CREB Centre de Recerca en Enginyeria Biomèdica
UNIVERSITAT POLITÈCNICA DE CATALUNYA

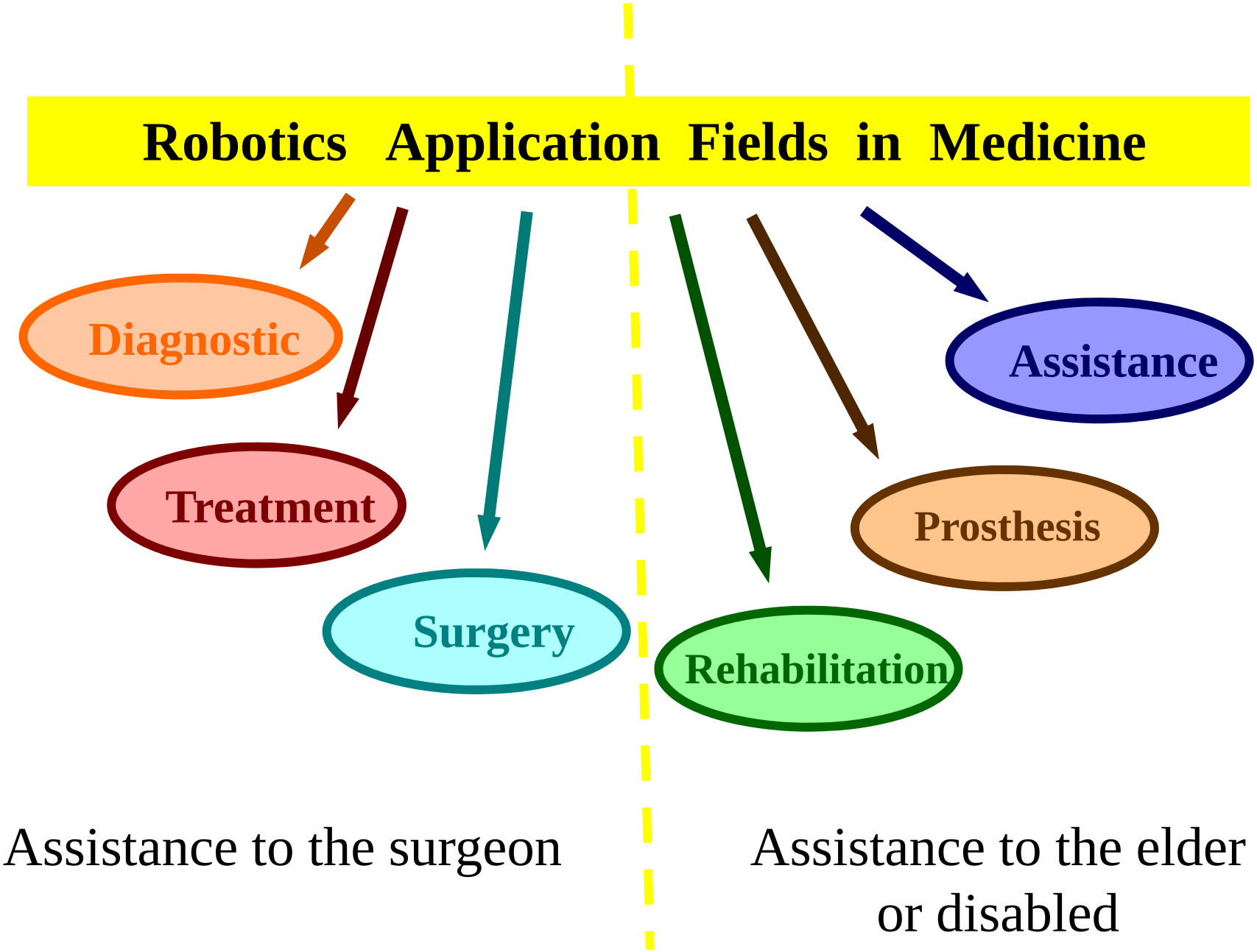
Course: Medical Robotics

PART I: Assistance and Rehabilitation

Alícia Casals

Master in Medical Image and Applications (MAIA)

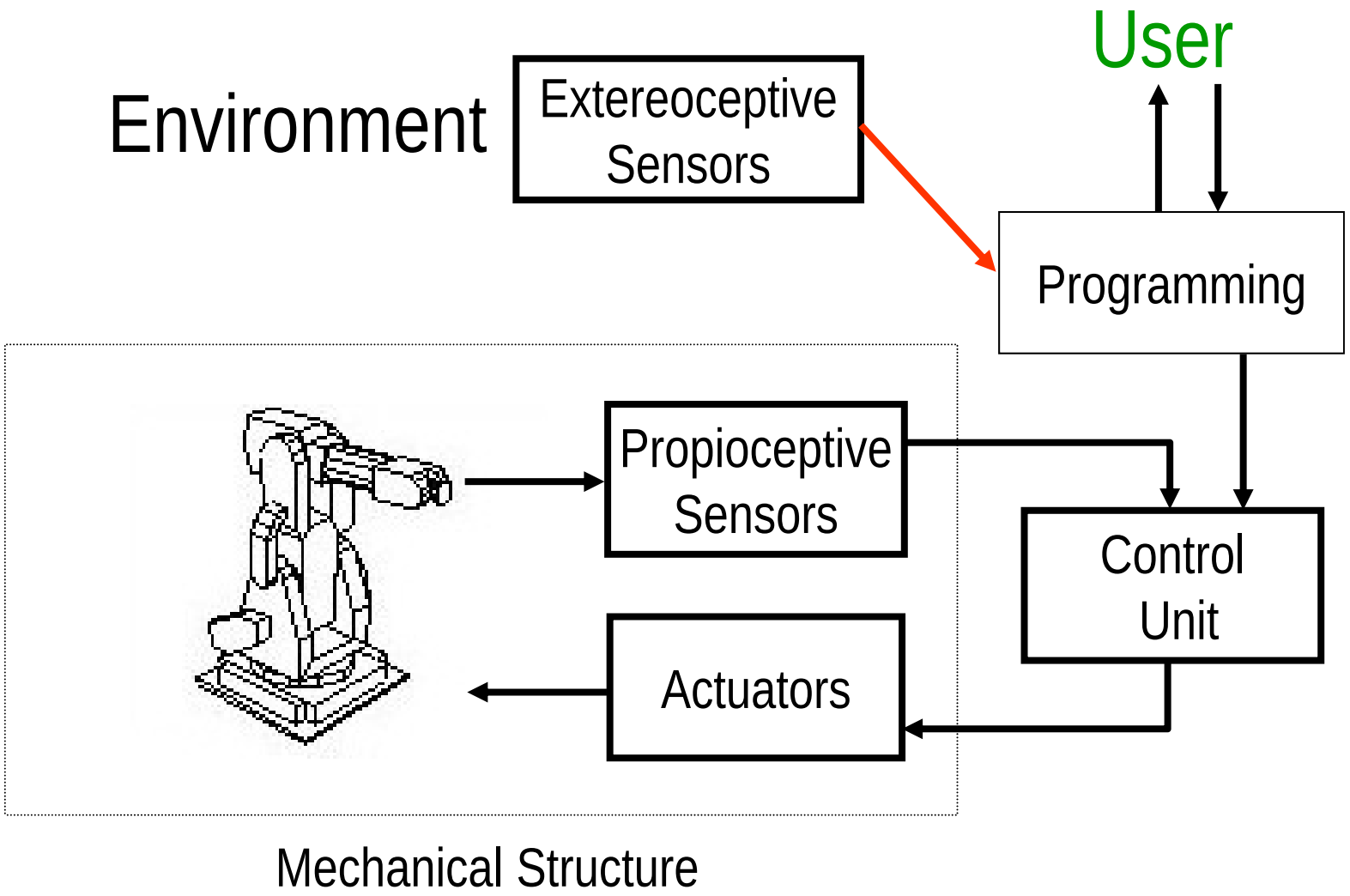
MAIA

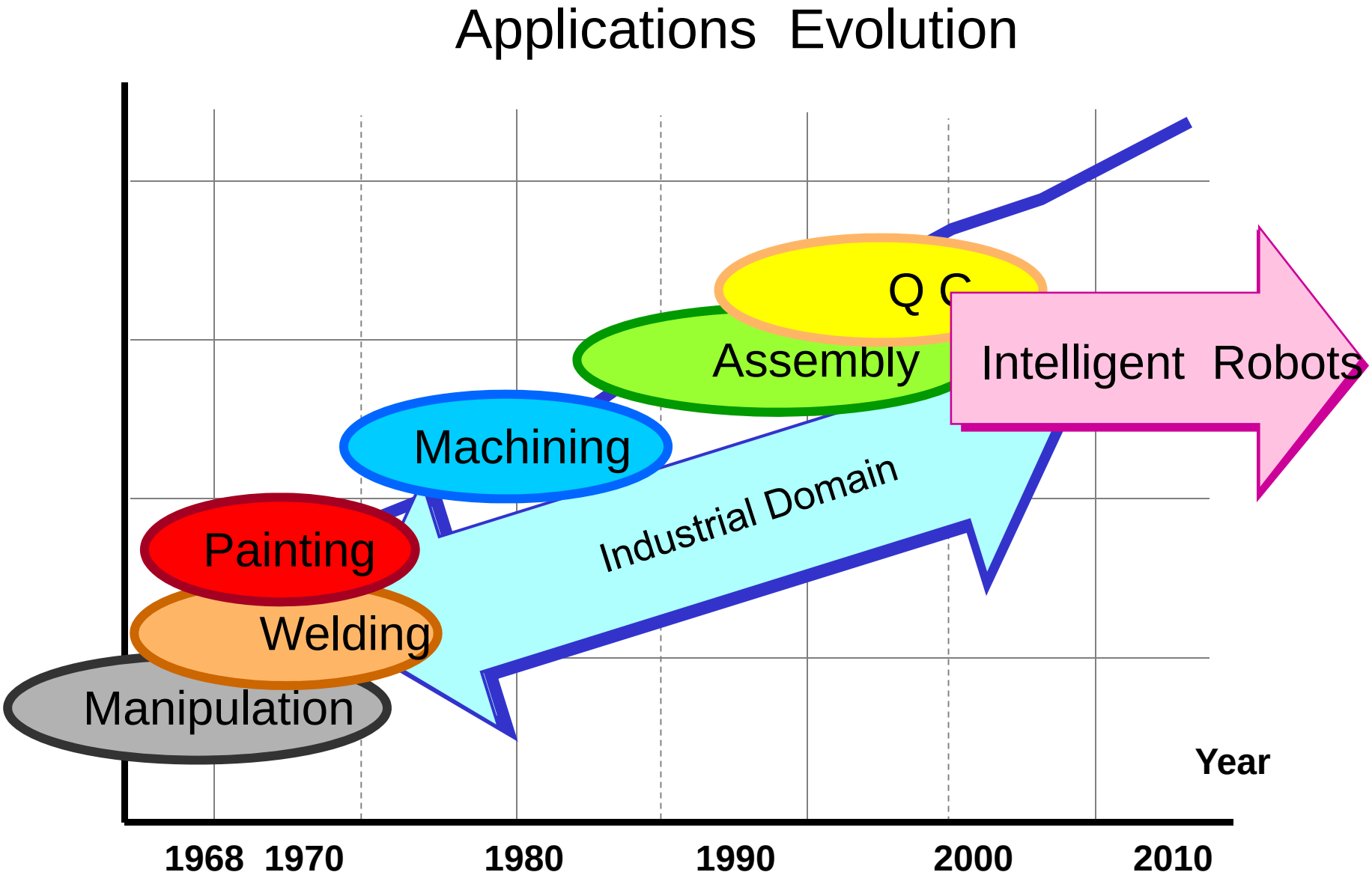

Robotics Application Fields in Medicine
Diagnostic
Treatment
Surgery
Rehabilitation
Prosthesis
Assistance
Assistance to the surgeon
Assistance to the elder or disabled

Contents

- Introduction
- Assistive Robotics
- Rehabilitation Robotics
- Surgical Robotics (Part II)

Elements of a Robot




Applications Evolution
Q C
Assembly
Intelligent Robots
Machining
Industrial Domain
Painting
Welding
Manipulation
Year
1968
1970
1980
1990
2000
2010

INDUSTRIAL ROBOTS
VERSUS
SERVICE AND MEDICAL ROBOTS

Structured, predefined
- known environment

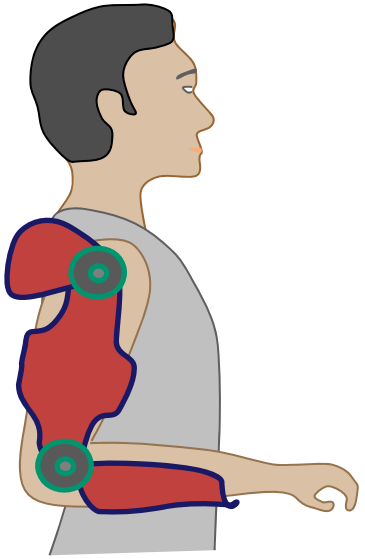
"Natural" environment
- unknown environment
- human safety
- humans in the loop
- mobile base
- specific architectures

INDUSTRIAL ROBOTS
VERSUS
SERVICE AND MEDICAL ROBOTS

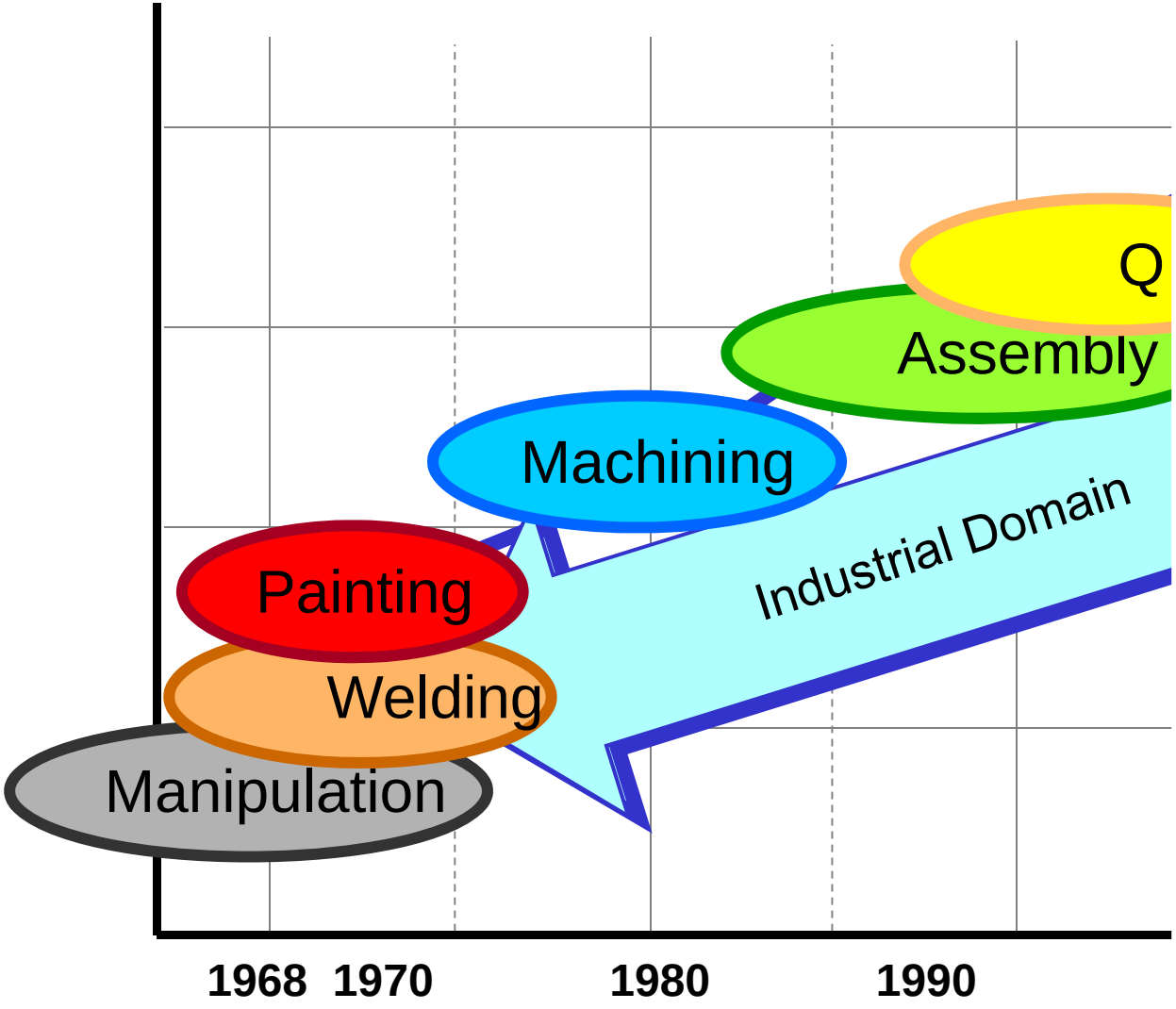
Structured, predefined

- known environment

"Natural" environment



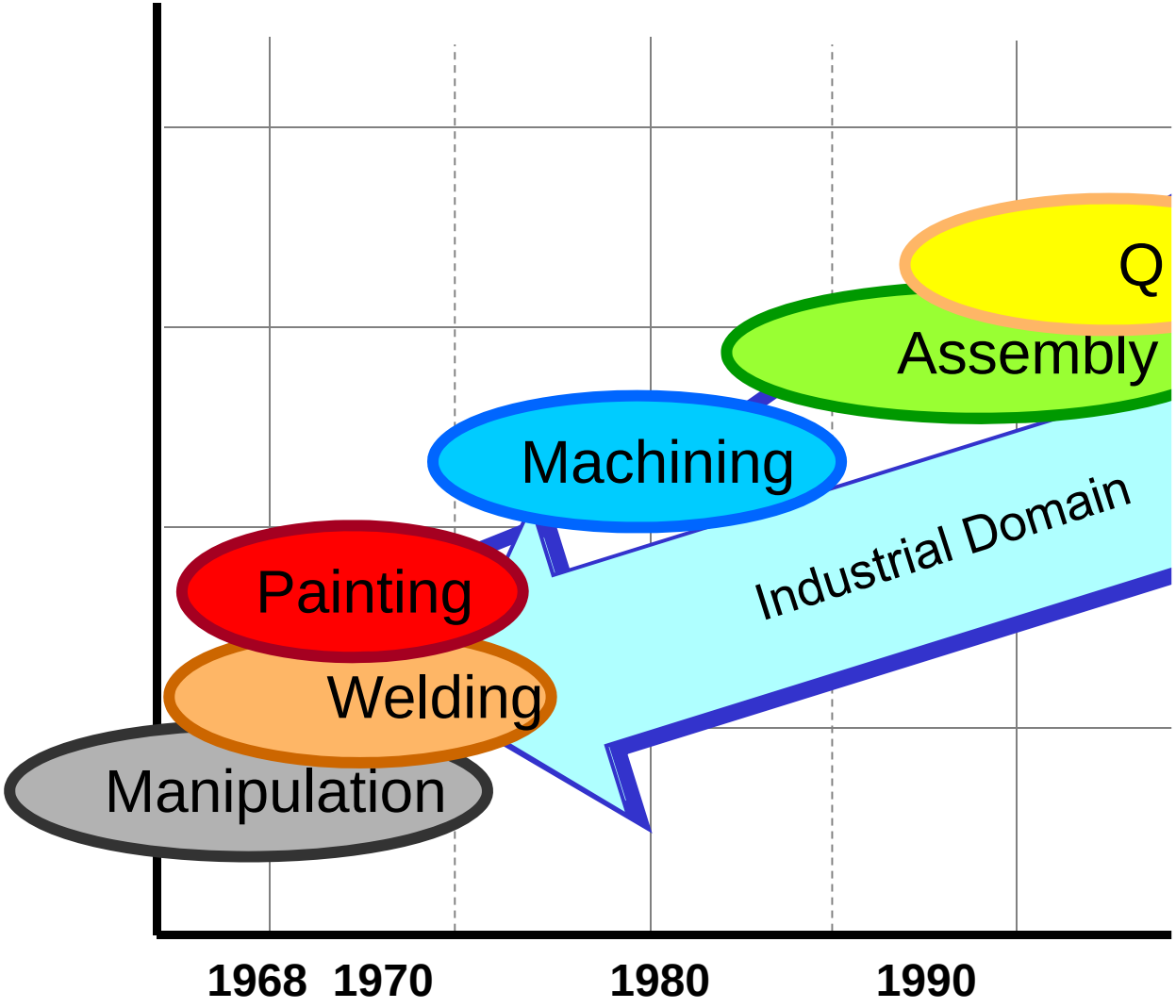
Applications Evolution



- Autonomous

- Interacting with humans (cooperation)

Applications Evolution



Cognitive sciences

Psychology

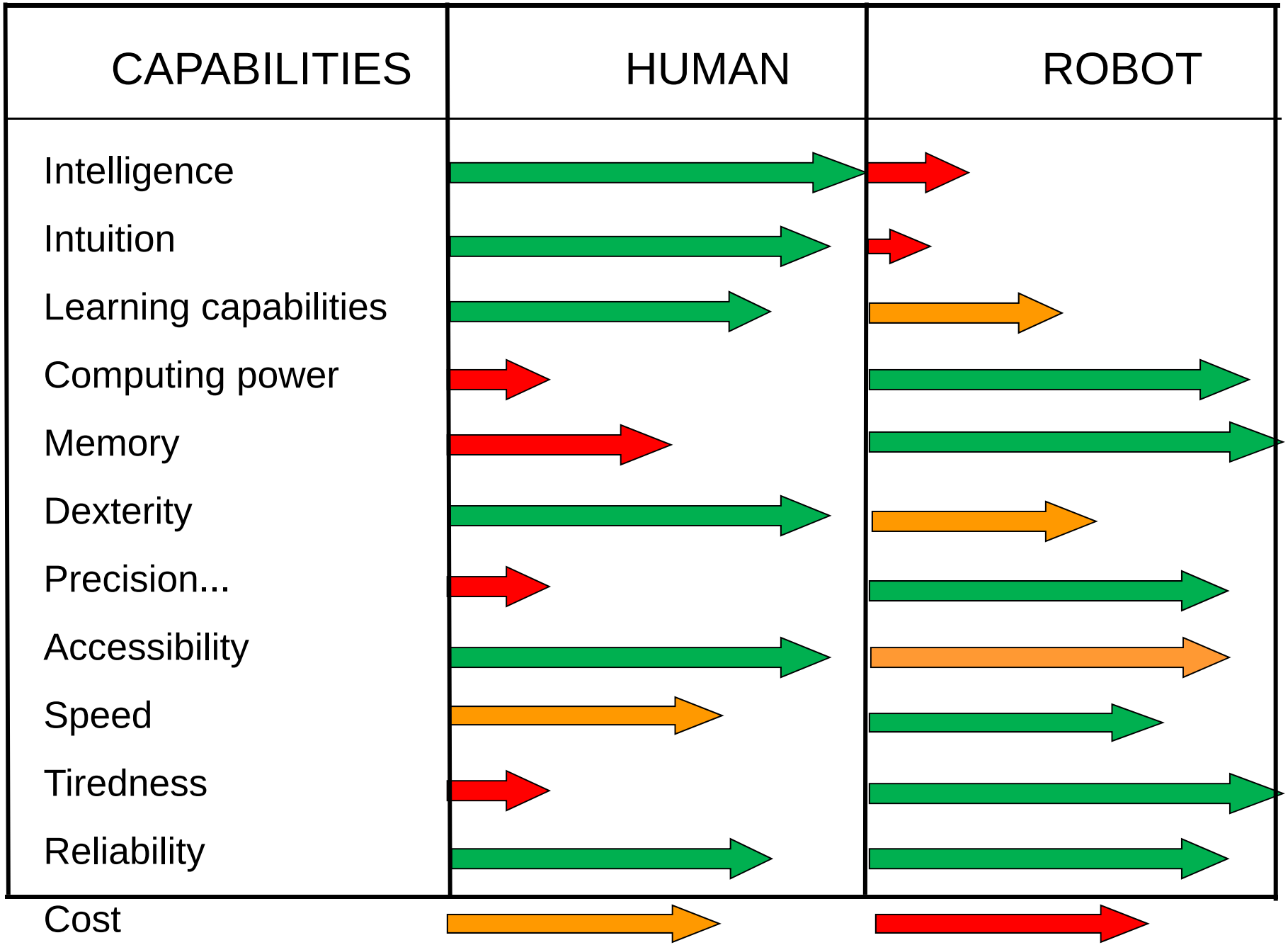
Neuroscience

Ergonomics

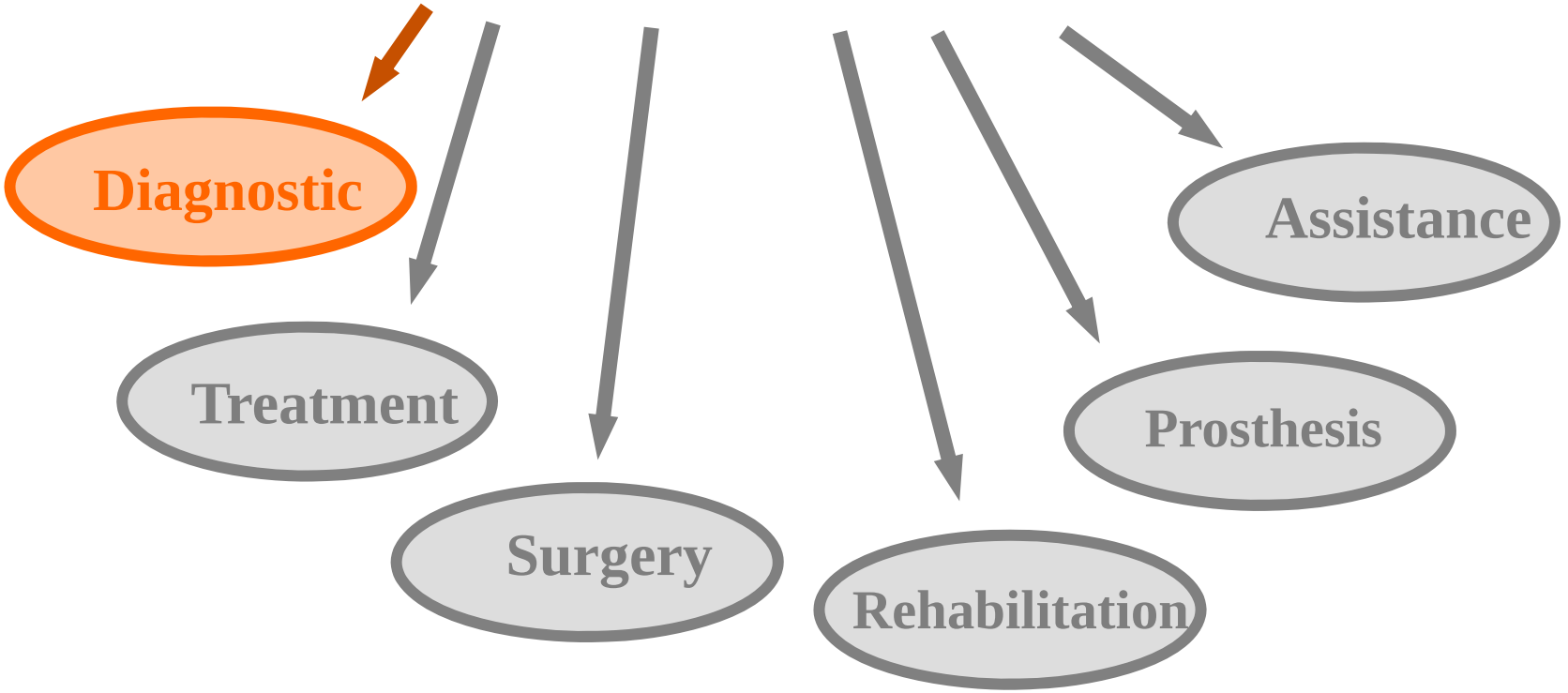
Sociology

Ethics

. . .


