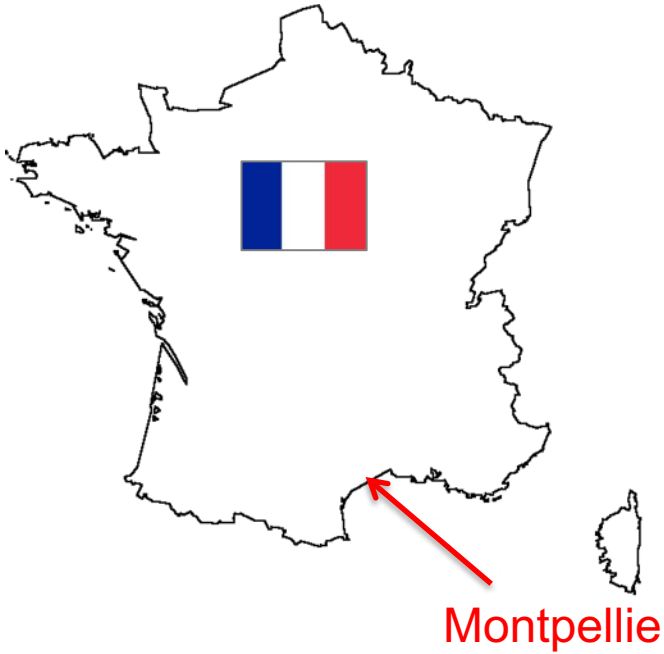
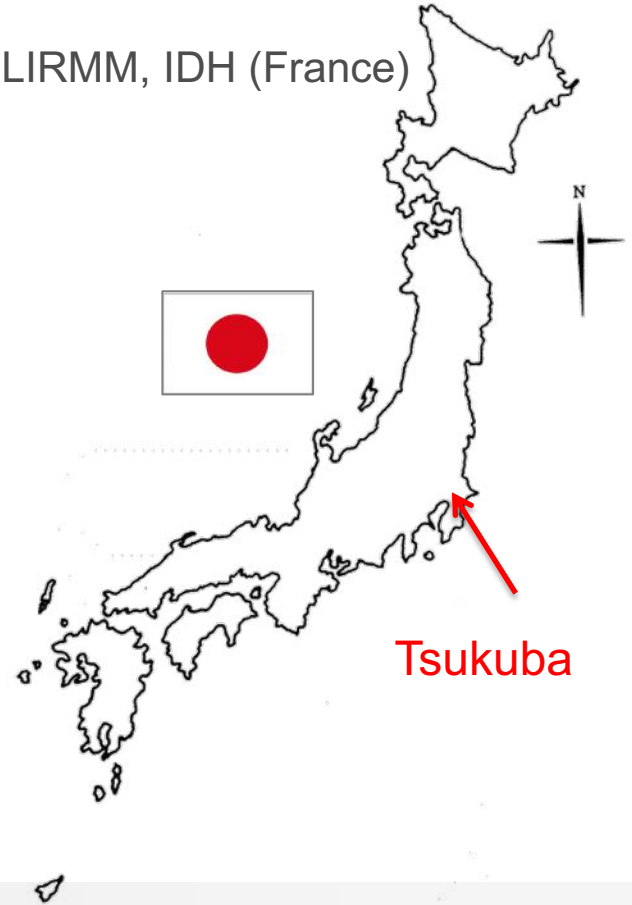
Introduction to Bionics

Abderrahmane Kheddar
CNRS–AIST Joint Robotics Laboratory, IRL, Japan
CNRS–University of Montpellier, LIRMM, France
kheddar@lirmm.fr

Labs

- CNRS-AIST JRL (Japan), CNRS-Univ. of Montpellier LIRMM, IDH (France)

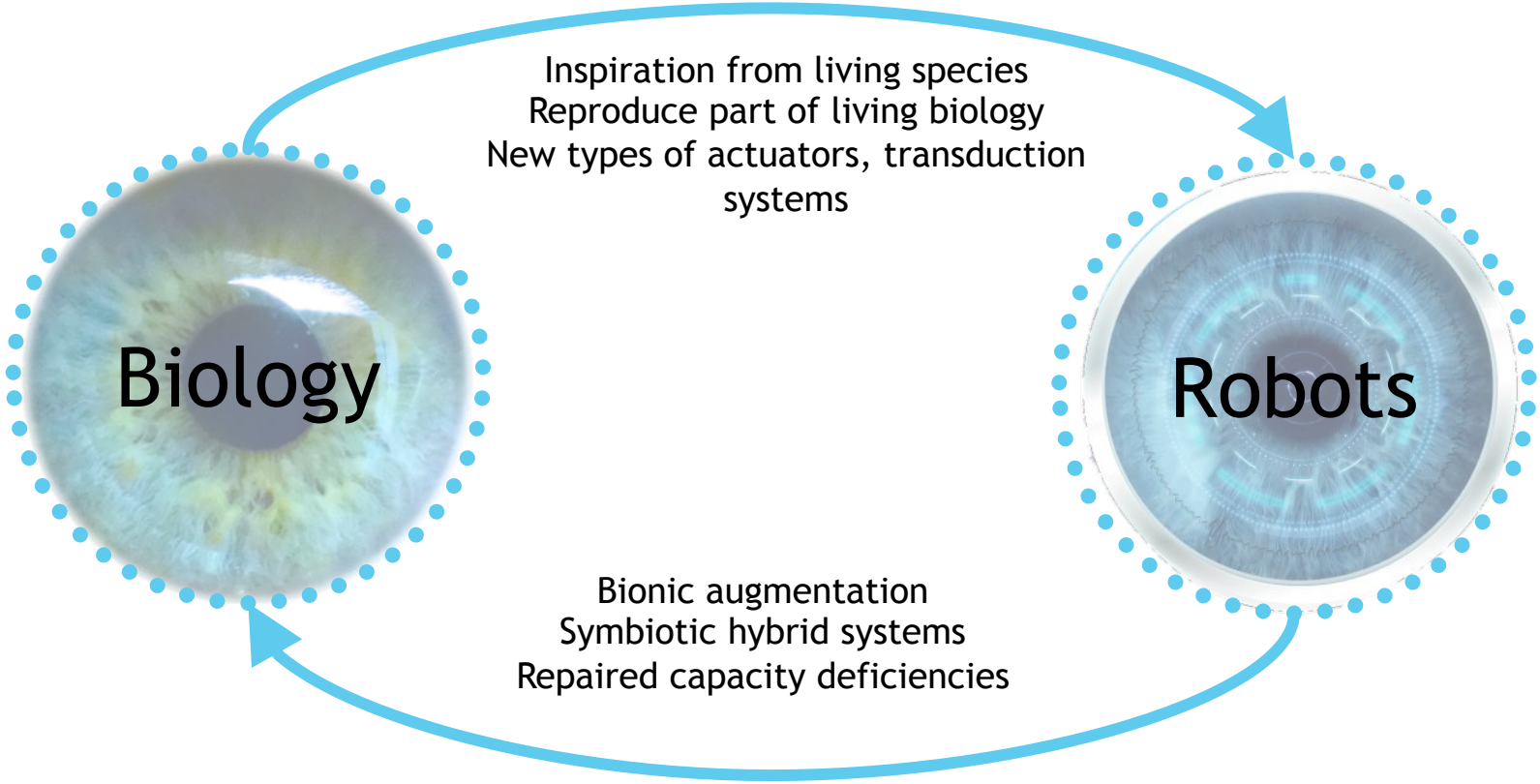




Bionics

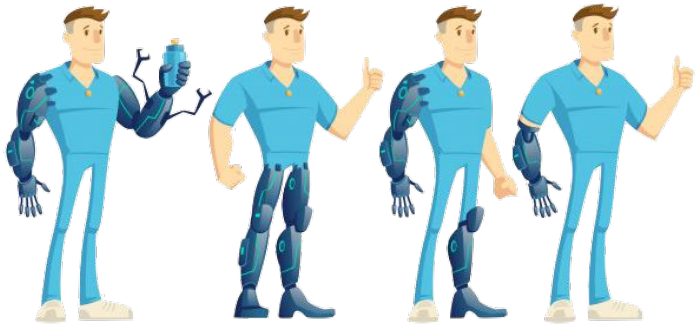
- Biologically inspired engineering
  - Coined by Jack E. Steele in 1958
  - Acronym for *bio*logy and electro*nics*
- Recent connotations
  - Biomimetics (Otto Schmitt 1950)
  - Cyborg (a novel by Martin Caidin 1972)
  - Cybernetics (control and communication in living species and machine, André-Marie Ampère 1834)
  - Human augmentation
    - Replicating human abilities
    - Supplementing human abilities
    - Extending/exceeding human abilities
  - Transhumanism
    - Human augmentation +
    - Suppress aging and death

Bionics and Robotics interplay

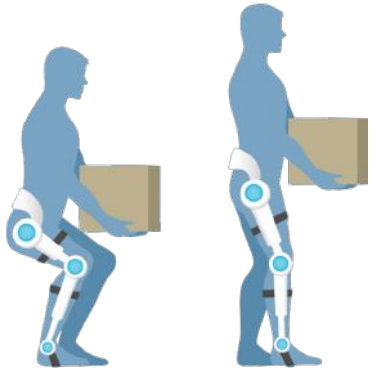


Bionics stakes

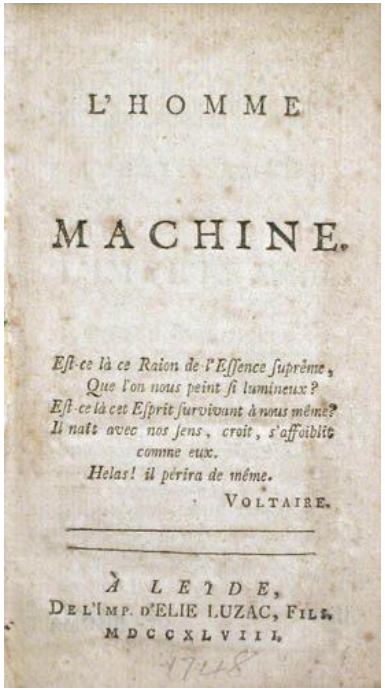
- Bridging the gap between *ability* and *disability*
  - Reduce costs i.e. dedicated infrastructures
  - Facilitate the “integration” of disabled people
  - Quality of life of the persons concerned



- Bridging the gap between human limitations and human potential (human augmentation)
  - Elderly and dependent persons
  - Fragile people



Man a Machine… 1748



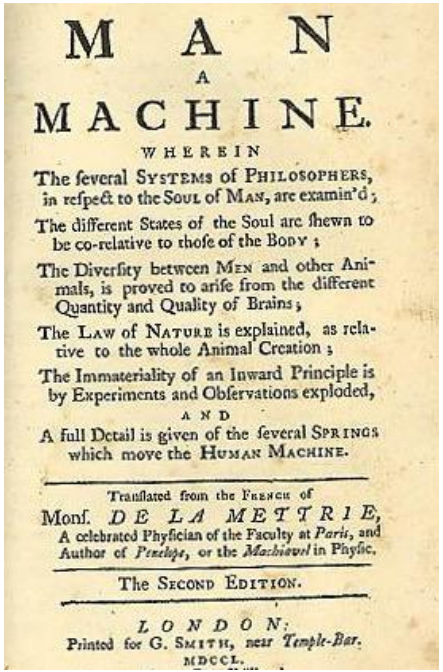
L' HOMME

MACHINE.

