1st year

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1st semester

Mandatory courses for all students

2nd semester

Statistical signal processing (Fulvio Gini)

Methods and techniques of measurement and data analysis (Angelo Sabatini)

Bioinspired computational methods

Biological data mining (Francesco Marcelloni + Pietro Ducange)

Neural and fuzzy computation (Beatrice Lazzerini)

Analysis of bionic and robotic systems

Principles of bionics and biorobotics engineering (Paolo Dario + Donato Romano)

Modeling of multi-physics phenomena (Alessandro Tognetti + Alessandro Lucantonio)

Mandatory courses for the students enrolled in the «Biorobotics» curriculum

Bioinspired and soft robotics

Mechanics of smart materials and structures (Antonio De Simone + Alessandro Lucantonio)

Soft robotics technologies (Matteo Cianchetti)

Mandatory courses for the students enrolled in the «Neural Engineering» curriculum

Applied brain science

Behavioural and cognitive neuroscience (Emiliano Ricciardi + Pietro Pietrini)

Computational neuroscience (Alessio Micheli + Claudio Gallicchio)

Elective courses (tot: 12 ECTS – namely 2 courses to be chosen by students)

Artificial intelligent systems for human identification (Enzo Pasquale Scilingo)

Neuromorphic engineering (Calogero Oddo + Alberto Mazzoni)

Robot Programming frameworks and IoT platforms (Egidio Falotico + Gastone Ciuti)

Advanced materials for bionics (Francesco Greco)

Electronics for bionics engineering (Daniele Rossi)

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2nd year – Curriculum Biorobotics

1st semester	*2nd semester*
Rehabilitation and assistive technologies	
Biomechanics of human motion (Vito Monaco)	Robotic and data-driven rehabilitation (Marco Controzzi + Andrea Mannini)
Advanced interventional and therapeutic technologies	
Robotics for minimally invasive and targeted therapy (Arianna Menciassi)	Bionic organs and tissues (Leonardo Ricotti)
Wearable robotics	
Prostheses (Christian Cipriani)	Exoskeletons (Nicola Vitiello + Simona Crea)
Design principles for bionic tissue engineering (Arti Ahluwalia)	

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2nd year – Curriculum Neural Engineering

1st semester		*2nd semester*
Integrative cerebral function and image processing		
Advanced image processing (Nicola Vanello + Gaetano Valenza)	=	Integrative cerebral functions (Angelo Gemignani)
Interactive Systems and Affective Computing		
Interactive systems (Daniele Mazzei)	=	Affective computing (Enzo Pasquale Scilingo)
Neural prostheses		
Neural tissue engineering (Giovanni Vozzi)	=	Neural interfaces and bioelectronic medicine (Silvestro Micera + Alberto Mazzoni)
Bionic senses (Alessandro Tognetti + Nicola Carbonaro)		

M.Sc. in Bionics Engineering

	1st year	
	1st semester	**2nd semester**
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M.Sc. in Bionics Engineering

2nd year – Curriculum: Biorobotics	
1st semester	**2nd semester**
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Prostheses (Christian Cipriani) – 6 ECTS	Exoskeletons (Nicola Vitiello) – 6 ECTS
Robotics for minimally invasive and targeted therapy (Arianna Menciassi) – 6 ECTS	Bionic organs and tissues (Leonardo Ricotti) – 6 ECTS
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2nd year – Curriculum: Neural Engineering	
1st semester	**2nd semester**
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Interactive systems (Daniele Mazzei) – 6 ECTS	Affective computing (Enzo Pasquale Scilingo) – 6 ECTS
Bionic senses (Alessandro Tognetti) - 6 ECTS	

Final duties: Lab training (3 ECTS) and Thesis (15 ECTS)

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Principles of bionics and biorobotics engineering

Focus

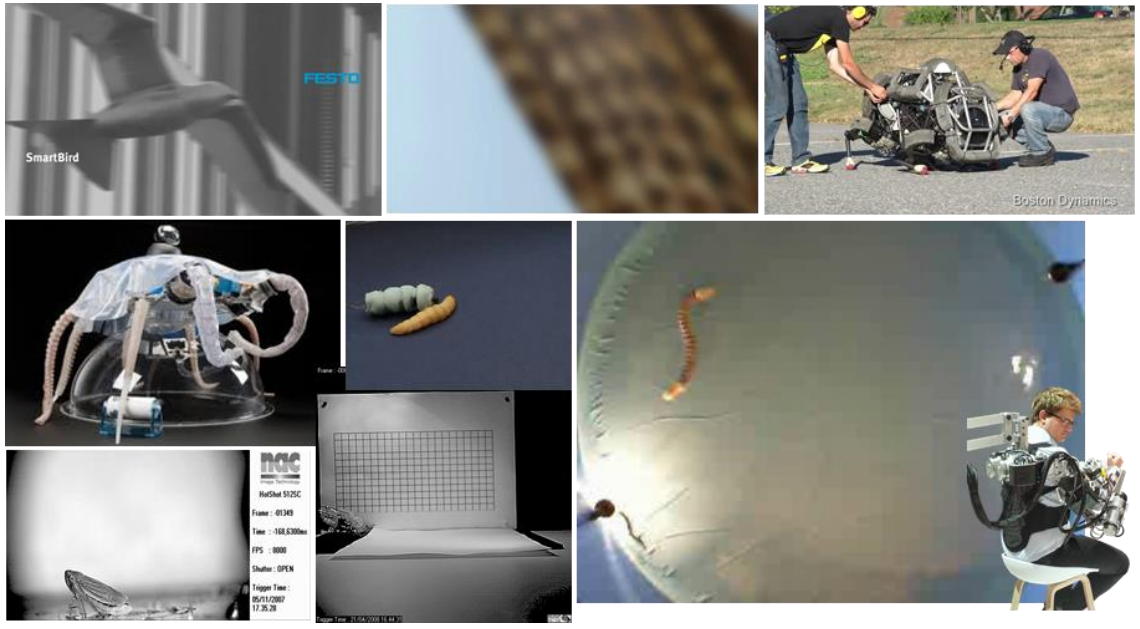
- Make students able to face frontier engineering problems, by combining science and hi-tech approaches (proper of bionics design)

Main Contents

- Historical evolution of bionics, related to robotics and bioengineering;
- Model organisms and biological locomotion principles in different media, and applications in robotics;
- Bionic energy management: comparison between organisms and robots;
- Fabrication technologies at different scales;
- Bioinspired structural design and advanced materials;
- Fundamentals of robot mechanics (schematic of the joints, homogeneous transformations, Jacobian, methods for kinematic and dynamic studies);
- Swarm robotics;
- Ethical issues and legal considerations.

