

Lecture 3. Intelligent Systems: Properties and Principles

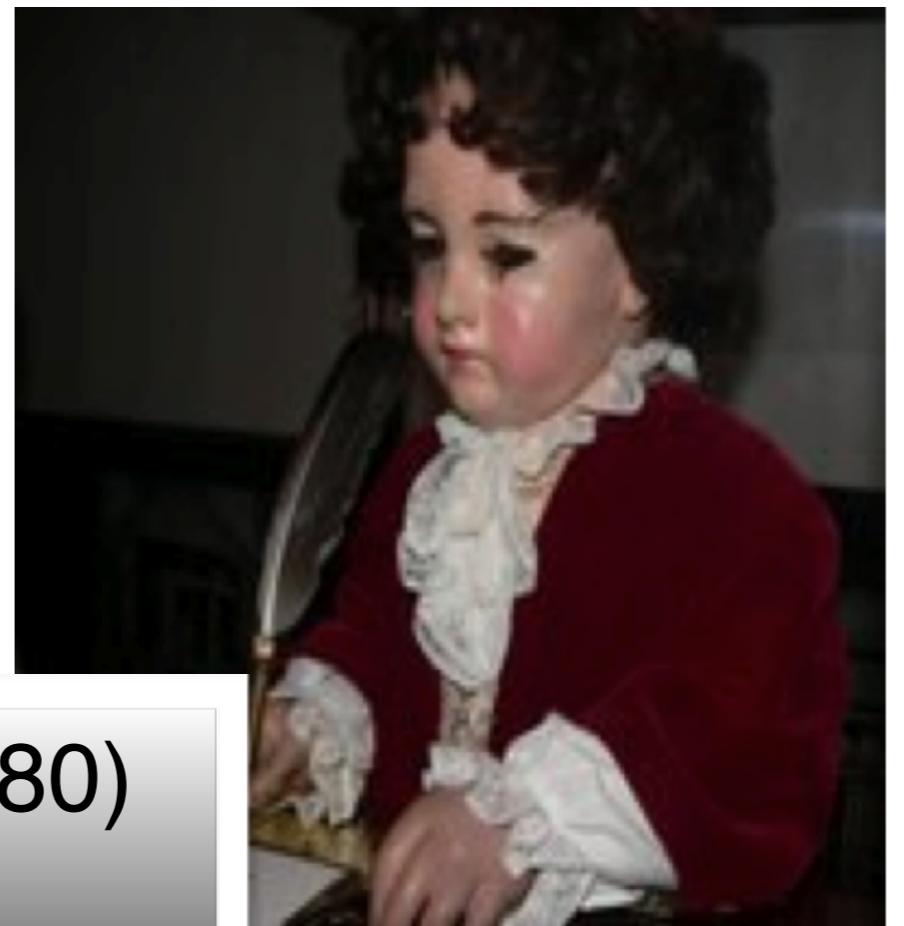
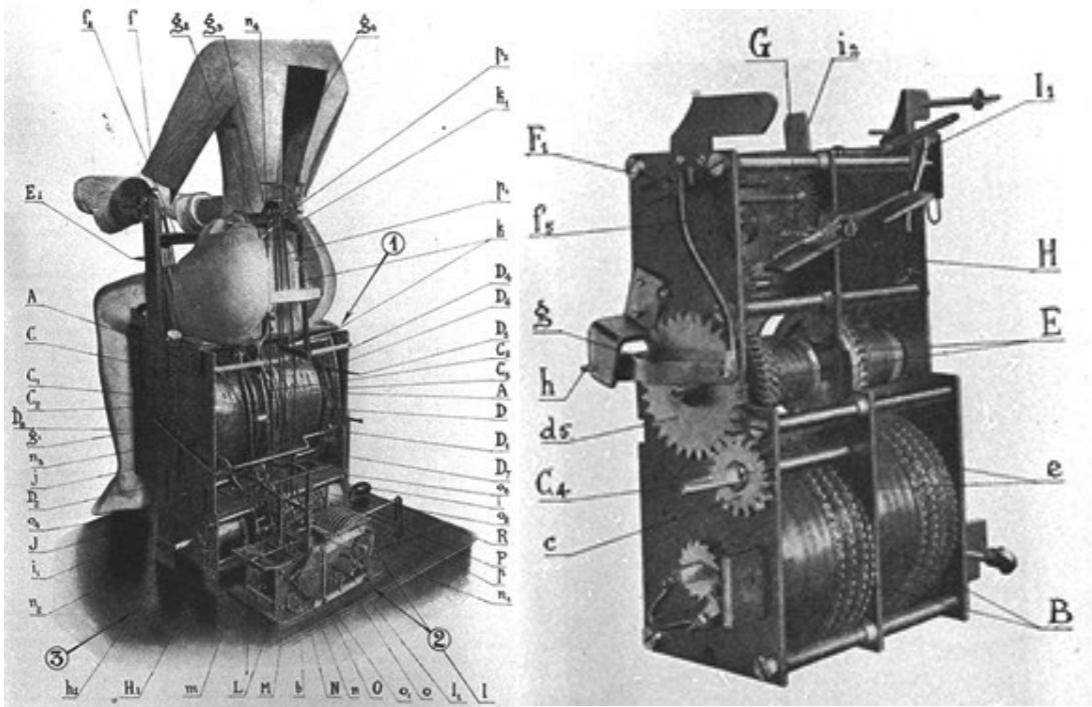


Fabio Bonsignorio

The BioRobotics Institute, SSSA, Pisa, Italy and Heron Robots



Old attempts



Jaquet-Droz Brothers (1720-1780)



Old attempts

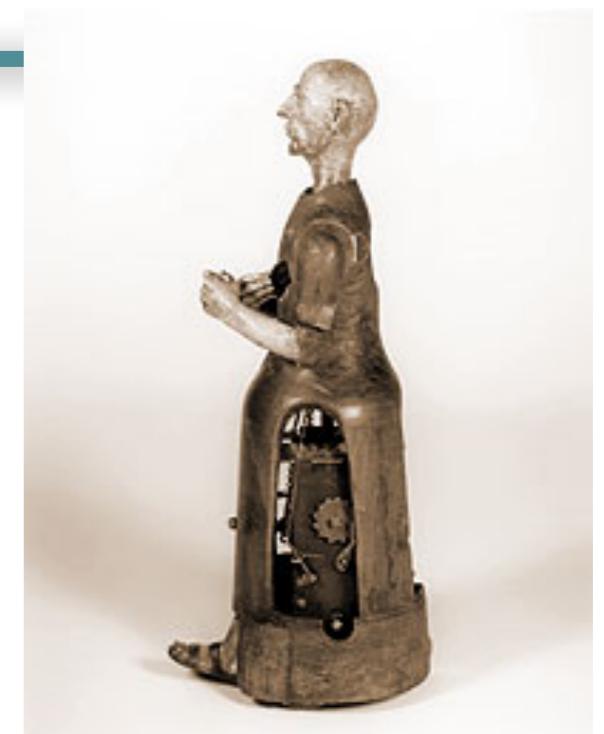


Karakuri Dolls
Chahakobi Ningyo (Tea Serving Doll) by SHOBEI Tamaya IX, and plan from 'Karakuri Zuii' ('Karakuri - An Illustrated Anthology') published in 1796.



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



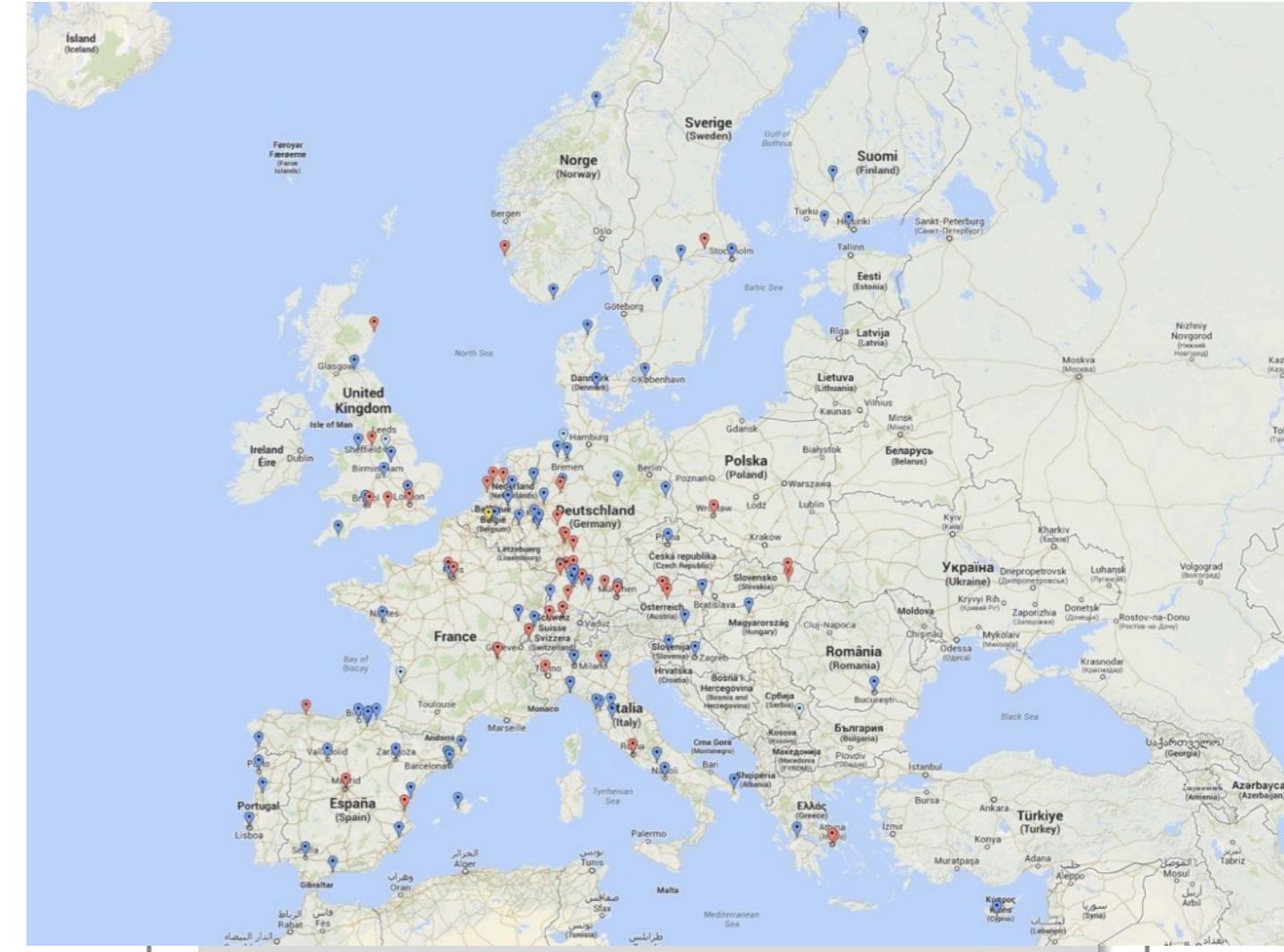


SPARC

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. [...]”