Eſt-ce là ce Raion de l'Eſſence ſuprême,
Que l'on nous peint ſi lumineux?
Eſt-ce là cet Eſprit ſurvivant à nous même?
Il nait avec nos ſens, croit, s'affoiblit
comme eux.
Helas! il périra de même.

VOLTAIRE.

À LEYDE,
DE L'IMP. D'ELIE LUZAC, FILS.
MDCCXLVIII.



MAN
A
MACHINE.

WHEREIN

The ſeveral SYSTEMS of PHILOSOPHERS, in reſpect to the SOUL of MAN, are examin'd;

The different States of the Soul are ſhewn to be co-relative to thoſe of the BODY;

The Diverſity between MEN and other Animals, is proved to ariſe from the different Quantity and Quality of Brains;

The LAW of NATURE is explained, as relative to the whole Animal Creation;

The Immateriality of an Inward Principle is by Experiments and Obſervations exploded,

AND

A full Detail is given of the ſeveral SPRINGS which move the HUMAN MACHINE.

Tranſlated from the FRENCH of
Monſ. *DE LA METTRIE*,
A celebrated Phyſician of the Faculty at *Paris*, and Author of *Penelope*, or the *Machiavel* in Phyſic.

The SECOND EDITION.

LONDON:
Printed for G. SMITH, near *Temple-Bar*.
MDCCL.

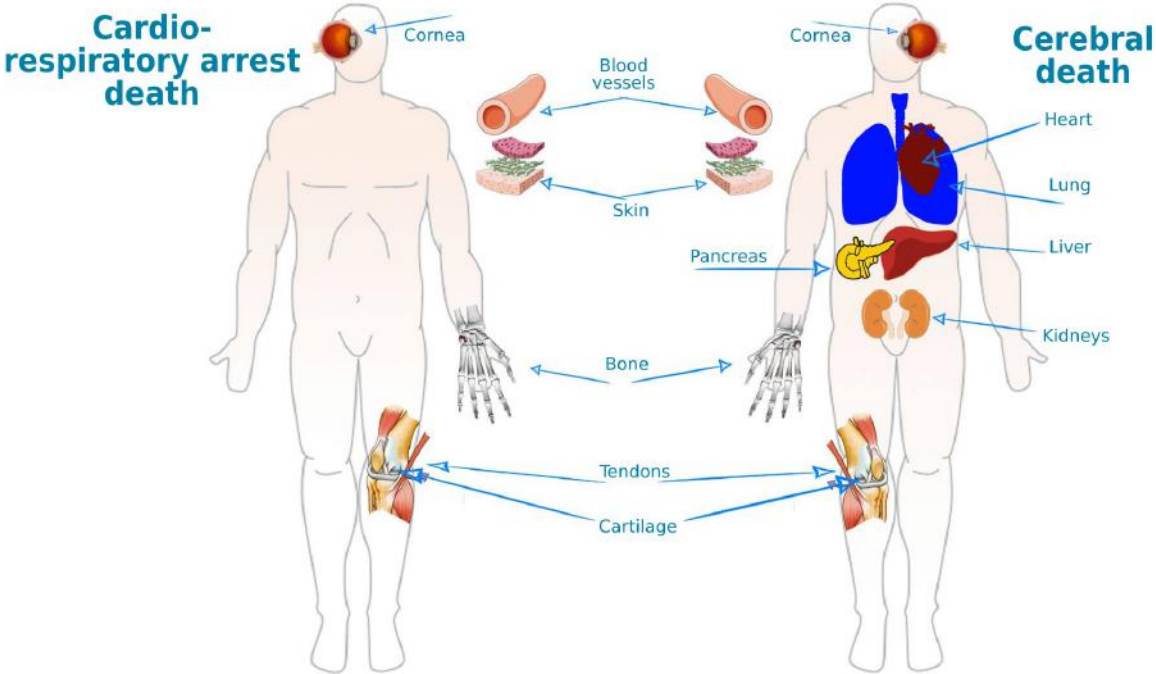
Julien Jean Offray de La Mettrie (1709-1751)

Man a Machine

- Human and living species are biology-material system
- Soul/spirit/consciousness are a different, but coupled, system
- If Human is a “machine”, so as any “machine” it can broke, have deficiencies and more importantly: *can be repaired*
- How to repair living bodies
  - Organ transplants
  - Engineered organs
    - Orthosis
    - Prostheses
    - Artificial organs
    - Inner assist technologies
    - External assist technologies

Organ transplants

- Take spare from deceased- or living-donor to persons in need
- Concerns mainly inner organs but outer one are also considered
  - e.g., hands, skin, penis, face, cornea…

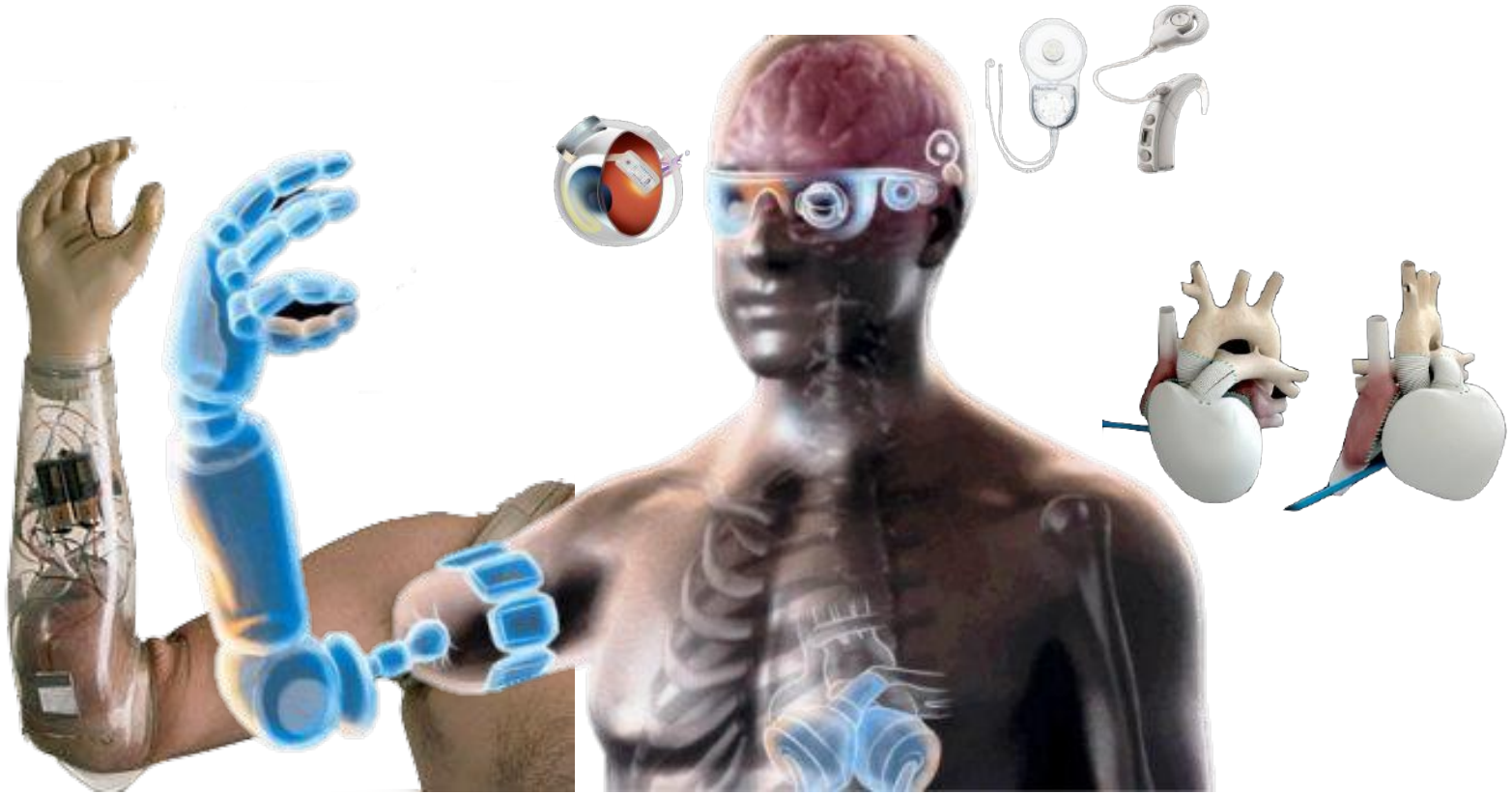


Organ transplants shortcomings

- Ethics
  - Controversy concerning brain death
  - Living donors
  - Psychology (living with donated organs)
- Price: relatively costly
- Waiting time relatively long depending on organs
- Transplant rejection
  - Need of immunosuppressors (for life)
  - Applies also to artificial organs
- Predicating medical success is difficult
- Whole limbs transplant very difficult
  - Current challenge head transplant (Sergio Canavero)

Vladimir Demikhov on January 13, 1959

Alternative: engineered organs… a huge market

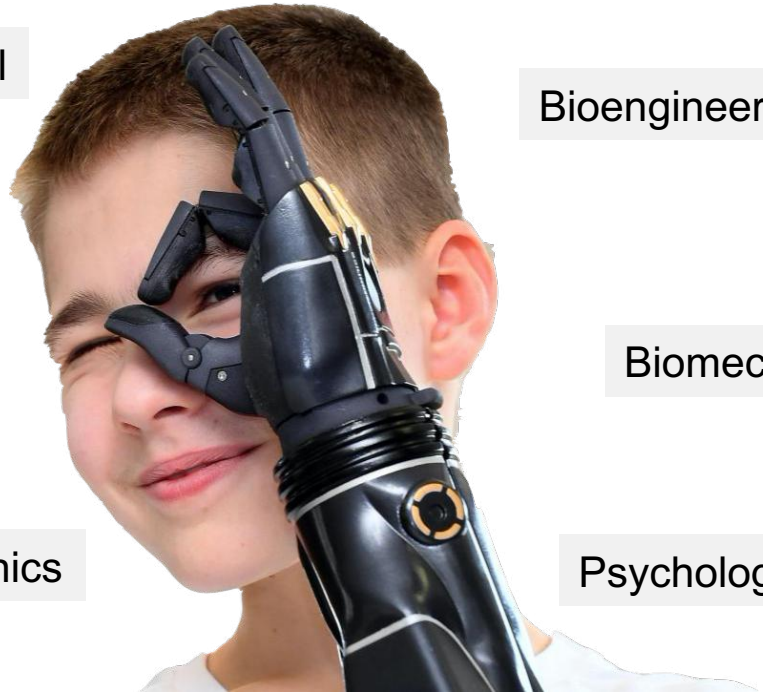


What are the main bionics ingredients

Medical fields

Biomaterial

Bioengineering



Robotics

Biomechanics

Microelectronics

Psychology

Oxandre and his bionics arm

Prosthesis

- Robotic devices to replace lost or missing common limbs
  - essentially parts of arms or legs
- Specific challenges
  - Customization
  - Actuator technology
  - Weight
  - Shape and integration
  - Wearability
  - Interface with human physiological sensors
  - Cleanness
  - Intuitiveness of use
  - Sensory feedback
  - Evolutivity (with age)

