Intent detection and somatosensory feedback

#01: Introduction: Human-Machine Interfaces, esp. in Reha- and Assistive Robotics

Claudio CASTELLINI, Sabine THÜRAUF

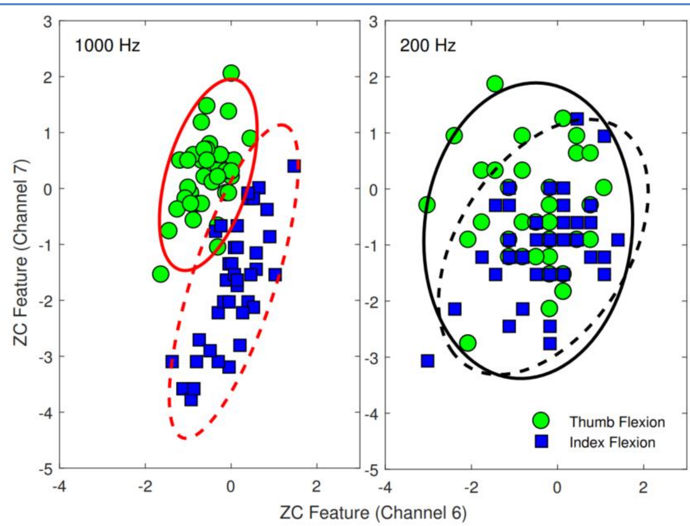

Figure 2. Differences in EMG patterns between using: (**left**) a 1000 Hz sampling rate; and (**right**) a 200 Hz sampling rate. ZC features are extracted from two different EMG channels (6 and 7) during thumb flexion (green circle markers and solid lines) and index flexion (blue square markers and dashed lines). Samples are from Subject 1 of Database 3.

EMG patterns related to two actions. Reproduced from Angkoon Phinyomark, Rami N. Khushaba and Erik Scheme, *Feature Extraction and Selection for Myoelectric Control Based on Wearable EMG Sensors*, MDPI Sensors 2018, 18, 1615

The *rubber hand illusion.* See Botvinick M, Cohen J., *Rubber hands 'feel' touch that eyes see.* Nature. 1998 Feb 19;391(6669):756. doi: 10.1038/35784. PMID: 9486643.

Lecture #01:

Introduction: Human-Machine Interfaces, esp. in Reha- and Assistive Robotics

- Introduction
  - motivation, terminology
- HMIs
  - especially in rehabilitation and assistive robotics
- Summary

Introduction

- The Institute of Medical Robotics is about robots in medicine
  - (how to build them)
  - how to control them
  - how to use them
  - how to put them at a patient‘s service.
- We focus (so far) on Rehabilitation and Assistive Robotics…
  - prosthetics
  - robots for musculoskeletal rehabilitation
  - robot aids to daily living
  - VR
- …and specifically, on
  - how to let our patients have these robots do
  - whatever they are supposed to do.
- examples: prosthetic control (myocontrol), exoskeleton control, exo-suit control.

Intent detection and somatosensory feedback

1. **Prosthetic Control**:Prosthetic control involves the interface between the user and the prosthetic limb, allowing the user to manipulate the limb in a way that simulates natural movement. This can include various control methods such as myoelectric control, where muscle signals from the residual limb are used to control the prosthetic, or mechanical control using cables and harnesses.
2. **Myocontrol:** Myocontrol specifically refers to a type of prosthetic control method that relies on electromyography (EMG) signals from the muscles in the residual limb. These signals are detected by sensors placed on the surface of the skin and are used to control the movements of the prosthetic limb. By contracting or relaxing specific muscles, the user can trigger different movements in the prosthetic device.
3. **Exoskeleton Control:** Exoskeletons are wearable robotic devices that augment the user's strength and endurance or assist with mobility. Exoskeleton control involves the interface between the user and the exoskeleton, allowing the user to command its movements. Control mechanisms can vary and may include joystick control, gesture recognition, or even brain-computer interfaces, where the user's brain signals are used to control the exoskeleton.
4. **Exo-suit Control:** Exo-suits are similar to exoskeletons but are typically more lightweight and focused on providing assistance with specific tasks rather than full-body support. Exo-suit control involves similar principles as exoskeleton control, allowing the user to manipulate the suit to perform desired actions. Control methods may include sensors embedded in the suit that detect the user's movements or external controllers.

Introduction

- Examples:
- prosthetic control (myocontrol)
- exoskeleton control
- exo-suit control
- controlling an avatar in VR
- teleoperation

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Introduction

- Examples:
- prosthetic control (myocontrol)
- exoskeleton control
- exo-suit control
- controlling an avatar in VR
- **Teleoperation**

Telemanipulation experiment or
humanoid platform TORO.
Participant's body pose monitor
IMUs.
Hand movement intention pred
based on sEMG.

- Teleoperation refers to the remote control of a device or system from a distance. In teleoperation, the operator is typically located away from the physical location of the device being controlled, often using some form of communication technology to transmit commands and receive feedback.

1. **SEMG (Surface Electromyography):** SEMG is a technique used to measure and record the electrical activity produced by muscles. It involves placing electrodes on the skin surface above the muscles of interest and detecting the electrical signals generated by muscle contractions. SEMG signals can provide information about muscle activation patterns, muscle fatigue, and force exertion.
2. **IMU (Inertial Measurement Unit):** An IMU is a device that measures and reports specific forces (acceleration) and angular rates (rotation) applied to the object it is attached to, typically in three axes (x, y, and z). It usually comprises sensors such as **accelerometers, gyroscopes, and magnetometers**. IMUs are commonly used in various applications, including motion tracking, navigation systems, robotics, and virtual reality. In the context of exoskeletons or prosthetics, IMUs can be used to detect the movement and orientation of limbs or joints, providing valuable data for control algorithms to adjust the behavior of the device accordingly.
3. **Acceleromete**r: An accelerometer is a sensor that measures acceleration forces along one or more axes. It detects changes in velocity and can determine the direction and magnitude of acceleration, whether it's caused by linear motion, gravity, or vibration.
4. **Gyroscope:** A gyroscope is a sensor that measures angular velocity or rotational motion around one or more axes. It provides information about changes in orientation and helps determine the rate of rotation or angular displacement.
5. **Magnetometer:** A magnetometer is a sensor that measures the strength and direction of a magnetic field. It can detect changes in magnetic fields caused by nearby ferromagnetic or magnetic materials, as well as the Earth's magnetic field.

Introduction

- Examples:
- prosthetic control (myocontrol)
- exoskeleton control
- exo-suit control
- **controlling an avatar in VR – Virtual Therapy arm**
- teleoperation

Introduction

- Examples:
- prosthetic control (myocontrol)
- **exoskeleton control**
- exo-suit control
- controlling an avatar in VR
- teleoperation

Motivation

- what do all examples have in common?
- the hardship the participants undergo while trying to control their artefacts.
- why is that?
- because they cannot operate normally their limbs any more
- that is why we need *smart* **Human-machine Interfaces** to operate these robots.

Motivation

- what do all exam
- the hardship the
- why is that?
- because they ca
- that is why we ne

CHAPTER

UPPER LIMB ACTIVE PROSTHETICS: AN OVERVIEW

19

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19.1 INTRODUCTION/MOTIVATION

The world around us is by and large shaped to be operated by *hands* and *arms:* our homes, our workplaces, the means of everyday transportation, etc. For this reason, the loss of an upper limb is a tragedy, leading to a severe impairment in daily-living operational functionality as well as to psychological damage. Given the current state of the art in upper limb prosthetics in general (not just in active prosthetics), such a loss is irreversible. The impact of upper limb loss in our modern, ever-safer societies is less dramatic than that of other severely disabling conditions, for example, diabetes, stroke, and neurodegenerative conditions, or even if compared to *lower* limb loss—in 2010 about 1900 traumati

Human-Machine Interaction

Human–computer interaction (**HCI**) is research in the design and the use of computer technology, which focuses on the interfaces between people (users) and computers. HCI researchers observe the ways humans interact with computers and design technologies that allow humans to interact with computers in novel ways.

A computer monitor provides a visual interface between the machine and the user.

As a field of research, human-computer interaction is situated at the intersection of computer science, behavioral sciences, design, media studies, and several other fields of study. The term was popularized by Stuart K. Card, Allen Newell, and Thomas P. Moran in their 1983 book, *The Psychology of Human-Computer Interaction,* although the authors first used the term in 1980,[1] and the first known use was in 1975.[2] The term is intended to convey that, unlike other tools with specific and limited uses, computers have many uses which often involve an open-ended dialogue between the user and the computer. The notion of dialogue likens human-computer interaction to human-to-human interaction: an analogy that is crucial to theoretical considerations in the field.[3][4]

- a Human-Machine Interface:
  - the system / channel through which interaction happens

- provocation:
  - can you think of a *really* autonomous, non-interactive *machine?*

HMIs

- a Human-Machine Interface: a system which
  - *(feedforward)* converts signals generated by a human being into control commands
  - *(such commands operate a machine in an environment)*
  - *(feedback)* converts environmental signals into physical stimuli

- prominent examples:
  - the handles of a wheelbarrow
  - the cockpit of your car
  - the surface of your smartphone + the operating system

HMIs

- a Human-Machine Interface: a system which
  - *(feedforward)* converts **signals generated by a human being** into **control commands**
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  - *(feedback)* converts **environmental signals** into **physical stimuli**

- prominent examples:
  - the handles of a wheelbarrow *(feedforward? feedback?)*
  - the cockpit of your car *(feedforward? feedback?)*
  - the surface of your smartphone + the operating system *(feedforward? feedback?)*

HMIs

- characteristics of a HMI:

1. reliability
2. dexterity
3. ease of use
4. flexibility

HMIs

- characteristics of a HMI:

1. **reliability**

   does the HMI enable you *precisely control* your machine?
   does your machine do *exactly* what you want it to do,
   exactly *when and only when* you want it to do it?

HMIs

- characteristics of a HMI:

1. reliability
2. **Dexterity -** "Dexterity" refers to skill and agility in performing tasks, especially those that require precision and coordination.
   can you fully control your machine?
   does it enable you use all its potential?
   can you control each of its degrees of freedom?

HMIs

- characteristics of a HMI:

1. reliability
2. dexterity
3. **ease of use**

   how long does it take you to master your machine, using this HMI?

   how big is the user‘s manual?

   how exciting and fun is it to use your machine via this HMI?