CAPABILITIES
HUMAN
ROBOT
Intelligence
Intuition
Learning capabilities
Computing power
Memory
Dexterity
Precision...
Accessibility
Speed
Tiredness
Reliability
Cost

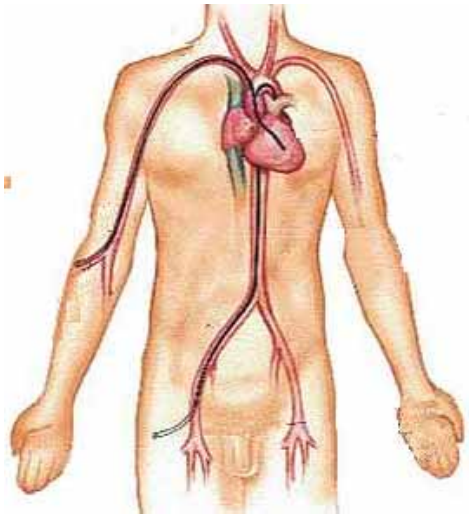
Robotics Application Fields in Medicine



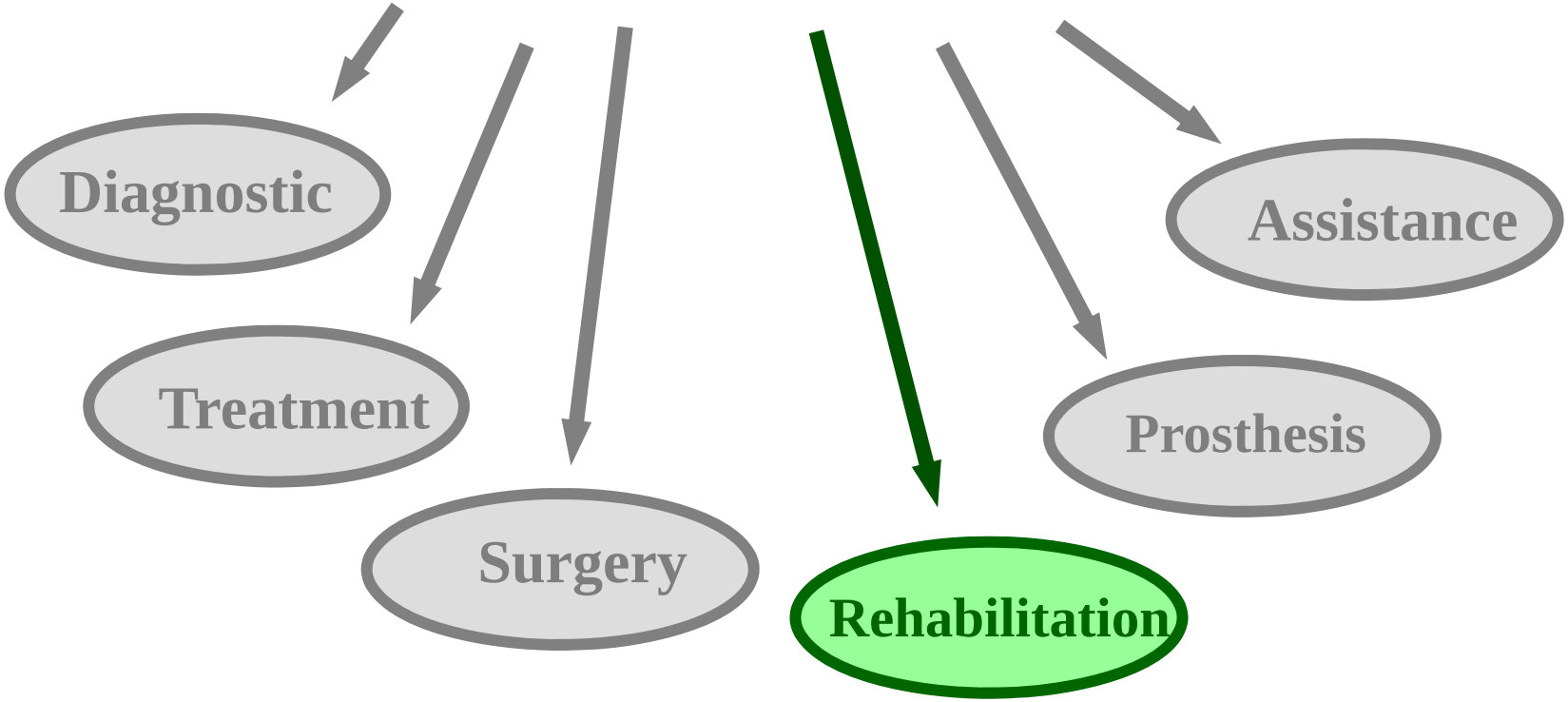
Internal observation:

Medical Imaging and

Microrobots and microsystems



Robotics Application Fields in Surgery



Motor Disorders

Effects of motor disorders

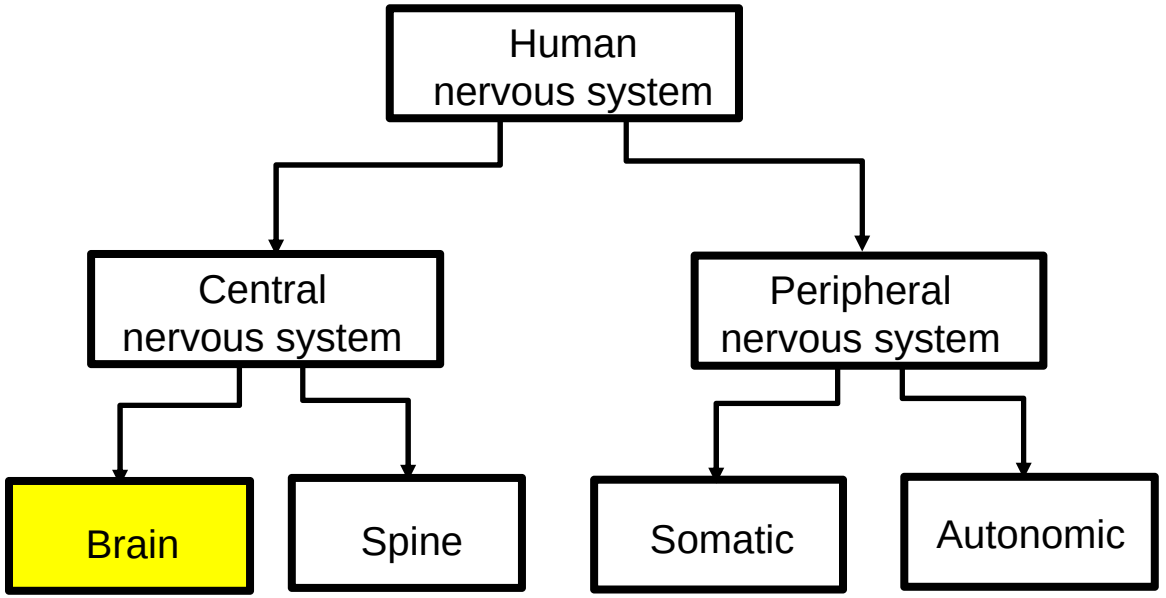
- Poor muscle control
- Pain or weakness
- Difficulty in reaching objects
- Difficulty in doing complex manipulation
- Mobility control and performance

Motor Disorders

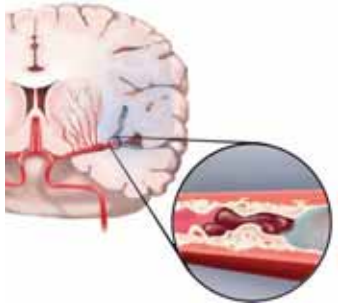
Causes of Impairment

- Trauma, orthopedic
- Central Nervous System (CNS) / Peripheral Nervous System (PNS)
- Muscular
- Diseases

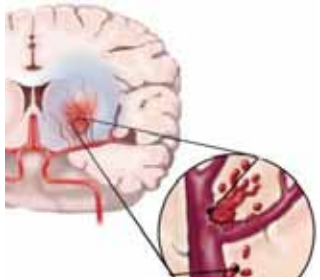
May also cause cognitive impairments



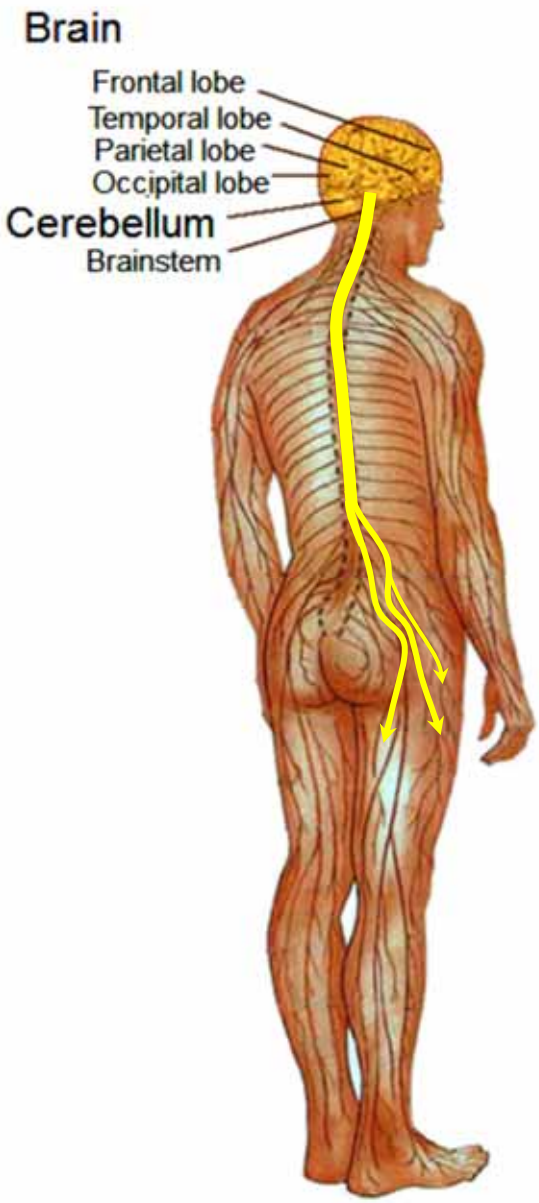
CVA (Cerebral Vascular Accident) / Stroke

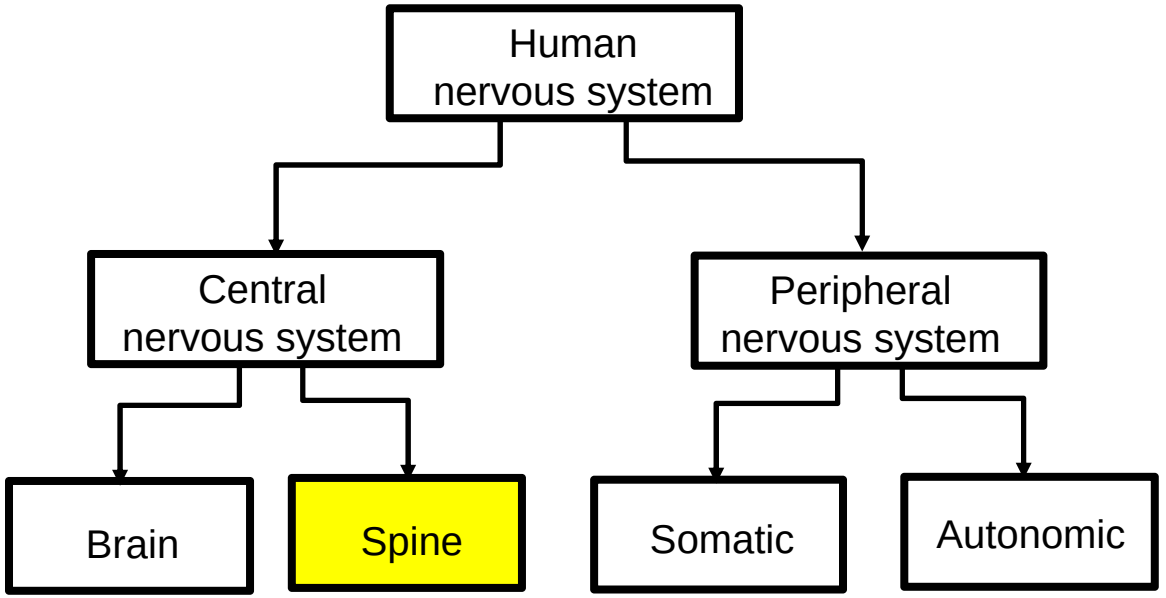


ischemia



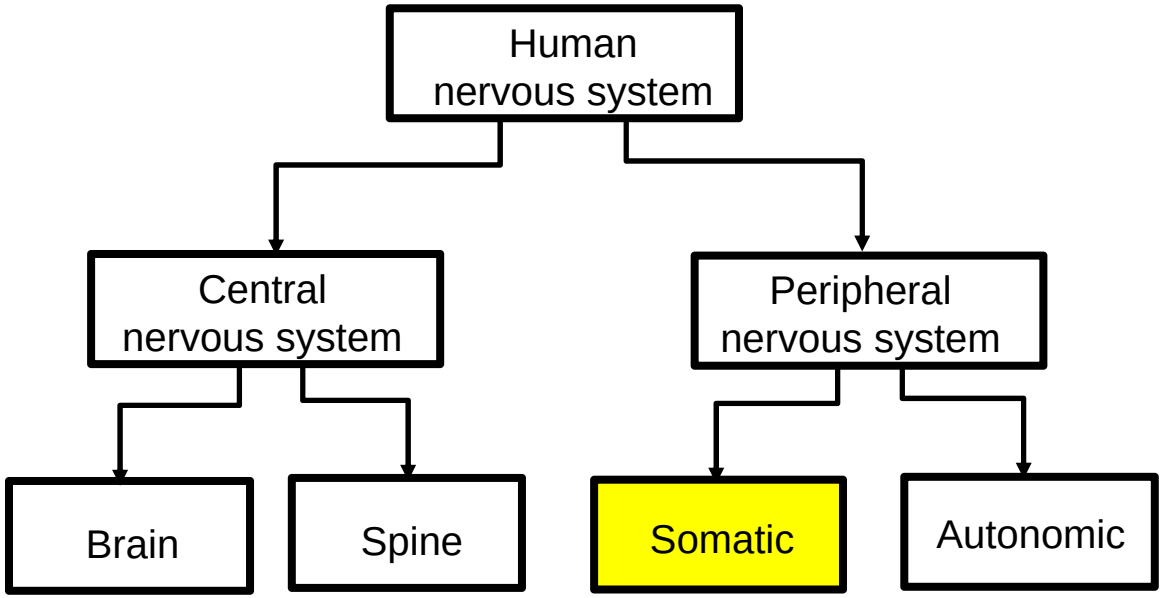
hemorrhagic





SCI

Spinal Cord Injury

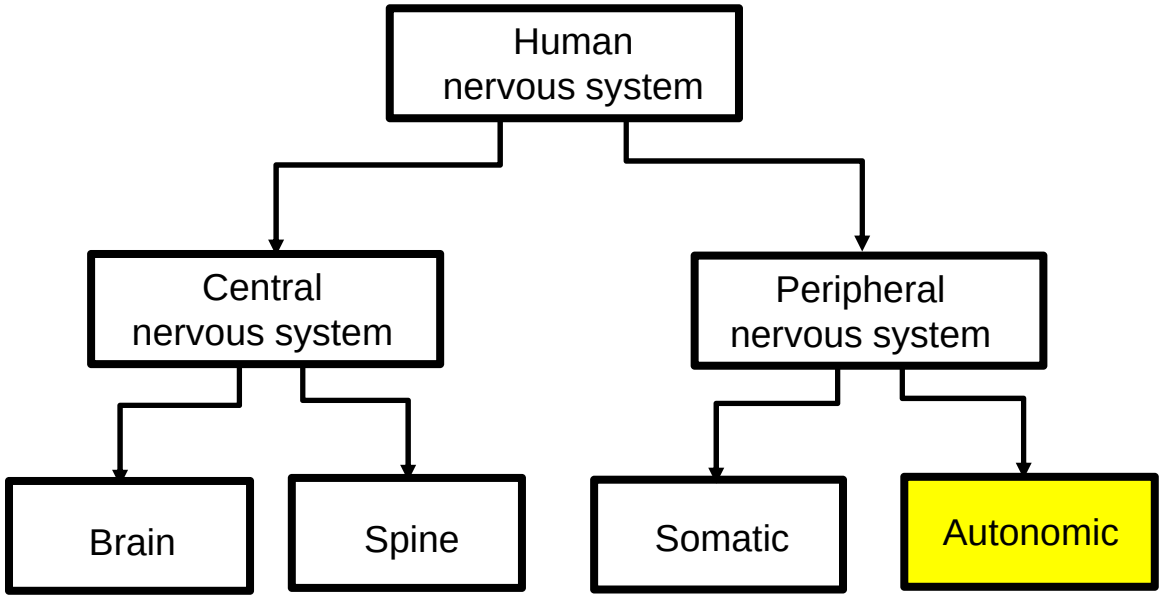


CVA / Stroke

SCI

Voluntary movements and reflex actions, perception

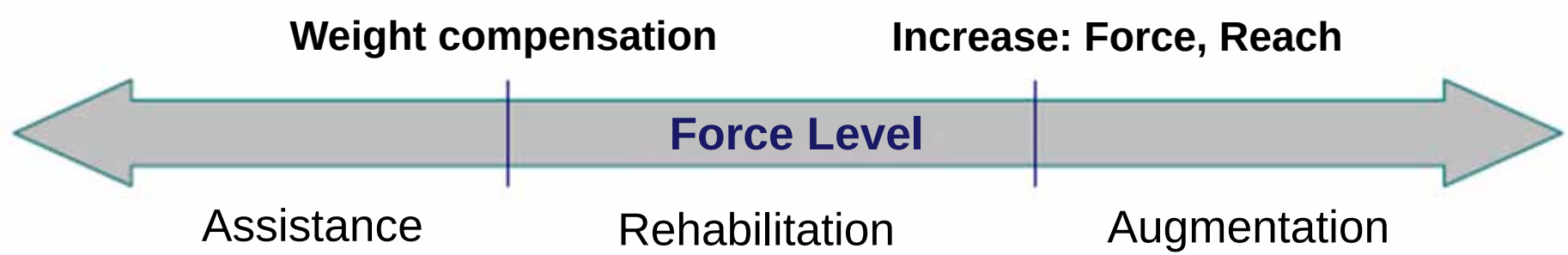
Afferent /sensory nerves
Efferent/motor nerves



Involuntary movements and functions

Robotic Systems in rehabilitation

- Upper limbs
  - Hand support
  - Exoskeleton
- Lower limbs
  - Hand support
  - Exoskeleton
  - Treadmill



Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

Active impedance

Objectives.

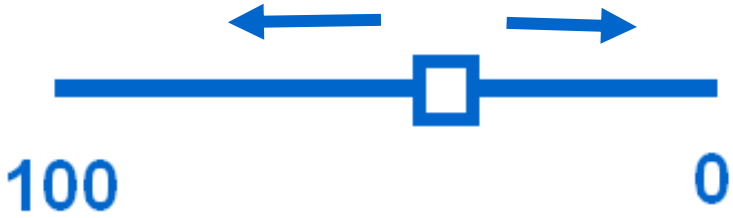
- Make exercises engaging the user (Images)
- Offer an adjustable resistance (Impedance Z)
- Amplify the human residual force (Human intention)

Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

Passive /Active

Physic/ Cognitive



Assist as needed

Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

Active impedance

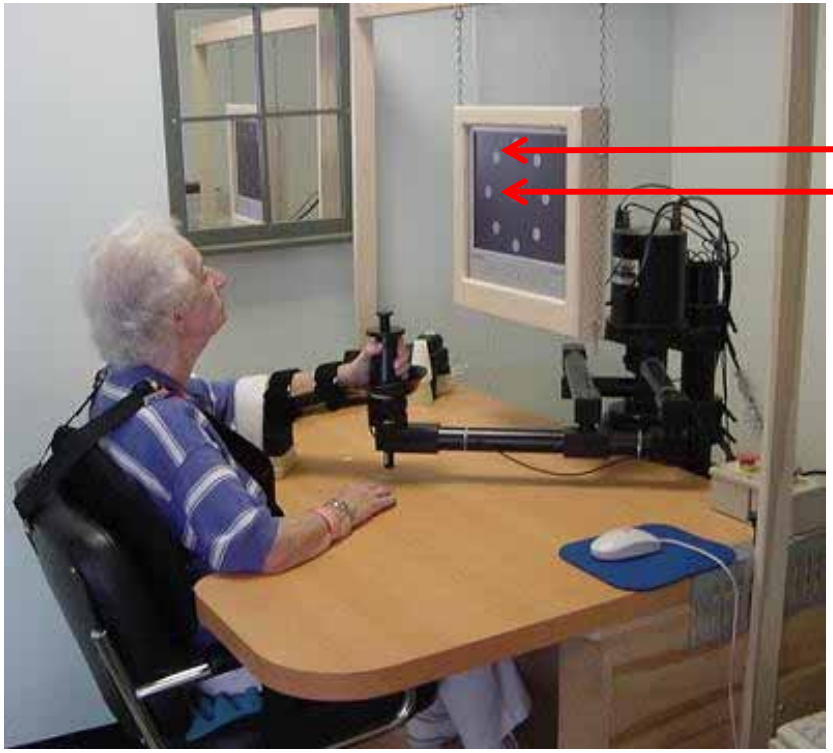
Objectives.

- Make exercises engaging the user (Images)
- Offer an adjustable resistance (Impedance Z)
- Amplify the human residual force (Human intention)

Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

System for Image generation:



Start exercise:

a) N = 0

b) Select a random destination

c) Visualize the movement to be executed

d) Evaluate the action (time)

e) If N = K End exercise

f) N = N + 1

Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

Active impedance

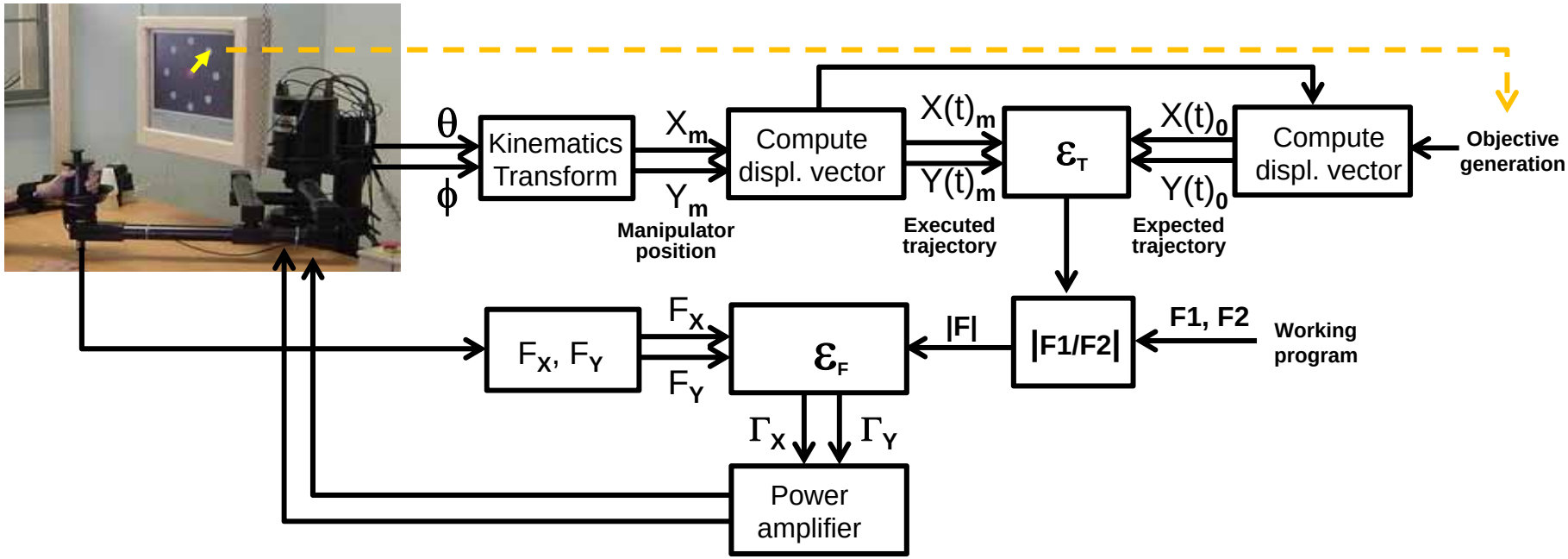
Objectives.

- Make exercises engaging the user (Images)
- Offer an adjustable resistance (Impedance Z)
- Amplify the human residual force (Human intention)

Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

Offer an adjustable resistance (Impedance Z)



Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

Active impedance

Objectives.

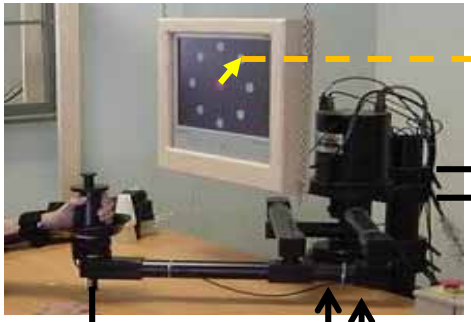
- Make exercises engaging the user (Images)
- Offer an adjustable resistance (Impedance Z)
- Amplify the human residual force (Human intention)

Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

- Amplify the human residual force (Human intention)

Objective: Help to execute the right trajectory with little intervention if it is correct.



Robotic Systems in rehabilitation: Upper limbs

Improve physical and cognitive capabilities

MIME: Hemiparesis after stroke

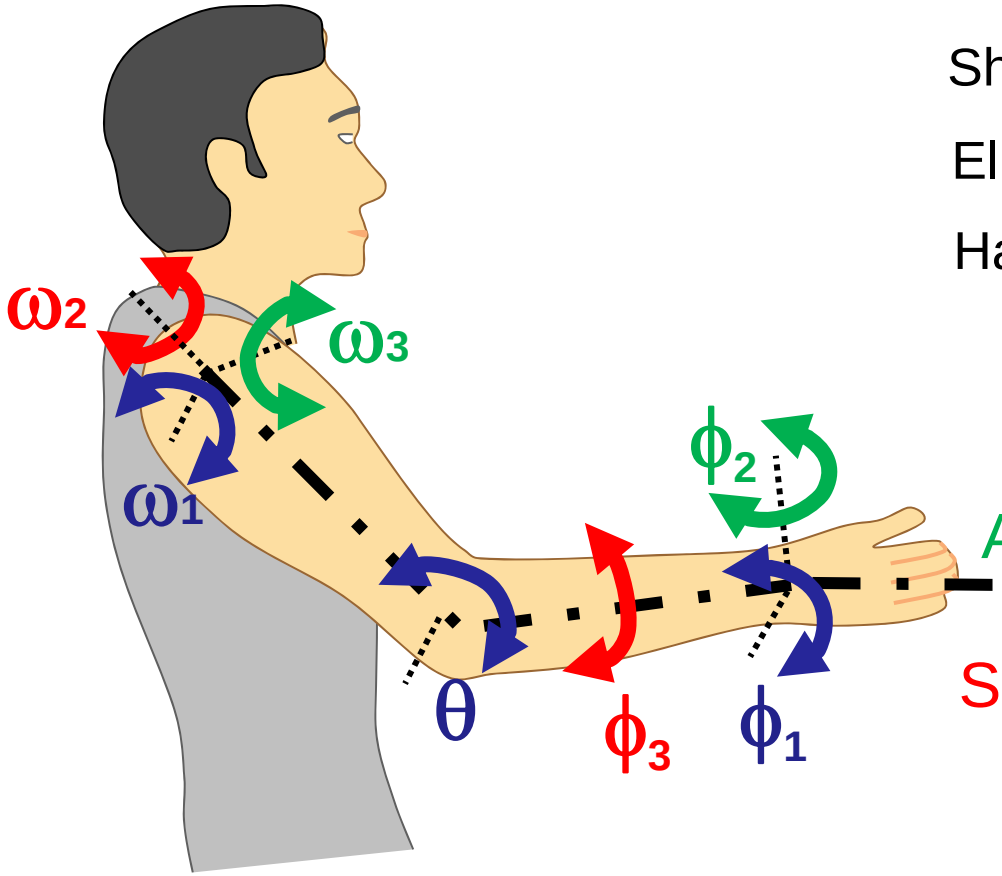
- Therapy modes: passive, active-assisted, active-constrained and bilateral.

- Diminishes spasticity
- Improves arm motor function
- Improves neglect syndrome

Robotic Systems in rehabilitation: Upper limbs

Exoskeletons →Human arm

Kinematics anatomic requirements: 5 D of F.



Shoulder: 2 +1 D of F.

Elbow: 1 D of F

Hand: 2 +1 D of F.