Learning Outcomes

- Providing basic knowledge and principles on design, fabrication, and control processes of bionics systems
- Highlighting current bionics systems and their applications
- Stimulating students directly to develop innovative bionic concepts by exploiting the knowledge acquired during the course



Statistical signal processing

Focus

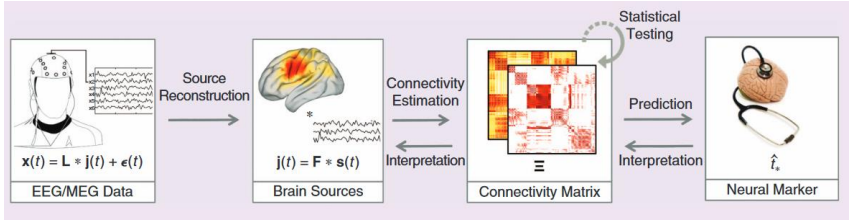
- Statistical signal processing methods for deterministic and random parameter estimation, data analysis, random signal recovery and filtering, model identification, power spectral density estimation.

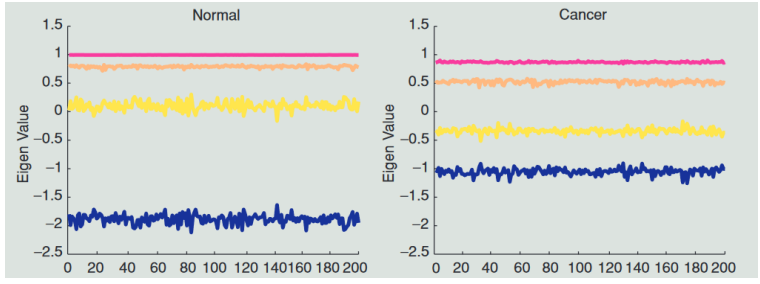
Main Contents

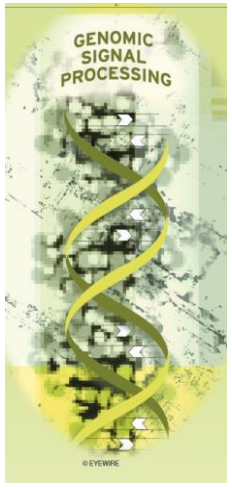
- Orthonormal base signal expansion, Principal Component Analysis (PCA), Sample estimators, Method of moments estimators, Maximum likelihood estimators, Linear and Non Linear Least Squares Least, Bayes estimation, Minimum Mean Square Error (MMSE) and Maximum A Posteriori (MAP) estimation, Linear MMSE (LMMSE) estimation, ARMA modeling, Wiener filter for signal filtering, prediction and interpolation, parametric and non Parametric power spectral density estimation.

Learning Outcomes

- Background knowledge necessary to solve typical problems by using methods of statistical signal processing







Biological data mining

Focus

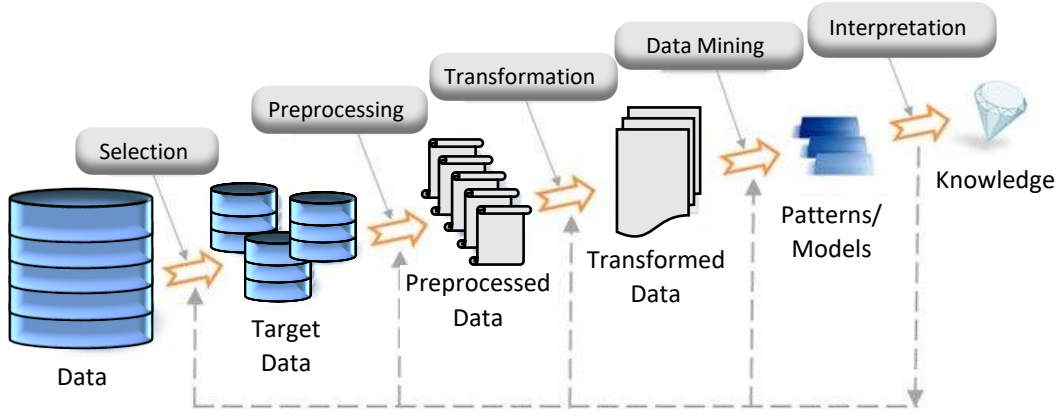
- Main techniques used in Data Mining

Contenuti principali

- Data Preprocessing
- Frequent pattern mining
- Classification
- Clustering
- Outlier Detection
- Laboratories on the application of the methods presented during the course

Learning Outcomes

- To provide a solid knowledge of the main techniques used in data mining. This knowledge will allow identifying the most suitable approach for solving each type of data mining problem.



M.Sc. in Bionics Engineering

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Modeling of multi-physics phenomena

Focus

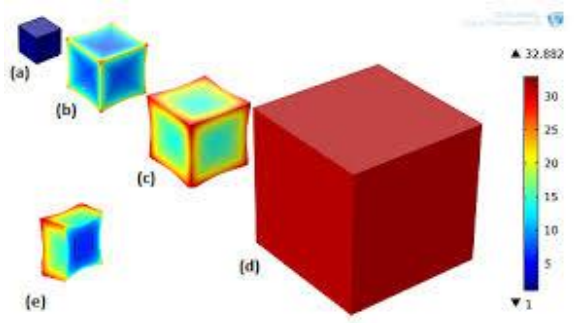
- Computational modeling of multi-physics systems with applications to bionics

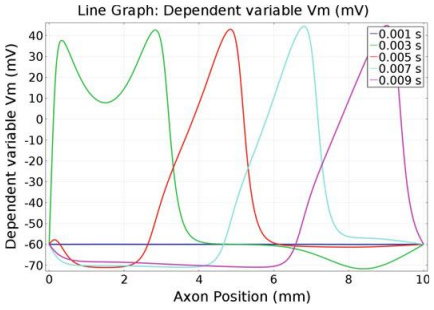
Main Topics

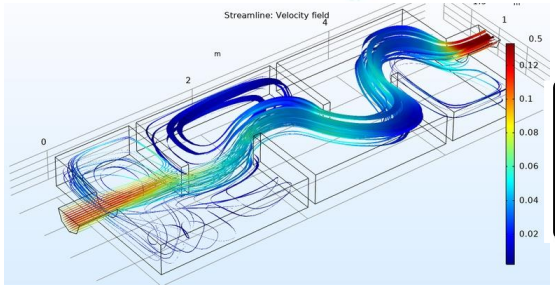
- Weak-form modeling and theory of the Finite Element Method
- Numerical methods and best practices for the solution of non-linear and transient problems
- Linear and non-linear elasticity
- Incompressible flows of Newtonian fluids
- Electromagnetism at low frequencies (biolectric phenomena and neural models)
- Design of sensors and bioinspired devices using computational tools

