# PhD Program in Bioengineering and Robotics

## Curriculum Cognitive Robotics, Interaction and Rehabilitation Technologies
## Research themes



In the spirit of the doctoral School on Bioengineering and Robotics the PhD Program for the curriculum "Cognitive Robotics, Interaction and Rehabilitation Technologies" provides interdisciplinary training at the interface between technology and life-sciences. The general objective of the program is to form scientists and research technologists capable of working in multidisciplinary teams on projects where human factors play a crucial role in technological development and design.

The themes offered this year as part of this curriculum are supported by the Robotics, Brain and Cognitive Sciences Department (RBCS), by the Unit for Visually Impaired People (U-VIP), by the Unit "Social Cognition in Human-Robot Interaction" (all at the Italian Institute of Technology) and also in collaboration with the Department of Informatics, Bioengineering, Robotics and System Engineering (DIBRIS).

Robotics, Brain and Cognitive Sciences

In RBCS we are merging top-level neuroscience research and top-level robotics research by sharing, as a fundamental scientific objective, the study of physical and social interaction in humans and machines (www.iit.it/rbcs). The research activity is articulated in three main streams:

i) The study of human sensorimotor and cognitive abilities with a focus on action execution and understanding;

ii) The implementation of sensorimotor and cognitive abilities in the humanoid robot iCub with a focus on human–robot cooperation;
iii) The exploitation of assistive technologies to alleviate sensory disabilities and the implementation of robotic rehabilitation devices with a special attention on user requirements and strict clinical assessment.

A factor, common to all three streams is learning and development and, in general, the dynamics of knowledge acquisition and update.

Besides the humanoid platform iCub and the support of professional electronic and mechanical design, RBCS research facilities include a fully equipped motion capture room with simultaneous electromyography recording and force-platforms, a Transcranial Magnetic Stimulation Lab, an Electrophysiology Lab for EEG recording, haptic devices for ergonomic measures of individual and dyadic interaction, haptic devices that exploit visuo-tactile sensory substitution, binaural acoustic feedback platforms, robot rehabilitation devices for the upper limbs including the wrist; This infrastructure supports our student's research activities including the realization of ad-hoc experimental set-ups and mechatronic devices.

U-VIP

The main aim of the unit is to identify spatial impairments possibly conditioning the life of children and adults with and without visual disability, with the ultimate goal to develop new technological solutions suitable since the first years of life to overcome impairments and enhance learning skills.

In particular the focus of the group is:

i) to investigate how integration between sensory and motor signals develops during childhood and identify solutions (technologies and rehabilitation procedures)
ii) ii) to enhance the sensorimotor abilities necessary to orient and move in space, to communicate, to access everyday information and, therefore, to interact in social contexts
iii) testing and validating with human-centered techniques the devices (friendly and ergonomic) developed by considering social and clinical contexts.

Unit “Social Cognition in Human-Robot Interaction”

The unit “Social Cognition in Human-Robot Interaction” focuses on examining mechanisms of cognition involved in social interactions with other humans and with artificial agents such as humanoid robots (the iCub robot specifically). The aims of this research are to:

i) understand how humans socially attune to others, what are the conditions of social attunement with artificial agents and what types of cognitive mechanisms of the brain are activated during various types of social interactions with natural and artificial agents;
ii) provide guidelines to roboticists regarding parameters of robot behaviour that facilitate social attunement on the side of the human counterpart;

iii) contribute to development of robot-assisted therapies for healthcare and elderly care through advising on design of socially-attuned humanoid robots.

Studies carried out within the unit make use of cognitive neuroscience methods (performance measures, eye- and head tracking, EEG) and naturalistic interactive protocols involving the iCub robot.

Research activities of the unit “Social Cognition in Human-Robot Interaction”are carried out in a lab dedicated to the unit, equipped with an iCub robot, an EEG system, a mobile eyetracker and four workstations for behavioural and psychophysical experiments.

The ideal candidates are students with a higher level university degree willing to invest extra time and effort in blending into a multidisciplinary team composed of neuroscientists, engineers, psychologists, physicists working together to investigate brain functions and realize intelligent machines, rehabilitation protocols and advanced prosthesis.

