Human Perception and Human-Machine Interfaces

Noise, Perception, and Learning: Applications in AI Art

Mikey Fernandez

Agenda (not necessarily in order)

- What is perception?
- How do humans perceive their environment?
- How do machines perceive their environment?
- What's similar? Different?
- Interfacing humans and machines

Perception

What is Perception?

- “Awareness of the elements of environment through physical sensation”
  - Do we have any issues with this definition?

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  - Do we have any issues with this definition?

- Nothing about the brain!
  - As Aspen showed, our physical senses can be easily tricked
  - Is it enough to suggest that physical sensations are what we perceive?

What is Perception?

- “Awareness of the elements of environment through physical sensation”
  - Do we have any issues with this definition?

What do we do when some form of sensation doesn’t work?

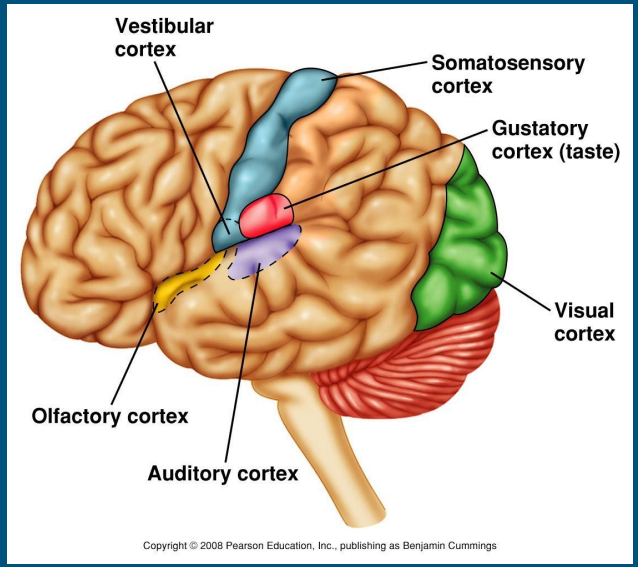
- Nothing about the brain!
  - As Aspen showed, our ph[illegible]ked
  - Is it enough to suggest that physical sensations are what we perceive?

(We’ll come back to this)

How many senses do we have?

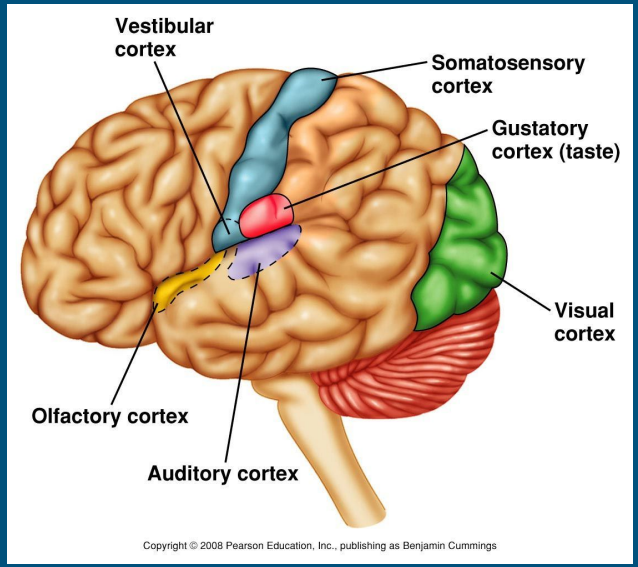
Human Perception

- The usual five:
  - Touch
  - Taste
  - Sight
  - Smell
  - Hearing



Human Perception

- The usual five:
  - Touch
  - Taste
  - Sight
  - Smell
  - Hearing
- And the oft forgotten…
  - Pressure, itch, thermoception, proprioception, nociception, equilibrioception, thirst, hunger, magnetoception, time



The 5 Senses - An Aristotelian Perspective

- Aristotle initiated the idea that we have 5 senses
  - They all work independently
  - Much like a house color changes from blue to white when someone paints it, our senses transmit to the brain when affected by the environment
  - Perception of the world is what distinguishes animals from plants

The 5 Senses - An Aristotelian Perspective

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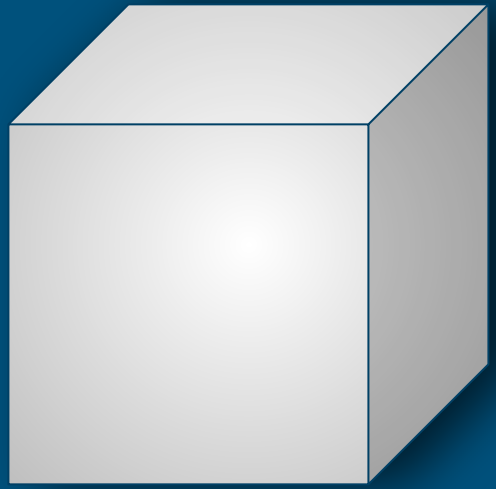
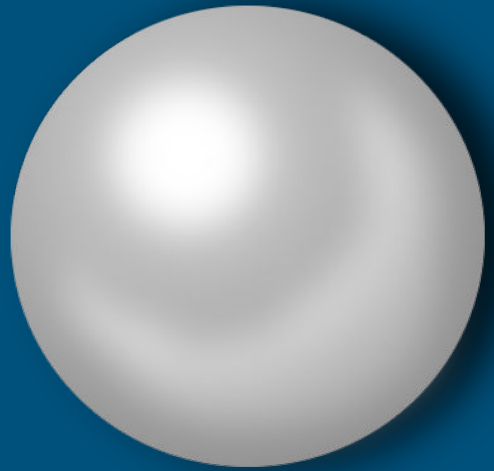
- Sadly, this isn't how it works…

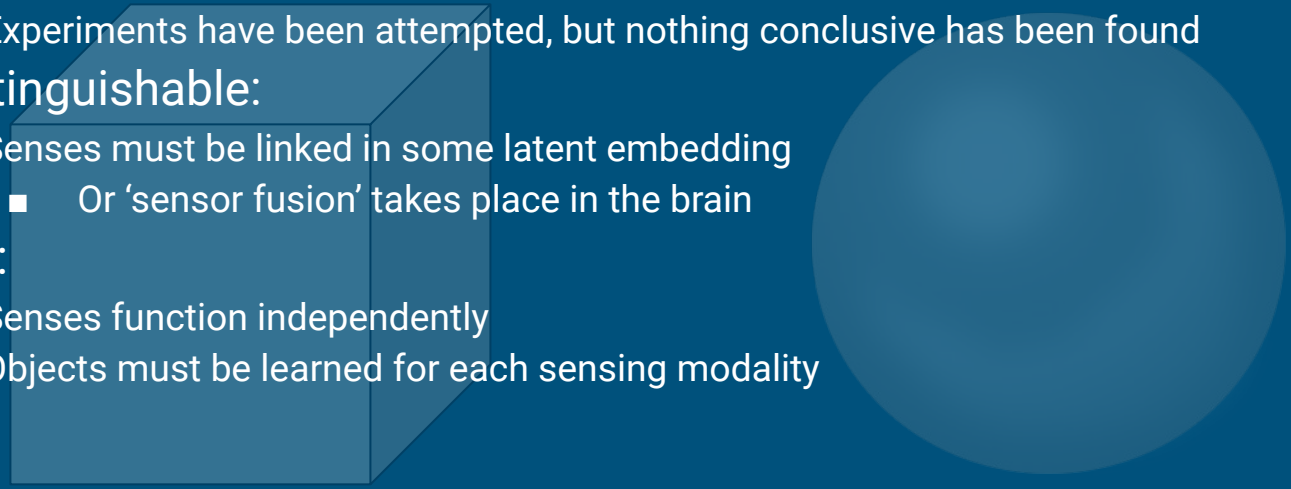
Molyneux’s Problem





Molyneux’s Problem

- Still an unanswered question in philosophy!
  - Experiments have been attempted, but nothing conclusive has been found
- If distinguishable:
  - Senses must be linked in some latent embedding
    - Or ‘sensor fusion’ takes place in the brain
- If not:
  - Senses function independently
  - Objects must be learned for each sensing modality



Now to the fun stuff...