HMIs

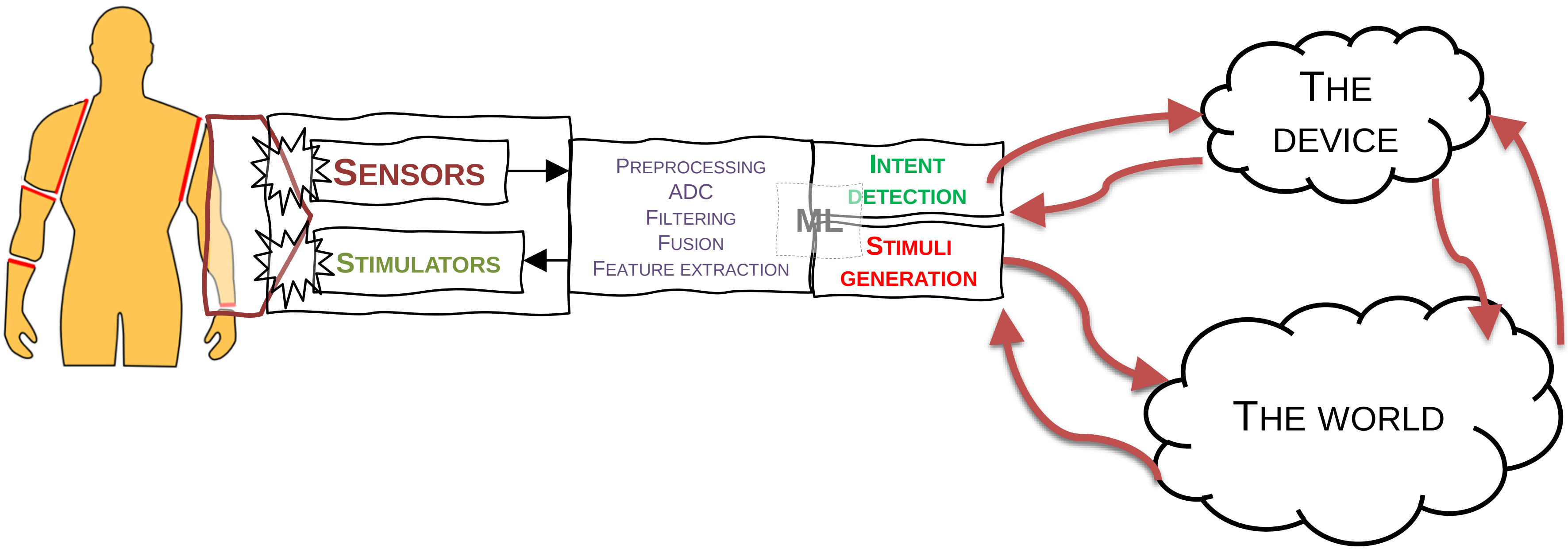
- characteristics of a HMI:

1. reliability
2. dexterity
3. ease of use
4. **flexibility**
   how much do you need to adapt to it?
   how much do you need to know about your machine to use it?
   is it suited for both end-users and experts?

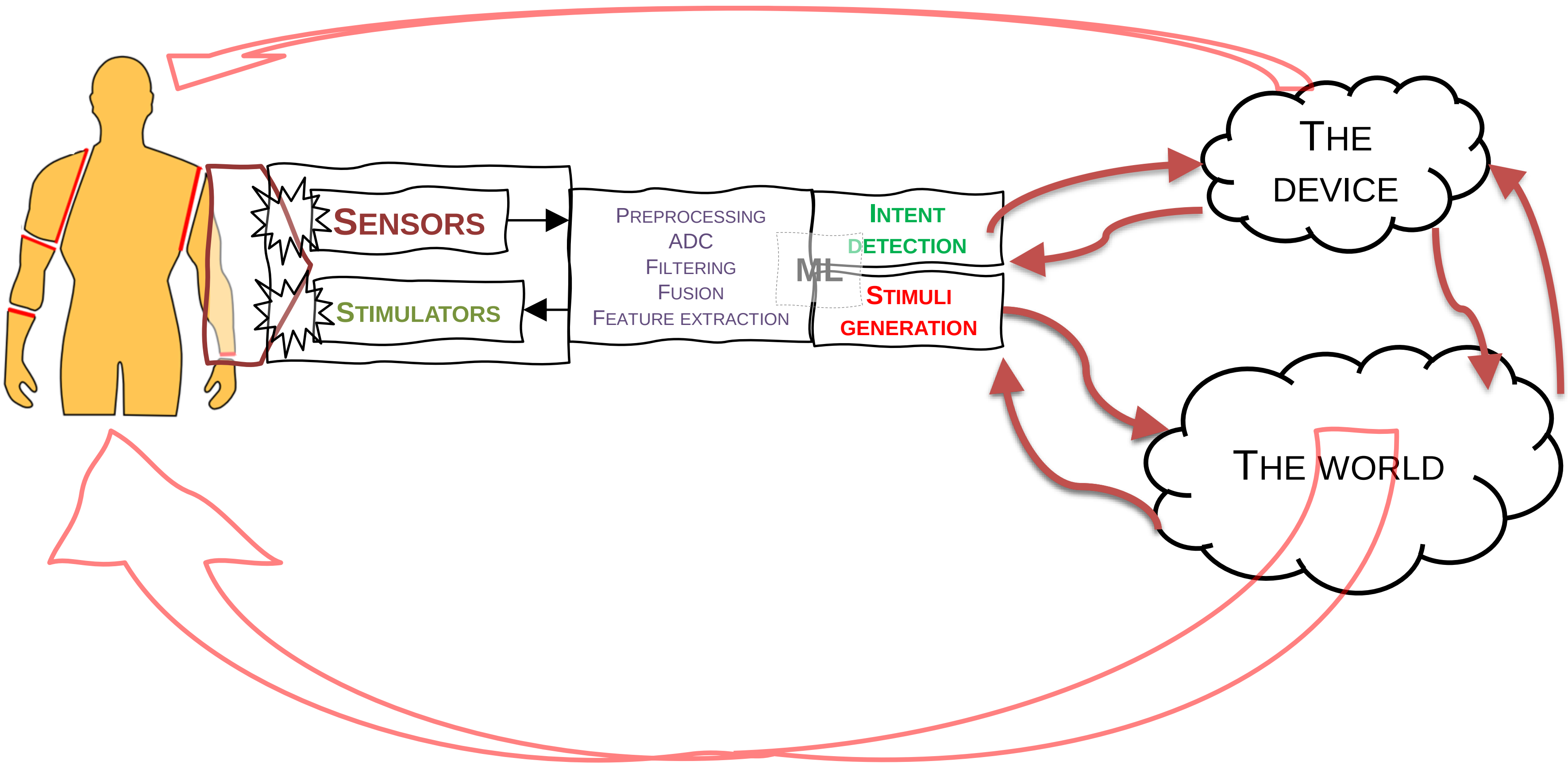
HMIs for the disabled

- not surprisingly however, most HMIs are operated through **arms/hands/fingers**
- what if you cannot use your limbs then?
- (still, the four afore-mentioned characteristics should hold.)
- in this case you “simply”
  - replace commands issued via fingers and hands with **signals denoting the intended activity**
  - replace force / contact feedback with **somato-sensory feedback**
  - replace standard physical interacting devices (joystick, handle, touchscreen, …) with a *socket*
- Specialized sensory receptors located in the skin, muscles, joints, and other tissues detect changes in the environment or the body.

