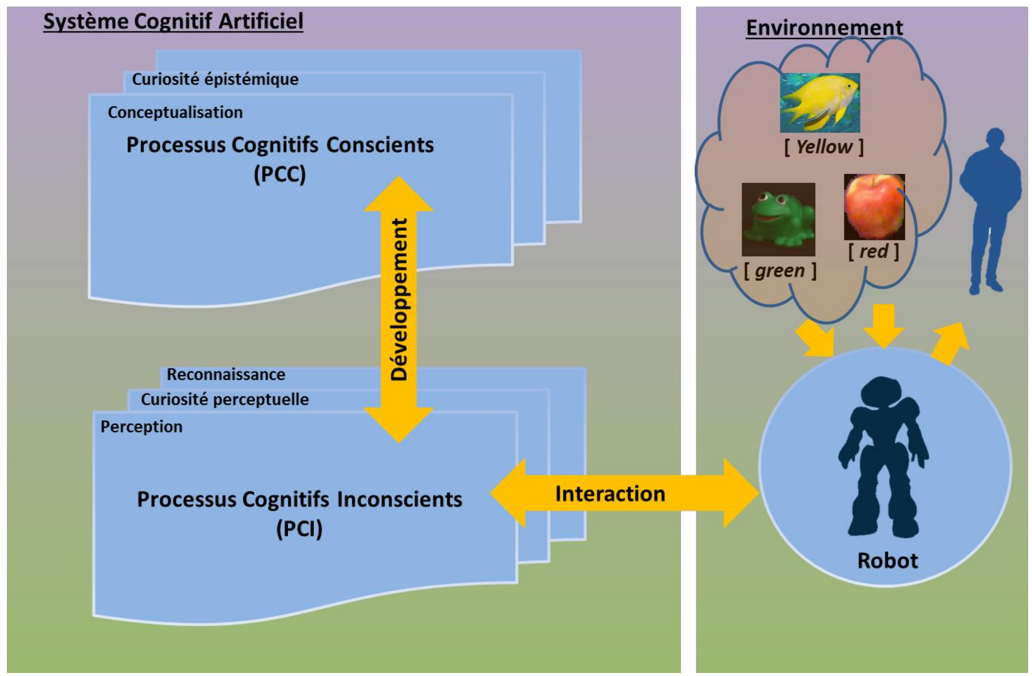


Perception and Knowledge Conceptualization





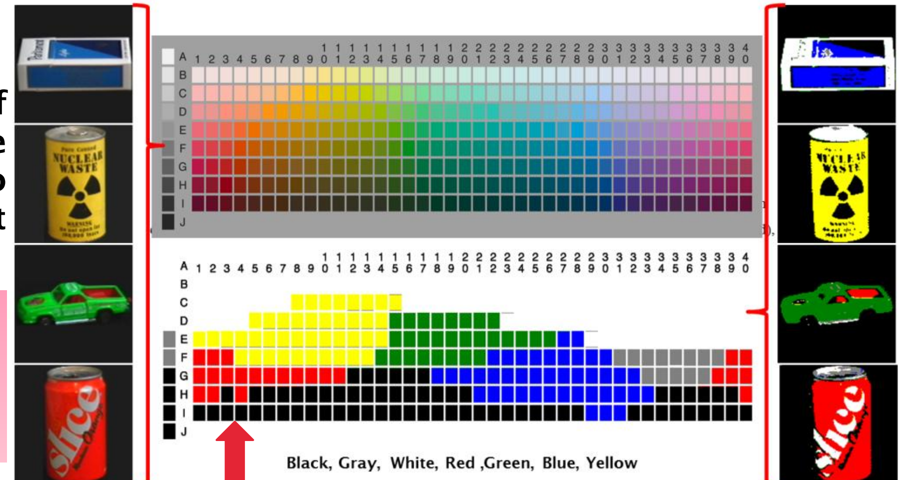
The acquisition and interpretation processes of perceived information are based on a set of observations (sensory information and words pronounced by a human being) and an optimization algorithm



The part of the visual perception system ensures the detection of the relevant objects as well as the extraction of the segments associated with it, by using the both visual saliency and image segmentation.