How do we Sense?

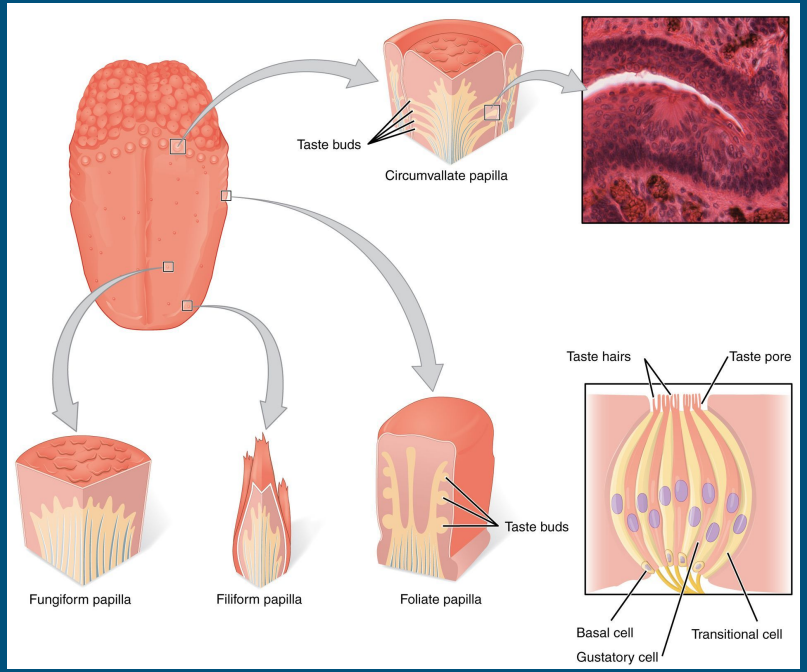
- Mechanically speaking:
  - Specialized **sensor** interfaces with the environmental **input**
  - Produces excitation in some afferent neurons (exactly how this happens depends on sense)
    - In all cases, energy is transformed to an electrical signal
  - Signal **transmits** to specific brain region
  - **Processing** occurs in the brain

Detailing the 5 Senses

- **Taste**
- Smell
- Hearing
- Vision
- Touch

How does Taste Work

- Surface of tongue coated in taste buds
  - Increases surface area of the tongue
  - Specialized taste/gustatory cells surround pore
- Input stimuli bond to chemical receptors
  - Binding causes opening of gated ion channels
  - Resultant depolarization causes signal cascade to brain



C. Machado, P.A. DeFina (2020). Covid-19: Anosmia and Ageusia Might be Initial or Unique Symptoms

How does Taste Work

- ‘Different Tastes’ detected based on presence of different substances
  - Sweet: saccharides and simple sugars
  - Salty: sodium
  - Umami: MSG, aspartate/aspartame
  - Sour: acidity → protons
  - Bitter: huge variety, mostly considered as environmental toxins by the body

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- Contrary to myth, there are no specialized taste regions on your tongue

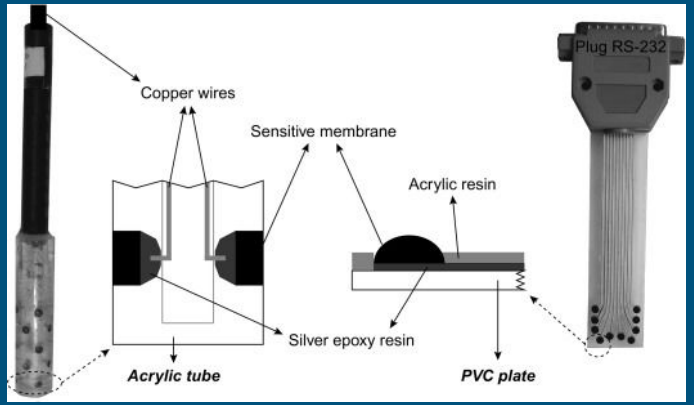
What qualities would an artificial taste system need?

Artificial Taste Would Need to...

- Be capable of detecting presence of different compounds in a sample
- Recognize the combinations of compounds that correspond to different foods
- Get these signals into the brain

The Electric Tongue

- An artificial taste system already exists!
  - Commonly used in pharma, food/beverage industry
- Current changes between sensors while dipped in a sample are recorded
  - How current changes correlates to presence of different substances in the sample
- Pattern recognition systems are used to match recordings to known samples



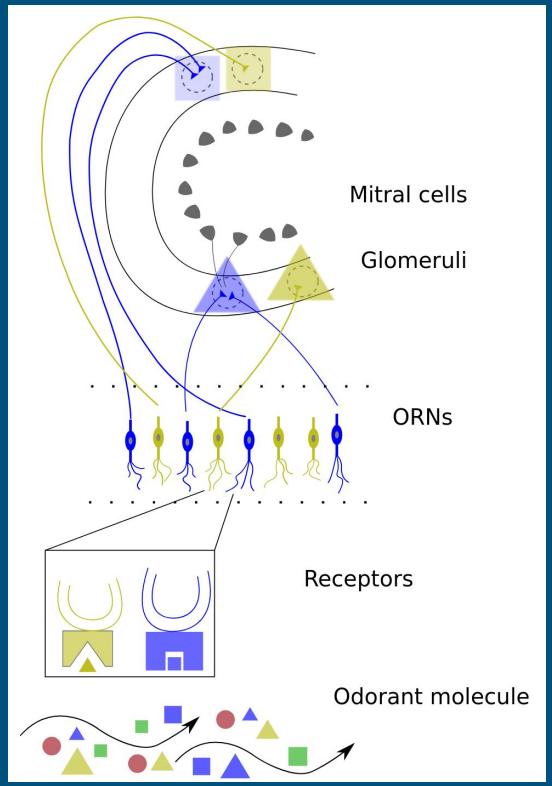
L.G. Dias, A.M. Peres (2017). Electronic tongues and aptasensors

Detailing the 5 Senses

- Taste
- **Smell**
- Hearing
- Vision
- Touch

How does Smell Work

- Smell operates rather similar to taste
- Odorants bind to chemoreceptors on the cilia in the nasal cavity
  - As in taste, there are multiple cell types (6 here)
  - Binding causes vibration of cilia
    - Frequency of vibration linked to perceived odor
- Excitation travels to the brain via specialized neural pathways
  - These project directly into the brain
  - Mucus protects us from infection!



