New AI and Robotics

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Introduction

To take robots out of the factories in everyday life is not a free lunch.

Have we the science or even the *concept* framework to deal with open ended unstructured environments?

Introduction

How the new paradigms in AI, from swarm intelligence to morphological computation and complex adaptive systems theory applications, (could) help robotics? Is robotics the science of embodied cognition?

Is there a need to extend computation theory to manage the interaction with the physical world?

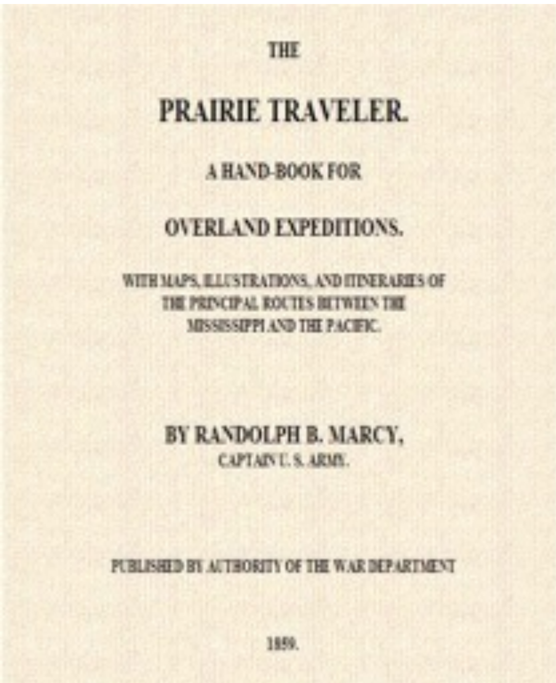
Does robotics needs a 'paradigm change' from top-down symbolic processing to emerging self-organized cognitive behaviors of complez adaptive dynamical systems?

Introduction

Which relations are there between new AI, the US NSF idea of CyberPhysical Systems Science, and the concepts of embodied and situated cognition popular in European cognitive sciences community and a significant part of the robotics community?

What does it mean in this context to be 'biomimetic'?

Caveat :-)



THE

PRAIRIE TRAVELER.

A HAND-BOOK FOR

OVERLAND EXPEDITIONS.

WITH MAPS, ILLUSTRATIONS, AND ITINERARIES OF THE PRINCIPAL ROUTES BETWEEN THE MISSISSIPPI AND THE PACIFIC.

BY RANDOLPH B. MARCY,
CAPTAIN U. S. ARMY.

PUBLISHED BY AUTHORITY OF THE WAR DEPARTMENT

1859.

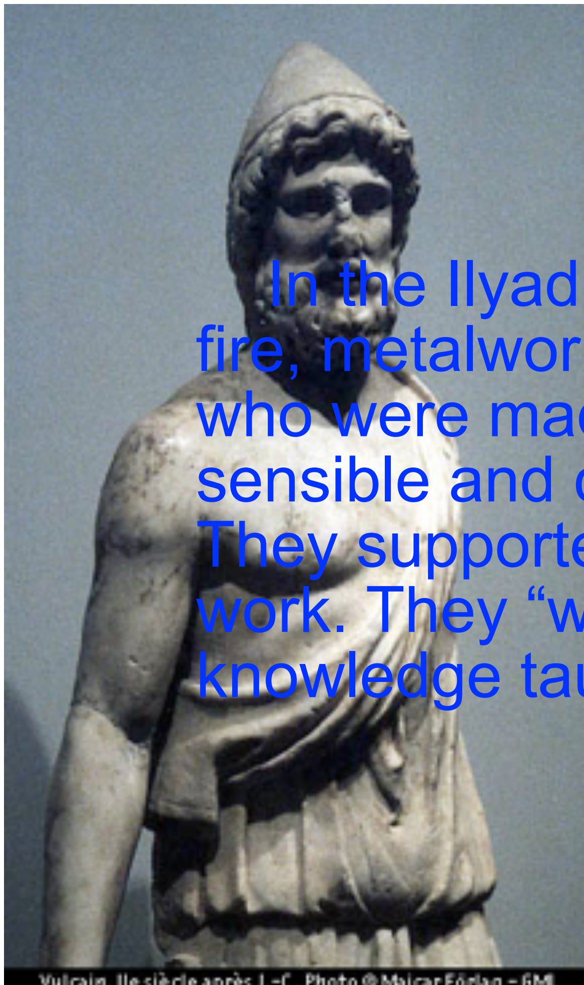
ROUTES TO CALIFORNIA AND OREGON

'EMIGRANTS or others desiring to make the overland journey to the Pacific should bear in mind that there are several different routes which may be traveled with wagons, each having its advocates in persons directly or indirectly interested in attracting the tide of emigration and travel over them.

Information concerning these routes coming from strangers living or owning property near them, from agents of steam-boats or railways, or from other persons connected with transportation companies, should be received with great caution, and never without corroborating evidence from disinterested sources'

From 'The Prairie Traveler', R. B. Marcy, Captain, U.S.A, 1859

An old dream



Vulcain. IIe siècle après J.-C. Photo © Maicar Förlag - GML

In the Ilyad, Hephaestus, the ancient Greek god of fire, metalworking and handicrafts, “forged” two maids who were made of gold. Those maids were “strong, sensible and could express themselves in words.” They supported and helped Hephaestus in his hard work. They “were in possession of every piece of knowledge taught by the immortal gods”

“If every tool, when ordered, or even of its own accord, could do the work that befits it, just as the creations of Daedalus moved of themselves . . . If the weavers' shuttles were to weave of themselves, then there would be no need either of apprentices for the master workers or of slaves for the lords.”

Aristotle

(from Atheniensium Republica, 322 BC)

History

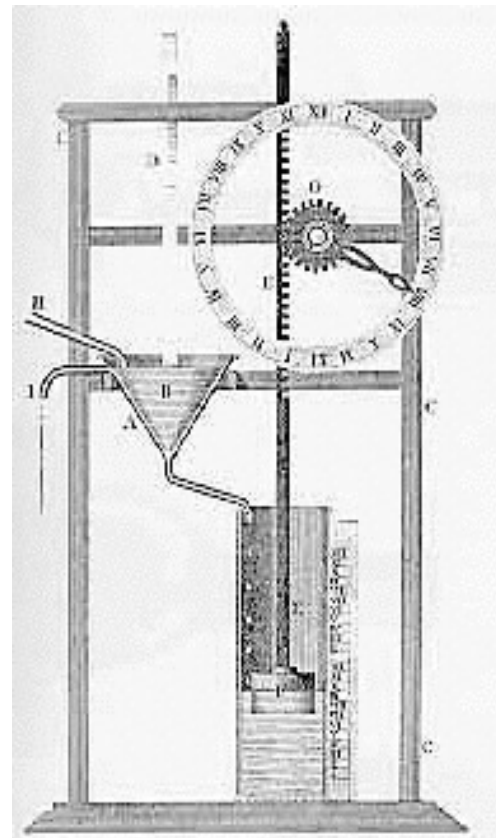
The South Pointing Chariot may date back to 2600 BC

The chariot consisted of a figure that always pointed south, regardless of the direction it was heading.