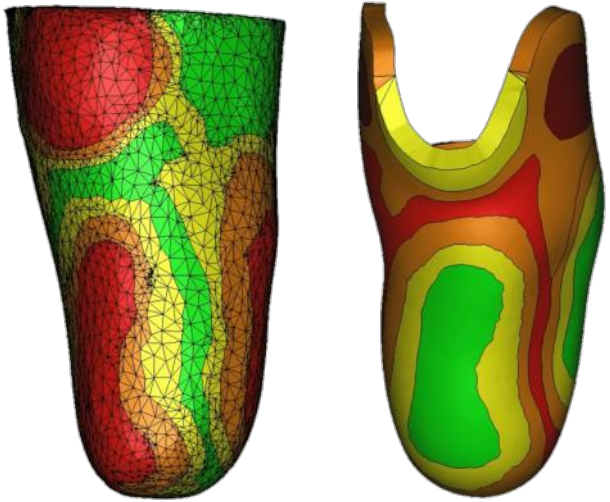
Human tissues/prosthesis interface

- Extremely difficult to design and optimize
- Impedance matching
- Comfort and safety

BioM, MIT use-case

Understand the inner structure

Customized robot to measure tissue characteristics



Stiffness map leg + prosthesis

Human intentions from electromyography (EMG)

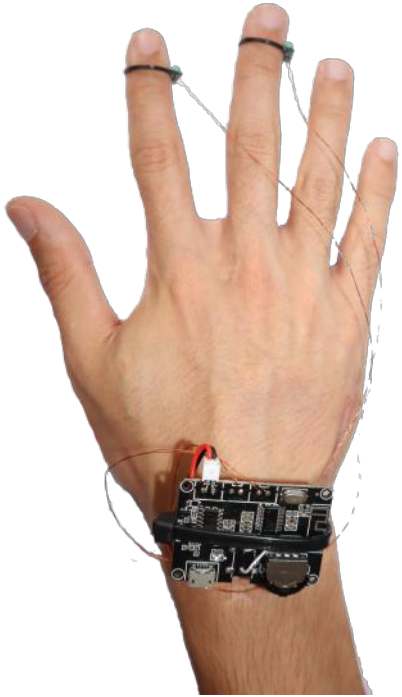
- Skin surface technology
- Sensors (wireless version exist) record the electrical activity produced by skeletal muscles
- Pattern recognition + training allows to convert existing (remaining) muscles (exploiting synergy properties) into control signal for the robotic prosthesis

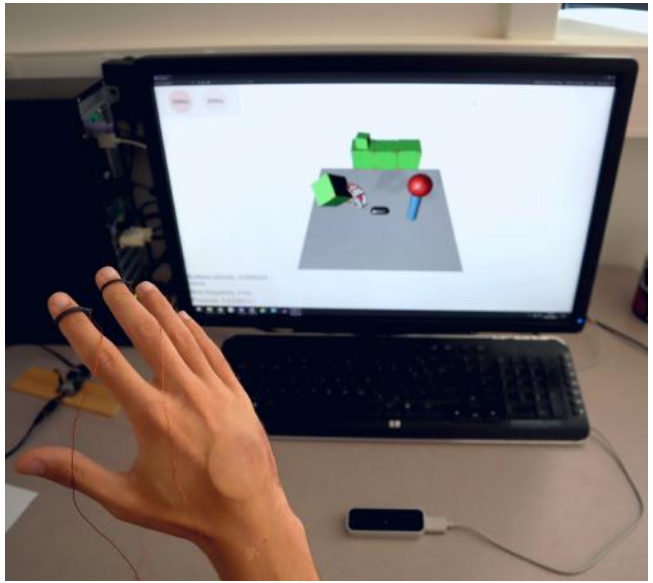
Implantable Myoelectric Sensor Systems

- The sensors are integrated to the muscle
- Powered wirelessly
- Transmit data at the same time
- Control systems more complex as there are many sensors implemented at different locations but also at different depth
- Requires surgery (invasive)

Human intentions from magnetomicrometry

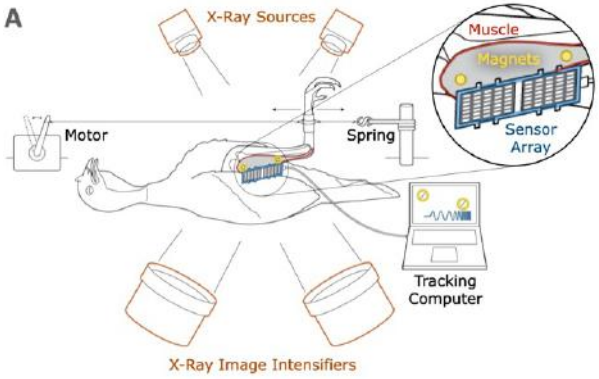
- Current trend: magnet implants for… “fun”, *A. Fougues, A. Kheddar, 2021*

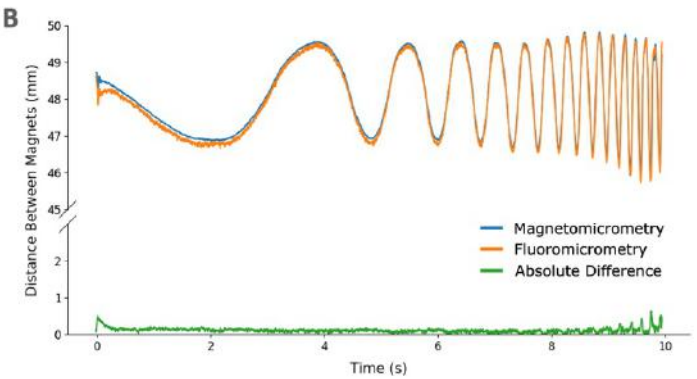


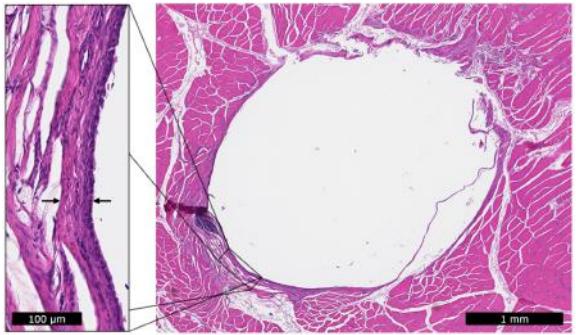


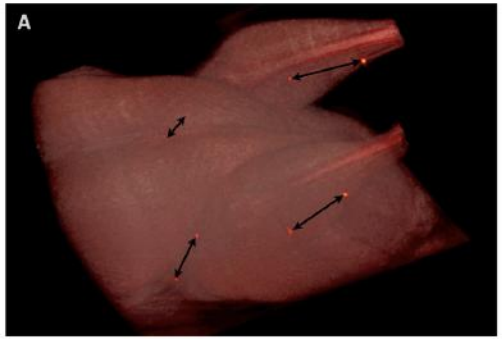
Human intentions from magnetomicrometry

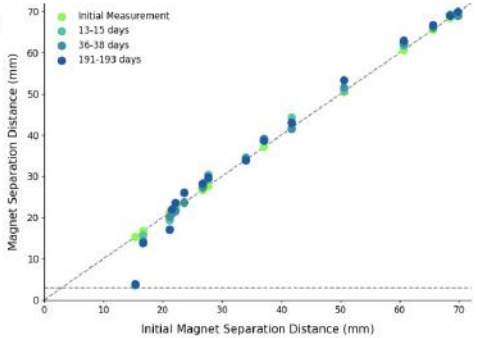
- Using magnetomicrometry to control prosthesis; Taylor *et al.*, Sci. Robotics 2021











Sensory feedback

- Prosthesis without feedback are complex to control
- Feels disconnected from the body
  - Phantom limb phenomena
- Controlled in a open-loop kind
- No sensation of contact nor touch

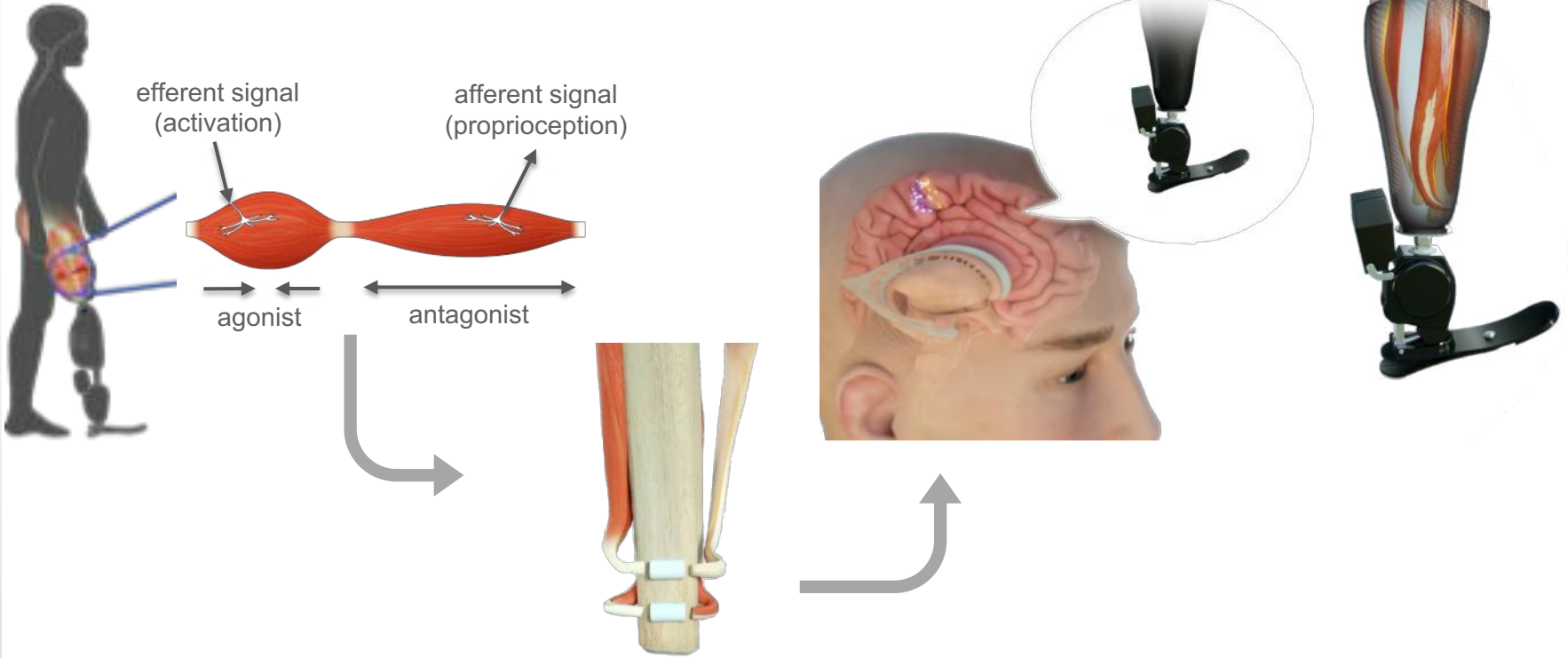
- Challenge: how to make the brain prosthesis-state aware?
  - Using sensory substitution
  - Using afferent pathway: how to connect mechatronics to nerves

