Brains for Robots

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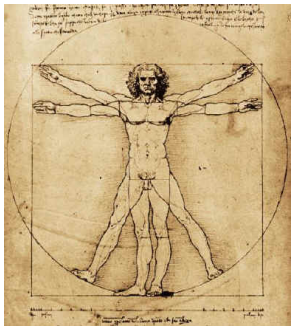
European Network for the Advancement of Artificial Cognition, Interaction and Robotics

EUCOG

…first of all let me define what's the main approach we are followig, which are our "real" priorities…

Human Centered Approach to Science

Cognition & Interacton



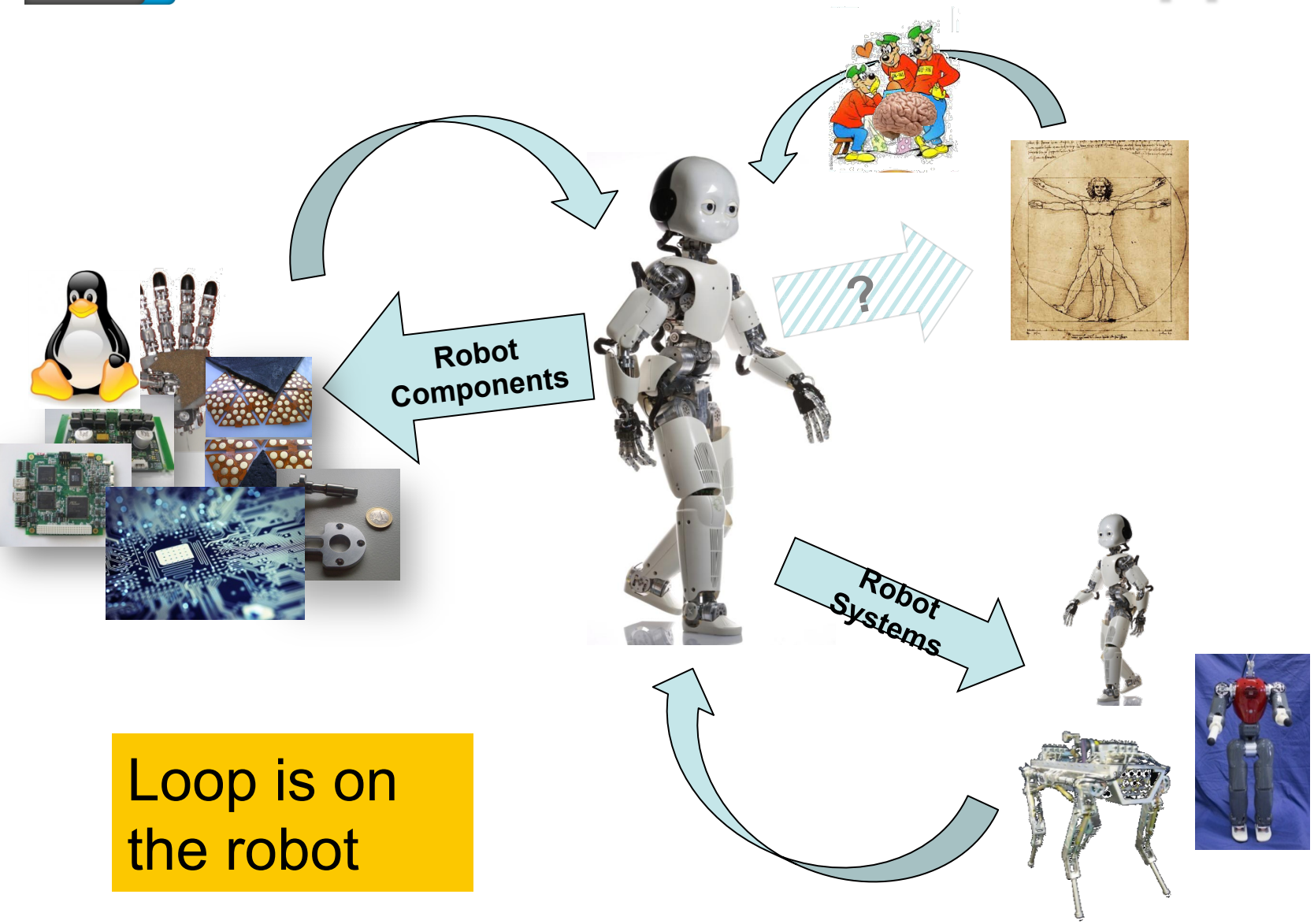
Robot Models

Human Cognition and *Brain Knowledge*

Humanoid Cognition and Robotics

Science loop is on the human

Vs. a "Robot-Centric" Approach



Loop is on the robot

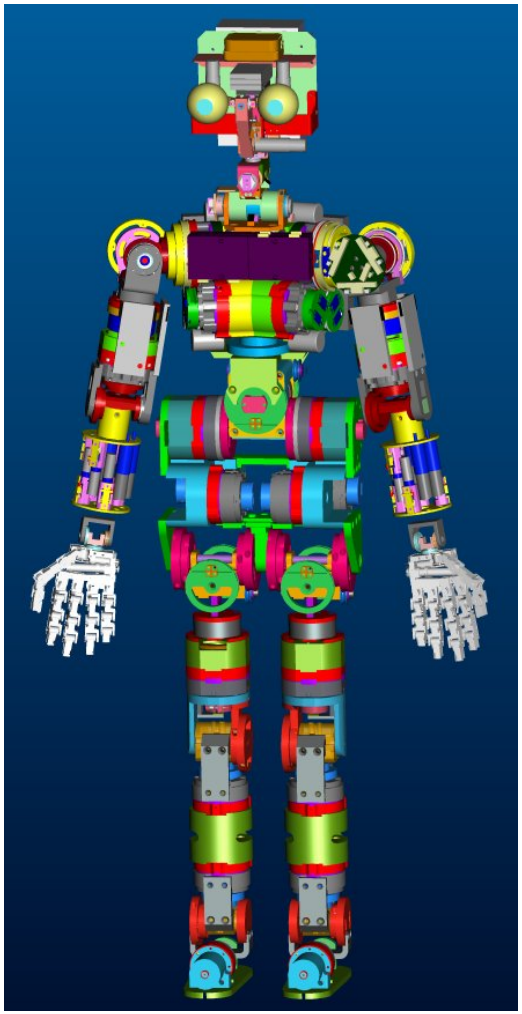
I think that only by sharing the goal of "understanding" Robotics and Neuroscience can fully profit from each other…

…the first important bridge.

…and I think we have enough (robot) technology today to address key aspects of research on "cognitive robotics" and Human Robot Interaction.

…we certainly need to invest on technology but I think technology is not the limiting factor (we need to understand better how humans interact with each other)

New technology comes from new scientific advancement



The first fundamental choice is to match the complexity of the robot to the complexity of the question asked

Just by doing this we understand what needs to be done and if it can be done

…if the robot is too complex most of the time is spent on fixing it…

…if the robot is too simple you can only address simple questions…

In both cases is not very useful

Matching the complexity of the robot to the complexity of the question asked is a joint task of Robotics and Neuroscience

Otherwise defining the level of complexity a robot must have, becomes an open ended problem with no (or too many) solutions

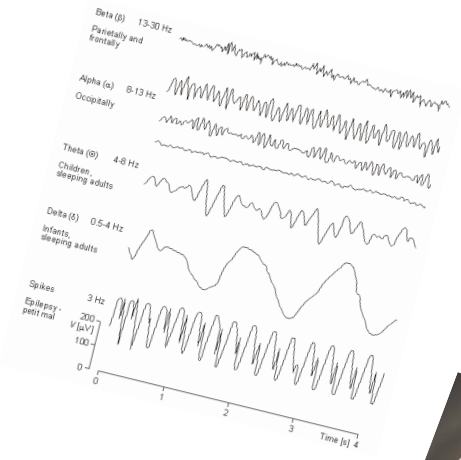
Another important question is:

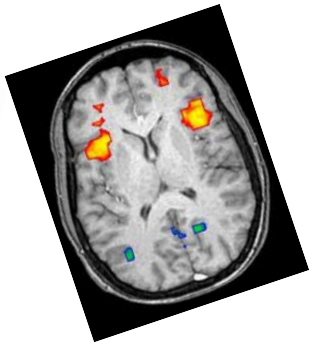
Which are the strong and weak points of Neuroscience and Robotics and where can they be synergic?

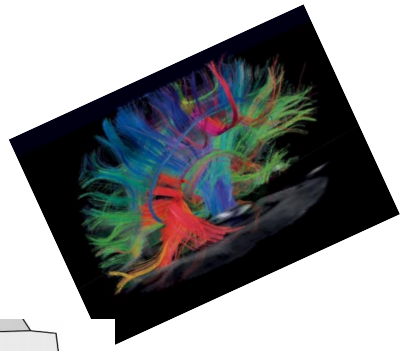
Constraints of neuroscience methods

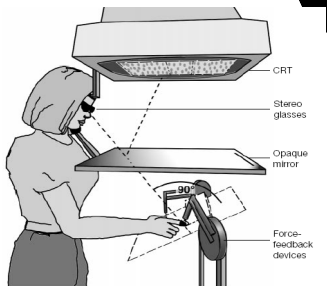
Experimentally only partial views are possible because of technical and technological limitations.

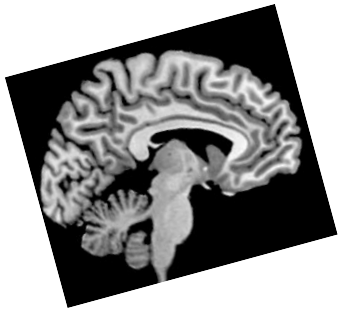
Knowledge advances through a variety of investigation methods producing very diversified results in terms of granularity, measured parameter, species, time resolution etc.

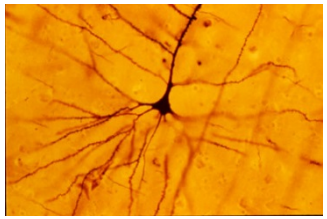






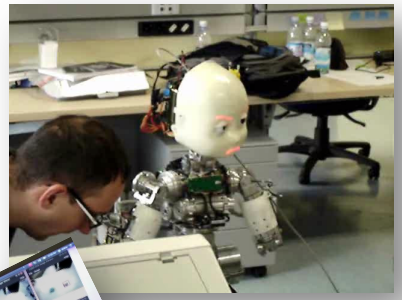


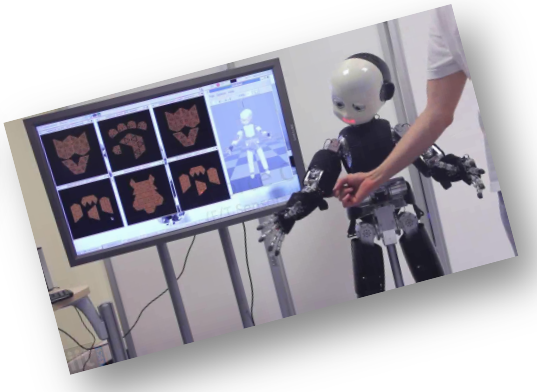


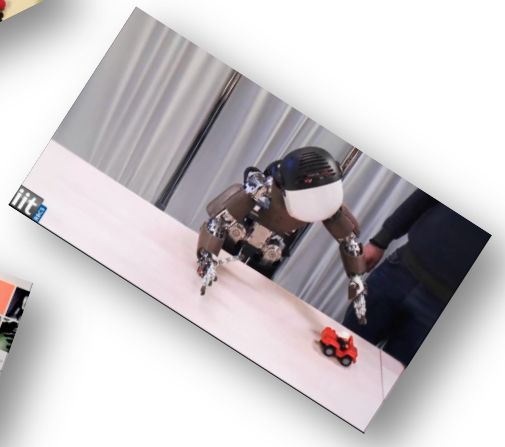


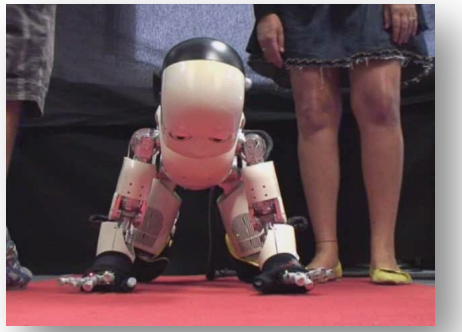
Limits of engineering implementation

Behavioural skills are often implemented (and/or learned) in isolation …. and this does not scale







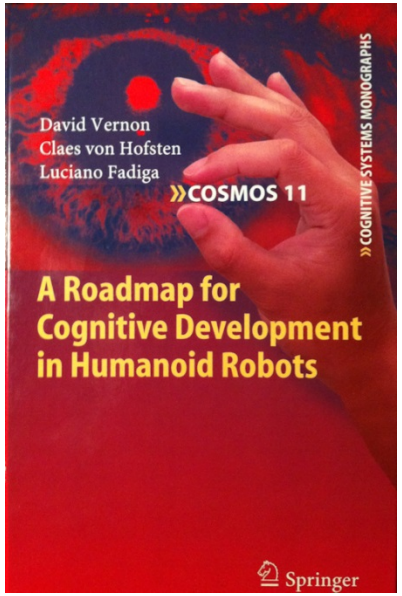


…in both fields functional and temporal continuity are often lost…

…in both fields functional and temporal continuity are often lost…

In both cases the «big picture» is missing

Need to have the “big picture” in mind to address explicitly how these pieces can be bound together in a cognitive architecture

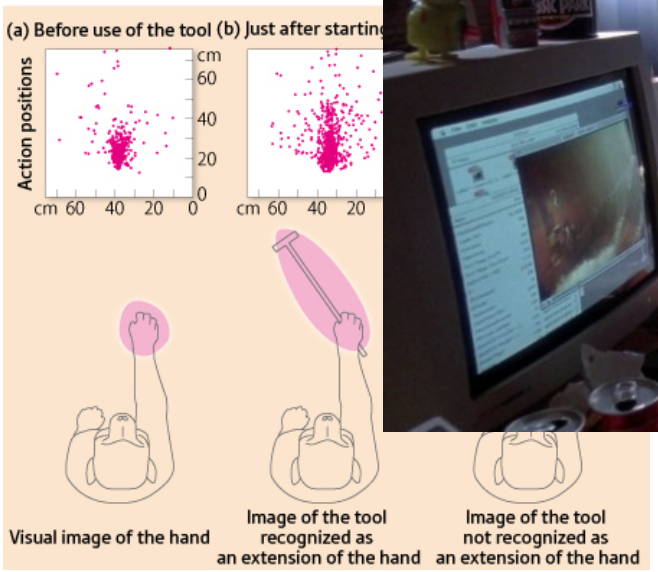


This is a question which is better addressed jointly

But how?

