Scuola Superiore Sant'Anna
di Studi Universitari e di Perfezionamento

ISTITUTO DI BIOROBOTICA

Scuola Superiore Sant'Anna

The BioRobotics Institute
Scuola Superiore Sant'Anna, Pisa

Open Issues in Cognitive Embodied AI Architectures for New Robotics

Fabio Bonsignorio[1,2,3,4,5]

SPARC TG Benchmarking and Competitions[1]
IEEE RAS TC-PEBRAS[2]
Member SPARC Board of Directors[2]

The BioRobotics Institute, SSSA[4]
and Heron Robots[5]

Older and newer attempts

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

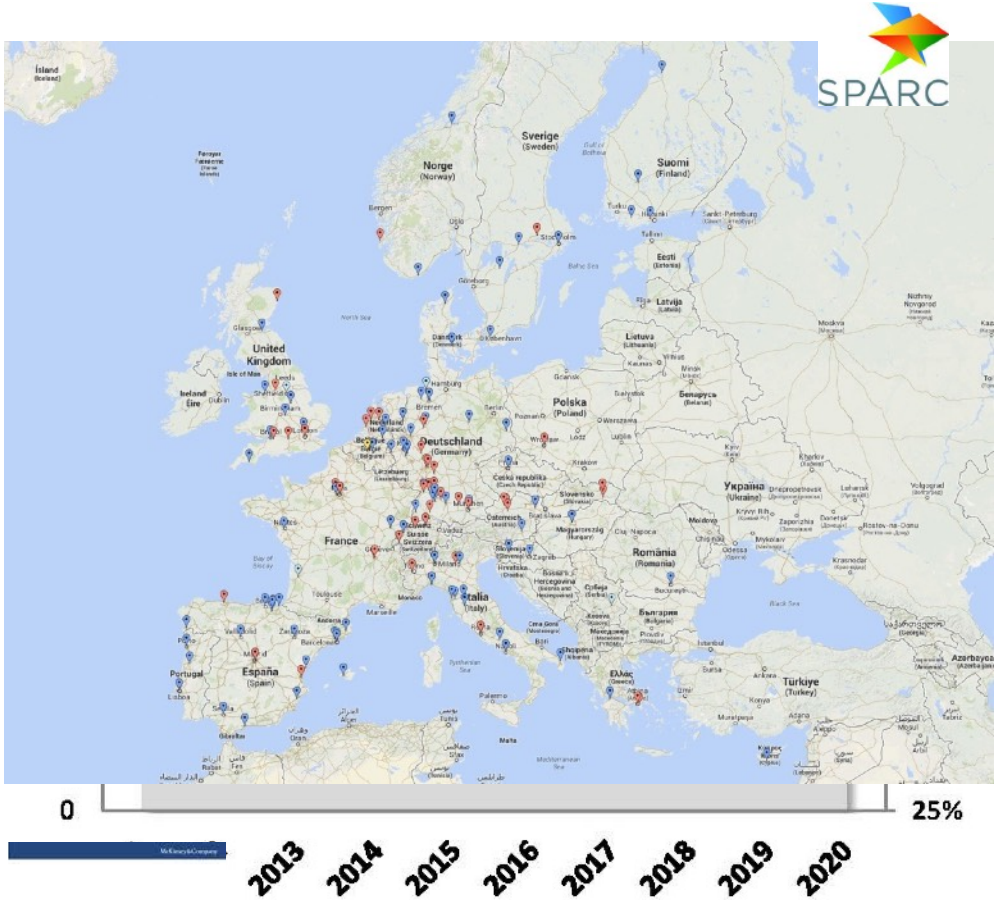
Hiroshi Ishiguro, early XXI century

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

Data are very important, but they are not all in a digital economy. ACTIONS, MOBILITY and STRENGTH are also needed! **Robotics**: a great opportunity to **innovate, connect** and **transform. Robotics is technology and business, but it is also creativity and fun!**

"[...] The size of the robotics market is projected to grow substantially to 2020s. This is a global market and Europe's traditional competitors are fully engaged in exploiting it. Europe has a 32% share of the industrial market. Growth in this market alone is estimated at 8%-9% per annum. Predictions of up to 25% annual growth are made for the service sector where Europe holds a 63% share of the non-military market. […]"

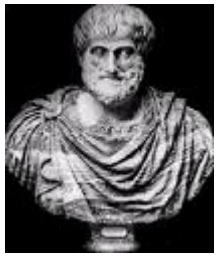
"[…] From today's €22bn worldwide revenues, robotics industries are set to achieve annual sales of between €50bn and €62bn by 2020. […]"



Robotics is one of the 12 disruptive technologies identified by McKinsey

http://sparc-robotics.eu/about/
SPARC Strategic Research Agenda

Old ideas

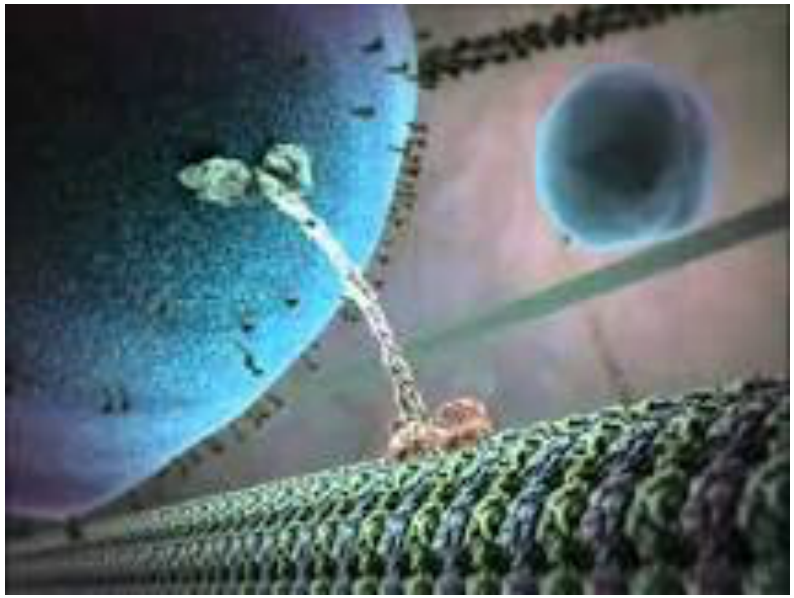


"If every tool, when ordered, or even of its own accord, could do the work that befits it, just as the creations of Daedalus moved of themselves . . . If the weavers' shuttles were to weave of themselves, then there would be no need either of apprentices for the master workers or of slaves for the lords."