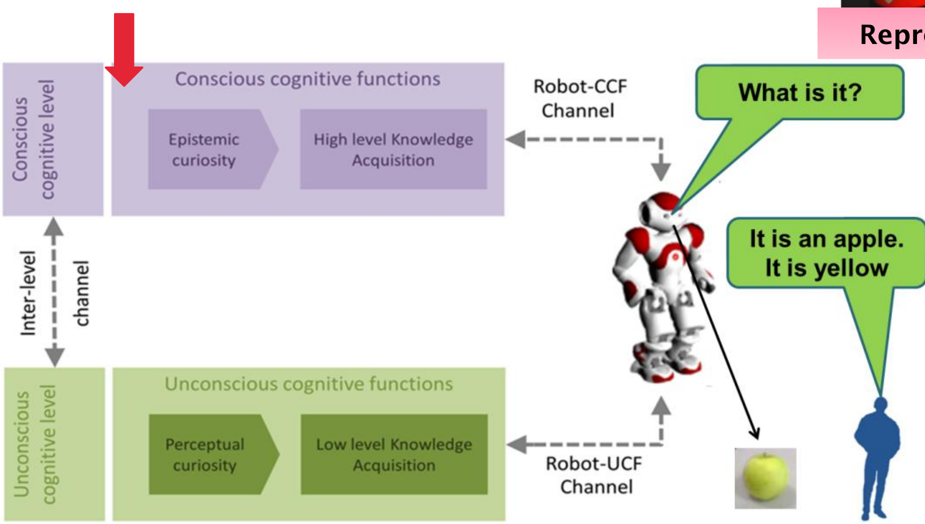
Classification example: the color categorization

Although the human eye is theoretically able of discriminating several millions of colors, humans use less than twenty words to classify them. It is also important to note that this classification is dependent on language and culture.



Representation of color classification after the learning stage

The robot, progressively, builds its representation and its interpretation of the world by using:
- **perception (vision, hearing, etc)**
- **interaction with humans**



https://www.youtube.com/watch?v=89oGyzHfHjI&t=2s

Example N°2: Acquisition and development of complex motor skills

Human motions are the result of a set of muscular contractions whose spatio-temporal organization is orchestrated by the central nervous system.

The motor activities of man evolve and enrich themselves throughout his life according to his own experiences (phylogenetic / ontogenetic abilities).

The Central Nervous System (CNS) involved in the generation of motions, and which controls all muscle activity, is composed of:

- the spinal cord,
- the brainstem circuit.

} Automatic motions (unconscious)

- the cerebellum,
- basal ganglia,
- motor cortex.

} Voluntary motions (Conscious)

D. Purves. Neuroscience (De Boeck) (In French & English)
C. Collet. Mouvements & cerveau : neurophysiologie des activités physiques et sportives