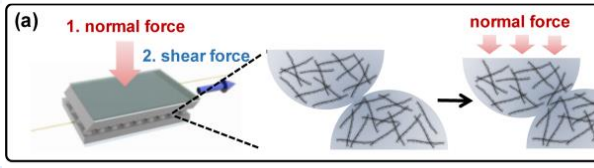
Learning Outcomes

- Fundamental physical concepts, numerical methods and tools for the computational modeling of a wide range of multi-physics phenomena









Methods and techniques of measurement and data analysis

Focus

- Methods and techniques in physical measurements for bionic applications

Learning Outcomes

- Measurement problem solving (acquisition and interpretation)

Main Contents

- Application and design of measurement systems
- Measurement systems explained through mathematical modeling
- Signal processing methods for analysis of experimental data

Neural and fuzzy computation

Focus

- Basic concepts and models of Computational Intelligence
- Application of the associated techniques to real-world problems in several application domains

Main Contents

- Artificial neural networks
- Deep learning
- Fuzzy logic
- Fuzzy systems
- Genetic algorithms

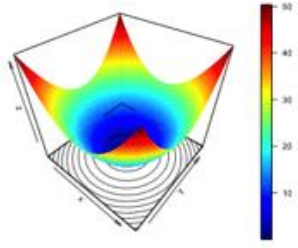
Learning Outcomes

- Design and develop intelligent systems with human-like capabilities in terms of reasoning, learning and adaptation

forecasting

profiling

decision making



Multi-objective optimization

M.Sc. in Bionics Engineering

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Mechanics of smart materials and structures

Focus

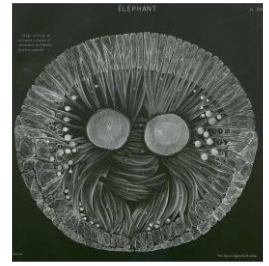
- Non linear mechanics of one-dimensional active and elastic systems in the regime of large deformations: from robotic arms to elephant trunks

Main Topics

- Infinitesimal and finite rotations
- Kinematics and equilibrium of deformable rods
- Material properties and consitutive models
- Prinicple of virtual powers, minimal potential energy, and the Finite Element Method
- Applications: wires and tendons, Euler's elastica and Galileo's beam, bending with large deformations, buckling and post-critical behavior of elastic systems

Learning Outcomes

- Methodological approach for the formulation and solution of shape control problems in biological and robotic systems



Soft robotics technologies

Focus

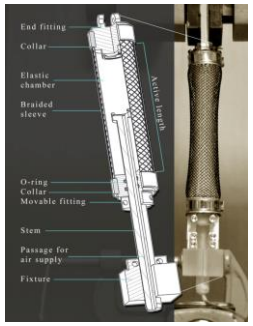
- Use of soft materials for developing soft robots and mechatronics technologies

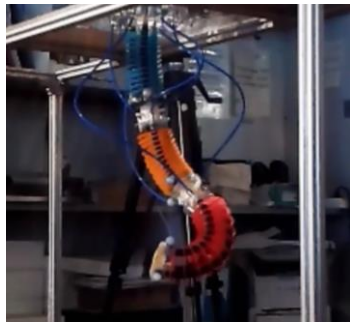
Main Contents

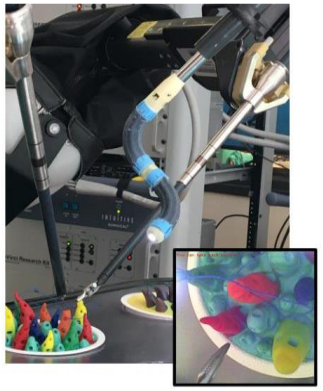
- Bioinspiration and morphological computation
- Novel sensing and actuation technologies
- FEM implemented in ANSYS software for non-linear analysis
- Behaviour and characterization of elastomeric materials

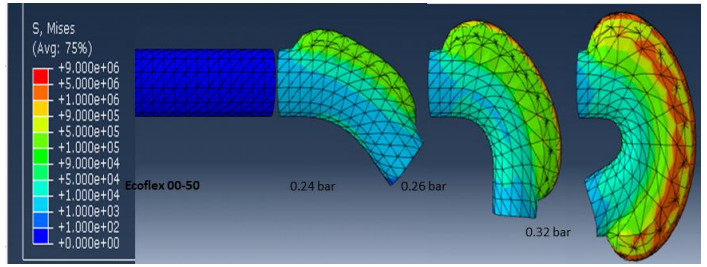
Learning Outcomes

- Use of soft/compliant materials for the design of mechatronic systems through advanced design principles









M.Sc. in Bionics Engineering

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Behavioral and cognitive neuroscience

Focus

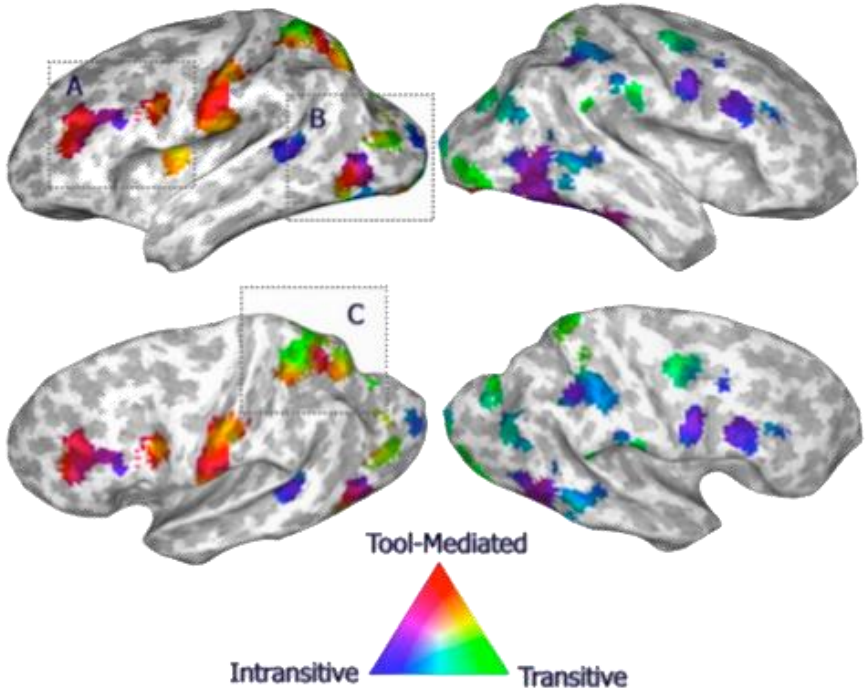
- Neuroimaging has revolutionized neuroscience, allowing us to investigate the neural correlates of behavior and mental functions