By the addition of drums connected to the wheels it could also probably measure distances (working as an odometer)

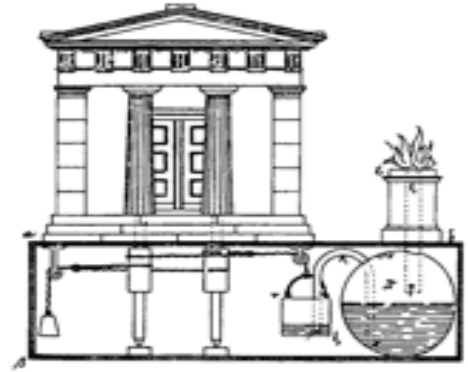
History
Ctesibius of Alexandria (250 B.C.)

He built water clocks with movable
figures and other automaton



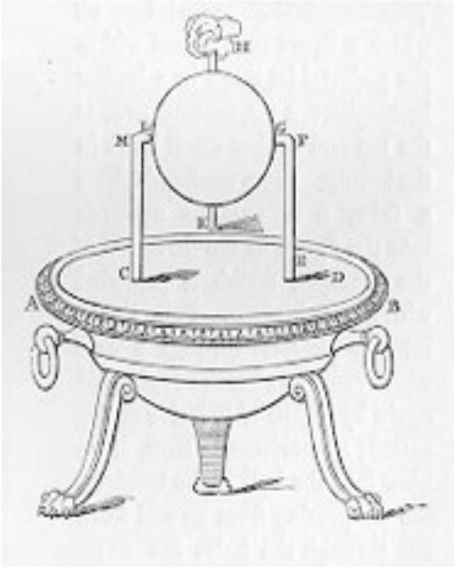
Hellenistic Technology
The Antikythera mechanism

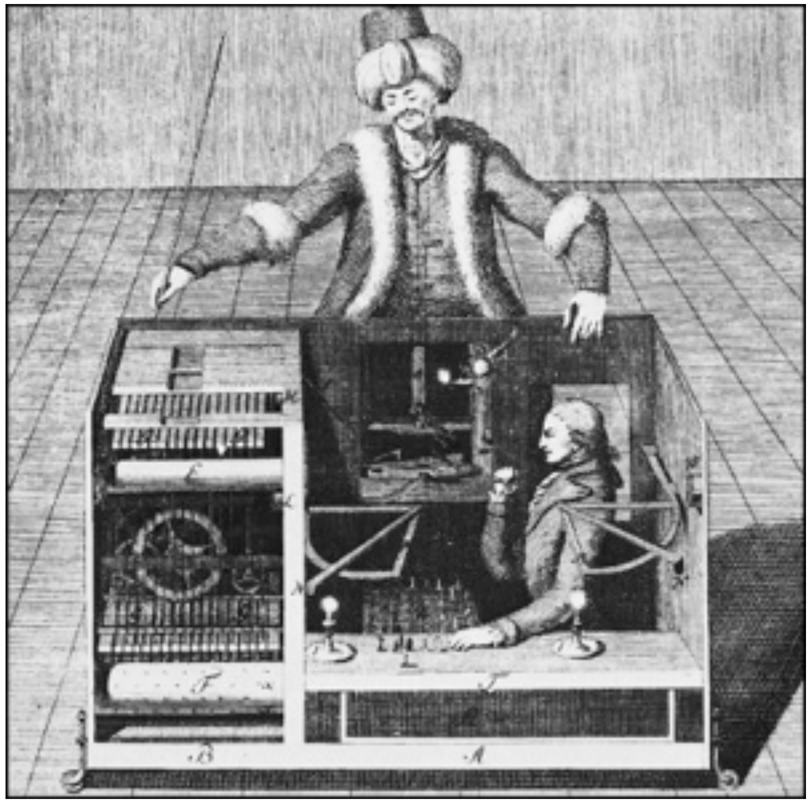
Hero (Heron) of Alexandria



„Tempeltüren öffnender Automat" des *Heron v. Alexandria* (aus *Περι Αυτοματοποιητικης* um 50 n. Chr.)

He was the inventor of the aeolipile, an early example of steam engine, almost two thousand of years before Watt, a designer of automas and automatisms, mostly for leisure and entertainment, or religious purpose, in the ellenistic age.