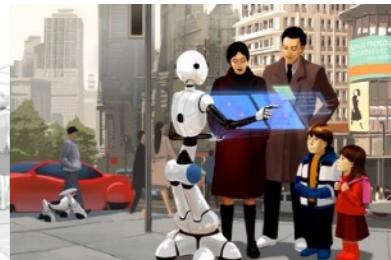
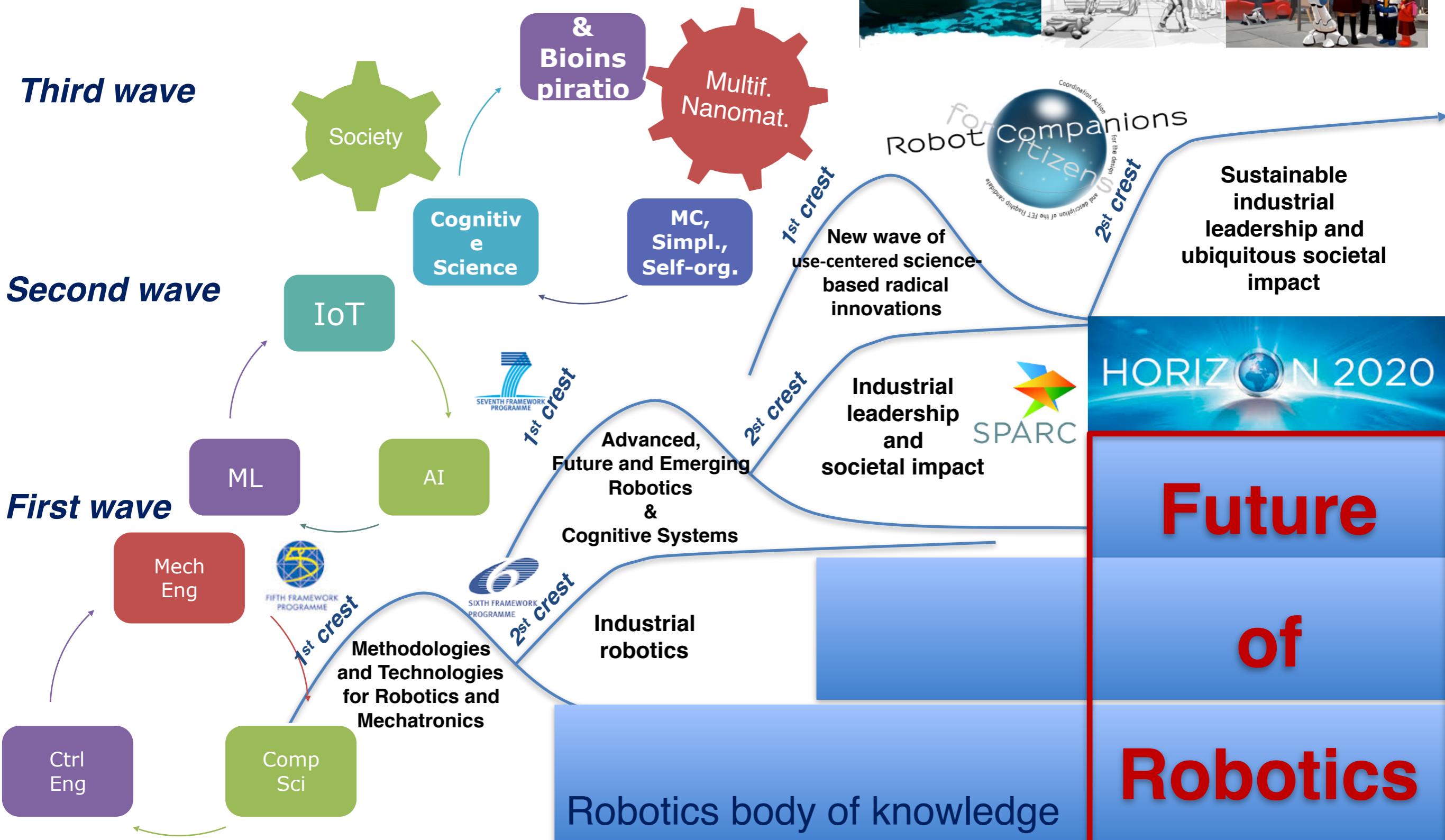
“[...] From today's €22bn worldwide revenues, robotics industries are set to achieve annual sales of between €50bn and €62bn by 2020. [...]”



Disruptive technologies:
Advances that will
transform life, business,
and the global economy

2013 2014 2015 2016 2017 2018 2019 2020
Robotics is one of the 12 disruptive technologies identified by McKinsey

The Waves of Robotics Innovation



The need for an embodied perspective

- “failures” of classical AI
- fundamental problems of classical approach
- Wolpert’s quote: Why do plants not have a brain? (but check Barbara Mazzolai’s lecture at the ShanghAI Lectures 2014)
- Interaction with environment: always mediated by body



Two views of intelligence

**classical:
cognition as computation**

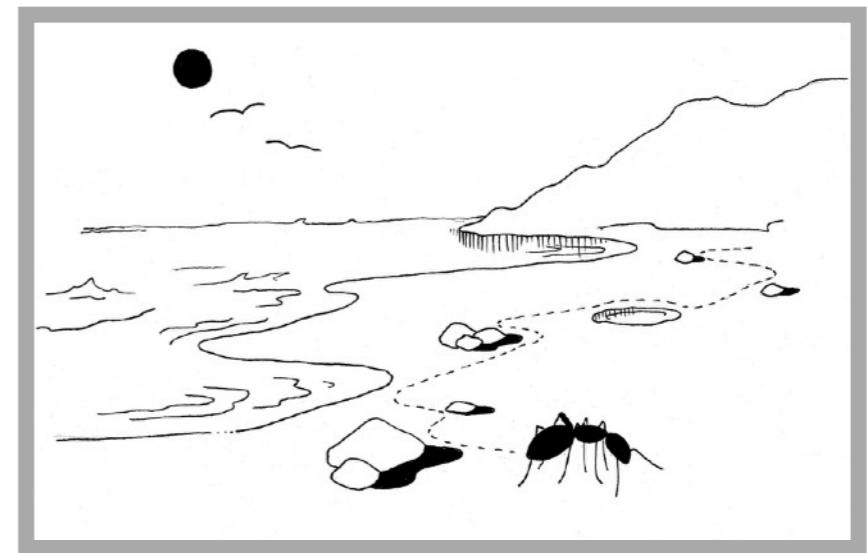


**embodiment:
cognition emergent from sensory-
motor and interaction processes**



“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



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!"