HMIs for the disabled



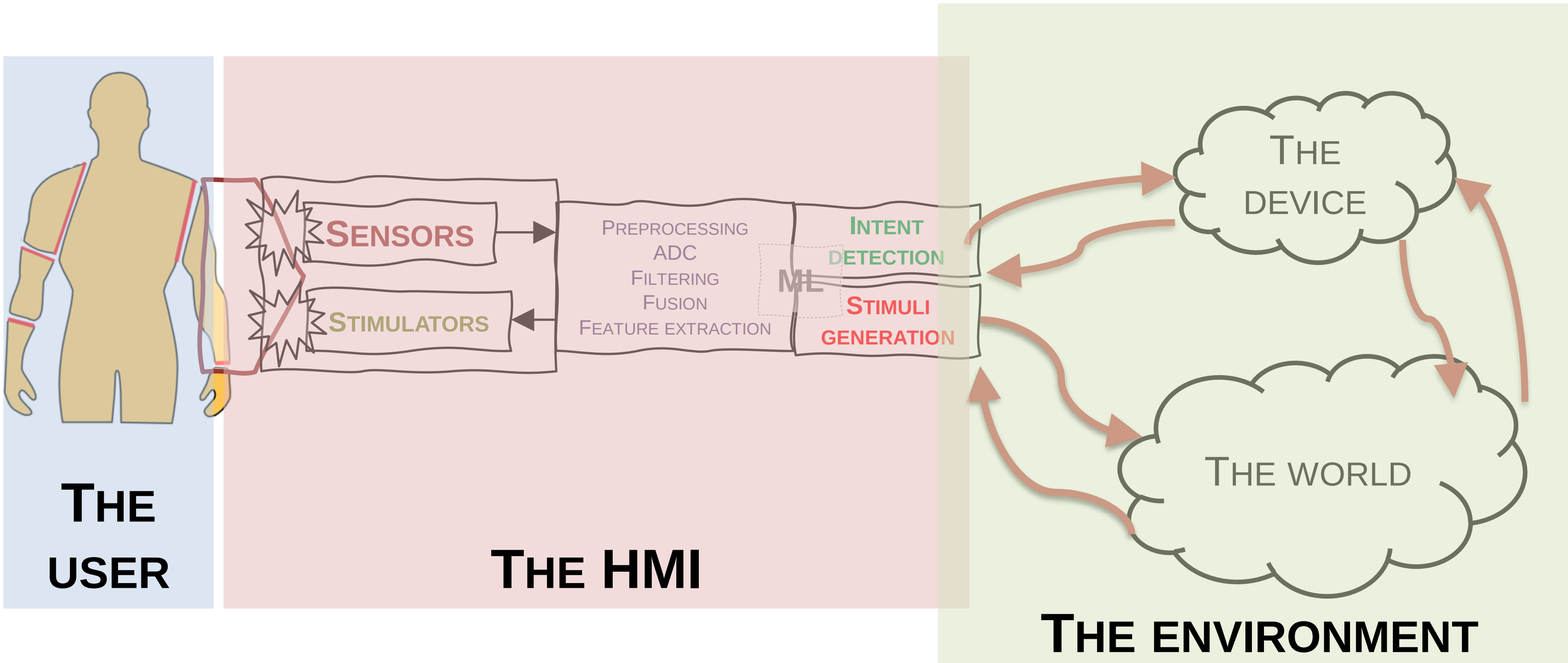
HMIs for the disabled



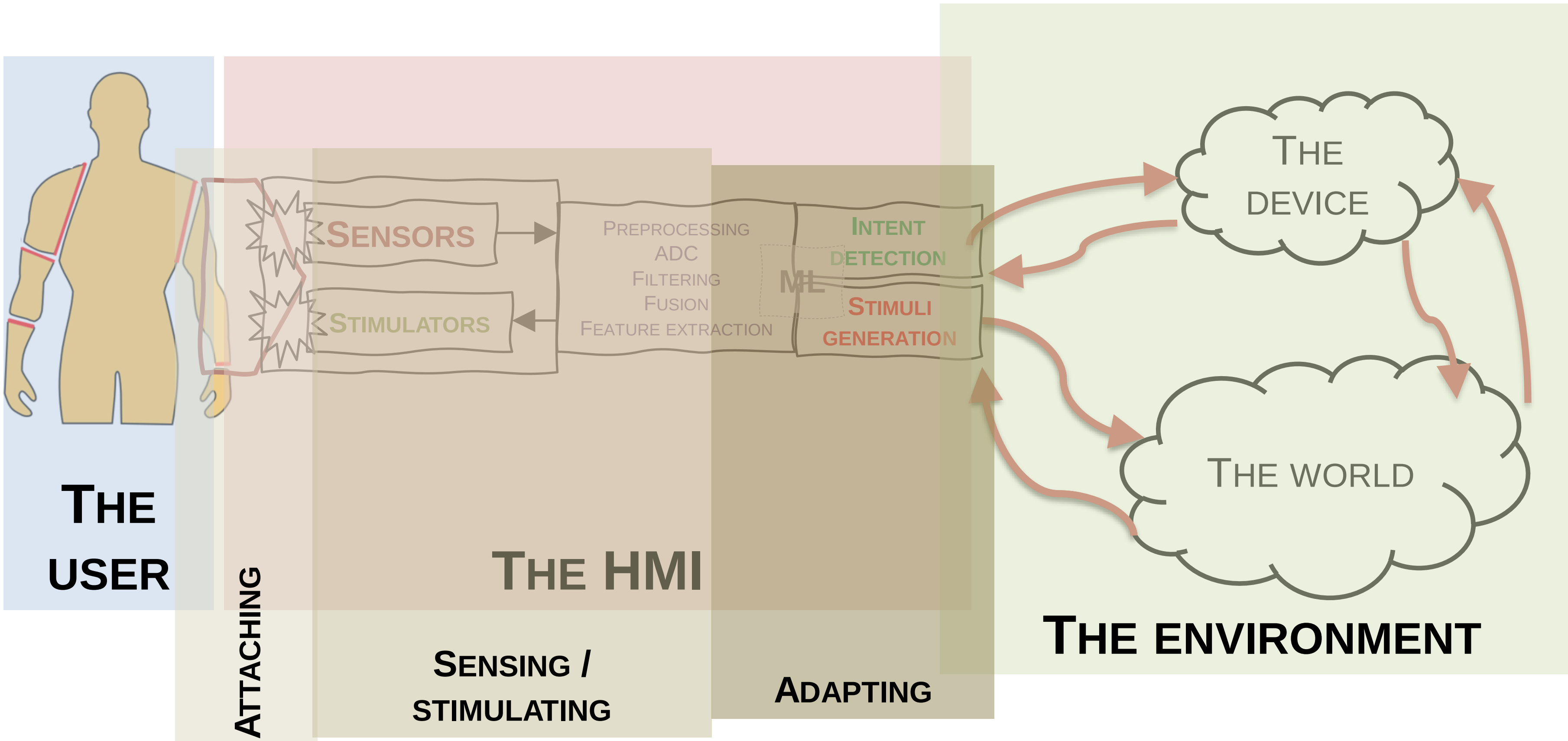
Intent detection and somatosensory feedback

1. Stimulating, on the other hand, refers to the act of applying controlled signals or energy to the human body or a biological system to evoke a response.
2. **Sensing:** Sensing refers to the ability of a device to detect or perceive information from its environment or from the human body itself.

HMIs for the disabled

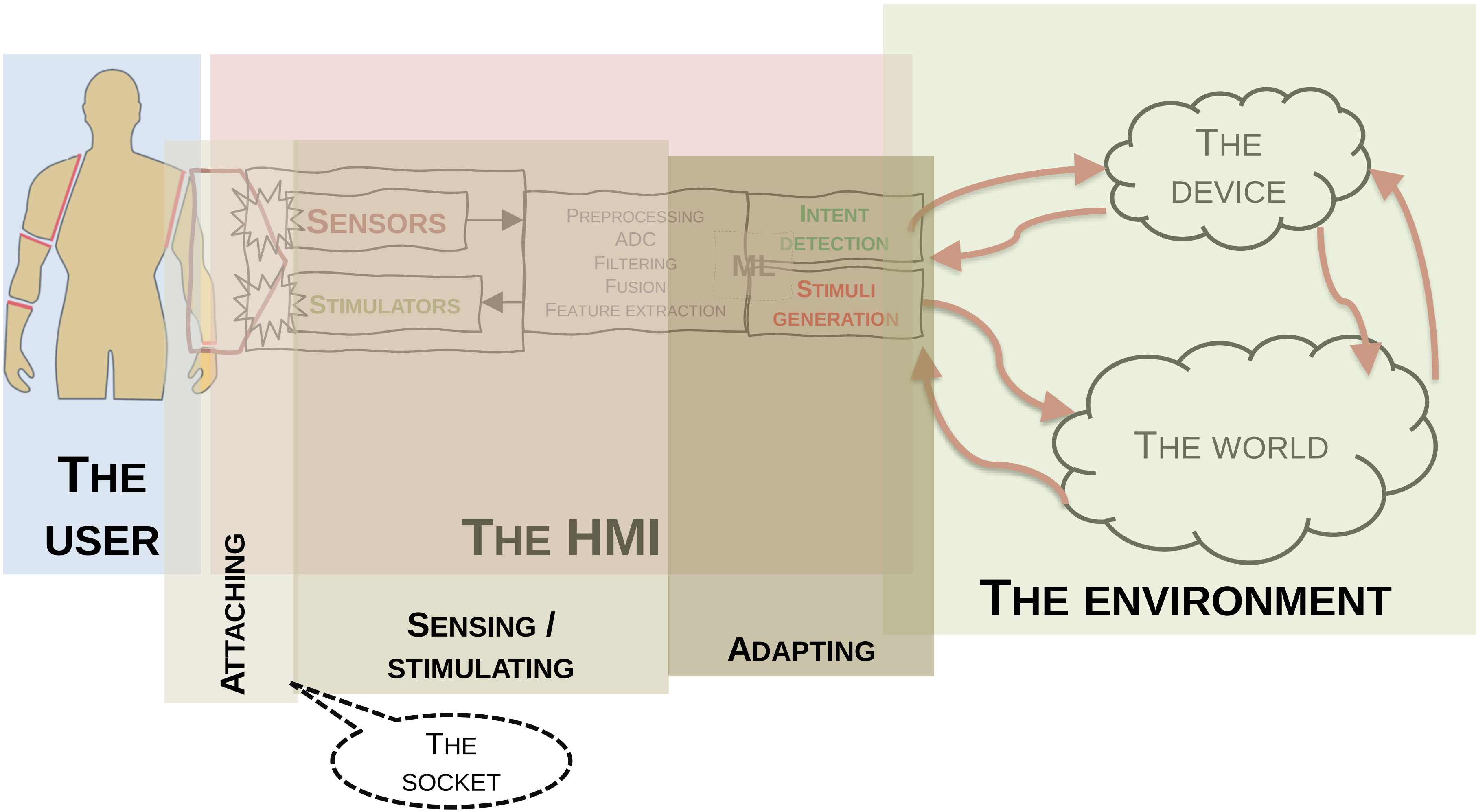


HMIs for the disabled



Intent detection and somatosensory feedback

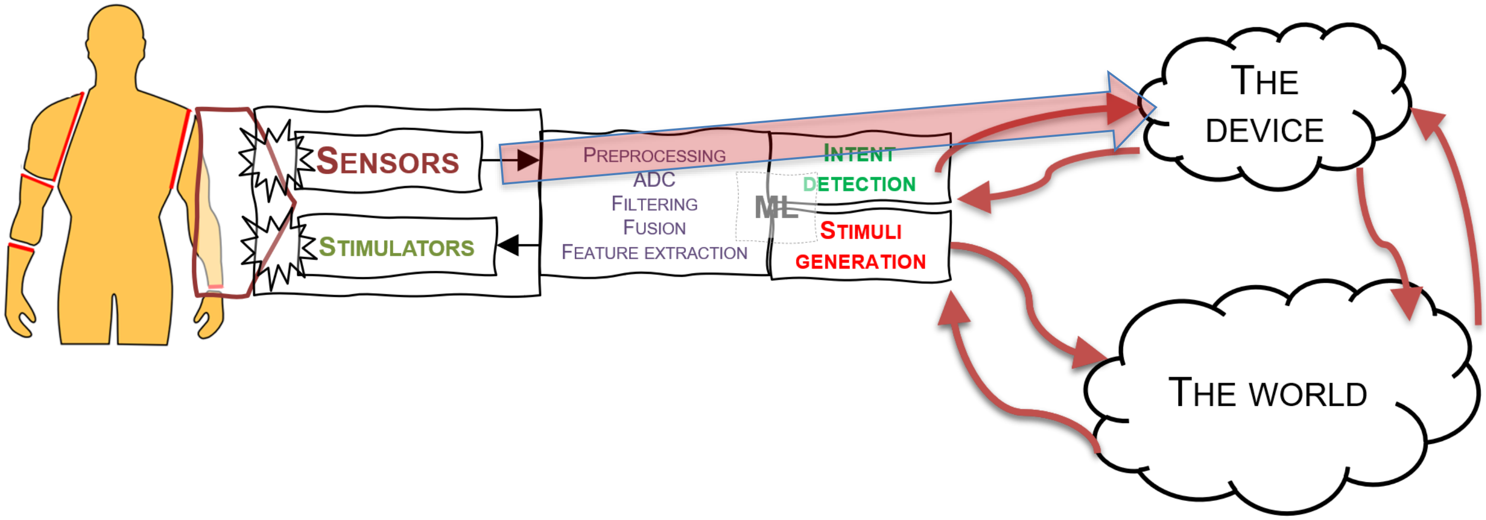
HMIs for the disabled



(more) Terminology

- intent detection: the feed-forward path
  - detecting signals out of the participant's body **using sensors**
  - converting them into control commands for your robot

