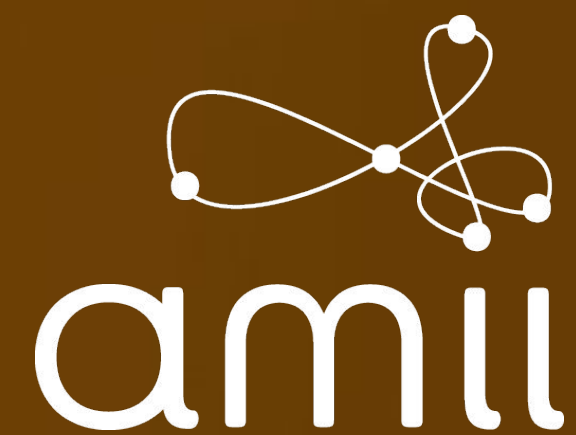


# PART III: Becoming Bionic


Patrick M. Pilarski



**UNIVERSITY  
OF ALBERTA**



# Learning Objectives

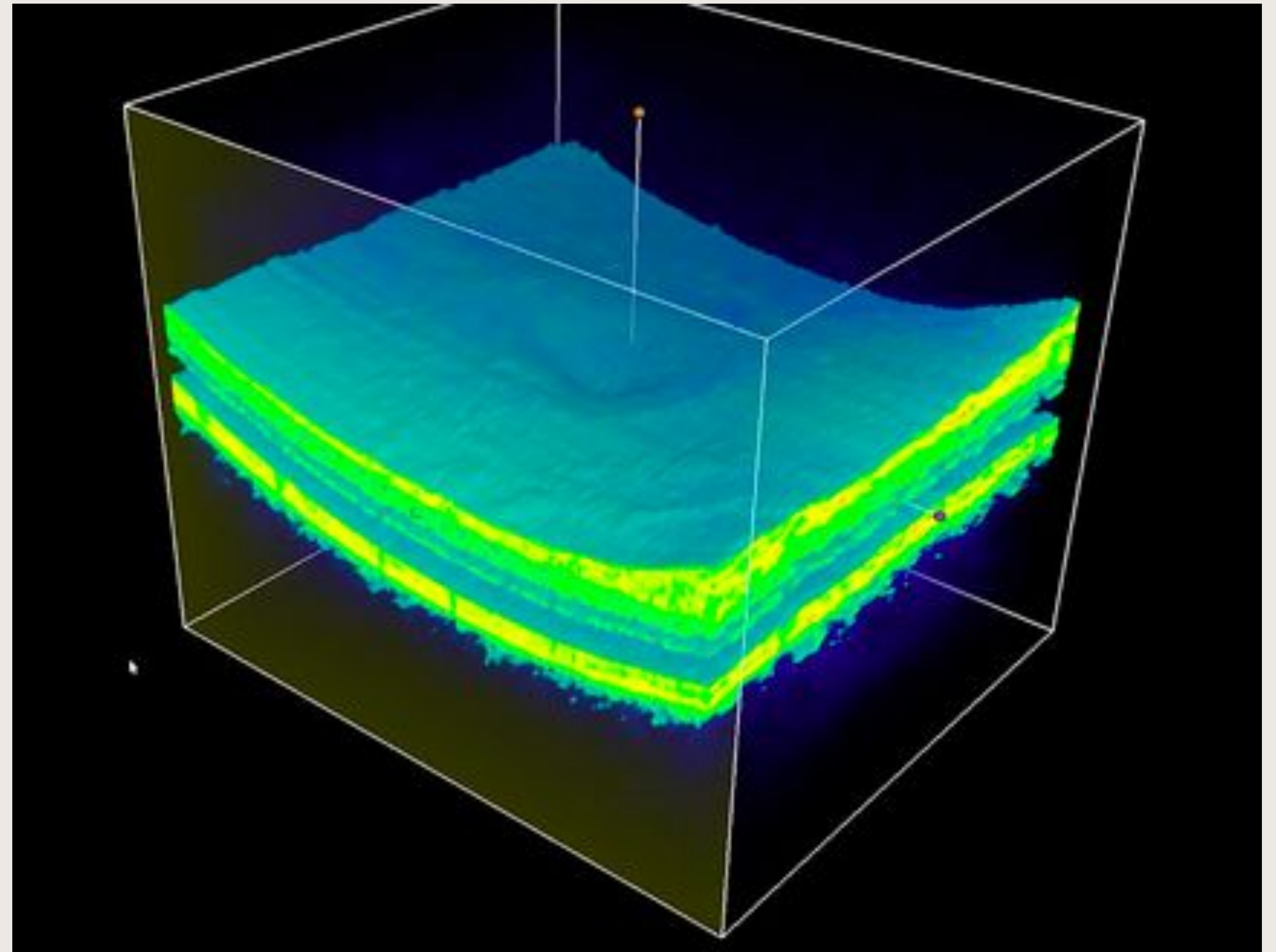
- 1.** Be aware of the capabilities of modern AI;
  - 2.** Be able to talk about and reflect on current advances in human-machine integration;
  - 3.** Be able to discuss AI's impact on health and medicine... especially the future of the human body and mind.
- 

# AI and ML in Medicine

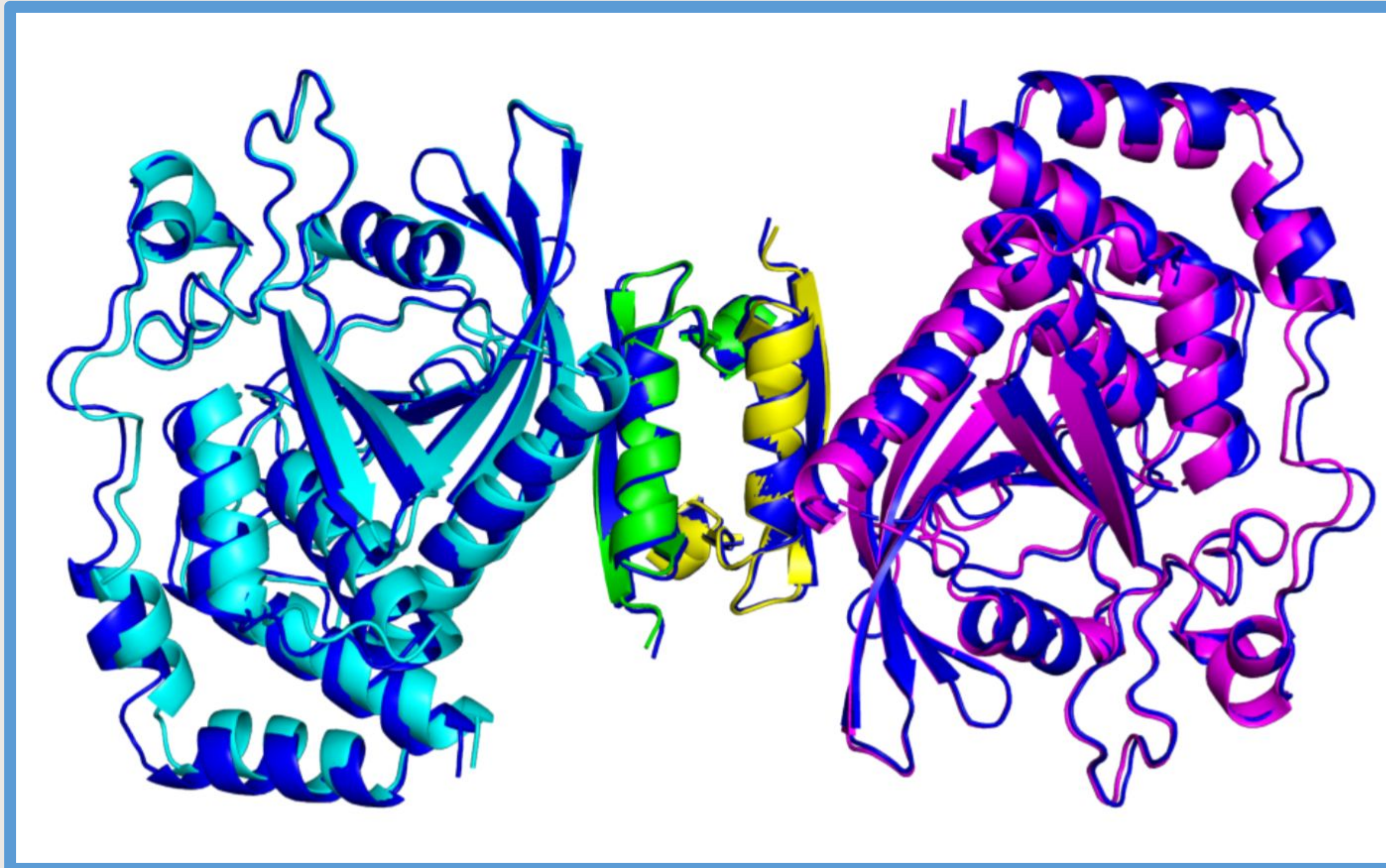
1. Helping to understand populations (**generalization**);
2. Helping to understand individuals (**personalization**);
3. Helping choose and improve interventions (**optimization**):
  - by connecting patients to assistive devices;
  - by helping deploy treatment strategies.



<http://www.humanconnectomeproject.org/>



J. De Fauw et al., *Nature Medicine* 24:1342–1350 (2018)



Evans et al. Protein complex prediction with AlphaFold-Multimer. *bioRxiv* 2021.10.04.463034 (2021)

Tunyasuvunakool et al. Highly accurate protein structure prediction for the human proteome. *Nature* 596, 590–596 (2021).

<https://alphafold.ebi.ac.uk/>

A 3D graphic of a map of Europe, where the landmasses are formed by stacks of blue and green cubes. The background is a light blue gradient.

# Welcome to Isomorphic Labs

<https://www.isomorphiclabs.com/news>

We're a digital biology company,  
here to redefine drug discovery with  
the power of artificial intelligence.



# Welcome to Isomorphic Labs

Isomorphic Labs announces **strategic collaborations with two of the world's leading pharmaceutical companies**, [due to] Isomorphic's approach to drug design".

<https://www.isomorphiclabs.com/news>



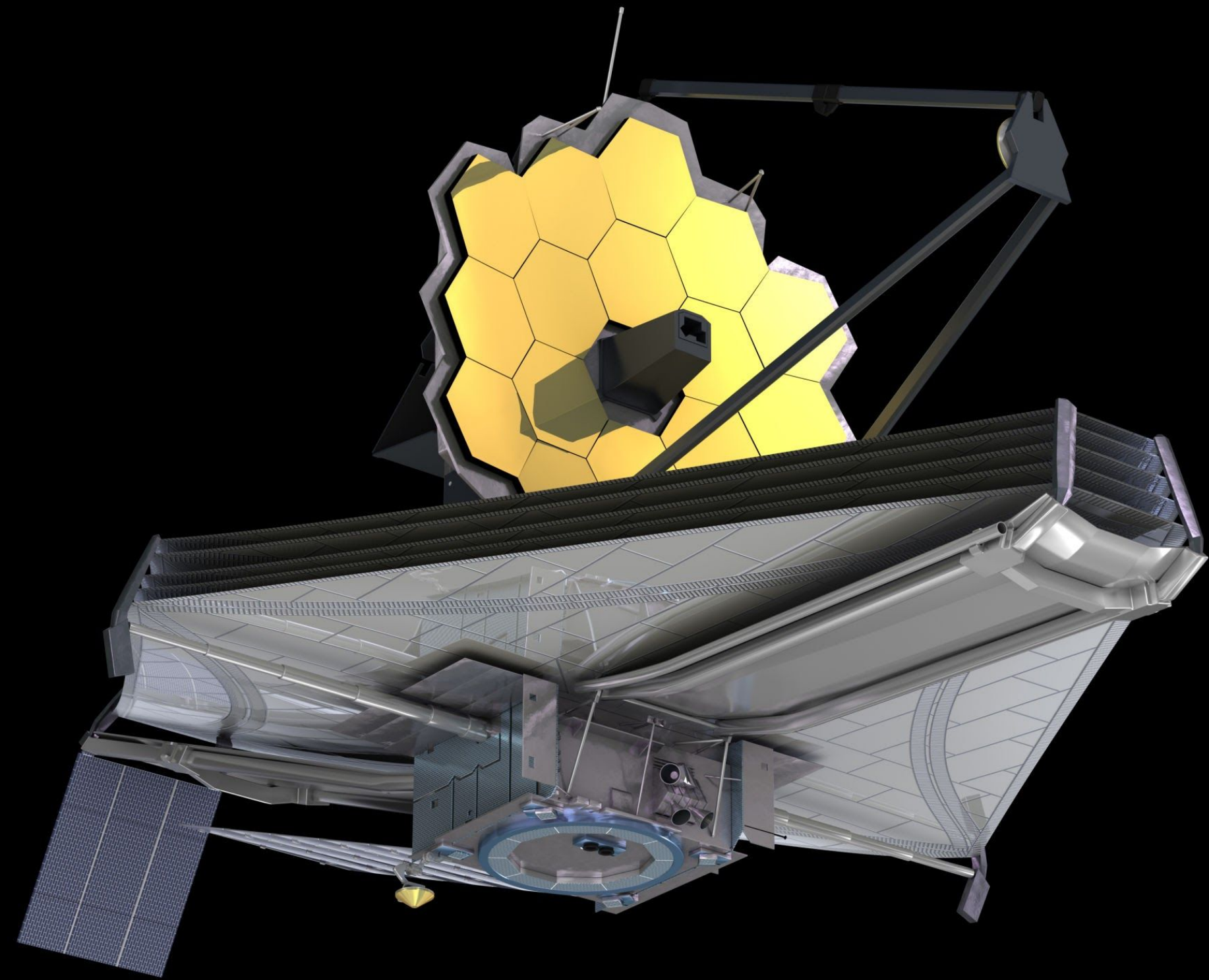


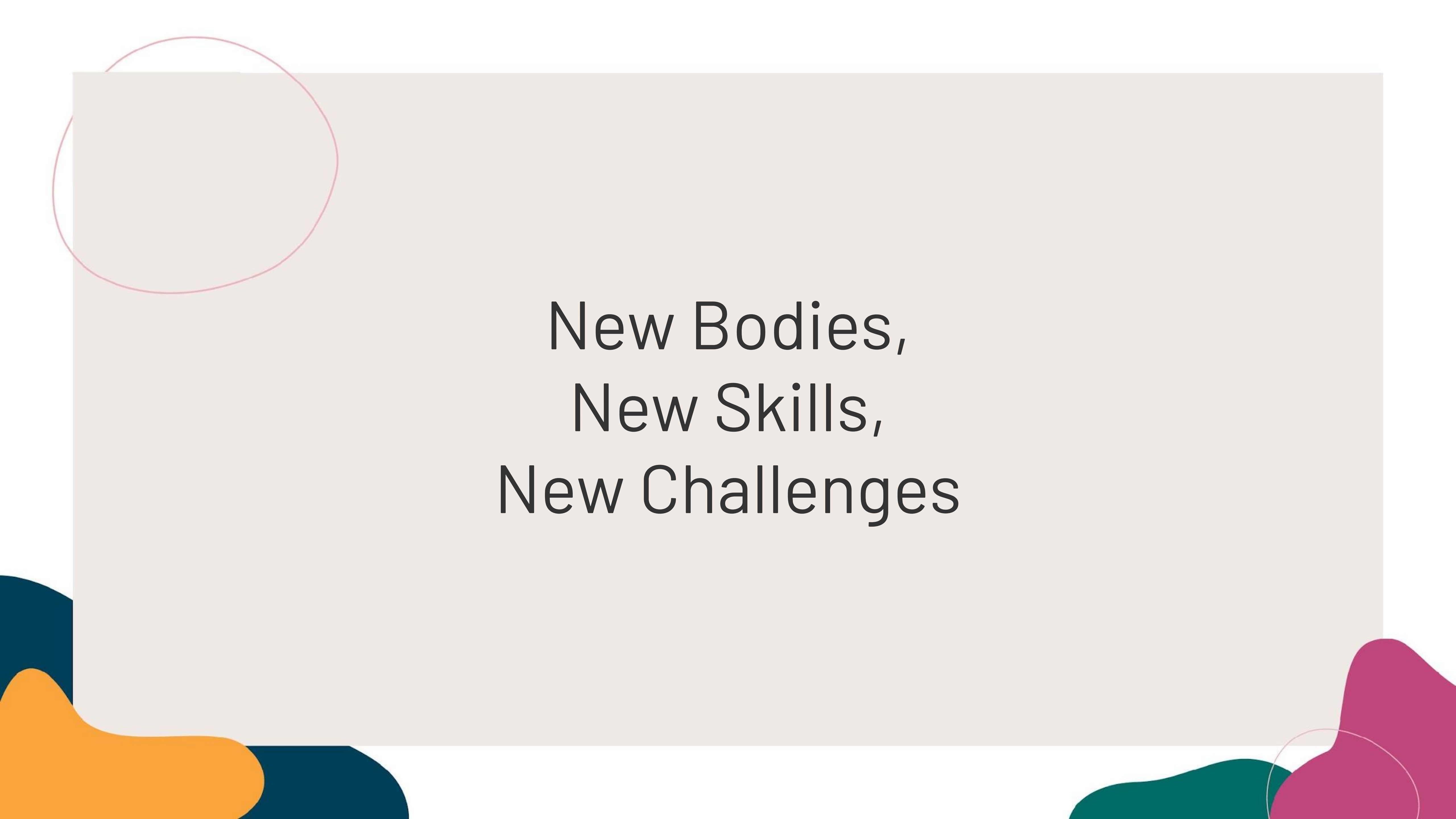


Modern Social Media  
Pieter Bruegel the Elder, 1568



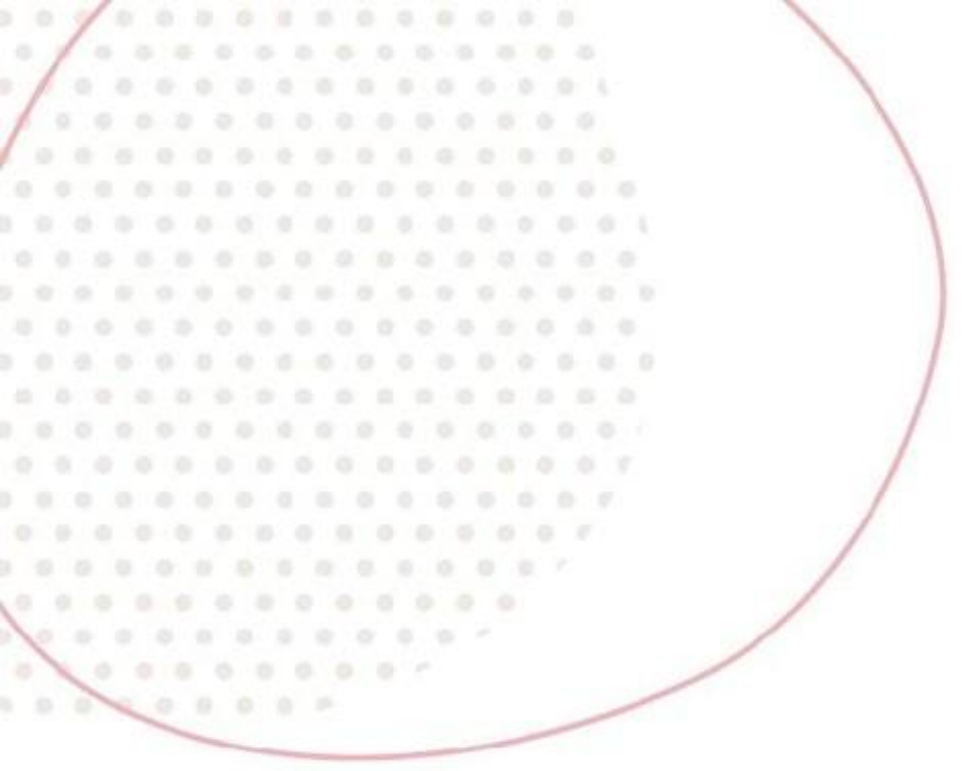
*The Blind Leading the Blind*  
Pieter Bruegel the Elder, 1568





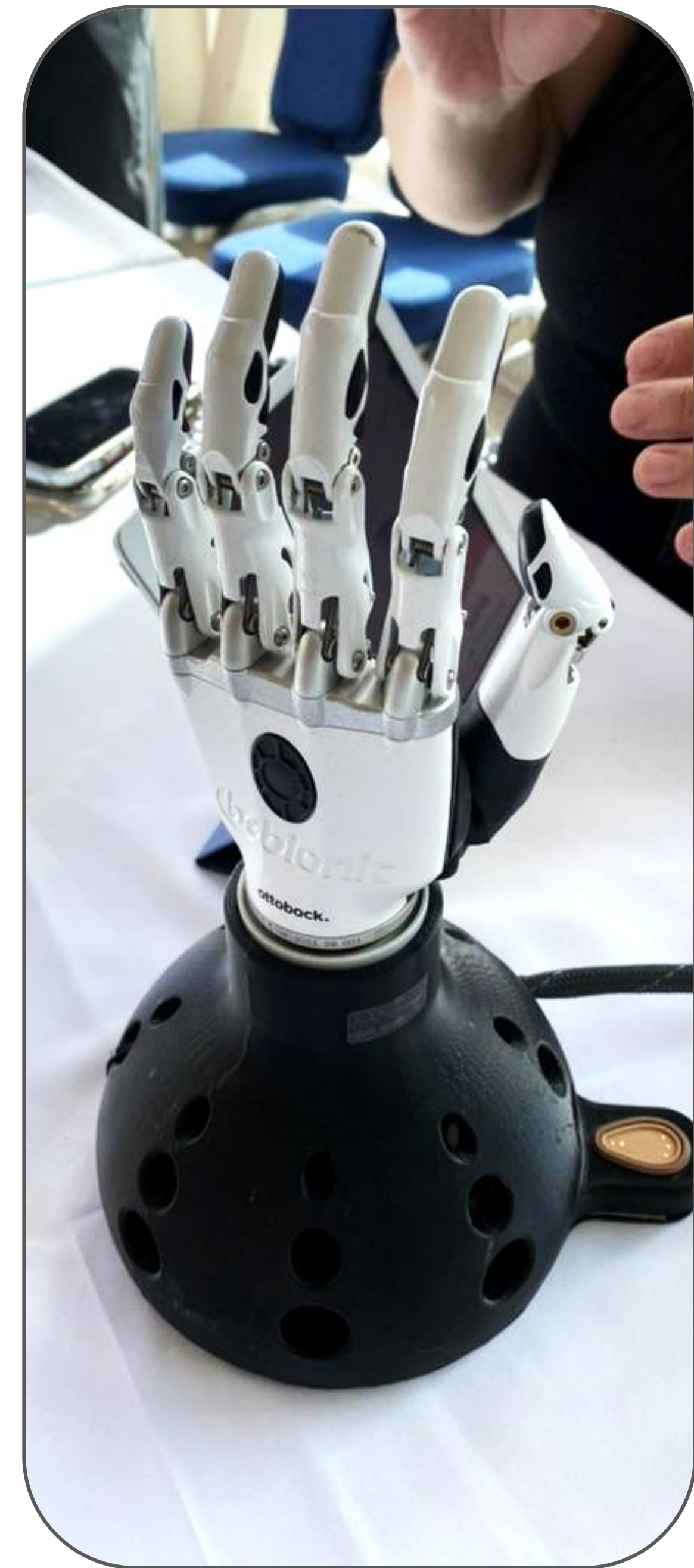
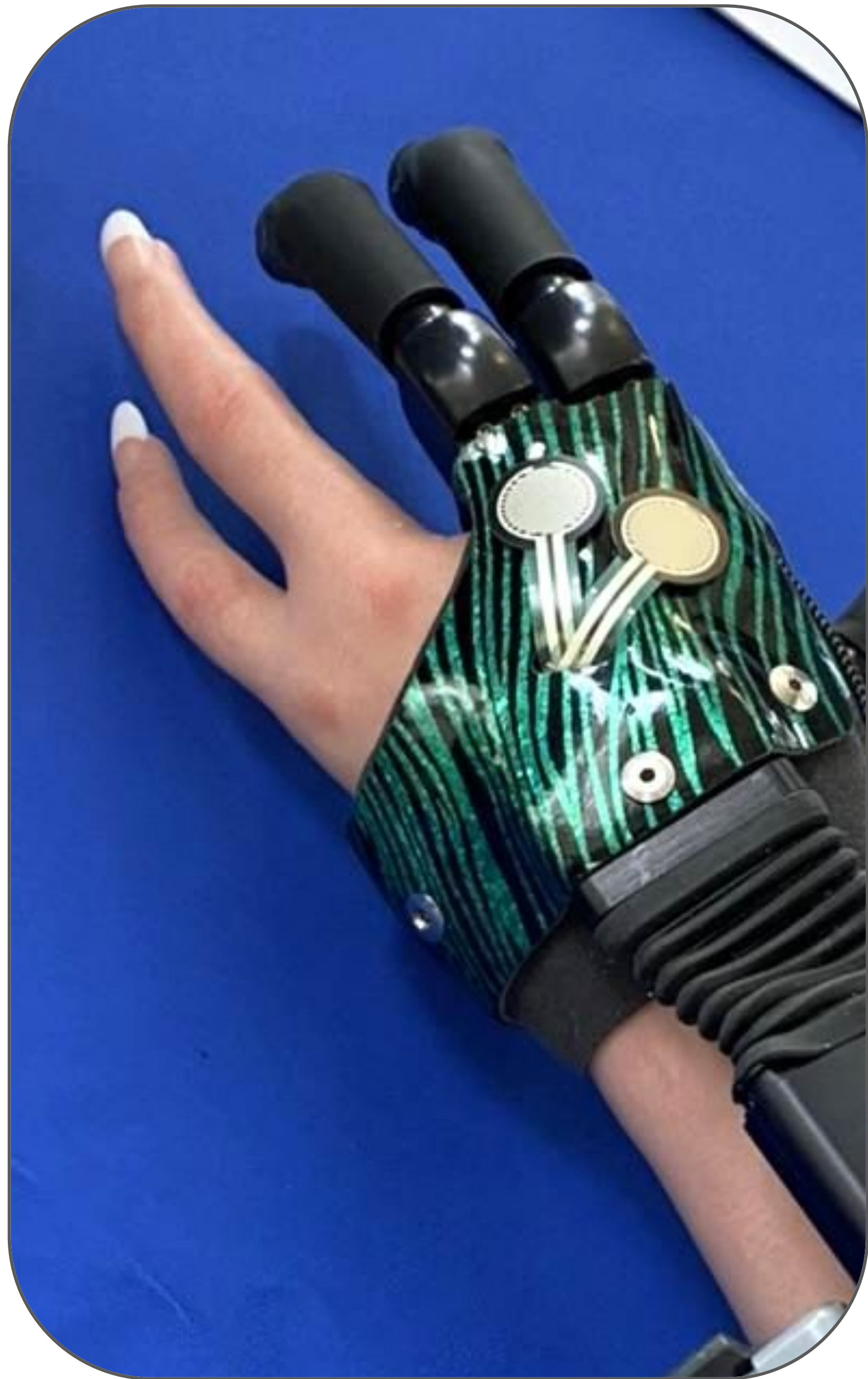
New Bodies,  
New Skills,  
New Challenges





**Some are in use every day ...**













## THE BIONIC-HAND ARMS RACE

The prosthetics industry is too focused on high-tech limbs that are complicated, costly, and often impractical.

