The ShanghAI Lectures

人工智能

上海授课

The ShanghAI Lectures
An experiment in global teaching

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The BioRobotics Institute, SSSA, Pisa, Italy

欢迎您参与
“来自上海的人工智能系列讲座”

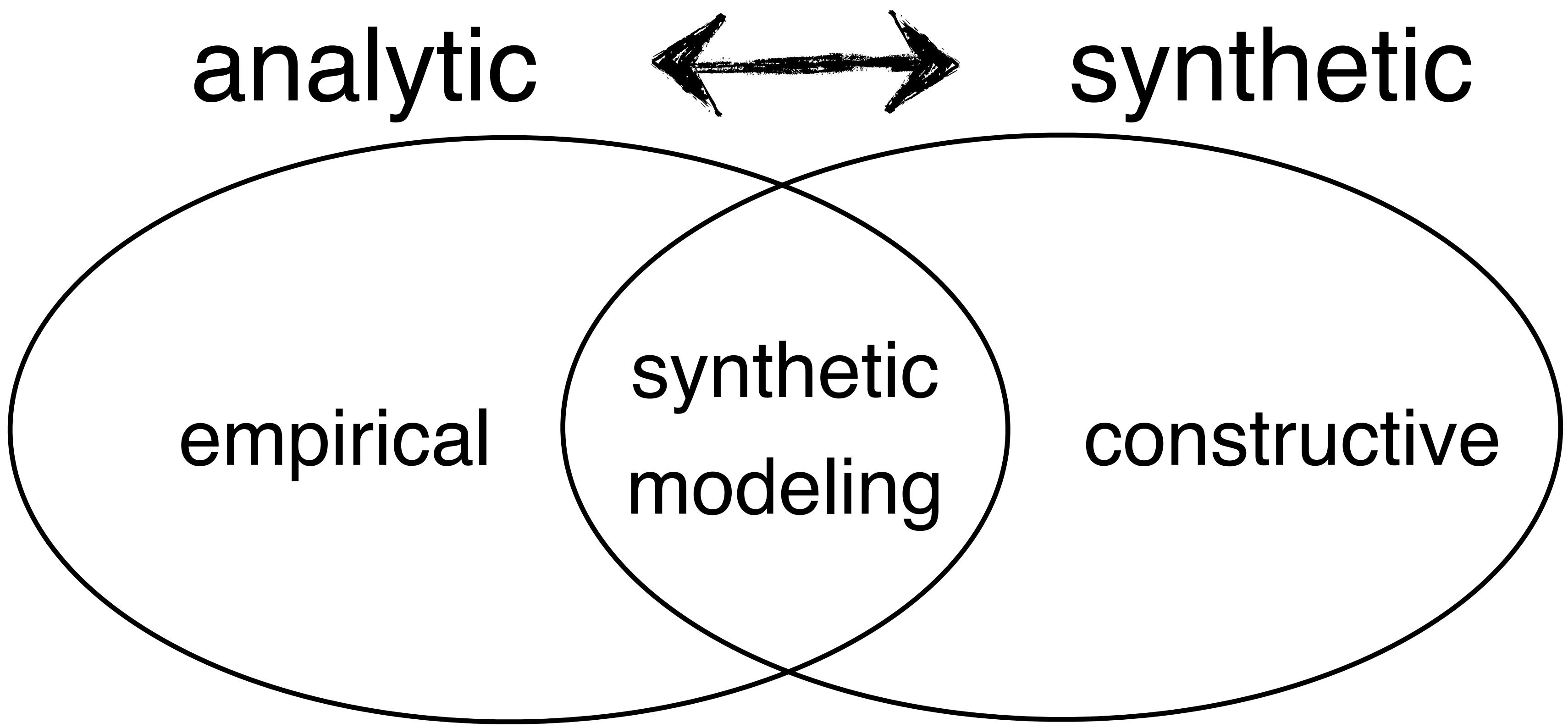
Lecture 5

Design principles for intelligent systems:

Soft Robotics and Bioinspiration

13 November 2014

How to study intelligence?



psychology
biology
neuroscience

artificial intelligence
engineering
cognitive science

The synthetic methodology

Slogan:

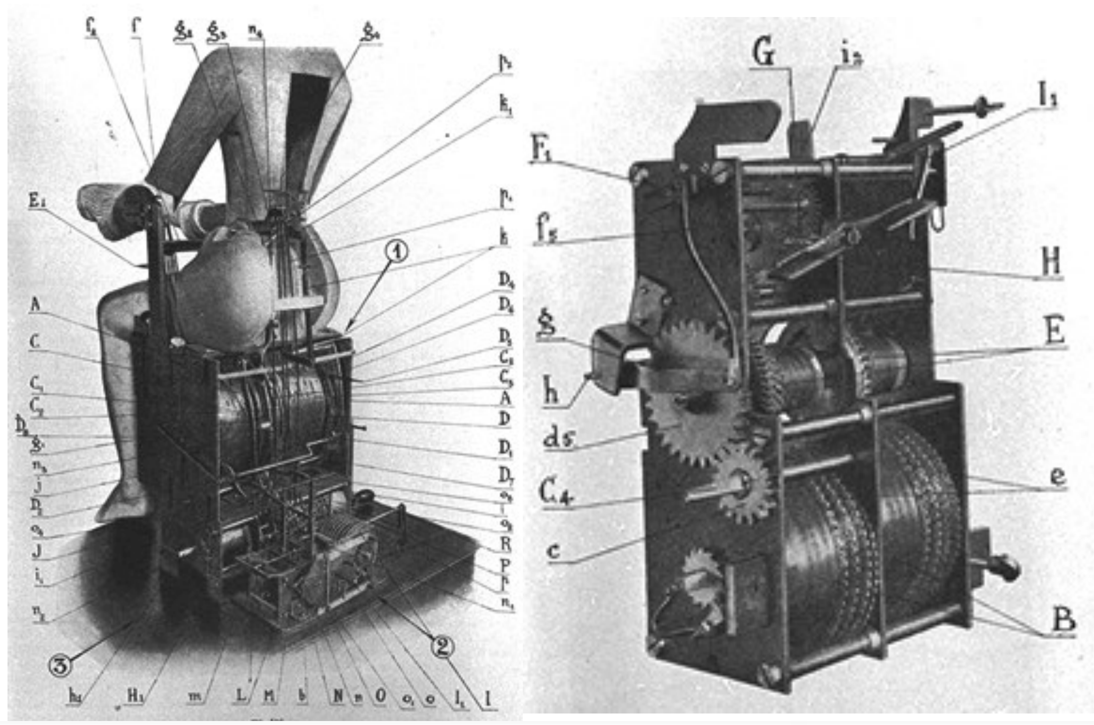
"Understanding by building"

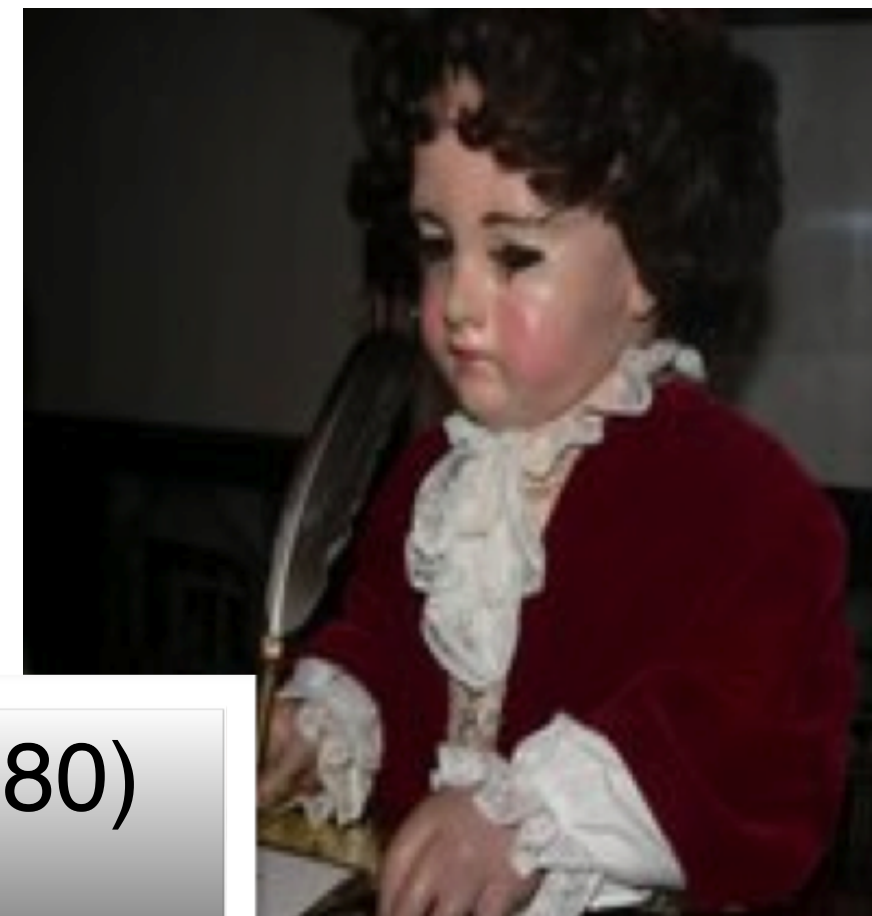
modeling behavior of interest
abstraction of principles

→

robots as tools for scientific investigation

Old attempts



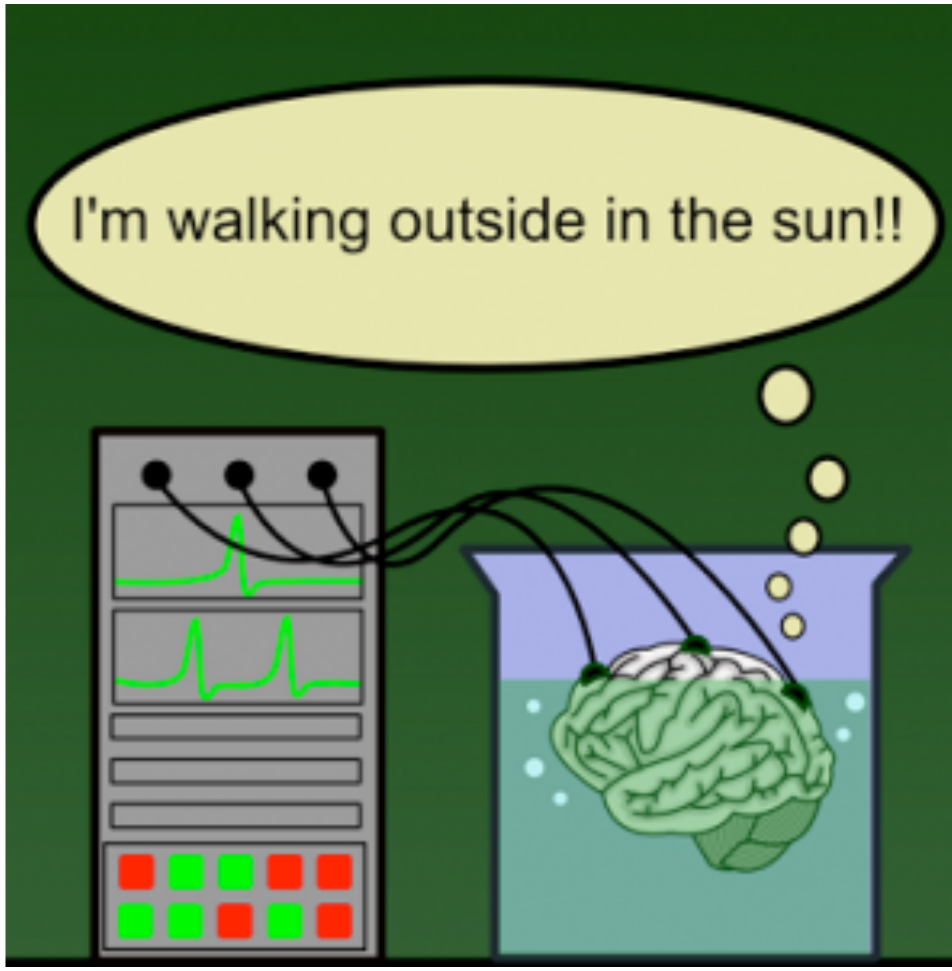


Jaquet-Droz Brothers (1720-1780)

Old attempts

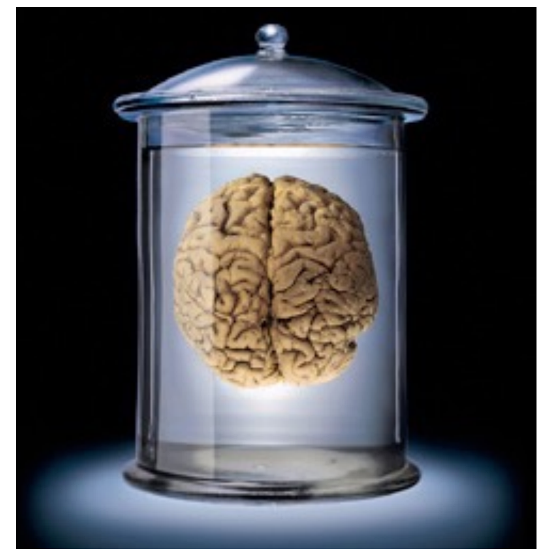
Karakuri Dolls

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

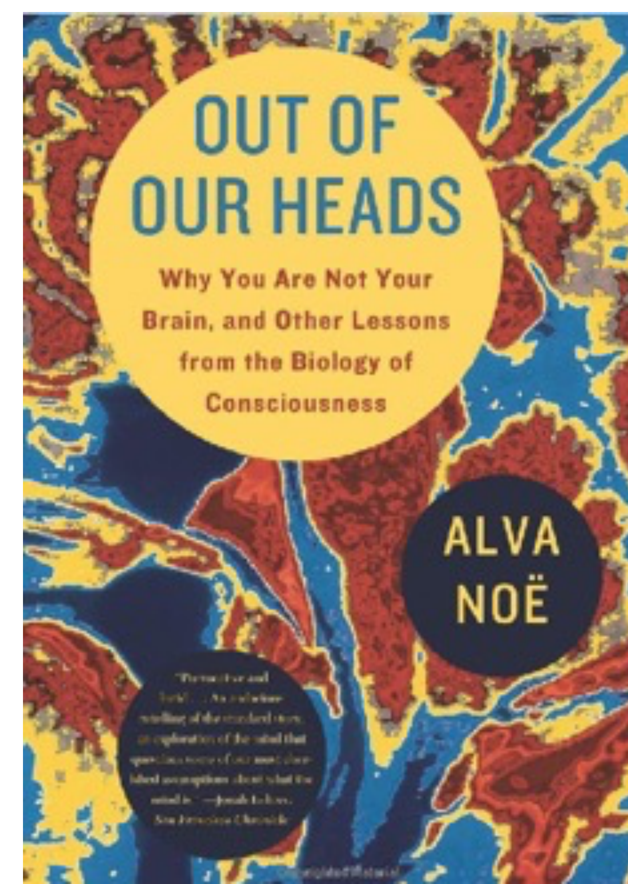


"Brain-in-a-vat"

Alva Noë, "Out of our heads - why you are not your brain", New York, Hill and Wang, 2009



- **supply energy**
- **flush away waste products**
- **complicated: providing stimulation comparable to that normally provided to a brain by its environmentally situated body**



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."

Life vs Cognition

?

Today's topics

- short recap
- characteristics of complete agents
- illustration of design principles
- parallel, loosely coupled processes: the "subsumption architecture"
- case studies: "Puppy", "Passive Dynamic Walkers"

Hard to agree on definitions, arguments

- **necessary and sufficient conditions?**
- **are robots, ants, humans intelligent?**

more productive question:

“Given a behavior of interest, how to implement it?”

Successes and failures of the classical approach

successes

applications (e.g. Google)

chess

manufacturing

("controlled"artificial worlds)

failures

foundations of behavior

natural forms of intelligence

interaction with real world

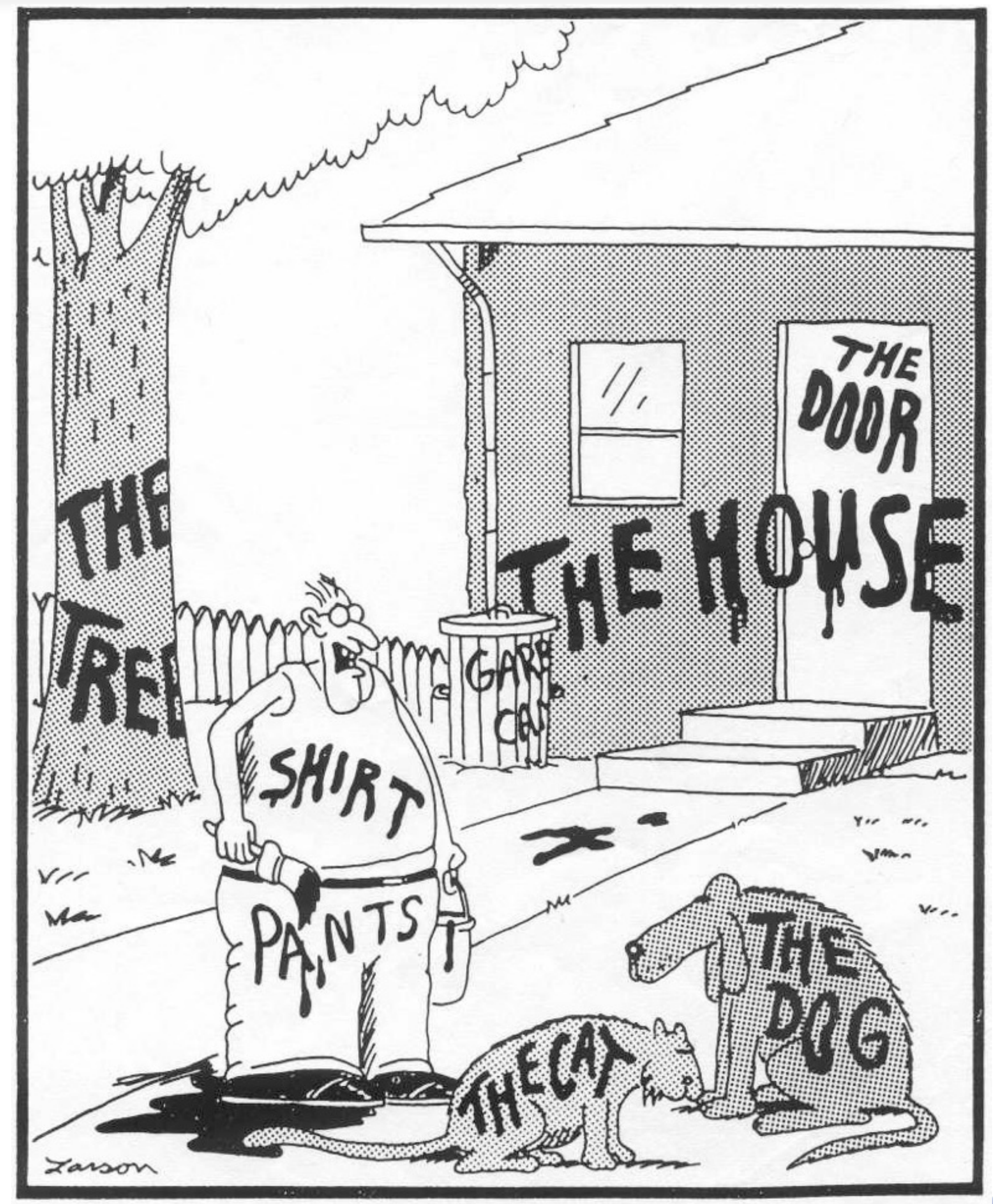
The “symbol grounding” problem

real world:
doesn’t come
with labels …

How to put the

labels??