Aristotle

(from Politics, Book 1, 1253b, 322 BC)

The future: is It Alive?



The next generation of robots will realize longstanding visions of robotics researchers and also of industry, transforming daily life on a scale potentially comparable to the internet.
The secret of the coming "**robotics revolution**" will be a profound re-thinking of robotics, based on an **intimate fusion of science and technology**.

Interview to Paolo Dario, World Economic Forum, March 2015
https://agenda.weforum.org/2015/03/qa-what-will-the-robots-of-the-future-look-like/

WORLD ECONOMIC FORUM

Q&A: What will the robots of the future look like?

"Next generation robotics" is one of 10 emerging technologies of 2015 highlighted by the World Economic Forum's Meta-Council on Emerging Technologies.

The real world is surprising

Columbus discovering America while looking for a short route to Asia (wikipedia)

Traders looking at screens during the global market crash of 2008 (seekingalpha.com)

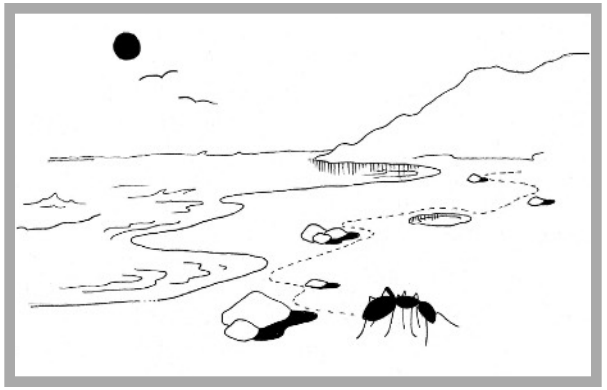
There are unexpected events that change the F-O-R (at many levels)

Two views of intelligence

classical:
cognition as computation

embodiment:
cognition emergent from sensory-motor and interaction processes

“Frame-of-reference” Simon’s ant on the beach



- **simple behavioral rules**
- **complexity in interaction, not — necessarily — in brain**

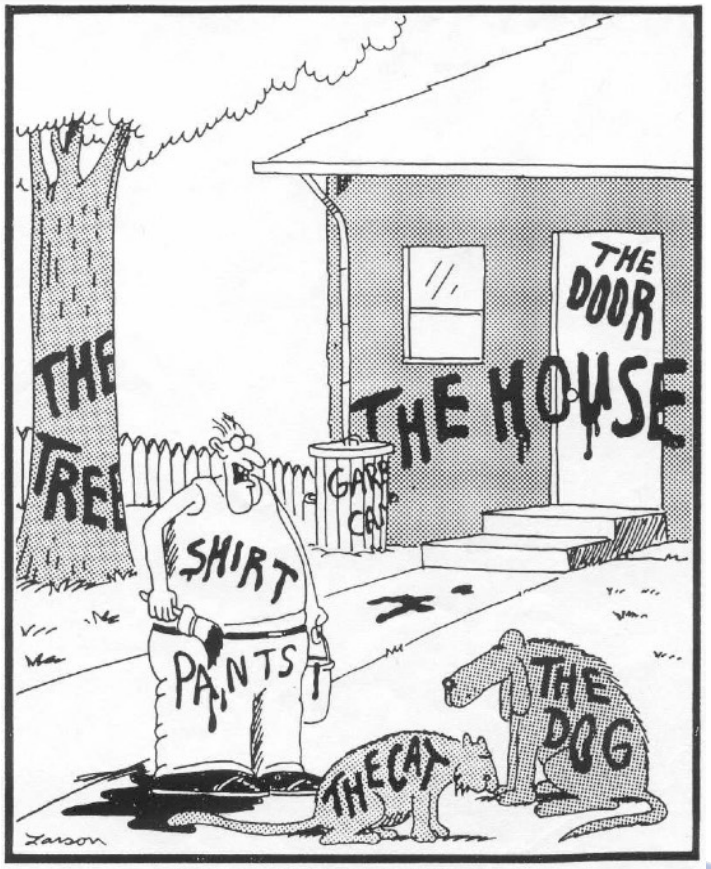
- thought experiment:
  increase body by factor of 1000
  everything else the same

The “symbol grounding” problem

real world: doesn’t come with labels …

How to put the labels??

