



Workshop on Robo-Ethics, Barcelona, April 18th, 2005

# Ethical issues involved in hybrid bionic systems research

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Scuola Superiore Sant'Anna



Scuola Superiore  
Sant'Anna

di Studi Universitari e di Perfezionamento

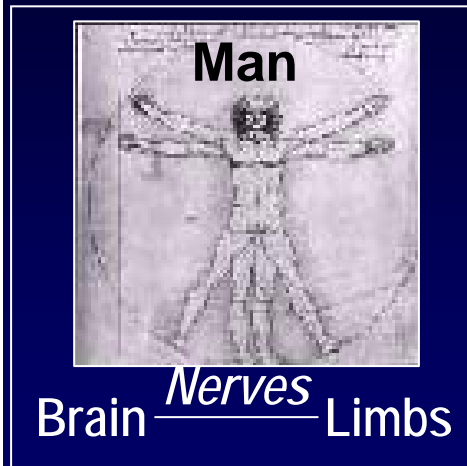


# Outline of the talk

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- Bionics: the connection of natural and artificial
- Case-study 1: the CYBERHAND Project
  - Developing a hand prostheses to be connected to the nervous system
- Case study 2: the NEUROBOTICS Project
  - Investigating the development of hybrid bionic systems
- Conclusions: the new role and ethical responsibilities of robotics researchers

# Bionics: the connection of natural and artificial



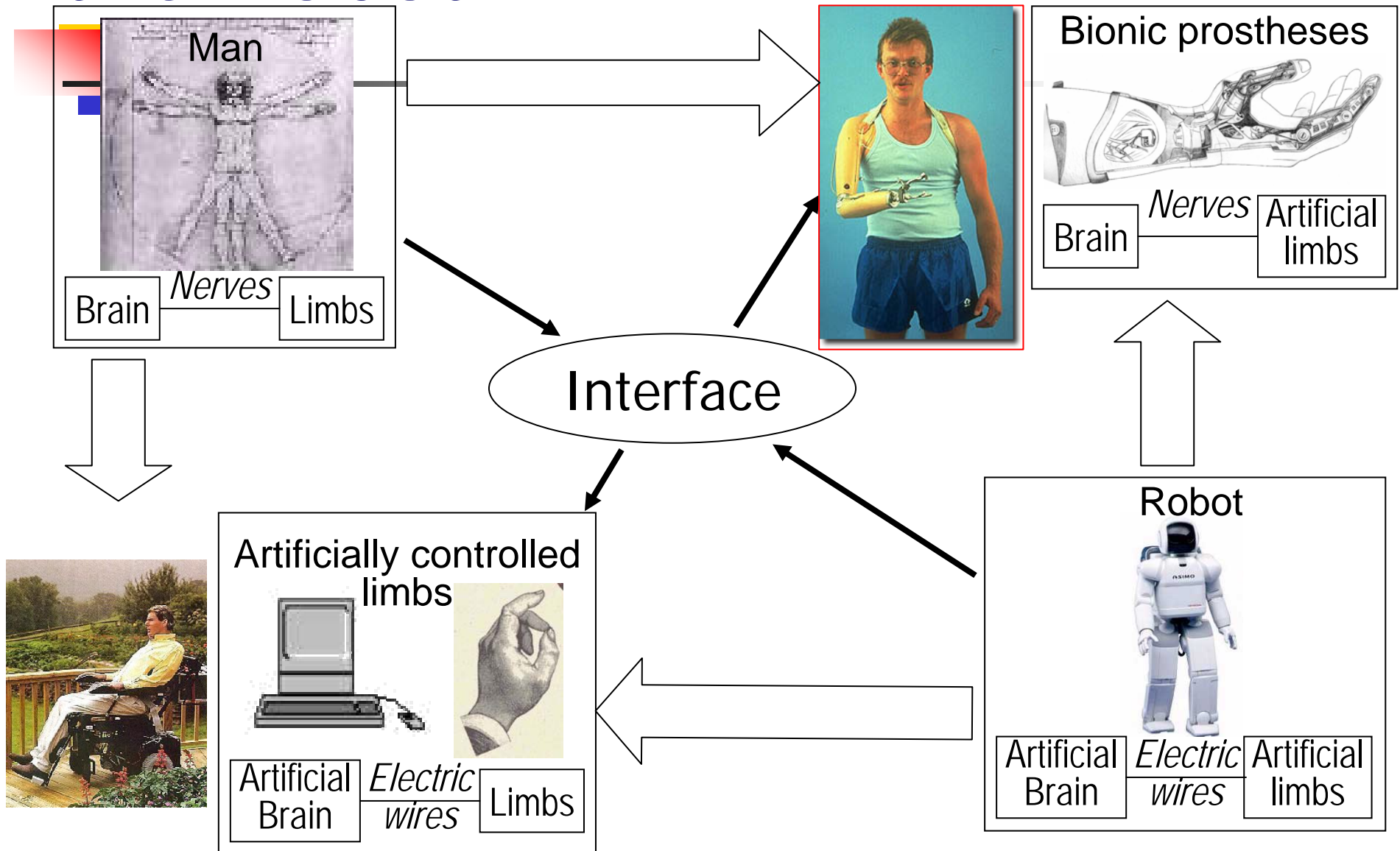
Biological models for  
the design of  
biomimetic robots

Interfacing  
Neuroscience  
and Robotics

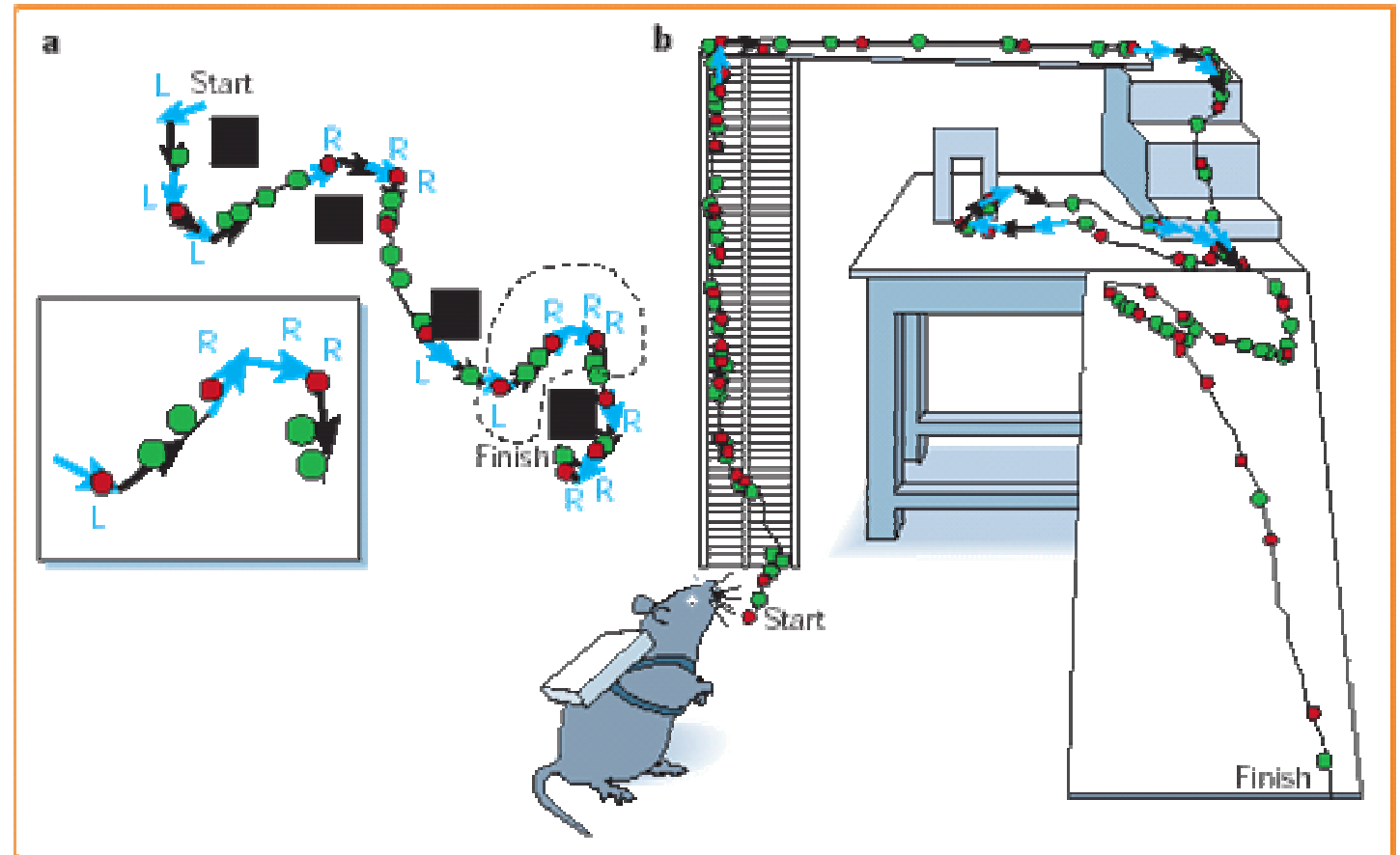
- New technologies for functional substitution
- Robots as physical platforms for validating biological models