## BRITT H. YOUNG

21 AUG 2022  
*IEEE Spectrum*



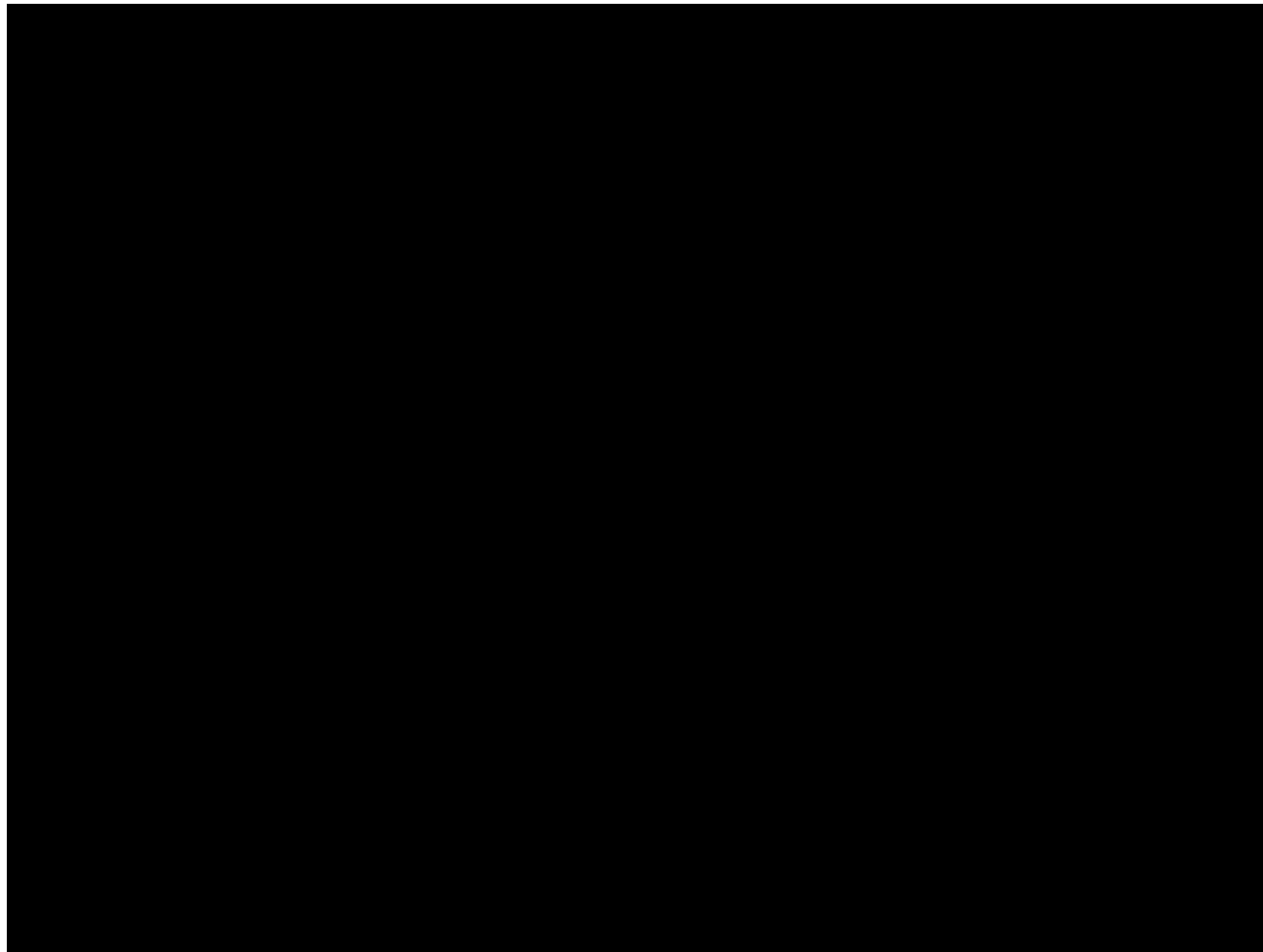
The author, Britt Young, holding her Ottobock iLimb bionic arm. GABRIELA HASBUN. MAKEUP: MARIA NGUYEN FOR MAC COSMETICS; HAIR: JOAN LAQUI FOR LIVING PROOF



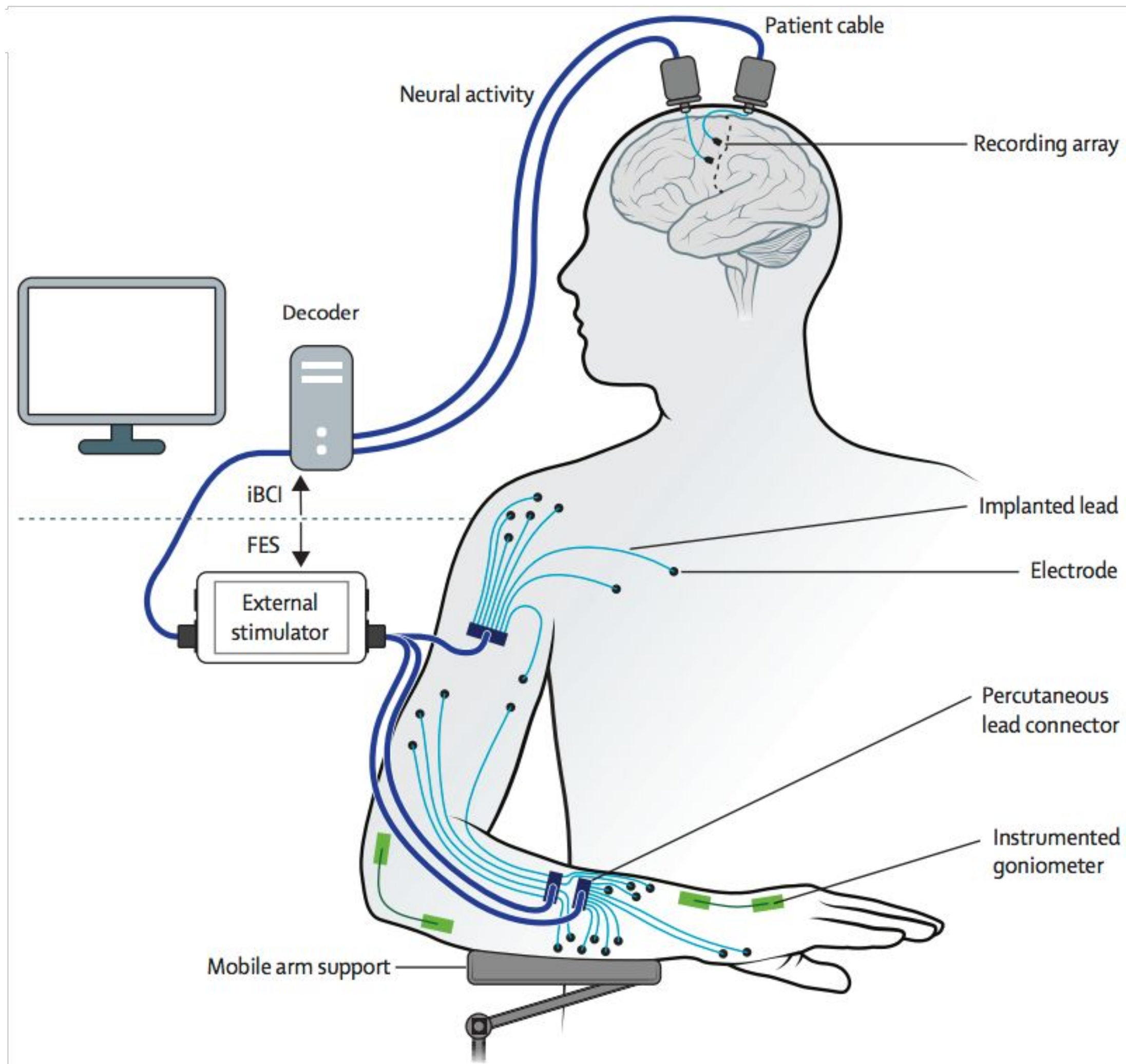
TRS makes a wide variety of body-powered prosthetic attachments for different hobbies and sports. Each attachment is specialized for a particular task, and they can be easily swapped for a variety of activities. FILLAUER TRS



**Some are coming soon ...  
(in research and development)**



**Direct brain-computer interfaces:** study participant Jan Scheuermann feeding herself with a robotic limb (University of Pittsburgh / UPMC); <http://www.upmc.com/media/media-kit/bci/Pages/default.aspx>



**Brain-body-machine interfaces:** “Restoration of reaching and grasping movements through brain-controlled muscle stimulation in a person with tetraplegia: a proof-of-concept demonstration” Ajiboye, A Bolu et al., *The Lancet*, Volume 389 , Issue 10081, 1821-1830, 2017.

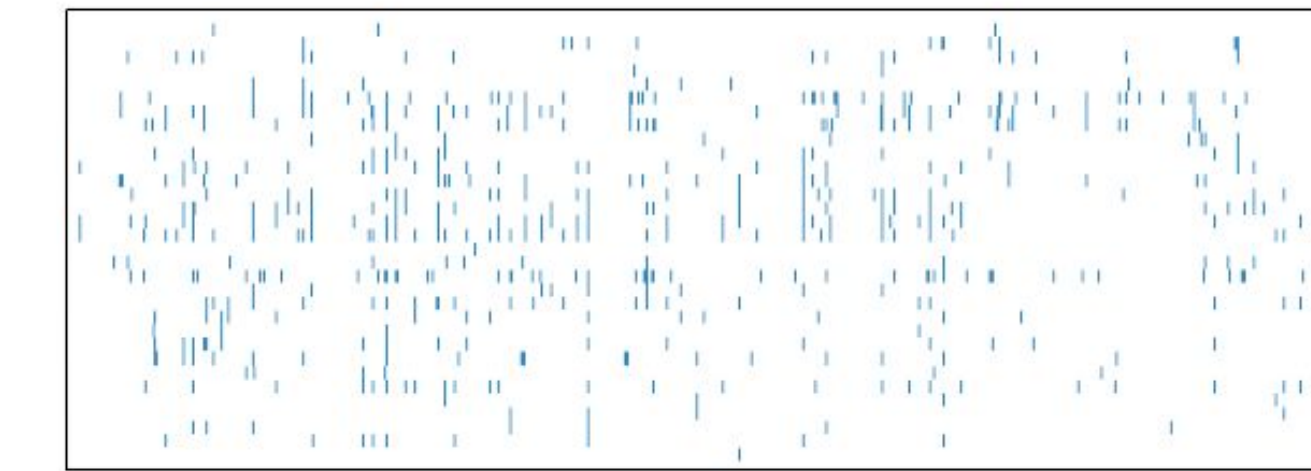
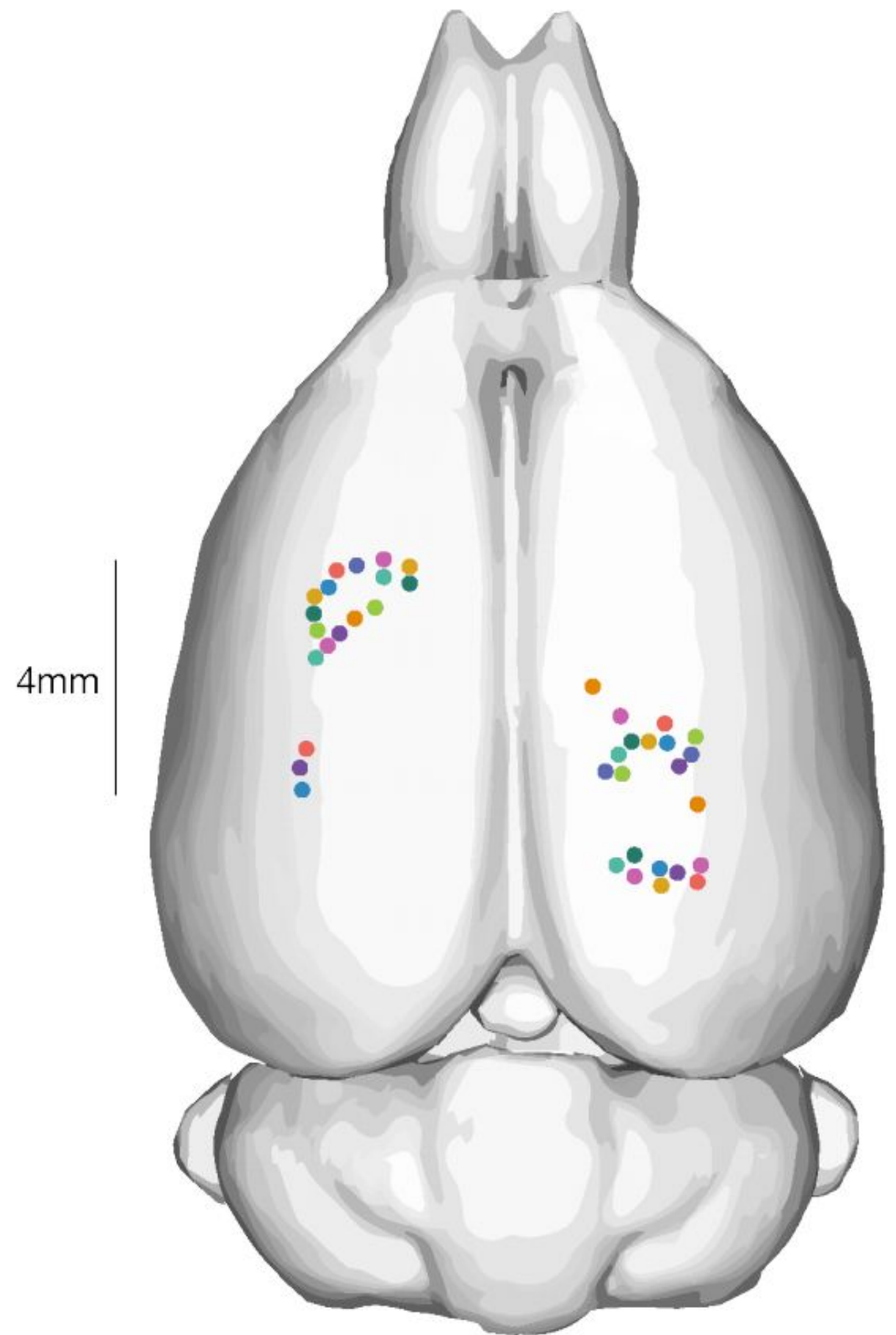
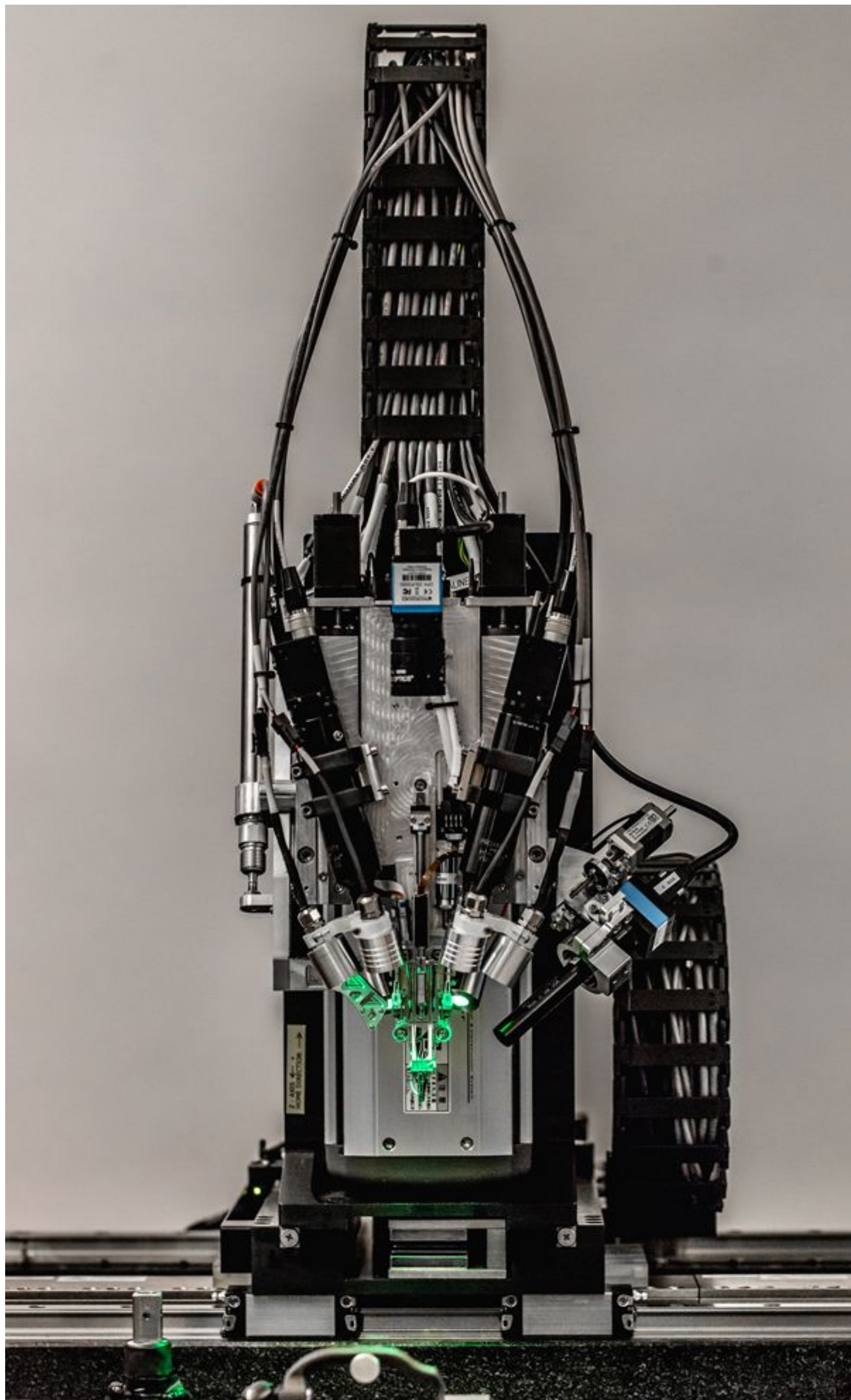


A microscopic image showing a neural implant in a brain. The implant consists of several thin, parallel channels that are illuminated in a bright cyan color. The surrounding brain tissue is a darker, textured blue. A scale bar in the top left corner indicates 500 micrometers. The letter 'A' is in the top right corner.

500 $\mu$ m

# *modern cortical implants*

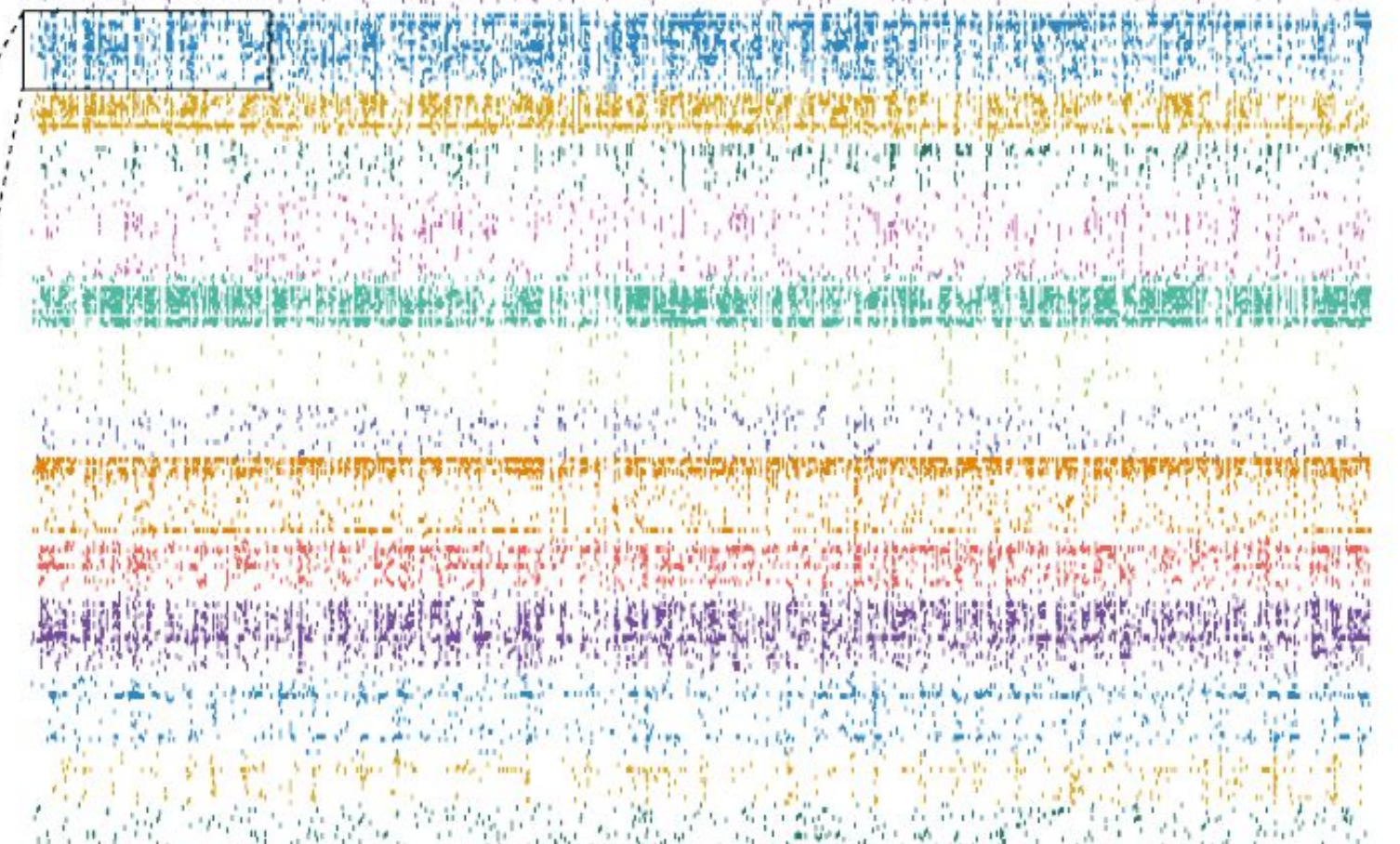
Elon Musk, Neuralink (2019). "An integrated brain-machine interface platform with thousands of channels," bioRxiv 703801; doi: <https://doi.org/10.1101/703801>

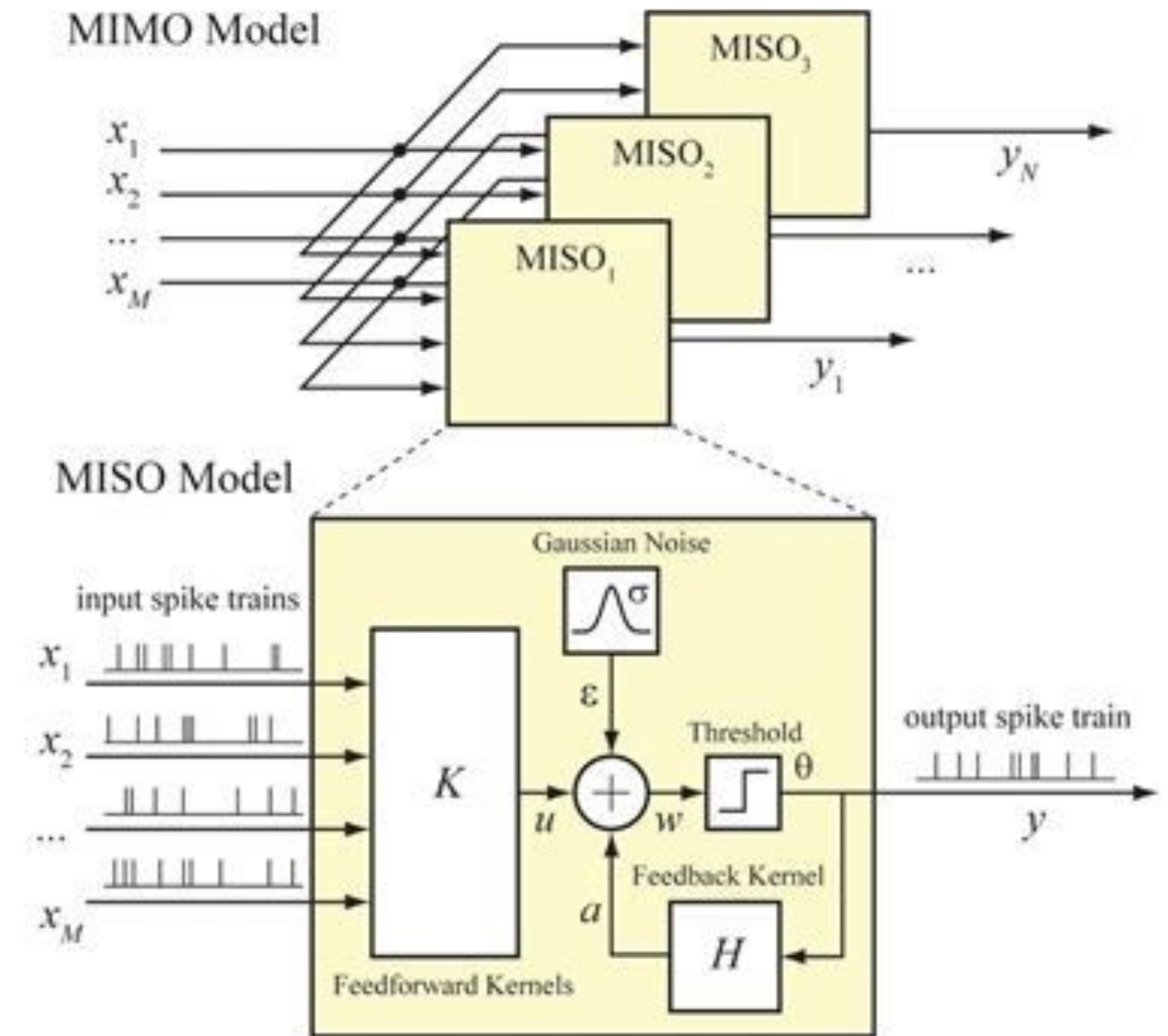
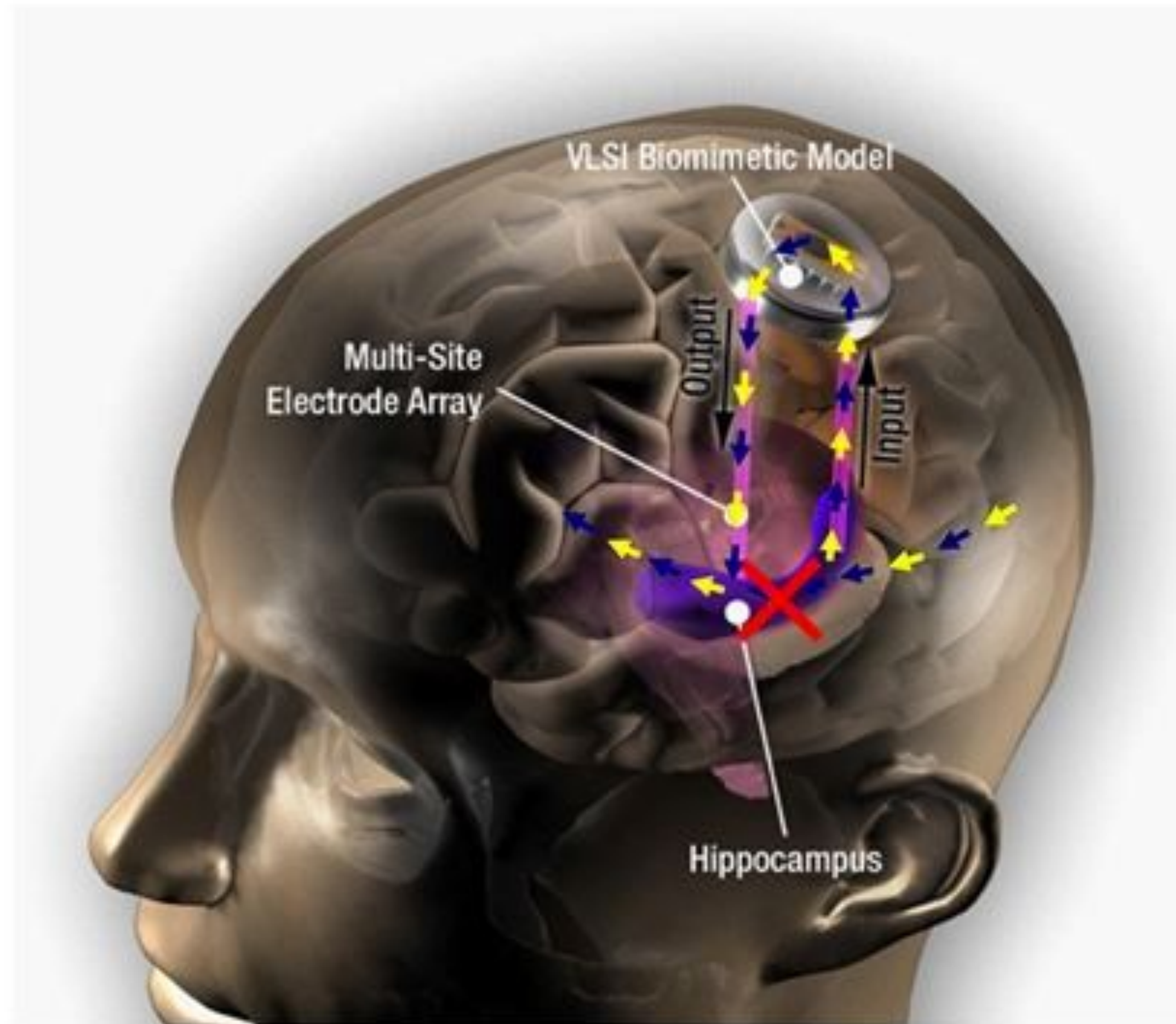


200 milliseconds

1020

500



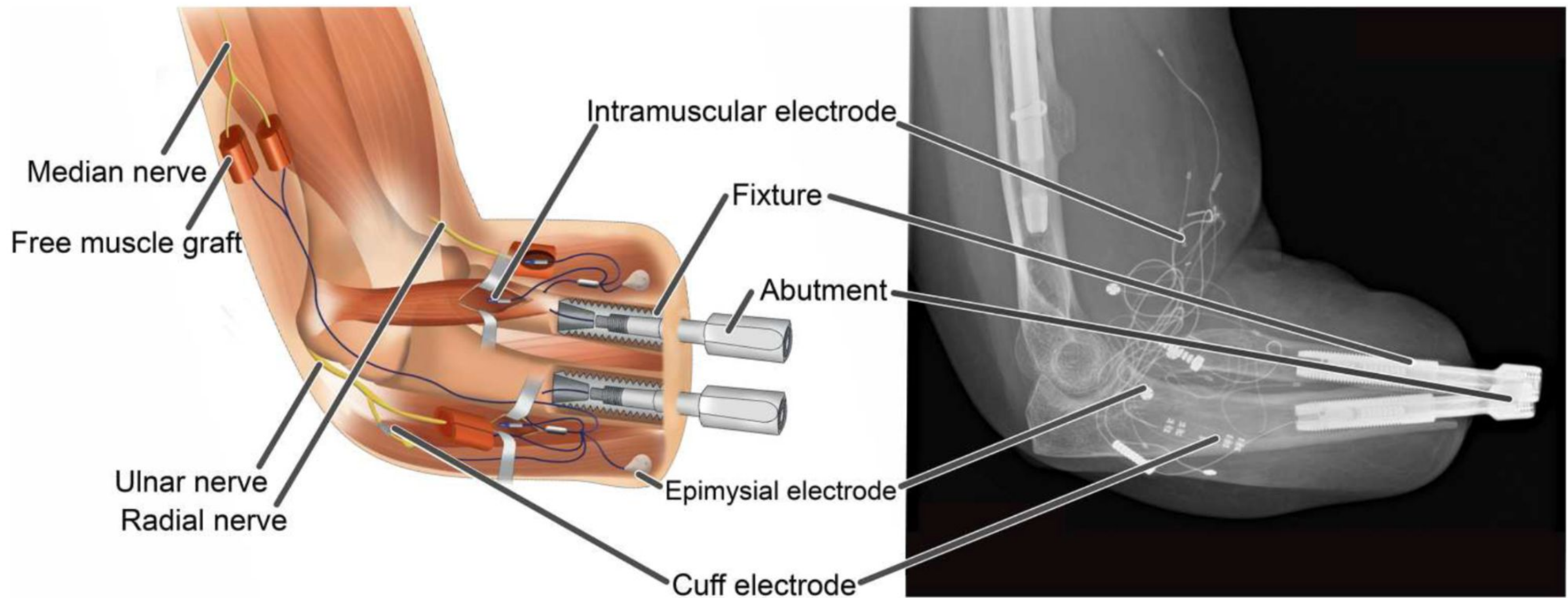


**Direct brain-computer interfaces:** *memory prostheses* from the Center for Neural Engineering, Viterbi School of Engineering. <https://cne.usc.edu/neural-prosthesis-for-hippocampal-memory-function/> and IEEE Trans Neural Syst Rehabil Eng. 2018, 26(2):272-280.