Monkey reaching….programming….robot reaching

Atsush



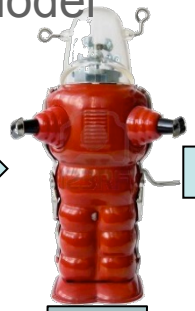
Don’t stop at the superficial level…

…need to go beyond (the superficial level of) interdisciplinarity

Behavioural experiment

Scientific paper

Robot model



Engineering paper

Reading

Joint Design

SCIENTISTS

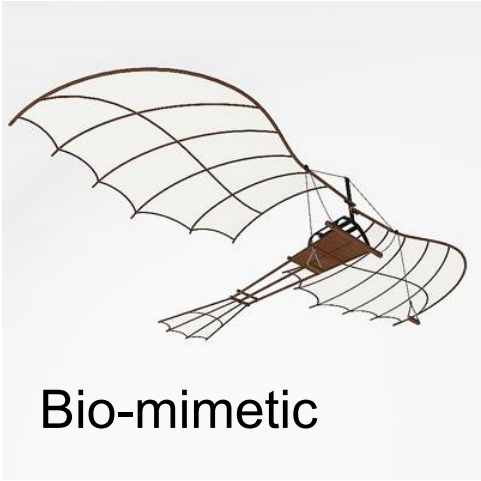
Need to establish a stronger (real) link between the embodied model and the behavioural experiment…

ENGINEERS

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

From descriptive to explanatory models

Descriptive Model

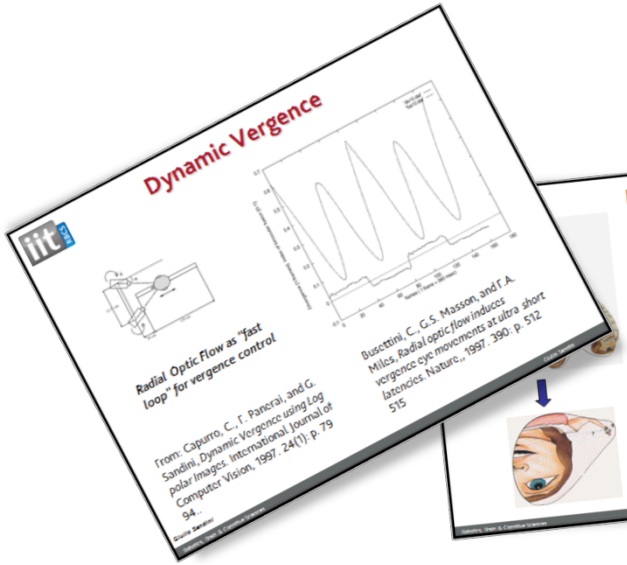


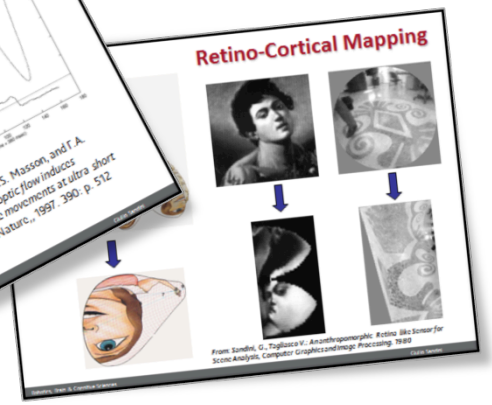
Bio-mimetic

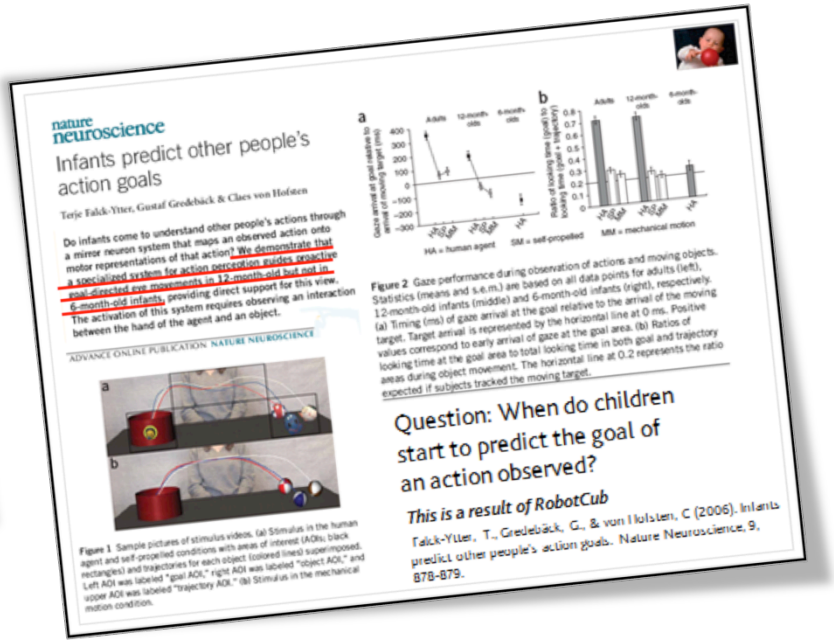
Explanatory Models
Describe the Principles

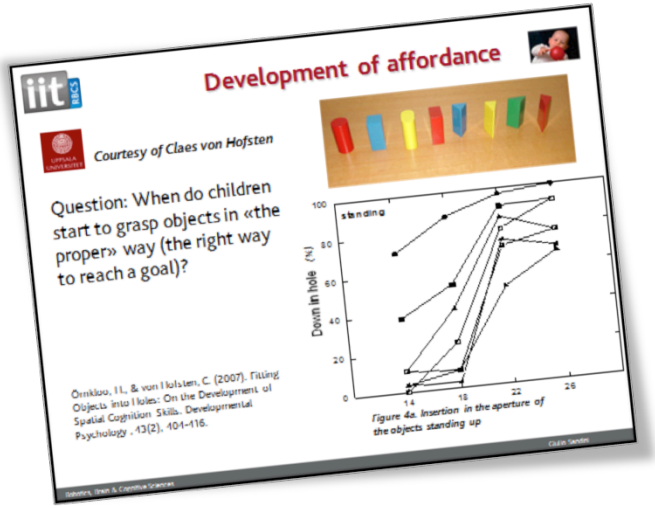
New Solutions

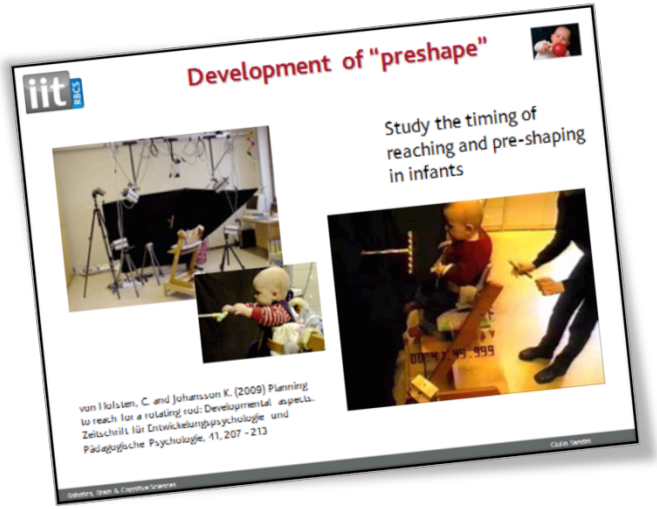
RobotCub outcomes (besides iCub)







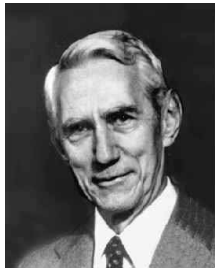




What do robots add?...

….mathematical models and theories have been very effective tools for the study of brain functions…

Vito Volterra

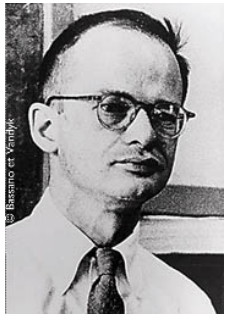


Claude Shannon

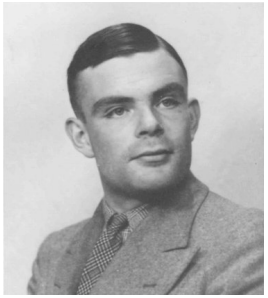
Norbert Wiener

John Von Neumann

Warren Mc Culloch



Walter Pitts

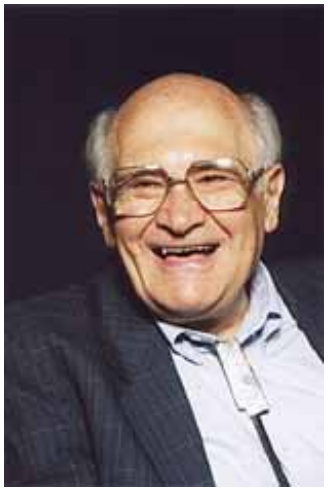


Alan Turing

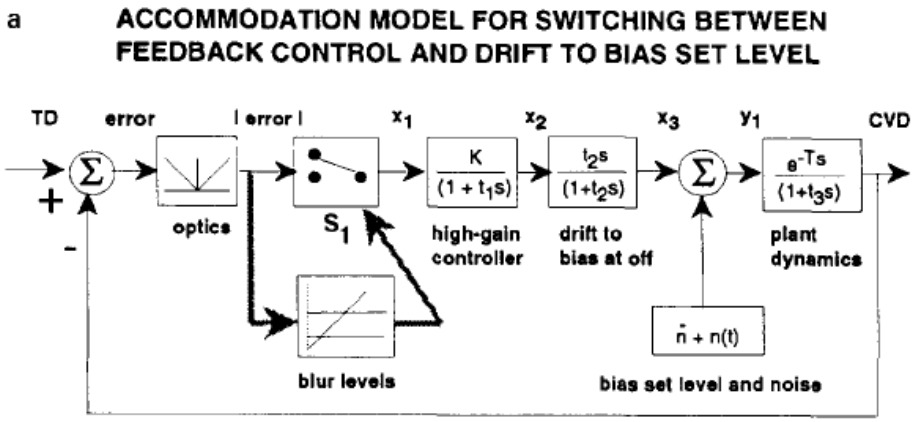
…and more…

…such as in the study of Motor Control…

Mathematical models and system's theory have been and still are fundamental research tools to describe parameters of neural models



Larry Stark



"…that made me see that control theory was the mathematical root to understanding how the brain controlled movement." *Larry Stark*

Robots add “real” environments..

- The questions we are asking are far too complex to be investigated only by means of mathematical models particularly if the “system” we want to model includes the environment (the complexity comes also from the interaction between the system and the environment)
- Engineering (synthetic) approach: understanding by building (the world itself is the referee).

learning to sit..

by itself

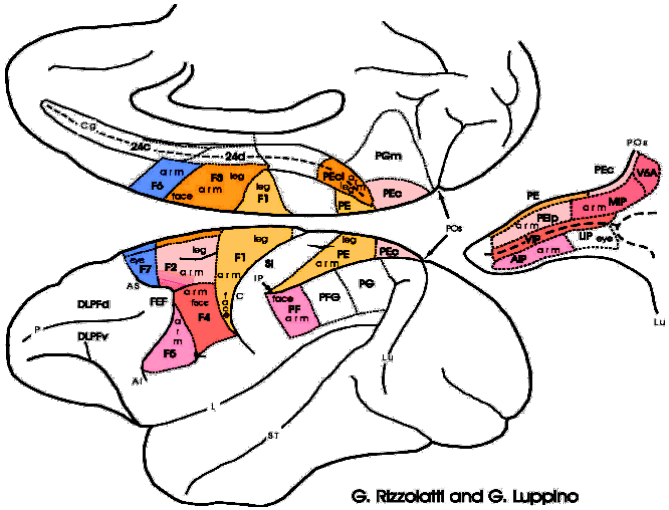
with balancing

With Toshihiko Shimizu and Ryo Saegusa

But if we are interested in Human Robot Interaction there are also scientific reasons why we need to take a physical body into consideration …

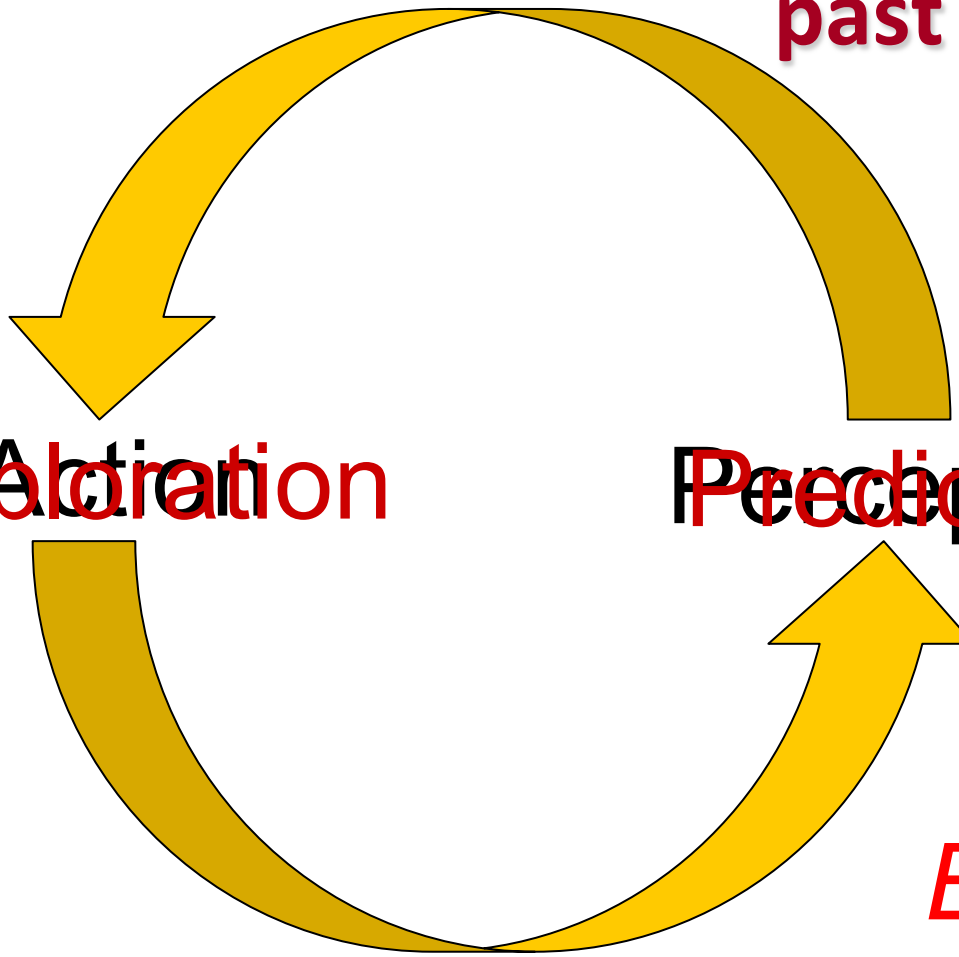
Building a robot able to interact with humans means to understand how humans interact with each other…

Mirror neurons showed the dual role of the body as an “executor” of actions and as a “communicator” of intentions



The same neuron codes the “execution” of a goal directed action and the “anticipation” of a goal directed action

Mirror neurons have extended the «perception-action» loop by introducing explicitely the goal of the action and the past experience



The crucial aspect of prediction and communication ..

