Artificial intelligence in Bionic Medicine

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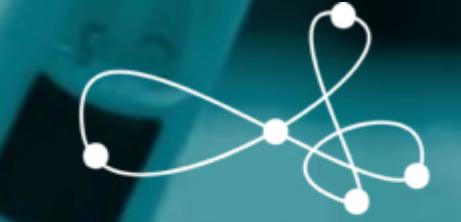
C.O.I. Disclosure

No affiliation (financial or otherwise) with pharmaceutical, medical device or medical communications organizations.

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Board of Directors, *Alberta Machine Intelligence Institute*

950BC – 700BC, The "Cairo Toe" (The University of Manchester), https://www.theatlantic.com/technology/archive/2013/11/the-perfect-3-000-year-old-toe-a-brief-history-of-prosthetic-limbs/281653/ Nerlich, *et al., Lancet*, 356: 2176–79, 2000.

Video courtesy:
Amii / Chris Onciul
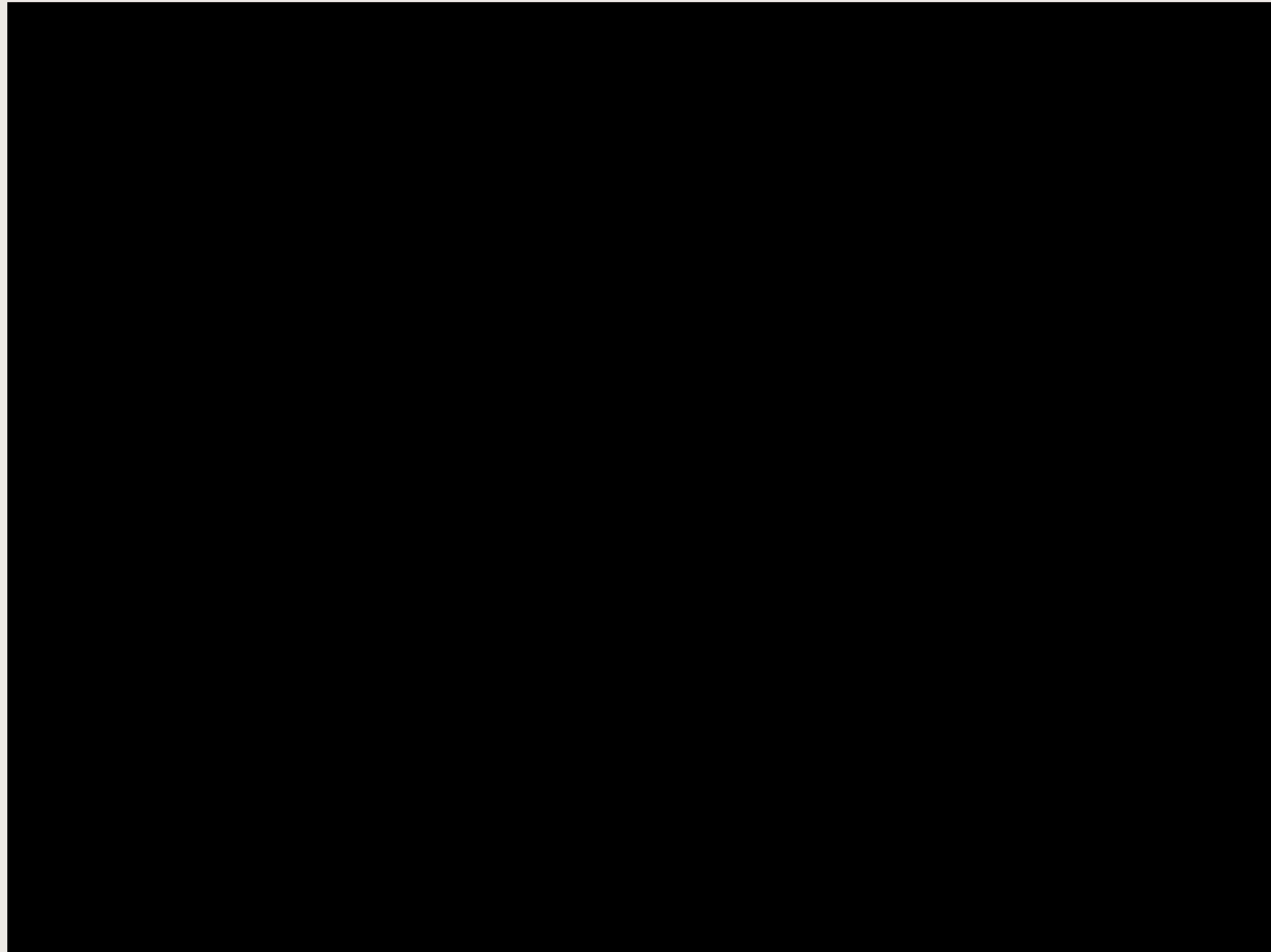
Direct brain-computer interfaces: study participant Jan Scheuermann feeding herself with a robotic limb (University of Pittsburgh / UPMC); http://www.upmc.com/media/media-kit/bci/Pages/default.aspx
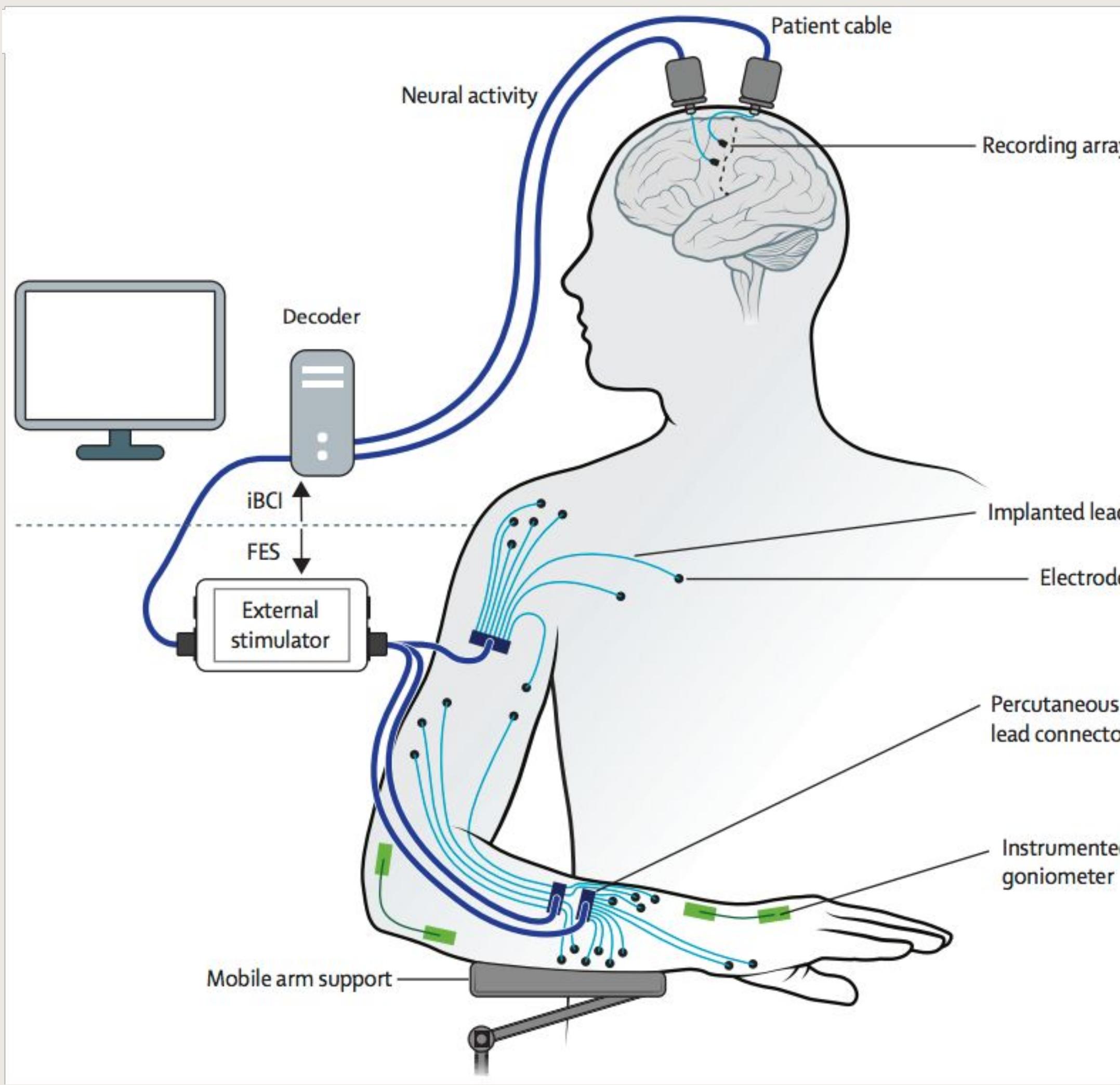
Brain-body-machine interfaces: "Restoration of reaching and grasping movements through brain-controlled muscle stimulation in a person with tetraplegia: a proof-of-concept demonstration" Ajiboye, A Bolu et al., *The Lancet*, Volume 389 , Issue 10081, 1821-1830, 2017.