B. Auffarth, B. Kaplan, A. Lansner (2011). Map formation in the olfactory bulb by axon guidance of olfactory neurons

What qualities would an artificial smell system need?

Artificial Smell Would Need to...

- Sweep small molecules into a cavity for detection
- Detect the presence of specific molecules in a mixture
- Correlate these molecules with their specific scents

The Electronic Nose

- To date, general purpose electronic noses don’t exist
  - Existing sensors can’t recognize a wide variety of signals
    - Specialized organize polymers
    - Metal-oxide semiconductors
    - Mass spectrometers
- Specialized electronic noses can recognize certain types of compounds

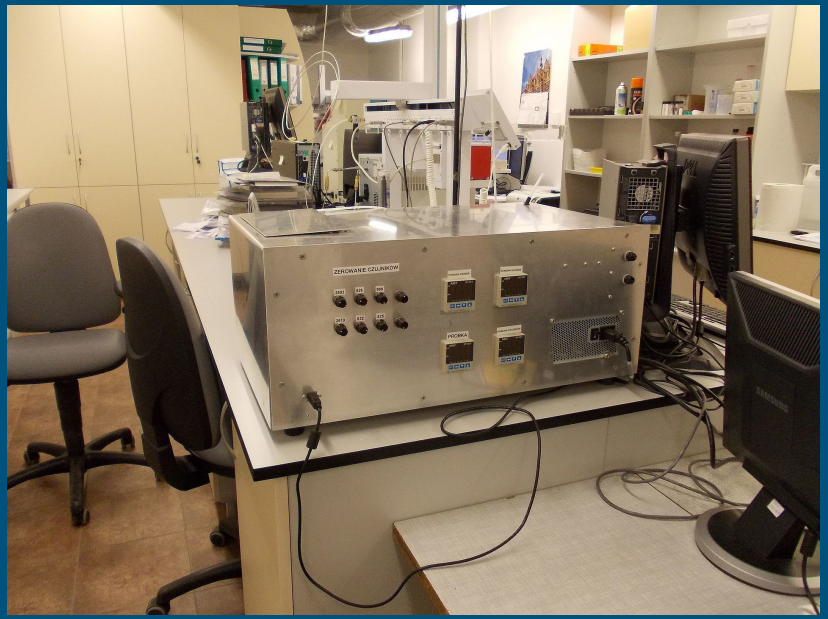


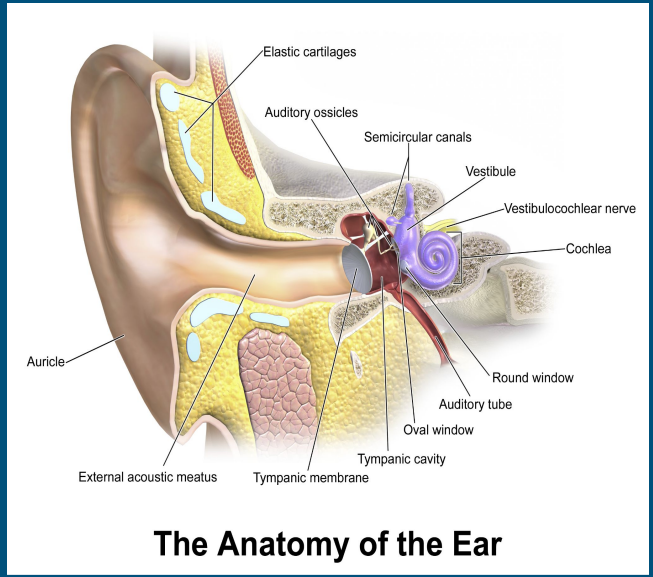
Photo taken by Lukasz Katlewa

Detailing the 5 Senses

- Taste
- Smell
- **Hearing**
- Vision
- Touch

How does Hearing Work?

- Sound is caused by pressure waves
- Sound waves are focused by the outer ear
  - Cause vibration of the eardrum
- Vibrations amplified by 3 smallest bones in the body (converted to mechanical energy)
  - Push directly on fluid filled cochlea
  - Fluid waves propagate through cochlea and vibrate tiny hairs, generating neural signals
  - Hair thickness/position in cochlea correspond to frequency of sound detected



Blausen.com staff (2014). Medical gallery of Blausen Medical 2014

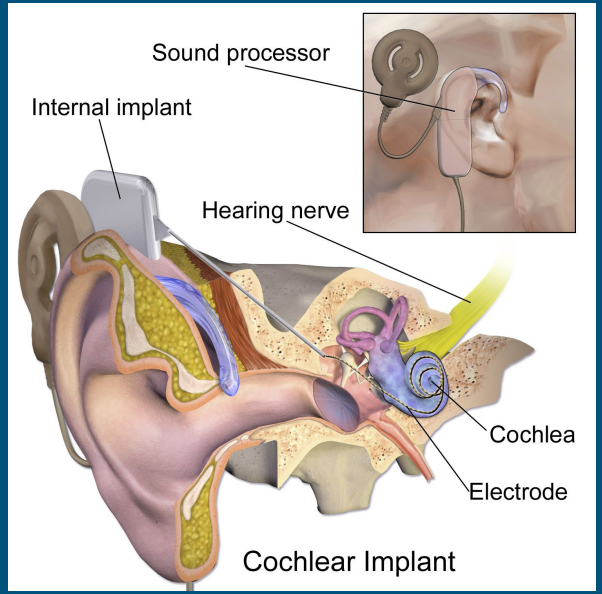
What qualities would an artificial hearing system need?

Artificial Hearing Would Need to...

- Convert pressure waves into electrical signals
  - These electrical signals must correspond to the frequency content of the sound being detected
    - Functionally, this is a Fourier transform!
- Microphones use similar principles
  - Vibration of a membrane moves a magnet to generate electrical signals
- We evolved the complex structure of the ear to protect the delicate sensors from damage; there is no need for electronic versions to be so complex

Cochlear Implants

- First neuroprosthetic device (mid 1950s!)
- Bypasses most of the peripheral auditory system
  - External microphone picks up sound
  - Digitized sound is transmitted into the cochlea
  - The implanted electrode stimulates the cochlear nerve directly
- Notable improvements in speech recognition capability reproduced across hundreds of studies



Blausen.com staff (2014). Medical gallery of Blausen Medical 2014

Detailing the 5 Senses

- Taste
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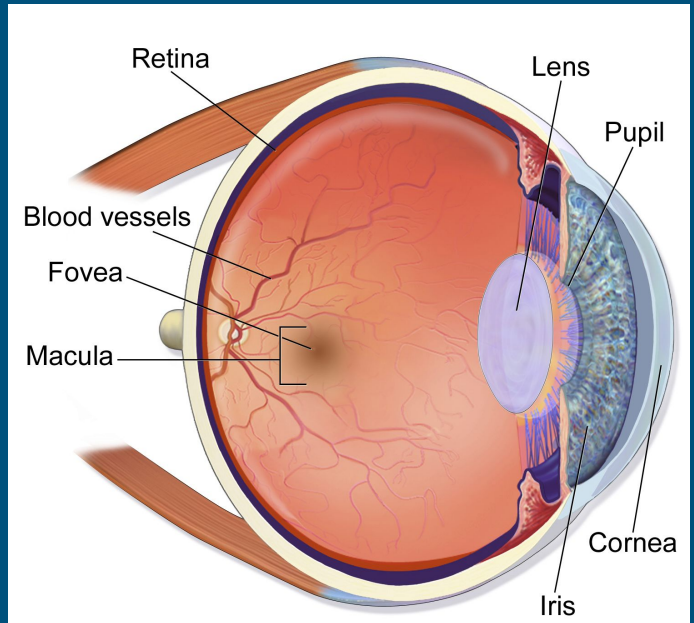
- **Vision**
- Touch

How does Vision Work?

