人工智能

The ShanghAI Lectures

上海授课

The Shanghai Lectures 2022

Natural and Artificial Intelligence in Embodied Physical Agents

November 24th, 2022

From Zagreb, Croatia

Today’s program (CET)

08:30 sites begin connecting
08:55 all sites are ready
09:00 (Fabio) Welcome
09:05 <u>Morphological Computation, Self-Organization of Behaviors and Adaptive Morphologies</u>
09:50 Break
10:00 Guest Lecture by Yukie Nagai, International Research Center for Neurointelligence, The University of Tokyo, Tokyo, Japan: <u>Cognitive Developmental Robotics</u>
10:45 Guest Lecture by Ezio Andreta, Foresight Project Coordinator, CNR Italy, Retired Director EU Commission, Brussels, Belgium: <u>From complexity to AI: Managing the ecological transition</u>
11:15 Wrap-up

Today’s Guest Lecture

10:10 Yukie Nagai, International Research Center for Neurointelligence,

The University of Tokyo, Tokyo, Japan

«Cognitive Developmental Robotics»

Stay tuned!

Today’s Guest Lecture

10:45-10:55 CET Ezio Andreta, Foresight Project Coordinator, CNR Italy, Retired Director EU Commission, Brussels, Belgium

«From complexity to AI: Managing the ecological transition»

Stay tuned!

Lecture 4

Morphological Computation, Self-Organization of Behaviors and Adaptive Morphologies

Fabio Bonsignorio
Professor, ERA CHAIR in AI for Robotics

University of Zagreb
Faculty of Electrical Engineering and Computing
Laboratory for Autonomous Systems and Mobile Robotics

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No. 952275

www.heronrobots.com

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

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

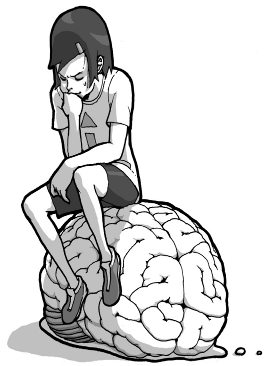
Director of the Intelligent Robotics Laboratory, part of the Department of Adaptive Machine Systems at Osaka University, Japan

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

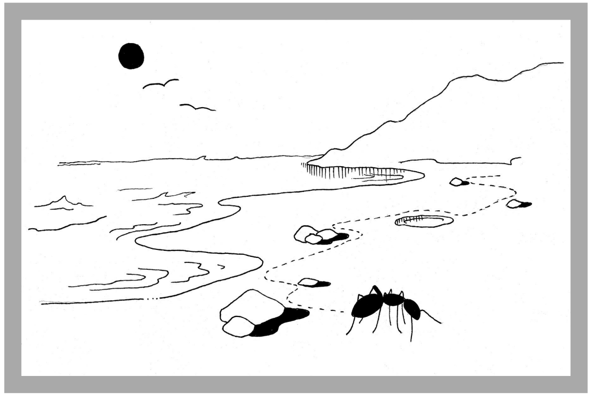
classical:
cognition as computation



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
everything else the same

The “symbol grounding” problem

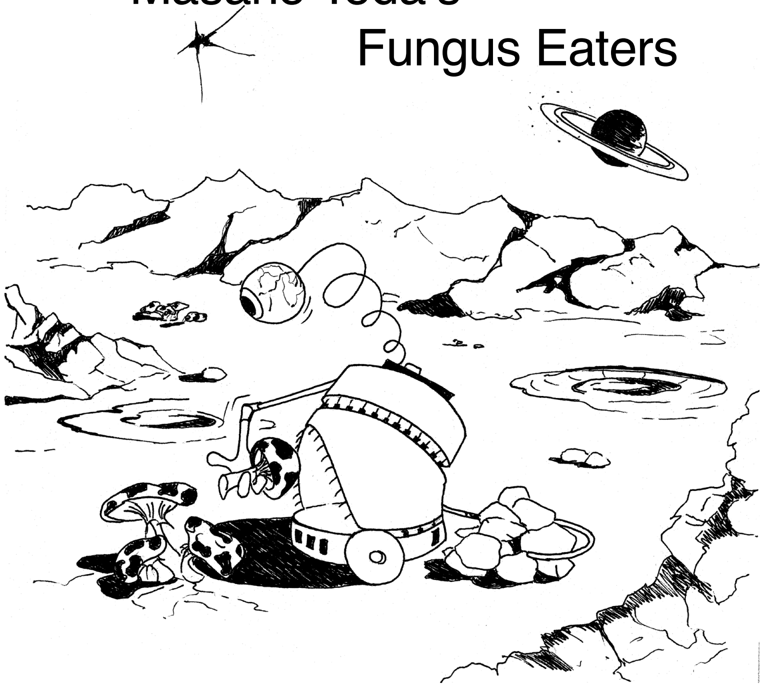
real world: doesn’t come with labels …

How to put the labels??