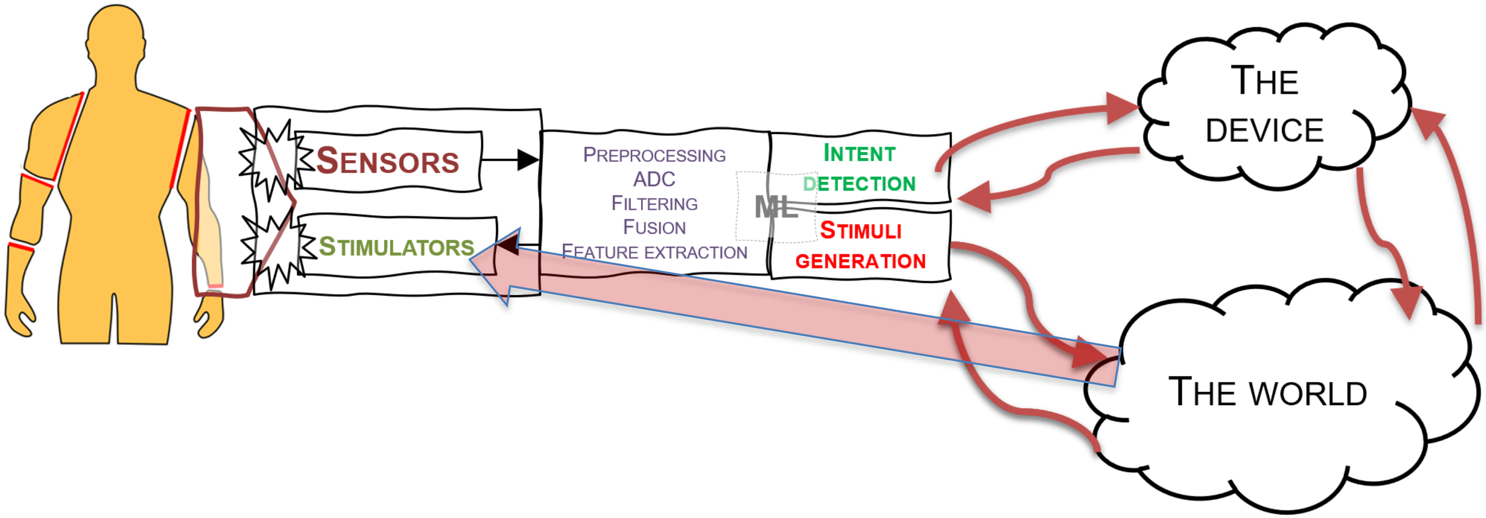
HMIs for the disabled



(more) Terminology

- somatosensory feedback: the feed-back path
  - detecting signals from the environment and the robot
  - converting them into bodily stimuli for your participant eg – to adjust the signals

HMIs for the disabled



(more) Terminology

- intent detection: the feed-forward path
  - detecting signals out of the participant‘s body – using sensors
  - converting them into control commands for your robot
- somatosensory feedback: the feed-back path
  - detecting signals from the environment and the robot
  - converting them into bodily stimuli for your participant – for force adjustment
- **bidirectional HMI**: an HMI putting together these two paths.
  - it must be unobtrusive - When something is described as "unobtrusive," it means that it doesn't attract attention or interfere with normal activities. In the context of sensing and stimulating technologies, designing them to be unobtrusive is important for ensuring that they integrate seamlessly into the user's life without causing discomfort or inconvenience.
  - it must work in real-time
  - it must be reliable and dexterous
  - and it must be low-power

(more) Terminology

- intent detection: the feed-forward path
  - detecting signals out of the participant's body
  - converting them into control commands for your robot
- somatosensory feedback: the feed-back path
  - detecting signals from the environment and the robot
  - converting them into bodily stimuli for your participant
- bidirectional HMI: an HMI putting together these two paths.
  - it must be **unobtrusive**
  - it must work in **real-time**
  - it must be **reliable** and **dexterous**
  - and it must be **low-power**
- this is our quest in IDF.

Terminology

- anatomical position, orientation, directions and planes

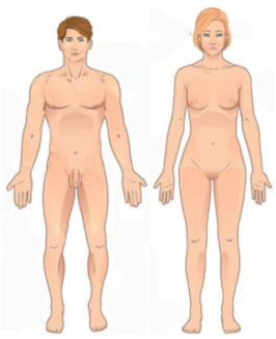
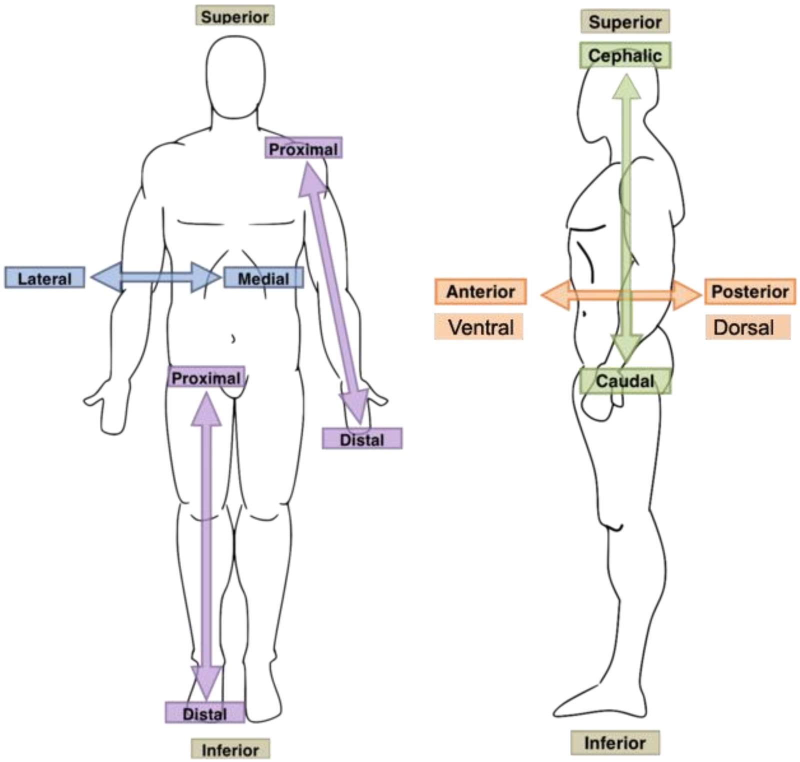


Figure 1-1. These two people are both in anatomical position.



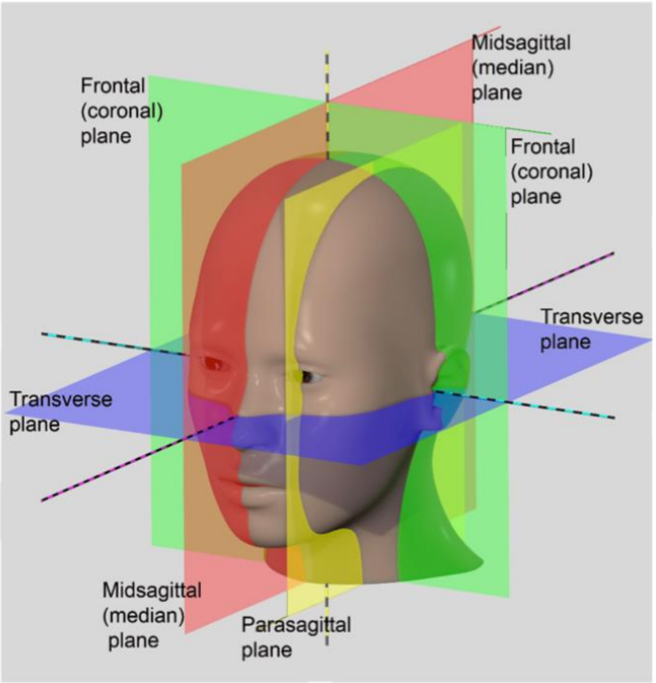


Figure 1-2. The different sectional planes used to expose internal structures.

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- **Paramedian plane**-"Sagittal" refers to a plane that divides the body into left and right halves.
- "Para-" means "near" or "alongside."
- Therefore, the "parasagittal plane" is a plane that runs parallel to the midline of the body but does not pass directly through it. It divides the body into unequal left and right portions.

- **Midsagittal** - **Midline:** The midline refers to an imaginary line that runs down the center of the body, dividing it into symmetrical left and right halves.

- The transverse plane, also known as the horizontal plane or axial plane, is an anatomical term used to describe a plane that divides the body into superior (upper) and inferior (lower) portions.
- **Transverse:** Transverse means across or perpendicular to the long axis of the body.

- The frontal plane, also known as the coronal plane, is an anatomical term used to describe a vertical plane that divides the body into front (anterior) and back (posterior) portions.

The **torso**, also referred to as the trunk, is the main part of the human body, excluding the head, neck, arms, and legs. It includes the chest, abdomen, and pelvis regions. The torso contains vital organs such as the heart, lungs, stomach, liver, intestines, and reproductive organs.

Terminology

- anatomy of the torso, bones

- shoulder
  - forms the *pectoral girdle*
- consists of two bones
  - the *scapula* (shoulder blade) – green – connects humerus and collar bone
  - the *clavicula* (collar bone)

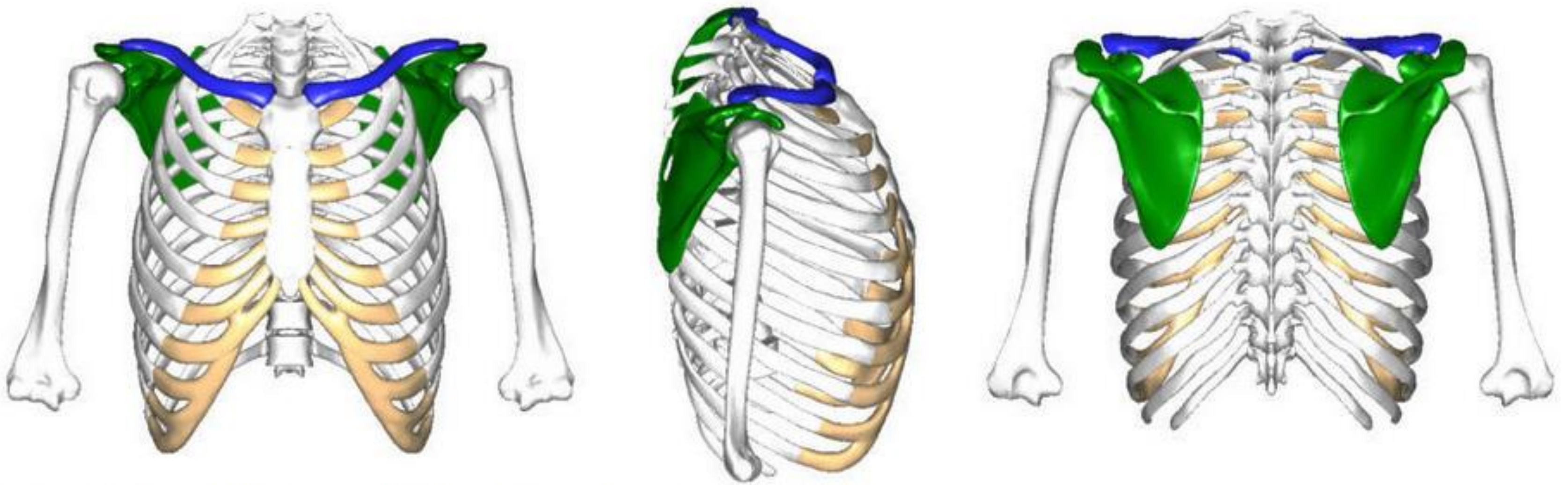

Figure 7-5. The pectoral girdle. The scapulae are in green and the clavicles are in blue.