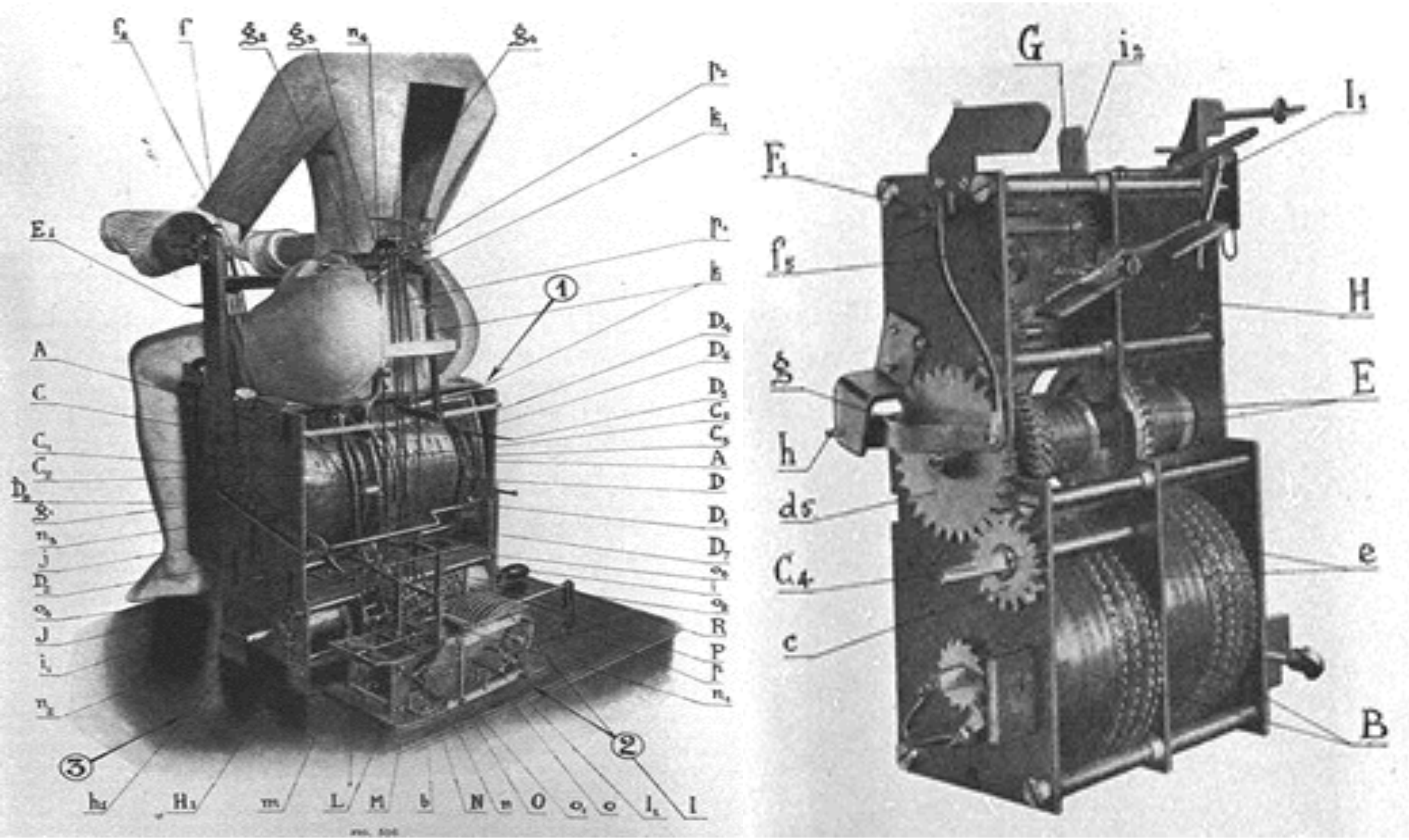




1769: Wolfgang von Kempelen: chess player

Jaquet-Droz Brothers (1720-1780)

The writer is the most complex of the three automata in Neuchatel museum(the others are the drawer and the player). He is able to write any custom text up to 40 letters long dThe text is code on a wheel where characters are selected one by one. He uses a goose feather to write, which he inks from time to time, including a shake of the wrist to prevent ink from spilling. His eyes follow the text being written, and the head moves when he takes some ink.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Karakuri dolls

Chahakobi Ningyo (Tea Serving Doll) by SHOBEI Tamaya IX, and plan from 'Karakuri Zuii' ('Karakuri - An Illustrated Anthology') published in 1796.

Chahakobi Ningyo (Tea Serving Doll) by SHOBEI Tamaya IX, and plan from 'Karakuri Zuii' ('Karakuri - An Illustrated Anthology') published in 1796.

History

1956: Joseph Engelberger founds Unimation and builds the first industrial robot UNIMATE

1962: General Motors installs the first robot from Unimation

Armed for duty. A Unimate robot—really, just an arm—picks up and puts down parts in a General Electric factory.

A typical industrial robot (COMAU)

Kuka LWR

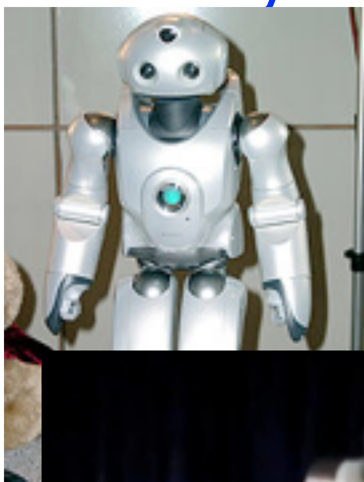
Today's mobile robots

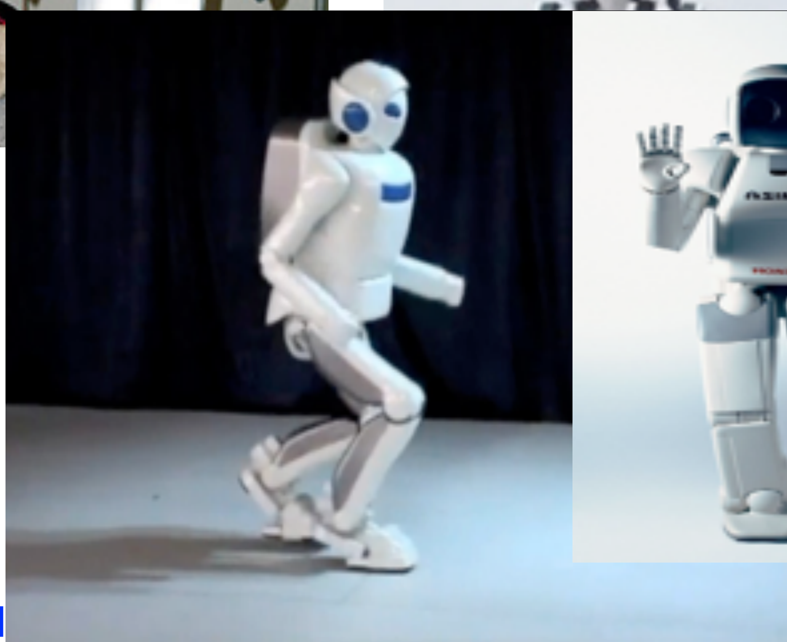
Today's 'service' manipulator examples

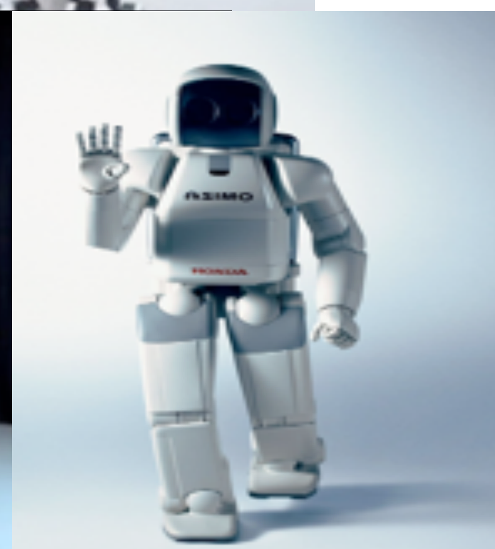
First humanoid

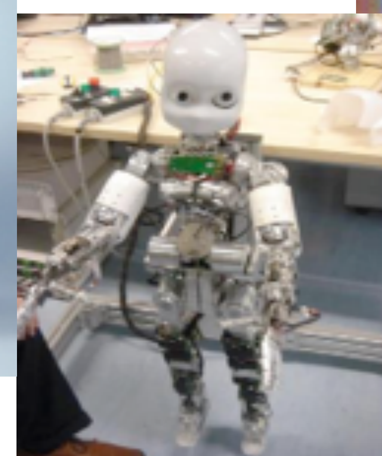
1937/38 Westinghouse creates ELEKTRO a human-like robot that could walk, talk, and smoke.

Today's humanoids









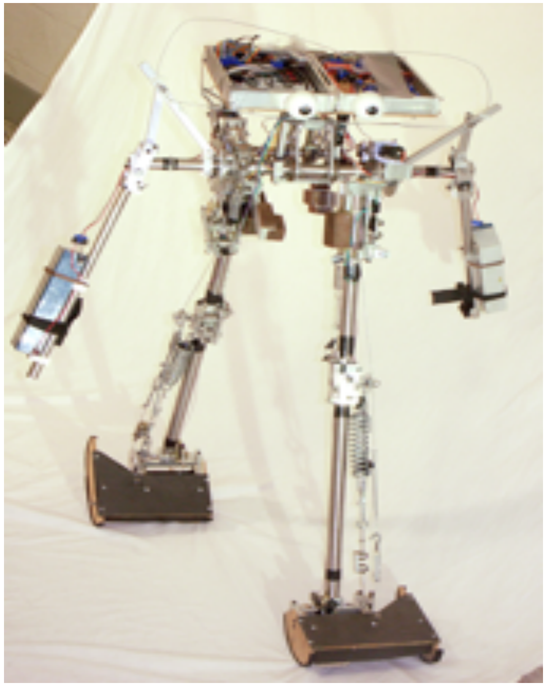
N

Juanelo Torriano alias Gianello della Torre, (XVI century) a craftsman from Cremona, built for Emperor Carl V a mechanical young lady who was able to walk and play music by picking the strings of a real lute.