Gary Larson



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

Two views of intelligence

classical:
cognition as computation

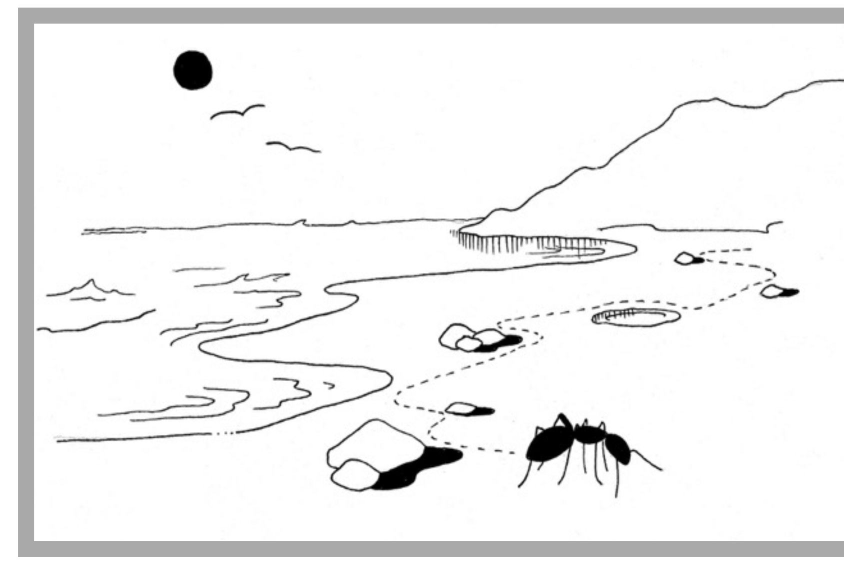
embodiment:
cognition emergent from sensory-motor and interaction processes

The need for an embodied perspective

- “failures” of classical AI
- fundamental problems of classical approach
- Wolpert’s quote: Why do plants not …? (stay tuned for Barbara Mazzolai’s lecture…)
- Interaction with environment: always mediated by body

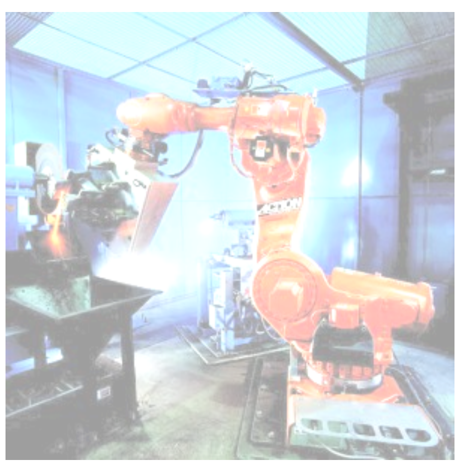
“Frame-of-reference” Simon’s ant on the beach

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



- thought experiment:
  increase body by factor of 1000

Industrial robots vs. natural systems



robots

principles:

- **low precision**
- **compliant**
- **reactive**
- **coping with uncertainty**

humans

→ **no direct transfer of methods**

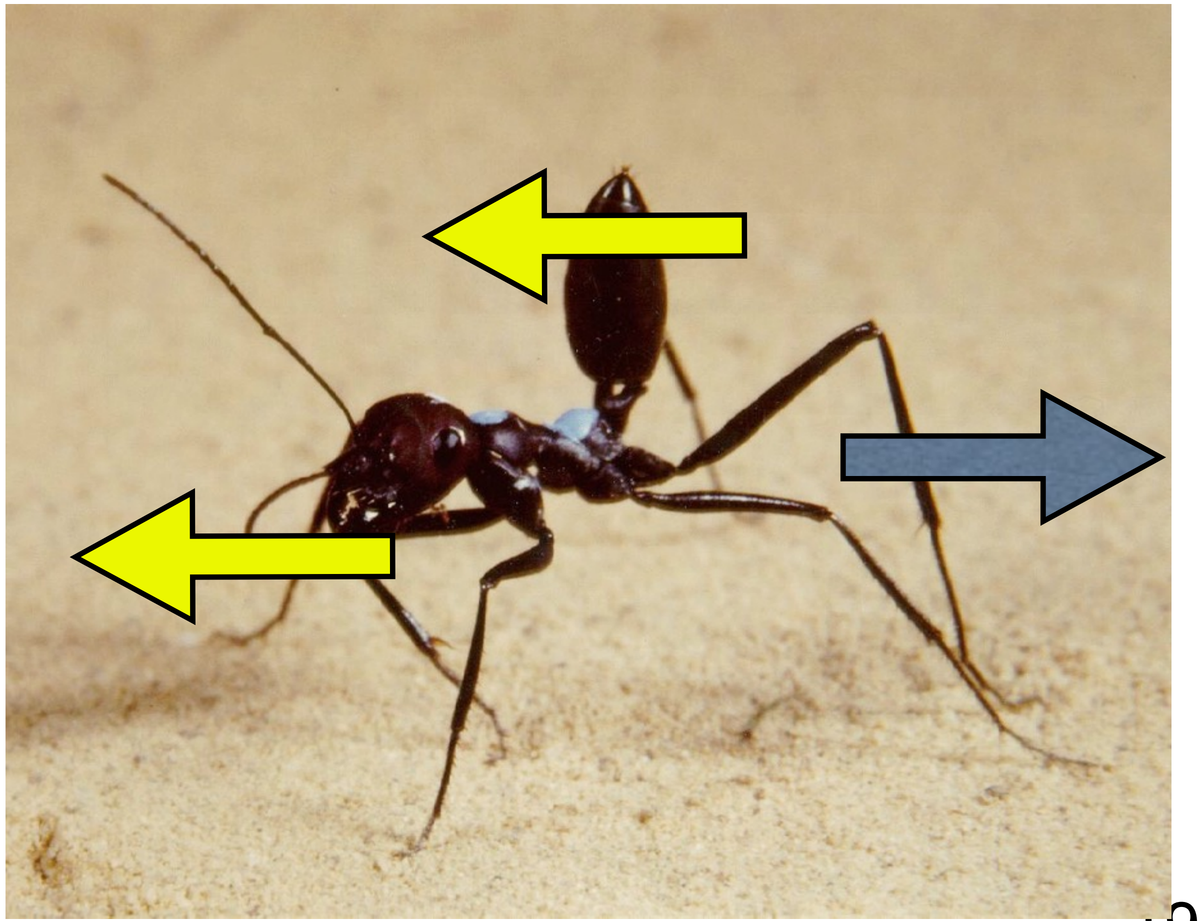
Communication through interaction with

- **exploitation of interaction with environment**

→ **simpler neural circuits**

angle sensors in joints

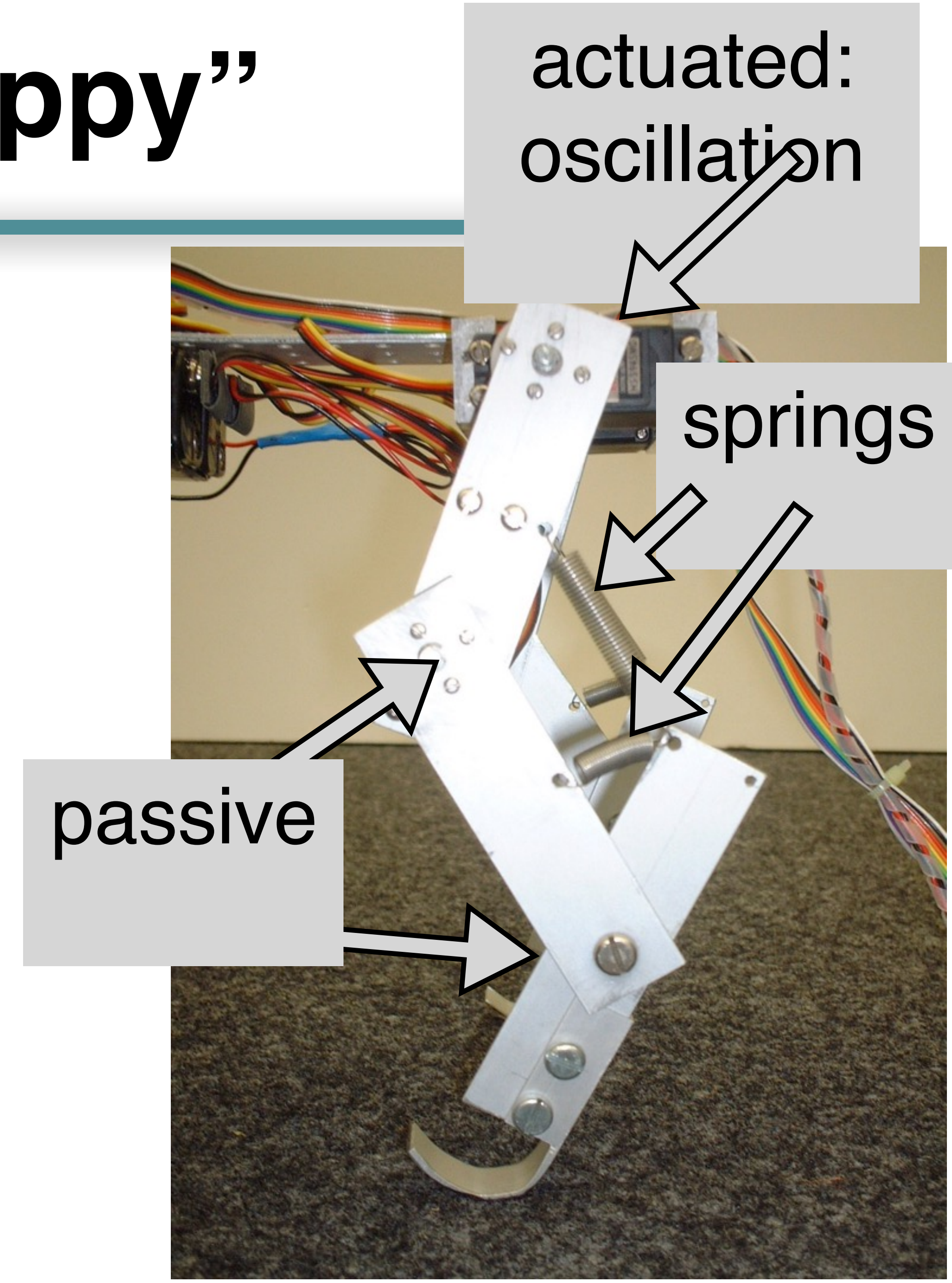
"parallel, loosely coupled processes"



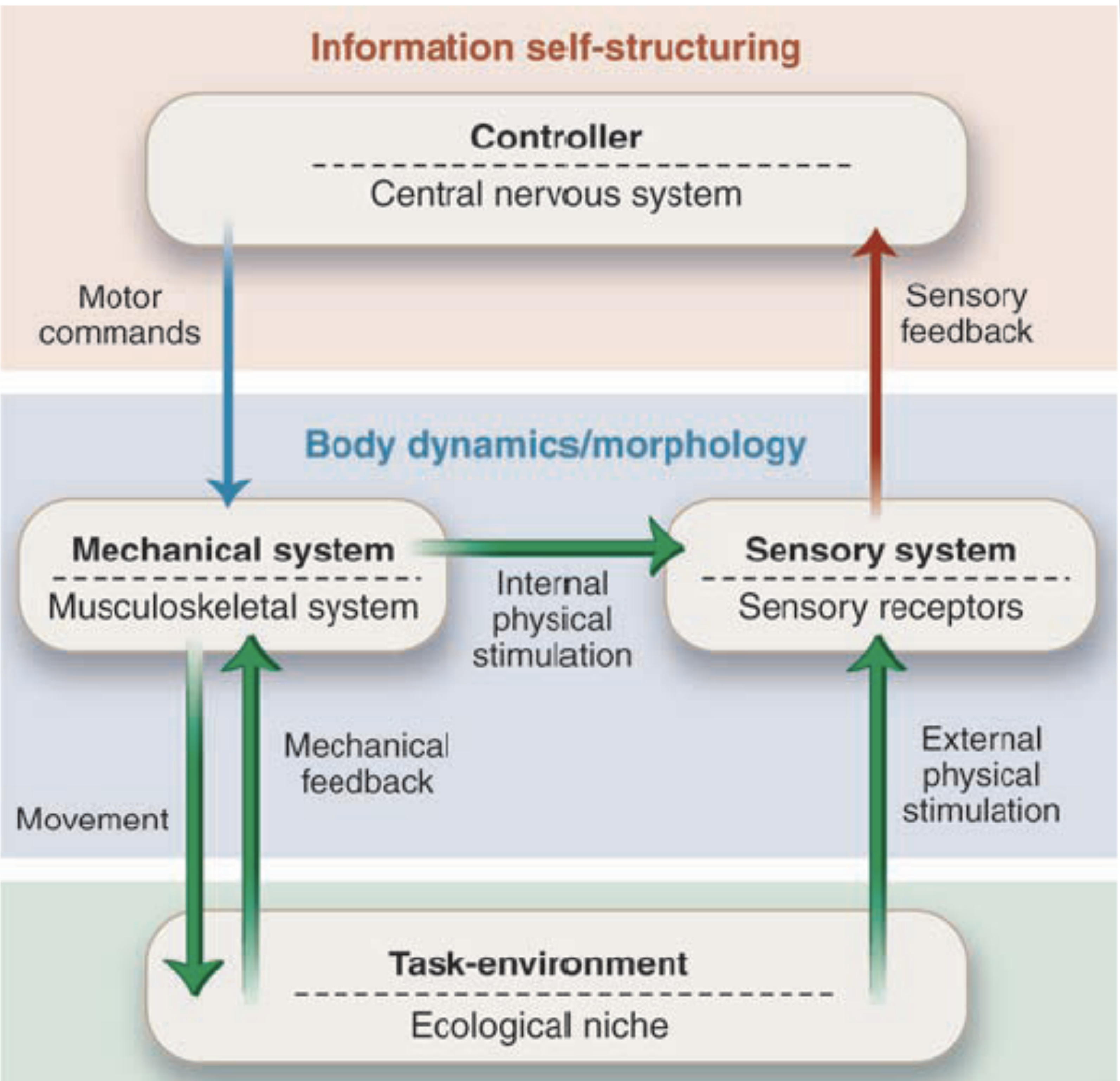
Emergence of behavior: the quadruped “Puppy”

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

→ morphological computation



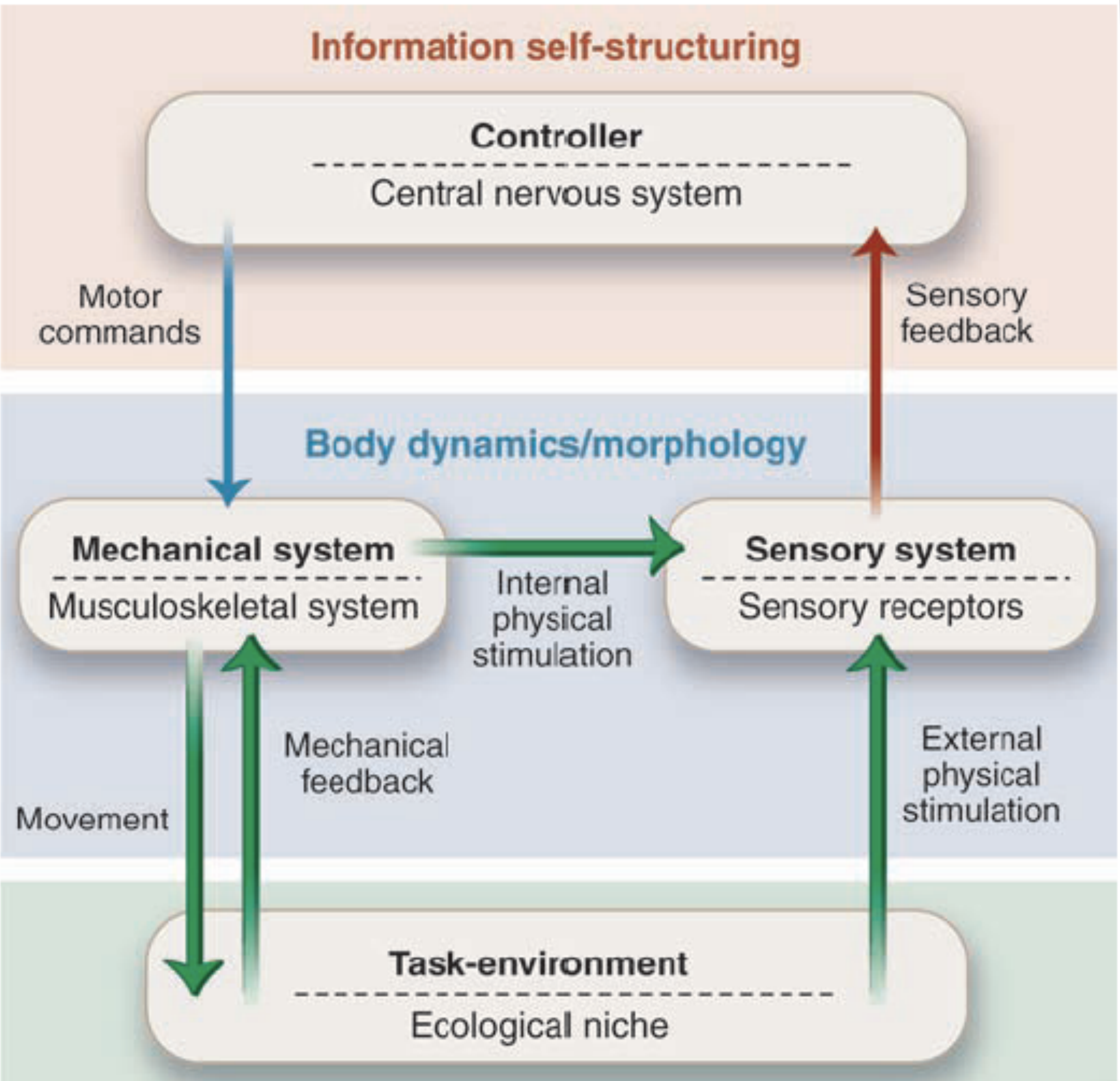
Implications of embodiment



"Puppy"

Pfeifer et al.,Science, 16 Nov. 2007

Implications of embodiment



"Puppy"

which part of diagram is relevant?