500μm

A

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

4mm

1020

500

200 milliseconds
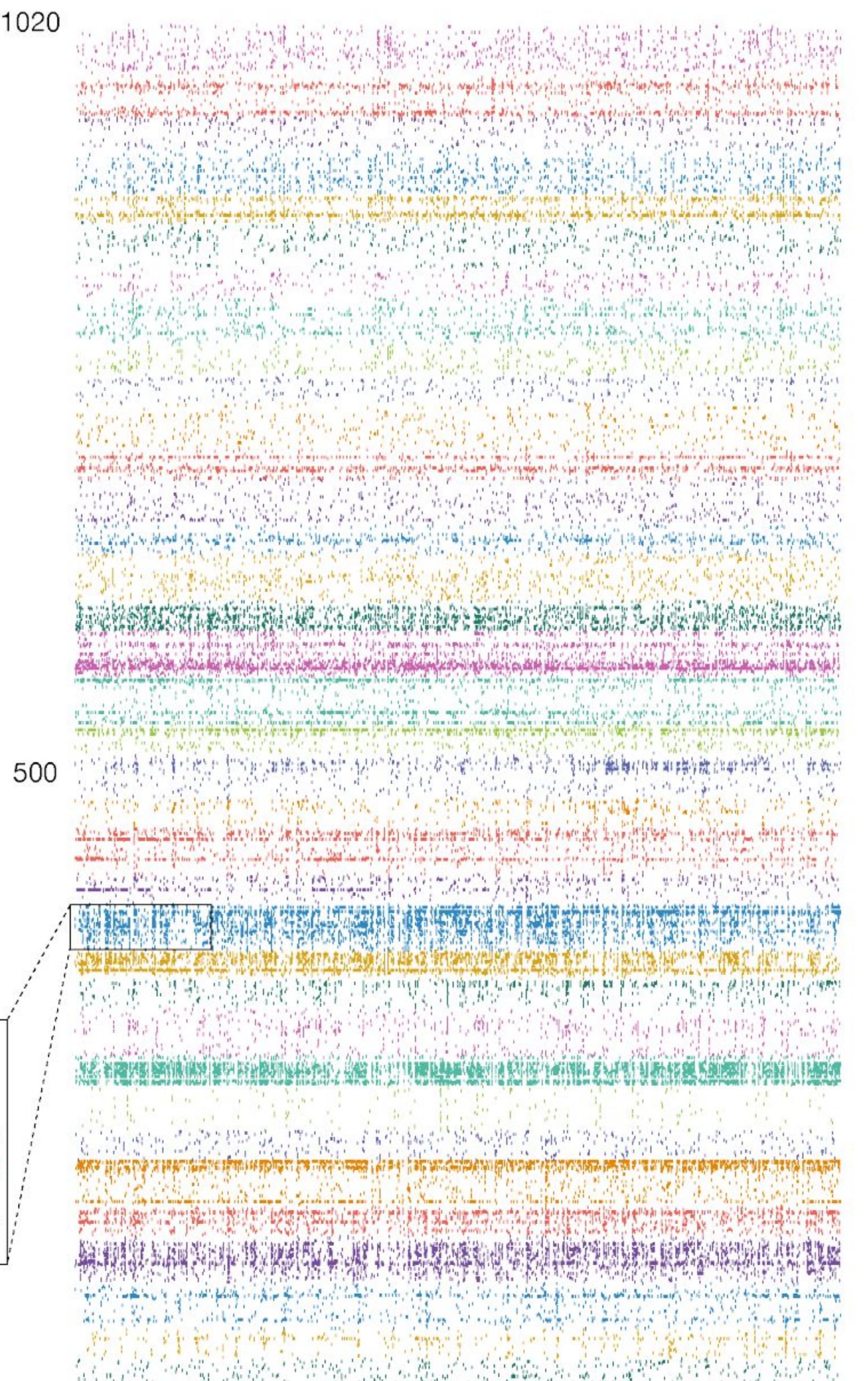