Hiroshi Ishiguro, early XXI century

Director of the Intelligent Robotics Laboratory, part of the Department of Adaptive Machine Systems at Osaka University, Japan

Conceptually different humanoid designs (mainly research)



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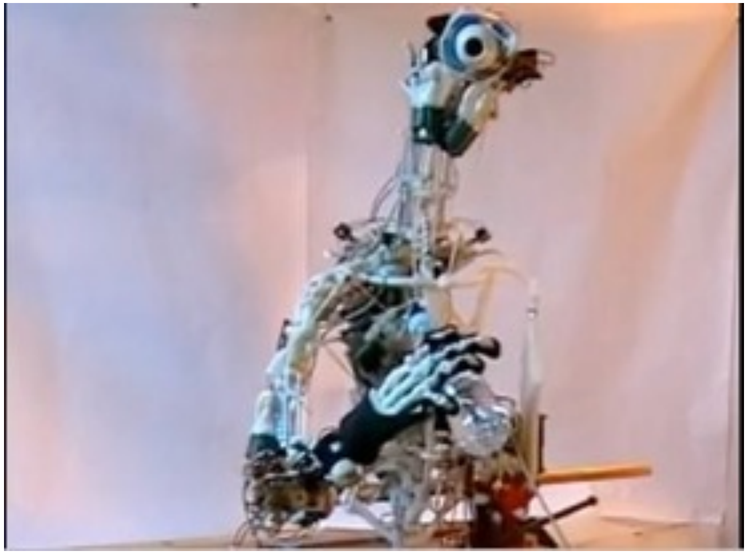
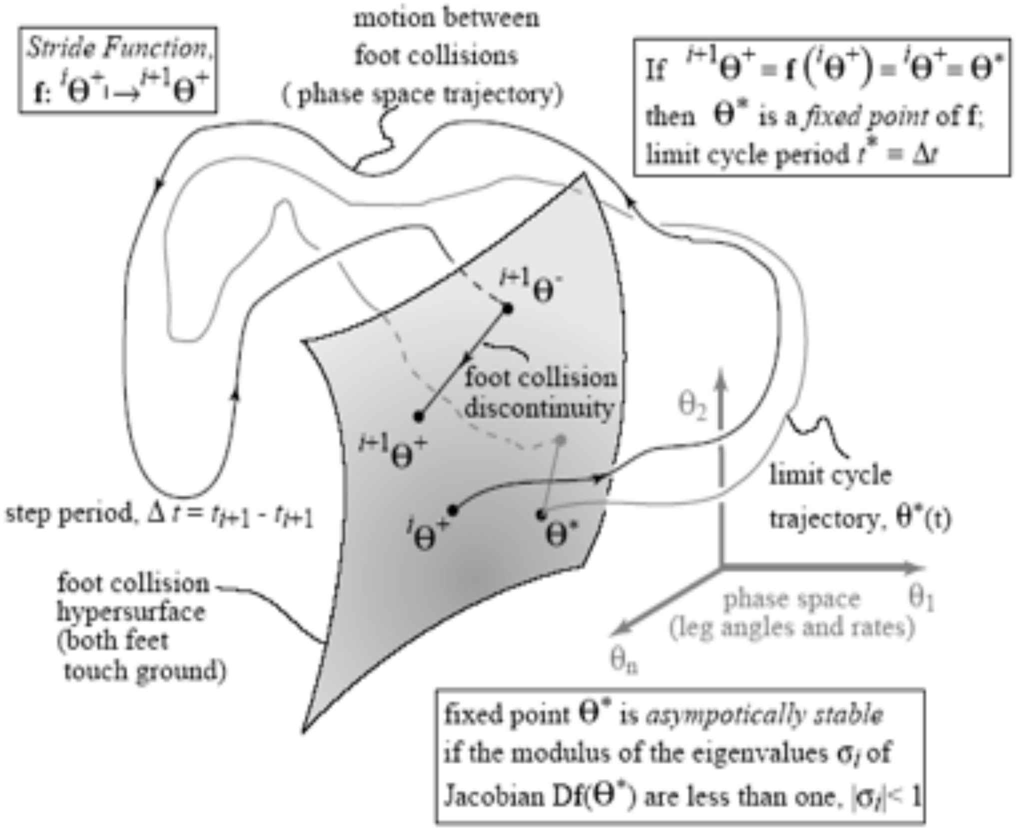


Poincarè Maps

This picture represents the dynamical behavior of the legs in the phase space

In the gait dynamics the continuous phase represented by continuous equations like those seen before alternate with the discontinuities due to foot impact with the floor, or when modeled with kneestrike.



New AI and Robotics
A really unfair comparison :-)

- The inner life of a cell
- One of the best existing humanoids bad day

New AI and Robotics

- In nature there are many kinds of loosely coupled networks of intelligent agents, largely varying in terms of quantity of agents and cognitive and adaptive capacity (i.e. of computational needs) of each agent.
- In the natural domain the most widely used method of 'intelligence', computation and 'cognition' are 'embodied' biological neural networks.

Introduction

A number of empirical and theoretical researches are investigating, on one side on the aspects and implication of 'embodiment', particularly interesting in the walking machine domain, on the other side on the 'emergence' of cognition from network interaction of physical agents

The (or ... some :-)) big questions

How the new paradigms in AI, from swarm intelligence to morphological computation and complex adaptive systems theory applications, (could) help robotics?

The (or ... some :-)) big questions

Is robotics the science of embodied cognition?

Is there a need to extend computation theory to manage the interaction with the physical world?

The (or ... some :-)) big questions

Does robotics needs a 'paradigm change' from top-down symbolic processing to emerging self-organized cognitive behaviors of complex adaptive dynamical systems?

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Which relations are there between new AI, the US NSF idea of CyberPhysical Systems Science, and the concepts of embodied and situated cognition popular in European cognitive sciences community and a significant part of the robotics community?

The (or ... some :-)) big questions

What does it mean in this context to be 'biomimetic'?

The (or ... some :-)) big questions
...last but not least...

How to quantify?