Gary Larson

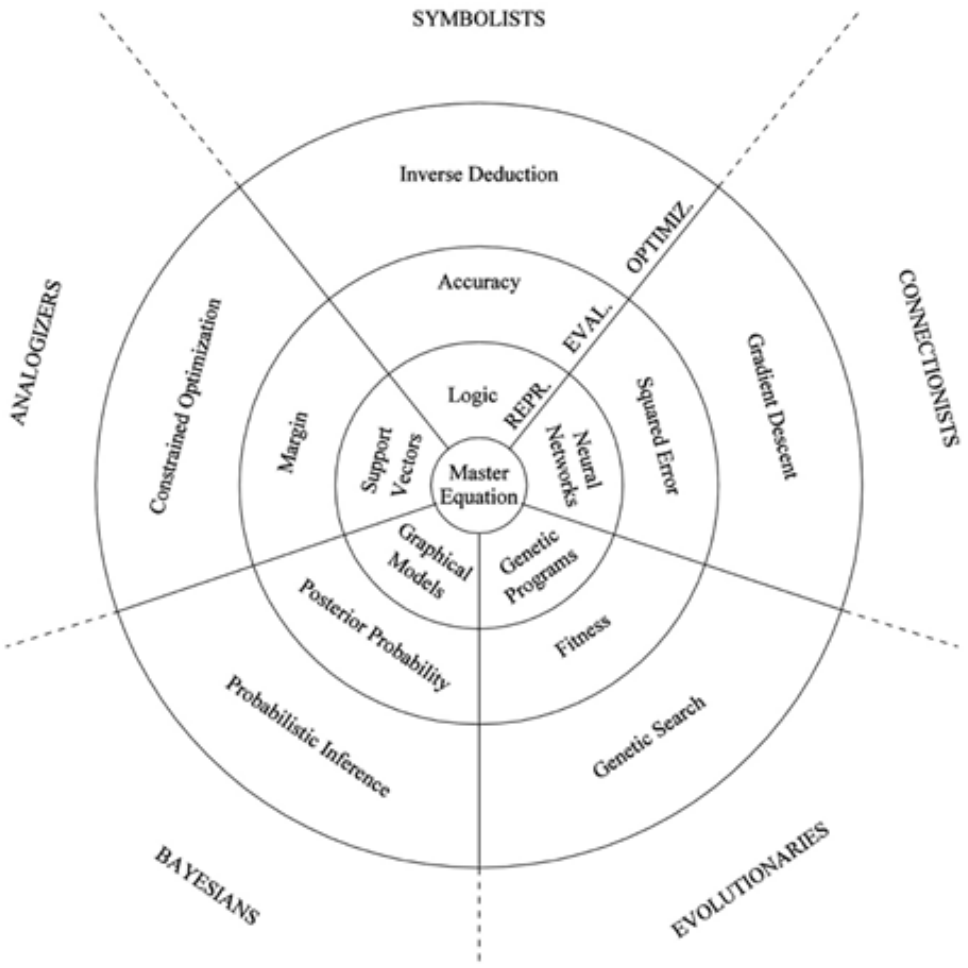


"Now! ... *That* should clear up a few things around here!"

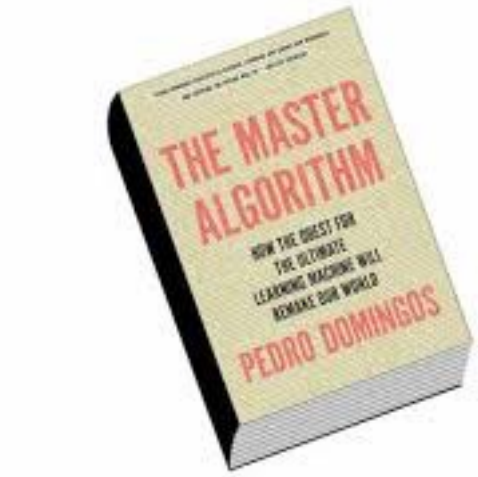
Complete agents

Masano Toda's
Fungus Eaters

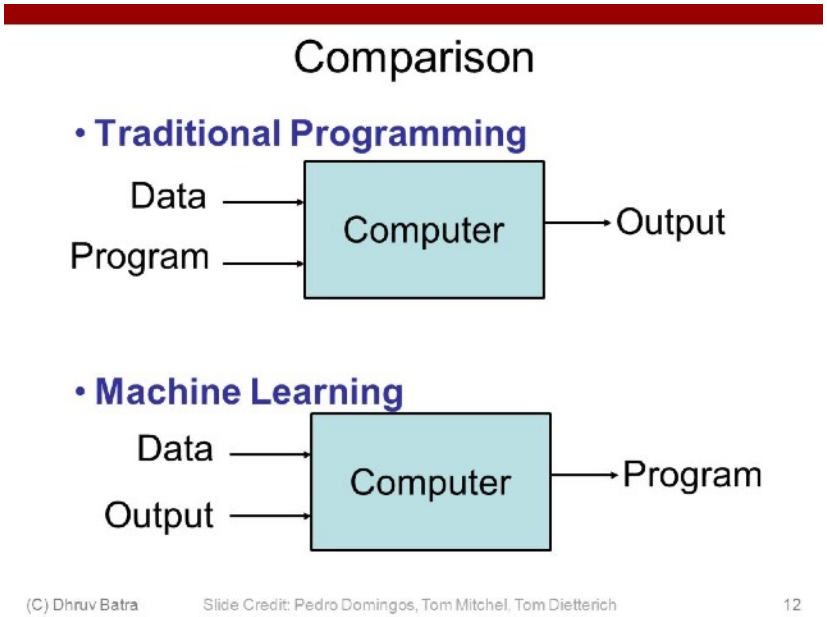
The quest for the “Master Algorithm”



P.Domingos,
The Master Algorithm,
Basic Books, 2015



The quest for the "Master Algorithm"



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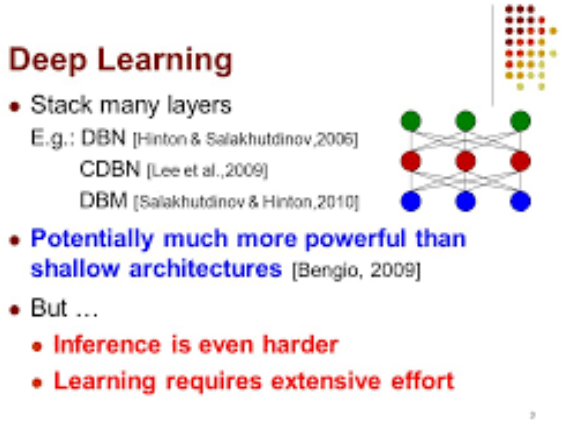