**International applications are encouraged and will receive logistic support with visa issues, relocation, etc.**

## 1. Make humanoids understand human goals

**Tutors:** Dr. Alessandra Sciutti, Dr. Francesco Rea, Prof. Giulio Sandini

**Institute: IIT (Istituto Italiano di Tecnologia)**
**Research Unit: Robotics, Brain and Cogntive Sciences (**https://iit.it/RBCS**)**

**Description**: Although traditionally collaboration has been modeled as relying mainly on a planning process, it is nowadays acknowledged that what makes human interactions fast and efficient is emergent coordination, a subconscious mechanism based on a tight link between action execution and perception. Neurophysiological evidence indicate that action observation activates in the observer a motor representation of the same action learned through execution, which yields to a rapid and automatic understanding of the goals and intentions of others. Hence, visual action understanding requires a sensori-motor action representation, previously built by performing the action. This mechanism supports also phenomena like mutual adaptation, synchronization and anticipation, which cut drastically the delays and the need of complex verbal instructions in the interaction and result in the establishment of joint intentions. It is crucial to have a similar process working in humanoid robots, in order to make human-robot interaction intuitive and natural.
The general aim of this project is to provide the humanoid robot iCub with visuo-motor matching skills, enabling it to build a multimodal, sensorimotor representation of its actions to be exploited to understand human goals. In particular the robot will have to learn the motor (efference copy) and sensory (visual, joint angles, forces) consequences of its own actions and find how to map these with the visual representation of human behaviors obtained through the observation of human actions. The work might take advantage of a computational system already available on the robot designed to localize the portion of the scene containing biological motion and extract some of its visual features .

**Requirements**: degree in robotics, bioengineering, computer science, computer engineering, or related disciplines, attitude for problem solving, c++ programming. A background on machine learning is an asset.

**References**:


- Vignolo A., Rea. F.,Noceti N., Sciutti A., Odone F. & Sandini G. 2016, 'Biological movement detector enhances the attentive skills of humanoid robot iCub' in IEEE/RAS International Conference of Humanoids Robotics, Cancun, Mexico November 15-17 2016.
- Sciutti A., Ansuini C., Becchio C. & Sandini G. 2015, 'Investigating the ability to read others' intentions using humanoid robots', Frontiers in Psychology – Cognitive Science, vol. 6,no. 1362
- L. Craighero, G. Metta, G. Sandini, and L. Fadiga, "The mirror-neurons system: data and models.," Prog. Brain Res., vol. 164, pp. 39–59, Jan. 2007


**Contacts**: Applicants are strongly encouraged to contact the perspective tutors before they submit their application: alessandra.sciutti@iit.it , francesco.rea@iit.it , giulio.sandini@iit.it

## 2. Binaural filtering techniques for augmented perception and understanding of sounds

**Tutor**: Luca Brayda, PhD; Prof. Giulio Sandini

**Institute: IIT (Istituto Italiano di Tecnologia)**
**Research Unit: Robotics, Brain and Cogntive Sciences (**https://iit.it/RBCS**)**
**Division: Spatial Awareness and Multisensory Perception**

**Description:** The Spatial Awareness and Multisensory Perception lab is doing research focussed on how to code and increase knowledge about the environment when deficits occur in humans. The lab is proposing sensory substitution and sensory enhancements techniques and technologies that so far supported blind and visually impaired individuals as well as persons with hearing disabilities. Recent evidences showed the potential benefit of auditory training in persons with developmental disorders. Similarly spatially filtered binaural audio improves speech understanding in noisy environments, where the attentional focus can be arbitrarily decided by the user.

The goal of this project is to implement and assess a binaural acoustic filtering method to enhance attentional capabilities in persons with attentional deficits, by means of technologies capable of actively conditioning surrounding sounds. In particular the goals of this PhD program are:

- To design speech and sound filtering techniques, able to condition binaural feedback in ways that go beyond a better understanding of speech
- To implement the techniques on a software-based technological platform
- To iteratively optimize the filtering technique on the kind of user that will wear the platform, in collaboration with neuroscientists

The project will be carried out in a multidisciplinary team, with the contribution of engineers, psychologists and rehabilitation practitioners.

**Requirements**: Applicants should have a degree in Computer Science, Computer Science Engneering, Biomedical Engineering or equivalent.