- Light travels through the iris, is focused by the lens, and lands on the retina
  - Contraction of iris muscles changes the shape of the lens, changing focal length
  - Images are flipped!
- Grid of specialized cells do photoreception
  - Allows localization
  - Cones are sensitive to different wavelengths
  - Rods see light intensity, but function in lower light
- Stimulation causes activation of optic nerve



Eye Anatomy

Blausen.com staff (2014). Medical gallery of Blausen Medical 2014

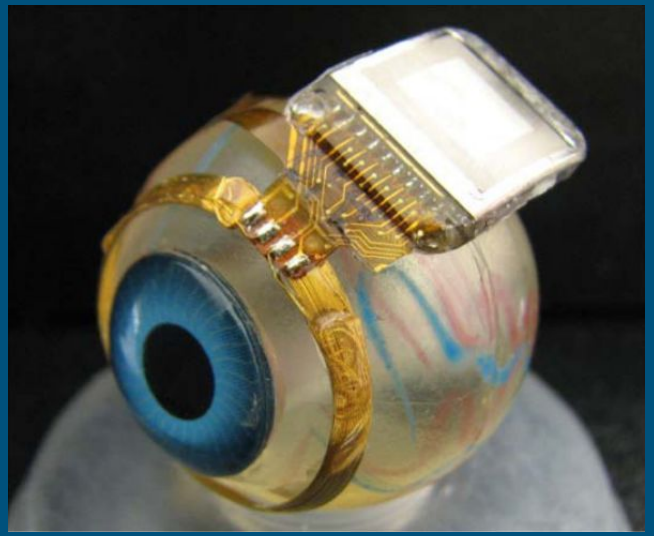
What qualities would an artificial vision system need?

Artificial Vision Would Need to...

- Capture an image of the environment
  - Cameras are ubiquitous today, but this is not trivial!
  - Film would obviously be impractical as it needs to be developed
- Analog to digital conversion to generate the electrical signals needed for vision
- Get this into the nervous system
  - This applies to all prior senses as well, but there are multiple choices for where to do this
    - At the sensor (in the retina)
    - In the brain (the visual cortex)

Retinal Implants

- Multiple systems have been researched
  - Harvard/MIT Retinal Implant at right
- External camera captures images
  - Translates them to stimulation patterns transmitted into the eye socket
  - Direct stimulation of retinal ganglion cells
    - These are the cells activated by rods/cones
- Much lower resolution than native eye
  - Would need stimulation of ~1000 sites for anything remotely reasonable



S. Kelly et al (2011). A Hermetic Wireless Subretinal Neurostimulator for Vision Prostheses

Detailing the 5 Senses

- Taste
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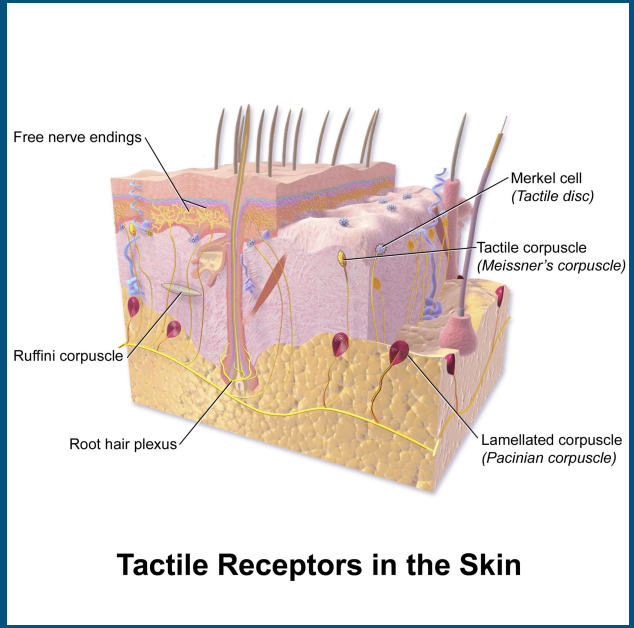
- Vision
- **Touch**

How does Touch Work?

- The most multifaceted of these senses
  - Touch captures all other environmental interactions
  - Activity of mechanoreceptors, thermoreceptors, and nociceptors
- Focusing on mechanoreceptors…
  - Different cell types are suited to detect contact, pressure, vibration, stretch, roughness, etc.
  - In physiology, function follows form
    - Activation potentials generated in nerves based on conformational changes in the mechanoreceptors



Blausen.com staff (2014). Medical gallery of Blausen Medical 2014

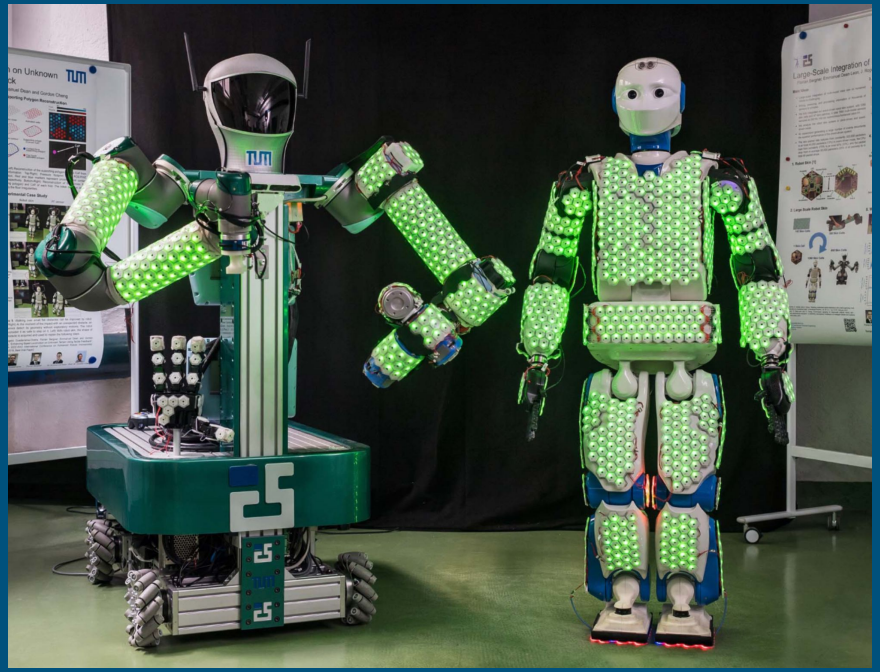
What qualities would artificial skin need?