Central Nervous System (CNS) involved in motion generation

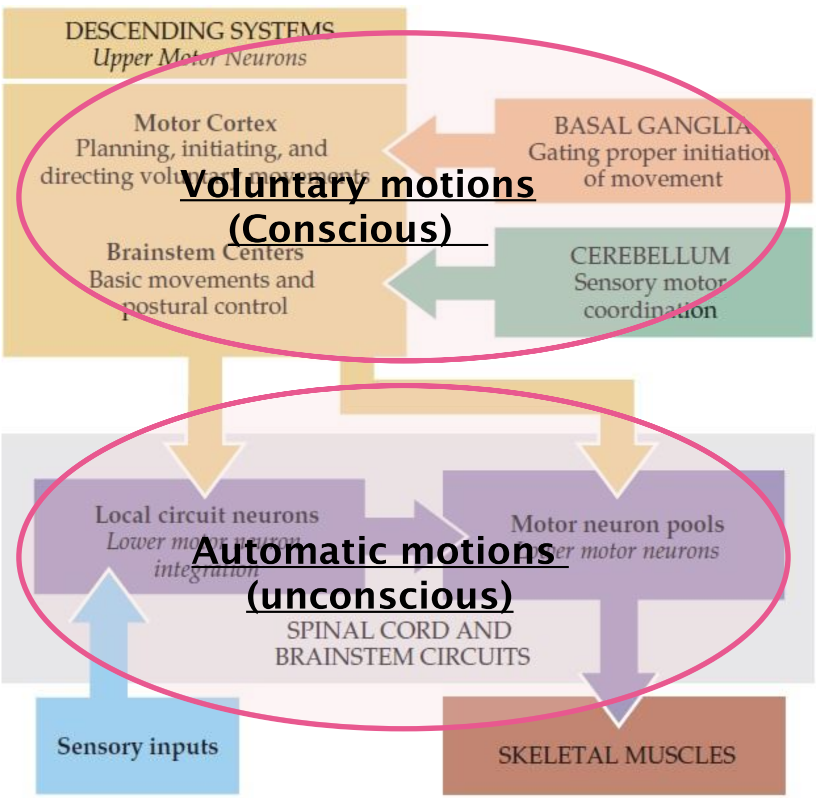
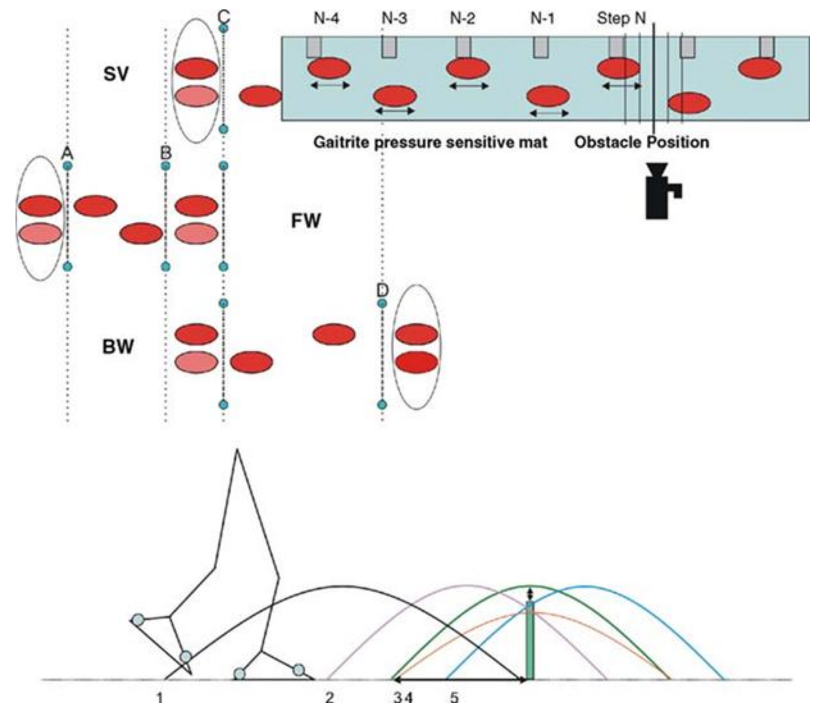
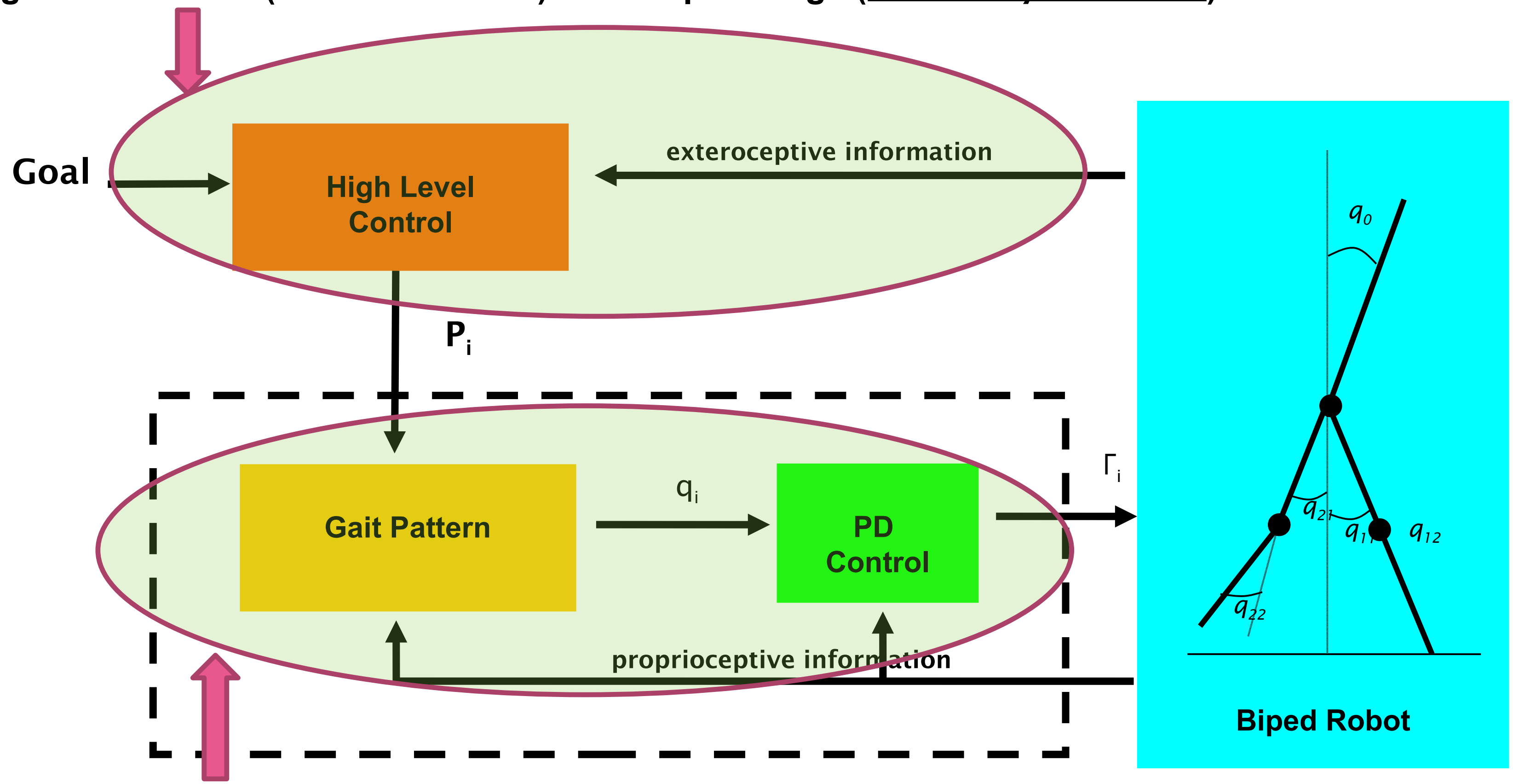