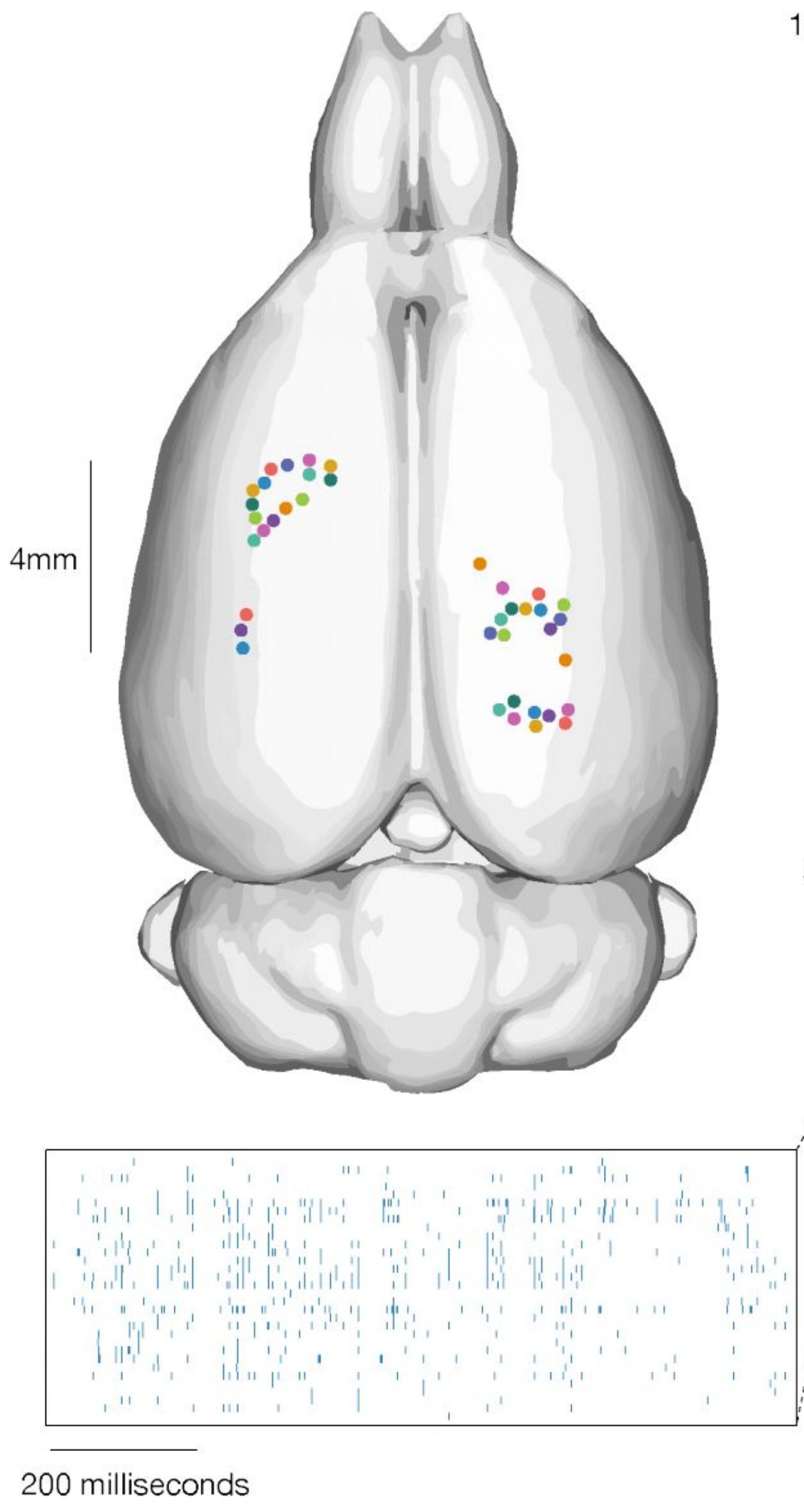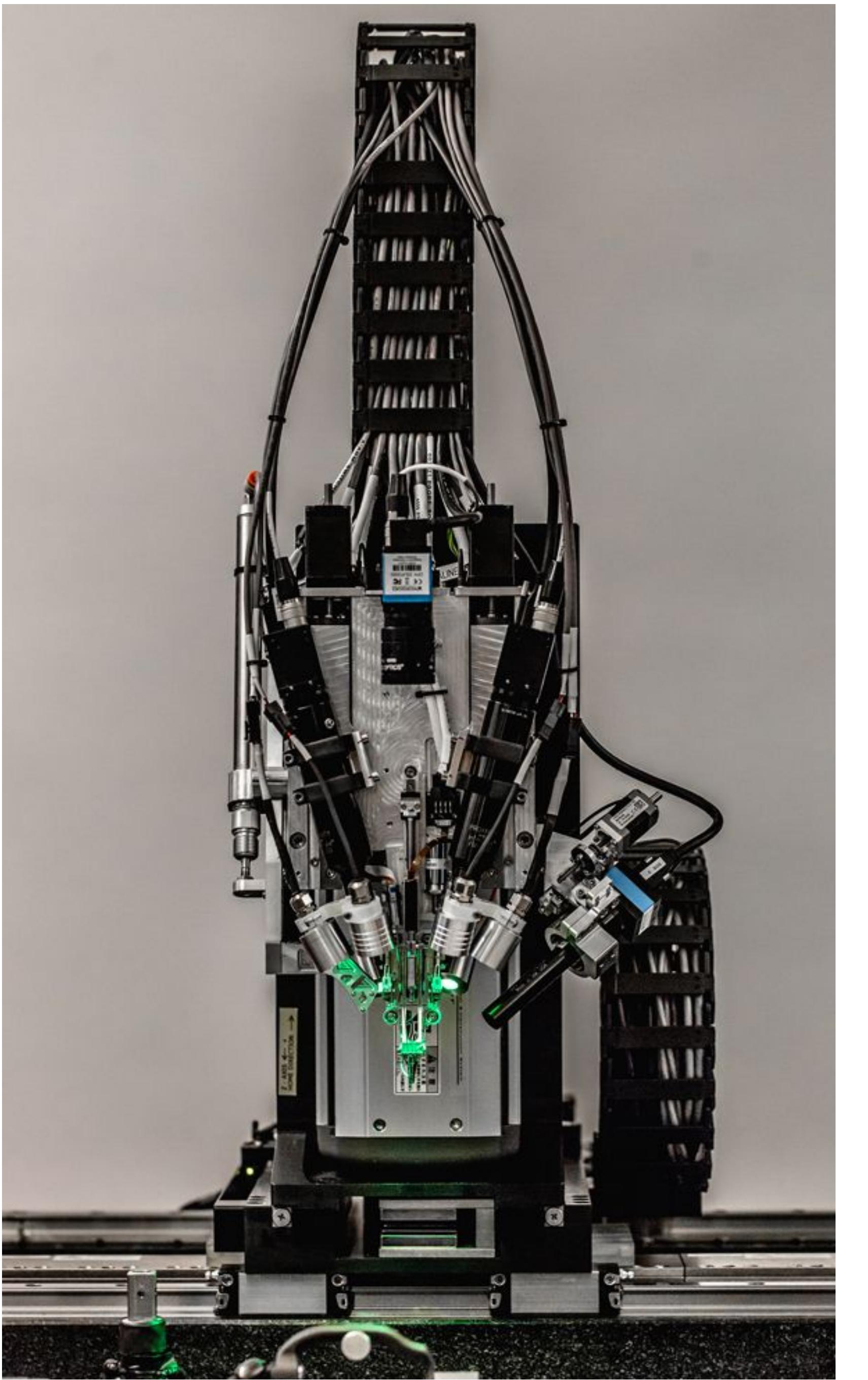
bone, muscle, and nerve integration