# "Connecting" the Man and the Robot



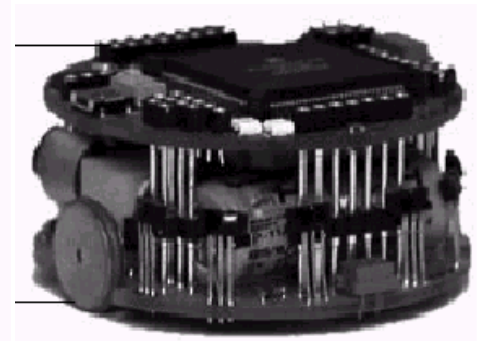
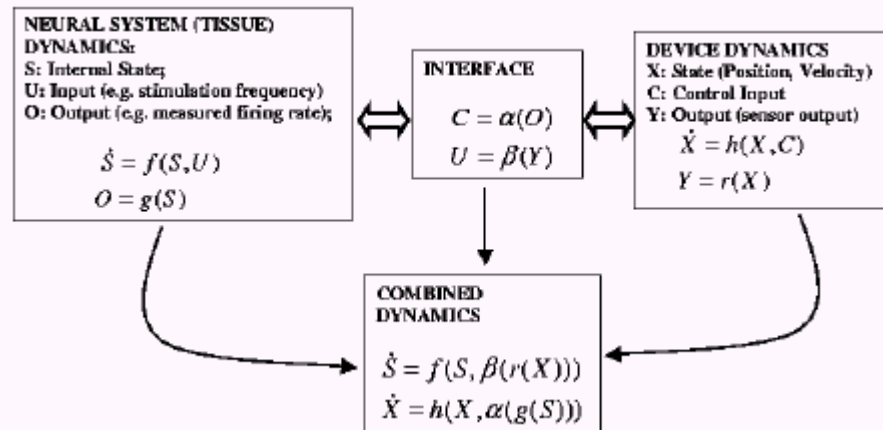
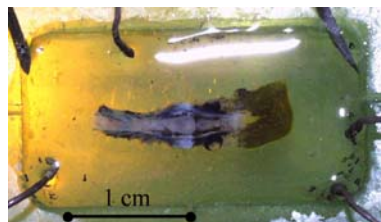
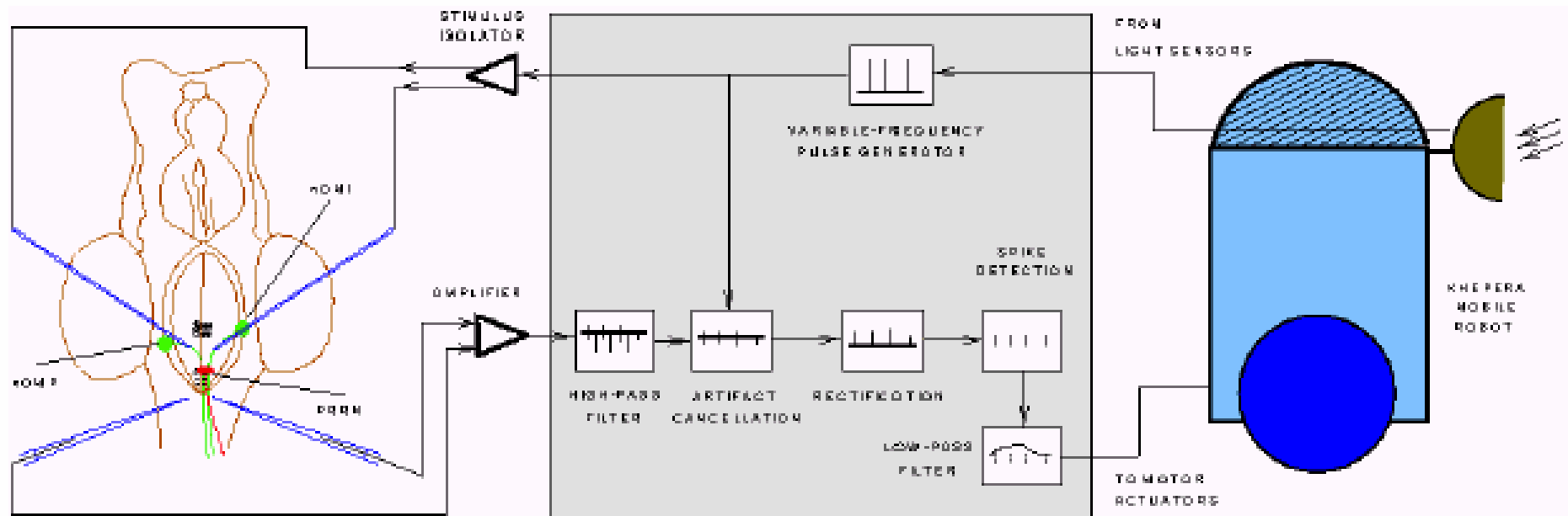
# Controlling biological systems by artificial stimulation

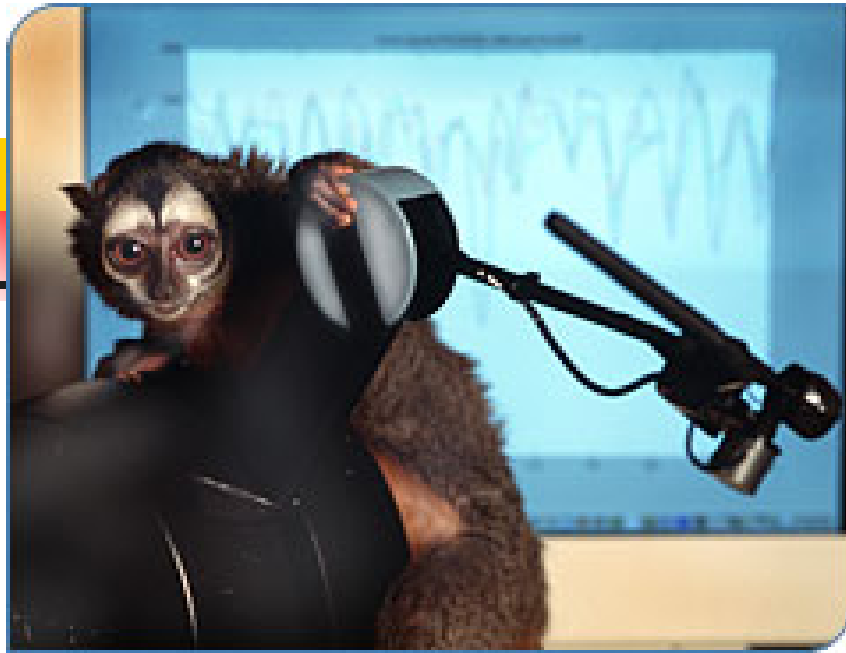


S. K. Talwar, S. Xu, E.S. Hawley, S. A. Weiss, K. A. Moxon, J. K. Chapin, “Behavioural neuroscience: **Rat navigation guided by remote control**” Nature 417, 37 - 38 (2002)

# Neural tissue as a controlling device: brain-machine interface

(S. Mussa-Ivaldi)





**“Brain to Computer Interface  
is one of the 10 Emerging  
Technologies that will change  
the world”**

***Technology Review, January/February, 2001***





# Cyberhand Project

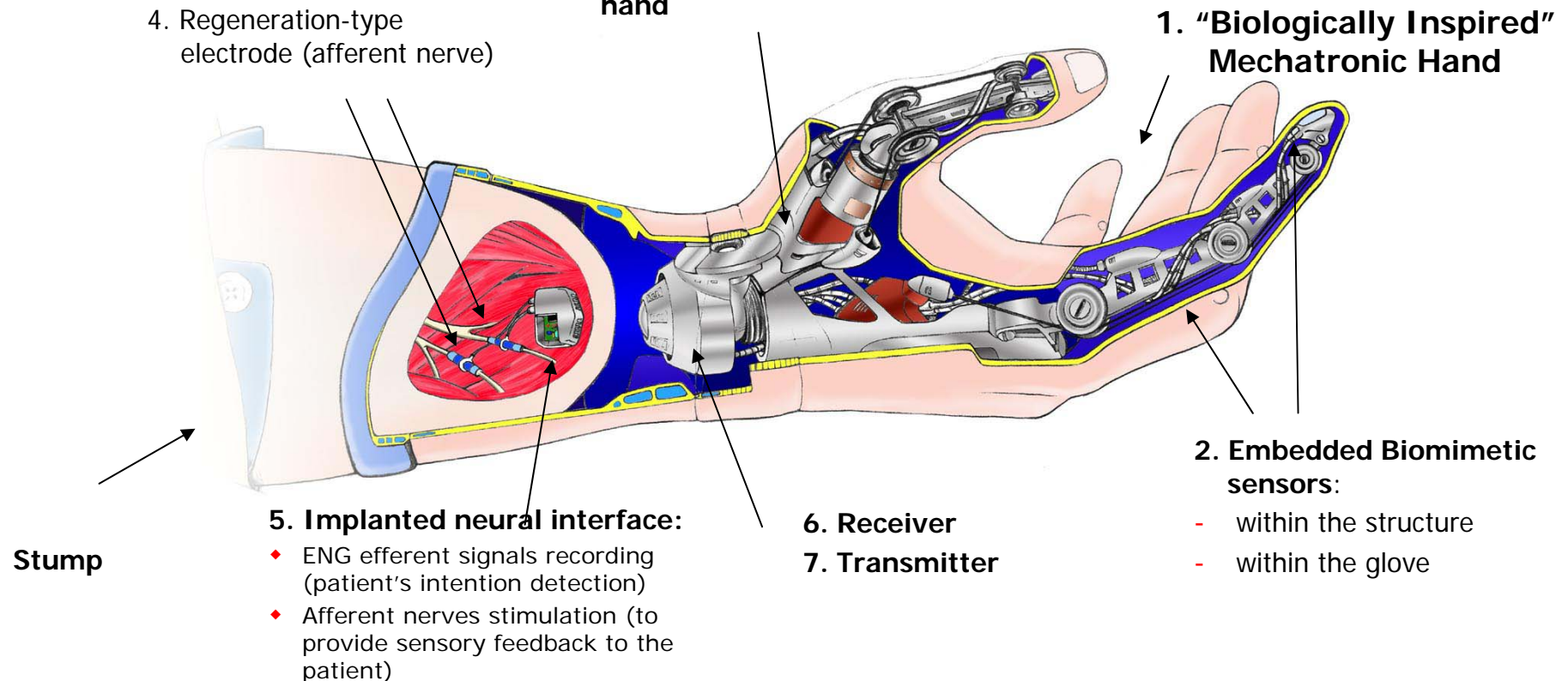
IST-FET Project #2001-35094  
(01/05/2002 – 30/04/2005)

## Regeneration-type electrodes:

3. Regeneration-type electrode (efferent nerve)
4. Regeneration-type electrode (afferent nerve)

## 8. Decoding patient's intentions and Embedded closed-loop control of the artificial hand

1. "Biologically Inspired" Mechatronic Hand
2. Biomimetic sensors
3. Regeneration-type electrode (efferent nerve)
4. Regeneration-type electrode (afferent nerve)
5. Implantable system for neural stimulation and recording
6. Efferent telemetric link
7. Afferent telemetric link
8. External unit for decoding patient's intentions and for prosthesis control
9. Cognitive feedback

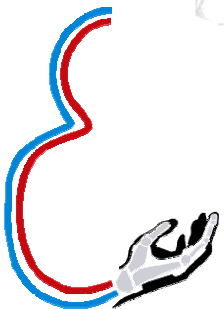
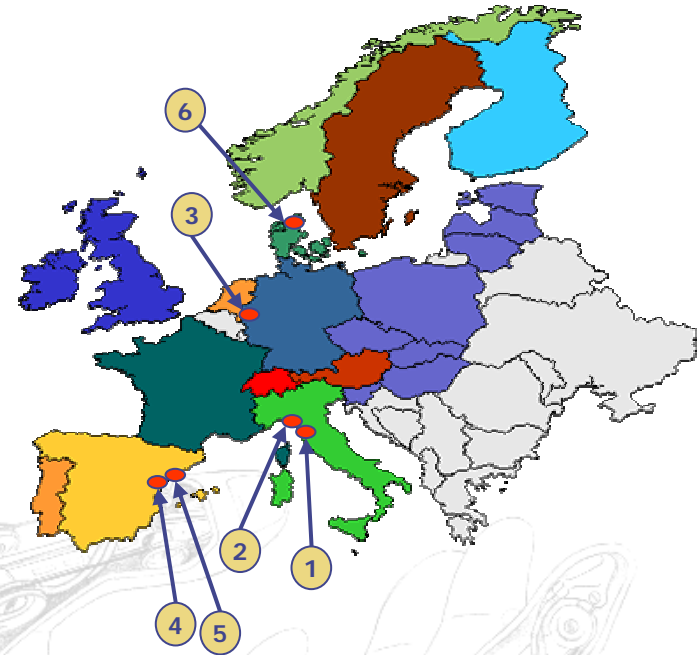