Flexion-Extension

Abduction-Adduction

Supination-Pronation

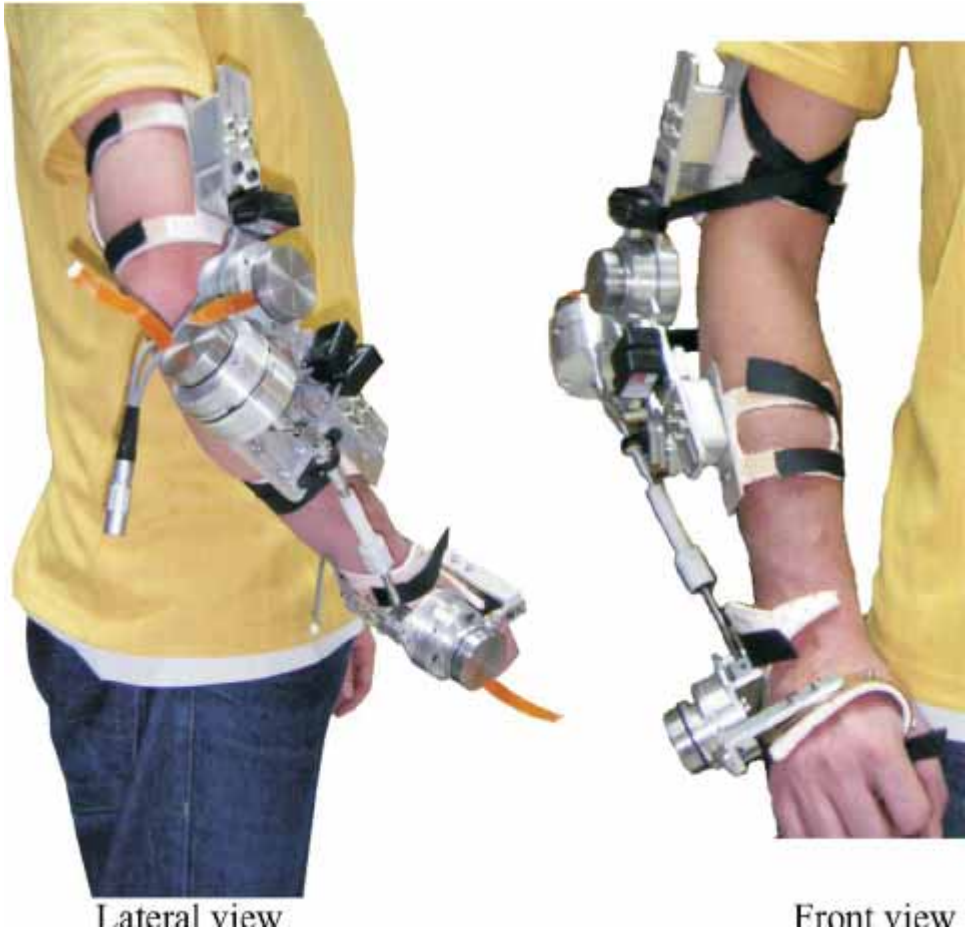
Robotic Systems in rehabilitation: Upper limbs

ARMin: Exoskeleton

- Feedback to increase motivation of the patient.
- Therapy modes are:
  - repeating movement
  - game scenarios
  - training of daily activities.

Robotic Systems in rehabilitation: Upper limbs

Need of Measuring Interaction Forces



Lateral view Front view

Wotas (wearable): Tremor compensation

Robotic Systems in rehabilitation

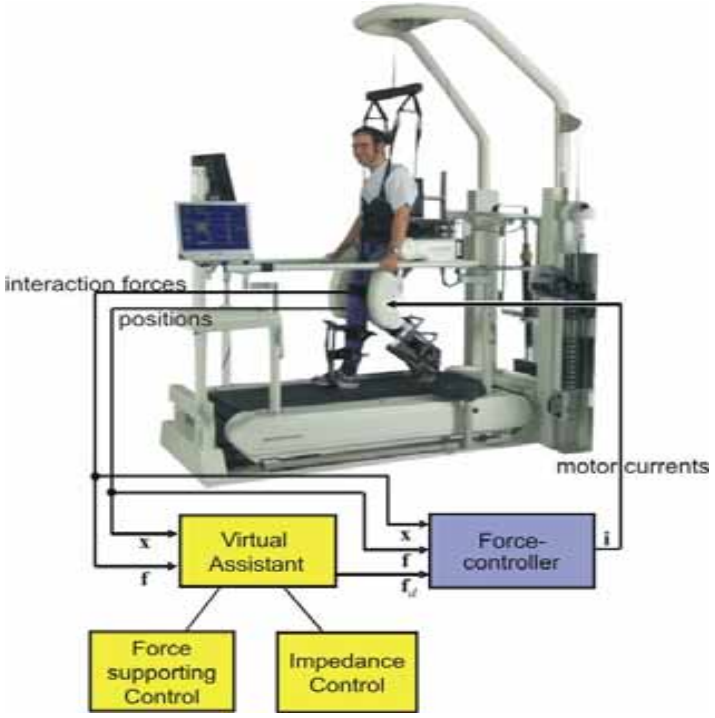
- Upper limbs
  - Hand support
  - Exoskeleton
- Lower limbs
  - Hand support
  - Exoskeleton
  - Treadmill

Robotic Systems in rehabilitation: Lower limbs

- REHABOT
- Computer control
- Postural Support
- Prescribed weight bearing
- Robotic arm plus an harness with non constrained movements

Robotic Systems in rehabilitation: Lower limbs

- LOKOMAT
- Motor Driven Exoskeleton Device
- Automated Tasks
- Position controlled trajectories that mimic normal human gait patterns
- Cooperative Control Strategies
- Gait patterns adapted to the patient
- Impedance Control
- Sensors in the motors provide an indirect indicator of the amount of effort the patient is generating

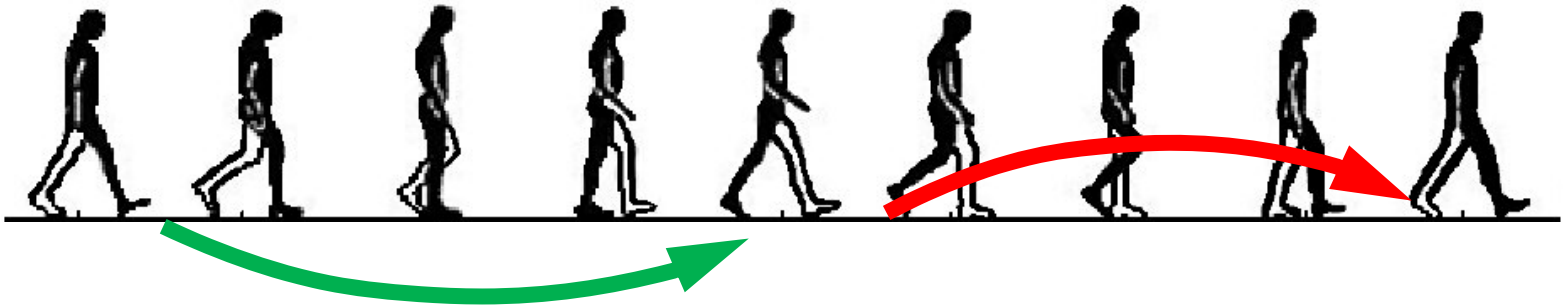


Lokomat

Exoskeleton + Treadmill + Body support

Treadmill (speed control)

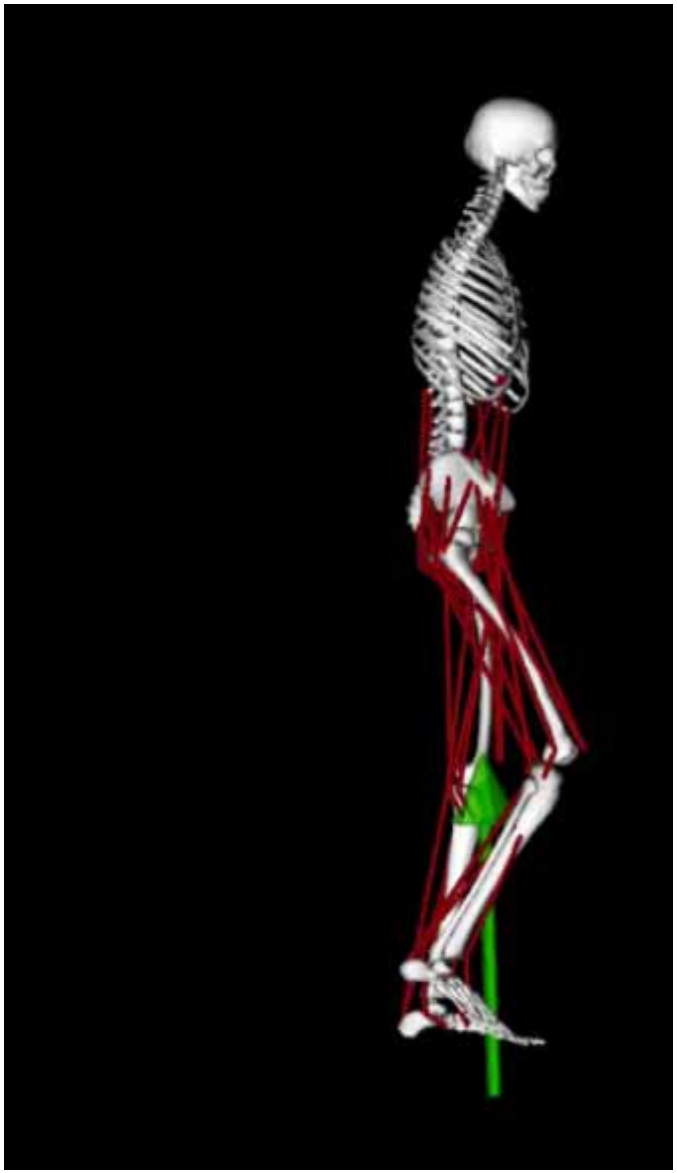
Gait patterns



Heel contact . . . . . .Toe off

No contact with the floor

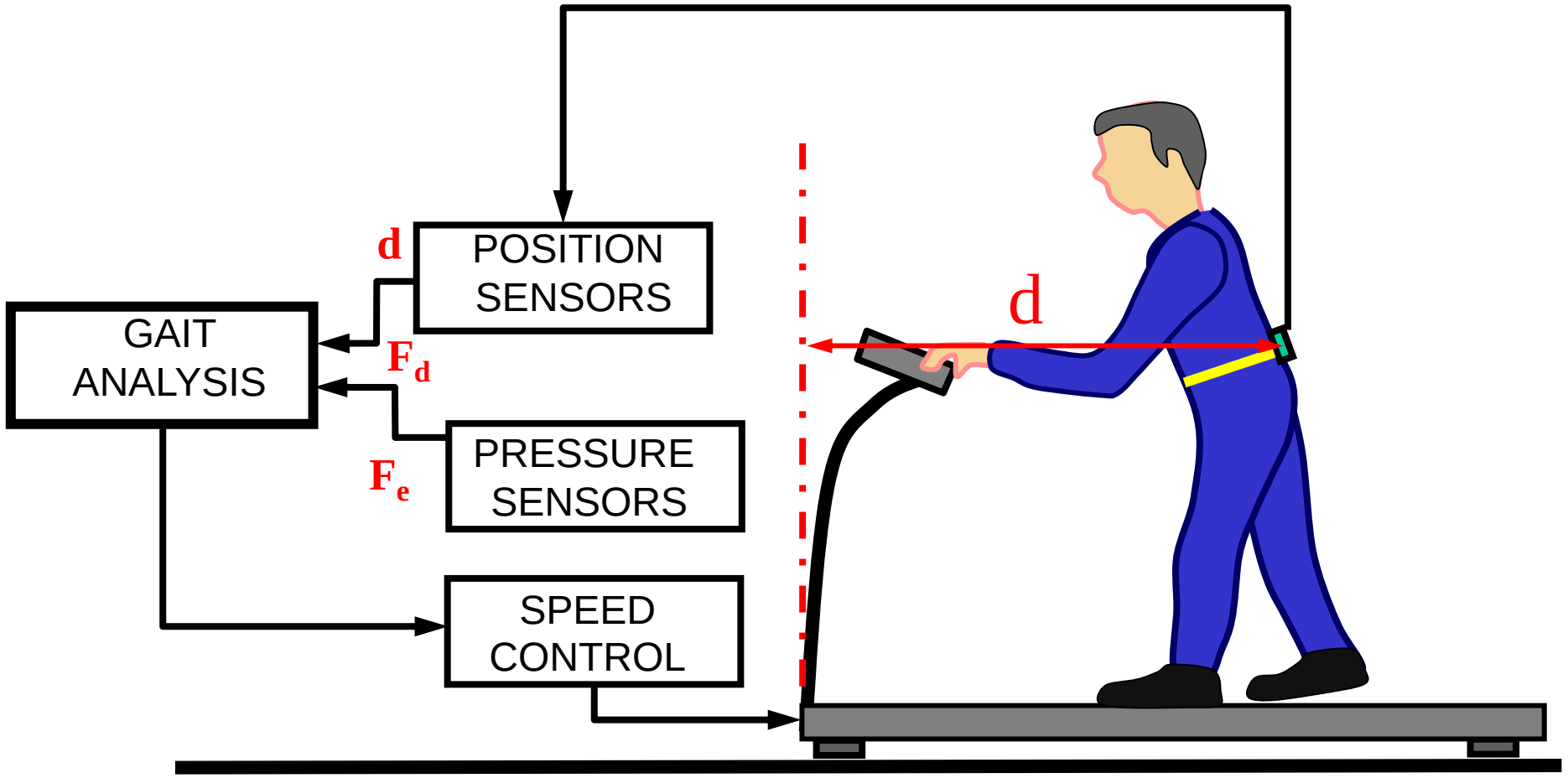
- Step length
- Stride
- Walking base
- Cadence
- . . .



OPENSIM

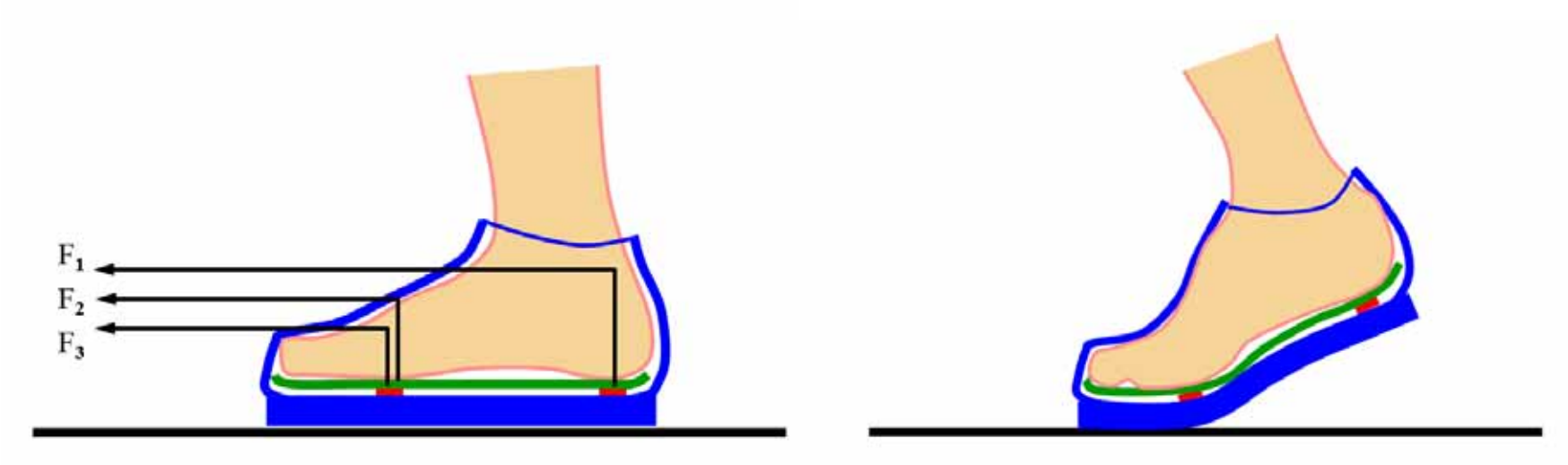
Library for analysis
of the
musculoskeletal
behavior

CONTROL OF *TREADMILL* FROM USER'S MOVEMENTS



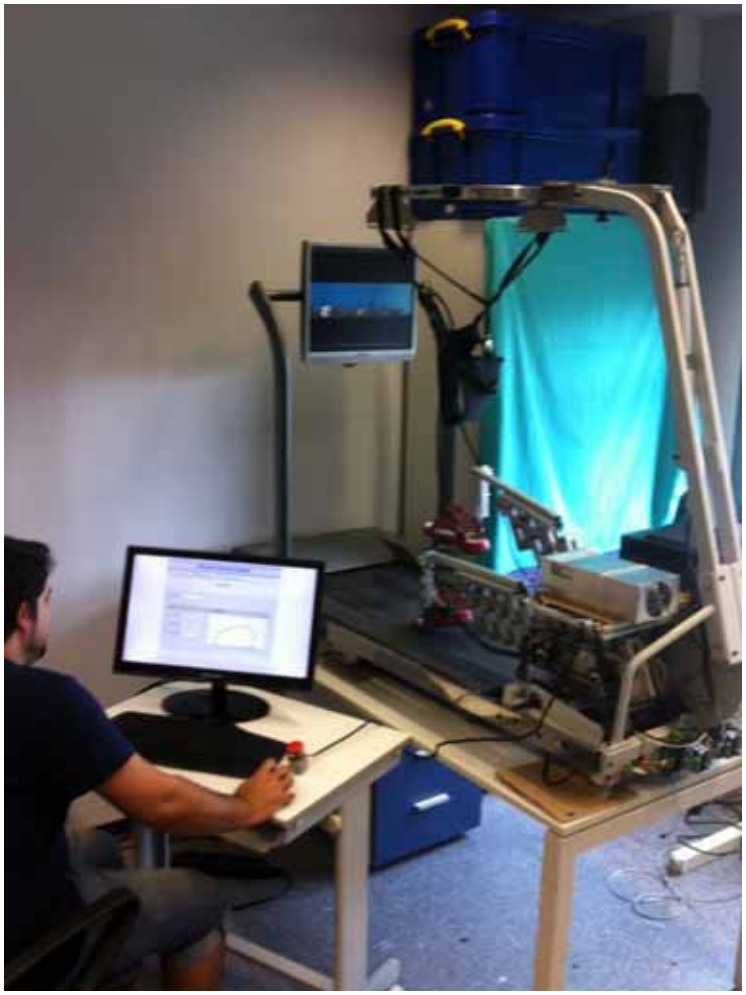
CONTROL OF *TREADMILL* FROM USER'S MOVEMENTS

Pressure sensors (soil)



Robotic Systems in rehabilitation: Lower limbs

CAMPE

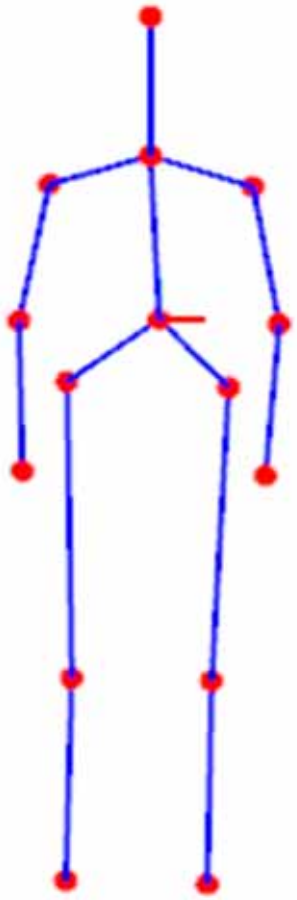


Programming the gait

Robotic Systems in rehabilitation: Lower limbs

Body posture detection

Optical markers/ 3D cameras



Body posture detection

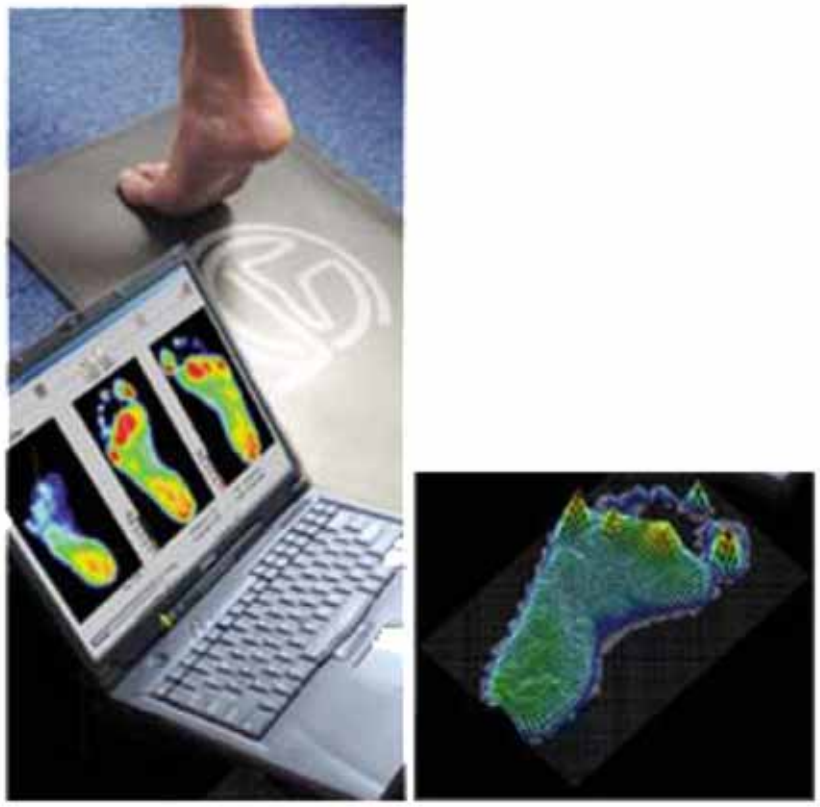
Electrogoniometers

Optical markers

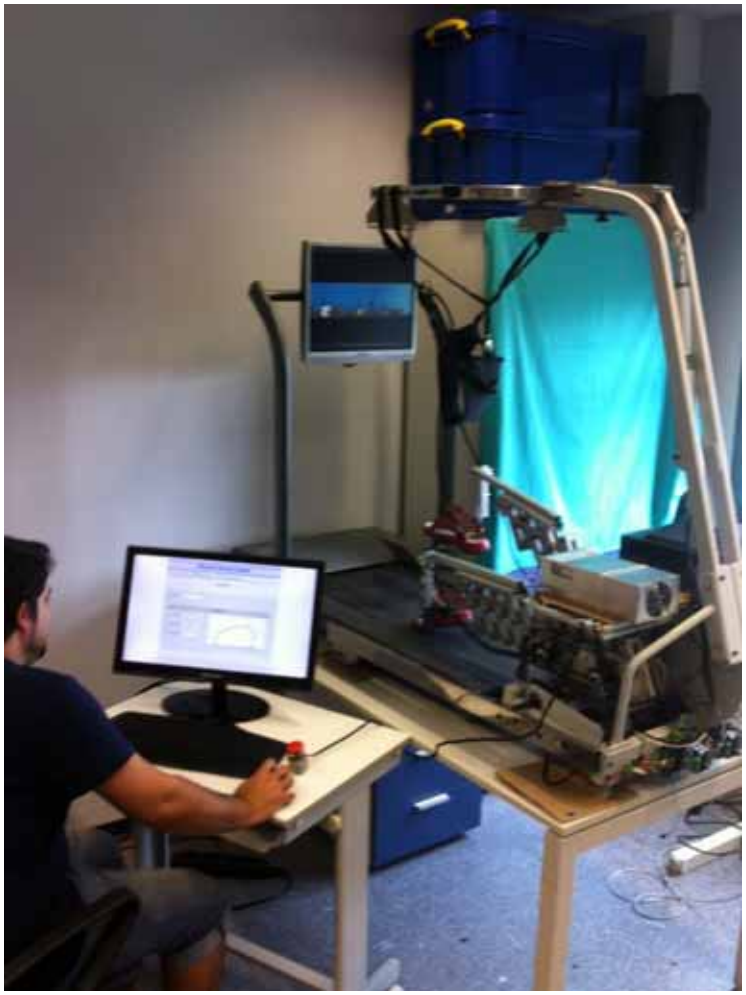
Accelerometers

EMG

Tactile



CAMPE

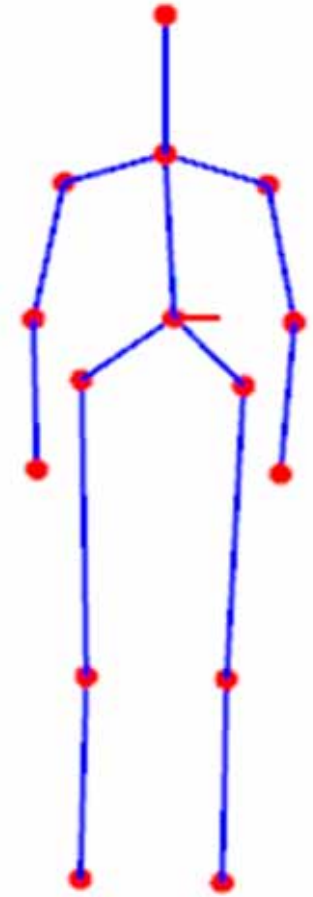


Programming the gait

Robotic Systems in rehabilitation: Lower limbs

Body posture detection

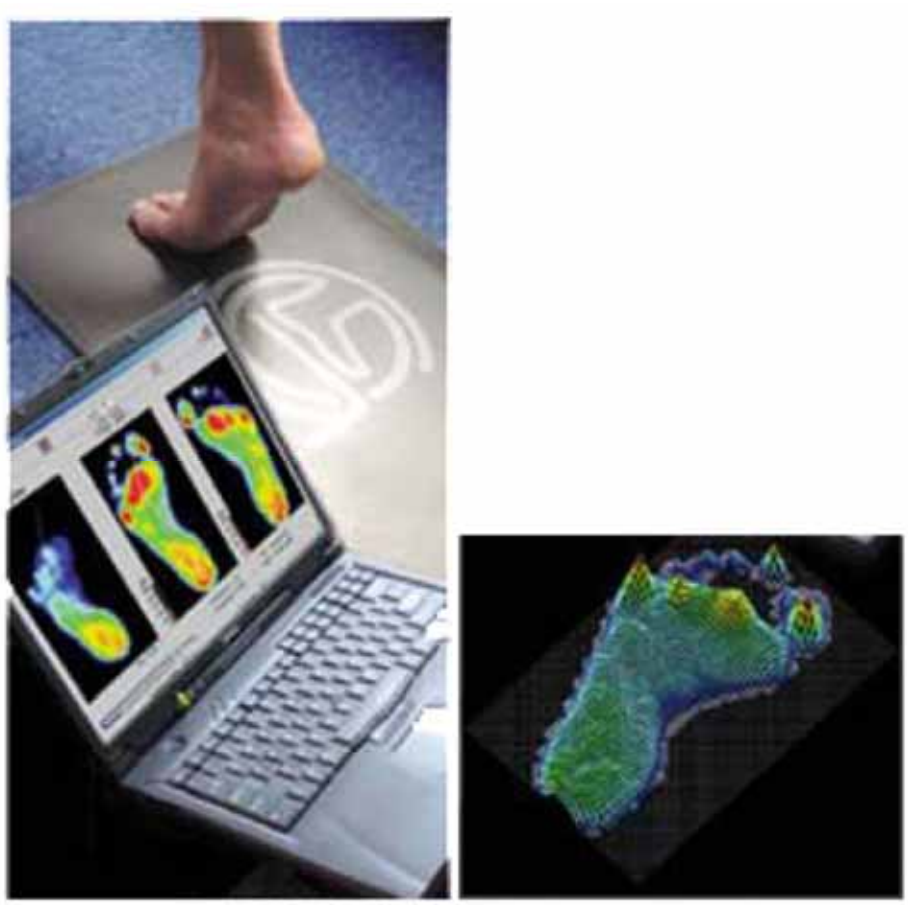
Optical markers/ 3D cameras



Robotic Systems in rehabilitation: Lower limbs

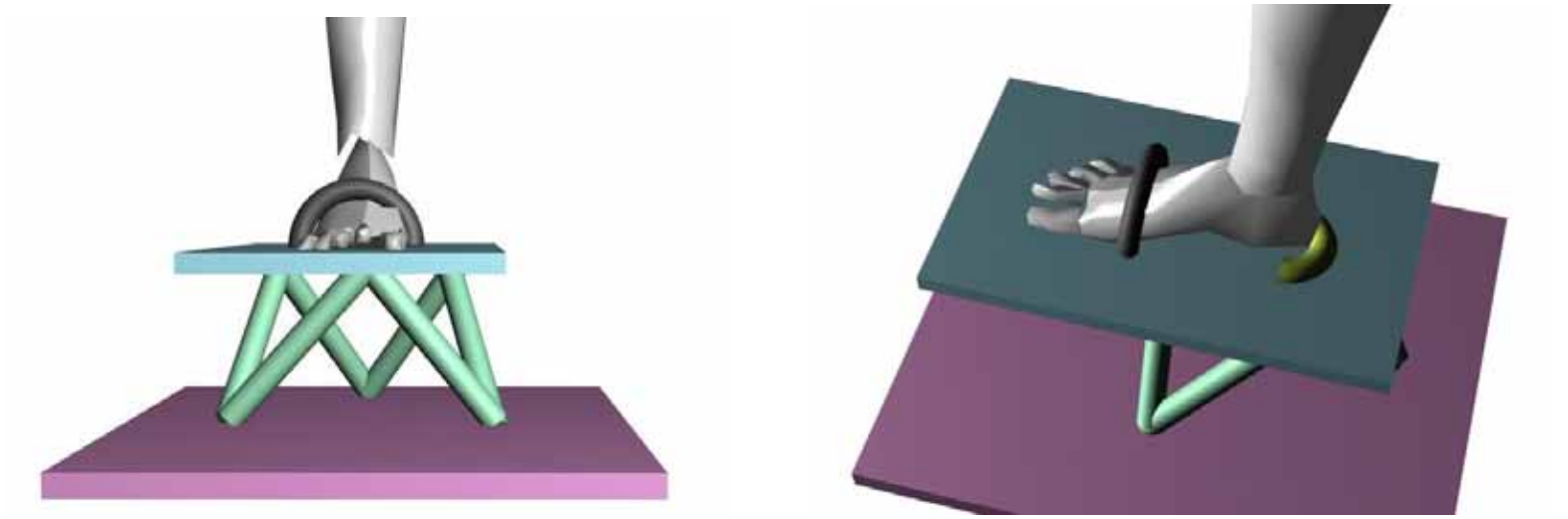
Body posture detection

Tactile



Robotic Systems in rehabilitation: Lower limbs

Post trauma



Gait simulation

On a Robotics platform

Rutgers University 2004

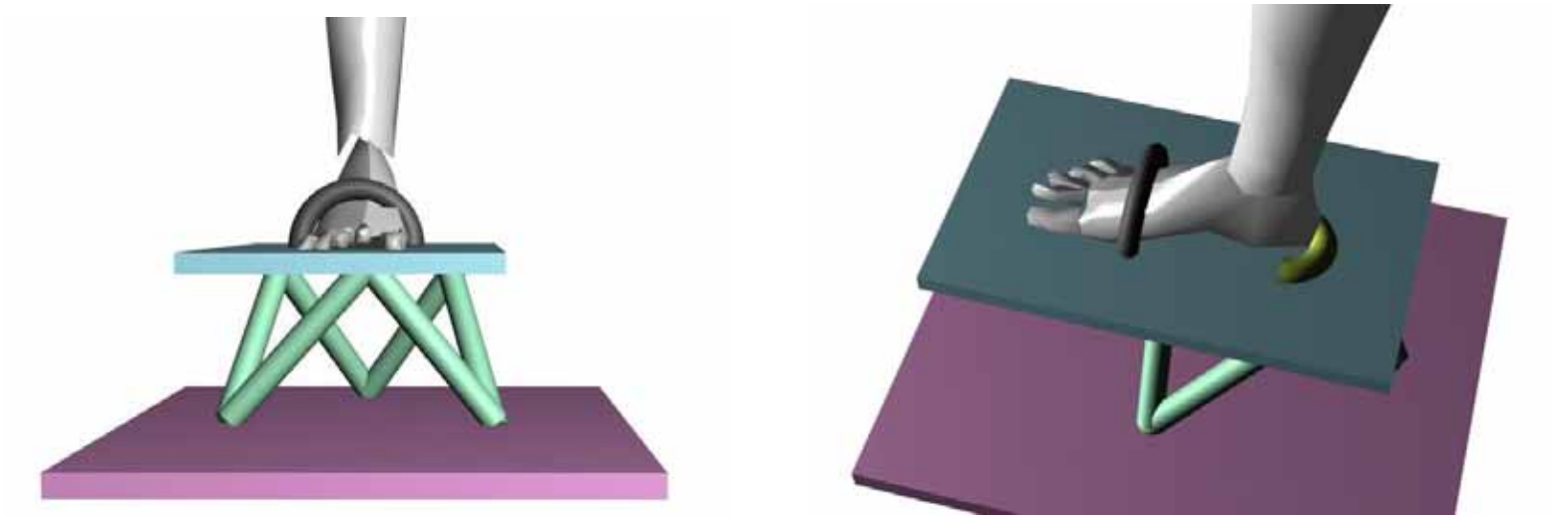
Robotic Systems in rehabilitation: Lower limbs