Sensory feedback: key concepts

- **Sensory nervous system**
  - Identifying the nerves responsible for gathering information from your senses
- **Neuroplasticity**
  - The ability of the brain to reorganize and learn new patterns, create new pathways
- **Embodiment**
  - The feeling that the parts of your body belong to you (ownership)
- **Authorship**
  - The feeling that you are in control of your body's actions
- **Cognitive engagement**
  - Amputees perceive that their prosthetic limb is under their control, and a part of their body

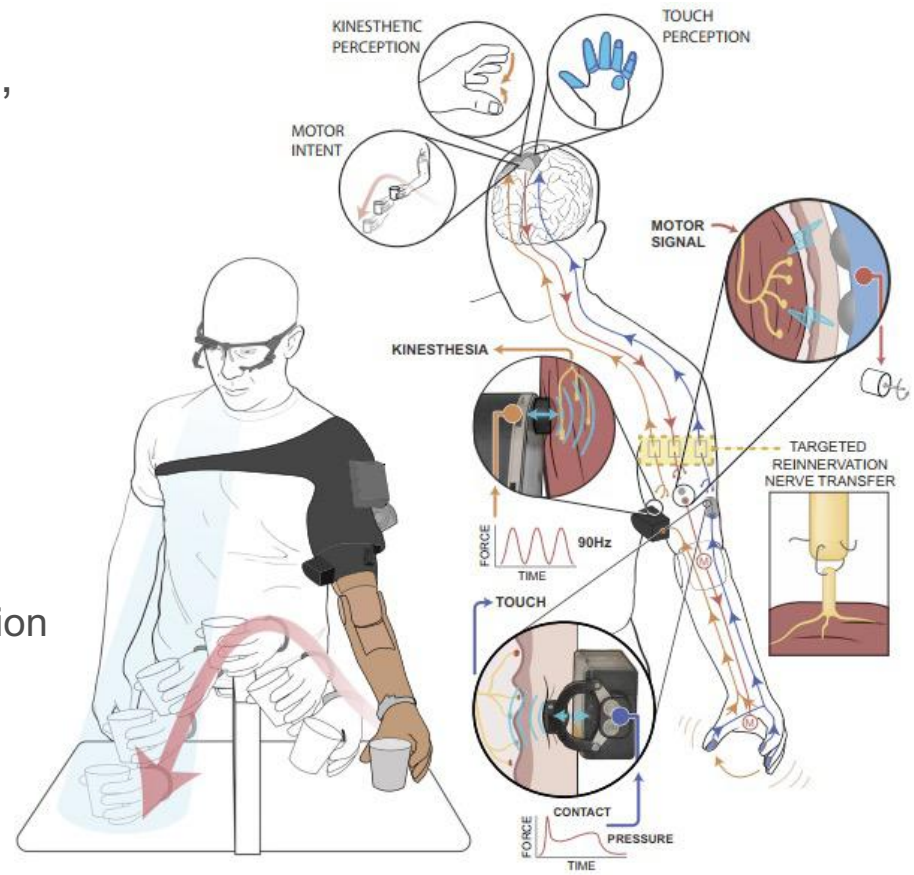
Sensory feedback: example AMI

- Agonist-antagonist myoneural interface (AMI); BioM MIT Extreme Bionics



Sensory feedback: “reinnervation”

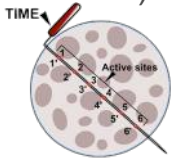
- Simultaneous integration of touch, kinesthesia and movement intent
- Bidirectional prosthesis
- Combined
  - Targeted muscle reinnervation
  - Targeted sensory reinnervation
- In practice
  - TMR motor-intent > EMG
  - Touch prosthetic sensors > Vibration display (90Hz) as feedback substitution
  - Enough to increase substantially



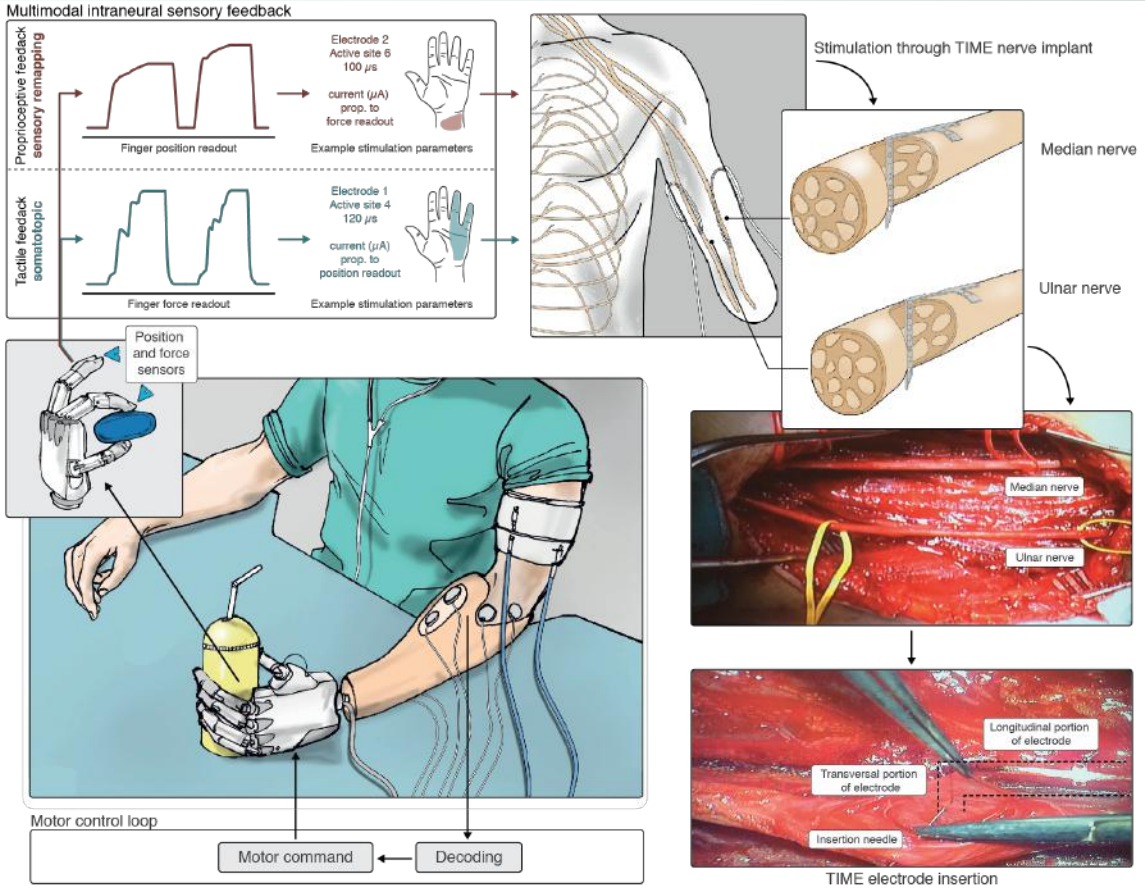
P.D. Marasco *et al.*, Sci Robotics 2021

Sensory feedback: TIME nerve implant

- Robotic hand driven by EMG
- Robotic hand pressure and position are measured in real-time
- Position / pressure encoded into pulses
- Stimulation amplitude prop. to finger position or pressure
- Pressure perception restored using somatotopic
- Position (proprioception) restored using sensory substitution
- Both sensory streams are delivered using intraneural stimulation by TIME (transverse intrafascicular multichannel electrodes)



E. D'Anna *et al.*, Sci. Robotics, 4(27), 2019



Bionics for human augmentation

- Obviously design a robotic substitute come also with the ability to make it do better than biology in some aspects
- The quest for human augmentation or substitution?

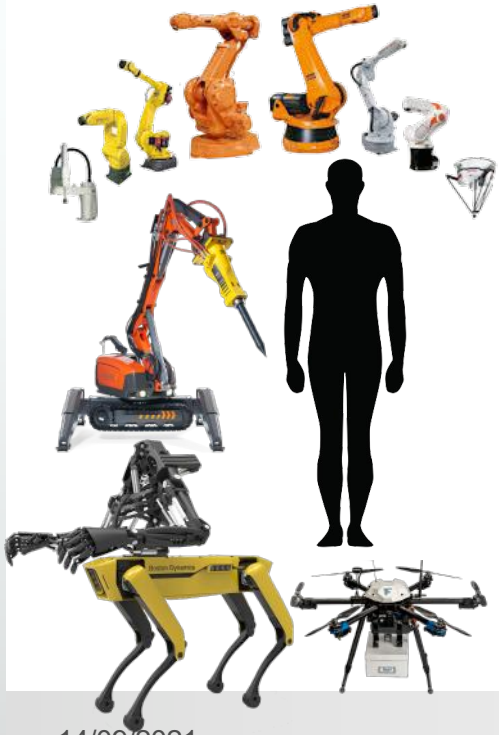
- Enhancing intellectual capabilities
  - Mathematics, computers (toward wearable) and software, chemical, etc.
- Enhancing perceptual capabilities
  - Night vision systems, access to third parties thought, etc.
- Enhancing physical capabilities
  - Different tools, machines, vehicles, chemicals, etc.

- Robotics and AI
  - Gathers almost all three in one system!

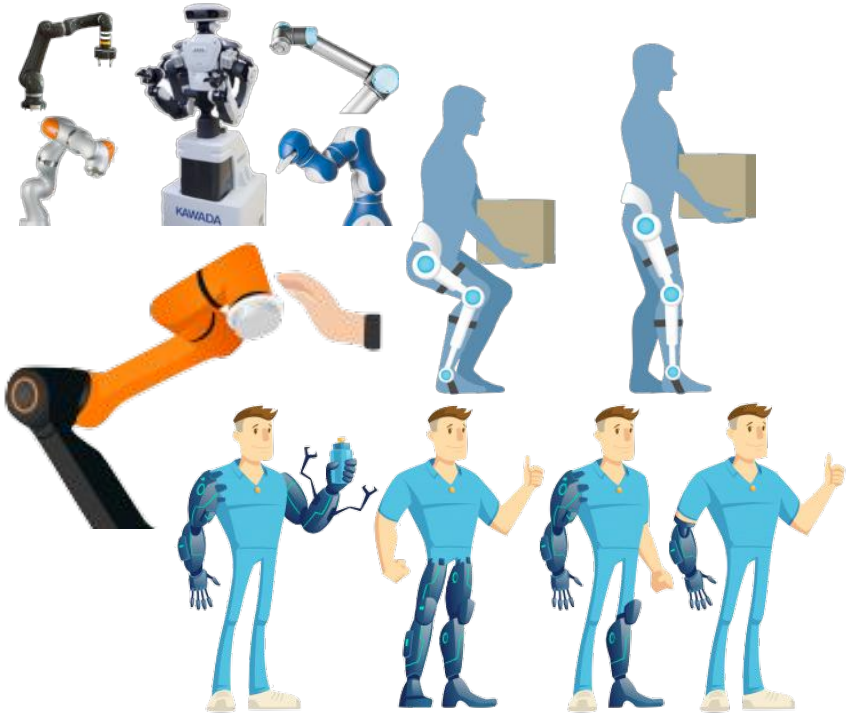
Sum-up of robotics taxonomy

- Can be defined by the physical distance δ between human and robot

$\delta > 0$



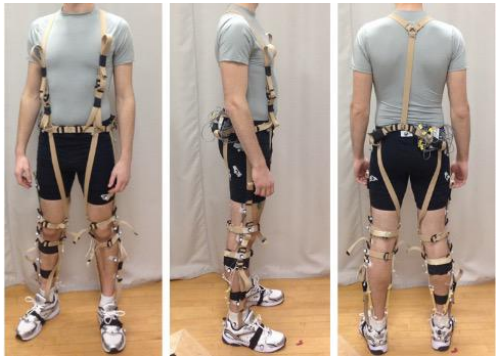
$\delta = 0$



$\delta < 0$

Exoskeletons

- A bad “good-idea”
  - Rehabilitation OK
  - Other applications (e.g. infantryman)
    - Should be consumed with moderation
- Nature has its laws
  - Physics fixes the game rules
    - Allometry
  - How many living beings have exoskeletons?
    - The biggest known is the coconut (or robber) crab *birgus latro*
      - Not possible with the current law of physics to have bigger living species with exoskeleton
    - Yet roboticists are keep trying ☺