Main contents

- basics of brain anatomy and physiology
- neuroimaging methodologies: principles, applications, methods of analysis
- neurobiological correlates of cognition and behavior
- functional neuroanatomy of perception, consciousness and sleep, language, emotions and behavior motor control and representation of action, development of brain-computer interfaces

Objective

The course introduces the theoretical and methodological aspects of cognitive and social neuroscience, introducing to the fundamentals of brain anatomy and physiology, and to neuroimaging techniques



Computational neuroscience

Focus

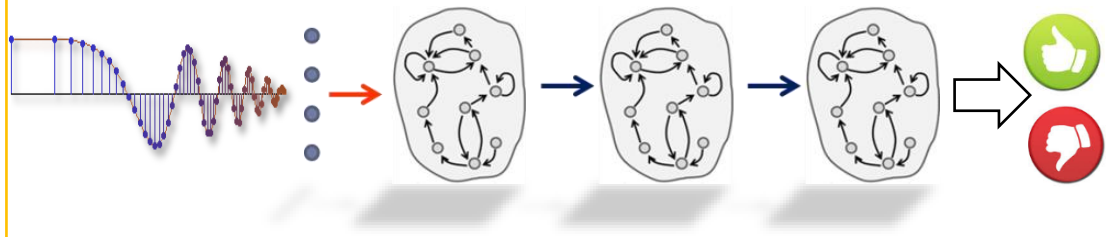
- Introduction to fundamentals of the CNS considering both the bio-inspired neural modelling and computational point of view

Learning Outcomes

- Capability of analysis and development of advanced CNS/Machine Learning models

Main Contents

- Neuroscience modeling
- Spiking and reservoir computing neural networks
- Advanced computational learning models
- Dynamical/Recurrent neural networks



Deep Recurrent Neural Network

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Artificial intelligent systems for human identification

Focus

- Advanced techniques to verify or recognize the identity of a living person based on the analysis of biological/physiological traits and/or behavioural features.

Main contents

- Recognition, identification and verification
- Privacy, security and ethics
- Physiological biometric systems: fingerprint recognition, face recognition, iris recognition, retina recognition, hand recognition, vein patterns
- Behavioral biometric systems: keystroke dynamics, signature recognition, voice recognition, gait recognition

Learning Outcomes

- Acquire basic knowledge to process physiological and behavioural features to recognize the identity of a living person.

Neuromorphic engineering

Focus

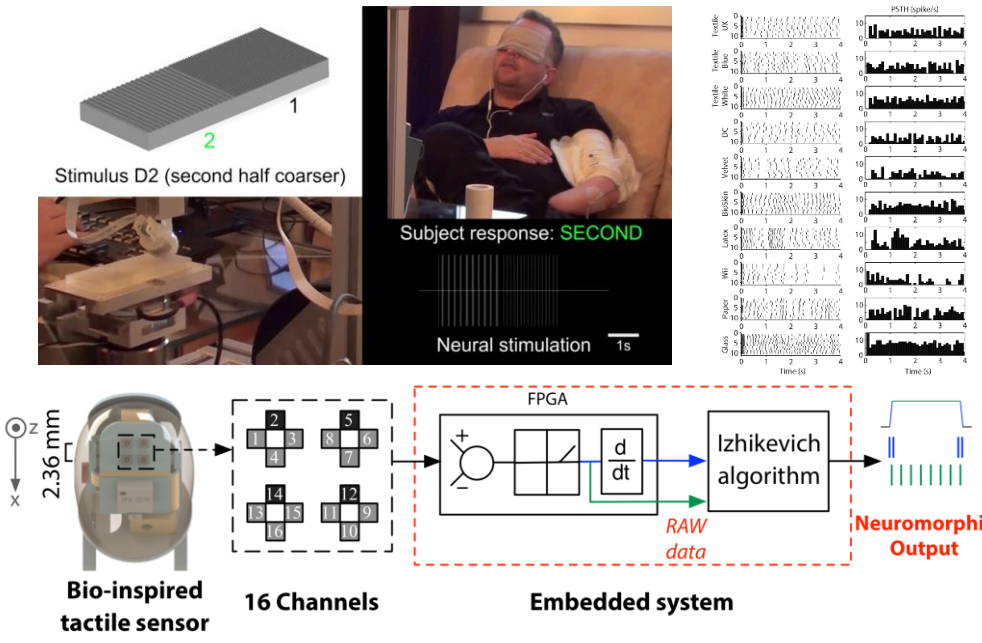
- Computational and physical models that emulate neuron dynamics

Main Contents

- Technologial solutions for embedded spiking systems
- Signal processing techniques for spiking signals (artificial or physiological)
- Methods for simulating neuron dynamics (e.g. Izhikevich model)
- Use and design of neuromorphic systems

Learning Outcomes

- Neurorobotic systems and neurophysiological data for restoring sensori-motor functions



Robot programming frameworks and IoT platforms

Focus

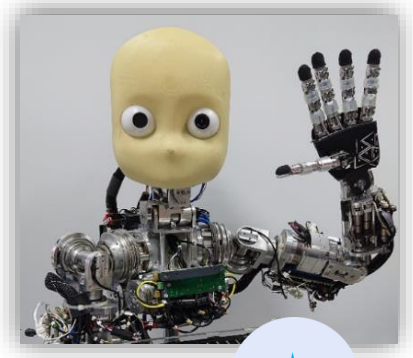
- Software design of autonomous robots and systems
- Robot programming based on different middleware, enhanced by IoT platforms and ancillary hardware peripherals

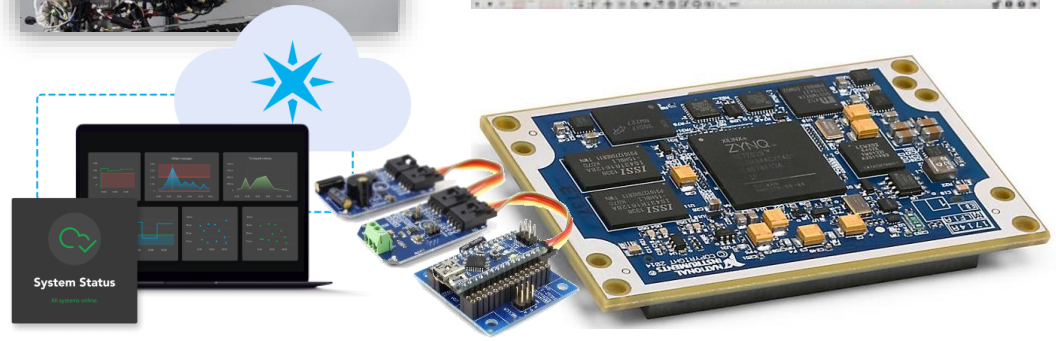
Main Topics

- Robotic middleware (ROS, YARP)
- Communication mechanisms
- Robot control with robotic operative systems
- SoM programming with hardware peripherals
- IoT platforms and cloud programming