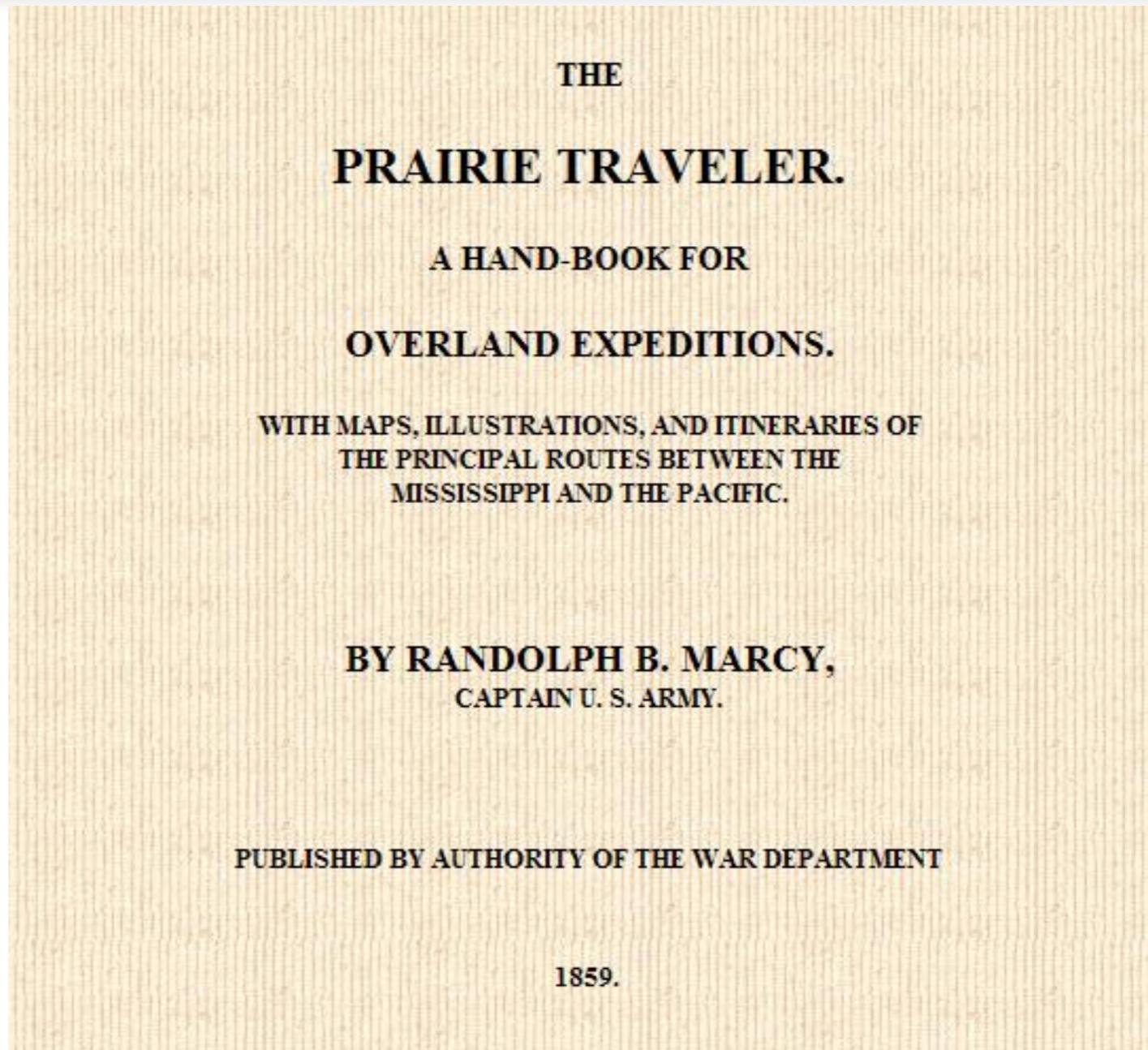


Goals

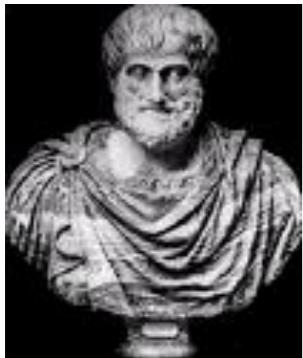
- What is intelligence? Natural and artificial?
- conceptual and technical know-how in the field
- informed opinion on media reports
- things can always be seen differently
- new ways of thinking about ourselves and the world around us



‘Caveat’



Old ideas



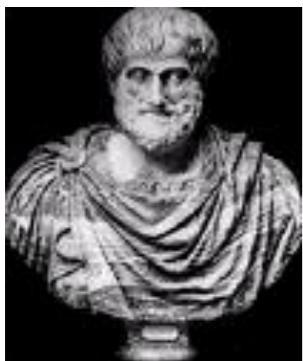
“If every tool, when ordered, or even of its own accord, could do the work that befits it, just as the creations of Daedalus moved of themselves . . . If the weavers' shuttles were to weave of themselves, then there would be no need either of apprentices for the master workers or of slaves for the lords.”

Aristotle

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



Old ideas



The part of the quote "or even of its own accord" is elsewhere translated as "or by seeing what to do in advance" etc. (you may find many translations).

I think this is an important part of the quote, so it's good to go back to the original text:

Aristotle uses the word "προαισθανόμενος" – proaisthanomenon this means literally: pro = before, aisthanomenon = perceiving, apprehending, understanding, learning (any of these meanings in this order of frequency) in my view it is clearly a word that is attributed to intelligent, living agents....i.e. ones with cognitive abilities (!)

personal communication, Dr. Katerina Pastra
Research Fellow
Language Technology Group
Institute for Language and Speech Processing
Athens, Greece



Two views of intelligence

**classical:
cognition as computation**



**embodiment:
cognition emergent from sensory-
motor and interaction processes**



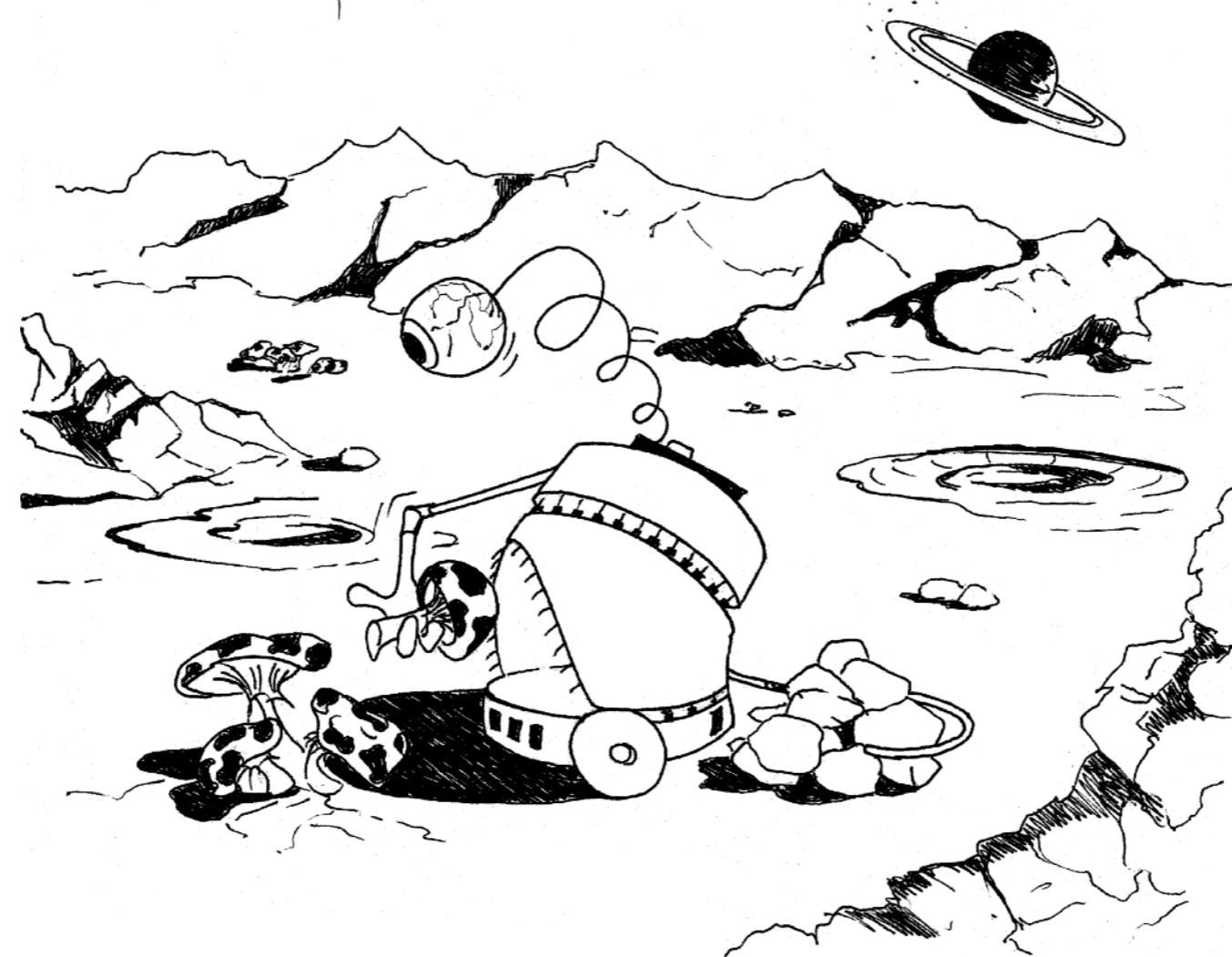
The need for an embodied perspective

- “failures” of classical AI
- fundamental problems of classical approach
- Wolpert’s quote: Why do plants not ...?
- Interaction with environment: always mediated by body



Complete agents

— Masano Toda's
Fungus Eaters



Properties of embodied agents

- **subject to the laws of physics**
- **generation of sensory stimulation through interaction with real world**
- **affect environment through behavior**
- **complex dynamical systems**
- **perform morphological computation**



Complex dynamical systems

**non-linear system -
in contrast to a linear one
→ Any idea?**



Complex dynamical systems

concepts: focus box 4.1, p. 93, “How the body ...”

- **dynamical systems, complex systems, non-linear dynamics, chaos theory**
- **phase space**
- **non-linear system – limited predictability, sensitivity to initial conditions**
- **trajectory**



Today's topics

- short recap
- characteristics of complete agents
- **illustration of design principles**
- parallel, loosely coupled processes: the “**subsumption architecture**”
- case studies: “**Puppy**”, biped walking
- “**cheap design**” and redundancy



Design principles for intelligent systems

Principle 1: Three-constituents principle

Principle 2: Complete-agent principle

Principle 3: Parallel, loosely coupled processes

Principle 4: Sensory-motor coordination/ information self-structuring

Principle 5: Cheap design

Principle 6: Redundancy

Principle 7: Ecological balance

Principle 8: Value



Three-constituents principle

define and design

- “**ecological niche**”
- **desired behaviors and tasks**
- **design of agent itself**

design stances

scaffolding



Complete-agent principle

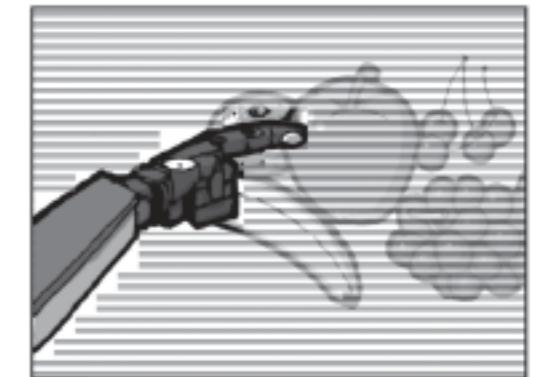
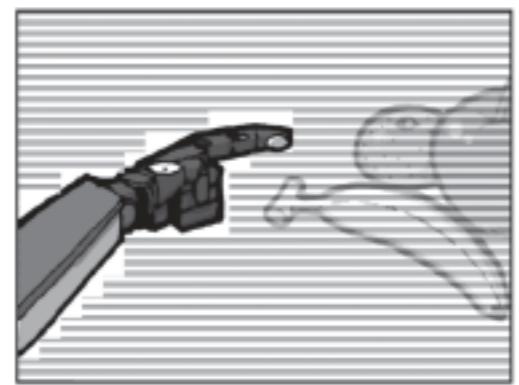
- **always think about complete agent behaving in real world**
- **isolated solutions: often artifacts – e.g., computer vision (contrast with active vision)**
- **biology/bio-inspired systems: every action has potentially effect on entire system**



can be exploited!