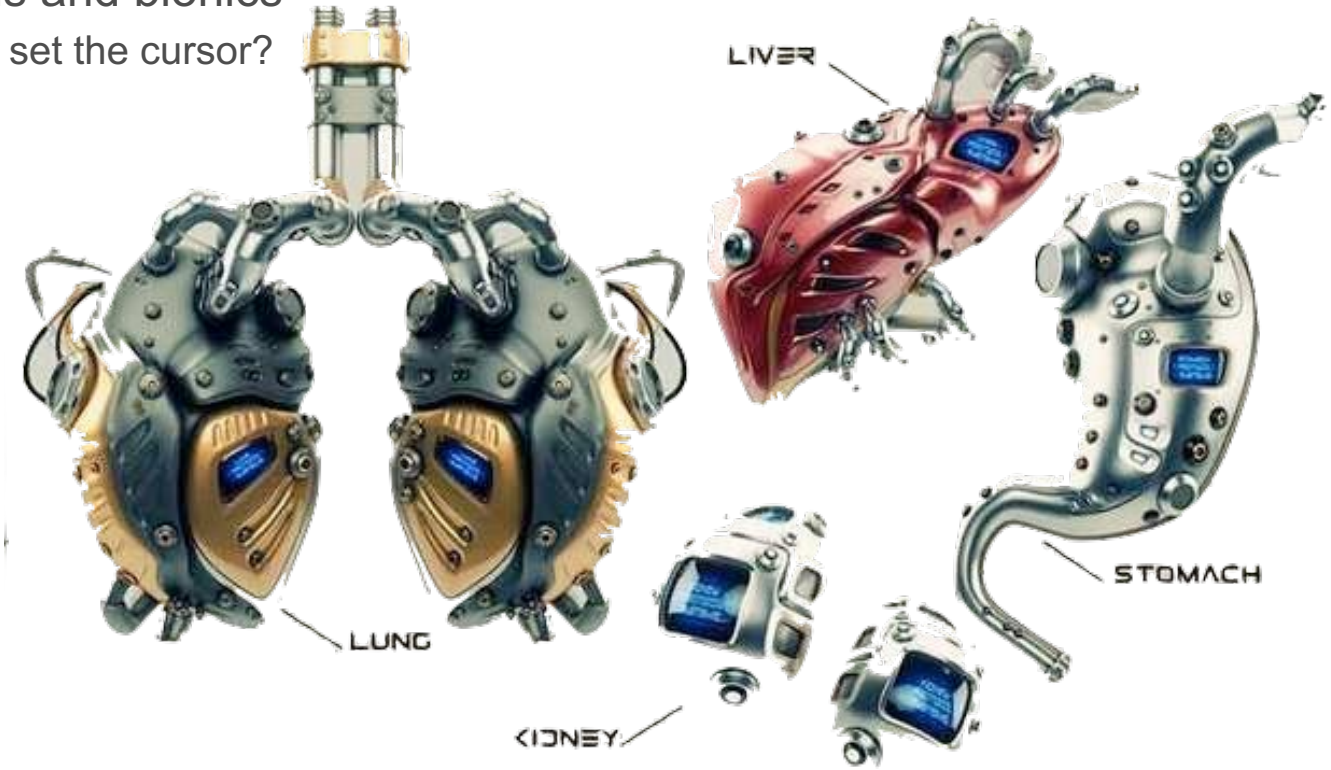
Extra “robotic” limbs for human

- Supernumerary-fingers
- Extra-arms
  - Solution envisioned in large-scale manufacturing e.g. Boeing
  - The idea is to “wear” a robotic system to increase the number of limbs and/or strength

- Problem
  - Control interface
  - Thought-based control?
  - Similarities with exoskeletons and human extenders

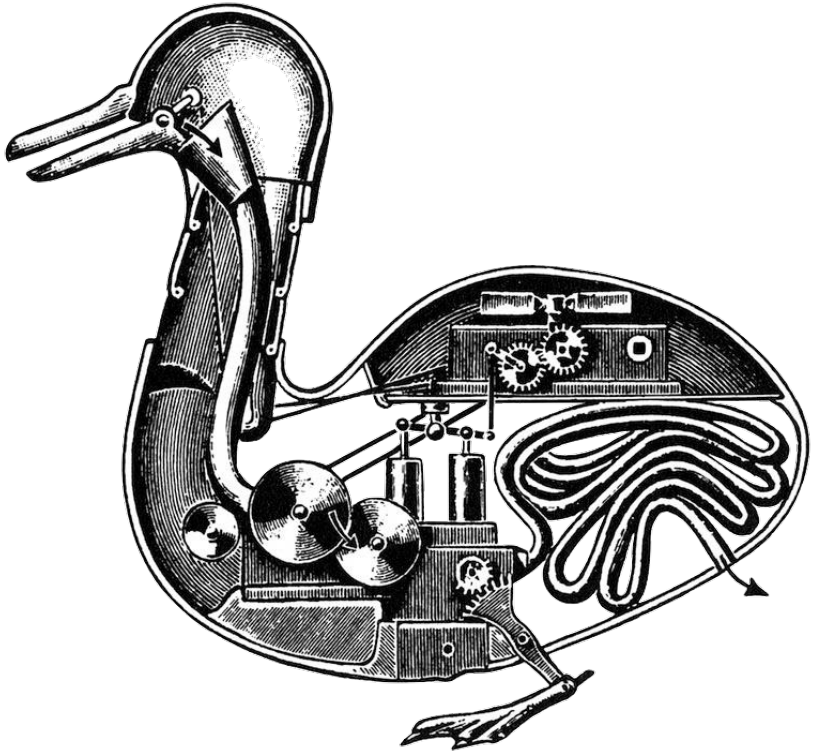
Machine a Man

- Artificial organs and bionics
  - Where de we set the cursor?



Machine a… duck

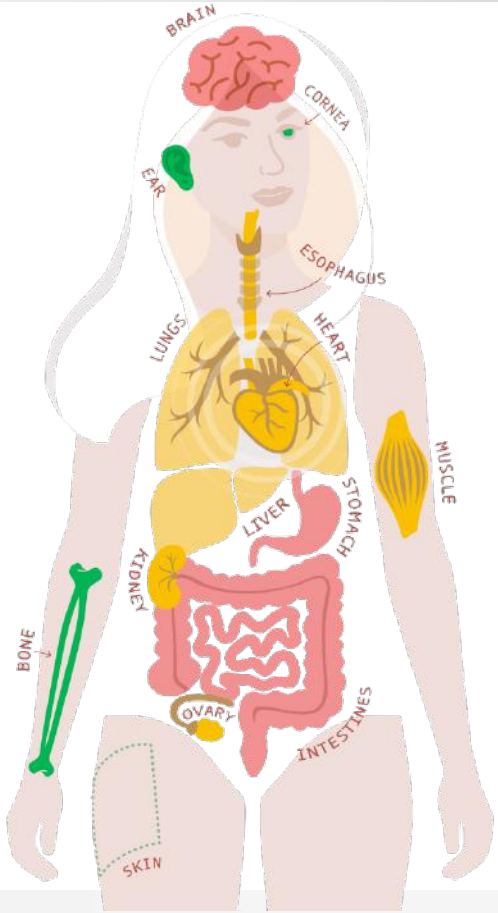
- Jacques de Vaucanson duck 1738



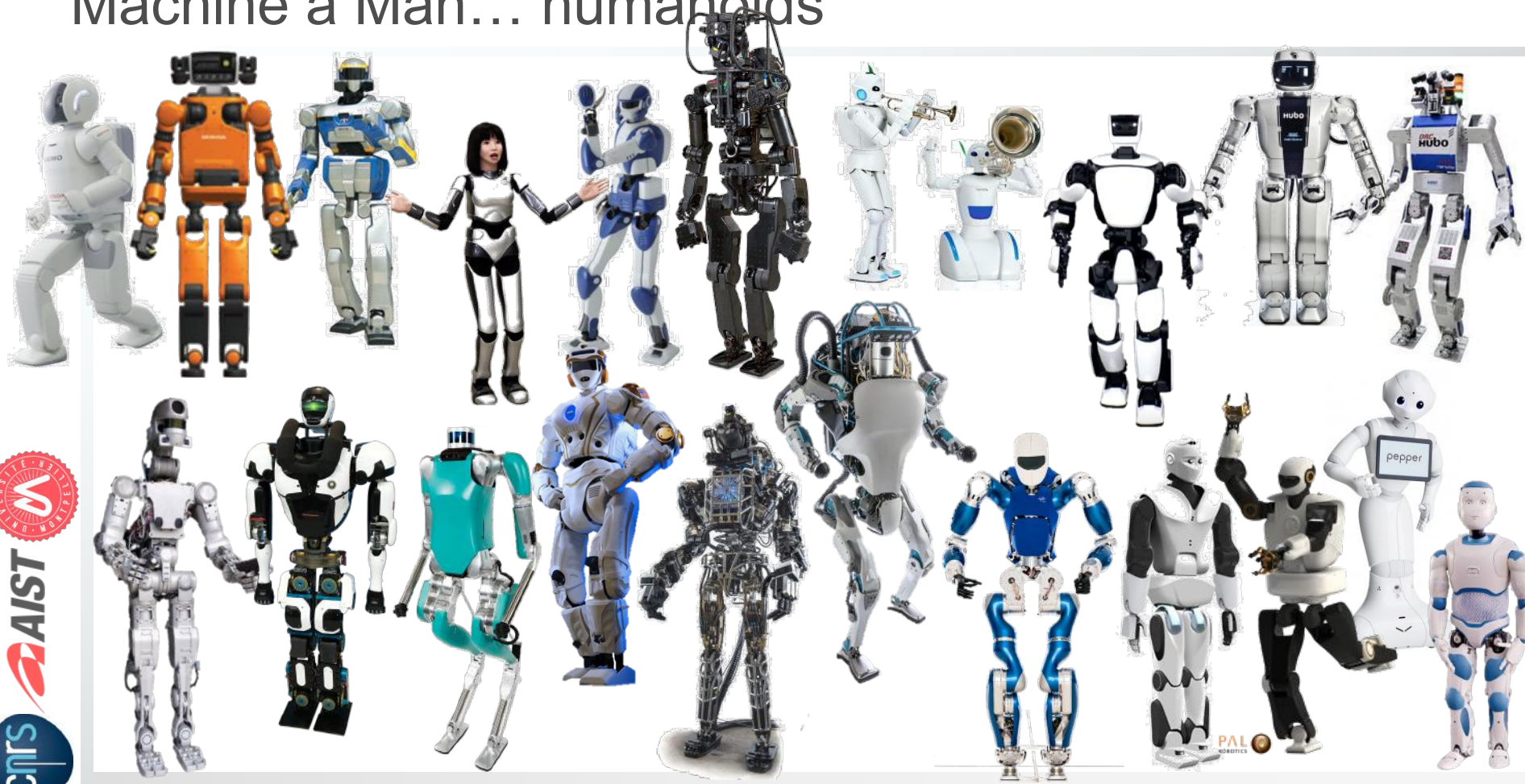
3D printed organs

- Already in use in dental implants, prosthetics…
- Genesis
  - Microfluidics model of tissues, mini-organoids, organs on chip, etc.
- Printing with cells
  - Ideally built from cell recognized by the patient immune system