Robotic ankle

Gait simulation

Robotic Systems in rehabilitation: Lower limbs

Post trauma

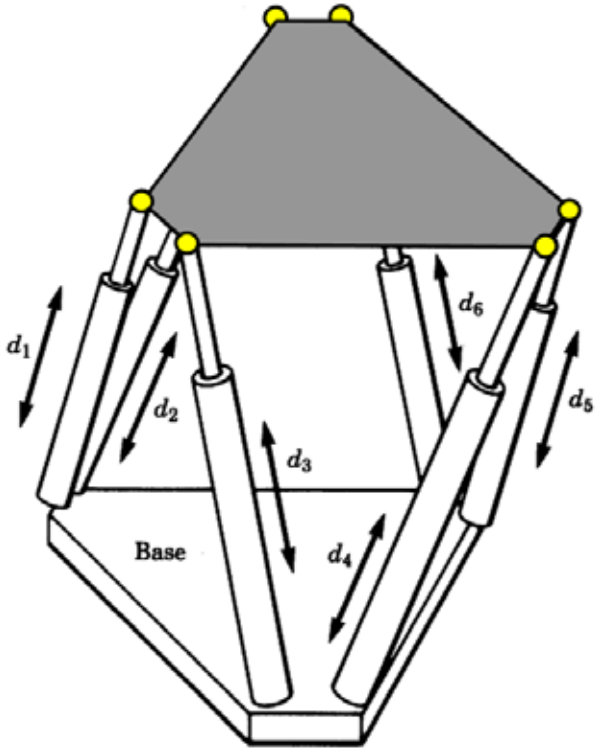


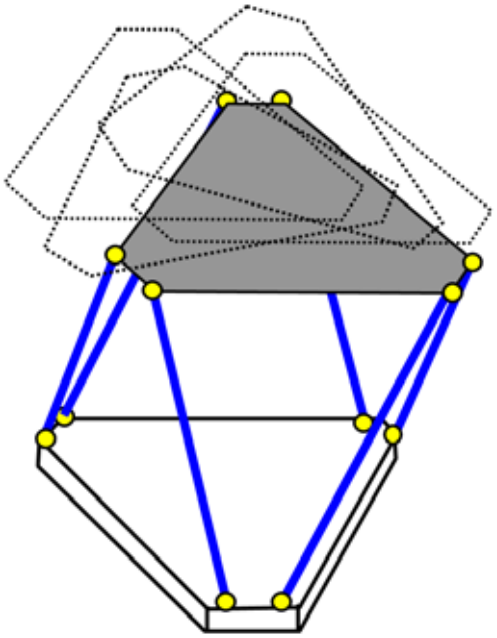
Gait simulation

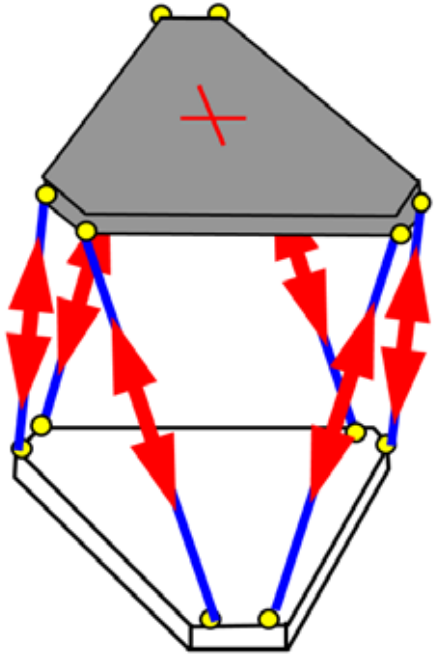
On a Robotics platform

Rutgers University 2004

Stewart Platform



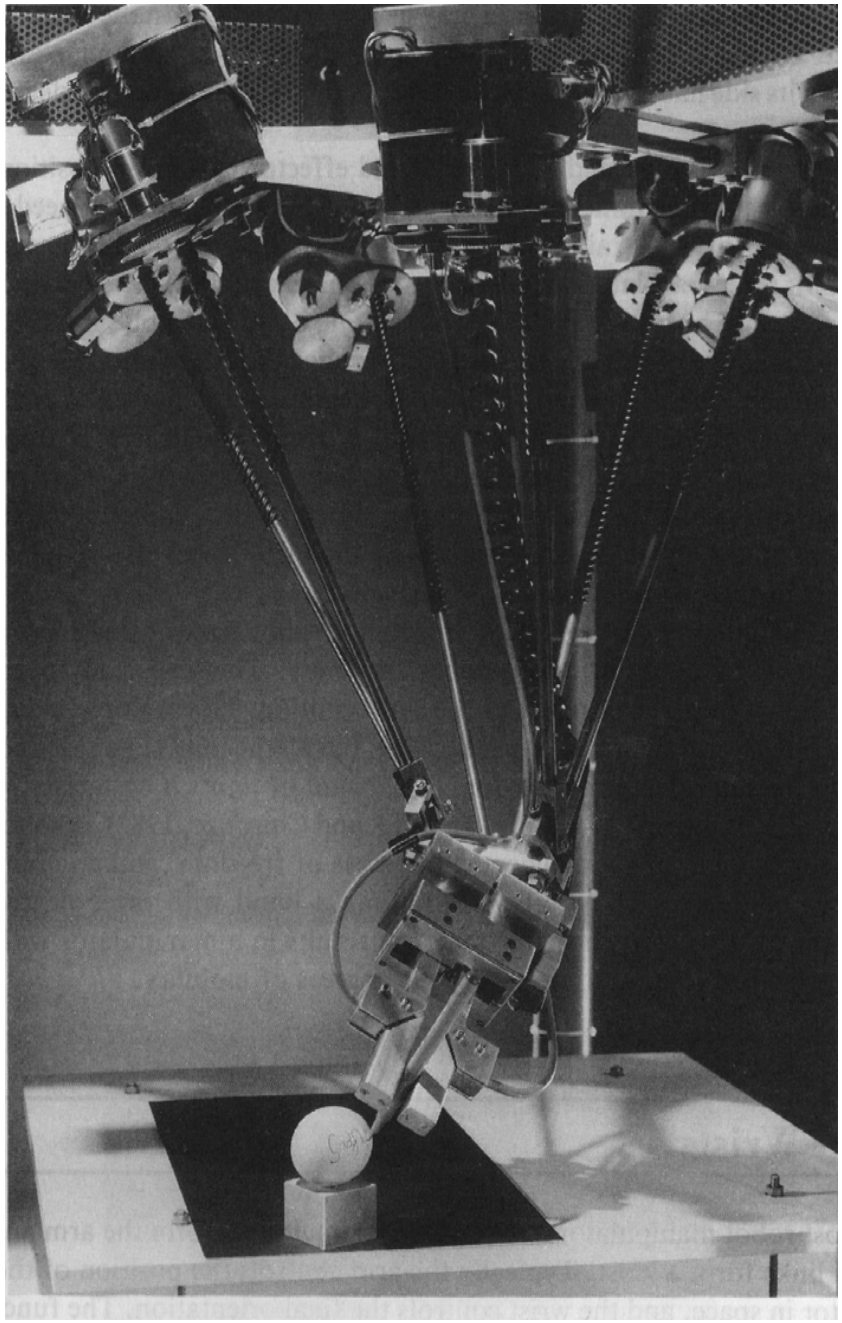




$\pm X, \pm Y, \pm Z$

$\pm \varphi \pm \phi, \pm \theta$

Example of Robot "Stewart"



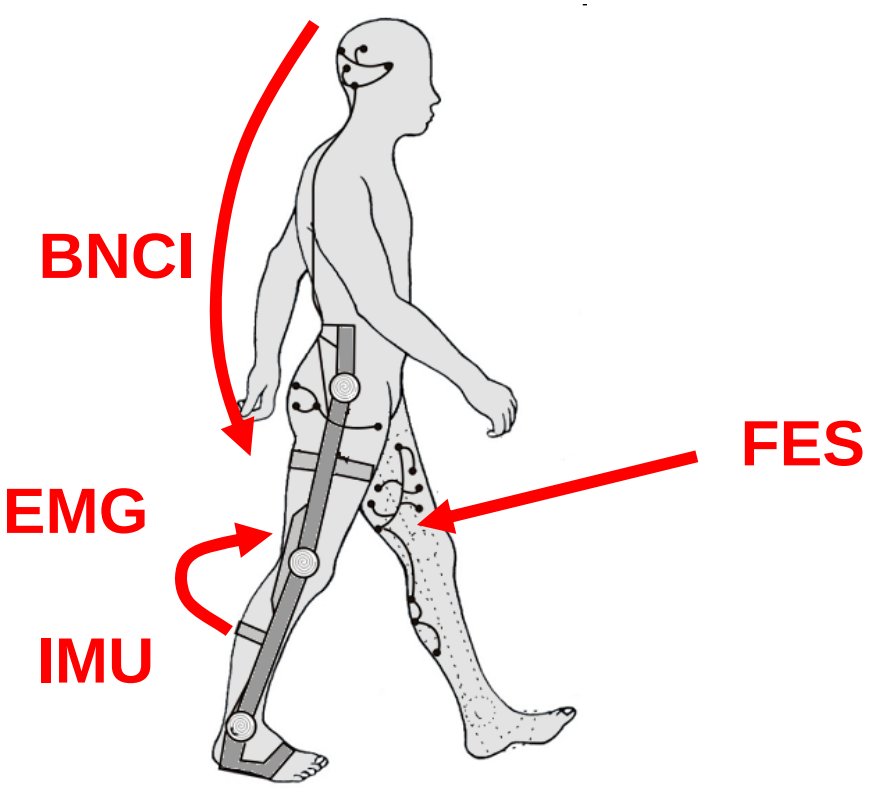
Robotic Systems in rehabilitation

Gait simulation

On a Robotics platform

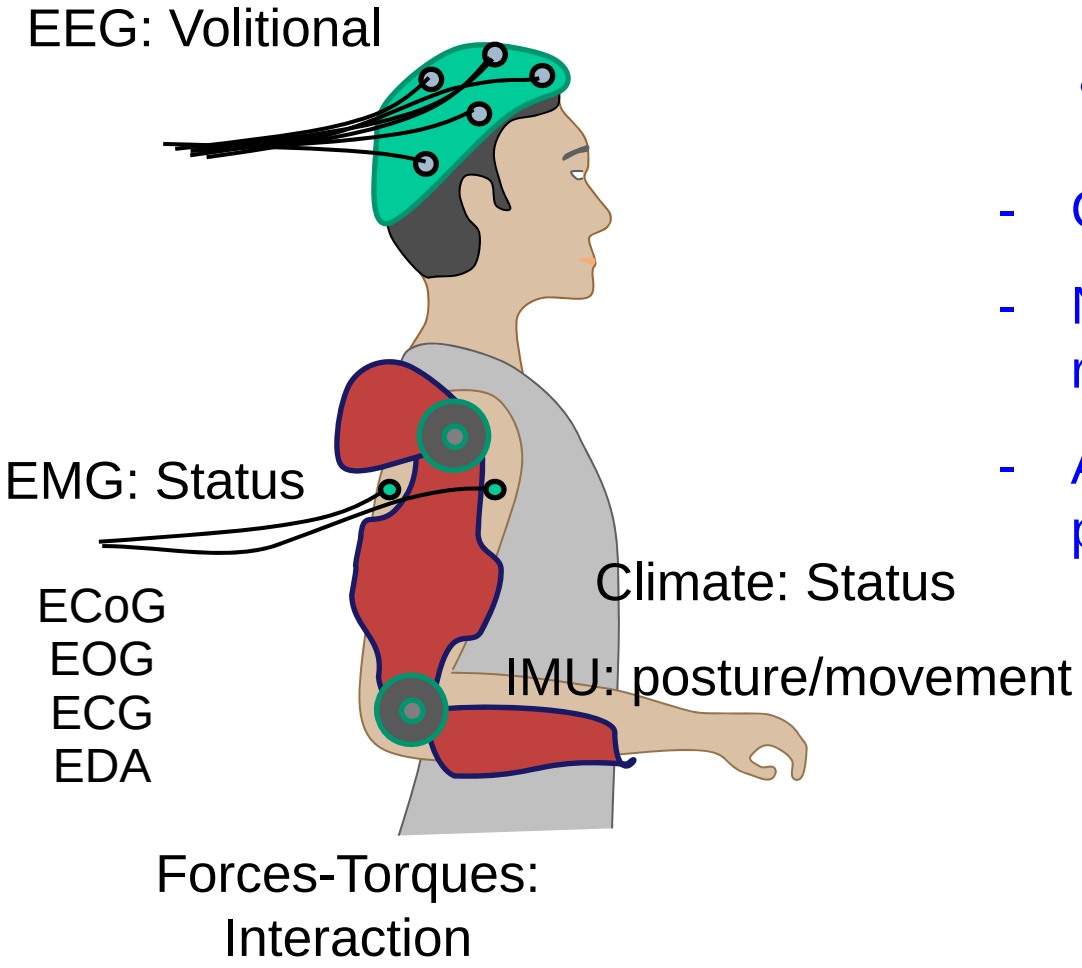
Rutgers University 2004

Neurorehabilitation



BCI Brain computer interface
IMU Inertial Measurement Unit
EMG Electromyography
FES Functional Electrical Stimulation

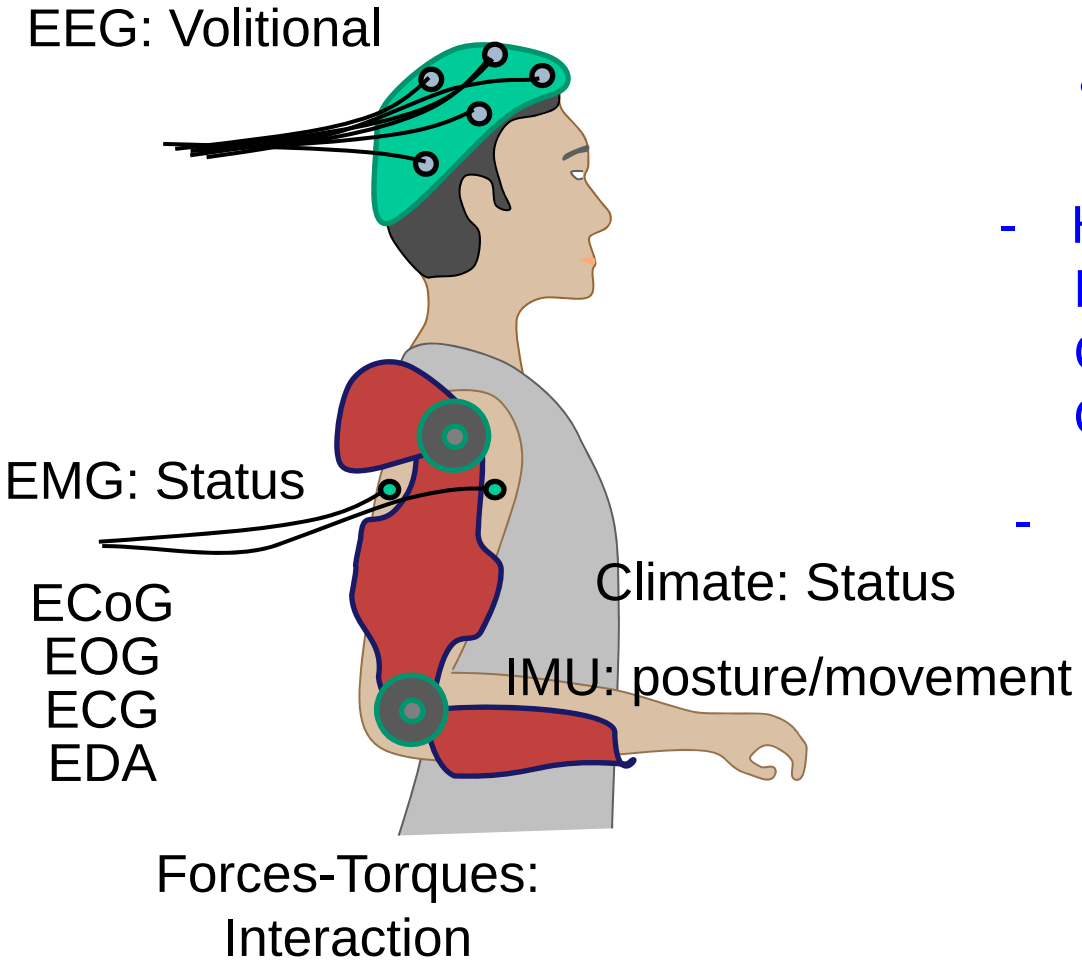
Neurorehabilitation



- **Human in the loop**

- Complex behavior
- Non repetitive musculoskeletal response.
- Ambiguous interpretation of physio and biological signals

Neurorehabilitation

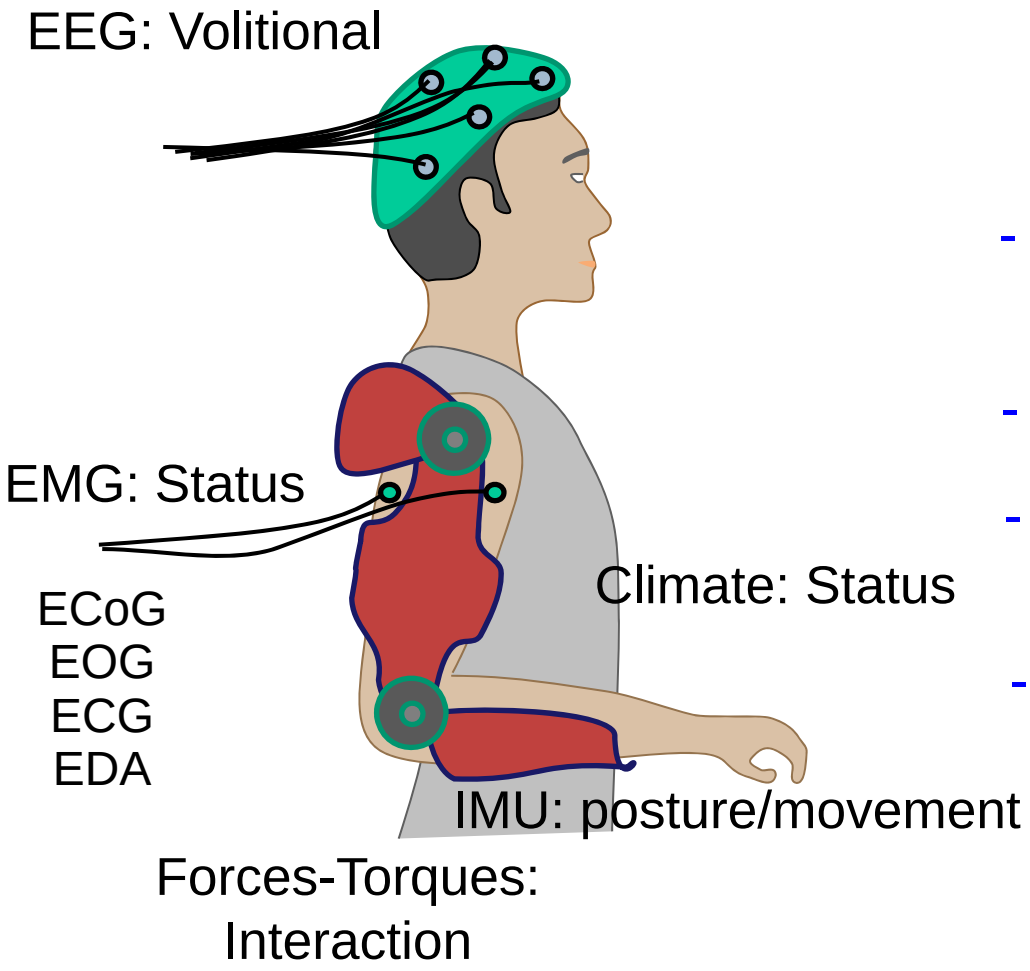


- **Human in the loop**

- Heterogeneous data:
  Physical or physiological data.
  Continuous and punctual inputs.
  Quantitative/qualitative inputs.

- Personalized therapy
  Adaptive
  Learning
  Tolerant

Neurorehabilitation



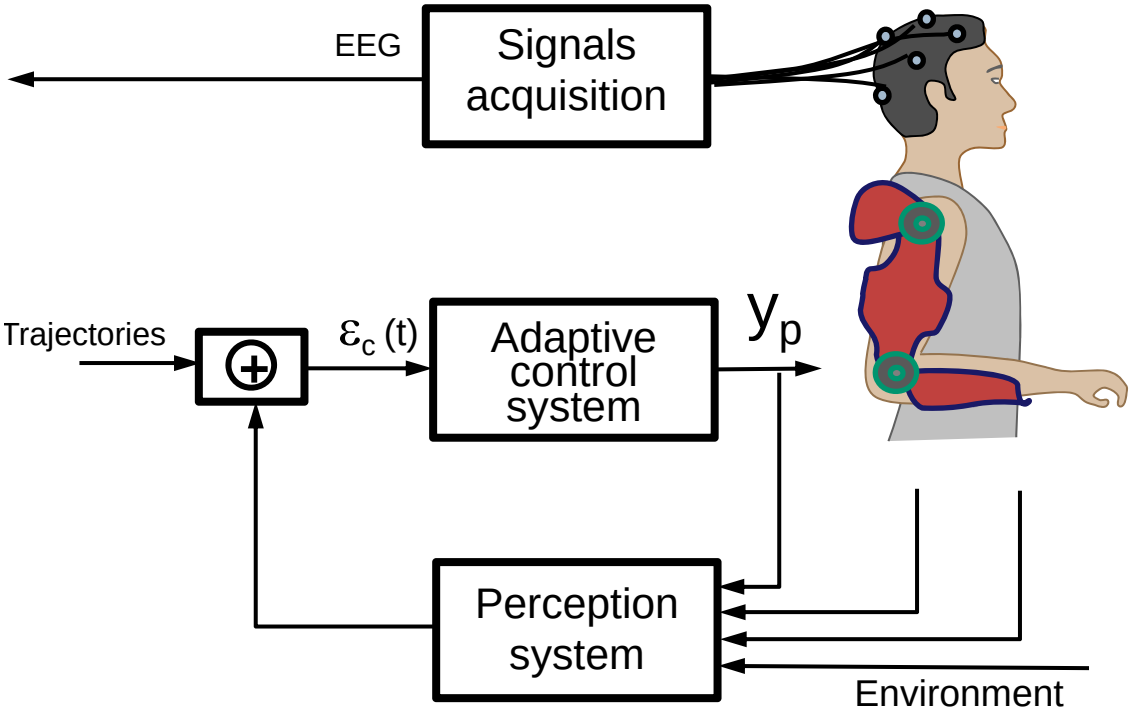
- **Interface requirements**

- Operation very close to humans (contact)
- Adaptable architecture
- Force capability versus lightness.
- High monitoring capabilities.