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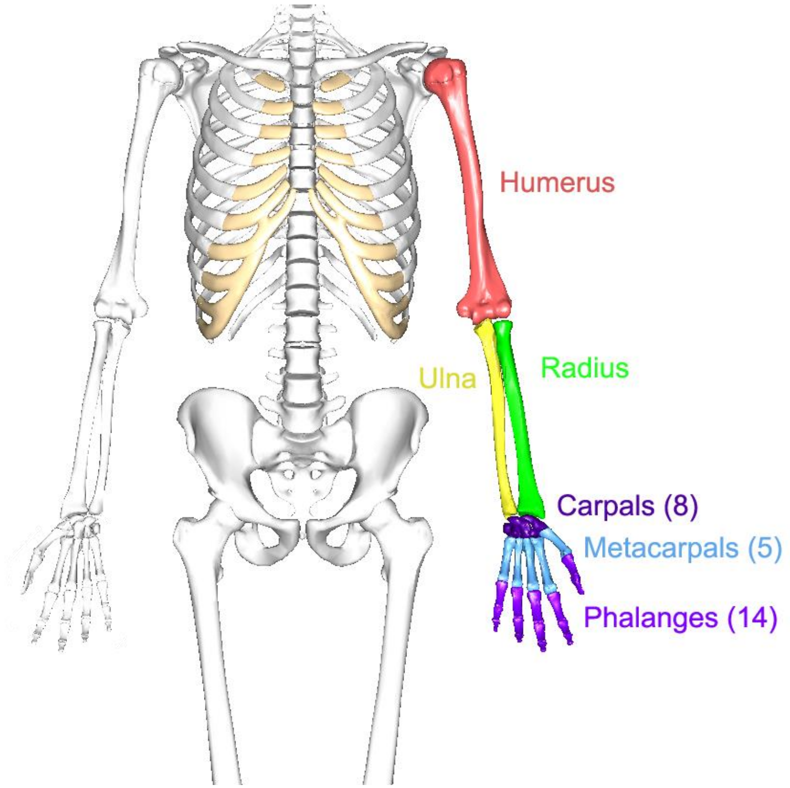
Terminology

- anatomy of the upper limb, bones



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- 30 bones in total
  - try to distinguish the ulna from the radius! (URT)

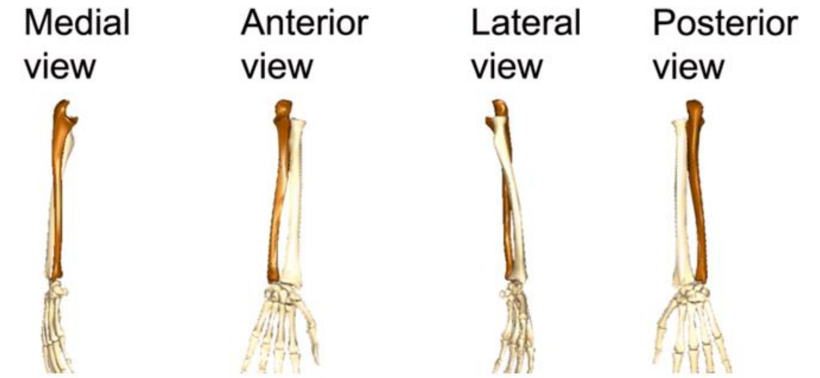


Figure 7-10. The left ulna (in brown) and its major markings and processes.

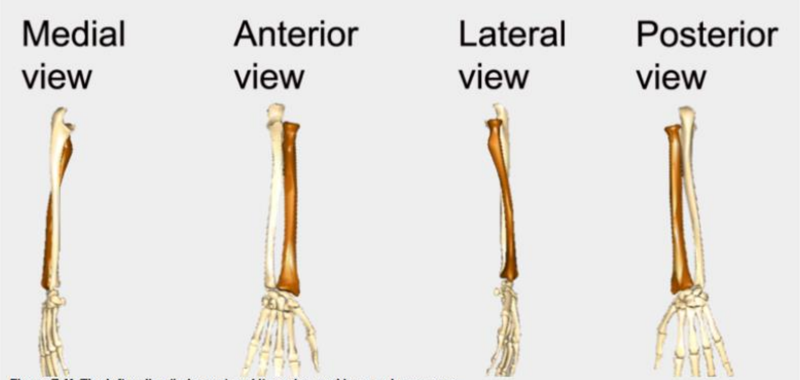
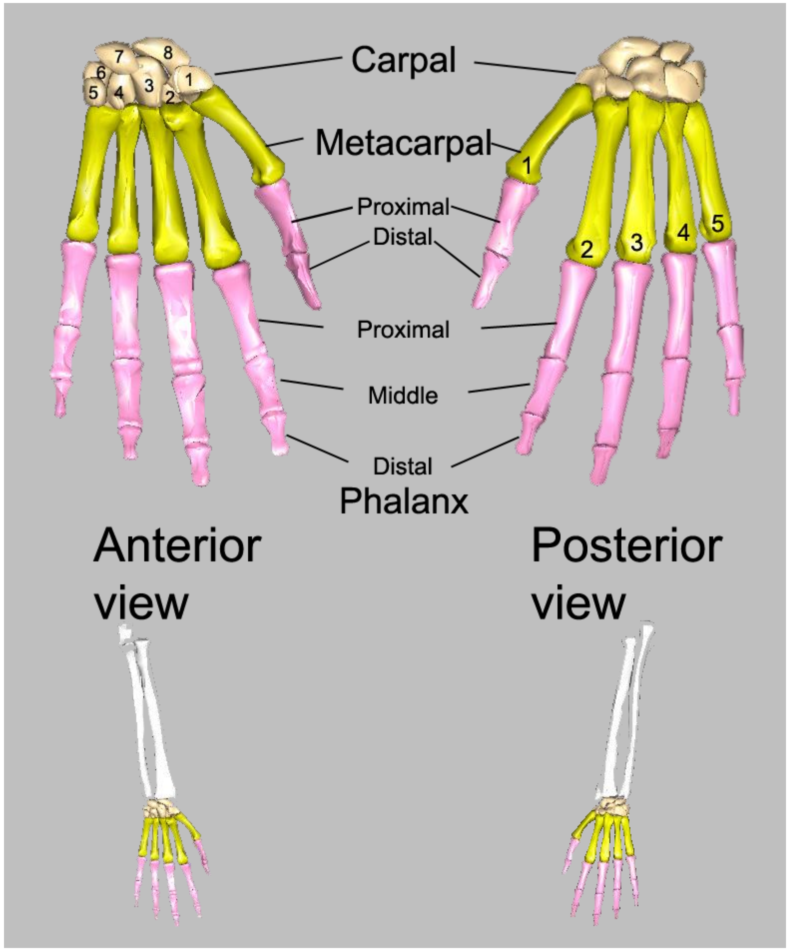


Figure 7-11. The left radius (in brown) and its major markings and processes.

Terminology

- anatomy of the upper limb, bones
- 30 bones in total
  - try to distinguish the ulna from the radius! (URT)
- in the hand, joints are called after the bones they refer to:
  - MCP, metacarpo-phalangeal
  - PIP, proximal inter-phalangeal
  - DIP, distal inter-phalangeal



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Terminology

- anatomy, movements relative to the body

• *Flexion*	Decreasing the angle between two bones
• *Extension*	Increasing the angle between two bones
• *Abduction*	Moving a body part away from the midline
• *Adduction*	Moving a body part towards the midline
• *Rotation*	Turning movement of a bone about its long axis
• *Supination*	Rotation of the forearm or foot so that the palm or sole is moved to face anteriorly
• *Pronation*	Rotation of the forearm or foot so that the palm or sole is moved to face posteriorly

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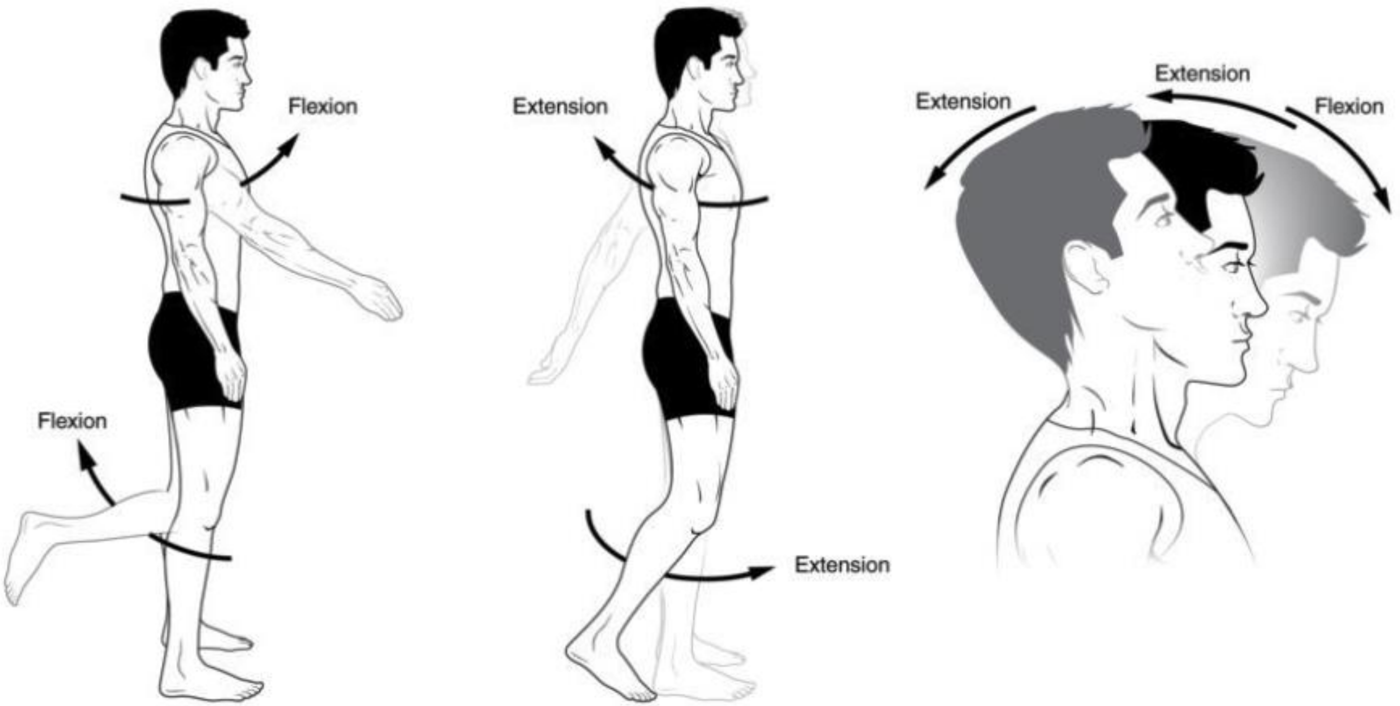
Terminology