- 3D printed tissues already in clinical testing
- 3D printed tissues in development, no clinical test yet
- 3D printed tissues farthest from clinical use

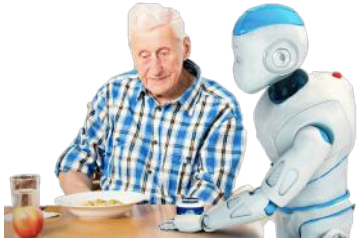


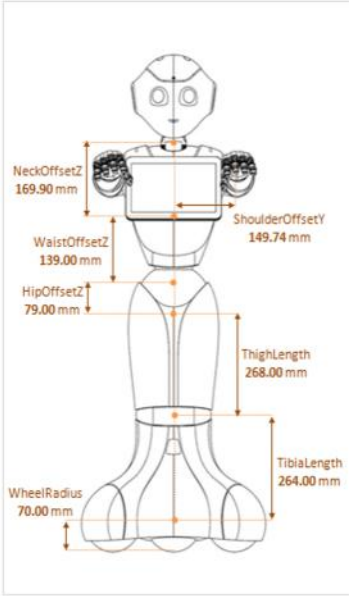
Machine a Man… humanoids



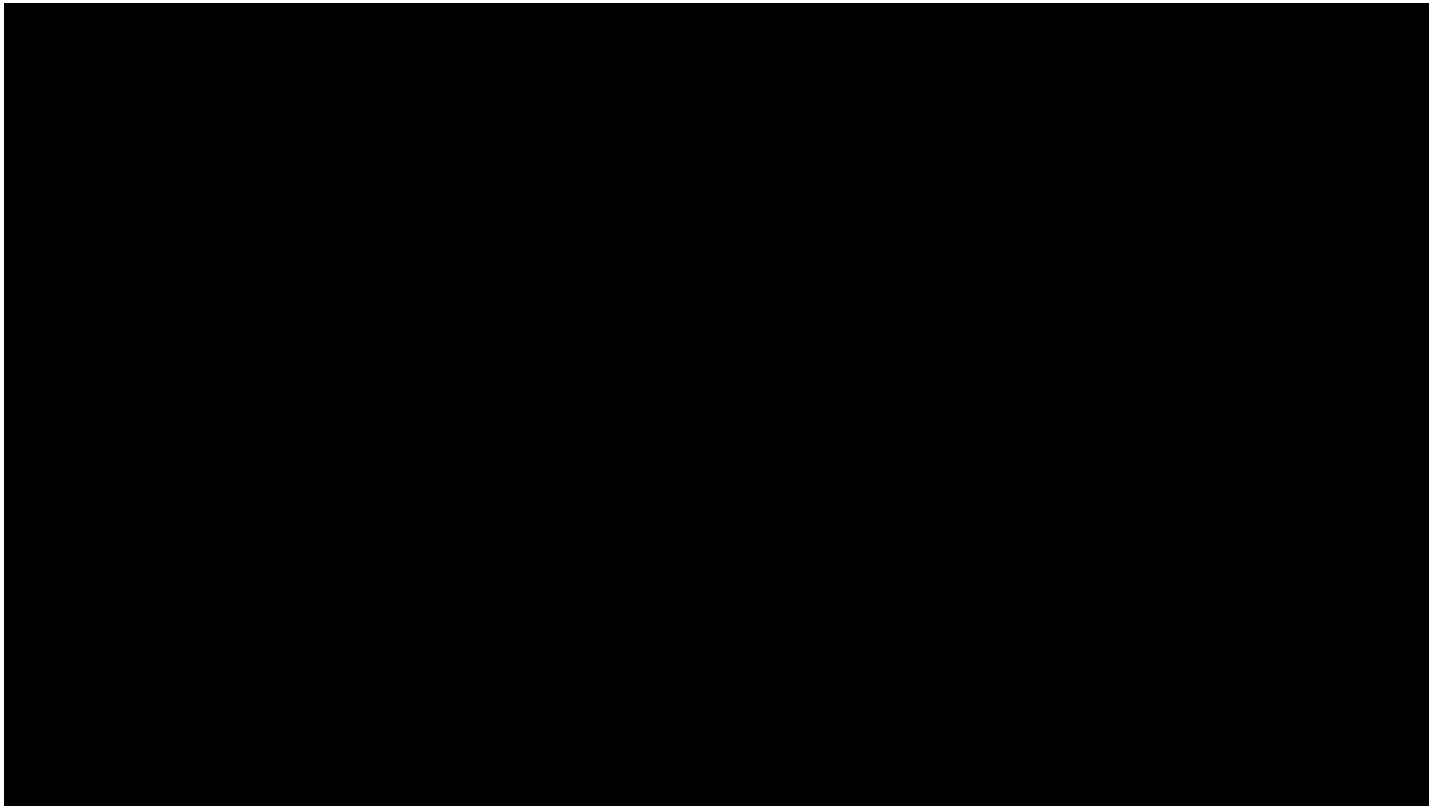
Humanoids@Services

- Sustaining autonomy for frail / aging persons
- Non-added value tasks in nursing
- Better design of assistance robots
  - AI but also intelligent hardware





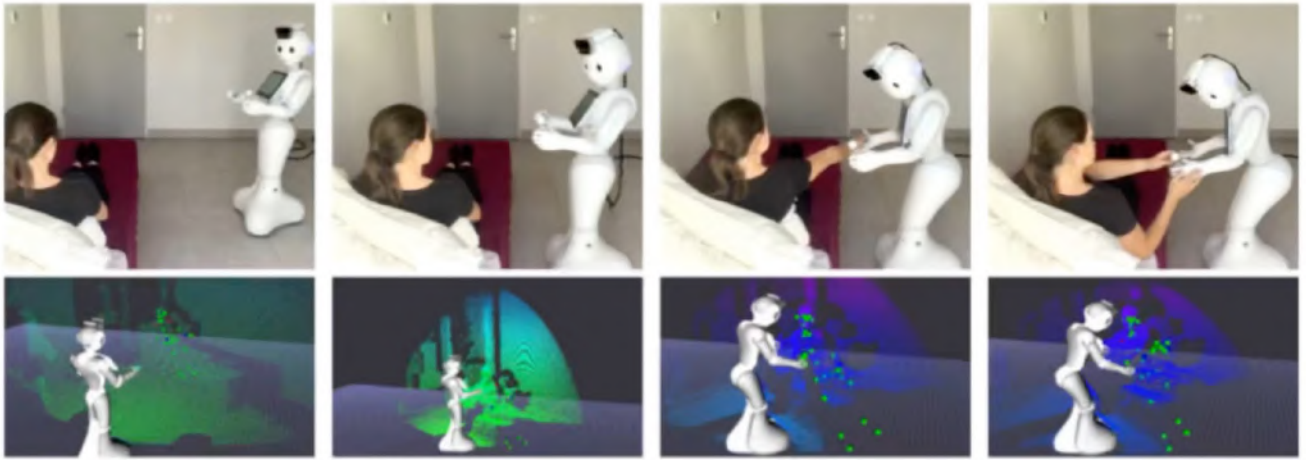
Humanoids@touchable



Bolotnikova *et al.*, IEEE Ro-Man 2018, IEEE Humanoids 2018

Humanoids@daily assistance

Advanced controller use-case example demonstrating HRI application with a real human inspired from an assistance scenario

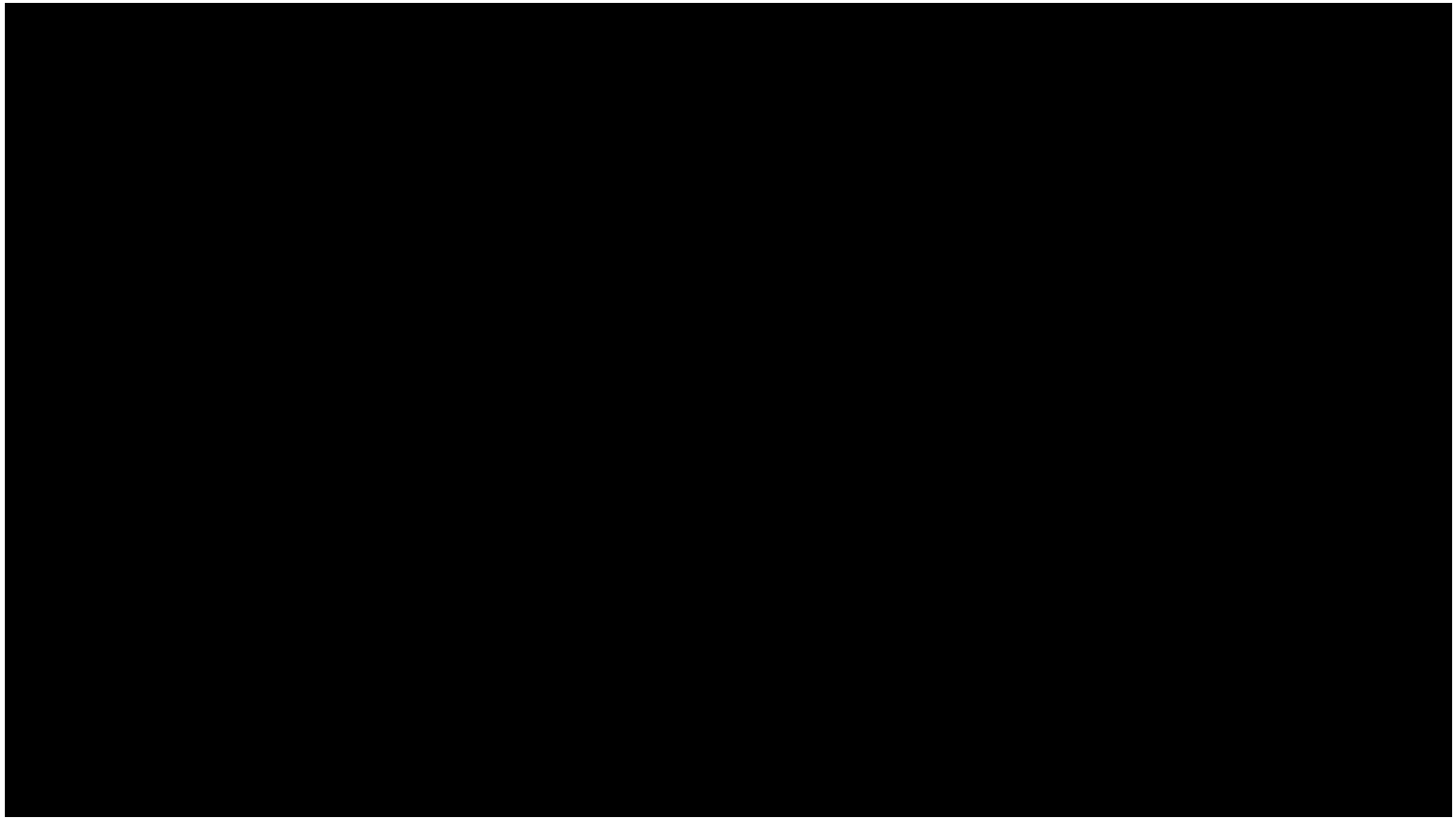


(a) Navigation to human (b) Verbal communication (c) Human takes pills (d) Human takes bottle

