ISTITUTO ITALIANO
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Body and mind of a humanoid robot: where technology meets physiology

Giorgio Metta and many contributors

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Dept. of Robotics, Brain and Cognitive Science
Italian Institute of Technology

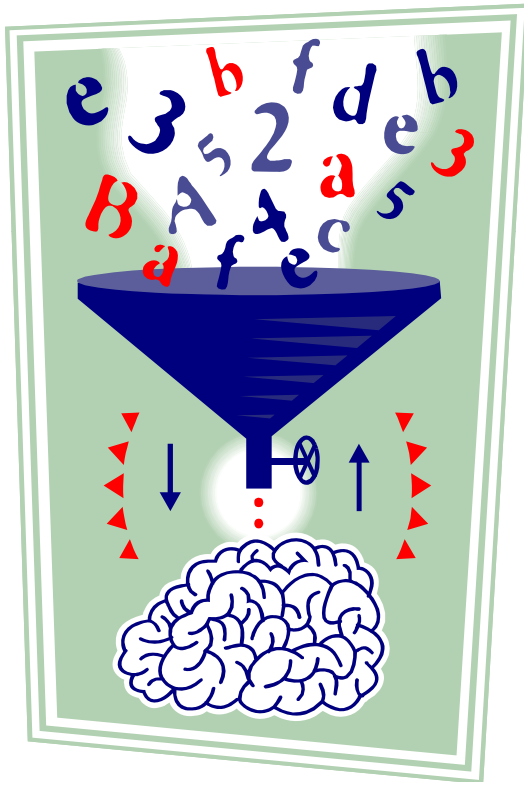
Cogsys
Cognitive Systems

RobotCub

Our background

- The main focus of our activities is in the implementation of biologically sound models of cognition in robots of humanoid shape
- This has the two-fold aim of:
  - furthering our understanding of brain functions
  - realizing robot controllers that can learn and adapt from their mistakes

The kernel of the problem



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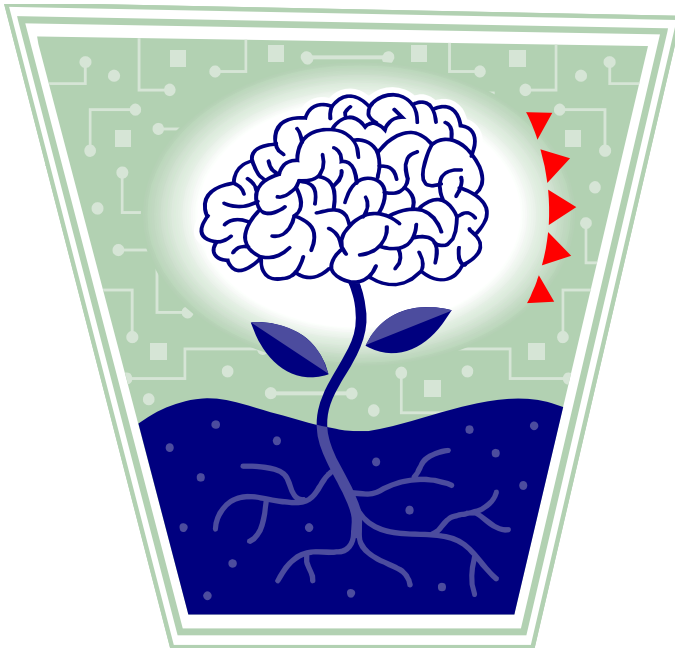
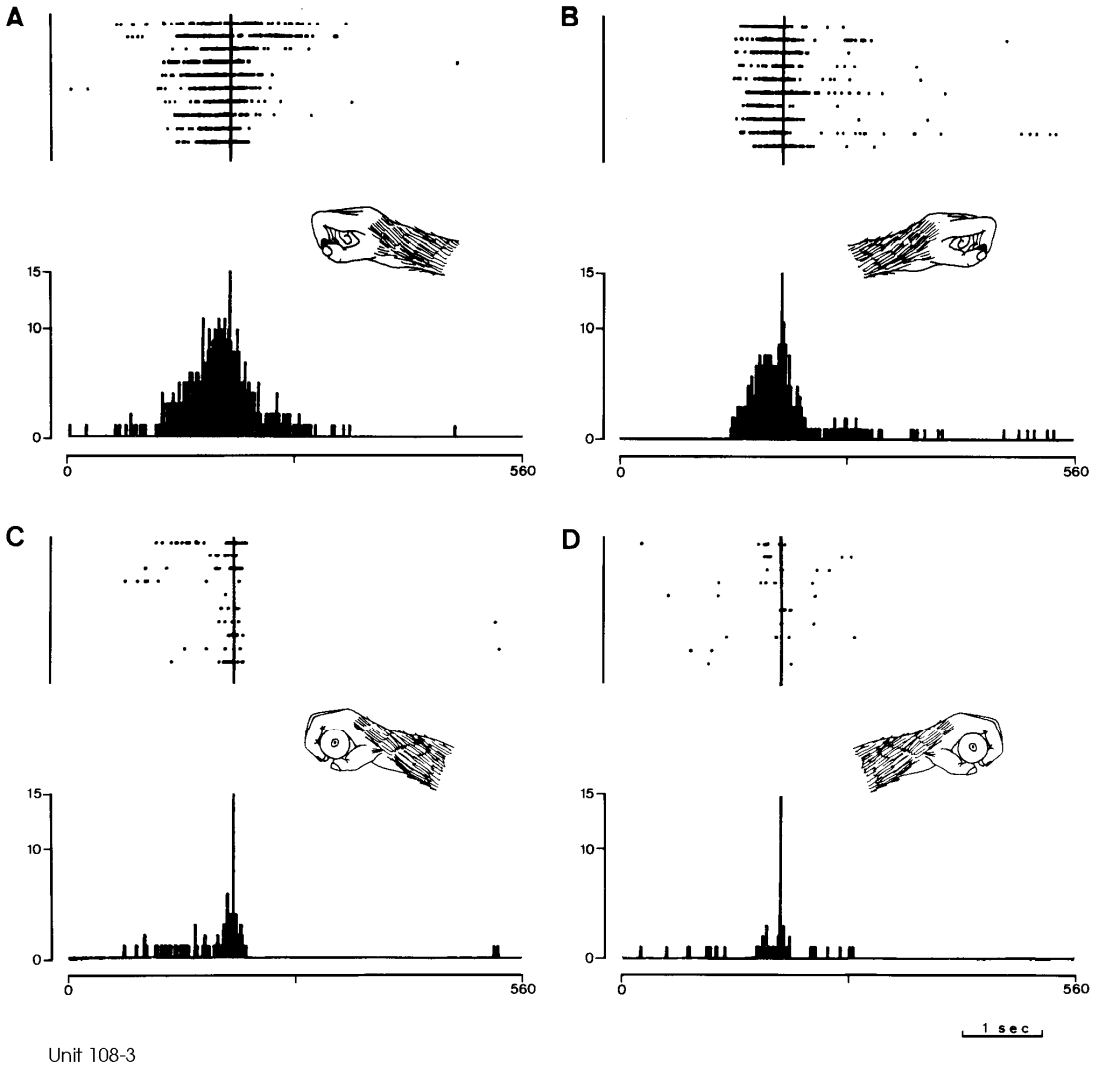
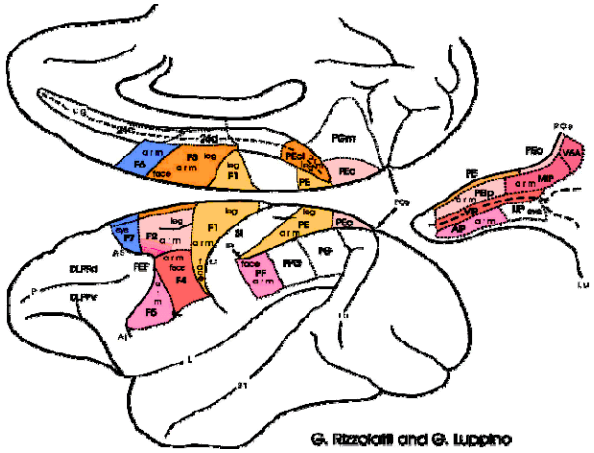


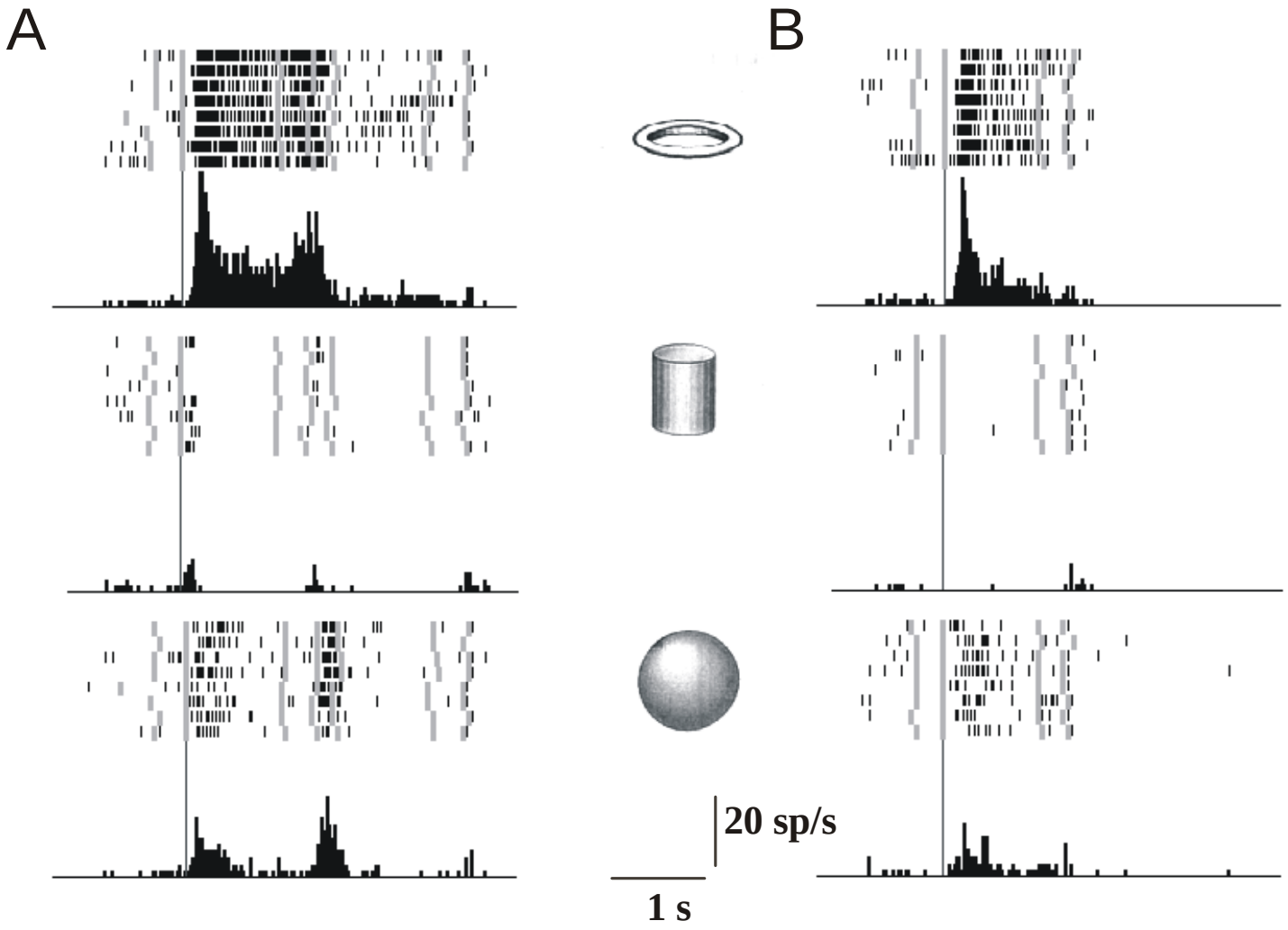
Grasping neurons





Fadiga et al. (various sources)