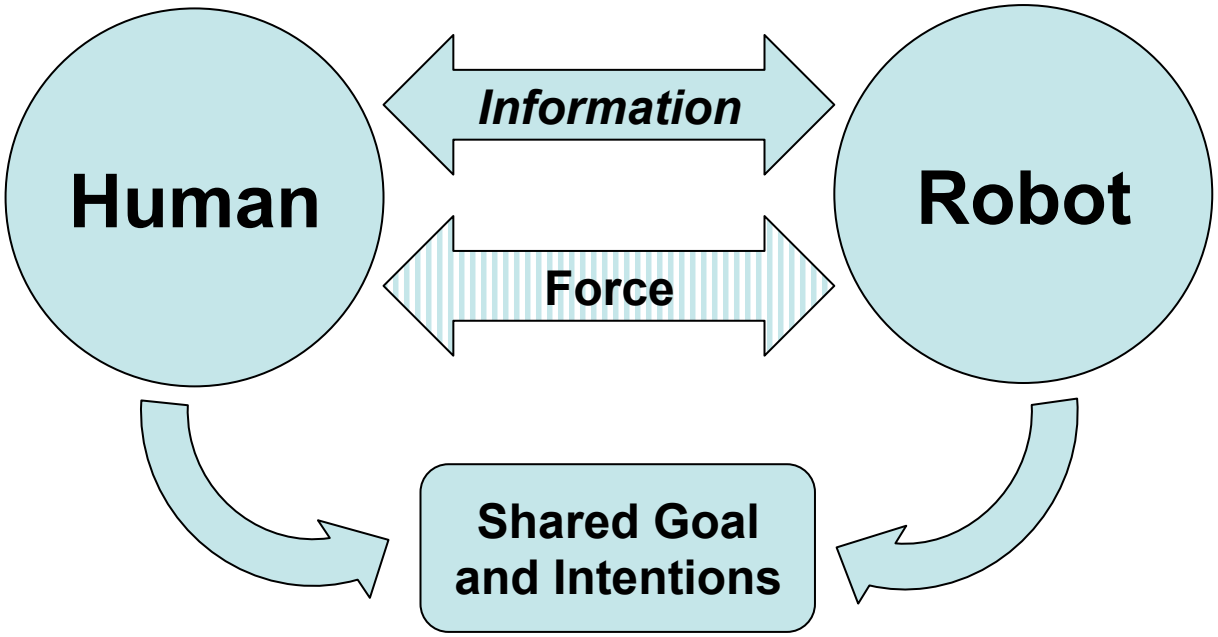
From living on the present to living in the future (the spatial and temporal mental travel)

Interaction with a communicative content is a much needed technology…

Beyond keyboards…

William Davidow: IEEE Spectrum August 2012

Human-like Interaction is much richer and involves many senses and communication through actions



(Inter)Action related communication

Actions often speak louder than words…

http://www.blaescommunications.com/2012/12/actions-often-do-speak-louder-than-words/

The Approach to the study of Human Machine Interaction

- Brain (human) Centric
- Technology Enabled
- Social Inclusion

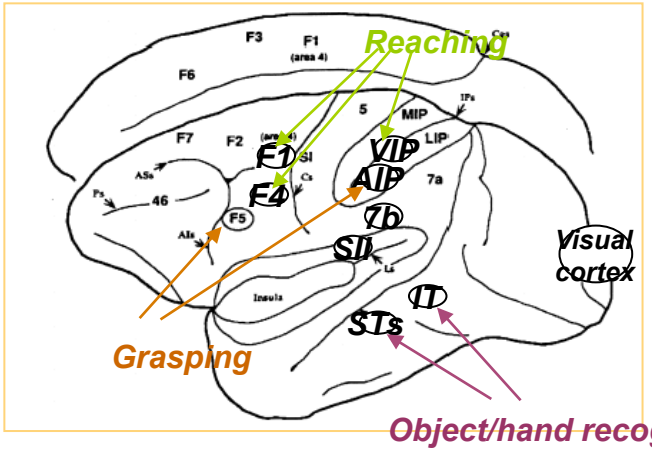
From science to social inclusion…

Interaction Science

- Brain (human) Centric
- Enabling Technologies
- Society Driven

The study of human behaviour is not a choice, is a requirement

Interaction Science



it is a necessity not a fashion to understand how humans interact

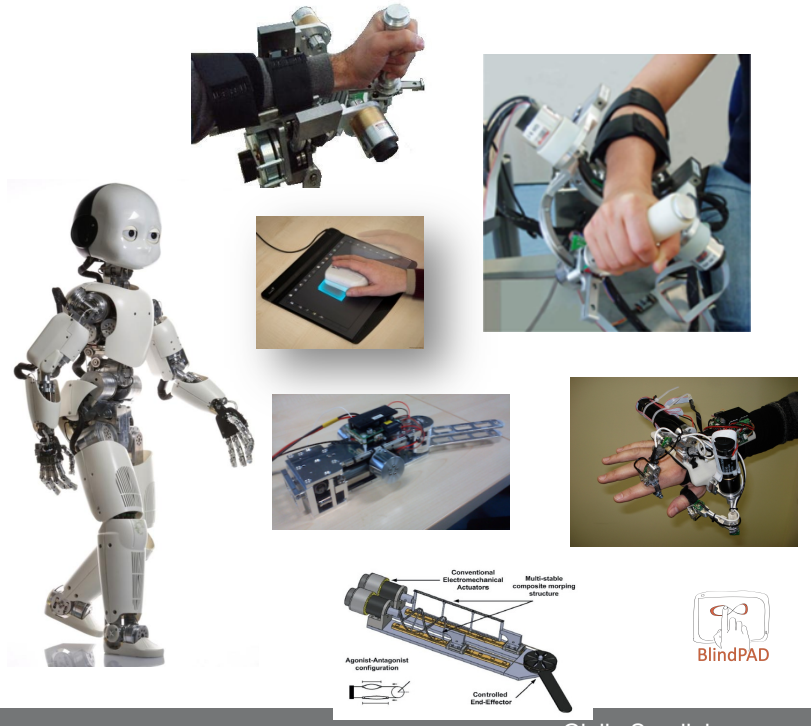
Technology &Engineering

- Brain (human) Centric
- **Enabling Technologies**
- Social Inclusion

Building Systems as tools to:

- Demonstrate Theories (how to build a cognitive system)
- Link experimental results to practical use (e.g. assistive devices).

Interaction Science → Technology Enabled



Societal Inclusion

- Brain (human) Centric
- Enabling Technologies
- **Social Inclusion**

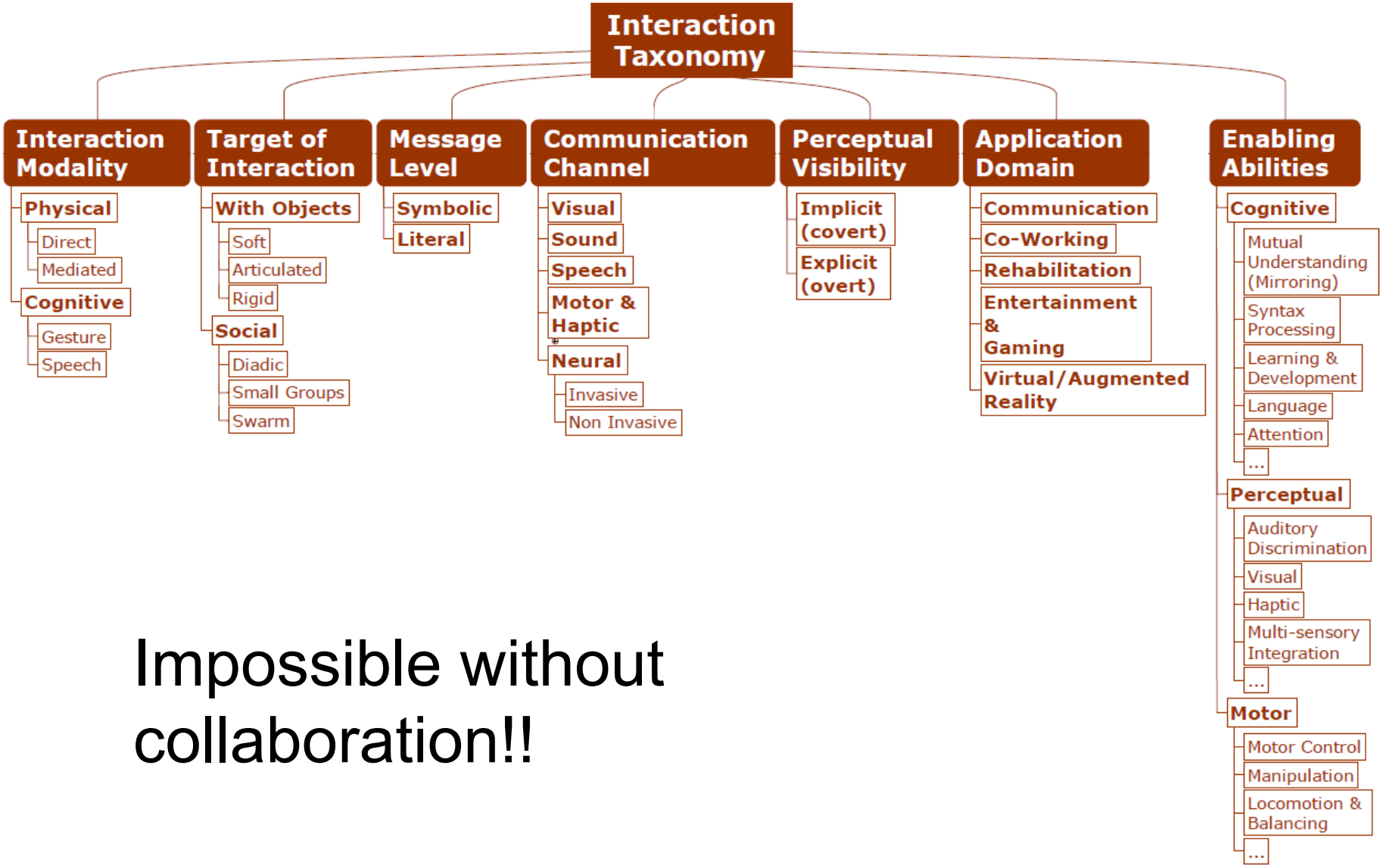
Ultimate goal is to support societal need to:

- **Restore** Function (Rehabilitation)
- **Assist** Function (Weakness)
- **Establish** Function (Disability)

Interaction Science → Technology Enabled → Social Inclusion

Which Ingredients for Interaction?

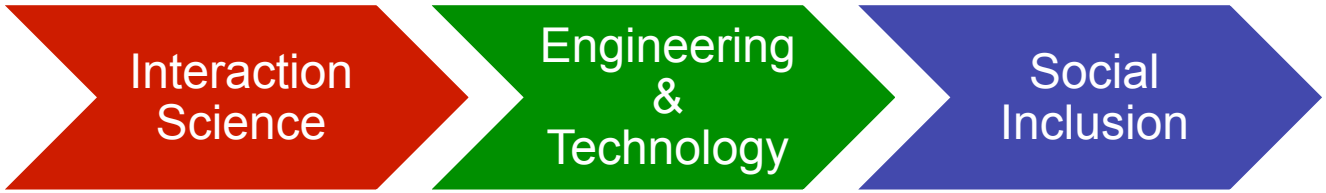
Taxonomy of Interaction



Impossible without collaboration!!