—>

Pfeifer et al.,Science, 16 Nov. 2007

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Soft Robotics

Research, challenges, and applications

adapted from Iros 2014 session keynote on soft robotics

by Cecilia Laschi

The BioRobotics Institute

Scuola Superiore Sant’Anna, Pisa, Italy

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Image: Massimo Brega, The Lighthouse

Image: Jennie Hills, London Science Museum

IROS - *IEEE/RSJ International Conference on Intelligent Robots and Systems*

Chicago, Illinois, September 15, 2014

Outline

* A working **definition** of Soft Robotics
* The **need** for soft robots: from robotics, from one side, and AI, from another side
* The **challenges** of Soft Robotics, at the merge of many disciplines and technologies
* The **innovation potential** of Soft Robotics: fields of application
* **Perspectives** of Soft Robotics: increasingly rich state of the art, promising research and technological developments, growing and active community, coordination activities

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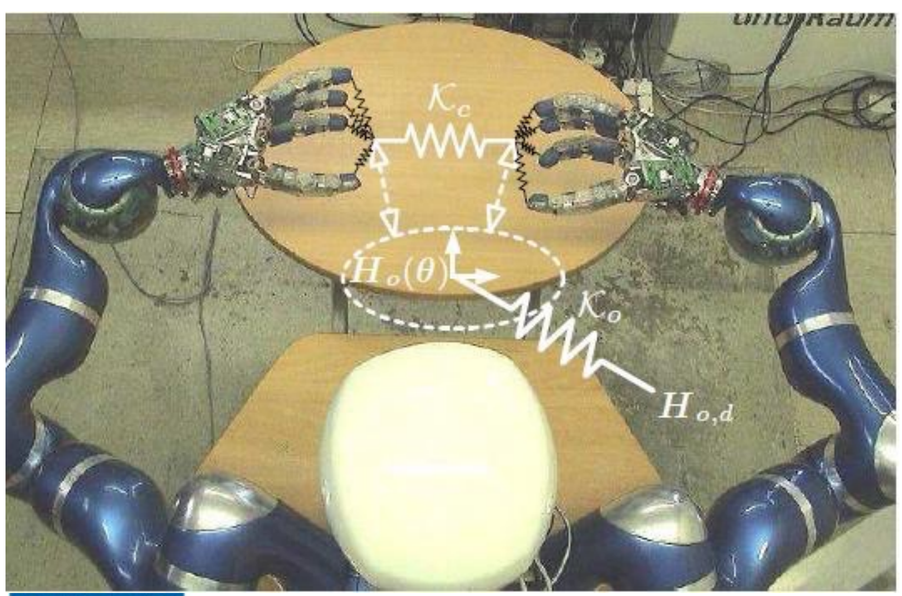
Soft Robotics: a working definition

Variable impedance actuators and stiffness control

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



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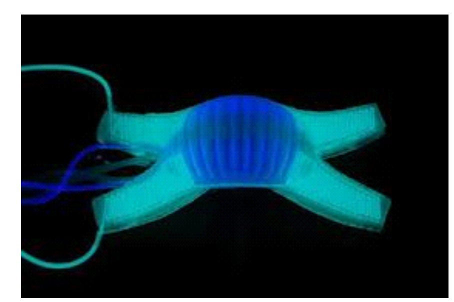
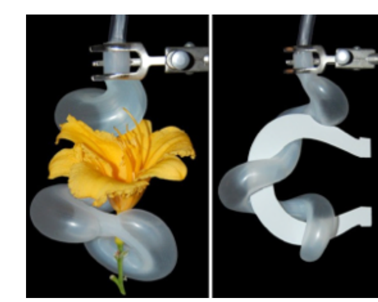
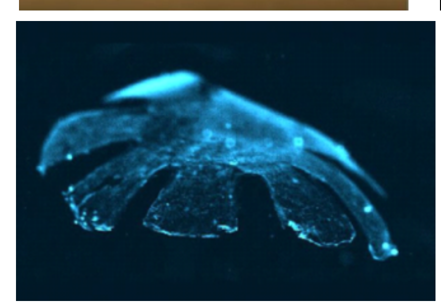
IEEE Robotics and Automation Magazine, Special Issue on Soft Robotics, 2008
A. Albu-Schaffer et al. (Ed.s)

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)

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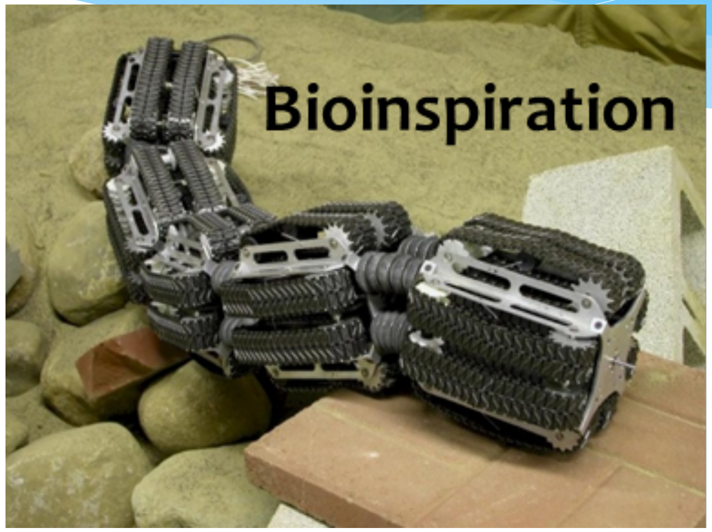
Soft Robotics stems from robotics, from one side…

Robotics

From industrial to service robotics



Biological systems exploit **soft structures** to move effectively in complex environments

Soft robotics

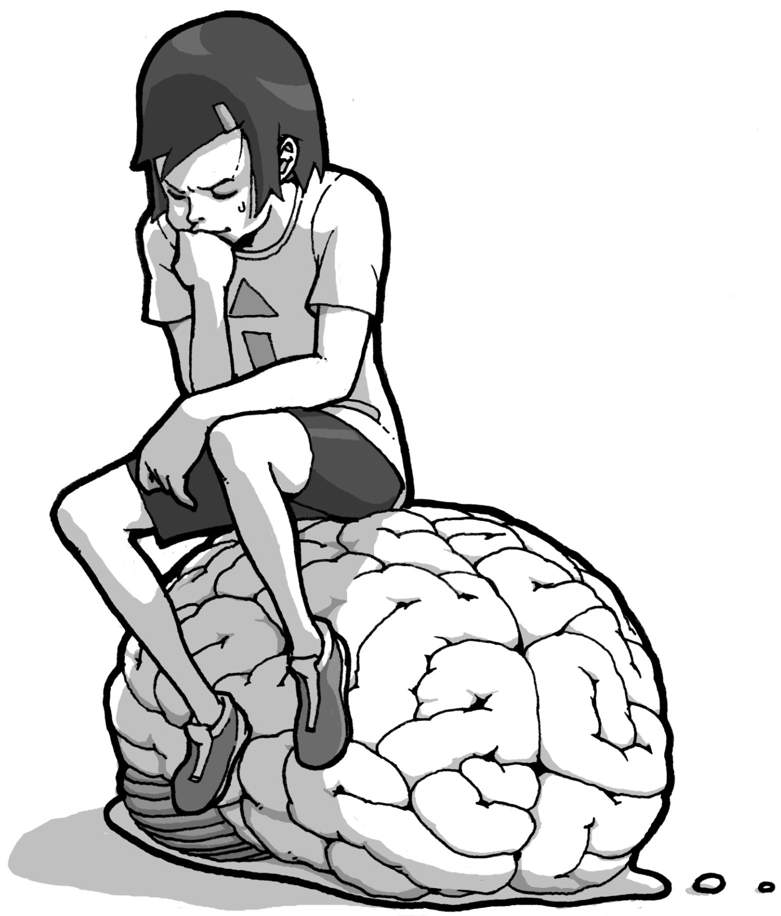
Embodied Intelligence or Morphological Computation: the modern view of Artificial Intelligence

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



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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 stems from robotics, from one side, and AI, from another side

Soft Robotics at the convergence of Robotics and AI

Robotics

From industrial to service robotics

Soft robotics is going to stand as a **novel approach to robotics and artificial intelligence**, and it has the potential to produce a new generation of robots, in the support of humans in our natural environments.

Soft robotics is not just a new direction of technological development.
The use of soft materials in robotics is going to unhinge its fundamentals.

Soft robotics

Artificial Intelligence

From central processing to Morphological Computation

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The OCTOPUS showcase

Image: London Science Museum/Jennie Hills

OCTOPUS IP (2009-2013)

Novel Design Principles and Technologies for a New Generation of High Dexterity Soft-bodied Robots Inspired by the Morphology and Behaviour of the Octopus

SEVENTH FRAMEWORK PROGRAMME

EU-funded Project # 231608
ICT-FET Proactive:
ICT-2007.8.5 "Embodied Intelligence"
Total grant: 7.6 M€

C. Laschi, B. Mazzolai, M. Cianchetti, L. Margheri, M. Follador, P. Dario, "A Soft Robot Arm Inspired by the Octopus", *Advanced Robotics (Special Issue on Soft Robotics)*, Vol.26, No.7, 2012.
M. Calisti, M. Giorelli, G. Levy, B. Mazzolai, B. Hochner, C. Laschi, P. Dario, "An octopus-bioinspired solution to movement and manipulation for soft robots", *Bioinspiration & Biomimetics*, Vol.6, No.3, 2011, 10 pp.
C. Laschi, B. Mazzolai, V. Mattoli, M. Cianchetti, P. Dario, "Design of a biomimetic robotic octopus arm", *Bioinspiration&Biomimetics*, Vol.4, No.1, 2009.

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The octopus as a model for both soft robotics and embodied intelligence

What are the principles that give rise to the octopus dexterity and intelligence?

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Soft Robotics is at the merge of many disciplines and technologies

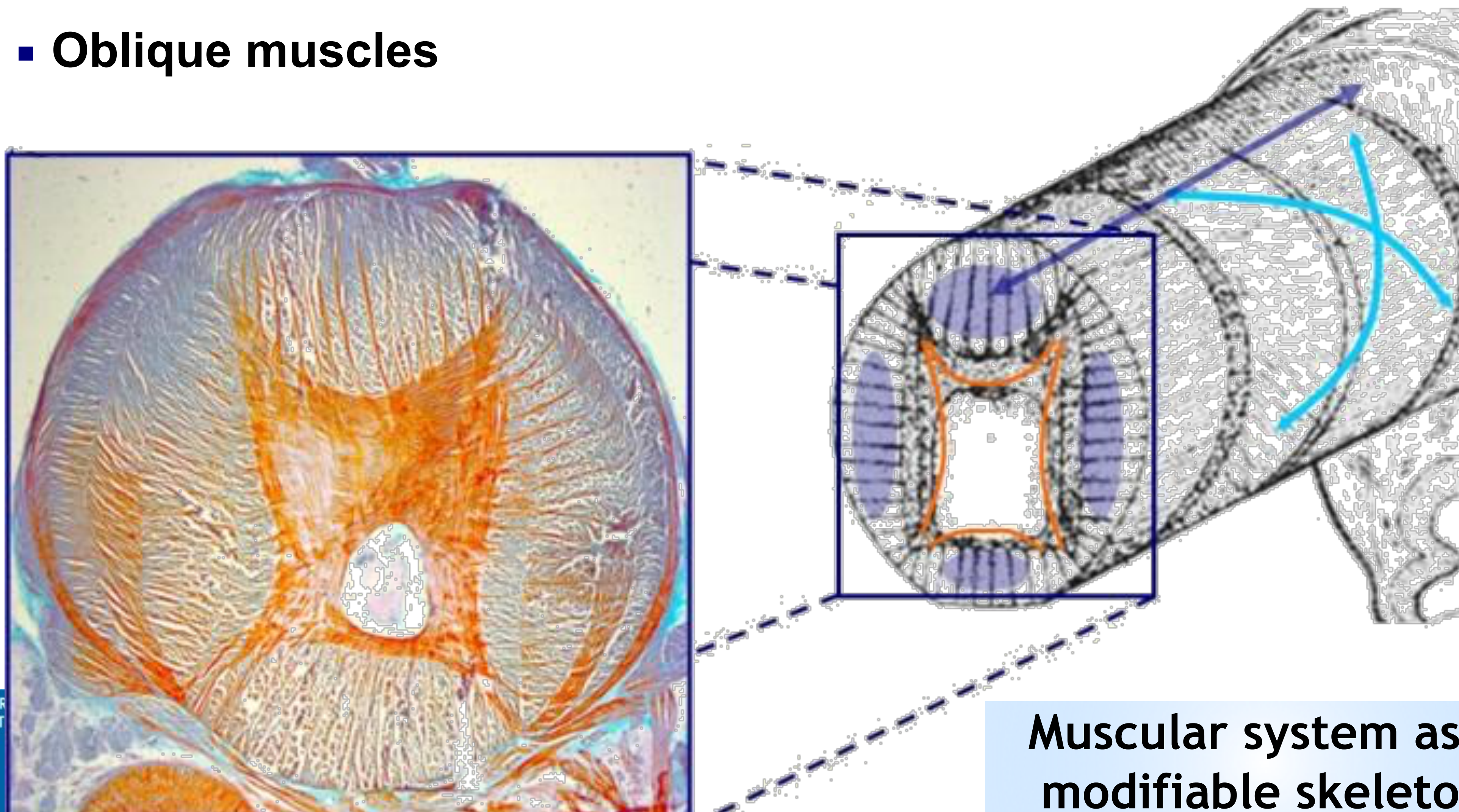
From biology to robotics

L. Margheri, C. Laschi, B. Mazzolai, "Soft robotic arm inspired by the octopus. I. From biological functions to artificial requirements", *Bioinspiration & Biomimetics*, Vol.7, No.2, June 2012.
B. Mazzolai, L. Margheri, M. Cianchetti, P. Dario, C. Laschi, "Soft robotic arm inspired by the octopus. II. From artificial requirements to innovative technological solutions", *Bioinspiration & Biomimetics*, Vol.7, No.2, June 2012.

The octopus muscular hydrostat

Constant volume during contractions

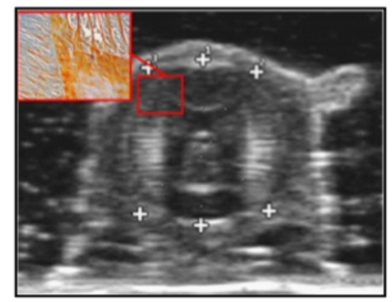
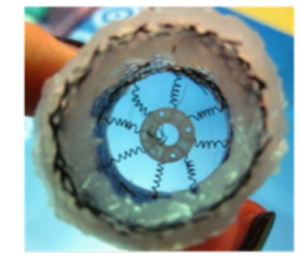
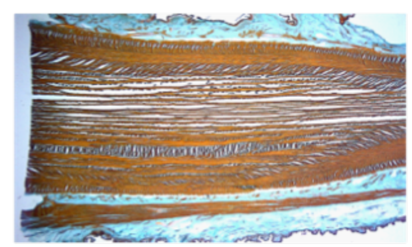
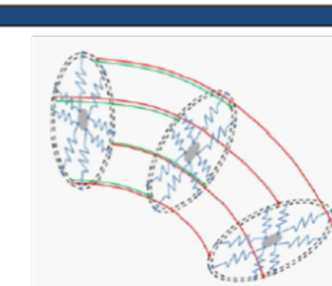
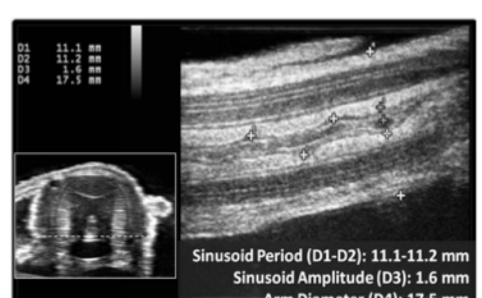
- **Longitudinal muscles**
- **Transverse muscles**
- **Oblique muscles**



Muscular system as a modifiable skeleton

From biology to robotics

L. Margheri, C. Laschi, B. Mazzolai, “Soft robotic arm inspired by the octopus. I. From biological functions to artificial requirements”, *Bioinspiration & Biomimetics*, Vol.7, No.2, June 2012.
B. Mazzolai, L. Margheri, M. Cianchetti, P. Dario, C. Laschi, “Soft robotic arm inspired by the octopus. II. From artificial requirements to innovative technological solutions”, *Bioinspiration & Biomimetics*, Vol.7, No. 2, June 2012.

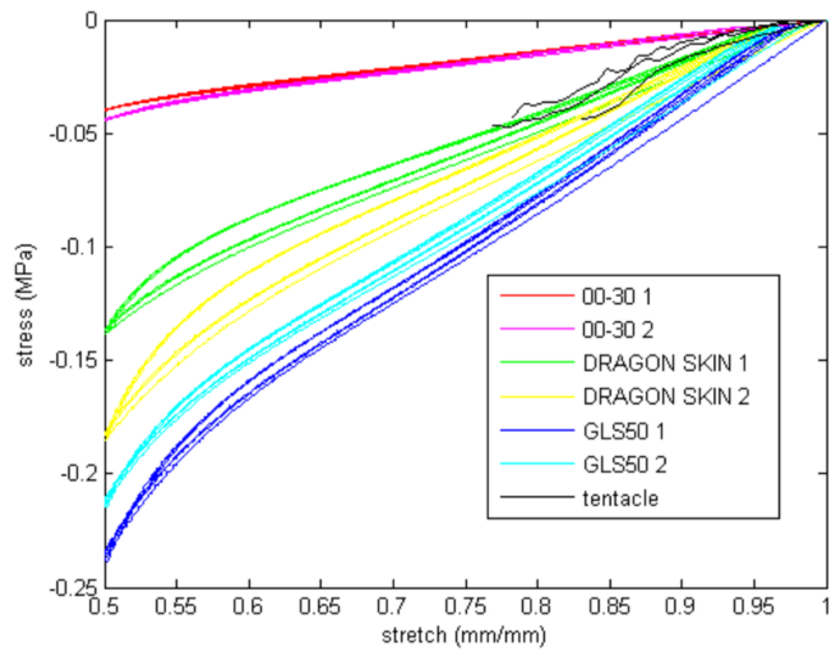
		Biological Specification (*Octopus vulgaris*)			Robotic Solution and Performance
Transverse Muscles	**Design Arrangement**				 **Patent pending**
	Mechanical performance	70% of arms mean elongation corresponding to 23% of diameter reduction			Input to model for the design of the SMA: · NiTi Alloy mechanical properties · Wire diameter · Average spring diameter · Number of coils · Heat treatments
Longitudinal Muscles	**Design Arrangement**				
	Mechanical performance	**Max Pulling Force**	**Mean Pulling Force**	**Time**	· Longitudinal cables · sheaths to reduce friction and avoid silicon damages · Calibration parameters (*t, F*)
		49.8N @ 400mm (m=1600g) 26.8 @ 200mm (m=476g)	40 N with arm length 400mm (~100g)	1-2 sec.	
Grasp Point Position		0.75 of total arm length			End effector position and active arm length
Nerve Cord Arrangement	**Design Arrangement**		Sinusoidal arrangement at the arm rest length while has a distension during the elongation		Wire sinusoidal arrangement 

Soft Robotics is at the merge of many disciplines and technologies

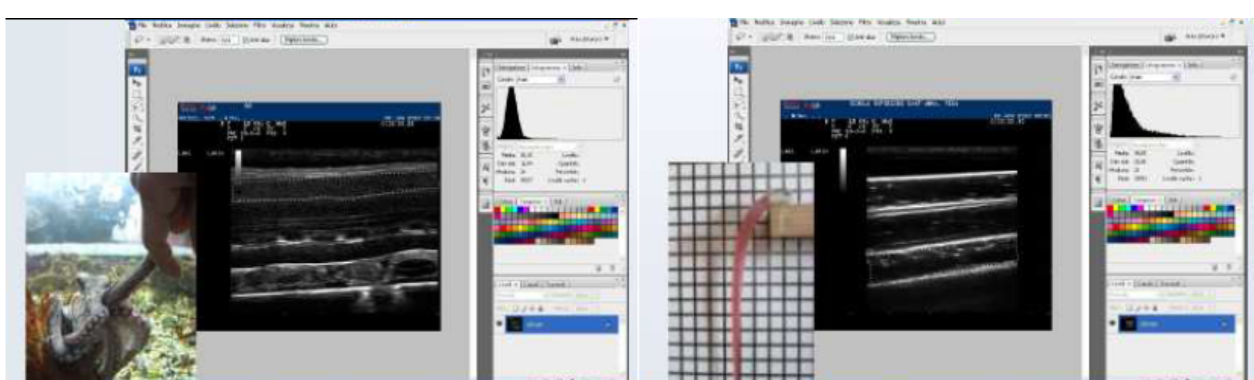
Materials

Mechanical properties

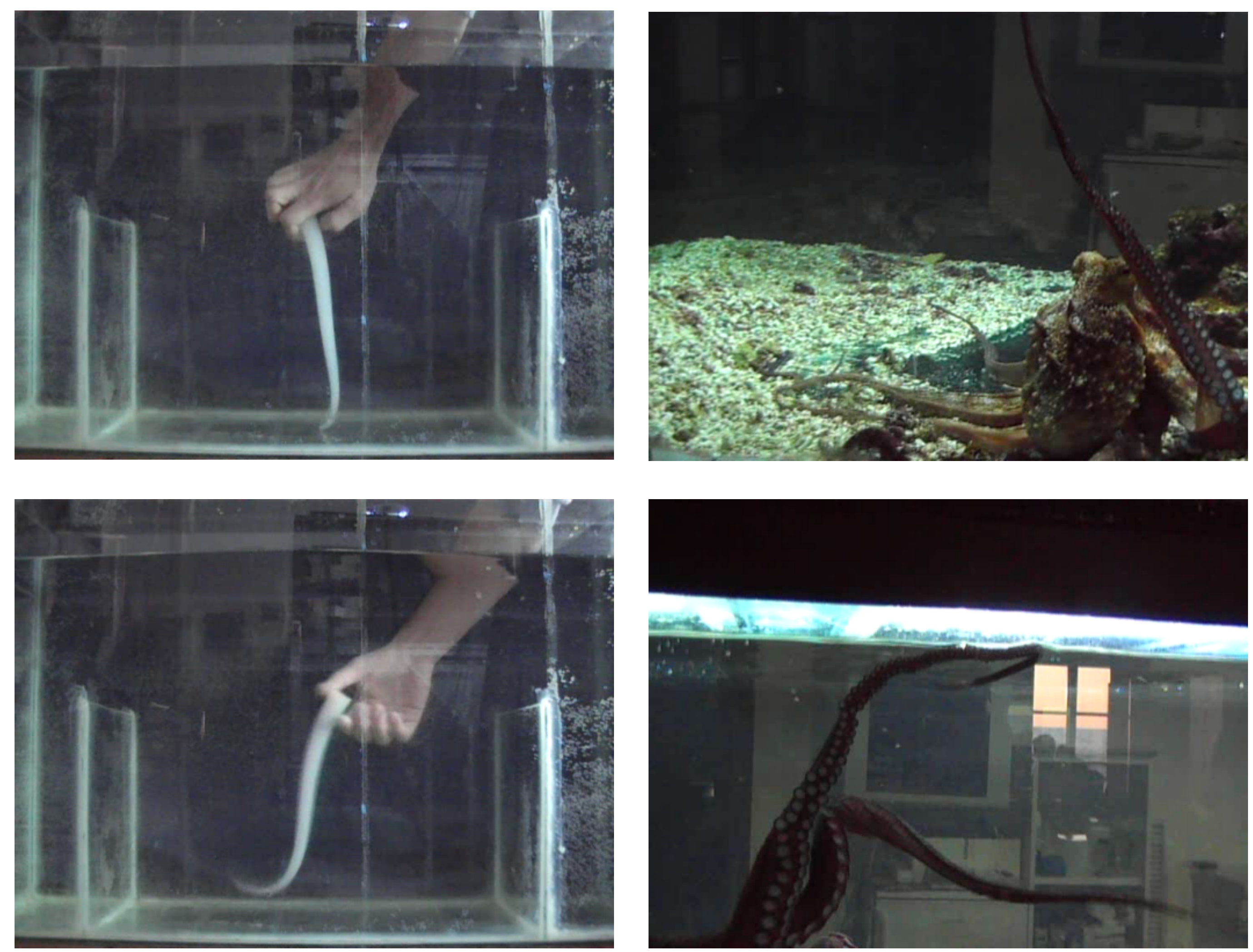
Stiffness



Density (US investigation)