F5 canonical neurons

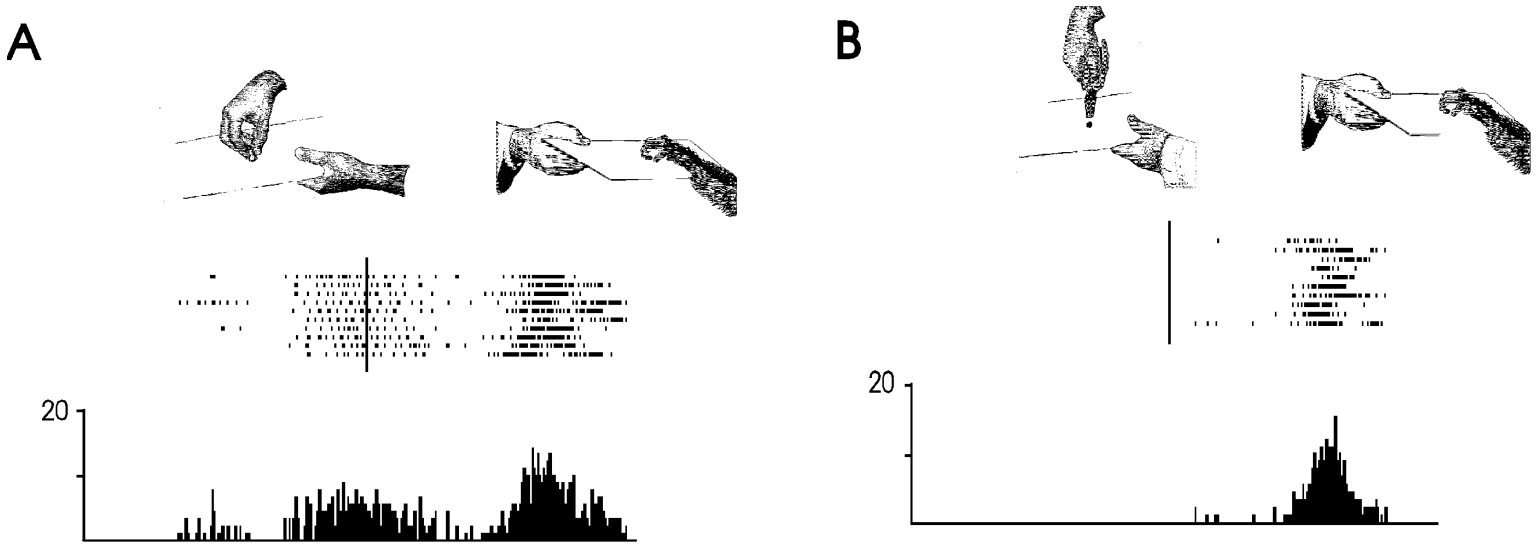


Observation + action

Observation only

Mirror Neurons

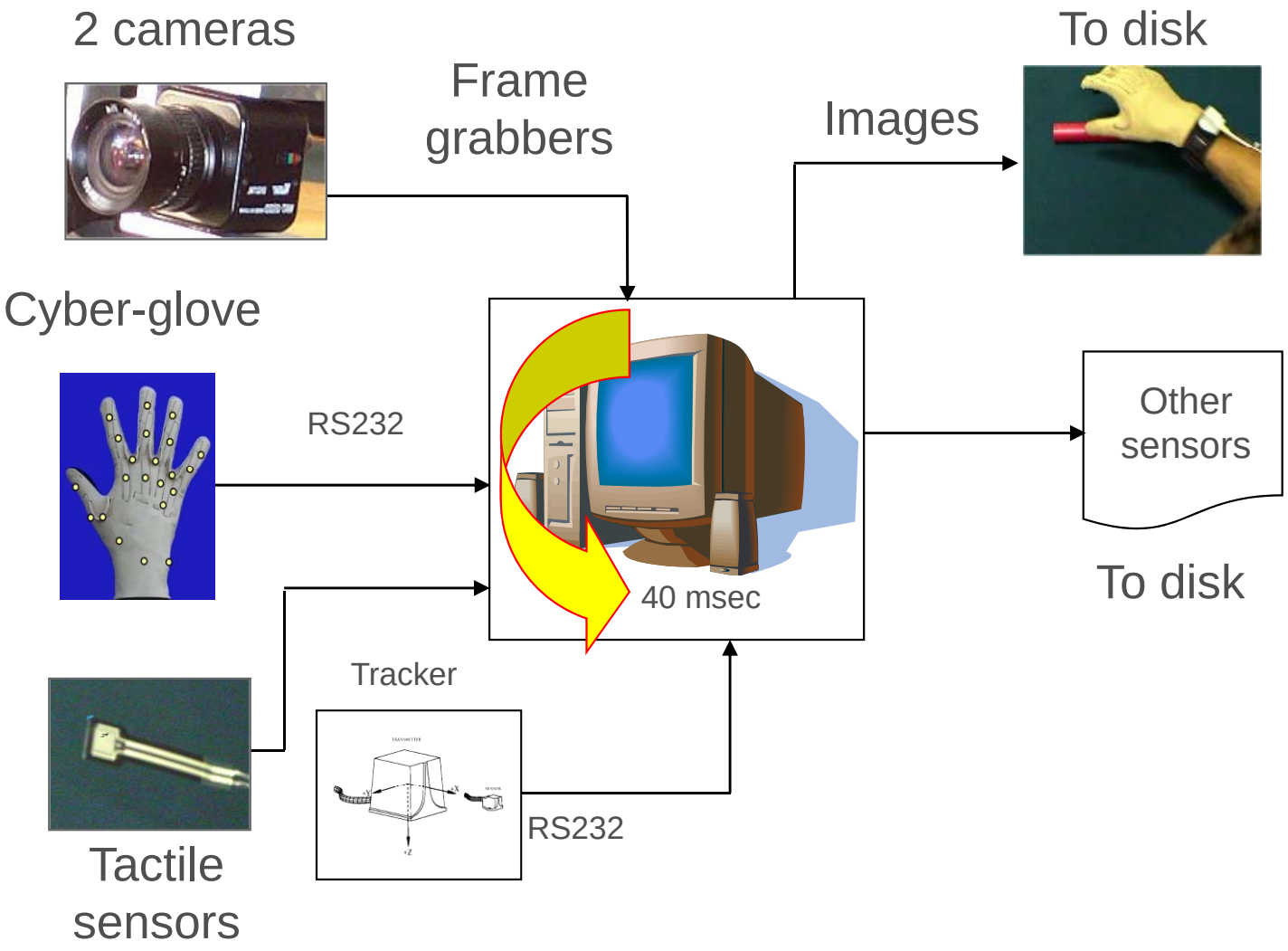
The neuron is activated by “seeing” someone else’s hand performing a manipulative action **and** while the monkey is performing the same action



The type of action seen is relevant

From: Fadiga, L., L. Fogassi, V. Gallese, and G. Rizzolatti, *Visuomotor Neurons: ambiguity of the discharge or "motor“ Perception?* Internation Journal of Psychophysiology, 2000. **35**: p. 165-177.

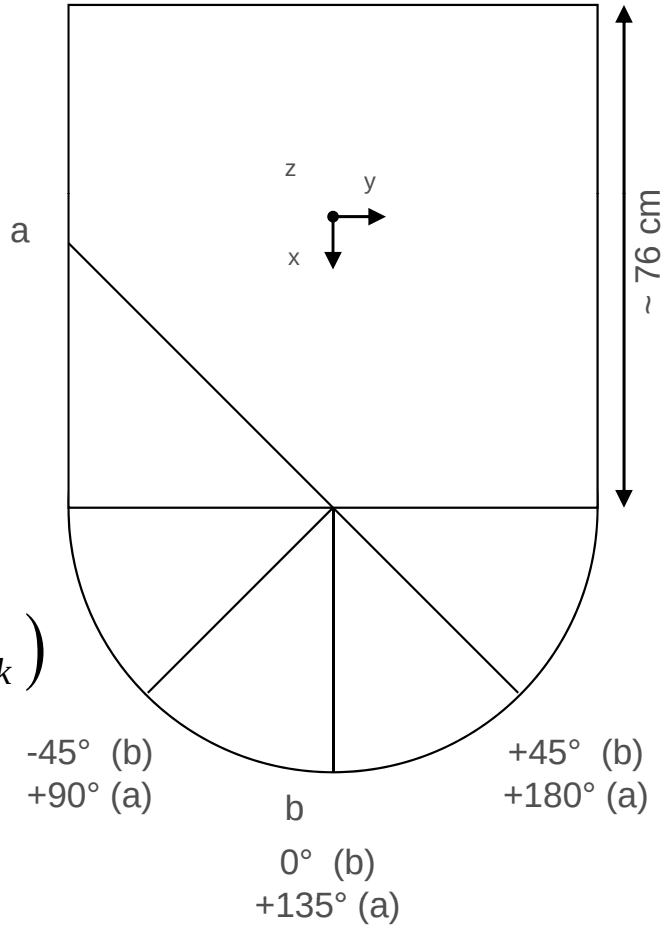
Data from human grasping



Bayesian classifier

{*Gi*}: set of gestures
F: observed features
{*Ok*}: set of objects

168 sequences per subject
10 subjects
6 complete sets

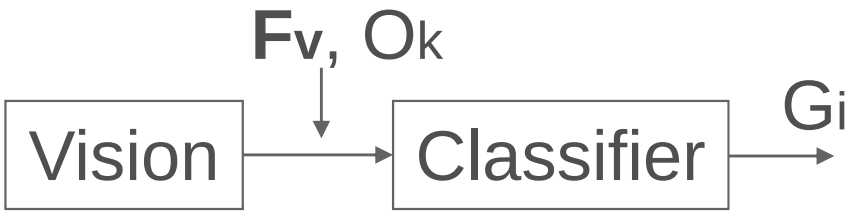


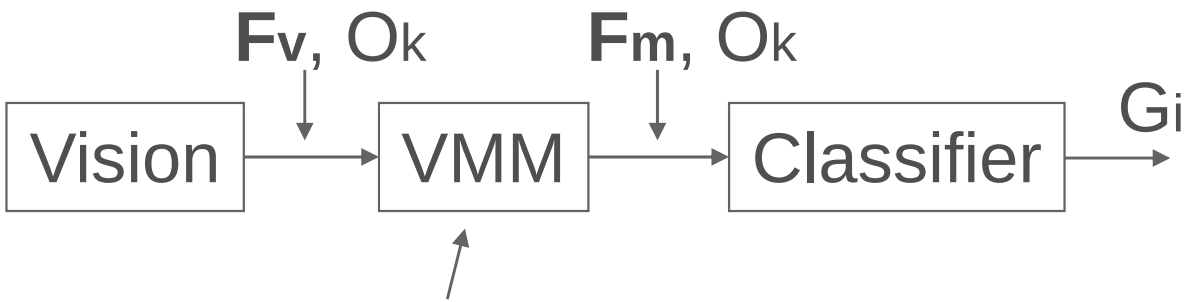
p(Gi|Ok): priors (affordances)
*p(***F**|*Gi,Ok)*: likelihood to observe **F**

$$p\left(G_i \mid \mathbf{F}, O_k\right) = p\left(\mathbf{F} \mid G_i, O_k\right) p\left(G_i \mid O_k\right) / \; p\left(\mathbf{F} \mid O_k\right)$$

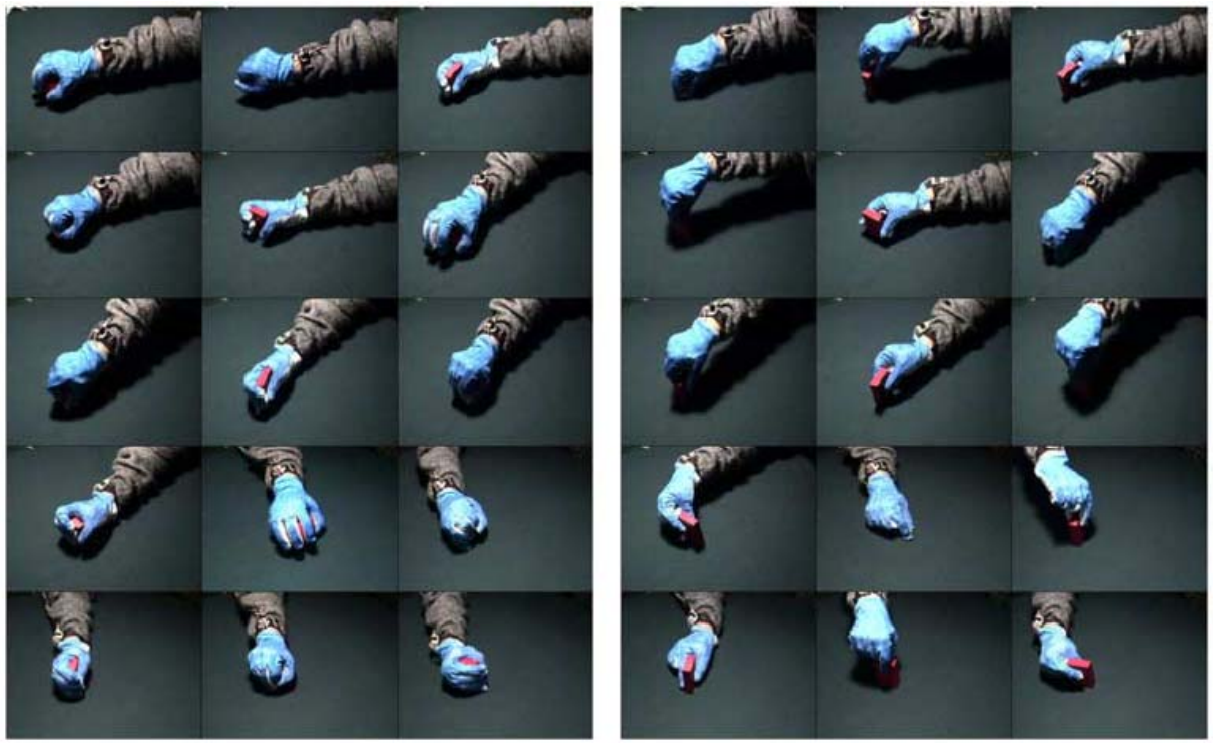
$$\hat{G}_{MAP} = \arg\max_{G_i} \left(G_i \mid \mathbf{F}, O_k\right)$$