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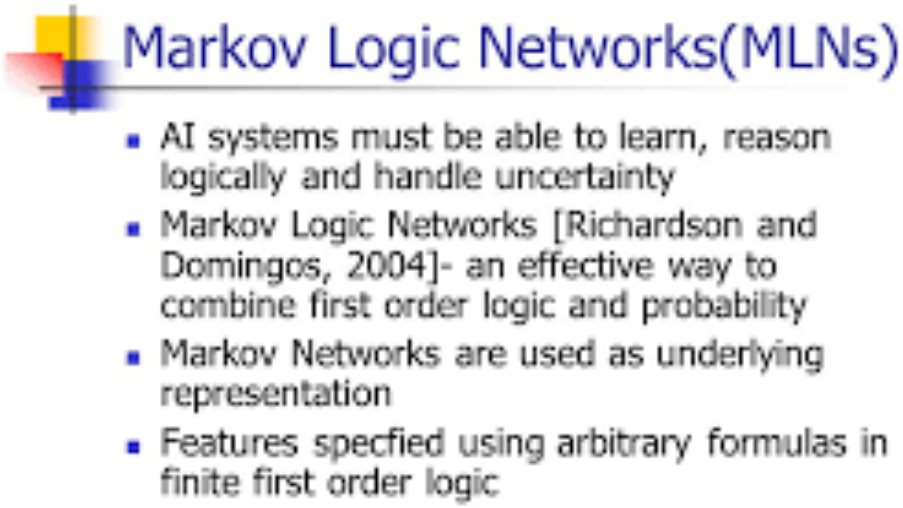
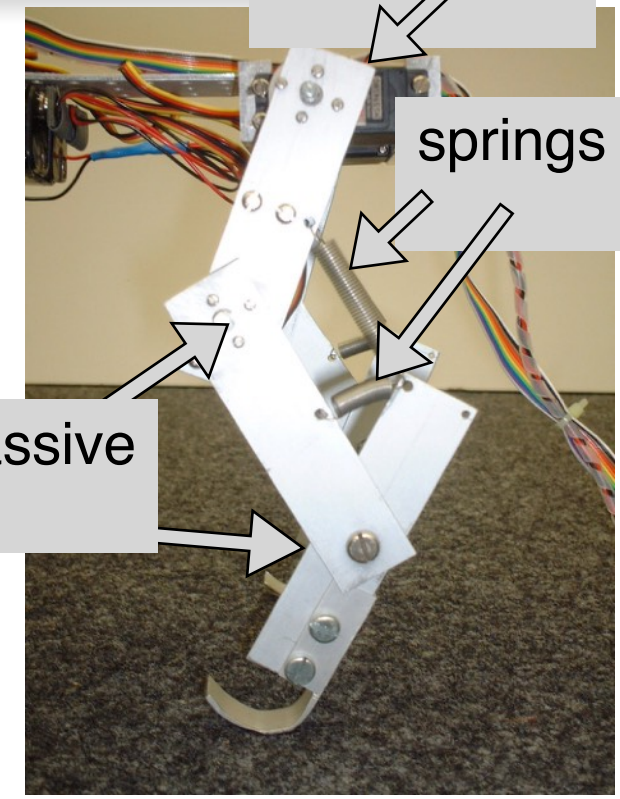


P.Domingos,
The Master Algorithm,
Basic Books, 2015

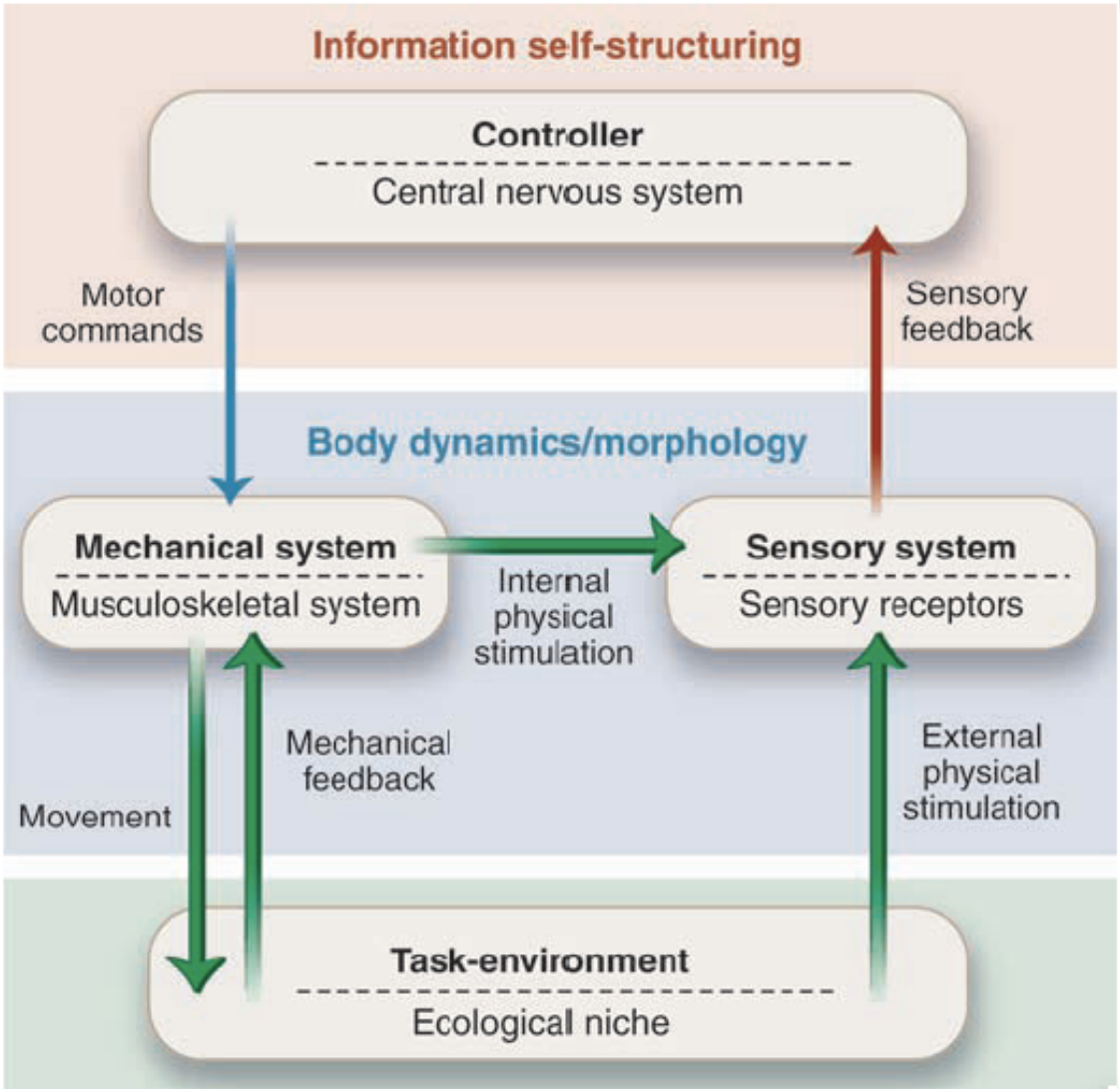
Emergence of behavior: the quadruped “Puppy”

- **simple control (oscillations of “hip” joints)**
- **spring-like material properties (“under-actuated” system)**
- **self-stabilization, no sensors**
- **“outsourcing” of functionality**

morphological computation



Implications of embodiment



"Puppy"