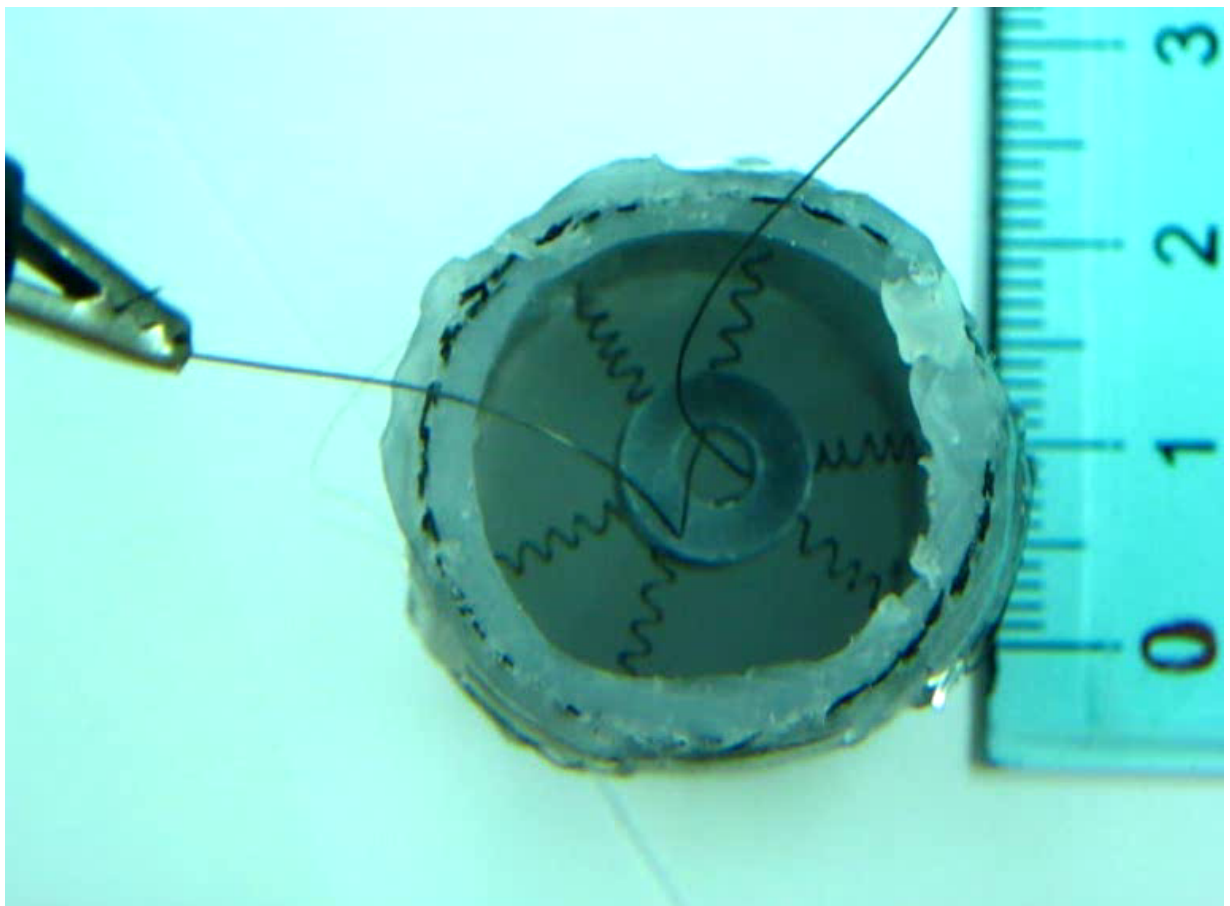
Passive interaction with water



B. Mazzolai, C. Laschi, M. Cianchetti, F. Patanè, L. Bassi-Luciani, I. Izzo, P. Dario, “Biorobotic Investigation on the Muscle Structure of an Octopus Tentacle”, *IEEE Annual International Conference of the Engineering in Medicine and Biology Society (EMBC 2007)*, Lyon, France, August 23-26, 2007, pp.1471-1474.

Soft Robotics is at the merge of many disciplines and technologies:
soft actuators

1 second of 600 mA direct current and then 50% duty cycle pulse current



6 SMA springs:

- 0.2 mm Flexinol® wire diameter
- <D>/d = 6 (cycle life parameter)
- Spring internal diameter = 1 mm

Silicone / braided sleeve:

- External diameter = 28mm
- Internal diameter = 20mm

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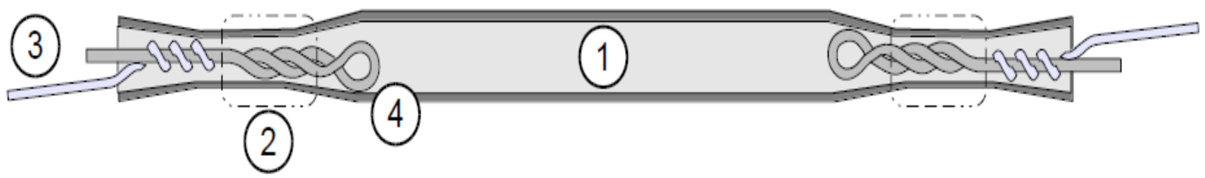
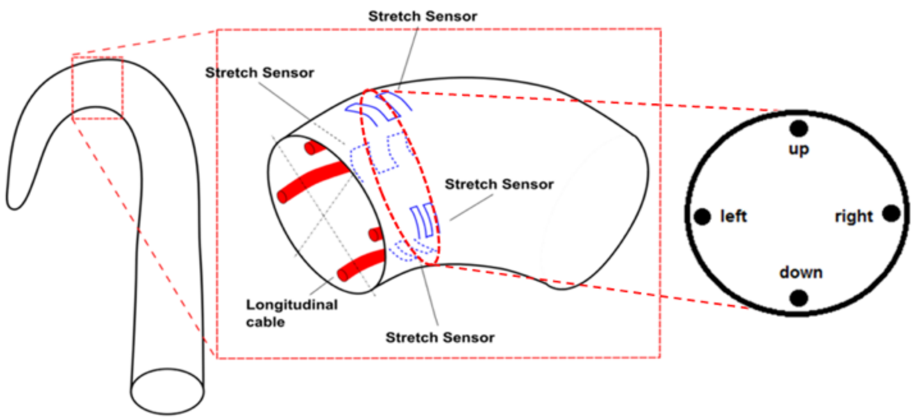
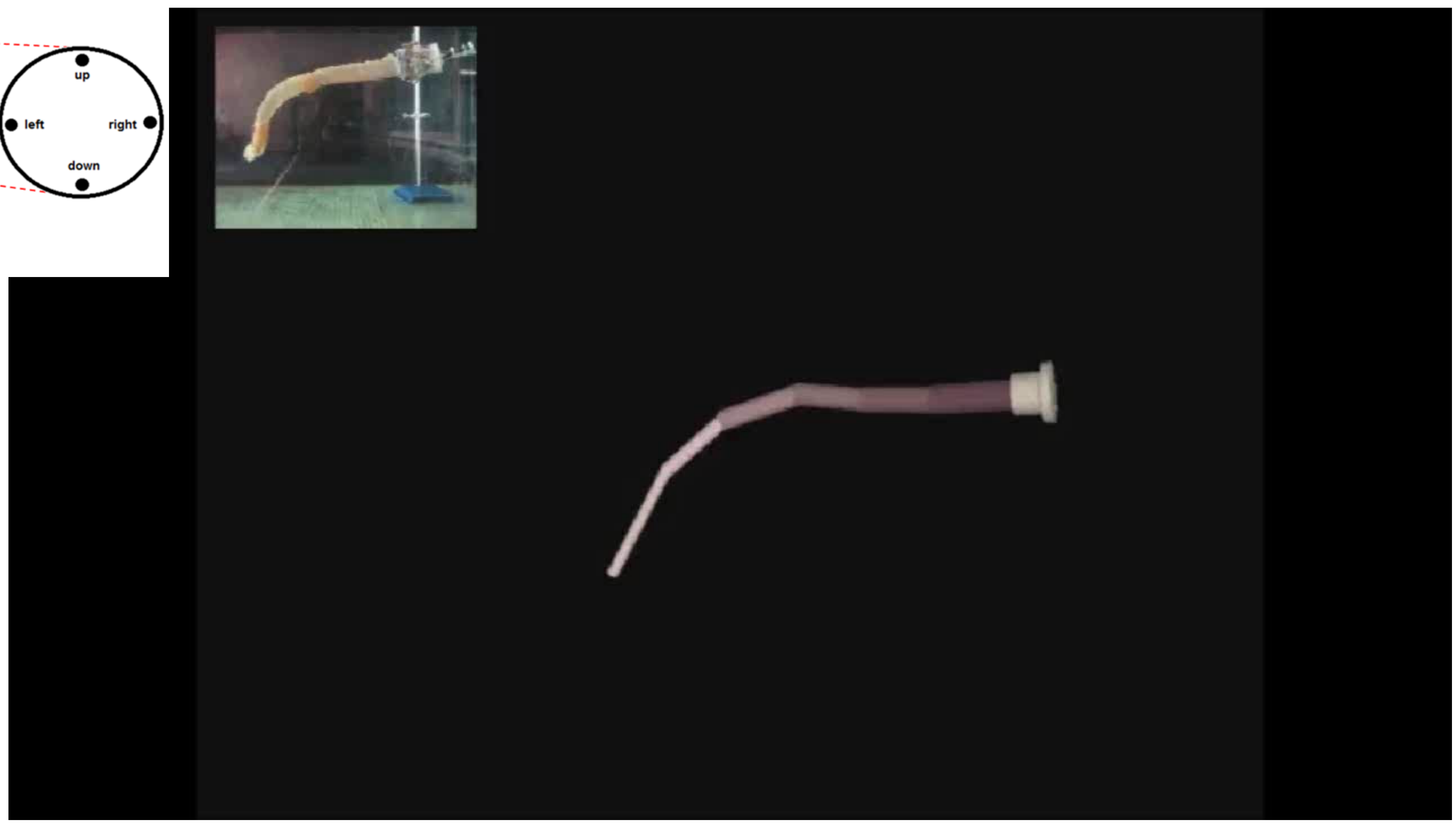
M. Cianchetti, A. Arienti, M. Follador, B. Mazzolai, P. Dario, C. Laschi, "Design concept and validation of a robotic arm inspired by the octopus", *Materials Science and Engineering C*, Vol.31, 2011, pp.1230-1239.

Soft Robotics is at the merge of many disciplines and technologies: **soft sensors**

Electrolycra tubular body







Five groups of four sensors (quadruplets) placed along the arm

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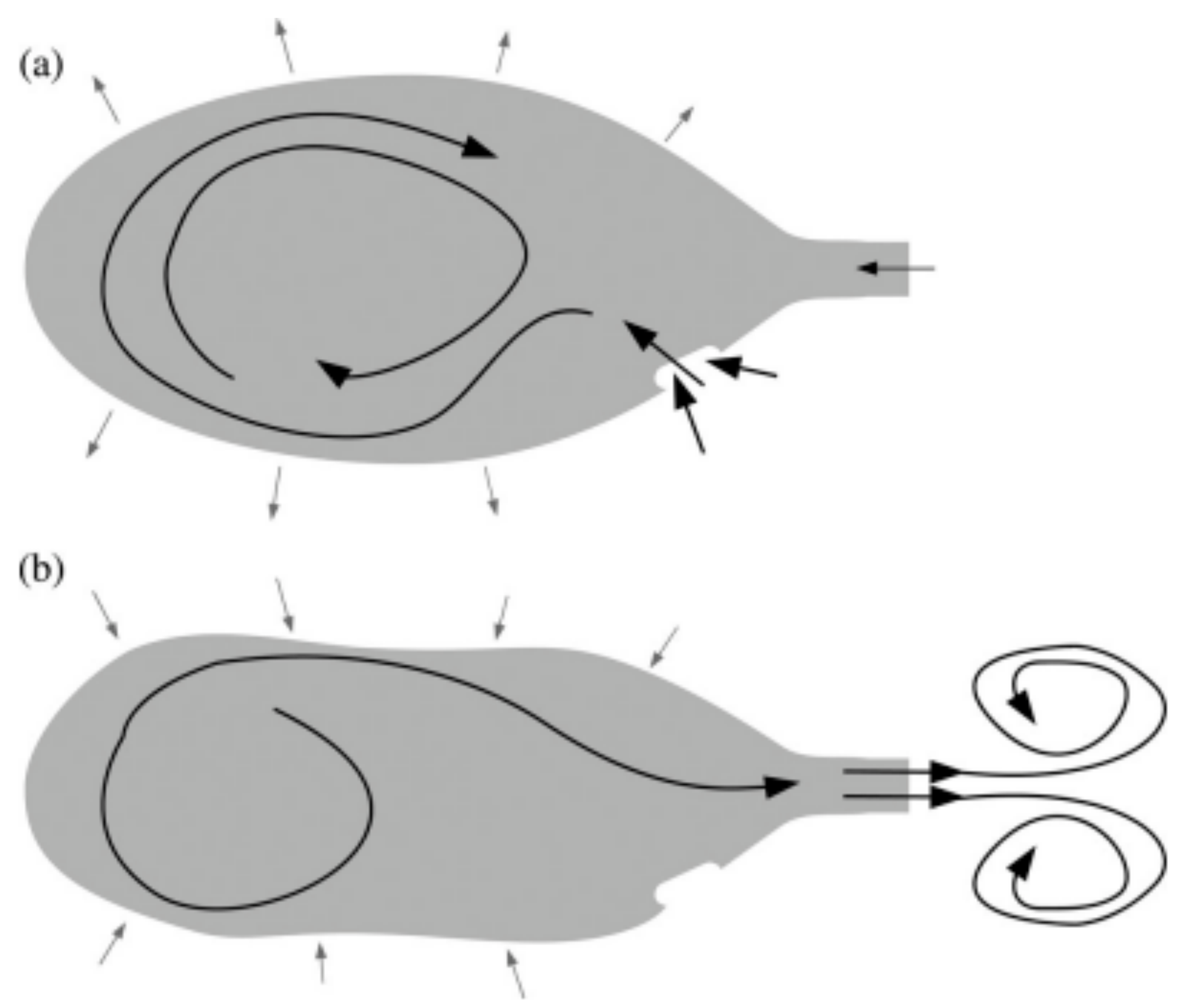
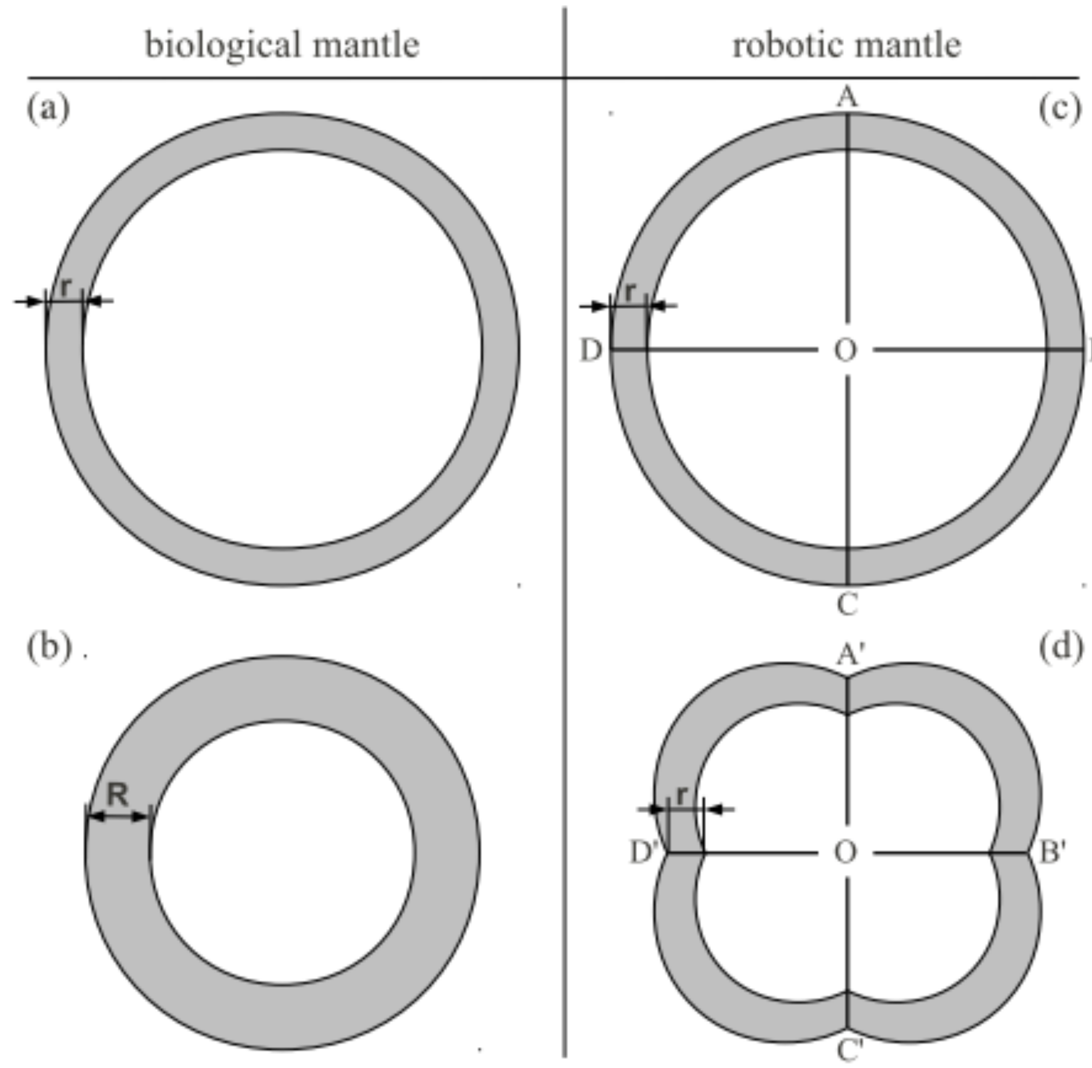
Soft Robotics is at the merge of many disciplines and technologies: **fluido-dynamics**

Pulsed-jet propulsion in cephalopods

How does a cephalopod swim?



How do we translate this into a soft robot?