Illustration based on fig. from D. Purves. Neuroscience

Influence of vision on the trajectory planning (obstacle avoidance)

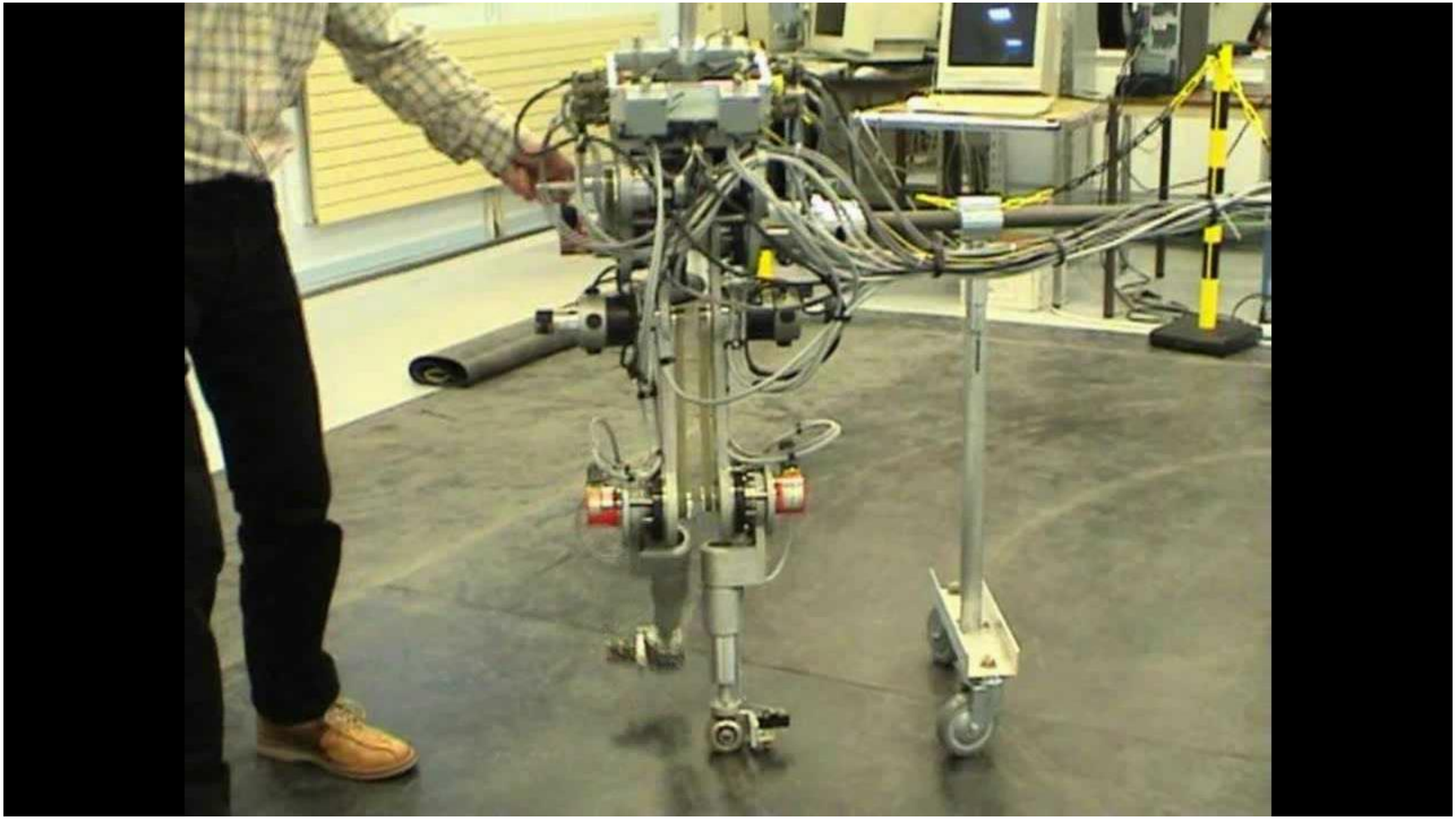


High control level (Conscious level) : Path planning (Voluntary motions)



Low Level Control (Unconscious level): walking (Automatic motions)