Enabling Abilities

- Cognition (predictive systems – Interaction is not about “reaction” but about “prediction”)
- Multisensory Integration (e.g visuo-haptic, visuo-acustic – visuo-tactile) to obtain, for example a unitary perception of body and space
- Whole body control and multiple contacts (Unity of Body Representation)
- Speech, Gestures (syntax, communication) from motor primitives to complex behaviour
- Perceptual and motor learning…



Few examples…

Cooperation between engineers and neuroscientists has generated suggestions for new experiments which have produced new scientific results

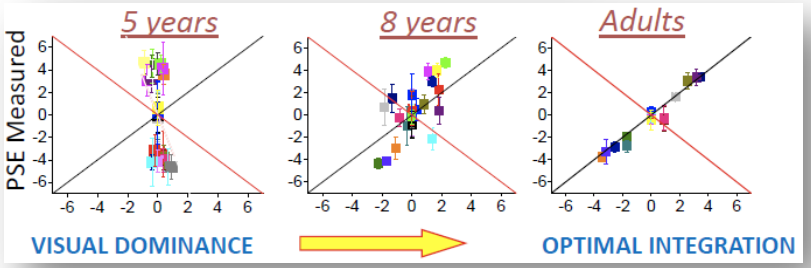
Multisensory Integration & Social Inclusion

(M. Gori, A. Tommassini, T. Vercillo, G. Sandini)

Development of Multisensory Integration

Audio Bracelet for Blind Interaction

Social Inclusion: Establish



ABBI

"IIT – Chiossone" Joint Lab

Gori, Del Viva, Sandini & Burr Current Biology 2008

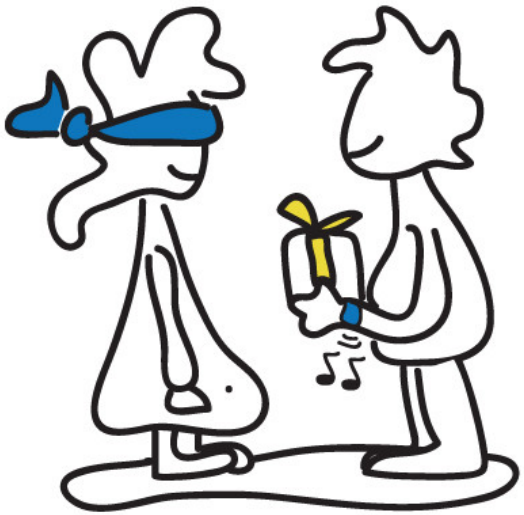
Gori, Martinoli, Sandini & Burr Brain 2014

Audio Bracelet for Blind Interactions

Monica Gori, Gabriel Baud-Bovy,Giulia Cappagli, Sara Finocchietti

ABBI

SELF



SOCIAL

STREP Objective ICT-2013.5.3 for smart and personalised inclusion
Coordinator: Monica Gori, IIT
Duration: 36 (01/02/2014 – 31/01/2017)

www.abbiproject.eu
Facebook: Abbiproject

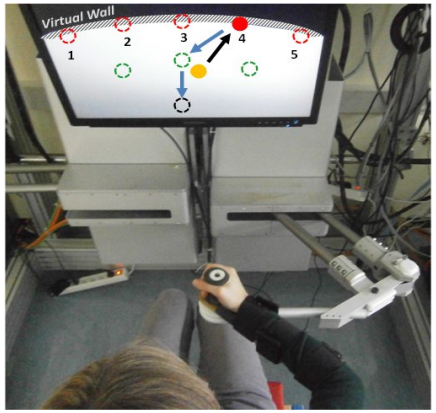
Motor Learning & Rehabilitation

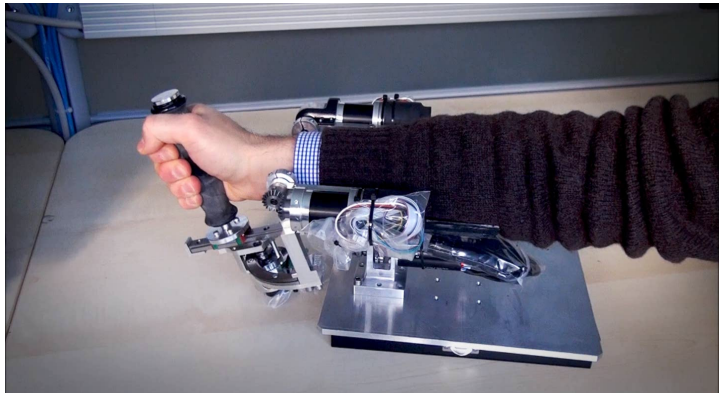
(P. Morasso, L. Masia, V. Squeri, J. Zenzeri, D. DeSantis, V. Cuppone, L. Cappello, G. Sandini)

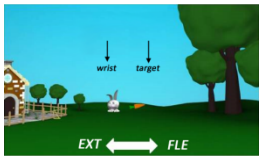
Intermittent Control

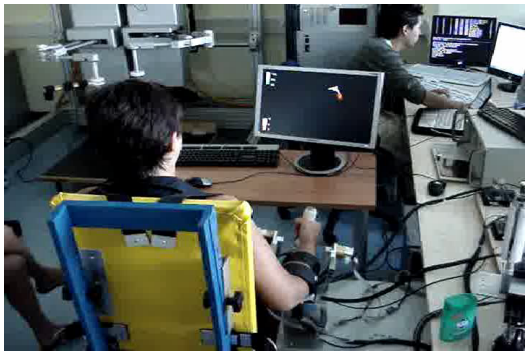
"Upper Limb" Robots

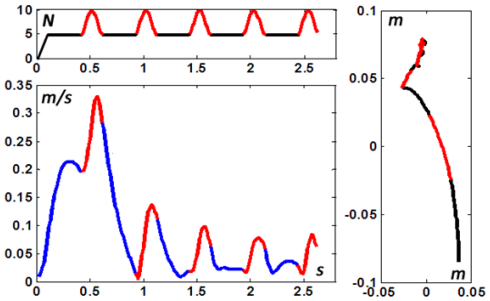
Interactive Robot Therapy

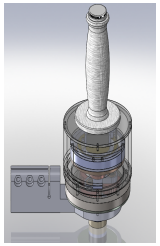


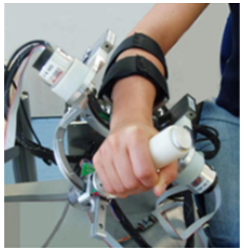












INAIL - Volterra

Masia L. , Squeri V., Sandini G. and Morasso P. ' Wrist coordination in a kinematically redundant stabilization task'. IEEE Transaction on Haptics, pp. 231-239, Third Quarter, 2012

Interaction with the Physical World

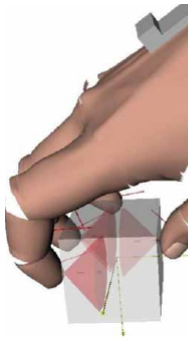
(G. Baud-Bovy, N. Gurari, F. Tatti, A. Akhras)

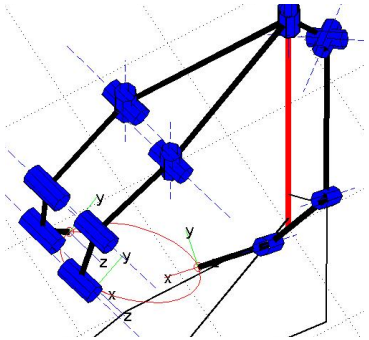
Haptic Interaction

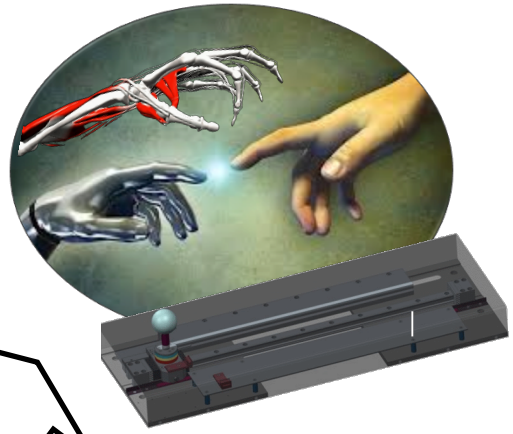
Human Performance and Haptic Technology

Ergonomics and Human factors

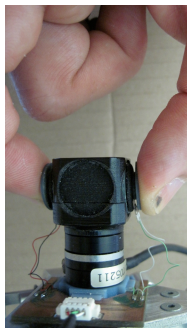
Motor function: Interaction force, grasping

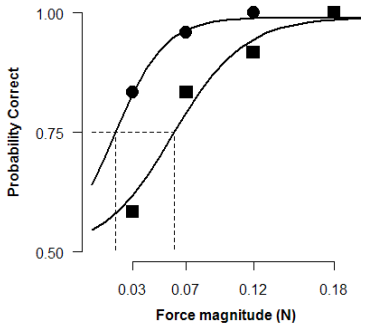






Perceptual function: Force and shape perception



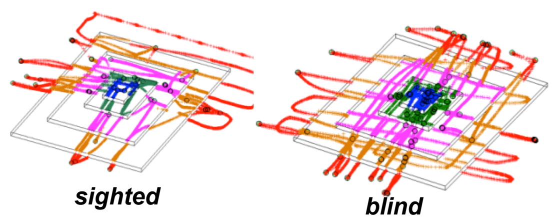


Psychophysics

Sensory Enhancement & Spatial Awareness

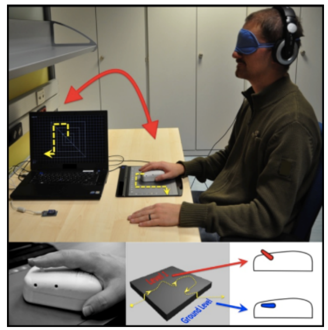
(Luca Brayda, Mariacarla Memeo, Wissawin

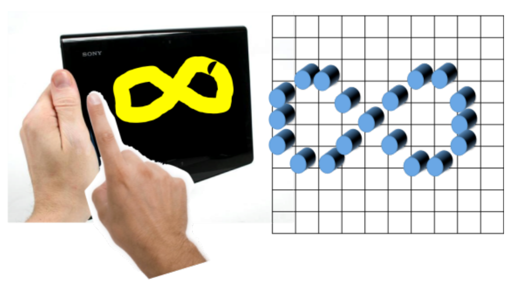
Construction of Cognitive Maps from Touch → **Touch and force displays for disabilities** → **Social Inclusion: Assist Space Perception**



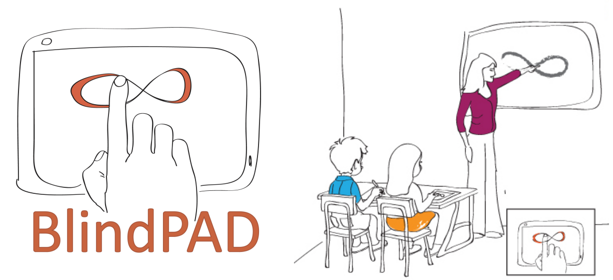
- vision-independence of maps
- predicting success of map construction

Campus et al. Journal. of Neurophysiol, 2012
Brayda et al. IEEE Transactions on Haptics, 2013





- cost-effective devices
- using new materials
- (EU Blindpad project)



Despina Fragouli
Athanassia Athanassiou

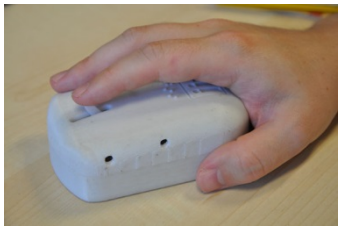
Simona Petroni
Massimo De Vittorio

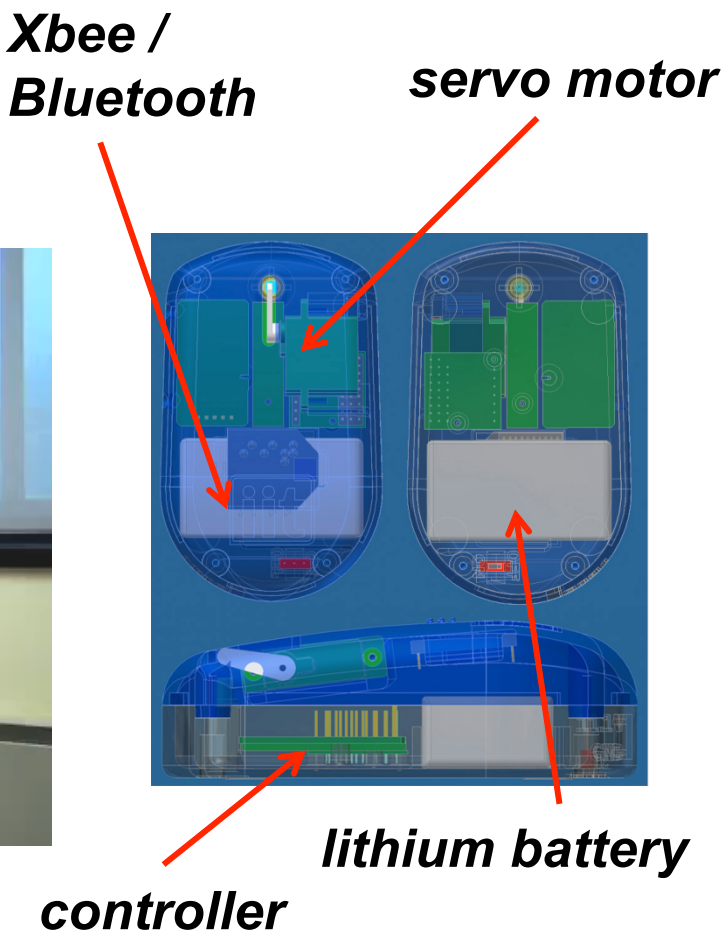
- non-visual internet navigation
- tactile mathematics
- artificial rehabilitators

The Tactile Mouse (TAMO) Project

(Luca Brayda, M. Memeo, Wissawin Kunchornsup)

A mouse with haptic feedback for transmission of 3D and/or graphic information





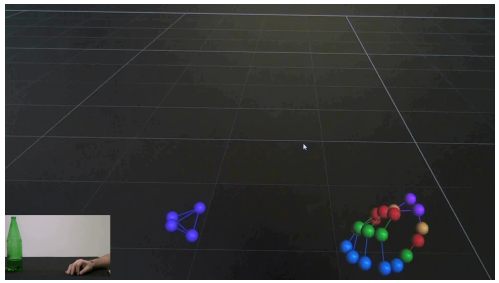
Intention from movement understanding

(Cristina Becchio, Caterina Ansuini,

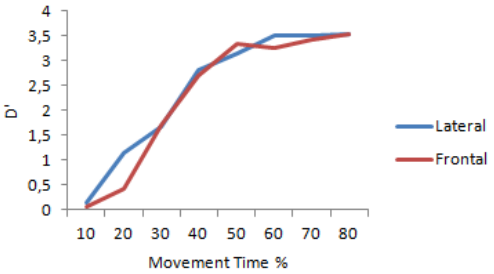
Encoding intention: kinematics and EMG analysis