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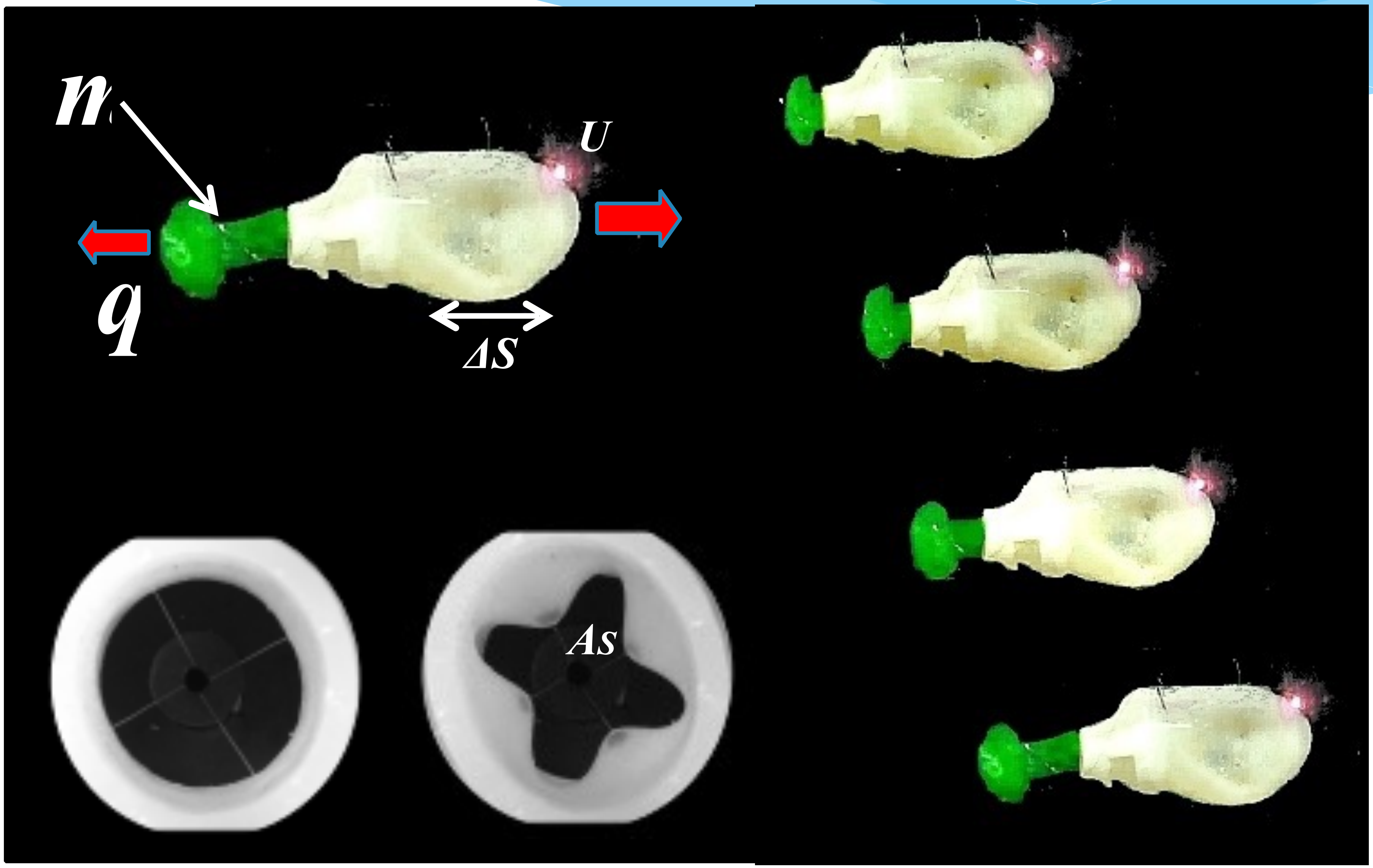
Giorgio Serchi F., Arienti A. and Laschi C. (2013) "Biomimetic Vortex Propulsion: Toward the New Paradigm of Soft Unmanned Underwater Vehicles", *IEEE/ASME Transactions on Mechatronics*, 18(**2**), pp. 484-493

Soft Robotics is at the merge of many disciplines and technologies: **fluido-dynamics**

Pulsed-jet propulsion in cephalopods



Giorgio Serchi F., Arienti A. and Laschi C. (2013) "Biomimetic Vortex Propulsion: Toward the New Paradigm of Soft Unmanned Underwater Vehicles", *IEEE/ASME Transactions on Mechatronics*, 18(**2**), pp. 484-493

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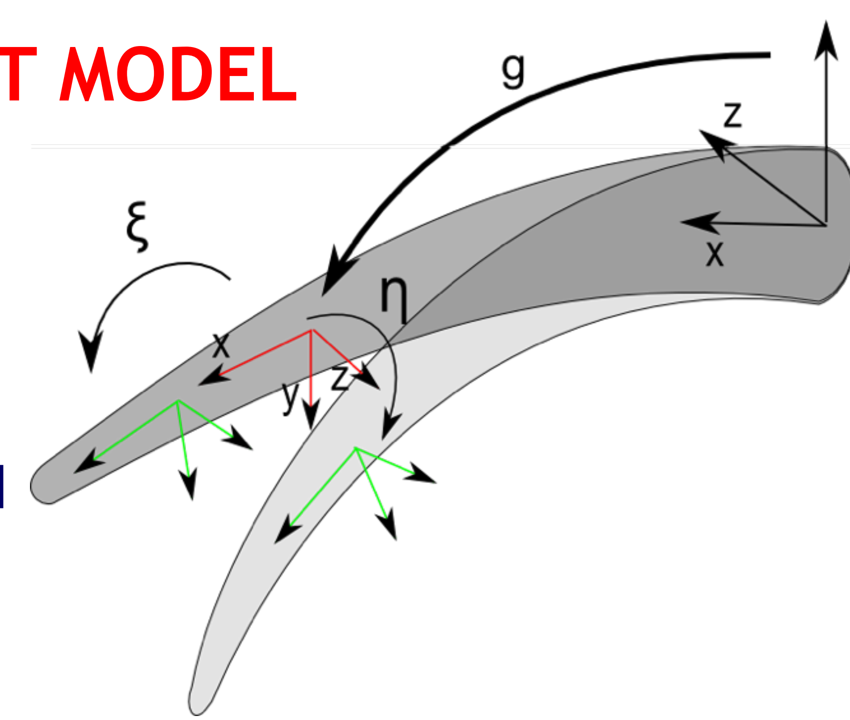
Soft Robotics is at the merge of many disciplines and technologies

Modelling and control

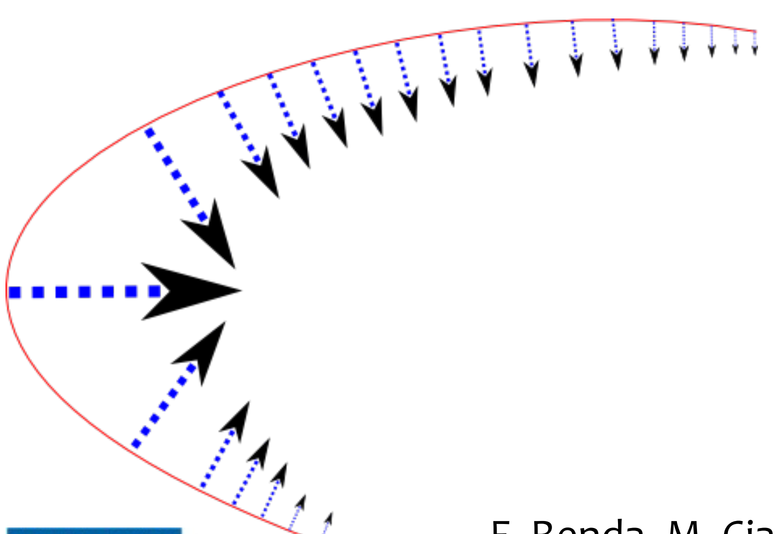
CABLES TENSION function of time → ROBOT CONFIGURATION parameterized by the curvilinear abscissa X and time t

FORWARD DYNAMICS with a:

COSSERAT GEOMETRICALLY EXACT MODEL

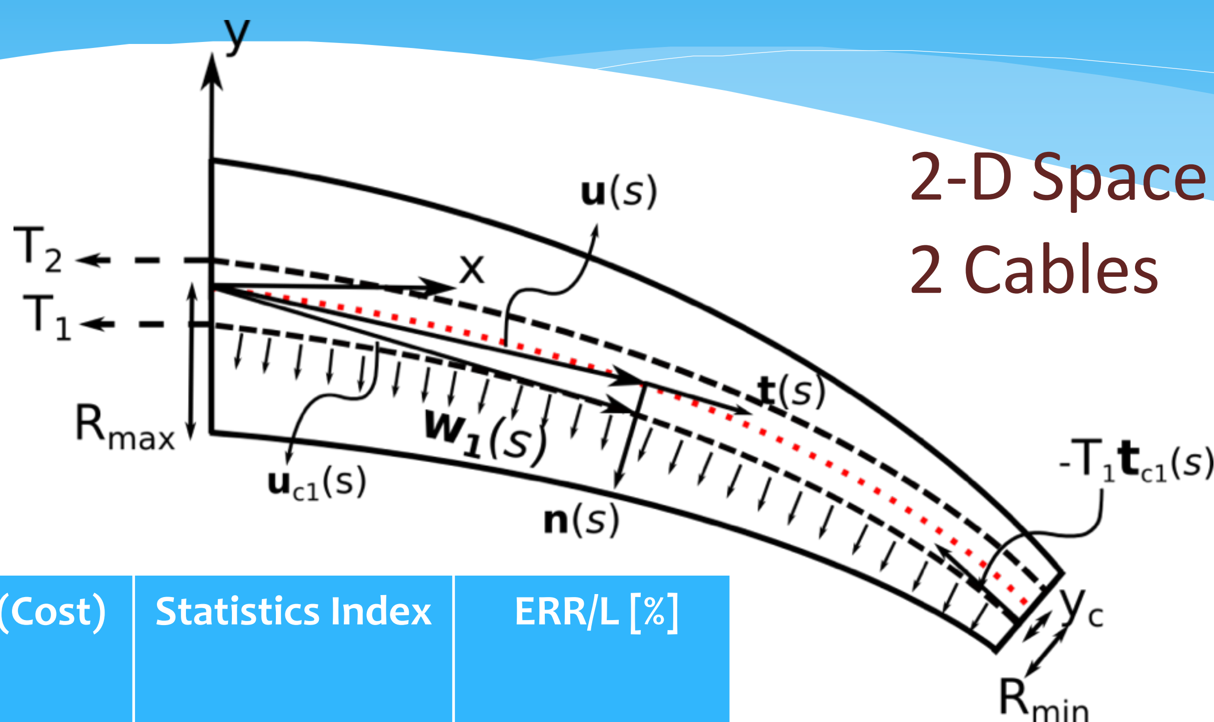


- The cables are embedded inside the body of the soft robot
- They exert a load proportional to the cable tension and to the curvature and it is directed toward the centre of the curvature



F. Renda, M. Cianchetti, M. Giorelli, A. Arienti, C. Laschi, "A 3D Steady State Model of a Tendon-Driven Continuum Soft Manipulator Inspired by Octopus Arm", *Bioinspiration & Biomimetics*, Vol.7, No.2, June 2012.
Renda F, Giorelli M, Calisti M, Cianchetti M, Laschi C, "Dynamic Model of a Multi-Bending Soft Robot Arm Driven by Cables", *IEEE Transactions on Robotics*, June 2014

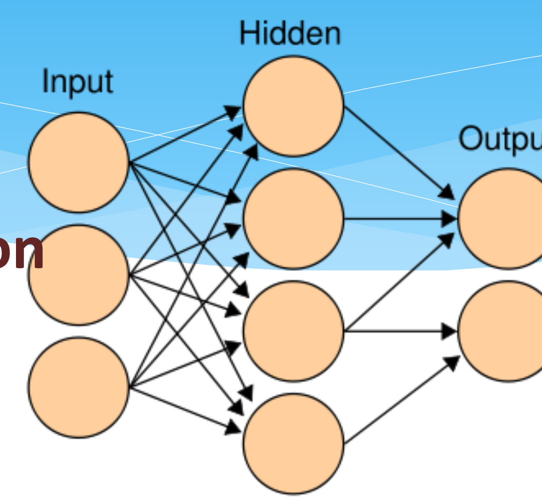
Inverse Kinematics: Jacobian Method (JM) or Neural Networks (NN)?



2-D Space

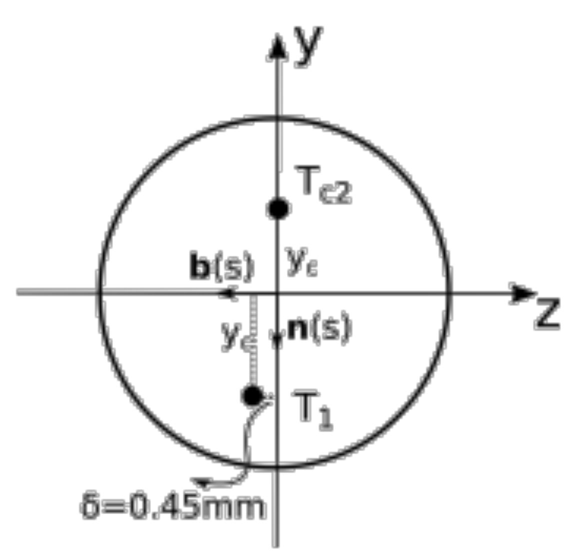
2 Cables

Tip Position



Cable Forces

Method (Cost)	Statistics Index	ERR/L [%]
JM (351ms)	*Mean*	*0.27*
	Std	*0.03*
	Max	*0.32*
NN (0.125ms)	*Mean*	*0.73*
	Std	*0.55*
	Max	*3.1*



Defective Model

Method (Cost)	Statistics Index	ERR/L [%]
JM (351ms)	*Mean*	*1.30*
	Std	*0.55*
	Max	*2.62*
NN (0.125ms)	*Mean*	*0.75*
	Std	*0.68*
	Max	*3.51*

M Giorelli, F Renda, G Ferri, C Laschi, “A Feed-Forward Neural ... tant Curvature Soft Manipulators Driven by Cables”, *ASME Dynamical Systems and Control Conference*, October 21-23, Stanford University, Palo Alto, CA, USA, 2013

Outline

* A working **definition** of Soft Robotics
* The **need** for soft robots: from robotics, from one side, and AI, from another side
* The **challenges** of Soft Robotics, at the merge of many disciplines and technologies
* The **innovation potential** of Soft Robotics: fields of application
* **Perspectives** of Soft Robotics: increasingly rich state of the art, promising research and technological developments, growing and active community, coordination activities

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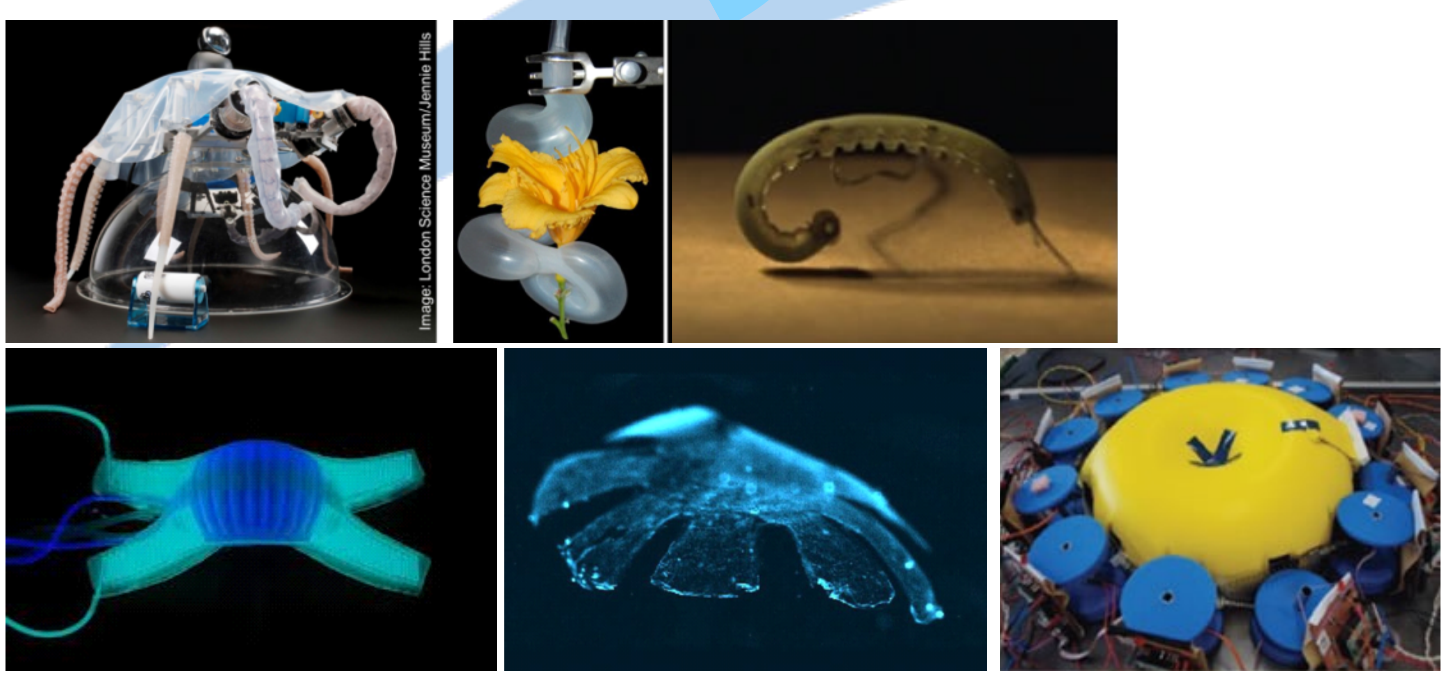
Soft Robotics applications

Biomedical applications: endoscopy, assistance to elderly and disabled people

The initial challenge: can we build robots with soft materials?



Application of OCTOPUS technologies in surgery

KING'S College LONDON

University of London

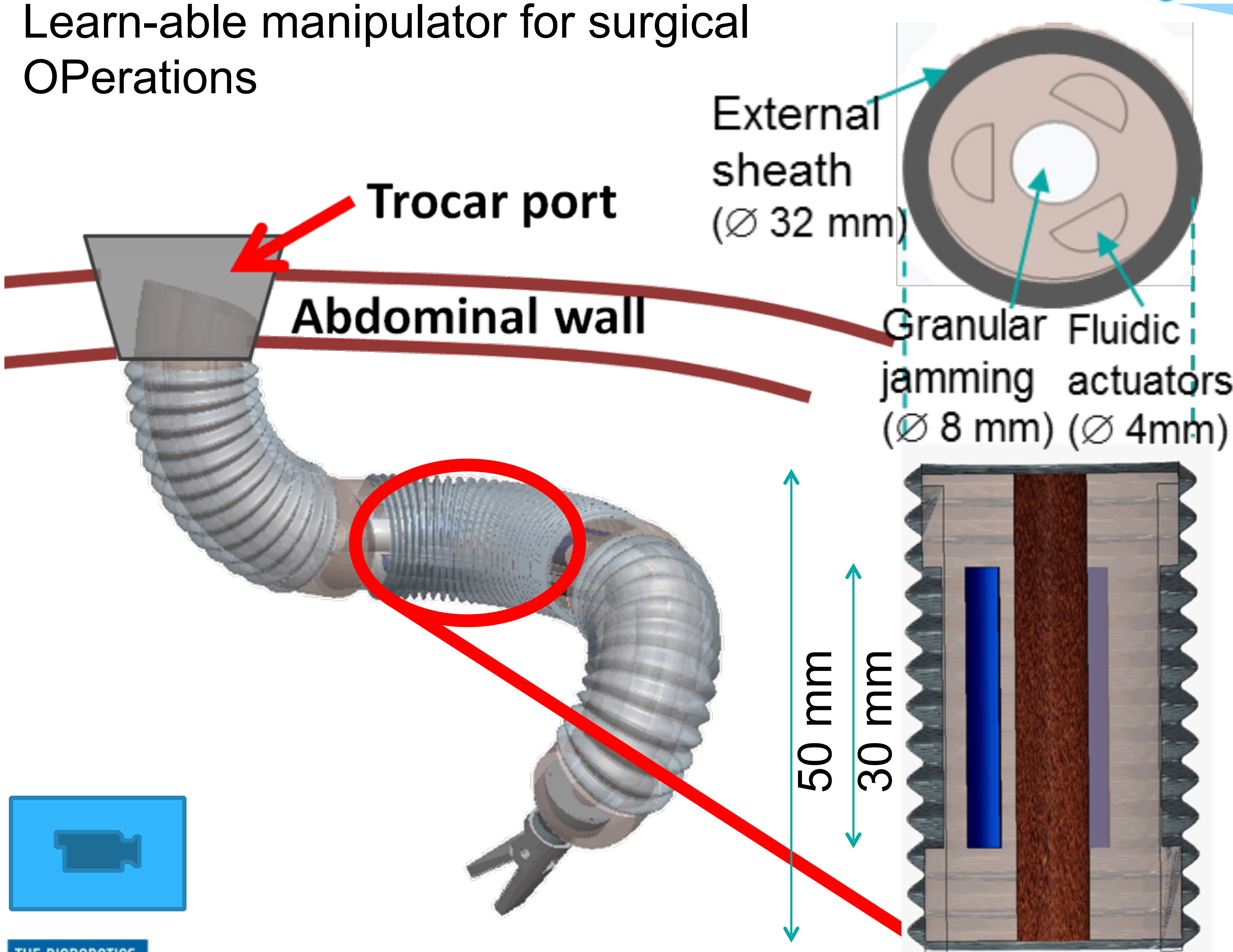
http://www.stiff-flop.eu/index.php/home

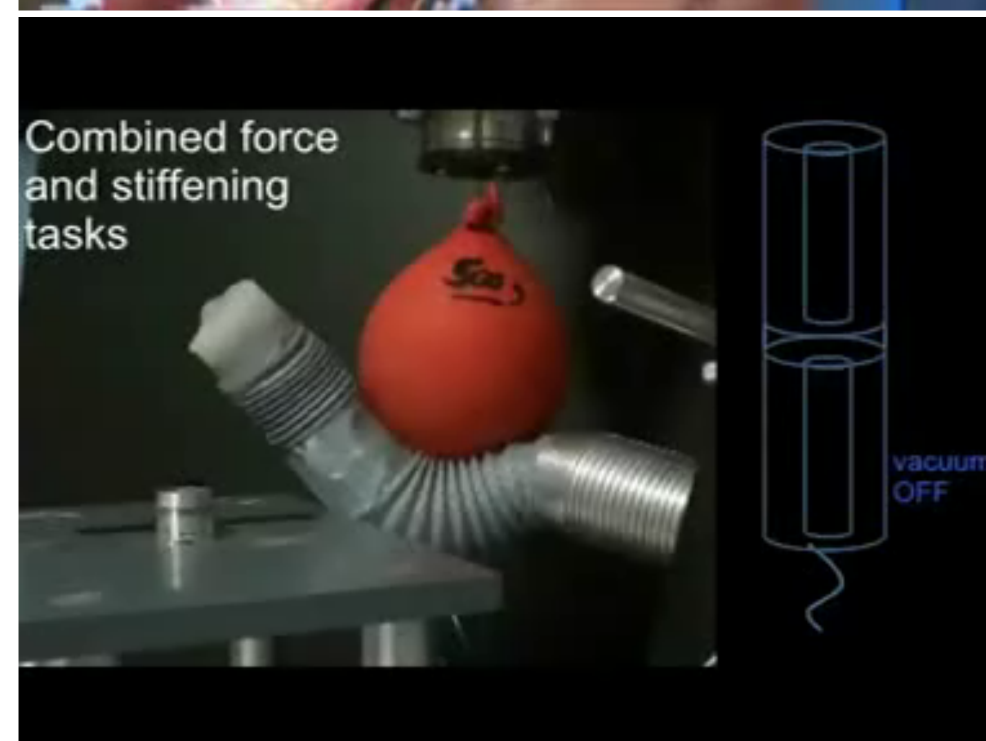
STIFF flop

The STIFF-FLOP robotic manipulator

WWW.STIFF-FLOP.EU

STIFFness controllable Flexible and Learn-able manipulator for surgical OPerations