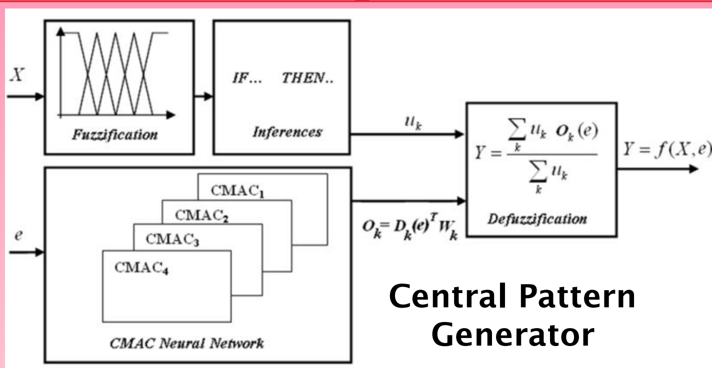
Acquisition and development of complex motor skills

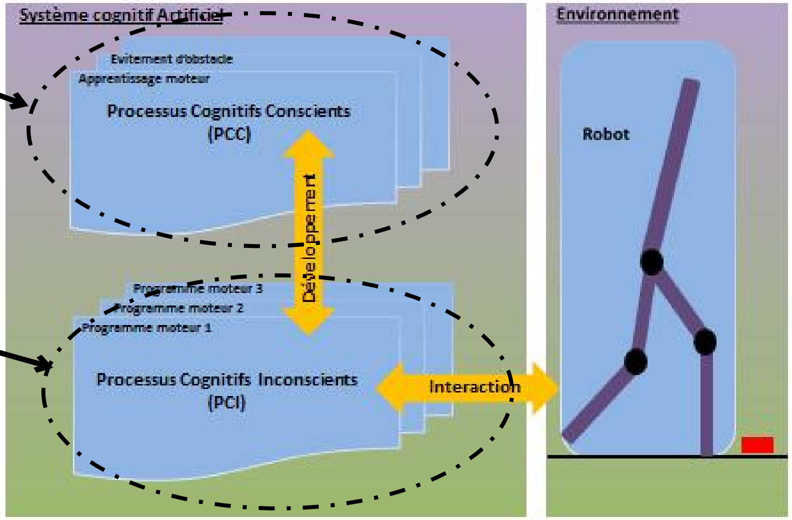


Acquisition and development of complex motor skills

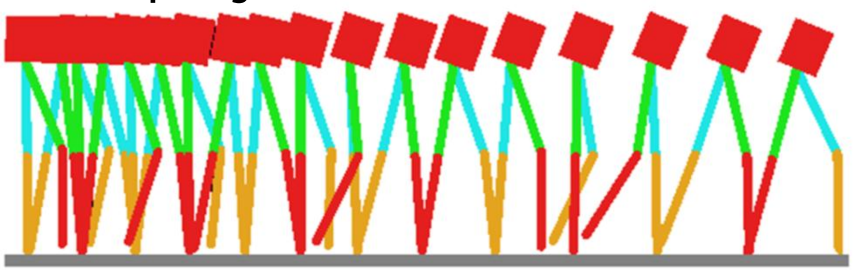
Locomotion control is based on two parts:
- **generation of quasi-automatic walking motion (step length modulation)**
- **control of voluntary motion (obstacle avoidance)**