Gary Larson

Complete agents

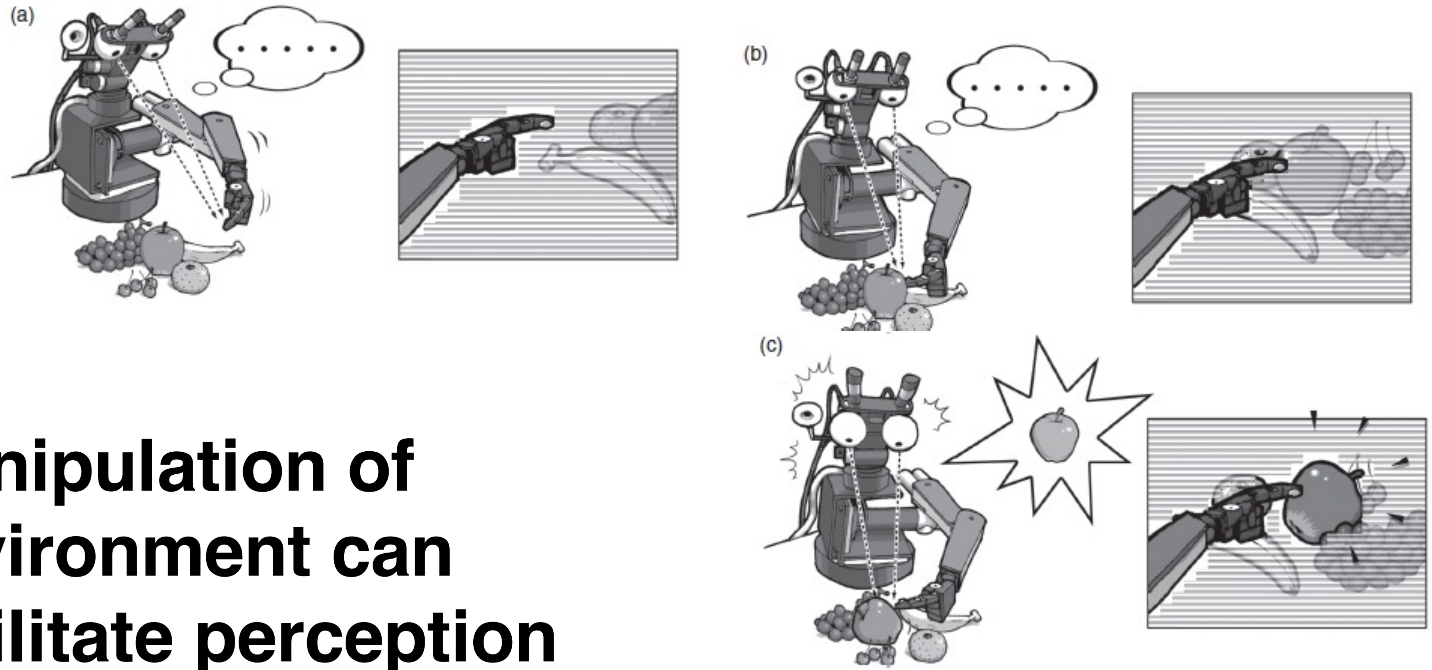
Masano Toda's
Fungus Eaters



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

Recognizing an object in a cluttered environment



manipulation of environment can facilitate perception

Illustrations by Shun Iwasawa

Experiments: **Giorgio Metta and Paul Fitzpatrick**

The subsumption architecture
the “behavior-based” approach

classical, cognitivistic

sensors

perception - modeling - planning - acting

actuators

sense-model-plan-act

sense-think-act

“behavior-based”, subsumption

sensors

explore

collect object

avoid obstacle

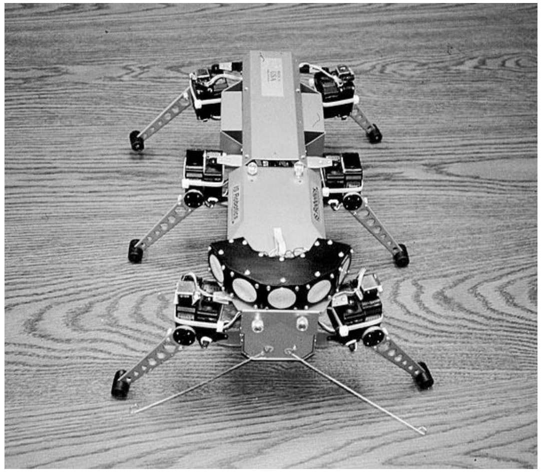
move foreward

actuators

Mimicking insect walking

- **subsumption architecture well-suited**

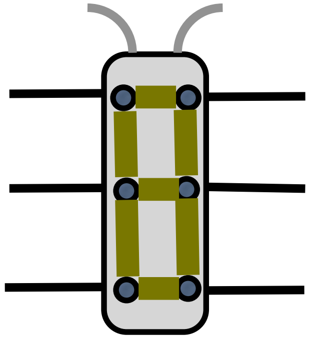
six-legged robot “Ghenghis”



Disney Animatronics

Insect walking

Holk Cruse,
German biologist



neural connections →

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

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.”

