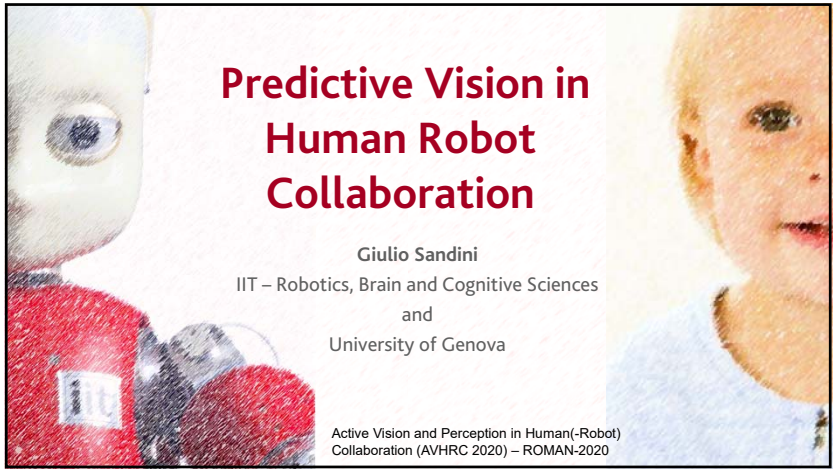

Predictive Vision in Human Robot Collaboration

Giulio Sandini
IIT – Robotics, Brain and Cognitive Sciences
and
University of Genova

Active Vision and Perception in Human(-Robot) Collaboration (AVHRC 2020) – ROMAN-2020

Goal of talk

To revisit some of our past work on Cognitive Robotics and to propose a few research topics and methodologies which I consider important for the advancement of Social Cognition (in humans and robots)…

…no solutions…just aspects to think about and, perhaps, address more specifically in the future…

…from a biased point of view…

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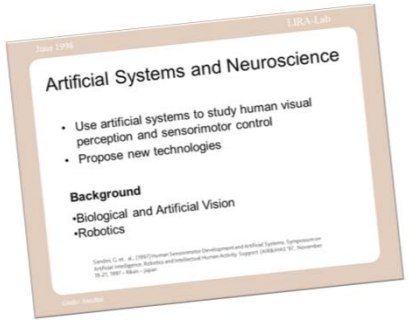
…use artificial systems to study humans…



Outline of Talk:

- How I got here…
  (a bit of history)
- Cognition: "Beyond Real-time"
  (internal models…)
- Timeframes of adaptation
  (a role for Deep Learning?)
- Social Interaction and HRI
  (Few examples)
- Interdisciplinarity
  (…and the ethics of science)

Sandini, G. et.. al., (1997) Human Sensorimotor Development and Artificial Systems. Symposium on Artificial Intelligence, Robotics and Intellectual Human Activity Support (AIR&IHAS '97, November 19-21, 1997 – Riken – Japan

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…use artificial systems to study humans…

Outline of Talk:

- How I got here…
  (a bit of history)
- Cognition: "Beyond Real-time"
  (internal models…)
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Sandini, G. et.. al., (1997) Human Sensorimotor Development and Artificial Systems. Symposium on Artificial Intelligence, Robotics and Intellectual Human Activity Support (AIR&IHAS '97, November 19-21, 1997 – Riken – Japan

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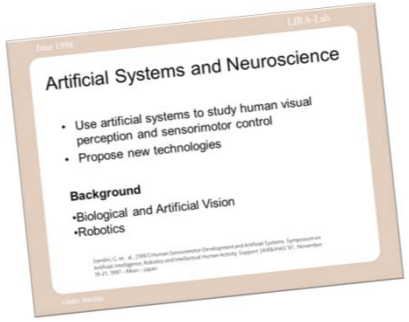
How I got here…

(a brief history of the parallel between neuroscience and the study of artificial systems)



Sandini, G. et.. al., (1997) Human Sensorimotor Development and Artificial Systems. Symposium on Artificial Intelligence, Robotics and Intellectual Human Activity Support (AIR&IHAS '97, November 19-21, 1997 – Riken – Japan

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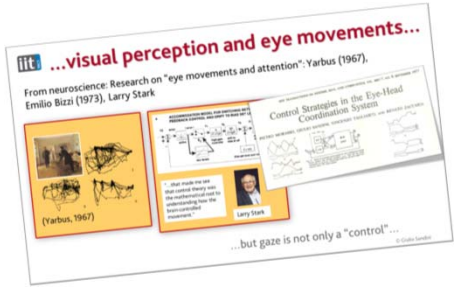
…master thesis (bioengineering) on modelling eye-head coordination

(a hot topic at the time)



…but gaze is not only "control" and…

…I fell in love with "vision".

Morasso P., Sandini G., Tagliasco V., Zaccaria R., (1977) "Control Strategies in the Eye-Head Coordination System": IEEE Trans. Systems, Man and Cybernetics, SMC-7

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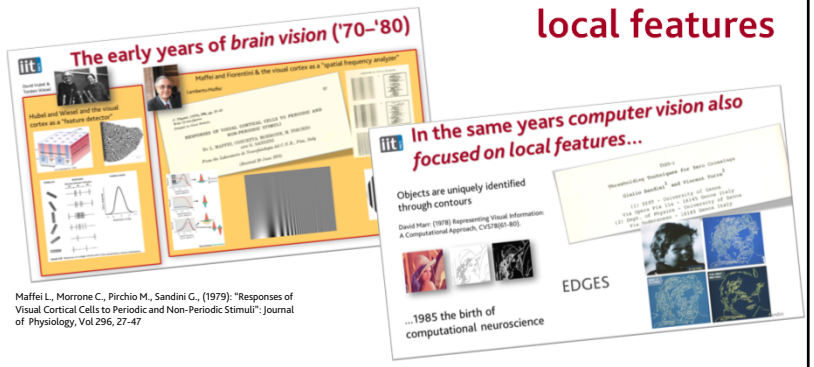
…a PhD in neuroscience …at the time of local features



Maffei L., Morrone C., Pirchio M., Sandini G., (1979): "Responses of Visual Cortical Cells to Periodic and Non-Periodic Stimuli": Journal of Physiology, Vol 296, 27-47

Sandini G., Torre V., (1983): "Thresholding Techniques for Zero Crossings": Proc. Optical Society of America

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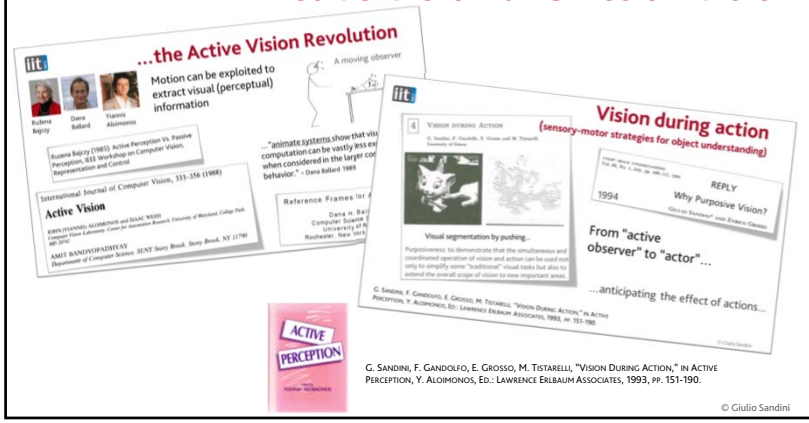
Active Vision and *Action Vision*



G. Sandini, F. Gandolfo, E. Grosso, M. Tistarelli, "Vision During Action," in Active Perception, Y. Aloimonos, Ed.: Lawrence Erlbaum Associates, 1993, pp. 151-190.