Two types of experiments





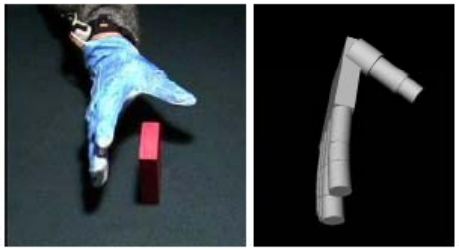
Role of motor information in action understanding



Grasping actions

Object affordances (priors)

Visual space Motor space



Classification (recognition)

Understanding mirror neurons: a bio-robotic approach. *G. Metta, G. Sandini, L. Natale, L. Craighero, L. Fadiga*. Interaction Studies. Volume 7 Issue 2. 2006

Some results

	Exp. I (visual)	Exp. II (visual)	Exp. III (visual)	Exp. IV (motor)
	Training			
# Sequences	16	24	64	24
# of view points	1	1	4	1
Classification rate	100%	100%	97%	98%
# Features	5	5	5	15
# Modes	5-7	5-7	5-7	1-2
	Test			
# Sequences	8	96	32	96
# of view points	1	4	4	4
Classification rate	100%	30%	80%	97%

Additional neurophysiology

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Report

The Motor Somatotopy of Speech Perception

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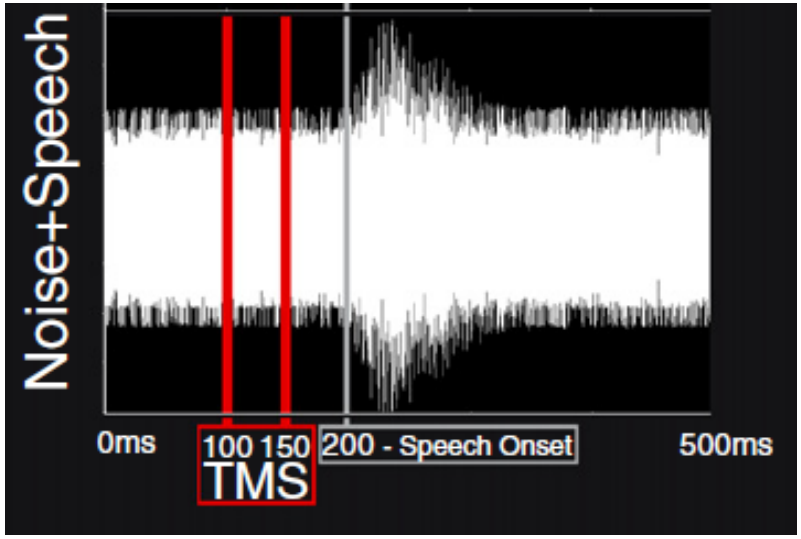
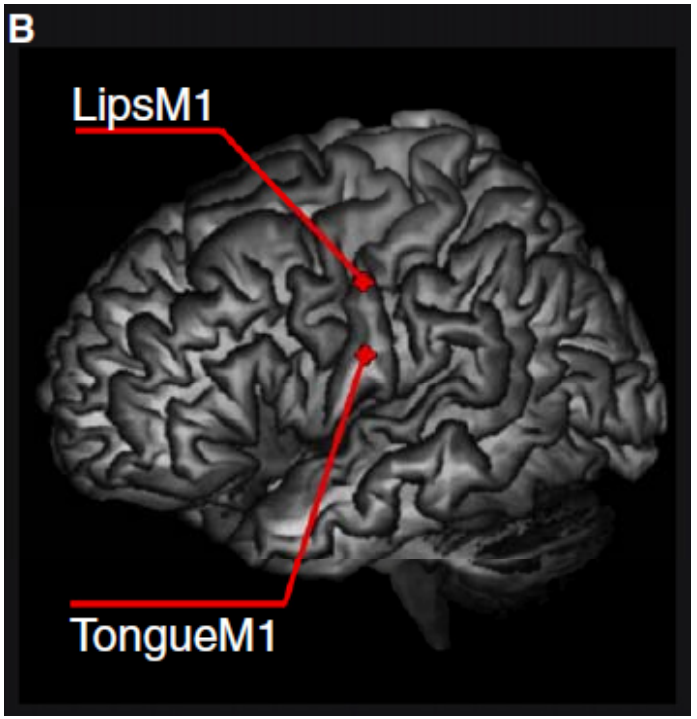
(MTSP) [3], an early precursor of a new zeitgeist, most radically postulated that the articulatory gestures, rather than sounds, are critical for both production and perception of speech (see [4]). On neurobiological grounds, fronto-temporal circuits are thought to play a functional role in production as well as comprehension of speech. The coactivation of motor circuits and the concurrent perception of self-produced speech sounds during articulations might lead to correlated neuronal activity in motor and auditory systems, triggering long-term plastic processes based on Hebbian learning principles [15–17]. The postulate of a critical role of actions in the formation of speech circuits is paralleled in more general action-perception theories emphasizing a critical role of action representations in action-related perceptual processes [18]. However, a majority of researchers are still skeptical toward a general role of motor systems in speech perception, admit-

TMS experiment

- Listening to [b] and [p], labial phonemes
- Listening to [t] and [d], dental phonemes