## CYBERHAND at-a-glance

- ❑ Starting date: May 1, 2002
- ❑ End date: April 30, 2005
- ❑ Cost: 2,500 K€
- ❑ Funding: 1,683 K€
- ❑ Partners:

1. **Scuola Superiore Sant'Anna (SSSA)** - Pisa (I) – Co-ordinator
2. **INAIL RTR Center (CP-RTR)** – Viareggio (I)
3. **Fraunhofer Institut für Biomedizinische Technik (FhG-IBMT)** - St. Ingbert (D)
4. **Centro Nacional de Microelectronica (CSIC-CNM)** - Instituto de Microelectronica de Barcelona (E)
5. **Universidad Autonoma de Barcelona (UAB)**, Barcelona (E)
6. **Center for Sensory-Motor Interaction (AAU-SMI)**, Aalborg (DK)



# Objectives of the CYBERHAND project

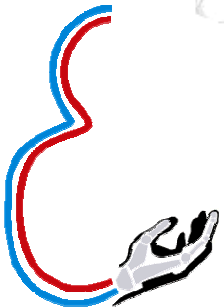
## □ Long-Term Objective:

to increase the basic knowledge of **neural regeneration** and **sensory-motor control** of the hand in humans

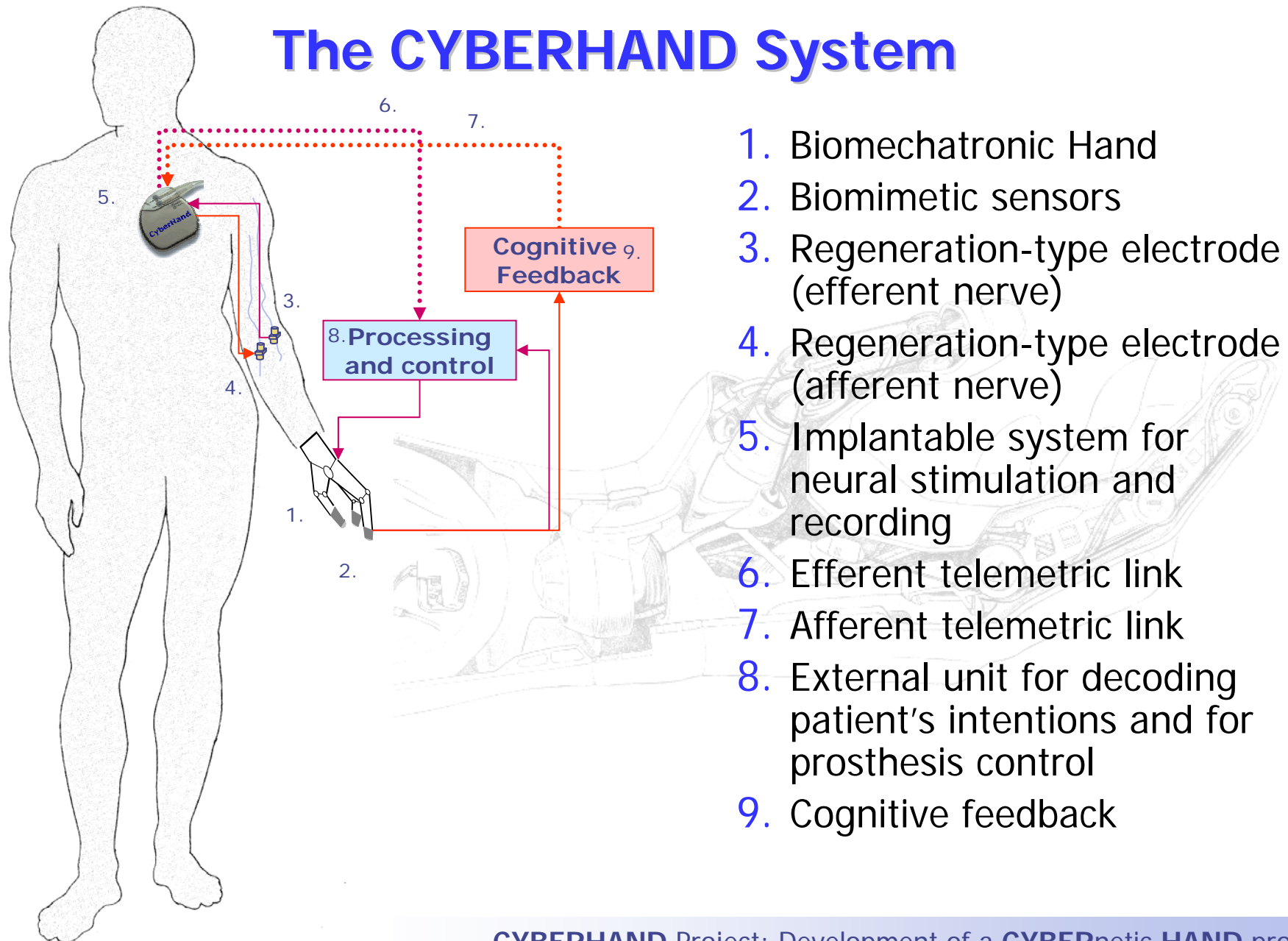
## □ Middle-Term Objective:

to exploit this knowledge to develop a **new kind of hand prosthesis** which will overcome some of the drawbacks of current hand prostheses. This new prosthesis will:

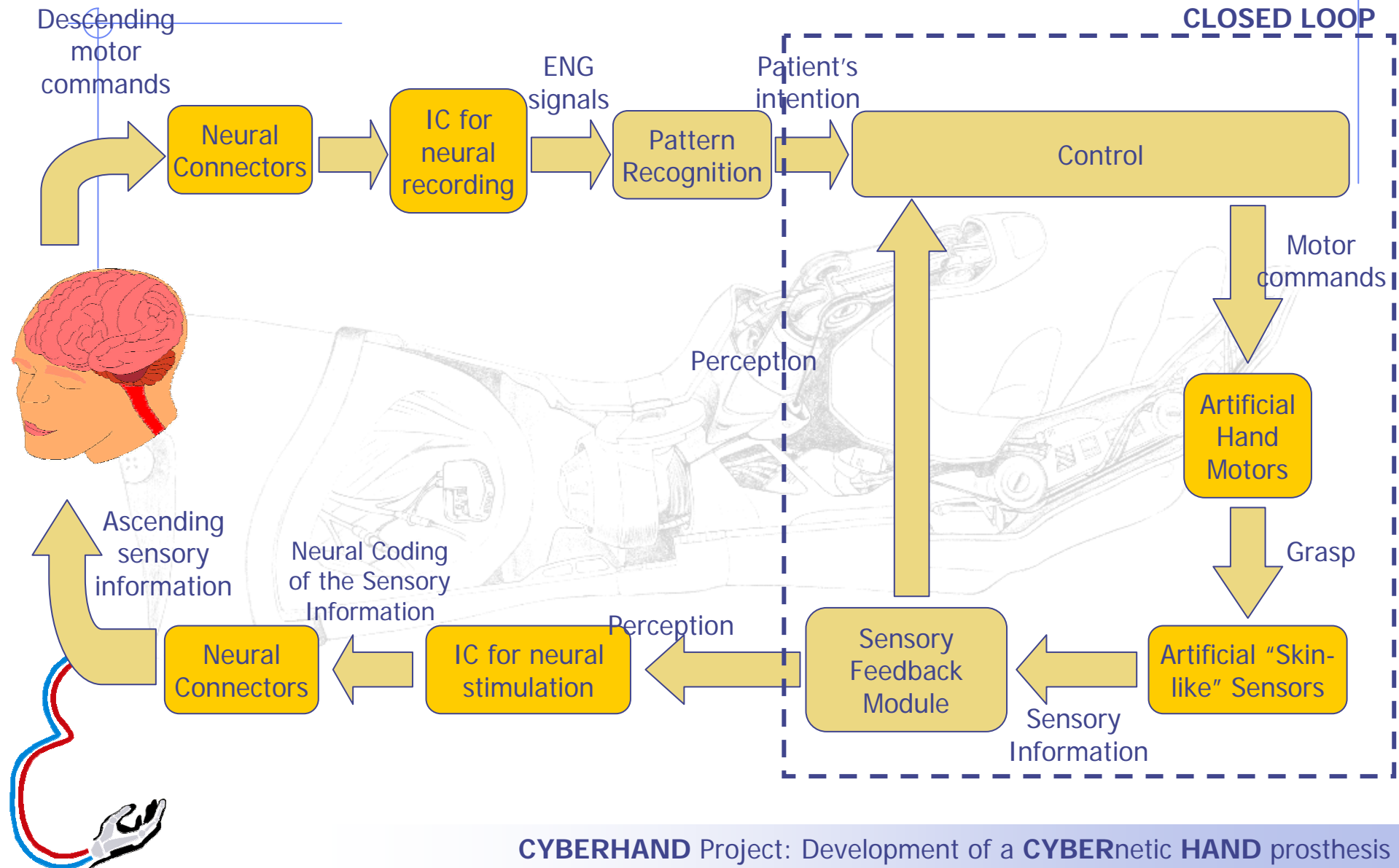
- ♦ be felt by an amputee as the lost natural limb delivering her/him a natural sensory feedback by means of the stimulation of some specific afferent nerves;
- ♦ be controlled in a very natural way by processing the efferent neural signals coming from the central nervous system