Bolotnikova *et al.*, IEEE RA-L 2019, IEEE RA-L 2021,

Humanoids@HiFi teleoperation

Humanoids@Telepresence TELESAR history

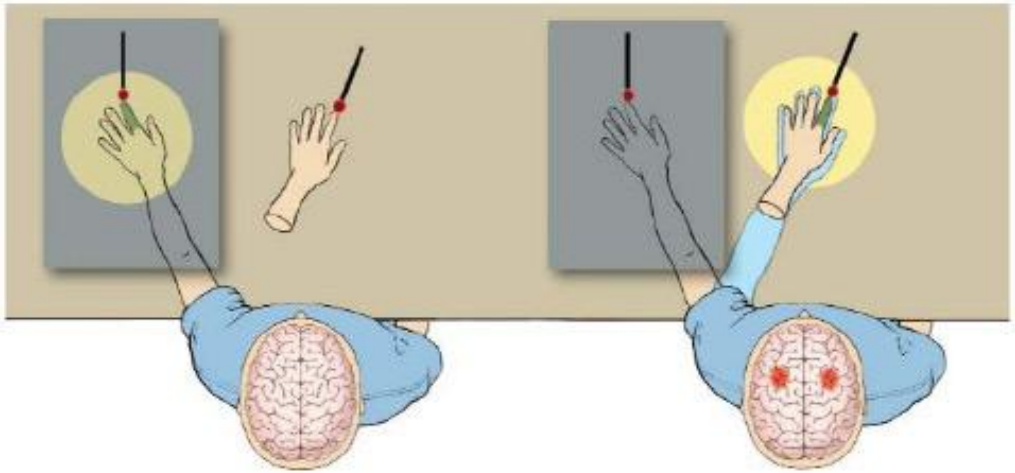


Humanoids@Surrogate

Humanoids@Geminoids

Commonalities: “Embodiment”

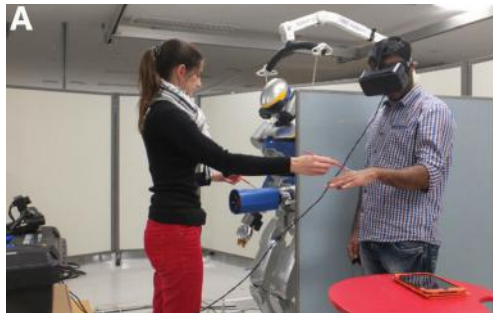
- It is not enough to have a reliable human-centric technology
- Trust in its usage is important
- Embodiment is an unknown concept in robotics
  - Beyond telepresence

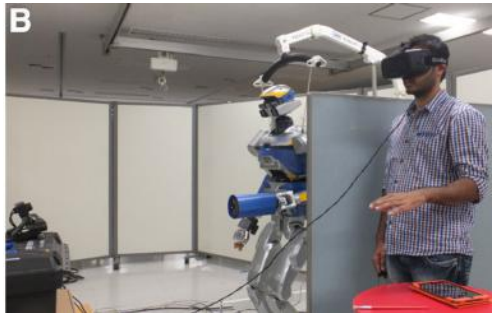


M. Botvinick, J. Cohen, *Nature*, 1998

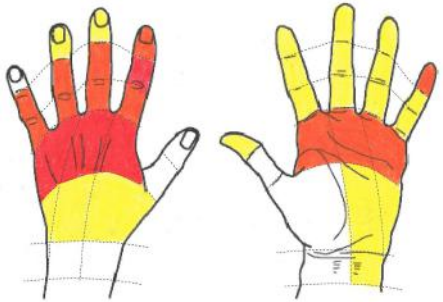
Humanoids@embodiment

- Can non-human humanoid arm be perceived as own body?
- Shape doesn't matter: high embodiment scores





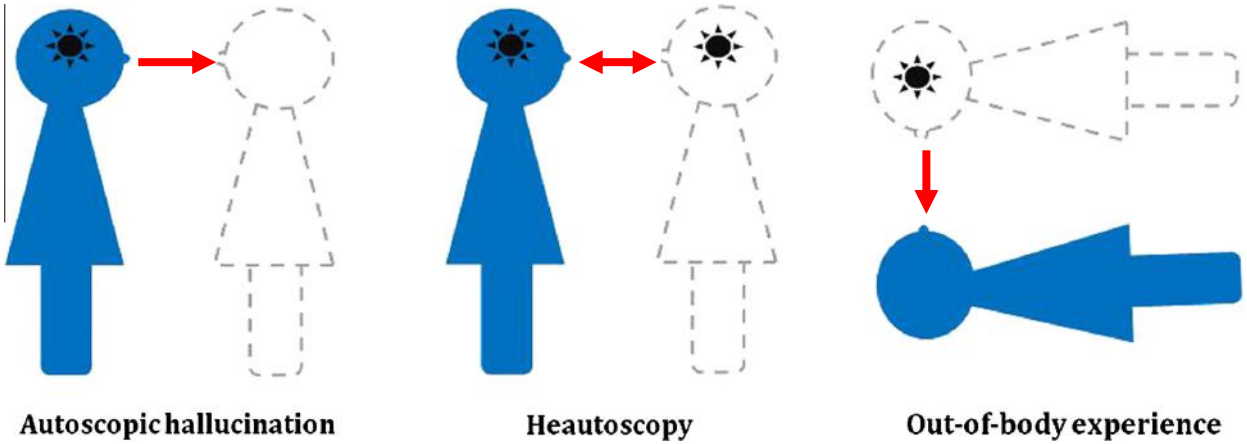
- Touch by a humanoid avatar induces haptic sensation in the real hand




Aymerich-Franch *et al*., Journal of Social Robotics 2017

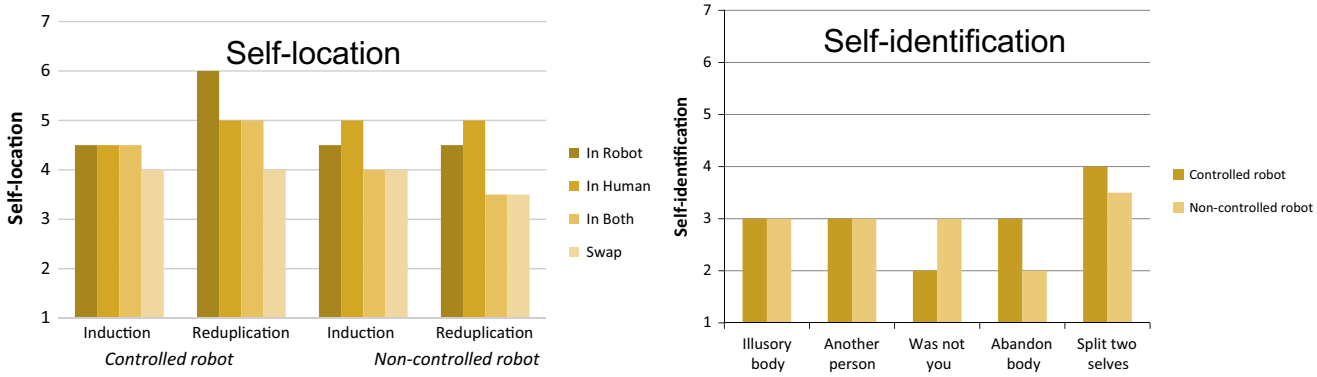
Aymerich-Franch *et al*., J. Computer-Mediated Com. 2017

Humanoids@basic findings



- Self-location and self-identification in autoscopic phenomena: Blanke and Metzinger (2009)
  - **Blue figure: the real body**
  - **Gray figure: the illusory body**
  - The **black start (*)** : **self-location** and **self-identification** with that body
  - **Red arrow** → : the perspective from which the person perceives the surroundings

Humanoids@hautoscopy “reproduction”



Aymerich-Franch *et al.*, Consciousness and Cognition 2016

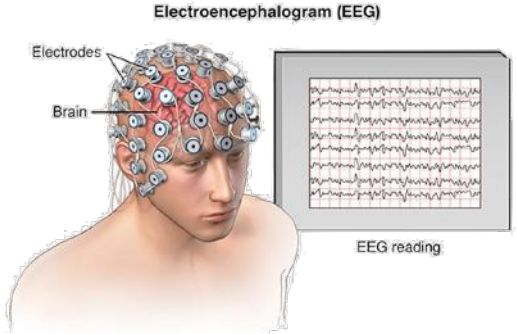
Some shades in the approaches

- What does these preliminary findings tell us about embodiment?
  - Shape doesn't matter
  - Self-localization and self-identification are misleading/fuzzy
  - Sensory perception (as we have been thought it is) can be biased

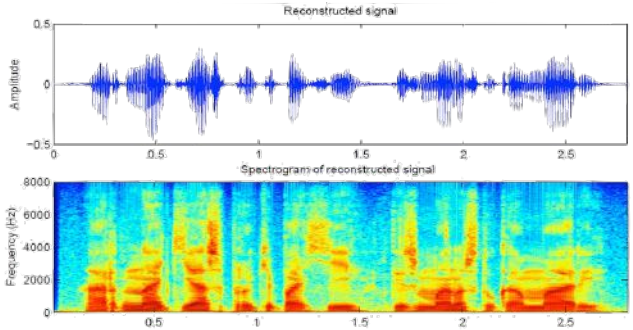
- Human science
  - Exception confirms the rule
- Math / engineering
  - Exception invalidates the rule

Humanoids@BCI

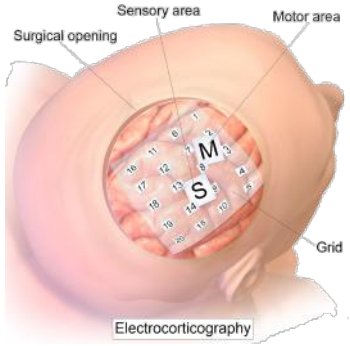
- Monitoring of brain activities



- Processing brain data (off-line or on-line)