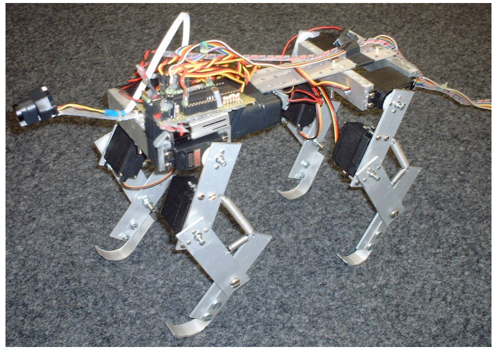
Case study: “Puppy” as a complex dynamical system

- **running: hard problem**
- **time scales: neural system — damped oscillation of knee-joint**
- **“outsourcing/offloading” of functionality to morphological/material properties**

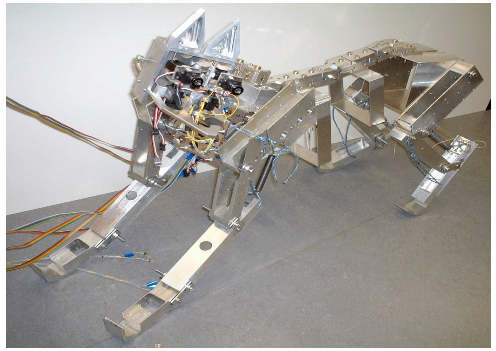
→ morphological computation

Recall: “Puppy’s” simple control

rapid locomotion in biological systems



recall: emergence of behavior

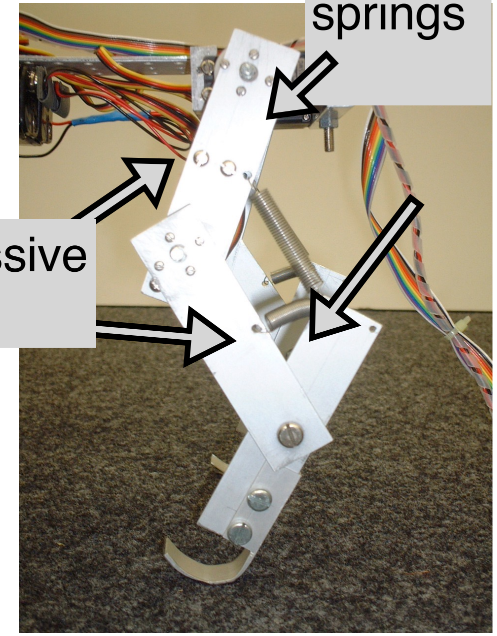