Decoding intention: TMS, EEG, and fMRI

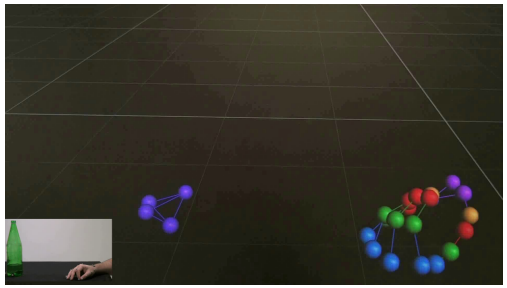
Grasping others' intention



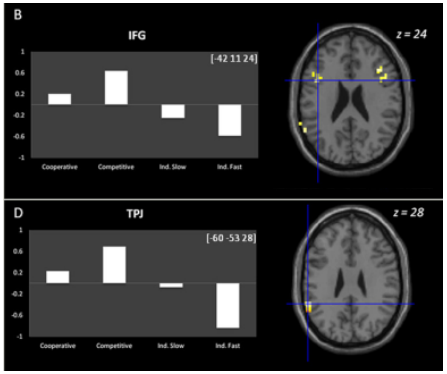
to place

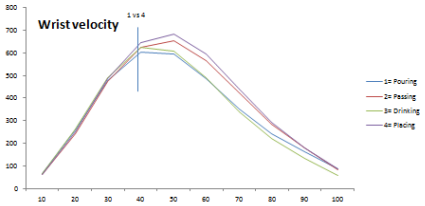


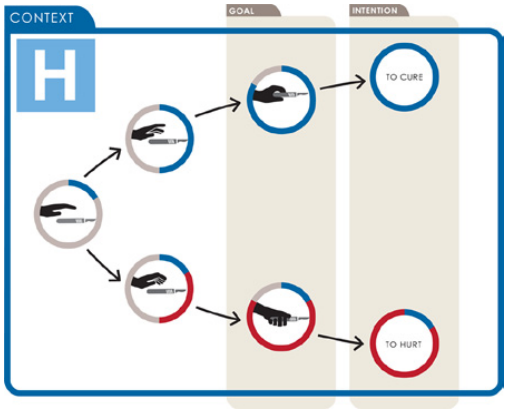
new perspectives into the neurobiology of how we know other minds and predict others' behavior



to pour





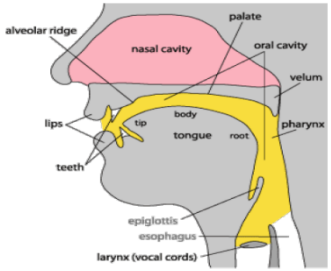


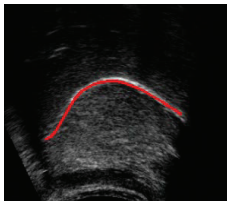
Speech, Gesture & Communication

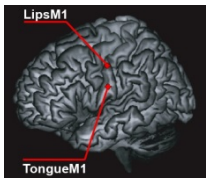
Motor Contribution to Speech Perception

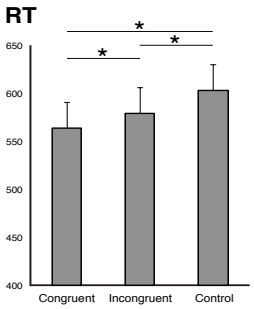
Robust Automatic Speech Recognition

Decoding Communicative Intentions

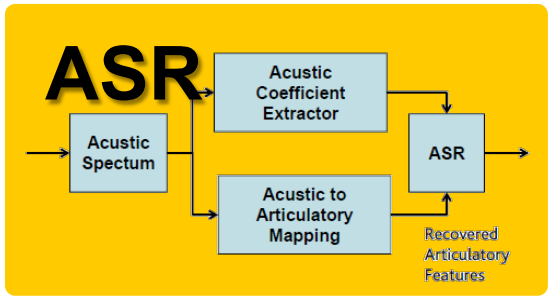


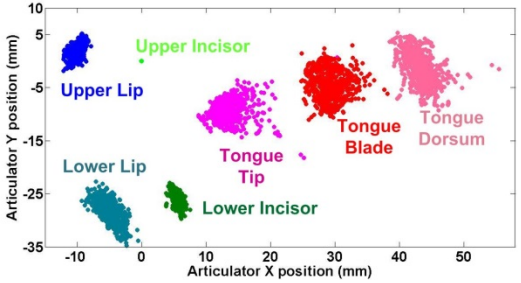




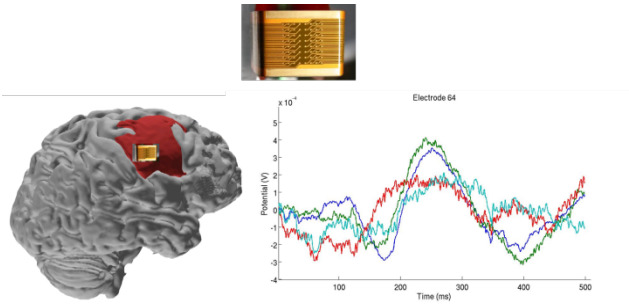


Transcranial Magnetic Stimulation, EEG , Motion Kinematics, Behavioral methods





ElectroMagneticArticulography, Deep Neural Networks



Recording with Electrocorticography matrices from motor cortex during reading

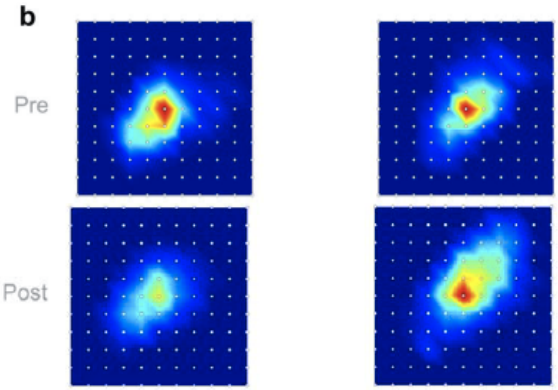
Action Observation & Motor Rehab.

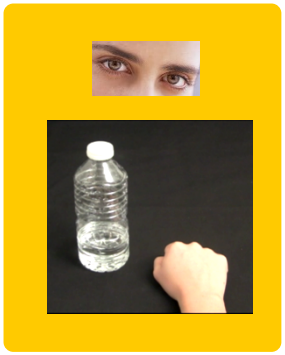
(T. Pozzo, L. Fadiga, A. Inuggi)

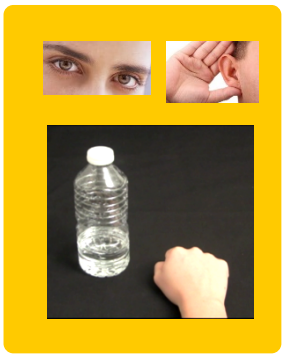
Action Observation and Brain Plasticity: a TMS study

Multimodal Action Observation and EEG Analisys

Restore: Neurorehab*ilitation*

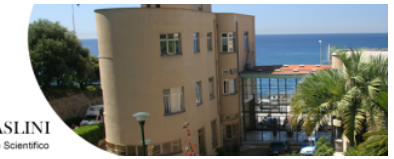






Mirror neurons open a gate to the motor system of stroke patients and new rehabilitation procedures

ISTITUTO GIANNINA GASLINI
Istituto Pediatrico di Ricovero e Cura a carattere Scientifico



LA FONDATION MOTRICE
RECHERCHE SUR LA PARALYSIE CÉRÉBRALE

Bassolino M., Campanella M., Bove M., Pozzo T. & Fadiga L., (2013) Cerebral Cortex

Small Group Interaction

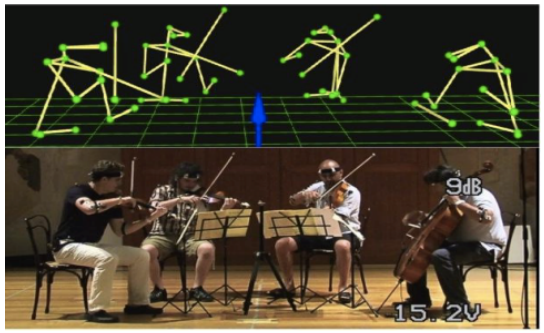
(L. Fadiga, L. Badino, A. D'Ausilio)

Measuring Sensorimotor Communication

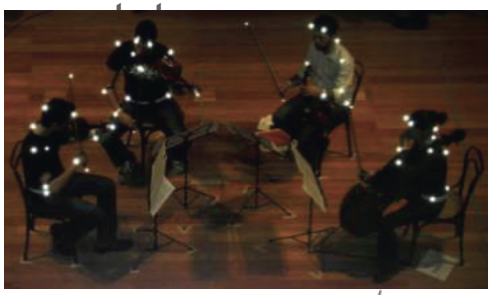
Real-time Extraction and Processing

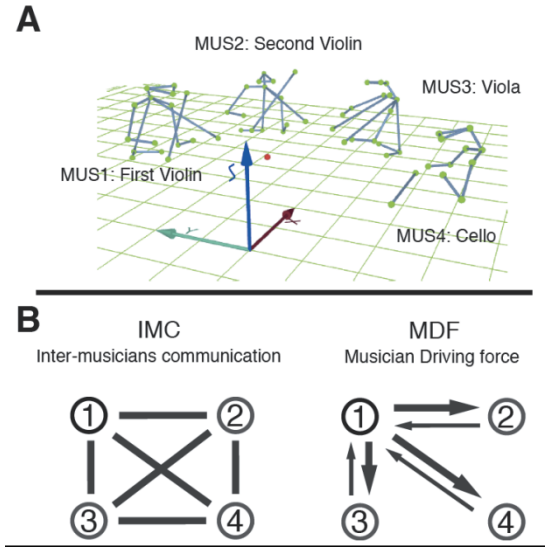
Group Collaboration Enhancement

Sensorimotor Communication in Orchestras



Leadership in



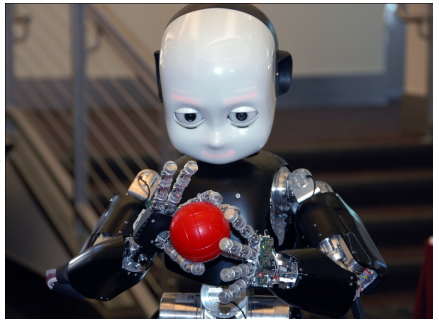


In collaboration with casa Paganini

…we are following a dual path

Study Humans
(and the way they interact)

Use *Robots*
(as models and stimuli)

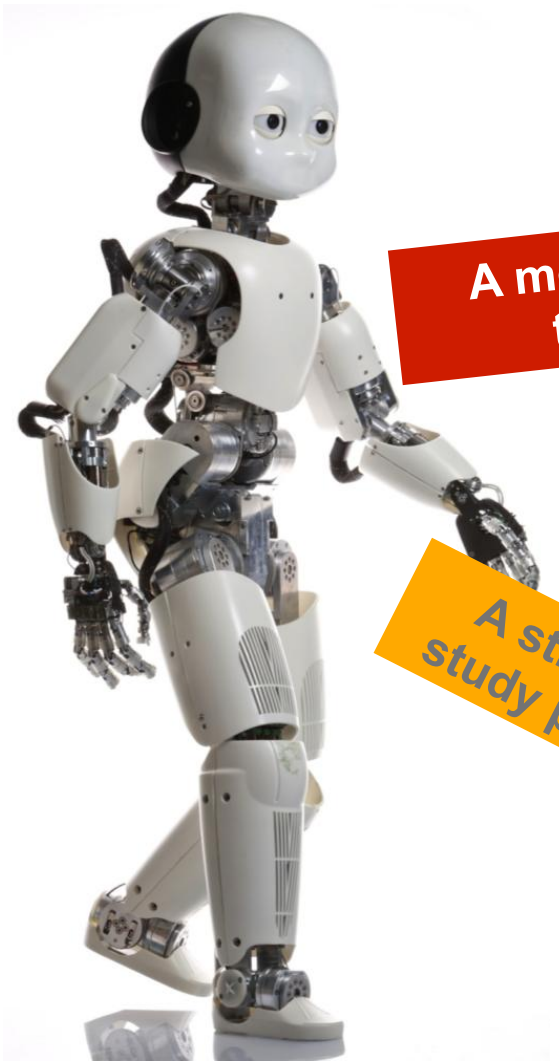


Explore the Interaction

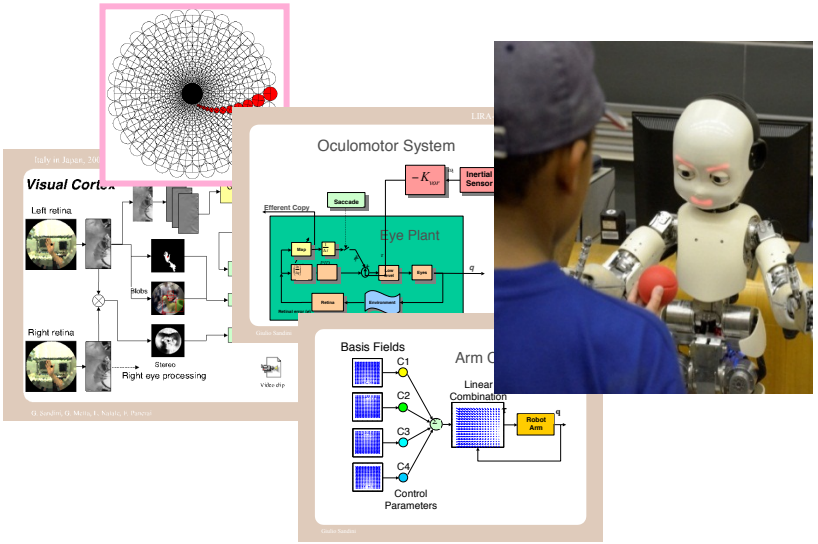
Study how humans develop their motor, perceptual and cognitive and social abilities

Build embodied models of the development of human motor, perceptual and cognitive abilities

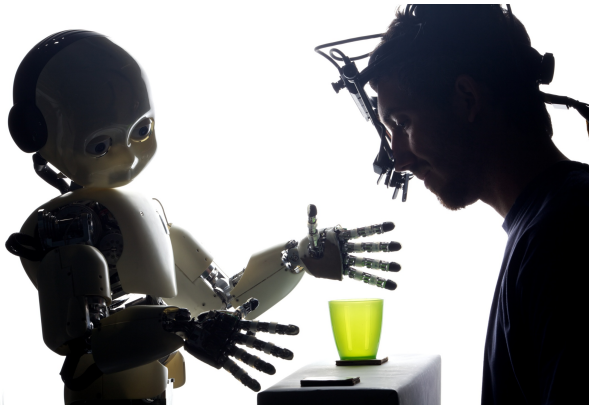
We use the robot in two ways:



A model to test theories

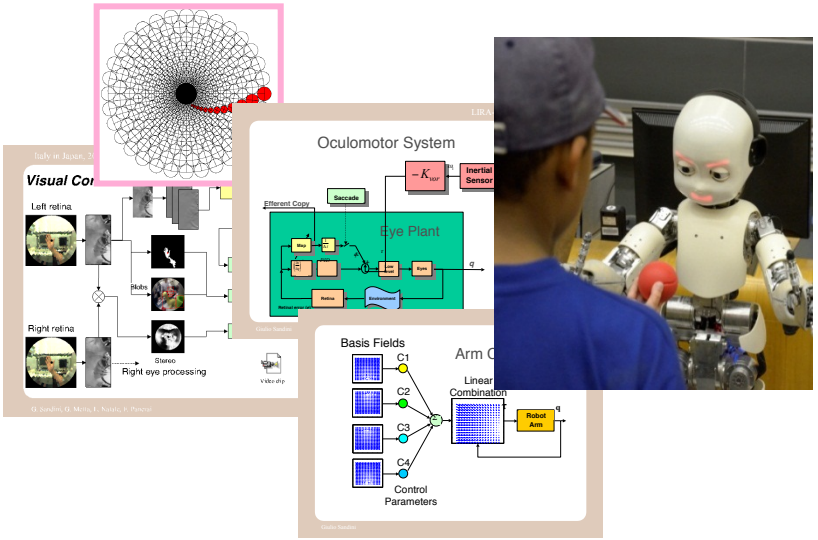


A stimulus to study principles



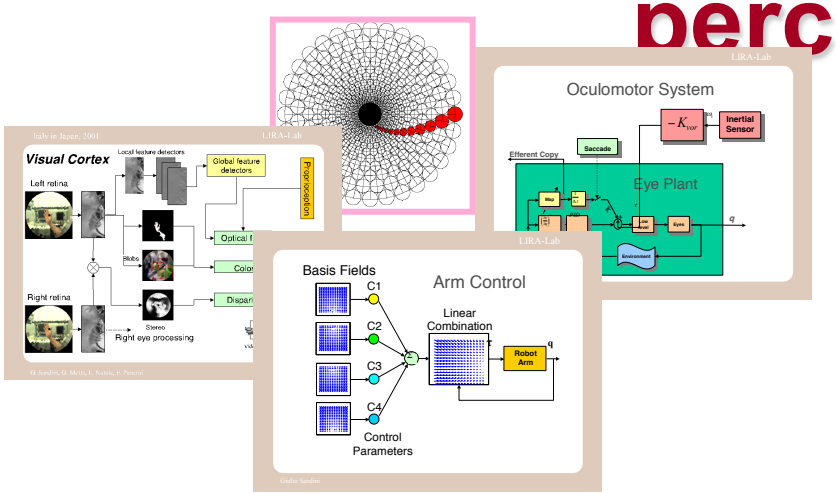
Use humanoids as models:

A model to test theories

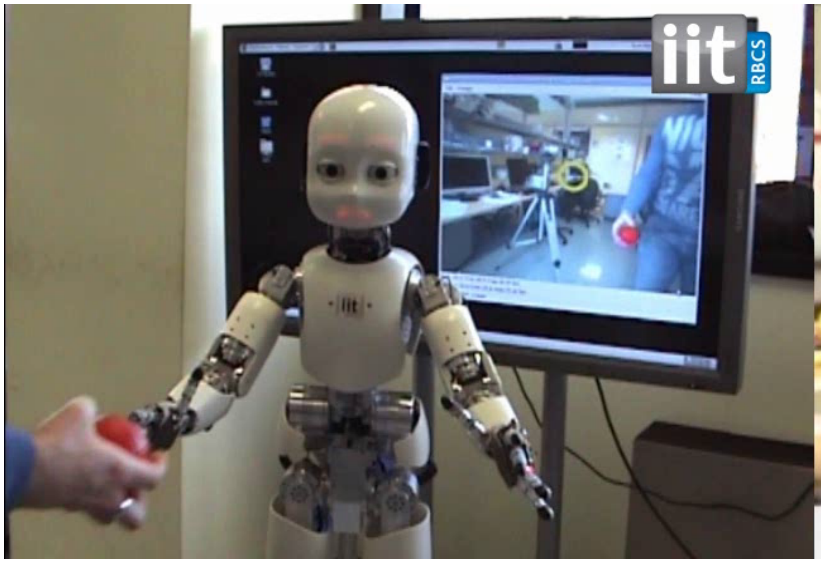


Test hypothesis about how individual as well as social behaviors are controlled and learned

Need to study human-like perception and control…



…to move «like a human»



Whole Body Motion Control with Multiple Contacts (F. Nori, D. Pucci, F. Romano, L. Fiorio, S. Traversaro, J. Eljaik)

Basic science

Adaptive control

Adaptive control of underactuated mechanical systems.

Collocated Adaptive Control of Underactuated Mechanical Systems. F. Romano, D. Pucci, F. Nori

Dynamic estimation

Library for identifying whole-body dynamics in free floating robots.

BERDY: Bayesian Estimation of Robot Dynamic variables. F. Nori.

Muscles modeling

A passive noise rejection variable stiffness actuator.

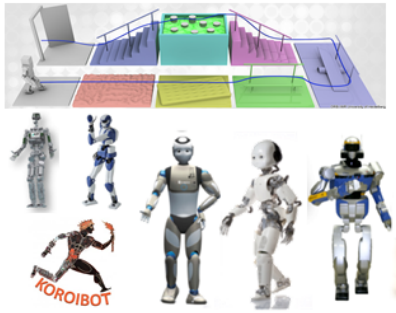
Control of a single Degree of Freedom Noise Rejecting - Variable Impedance Actuator. F. Nori, B. Berret, L. Fiorio, A. Parmiggiani, G. Sandini

3/21/2014 17

FP7-EU project CoDyCo

3/21/2014 3

FP7-EU project Koroibot



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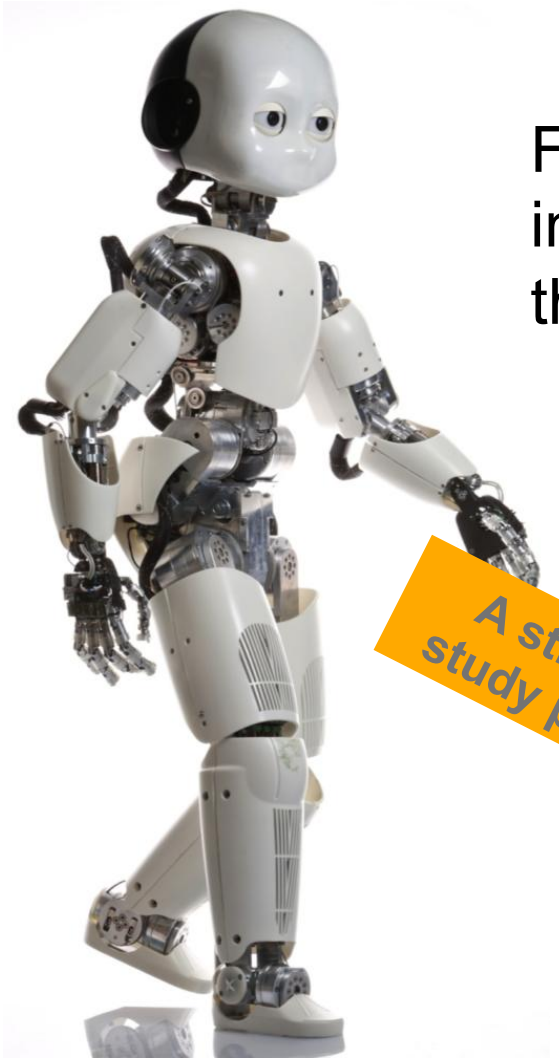
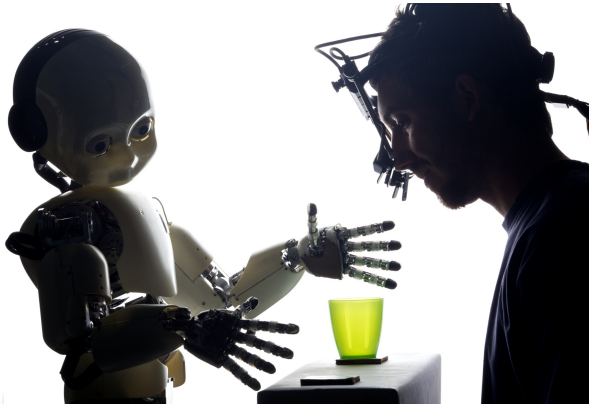
With

Use a humanoid as a stimulus
(studying the principles)



Find the principles behind human-human interaction by manipulating quantitatively the way the robot moves and react

A stimulus to study principles



To ask questions like…

- Which are the visual cues of actions activating motor resonance?
- What can I discover about (inter)action from the way my partner moves and acts?
- How do I adjust my pace with my partner's?

Using the robot as stimulus to investigate interaction

Implicit communication between humans is mediated by action observation: which elements of gaze and body motions are fundamental for efficient interaction?

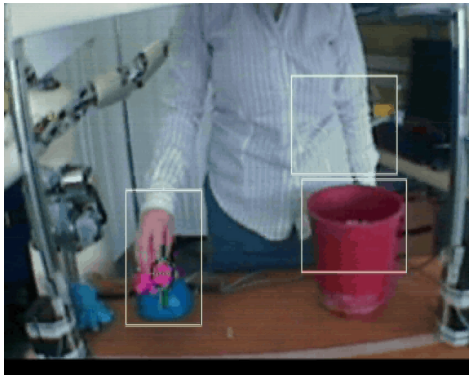
The role of gaze

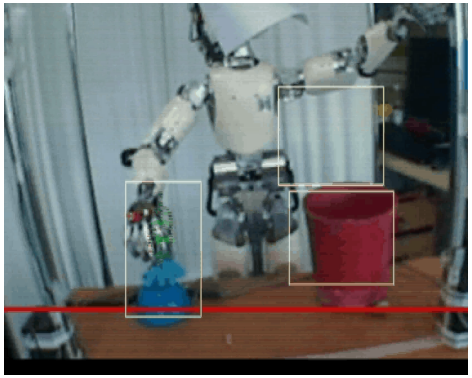
Communicative gaze

Non-communicative gaze

Sciutti, Del Prete, Natale, Burr, Sandini & Gori Human Robot Interaction Conference 2013

The role of action goal

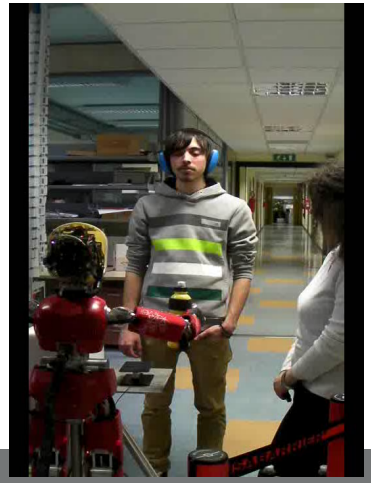




Sciutti, Bisio, Nori, Metta, Fadiga & Sandini Interaction Studies 2013

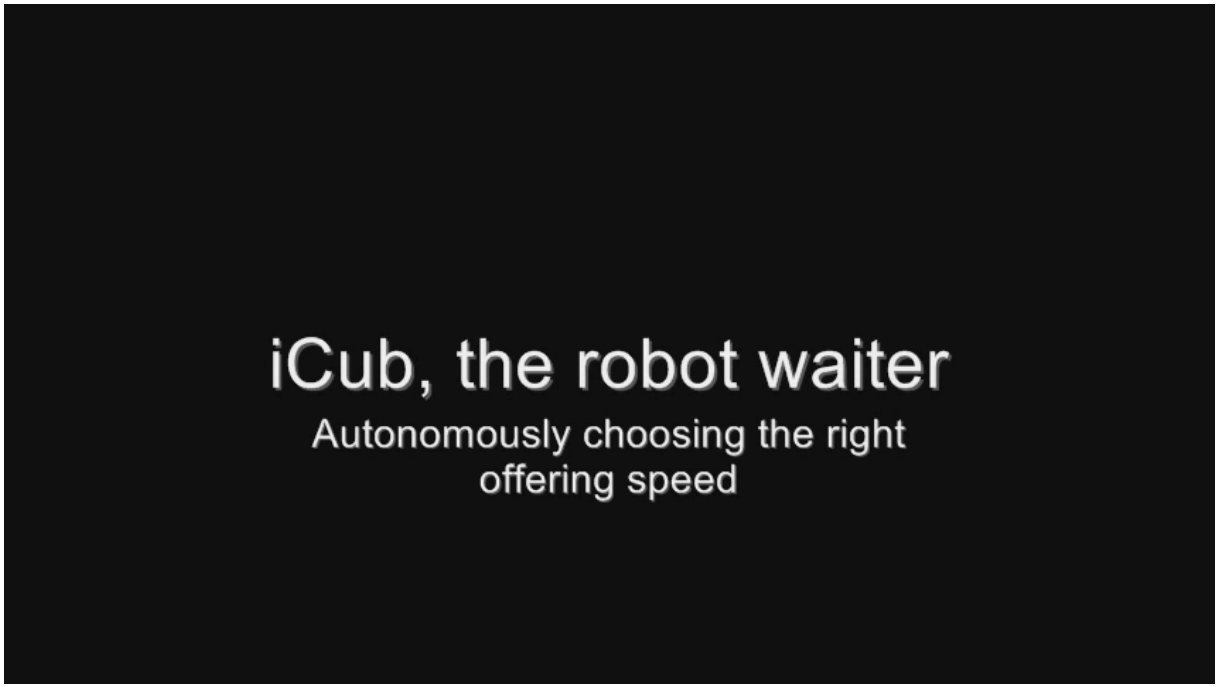
The role of movement kinematics

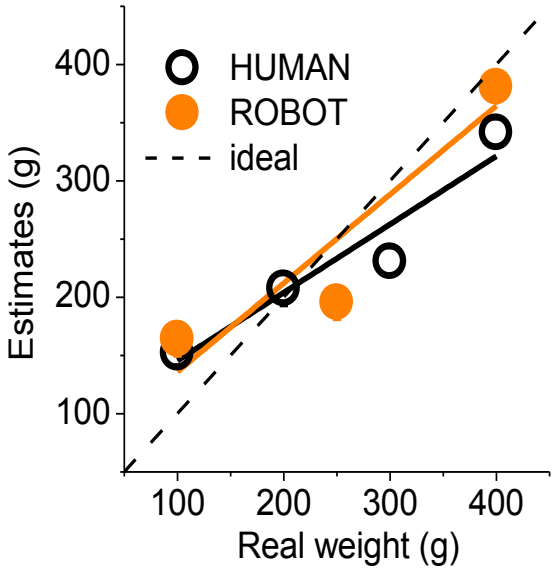
Sciutti, Patanè, Nori & Sandini , IEEE Transactions on Autonomous Mental Development 2014



Bisio, Sciutti, Nori, Metta, Fadiga, Sandini, & Pozzo, PloS one, 2014

Making the robot select the most communicative motions..