Artificial Skin Would Need to...

- Achieve high spatial density of sensors
  - Two-point discrimination on the fingertips ~4 mm
- Include multiple sensing modalities
- Prevent readings on sensors during alternative modes
  - e.g. vibration sensor should not activate during stretching of the skin

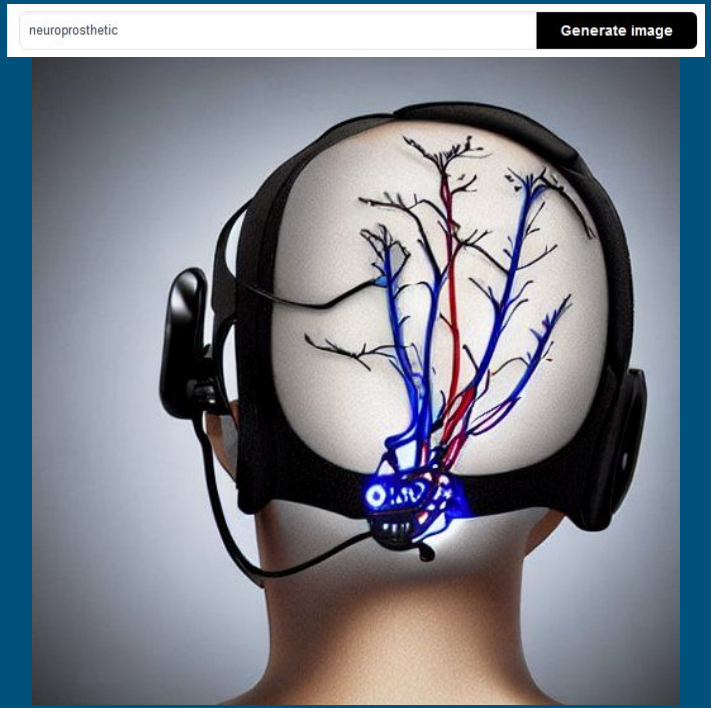
Artificial Skin Technology

- Modular robotic skin (TUM)
  - 13k sensors (on the right) detect temperature, pressure, proximity, and acceleration
  - Large sensors, fragile, expensive
- ‘Smart skin’ (TU Graz)
  - Thinner + higher resolution sensing than human skin!
  - Senses pressure, humidity, temperature



G. Cheng et al (2019). A Comprehensive Realization of Robot Skin: Sensors, Sensing, Control, and Applications

Human-Machine Interfaces



Human-Machine Interfaces

- A specific aspect of *user interfaces*
  - HMI consists of physical input/output hardware for humans to interact with
- Technically speaking: mice, keyboards, monitors, printers are all HMI

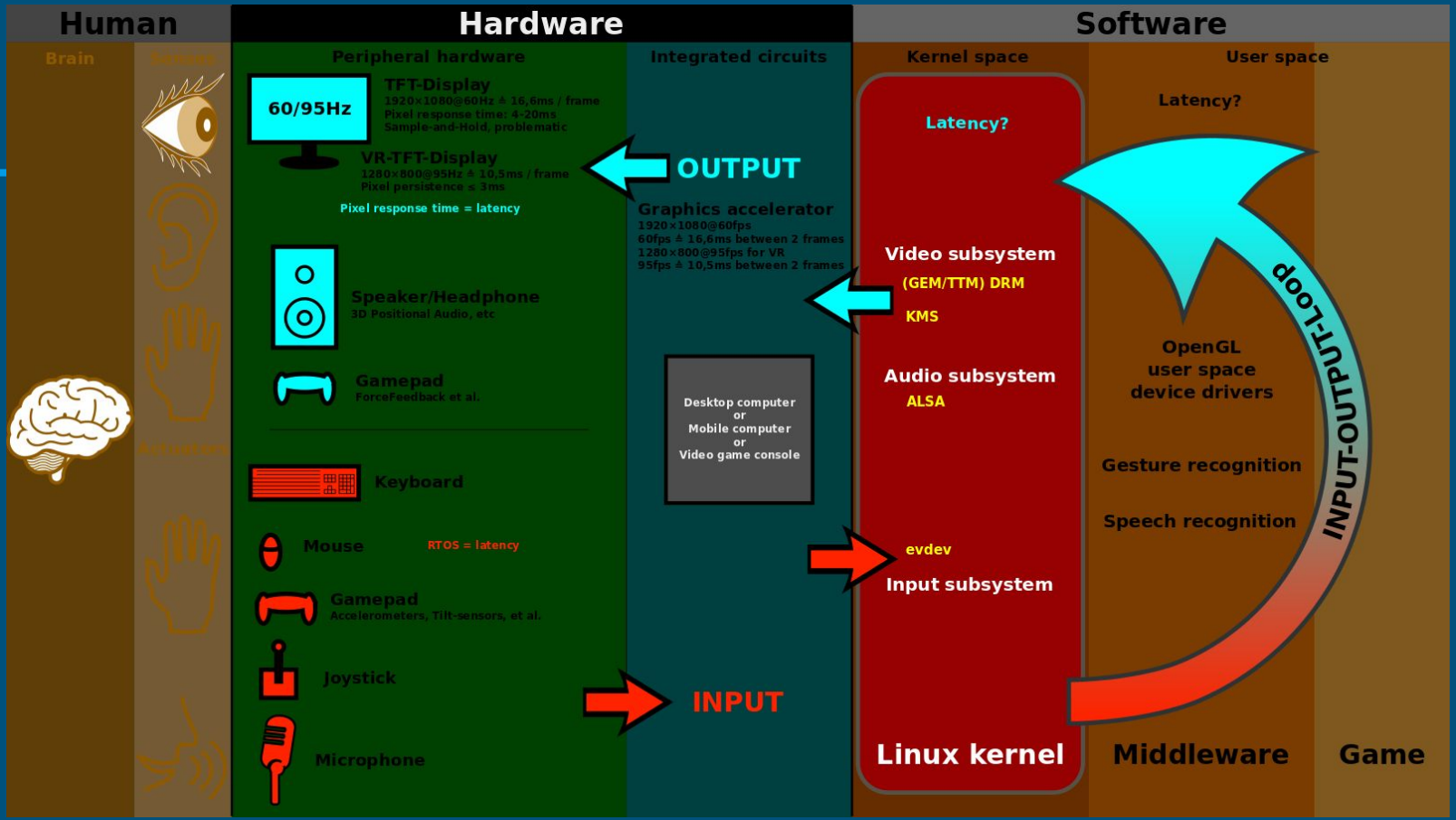


Image generated by ScotXW

Brain-Computer Interfaces

- Direct communication between the brain’s electrical activity and hardware
  - Useful for recording data, augmenting/replacing impaired brain function
- Range between noninvasive and invasive
  - Depends on how close electrodes are to brain tissue
  - Noninvasive: EEG, MEG, MRI
  - Partially Invasive: Electrocorticography (ECoG)
  - Invasive: Microelectrode arrays, Neuralink

Noninvasive BCIs

- Use external sensor arrays to measured changes in the brain
  - These can be induced changes, as in fMRI
  - Or natural activity, as in EEG
- With pattern recognition, noninvasive BCIs can be used for hardware control
  - Concentrating on desired destination provides input commands to an autonomous navigation system