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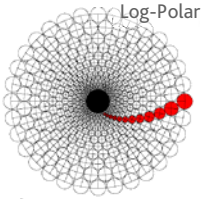
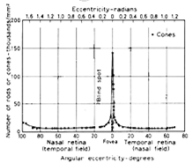
From eye movements and *space-variant* retina

Alfred Yarbus studies of scanpaths in the '50 and '60

Need to move the eyes to explore a scene





Retino-cortical mapping and the cortical magnification factor

G. Sandini, V. Tagliasco (1980): An Anthropomorphic Retina-like Structure for Scene Analysis, Computer Graphics and Image Processing, Vol.14 No.3, pp.365-372.

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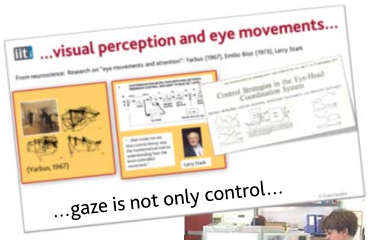
..from mathematical models to embodied (robotic) implementation

(e.g. gaze control and reaching)



1997

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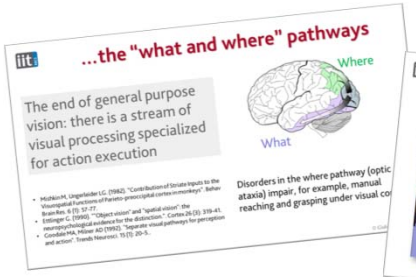
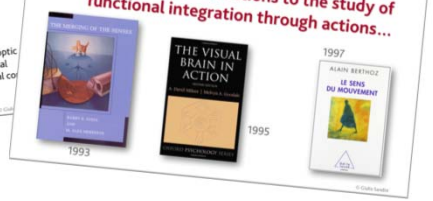
...from general purpose vision to embodiment and multimodality





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From Babybot to iCub to investigate the development of intelligent behaviour...

Babybot (1998)

James (2002)

Robotcub (2004)

EU Project
11 Partners
9 M€

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RobotCub

RobotCub Project
1 Sept 2004 – 31 Jan 2010

https://cordis.europa.eu/project/rcn/71867/factsheet/it

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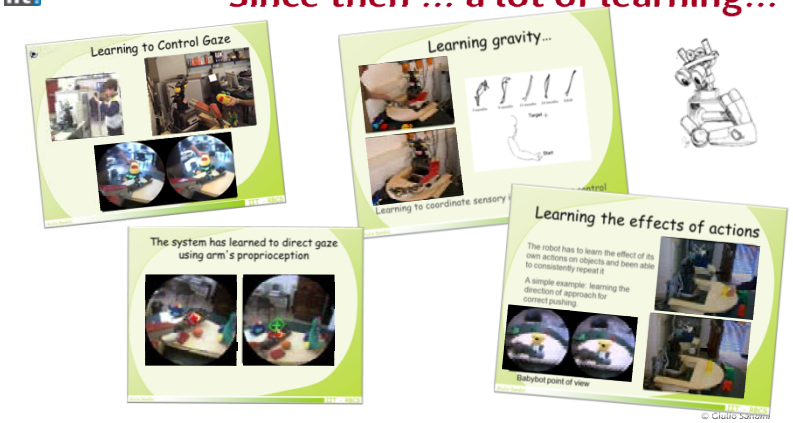
Since then … a lot of learning…



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…a lot of "individual" learning…

Learning to track faces

Learning to repeat actions

Learning to name objects

Zero force control

Learning object's affordance

Learning to sit

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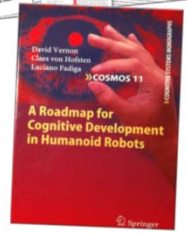
…a lot of friends…

…a lot of science

…a lot of Software …and counting..

5 million lines of code (excluding comments…)



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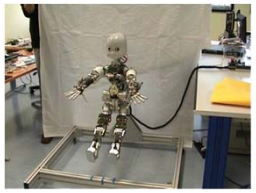
Robot Bodies Have Evolved…

1996: Babybot

Babybot trying to reach the red object

2001: James

2008: iCub



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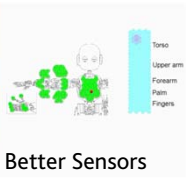
……and still do…

Better set-ups



Better Sensors

Better Control

Daniele Pucci

Francesco Nori

© Giulio Sandini

© Giulio Sandini

…I think we have enough *bodyware* technology to advance key aspects of research on cognitive robotics…

…but I also think we need to refocus our research on developmental robotics

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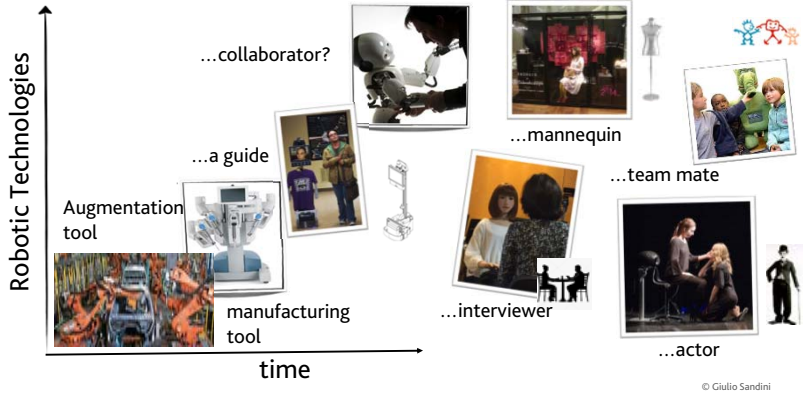
…robots are getting closer to us…



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Sometimes it looks like we are (close to) delivering…

…and the scientific communities have contributed to create the illusion that robots will soon be among us in the form of autonomous cars, personal robots and robot companions.