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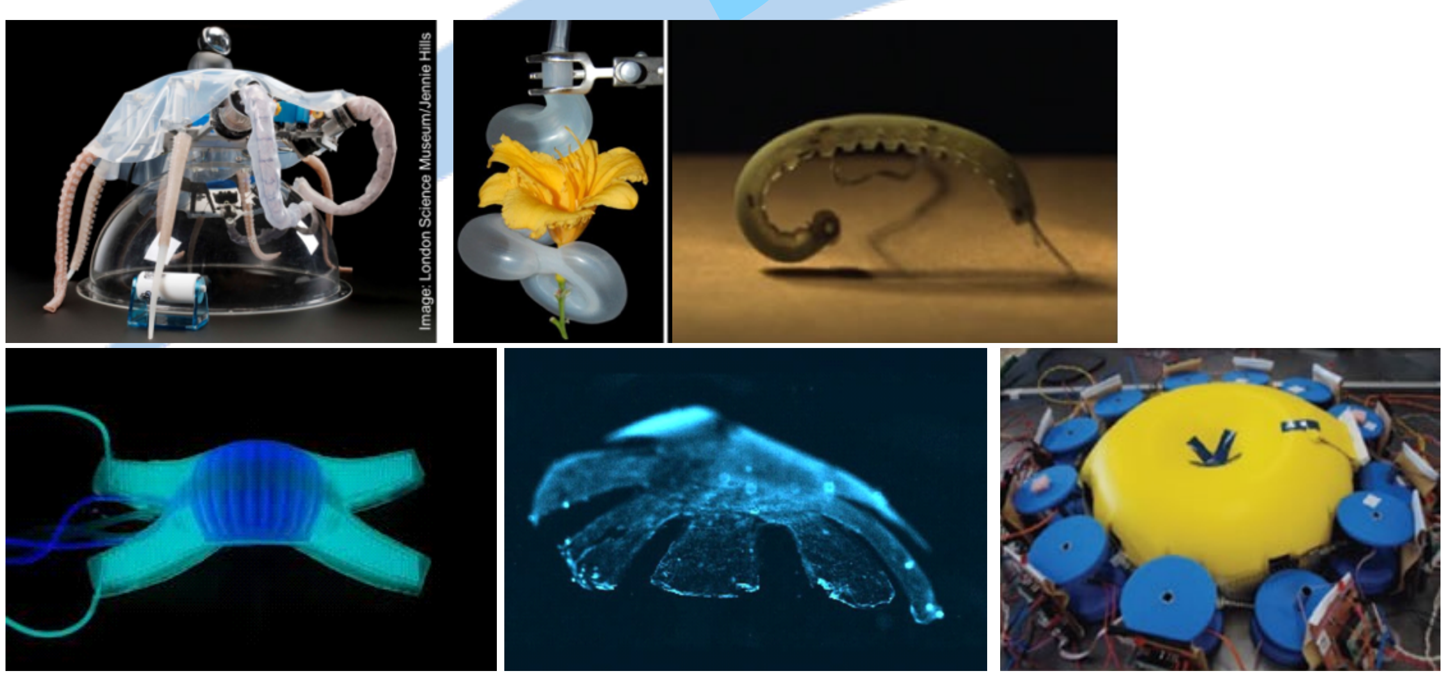
Cianchetti M, Ranzani T, Gerboni G, De Falco I, Laschi C, Menciassi A (2013) "STIFF-FLOP Surgical Manipulator: mechanical design and experimental characterization of the single module", *IEEE on Intelligent and Robotic Systems – IROS 2013*, 3567-3581

Soft Robotics applications

Biomedical applications: endoscopy, assistance to elderly and disabled people

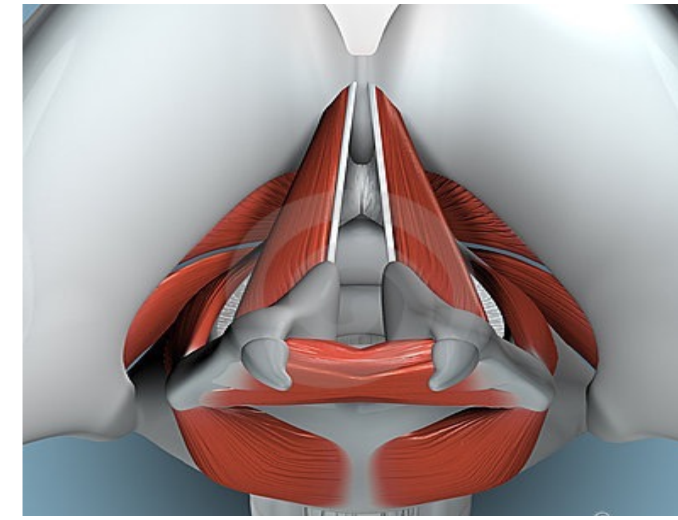
Realistic simulators of body parts

The initial challenge: can we build robots with soft materials?



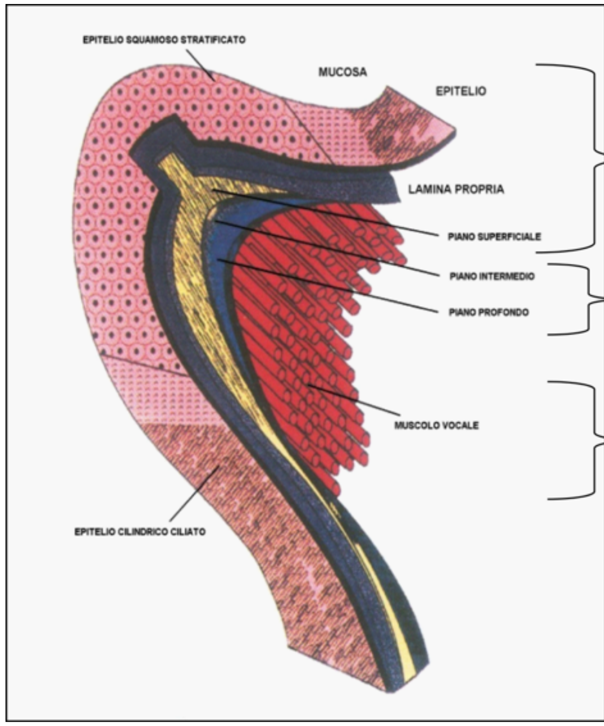
Realistic larynx simulator

Artificial biomimetic device mimicking the principal functions of a larynx by replicating its **main structures and material properties**.



In collaboration with University of Pisa, Cisanello Hospital, Prof. Ursino

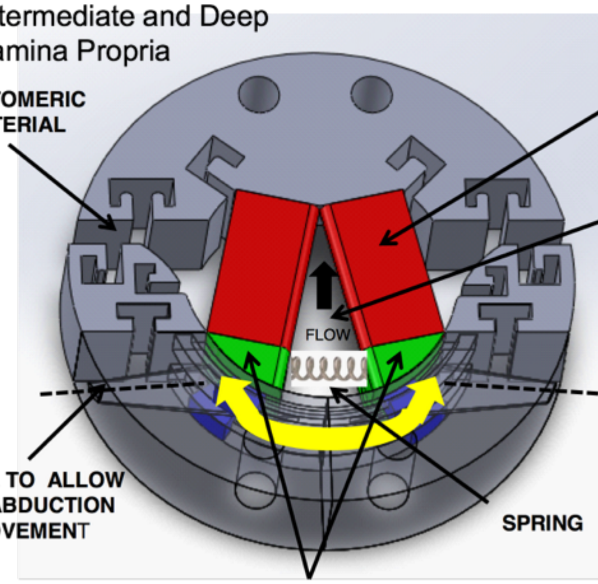
Vocal cord

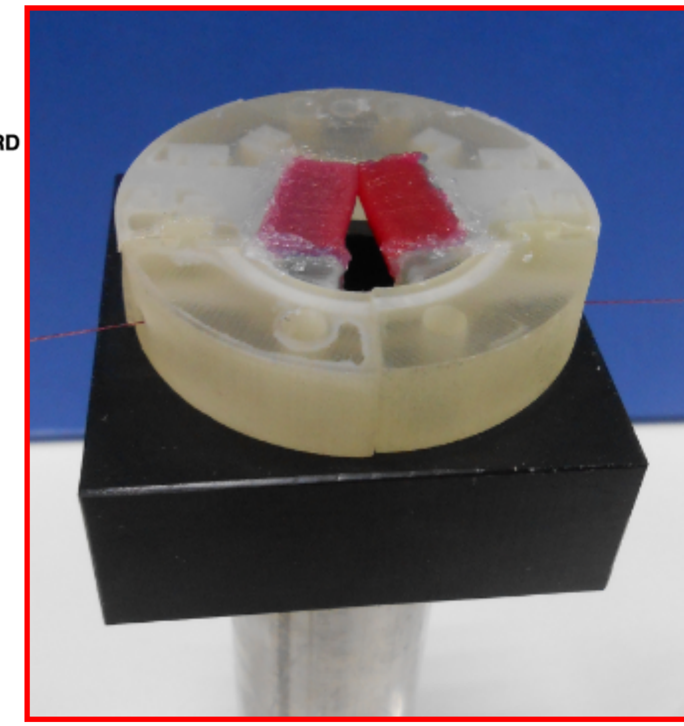


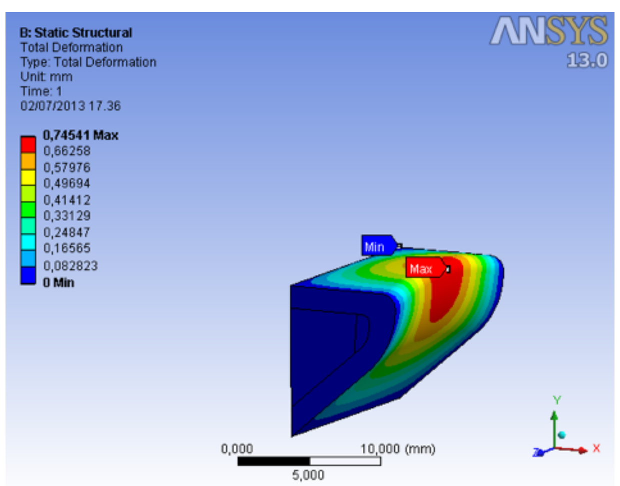
COVER: Epithelium and Superficial Lamina Propria

VOCAL LIGAMENT: Intermediate and Deep Lamina Propria

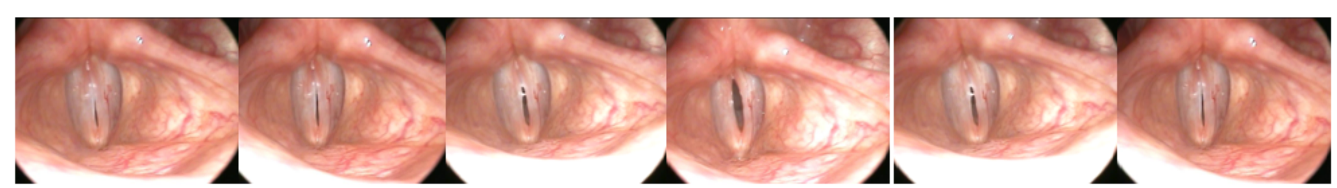
BODY: Vocal Muscle



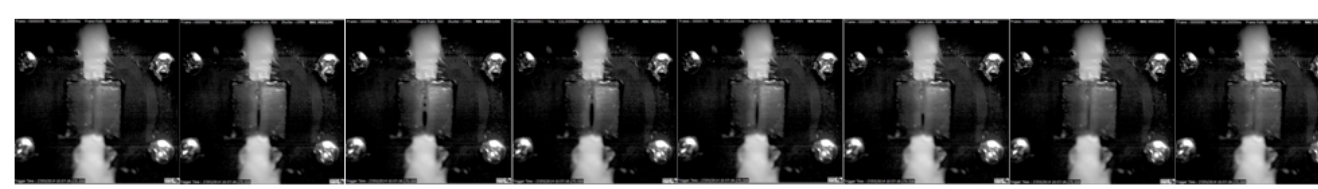




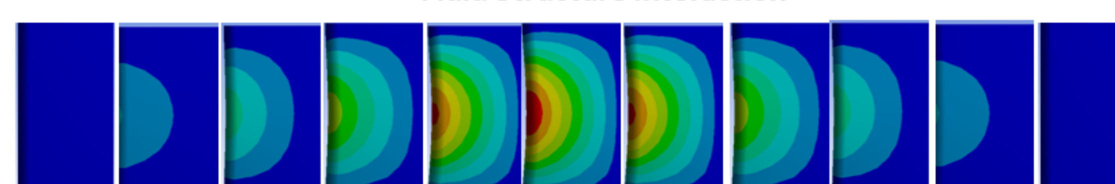
Biological model : Laringostroboscopy

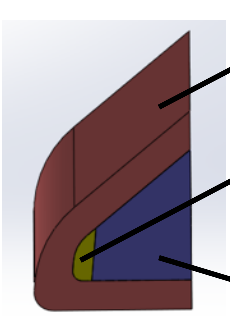


Full Larynx Configuration: High Speed Camera



Fluid Structure Interaction

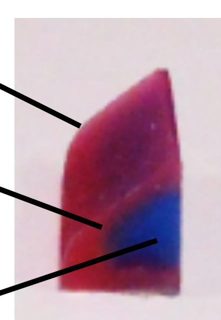




cover

vocal ligament

body



CAD

artificial

Anisotropic materials

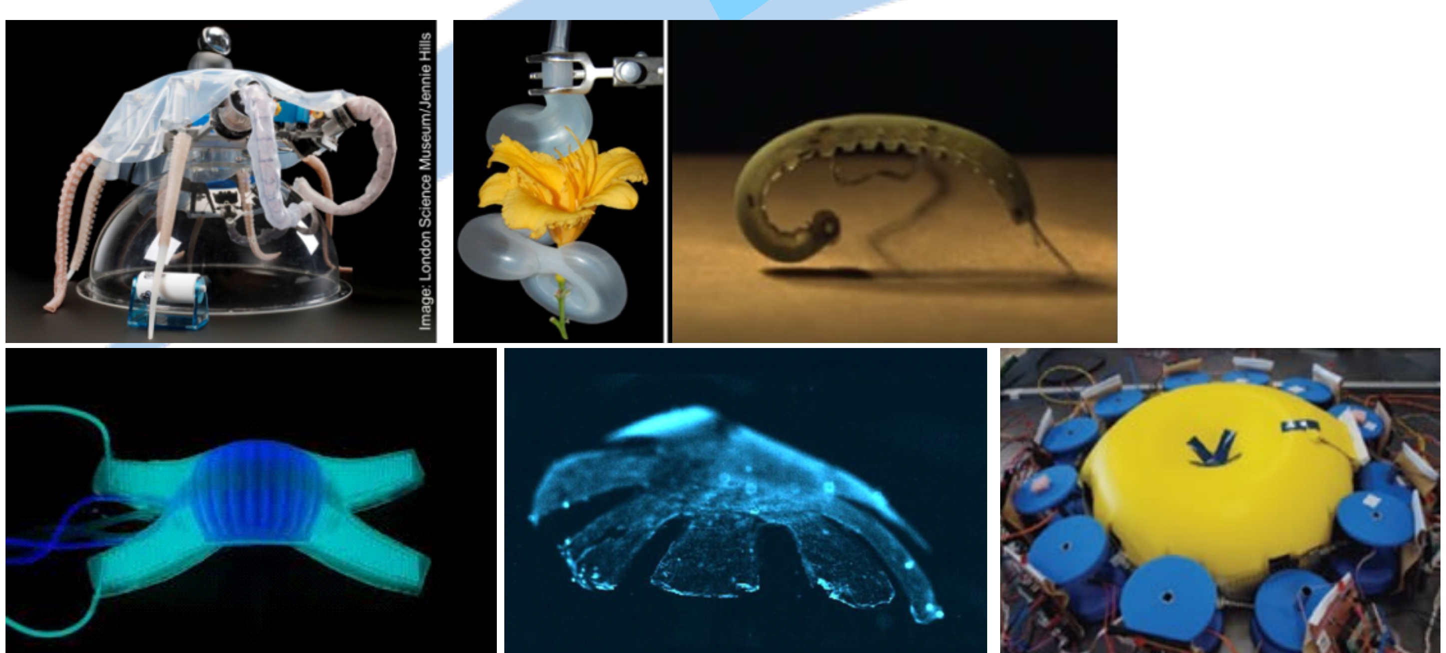
Soft Robotics applications

Biomedical applications: endoscopy, assistance to elderly and disabled people

Realistic simulators of body parts

Industrial project on soft actuators

The initial challenge: can we build robots with soft materials?