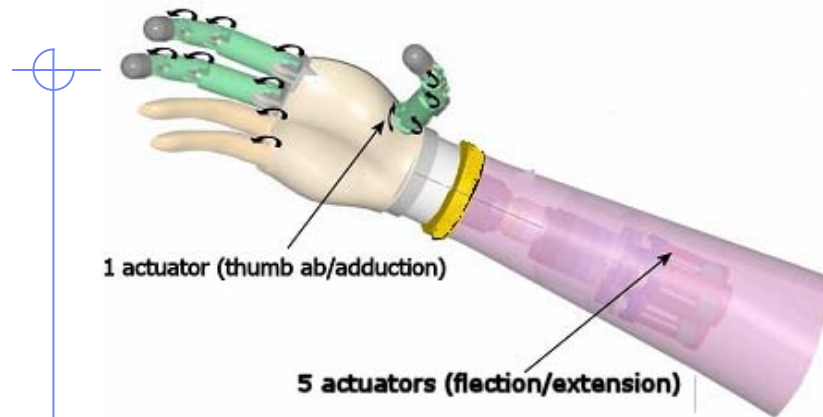
# The CYBERHAND System



# The CYBERHAND System



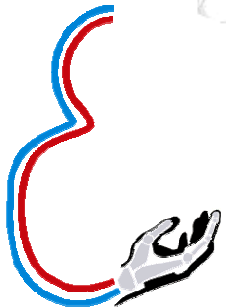
# The CYBERHAND prosthesis



The ROBOCASA Hand

## Mechanical specifications:

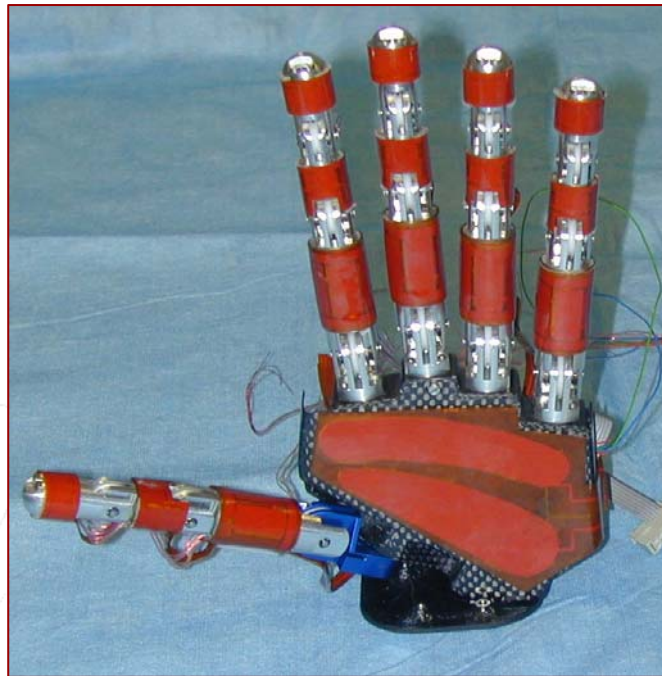
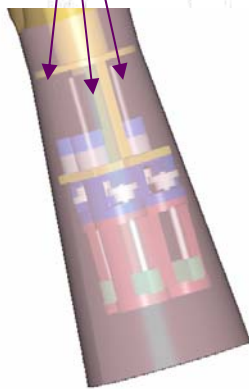
- 5 fingers
- 16 DoF
- 6 DoM (1 motor integrated into the palm for thumb positioning (adduction/abduction), 5 motors integrated in the forearm for each finger (flexion/extension))
- Underactuated fingers, each driven by a single cable actuated by a motor.
- 6 DC 6V motors
- Weight: Palm+fingers about 320 gr., Socket interface (actuation and transmission system) about 700 gr.
- Maximum grasping force 45 N (expected)
- Anthropomorphic size, and kinematics





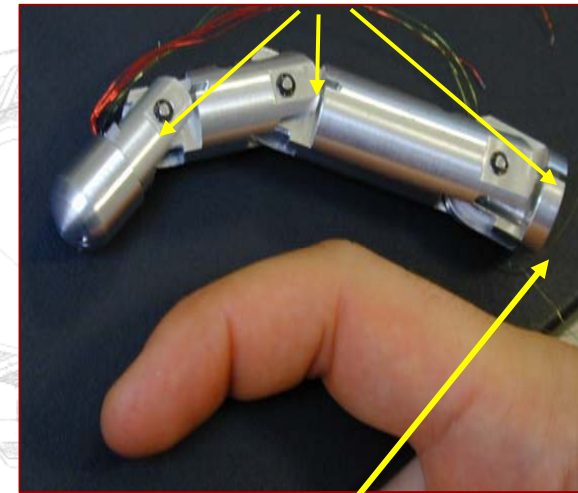
# Proprioceptive sensory system

5+1 Encoders in the Actuation System



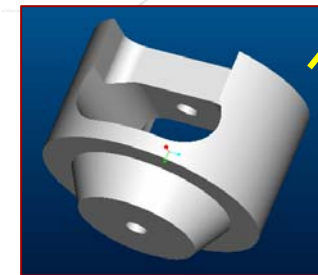
15 Embedded Joint Angle Sensors (Hall effect)

(Operational range: 0 – 90 degrees, Resolution: ~0.1 degrees).



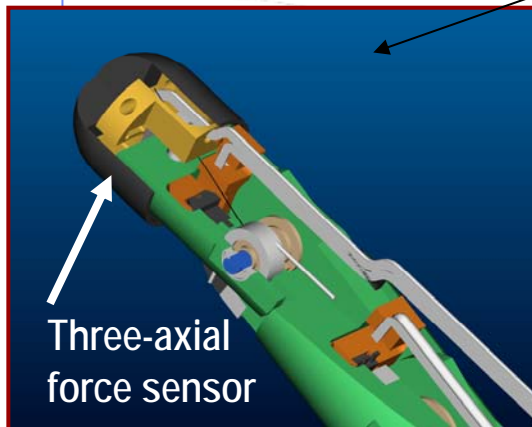
5 cable/tendon tension sensors

(Operational range: 0 – 35 N, output characteristic: linear, resolution: ~20 mN)



# Exteroceptive sensory system

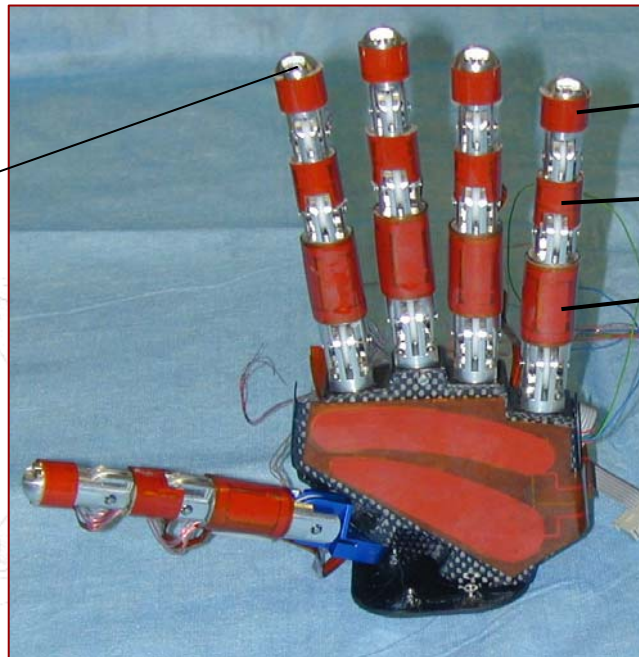
Three-axial strain gauge force sensors integrated in the fingertips



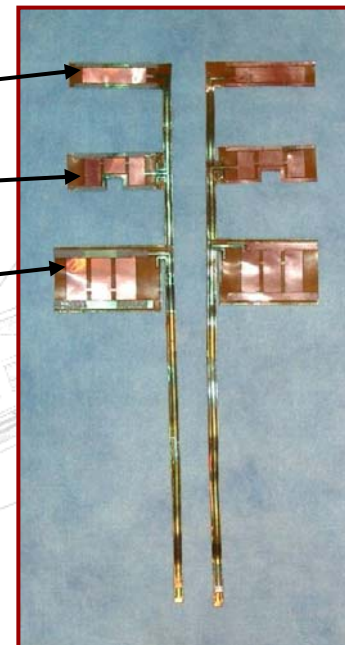
Maximum Force (N)

Fx max	4.62
Fy max	5.96
Fz max	4.62

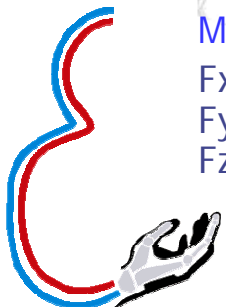
Maximum force magnitude 8,75 N



Distributed contact sensors

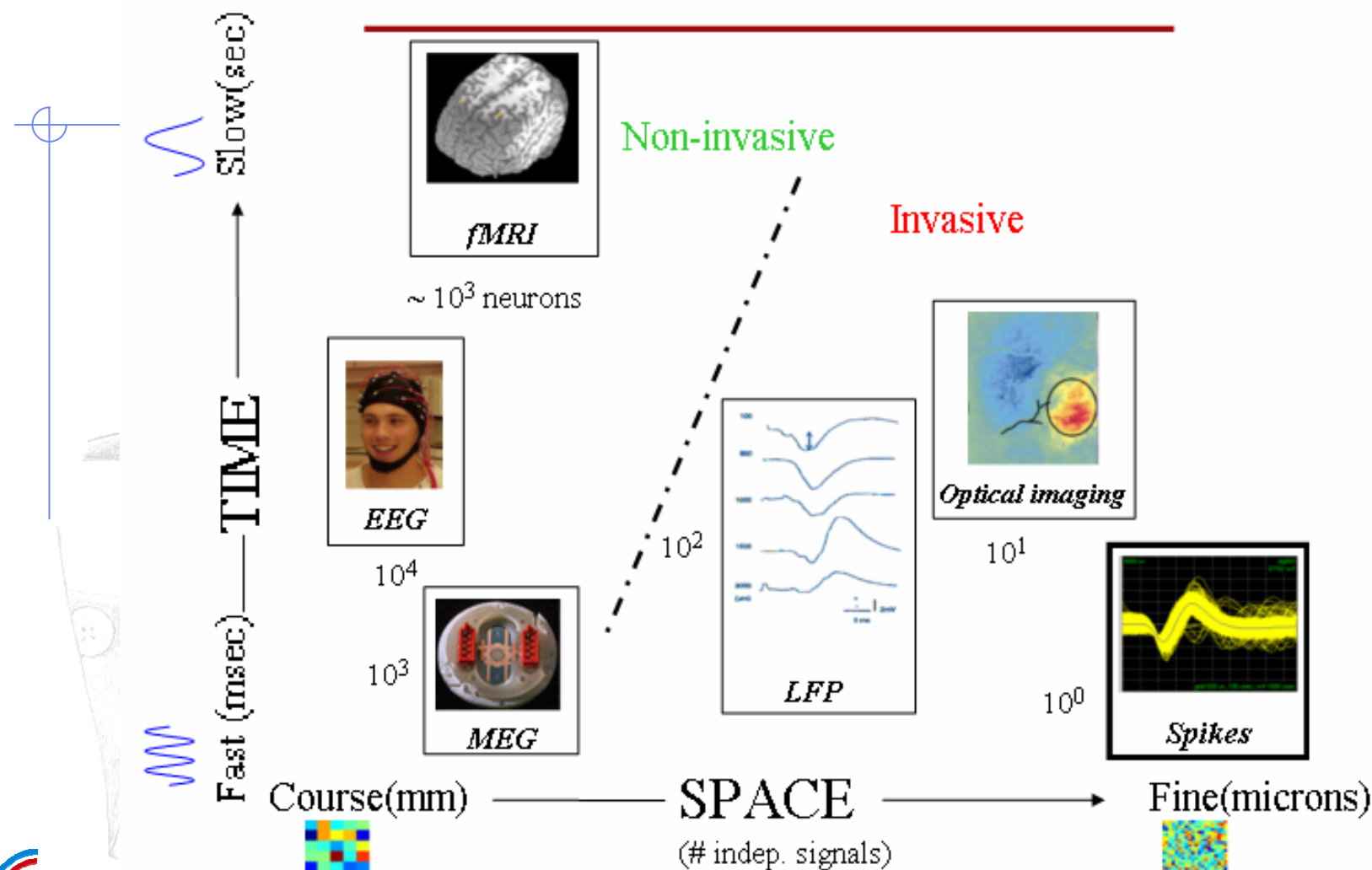


Contact sensors at fingertips and palm (threshold ~60 - 100 mN)





# SENSING THE BRAIN

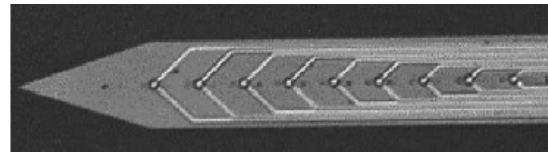


Sensing technologies that can be used to observe neural activity, divided by non-invasive vs. invasive, spatial and temporal resolution.