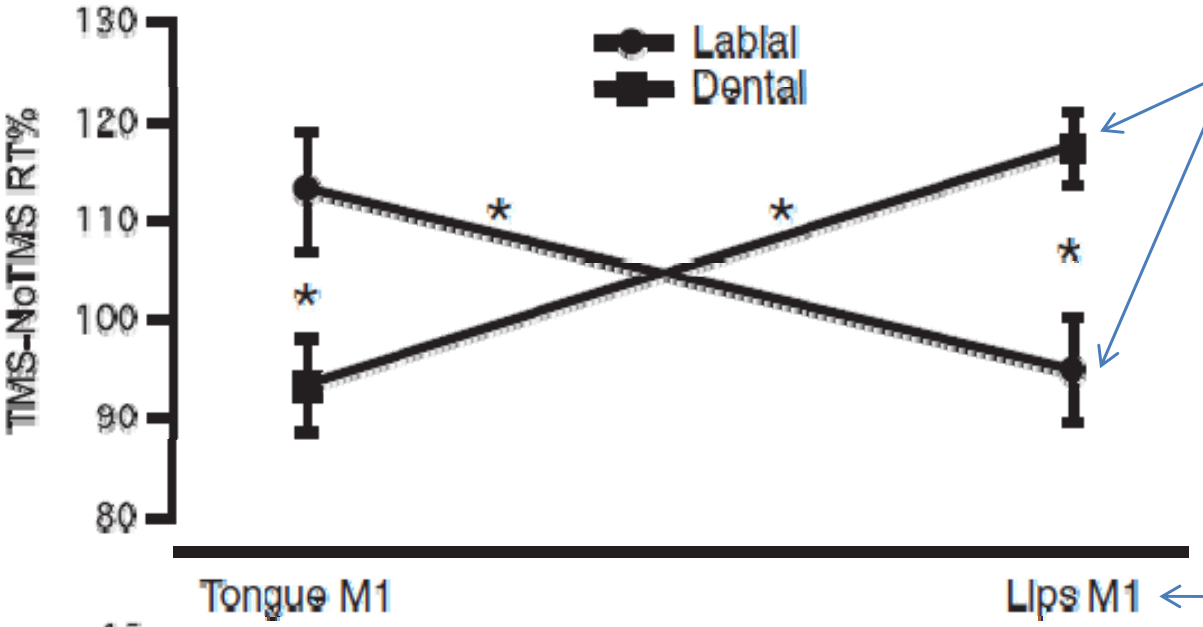


Stimulus



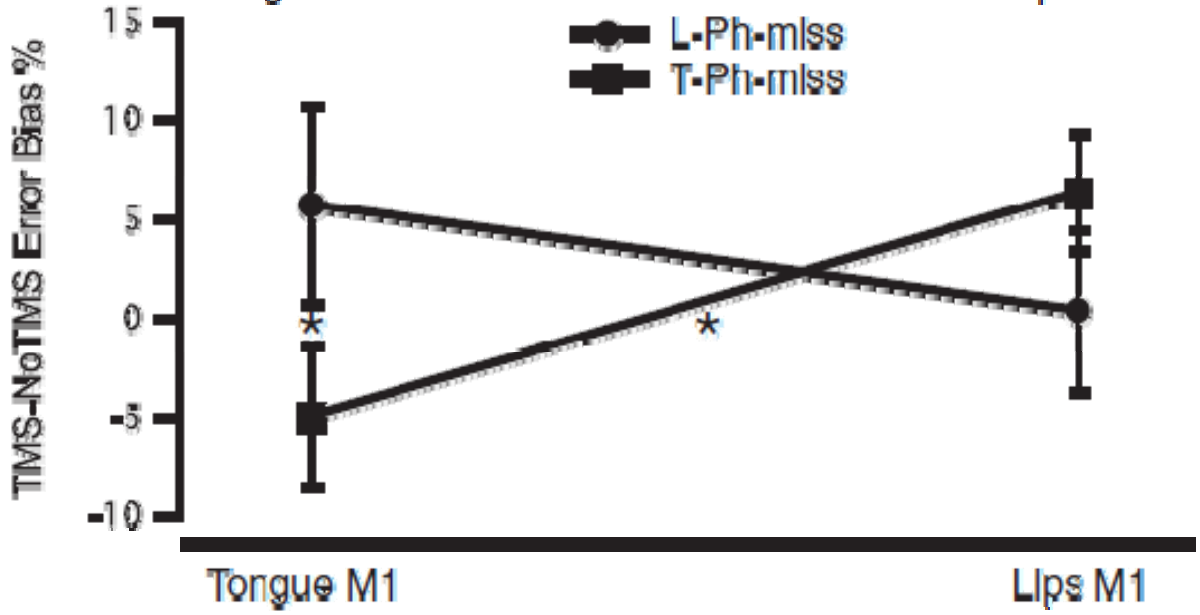
Stimulation

Results

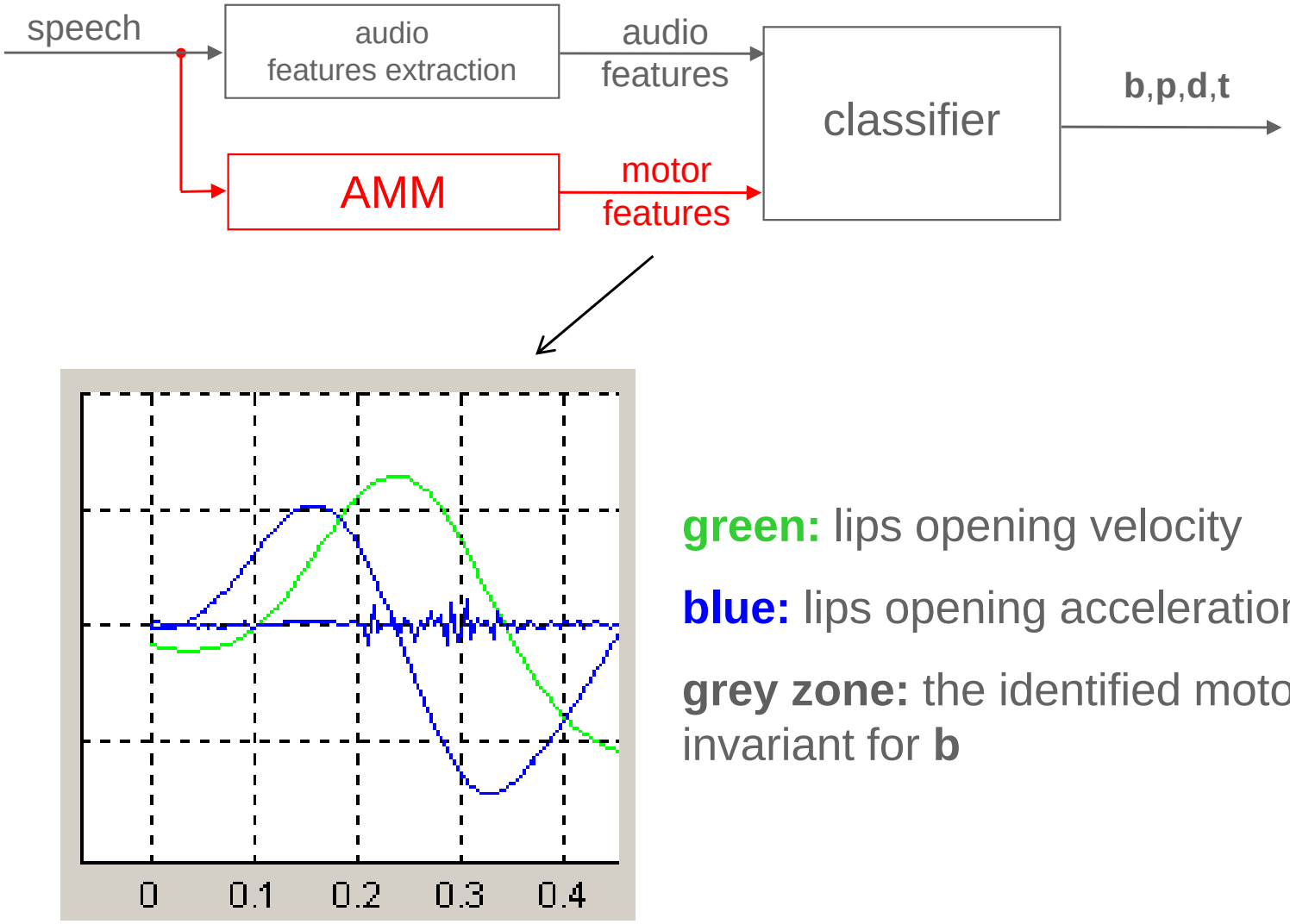


Acoustic stimulus

TMS site



Motor feature based recognition

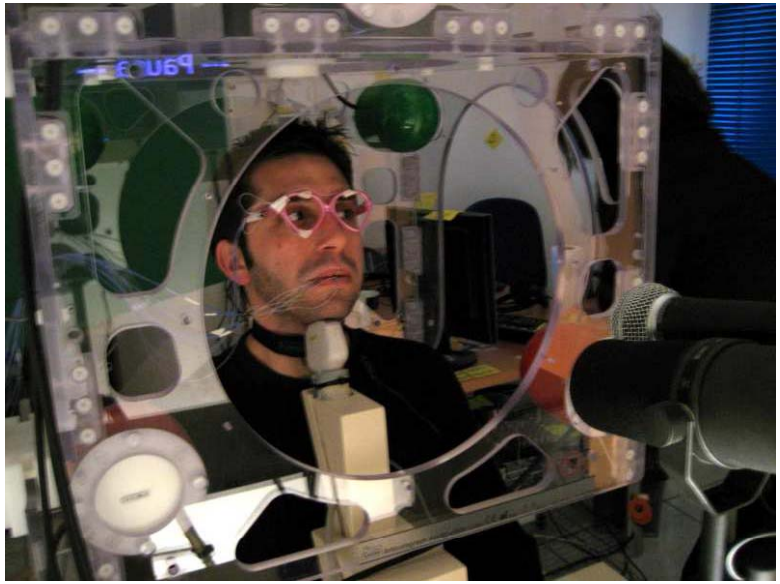


green: lips opening velocity

blue: lips opening acceleration

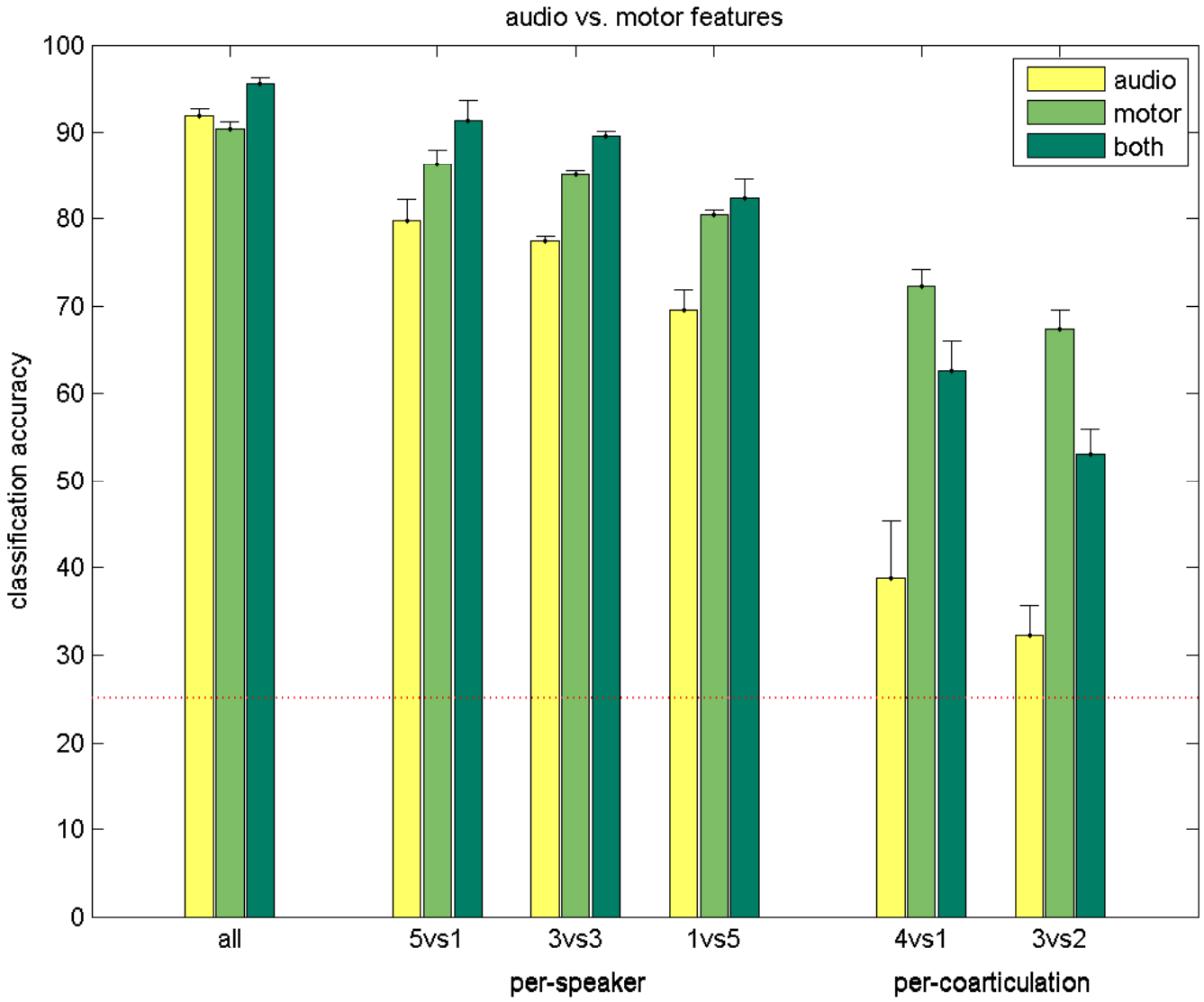
grey zone: the identified motor invariant for **b**

Data collection



- 9 speakers, 74 (pseudo)words and syllables
- magnetic tracking of tongue, lips and teeth
- ultrasound imaging of tongue
- video of face
- laryngography of vocal folds

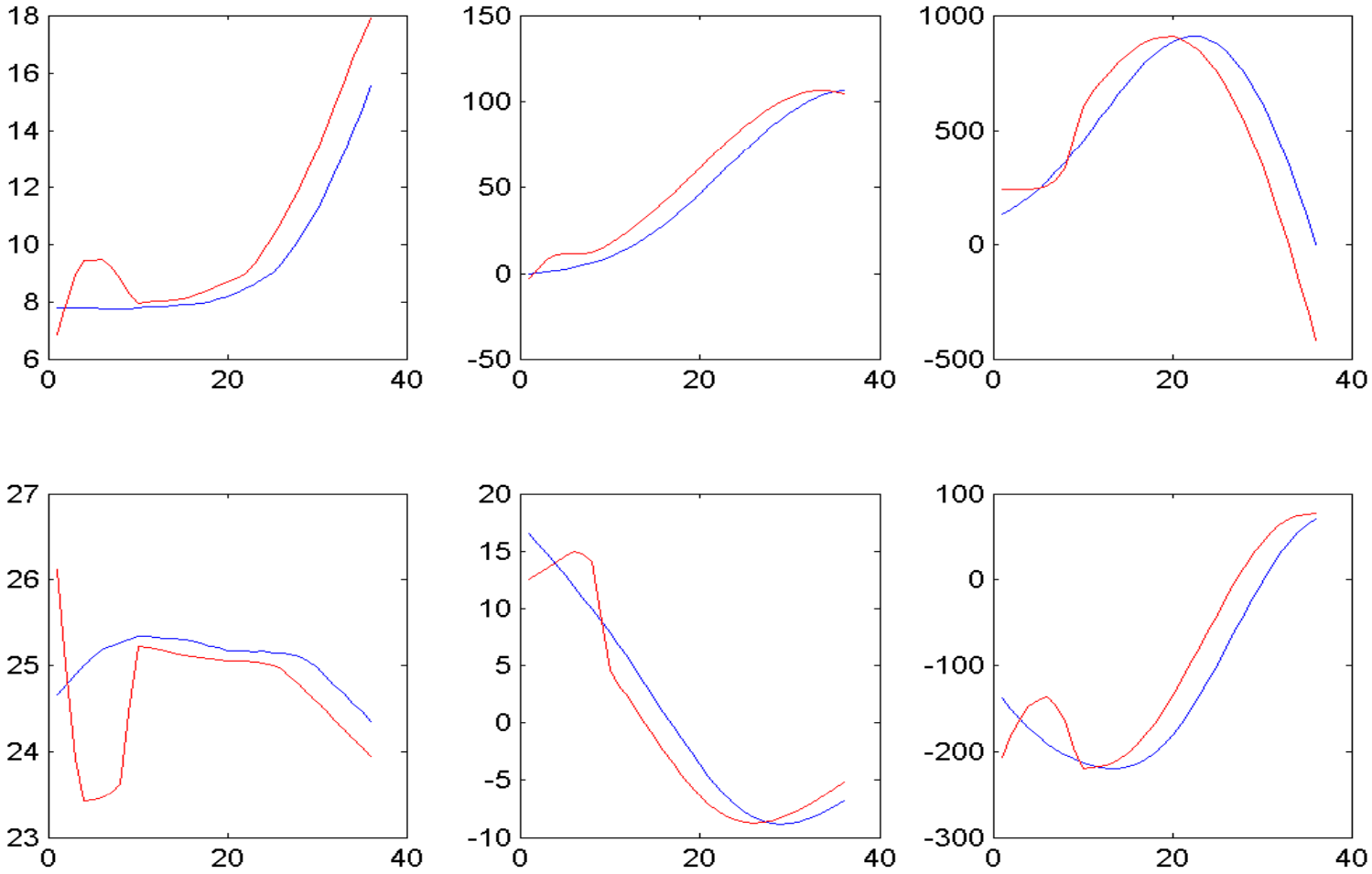
Baseline experiment



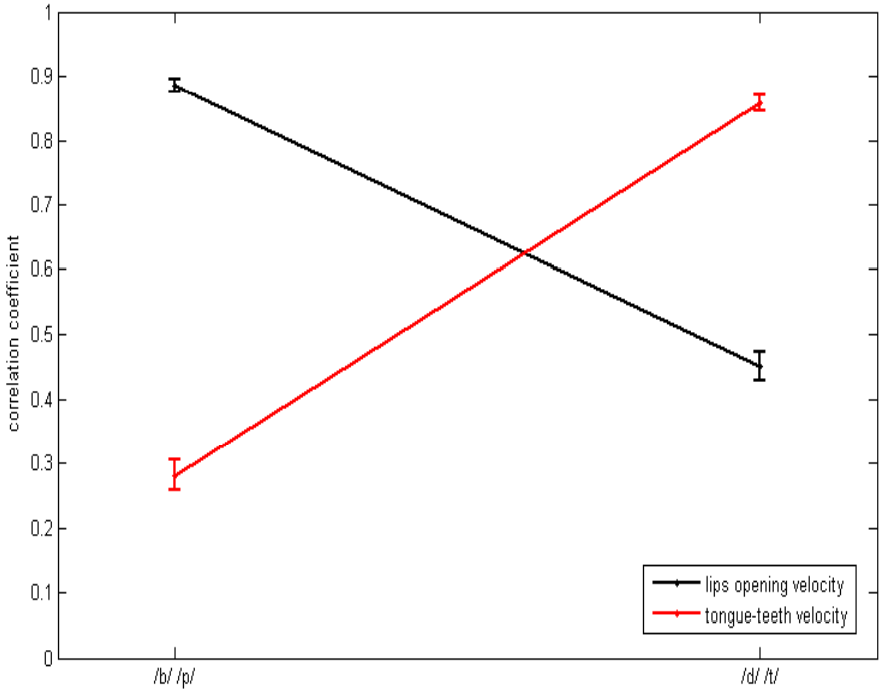
Audio-motor map

- Training the AMM:
  - *input space:* 200ms. Mel-scale spectrogram (20 filters) of speech ($\mathbf{R}^{380}$)
  - *output space:* point-by-point *VliO*, *AliO*, *VttU*, *AttU* over utterance ($\mathbf{R}^{4}$)
  - ANN w/ sigmoidal activation function, cross-validation, regularization, 10 random restart (the best is stored)
- Cross-validation:
  1. over all utterances
  2. per-speaker