Learning Outcomes

- Theoretical and practical competences in robotic and SoM programming with IoT platforms and ancillary hardware peripherals





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Advanced materials for bionics

Focus

- Materials Science & Engineering: materials classes, structure, properties
- Advanced Concepts and applications of materials in Bionics

Learning Outcomes

- solid background in Materials Science & Engineering
- knowledge of uses of modern advanced materials in Bionics Engineering

Main Topics

- Basic traditional topics of Materials Science & Eng.
- Metals, Ceramics, Polymers, Composites
- Advanced Materials Concepts: Biocompatibility, complex Soft Matter, Nanotechnology & Nanostructures, Bioinspired & Stimuli Responsive Materials.
- Investigation & Fabrication Techniques
- Technology & Bionics Applications: materials for bionics, bioelectronics, sensors&actuators in robotics

Electronics for bionics engineering

Focus

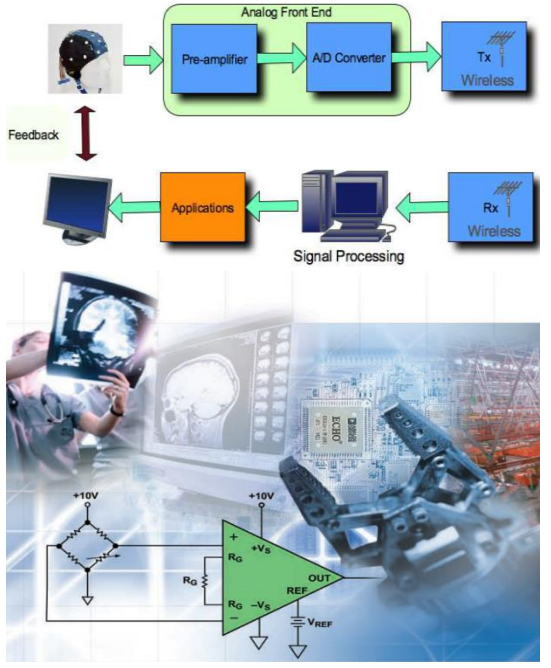
- Analysis and design of the building blocks of an electronic system for the acquisition and processing of biological sensor data

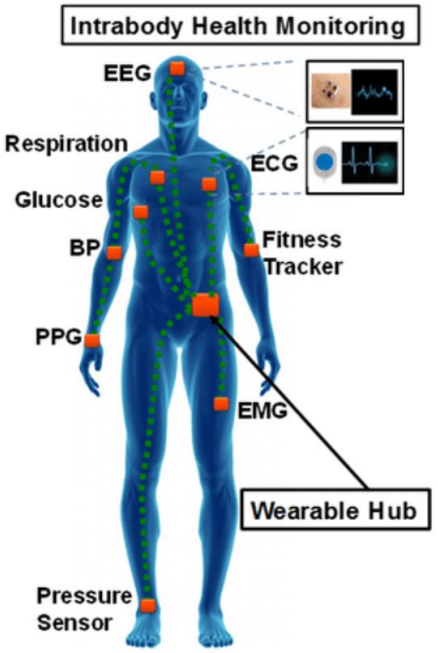
Learning Outcomes

- Acquisition of a solid knowledge of the techniques and methods related to the design of sensor based electronic systems

Main Contents

- Analog front-end building blocks: instrumentation amplifiers, filters and ADC/DAC converters
- Digital interfaces transferring digitalised sensor data to an embedded microcontroller
- Design principles for energy and power efficient electronic systems for wearable applications





M.Sc. in Bionics Engineering

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Final duties: Lab training (3 ECTS) and Thesis (15 ECTS)

Biomechanics of human motion

Focus

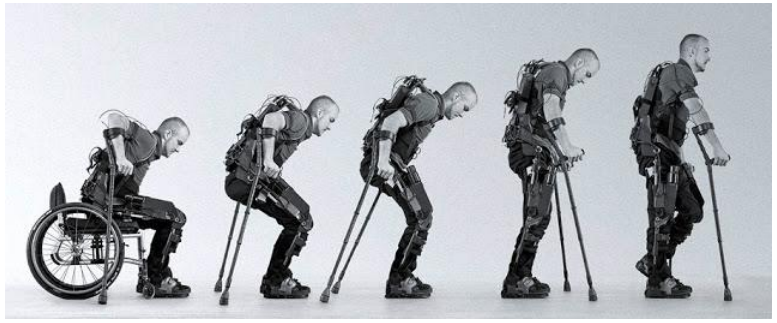
- Biomechanics of human movements and physiological principles underlying motor control.

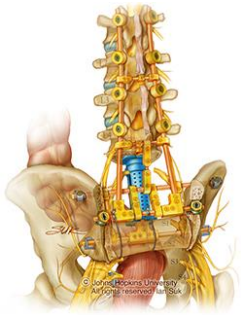
Main Topics

- 3D kinematics and kinetics;
- physiology of muscle contraction
- modeling of muscle-tendon actuators;
- numerical methods to solve dynamic models adopted in biomechanics;
- EMG signals
- instruments in a motion lab

Learning Outcomes

- Methodological approach for the study of human motion during dynamic motor tasks mediated by muscle-tendon actuators





Prostheses

Focus

- Upper limb prostheses
- Embedded controls

Main Contents

- Basic components of myoelectric and body-powered arms (batteries, mechanical, electrical, suspension systems)
- Architecture, operation and peripherals of the microcontroller

Learning Outcomes

- Ability to discuss the design choices of a modern prosthetic arm
- Ability to design and implement in a microcontroller a control system for a prosthesis

Robotics for minimally invasive and targeted therapy

Focus

- Robots, intelligent tools, integrated mechatronic systems, from the *MACRO* to the *micro* scale, to improve accuracy and repeatability in medical interventions.

Main Contents

- Contributions of robotics, mechatronics and bioengineering in minimally invasive surgery and targeted therapy.
- Autonomous robots, tele-operated robots, hand held tools, shared control robots for surgery.
- Endoluminal approaches and miniature robots towards the micro scale.

Learning Outcomes

- Knowledge and tools to design robots and mechatronic tools for surgical / diagnostic / therapeutic applications.