Design and construction:
Fumiya Iida, AI Lab, UZH and ETH-Z

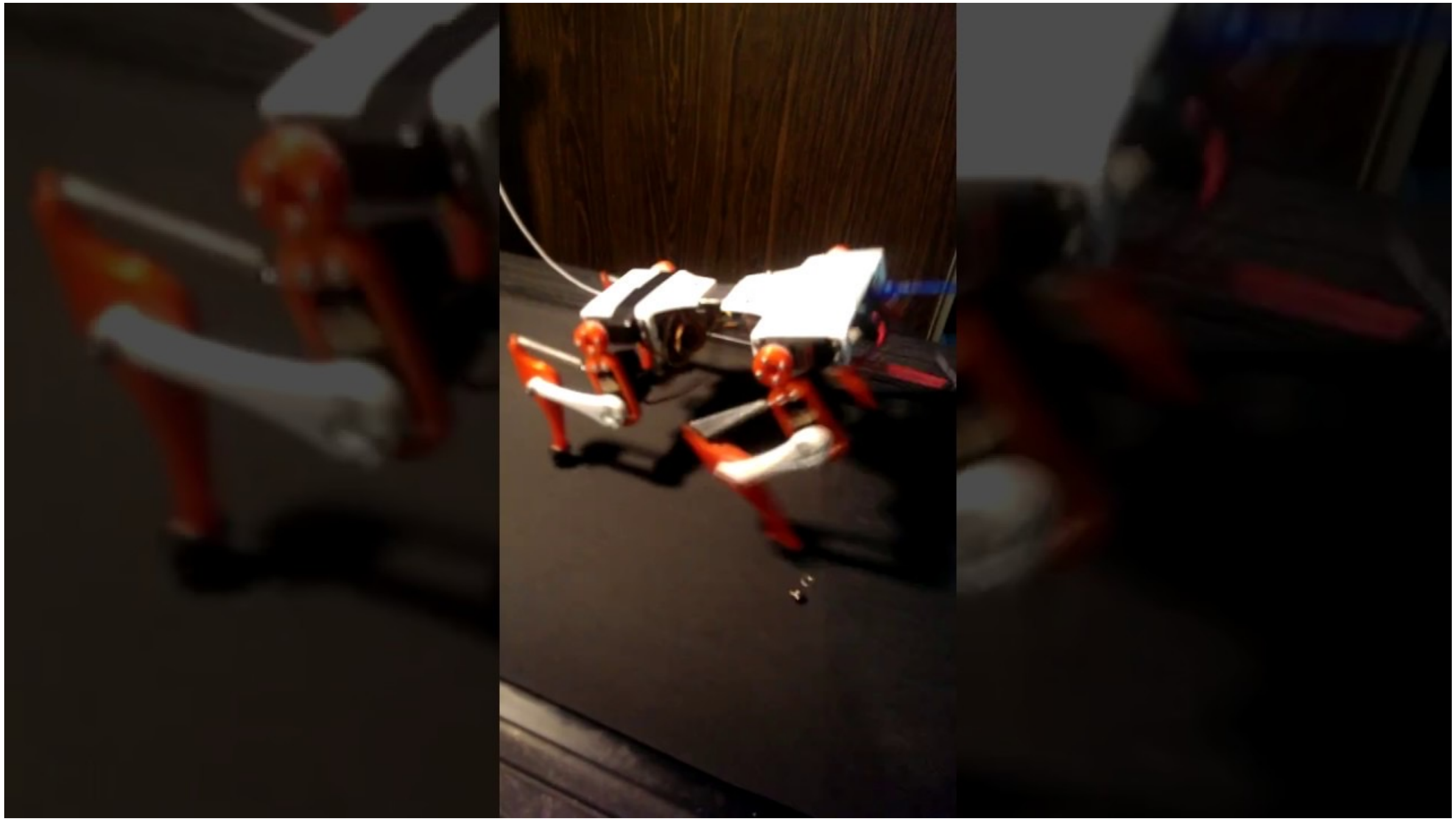
Emergence of behavior: the quadruped “Puppy”

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

→ morphological computation



Self-stabilization:



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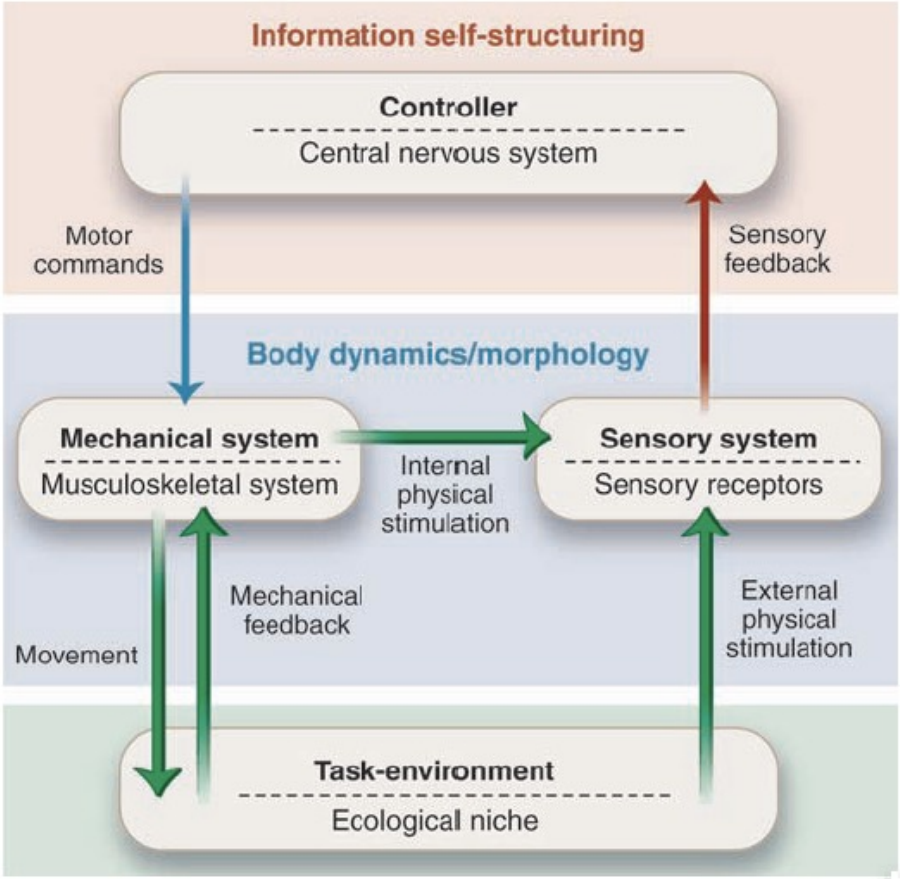
“Cheetah” on a treadmill

Implications of embodiment
Self-stabilization



„Puppy"

Pfeifer et al.,Science, 16 Nov. 2007

Short question

memory for walking?