Ortiz-Catalan et al., *N Engl J Med* 2020; 382:1732-8.
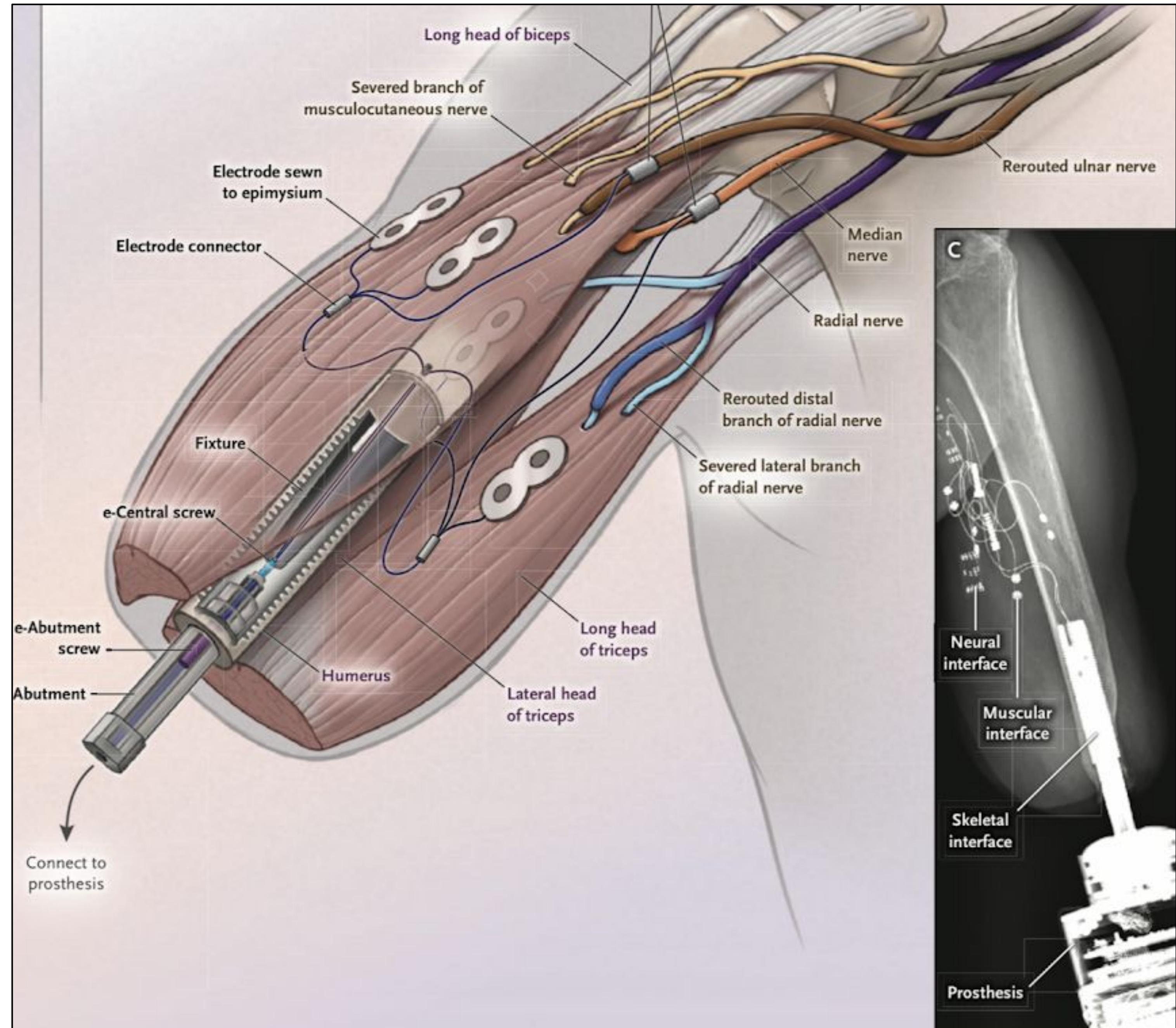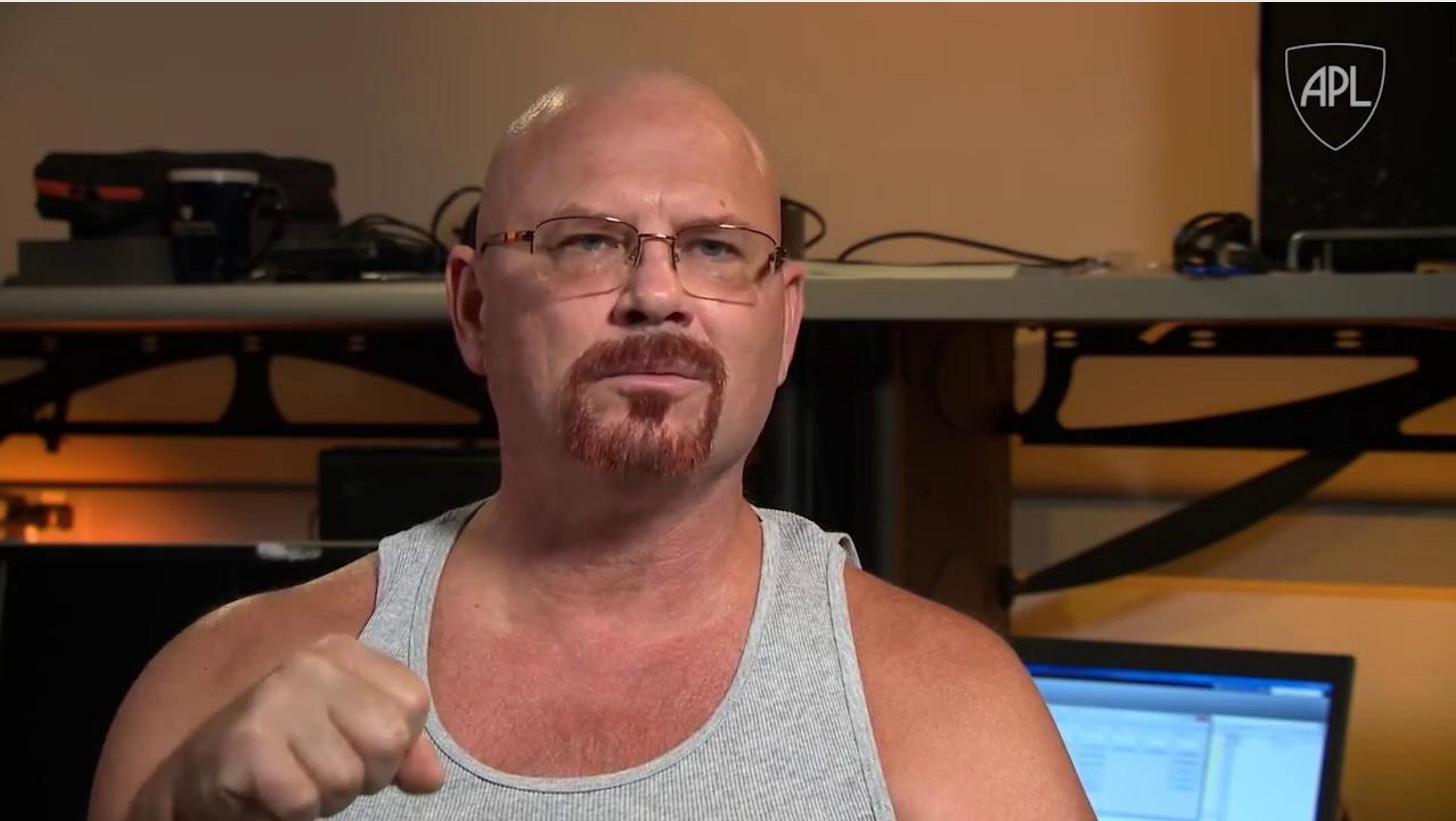
**Brain-body-machine interfaces:** "APL's Modular Prosthetic Limb Reaches New Levels of Operability" (JHU Applied Physics