My point of view :-)

- Information related measures coming from Shannon entropy may help the understanding of intelligent cognitive controlled systems
- What we probably need to be able to build 'real' artificial cognitive systems is a deep interchange of concepts, methods and insights between fields so far considered well distinct like information and control theory, non linear dynamics, general AI and psycology and neurosciences.
- Do we??? :-)

Lungarella, Sporns (2006)

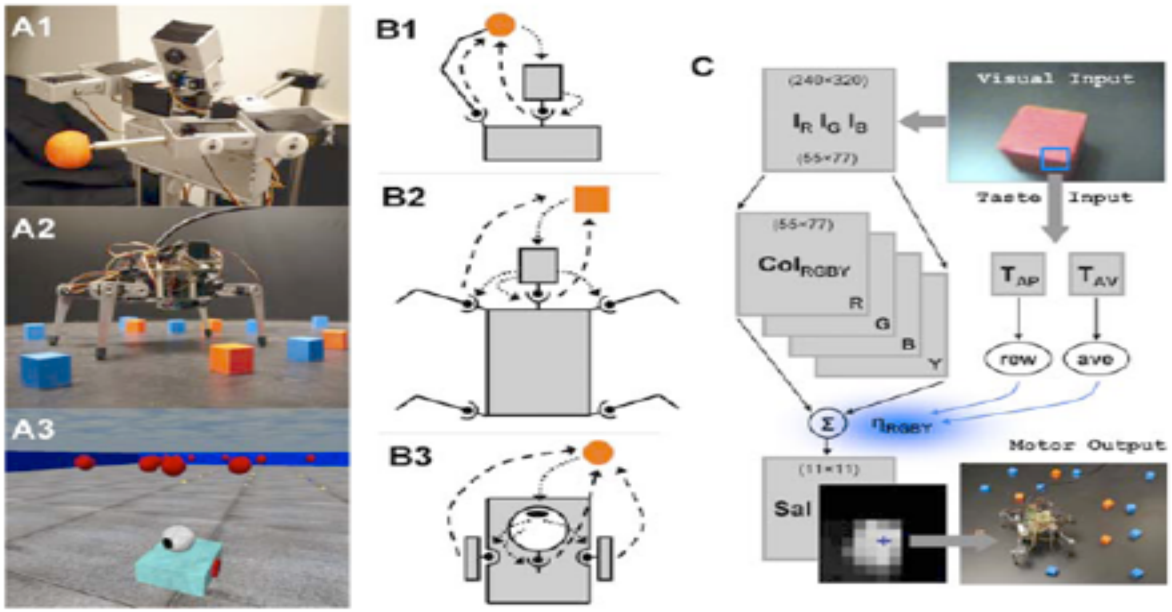


Figure 1. Robots, Sensorimotor Interactions, and Neural Control Architecture
(A1) *Roboto* has a total of 14 DOF, five of which are used in the current set of experiments. Note the head-mounted CCD camera, the pan-tilt head system (2 DOF), and the moveable left arm with shoulder, elbow, and wrist joints (3 DOF). The object is a red ball (1.25 inches diameter) attached to the tip of the last joint.
(A2) *Strider* has a total of 14 DOF, with four legs of 3 DOF each and 2 DOF in the pan-tilt head system. Objects are red and blue blocks (1 inch cubes). *Strider* is situated in an environmental enclosure with black walls.
(A3) *Madame* has 4 DOF, with 2 DOF in the pan-tilt system and 2 DOF for the wheels, which are both located on an axis vertical to the main body axis. The environment is a square arena bounded by blue walls containing 20 red-colored floating spheres.
(B1) *Roboto* engages in sensorimotor interactions via the head system and arm movements; sensory → motor (dotted arrows), motor → sensory (dashed arrows).
(B2) *Strider* engages in sensorimotor interactions via the head system, as well as via steering signals generated by the head and transmitted to the four legs.
(B3) *Madame*'s behavior consists of a series of approaches to colored objects and ovations. Fixations to the objects are maintained by independent action of head and body.
(C) Neural control architecture. The architecture common to all robots is composed of color image arrays I_R, I_G, I_B, color- intensity map $\mathbf{Col}_{RGBY}$, and saliency map *Sal* (see text for details). The peak of the saliency map (blue cross) determines the pan-tilt camera motion and body steering. In addition, *Strider*'s neural system contains a value system with taste sensory inputs relayed via a virtual taste sensor (blue square in visual image) to taste neurons ($T_{AP,AV}$), which in turn generates reward and aversiveness signals (rew, ave). These signals are used to modulate the strengths of the saliency factors η_{RGBY} (see text for details).
DOI: 10.1371/journal.pcbi.0020144.g001