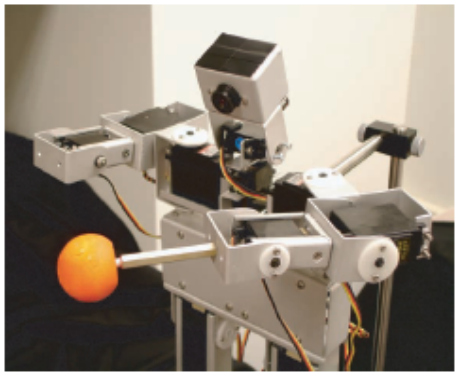
Pfeifer et al.,Science, 16 Nov. 2007

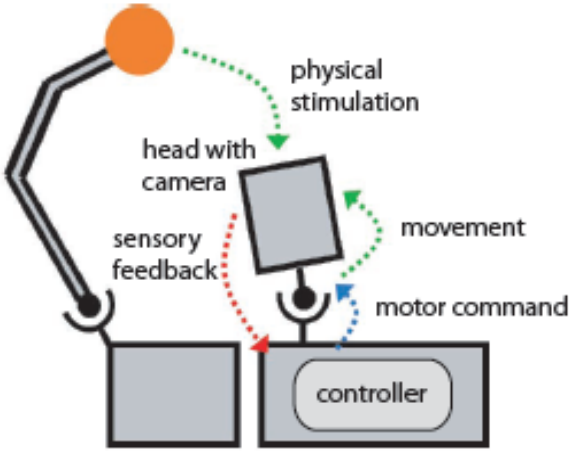
How to quantify?

Information self-structuring

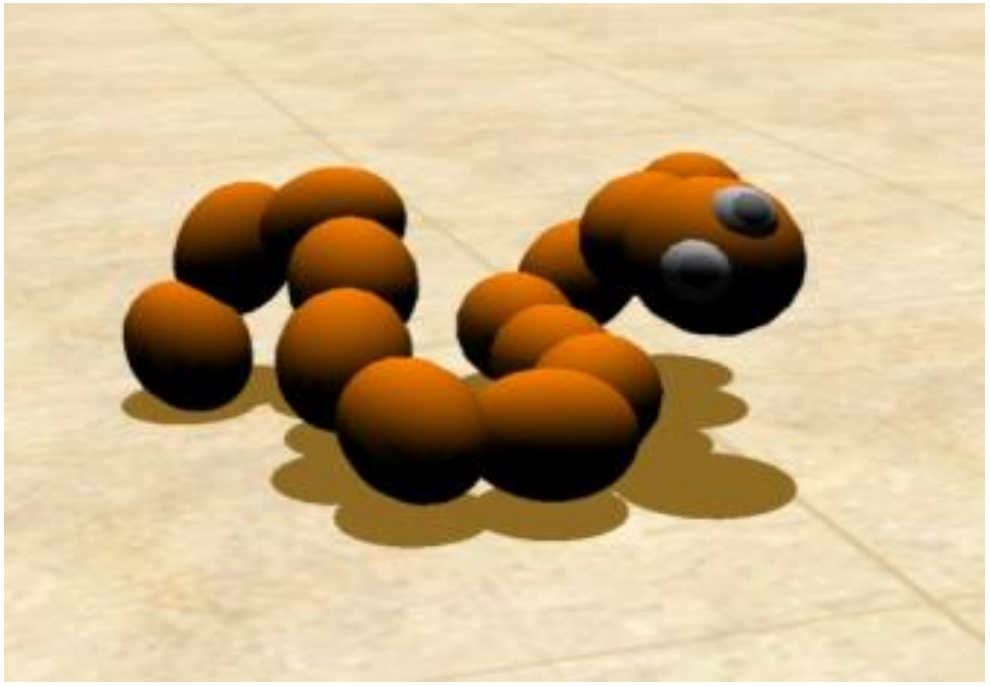
Experiments:

Lungarella and Sporns, **2006**
Mapping information flow in sensorimotor networks
PLoS Computational Biology



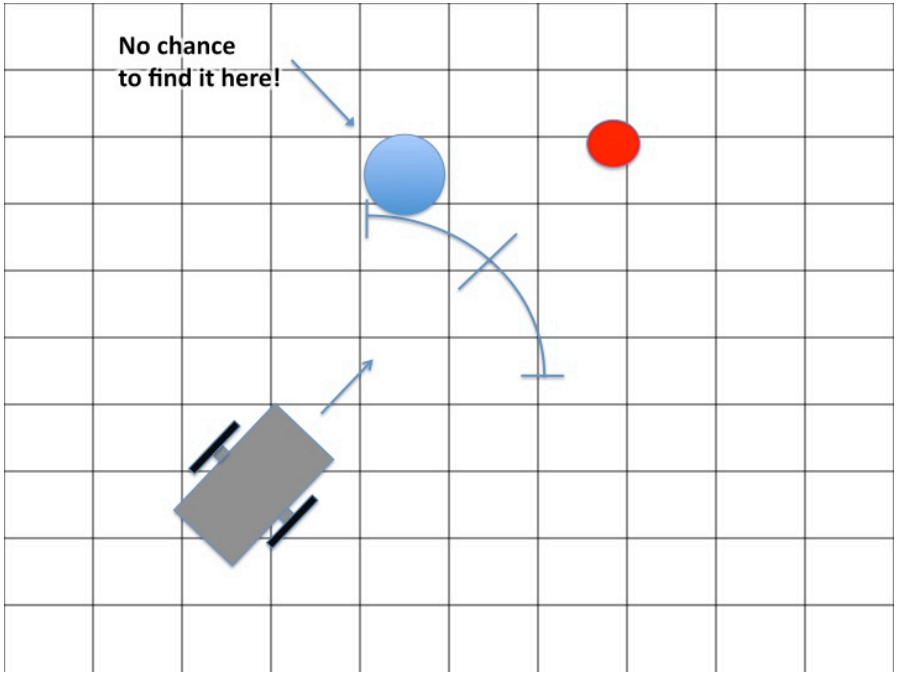


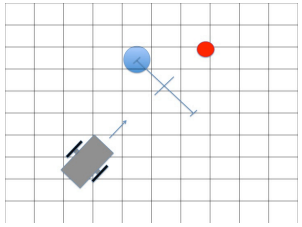
Snakebot



see: **Tanev et. al, IEEE TRO, 2005**

Maybe not GOF Euclidean space? :-)





see: **Bonsignorio, Artificial Life, 2013**

Embodied Intelligence or Morphological Computation: the modern view of Artificial Intelligence