- anatomy, movements relative to the body



(a) and (b) Angular movements: flexion and extension at the shoulder and knees

(c) Angular movements: flexion and extension of the neck

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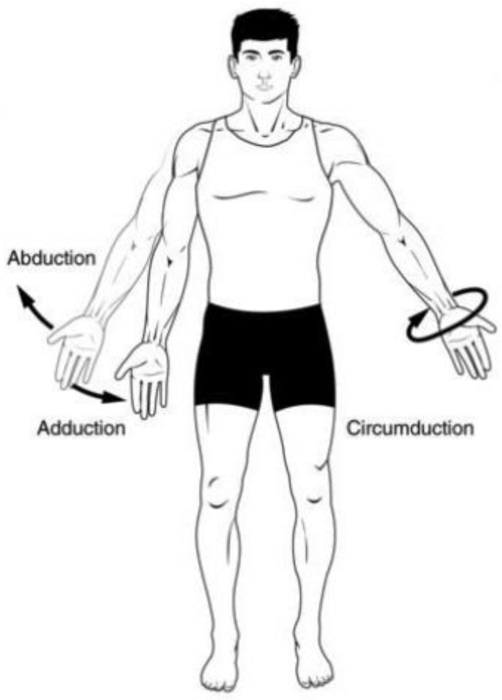
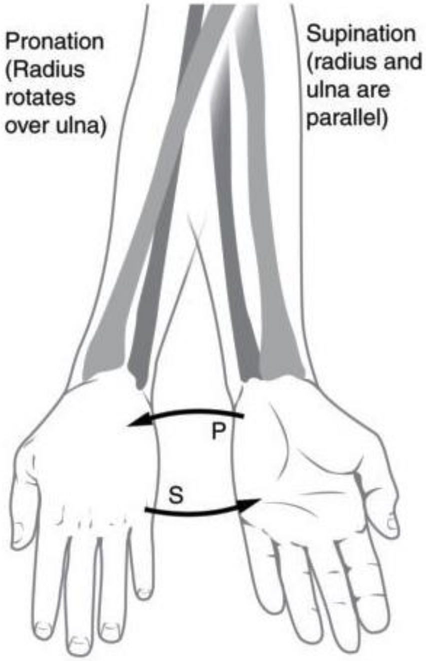
Terminology

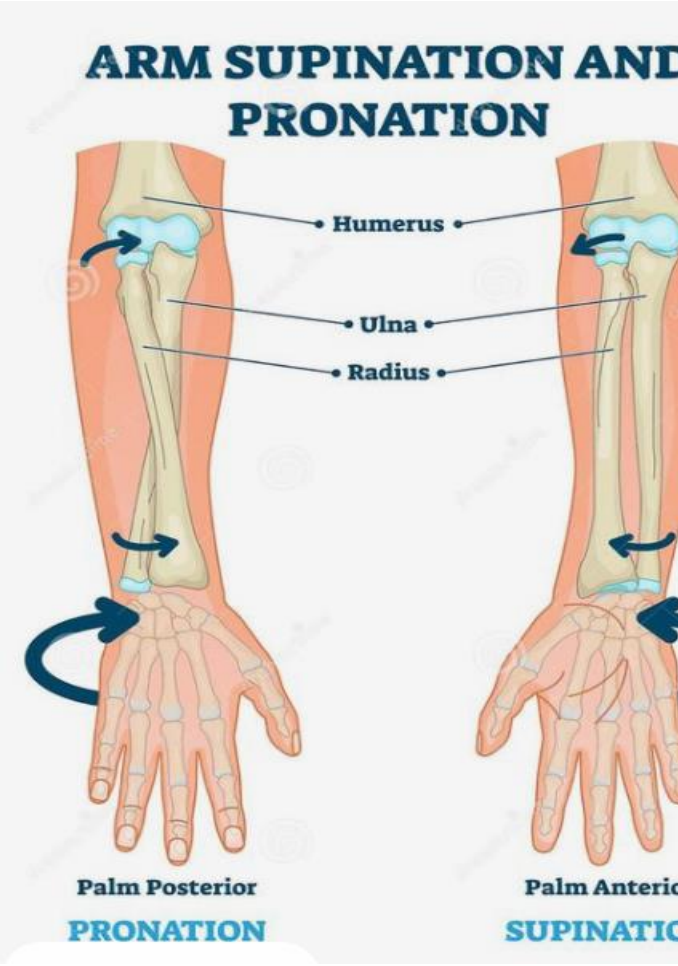
- anatomy of the upper limb, movements



(e) Angular movements: abduction, adduction, and circumduction of the upper limb at the shoulder



(g) Pronation (P) and supination (S)



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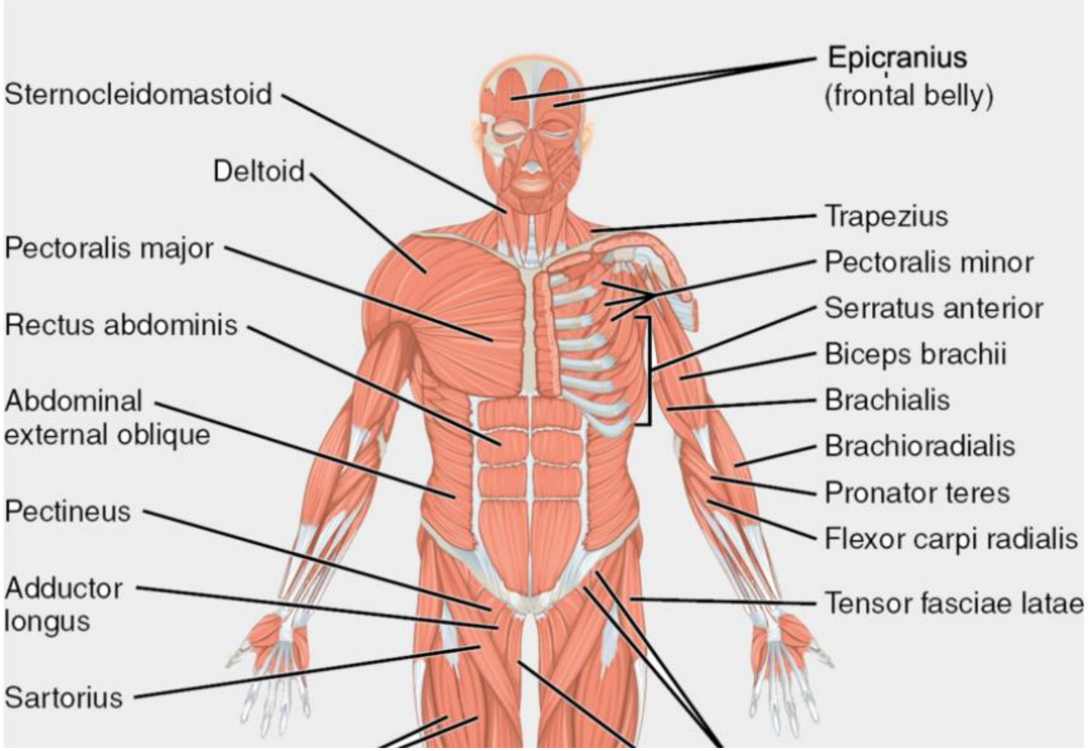
Terminology

- anatomy, muscles

- shoulder
  - operated by a complex set of muscles, of which these are of interest to us:
  - *M. Trapezius*
  - *M. Deltoideus*



(anterior view)

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Terminology

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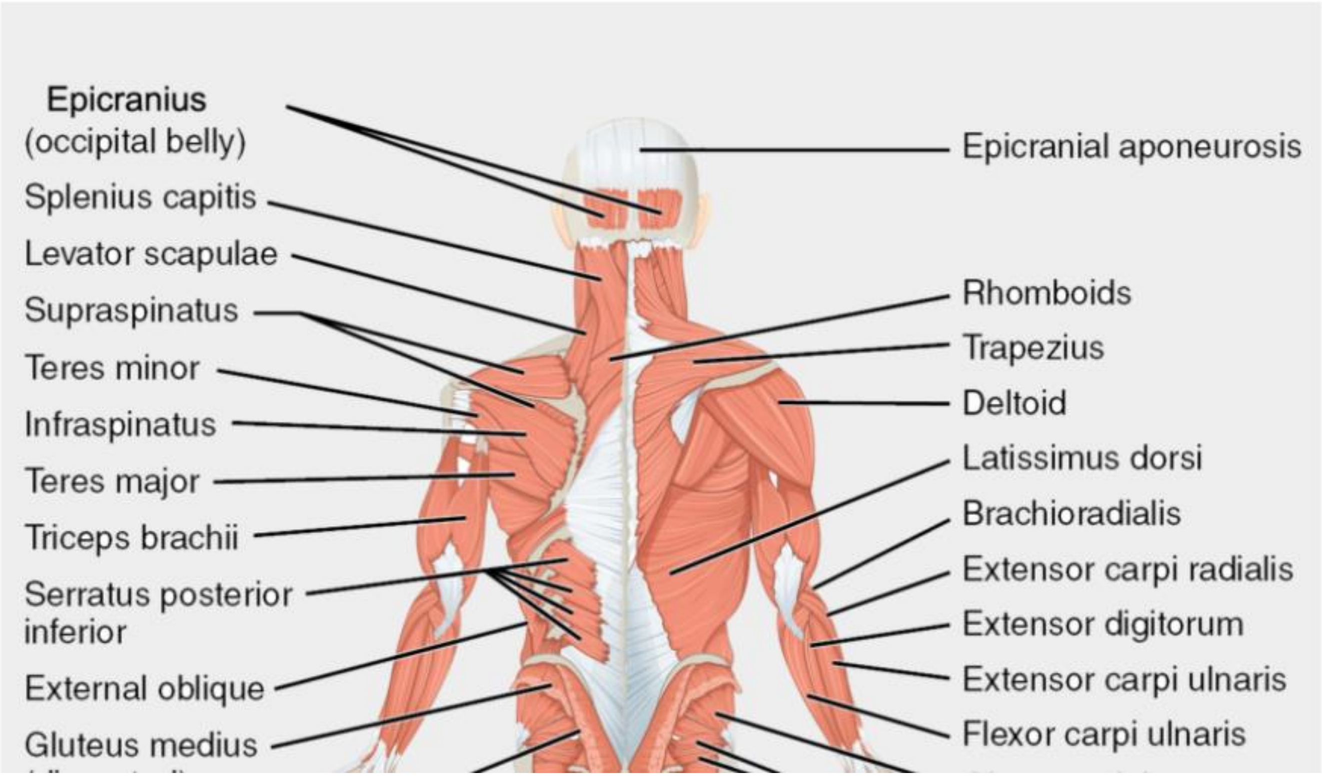

(posterior view)

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Terminology

- anatomy of the upper limb, muscles

- Biceps
  - actuates the flexion of the elbow
- Triceps
  - actuates the extension of the elbow
- Biceps and Triceps operate in an *agonist / antagonist* fashion
  - if they both work at the same time, *co-contraction* is obtained
  - leading to no movement but increasing the *stiffness* of the elbow joint

  - An antagonist is a compound that has
  - the opposite effect of an agonist.