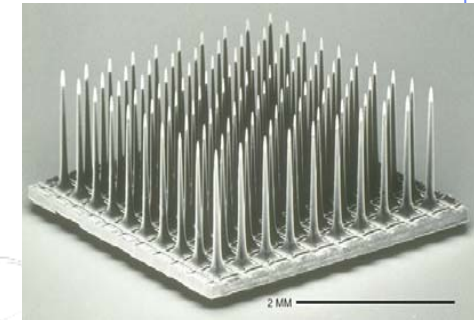
# Approach #1: Development of a Brain Computer Interface (BCI)

*"A Brain Computer Interface is a communication system that does not depend on the normal brain's output pathways of peripheral nerves and muscles"*

Wolpaw, University of New York, IEEE Trans Rehab Eng 2000

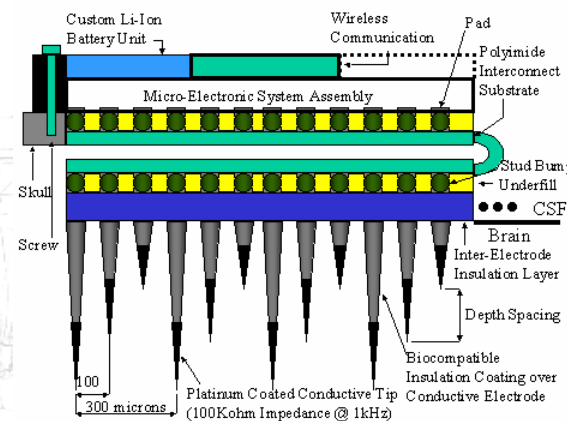
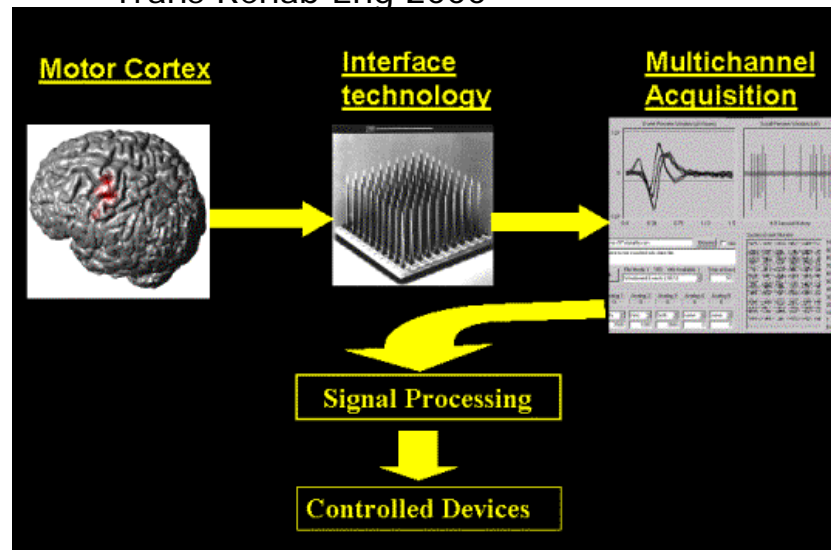


IBMT, Germany, Sensors and Actuators, 2002

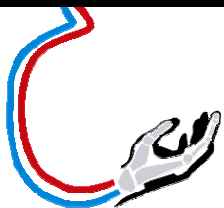


Utah Electrode Array, Bionic Technologies

MIT Bioinstrument Lab

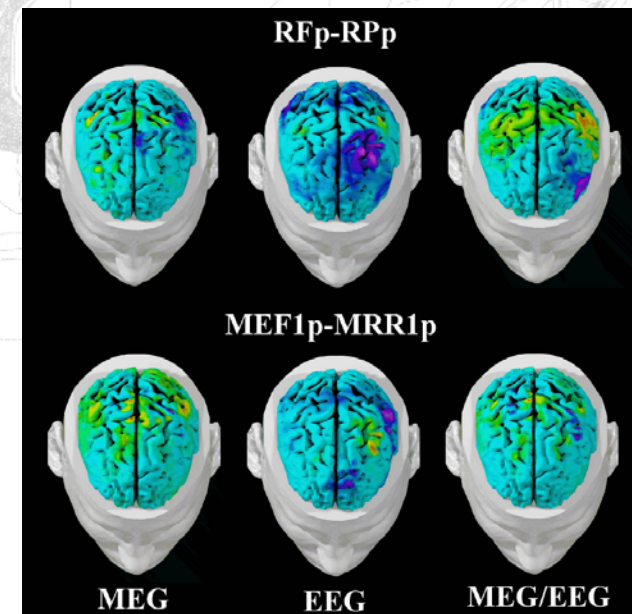
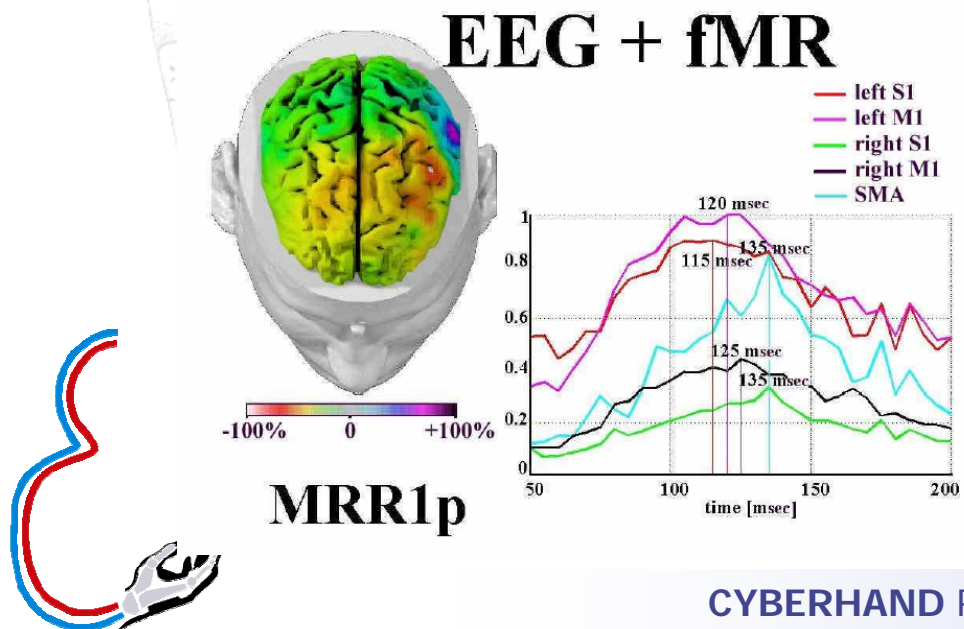


Several strategies can be used to implement a BCI



# Innovative non-invasive interfaces

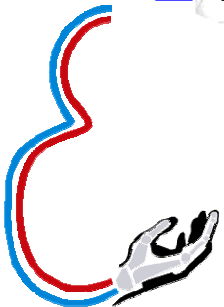
- Many of the limits of the non-invasive interfaces could be overcome by combining different imaging techniques such as fMRI, EEG and MEG
- This new “combined non-invasive cortical interface” could be used as BCI and to investigate important neuroscientific problems



# Approach #2

## Interface with the PNS

- ❑ In order to restore this bidirectional link as naturally as possible the following aspects have to be addressed:
  - Development of a selective neural interface
  - Development of an effective algorithm for the extraction of patient's intentions from the efferent neural signals
  - Development of a sensory feedback by stimulating the afferent nerves in a "natural" way
- ❑ Many different neural interfaces can be used
  - Intraneural electrodes
  - Cuff electrodes
  - Regeneration electrodes
- ❑ Regeneration electrodes are interesting for their high selectivity



# Selectivity



00012565 100 μm

**Inter Interface**

Distal nerve stump

Guidance channel

Proximal nerve stump

Perforated dice  
[the external connector is not shown in the figure]

The diagram shows a cylindrical guidance channel with a yellow proximal section and a blue distal section. A red and white checkered 'perforated dice' is positioned at the interface between the two sections. The proximal nerve stump is shown entering the yellow section, and the distal nerve stump is shown entering the blue section. The dice has a grid of small holes. A note indicates that the external connector is not shown in the figure.

In order to control many DoFs  
and to deliver a sensory feedback  
a good selectivity is crucial



Information Society Technologies  
Future and Emerging Technologies



# ***The NEUROBOTICS IP Project*** (Duration: 5 years)

***The fusion of NEUROscience and RoBOTICS for  
augmenting human capabilities***

## **Participants**

- 1. SSSA: Scuola Superiore Sant'Anna, Pisa, Italy (prof. Paolo Dario) – Project Coordinator**
2. CDF: Collège de France, CNRS, Paris, France (prof. Alain Berthoz)
3. DLR: Deutsches Zentrum für Luft und Raumfahrt, Oberpfaffenhofen, Germany (prof. Gerd Hirzinger)
4. IBMT: Fraunhofer Institute for Biomedical Engineering, St. Ingbert, Germany (Dr. Thomas Stieglitz)
5. KI: Karolinska Institutet, Stockholm, Sweden (prof. Sten Grillner)
6. KUL: KU Leuven, Belgium (prof. Guy Orban)
7. KTH: Kungl Tekniska Högskolan, Stockholm, Sweden (prof. Henrik Christensen)
8. NTUA: National Technical University of Athens, Greece (prof. Kostas Kyriakopoulos)
9. UMEA: Umeå Universitet, Sweden (prof. Roland Johansson)
10. UAB: Universitat Autònoma de Barcelona, Spain (prof. Xavier Navarro)
11. UGDIST: University of Genova, Italy (prof. Giulio Sandini)
12. UNIPR: University of Parma, Italy (prof. Giacomo Rizzolatti)
13. UPMC: Université P. et M. Curie / INSERM U483, Paris, France (prof. Yves Burnod)