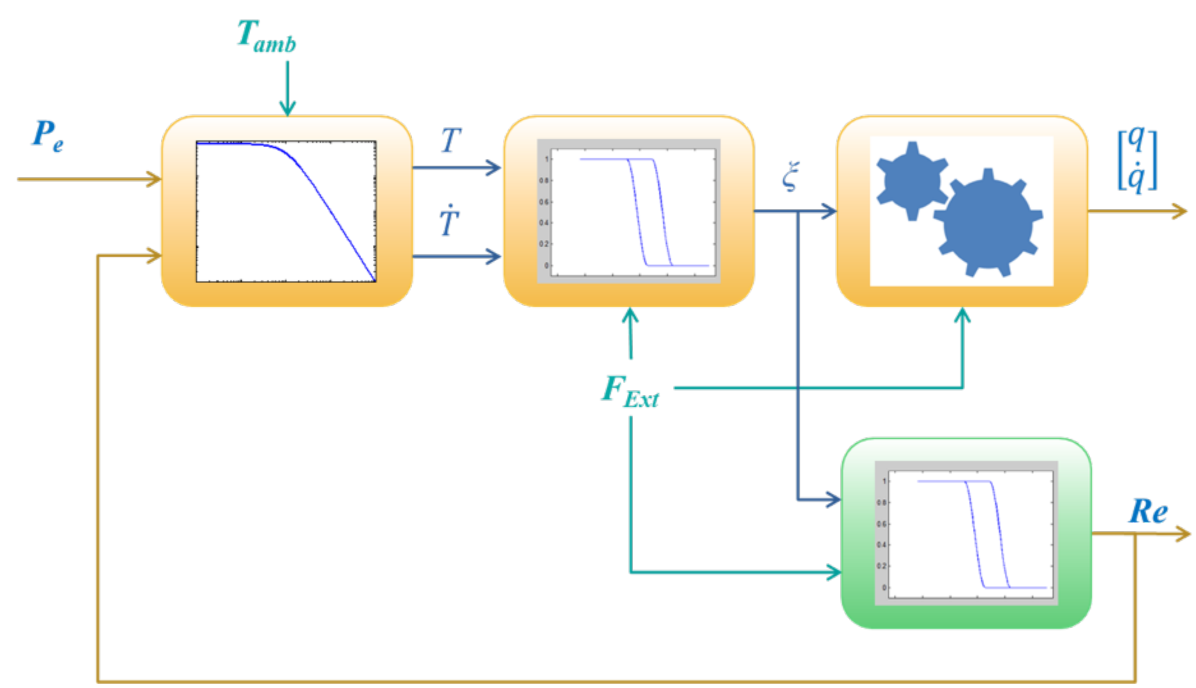


Industrial project on soft actuators

Leader in consumer electronics

Leader in SMA providing
and manufacturing

The use of Shape Memory Alloys for actuation represents a technological opportunity for replacing the today's electro-mechanical actuators with simpler, more compact and reliable ones.



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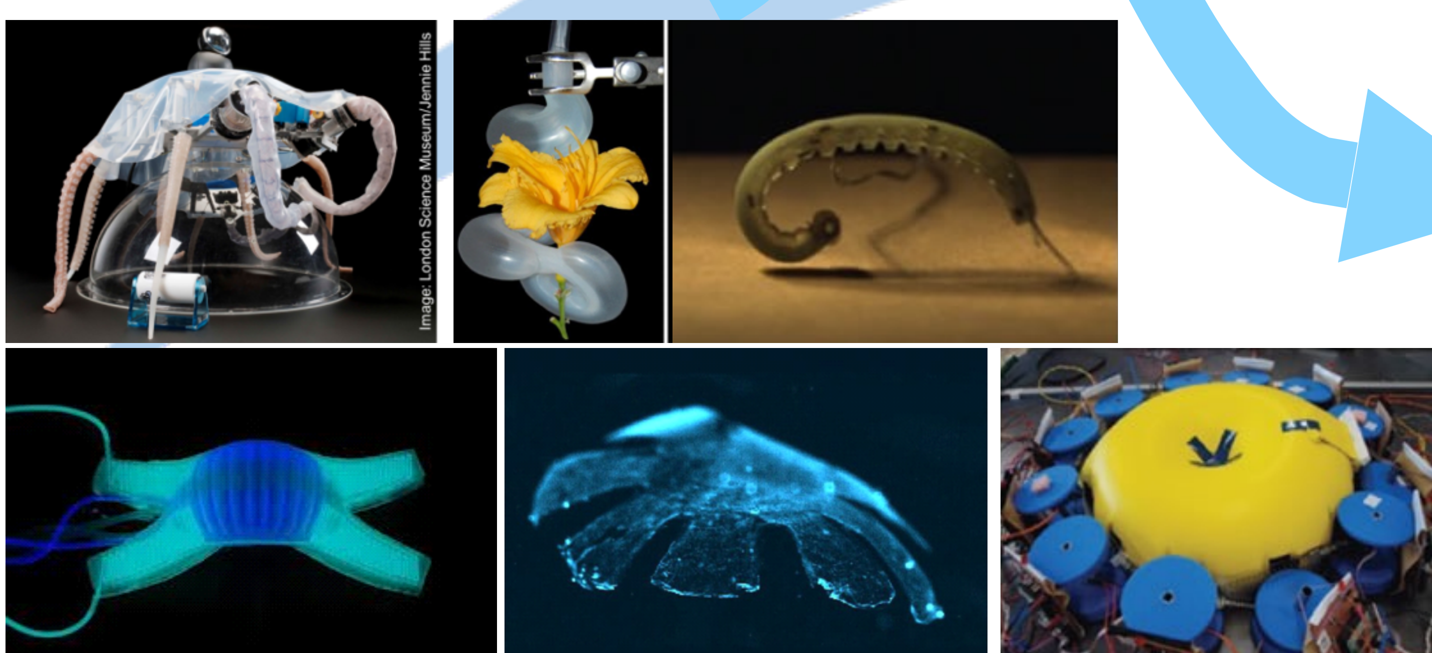
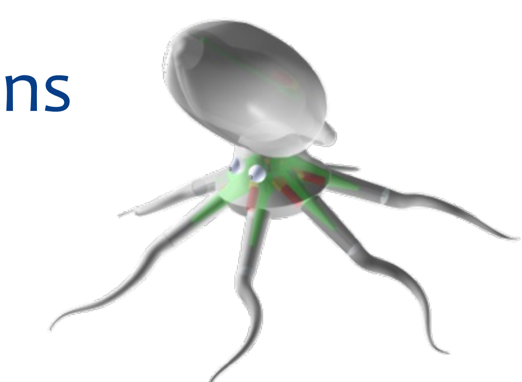
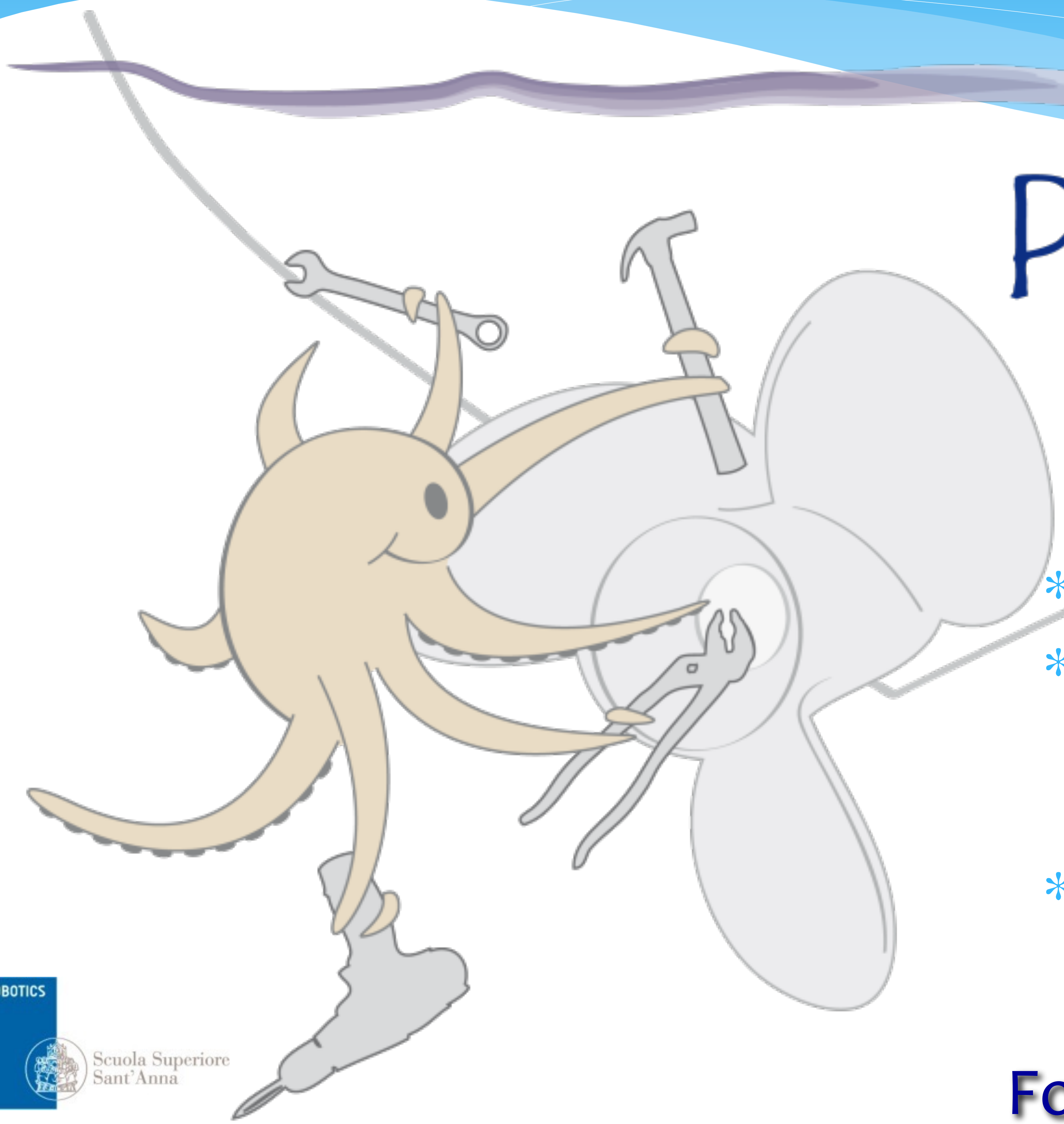


Marine applications



Soft Robotics for marine applications



PoseiDrone

* Marine ‘soft’ robot
* Can operate in contact with the sea bottom or the manufacts to explore
* Locomotion and grasping capabilities

Fondazione Livorno, 2012 – 2015

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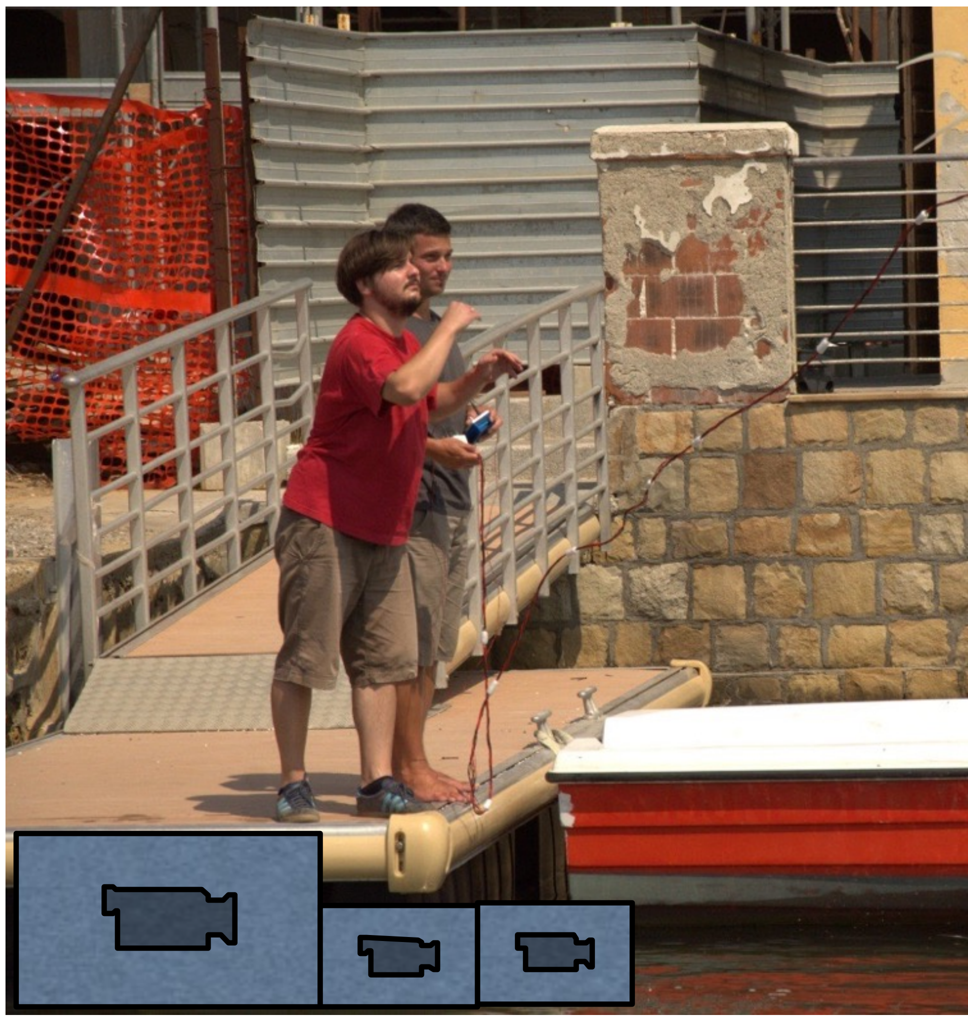
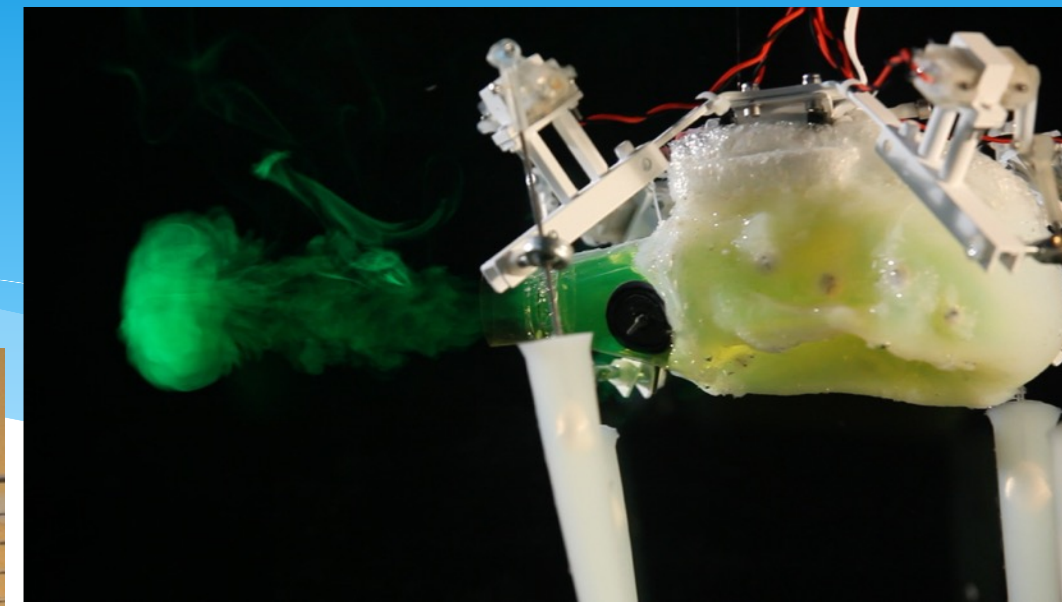
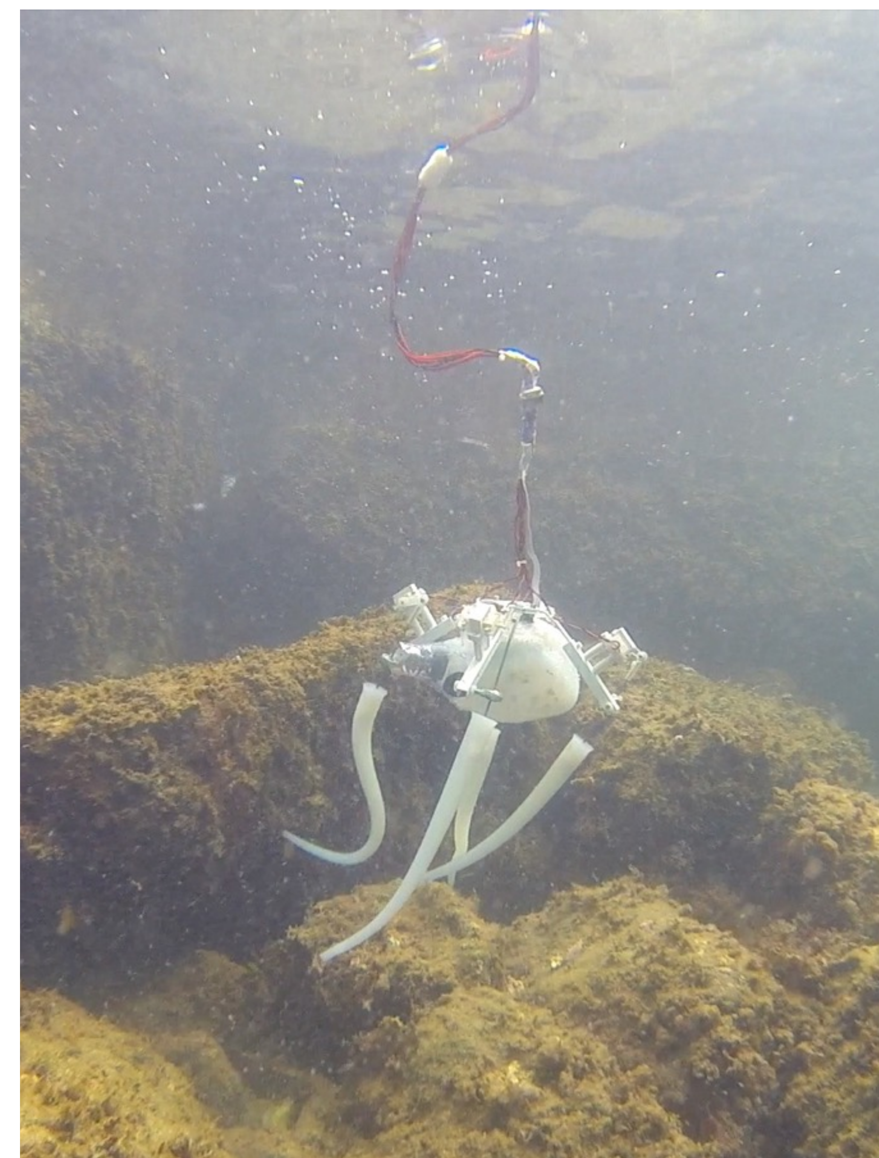
First PoseiDRONE prototype







F. Giorgio Serchi, et al, 2013 OCEANS

M. Giorelli et al, 2013 OCEANS

A. Arienti et al, 2013 OCEANS

M. Calisti et al, 2013 SoftRob

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Soft Robotics applications

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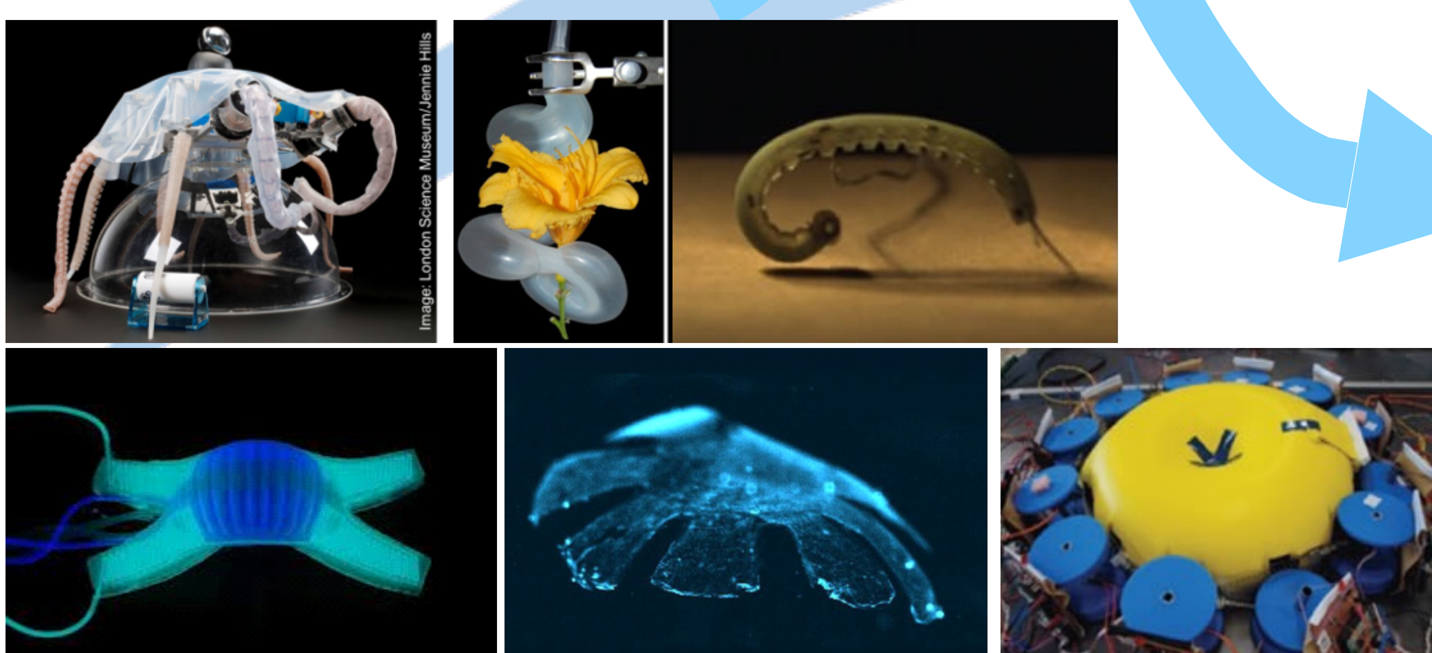
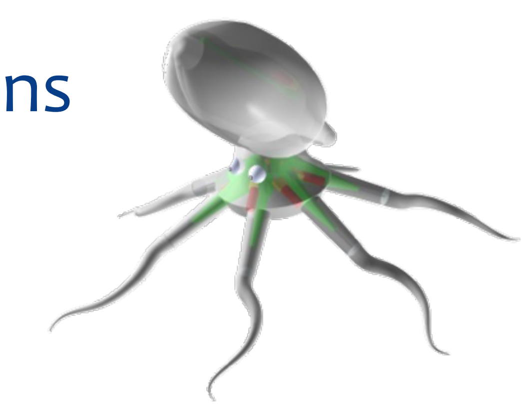
Manufacturing, Agriculture

Marine applications





SMART-E ITN (Marie Curie)

Topic1: Dexterous, Soft and Compliant Robotics in Manufacturing

This topic area will address issues in development of end-effectors focusing on novel mechanical design that promotes **a new softer, more compliant philosophy**.
This will require research in mechanism design, actuation, control, sensing and cognition and this will form key research targets.
New research sub-programmes will investigate **specific issues on soft robotics and morphological computation** based control for manufacturing.