Classical approach

The focus is on the brain and central processing

Modern approach

The focus is on interaction with the environment. Cognition is emergent from system-environment interaction

PARADIGM CLASHES

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Rolf Pfeifer and Josh C. Bongard, *How the body shapes the way we think: a new view of intelligence*, The MIT Press, Cambridge, MA, 2007

Soft Robotics: a working definition

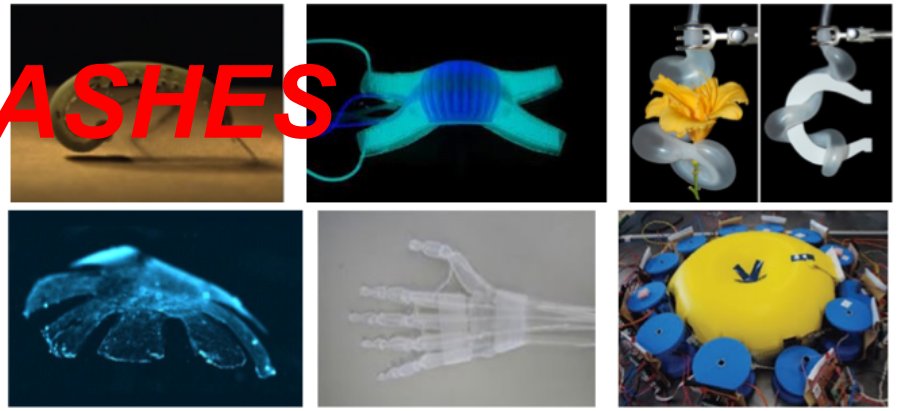
Variable impedance actuators and stiffness control

* Actuators with variable impedance
* Compliance/impedance control
* Highly flexible (hyper-redundant or continuum) robots

IEEE Robotics and Automation Magazine, Special Issue on Soft Robotics, 2008
A. Albu-Schaffer et al. (Ed.s)

Use of soft materials in robotics

* Robots made of soft materials that undergo high deformations in interaction
* Soft actuators and soft components
* Control partially embedded in the robot morphology and mechanical properties



Kim S., Laschi C., and Trimmer B. (2013) Soft robotics: a bioinspired evolution in robotics, *Trends in Biotechnology*, April 2013.
Laschi C. and Cianchetti M. (2014) "Soft Robotics: new perspectives for robot bodyware and control" *Frontiers in Bioengineering and Biotechnology*, 2(3)

PARADIGM CLASHES

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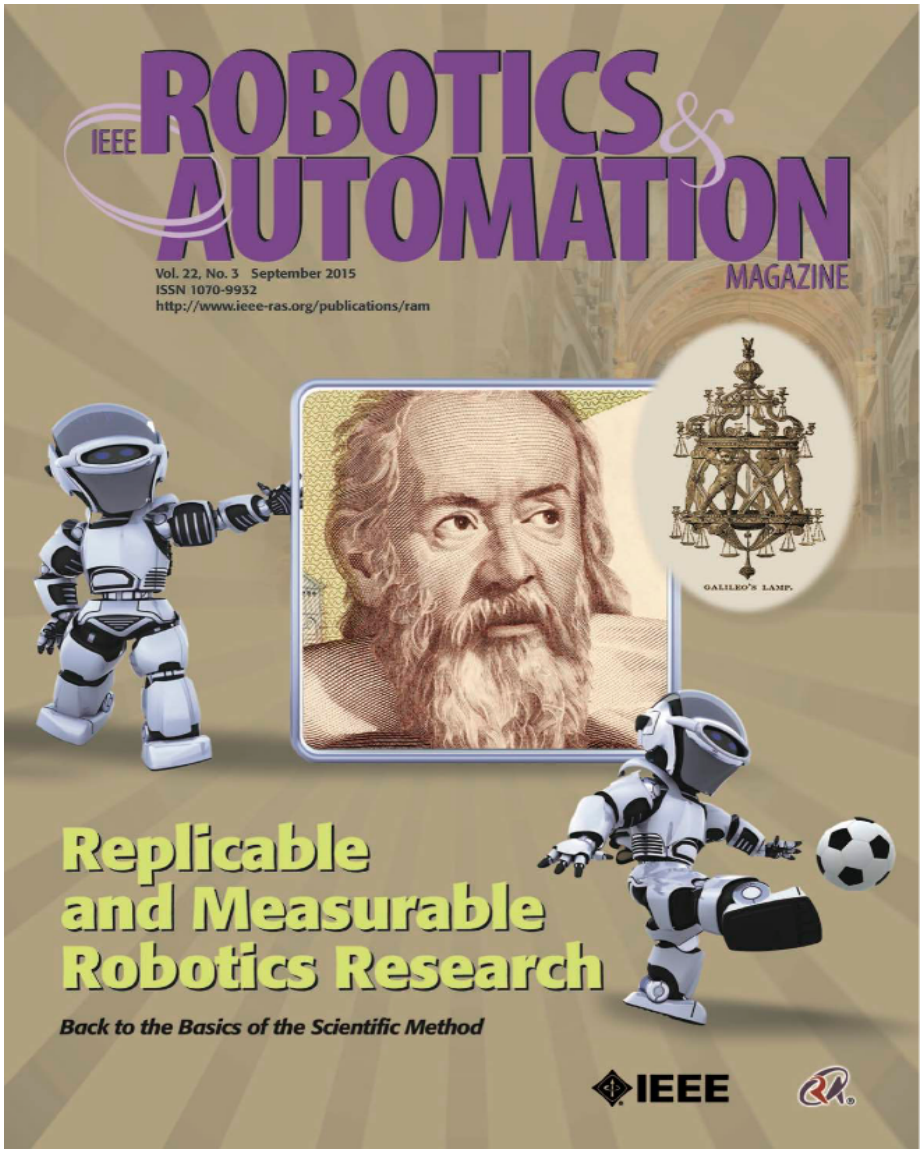
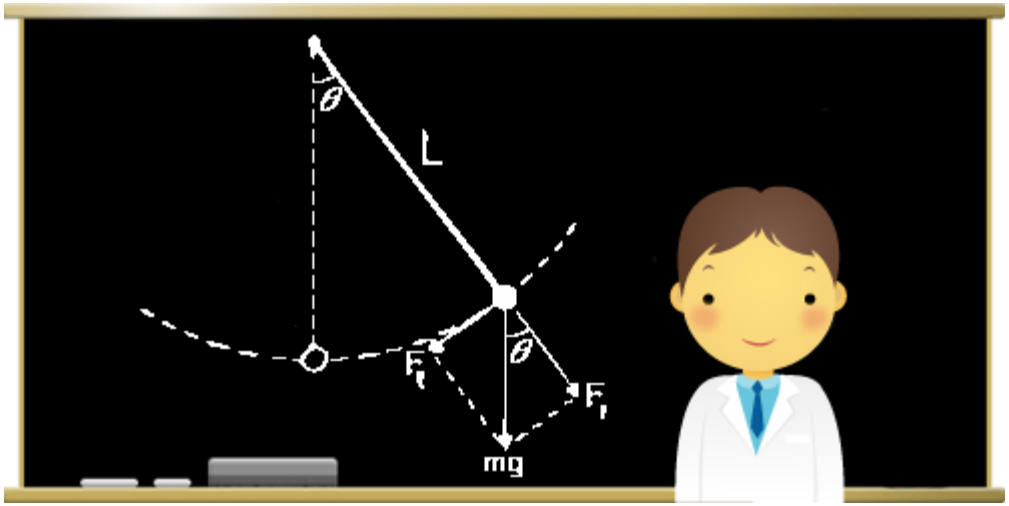