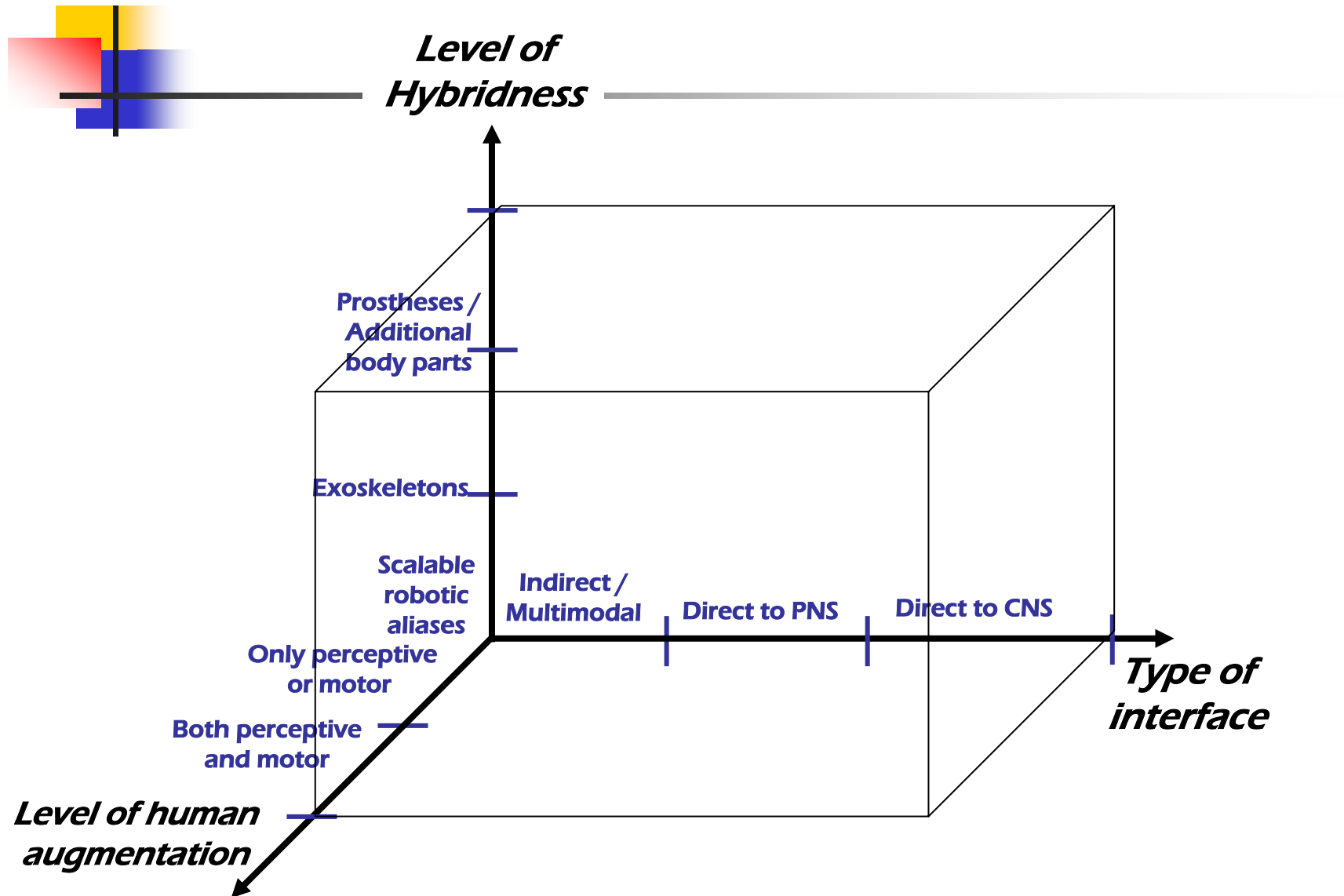
## **International Partners:**

Brown University, Providence, RI, USA (Prof. John Donoghue)

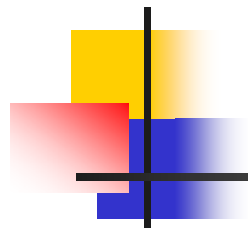
Waseda University, Tokyo, Japan (Prof. Atsuo Takanishi)



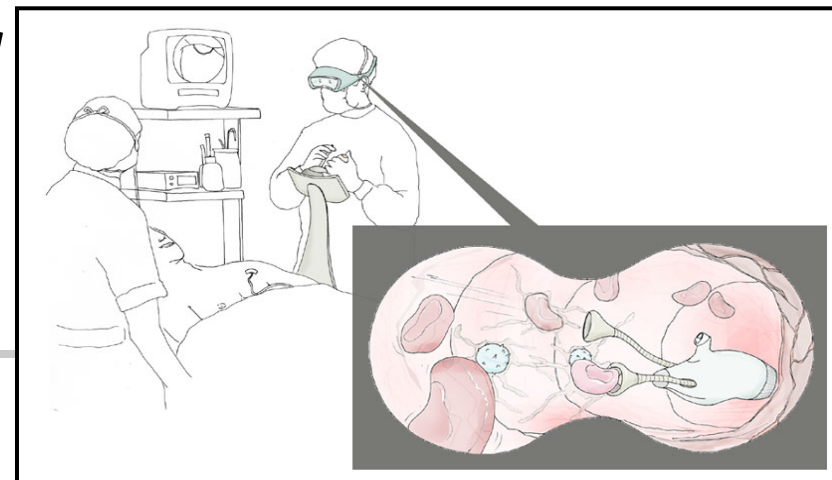
# 3D representation of the domain of NEUROBOTICS