The SMART-E training network will prepare the next generation of leading Advanced Roboticists to ensure a Sustainable Manufacturing sector in Europe.

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USAL (UK)
UNIVERSITY OF SALFORD
Samia Nefti-Meziani

SSSA (IT)
SCUOLA SUPERIORE SANT'ANNA
Cecilia Laschi

The University Of Sheffield.

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UNIVERSITY OF SHEFFIELD
Keith Ridgway

TECHNISCHE UNIVERSITÄT MÜNCHEN

TUM (DE)
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Darwin Caldwell

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AIRBUS OPERATIONS LIMITED
Mark Summers

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Soft Robotics applications

Biomedical applications: endoscopy, assistance to elderly and disabled people

Realistic simulators of body parts

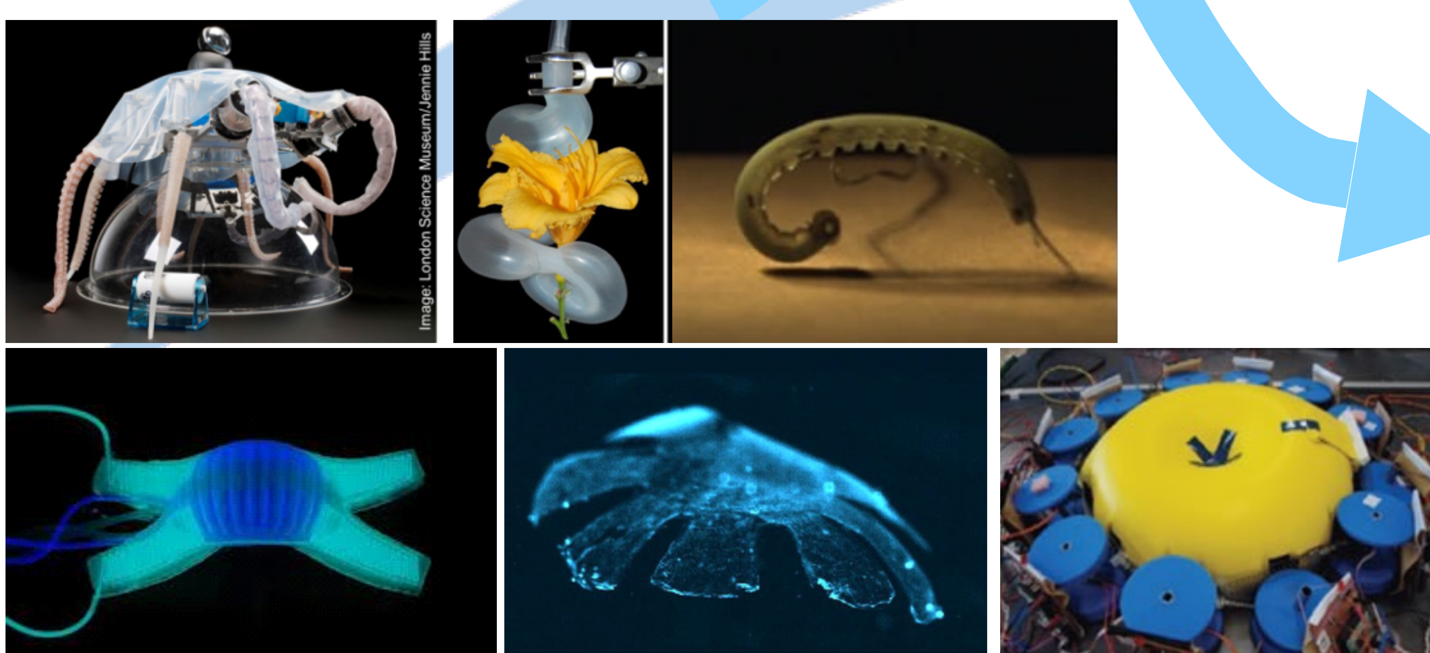
More to come!

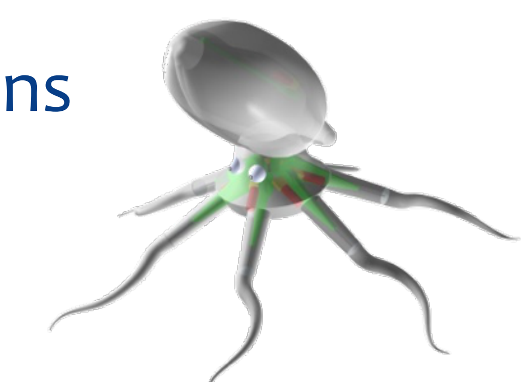
Industrial project on soft actuators

The initial challenge: can we build robots with soft materials?

Manufacturing, Agriculture

Marine applications





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Soft Robotics worldwide

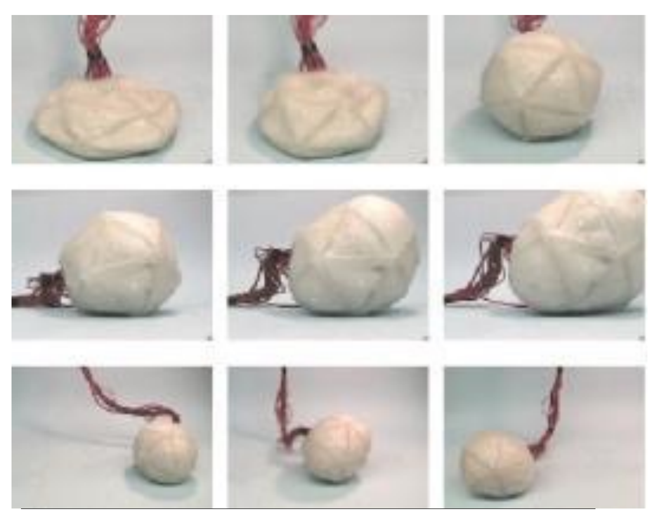
Locomotion

Umedachi et al., *IROS*, **2013**

Seok et al., *ICRA*, **2010**

Majidi et al., *Int. J. Robotics Research*, **2013,**

Lin et al., *Bioinsp. & Biomim.*, **2011**



Steltz et al., *IROS*, **2009**

Marchese et al.,
Soft Robotics, **2014**

Soft Robotics worldwide

Manipulation

Deimel et al., ICRA, **2013**

Suzumori, J. Robotics & Mechatronics, **1993**

Shepherd et al., PNAS, **2011**

Brown et al., *PNAS*, **2010**

Martinez et al., Advanced Materials, **2013**

Cheng et al., *ICRA*, **2012**

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Cecilia&friends (non exhaustive list)

Research Centre on Marine Robotics, Livorno, Italy

Soft Robotics Team:

- Paolo Dario
- Matteo Cianchetti
- Laura Margheri
- Marcello Calisti
- Francesco Giorgio-Serchi
- Maurizio Follador
- Michele Giorelli
- Federico Renda
- Andrea Arienti
- Alessia Licofonte
- Serena Tricarico
- Mariangela Manti
- Vito Cacucciolo
- Francesco Corucci

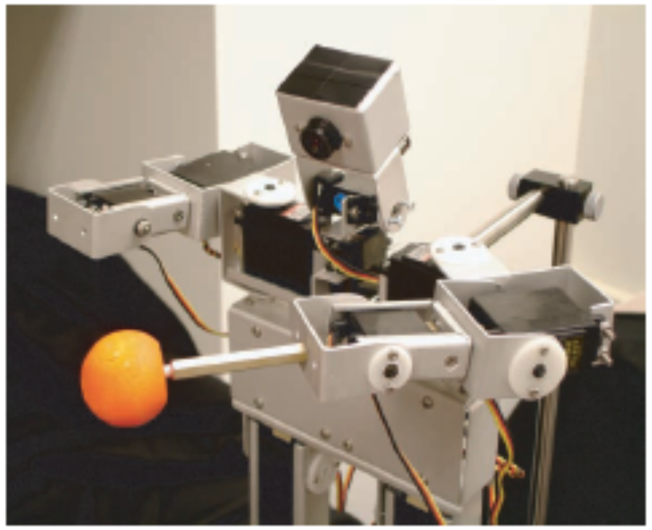
- PoseiDRONE, Fondazione Livorno
- RoboSoft CA, ICT FET-Open
- Smart-e, Marie Curie ITN
- OCTOPUS, ICT FET
- OCTO-Prop, Marie Curie Grant

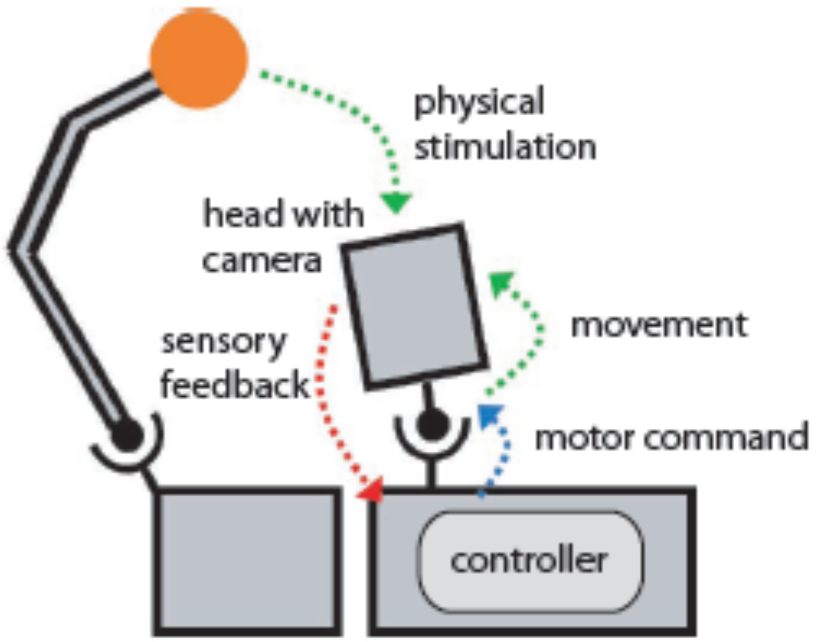
How to quantify?

Information self-structuring

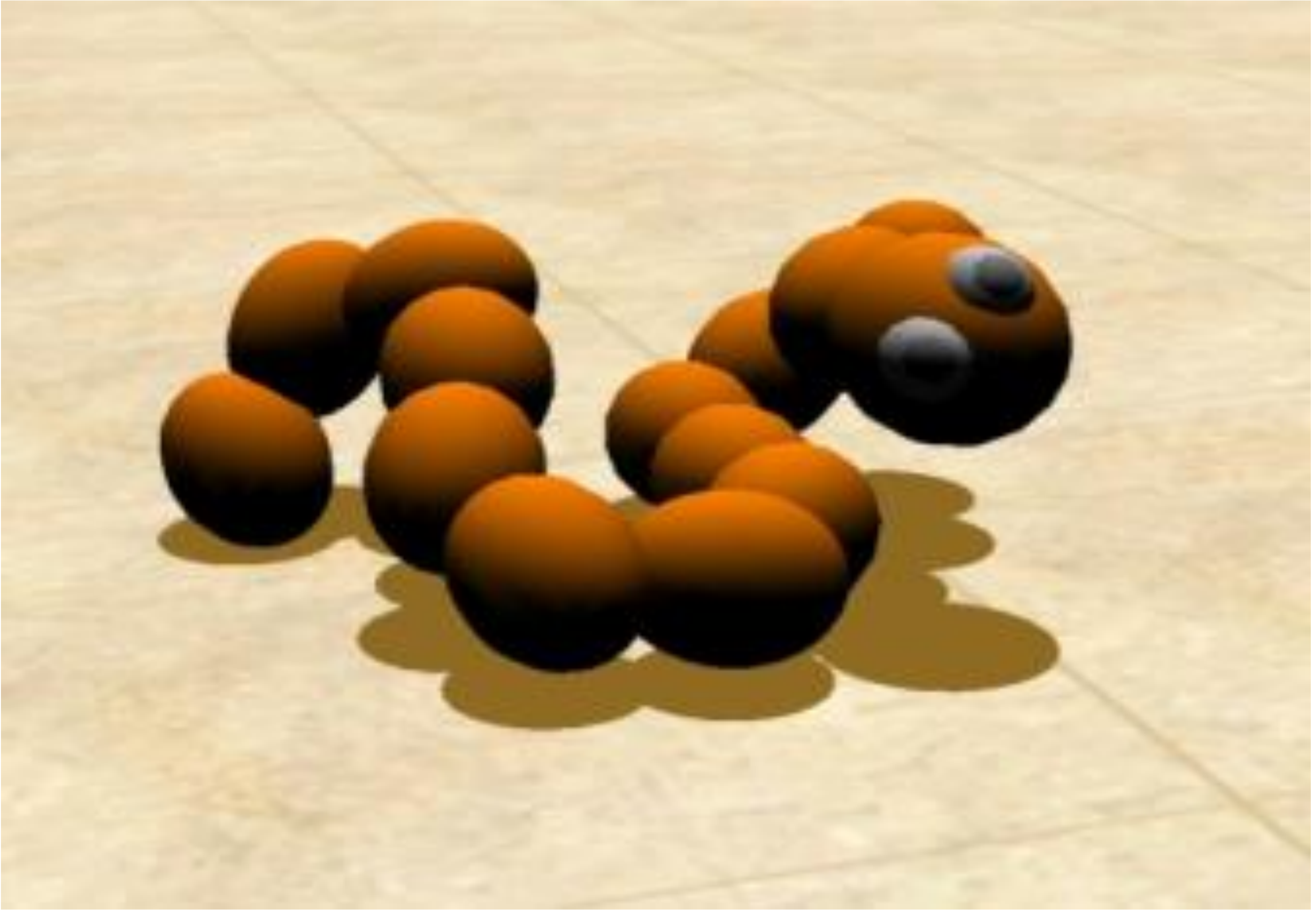
Experiments:

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



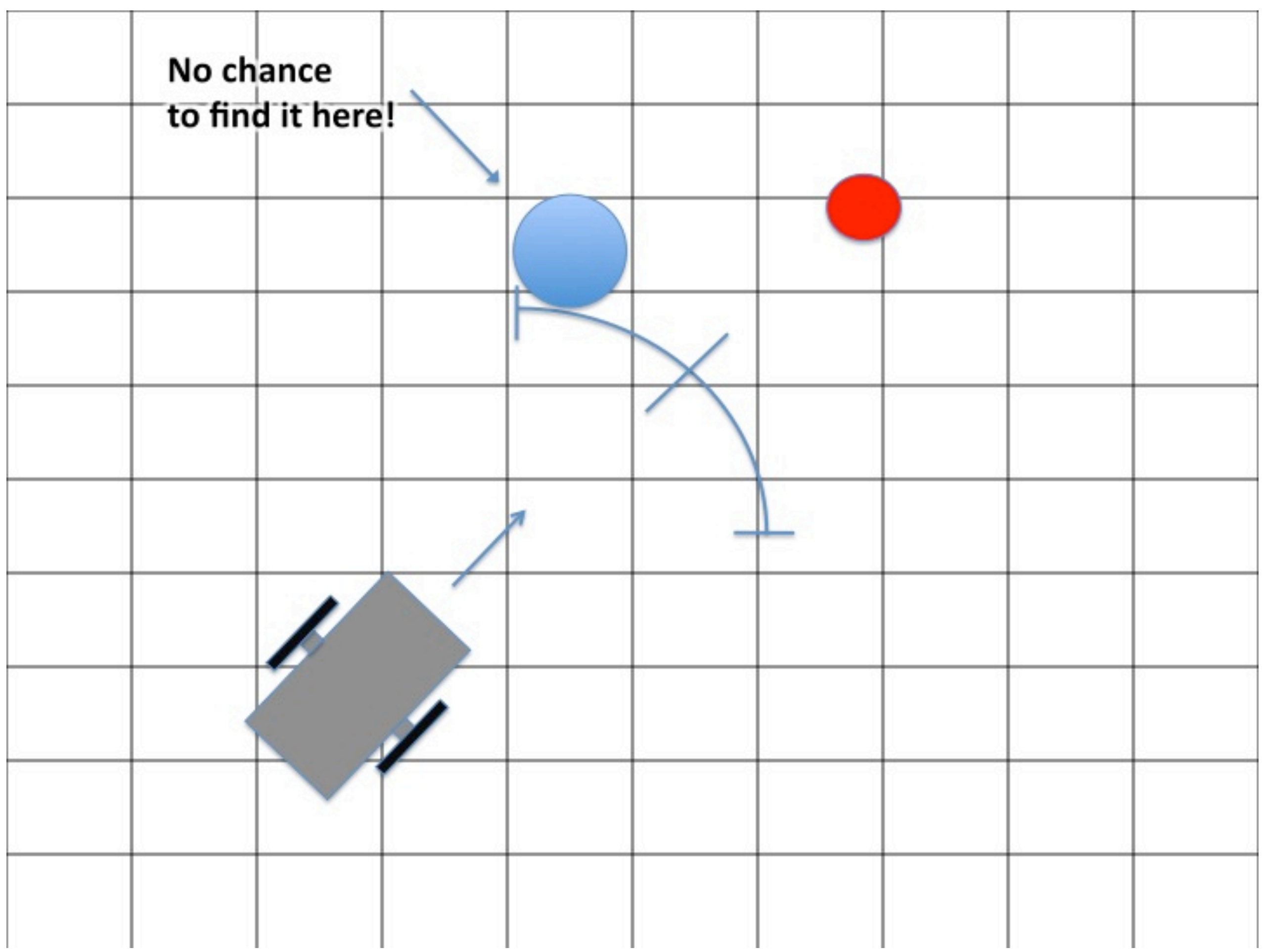


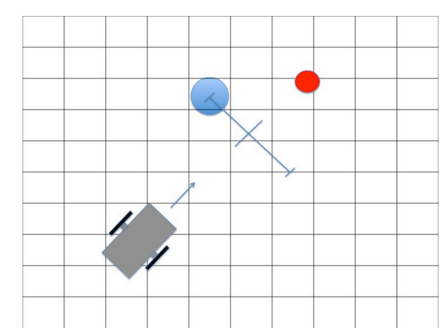
Snakebot



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

Maybe not GOF Euclidean space? :-)





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

Next lecture: Cognition and embodiment

- **Check chapters 6 and 7 in "How the body …"**

End of lecture 5

Thank you for your attention!

stay tuned for Lecture 6

"Cognition and embodiment"