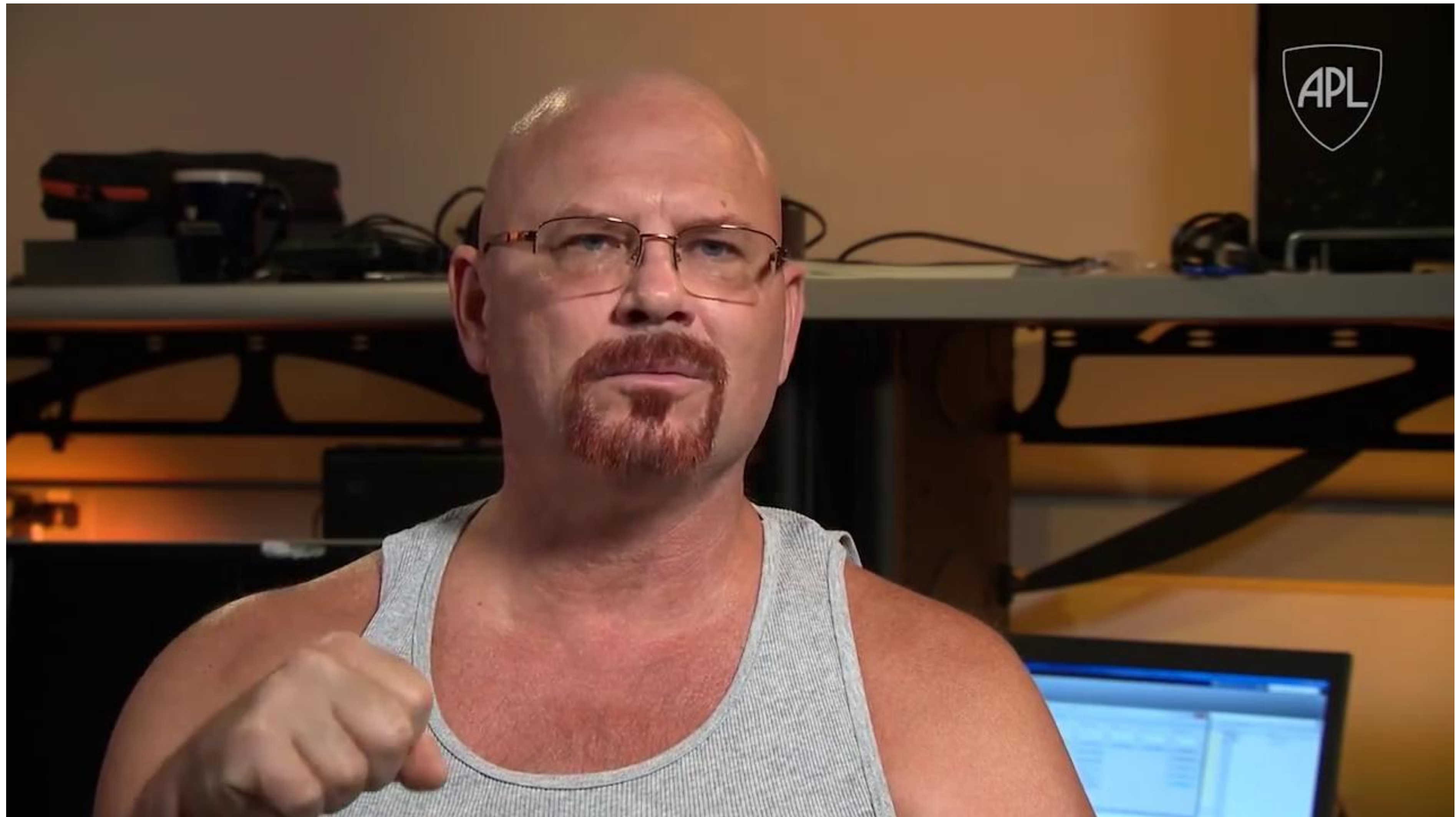


**Brain-body-machine interfaces:** "Amputee Makes History with APL's Modular Prosthetic Limb" (JHU Applied Physics Laboratory); <https://youtu.be/9N0ncx2jU0Q>

# *bone, muscle, and nerve integration*

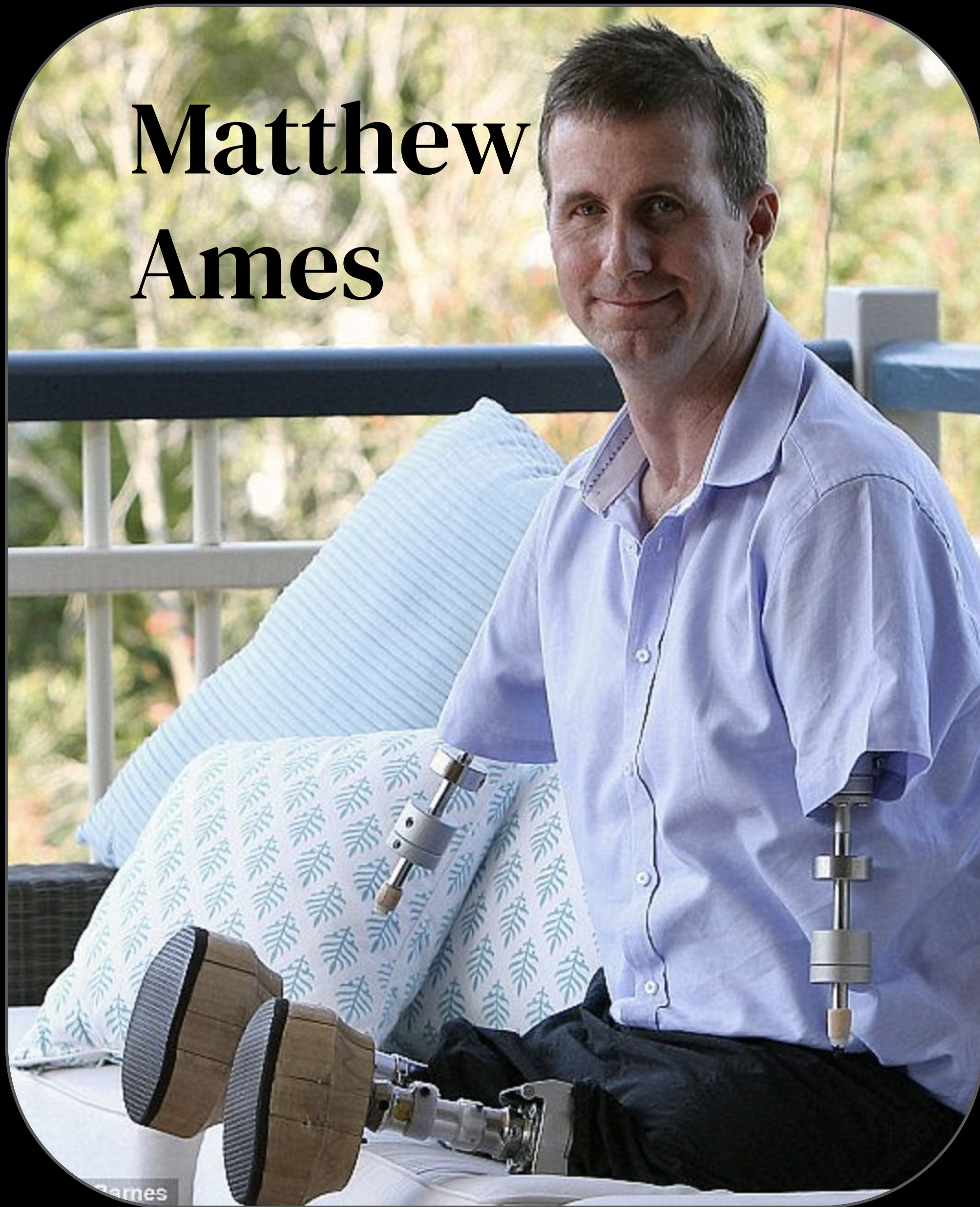


Max Ortiz-Catalan et al.,  
*Sci. Robot.* 8, eadf7360 (2023).



**Brain-body-machine interfaces:** “APL’s Modular Prosthetic Limb Reaches New Levels of Operability” (JHU Applied Physics Laboratory); <https://youtu.be/-0srXv0Qlu0>

# Matthew Ames



<https://www.couriermail.com.au/lifestyle/qweekend/matthew-ames-opens-up-on-his-life-today-10-years-after-losing-his-limbs-to-sepsis/news-story/1309e86a50559c4f75f04606d204cd3f>



<https://www.dailymail.co.uk/news/article-3100224/It-happen-shouldn-t-Father-four-arms-legs-amputated-sore-throat-turned-life-threatening-virus-sue-doctors-treated-him.html>

# Matthew Ames



<https://www.bionicsgamechangers.com/seven-years-on-the-journey-of-matthew-ames/>

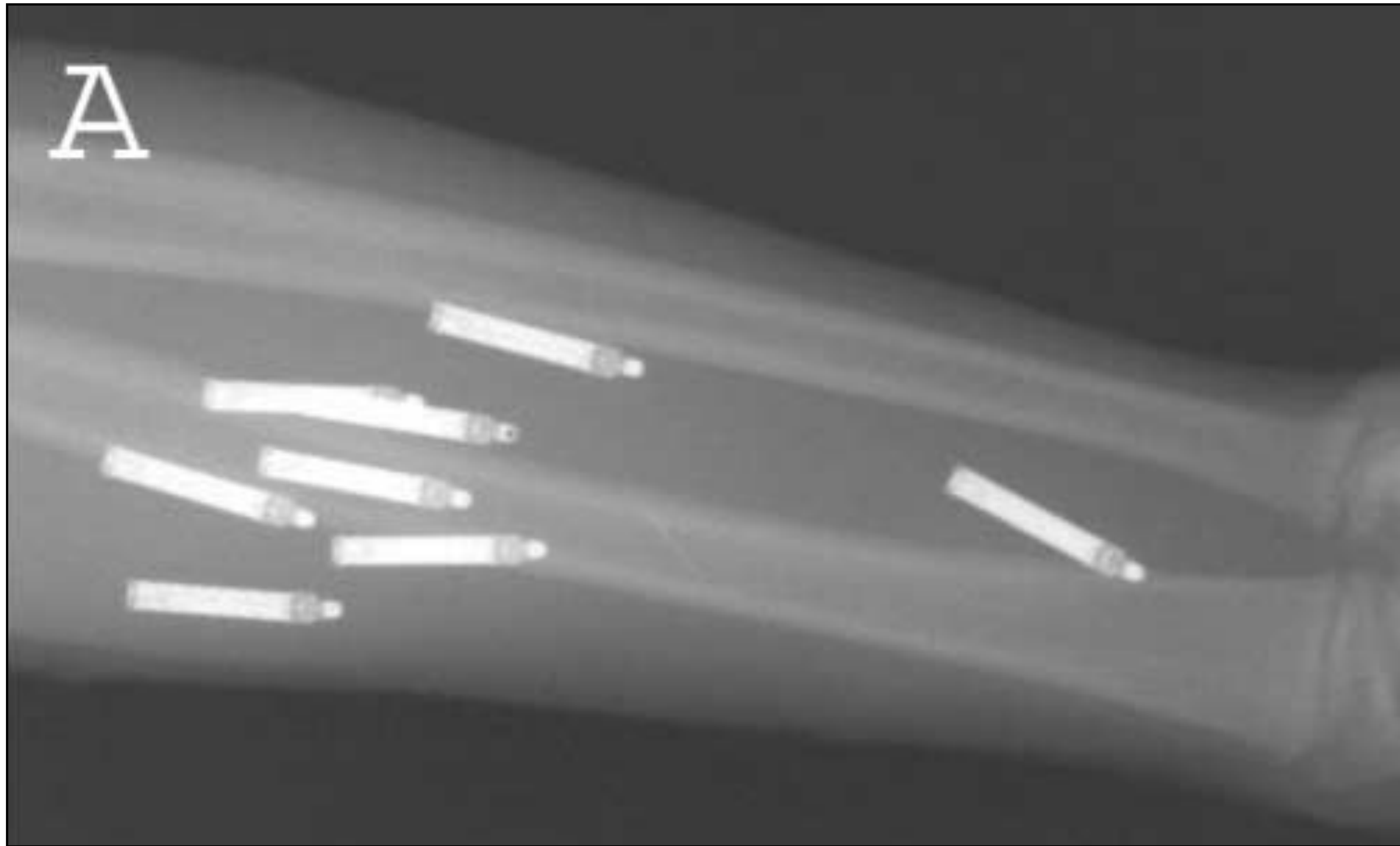
<https://www.couriermail.com.au/lifestyle/qweekend/matthew-ames-opens-up-on-his-life-today-10-years-after-losing-his-limbs-to-sepsis/news-story/1309e86a50559c4f75f04606d204cd3f>



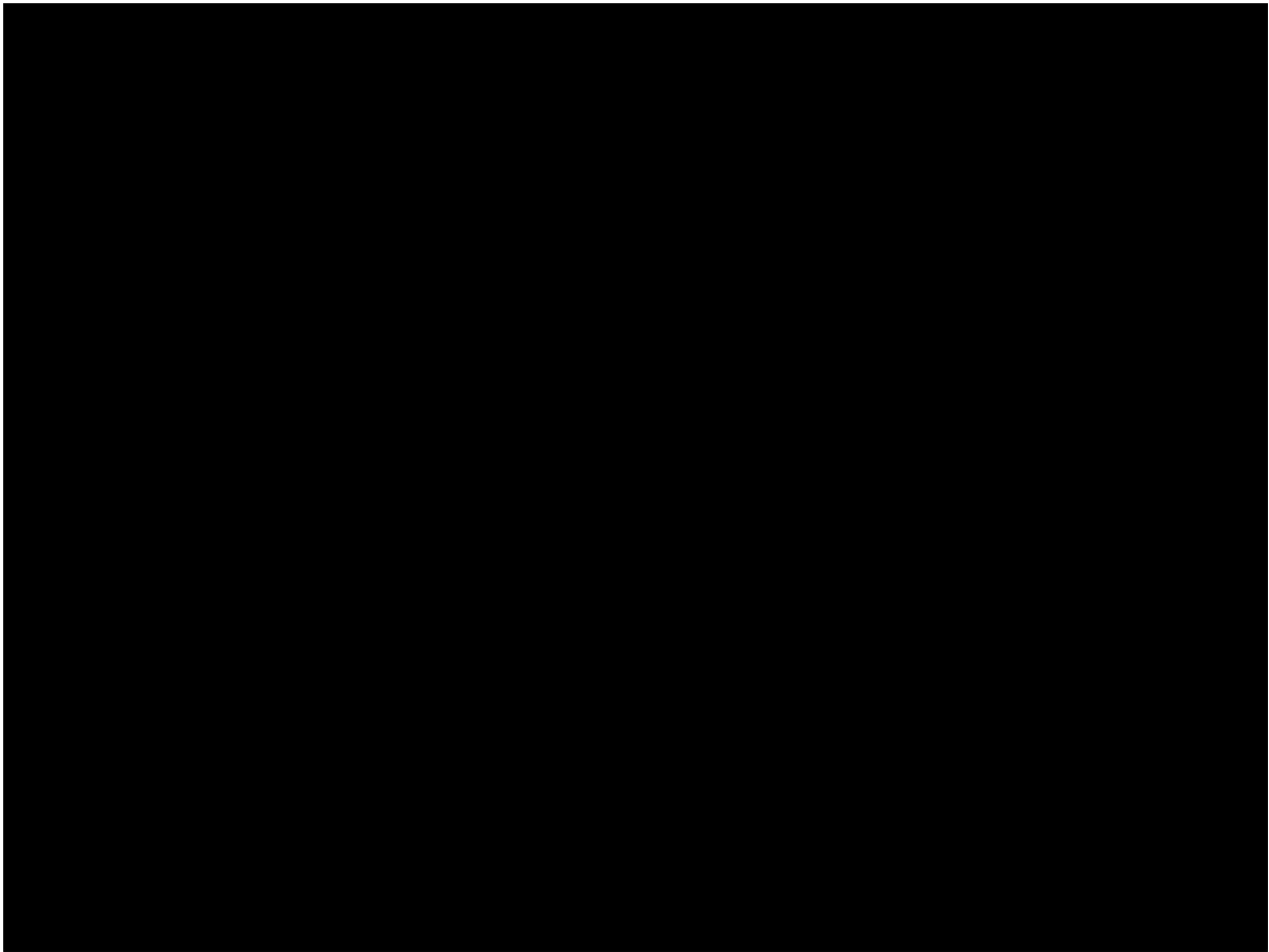


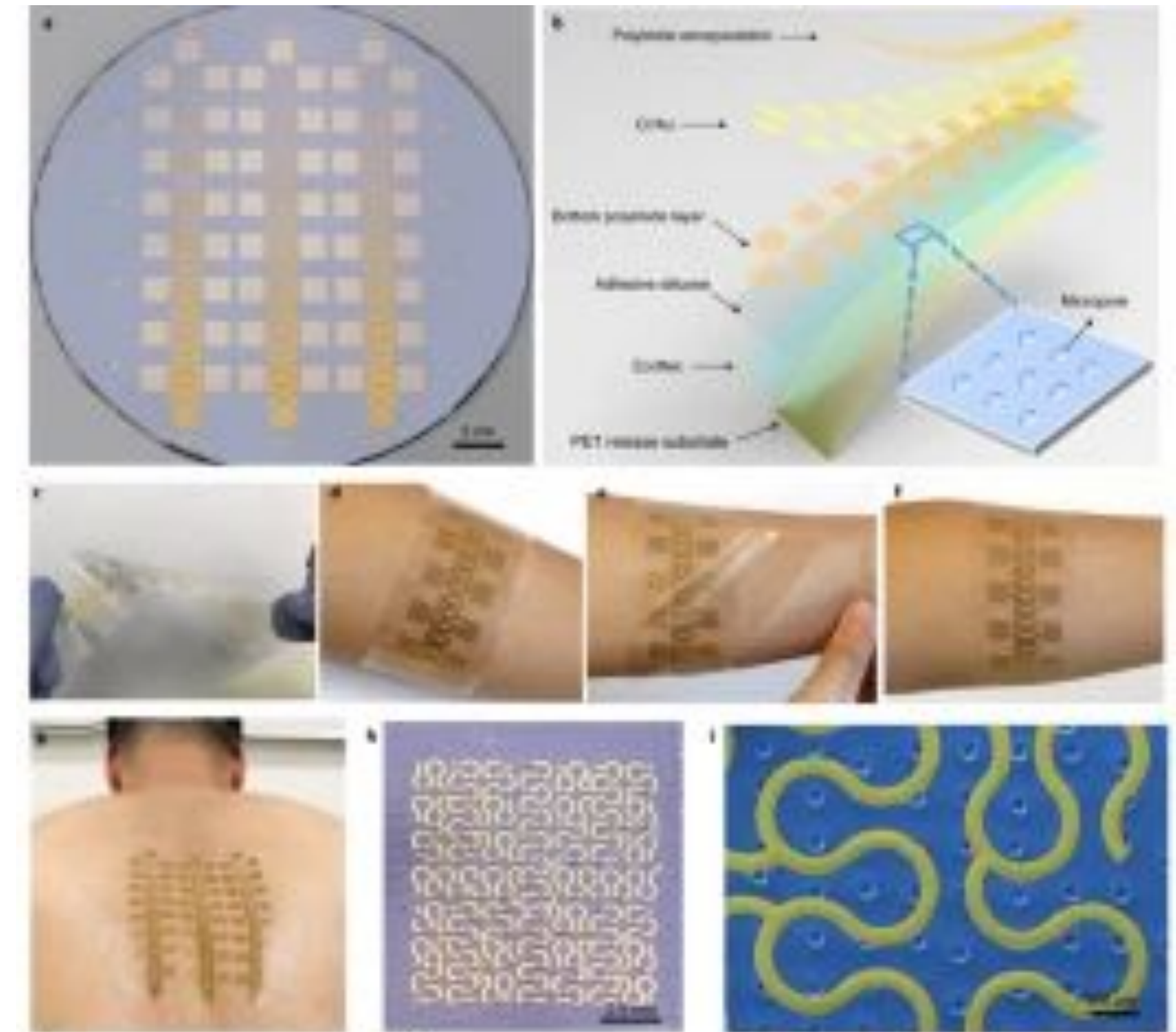
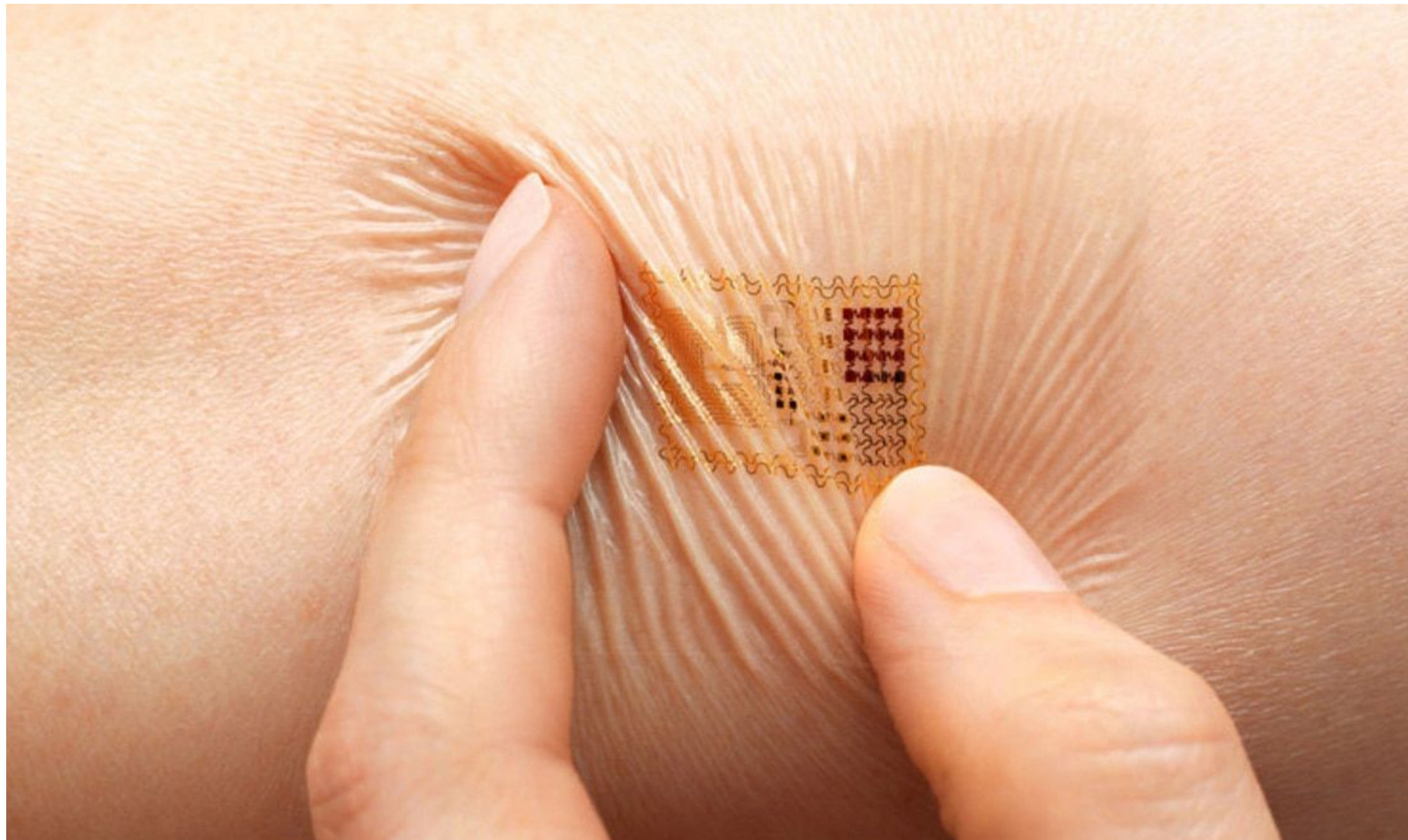


**Biotechnology has also  
gone low-profile and wireless!**



**Brain-body-machine interfaces:** Baker et al., "Continuous Detection and Decoding of Dexterous Finger Flexions With Implantable MyoElectric Sensors," *IEEE TNSRE* 18(4):424-32, 2010.