Design principles for bionic tissue engineering

Focus

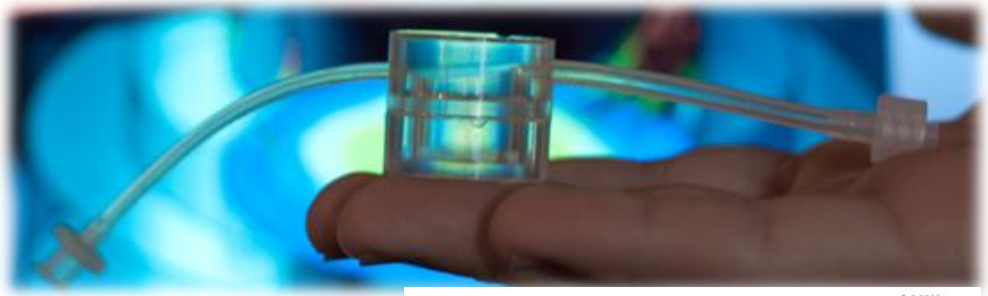
- *in vitro* models, artificial organs & delivery systems using technology based on stem cells, organoids, smart materials & smart fabrication

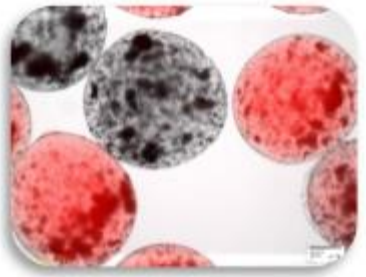
Main contents

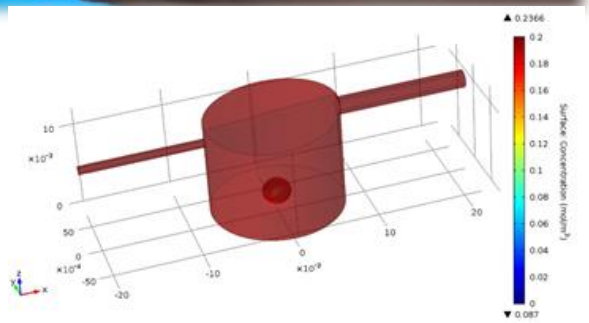
- Cells and cellular models
- Quantitative models of cell-material interaction
- Stem cell and organoid technology
- Design criteria for 3D constructs
- Fluidic system design

Learning Outcomes

- Design and application of cell-based models







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Robotic and data-driven rehabilitation

Focus

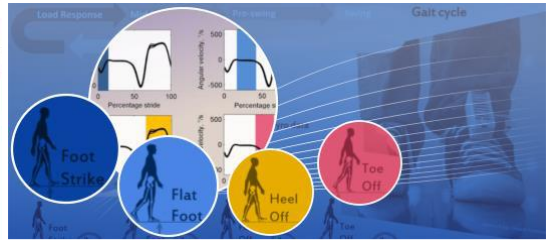
- Robotics and its current scenario for rehabilitation
- Data-driven and evidence-based translational research in rehabilitation

Main Topics

- the fourth industrial revolution and the digital transformation: evolution of robotics (rehabilitative, assistive, collaborative, social)
- basic translational and experimental research to assess robotic prototype in clinical settings;
- evidence-based studies in clinical rehabilitation
- machine learning methods implementation, validation and its diagnostic tools in applications in the field of bioengineering and rehabilitation

Learning Outcomes

- current trends in rehabilitation
- clinical trials and translational research
- data-driven and evidence-based rehabilitation



Exoskeletons

Focus

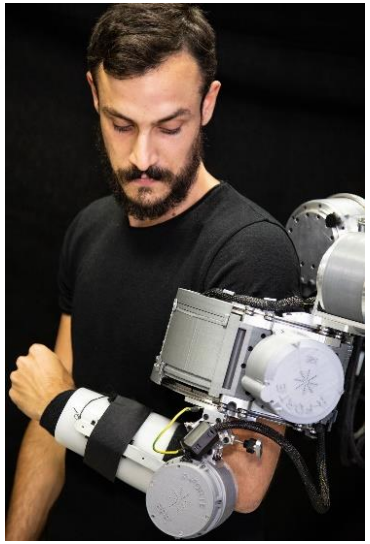
- Lower- and upper-limb exoskeletons for rehabilitation and assistance
- Exoskeletons for industrial applications
- Lower-limb prostheses

Main Contents

- State of the art of lower-limb prostheses, lower- and upper-limb exoskeletons for rehabilitation and asssistance
- Design principles of ergonomic wearable robots
- Series-elastic actuators
- Physical and cognitive human-robot interfaces
- Control architectures for exoskeletons and prostheses
- Hands-on programming of real-time embedded controllers

Learning Outcomes

- Design of wearable powered robots for movement assistance, rehabilitation, augmentation and/or functional replacement
- NI LabVIEW Real-Time and FPGA programming



Bionic organs and tissues

Focus

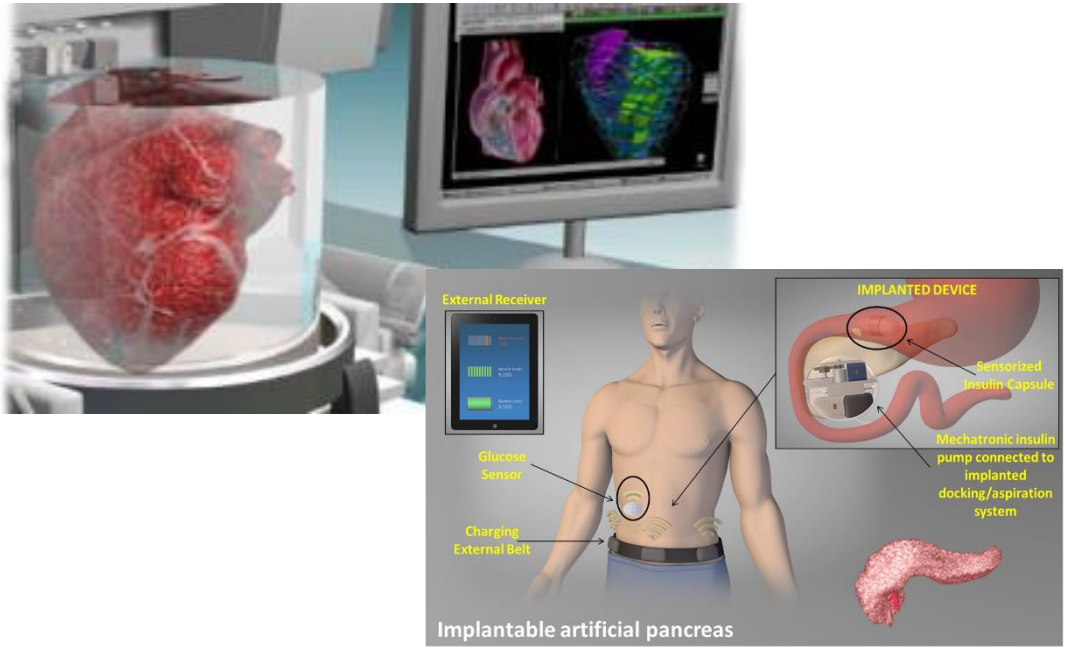
- Artificial and bioartificial organs and tissues
- Regenerative medicine