© Giulio Sandini

…the reality: failure of "personal robots" … and cobots as well…

Working *next to* humans
vs.
Working *with* humans

"…Collaboration … is the close proximity at which our collaborative robot (cobot) work hand-in-hand with operators…."

E-Series Brochure – Universal Robots

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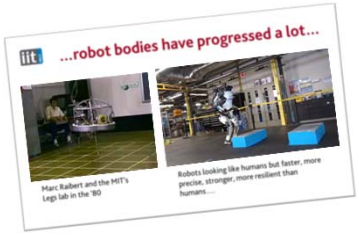
Athletic abilities of robots have evolved faster than their ability to understand…



Still very much exploiting the adaptability of human mind

© Giulio Sandini

There is a mismatch between *acting* and *understanding*

…due to the limited robot's ability to read, interpret and adapt to "human skills"…

…the limited ability to understand intentions and internal states of humans

Most failures of "personal robots" are due to exaggerated expectations about robot "understanding" not about robot mobility and/or sensing

© Giulio Sandini

…we need to make explicit the relationship between the body of the actor and the mind of the observer

(and viceversa…)

The central question is how to map visual input into "internal" motor representations for perception and from intention to motor representation in the case of production.

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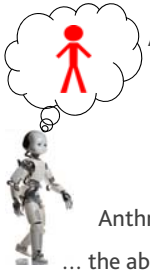
…need to reduce the asymmetry between the two sides of anthropomorphism



Anthropomorphism of the mind

…the ability to relate to an anthropomorphic body (to *think* like a human)

Hidden/Covert humanoid

Anthropomorphism of the body

… the ability to sense and to move like a human

Explicit/Overt humanoid

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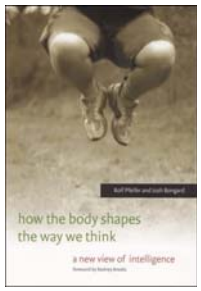
…exploiting the strings between our body and how we interpret the world around us



Rolf Pfeifer and Josh Bongard (2006)

Embodiment!!

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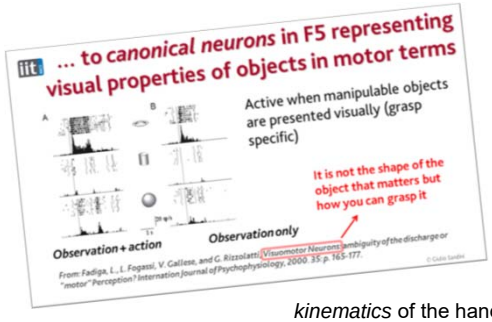
We interpret the world using an anthropometric geometry



Abstract geometrical shape does not count, does not have a survival value…

kinematics of the hand is the metric of shape…

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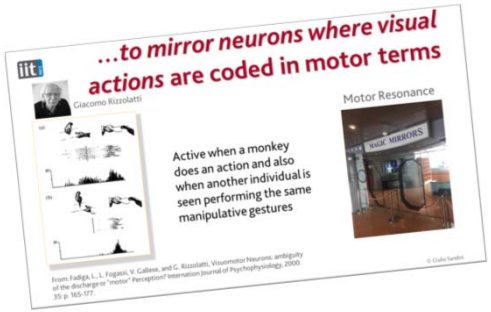
We interpret the others using the knowledge of our own body



the better we act the better we understand…

Vision activates the *motor system*…

© Giulio Sandini

A robot does not need an anthropomorphic body to act on objects

Even if it may help to use tools designed for humans…

However…

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…an *anthropomorphic mind* is necessary to imagine the affordances of objects built for humans … (e.g. to give a meaning to "chairs")

The "concept" of chair is an action not a shape

A chair is "*something I can sit on*"…

© Giulio Sandini

…an *anthropomorphic mind* is necessary to imagine the affordances of humans…
(to give a meaning to "human")

The "concept" of human is a relationship…

A human is "*something like me*" …

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The internal model of ourselves is used as an inverse model to "understand" others

…the advantage of being conspecific…

…without shared internal models would be like living in a world populated by aliens…

(*) e.g.
- Kanakogi Y, Itakura S. (2011) Developmental correspondence between action prediction and motor ability in early infancy. Nat Commun 2: 341,
- Falck-Ytter T, Gredebäck G, von Hofsten C. (2006) Infants predict other people's action goals. Nat Neurosci 9: 878–879.

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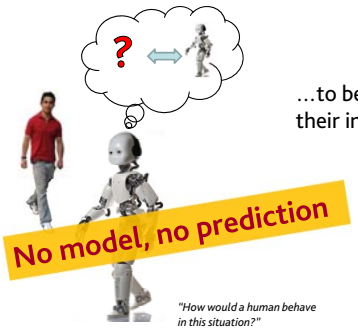
…main target is to build a causal relationship between robots and humans…



…to be able to understand humans, to anticipate their intentions and to communicate robot's.

…in order to *understand humans* shape is not essential as long as the robot has an *anthropomorphic mind*

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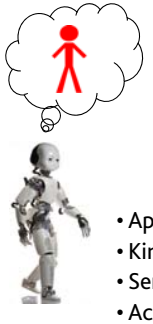
…need to address which anthropomorphic features to embed for the robot to become "personal"…<u>and how</u>



- Speech
- Body Language
- Emotions & Feelings
- Affective signals
- Cognitive Skills
- …

Which combination is needed to exchange goals and intentions as well as internal emotional states

- Appearance
- Kinematics
- Sensing
- Actuation

…searching the moderate amount of anthropomorphism for personal use…

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…a focus on the role of social interaction as a tool to *develop internal models*

Vygotsky's view of cognitive development makes explicit two *Key Issues*…

"adult guidance or in collaboration with more capable peers" …the key role of social interaction

"prospectively" …It is not what you know but where you can go, from where you are…

…the internal model is built by looking at others but also by self-adapting our own internal model

The role of cognitive development…

Vygotsky, L. (1978): Interaction between learning and development. From: Mind and Society – pp 79-91 – Harvard Univ. Press

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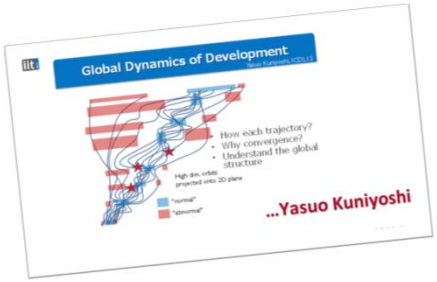
…need to study *Development (Cognition, Intelligence) as a Dynamic and Interaction Process…*



Development is not a sequence of disconnected states…

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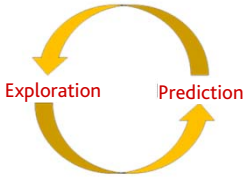
…social interaction and prospection needs systems with intrinsic motivations (internal rewards)…