The Cornell Ranger

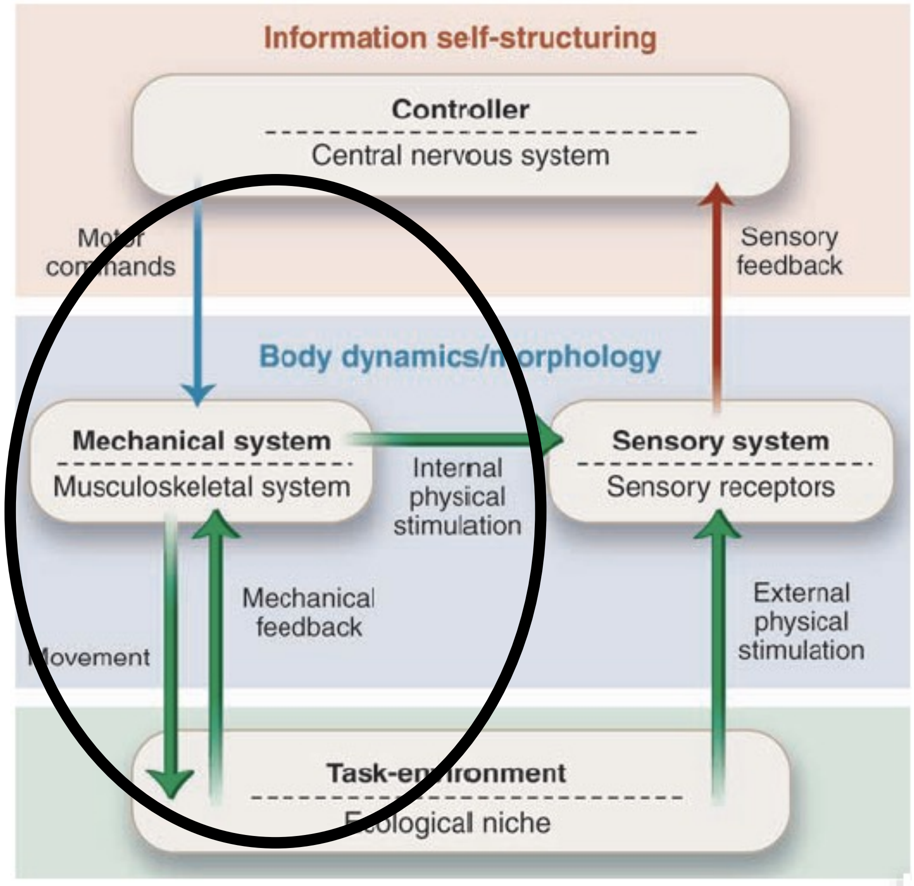
design and construction:
Andy Ruina
Cornell University

exploitation of passive dynamics

65km with one battery charge!

The Cornell Ranger

Self-stabilization in Cornell Ranger

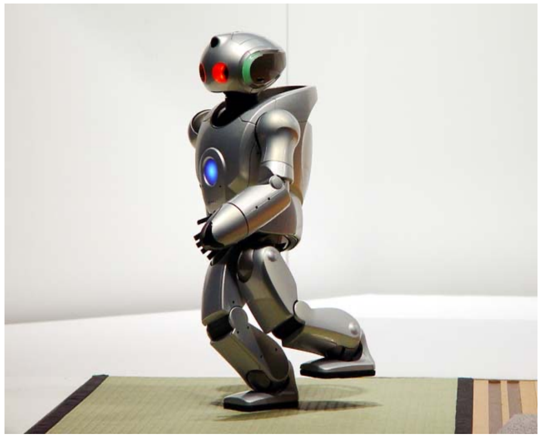


Pfeifer et al.,Science, 2007

Contrast: Full control

Honda Asimo

Sony Qrio



Boston Dynamics Atlas

Tesla Optimus

Principle of “ecological balance”