Main Contents

- Artificial and bioartificial substitutes of muscle, cartilage, pancreas, heart, kidney, etc.
- Miniaturized implantable mechatronic devices
- Biomaterials promoting tissue regeneration
- Microfabricated structures and smart materials for bionic organs and tissues

Learning Outcomes

- Technologies and approches to regenerate or substitute human organs and tissues
- Hands-on awareness of chemistry, microfabrication and molecular biology



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Advanced image processing

Focus

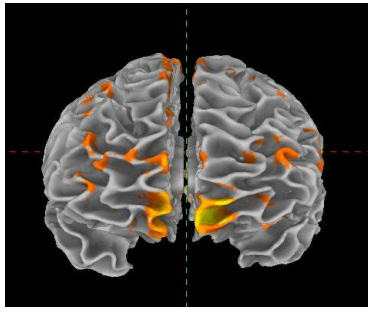
- Models and Methods fo brain function analysis

Main Contents

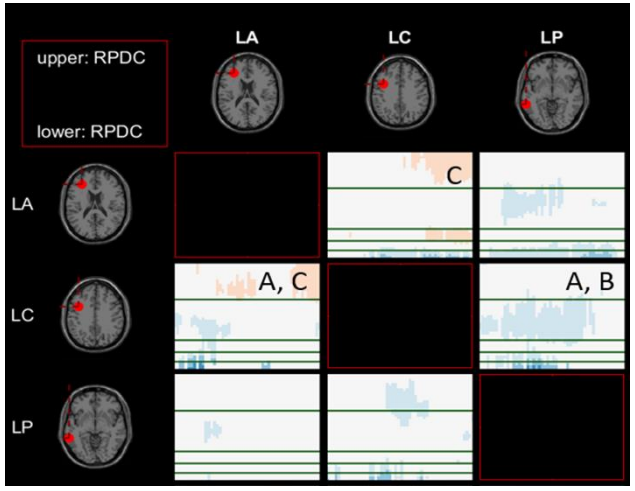
- Functional Magnetic Resonance Imaging (fMRI)
- Brain connectivity from fMRI and Electroencephalography (EEG)
- Source imaging from EEG e MRI

Learning Outcomes

- How different methods for brain function studies are applied
- Link between experimental desgin and data analysis approaches



fMRI analysis



Time frequency analysis of brain connectivity

Neural tissue engineering

Focus

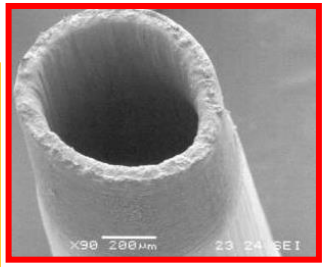
- Technological processes and materials to build neural grafts and promote their interaction with physiological neural tissue

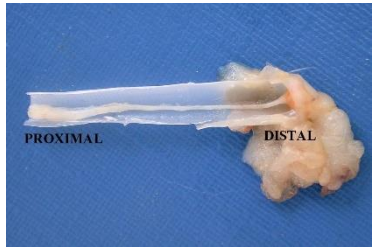
Learning Outcomes

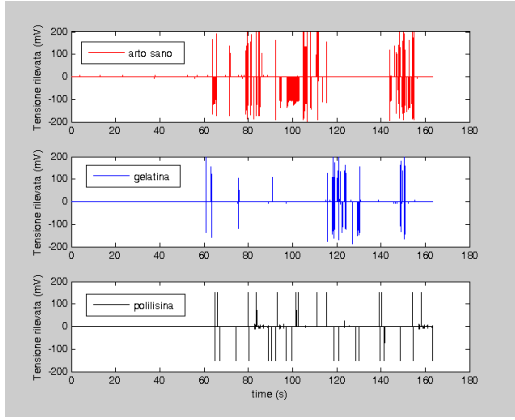
- Acquire the strategies to develop grafts and scaffolds that can be implanted to promote nerve regeneration and to repair neural damage

Main Contents

- Bioactive materials and their characterisation
- 2D and 3D Fabrication
- Neuro-Chemical functionalisation







Interactive systems

Focus

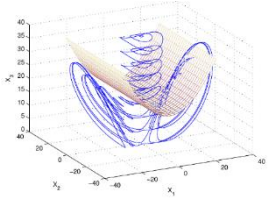
- Design of interactive robots and machines
- Advanced techniques for monitoring and process physiological signals for studying emotions

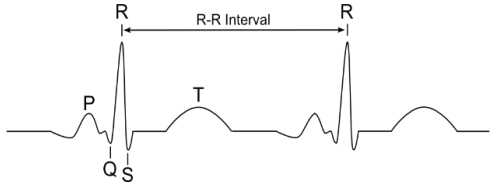
Main Contents

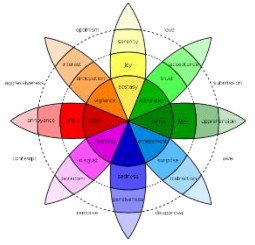
- Human-centred Design
- Internet of things
- Physiology of emotional response
- Computatitonal modeling of emotions
- Eye tracking, body movement analysis and facial emotion recognition

Learning Outcomes

- Design of systems able to interface with humans and based on a “human-centered design”
- monitor and process of physiological signal corresponding to different emotional states