Laboratory); https://youtu.be/-0srXvOQlu0
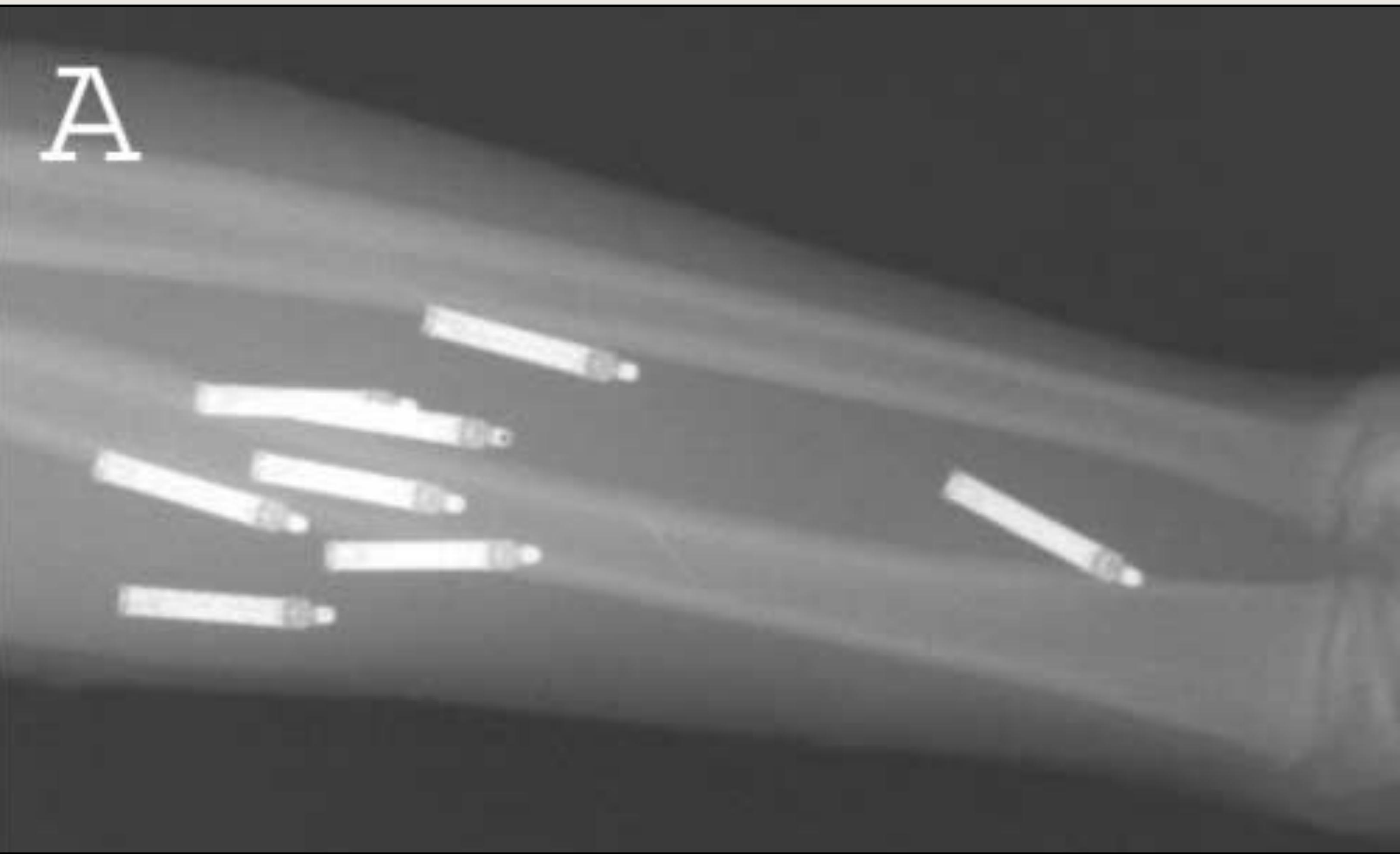
Brain-body-machine interfaces: Baker et al., "Continuous Detection and Decoding of Dexterous Finger Flexions With Implantable MyoElectric Sensors," IEEE TNSRE 18(4):424-32, 2010.