"…development is about systems with the urge to act and explore" (Claes von Hofsten)



…beyond the action perception loop…

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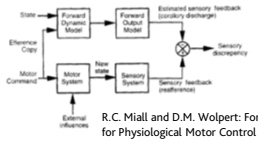
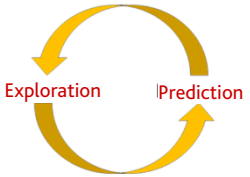
Study the role and structure of *Internal Models* to develop robots able to act prospectively



R.C. Miall and D.M. Wolpert: Forward Models for Physiological Motor Control (1996)

The Mental Simulation Theory of **Marc Jeannerod**: real movements (overt generation of actions) are consequences of "covert internal simulation" thus simulation and generation of movements share the same cortical and computational basis

Marc Jeannerod: Neural Simulation of Action: A Unifying Mechanism for Motor Cognition, NeuroImage 14, S103–S109 (2001)



From inverse models to mental simulation and beyond…

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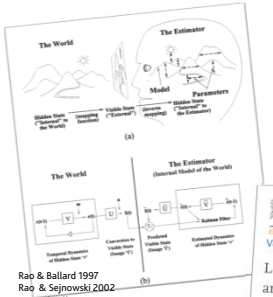
The research stream of *Predictive Coding* and *Active Inference*



Rao & Ballard 1997
Rao & Sejnowski 2002
R. C. O'Reilly 1996

"…combining information from input-driven bottom-up signals and expectation-driven top-down signals."

OPEN ACCESS Freely available online July 2009 PLoS one

Reinforcement Learning or Active Inference?

Karl J. Friston*, Jean Daunizeau, Stefan J. Kiebel

Neural Networks
Volume 12, Issues 7–8, October–November 1999, Pages 1131-1141

Learning to perceive the world as articulated: an approach for hierarchical learning in sensory-motor systems

J. Tani [a] ✉ … S. Nolfi [b]

"learning to predict the next sensation"

"…from reinforcing desired behaviors towards teaching the succession of sensory states that lead to desired outcomes."

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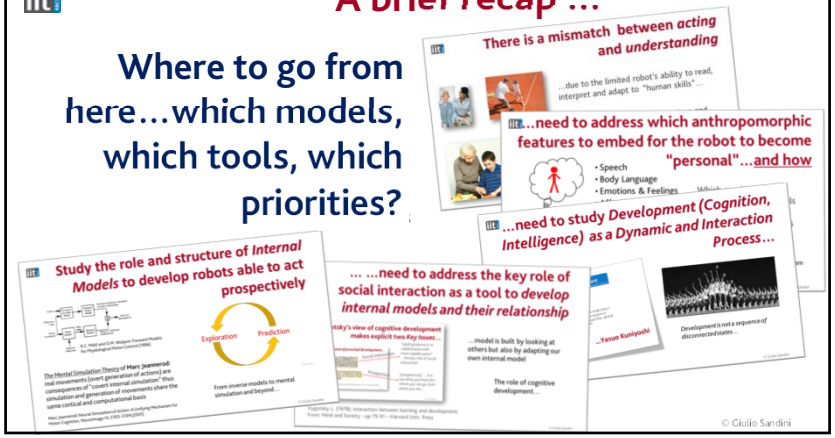
A brief recap …

Where to go from here…which models, which tools, which priorities?



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…which role for deep learning?

https://www.vlab.org/events/deep-learning/

? Is Deep Learning a way to achieve intelligent systems?

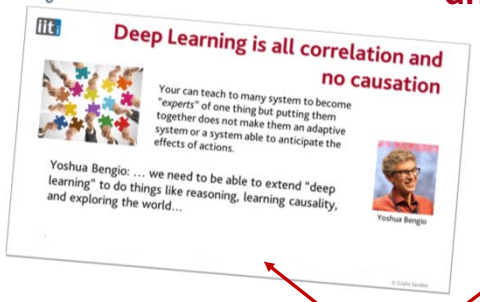
"I personally don't like opacity, so I won't spend my time on deep learning, but I know that it has a place in the makeup of intelligence"

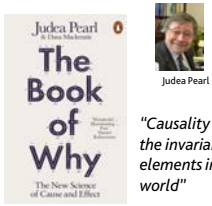
? which model

Chapter 2
THE LIMITATIONS OF OPAQUE LEARNING MACHINES
JUDEA PEARL

© Giulio Sandini

…Deep Learning gives a fragmented view and no causation…





Judea Pearl

"Causality encodes the invariant elements in the world"

CAUSALITY

"So rather than experimenting with opaque learning machines I am trying to understand their limitation… in the context of causal-reasoning tasks"

© Giulio Sandini

…weak on *generalization* and *transfer*…

A Meta-Transfer Objective for Learning to Disentangle Causal Mechanisms

Yoshua Bengio[1,2,5], Tristan Deleu[1], Nasim Rahaman[1], Nan Rosemary Ke[1], Sébastien Lachapelle[1], Olexa Bilaniuk[1], Anirudh Goyal[1] and Christopher Pal[3,5]

arXiv:1901.10912v2 [cs.LG] 4 Feb 2019

"Current machine learning methods seem weak when they are required to generalize beyond the training distribution"

*"…we would like what has been learned previously to form a rich base from which very fast adaptation to a new but related distribution can take place, i.e., **obtain good transfer**."*

…after all…learning how to use the hands may cover the basis of tool use in general…

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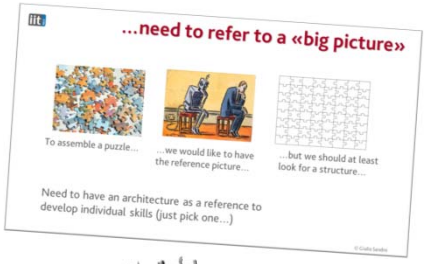
Swiss Army Knife approach does not scale

Assembling a set of "intelligent" solutions by learning task-specific representations using large-scale data does not produce an intelligent, adaptive system…



This is a good idea…

This may be a better one

This does not work….

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…we should consider the different timescales of human adaptation

Timescales of human adaptation: the role of epigenetic processes

Kuzawa & Thayer

Epigenomics (2011) **3**(2), 221–234

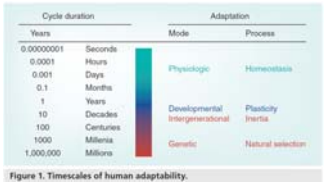

Figure 1. Timescales of human adaptability.