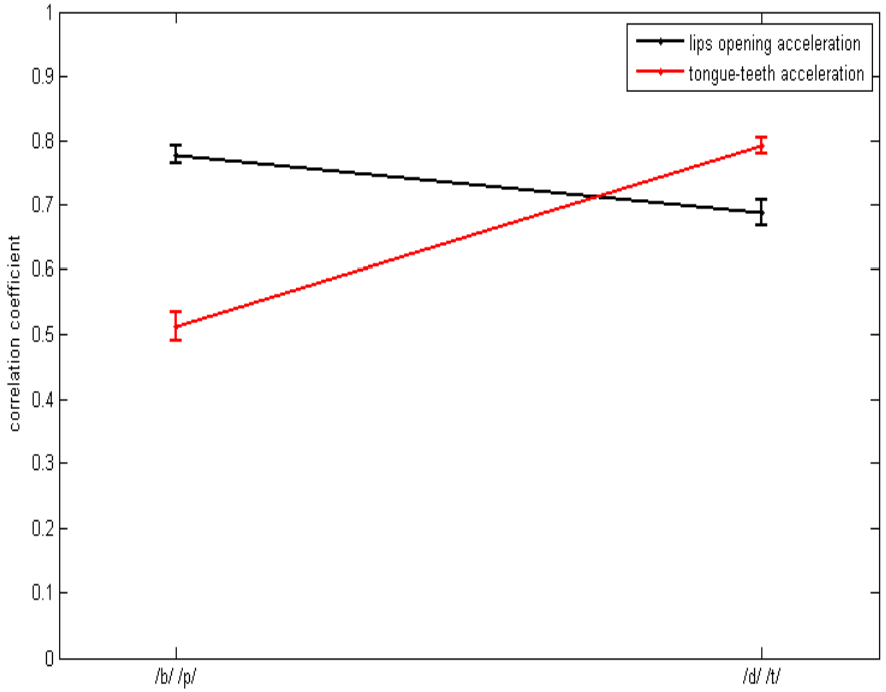
papa


18
16
14
12
10
8
6
0
20
40
150
100
50
0
-50
0
20
40
1000
500
0
-500
0
20
40
27
26
25
24
23
0
20
40
20
15
10
5
0
-5
-10
0
20
40
100
0
-100
-200
-300
0
20
40