EEG

EMG

Consumer-Available BCI and BMI
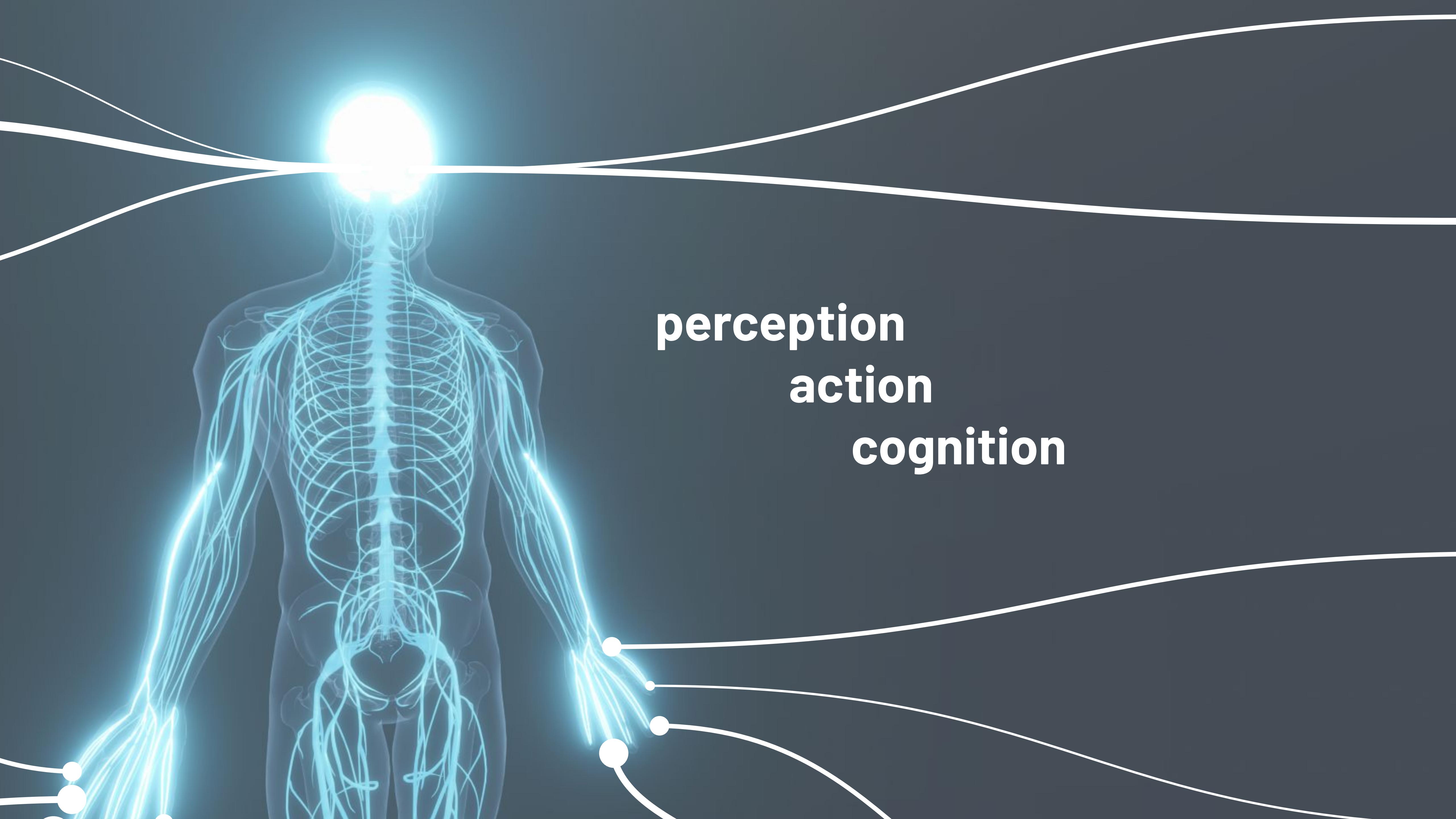
perception