Evolution, development and learning acts at different timescales and systems may need different tools to "acquire experience"

REVIEW

www.sciencemag.org SCIENCE VOL 331 11 MARCH 2011

How to Grow a Mind: Statistics, Structure, and Abstraction

Joshua B. Tenenbaum,[1]* Charles Kemp,[2] Thomas L. Griffiths,[3] Noah D. Goodman[4]

"Hierarchical Bayesian models (HBMs) may answer some questions about the origins of knowledge…but surely some aspects of mental representation are innate"

© Giulio Sandini

…the blueprints selected by evolution

21 August 2019

nature COMMUNICATIONS | NATURE COMMUNICATIONS | (2019)10:3770

PERSPECTIVE OPEN

A critique of pure learning and what artificial neural networks can learn from animal brains

Anthony M. Zador[1]

"…much of our sensory representations and behavior are largely innate."

"Thus, it appears that a large component of an animal's behavioral repertoire is not the result of clever learning algorithms — supervised or unsupervised — but rather of behavior programs already present at birth."

"These blueprints have been selected by evolution over hundreds of millions of years, operating on countless quadrillions of individuals. The circuits specified by these blueprints provide the scaffolding for innate behaviors, as well as for any learning that occurs during an animal's lifetime."

the source of big data is not in the experience of a single individual

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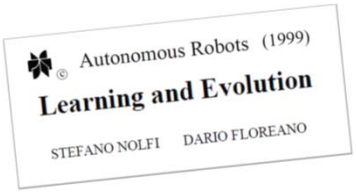
…revisit the relationship between evolution and learning



Genetically inherited predisposition to learn may consist of different things:

1. Presence of starting conditions at birth (e.g. initial weights for learning) that canalize learning in the right direction
2. An inherited tendency to behave in such a way that the individual is exposed to the appropriate learning experiences

This paper demonstrates that learning can change the outcome of evolution, i.e., lead to a genetic configuration that does not correspond to the plastic response.

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Innate functions … and the shortcuts of evolution…

"The behavioral characteristics of an individual are determined by its genes and by its physical and social environment."

"Not only the individual's early life and current environment is of importance, but also the environment of previous generations"

"Epigenetic mechanisms that support instinct by operating on developmental time scales also support learning by operating on physiological time scales."

"Evolutionary processes can adjust the extent to which behavioral response is learned or instinctive by acting on where, when, and how epigenetic mechanisms operate."

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Deep Learning may be part of the solution (in the framework of developmental robotics)

…may be with developmental approach we have been trying to "learn too much" and with the wrong tools…

t_0

…Deep Learning may be a better approach to obtain the blueprints in the form of a useful *set of tools* at t_0 with which to *develop the system* (may be it can be used to implement an evolutionary process based on a random "acquisition" of huge amount of data with no on-line feedback?)

…may be the important contribution of Deep Learning is not to learn a function but to embed instincts (implicit knowledge) in the morphology of the network.

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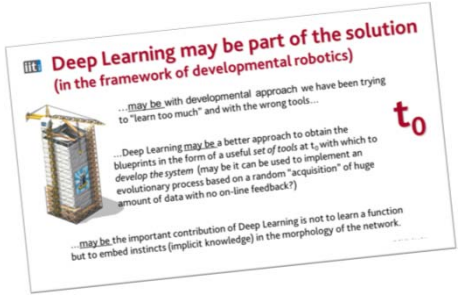
Need to harmonize the different timescales and tools…



Which tools for evolution?
Which tools for epigenetics?
Which tools for development?
Which tools for learning?

Keeping in mind the limitations of our model but also the fact that we are dealing with an active and social learner

The body (embodiment) is the common reference for *understanding*

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…evolutionary priors

Basic primitives which are coded in the morphology of the brain and body and give a predisposition to learn higher order functions (and are passed from an individual to the next through DNA)

- Discriminate color (function to distinguish one color from another)
- Discriminate sounds (function to distinguish different frequencies)
- Activate muscles synergies
- Identify biological motion
- Discriminate faces from other shapes
- Discriminate basic odors
- Sensorimotor reflexes…
- …

© Giulio Sandini

Innate Social Skills… (the bootstrap loader)

…are represented by a disposition toward "human features" like face-related features, sound of voices, biological motion, emotional states (as basis of a value system)

…and are based on tools such as mouth, face, eyes, hands, voice, body and processed through vision, audition, touch and haptics, proprioception…

→ …a full human body

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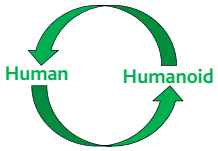
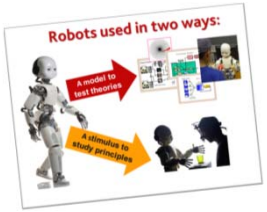
…a humanoid is an ideal tool to study human's internal models and their role in social interaction

iCub is a stimulus I can relate with motorically



..use robots to understand humans to build robots



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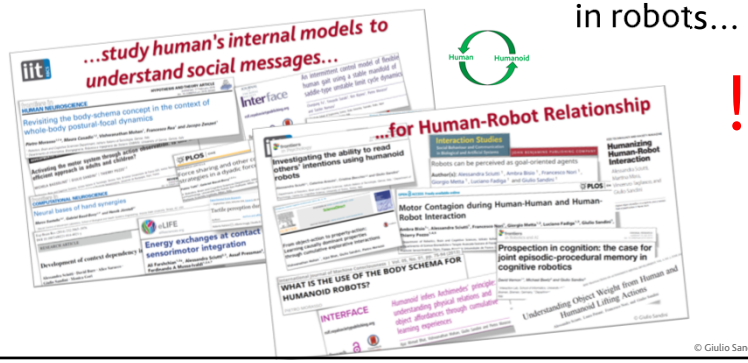
….study human's internal models to understand social messages to be implemented in robots…



!

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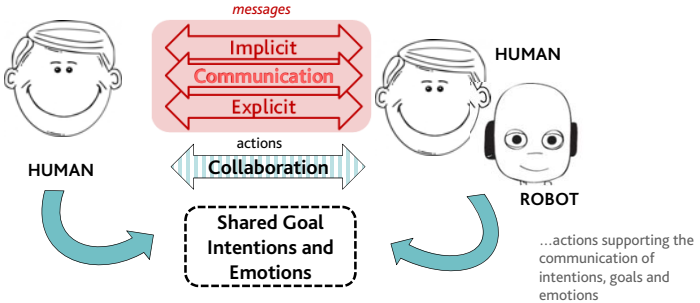
…exploit the dual role of actions

Exploit the body not only to execute the actions required to reach the goal but also to communicate the intended goals, skills and values