**References**:


- Leo F., Cocchi E., Brayda L. (2016), The effect of programmable tactile displays on spatial learning skills in children and adolescents of different visual disability, in IEEE Transactions on Neural Systems and Rehabilitation Engineering, DOI 10.1109/TNSRE.2016.2619742
- Tonelli A., Gori M., Brayda, L. (2016), The influence of tactile cognitive maps on auditory space perception in sighted persons, Frontiers in Cognitive Sciences, DOI 10.3389/fpsyg.2016.01683
- Brayda L., Campus C., Memeo, M., Lucagrossi L. (2015) The importance of visual experience, gender and emotion in the assessment of an assistive tactile mouse IEEE Transaction on Haptics, 2015, DOI: 10.1109/TOH.2015.2426692
- Giuliani L., Brayda L., Sansalone S., Repetto S., Ricchetti M., (2017), Evaluation of a complementary hearing aid for spatial sound segregation”**,** in Proceedings of International Conference of Acoustics, Speech and Signal Processing (ICASSP 2017)



**Contacts:** luca.brayda@iit.it, giulio.sandini@iit.it

## 3. Embodied "social" intelligence for human robot interaction (Robocom++ project)

**Tutors**: Francesco Rea, PhD; Alessandra Sciutti, PhD; Prof. Giulio Sandini

**Institute: IIT (Istituto Italiano di Tecnologia)**
**Research Unit: Robotics, Brain and Cogntive Sciences (**https://iit.it/RBCS**)**

**Description:** Purposive behavior with anticipation of the consequences of one's actions and other's actions are critical desirable features if robots are to truly become companions in everyday tasks. It is one objective of the pilot study in Robocom++[1] to adopt a brain-guided approach to enable robotic companions to instantaneously simulate the perspective of the "other" (like humans), thereby engaging in cooperative behaviors.
Presently, while emerging trends in neurosciences like the discovery of the default mode network [2], action observation network [3,4] are revolutionizing our understanding of the cortical basis of social intelligence, the underlying mechanistic/computational mechanisms remain challenging research topics. The aim of this project is to address the objectives of Robocom++ and to provide computational processes that allow us to "perceive, act and remember" and to recycle them in order to simulate the perspective of others. In other words we aim at developing mechanisms that allow us to reuse our own episodic experiences to adopt the viewpoint of the other by analogy.

The PhD program will comprise at least one of the following research topics:

- To represent and simulate other`s actions in humanoid robots
- To develop reciprocal recognition of agency in HRI
- To enable perspective taking from episodic memory in humanoid robots
- To integrate Embodied Social Intelligence in a framework of cognitive reasoning.
- To validate Humanoid Social Behaviour in ecological context

**Requirements**: degree in robotics, bioengineering, computer science, computer engineering, or related disciplines, attitude for problem solving, c++ programming. A background on machine learning is an asset.

**References**


1. http://sssa.bioroboticsinstitute.it/news/robocomplusplus
2. Mohan V, Sandini G, Morasso P. (2014). A neural framework for organization and flexible utilization of episodic memory in "cumulatively" learning baby humanoids, Neural Computation 26(12), 2692-2734, MIT Press.
3. Gallese, V., Sinigaglia, C. (2011). What is so special with Embodied Simulation. Trends in Cognitive Sciences. 15(11):512-9.
4. Bressler, S,L., Menon, V. (2010). Large-scale brain networks in cognition: emerging methods and principles. Trends in cognitive sciences *Volume 14, Issue 6*, June 2010, Pages 277–290


**Contacts:** Applicants are strongly encouraged to contact the perspective tutors before they submit their application: francesco.rea@iit.it, alessandra.sciutti@iit.it, giulio.sandini@iit.it

## 4. Sensorimotor modeling to enhance skill learning and skill recovery

**Tutor**: Prof. Gabriel Baud-Bovy, Dr. Jacopo Zenzeri

**Institute: IIT (Istituto Italiano di Tecnologia)**
**Research Unit: Robotics, Brain and Cogntive Sciences**
https://iit.it/RBCS

**Description:** Shaping sensorimotor processes through physical human-robot interaction is the key to promote skill learning and skill recovery. In particular proprioception has a critical role in promoting or hindering learning mechanisms. These mechanisms are related to the body schema concept: a dynamical system that generates goal-oriented, spatio-temporal, sensorimotor patterns, integrating a direct and inverse internal model in a multi-referential framework, and that plays a fundamental role in haptic exteroception and motor control. Proprioception may be considered as the "glue" that keeps the coherence of the body-schema during its incessant evolution. Modeling these sensorimotor processes can be fundamental to intervene when the goal is, for example, the optimization of skill recovery after a brain injury. The research will involve experiments with human subjects (healthy and impaired) using haptic interfaces, analysis of movements, interaction forces and their neural correlates (using EMG, EEG, TMS). The knowledge gained from the experiments will also be used to design more effective robotic systems that exploit the models of sensorimotor processes.