action

cognition
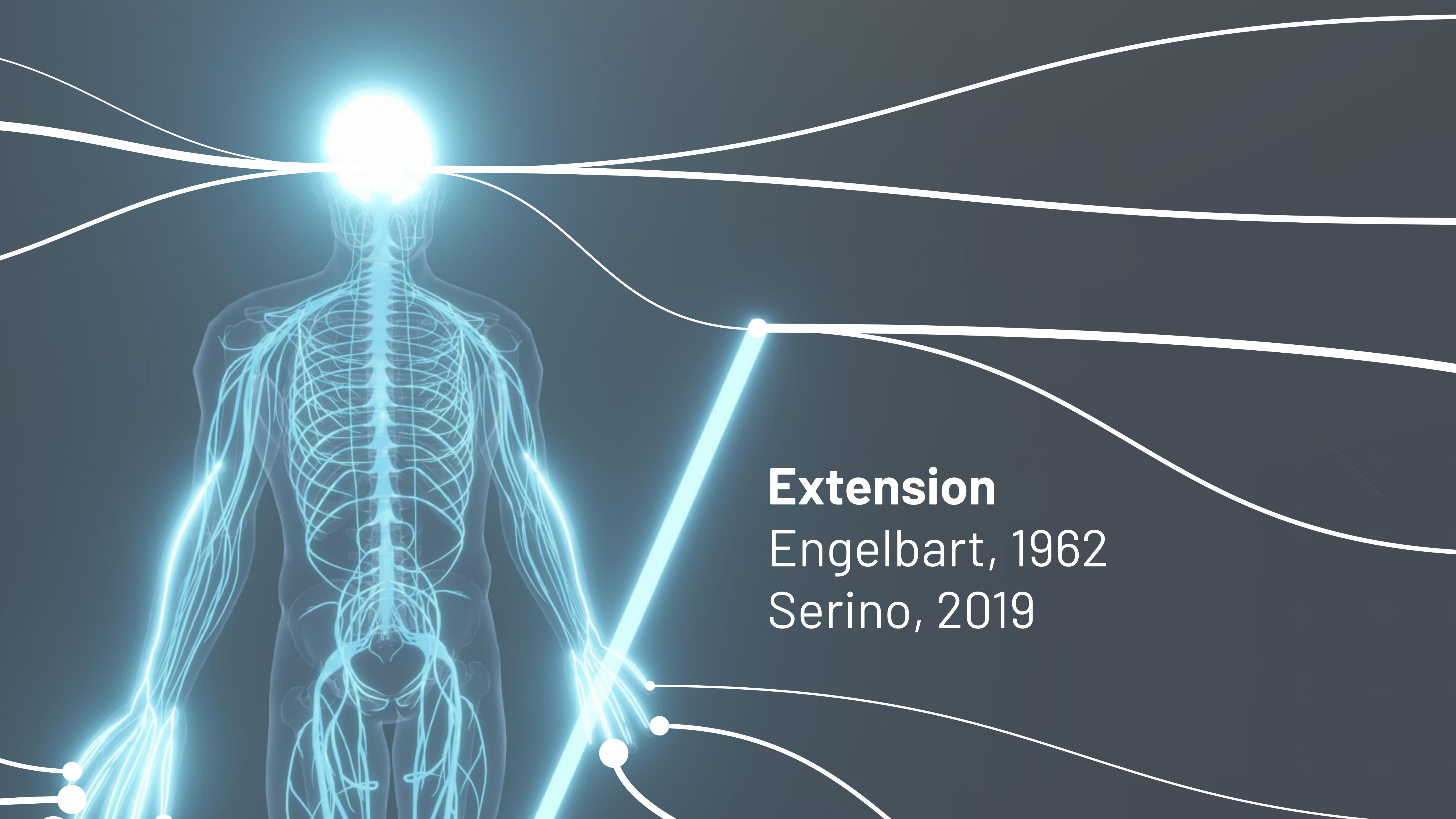
Extension
Engelbart, 1962
Serino, 2019
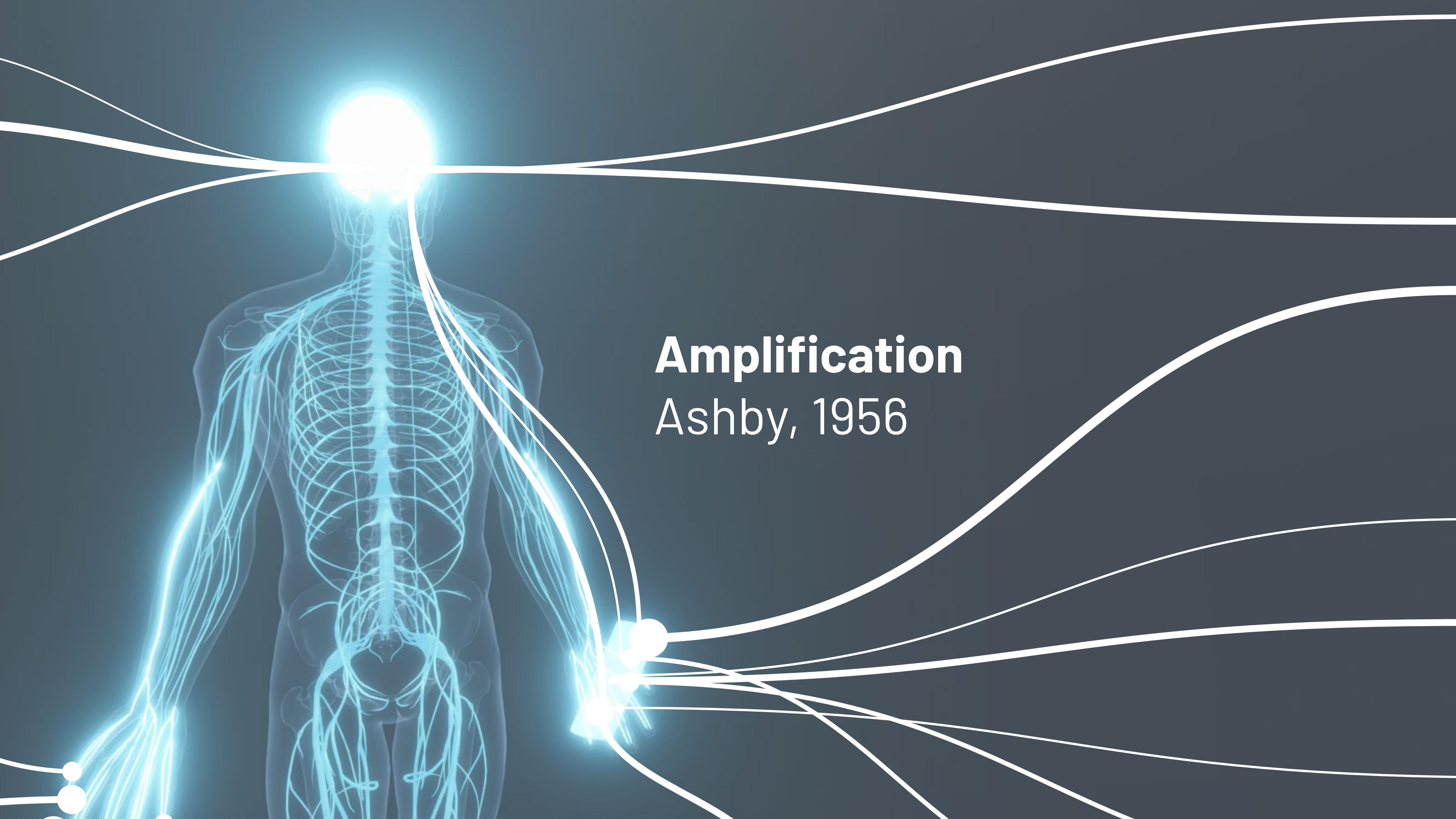