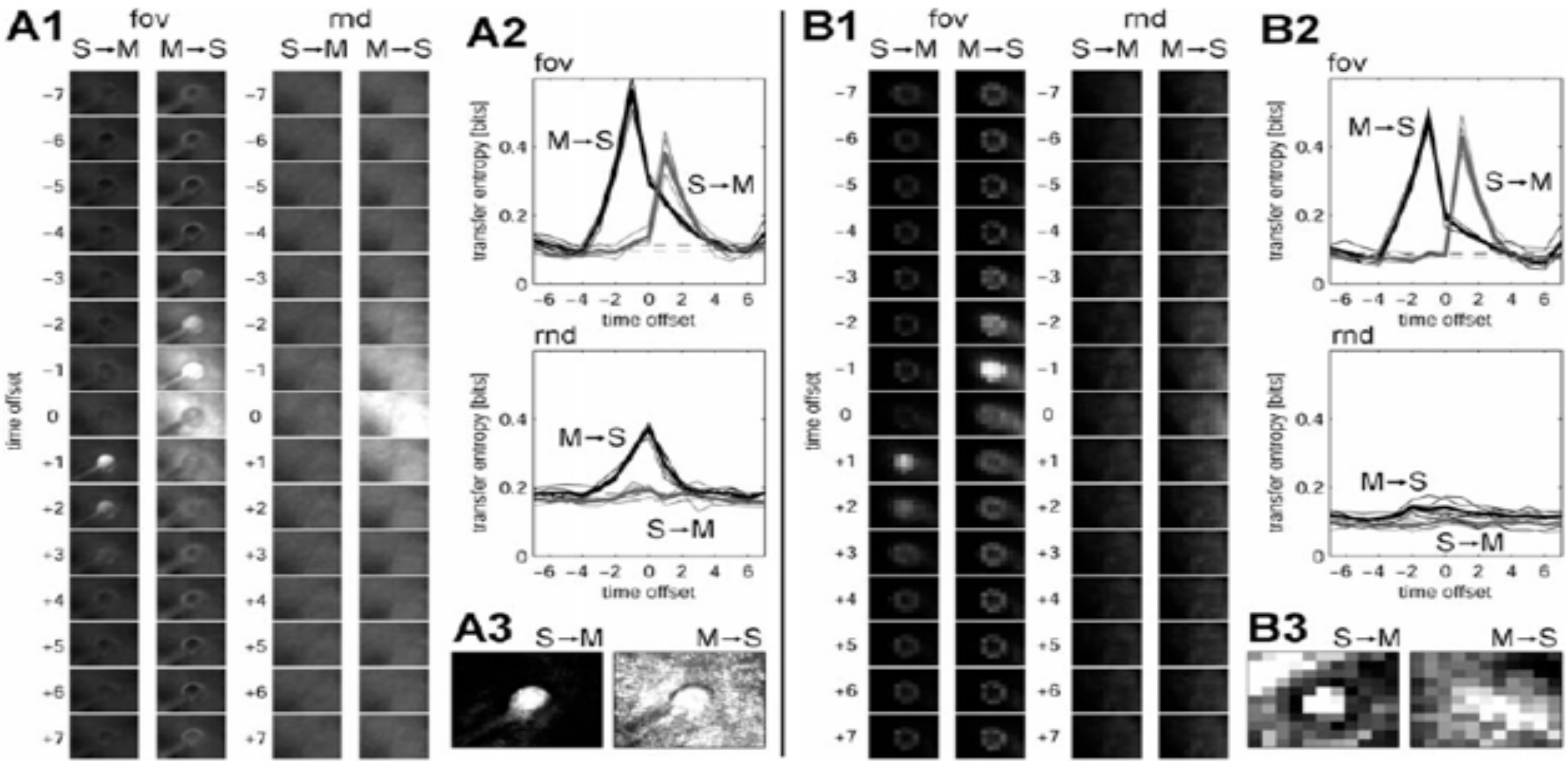


Figure 3. Information Flow (Transfer Entropy) between Sensory Input, Neural Representation of Saliency, and Motor Variables in *Roboto*

(A1) Transfer entropy between array I_R (variable S) and pan-tilt amplitude (variable M). Series of plots show maps of transfer entropy from S to M (S → M) and from M to S (M → S) over visual space (55 × 77 pixels), calculated for offsets between −7 ("M leading S") and +7 ("S leading M") time steps. Plots show data for conditions "fov" and "rnd." The gray scale ranges from 0.0 to 0.5 bits (for all plots in panels A1 and B1).

(A2) Curves show transfer entropy for five individual runs (thin lines) as well as the average over five runs (thick lines) between the single central pixel of array I_R (S) and pan-tilt amplitude (M), for directions M → S (black) and S → M (gray).

(A3) z-Score maps of significant image regions (plotted between z = 0 and z = 6). The z-scores are expressed as number of standard deviations above background at time offset +1 (S → M) and −1 (M → S). Mean and standard deviation of background is calculated from transfer entropy values at maximal time delays (−7,+7 time steps).

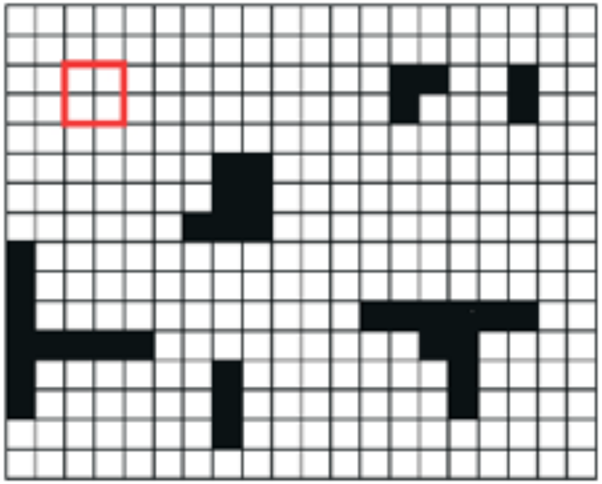
(B) All three panels have the same format as (A), but the neural activations of the saliency map *Sal* are substituted as variable S (11 × 11 neural units).

DOI: 10.1371/journal.pcbi.0020144.g003

Lampe, Chatila (2006): Environment complexity

- H is defined as the entropy related to density of obstacles:

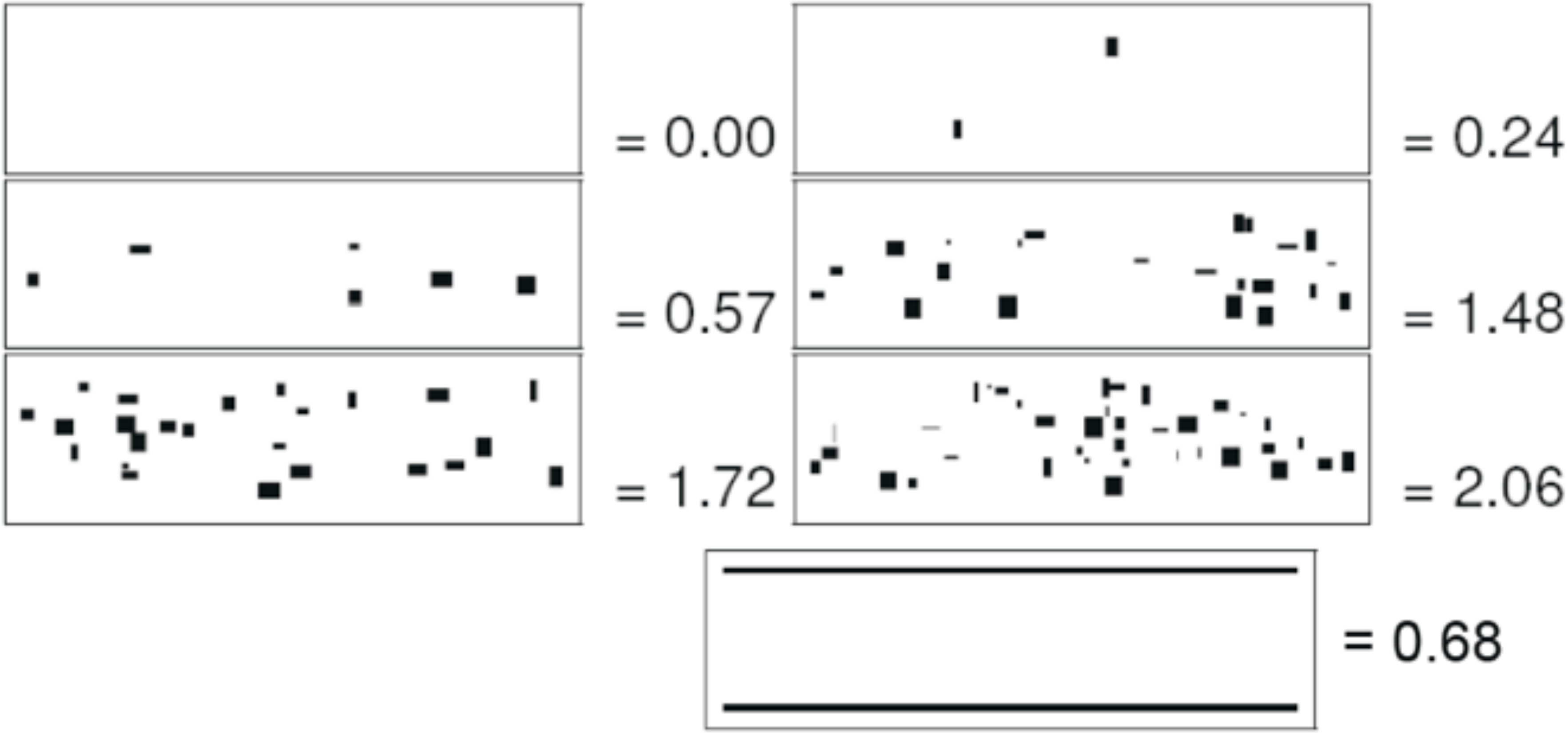
$$H = \sum_i -p(d_i) \log p(d_i)$$



$p(d_i)$ density of i-th density level in the occupancy grid,

with: $\sum_i p(d_i) = 1$

Lampe,Chatila (2006) : Entropy of cluttered environment



Information Driven Self Organization

- Several researchers have shown the importance of Information Driven Self Organization. IDSO (Information Driven Self Organisation) In particular Prokopenko , Ralf Der and other have shown simple demonstrators, mainly in simulation, with snake-bots, humanoids and grasping systems. These approaches seem very promising.