***Level of Hybridness***



Prostheses /  
Additional  
body parts

Exoskeletons

Scalable  
robotic  
aliases

Indirect /  
Multimodal

Direct to PNS

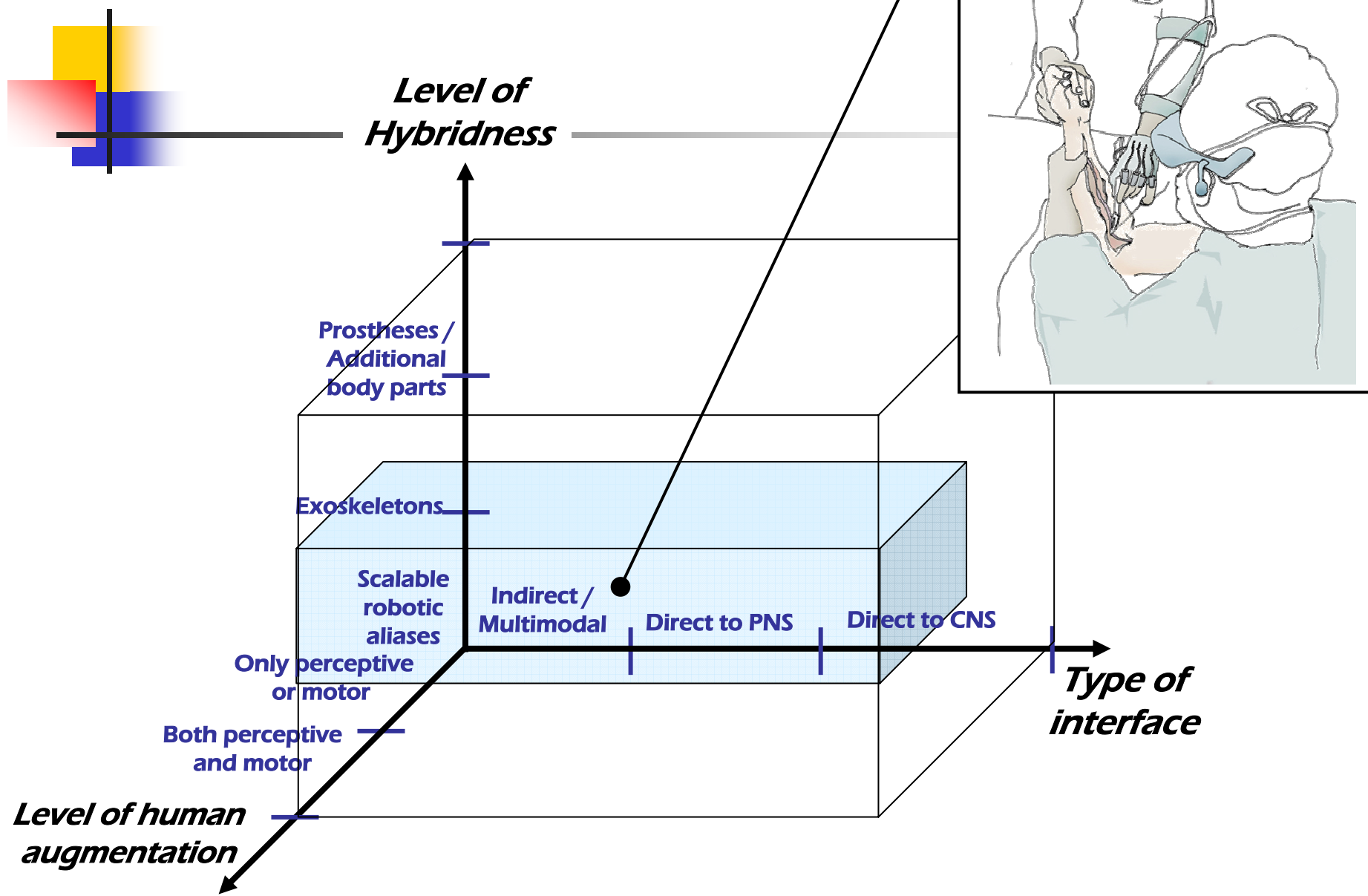
Direct to CNS

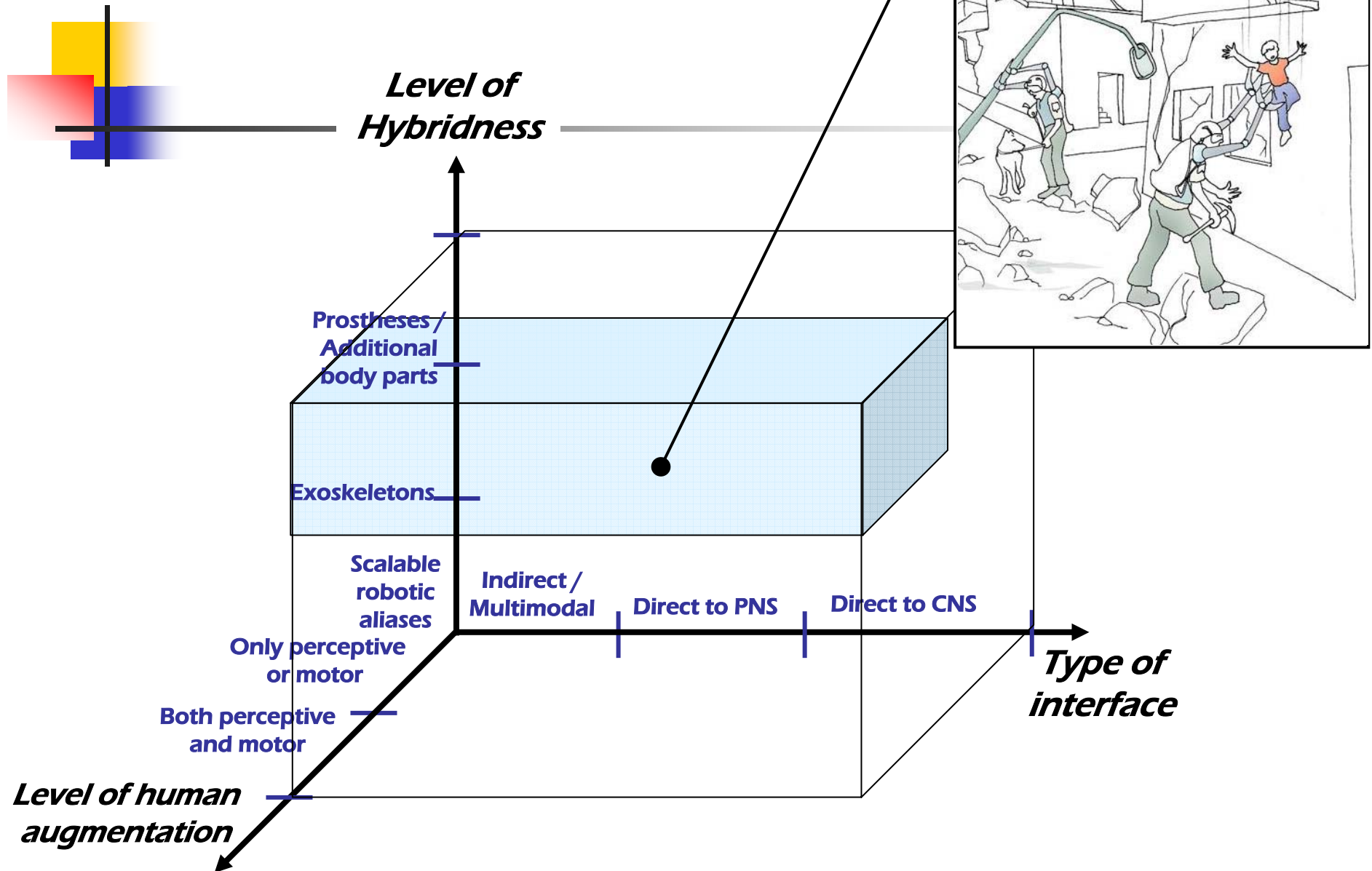
Only perceptive  
or motor

Both perceptive  
and motor

***Type of  
interface***

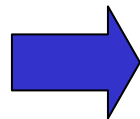
***Level of human  
augmentation***



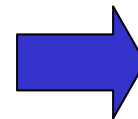


# NEUROBOTICS ethical events

NEUROBOTICS proposal  
(ethical aspects covered  
in section B.9)



NEUROBOTICS  
proposal submission  
(April 24, 2003)



Request of an **ethical  
review** by the Unit C3,  
Ethics and Science of EU  
(August 6, 2003)

## Ethical

- Resp
- Resp
- prim
- Poten

## Recom

- Identification of countries where research will be carried out
- identification of any important national regulations relating to the research and confirmation that the national regulations in those countries will be observed
- confirmation that the Commission will be informed of local or national ethics approval being obtained before relevant research is carried out.
- identification of relevant EU and International legislation and confirmation that this will be observed.
- identification of research on humans or their tissues for which informed consent will be required together with details of the information that will be provided to those taking part and any provision made for their support and welfare.
- indication of how data storage and handling processes will ensure patient data protection and confidentiality
- justification for use of animals especially where this relates to non-human primates and transgenic animals - this should include justification of numbers and species and indicate clearly how the principles of reduction, refinement and replacement have been employed.
- further information on any ethics component in the proposal, including details of those involved and clarification of the role, remit and integration of that element.

NEUROBOTICS ANNEX I



# Recommendations by the Ethical Panel to the proposal

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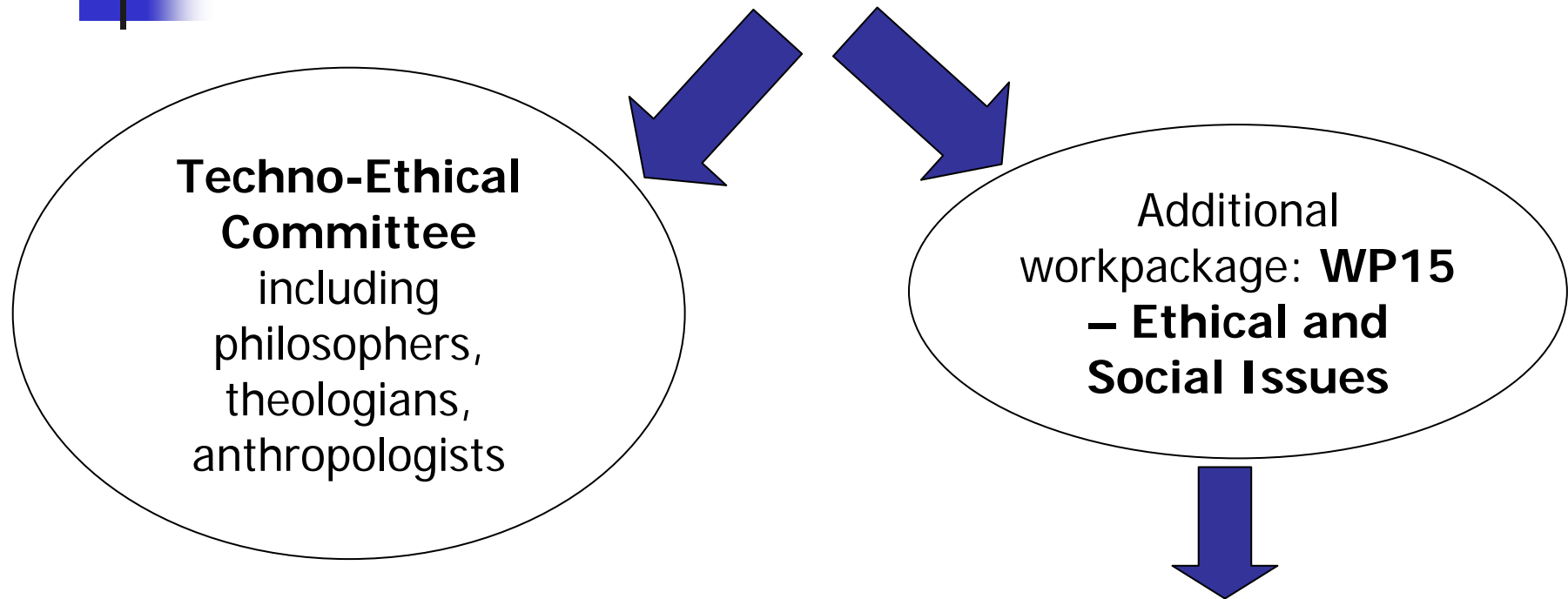
- The Panel strongly recommends a new workpackage on the ethical and social implications of the research and its potential uses. This must have wide and multidisciplinary involvement across the EU from experts and the general public.
- In particular the issues of warfare and enhancement of the able-bodied should be addressed.
- The Panel recommends that the applicants abandon Key Research Action 3.2

Recommendations of the Ethical Panel	Modifications on the NEUROBOTICS Annex 1
<p>The Panel strongly recommends a <b>new workpackage</b> on the ethical and social implications of the research and its potential uses. This must have wide and multidisciplinary involvement across the EU from experts and the general public.</p>	<p><b>A new Key Research Area and a new WP have been created</b> in order to study the complex ethical and social implications of the research that will be carried on in NEUROBOTICS framework and to prevent the misuse of the technology.</p>
<p>In particular the issues of warfare and enhancement of the able-bodied should be addressed.</p>	<p>The new KRA and WP will also focus their activities on the prevention of the misuse of the technology enhancing the capabilities of the able-bodied persons.</p>
<p>The Panel recommends that the applicants abandon Key Research Action 3.2</p>	<p>The KRA3.2 will NOT be activated during the first 18 months. A new detailed description of the activities on invasive cortical interfaces will be submitted to the Ethical Panel at the end of the first year.</p>
<p>The Techno-Ethics committee was thought to be too restrictive in terms of scope and membership.</p>	<p>Two internal panels:</p> <ul style="list-style-type: none"> <li>• An internal panel composed of prof. Dario (SSSA), prof. Berthoz (CDF), and prof. Hirzinger (DLR)</li> <li>• an enlarged internal panel (prof. Dario (SSSA), prof. Berthoz (CDF), prof. Hirzinger (DLR), prof. Rizzolatti (UNIPR), prof. Grillner (KI), prof. Orban (KUL), prof. Rossini (UCBM), prof. Sandini (UGDIST), prof. Christensen (KTH), and prof. Kyriakopoulos (NTUA))</li> </ul> <p>Two workshops:</p> <ul style="list-style-type: none"> <li>• The first will involve international multidisciplinary experts</li> <li>• the second event (workshop or Conference) will be public and will involve also associations of disabled persons, politicians, NGO</li> </ul>



# Turning the ethical “problems” of NEUROBOTICS into opportunities

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**Techno-Ethical  
Committee**  
including  
philosophers,  
theologians,  
anthropologists

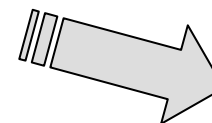
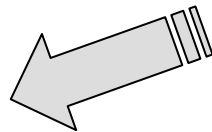
Additional  
workpackage: **WP15**  
– **Ethical and  
Social Issues**

To investigate and define an appropriate ethical and methodological framework for exploring the relationships between robotics, neuroscience, and ethics in a broad sense



# Ethics and Technology

- "It is ethically right to withhold further development of a technology that promises to increase the quality of life for the disabled and allow them to more fully participate in European society?"

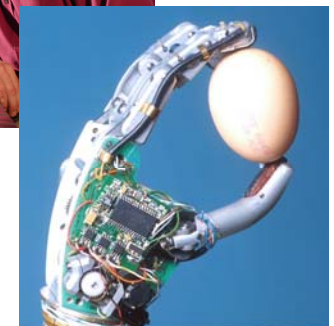
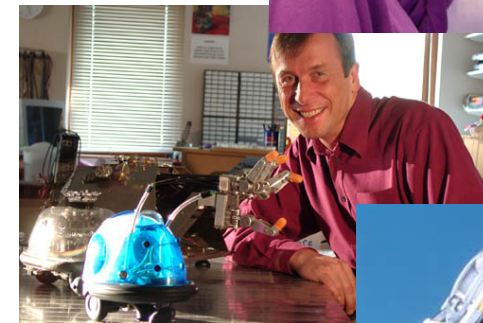
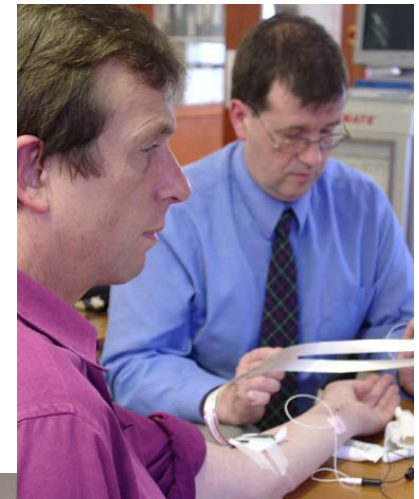


# The Warwick's experience

In order to assess the usefulness, compatibility and long term operability of a microelectrode array into the median nerve, an electrode has been surgically implanted in the left arm of Prof. K. Warwick implant, as healthy volunteer.

(K. Warwick et al., *The application of implant technology for cybernetic systems*, Arch Neurol. 2003; 60:1369-1373)

- Is the experiment ethically right?
- Is a needful brave step for the innovation?
- Is this the way to go beyond the experiments on "non human primate"?