http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=100

Reminder: the pendulum experiment by Galileo

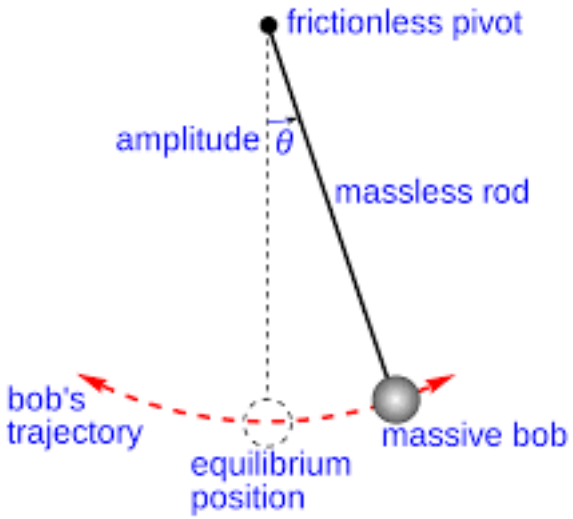


$$\frac{d^2\theta}{dt^2} + \frac{g}{\ell}\sin\theta = 0$$

$$T \approx 2\pi\sqrt{\frac{L}{g}}$$

What is an 'experiment' in robotics?

Replication of experiments



If robotics aims to be serious science, serious attention must be paid to experimental method.

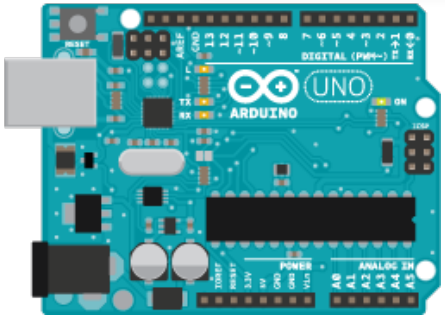
Again, what is an 'experiment' in robotics?

Performance evaluation

Dyson's new robot vacuum cleaner should be considered more intelligent than the Roomba? (it costs 3 times as much….)

How to compare, classify and rank complex adaptive behaviors (Intelligent/Cognitive)?

‘Street Robotics’



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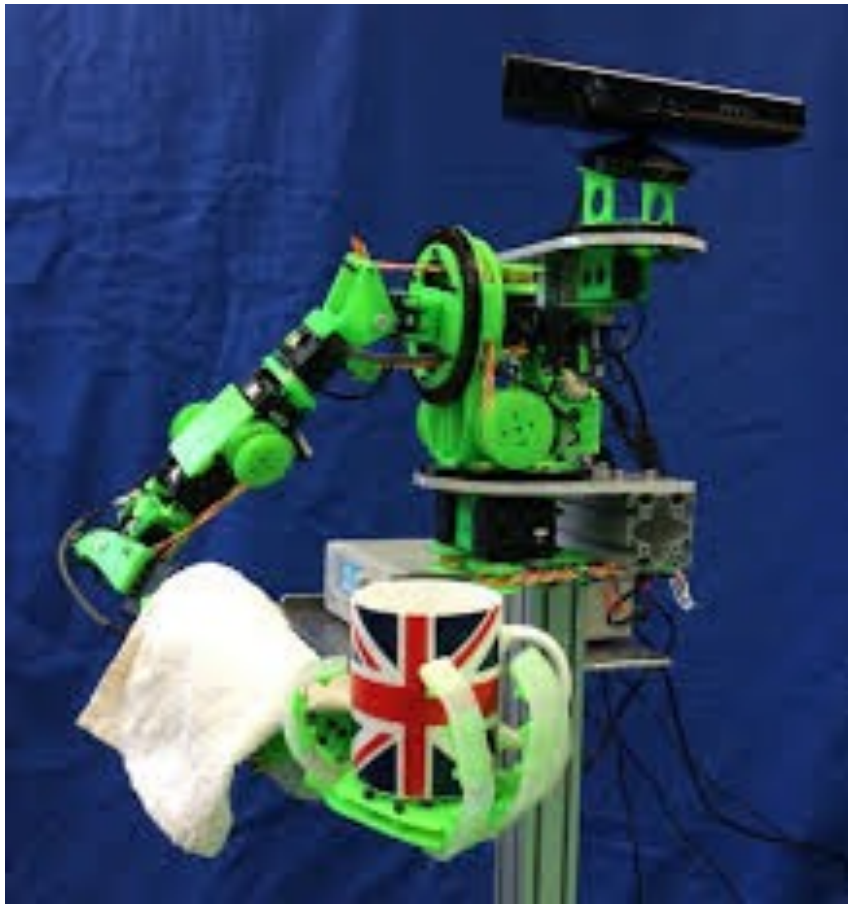
Gummiarm!