Adaptive Control

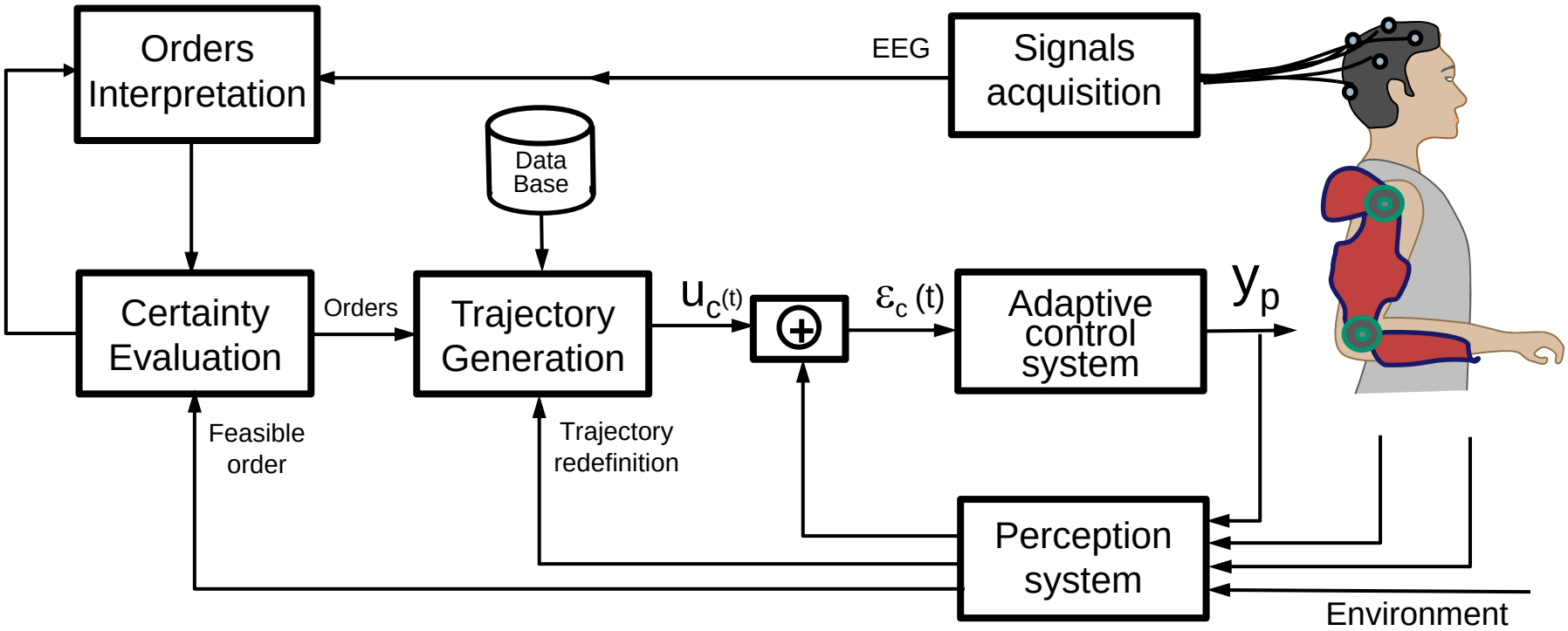
Interpretation of volitional orders

Relaxed state volitional order



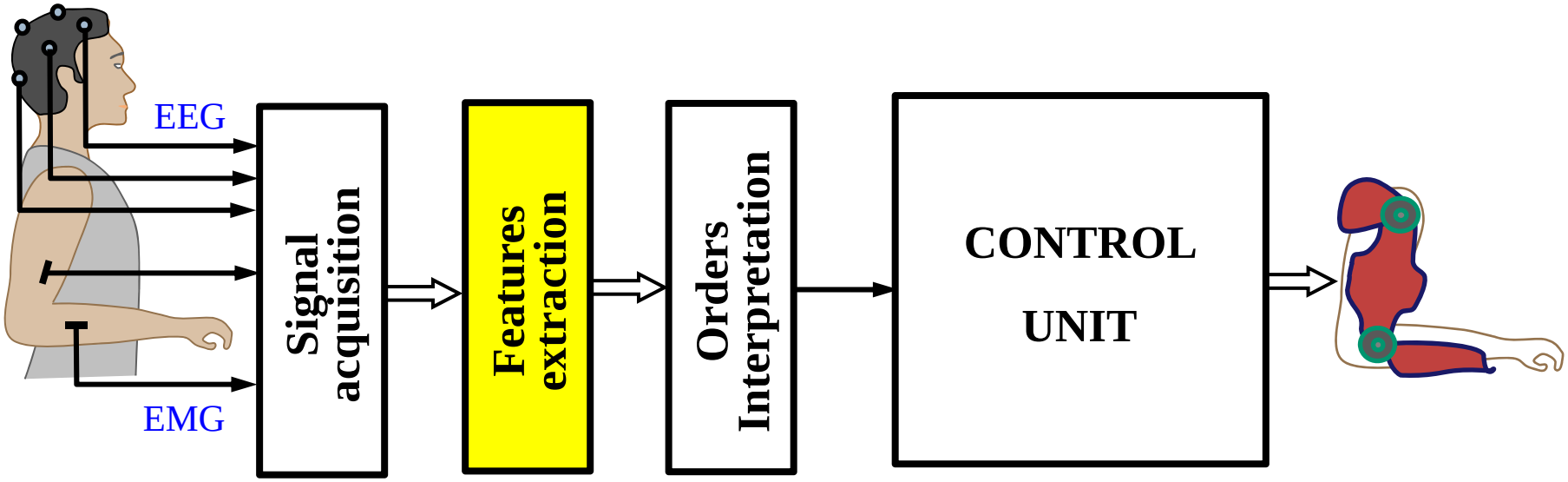
Adaptive Control

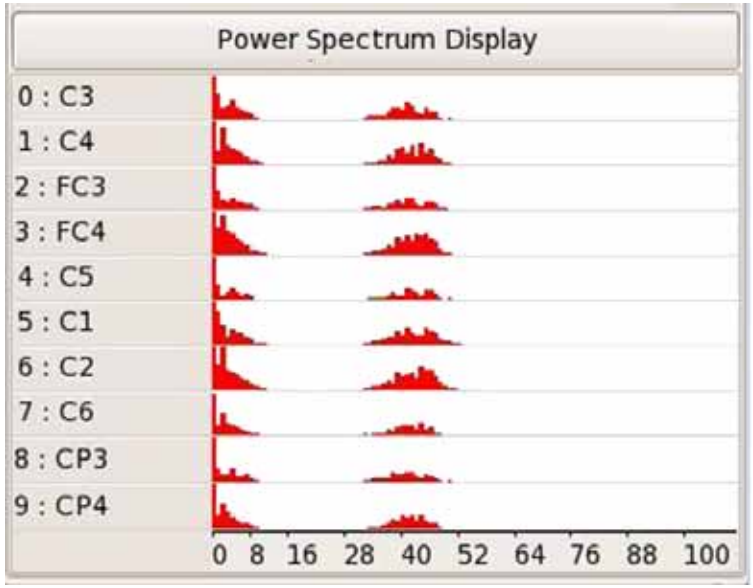
Interpretation of volitional orders



Adaptive Control

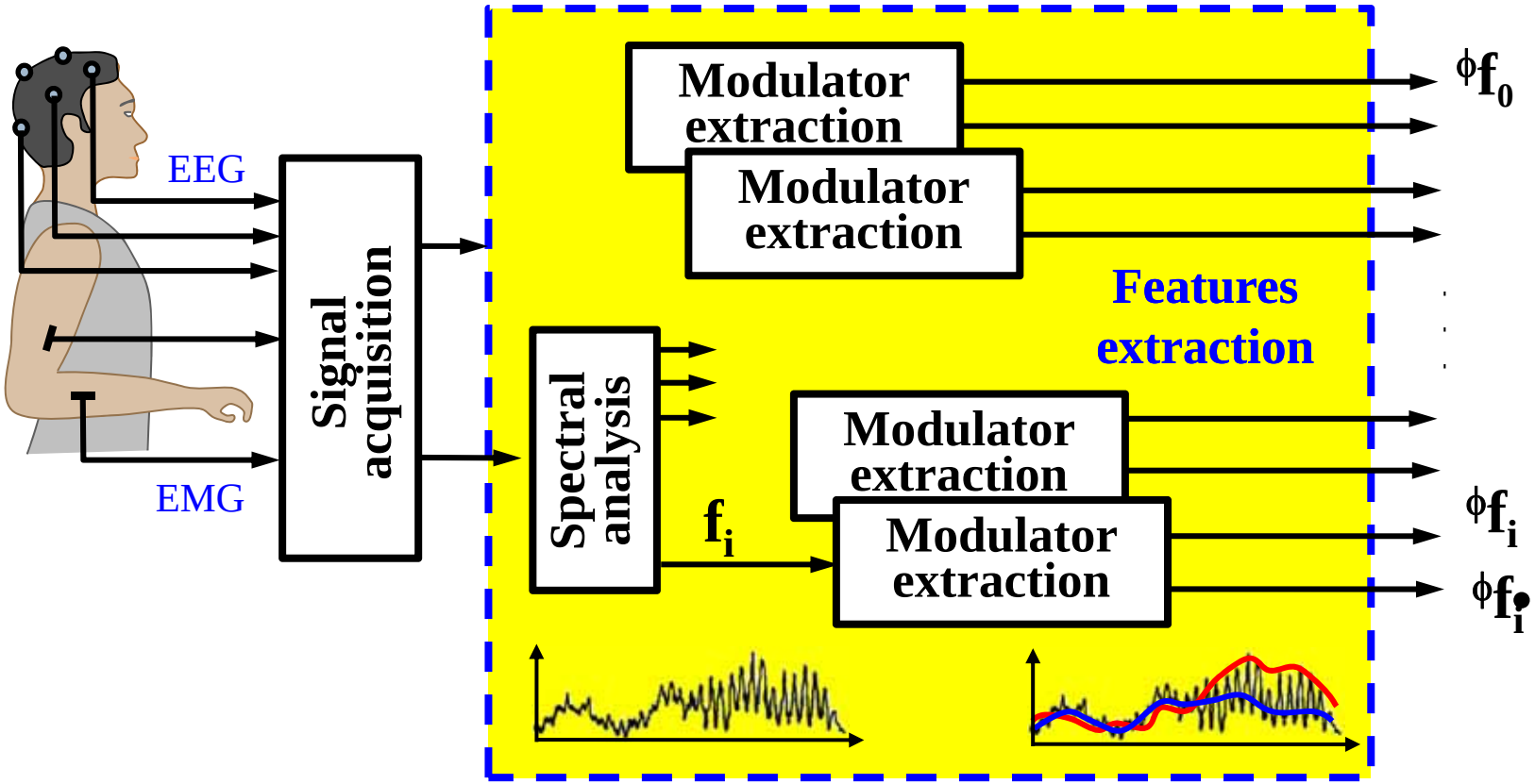
Interpretation of volitional orders





Adaptive Control

Interpretation of volitional orders



Orders interpretation

Features extraction and recognition

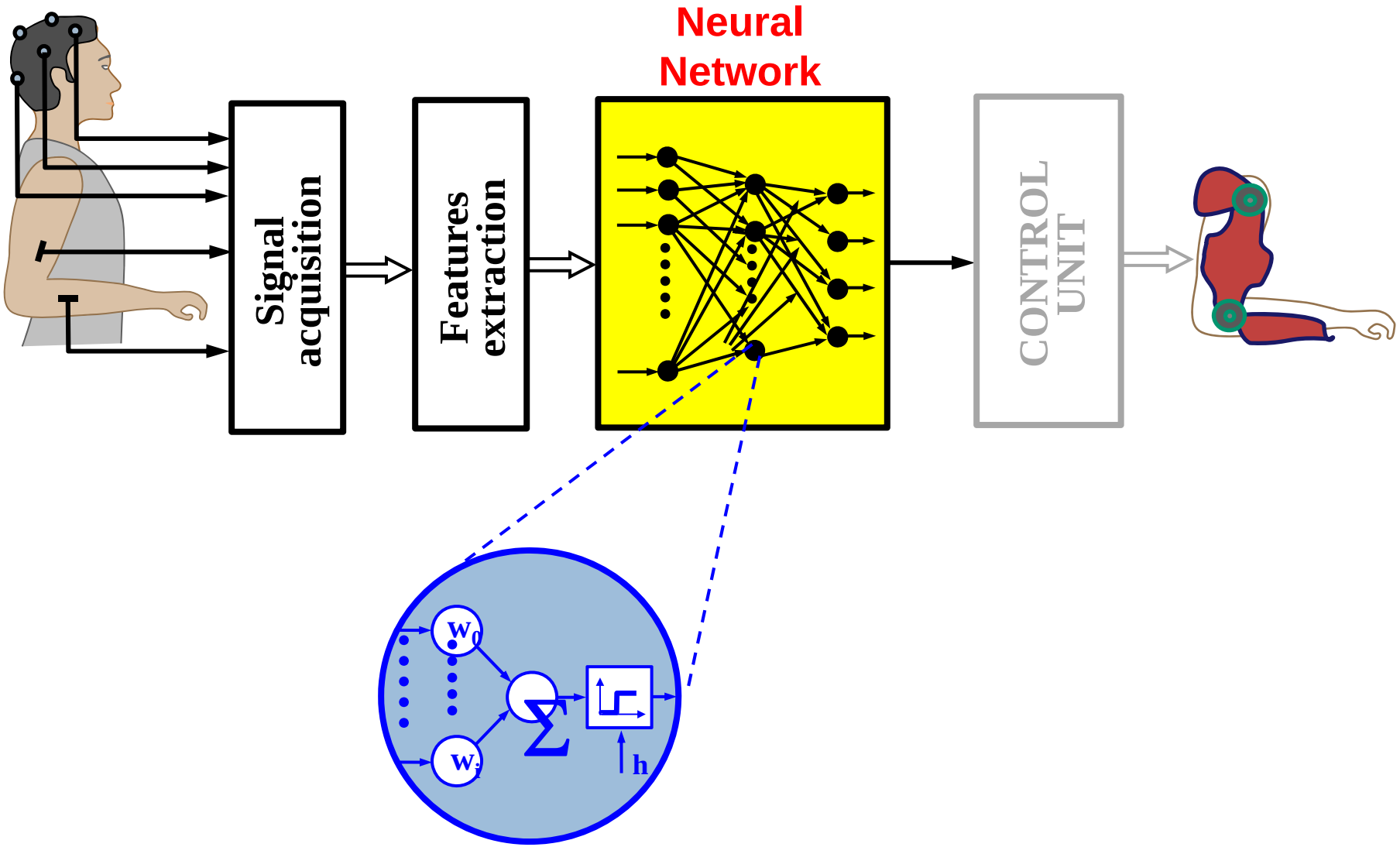
- Linear function plus threshold

- Frequency identification through FFT
- Wavelets decomposition
- Principal components Analysis (PCA)
- Independent components analysis (ICA)