Image from University of Zaragoza, EEG wheelchair project

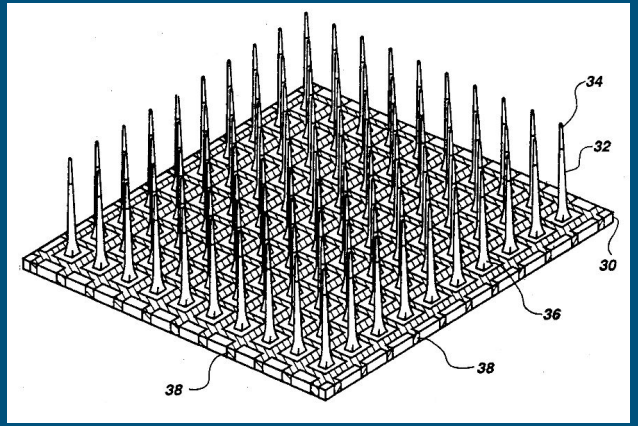
Noninvasive BCIs

- This tech has even made its way into children's games!
- Large hacker community around the Mindflex
  - Write poetry by thinking hard
  - Order drinks by thought

NeuroSky's Mindflex

Invasive BCIs

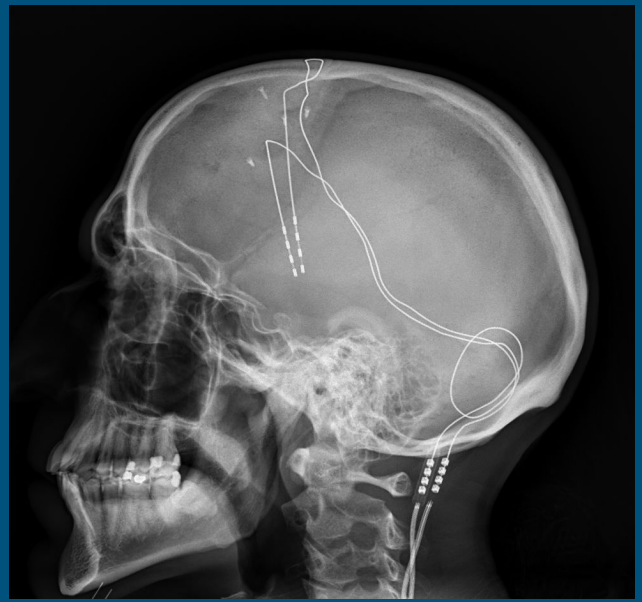
- Potentially much more impactful area of work
- Implantable microelectrode arrays can selectively activate and read from neural circuitry
  - Risk of damage to brain tissue
  - Immune response



Richard A. Normann, US Patent #5,215,088

Deep Brain Stimulation

- Most famous example of BCI
- Neurostimulator sends electrical impulses to target areas of the deep brain
- Exact mechanism actually *unknown!*
  - Synaptic inhibition, interruption of abnormal activity, or other mechanism
- Successfully shown to improve:
  - Parkinson's, OCD, epilepsy, major depression



Jmarchn, Lateral X-ray of the head: Deep brain stimulation in obsessive–compulsive disorder (Medtronic 3391)

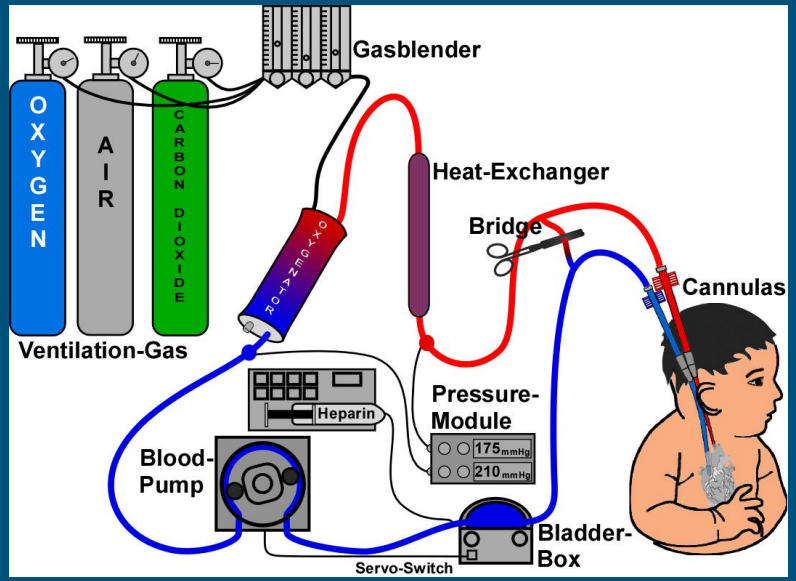
Neuralink

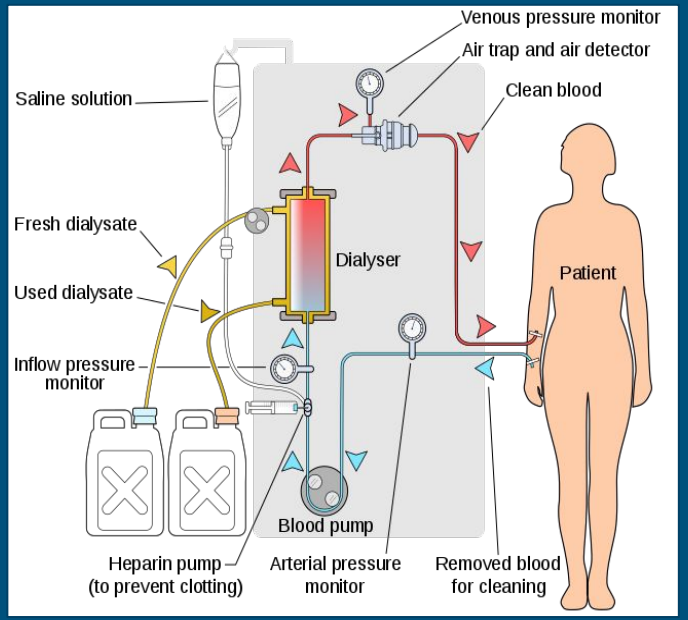
- Founded 2016, seeks to merge humans with artificial intelligence
  - Starting by trying to treat serious brain diseases
- Involves implantation of thousands of electrodes distributed throughout the brain
  - Read and stimulate to interact with the environment

Jmarchn, Lateral X-ray of the head: Deep brain stimulation in obsessive–compulsive disorder (Medtronic 3391)