Audio-motor map

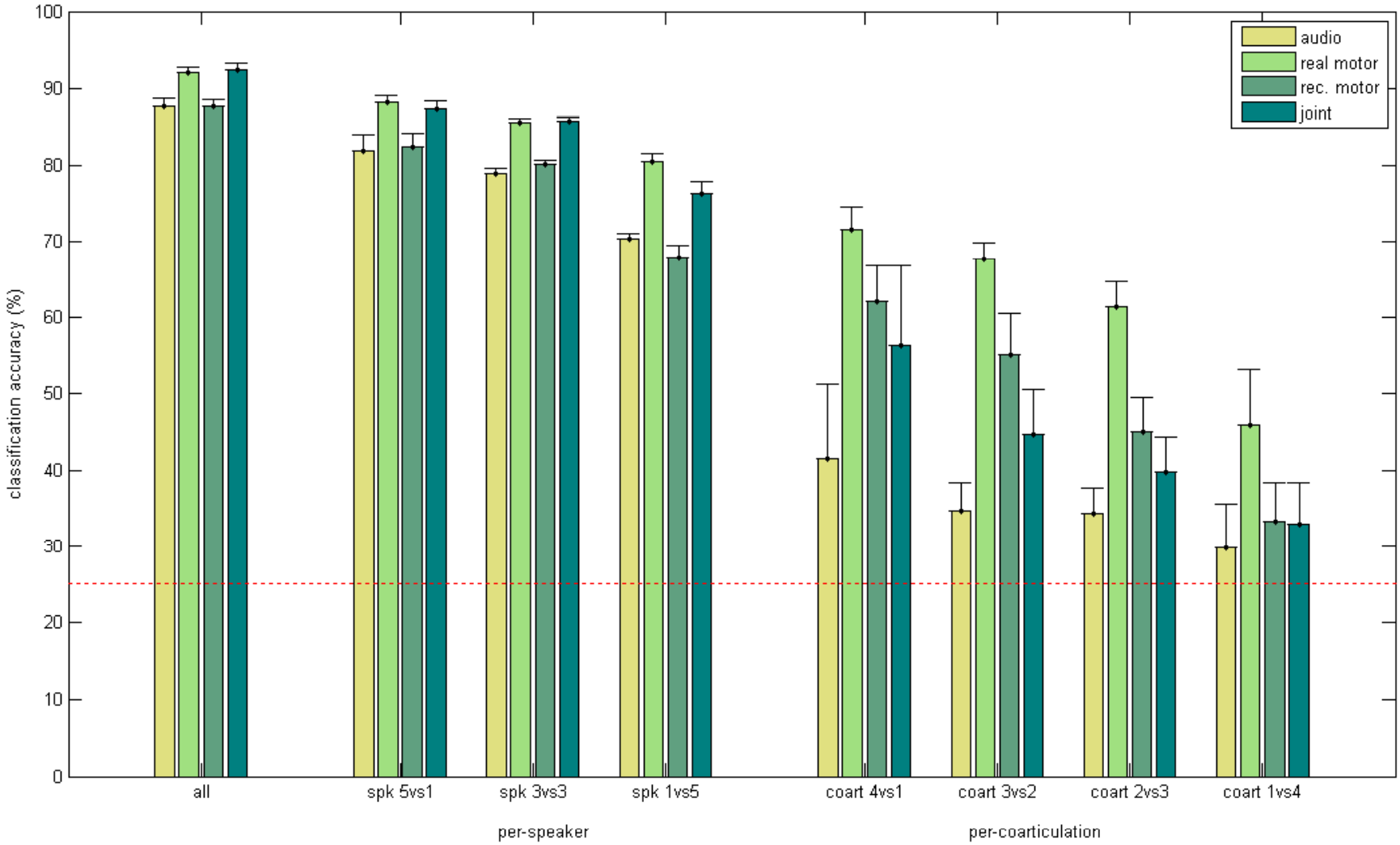


Velocity

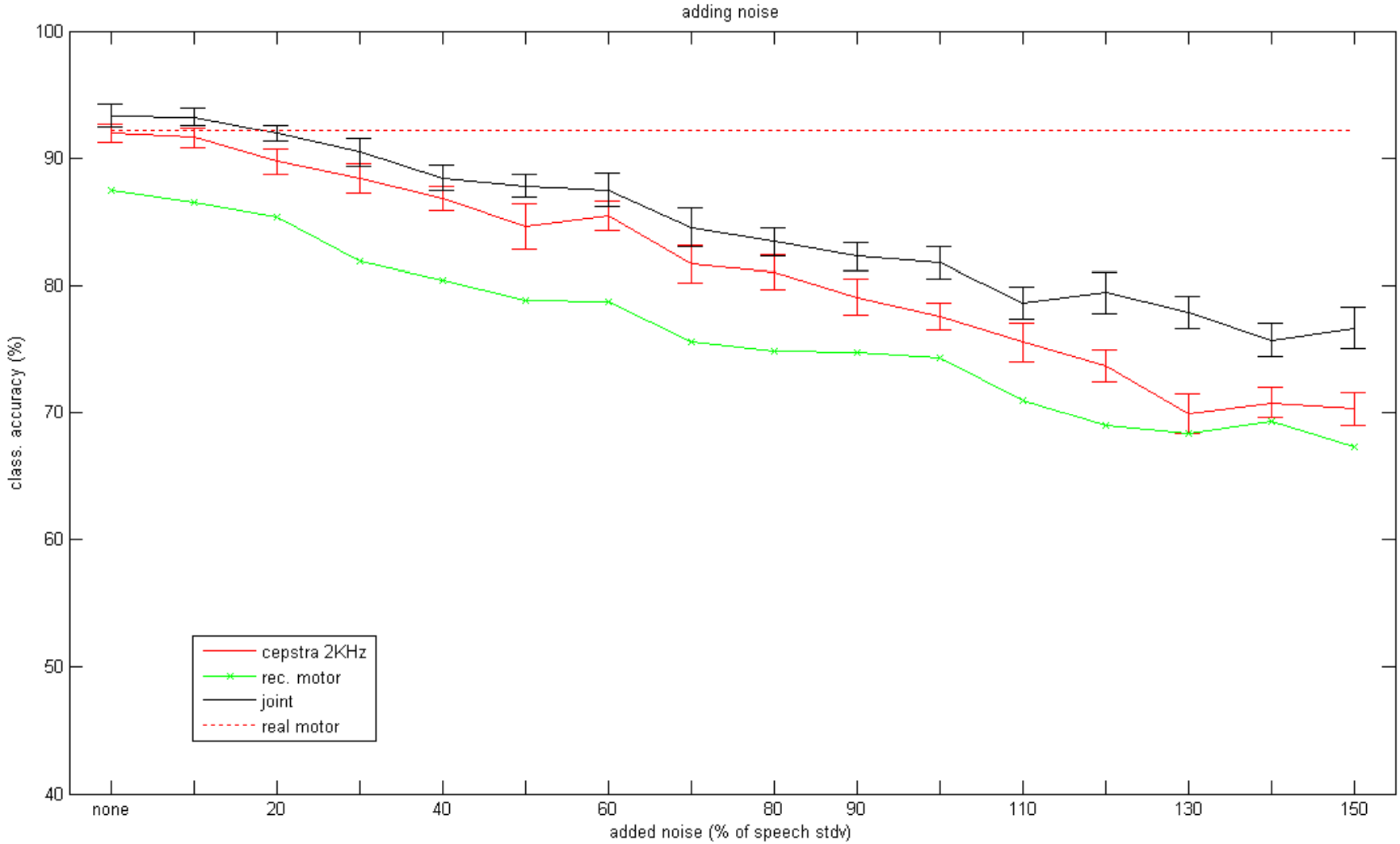


Acceleration

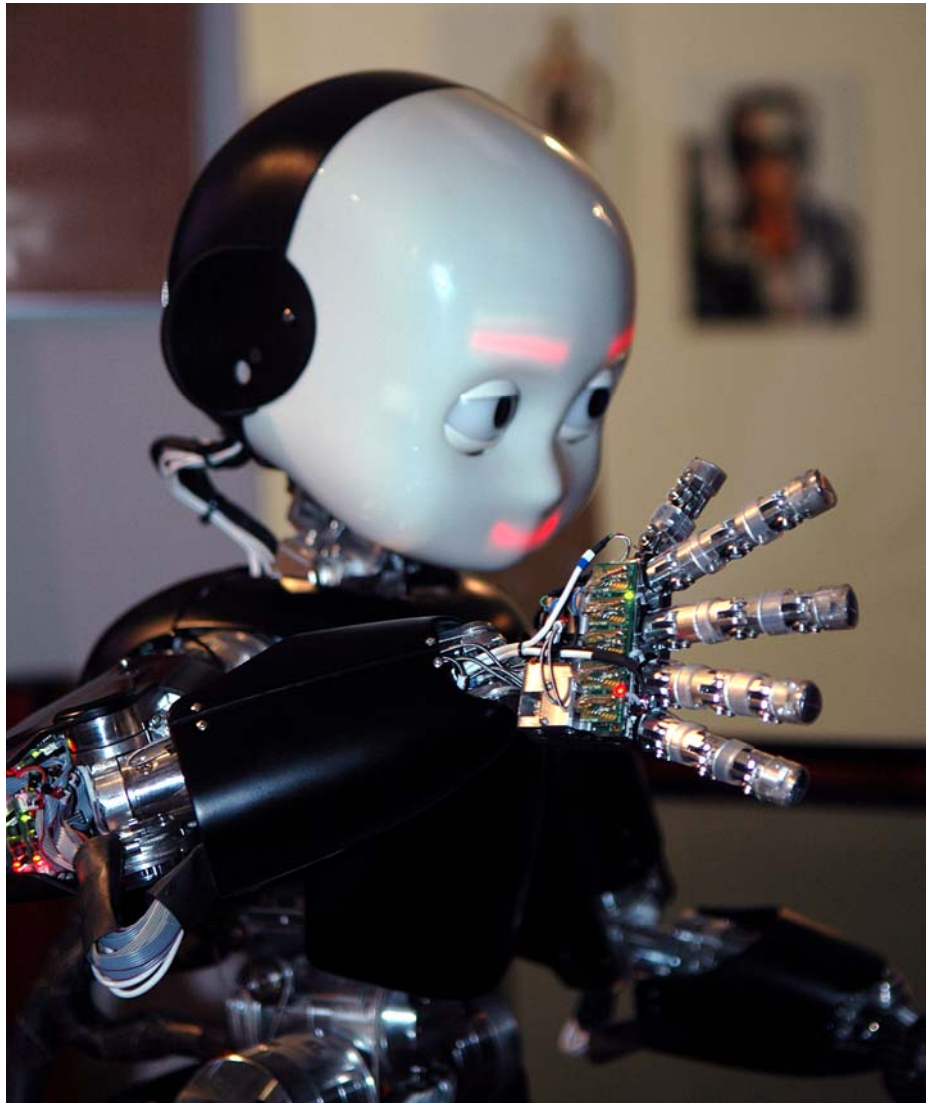
With reconstructed motor signals



Increasing noise



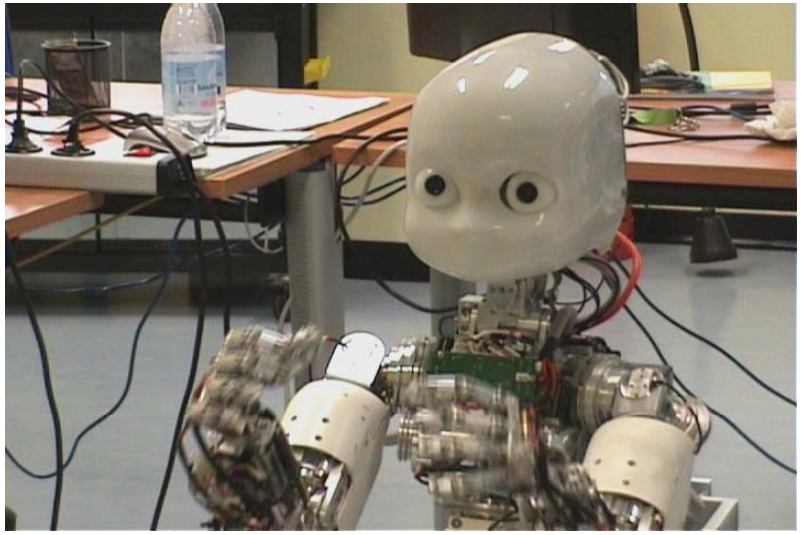
The iCub

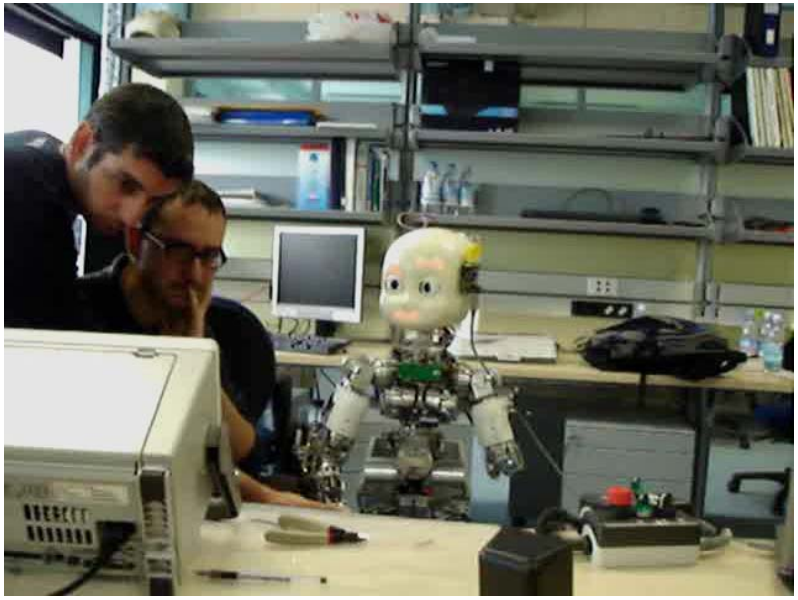


The iCub: quick summary

The **iCub** is the humanoid baby-robot designed as part of the **RobotCub** project

- The iCub is a full humanoid robot sized as a three and half year-old child
- The total height is 104cm
- It has 53 degrees of freedom, including articulated hands to be used for manipulation and gesturing
- The robot will be able to crawl and sit and autonomously transition from crawling to sitting and vice-versa
- The robot is GPL/FDL: software, hardware, drawings, documentation, etc.



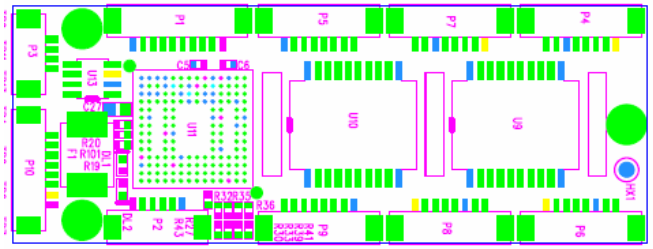


Sensorization

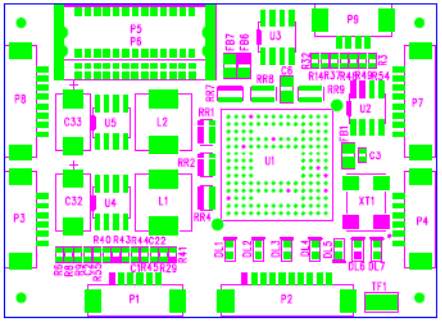
- Absolute position
  - On most joints, AMS magnetic encoder (12 bits)
- Cameras
  - Pointgrey Dragonfly2 firewire cameras (typical 640x480@30pfs)
- Microphones, speaker
  - Standard condenser electrect miniature microphones
  - Pinnae
- Gyroscopes, linear accelerometers
  - Xsense: Mtx

Custom electronics

- Motor control
  - C programmable DSP 40 MIPS
  - Motorola DSP56F807
  - PWM, ADC, Digital I/O, etc.
  - 4DC motors (1A max each)
  - 2BL motors (6A cont, 20A peak)
  - CAN bus interface



80x30mm

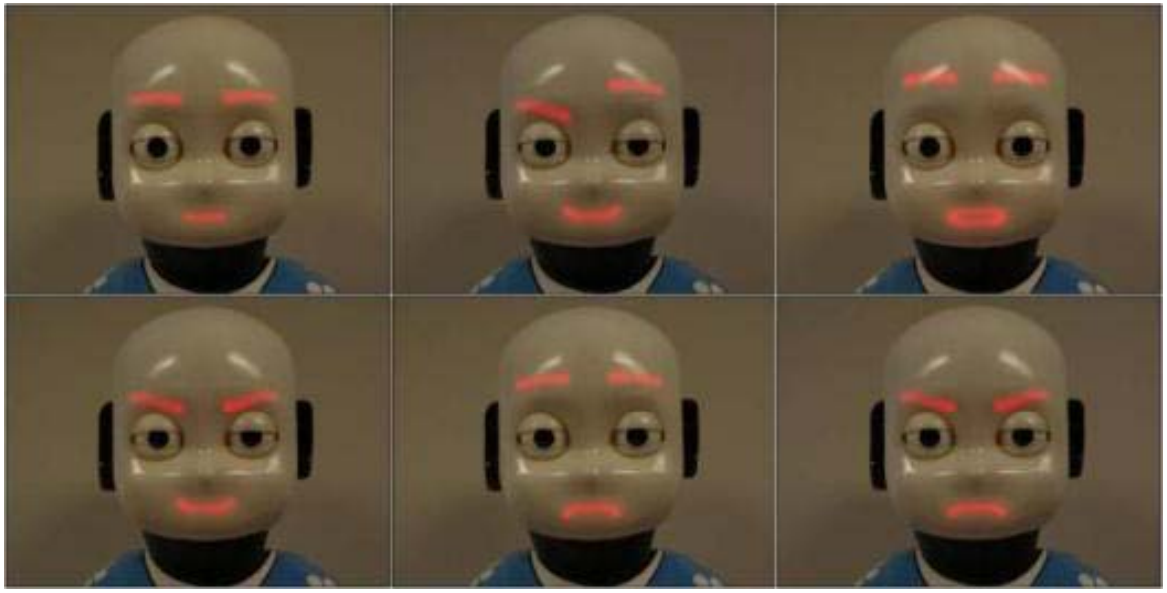


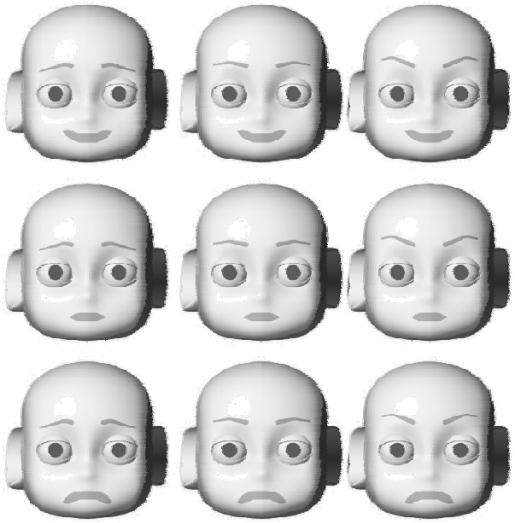
58x42mm

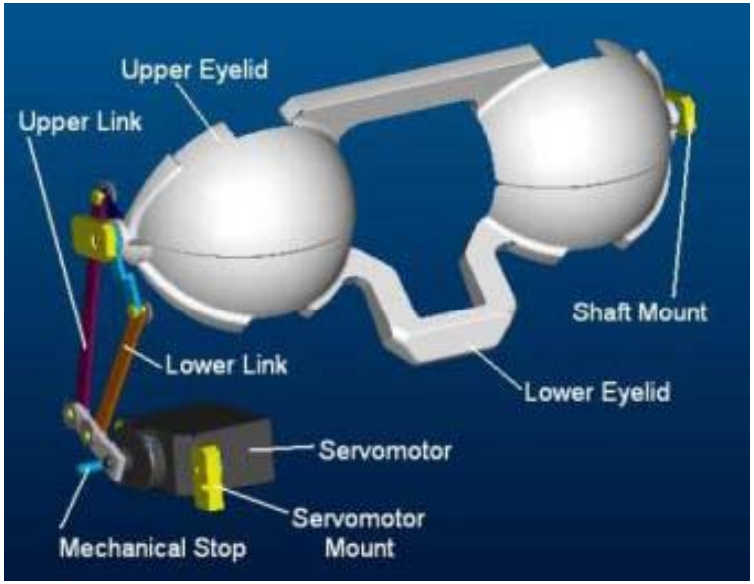
Input/output:

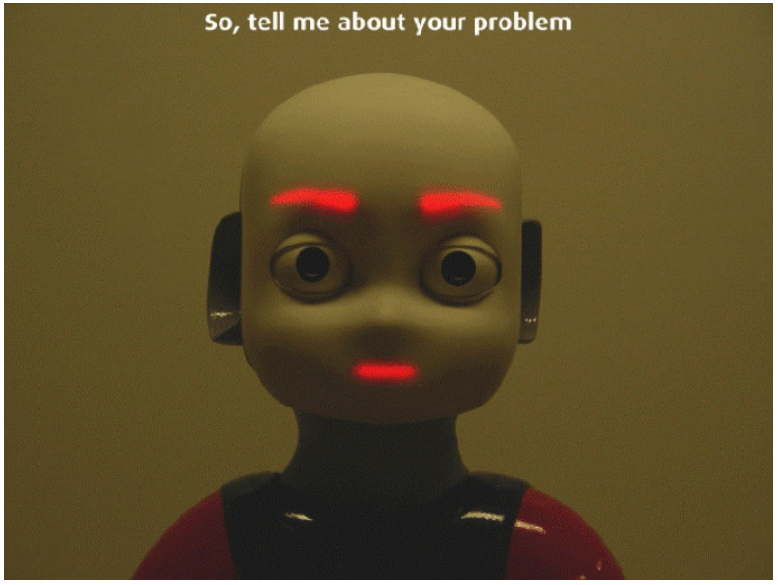
- PC104 digital I/O card with 4 CAN bus (soon 10), firewire, and audio amplification
- Miniature analog to CAN converter card
- Miniature strain gauge signal conditioning and acquisition card