- Artificial neural networks ANN → Deep Learning

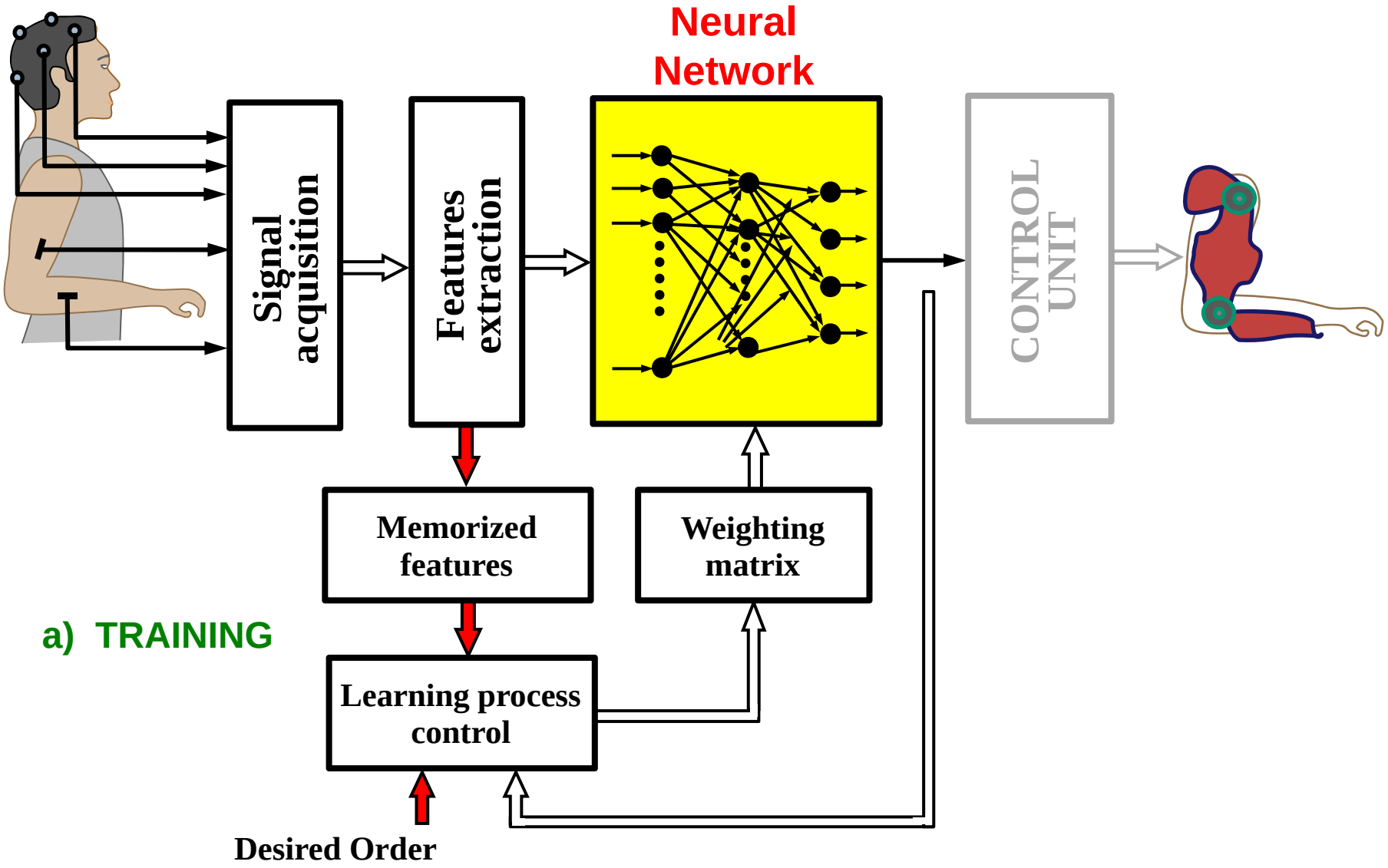
Adaptive Control

Interpretation of volitional orders



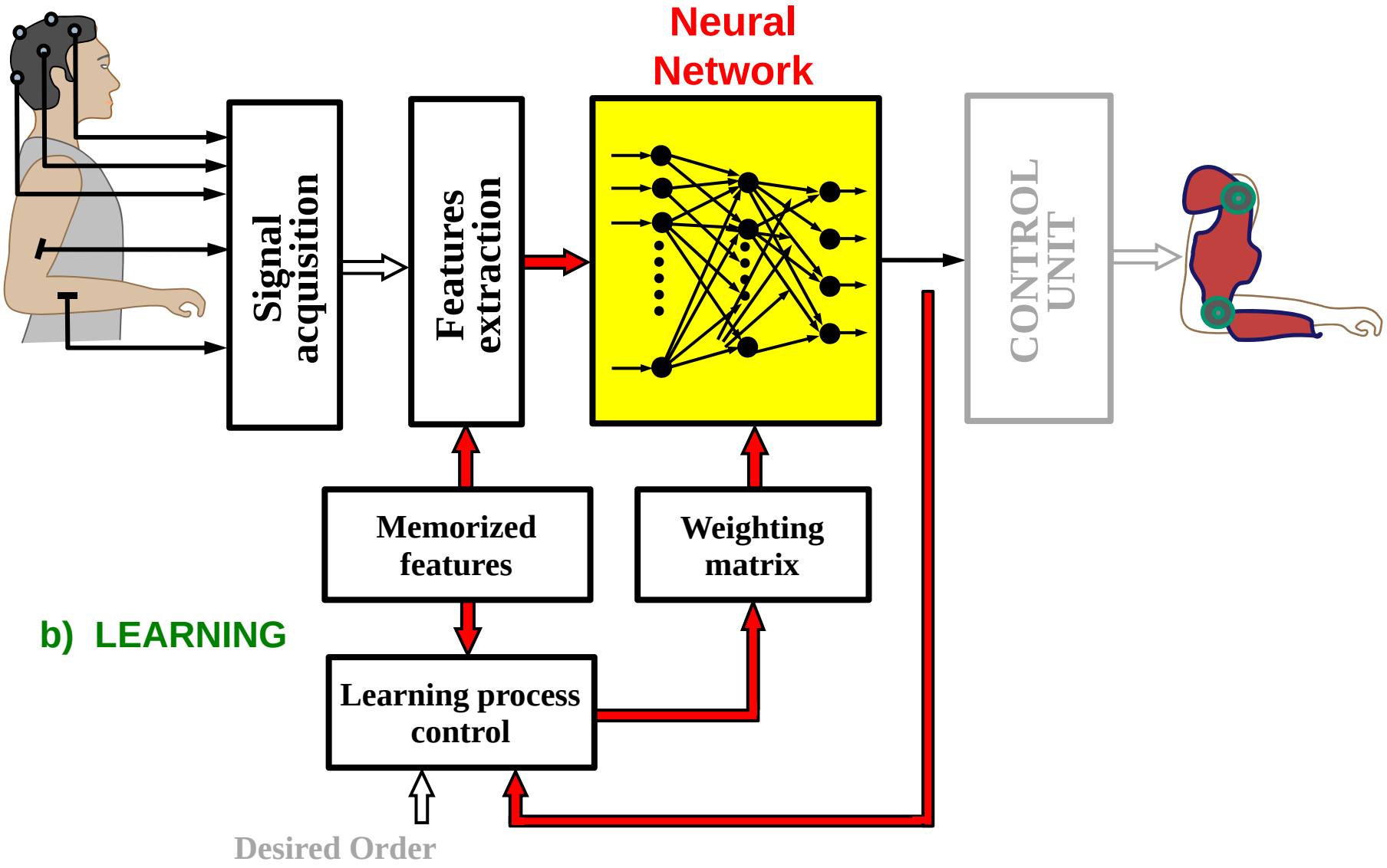
Adaptive Control

Interpretation of volitional orders



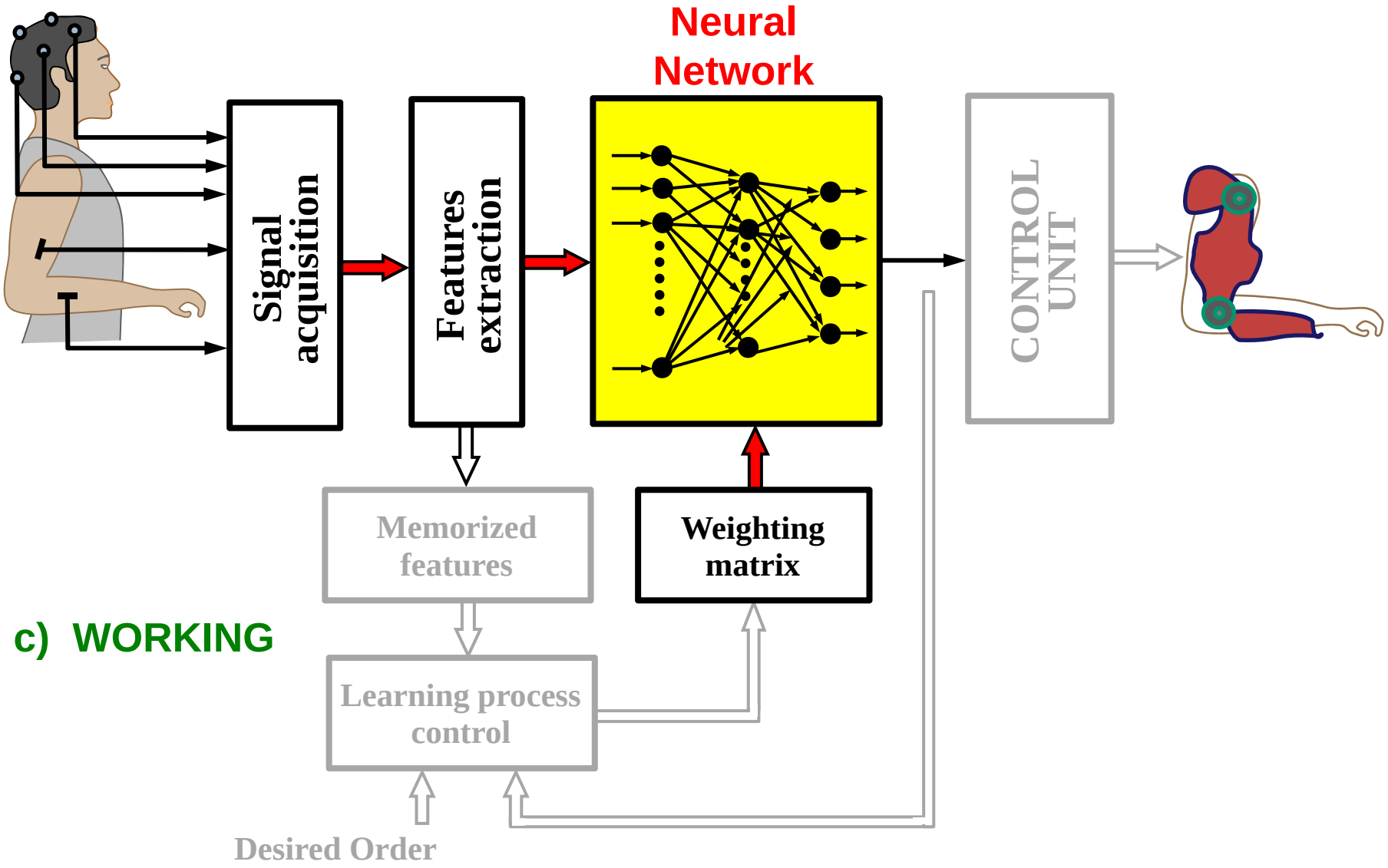
Adaptive Control

Interpretation of volitional orders



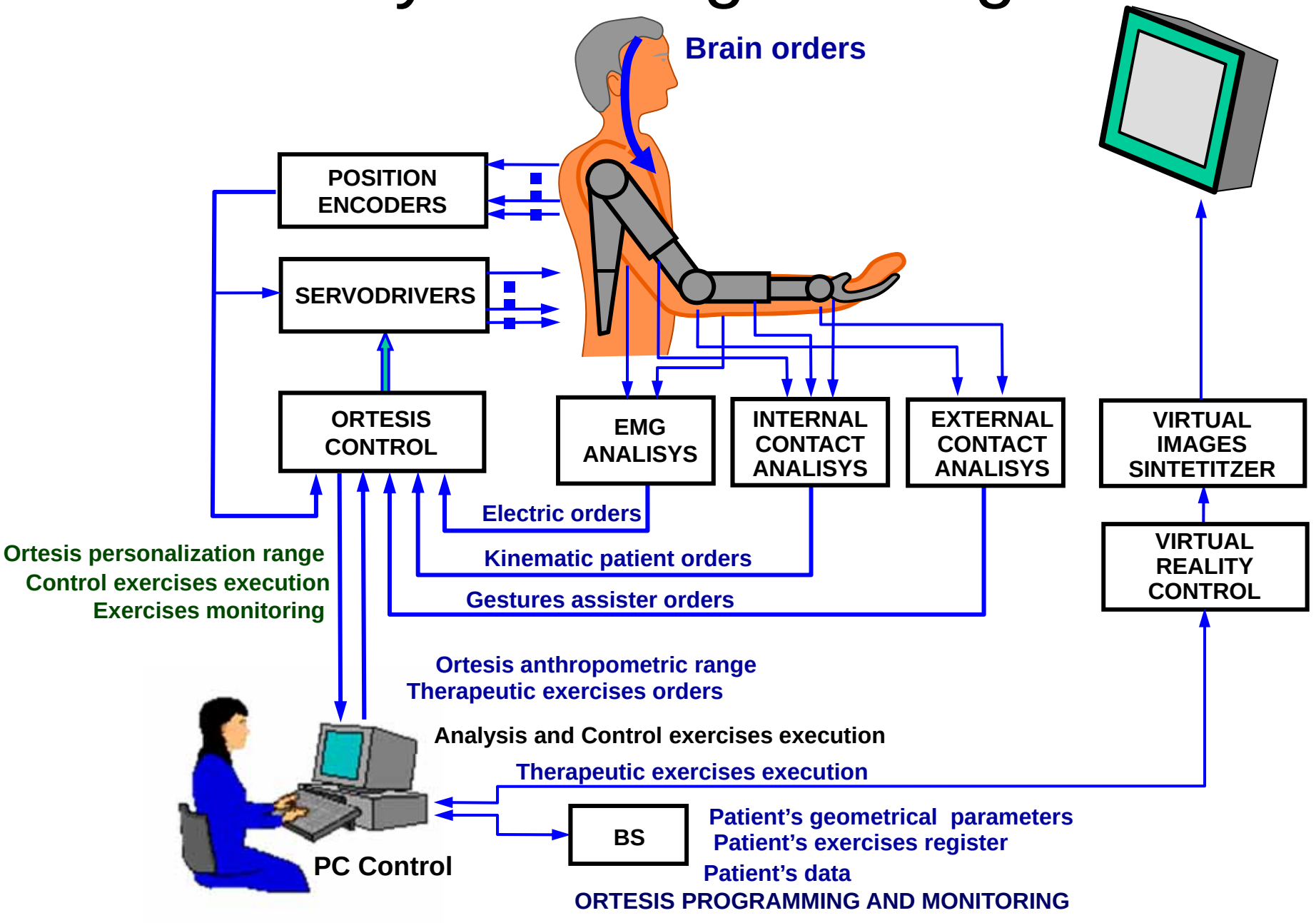
Adaptive Control

Interpretation of volitional orders

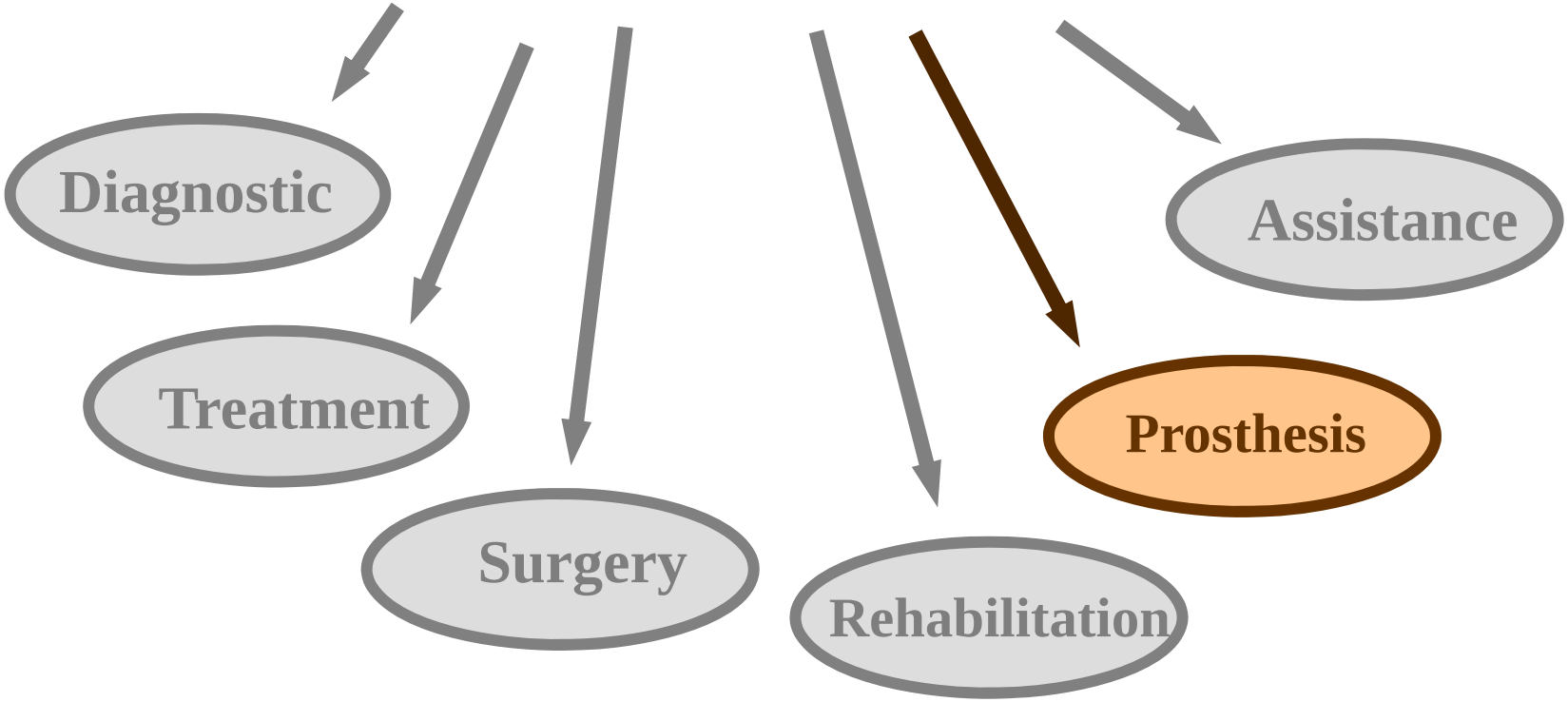


c) WORKING

System engineering



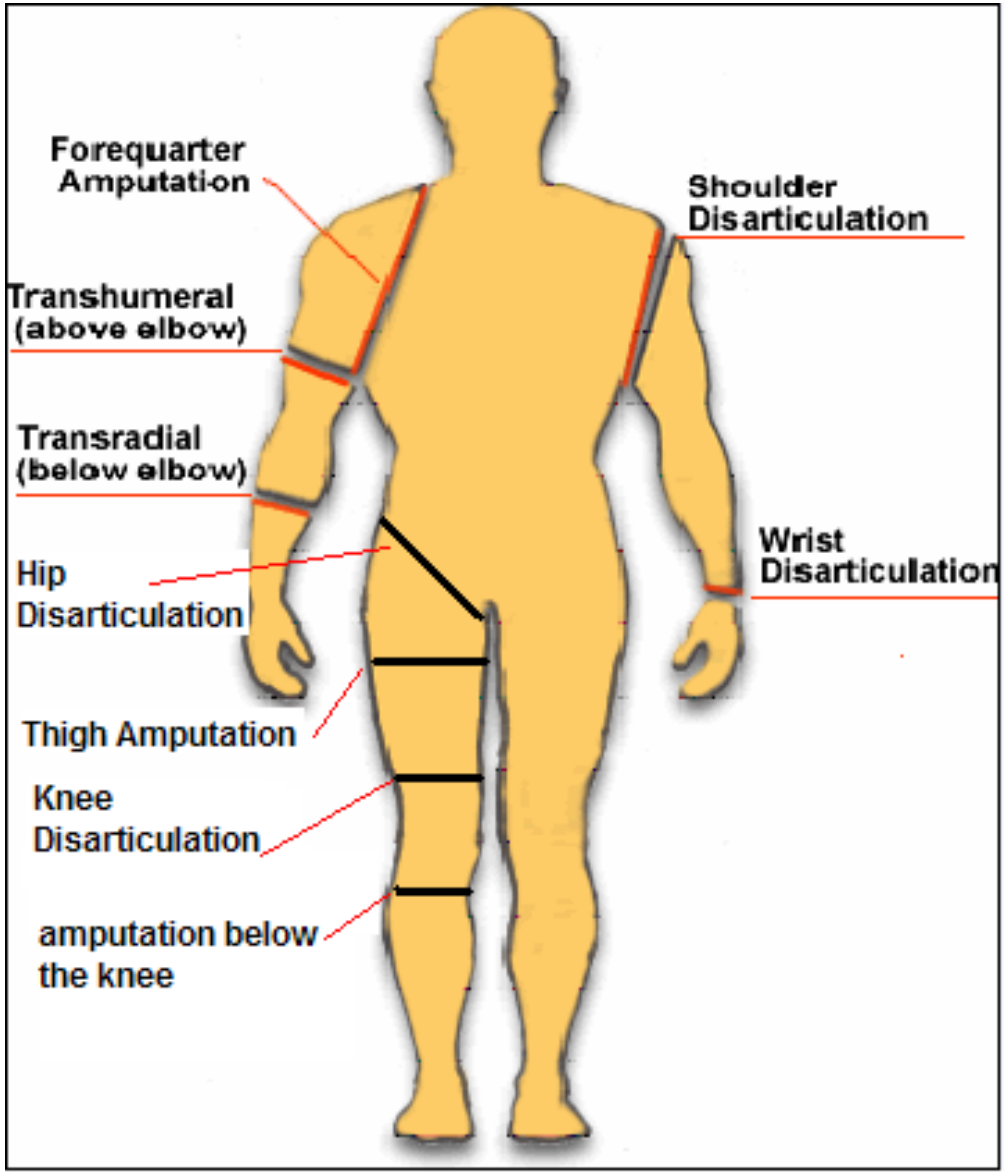
Robotics Application Fields in Surgery



Prosthetic devices

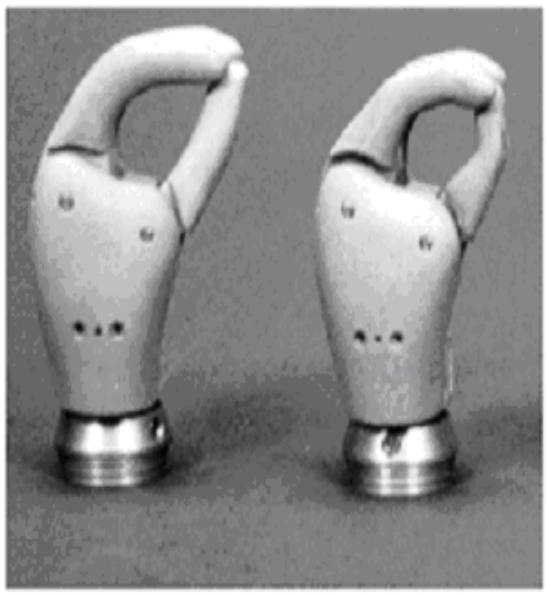
Restoration of the functionality of missing limbs

- Amputees
- Congenital missing of a limb or member



Hand prosthesis

Clinical



Dexterous: Robotic Hands

Control problem: H-M Communication

Hand prosthesis

- Main requirement: Physical appearance

size

weight

Hand prosthesis

- Passive: Adaptation (socket, harness…)

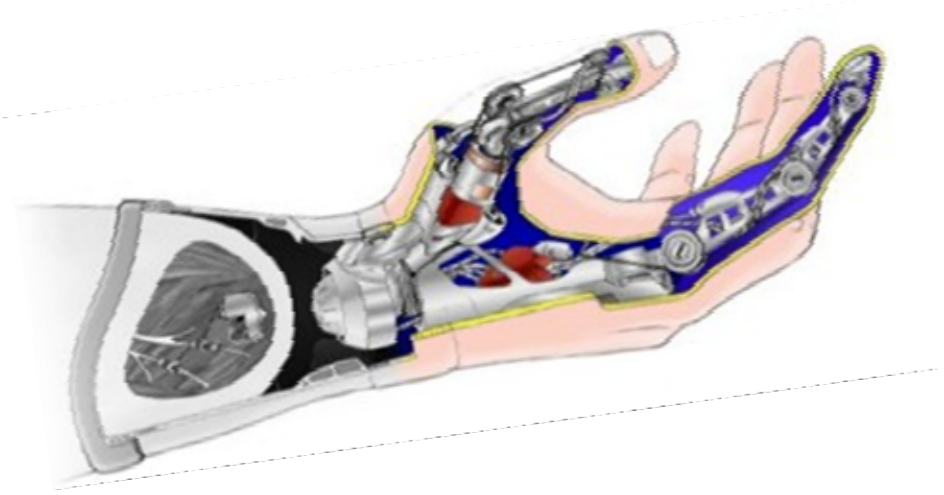
Body powered

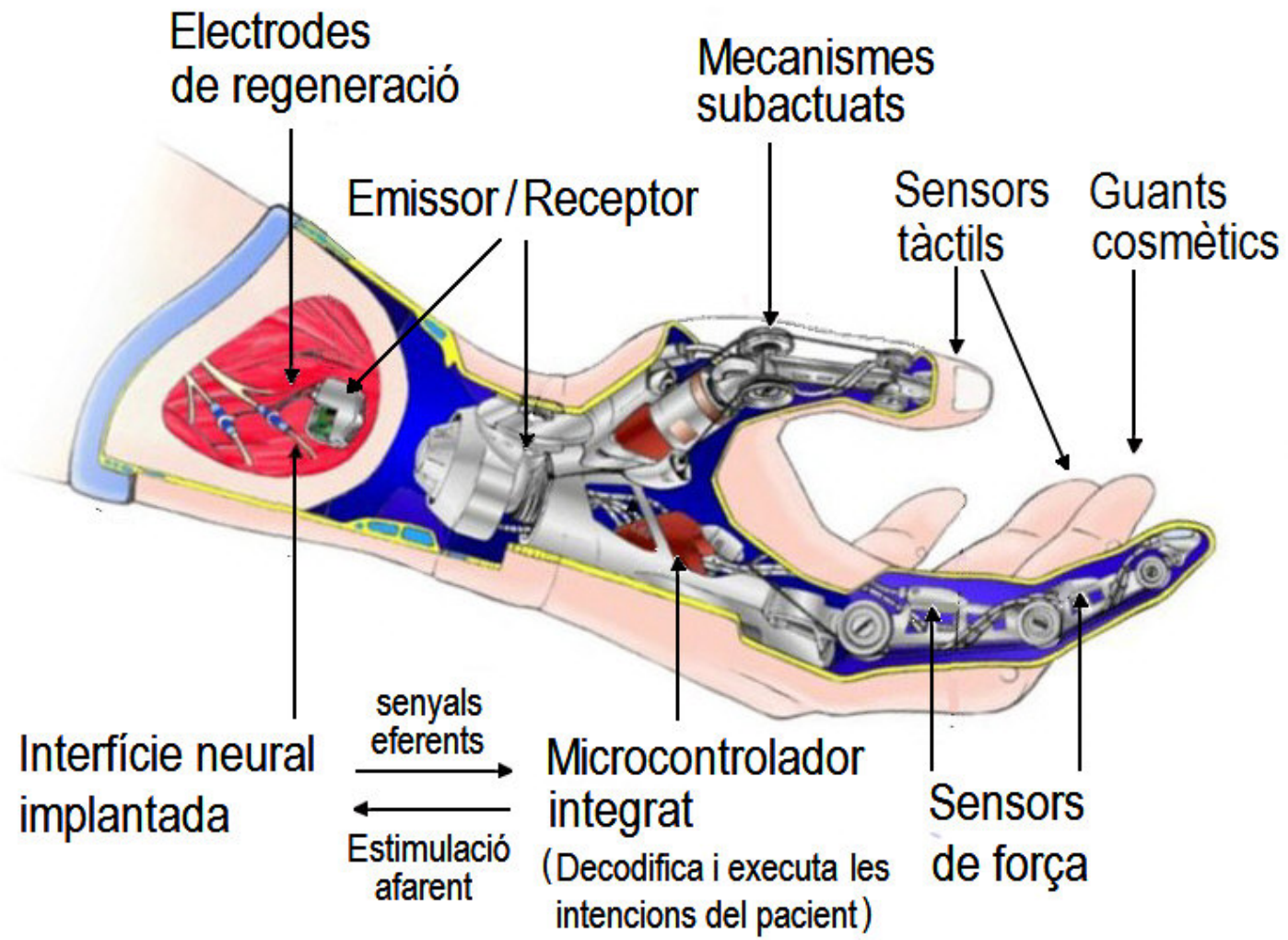
- Active: EMG (Electro Miographic Signal)

Clenching the biceps→ bends the elbow

Cyberhand

- It has 5 completely sensitive fingers
- It has 16 degrees of freedom and 6 small motors
- Articulated fingers and a motor for the automatic control of flexion.
- It has 21 position sensors, 8 force sensors and 15 touch sensors.
- Opposed thumb able to execute different types of grasping.
- Cyberhand weights 450 grams.



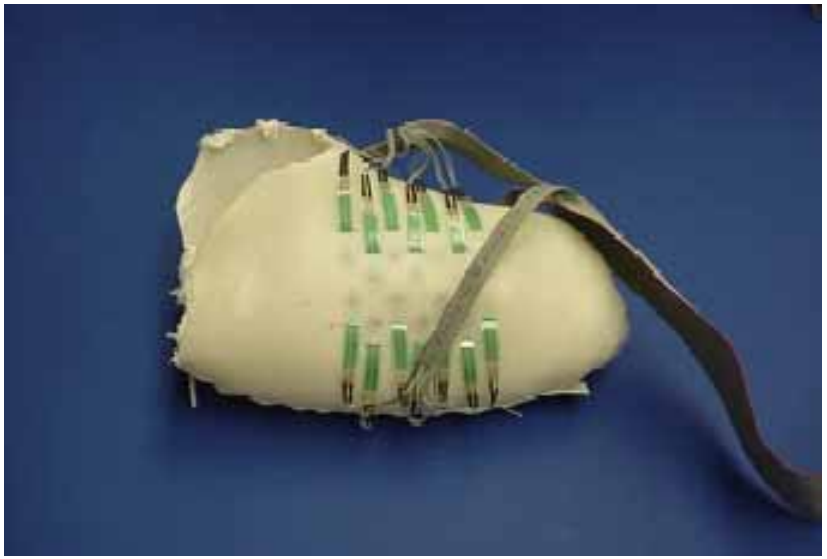

Electrodes
de regeneració
Mecanismes
subactuats
Emissor / Receptor
Sensors
tàctils
Guants
cosmètics
Interfície neural
implantada
senyals
eferents
Estimulació
afarent
Microcontrolador
integrat
(Decodifica i executa les
intencions del pacient)
Sensors
de força

Learning how to use a prosthesis

Virtual Reality
CREB-UPC

J Prosthet Orthot. 2012 Apr; 24(2): 56–64.
doi: [10.1097/JPO.0b013e3182515437]

Learning how to use a prosthesis



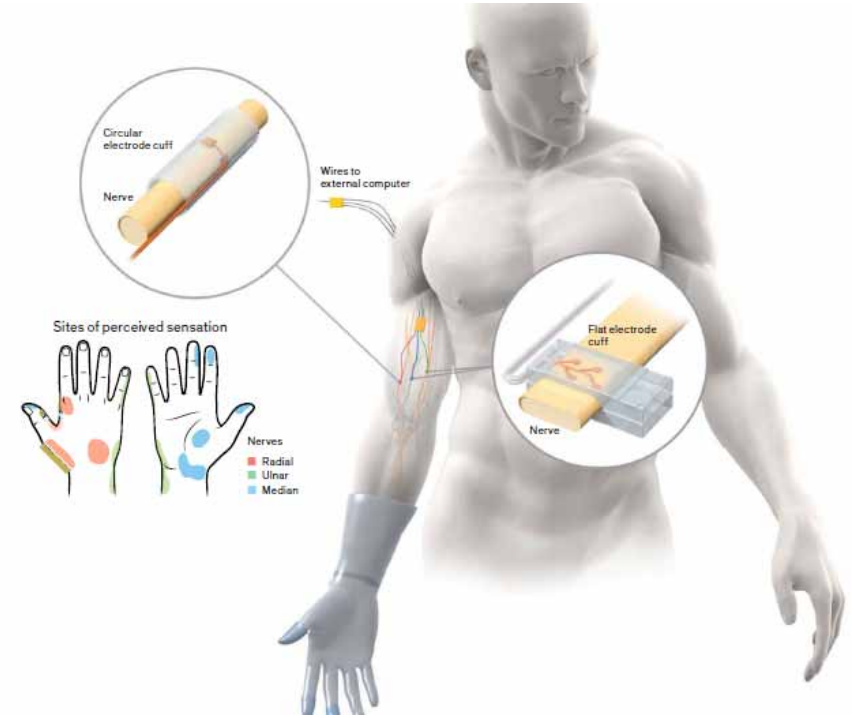
Feedback of remaining mobility.
Sensitive cover
Rutgers University 2004

Learning how to use a prosthesis

Feedback of remaining mobility.

Sensitive cover of the amputee limb

Improving prosthesis use



Prosthetics: Restoring the human touch

Spectrum May 2016

Which factors limit their extensive use?

- Aesthetics
- Autonomy
- Weight
- Noise
- Ergonomics
- Interaction with the user

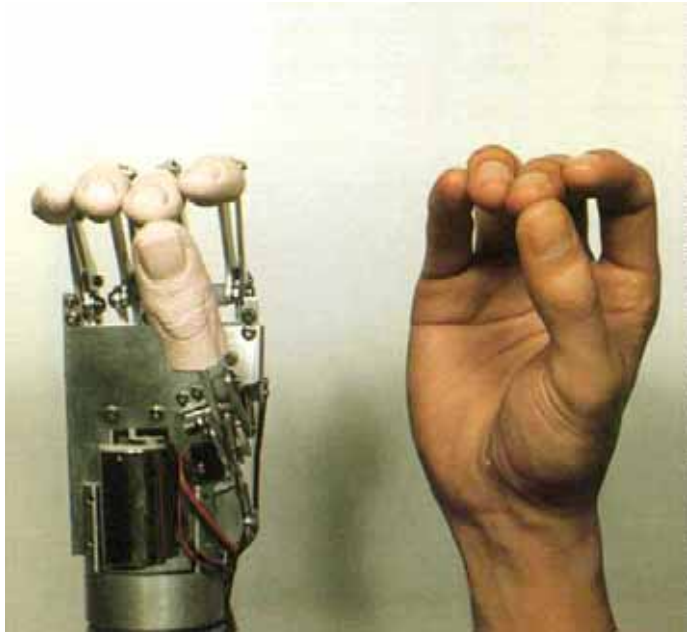
Which factors limit their extensive use?

- Aesthetics
- Autonomy
- Weight
- Noise
- Ergonomics
- Interaction with the user

- Silicones
- Thermoelastic materials
- Titanium

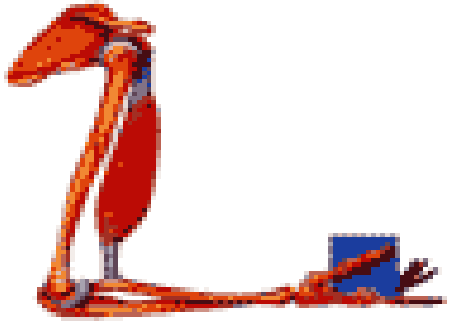
Which factors limit their extensive use?

- Aesthetics
- Autonomy
- Weight
- Noise
- Ergonomics
- Interaction with the user

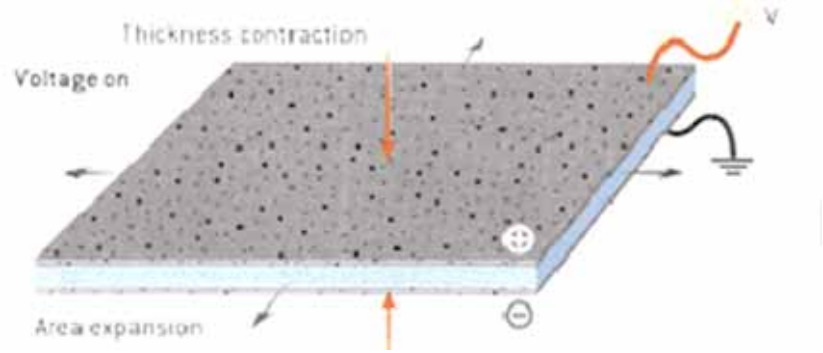


Which factors limit their extensive use?

- Aesthetics
- Autonomy
- Weight
- Noise



Electro active Polymers



ser

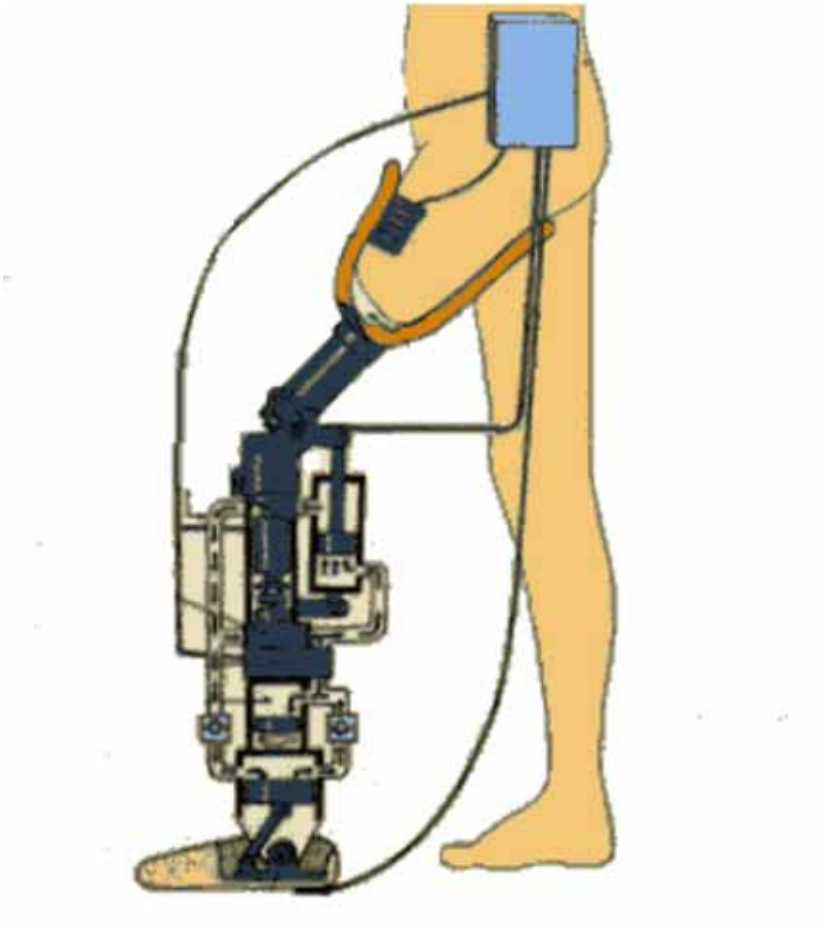
SMA: Shape Memory Alloy

Which factors limit their extensive use?

- Aesthetics
- Autonomy
- Weight
- Noise
- Ergonomics
- Interaction with the user (feel like natural hand/arm/foot/leg)

Lower limbs

- Less dexterity
- More weight
- Stability issues



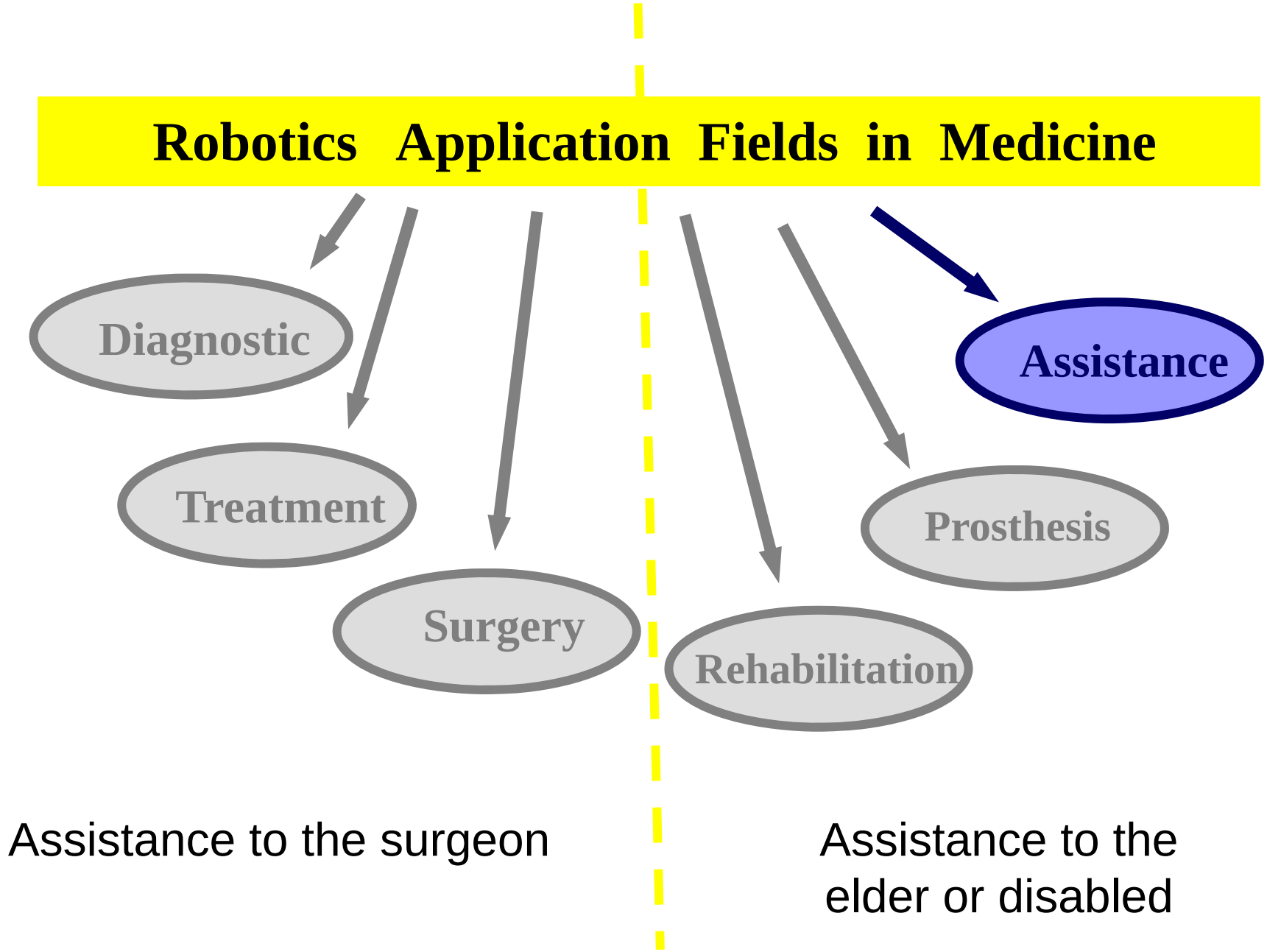
Lower limbs

ottobock.