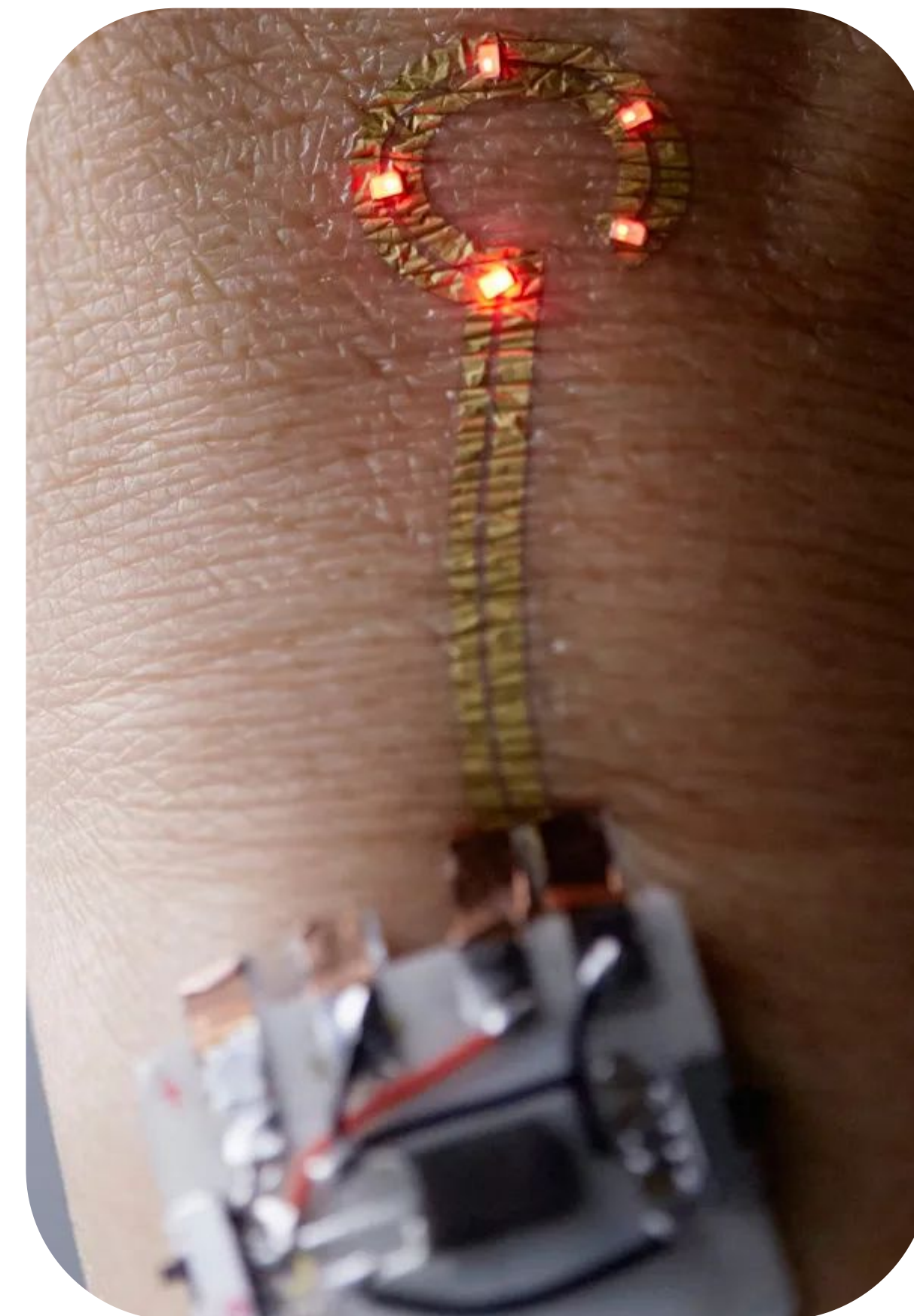
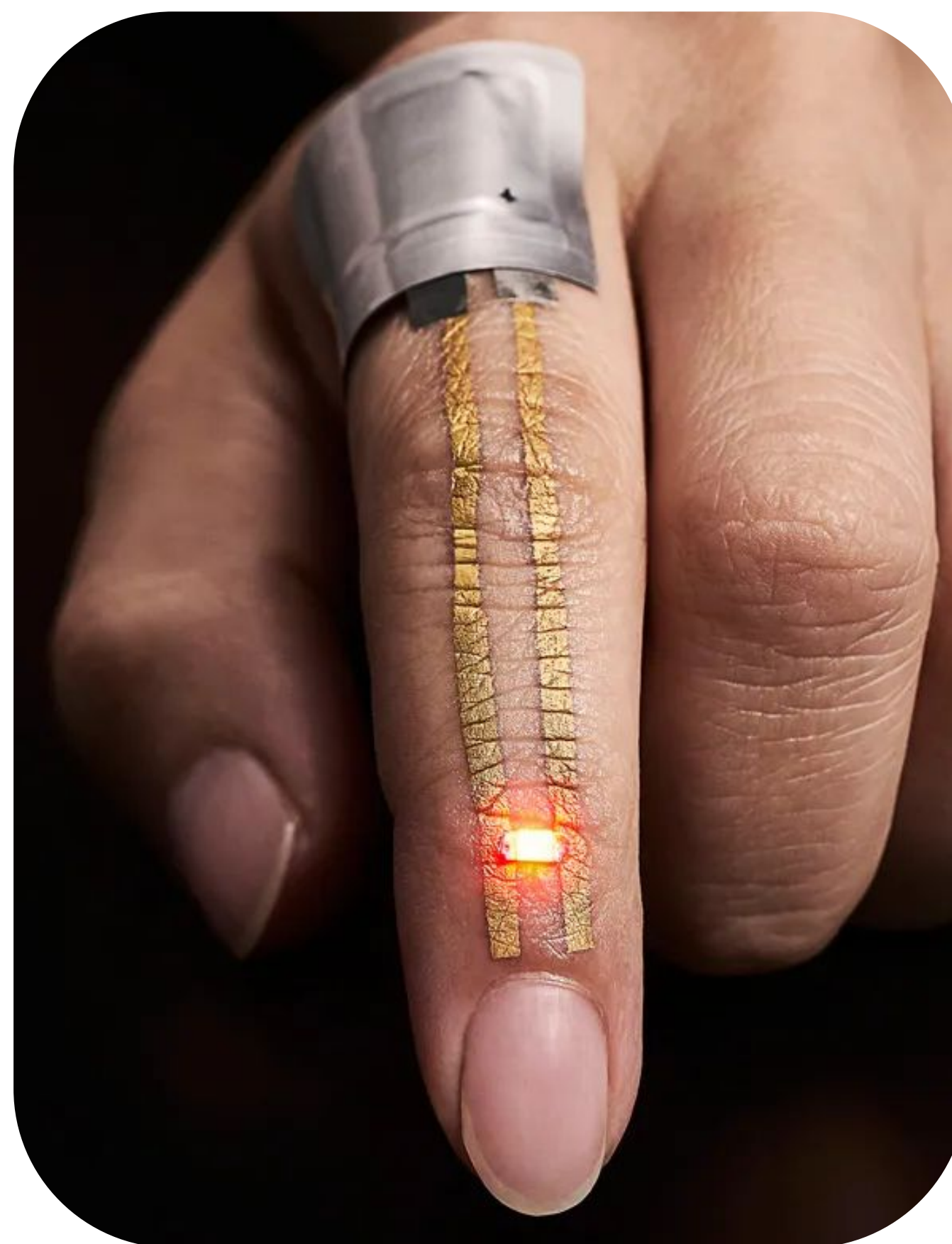
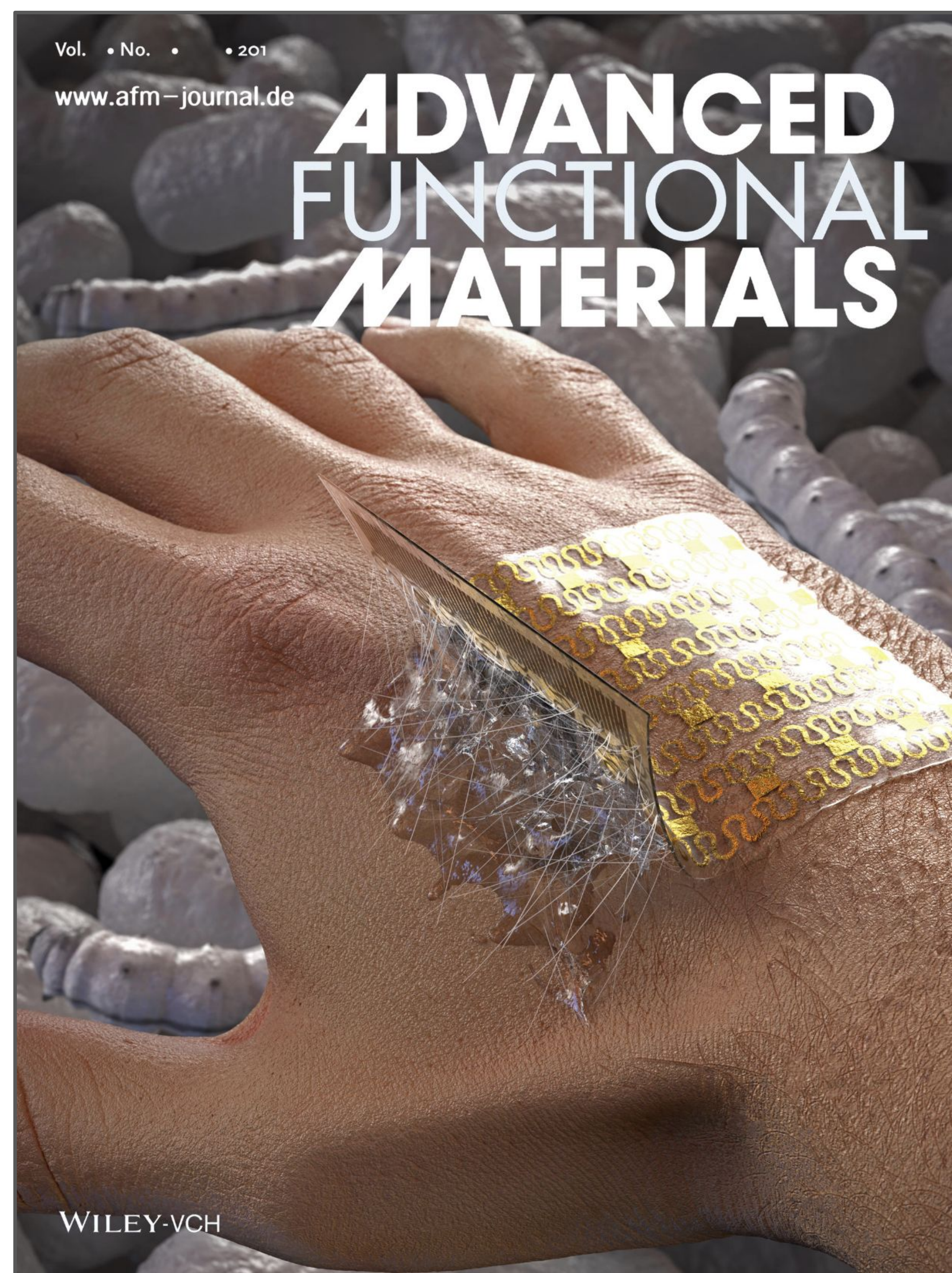


Tian, L., Zimmerman, B., Akhtar, A. et al. **Large-area MRI-compatible epidermal electronic interfaces for prosthetic control and cognitive monitoring.** Nat Biomed Eng 3, 194–205 (2019).

<https://doi-org.login.ezproxy.library.ualberta.ca/10.1038/s41551-019-0347-x>

**Epidermal Electronics** (2011) Dae-Hyeong Kim, Nanshu Lu, Rui Ma, Yun-Soung Kim, Rak-Hwan Kim, Shuodao Wang, Jian Wu, Sang Min Won, Hu Tao, Ahmad Islam, Ki Jun Yu, Tae-il Kim, Raed Chowdhury, Ming Ying, Lizhi Xu, Ming Li, Hyun-Joong Chung, Hohyun Keum, Martin McCormick, Ping Liu, Yong-Wei Zhang, Fiorenzo G. Omenetto, Yonggang Huang, Todd Coleman, and John A. Rogers Science, 333 (6044), • DOI: 10.1126/science.1206157

# ADVANCED FUNCTIONAL MATERIALS




<https://spectrum.ieee.org/skin-displays-will-give-wearables-their-independence>

<https://doi.org/10.1002/adfm.201870250>

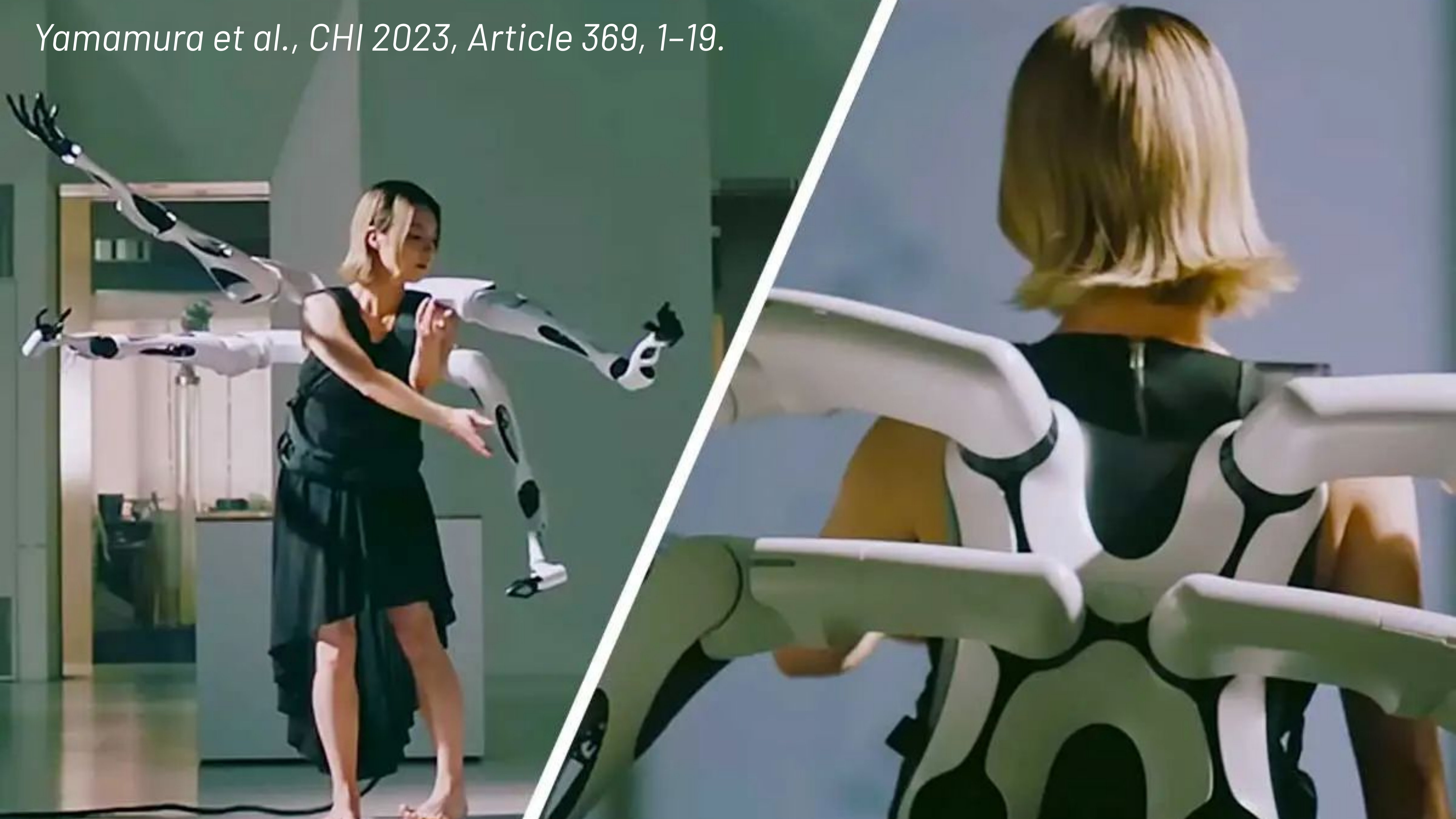


**Meanwhile, at the  
University of Tokyo ...**




自在肢

JIZAI ARMS

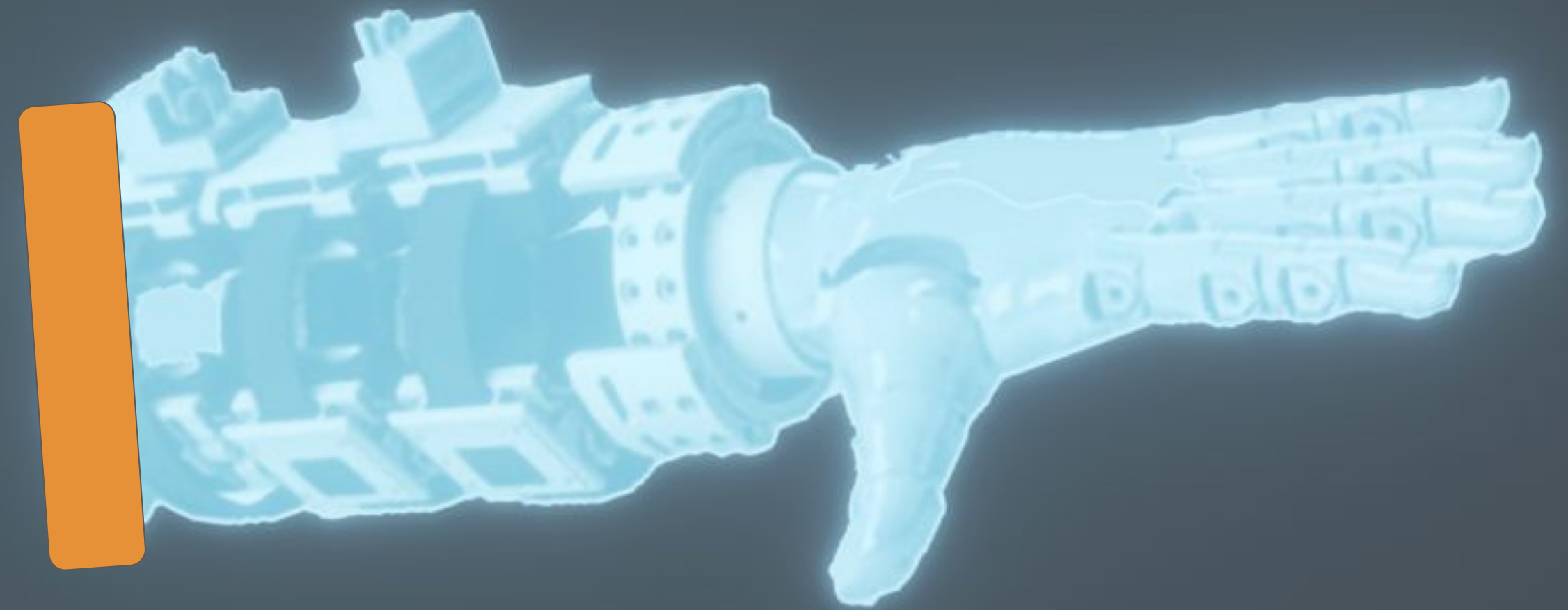
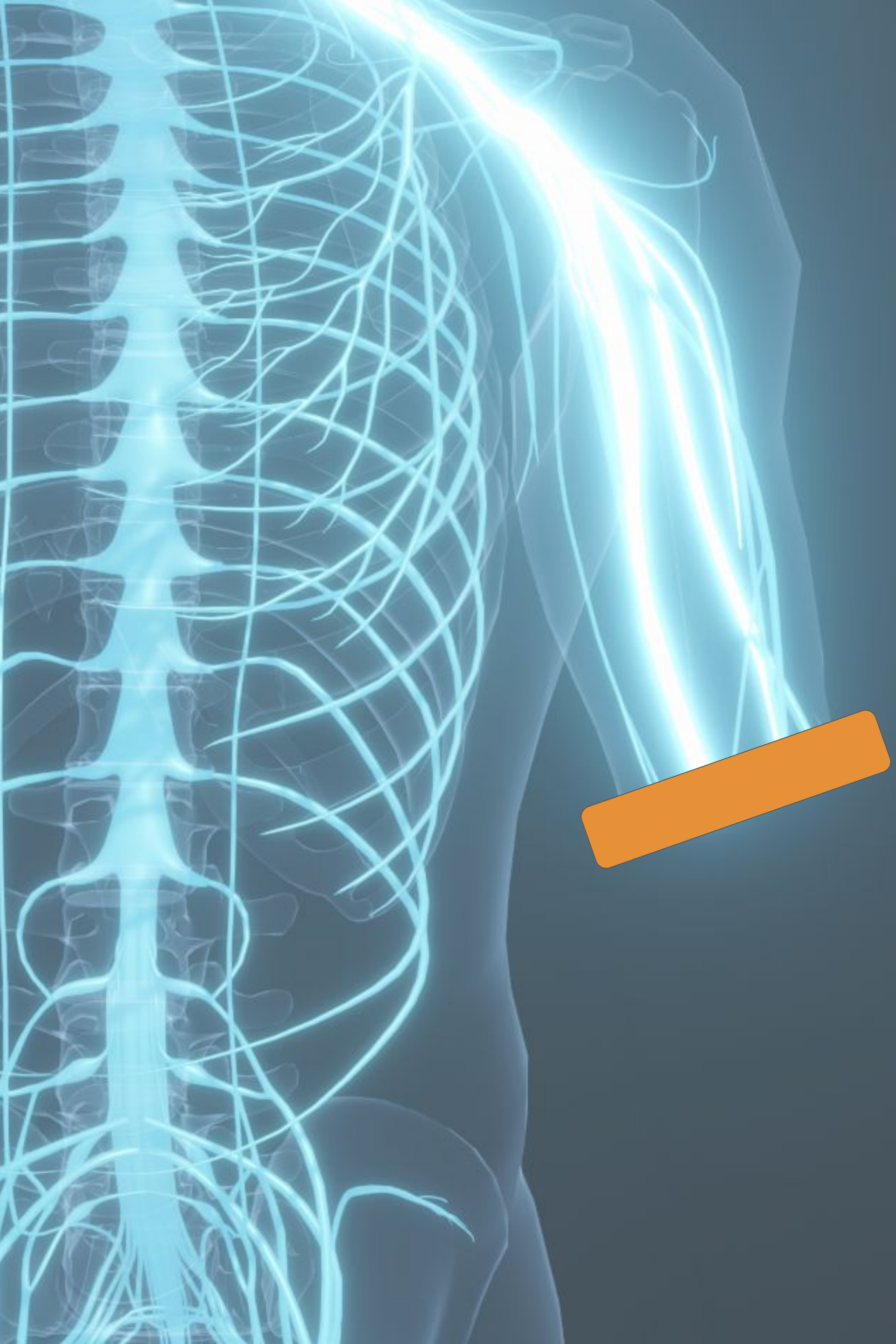


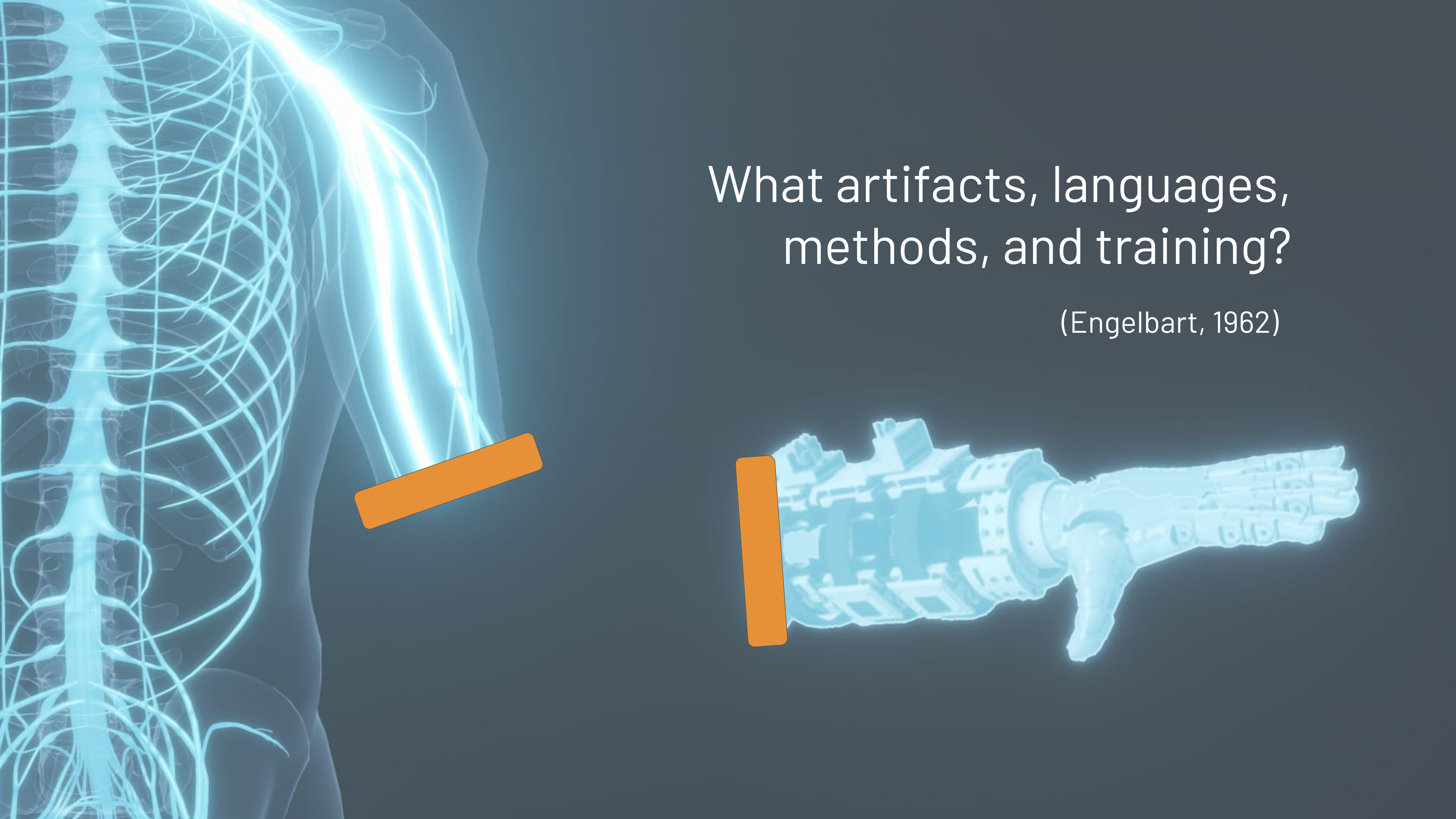




# Beyond Engineering (From Tools to Partners)

What connects the person  
and the machine?

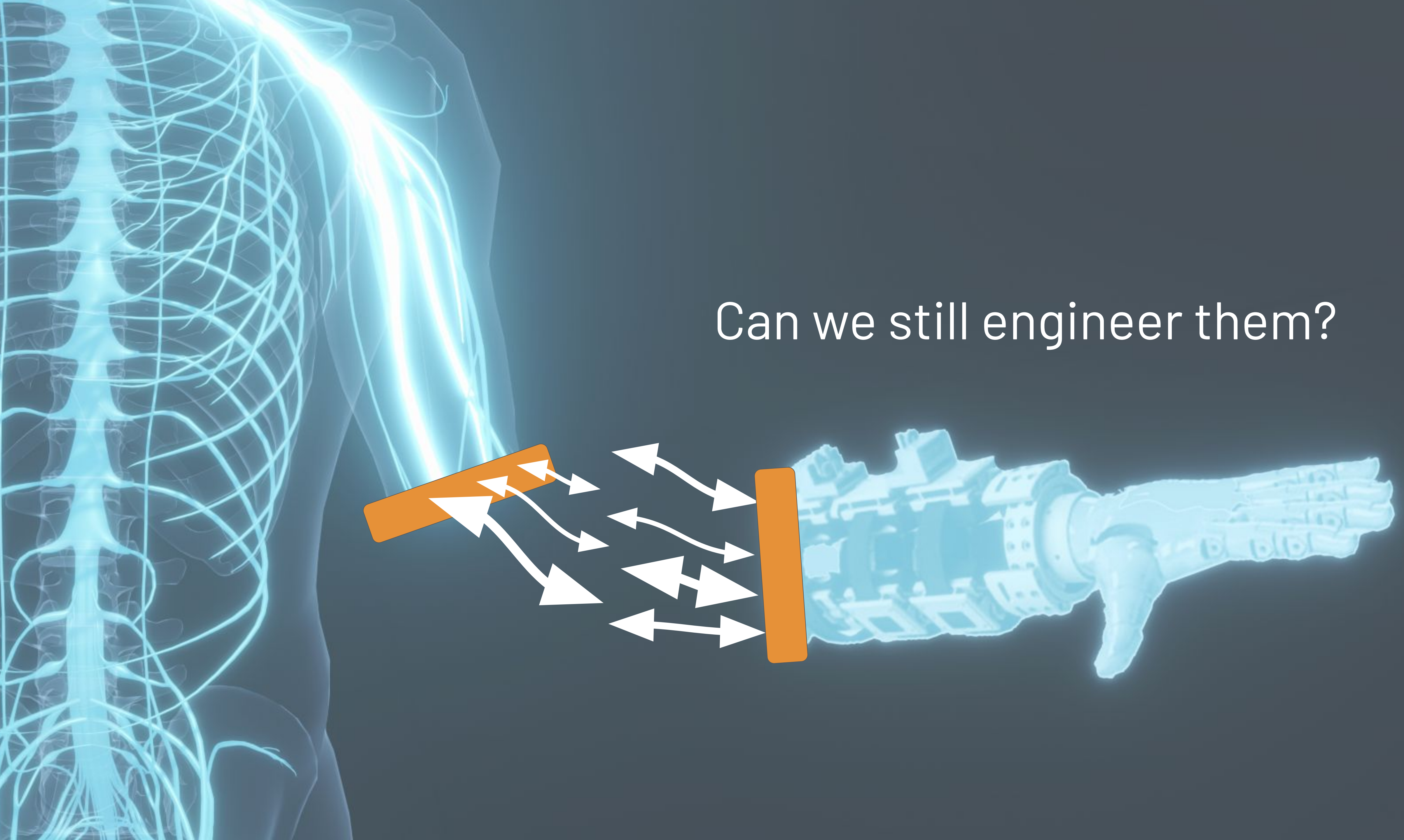


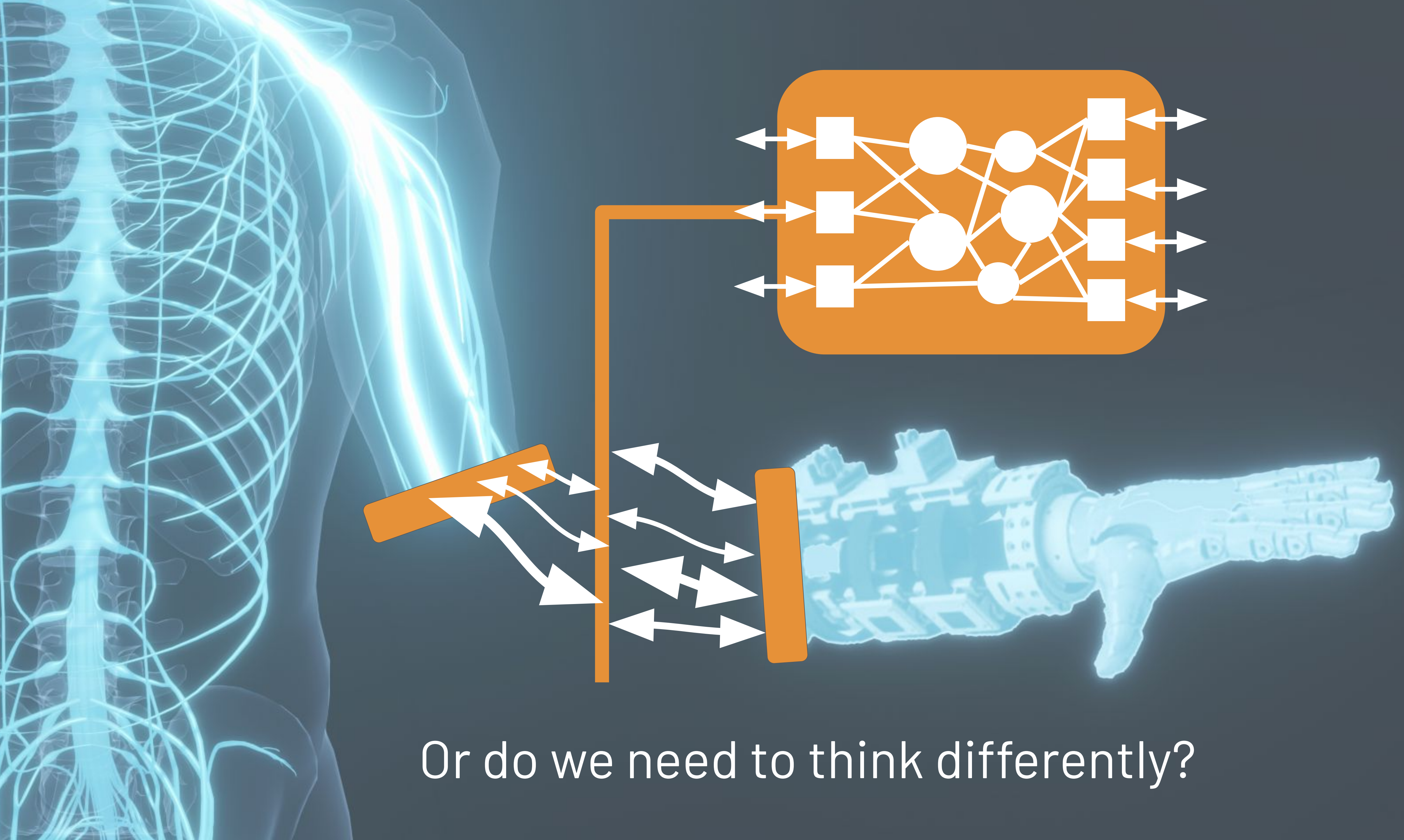


What artifacts, languages,  
methods, and training?