- upper arm
  - *M. Biceps Brachii*
  - *M. Triceps Brachii*
  - *M. Brachialis*

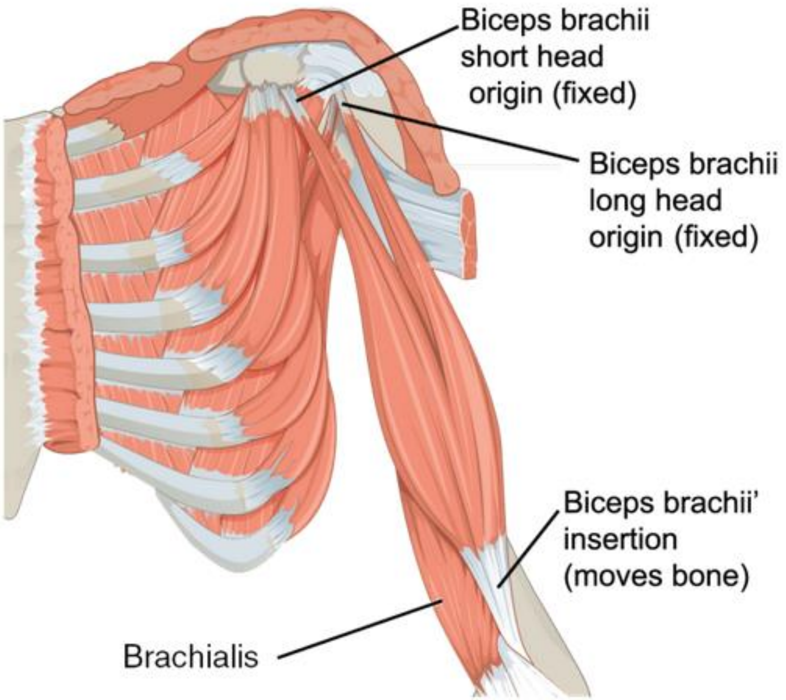

Figure 9-3. The muscles of the arm.

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1. **Biceps:** The biceps brachii muscle is located on the front of the upper arm and is responsible for flexing the elbow joint, which brings the forearm closer to the upper arm. When you bend your arm, like when you're lifting a weight towards your shoulder, the biceps muscle contracts.
2. **Triceps:** The triceps brachii muscle is located on the back of the upper arm and is responsible for extending the elbow joint, which straightens the arm. When you push something away or straighten your arm, like when you're pushing yourself up from a chair, the triceps muscle contracts.
3. When both the agonist and antagonist muscles contract simultaneously in a state of co-contraction, it can indeed lead to no movement occurring at the joint. Instead, co-contraction increases the stiffness of the joint, making it more resistant to movement.
4. Agonist Muscles: These muscles are primarily responsible for producing a specific movement.
5. Antagonist Muscles: These muscles oppose the action of the agonist muscles to provide balance and control.

Arm Flexion:

1. Agonist: Biceps contract to bend the elbow.
2. Antagonist: Triceps relax to allow the bending motion.

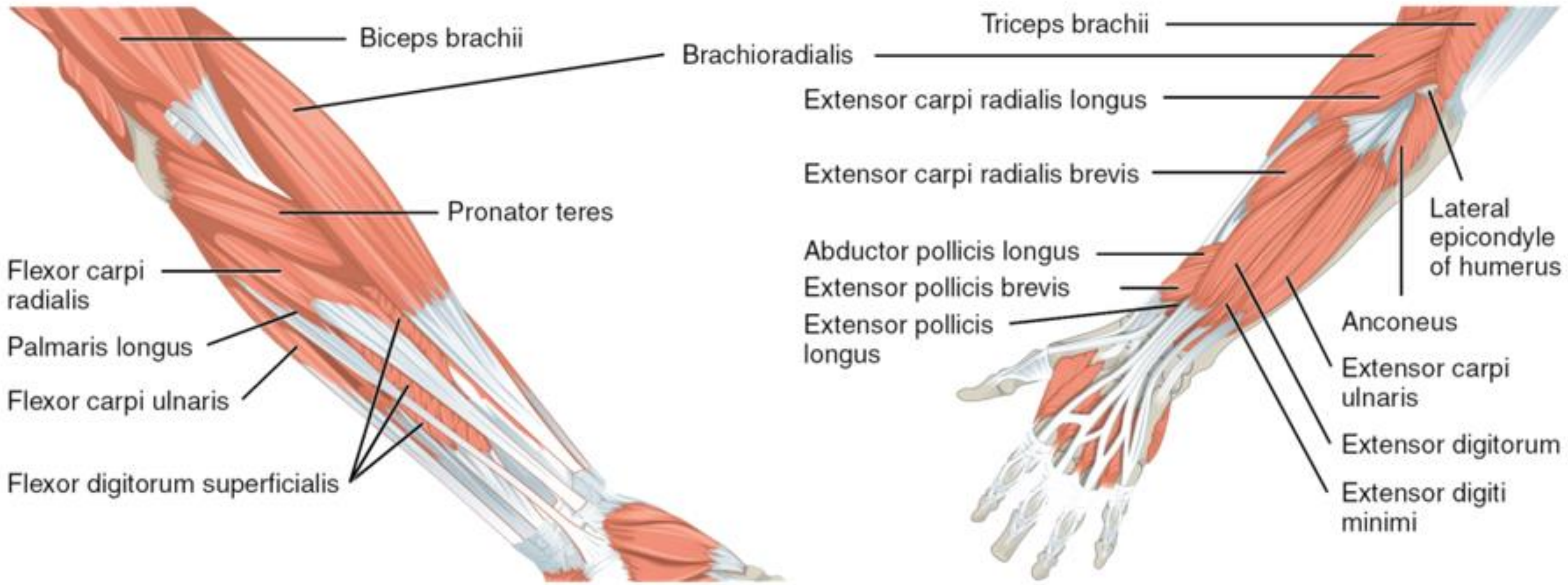
Arm Extension:

1. Agonist: Triceps contract to straighten the elbow.
2. Antagonist: Biceps relax to allow the straightening motion.
3. In co-contraction, both the agonist muscle (the muscle primarily responsible for a movement) and the antagonist muscle (the muscle opposing the movement) contract at the same time.

Terminology

- anatomy of the upper limb, muscles

- lower arm (forearm or *antebrachium*)
  - *M. Flexor Digitorum Superficialis*
  - *M. Extensor Digitorum*
  - *M. Brachioradialis*
  - *M. Pronator Teres*



Left forearm superficial muscles (palmar view)

Left forearm superficial muscles (dorsal view)

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Terminology

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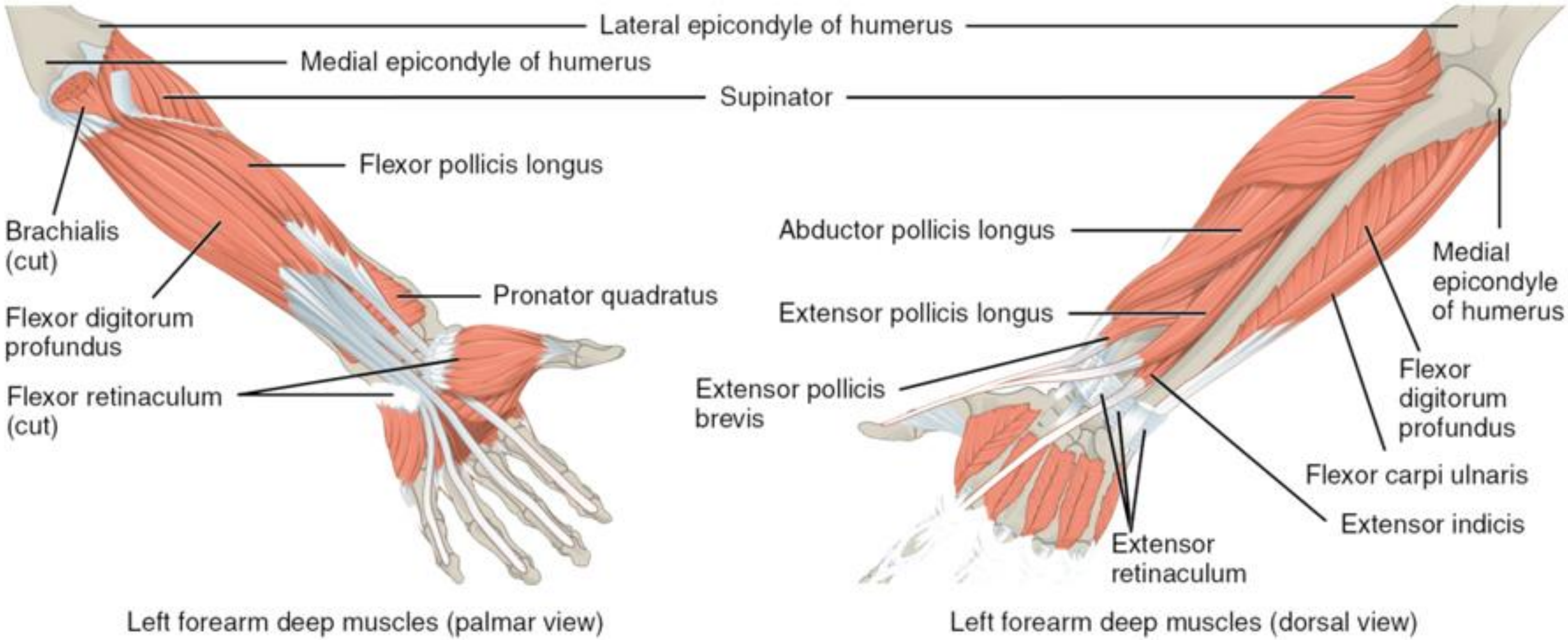
  - *M. Extensor Digitorum*
  - *M. Brachioradialis*
  - *M. Pronator Teres*