Controlling Robotics with the Mind

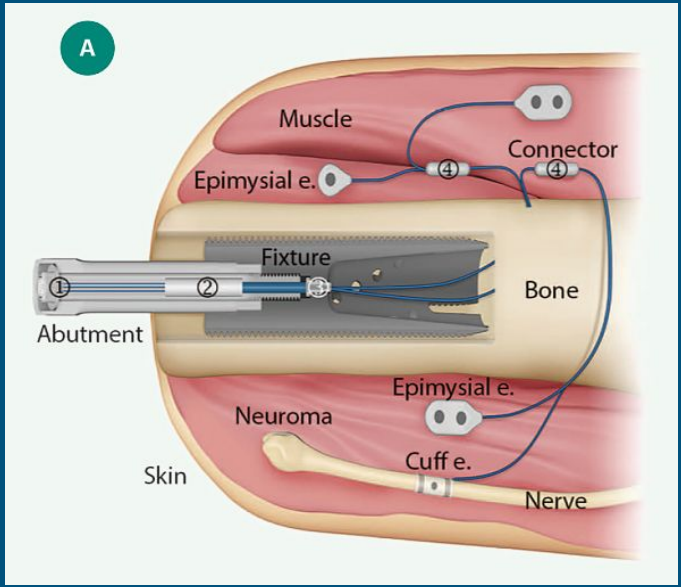
Peripheral HMI

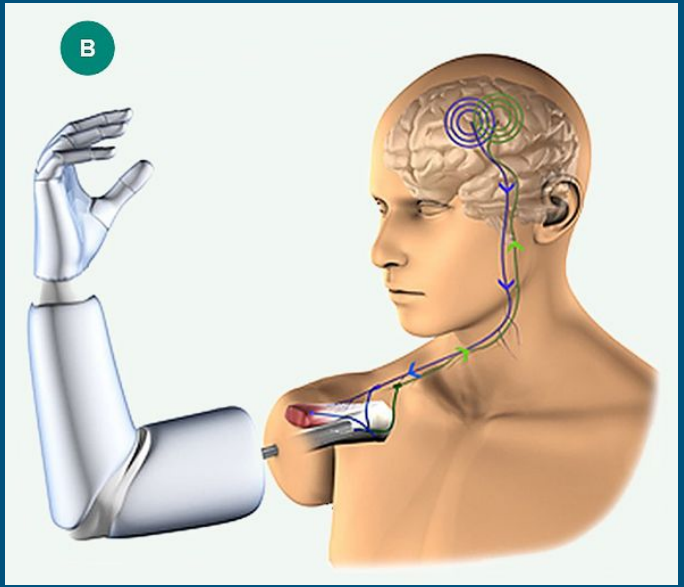




Left: J. Schaub (2007). Ecmo schema, to provide extracorporeal oxygenation
Right: Y. Mrabet (2008). Simplified hemodialysis circuit