balance in complexity

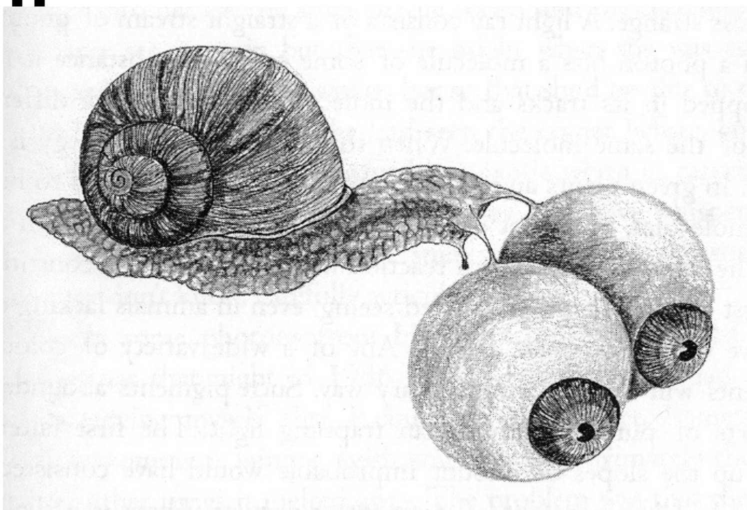
given task environment: match in complexity of sensory, motor, and neural system

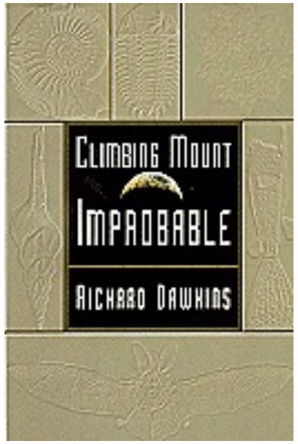
balance / task distribution

brain (control), morphology, materials, and interaction with environment

Richard Dawkins's snail with giant eyes

ecologically unbalanced system





Author of:
"The selfish gene" and
"The blind watchmaker"

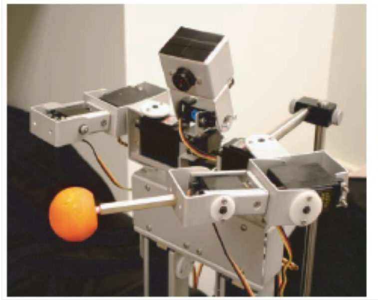
Probabilistic Model Of Control

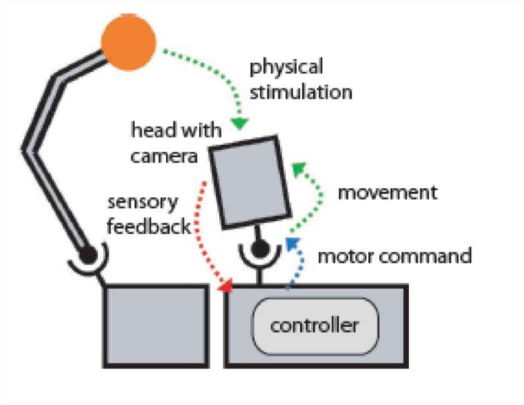
- Although it may seem strange only in recent times the classical results from Shannon theory, have been applied to the modeling of control systems.
- As the complexity of control tasks namely in robotics applications lead to an increase in the complexity of control programs, it becomes interesting to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

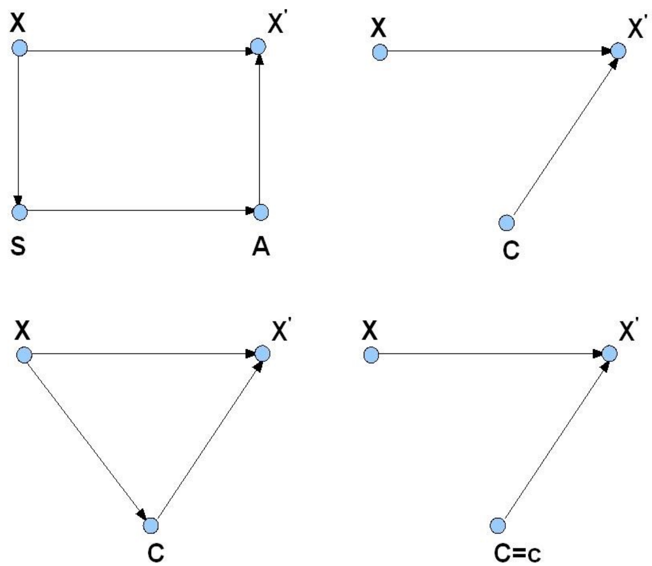
Lungarella and Sporns, **2006**
Mapping information flow
in sensorimotor networks
PLoS Computational Biology





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) 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.