Information Driven Self Organization

- Snakebot (Tanev et. al.)
- An information-driven grasping procedure embryonic system (Der et al.)

Information Driven Self Organization 'WEAK' form

Information metrics can be regarded as a quantitative criteria to compare the efficiency of different design for cognitive/ intelligent/controlled systems.

“For instance, imagine a completely centralised modular robot, controlled from a single module/segment that regularly receives data from other segments, computes the best actions for every segment, and sends the instructions back. How would one systematically compare this design with other, more modular, designs? Measuring instructions' size, number of packets, memory usage, etc. would be prone to ambiguities. On the other hand, carrying out the analysis information-theoretically has the advantage of employing "the lingua franca" for multiple approaches.”

Information Driven Self Organization
'STRONG' form

Is maximization of information transfer through certain channels one of the main evolutionary pressures?

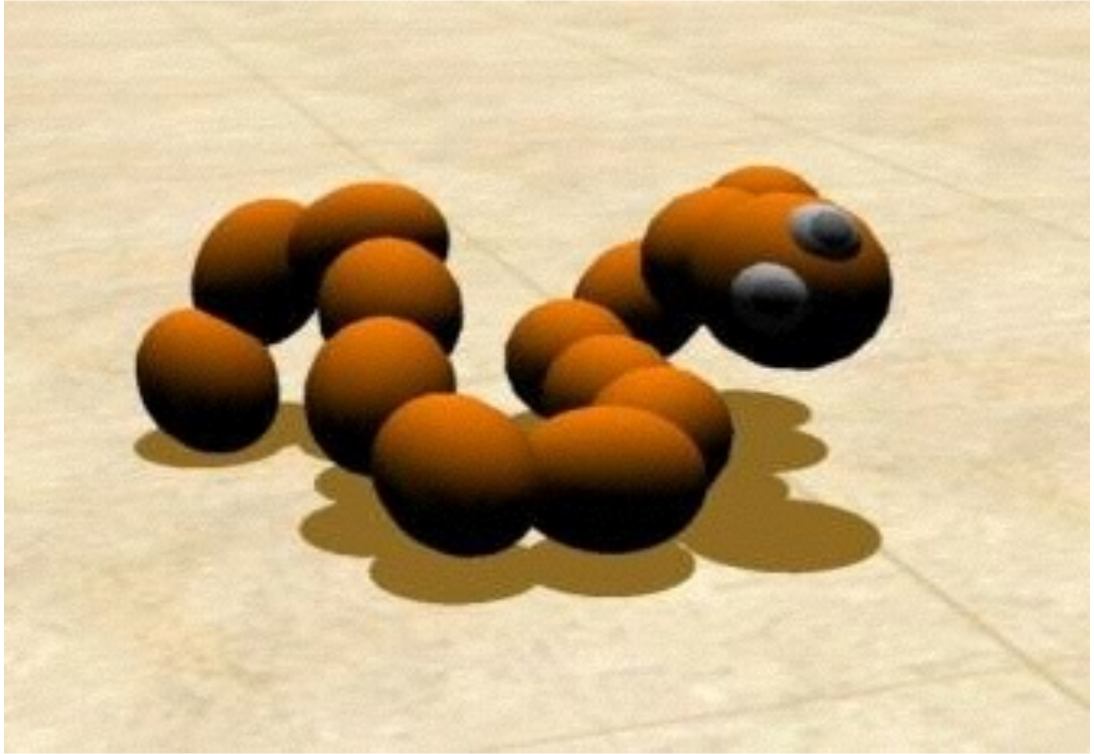
Information Driven Self Organization 'SNAKEBOT'

- Snakebot by Tanev is an example of a system built according to this principles.
- It can be shown that the amount of predictive information between groups of actuators (measured via generalised excess entropy) grows as the modular robot starts to move across the terrain. T
- The distributed actuators become more coupled when a coordinated side-winding locomotion is dominant.

Information Driven Self Organization 'SNAKEBOT'

Note that if the states of the remote segments are synchronised then some information has been indirectly transferred via stigmergy (due to the physical interactions among the segments, and with the terrain)

Information Driven Self Organization 'SNAKEBOT'



QUANTIFYING THE EVOLUTIONARY SELF STRUCTURING OF EMBODIED COGNITIVE NETWORKS

Information Driven Self Organization Issues

- In general the amount of information managed by the controller can be measured ex-post from the information measures computed on the variables of interest: the data stream coming from propio and exteroceptor (actuation generalized torques, encoders positions and video).
- These measures can derive from simulations models or they can come from a physical system.
- One of the major issues is to develop a formal method to predict them from a given system

Network growth model

- So far researcher interest has focused mainly on the structural properties of random complex networks in communications, biology, social sciences and economics.
- A number of giant artificial networks of such a kind came into existence recently. This opens a wide field for the study of their topology, evolution, and complex processes occurring in them.

Network growth model

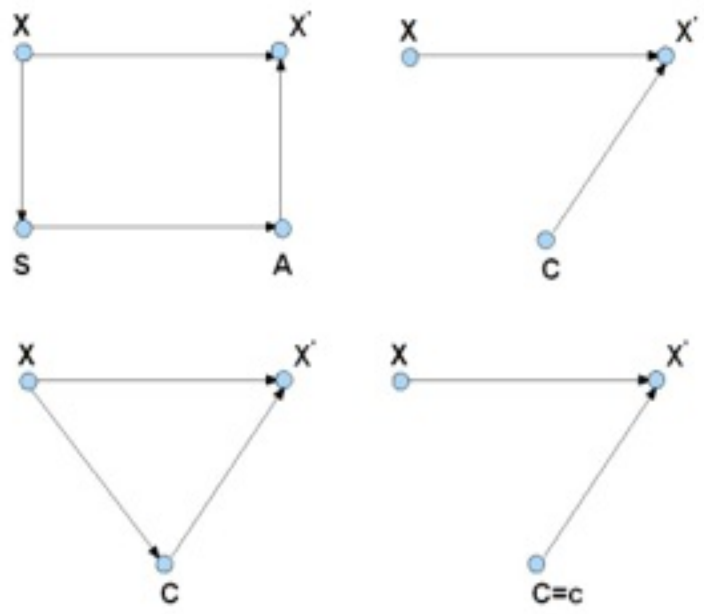
- Such networks possess a rich set of scaling properties. A number of them are scale-free and show striking resilience against random breakdowns. In spite of large sizes of these networks, the distances between most their vertices are short, a feature known as the “small world” effect.
- It is known that growing networks self-organize into scale-free structures through the mechanism of preferential linking.