**Requirements:** a degree in Computer Science Engineering, Experimental Psychology, Bioengineering or equivalent, with high interests in human sciences. Attitude for experimental work, problem solving and computational modeling will constitute factors of preference.

**References:** Morasso, P., Casadio, M., Mohan, V., Rea, F., & Zenzeri, J. (2015). Revisiting the body-schema concept in the context of whole-body postural-focal dynamics. Frontiers in Human Neuroscience, 9, 83.

**Contacts:** gabriel.baud-bovy@iit.it , jacopo.zenzeri@iit.it

## 5. Social cognition in human-robot interaction

**Tutor**: Agnieszka Wykowska

**Institute: IIT (Istituto Italiano di Tecnologia)**
**Research Unit: Social cognition in human-robot interaction**
https://www.iit.it/research/lines/social-cognition-in-human-robot-interaction

**Description:** The theme **"Social cognition in human-robot interaction"** is related to a European project "Intentional stance for social attunement" (an ERC grant) which aims at examining mechanisms of human social cognition during interactions with artificial agents. The key question is whether and when humans attribute mental states to others, and how this influences social attunement in an interaction. In particular, we are interested in behavioural characteristics of an agent that allow for mind attribution. This is examined with experimental protocols involving naturalistic scenarios in which participants interact with the humanoid robot iCub. To design various behavioural characteristics of the robot, human-human interaction studies are first conducted in order to measure human-like behavioural characteristics. The robot is then programmed to behave in a similar manner. The question of interest is whether humans have sensitivity to subtle human-like characteristics of behaviour and how this affects social attunement. To address these questions, methods of social cognitive neuroscience are used, namely behavioural measures (reaction times, accuracy, eye- and head tracking) as well as EEG and physiological measures (heart rate, Galvanic Skin Response).

**Requirements:** The candidates should have:

- Master's Degree in Psychology, Cognitive or Social Neuroscience, or equivalent;
- Experience with empirical research in Cognitive Psychology or Cognitive/Social Neuroscience;
- Experience with data analysis (behavioural and possibly EEG);
- Excellent knowledge of statistics and experience with hands-on statistical analyses;
- Excellent English language skills (oral and written);
- Experience in writing scientific papers or publication-like reports.

**References:**


- **Wykowska, A**., Chaminade, T., & Cheng, G. (2016). Embodied artificial agents for understanding human social cognition. Philosophical Transactions of the Royal Society London: B. Biological Sciences, 371, 20150375. http://dx.doi.org/10.1098/rstb.2015.0375.
- **Wykowska, A**., Wiese, E., Prosser, A., Müller, H.J. (2014). Beliefs about the minds of others influence how we process sensory information. *PLOS ONE*, 9 (4), e94339
- **Wykowska, A.**, Kajopoulos, J., Ramirez-Amaro, K., Cheng, G. (2015). Autistic traits inversely correlate with implicit sensitivity to human-like behavior. *Interaction Studies, 16:2, 219-248*.



**Contacts:** agnieszka.wykowska@iit.it

## 6. From science to technology for learning skills in children

**Tutor:** Dr. Monica Gori

**Institute: IIT (Istituto Italiano di Tecnologia)**
**Research Unit: Unit for Visually Impaired People**
https://www.iit.it/it/linee/unit-for-visually-impaired-people

Technologies supporting smart and personalized learning of children with and without sensory and motor disabilities is one of the big challenges of our society. Unit for Visually Impaired People (IIT) is looking for a PhD in the field of multisensory development in children .
The goal of the project is to develop learning technologies to support the inclusion of children with and without disabilities through:

- The study of multisensory development
- The development of a new set of devices to improve learning skills.
- The demonstration and the validation of the technology through user, experimental and clinical studies.

**Requirements:** The PhD student will be involved in doing psychophysical experiments with children and to help in the development of device from the electronic and software point of view. A background in biomedical engineering, basic neuroscience, and programming skills are required.

**Contacts:** Monica.gori@iit.it