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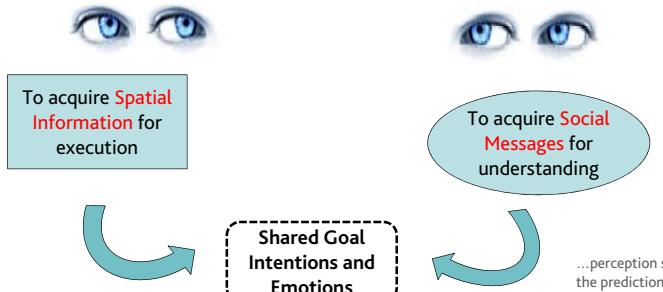
…exploit the dual role of vision (perception) during actions



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…embodied, full-body messages based on a very rich set of messages

Explicit (overt and stated: can be purposively acted and perceived)

Implicit (covert and tacit: they are only *imagined* from the way humans act);

A. Sciutti and G. Sandini: "Exploring Biological Motion Regularities of Human Actions: A New Perspective on Video Analysis" in the ACM Transactions on Applied Perception (TAP), Volume 14 Issue 3, July 2017

© Giulio Sandini

…with a focus on "motion"…

(the implicit knowledge of each other) …

The way we move is characterized by dynamic and kinematics regularities

Biological Motion

Communicate emotions

Induce Imitation

Human movements and physical interaction embed "hidden" structures and social messages .

© Giulio Sandini

How does our "visual brain" transform a stream of images into an object, a "human body", an emotion, an action and a goal to be reached?

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...it's a team work

Alessandra Sciutti

Francesco Rea

19 females and 18 males!!

Which are the regularities of biological motion affecting the way we communicate with each other

How are these regularities mapped into cues perceived during interaction


Pietro Morasso


Gabriel Baud-Bovy


Monica Gori


Nicoletta Noceti, Francesca Odone, – University of Genoa

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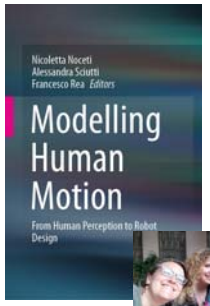
A recent publication with an interesting collection of contribution…



Francesco Rea

Nicoletta Noceti

Alessandra Sciutti

© Giulio Sandini

To establish priorities we can re-visit the taxonomy of action related social sign…

…and take into consideration the contribution of culture, evolution and the laws of physics governing our environment…

Cultural based social signs (acquired through rules, habits and conventions)


Vs.

Bodily Based Social Signs (embedded in the evolution of human embodiment and in the physics of the environment);


Photoreceptors' Mosaic


skeletal and muscle system


Gravity and other Physical Laws

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…considering that social messages can be seen often as "side effects" of evolution

The concept of exaptation: the process by which features acquire functions for which they were not originally adapted or selected.

Exaptation-A Missing Term in the Science of Form

Stephen Jay Gould; Elisabeth S. Vrba

Paleobiology, Vol. 8, No. 1. (Winter, 1982), pp. 4-15.

Exaptations: features that now enhance fitness but were not built by natural selection for their current role

Vs.

Adaptations: features built by selection for their current role

Gould, S., & Vrba, E. (1982). Exaptation-A Missing Term in the Science of Form. *Paleobiology, 8*(1), 4-15.

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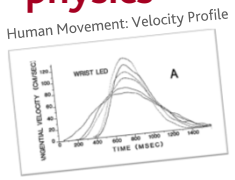
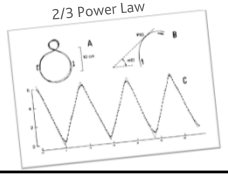
…the regularities of biological motion deriving from evolution and "physics"

- Shape of the movement's velocity profile;
- Relation between movement's trajectory curvature and velocity;
- Articulated structure of the human body
- Influence of gravity on trajectory;
- …



Morasso Mussa-Ivaldi 1982,

2/3 Power Law



Laquaniti, Terzuolo, Viviani (1983)

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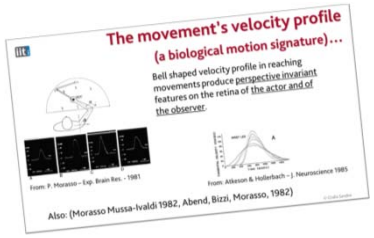
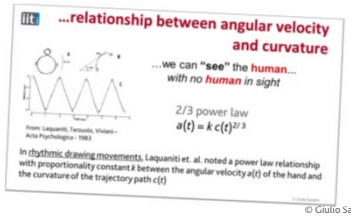
Regularities of biological motion



Have not evolved to embed "messages" but to optimize performance/energy relationship of biological actuators

…embodied social signs may be exapted functions (social meaning is not an evolutionary priority)



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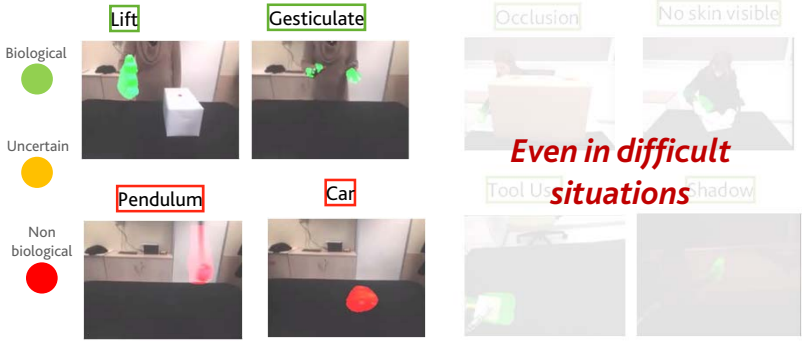
Biological vs Non-Biological detector

…we can "see" the human *with no human in sight*



Vignolo, A., N. Noceti, F. Rea, A. Sciutti, F. Odone, and G. Sandini, (2017) Frontiers in Robotics and AI: Detecting Biological Motion for Human–Robot Interaction: A Link between Perception and Action.

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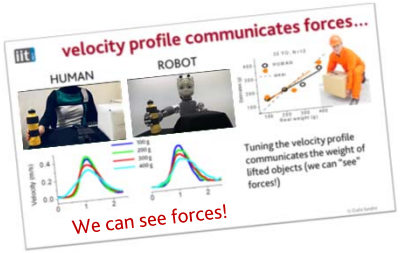
Velocity Profile and Action Reading



Sciutti, Patanè, Nori, Sandini: (2014) IEEE Trans. Autonomous Mental Development

A. Sciutti, L. Patanè, G. Sandini, Plos ONE (2019)

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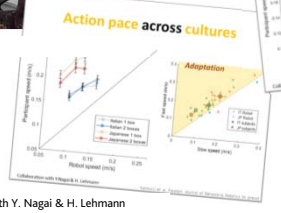
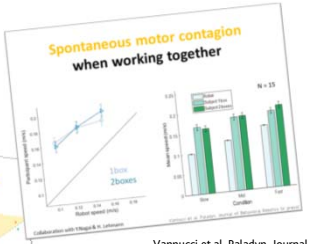
Motor Contagion is affected by motion parameters (but not cultural difference)