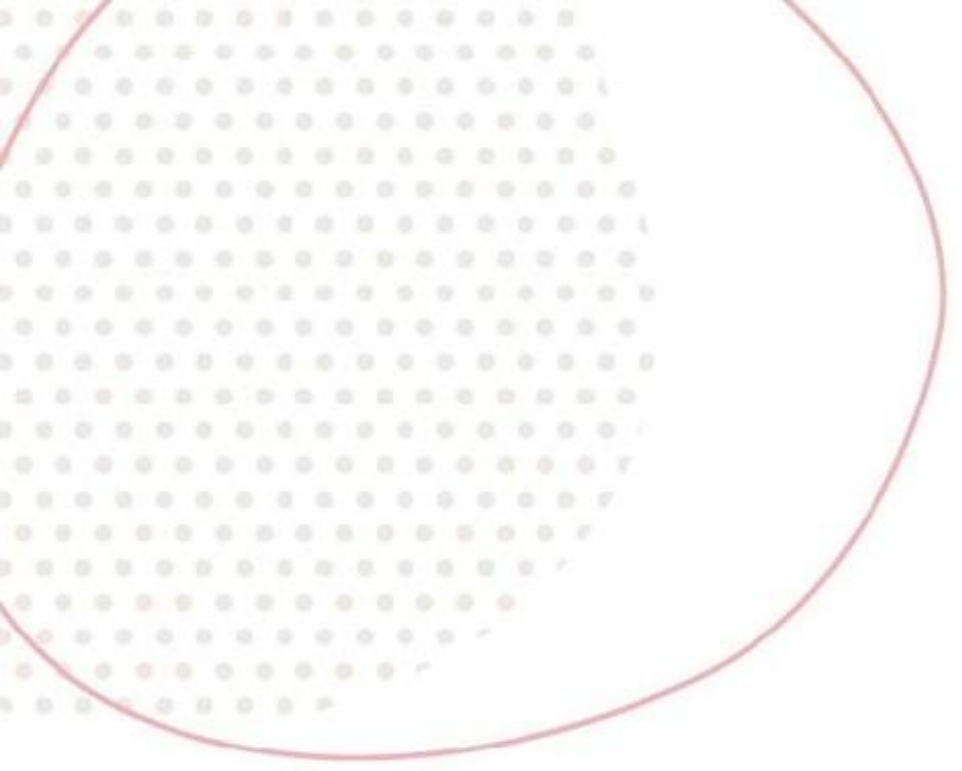
(Engelbart, 1962)

Can we still engineer them?

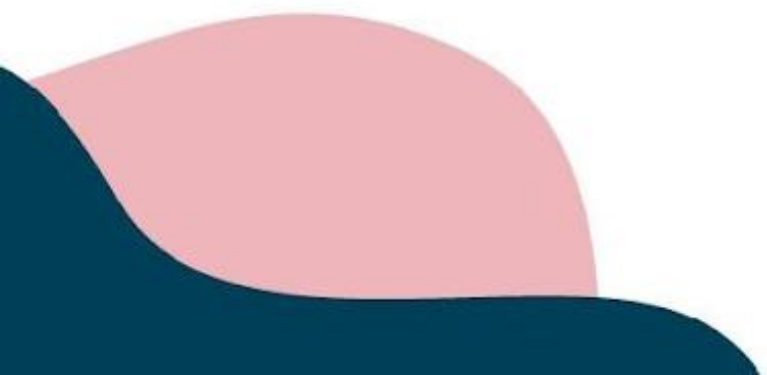


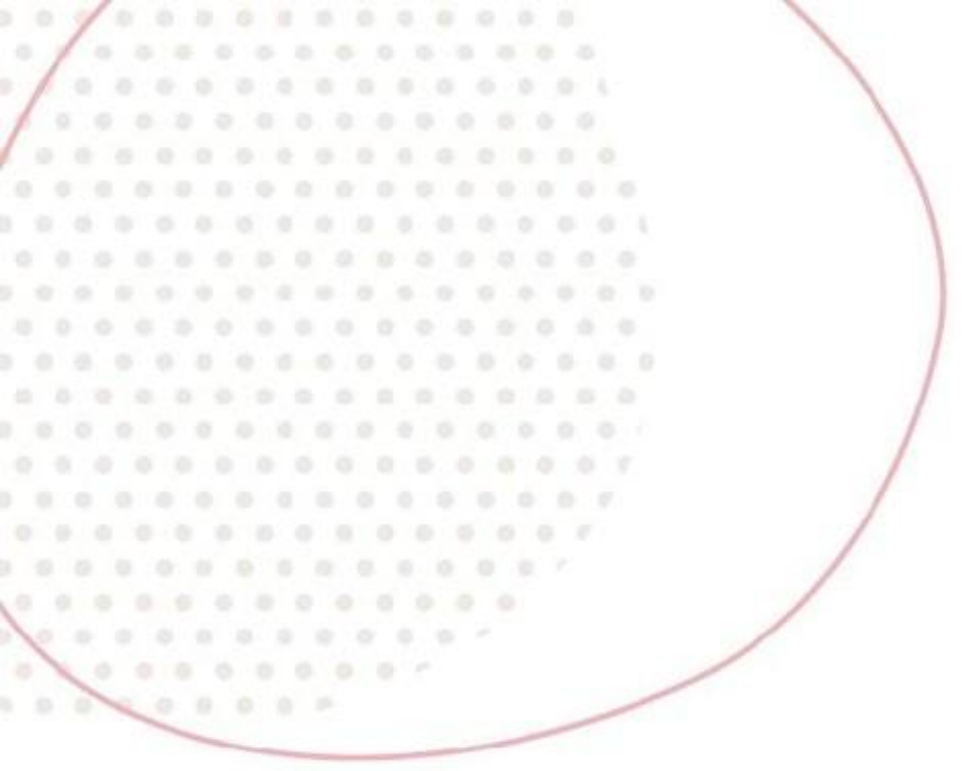


Or do we need to think differently?



# View 1

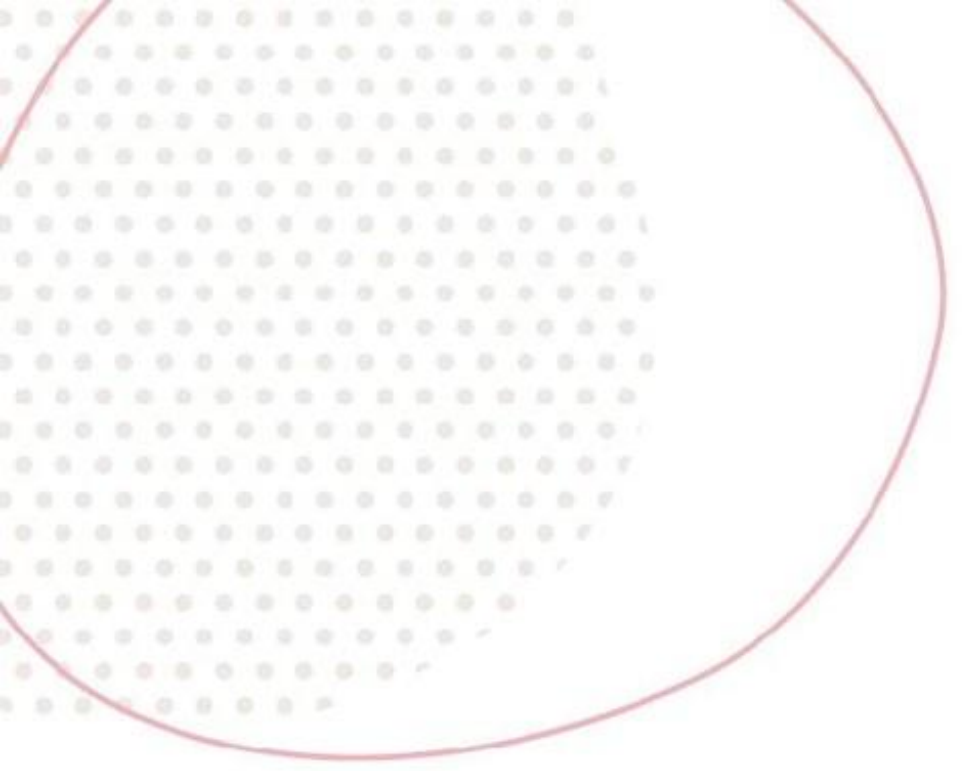




# **View 1**

## Dolphin Training





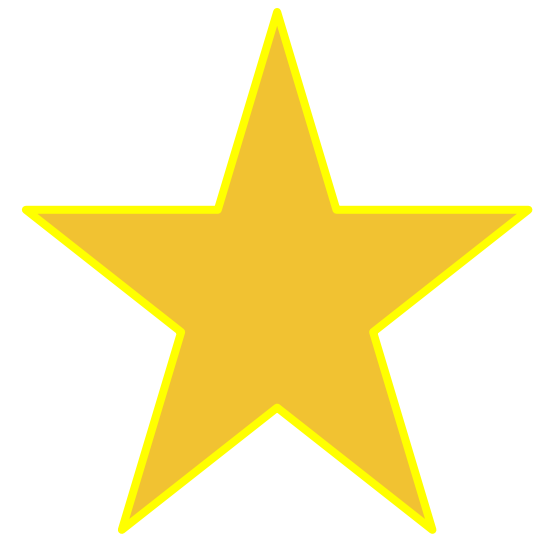
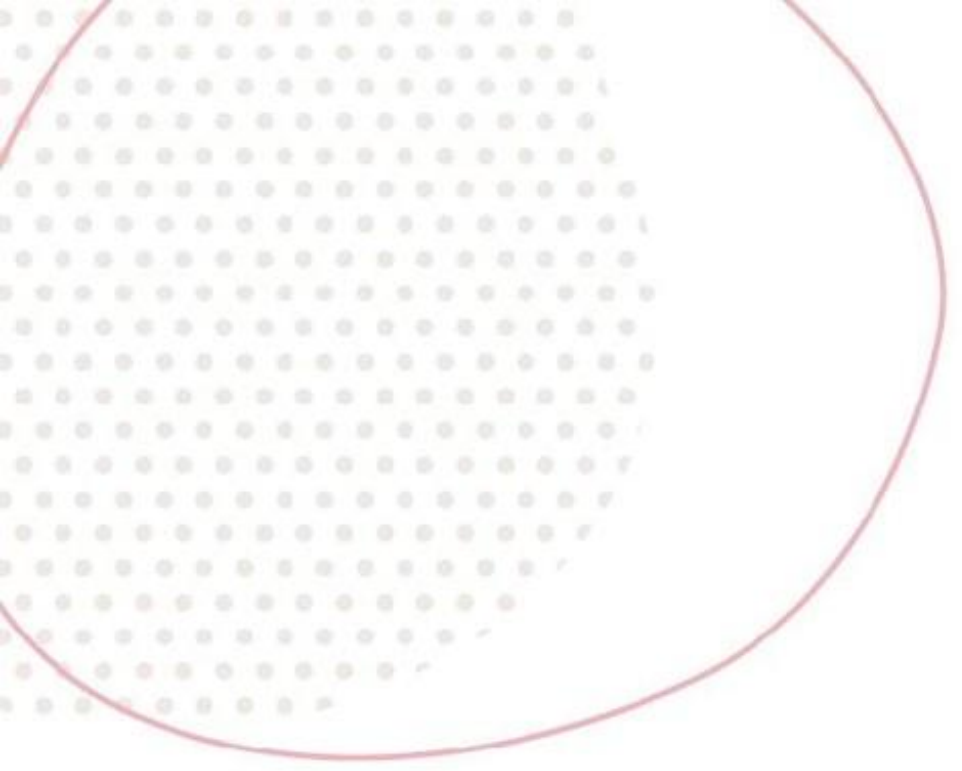
# **View 1**

## Dolphin Training

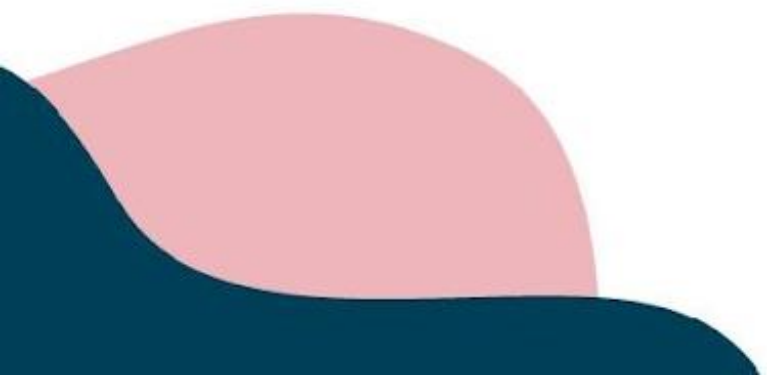
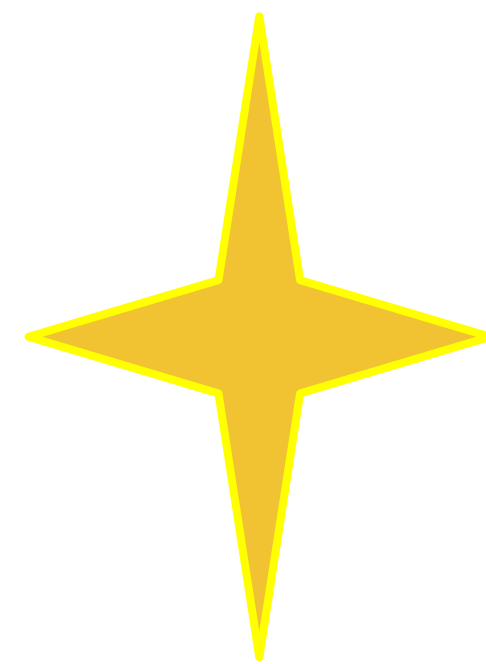
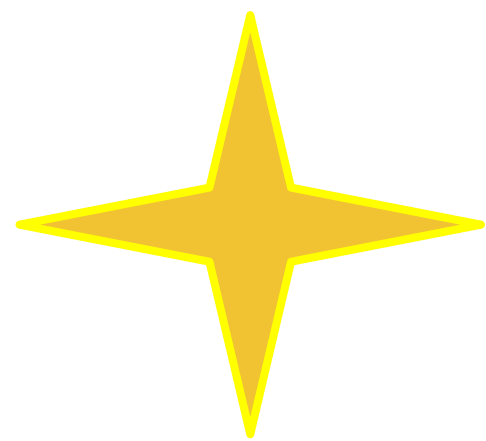
### Wait, what?

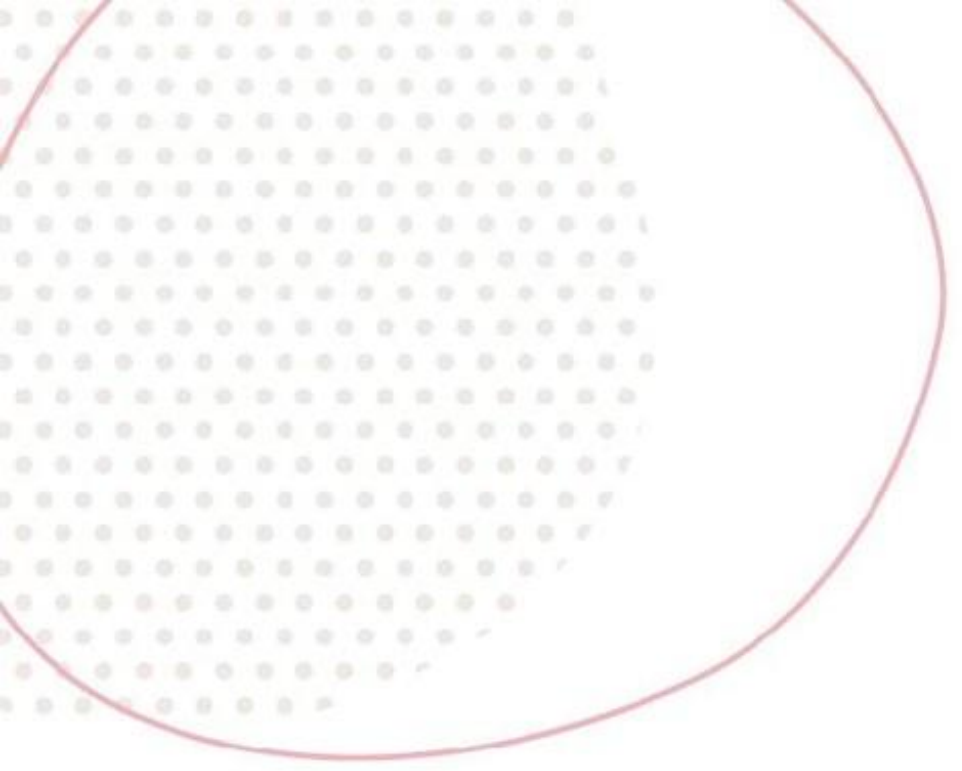






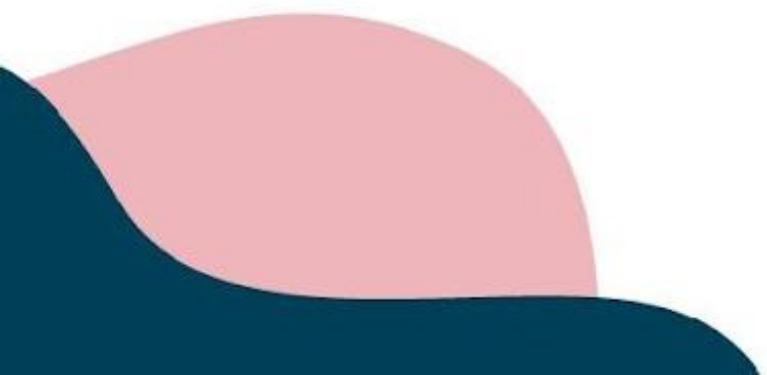
audience  
participation  
time!

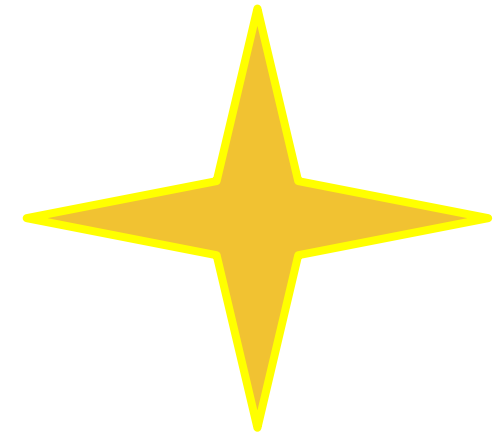
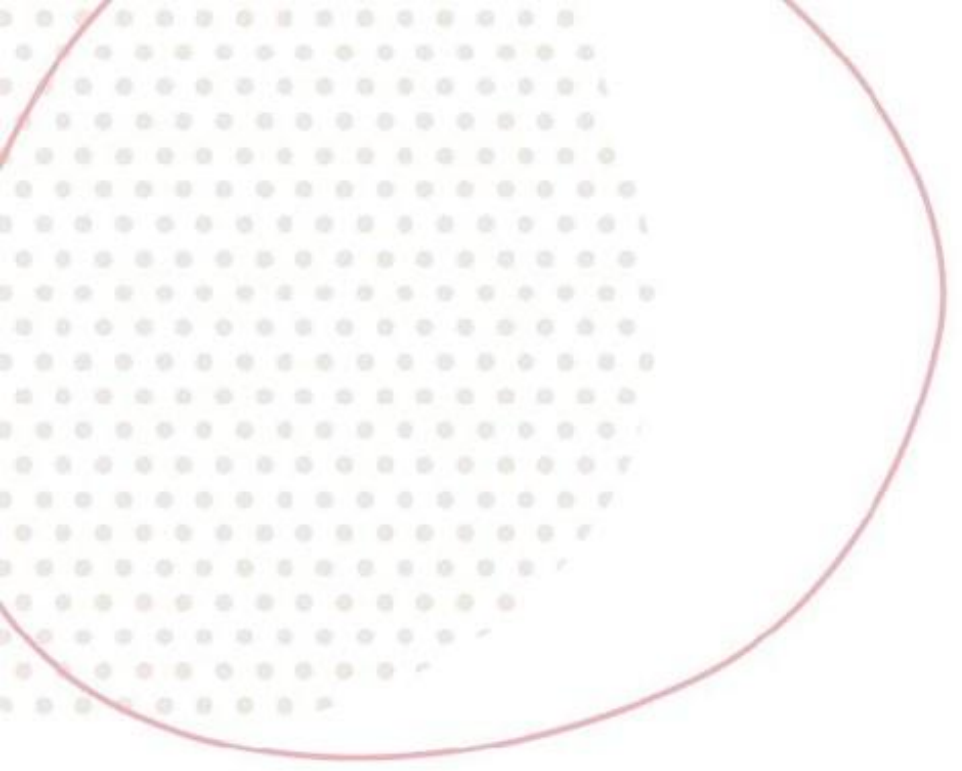




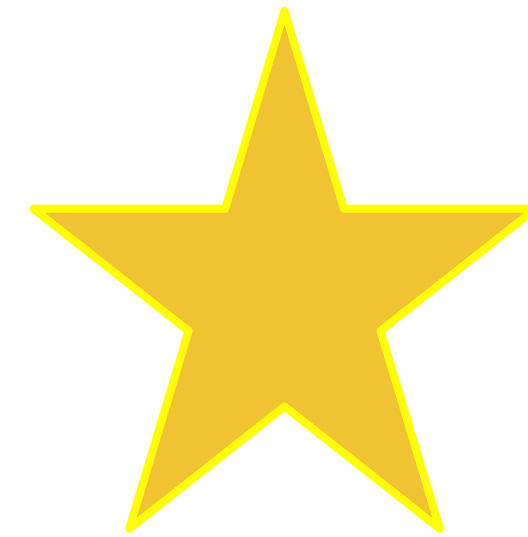
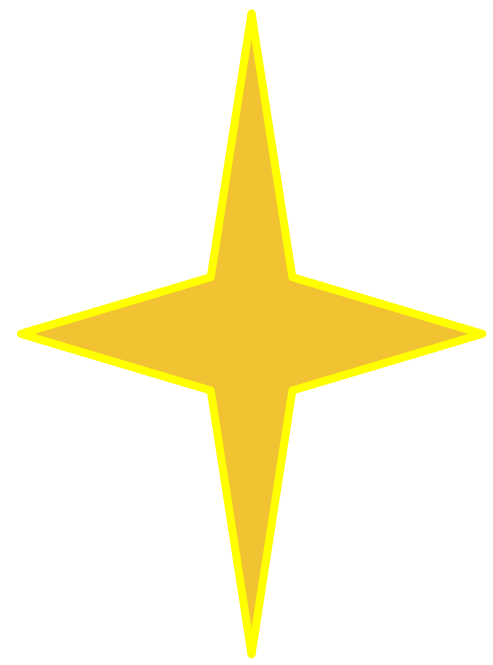
# View 2

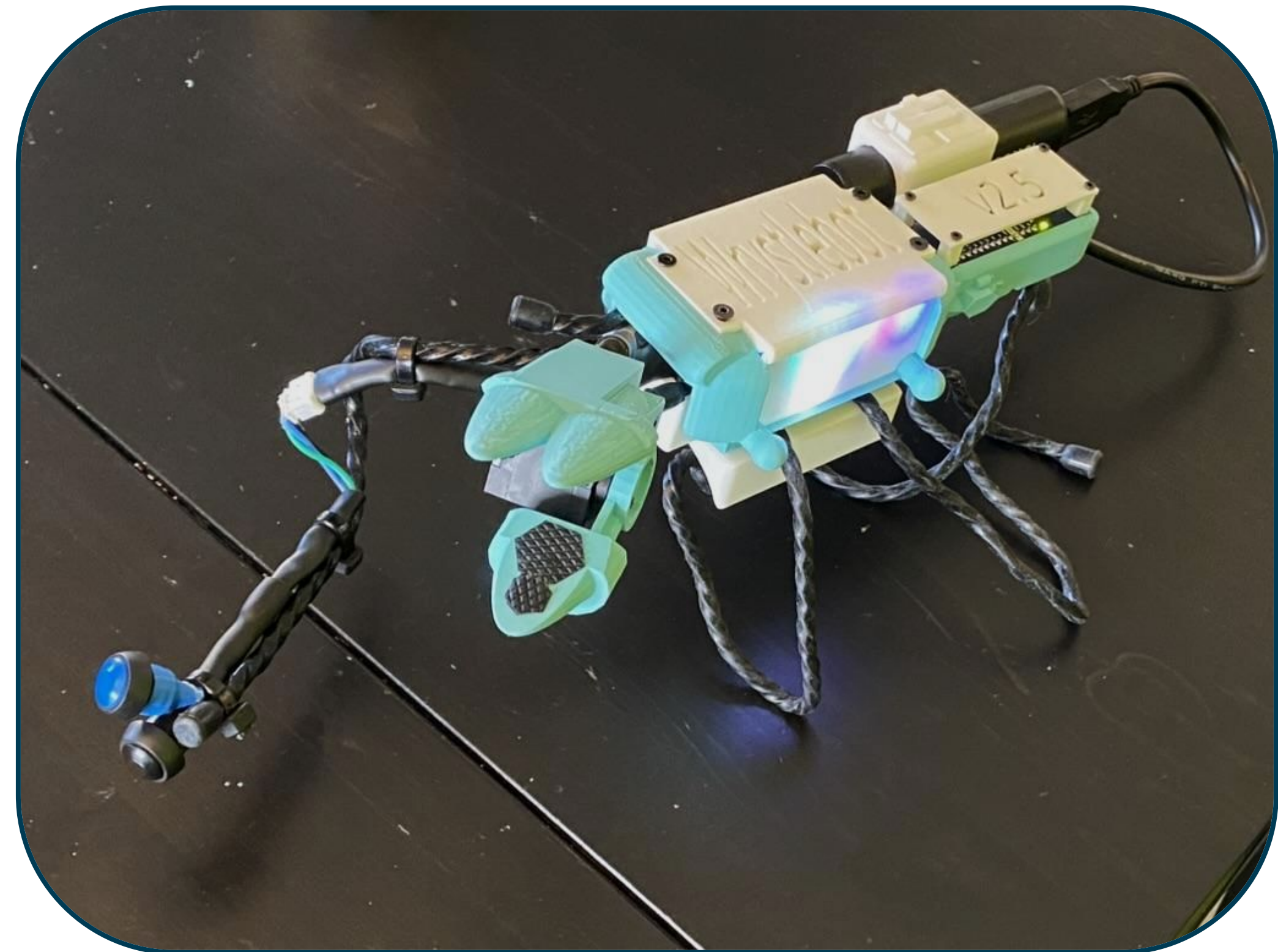
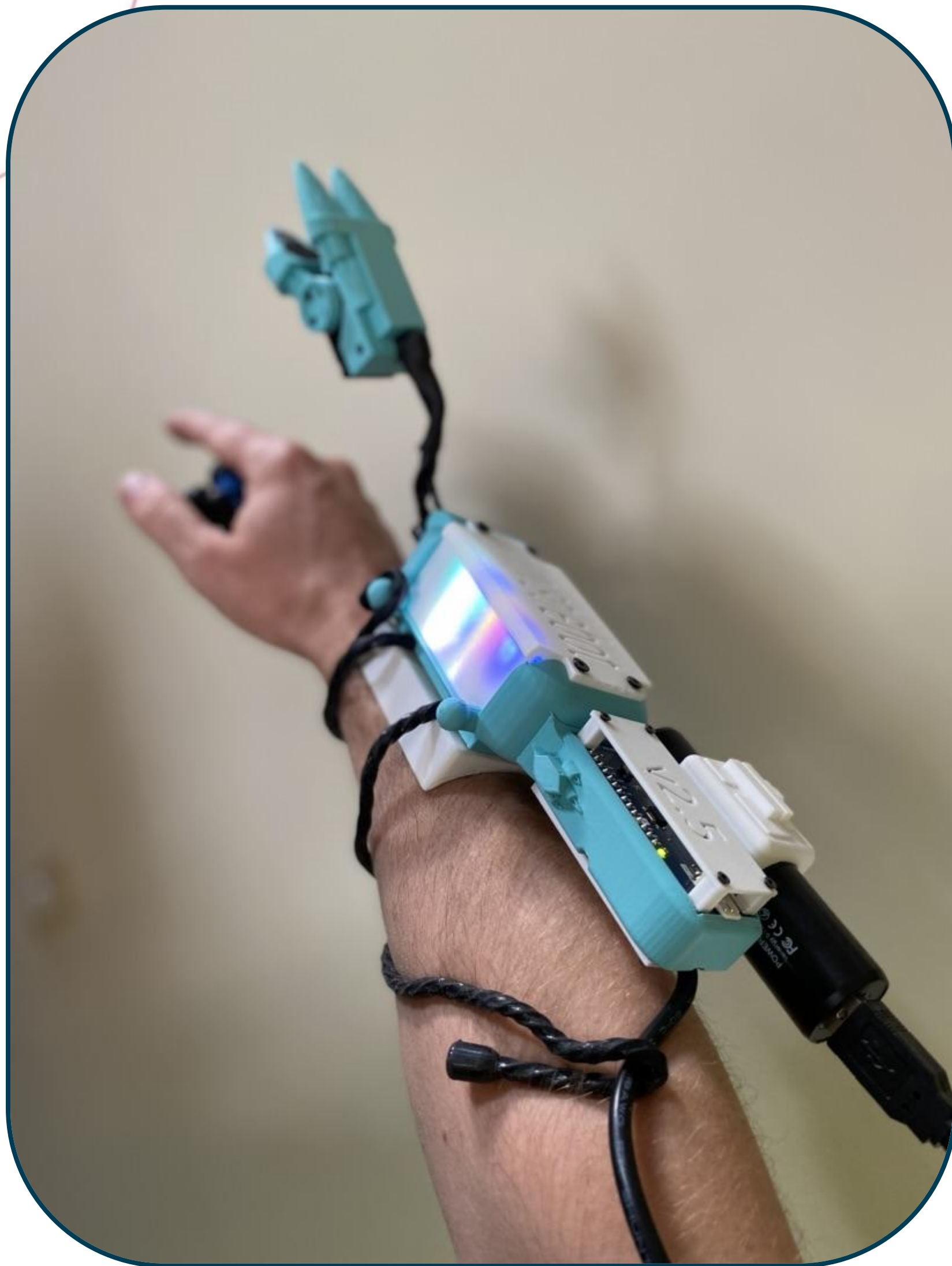
## Wrystlebot





