New AI and Robotics

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Heron Robots

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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 complex 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 :-)  

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

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)
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

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

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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. The 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.

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

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History

1956: Joseph Engelberger founds Unimation and builds the first industrial robot UNIMATE
1962: General Motors installs the first robot from Unimation
A typical industrial robot (COMAU)
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Kuka LWR
Today's mobile robots

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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
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

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Conceptually different humanoid designs (mainly research)
Conceptually different humanoid designs (mainly research)
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.

Stride Function:
\[ f: i^{i+1} \Theta^+ \rightarrow i^{i+1} \Theta^- \]

motion between foot collisions
(phase space trajectory)

foot collision discontinuity

step period, \( \Delta t = t_{i+1} - t_i \)

foot collision hypersurface (both feet touch ground)

limit cycle trajectory, \( \Theta^*(t) \)

phase space (leg angles and rates)

fixed point \( \Theta^* \) is asymptotically stable if the modulus of the eigenvalues \( \sigma_i \) of Jacobian \( Df(\Theta^*) \) are less than one, \( |\sigma_i| < 1 \)

New AI and Robotics
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 psychology and neurosciences.
- Do we??? :-)

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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).

(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 $C_{ol\_RGB}$, 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 $T_{REGION}$ (see text for details).

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

(A1) Transfer entropy between array I₀ (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 I₀ (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).

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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

New AI and Robotics
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. This is because 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 proprio 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

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 $C=c$.

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'Causality at different levels'.
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Hempel-Oppenheim Schema

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

E  explanandum
Methods Steps Forward?

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

...
Methods
Steps Forward?


Methods
Steps Forward?


Current state :-)  

1769: Wolfgang von Kempelen: chess player
Curious? Check the ShanghaiLectures website!!!
and….. stay tuned for 2014!!!!

www.shanghailectures.org

New AI and Robotics
Thank you!
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