Probabilistic Model Of Control

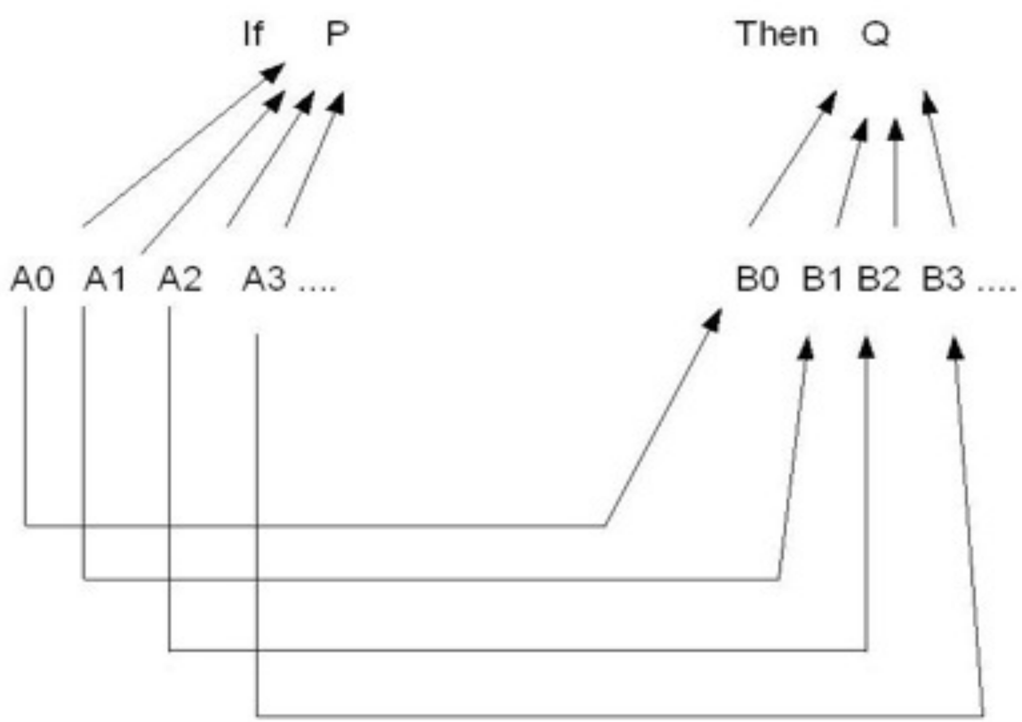
- Although it may seem strange only in recent times the classical results from Shannon theory, have been applied to the modeling of control systems.
- As the complexity of control tasks namely in robotics applications lead to an increase in the complexity of control programs, it becomes interesting to verify if, from a theoretical standpoint, there are limits to the information that a control program must manage in order to be able to control a given system.

Probabilistic Model Of Control

Touchette, Lloyd (2004)



Directed acyclic graphs representing a control process. (Upper left) Full control system with a sensor and an actuator. (Lower left) Shrinked Closed Loop diagram merging sensor and actuator, (Upper right) Reduced open loop diagram. (Lower right) Single actuation channel enacted by the controller's state C=c.



'Causality at different levels'.

L1, L2, L3, ..., Ln	covering laws	
		explanans
C1, C2, ..., Cn	initial conditions	

E	explanandum

Hempel-Oppenheim Schema

Methods
Steps Forward?

- IDSO in the 'real' world: (SE(3) with tangent space se(3)

- networks of chaotic oscillators

…

Methods
Steps Forward?

Bonsignorio,F.P., Preliminary Considerations for a Quantitative Theory of Networked Embodied Intelligence. In M. Lungarella et al. (Eds.): 50 Years of AI, Festschrift, LNAI 4850,112–123, Springer-Verlag Berlin Heidelberg, 2007

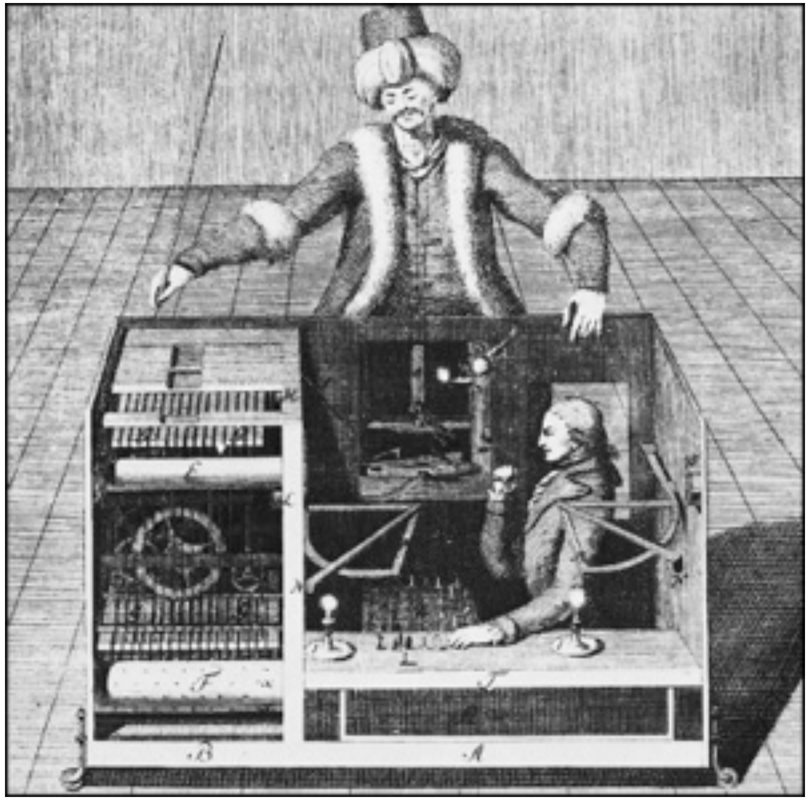
Bonsignorio,F.P.,Steps to a Cyber-Physical Model of Networked Embodied Anticipatory Behavior.In G. Pezzulo et al. (Eds.): ABiALS 2008, LNAI 5499, 77–94, Springer-Verlag Berlin Heidelberg, 2009

Methods
Steps Forward?

Bonsignorio, F., Quantifying the evolutionary self-structuring of embodied cognitive networks, Artificial Life, 19(2), 267–289, MIT Press, 2013

Bonsignorio, F., Zen, Robotics and the art of pushing swings, In: Morphological Computation, H. Hauser, R. M. Fuechslin, R. Pfeifer (Eds.) 2014 (invited submission, to appear)

Current state :-)



1769: Wolfgang von Kempelen: chess player

Curious? Check the ShanghaiLectures website!!!
and….. stay tuned for 2014!!!!

www.shanghailectures.org

Thank you!

Fabio P. Bonsignorio

fabio.bonsignorio@heronrobots.com