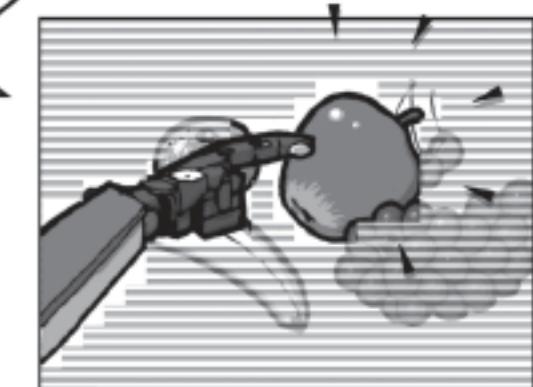
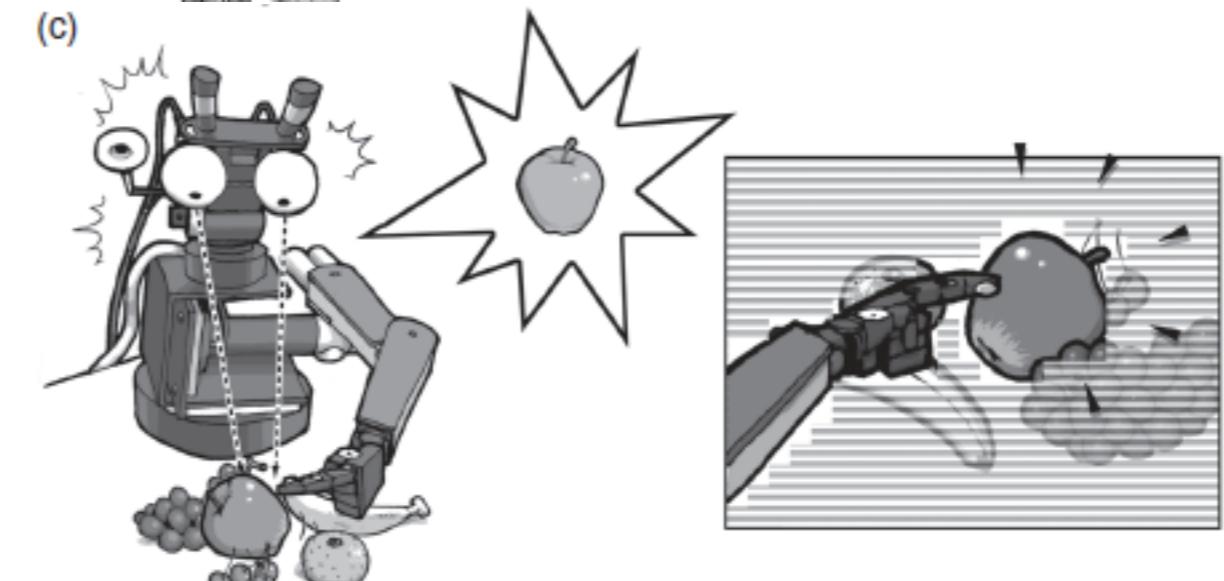


Recognizing an object in a cluttered environment



**manipulation of
environment can
facilitate perception**

Experiments: Giorgio Metta
and Paul Fitzpatrick



Illustrations by Shun Iwasawa

Today's topics

- short recap
- characteristics of complete agents
- illustration of design principles
- parallel, loosely coupled processes: the “subsumption architecture”
- case studies: “Puppy”, biped walking
- “cheap design” and redundancy



Parallel, loosely coupled processes

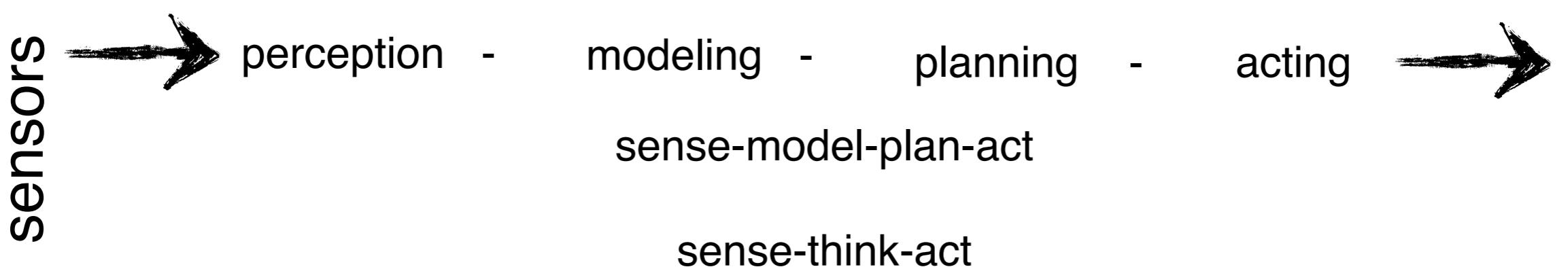
intelligent behavior:

- emergent from system-environment interaction
- based on large number of parallel, loosely coupled processes
- asynchronous
- coupled through agent's sensory-motor system and environment

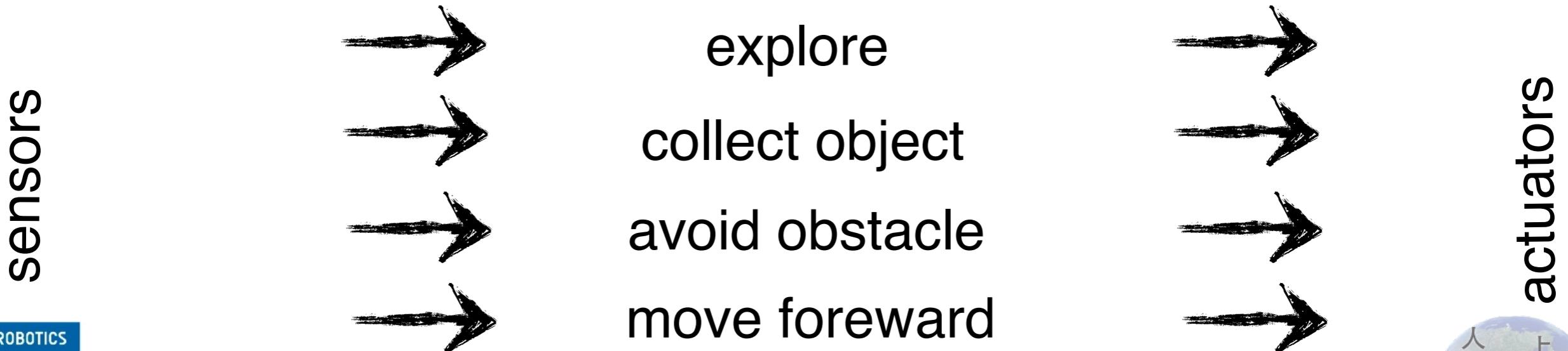


The subsumption architecture

classical, cognitivistic



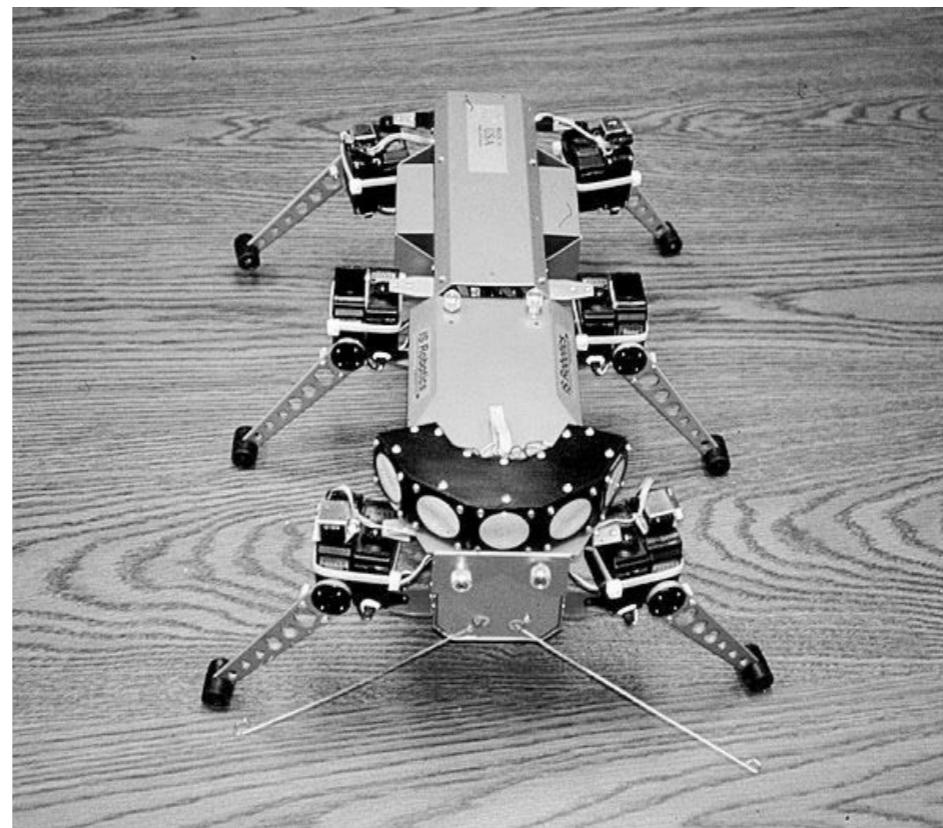
“behavior-based”, subsumption



Mimicking insect walking

- **subsumption architecture
well-suited**

six-legged robot “Ghenghis”