Bionic senses

Focus

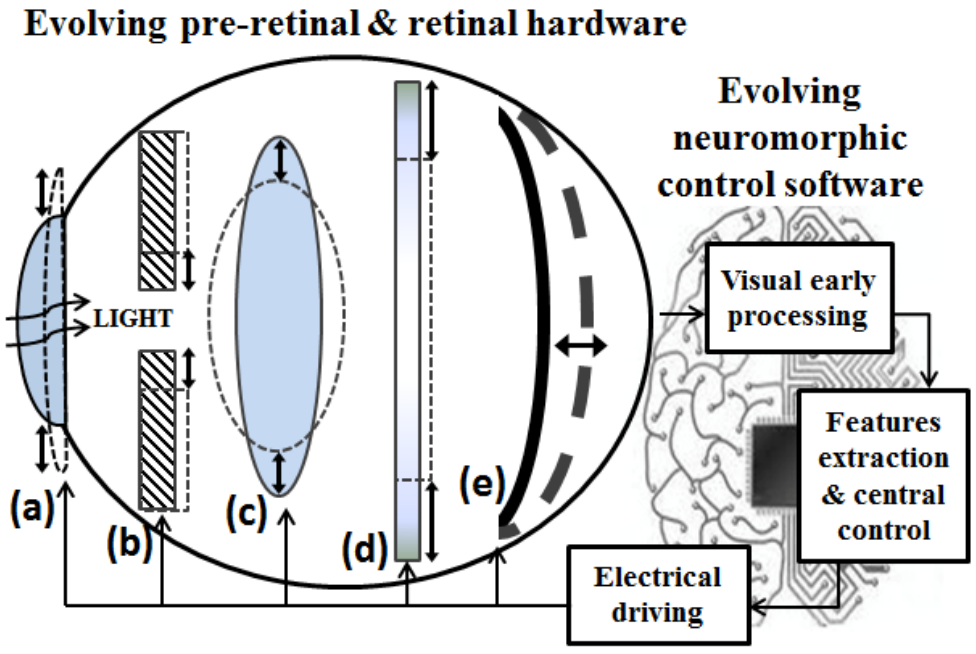
- Pre-neural and neural components of human and animal senses.
- Bionics senses design

Main Contents

- Introduction to natural senses
- Properties of biological receptors
- Physics of pre-neural media
- Sensations and perceptions
- The human senses
- Modeling and design of bionic senses

Learning Outcomes

- Engineering artificial sensing and perceptual systems through biological principles to implement neural-prostheses to restore lost functions, for human augmentation and bio-inspired perceptional machines



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Final duties: Lab training (3 ECTS) and Thesis (15 ECTS)

Integrative cerebral function

Focus

- Cognitive and emotional brain functions as the by-product of the activity of anatomo-functional distributed and integrated brain networks.

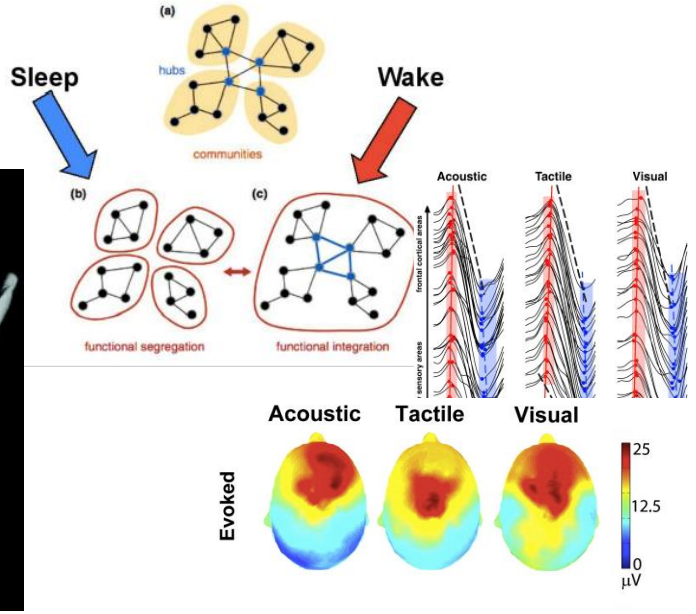
Main Contents

- Node and rich-clubs in the human connectome
- Sleep, mentation and dreaming
- Biological bases of consciousness
- Theory of mind and mirror neuron system
- Empathy in the emotional context

  Stress in the context of body and mind integration

Learning Outcomes

- Methodological aproach for the study of complex brain functions and their biological bases



Neural interfaces and bioelectronic medicine

Focus

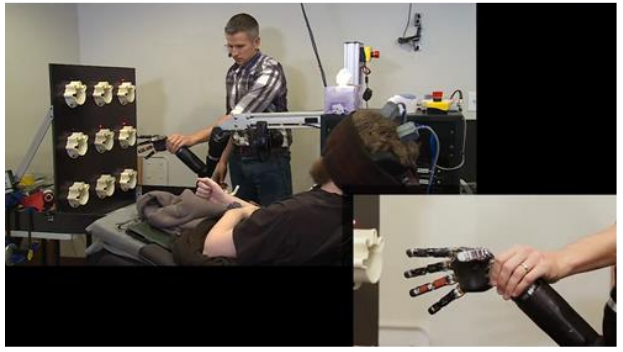
- Implantable neuroprostheses

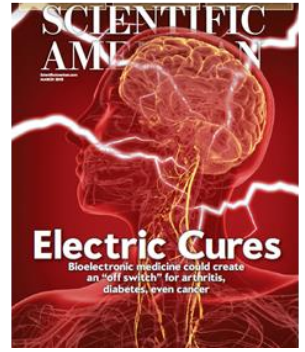
Main Contents

- Brain-to-machine interfaces
- Artificial limbs with neural control
- Sensory and motor neuroprostheses
- Neuromodulation of the autonomic nervous system

Learning Outcomes

- Provide students with methodologies for the development and validation of implantable systems for neuromodulation





Affective computing

Focus

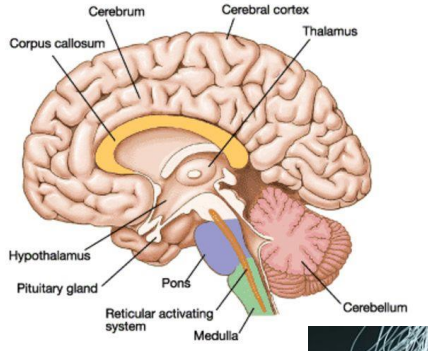
- Advanced computational techniques and instrumentations for monitoring and process physiological signals for studying emotions.

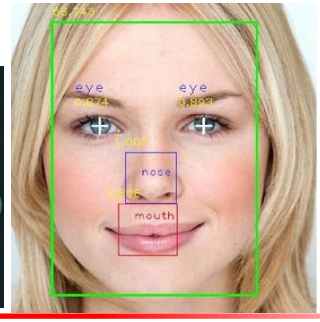
Main contents

- Physiology of emotional response; Computational modeling of emotions; Origin, processing and monitoring of ECG, breathing pattern, EDA and voice; Nonlinear methods and models for biomedical signal processing; Eye tracking, body movement analysis and facial emotion recognition

Learning Outcomes

- Acquire basic knowledge to monitor and process physiological signal corresponding to different emotional states.





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Lab training (3 CFU)

This activity will consist of 75 h of Lab training that the student will perform in dedicated facilities and laboratories, with the aim to increase his/her experience in laboratory practice.

Thesis (15 CFU)

The final examination involves the preparation of a report on a research activity, and in its presentation and discussion.