Models of 'Morphological Computation'

$$K(X) \overset{+}{\leq} \log \frac{W_{closed}}{W_{open}^{closed}} \qquad \text{(I)}$$

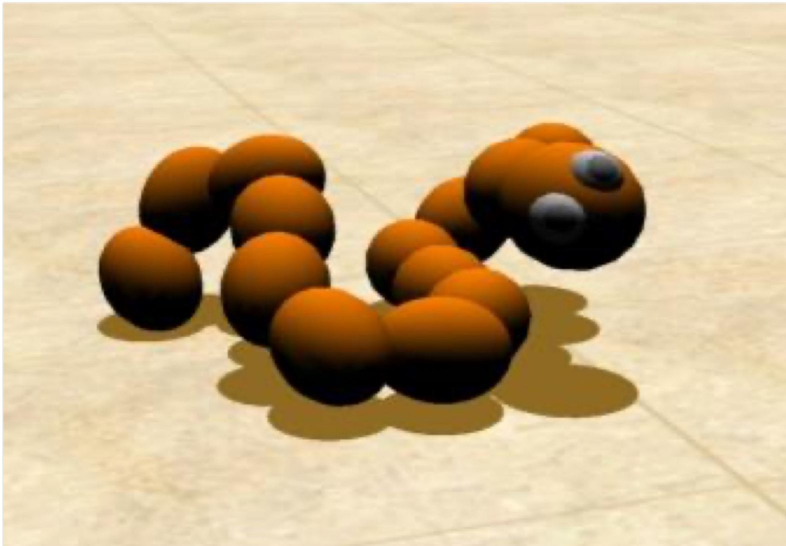
Relation (I) links the complexity ('the length') of the control program of a physical element to the state available in closed loop and the non controlled condition.
This show the benefits of designing stuctures whose 'basin of attractions' are close to the desired behaviors in the phase space.

Models of ‘Morphological Computation’

$$\Delta HN + \sum_{i}^{n} \Delta H_i - \Delta I \le I\left(X;C\right) \quad \text{(II)}$$

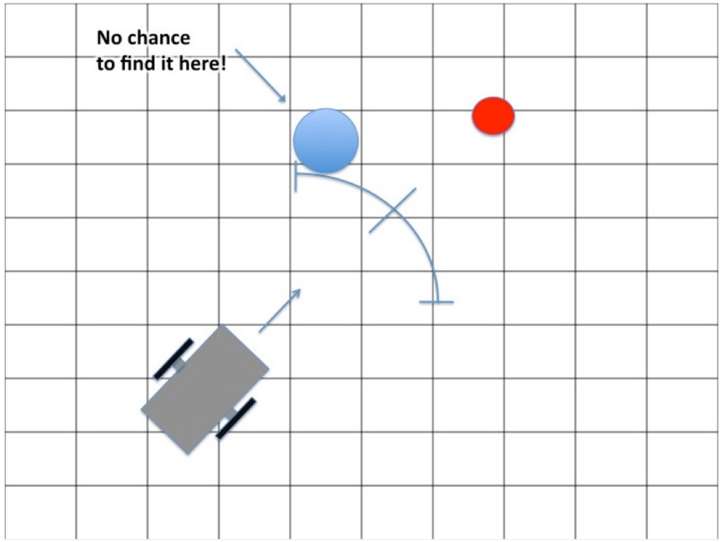
Relations (II) links the mutual information between the controlled variable and the controller to the information stored in the elements, the mutual information between them and the information stored in the network and accounts for the redundancies through the multi information term *ΔI*.

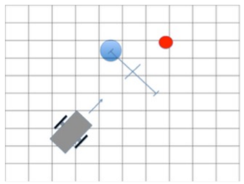
Snakebot



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

Maybe not GOF Euclidean space? :-)





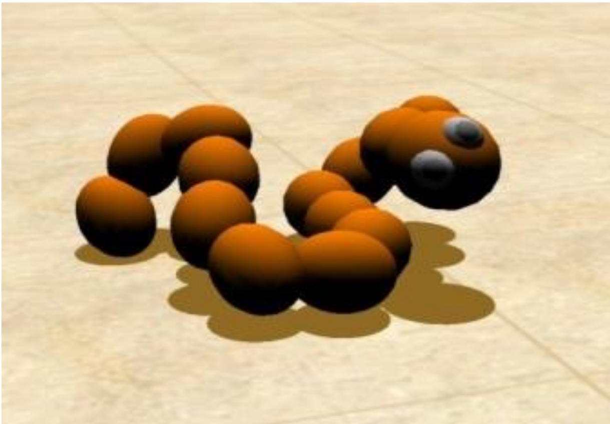
see: **Bonsignorio, Artificial Life, 2013**