Reinforcement learning
Fuzzy Q-learning

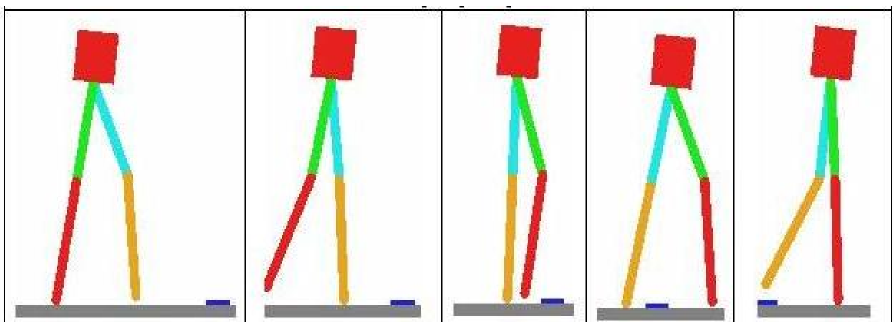




Step length modulation



Obstacle avoidance



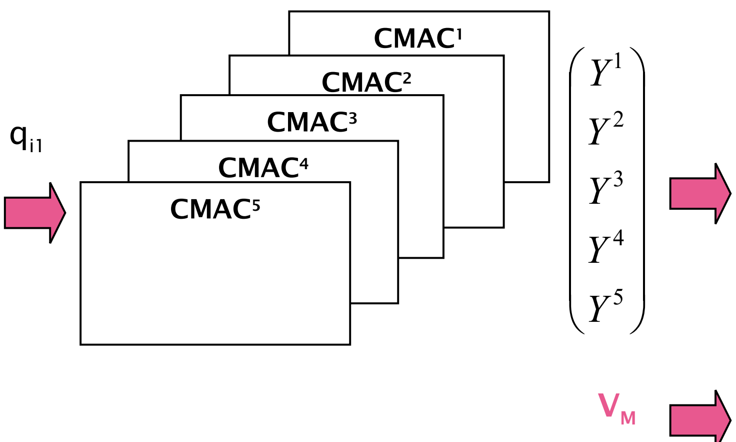
With step-length adaptation

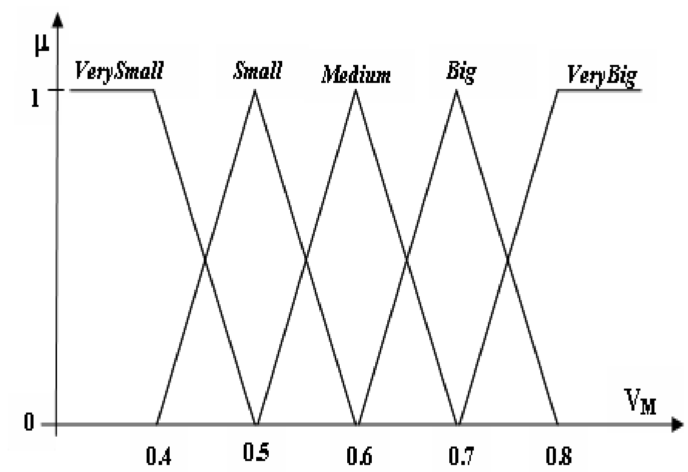
Five reference's walking

	V_M(m/s)	L_{step}(m)
$CMAC^1$	0.4	0.23
$CMAC^2$	0.5	0.28
$CMAC^3$	0.6	0.31
$CMAC^4$	0.7	0.36
$CMAC^5$	0.8	0.4

Five rules

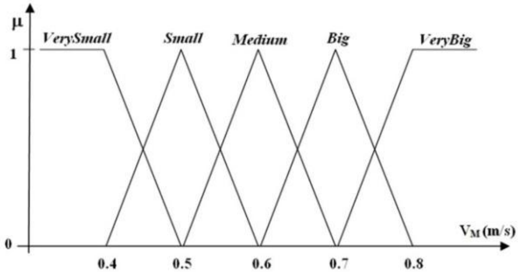
- IF V_M IS **VerySmall** THEN **Y=CMAC¹**
- IF V_M IS **Small** THEN **Y=CMAC²**
- IF V_M IS **Medium** THEN **Y=CMAC³**
- IF V_M IS **Big** THEN **Y=CMAC⁴**
- IF V_M IS **VeryBig** THEN **Y=CMAC⁵**





$$Y = \frac{\sum_l \mu^l \, Y_k^l}{\sum_l \mu^l}$$

Modulation according to Average velocity



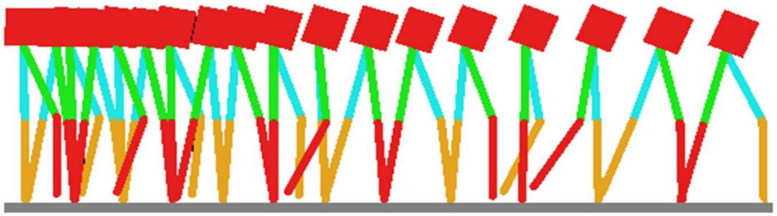
Règle N°1 ➡ IF V_M is $VerySmall$ THEN $Y = O_1$

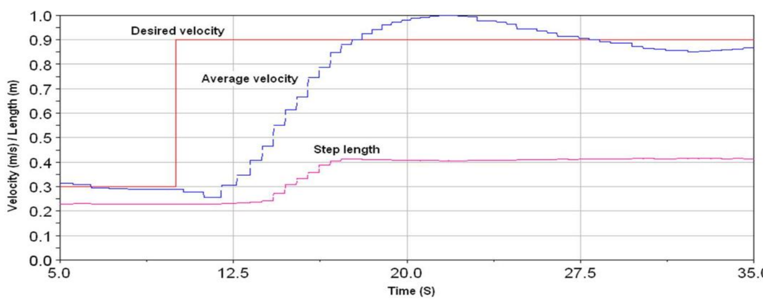
Règle N°2 ➡ IF V_M is $Small$ THEN $Y = O_2$