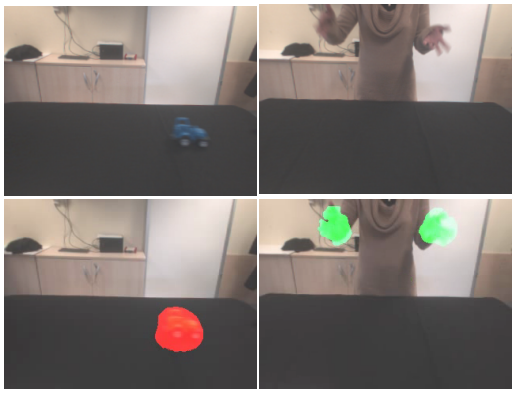
Palinko, Sciutti , Patané, Rea, Nori & Sandini, HUMANOIDS 2014

Sciutti, Patanè, Nori & Sandini , IEEE Transactions on Autonomous Mental Development 2014

Making the robot read…

human movements

Detect biological motion



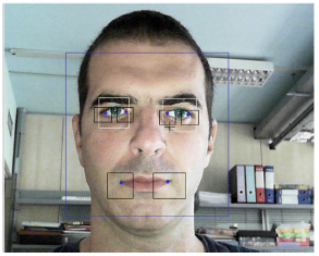
Sciutti, Noceti, Rea, Odone, Verri, Sandini, ECVP 2014

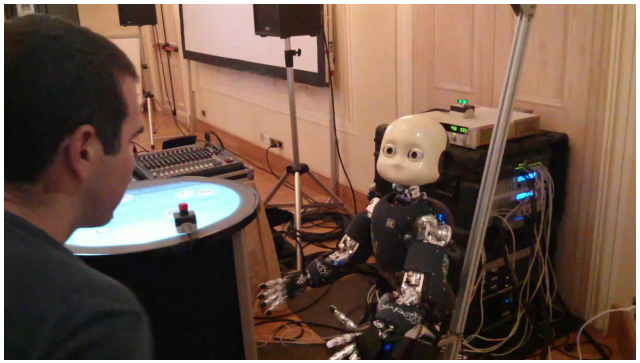
Read subtle action features (e.g., weight)

100g

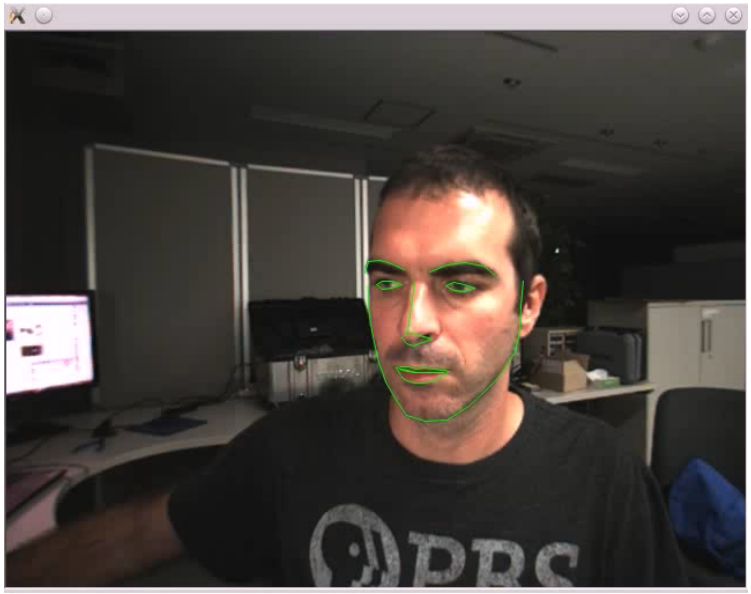
400g

human gaze

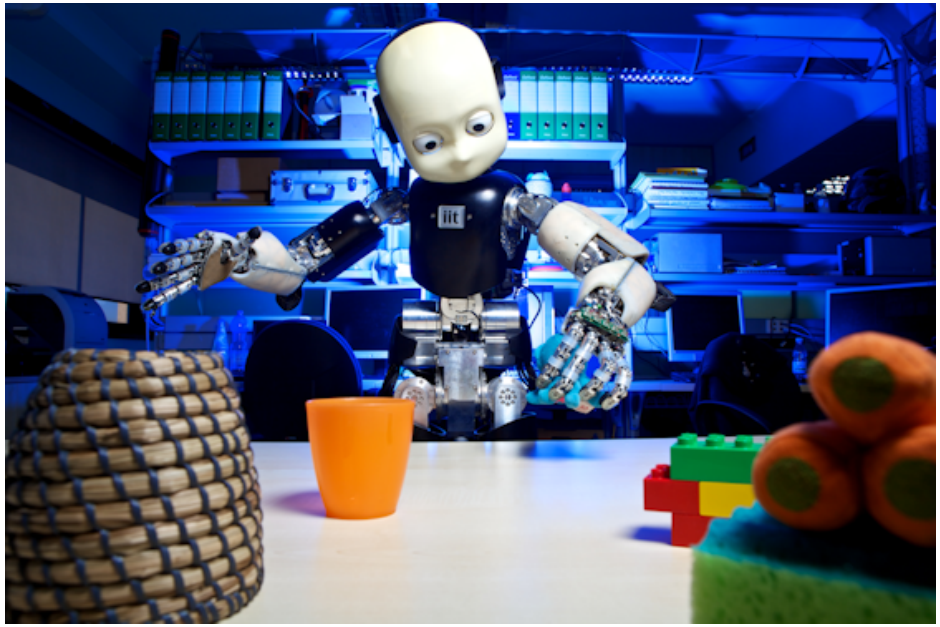




Palinko, Sciutti, Rea, Sandini, HAI 2014



…a functional humanoid robot as one of the tools to study the principles of human-like interaction …and mutual understanding



A humanoid can be an active, multimodal, learning, anthropomorphic display which can elicit motor resonance (I can relate with it motorically)

Is it possible to guide the two fields so that there is a real community of intentions and a mutual advantage?

…trying to go beyond (the superficial level of) interdisciplinarity

Behavioural experiment

Scientific paper
Engineering paper

Robot model

Reading

Joint Design

Trying to establish a stronger (real) link between the embodied model and the behavioural experiment…

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

Need to establish an integrative process

Interdisciplinarity is an **interactive pr** in which researchers **work jointly**, eac his or hear own discipline specific p ddress a **common research proble**

Transdisci **ntegrative process** in which researchers jointly to dev p and use a **shared conceptual framework** that **synt sizes and extends discipline specific theories**, concep and methods to create new models and language (*)

AND YOU NEED A LOT OF ENERGY (does not happen by itself…)

..from good ingredients..

The "magic Blend"

..to a new taste..

(*) P.L. Rosenfield: The potential of transdisciplinary research for sustaining and extending linkages between the health and the social sciences. Soc. Sci. Med; 35; 1342-57

…we need to invest more effort on establishing new research environments …

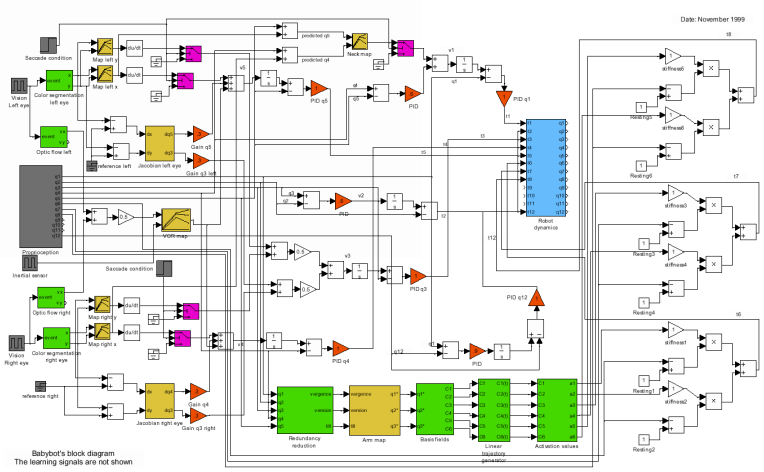
Concept of *scientific contamination* arising in scientific environments where scientists with different background "absorb" reciprocal knowledge by discussing similar issues starting from different perspectives.

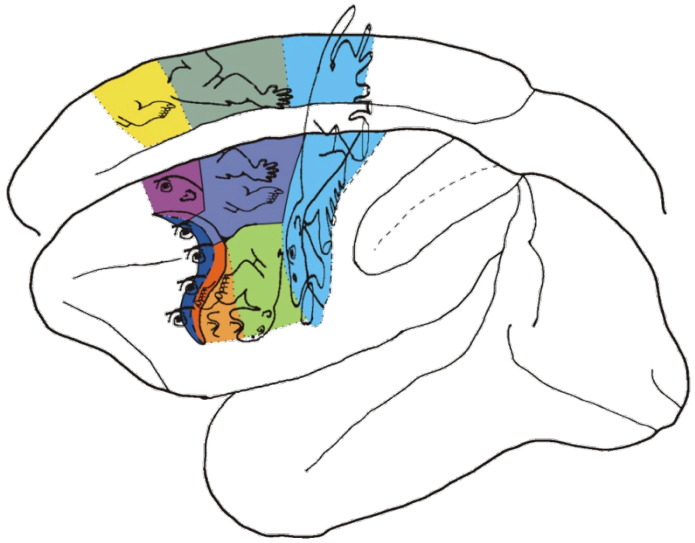
The “coffee machine” is necessary but not sufficient…

Chance favors only the prepared mind…

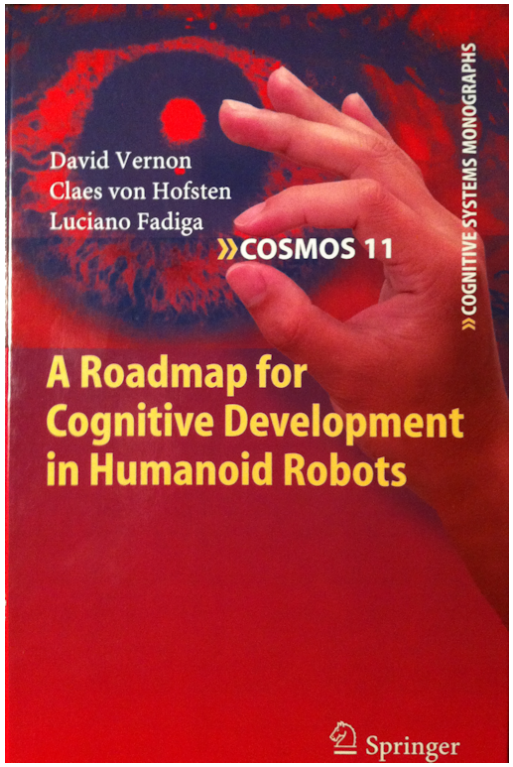
Forming a new community...

…composed of robotics engineers and neuroscientists studying the central role of the body in mediating the interaction between humans and between humans and robots



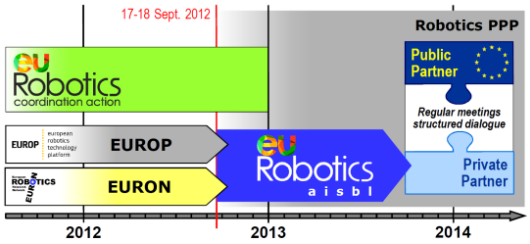


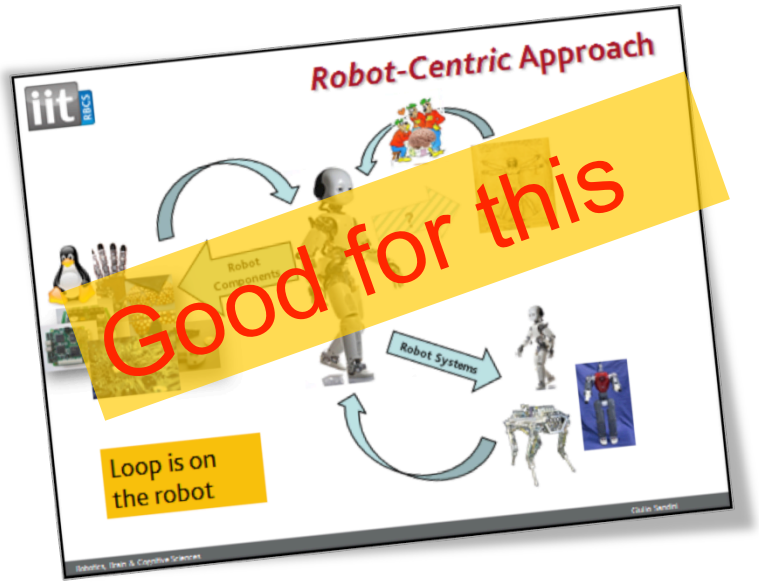
Engineers and Neuroscientists can work together on an architecture (the big picture) as a reference for the individual skill and a roadmap for future activities

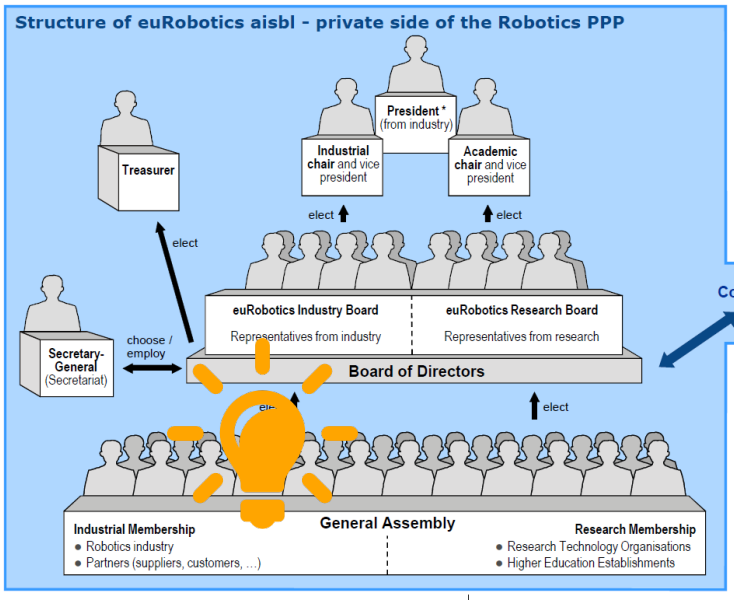


David Vernon (an engineer), Claes von Hofsten (a developmental psychology), Luciano Fadiga (a neuroscientist).