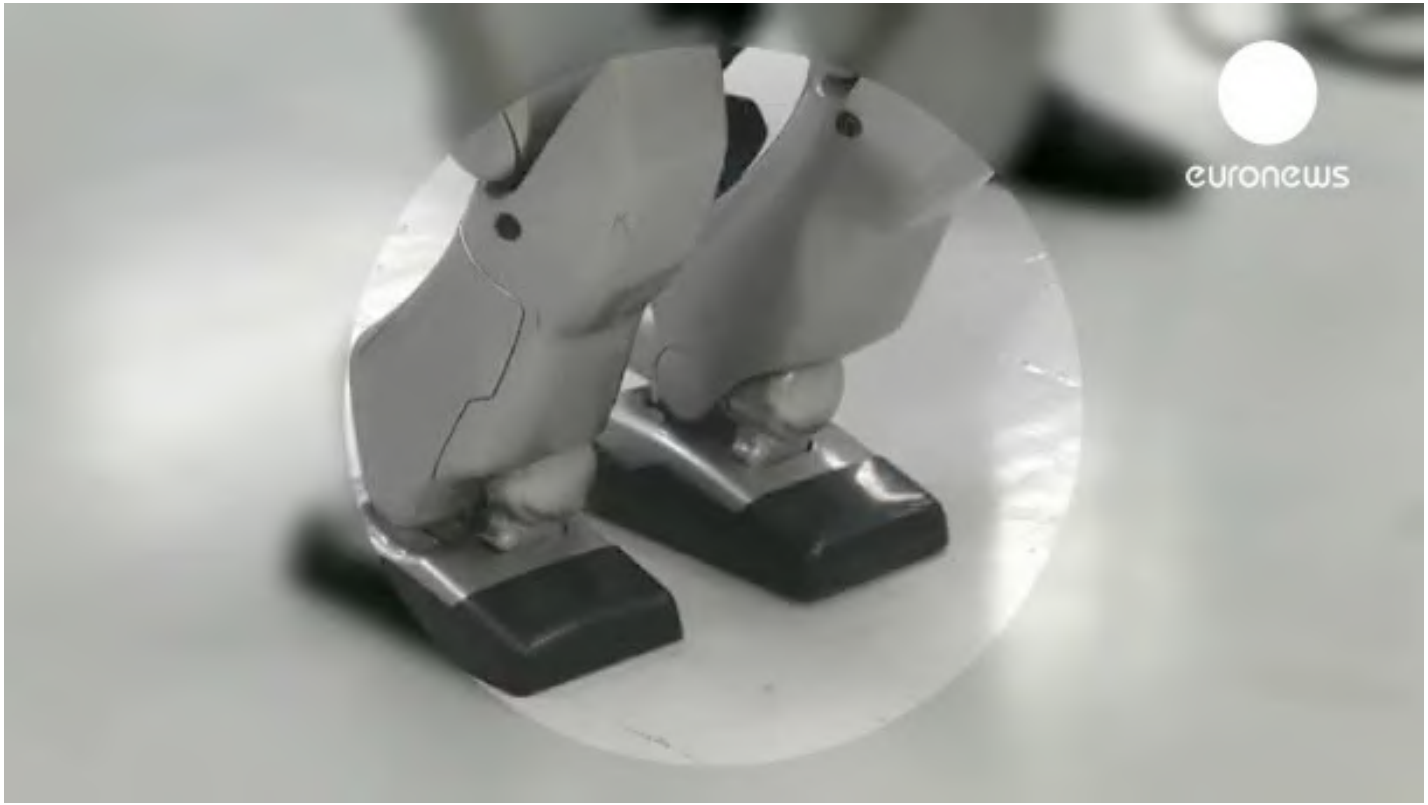
- Interpreting data for specific application purposes
  - Understanding the brain
  - Medical treatments e.g. awake brain surgery
  - Design of intuitive computer / machine interface
  - and… access brain data (police investigations, espionnage…)



Thought-based control

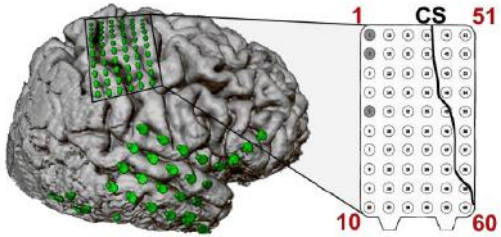
- It's more of a laboratory "product" than reality
- Neurofeedback is very limited
- Limited patterns of brain signal activities
- Current trends (successful)
  - Trajectory-based control
- What alternative?
  - Guess the intentions from brain activities and physiological signals related to task affordance (object affordance)
- Mind-controlled robot
  - Several benefits if latencies can be reduced and brain patterns better identified

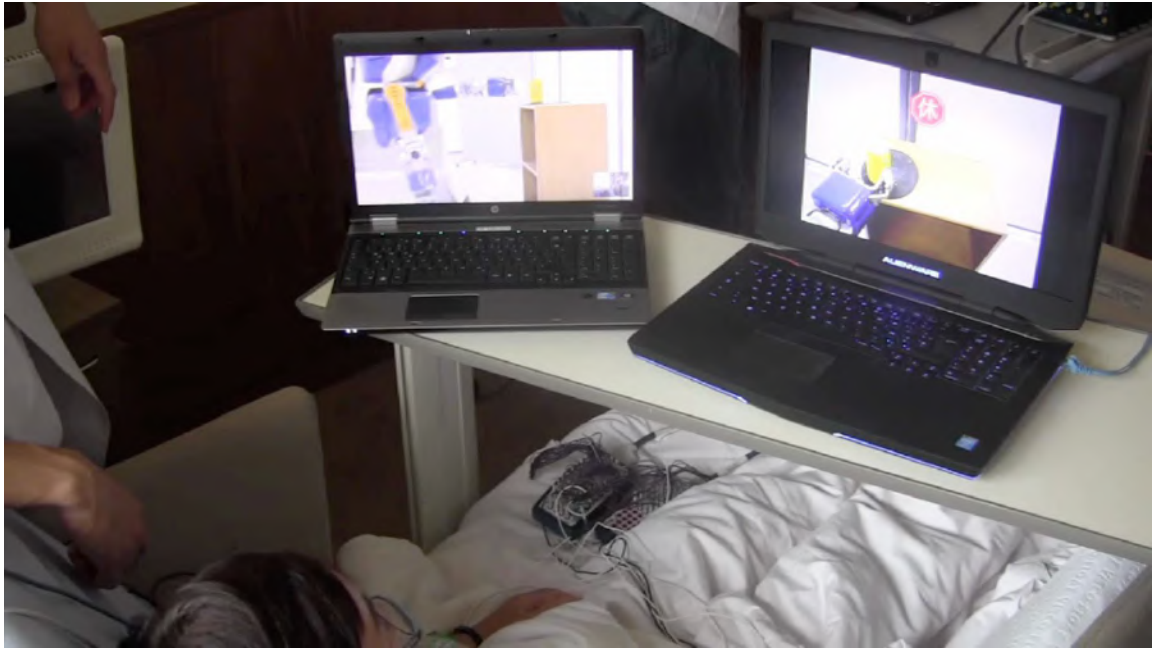
Humanoids@EEG BCI control



Gergondet, Kheddar, IEEE 2013

Humanoids@ECoG control

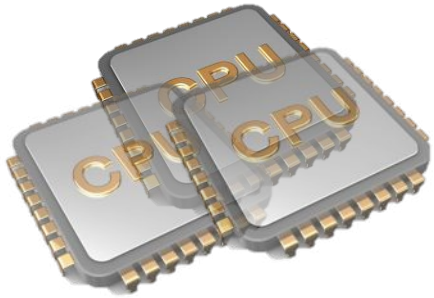




Kapeller *et al*., IEEE EMBC 2015, SNF 2015, NANS-NIC 2016

Transcription from biology to ICT: transhumanism

- The “brain”

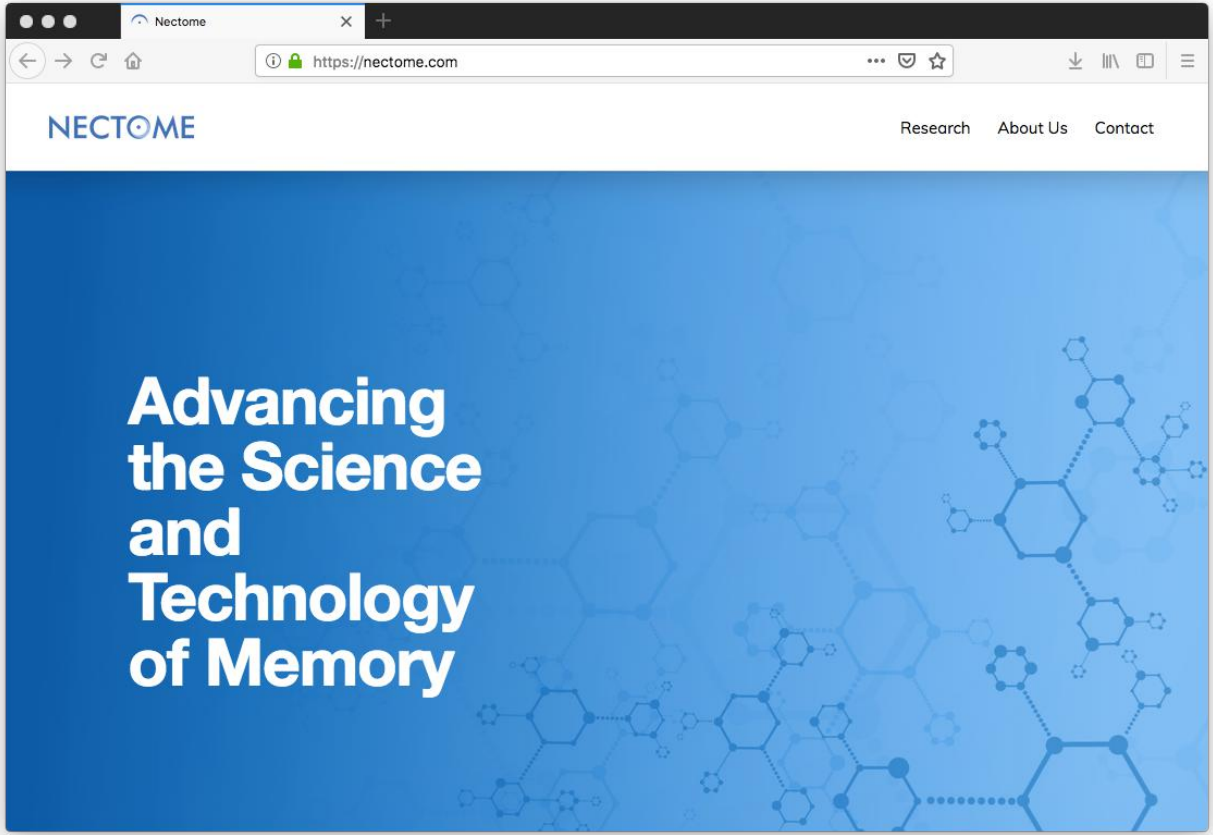


- The “body”

Gathering life experience and knowledge

- Big data
- Artificial Intelligence
- Whatever knowledge stored on various clouds (e.g. *social networks*)

Is that really possible!?



Conclusion

- Combining AI and Humanoid robotics toward a self-robotic clone?
  - Very long term challenge
  - Several technological barriers to overcome

- What for?
  - The sake of knowledge
  - Could provide insight to a better understanding
    - what intelligence is/means
    - what consciousness is/means
    - what being a human is/means
    - the limitations and barriers between living and engineered systems
    - etc.
- When bionics meets humanoids…