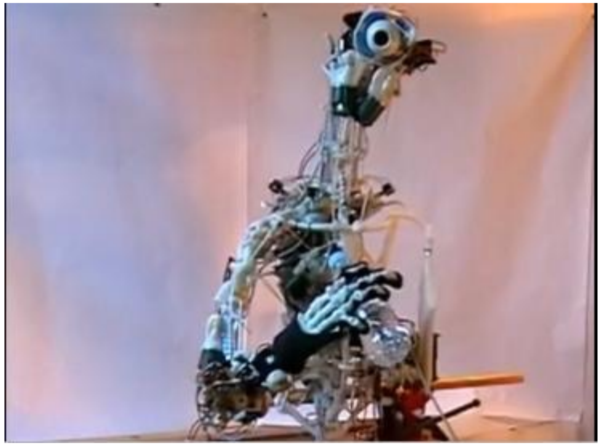
Synthetical methodology

In order to understand (and design)
the behaviors of this kind of systems…

Synthetical methodology

We may build, and mathematically model, simpler ones…

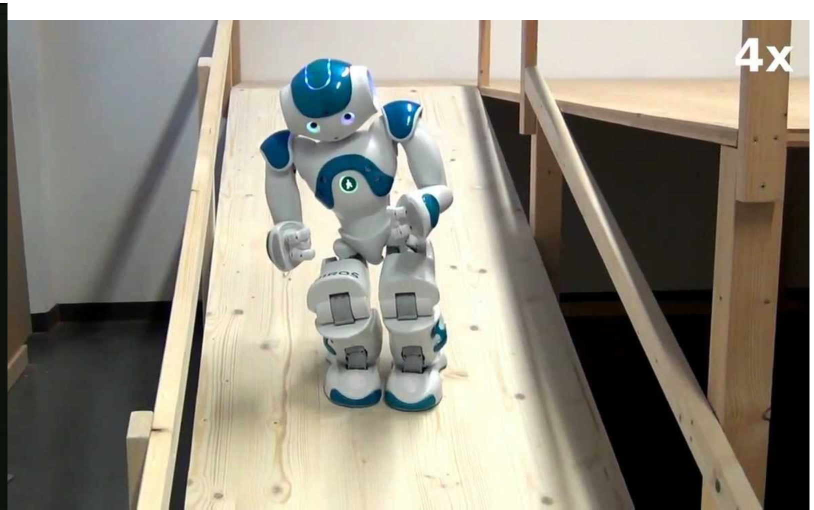




and design discriminating experiments…

[Cornell passive walker down a ramp]()

[Nao walking down a ramp]()



How to build a ‘new paradigm’ robot like the Cornell Ranger able to wave the hands like NAO? (and manipulate things…)

Today’s Guest Lecture

10:10 Yukie Nagai, International Research Center for Neurointelligence,

The University of Tokyo, Tokyo, Japan

«Cognitive Developmental Robotics»

Stay tuned!

Today's Guest Lecture

10:45 CET Ezio Andreta, Foresight Project Coordinator, CNR Italy, Retired Director EU Commission, Brussels, Belgium

«From complexity to AI: Managing the ecological transition»

Stay tuned!

Assignments for next week

- Check “How the body…” for self-study
- Think about how symbolic, emergentist approaches and … deep learning….

End of lecture 4

Thank you for your attention!

stay tuned for lecture 5

“Machine Learning and Deep Learning: an Embodied AI Perspective»

Short Bio

The ShanghAI Lectures 2013-

Prof. Fabio Bonsignorio is **ERA Chair in AI for Robotics** at FER, University of Zagreb, Croatia. He is **Founder and CEO of Heron Robots (advanced robotics solutions),** see **www.heronrobots.com**. He has been visiting professor at the **Biorobotic Institute of the Scuola Superiore Sant'Anna in Pisa from 2014 to 2019**. He has been a professor in the Department of System Enginering and Automation at the **University Carlos III of Madrid until 2014**. In 2009 he got the **Santander Chair of Excellence in Robotics** at the same university. He has been working for some 20 years in the high tech industry before joining the research community.

He is a **pioneer and has introduced the topic of Reproducibility of results in Robotics and AI**. He is a **pioneer in the application of the blockchain to robotics and AI (smart cities, smart land, smart logistics, circular economy). He coordinates the Topic Group of euRobotics about Experiment Replication, Benchmarking, Challenges and Competitions. He is co-chair of the IEEE Robotics & Automation Society (RAS) Technical Committee, TC-PEBRAS (PErformance and Benchmarking of Robotics and Autonomous Systems)**.

He is a **Distinguished Lecturer** for **IEEE Robotics and Automation Society.**' Senior Member of IEEE and member of the Order of the Engineers of Genoa, Italy.

He coordinates the task force robotics, in the G2net,an EU network studying the application of **Machine Learning and Deep Learning (Apprendimento Profondo) to Gravitational wave research, la Geophysics and Robotics**.

Has given invited seminars and talks in many places: MIT Media Lab, Max Planck Institute, Imperial College, Politecnico di Milano in Shenzhen, London, Madrid, Warsaw, San Petersburg, Seoul, Rio Grande do Sul.…

Thank you!

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