*live  
demo  
time!*



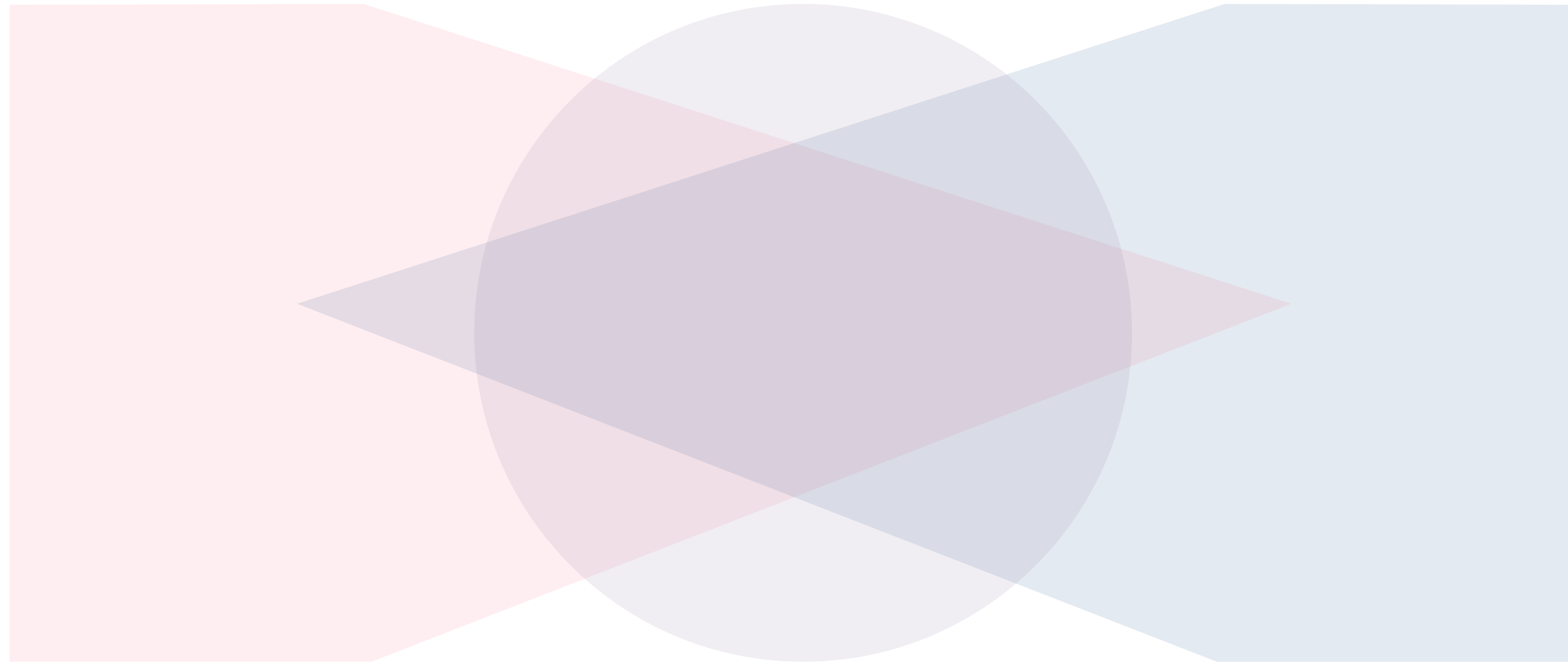


## **Wrystlebot v2.5**

P. Pilarski & R. Pilarski

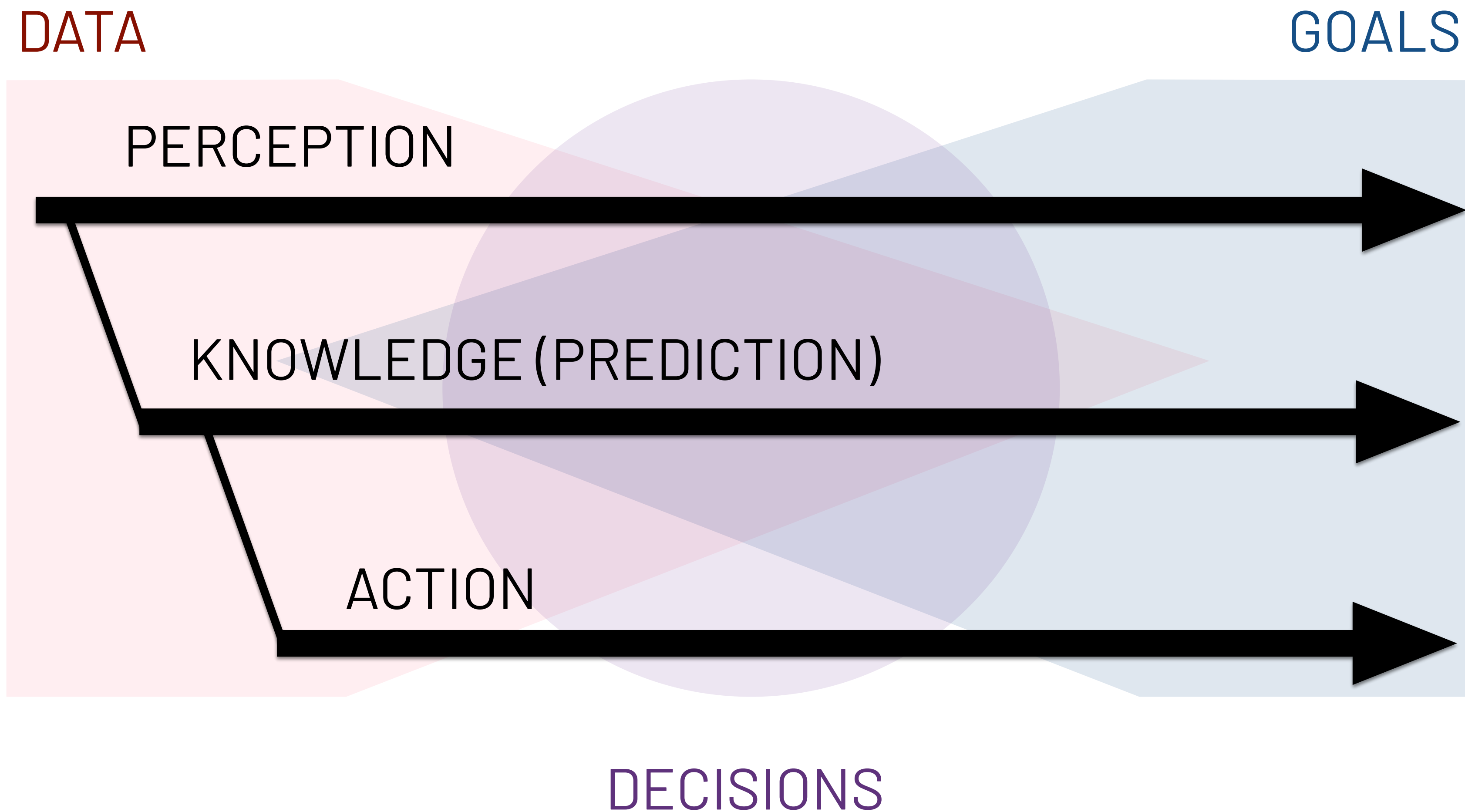
DATA

GOALS

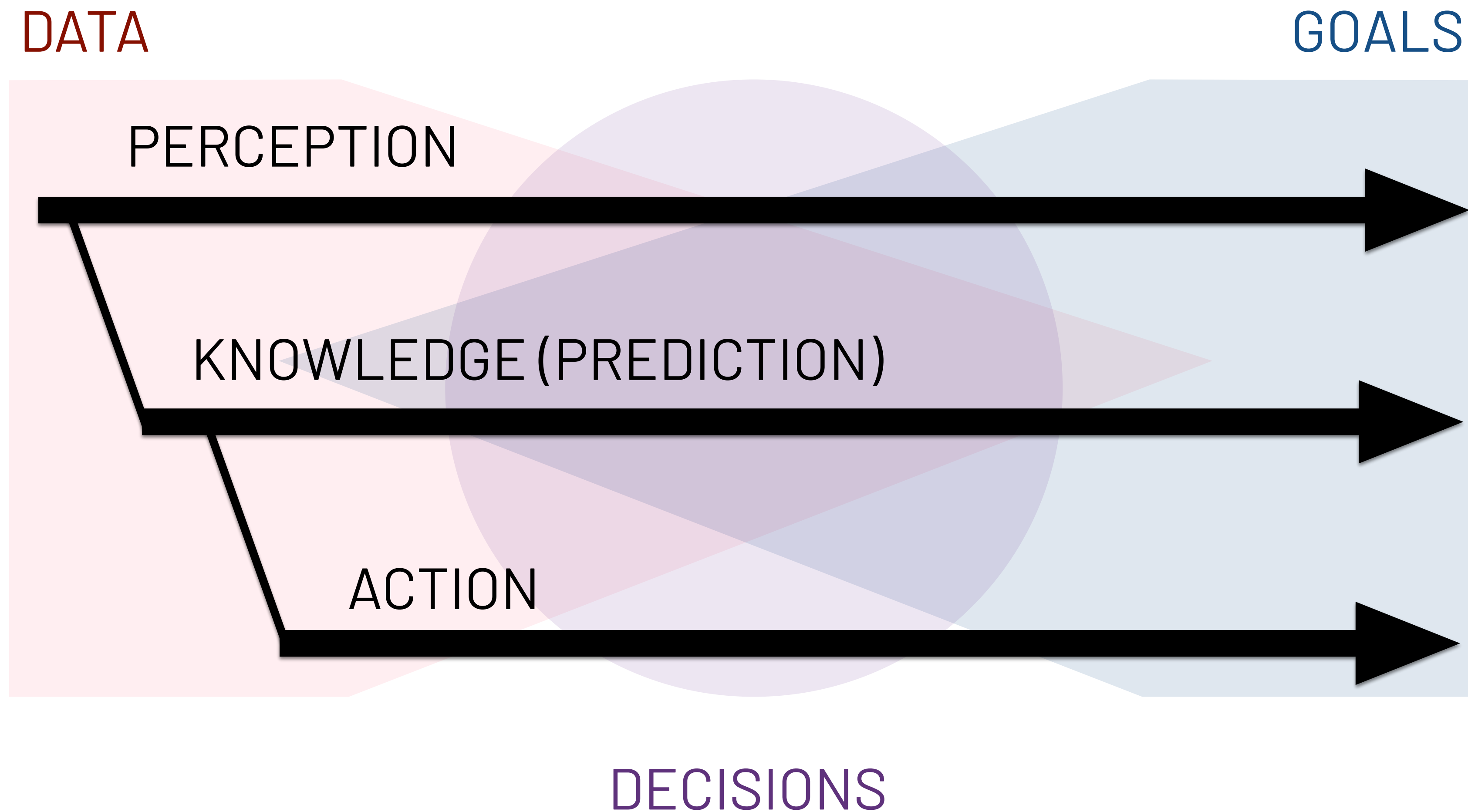


DECISIONS

**Let's Talk About Intelligence!  
Machine (and Human)**



**Let's Talk About Intelligence!  
Machine (and Human)**




**MACHINE LEARNING.** These things can all be learned and continually improved by a machine!



**Instead of engineering ... training?**





# Progress on the Home Front (University of Alberta)

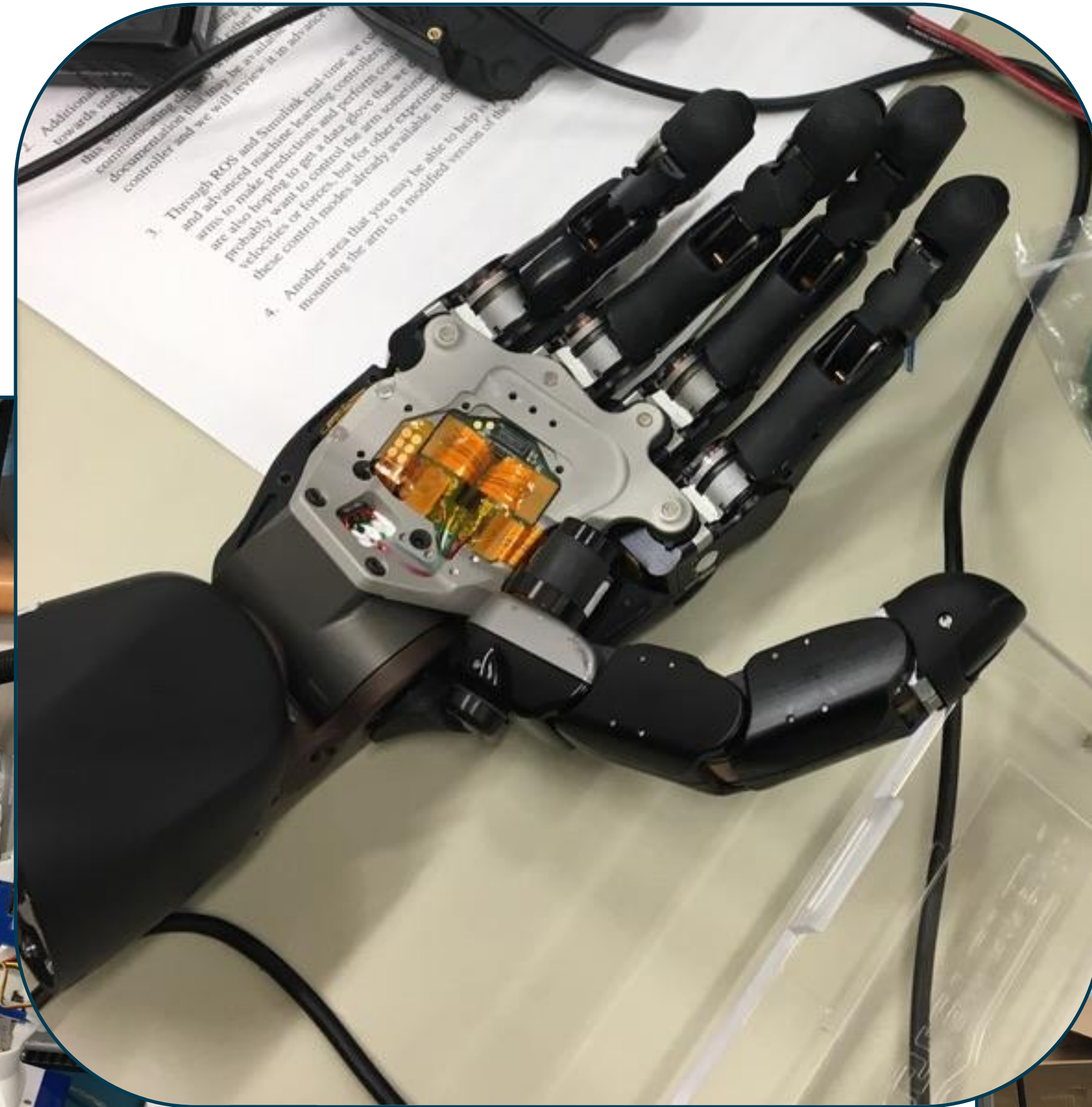
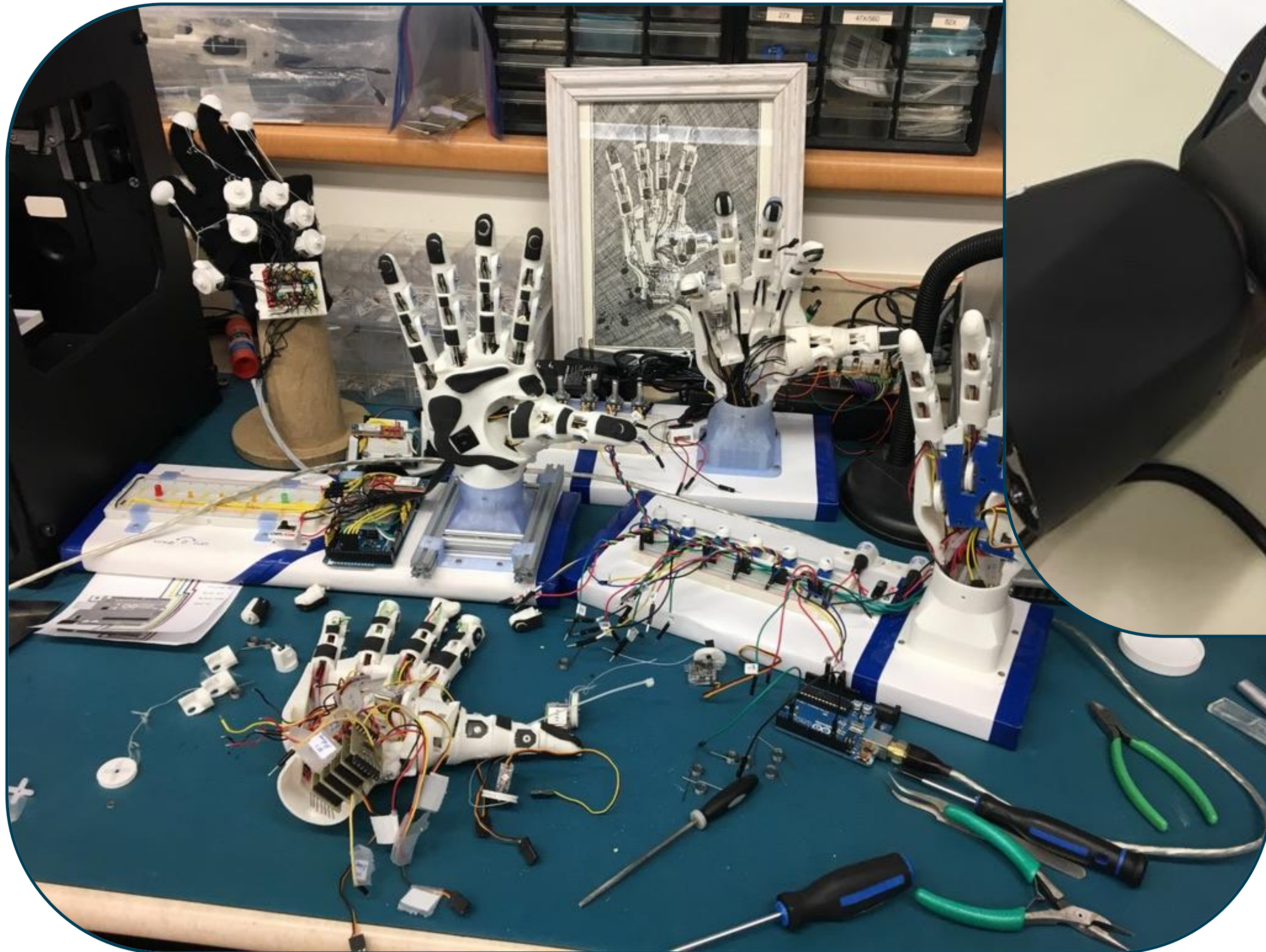


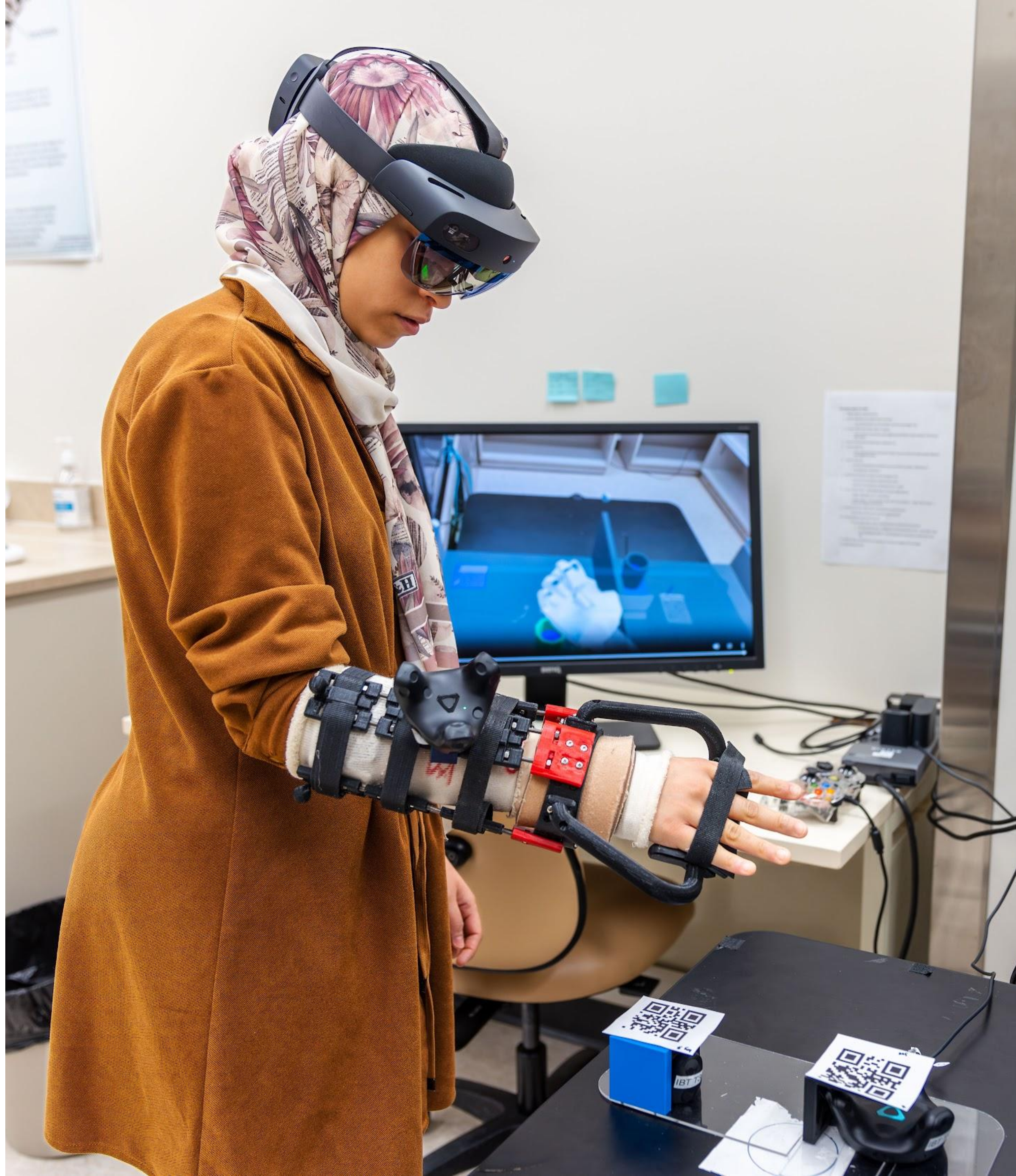
# BLINC



## SMART NETWORK

Sensory  
Motor  
Adaptive  
Rehabilitation  
Technology



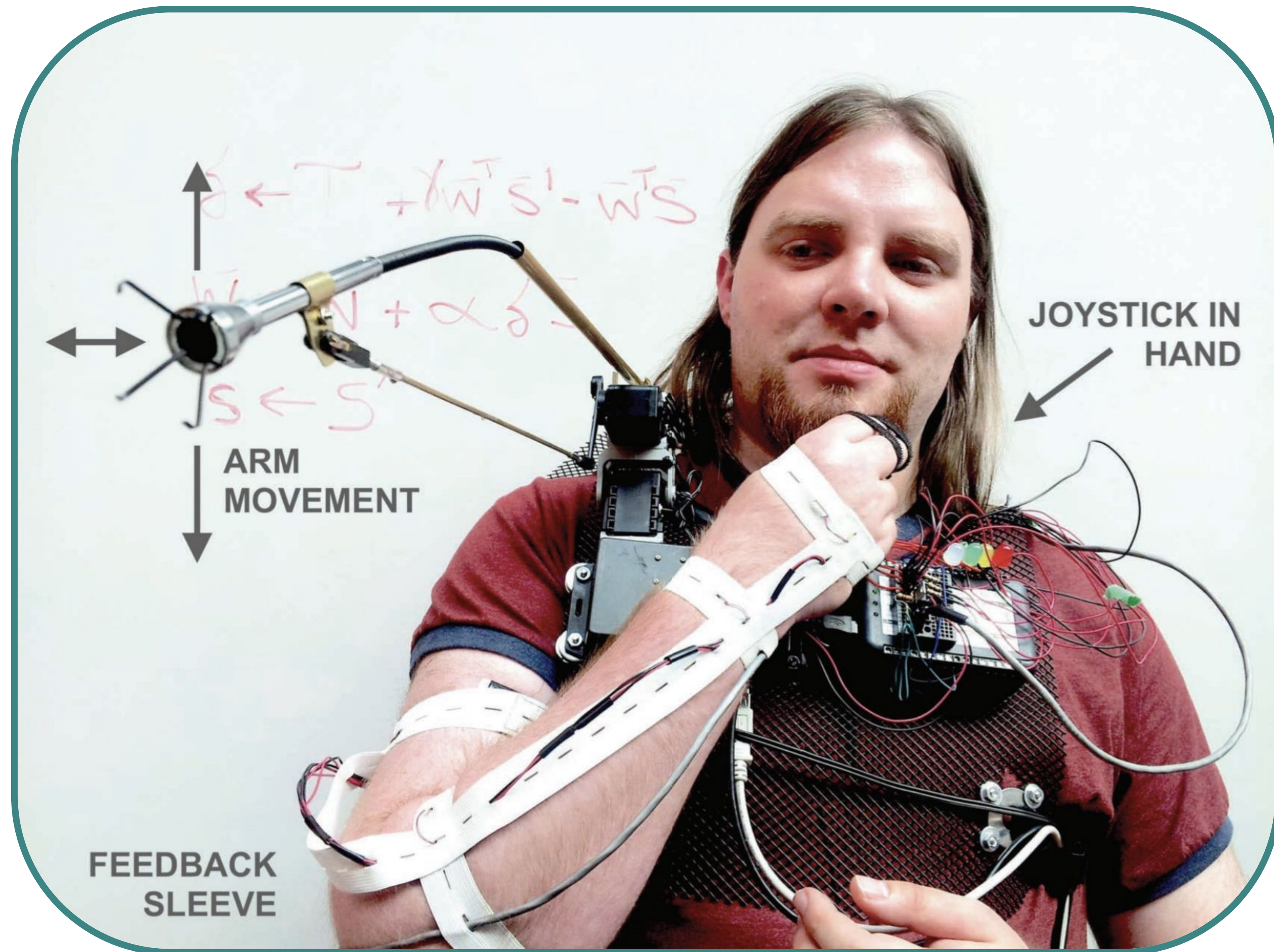


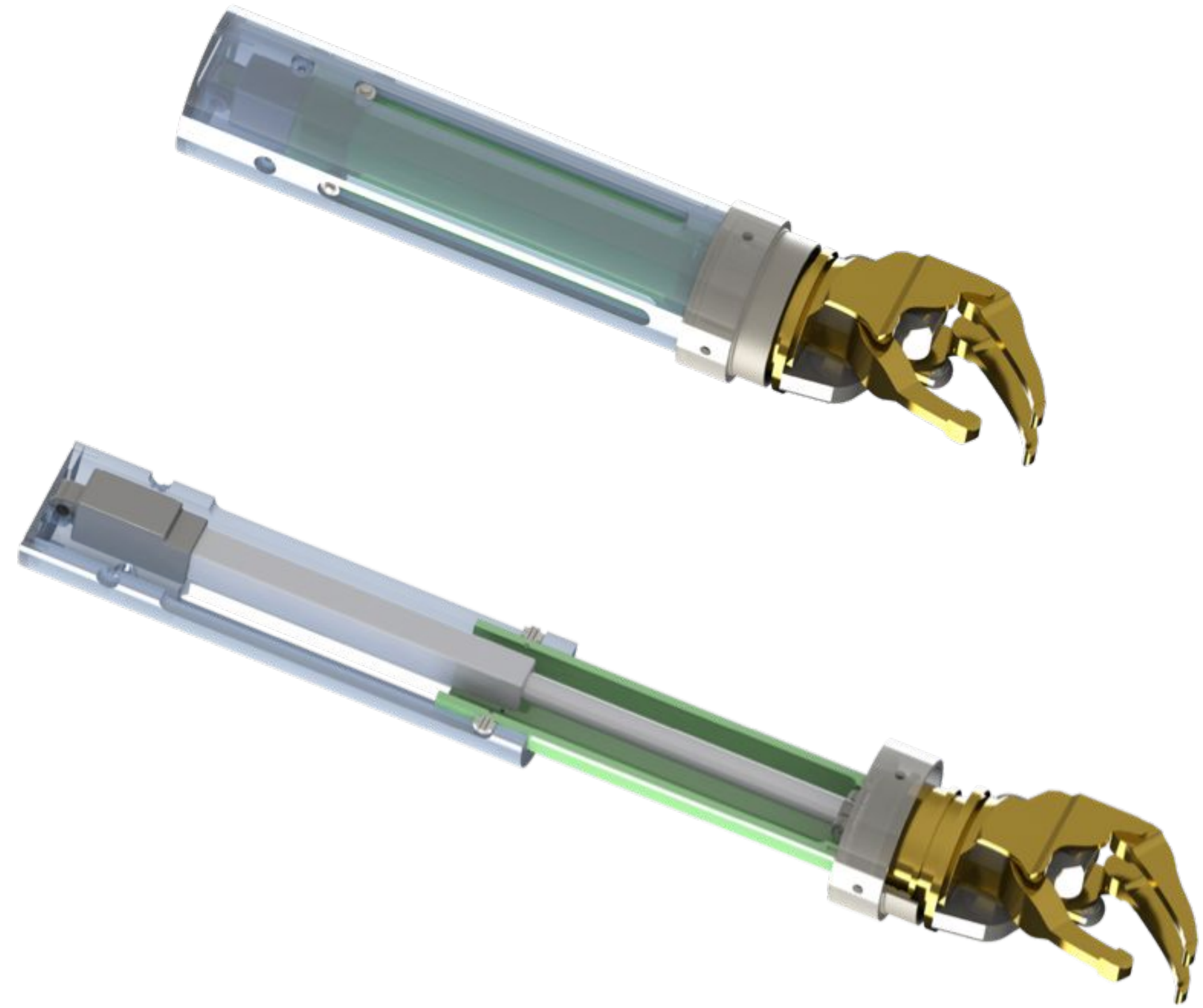


## **The Bento Arm and the HANDi Hand**

<http://blincdev.ca>

**The XRM**  
Parker *et al.*,  
*arXiv* 2014.





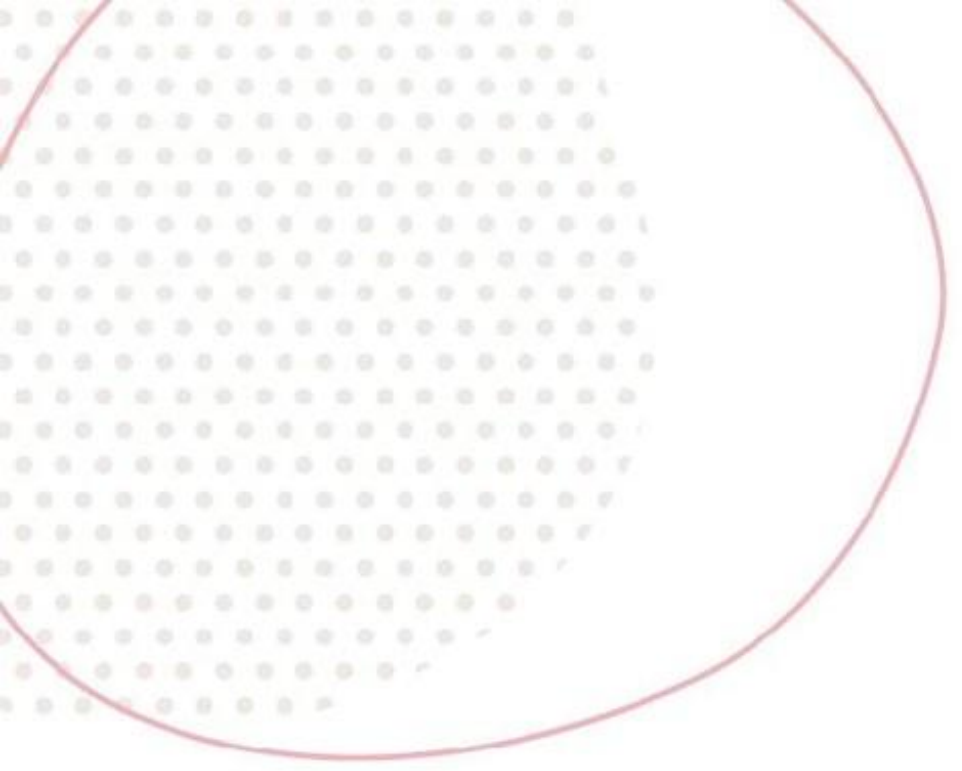
**Extendable Forearm Prosthesis**  
(a.k.a. the "Go-Go-Gadget Wrist")