Règle N°3 ➡ IF V_M is $Medium$ THEN $Y = O_3$

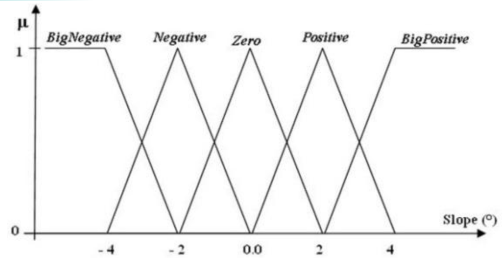
Règle N°4 ➡ IF V_M is Big THEN $Y = O_4$

Règle N°5 ➡ IF V_M is $VeryBig$ THEN $Y = O_5$





Modulation according to Slope of the ground



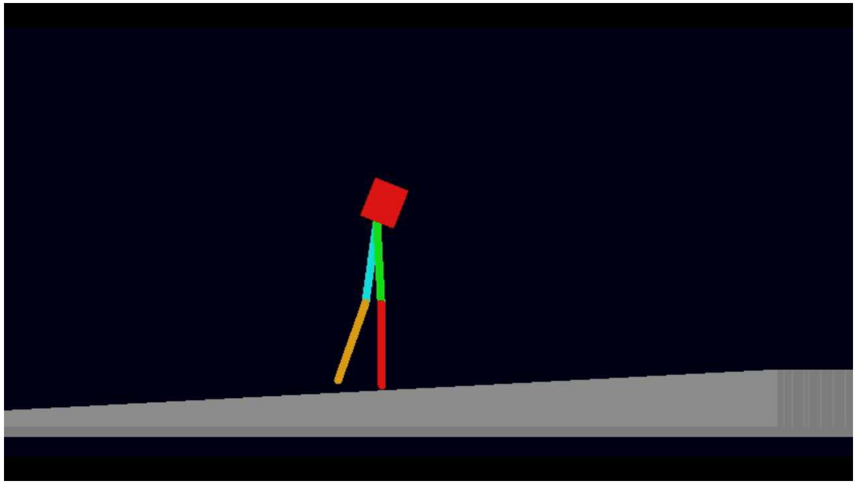
Règle N°1 ➡ IF $Slope$ IS $BigNeg$ THEN $Y = O_1$

Règle N°2 ➡ IF $Slope$ IS Neg THEN $Y = O_2$

Règle N°3 ➡ IF $Slope$ IS $Zero$ THEN $Y = O_3$

Règle N°4 ➡ IF $Slope$ is Pos THEN $Y = O_4$

Règle N°5 ➡ IF $Slope$ IS $BigPos$ THEN $Y = O_5$



Footstep planning based on Fuzzy QLearning:

d^n_{obs} → **Fuzzy QLearning algorithm** → $Gait^n \begin{cases} L^n_{step} \\ t^n_{step} \end{cases}$

v^n_{obs} → **Fuzzy QLearning algorithm**

The FQL algorithm uses a set of fuzzy rules such as:

$$If\ \ x\ \ is\ S_i\quad then\quad \begin{cases} \quad a[i,1]\ \ with\ \ q = q[i,1] \\ or\quad a[i,2]\ \ with\ \ q = q[i,2] \\ or\quad a[i,J]\ \ with\ \ q = q[i,J] \end{cases}$$

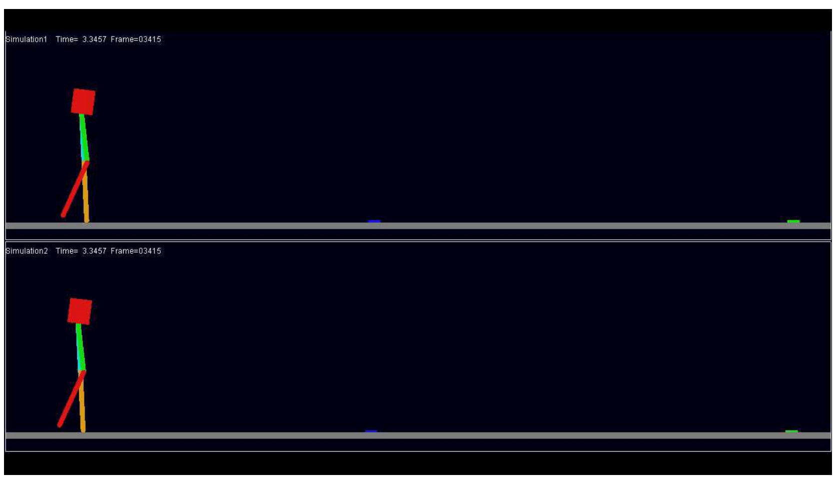
The learning agent has to find the best action *a(i)* for each rule *i*