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Terminology

- anatomy of the upper limb, muscles

- Flexor
  - actuates the flexion of wrist / fingers
- Extensor
  - actuates the extension of wrist / fingers
- Flexors and extensors operate, too, as a agonist / antagonist pair
  - helping control the stiffness of wrist and fingers
- Brachioradialis and Pronator operate the pronation / supination of the wrist
  - they operate close to the bones, so
  - their activity remains mostly deep

- lower arm (forearm or *antebrachium*)
  - *M. Flexor Digitorum Superficialis*
  - *M. Extensor Digitorum*
  - *M. Brachioradialis*
  - *M. Pronator Teres*

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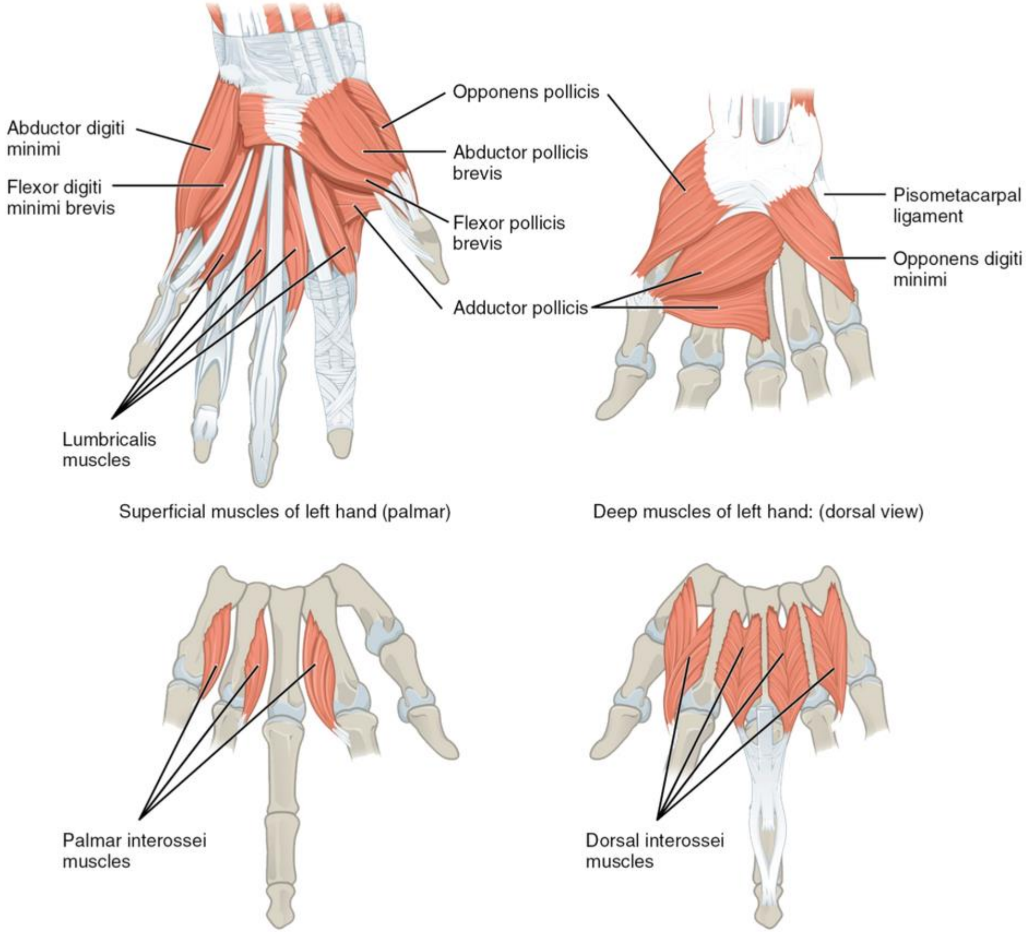
Terminology

- anatomy of the upper limb, muscles

  - hand – extremely complex
    - *M. Flexor Pollicis Brevis*
    - *M. Abductor Pollicis Brevis*
    - *M. Palmar / Dorsal Interossei*



Superficial muscles of left hand (palmar)

Deep muscles of left hand: (dorsal view)

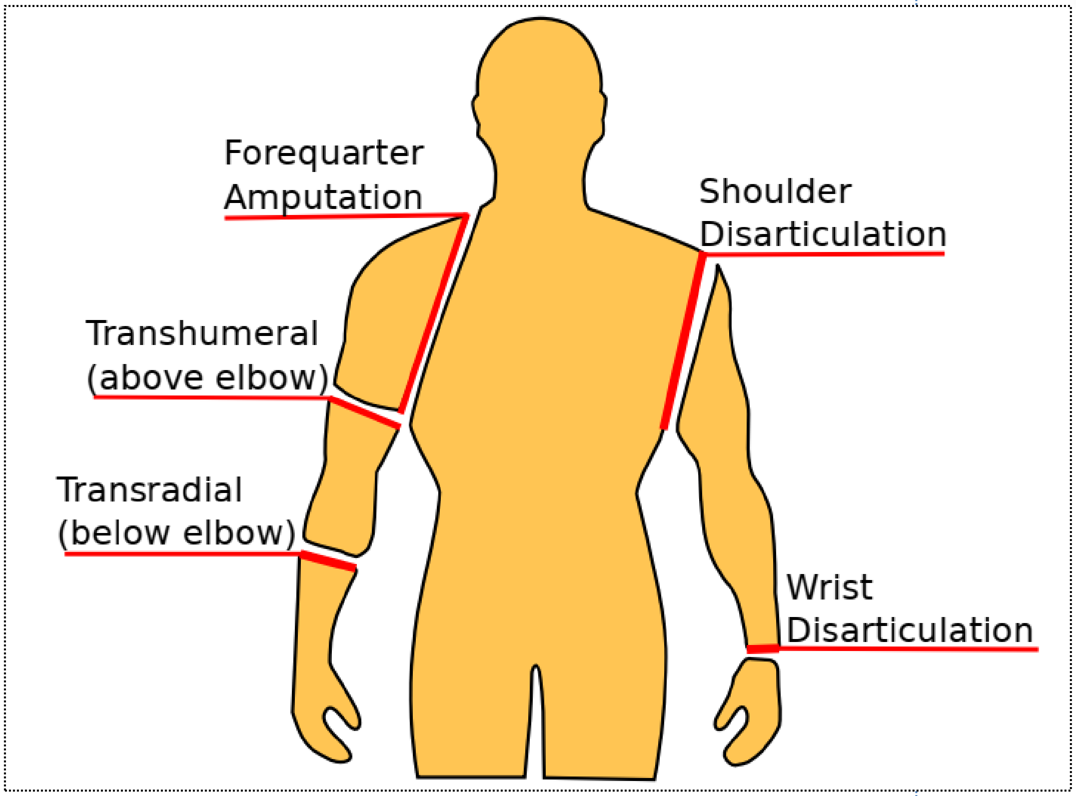
Interossei muscles of left hand (palmar view)

Interossei muscles of left hand (dorsal view)

https://courses.lumenlearning.com/ap1x94x1

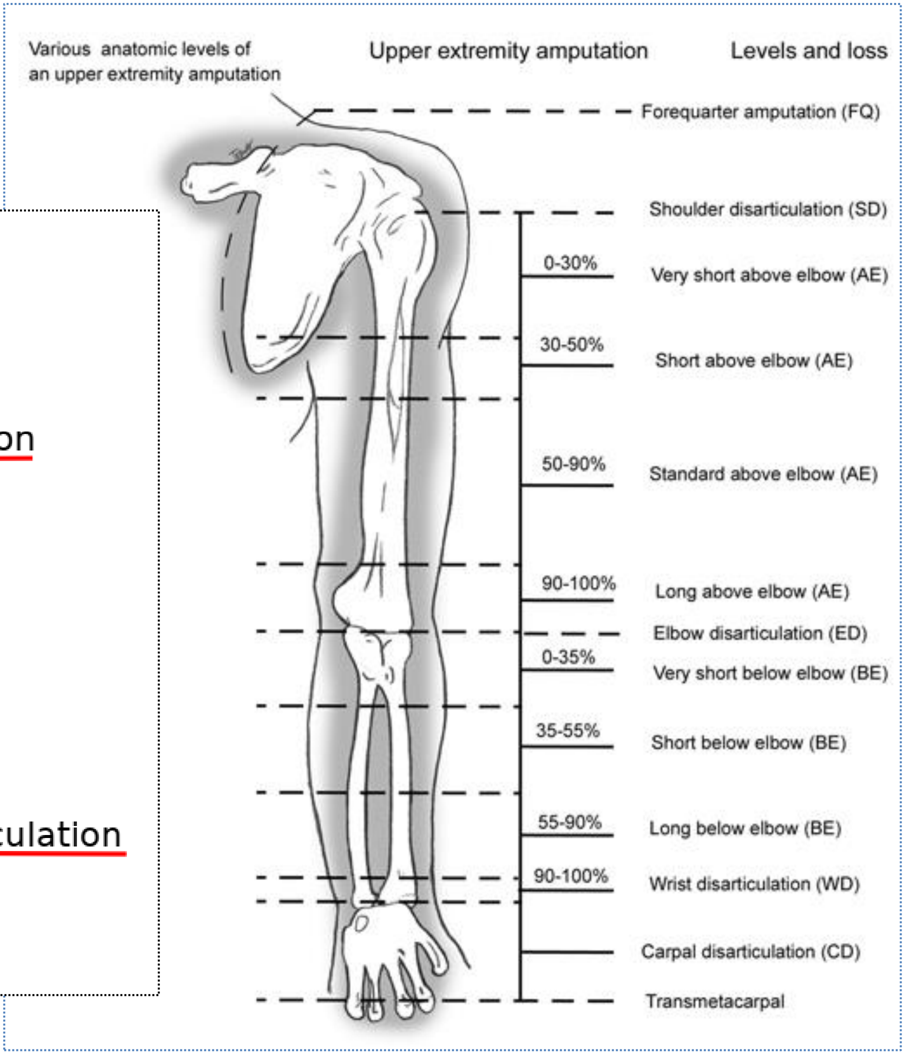
Terminology

- types of upper-limb deficiency (amputations)



https://www.cdha.nshealth.ca/amputee-rehabilitation-musculoskeletal-program/patient-family-information/upper-limb-amputations

https://www.physio-pedia.com/Principles_of_Amputation



Summary

- a few examples of devices in need of IDF
- human-machine interaction / interfaces
- intent detection and somatosensory feedback
- anatomical terminology

References

- Beckerle, P. et al. *Feel-good robotics: requirements on touch for embodiment in assistive robotics.* Frontiers in Neurorobotics 12, (2018).
- Beckerle, P., Castellini, C. & Lenggenhager, B. *Robotic interfaces for cognitive psychology and embodiment research: a research roadmap.* Wiley Interdisciplinary Reviews - Cognitive Science e1486 (2018) doi:10.1002/wcs.1486.