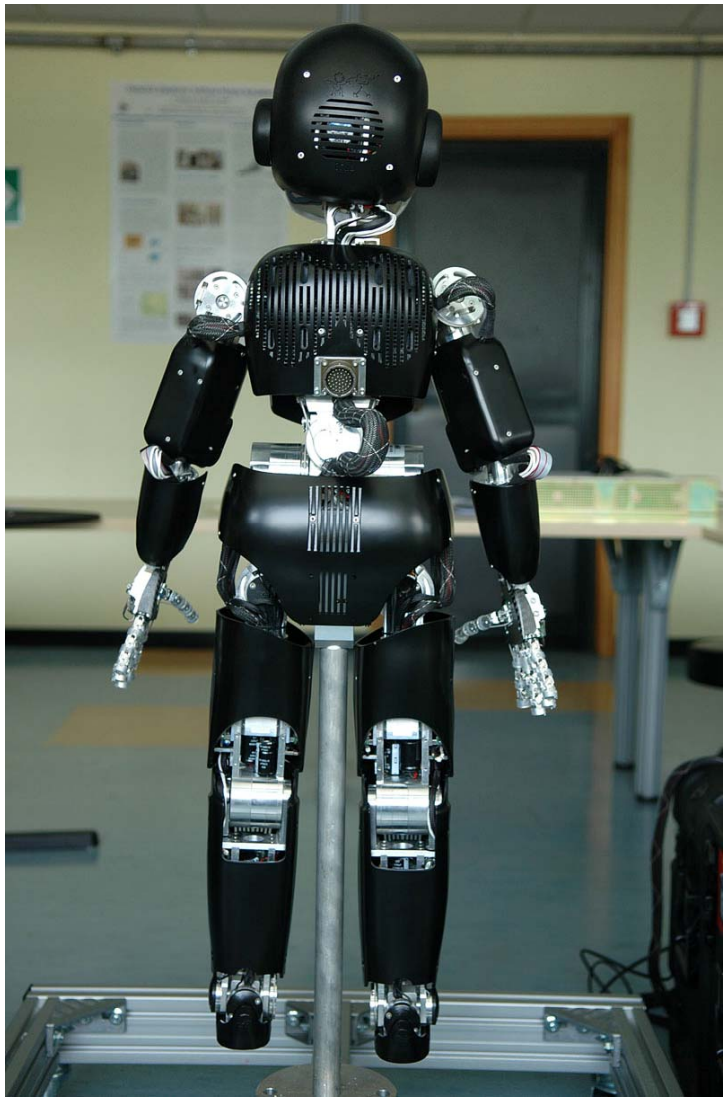
Facial expressions

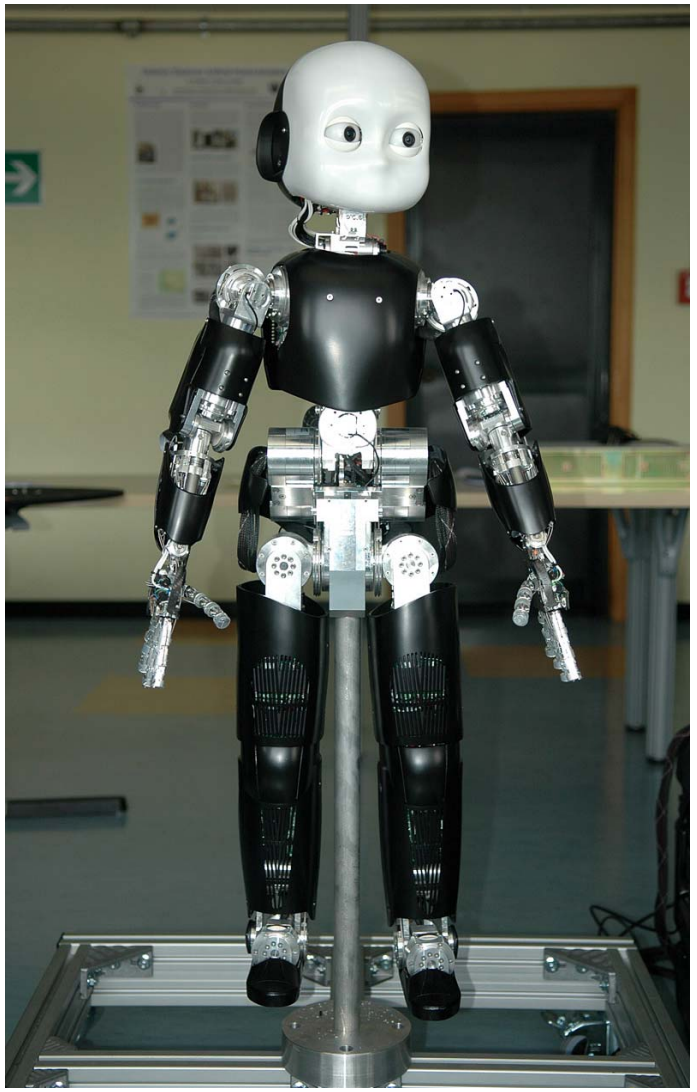










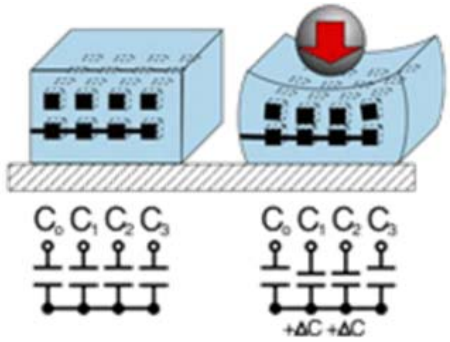


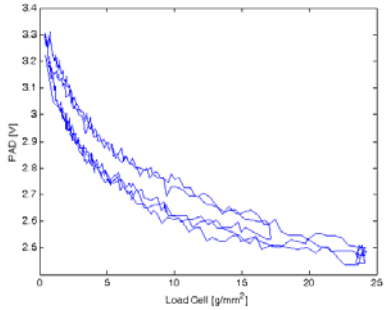
Promoting the iCub

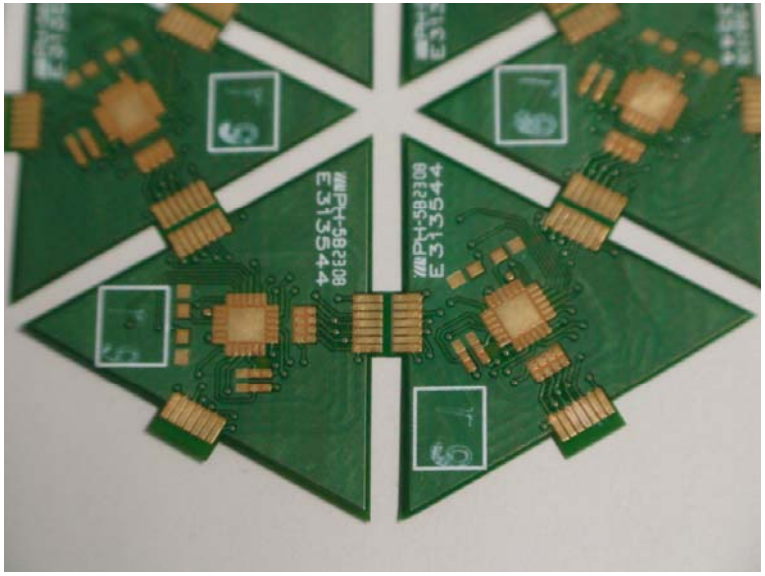
- RobotCub Open Call
  - 31 participants, 7 winners will receive a copy of the iCub free of charge
  - UPMC Paris, Imperial London, Inserm Lyon, TU Munich, METU Ankara, Pompeu Fabra Barcelona, Urbana-Champaign USA, IST Lisbon, EPFL Lausanne
- Further development…
  - EU project ITALK: 4 iCub's have been built
  - EU project ImClever: 3 iCub's will be built
  - EU project RoboSkin: a skin system compatible with iCub
  - EU project CHRIS: safety features for the iCub
- Collaborations
  - University of Karlsruhe: new and longer legs
- Simulator:
  - Open Source simulator based on ODE/Newton and as a model in Webots

The skin

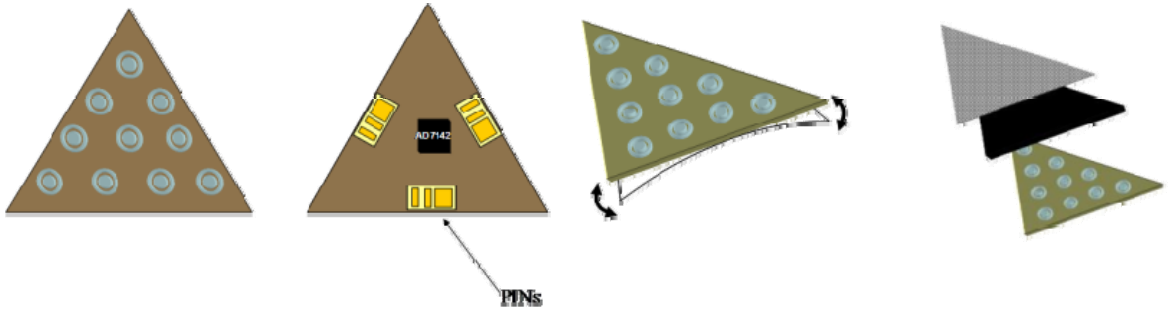
Principle

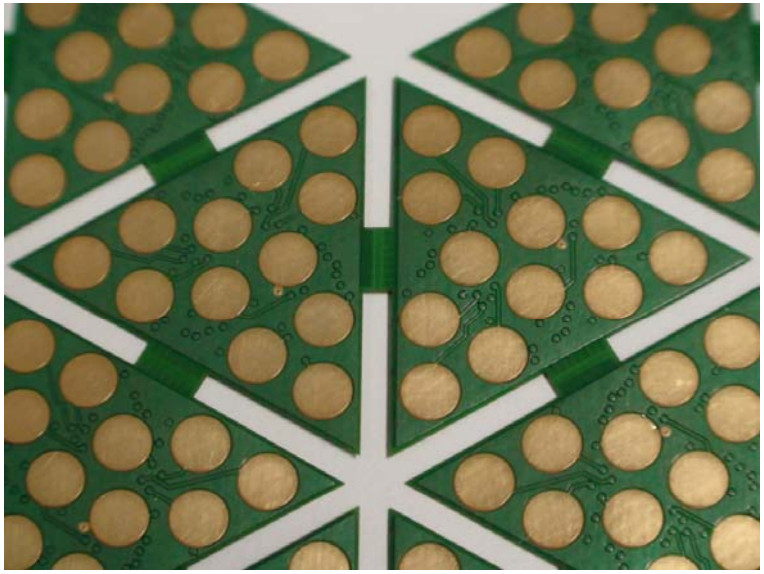




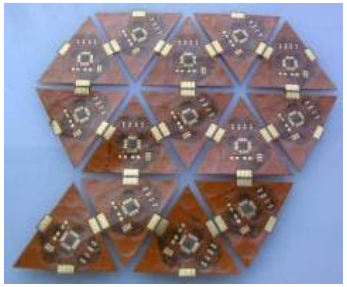


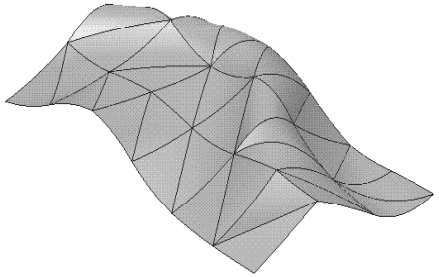
Lot of sensing points





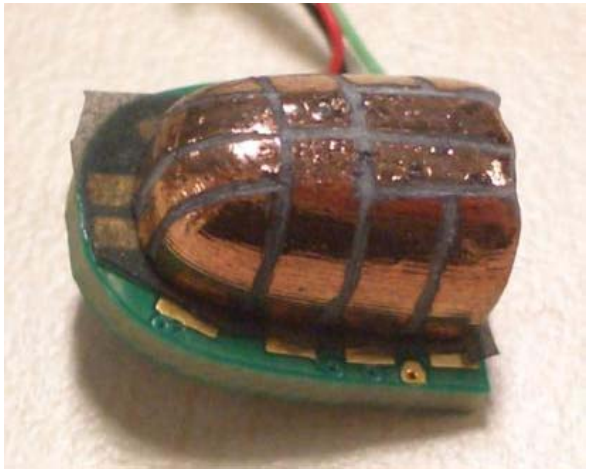
Structure of the skin

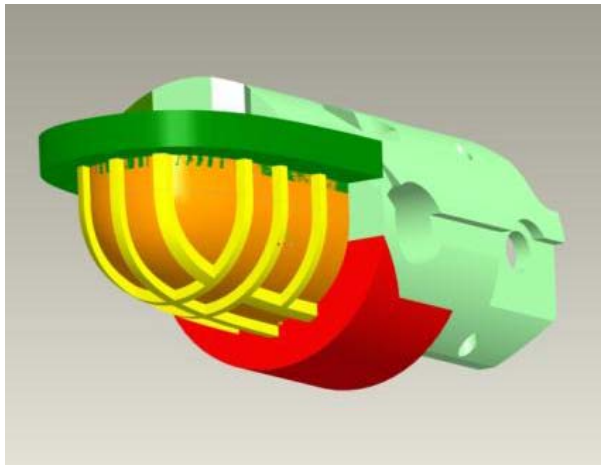




Fingertips

- Capacitive pressure sensor with 12 sensitive zones
- 14.5 mm long and 13 mm wide, sized for iCub
- Embedded electronics: twelve 16 bit measurements of capacitance
  - either all 12 taxels independently at 50 Hz or an average of the 12 taxels at about 500 Hz