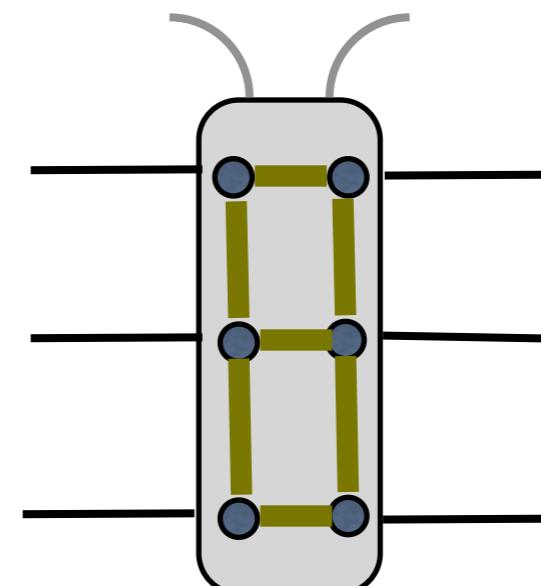
Insect walking



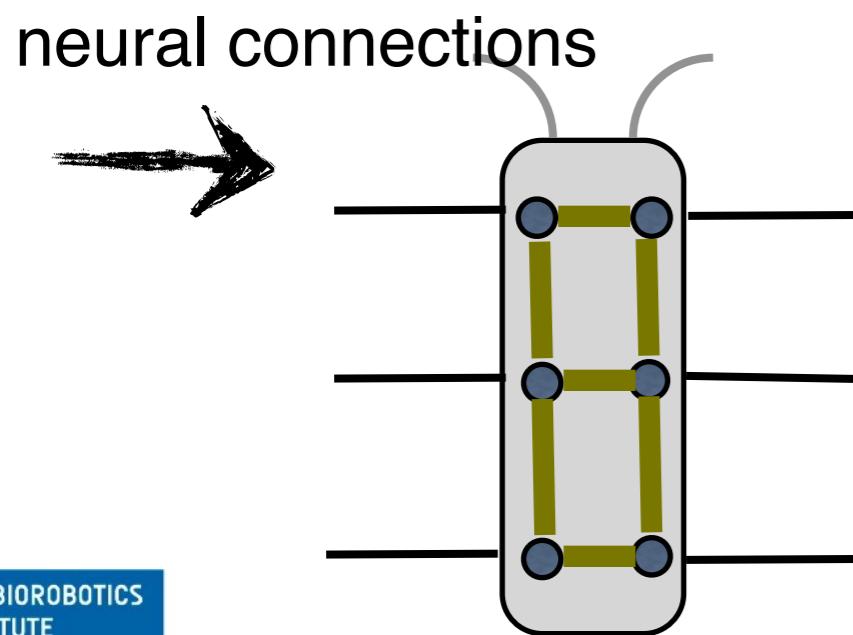
Holk Cruse, German biologist

- no central control for leg coordination
- only communication between neighboring legs

neural connections



Insect walking



Holk Cruse, German biologist

- no central control for leg coordination
- only communication between neighboring legs
- global communication: through interaction with environment



Communication through interaction with

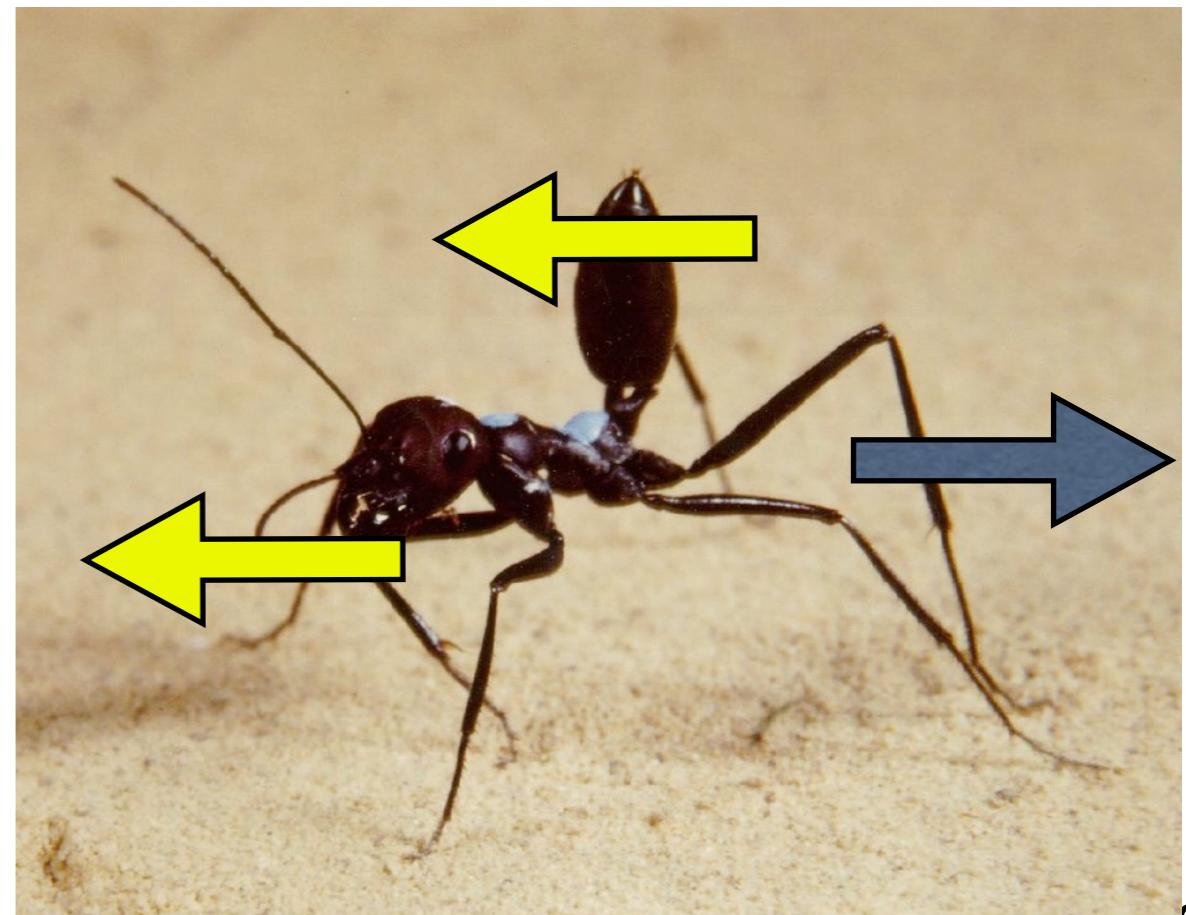
- exploitation of interaction with environment



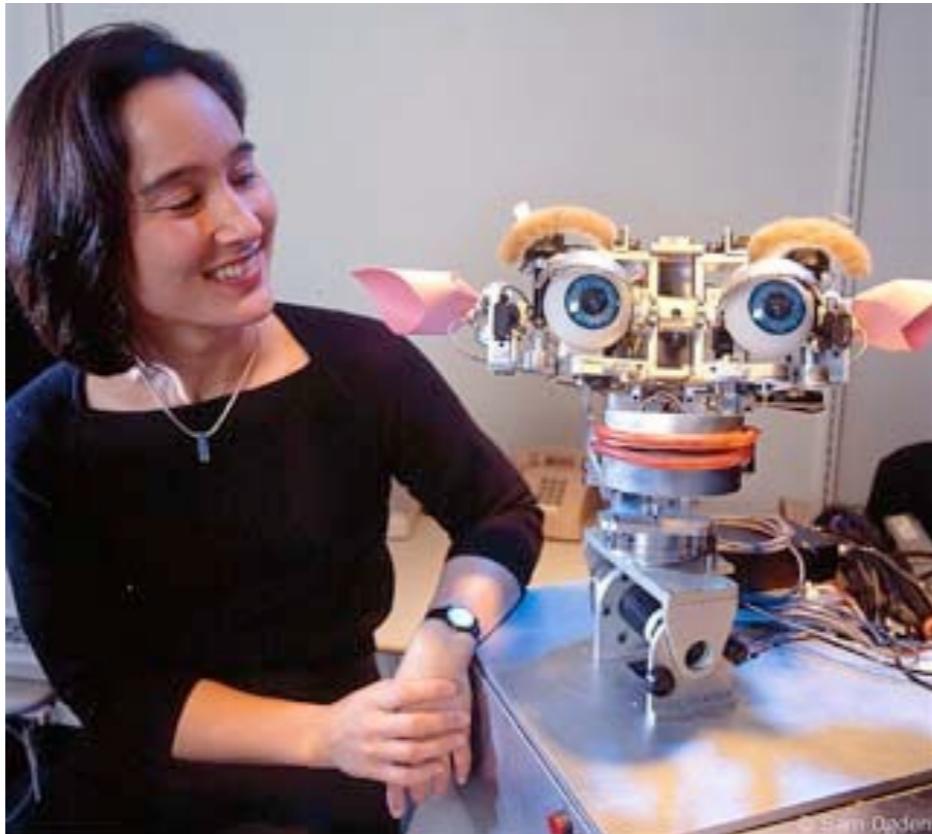
simpler neural circuits

angle sensors
in joints

“parallel, loosely coupled processes”



Kismet: The social interaction robot



Cynthia Breazeal, MIT Media Lab
(prev. MIT AI Lab)



Kismet: The social interaction robot



Video “Kismet”



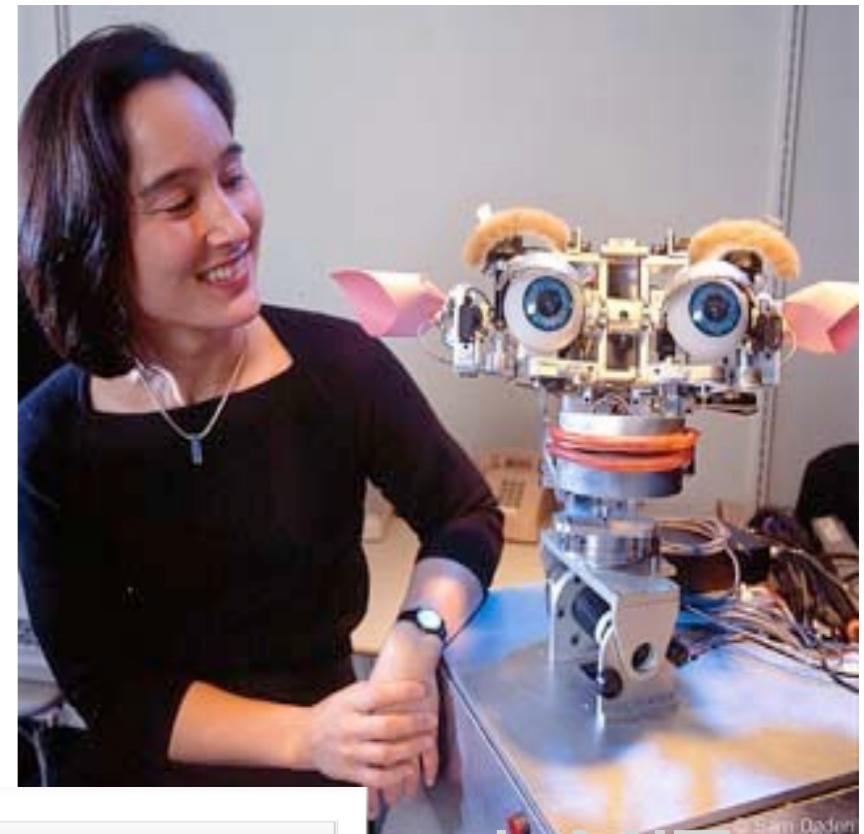
Cynthia Breazeal, MIT Media Lab
(prev. MIT AI Lab)