X3 waterproof prosthetic leg

1E95 Challenger foot

Above-Knee Fitness Prosthesis


Robotics Application Fields in Medicine
Diagnostic
Treatment
Surgery
Rehabilitation
Prosthesis
Assistance
Assistance to the surgeon
Assistance to the elder or disabled

Evolution of assistive technology. Towards robotics systems

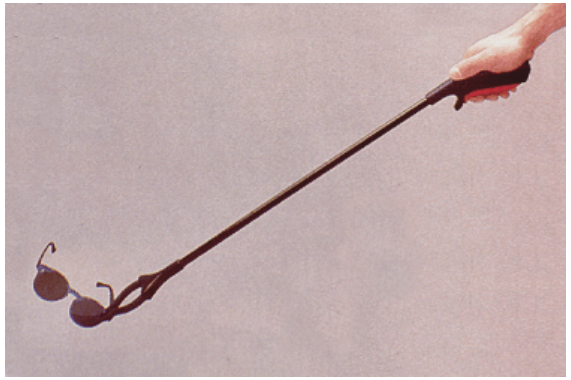
GOALS:

- Extend human capabilities
- Support to rehabilitation
- Increase user’s autonomy

MEANS:

- Simple electromechanical devices
- Robots as control interfaces or as a cognitive aid
- Complete robotic systems

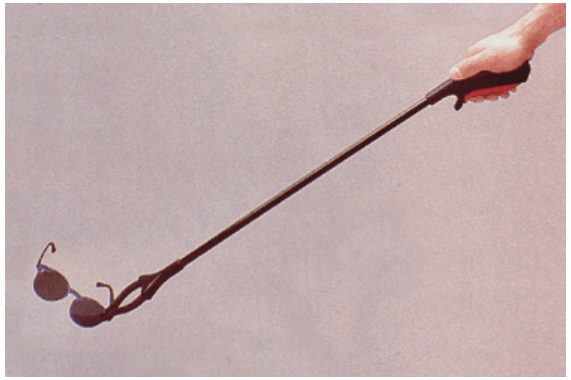
Evolution of assistive technology. Towards robotics systems



Human extension devices

Robotic systems for human extension

Evolution of assistive technology. Towards robotics systems



Human extension devices

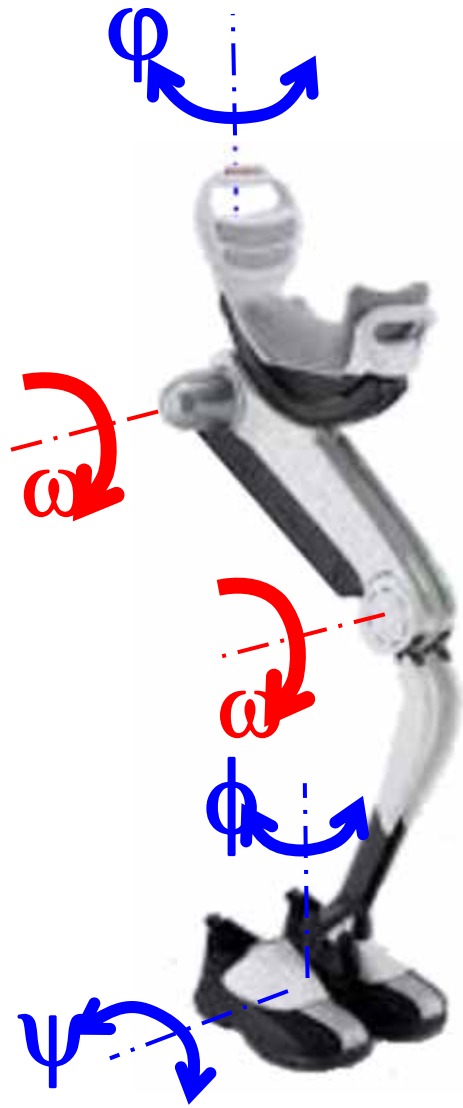
Robotic systems for human extension

Evolution of assistive technology. Towards robotics systems

Robotic systems for human extension

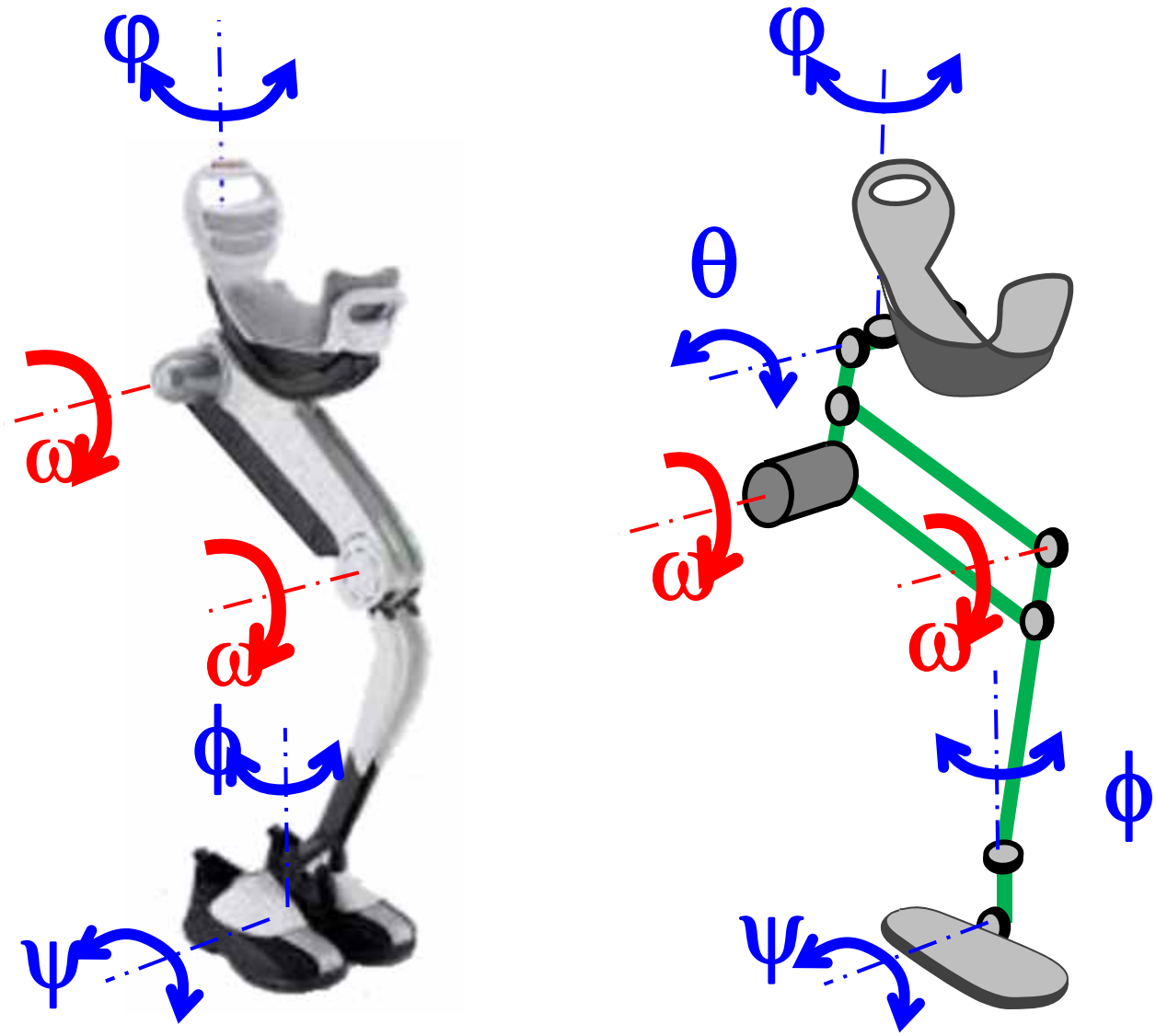
Analysis of the Honda Walker

Problem: Analysis of the walker kinematics



- Active movements
- Passive movements

Degrees of freedom


φ
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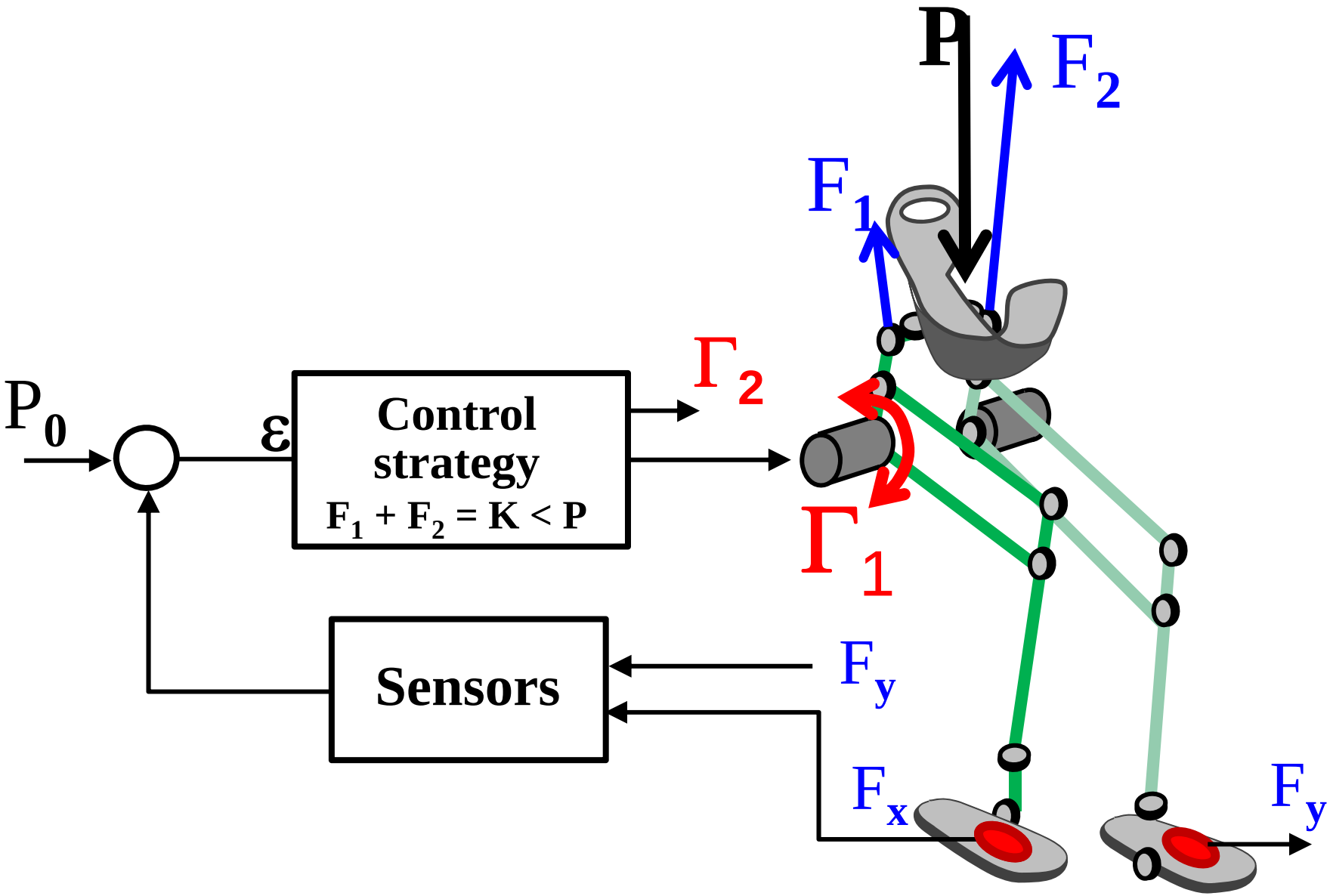
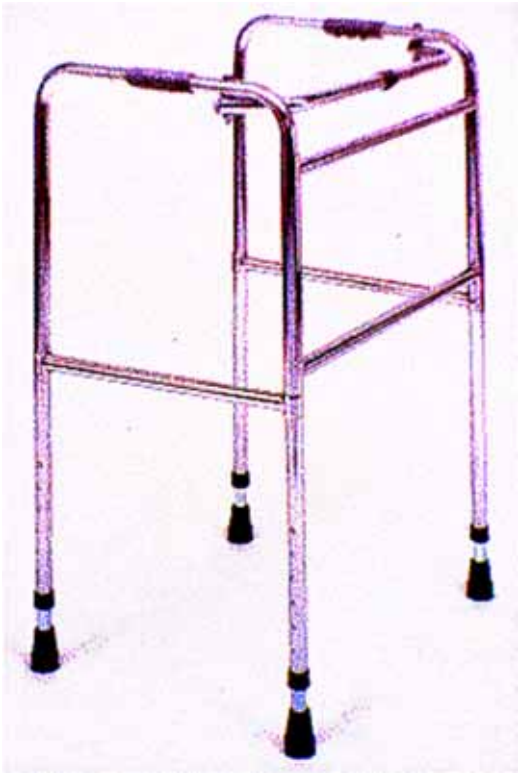


Control strategy

Other Honda products

Other orthesis

Evolution of assistive technology. Towards robotics systems

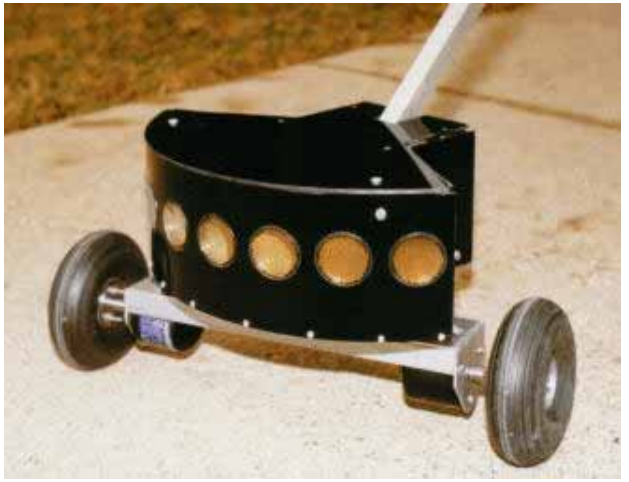


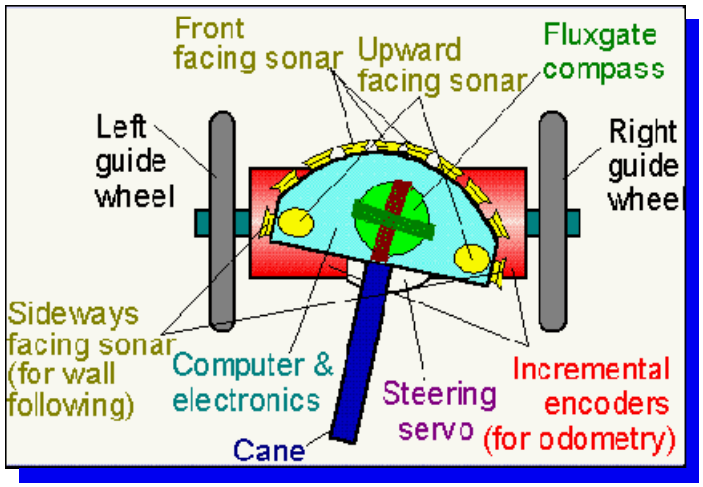
Assistant walker

Robotic walker assistant

Muscle weakness, joint pain, blindness → walkers

Evolution of assistive technology. Towards robotics systems





Robot assistance

Assistive

Permanent support

- No possible recovery
- For personal autonomy

- Intelligence /Interface
- Autonomy /Interaction
- Compliance

Robot manipulator: Feeder, assistant arm.

Prosthesis Replace missing limbs.

Mobile robots: Wheelchairs, Walker assistance, Intelligent canes (for mobility)

Humanoids: “ Human” assistant, co-worker, mate . . .

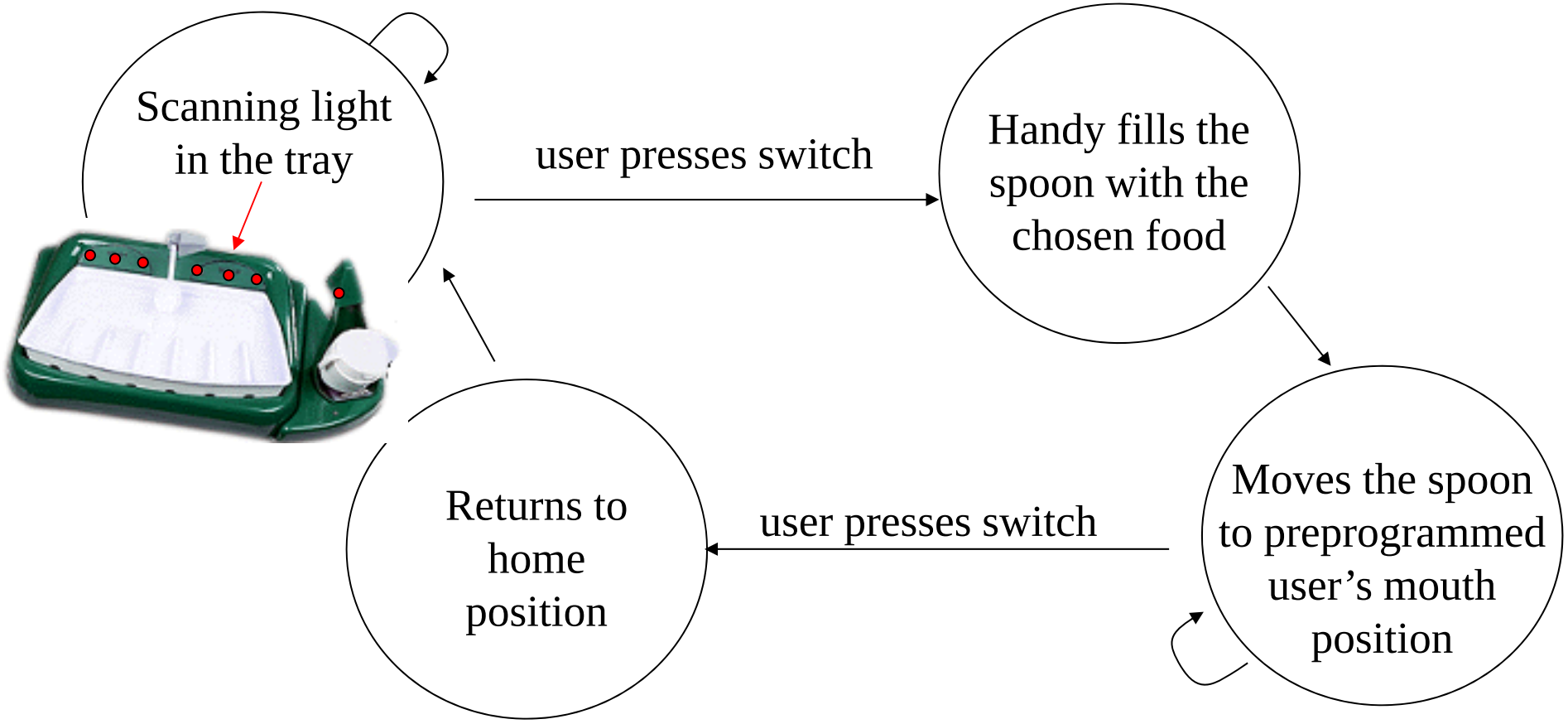
Assistant Robots (Robot manipulators)

Wheelchairs Human guided
Navigation capabilities

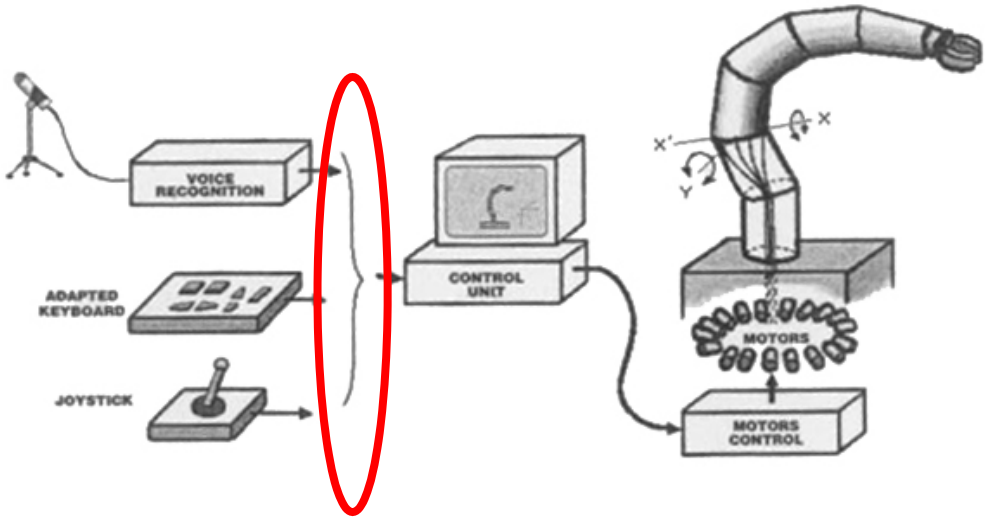
Robots specialized for an application: Handy

- Workspace
- Interface
- Programming
- Sensing
- Interface

Robots specialized for an application: Handy



Assistant robots: Tou



Standard communications

UPC (1989-94)

Simple operations: grasp and release objects, remove hair from the eyes, scratch oneself, turn pages.

Soft robotics, continuum

Assistant robots: ISAC

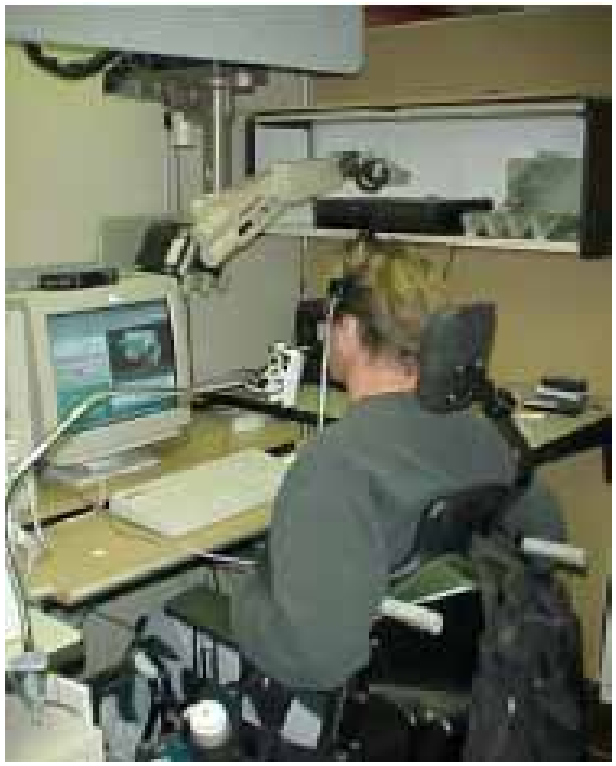
ISAC: Intelligent Soft Arm Control

University of Vanderbilt and manufactured in Japan (1993).

Integrated sensors for safety: vision, voice (real time face tracking), touch, proximity.

Arm with 6 joints and 12 Rubberactuators (reflex control) (agonist/antagonist)

Assistant robots: ProVAR and RAID



ProVAR: Professional Vocational Assistant Robot, Stanford University (1998)

- Industrial robot arm PUMA 260 on a rail for extended workspace

RAID: Robot to Assist the Integration of the Disabled

Robotic workstation.

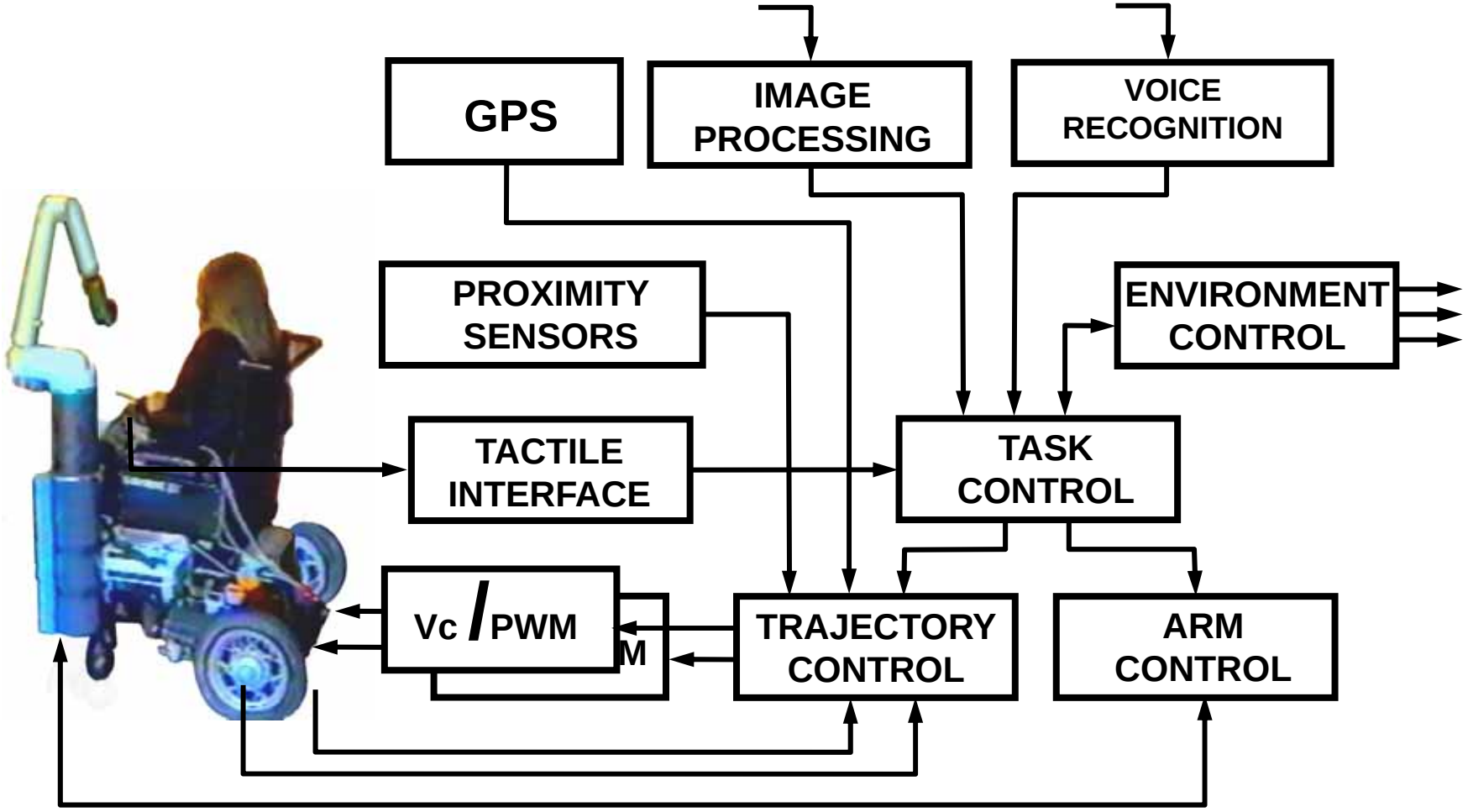
European project (1991-1996)

Robots mounted on wheelchairs

Manus(1992)

http://www.exactdynamics.nl

Robots mounted on wheelchairs



Robots on a mobile base: MOVAID

MOVAID - MObility and actiVity AssIstance system for the Disabled

European Project (1994-1998)