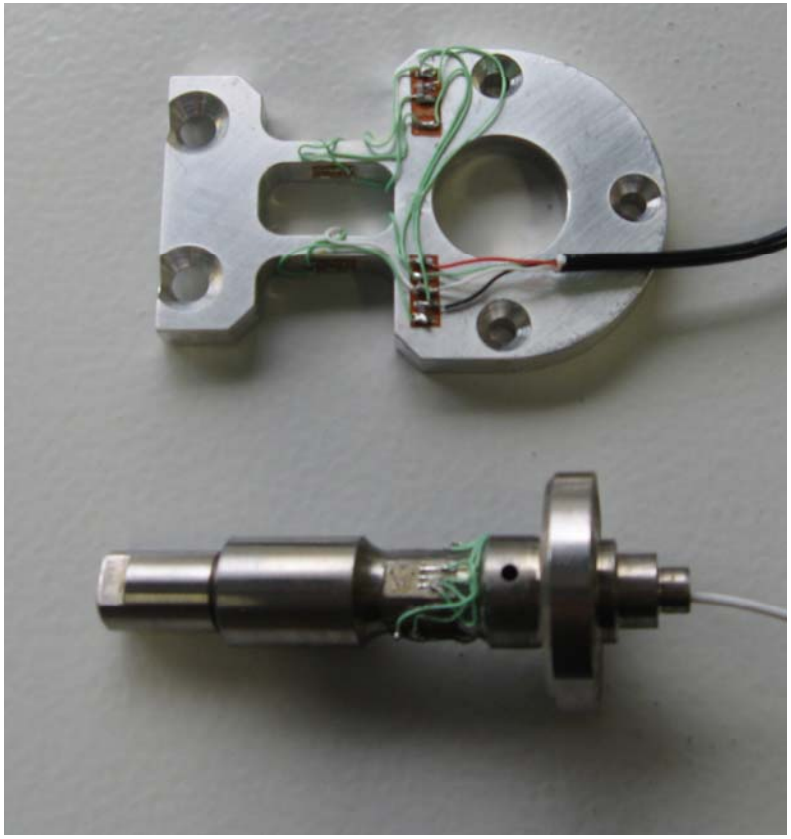




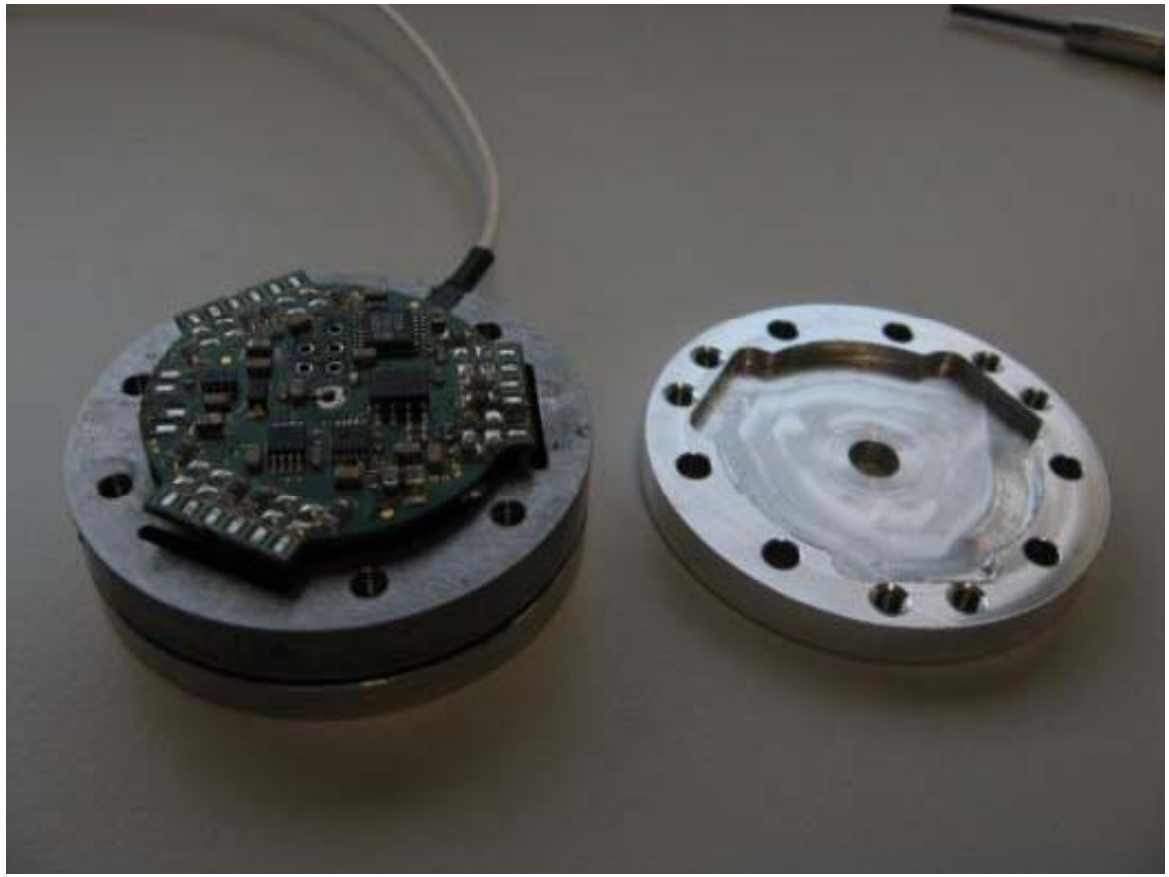
Sensor gauging and wiring

- Before

- After (gauges glued, 10h curing, pads gluing & wiring)



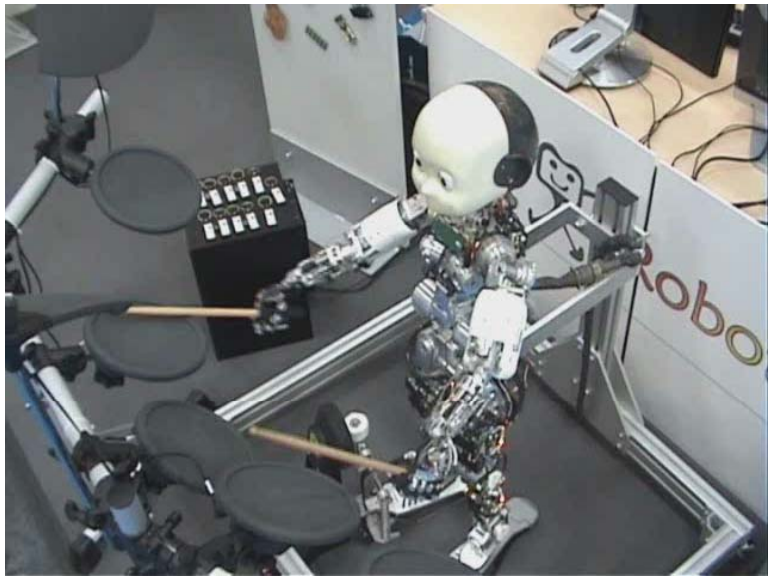
6-axis force/torque sensor



- Semiconductor strain gauges
- On board signal conditioning, sampling, and calibration
- Digital output: CAN bus

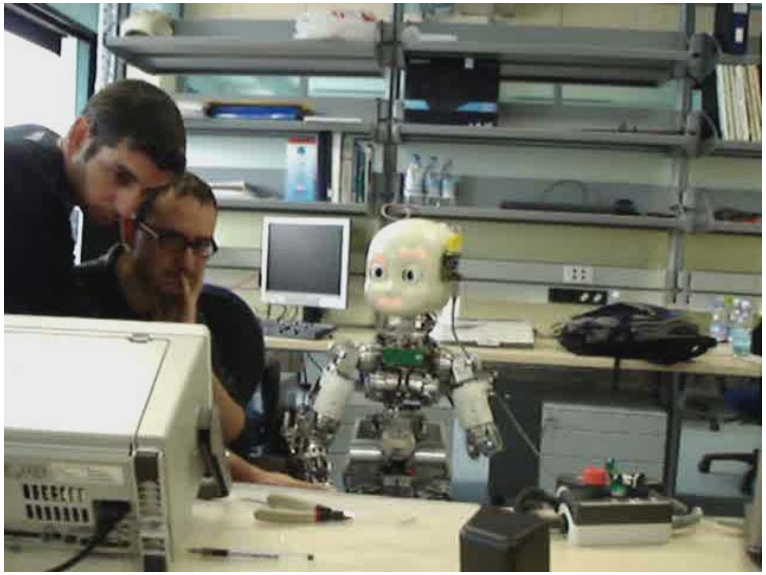
Design: Nikos Tsagarakis
Electronics: Claudio Lorini

With Peter Ford-Dominey (INSERM, Lyon)



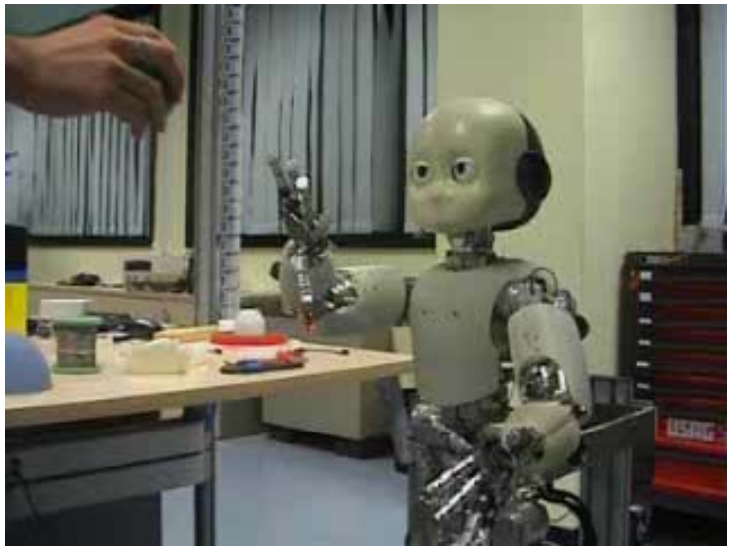
With Auke Ijspeert, Ludovic Righetti, Sarah Degallier (EPFL)

With a lot of students
@ RobotCub summer school 2008

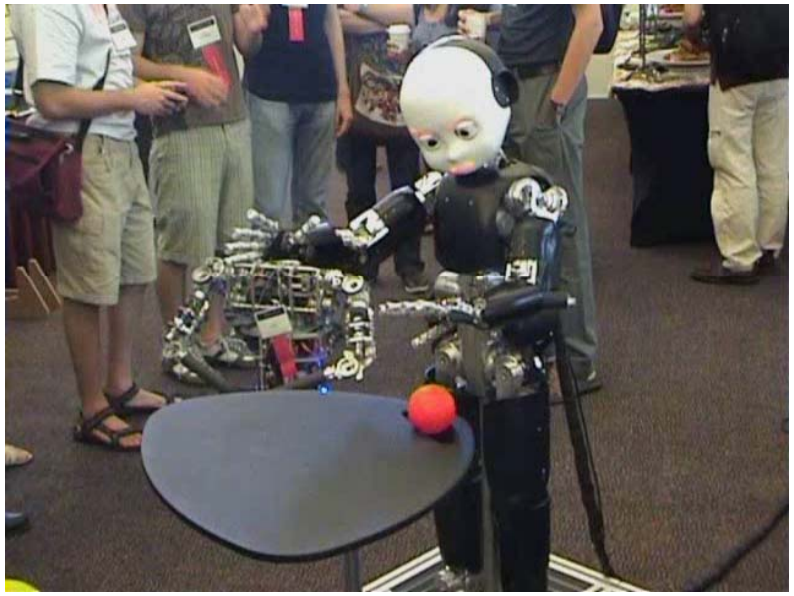


With VisLab (IST Lisbon)

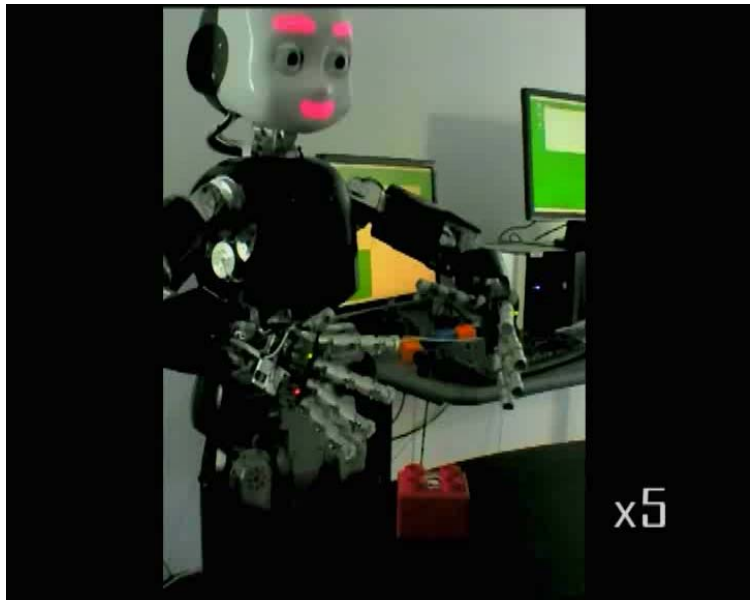
With Auke Ijspeert, Ludovic Righetti, Sarah Degallier (EPFL)



With VisLab (IST Lisbon)



IJCAI – Pasadena, CA
2009 manipulation challenge



RobotCub Summer School 2009
(Alex Maldonado, Federico Ruiz – TUM)

Conclusions

- Cognition: (internal) models connected to the motor system
- It might be advantageous to copy this solution in artificial systems
- …which ultimately require a body to generate sensorimotor patterns autonomously