Kismet: The social interaction robot

Reflexes:

- turn towards loud noise
- turn towards moving objects
- follow slowly moving objects
- habituation



principle of “parallel, loosely coupled processes”

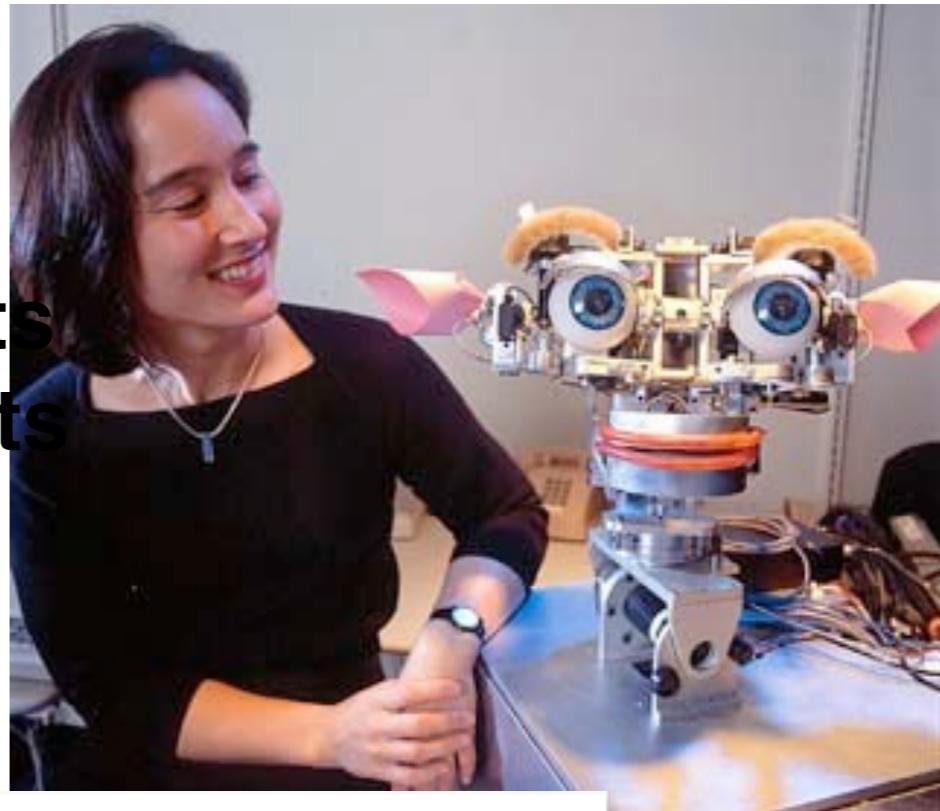
real, MIT
ras (prev. MIT AI Lab)



Kismet: The social interaction robot

Reflexes:

- turn towards loud noise
- turn towards moving objects
- follow slowly moving objects
- habituation



social competence: a collection of
reflexes ?!?!???

real, MIT
ras (prev. MIT AI Lab)



Scaling issue: the “Brooks-Kirsh” debate

insect level → human level?

David Kirsh (1991): “Today the earwig, tomorrow man?”

Rodney Brooks (1997): “From earwigs to humans.”



Scaling issue: the “Brooks-Kirsh” debate

insect level → human level?

David Kirsh (1991): “Today the ant, tomorrow man?”

Rodney Brooks (1991): “Today the ant, tomorrow man?”

volunteer for brief presentation on the “Brooks-Kirsh” debate - or generally, scalability of subsumption (on a later date)



Probabilistic Model Of Control

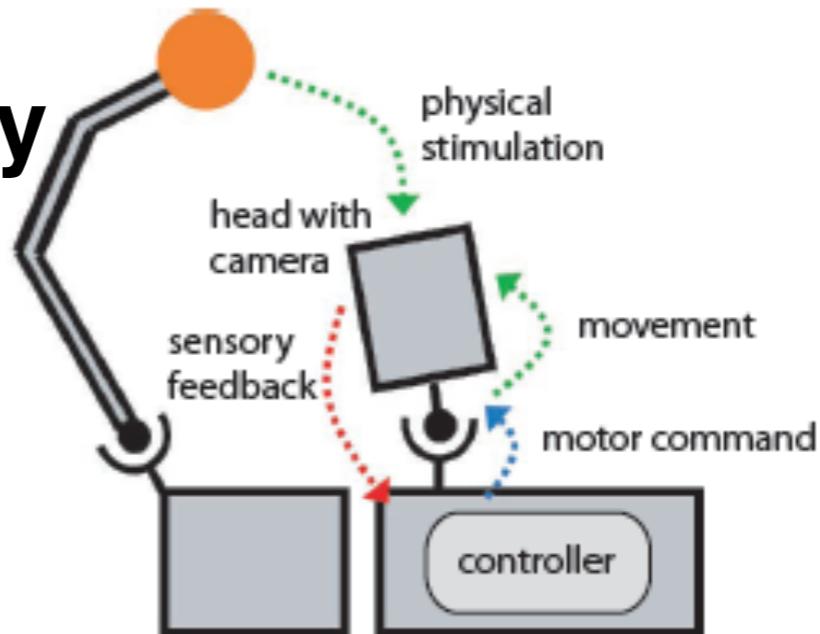
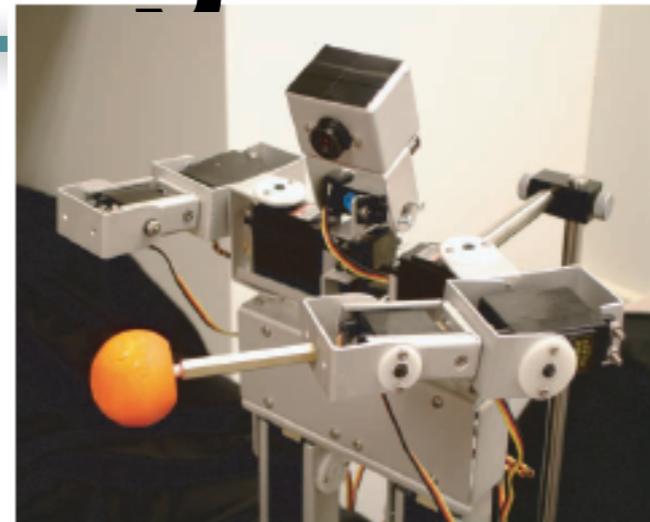
- Although it may seem strange only in recent times the classical results from Shannon theory, have been applied to the modeling of control systems.
- As the complexity of control tasks namely in robotics applications lead to an increase in the complexity of control programs, it becomes interesting to 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.



Information self-structuring

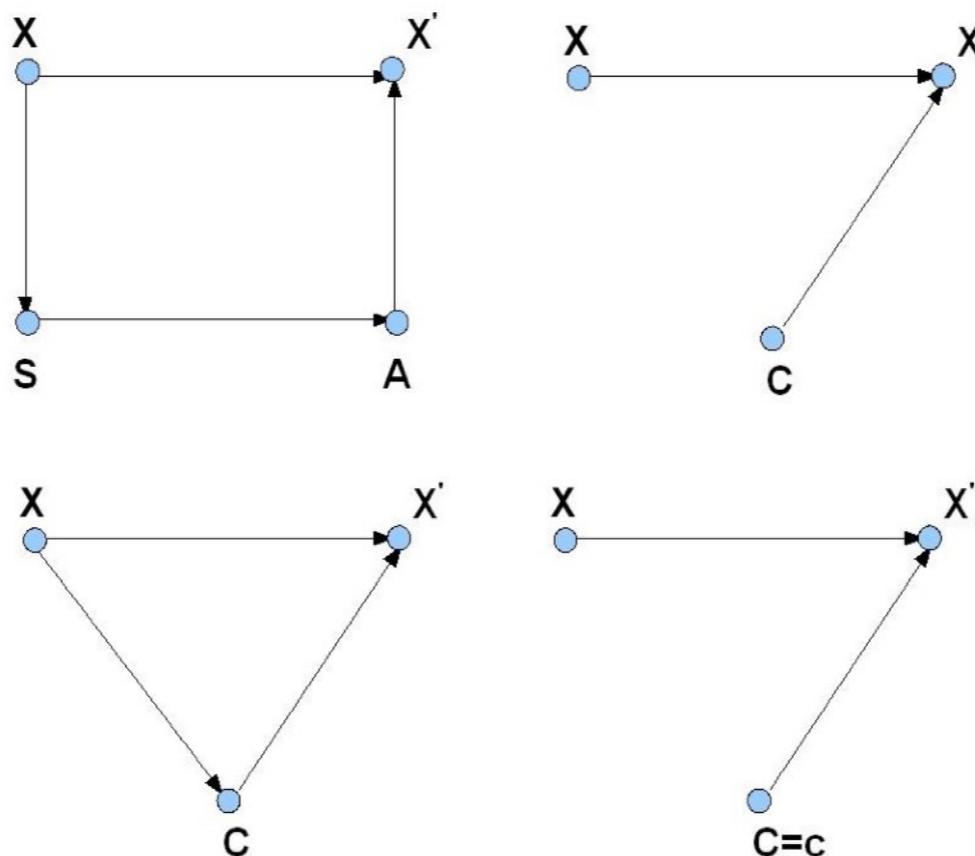
Experiments:

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



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) Shrunked Closed Loop diagram merging sensor and actuator, (Upper right) Reduced open loop diagram. (Lower right) Single actuation channel enacted by the controller's state $C=c$.