Fixed workstations at home

PC controlled

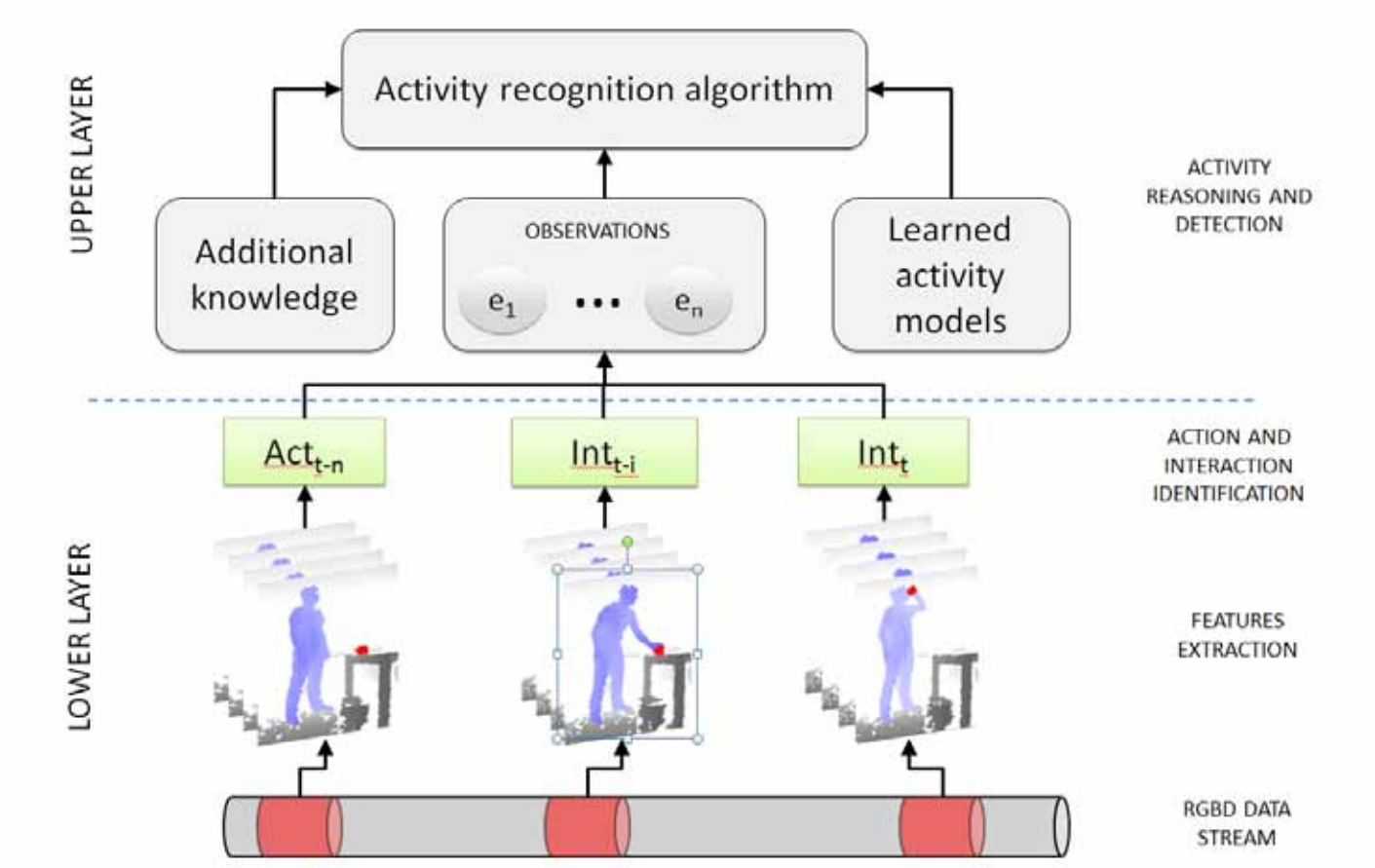
Robots on a mobile base: CARE-O-BOT

Robots on a mobile base: CARE-O-BOT

Robots on a mobile base: CARE-O-BOT

CAPDI: The GRINS (UPC) robotized kitchen

Robots in domestic environments



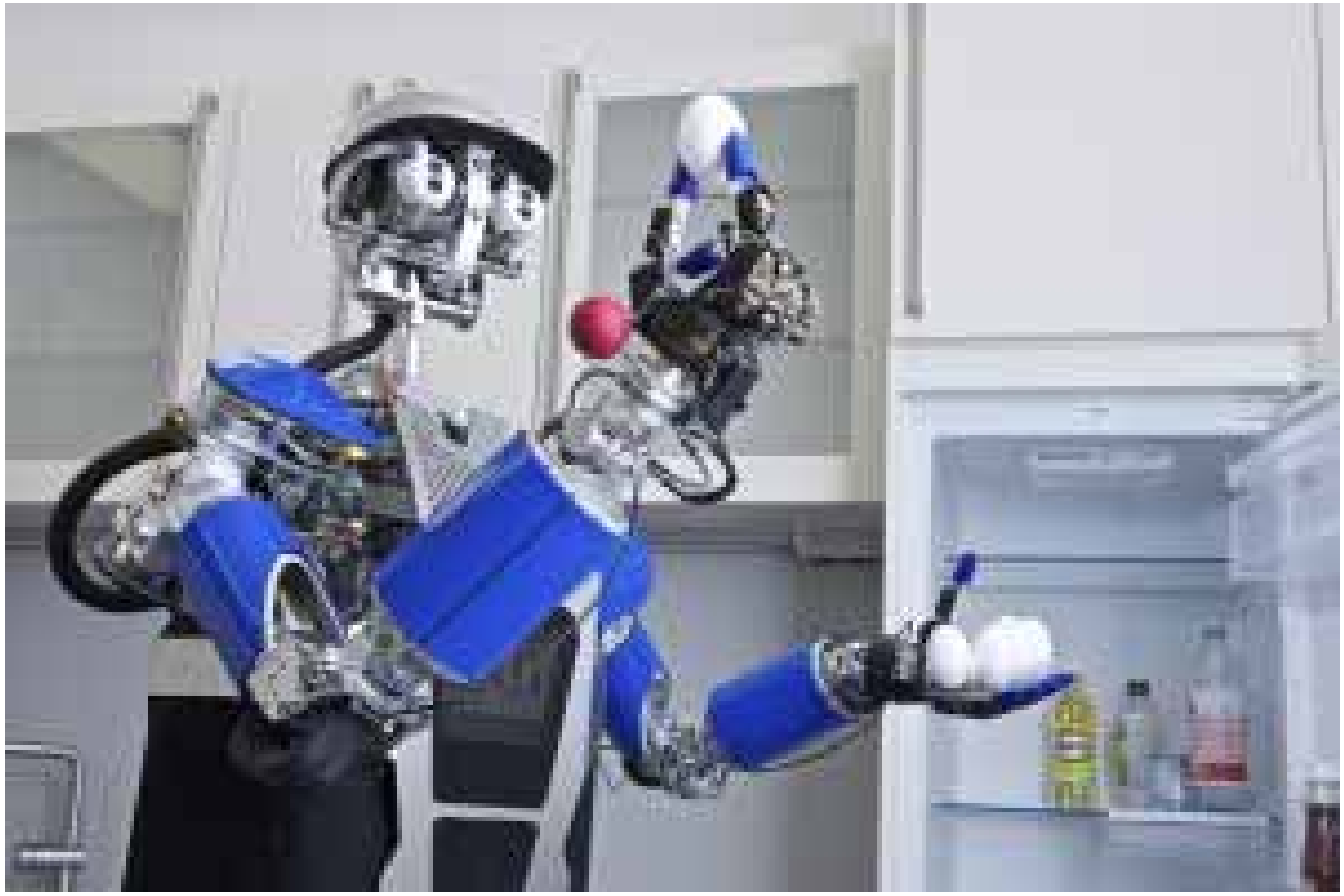
Interaction based on activity recognition

Half body- Humanoid

Manipulation:
Pick and place

Manipulation and actuation

Half body- Humanoid



Manipulation and actuation

The robot companion

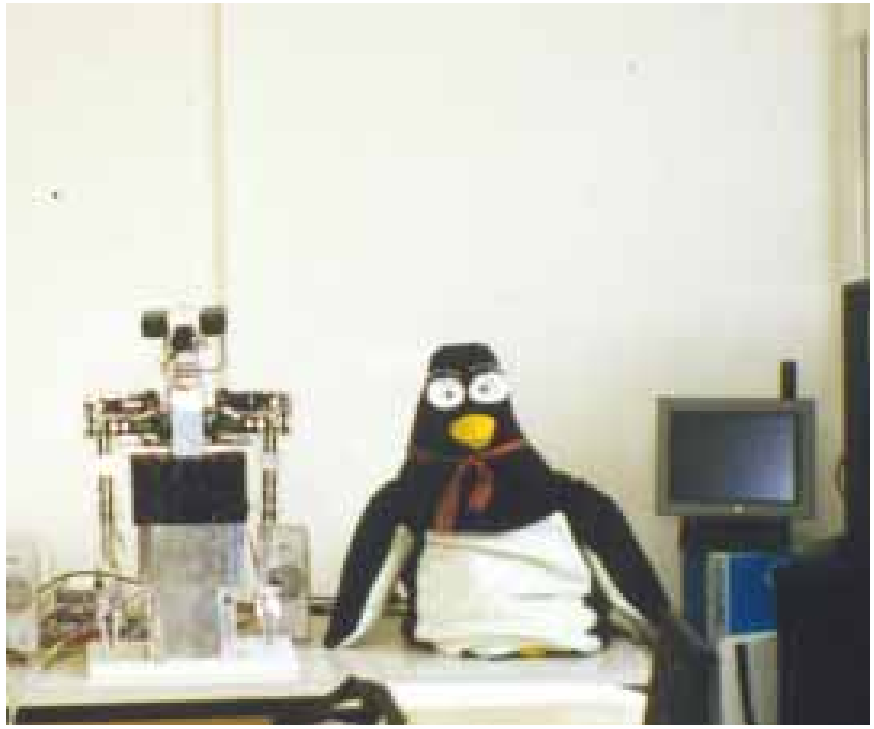
- Pets
- Toys /dolls
- Humanoids

Social Robots

The robot companion

Pets

The robot companion



Penguin: Robot receptionist (a precedent)

The robot companion

Toys / dolls

The robot companion

The robot companion

Humanoids

The robot companion

Humanoids

- Walking
- Stability
- Energy
- Autonomy

Assistant Robots (Manipulators, Robotic Wheelchairs)

Wheelchairs and Walkers

Human guided

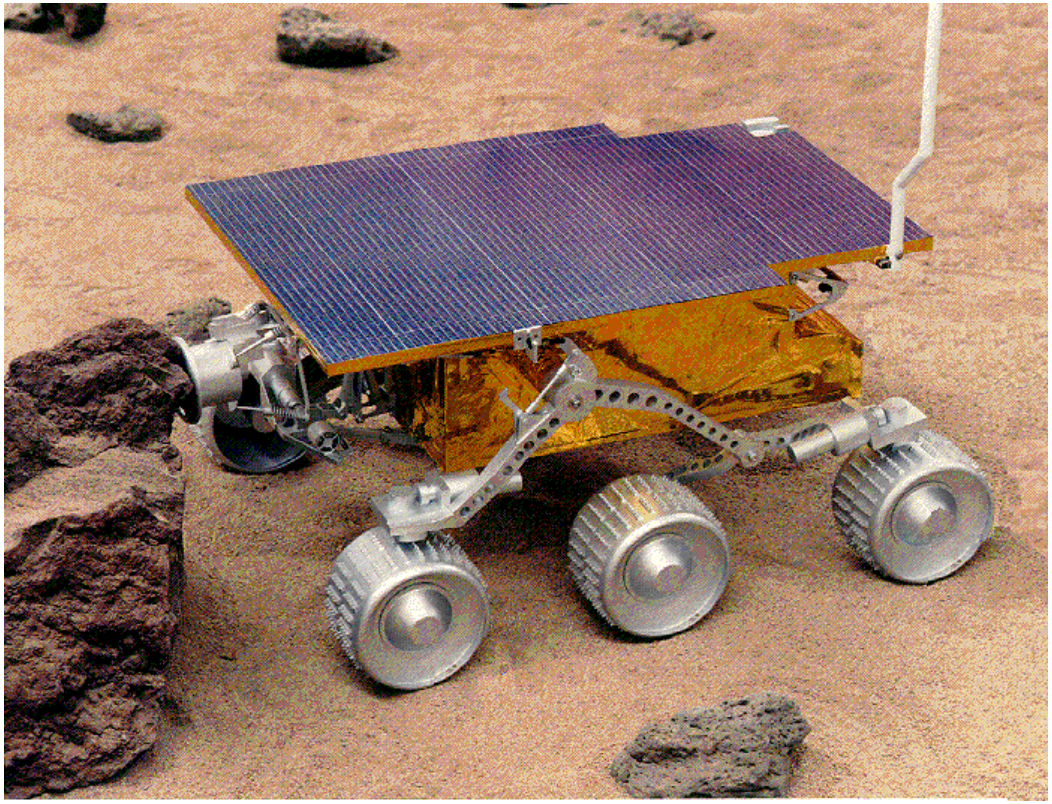
Navigation capabilities

Wheelchairs evolution

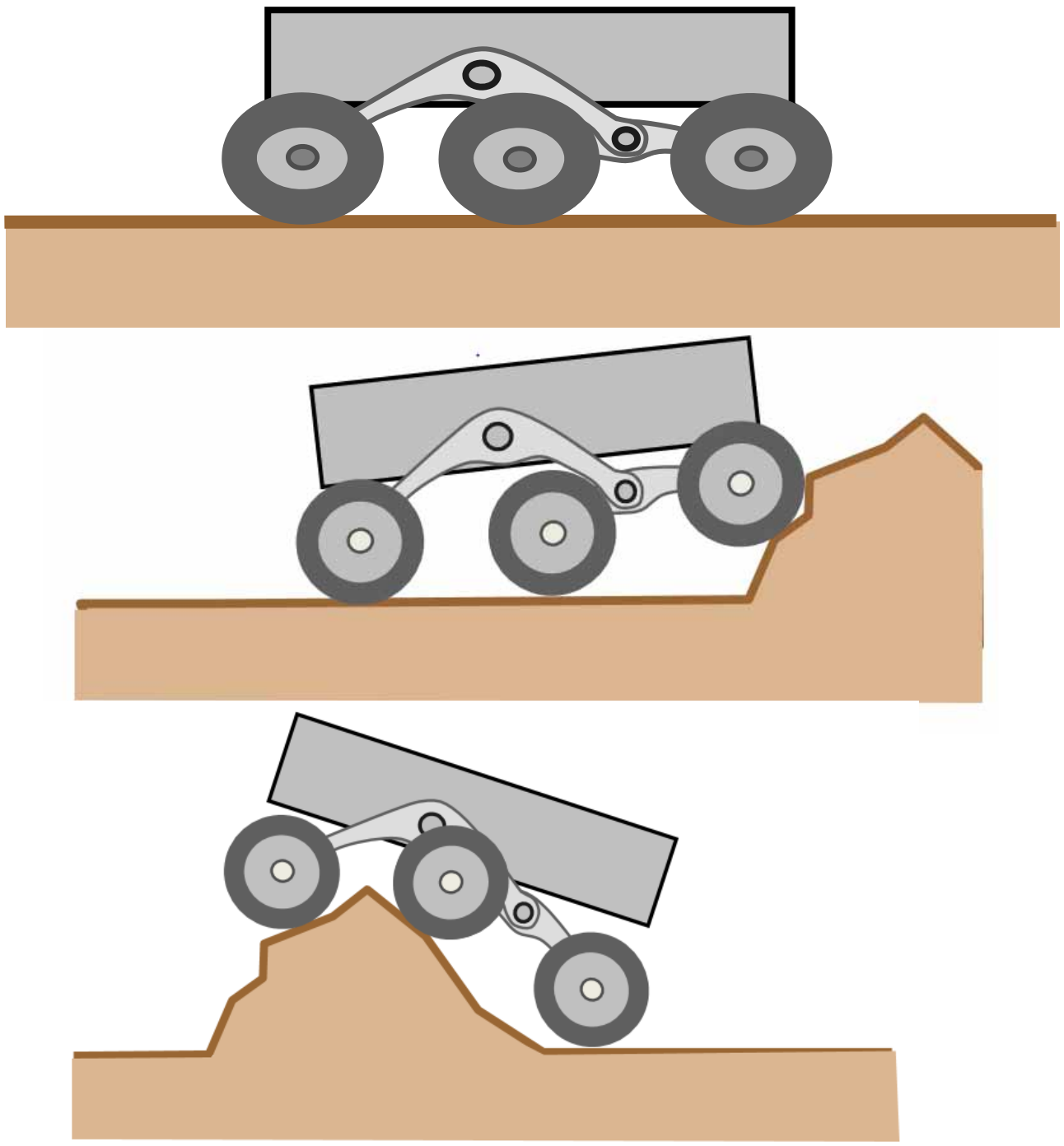
Adapted Vehicles

Wheelchairs evolution

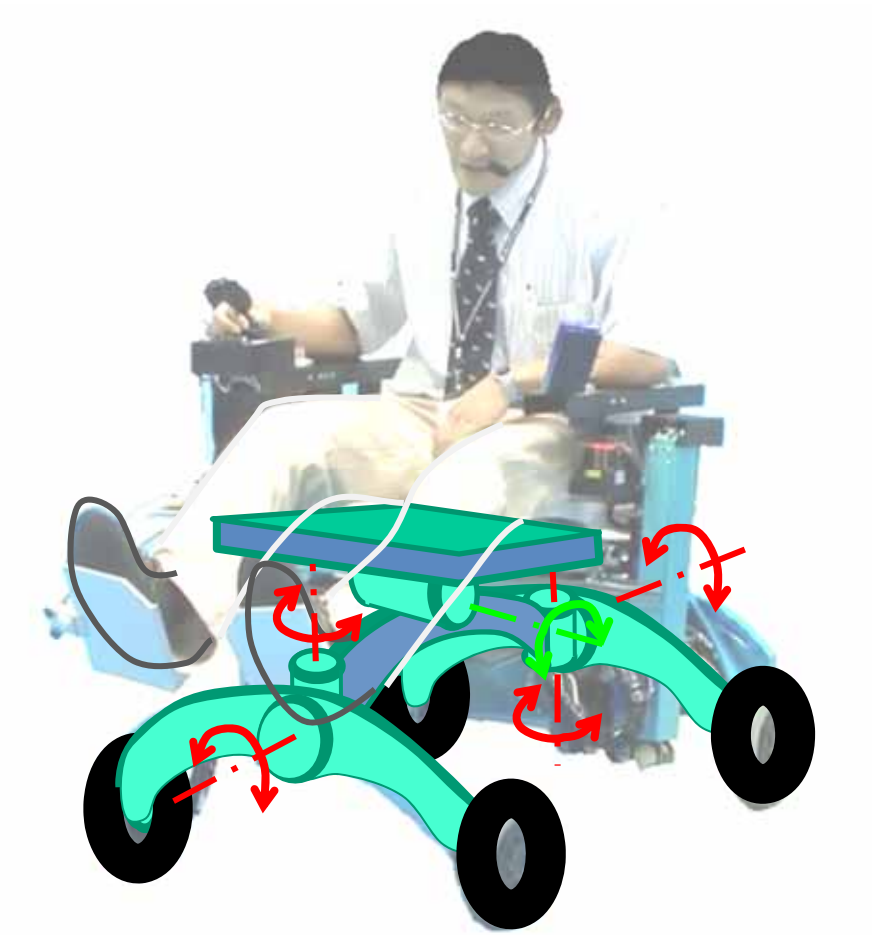
Multiple wheels



Mars exploration 1997, *Sojourner*



Wheelchairs evolution: articulated wheels



Wheelchair with robotized support

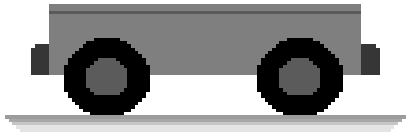
Type	Support	Speed	Characteristics
Wheels 	Flat surfaces No Obstacles	High (0-3m/s.)	Economic Light
Multiple wheels 	Flats surfaces No Obstacles	High (0-3 m/s.)	High maneuverability
Roller based wheels 	Very flats surfaces No Obstacles	Medium (0-1 m/s.)	Very High maneuverability
Caterpillar 	Irregular surfaces Climbing stairs	Medium (0-1 m/s.)	Adaptable to different heights. Standing up option. Ability to overcome obstacles
Legs 	Irregular surfaces No obstacles	Low on obstacles (0-0,4 m/s.)	Adaptable to different heights. Ability to overcome obstacles.
Hybrid 	Irregular surfaces No obstacles	Low on obstacles (0-0,4 m/s.)	Ability to overcome obstacles.

Robotizing wheelchairs

Automation

- Obstacle detection
- Speed regulation / Speed limit
- **Direction control**
- **Maneuverability / Trajectories**
- Localization / Navigation
- Wall following / lines

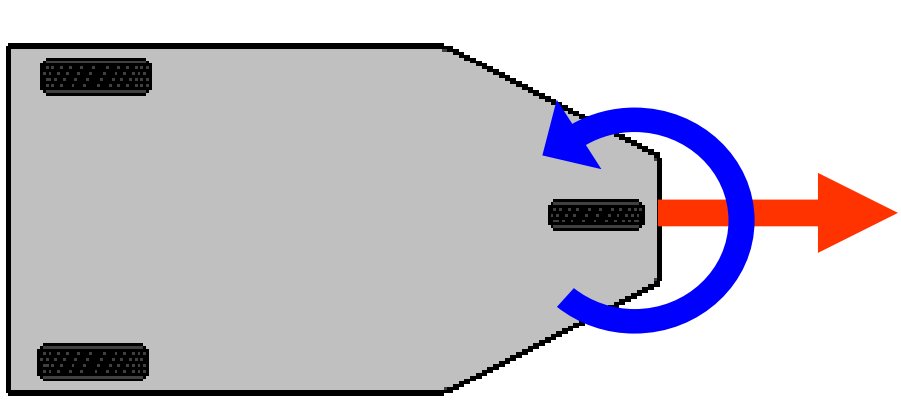
Trajectory → Inverse Kinematics

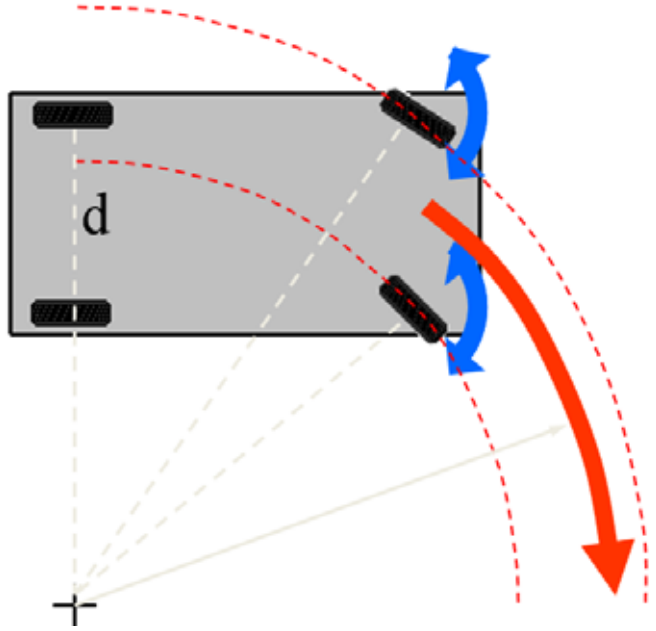


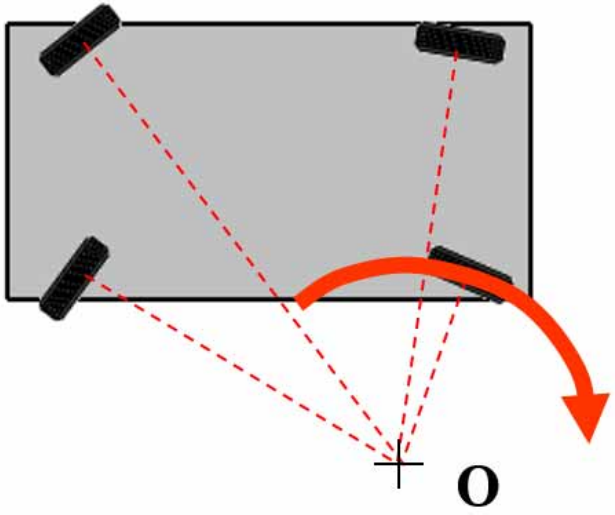
Wheels

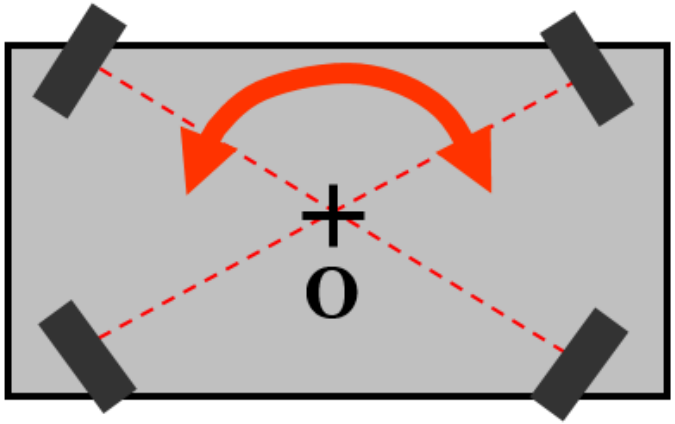
$X, Y, \theta \rightarrow \alpha_1, v_1, \alpha_2, v_2, \alpha_3, v_3, \alpha_4, v_4$

Example of architectures

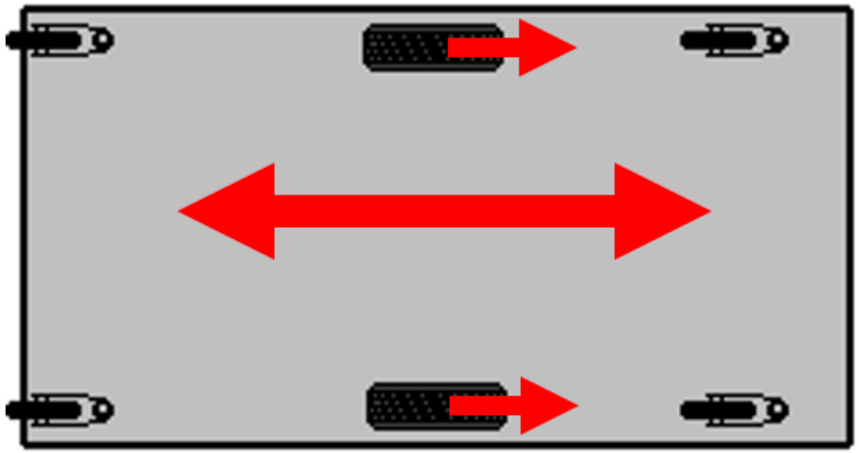








Example of architectures

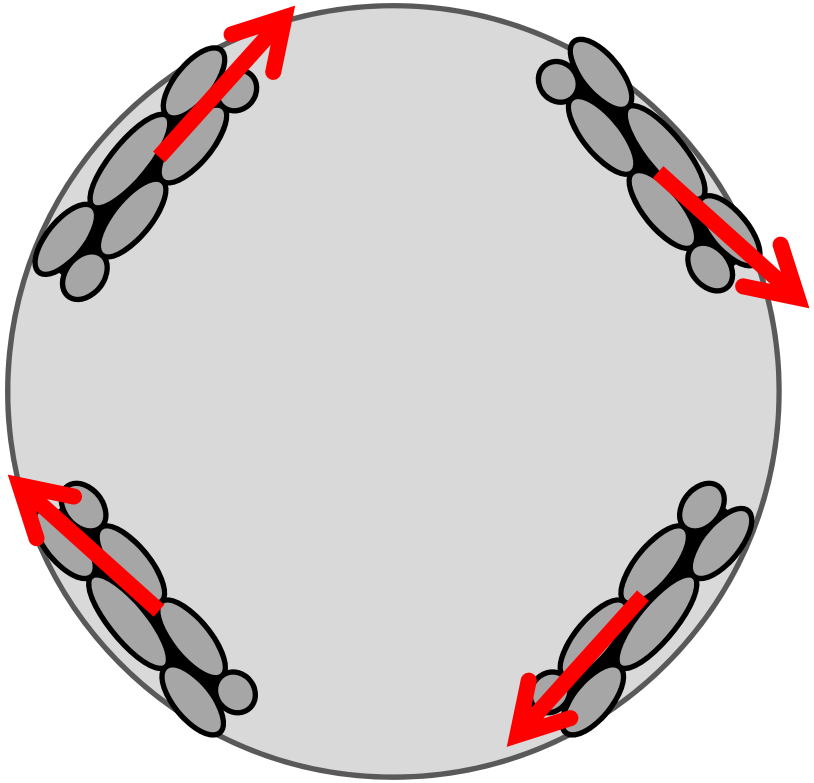


Special wheels

Mecano wheel

Omnidirectional

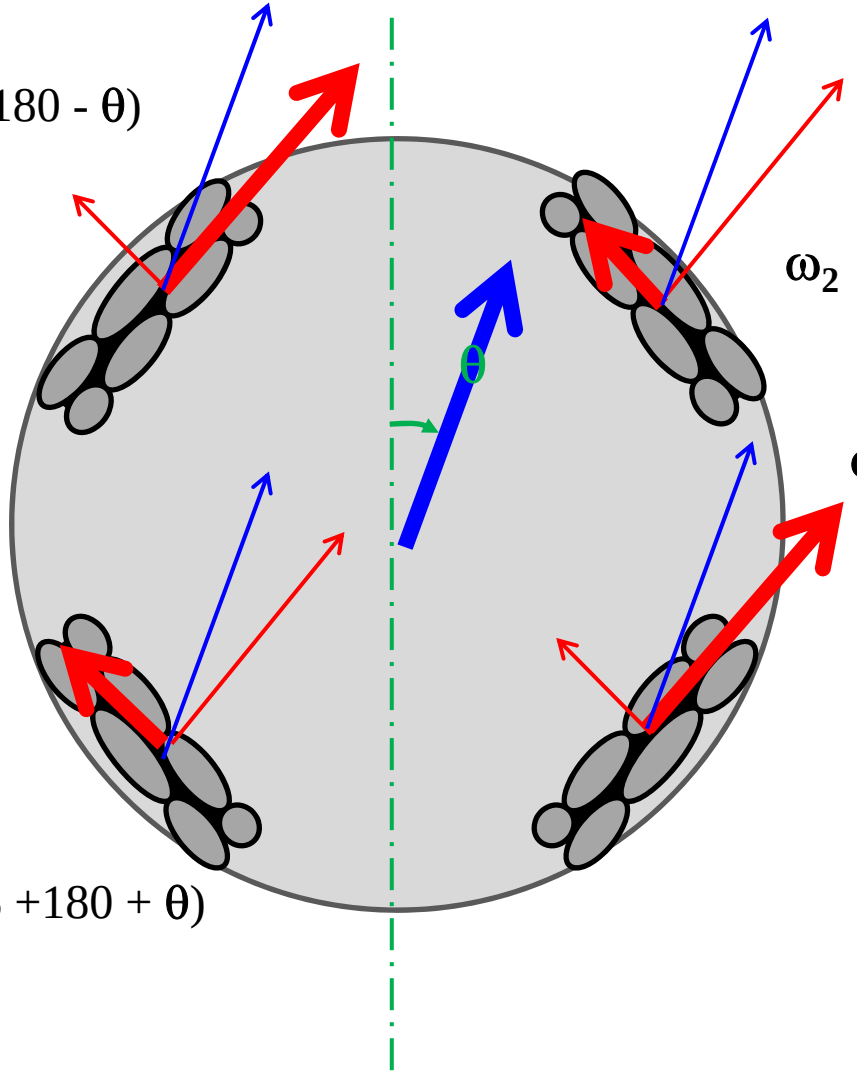
Vehicle with omnidirectional wheels



Same input to all wheels

How a vehicle with omnidirectional wheels can move straight ahead

$\omega_3 = V_c \cdot \cos(45 + 180 - \theta)$



$\omega_2 = V_c \cdot \cos(45 + \theta)$

$\omega_1 = V_c \cdot \cos(45 - \theta)$

$\omega_4 = V_c \cdot \cos(45 + 180 + \theta)$