# Bonsai World Forge

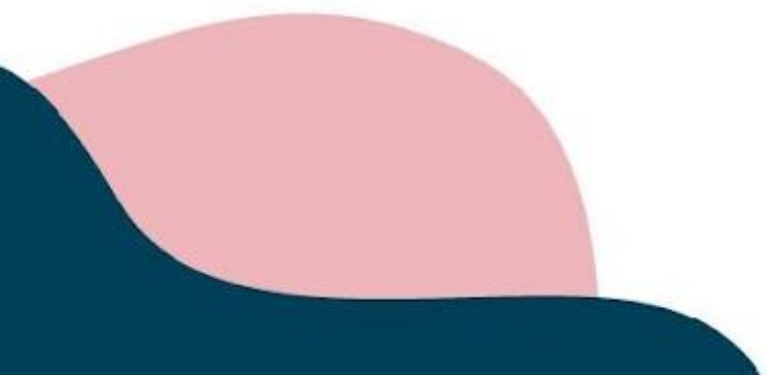
<https://github.com/pilarski/BonsaiWorldForge>

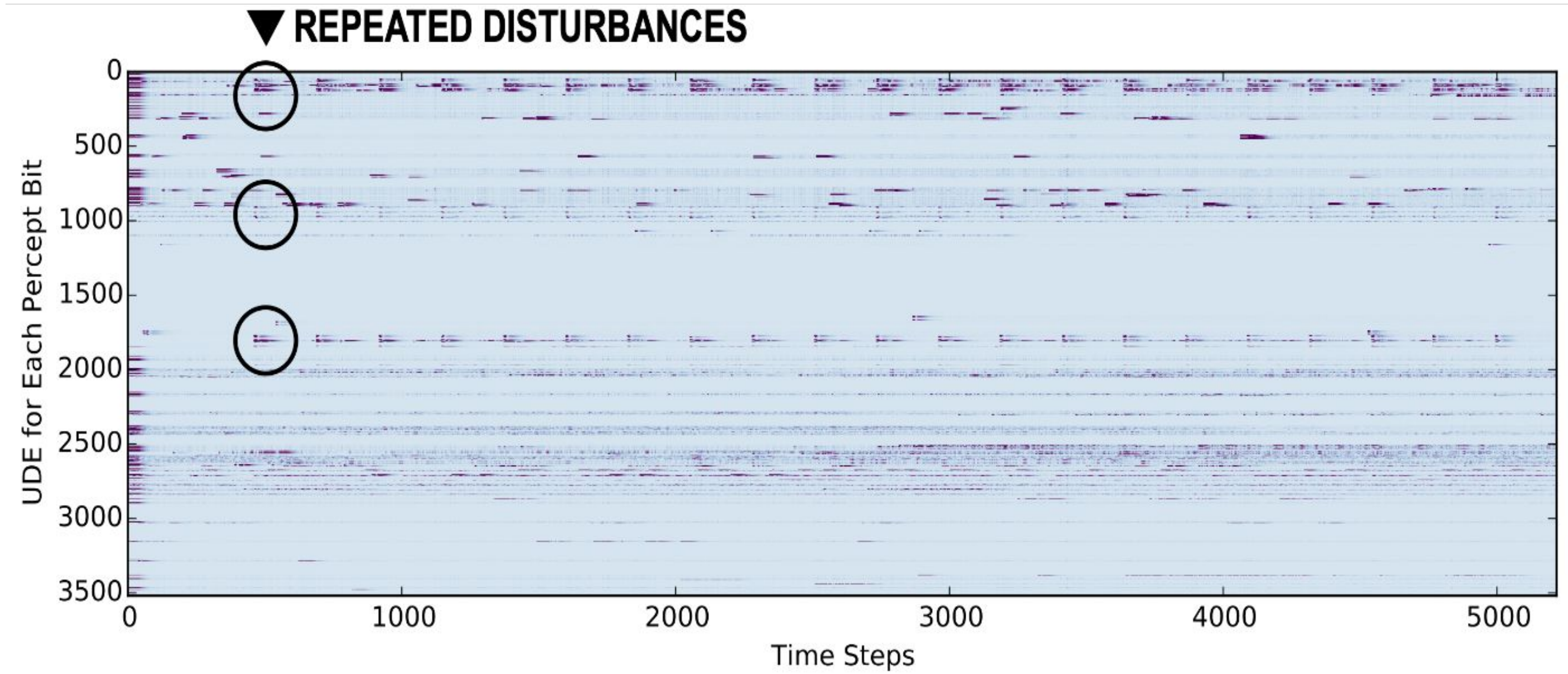
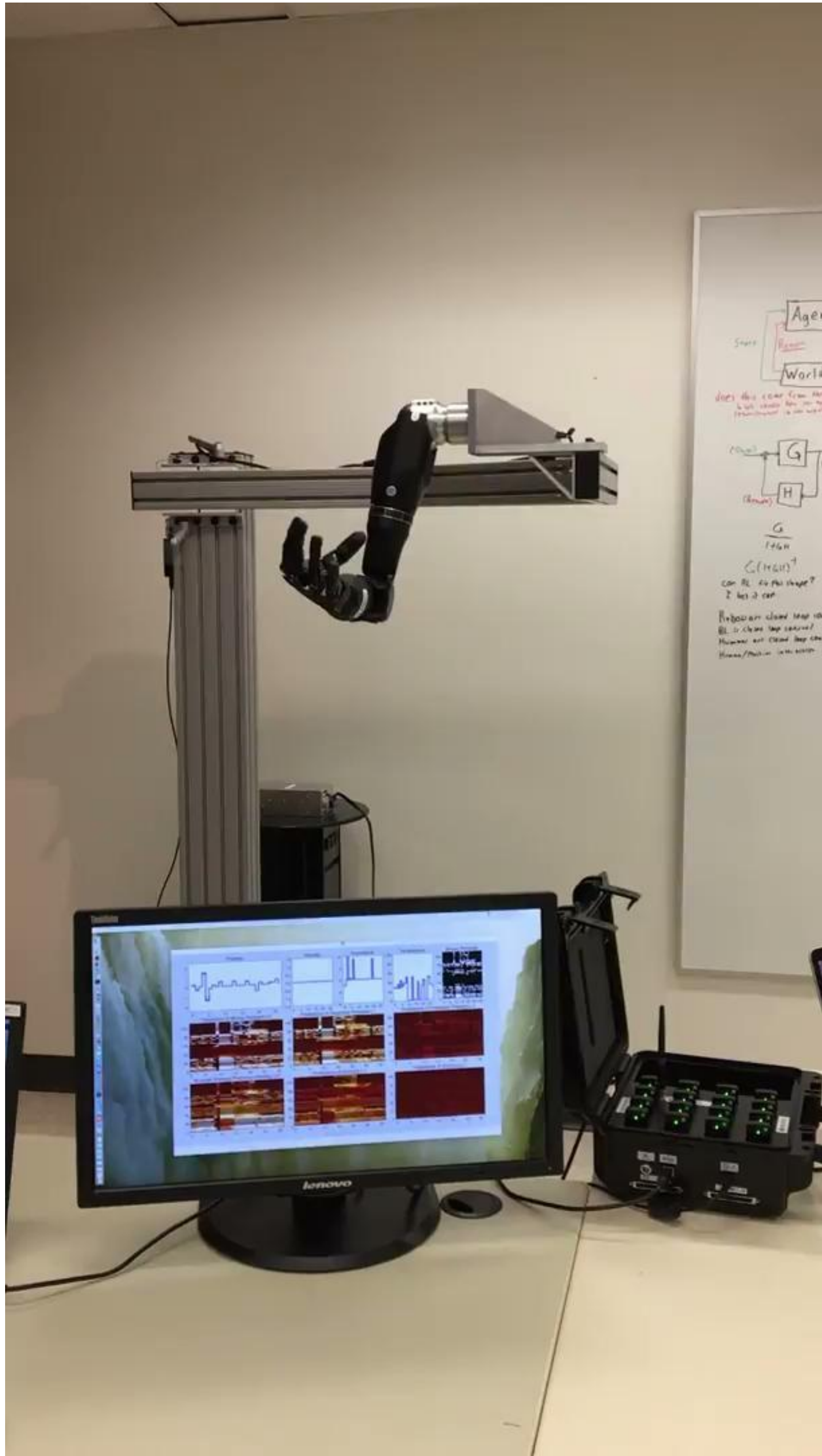






# **Training body parts, the easy (and hard) ways ...**





Günther *et al.*, Proc. AAAI Fall Symposium, 2018.

Günther *et al.*, Frontiers in Robotics and AI, vol. 7, no. 34, 2020.



## Adaptive Switching

Edwards et al., *MEC*, 2014

Edwards et al., *Prosthetics Orthotics Int.*, 2016

# Artificial Intelligence, On Board

Williams *et al.*, "Recurrent Convolutional Neural Networks as an Approach to Position-Aware Myoelectric Prosthesis Control," *IEEE TBME*, 2022.

Video courtesy:  
Amii / Chris Onciul

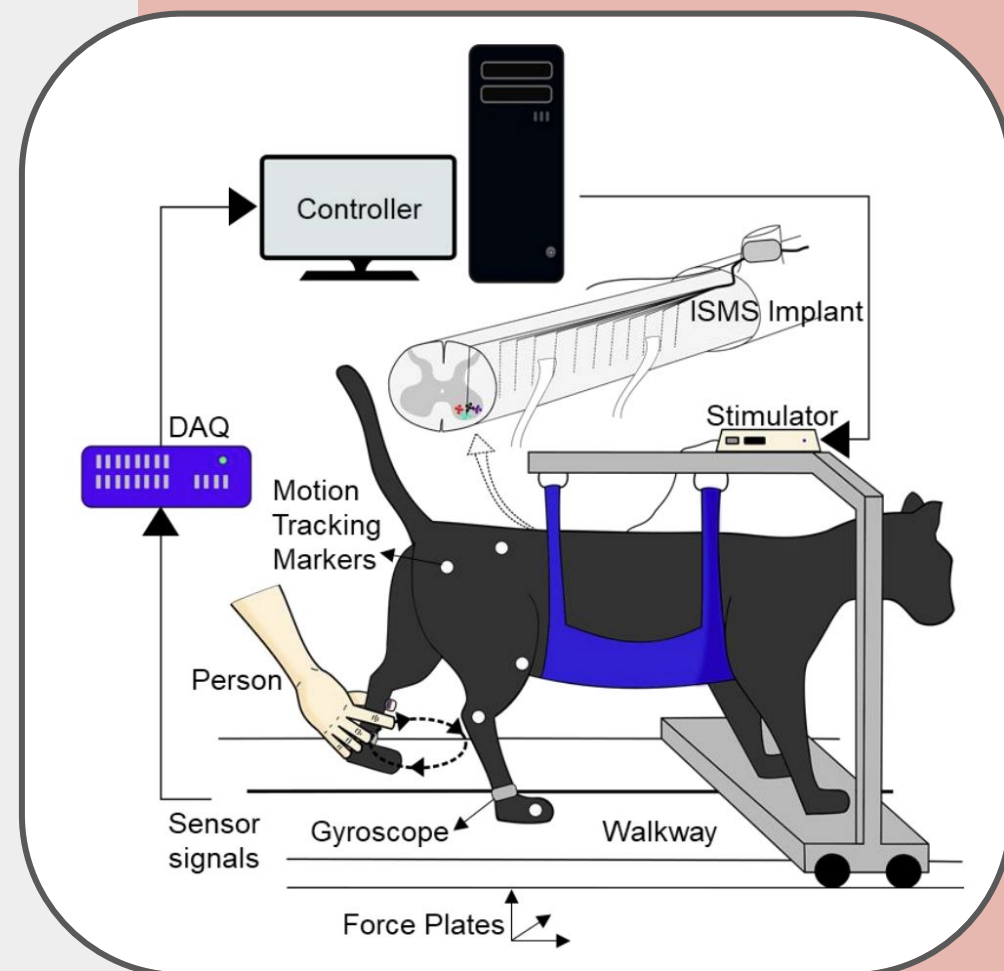
# Reinforcement Learning from Demonstration





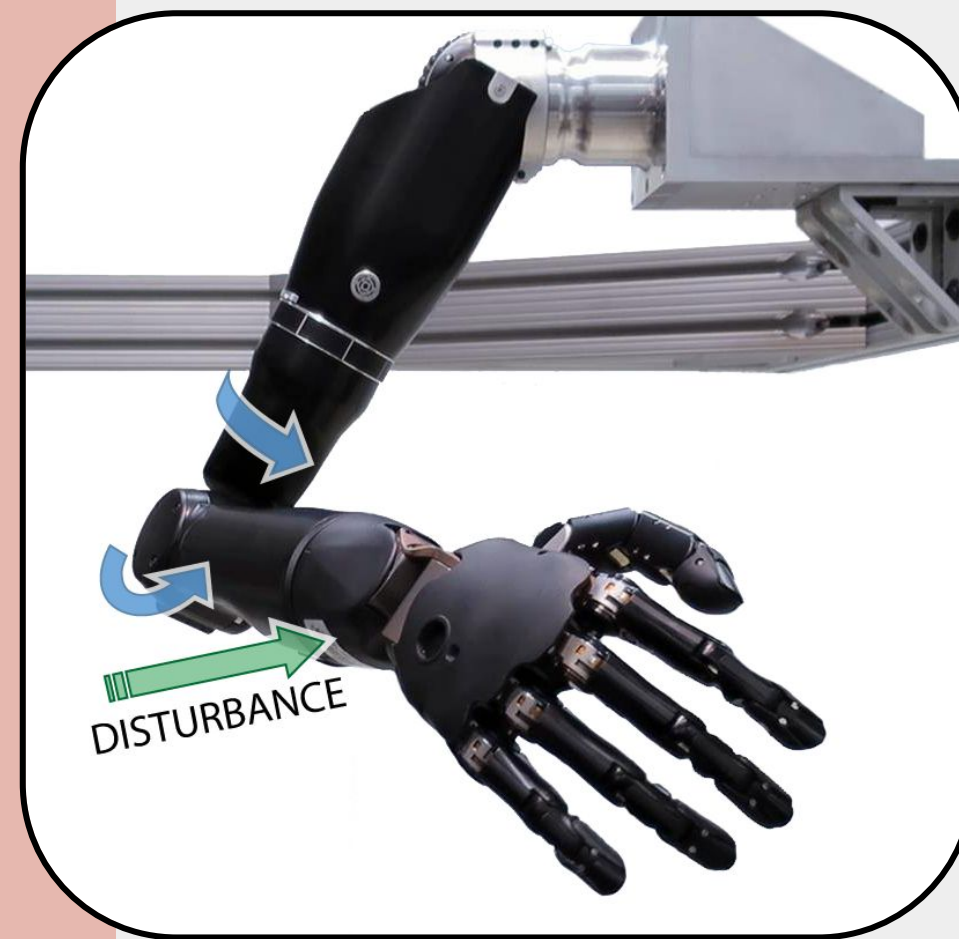
Adaptive switching in real-time **exoskeleton control.**

Faridi et al., *ICORR*, 2022.



**Intraspinal microstimulation** for walking.

Dalrymple et al., *J. Neural Eng.*, 2022.



Robot limb **failure and anomaly detection.**

Günther et al., *Front. Al.*, 2020.

Günther et al., *AAAI-FS*, 2018.



**Hazard prediction and machine learned feedback** in robot limbs and VR decision making.

Parker et al., *ICORR*, 2019.

Brenneis et al., *ALA*, 2022



Coordinating upper-limb **joint synergies.**

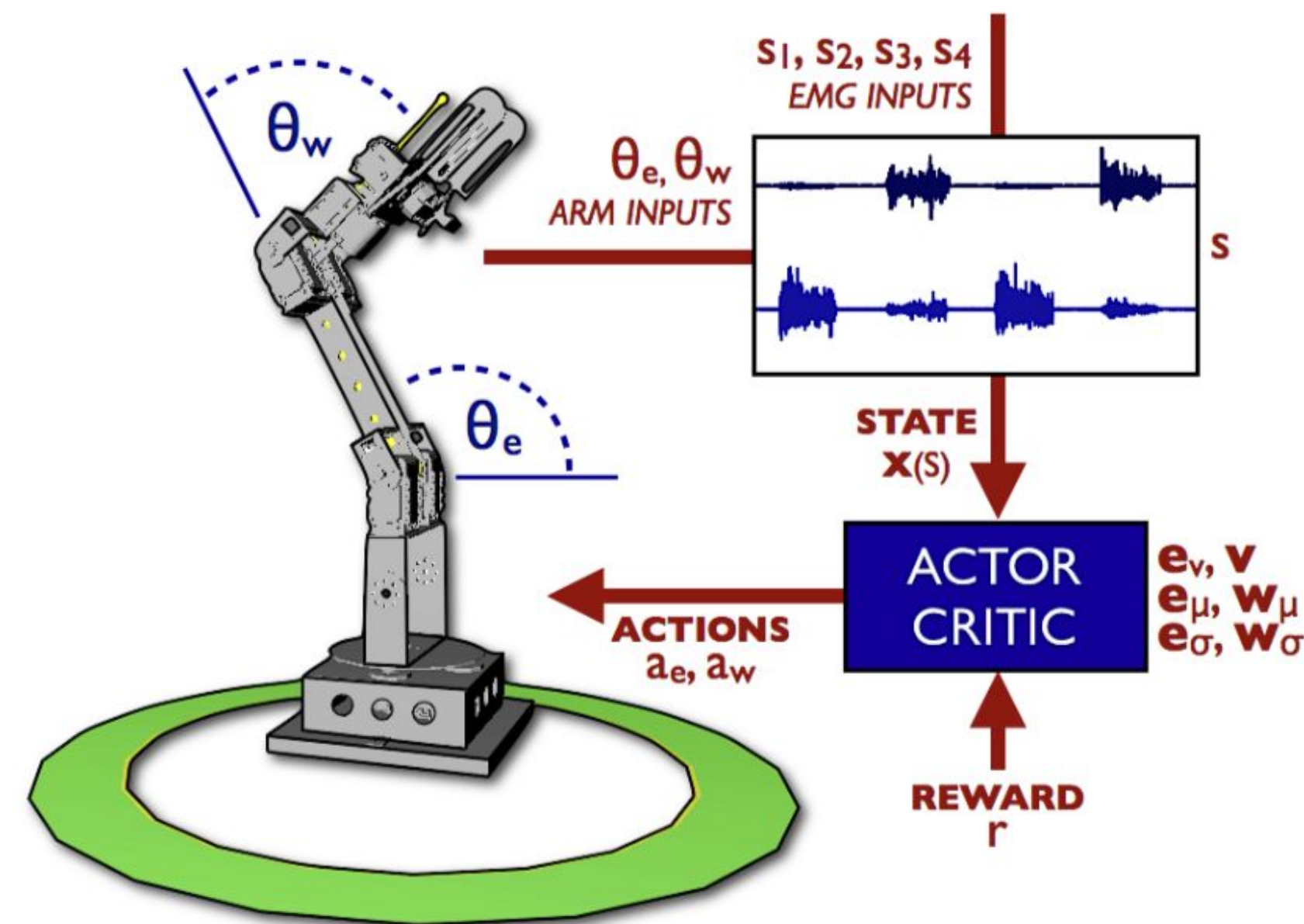
Sherstan, et al., *ICORR*, 2015.

Pilarski, et al., *ICORR*, 2013.

# Online Human Training of a Myoelectric Prosthesis Controller via Actor-Critic Reinforcement Learning

Patrick M. Pilarski, Michael R. Dawson, Thomas Degris, Farbod Fahimi, Jason P. Carey, and Richard S. Sutton

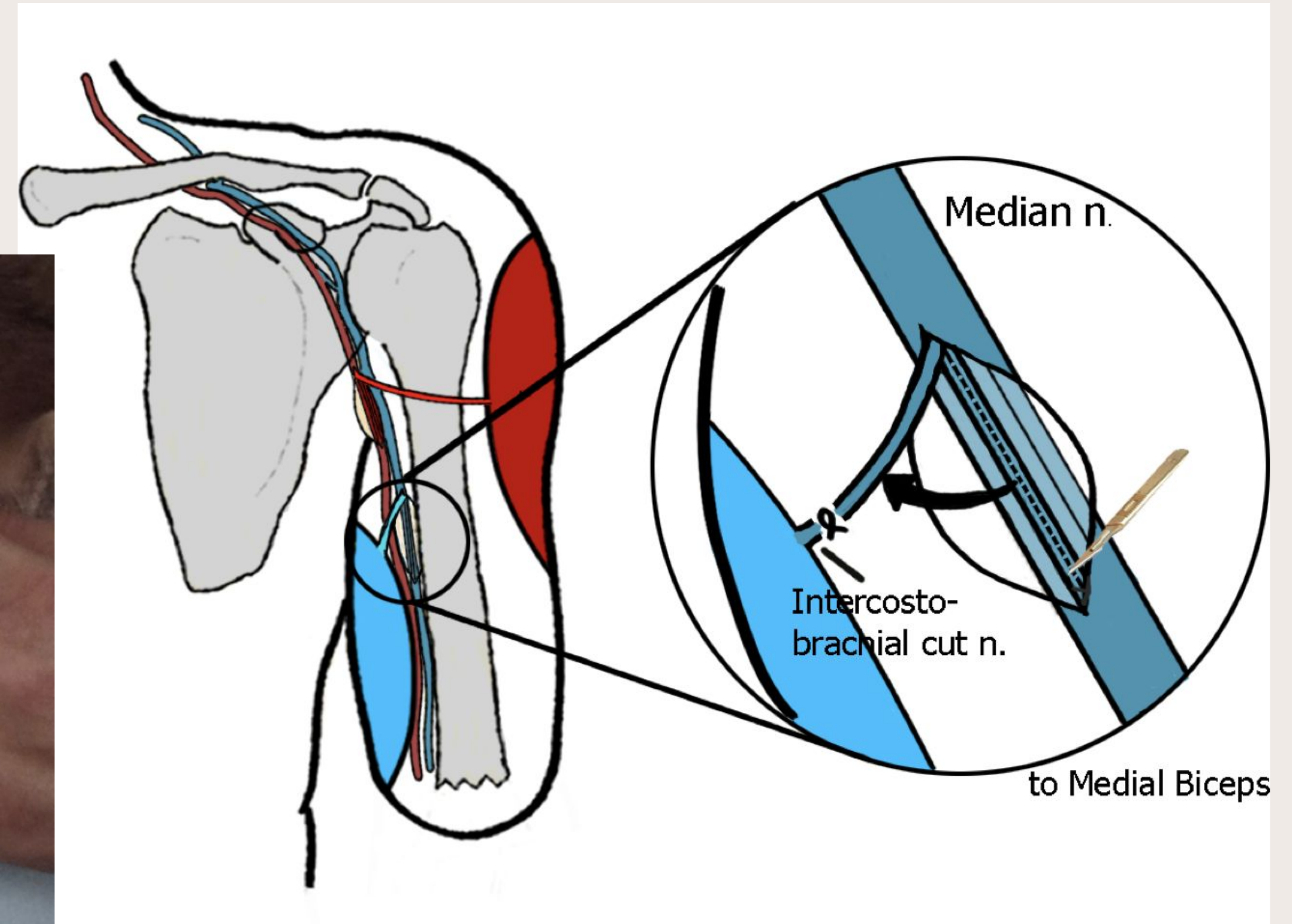
*Abstract*—As a contribution toward the goal of adaptable, intelligent artificial limbs, this work introduces a continuous actor-critic reinforcement learning method for optimizing the control of multi-function myoelectric devices. Using a simulated upper-arm robotic prosthesis, we demonstrate how it is possible to derive successful limb controllers from myoelectric data using only a sparse human-delivered training signal, without requiring detailed knowledge about the task domain. This reinforcement-based machine learning framework is well suited for use by both patients and clinical staff, and may be easily adapted to different application domains and the needs of individual amputees. To our knowledge, this is the first myoelectric control approach that facilitates the online learning of new amputee-specific motions based only on a one-dimensional (scalar) feedback signal provided by the user of the prosthesis.





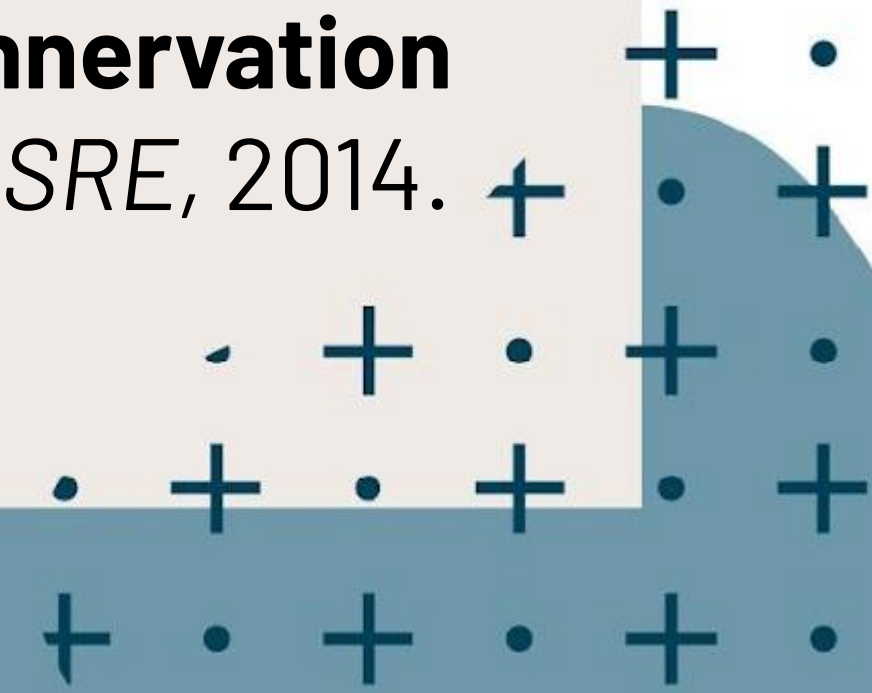
**Changing the body to change the  
machine to change the body ...**





## Targeted Motor and Sensory Reinnervation

Hebert *et al.*, *IEEE-TNSRE*, 2014.