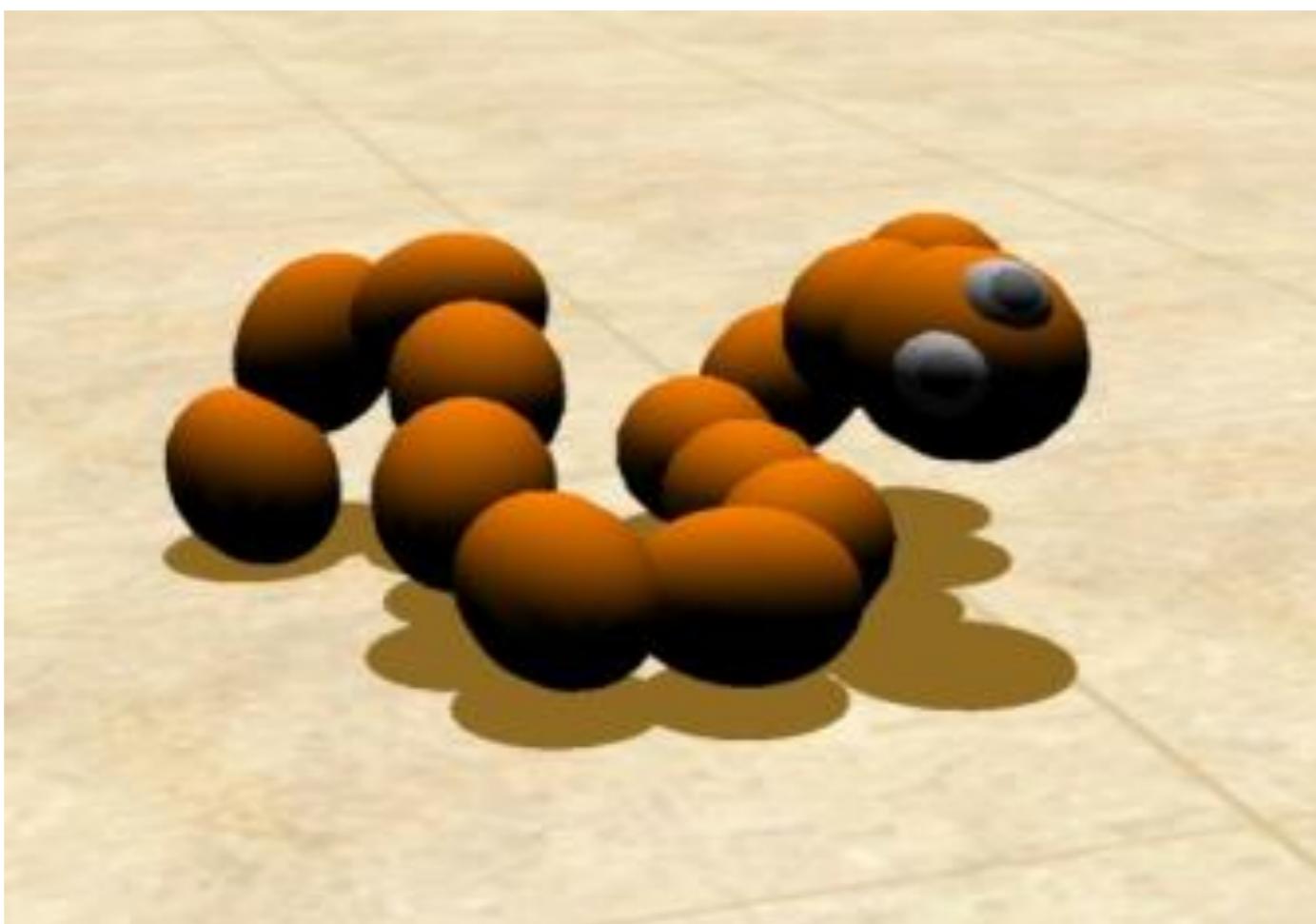
Models of ‘Morphological Computation’

$$\Delta H_N + \sum_i^n \Delta H_i - \Delta I \leq I(X; C) \text{ (II)}$$

Relations (II) links the mutual information between the controlled variable and the controller to the information stored in the elements, the mutual information between them and the information stored in the network and accounts for the redundancies through the multi information term ΔI .



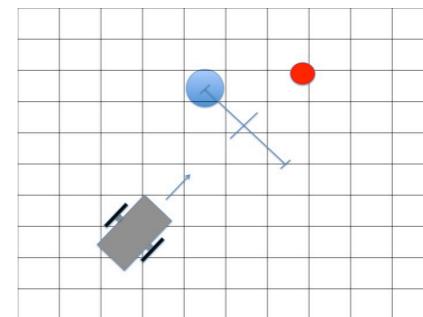
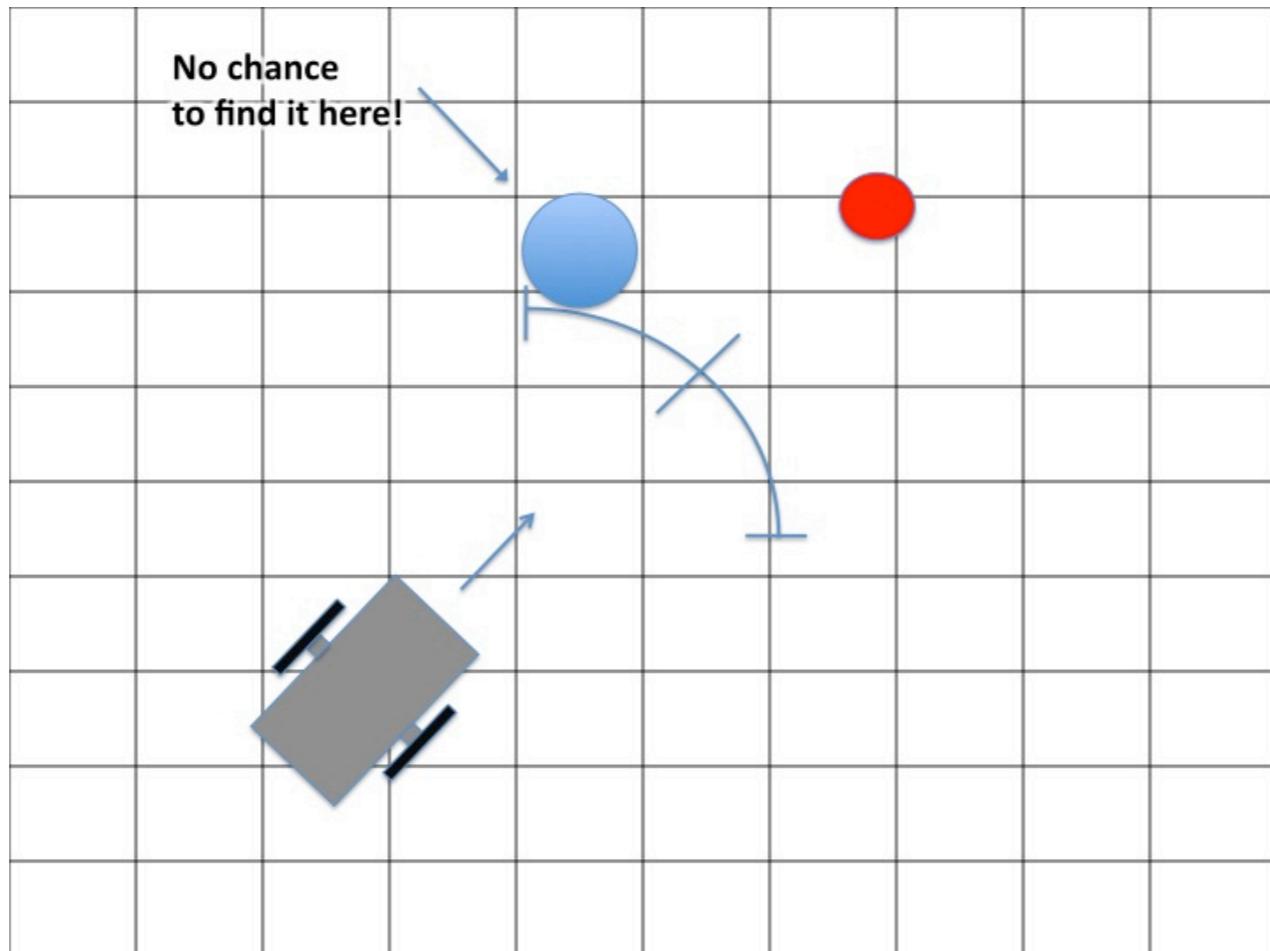
Snakebot



see: **Tanев et. al, IEEE TRO, 2005**



Maybe not GOF Euclidean space? :-)



see: Bonsignorio, Artificial Life, 2013



'Look Ma, No Hands' syndrome?