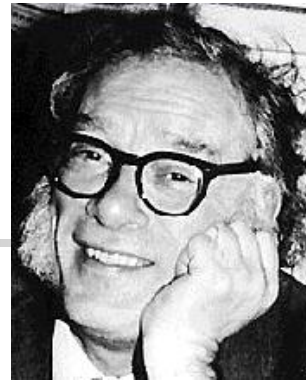


K Warwick : "Cyborg morals, cyborg values, cyborg ethics", Ethics and Information Technology, Vol.5, No.3, pp.131-137 (2004)

X Hong, P M Sharkey, K Warwick : "A robust nonlinear identification algorithm using PRESS statistic and forward regression", IEEE Trans on Neural Networks, Vol.14, No.2, pp454-458. (2003)

# Ethical Questions (1/3)

- Autonomous behavior of robots: what degree of autonomy should we give to the robot...
  - If uncontrolled robot actions can be dangerous to humans (*assistance robotics*)
  - if we wish to deal with cases when the user's will is "ethically" unacceptable (*robots used for military purposes*)
  - Are Asimov's Laws adequate?
  - Is realistically threatening the possibility of auto-replicating artificial entities?
- Ontological status of "cyborgs" and A.I. creatures:
  - What is machine and what is human?
  - Who may be re-programmed?
  - Can we have dissidents in a world of replicants?





## Ethical Questions (2/3)

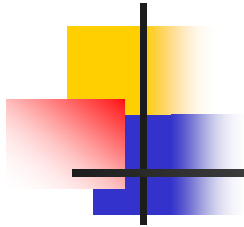
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- About Robotic Assistants/Rehabilitation
  - Can humans be suitably substituted by robots in assistive tasks in which emotions and empathy are involved?
  - Is it ethically right to eliminate less qualifying jobs?
- About Augmentation
  - Is socially desirable to extend the length of working life?
  - Can augmentation generate dangerous feelings of omnipotence or powerful super-humans?
- Is robotics affordable only by rich people?



# Ethical Questions

## (3/3)



- “What kind of privacy safeguards are needed if a machine can read your thoughts?”
- Will cognition enhancers exacerbate differences between rich and poor?
- Or, instead, will they relegate social diversity to the status of historical artifact?
- What happens if we deduce through neuroimaging the physiological basis for morality?
- Or, and by the way, what happens to free will?”

Scientific American (Editorial), September 2003



# Methodology for the identification of ethical questions

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1. to start with a list of fundamental rights of humans and animals (based on the Charter of Fundamental Rights of the EU)
2. to identify the **effects** of the
  - i. **results**
  - ii. **methods**of the NEUROBOTICS research
3. for each fundamental right, effect of a result, effect of a method, to instantiate the following schematic question:

in which way will the **effects** of NEUROBOTICS **results** and **methods** affect this particular fundamental **right**?

# Charter of Fundamental Rights of the European Union

## CHARTER OF FUNDAMENTAL RIGHTS OF THE EUROPEAN UNION

(2000/C 364/01)

- the Cologne European Council (3-4 June 1999) entrusted the task of drafting the Charter to a Convention,
- the Convention held its constituent meeting in December 1999 (*see annex for its composition*) and adopted the draft on 2 October 2000,
- the Biarritz European Council (13-14 October 2000) unanimously approved the draft and forwarded it to the European Parliament and the Commission,
- the European Parliament gave its agreement on 14 November 2000 and the Commission on 6 December 2000,
- the Presidents of the European Parliament, the Council and the Commission signed and proclaimed the Charter on behalf of their institutions on 7 December 2000 in Nice





## Intended functions, misuses and side-effects of technology

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Assuming an 'ethically right' use  
of technology, we must be  
aware of possible **misuses** and  
**side-effects** of our  
technological innovations



# Effects to be avoided: misuses and side-effects

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- **Misuses:** improper use of technology
  - **Not voluntary (*culpable*):**  
improper use of technology (possibly due to ignorance of advertisements) causing involuntary damages
  - **Malicious (*fraudulent*):**  
voluntarily improper use of technology

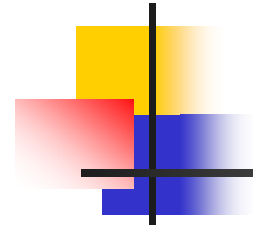


# Effects to be avoided: misuses and side-effects

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- **Side-effects:** proper use of technology, also causing effects different than those expected
  - Not yet known
  - Only vaguely known  
(typical of just released technologies, whose side-effects have not been yet exhaustively investigated)
  - Exhaustively known  
(affecting people in a low percentage)

# First list of NEUROBOTICS ethical issues



- Bionic technologies could be fraudulently applied for military purposes, thus limiting personal freedom and security.
- The research on hybrid bionic systems could allow one to override one's intentions, to disrupt personal free will or manipulate thoughts and ideas.
- The research on hybrid bionic systems could threaten the personal freedom of expression and information.
- What degree of autonomy should we give to neuro-robotic platforms if uncontrolled robot actions can be dangerous to humans?
- Bionic technologies could endanger right to life for humans by, for example, creating extremely powerful super-humans.
- New-generation exoskeletons could be used for physically controlling people, thus creating new forms of slavery and forced labour.
- What is machine and what is human? Which dignity and rights do hybrid bionic systems have?
- Is it socially desirable to extend the length of working life?
- Invasive research on humans could involve inhuman or degrading procedures.
- Invasive research on humans could lead to new torture or inhumane punishment techniques.
- Can humans be suitably substituted by robots in assistive tasks in which emotions and empathy are involved?
- Will be neuro-robotics results affordable only by rich people? Will cognitive and motor enhancers exacerbate differences between rich and poor?



# Events in the background

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- Talks on “Techno-Ethics” by Prof. José M. Galván at the Scuola Superiore Sant’Anna (Pisa, Italy) in 2001 and 2002
- Italy-Japan 2001 Workshop “Humanoids: a Techno-Ontological Approach”, Tokyo, Japan, November 2001
- Panel discussion at ICRA 2002 (IEEE International Conference on Robotics and Automation), Washington DC, USA, May 2002
- Discussion at the 11th International Symposium on Robotics Research, Siena, Italy, October 2003
- Paper by José Maria Galvan, “On Technoethics”, IEEE Robotics and Automation Magazine, December 2003
- Creation of an IEEE-RAS (Robotics and Automation Society) Technical Committee on RoboEthics (December 2003)
- First International Symposium on Roboethics, Sanremo, January 2004



# ISRR 2003

11th International Symposium  
of Robotics Research

October 19-22, 2003  
Siena, Italy

## Robotics Research in the Homeland of Renaissance Engineers



**IFRR**  
The International  
Foundation  
for Robotics  
Research



## First International Symposium on

# ROBOETHICS

The ethics, social, humanitarian and ecological aspects of Robotics

**30<sup>th</sup> - 31<sup>th</sup> January, 2004**

***Villa Nobel, Sanremo, Italy***



The ROBOETHICS Symposium aims to open a debate, among scientists and scholars of Sciences and Humanities, with the participation of people of goodwill, about the ethical basis which should inspire the design and development of robots.

The Symposium is an opportunity to encounter scientists and scholars committed to discuss new and sensitive problems that humankind is glimpsing at the horizon.

Philosophers, jurists, sociologists, anthropologist and moralists, together with robotic scientists, are called to contribute to lay the foundations of the Ethics in the design, development and employment of the Intelligent Machines, the Roboethics.

For this reasons the Distinguished Speakers will report their experience in a general way, with a special focus on the social and ethical problems they are identifying in their fields.

### **Program Commitee:**

**Paolo DARIO**

**José M. GALVÁN**

**Fiorella OPERTO**

**Jovan PATRNOGIC**

**Gianmarco VERUGGIO**

### **Organiser:**

**Scuola di Robotica**

### **Co-Organisers:**

**ARTS-Lab, Scuola Superiore Sant'Anna, Pisa, Italy**

**International Institute of Humanitarian Law**

**School of Theology, Pontifical University of the Holy Cross, Rome, Italy**

# ETHICBOTS project

## Emerging Technoethics of Human Interaction with Communication, Bionic, robOTic Systems

- Proposal for a Coordination Action on Technoethics for Call 9 of the “Science and Society” Priority
- Partners:
  1. University “Federico II”, Naples, Department of Physical Sciences and Department of Computer and Systems Engineering , Italy (DSF) (**Guglielmo Tamburrini**, Coordinator)
  2. Fraunhofer Institute for Autonomous intelligent Systems, Sankt Augustin, Germany (FhG/AIS)
  3. Scuola di Robotica, Genova, Italy (Scuola di Robotica)
  4. Institute of Applied Philosophy, Faculty of Theology, Lugano, Switzerland (IsFA)
  5. University of Reading, department of Cybernetics, UK (UNIRDG)
  6. Hochschule der Medien University of Applied Sciences, Stuttgart, Germany (HdM)
  7. LAAS-CNRS, Toulouse, France (CNRS)
  8. Scuola Superiore Sant’Anna, Pisa, Italy (SSSA)
  9. University of Pisa, Department of Philosophy, Italy (UNIFI)
  10. Middlesex University, Interaction Design Centre, School of Computing, London, UK (UM)

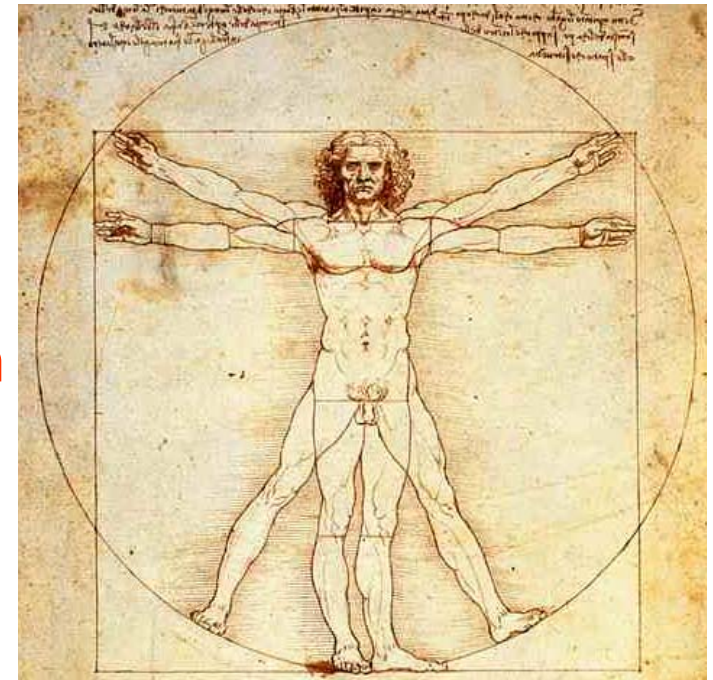
# The robotics researcher assumes a new role and new ethical responsibilities

**José Maria Galvan, "On Technoethics",  
IEEE Robotics and Automation Magazine,  
December 2003**

# A European model for education of the new engineer

(P. Dario, EURON Workshop on Education  
Weingarten, Germany, July 2001)

- **Inter-disciplinarity** among technical disciplines and **trans-disciplinarity** among engineering, life science and social and human science
- **Teaching** to have a global vision of problems, combined with an **education** in depth
- Capability of formulate a “systemic thought”
- Entrepreneur spirit
- Strong expertise and **attention to social and ethical problems**







# New PhD Program in **Biorobotics Science and Engineering**

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