…is this the right way to go?





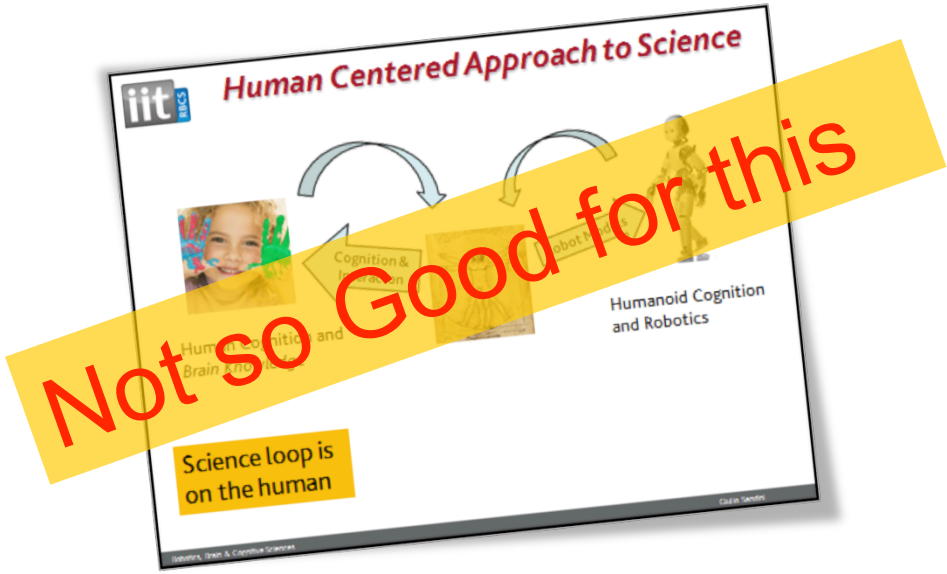


Organisation Structure

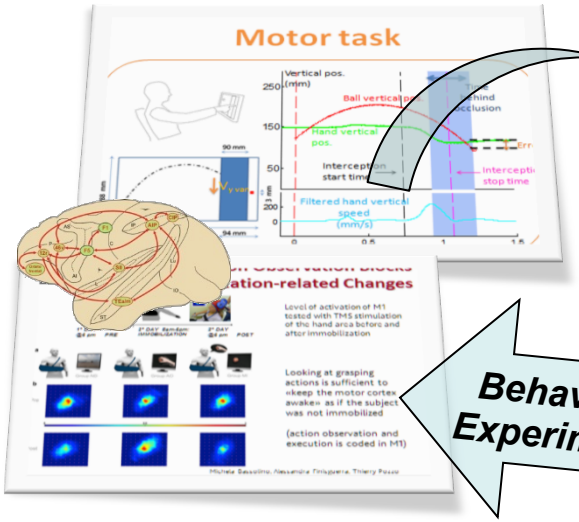
euRobotics aisbl *has a balanced representation of industry and research in its Board of Directors.*

A well known representative of European robotics is suggested by the board of directors and elected by the general assembly as President to represent the organisation vis-à-vis political institutions at highest levels.

http://www.eu-robotics.net/about/about-eurobotics-aisbl/

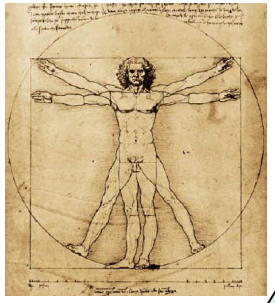


Human Centered & Science Driven



Human Cognition and Brain Knowledge

Behaviour Experiments



Robot Models

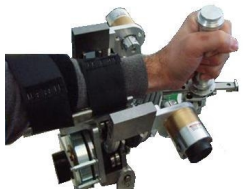
Humanoid Cognition and Robotics

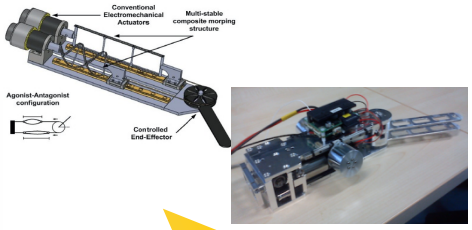
Interaction & Interface

Robotic Rehabilitation a Brain Machine Interface

Advance knowledge of ourselves

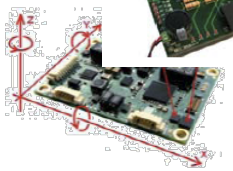
…from Science to Technology…



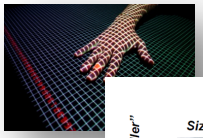


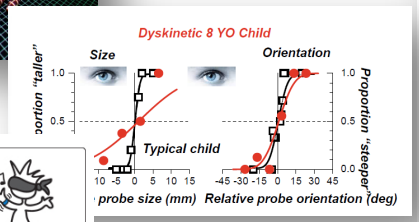
Rehab Tools and Protocols

Machine Intelligence HW & SW devices

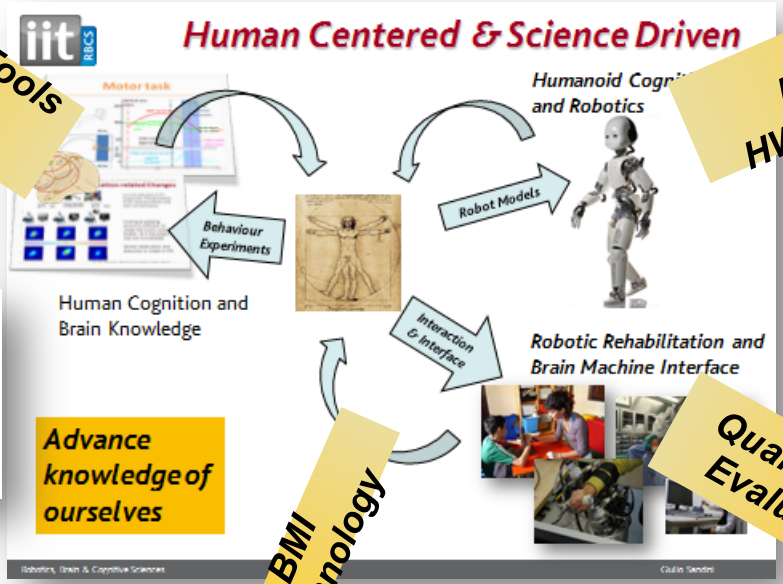


BlindPAD



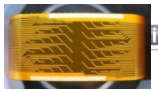


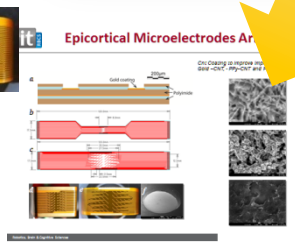
ABBI

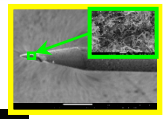


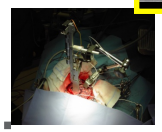
BMI Technology

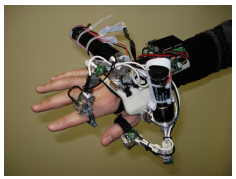
Quantitative Evaluation







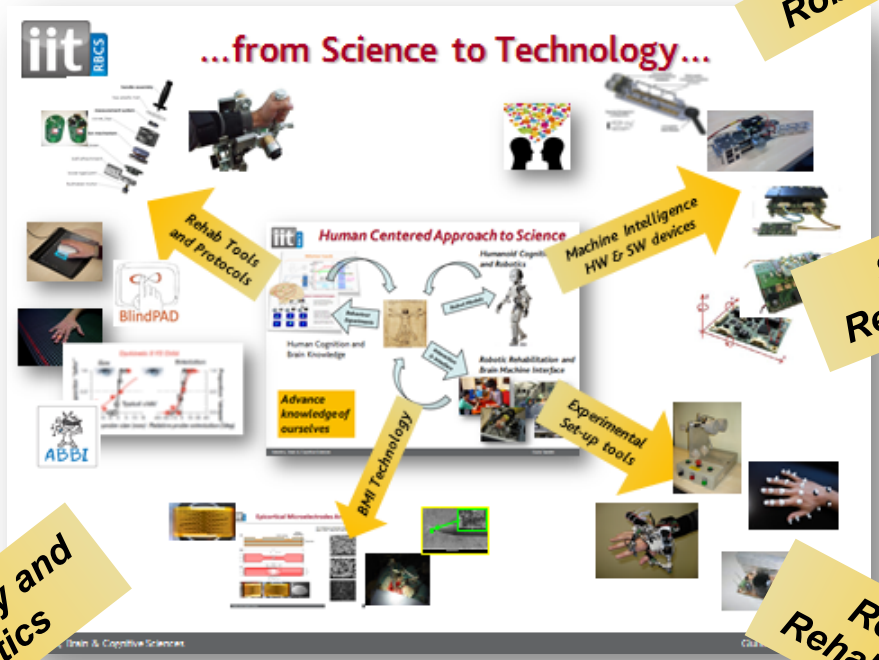




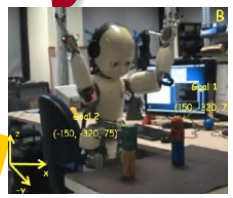
…from Technology to Society

Joint Lab with
Gaslini Children's Hospital – Paolo Moretti

Clinical Investigation



Robot Friends



David Chiossone Institute for blind in Genova and Stella Maris in Pisa

Sensory Rehabilitation

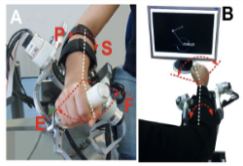
BlindPAD ABBI

Neurosurgery and Prosthetics

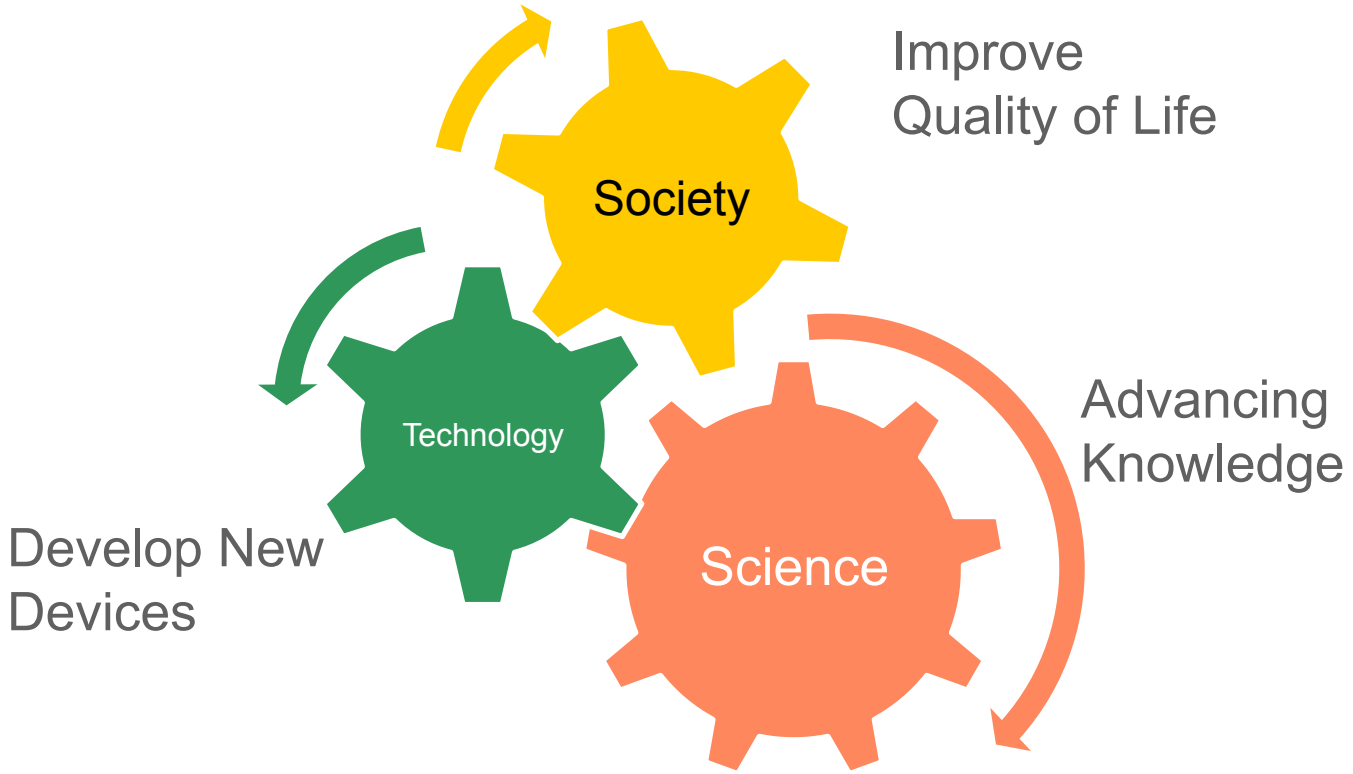
Ospedale della Misericordia Udine – Miran Skrap

Robotic Rehabilitation

Joint Lab with INAIL Volterra



….Human centric approaches offer the possibility to go one step beyond generating Scientific and Technological Values to also add Social Values




Grazie!