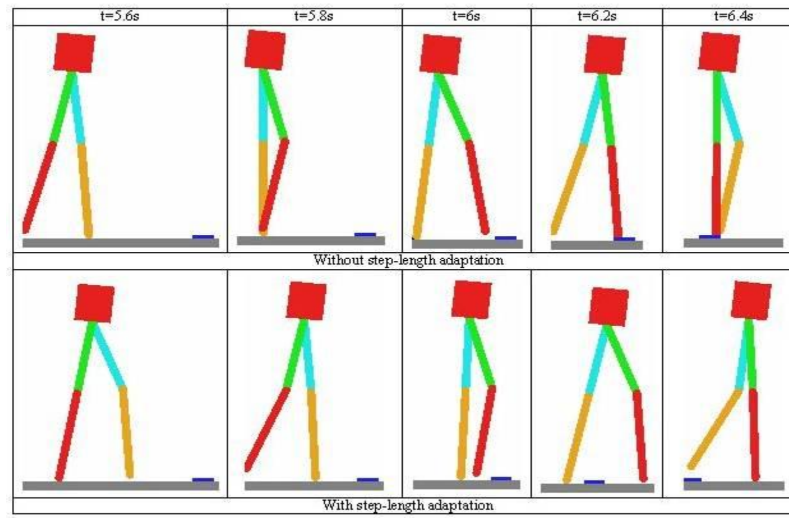
Gait patern :

Gait	L_{step} (m)	T_{step} (s)	V_M (m/s)
Gait^1	0,24	0,6	0,4
Gait^2	0,3	0,6	0,5
Gait^3	0,34	0,567	0,6
Gait^4	0,38	0,543	0,7
Gait^5	0,43	0,543	0,8

Rule base:

V_{obs} / d_{obs}	Small	Medium	Big
Very Small	Gait^3	Gait^3	Gait^3
Small	Gait^5	Gait^4	Gait^1
Medium	Gait^5	Gait^2	Gait^1
Big	Gait^3	Gait^3	Gait^3
Very Big	Gait^5	Gait^5	Gait^5





Conclusion
&
Bibliography

Conclusion

- In the 21st century, robots and humans coexist in the same environment, which creates new problematic.
- Robotic systems will therefore have to be very adaptable in developing, through their experiences, new cognitive skills allowing them to learn to cohabit progressively with human beings.
- Cognitive sciences give a transversal theoretical framework favorable to the development of artificial cognitive systems for robotics..
- Conception of an artificial cognitive system for robotics based on the three main paradigms of cognitive sciences (enactivism, cognitivism, connectionism)
- Decomposition of the cognitive system into two distinct parts; one part is dedicated to conscious cognitive functions, the other part for the concussions cognitive functions..
- Cognitive Conscious functions contribute to the development of new skills / knowledge.
- Unconscious Cognitive functions corresponds to pre-programmed skills and knowledge.
- Application for the acquisition and development of complex motor skills and for the acquisition of new knowledges.
- Extension to distributed systems.

Bibliographie

Papers:

- **Kotseruba et J. K. Tsotsos, « 40 years of cognitive architectures: core cognitive abilities and practical applications », Artif Intell Rev, juill. 2018, doi: 10.1007/s10462-018-9646-y.**
- **Asada, M., Hosoda, K., Kuniyoshi, Y., Ishiguro, H., Inui, T., Yoshikawa, Y., ... & Yoshida, C. (2009). Cognitive developmental robotics: A survey. IEEE Transactions on Autonomous Mental Development, 1(1), 12-34.**
- **David Vernon, Giorgio Metta & Giulio Sandini. A Survey of Artificial Cognitive Systems : Implications for the Autonomous Development of Mental Capabilities in Computational Agents. IEEE Transactions on Evolutionary Computation, vol. 11, no. 2, pages 151–180, April 2007.**
- **A. J. Ijspeert. Central pattern generators for locomotion control in animals and robots : A review. Neural Networks, vol. 21, no. 4, pages 642 – 653, 2008.**
- **J. E. Laird, K. R. Kinkade, S. Mohan & J. Z. Xu. Cognitive robotics using the Soar cognitive architecture. In Workshops at the Twenty-Sixth AAAI Conference on Artificial Intelligence, July 2012.**

Books:

- David Vernon, Claes von Hofsten & Luciano Fadiga. A Roadmap for Cognitive Development in Humanoid Robots. Springer Science & Business Media, December 2011.
- D. Andler. Introduction aux sciences cognitives. Folio, Paris, October 2004. (In French)
- Francisco Varela, Evan Thompson, Elor Rosch. L’inscription corporelle de l’esprit : Sciences cognitives et expérience humaine. Seuil, Paris, March 1999. (In French)
- A. Cangelosi et M. Asada, Éd., Cognitive Robotics. The MIT Press, 2022. doi: 10.7551/mitpress/13780.001.0001.

Artificial cognitive systems: from concept to the development of intelligent behaviors in autonomous robotics

Questions ?

Christophe SABOURIN
sabourin@u-pec.fr
Laboratoire Images, Signaux et Systèmes Intelligents (LISSI)