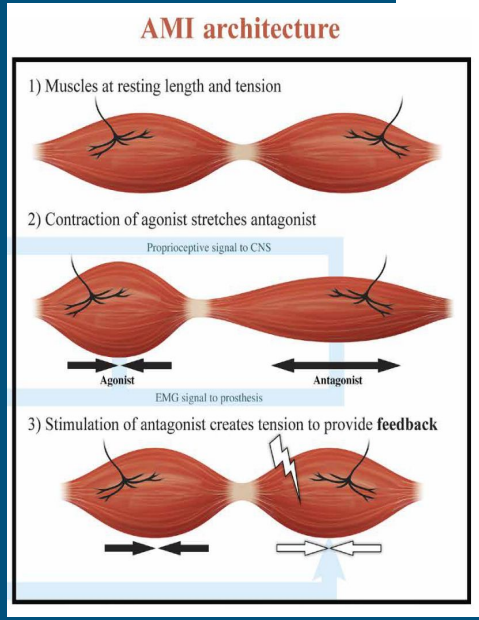
Osseointegrated Prostheses

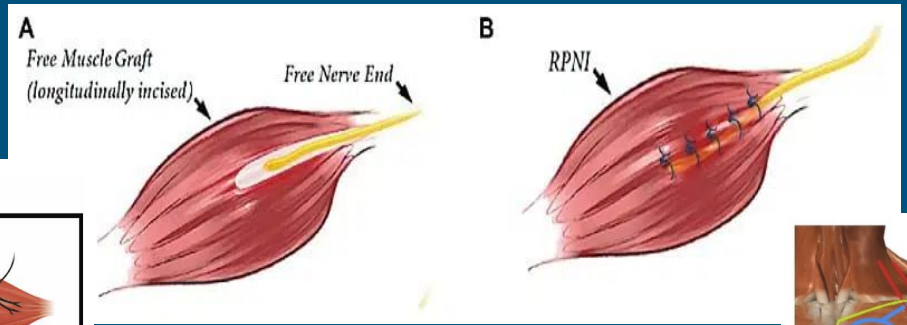


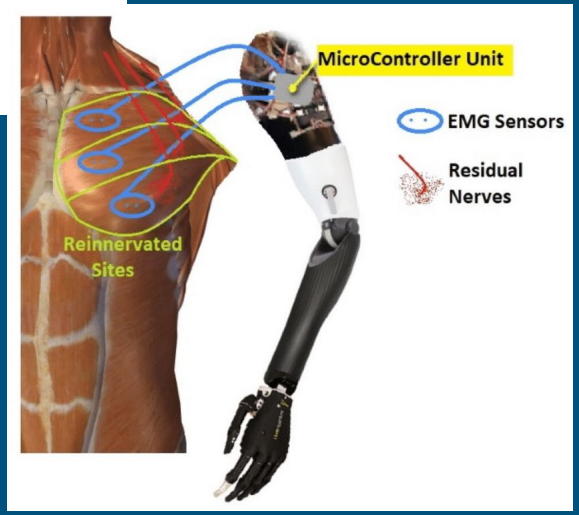


https://integrum.se/what-we-do/our-products-future-solutions/e-opra/

Peripheral Neural Interfaces

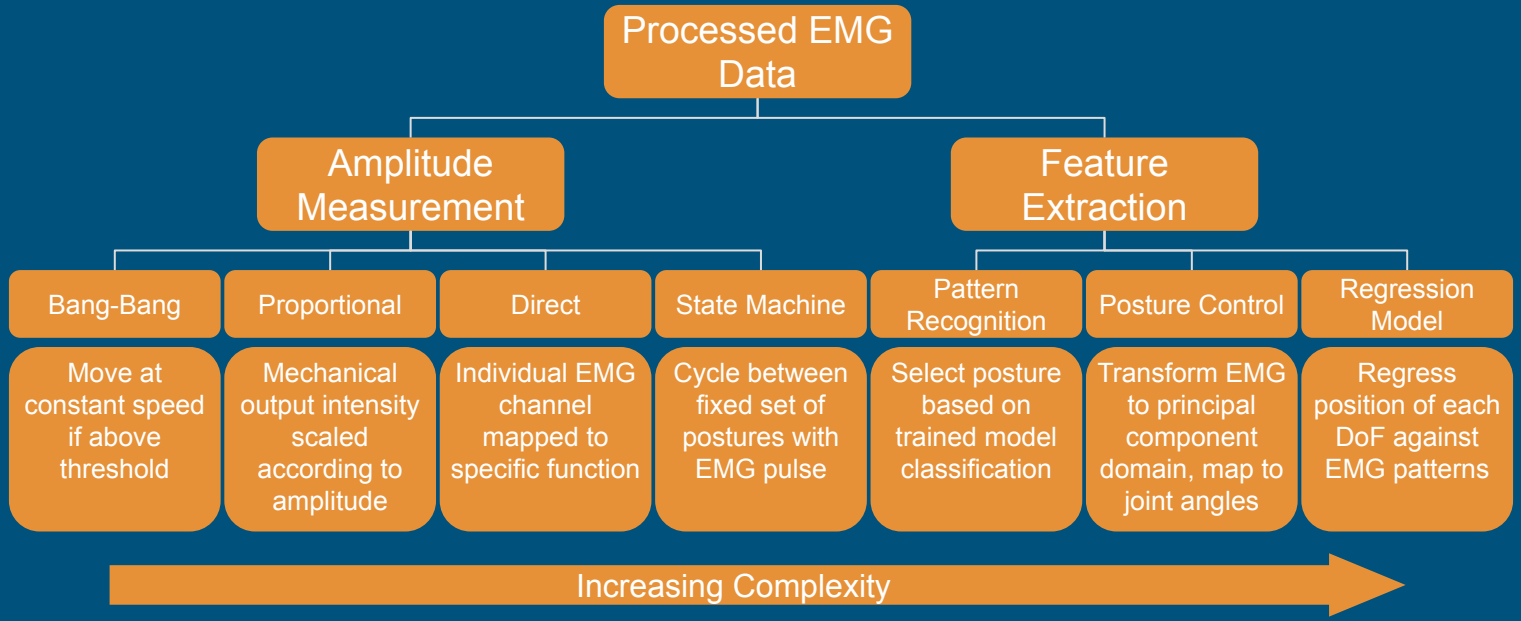






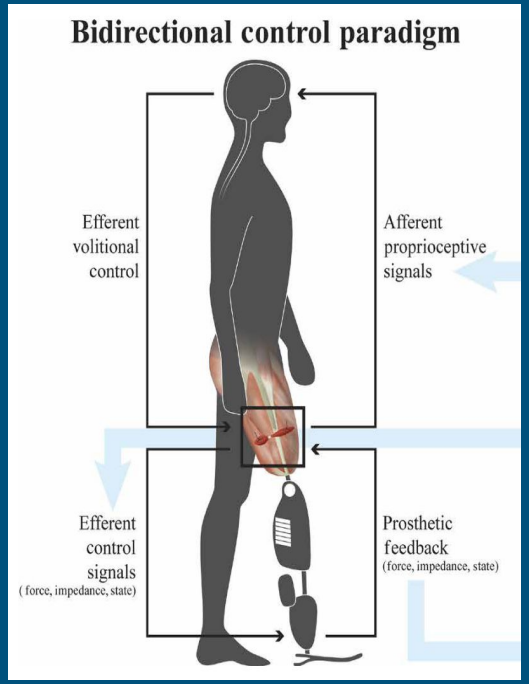
Left: T. Clites et al (2017). Proprioception from a Neurally Controlled Lower-Extremity Prosthesis
Top: G.Ives et al (2018). Current State of the Surgical Treatment of Terminal Neuromas
Right: F. Mereu et al (2021): Control Strategies and Performance Assessment of Upper-Limb TMR Prostheses: A Review

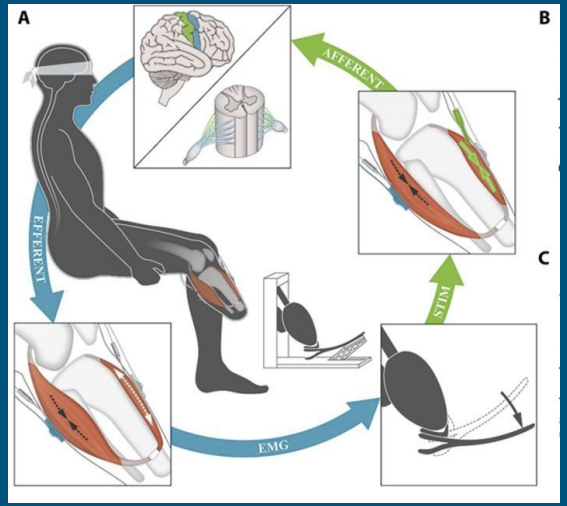
Prosthesis Control



Modified From G Purushothaman (2016). Myoelectric Control of Prosthetic Hands: State-of-the-Art Review.

Prosthesis Control





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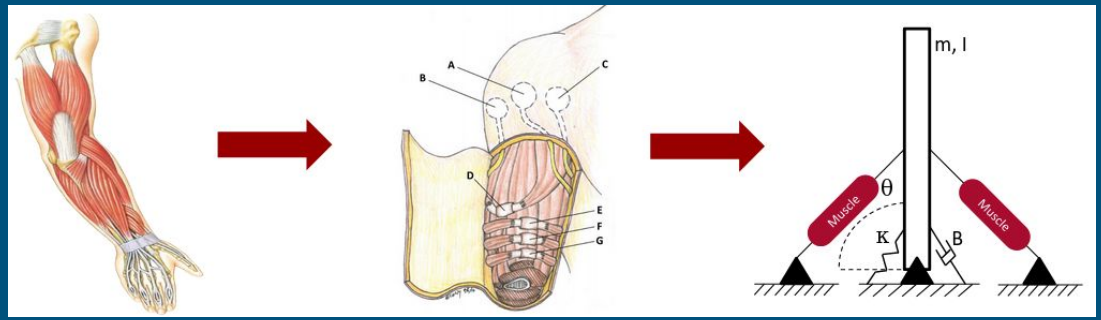
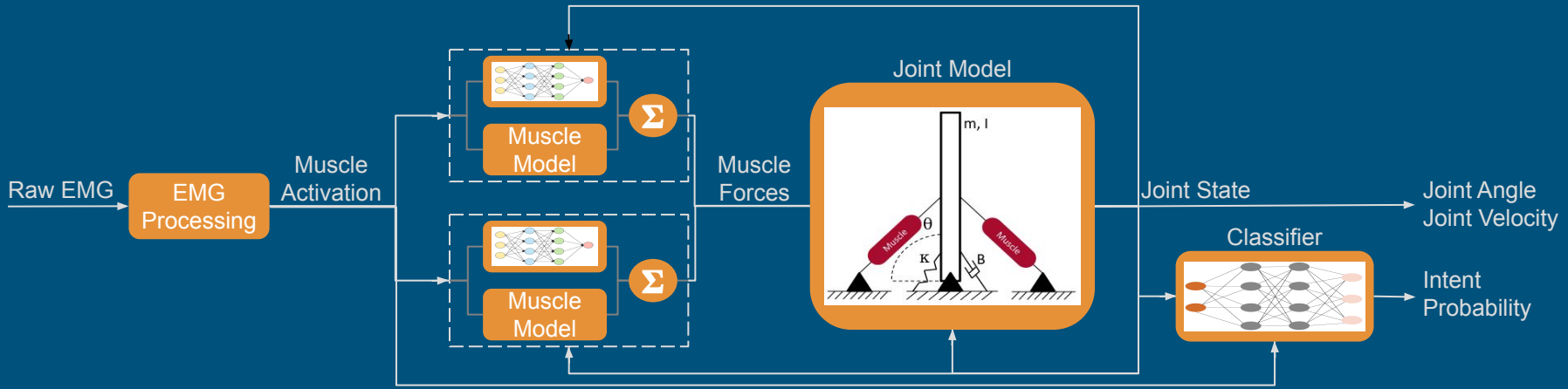
Prosthesis Control





Thank You!
Open to Questions

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