Object Grasping Task  
July 5th, 2012

**Targeted muscle  
reinnervation  
(TMR)**



**Targeted sensory  
reinnervation  
(TSR)**

also using continual machine learning  
to streamline limb control

# David's Story



David's  
Story




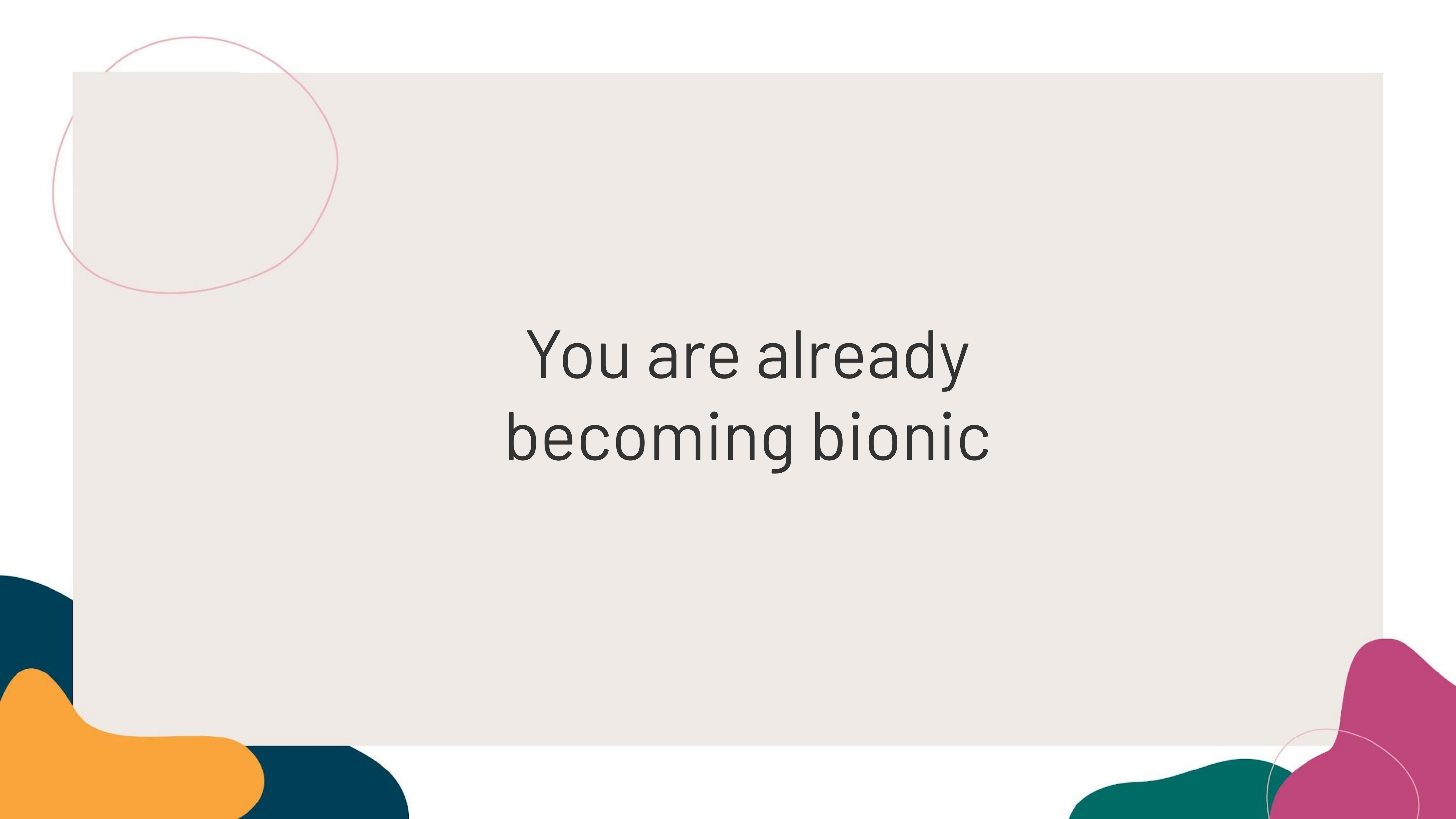
<https://www.youtube.com/watch?v=NheJKcYwkNg>

Post-surgery Osseointegration  
Rehabilitation conducted at the  
Glenrose Rehabilitation Hospital

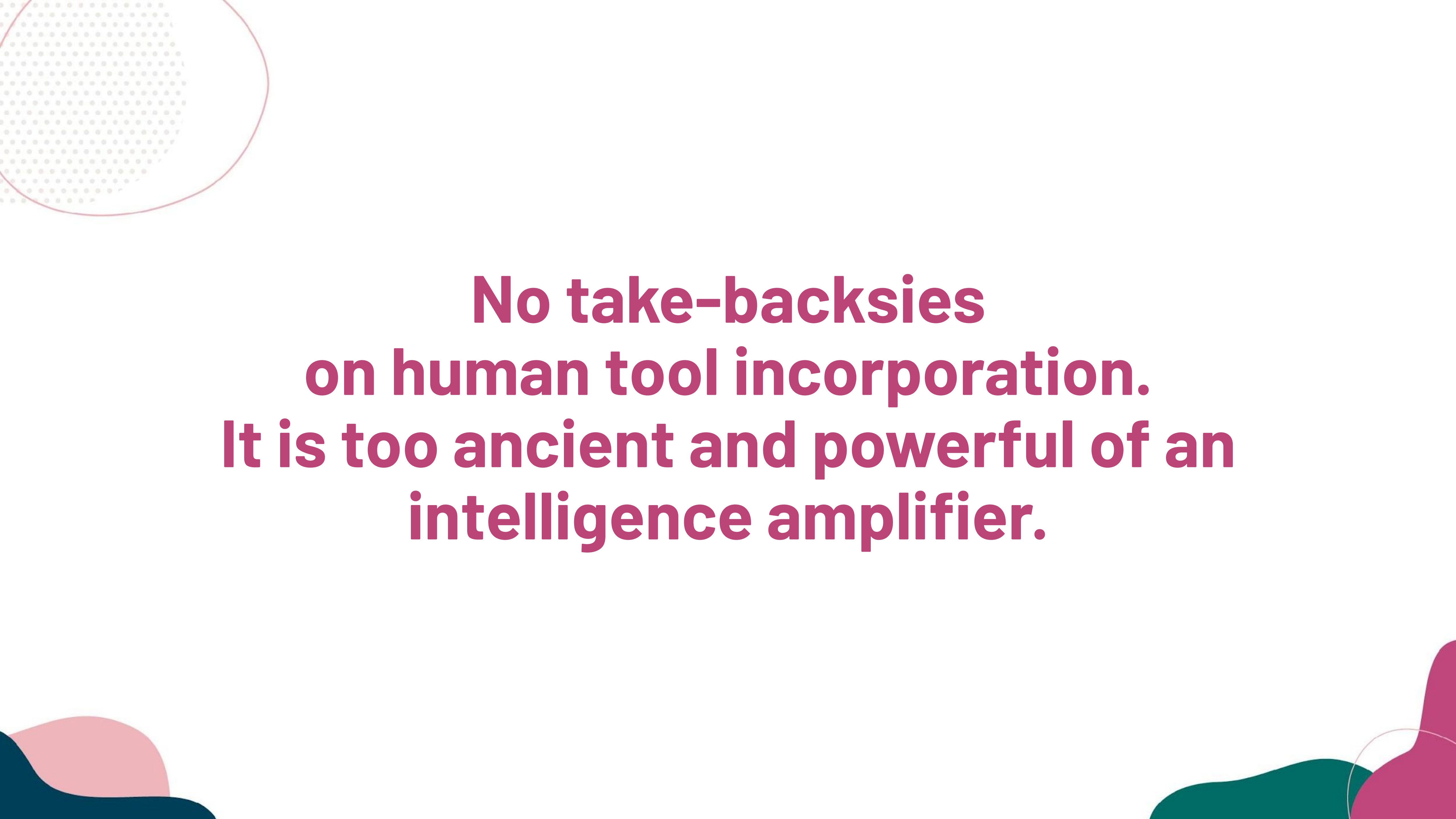


# Learning Objectives

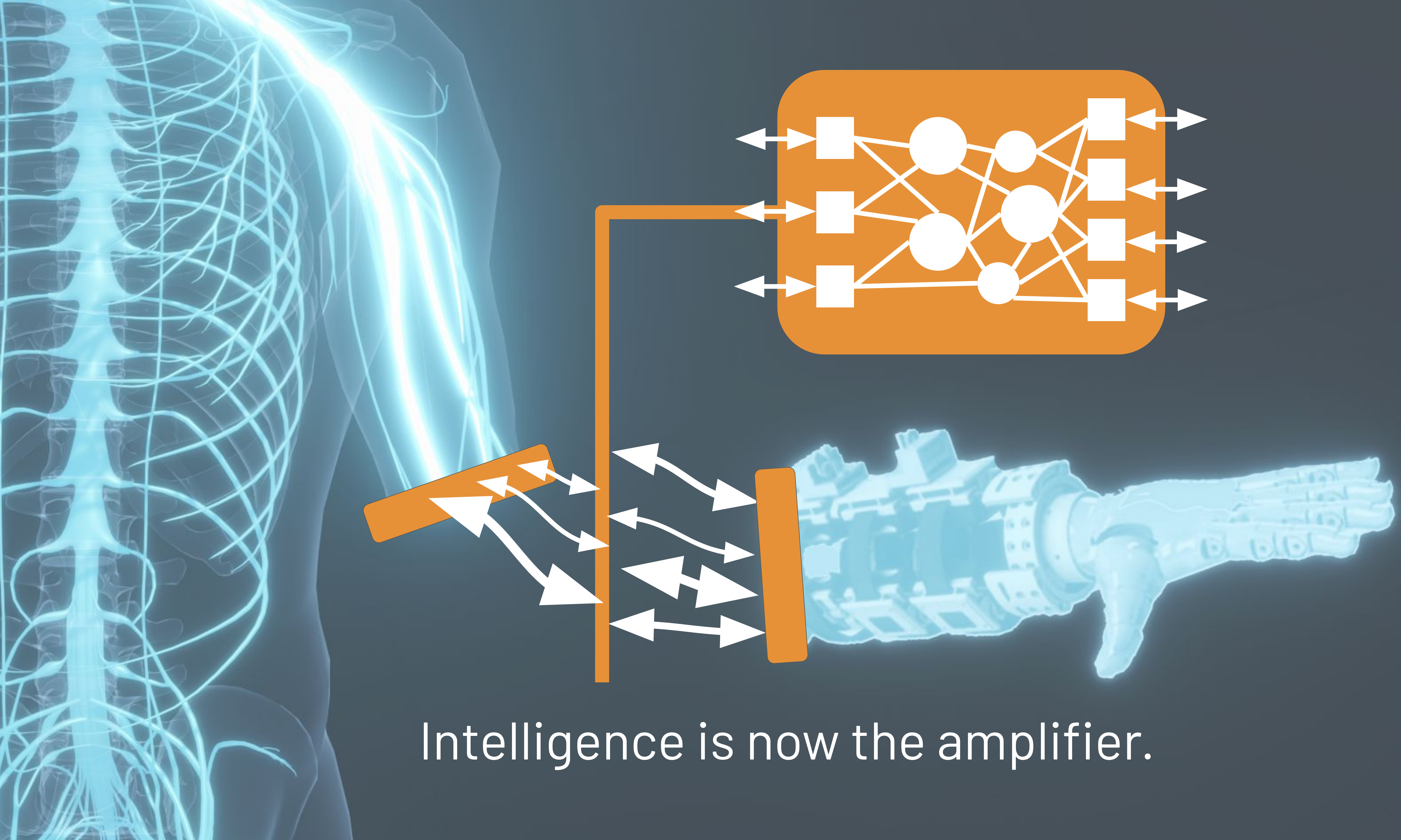
- 1.** Be aware of the capabilities of modern AI;
  - 2.** Be able to talk about and reflect on current advances in human-machine integration;
  - 3.** Be able to discuss AI's impact on health and medicine... especially the future of the human body and mind.
- 



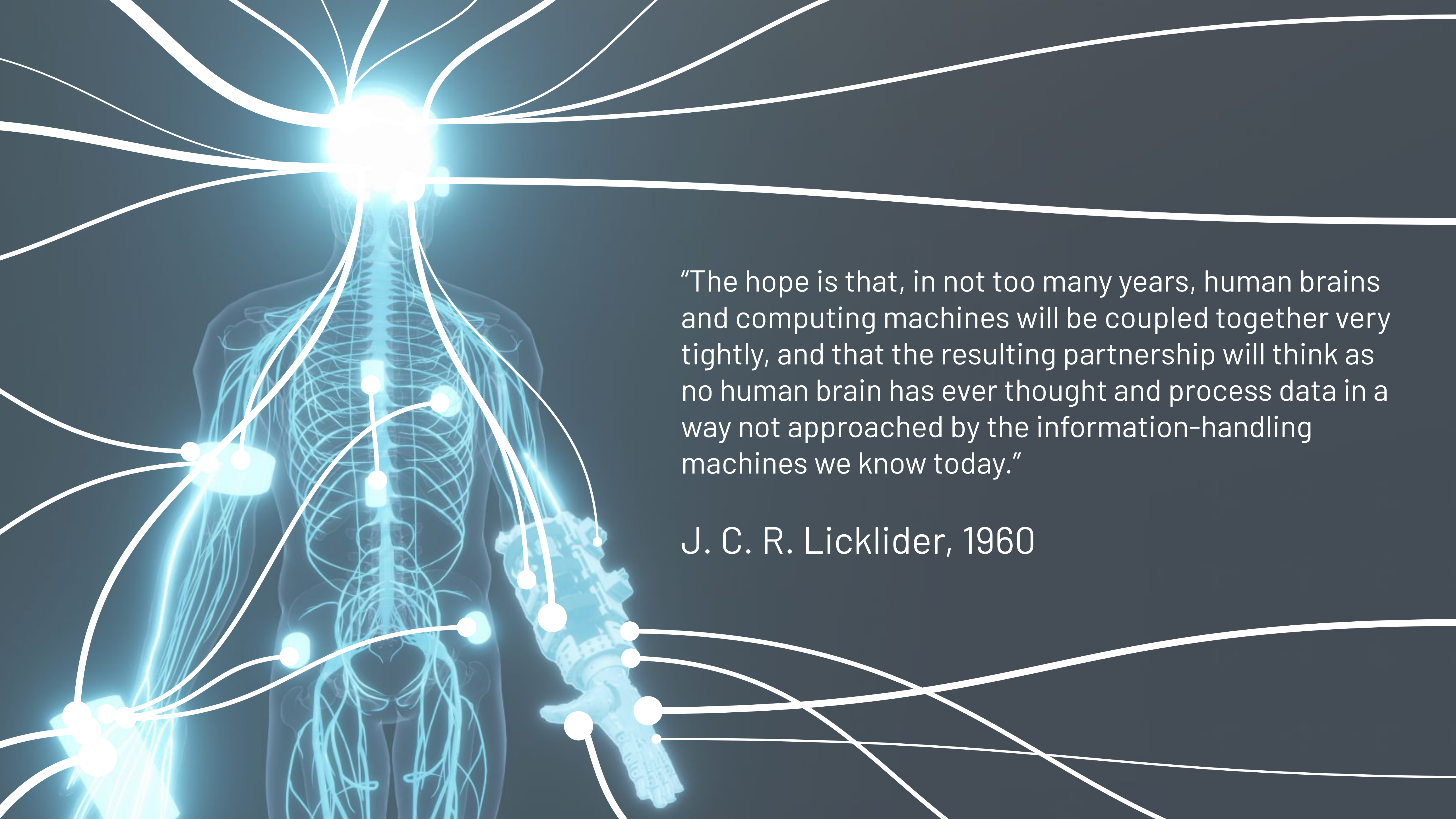
You are already  
becoming bionic



**No take-backsies  
on human tool incorporation.  
It is too ancient and powerful of an  
intelligence amplifier.**



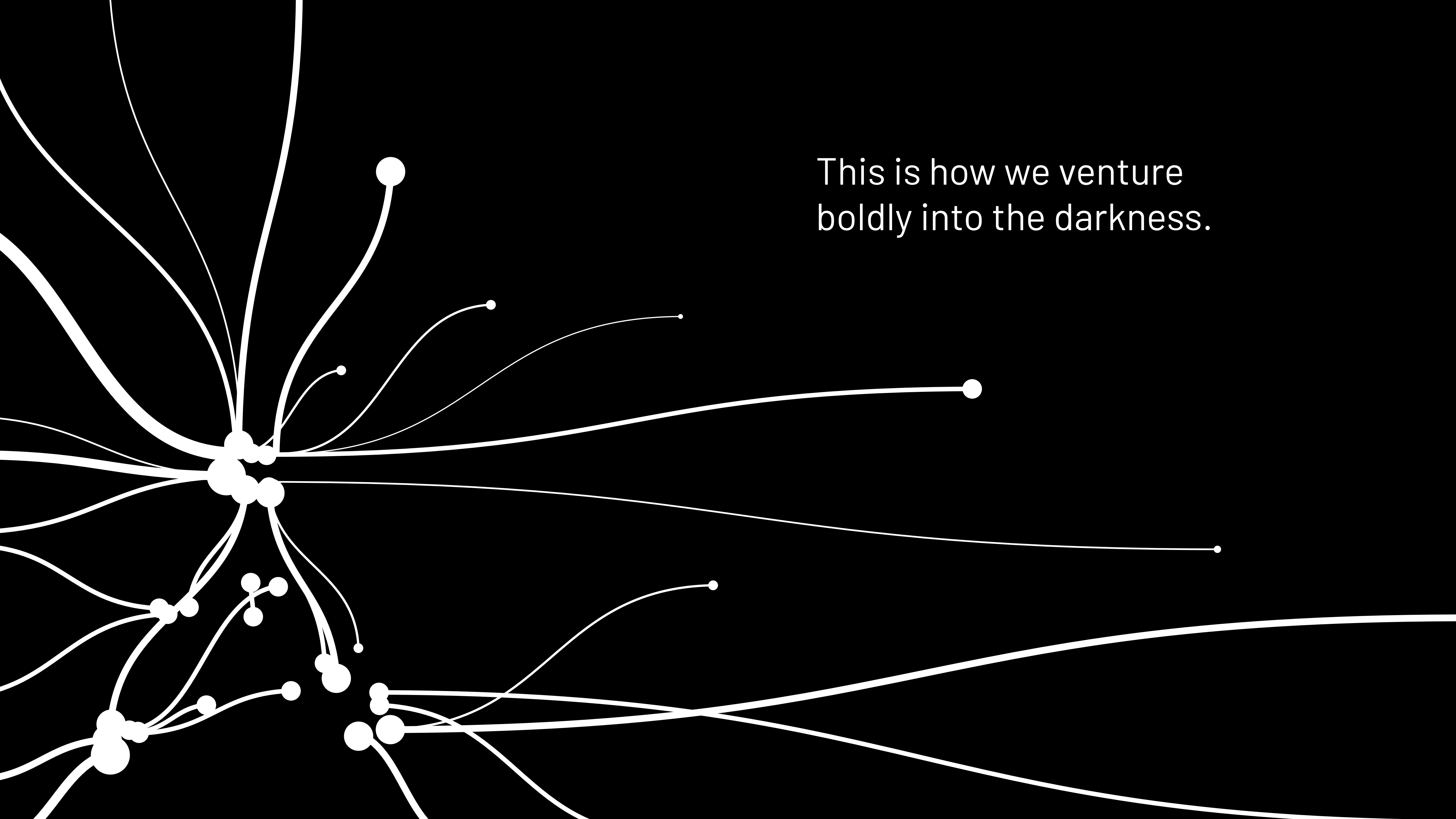
Intelligence is now the amplifier.



"The hope is that, in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today."

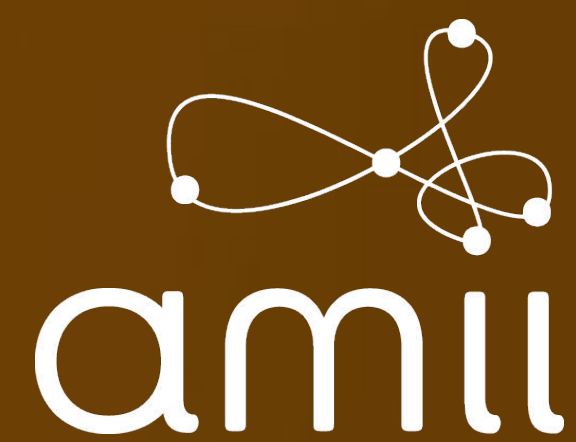
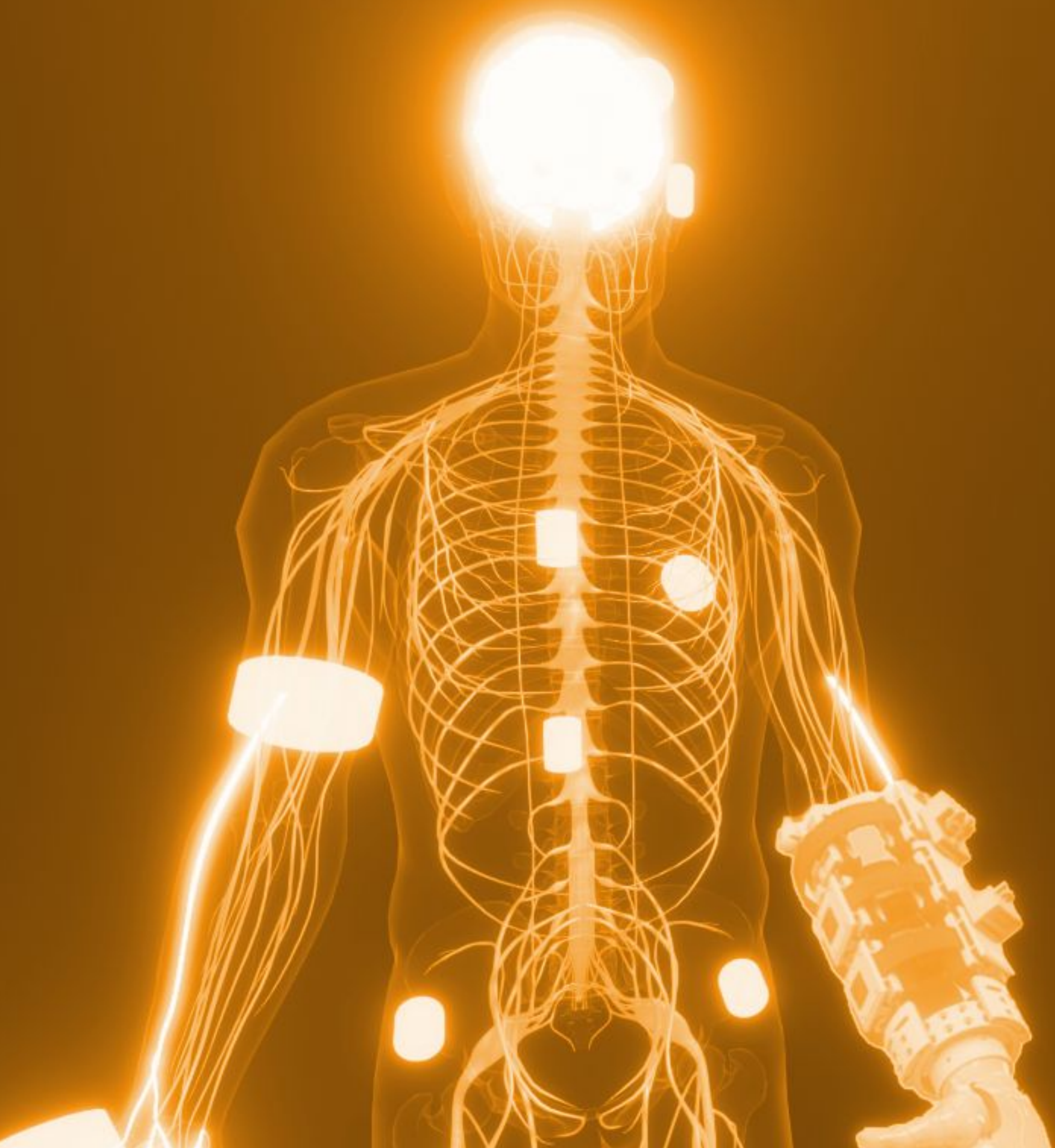
J. C. R. Licklider, 1960





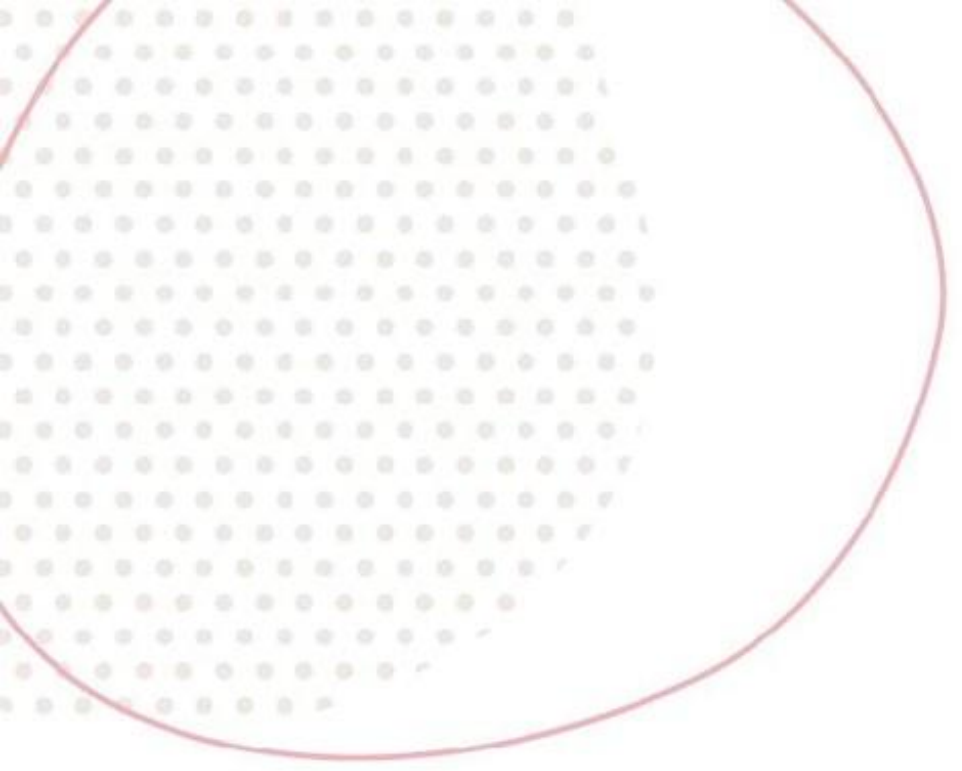
This is how we venture  
boldly into the darkness.

**Thank you  
for being here!**



**UNIVERSITY  
OF ALBERTA**

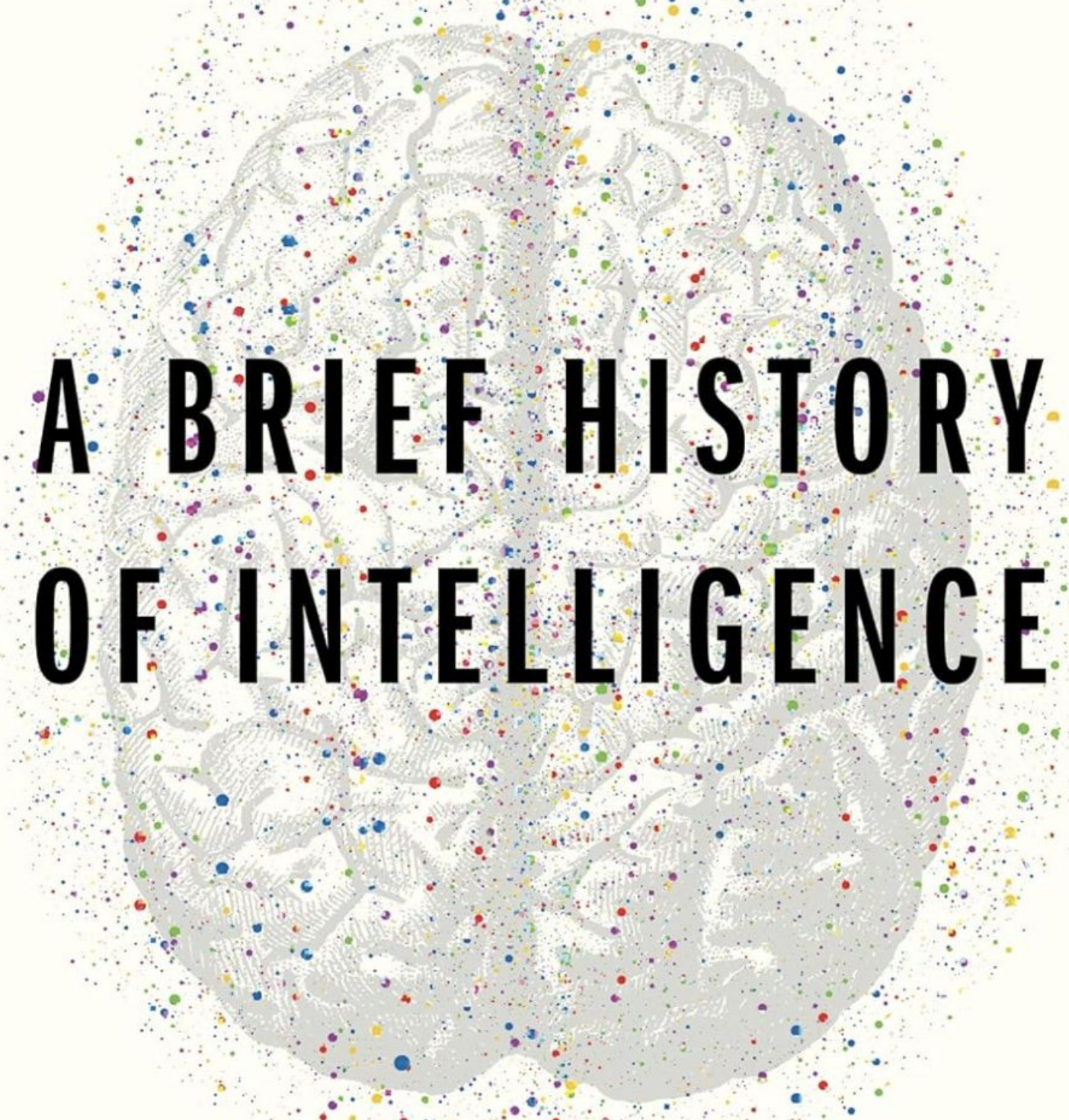




# SOME BOOKS



EVOLUTION, AI, AND THE  
FIVE BREAKTHROUGHS  
THAT MADE OUR BRAINS



**A BRIEF HISTORY  
OF INTELLIGENCE**

MAX BENNETT