Vannucci et al. RO-MAN 2017





Vannucci et al. Paladyn. Journal of Behavioral Robotics (in press)

Collaboration with Y. Nagai & H. Lehmann

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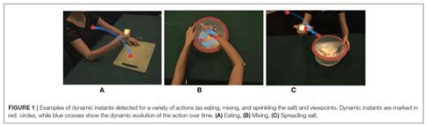
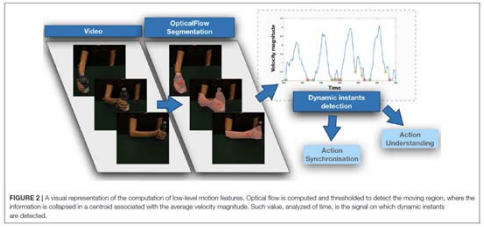
Human Motion Understanding



Identification of relevant time instants in an observed action, called dynamic instants, informative on the partner's movement timing



MoCA) Multimodal Cooking Actions Dataset

Rea F. et al. : (2019) Front. Robot. AI, Human Motion Understanding for Selecting Action Timing in Collaborative Human-Robot Interaction.

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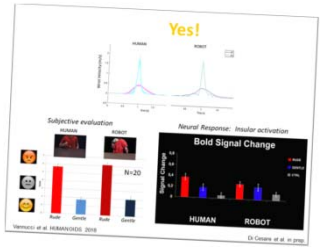
Study which movement's parameters encode the style of actions (communicate internal state)

Vannucci et al. HUMANOIDS 2018

iCub elicits the same subjective and physiological changes if motion parameters are "naturalistic"



Collaboration with Giuseppe Di Cesare & Giacomo Rizzolatti, U. Parma

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Social messages mediated by eye movements …

…social use of gaze is an exapted function…

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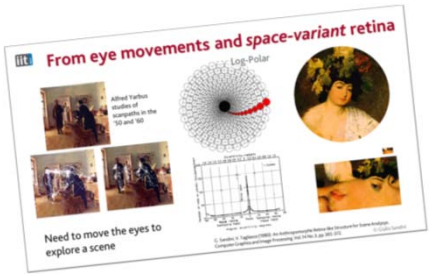
Retina is space-variant is to optimize its feasibility and survival functions…



Need to move the eyes to explore a scene: it is an "exapted message" of where your interest is…a view of your mental state

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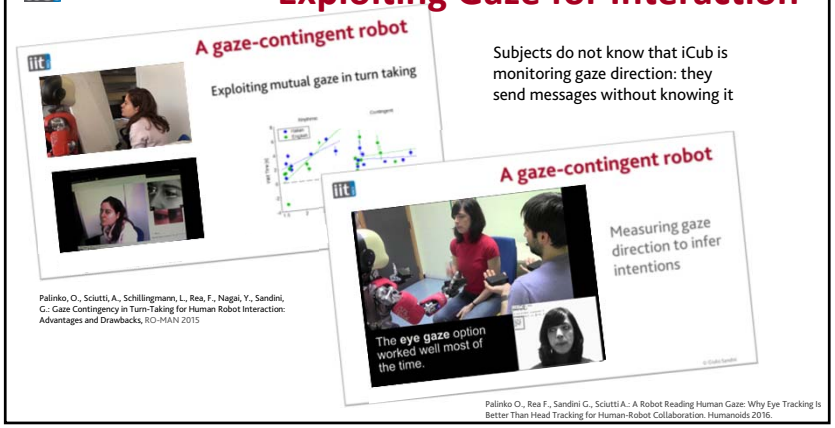
Exploiting Gaze for Interaction



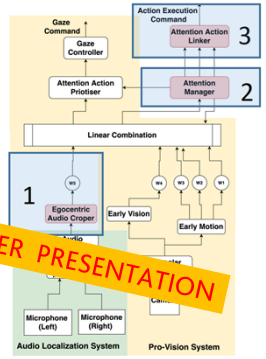
Subjects do not know that iCub is monitoring gaze direction: they send messages without knowing it

Palinko, O., Sciutti, A., Schillingmann, L., Rea, F., Nagai, Y., Sandini, G.: Gaze Contingency in Turn-Taking for Human Robot Interaction: Advantages and Drawbacks, RO-MAN 2015

Palinko O., Rea F., Sandini G., Sciutti A.: A Robot Reading Human Gaze: Why Eye Tracking Is Better Than Head Tracking for Human-Robot Collaboration. Humanoids 2016.

…extended to multimodal Joint Attention

1. Integration (Audio + Visual)
2. Acyclic extraction of a saliency (hot Point)
3. Retinotopic response projection into allocentric spatial representation



MORE LATER IN OMAR ELDARDEER PRESENTATION

Gonzalez Billandon J., Sciutti A., Tata M., Sandini G., Rea F.,"Audiovisual cognitive architecture for autonomous learning of face localisation by a Humanoid Robot","2020 International Conference on Robotics and Automation

Tata M., Kothig A., Rea F.,"A Bayesian System for Noise Robust Binaural Speaker Counting for Humanoid Robots","IEEE International Conference on Robotics and Automation

…what is salient depends on the task being executed…

Facial Expressions … and Aerodigestive Behaviors

commentary

Beyond aerodigestion: Exaptation of feeding-related mouth movements for social communication in human and nonhuman primates

Lynne Murray,[a,b,c] Valentina Sclafani,[a] Holly Rayson,[a] Leonardo De Pascalis,[d] Laura Bozicevic,[a] and Pier Francesco Ferrari[e]

"The primary problem of the aerodigestive system is ensuring that air ends up in the lungs and fluids/saliva/masticated food in the stomach"

Keven & Akins, (2017) Behavioral and Brain Sciences

"Therefore, while both Tongue Protrusion and Lips Smacking may indeed have aerodigestive origins, they have also been **exapted** for uniquely social purposes."

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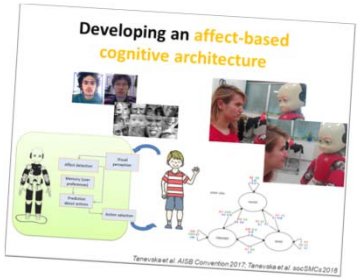
Reading Expressions and Affect-based Cognitive Architecture

Tanevska et al. AISB Convention 2017: Symposium on Computational Modelling of Emotion



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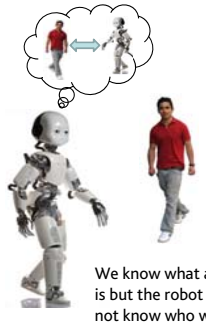
…and so on…to establish mutual understanding and anticipatory behaviours



We know what a robot is but the robot does not know who we are…

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Cognitive Interaction Technology is bounded by our lack of knowledge about human's *mind* …

…disruptive technology will be on robots without "threads" behaving and communicating as predictable machines (relating naturally to humans)

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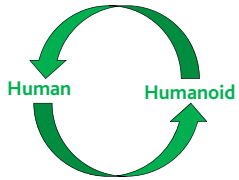
To be fair with the society we have to declare this lack of knowledge and start addressing in parallel how to advance robot technology and how to extend knowledge of humans

..use robots to understand humans to build robots



How?