Things to do (imho!) 1

In the short-medium term (2-5 years):

- To implement hybrid approaches while building up a scalable and evolvable HW/SW architecture for Embodied/Embedded AI/cognition systems for robotics
- To build opportunistically on the fittest approaches already proposed in the literature to implement new functions and improve the already implemented ones
- To define realistic test-beds, reproducible research processes, proper benchmarking and evaluation procedures, to provide objective experimental feedback to the research activities
- To progress basic research on self-organization of behaviours in robots integrating rigid and soft body components and subsystems
- To develop innovative products (robots, robotics appliances, smart systems and spaces, AI/Cognitive apps)

Things to do (imho!) 2

In the short-medium term (2-5 years):

In the long-term (5-10 years):

- **To develop an Embodied AI/Cognition architecture for new paradigm robots exploiting orchestrated emergent control, soft materials able to robustly, dependably and adaptively perform complex service tasks interacting and cooperating with humans in loosely structured environment.**
- **To provide remarkable examples of ‘dog-level’ Embodied AI thus enabling a huge number of novel applications at home, in the factory and everywhere.**

Things to do (imho!) 3

We should aim to:

- tackle the hard (by many underestimated) scientific challenge of building embedded cognitive systems able to fluently interact and cooperate with humans in dynamic semi-structured and unstructured environments
- implement a long term scientific disruptive strategy to make possible an ubiquitous utilization of Cognitive Robots
- harvest from Day 1 the Low-hanging fruits in term of research results and innovation
- set up an innovation pipeline from day 1 (for example by starting a breed of dedicated New AI/cognition enabled apps for smart appliances and smart robots)
- set up organisational processes for the exponential generation of results

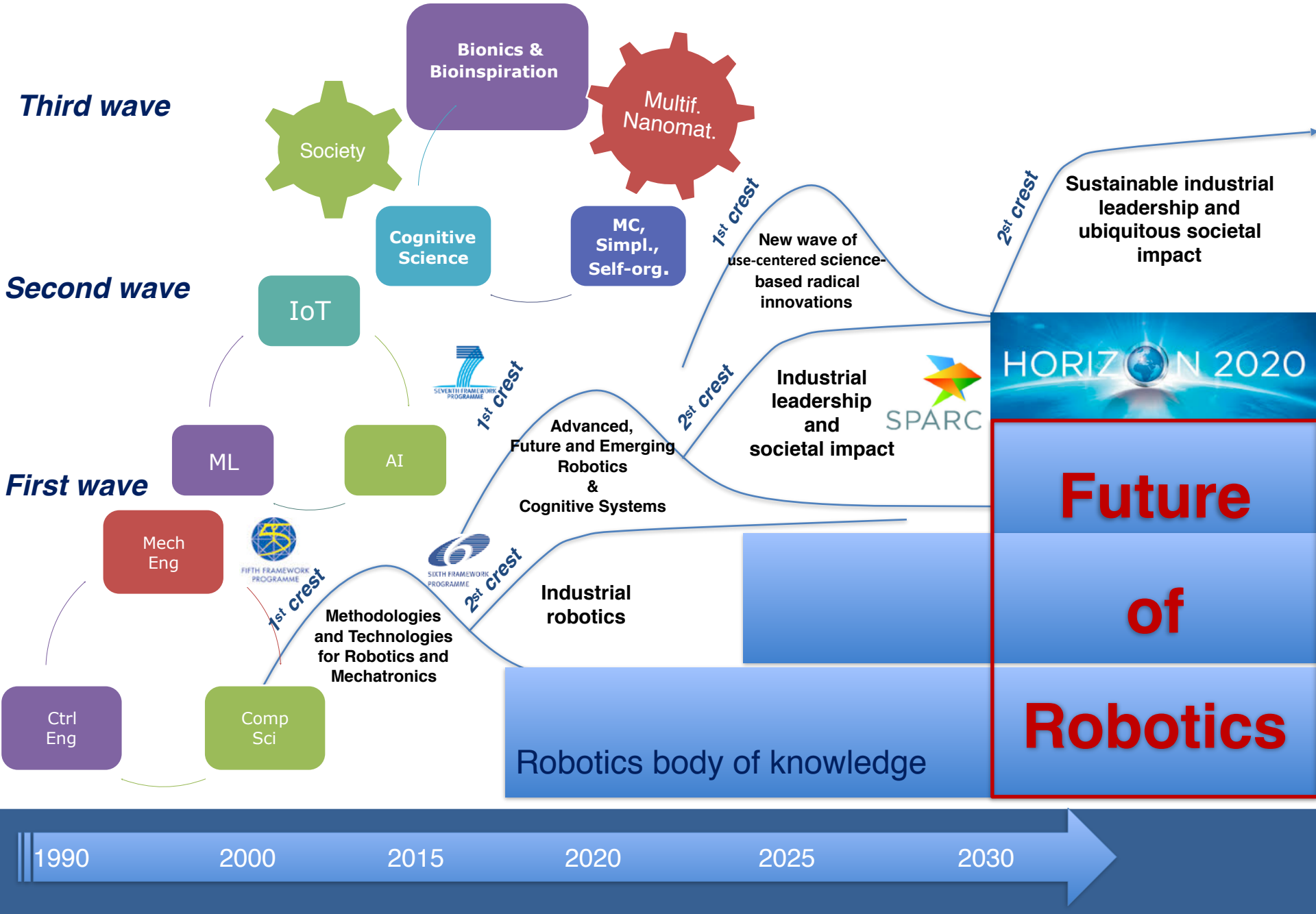
Things to do (imho!) 4

We should aim to do for embodied AI/Cognition what has been done for disembodied AI/ML in the latest decade and thus advancing AI/Cognition itself, by:

- **Embodying ML/AI/Cognition methods and conceptually redefine for real time (in particular by exploiting and adapting tools such as Markov Networks and Markov Logical Networks (Domingos, P. and Lowd, D. 2009, Acerbi, L., Vijayakumar S., Wolpert, D. 2014, Nikolaidis, F. et al. 2016, Khan, S.G. et al. 2012)**

- **Giving much more relevance to embodied anticipatory behaviours and prediction algorithms and systems (Bonsignorio, F.P. 2009)**

The Waves of Robotics Innovation



The fears…

May 6, 1937
Naval Air Station Lakehurst in Manchester Township, New Jersey, United States

and the promise of robotics….

Thank you!