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

Modern approach

Classical approach

The focus is on the brain and central processing

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



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

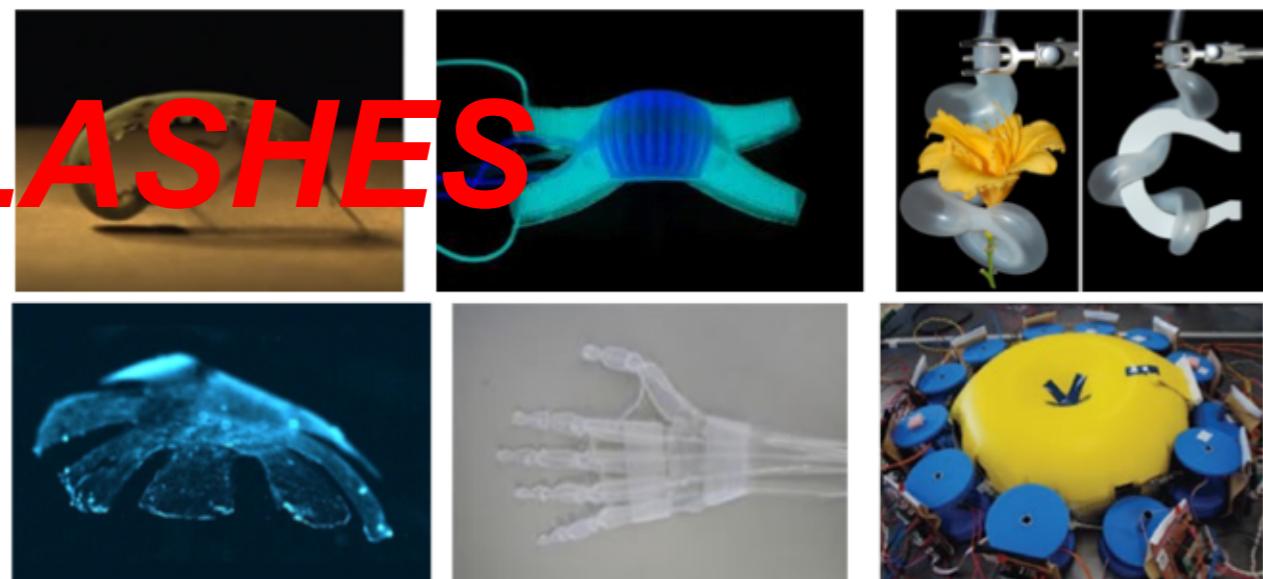
- * Actuators with variable impedance
- * Compliance/impedance control
- * Highly flexible (hyper-redundant or continuum) robots



PARADIGM CLASHES

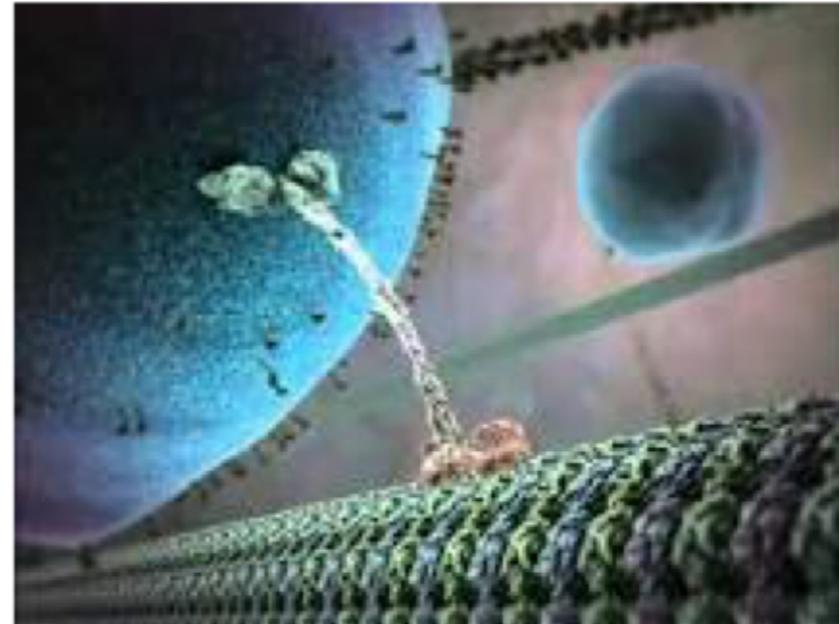
Use of soft materials in robotics

- * 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

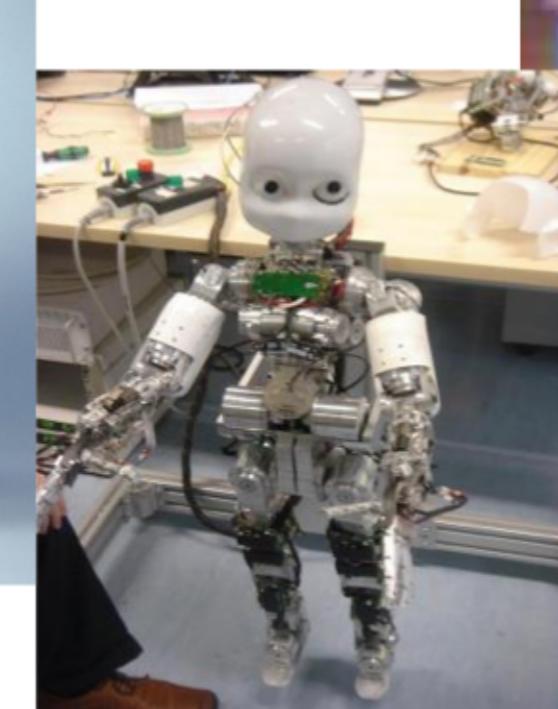
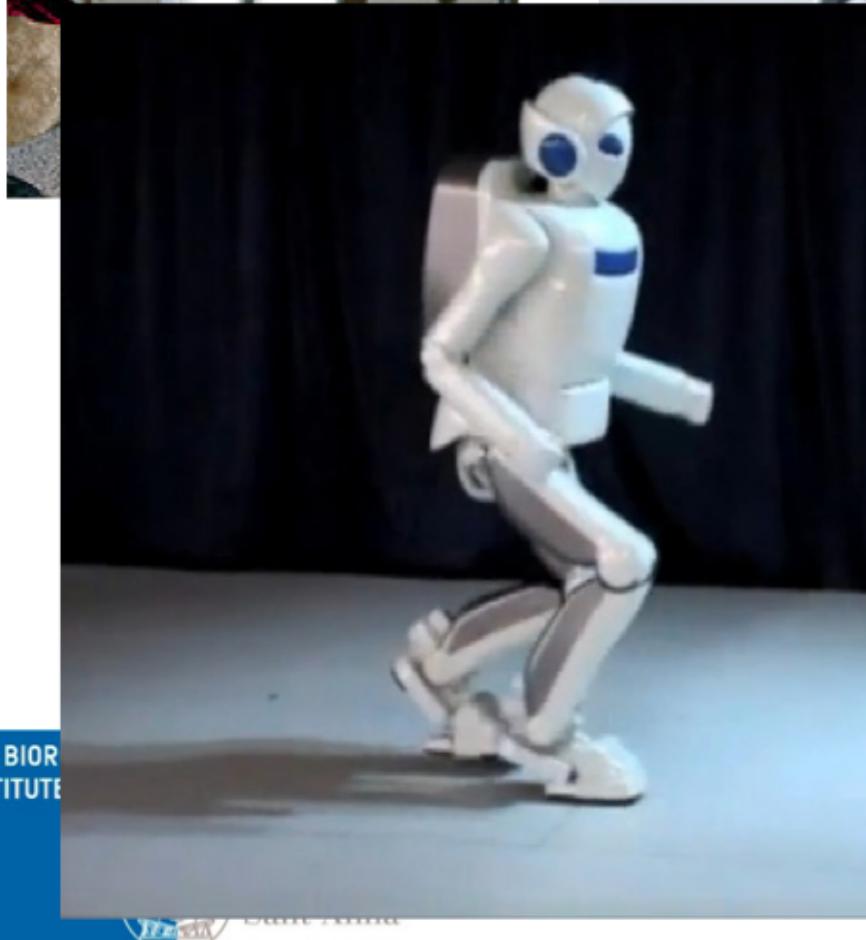


Kim S., Laschi C., and Trimmer B. (2013) Soft robotics: a bioinspired evolution in robotics, *Trends in Biotechnology*, April 2013.
Laschi C. and Cianchetti M. (2014) "Soft Robotics: new perspectives for robot bodyware and control" *Frontiers in Bioengineering and Biotechnology*, 2(3)

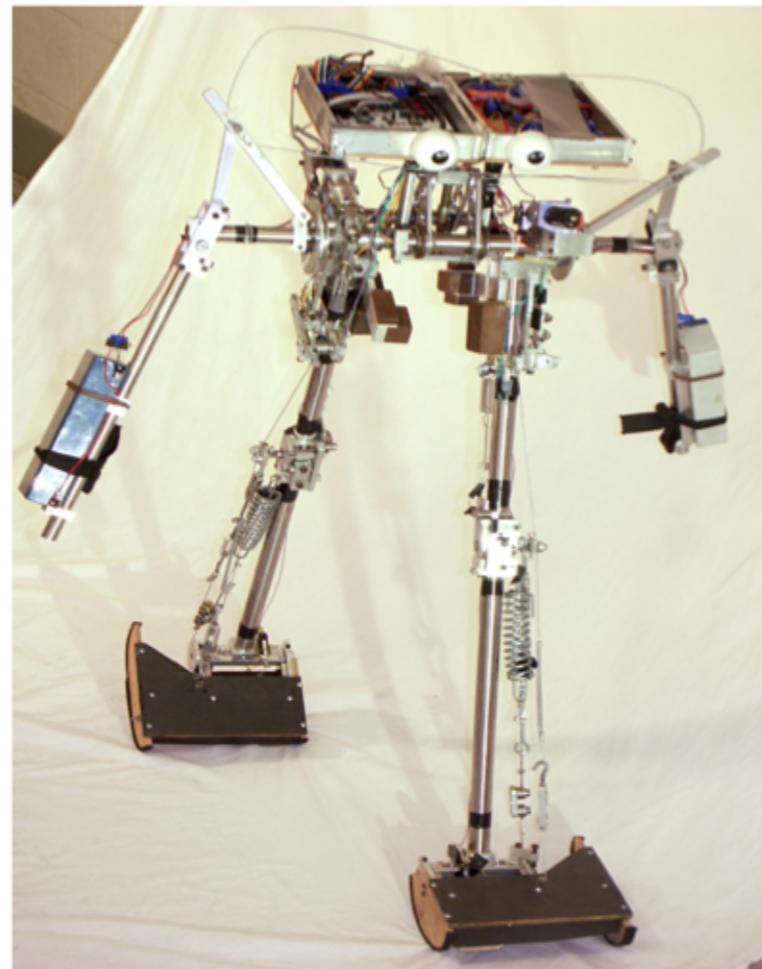
Is It Alive?



Today's humanoids



Conceptually different humanoid designs (mainly research)



Thank you for your attention!