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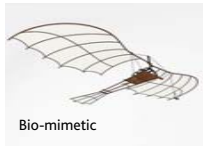
...to move beyond biomimetic models :

(don't stop at asking how it works...)

Descriptive Model

Explanatory Models
Study the Principles



...but study the principles behind...
(why it works like that)

...to find different (disruptive?) technologies for artificial systems

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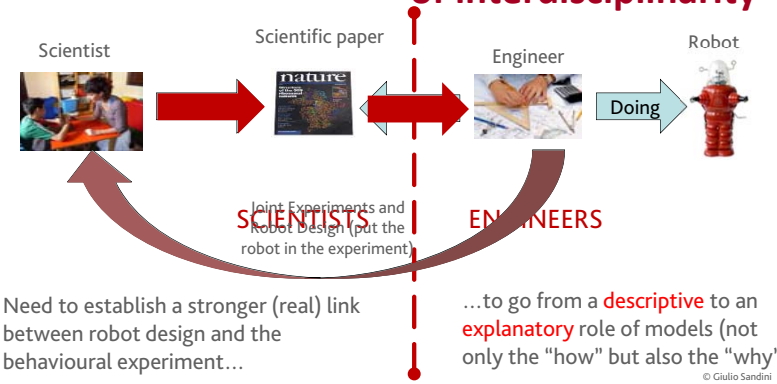
...need to go beyond a superficial level of interdisciplinarity



Need to establish a stronger (real) link between robot design and the behavioural experiment...

...to go from a descriptive to an explanatory role of models (not only the "how" but also the "why")

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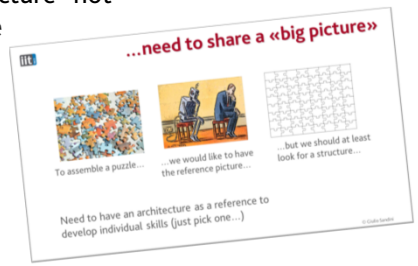
...need to join the forces of groups interested in robots able "to understand"!!

...by sharing a "cognitive architecture" not only the bodies and the software architecture



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...need to join forces of all actors!!

Each actor involved has to give its own contribution: academia, industries, policy makers, scientific and *social media, artists.*

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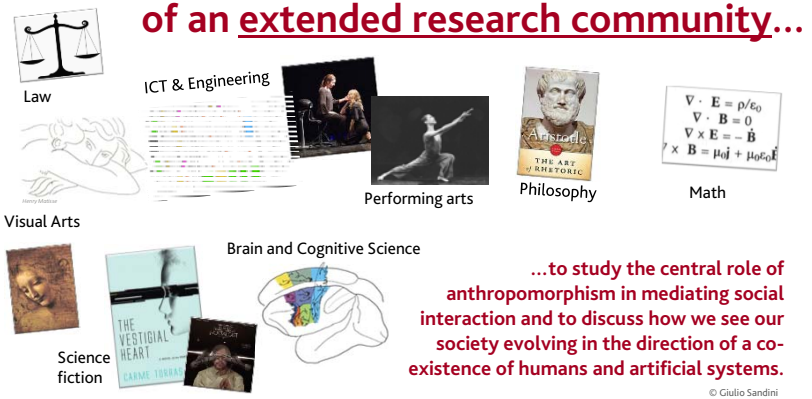
...academia need to nurture the formation of an extended research community...



...to study the central role of anthropomorphism in mediating social interaction and to discuss how we see our society evolving in the direction of a co-existence of humans and artificial systems.

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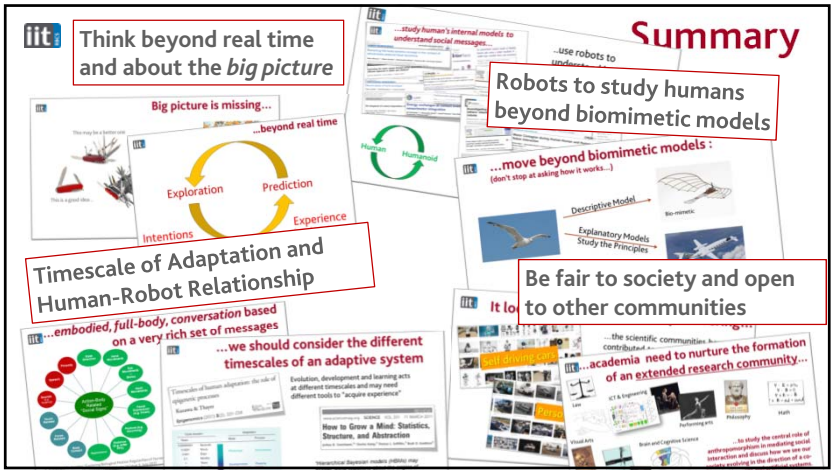
Summary

Think beyond real time and about the *big picture*

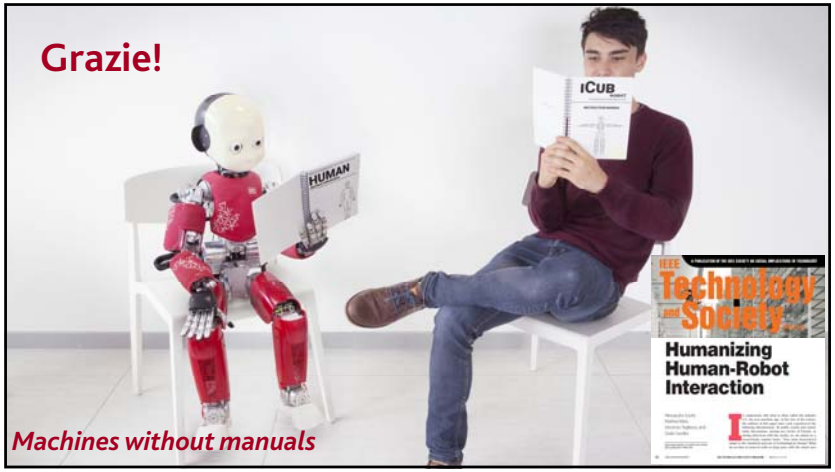
Robots to study humans beyond biomimetic models

Timescale of Adaptation and Human-Robot Relationship

Be fair to society and open to other communities



Grazie!



Machines without manuals