Amplification
Ashby, 1956
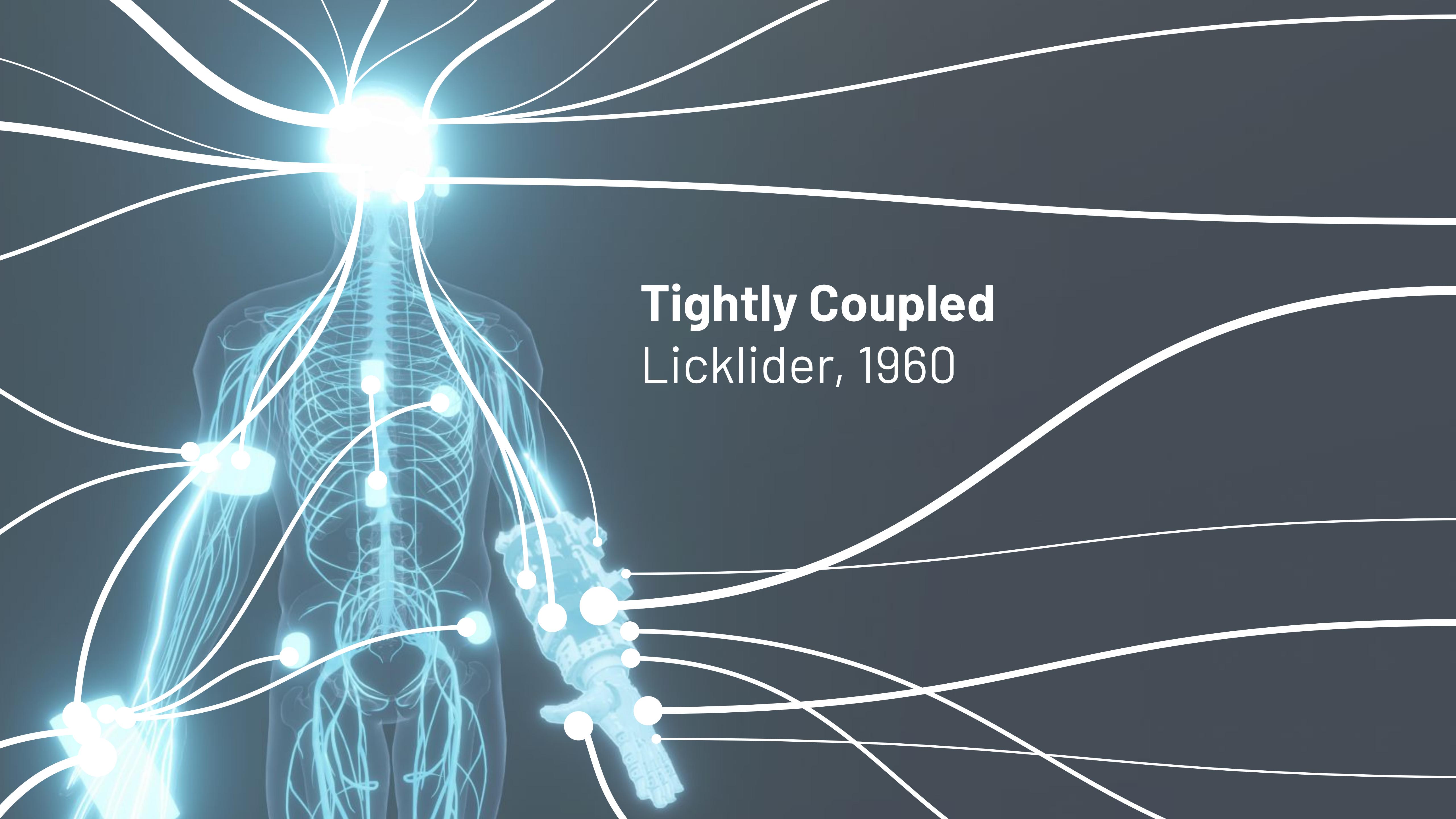
Tightly Coupled
Licklider, 1960
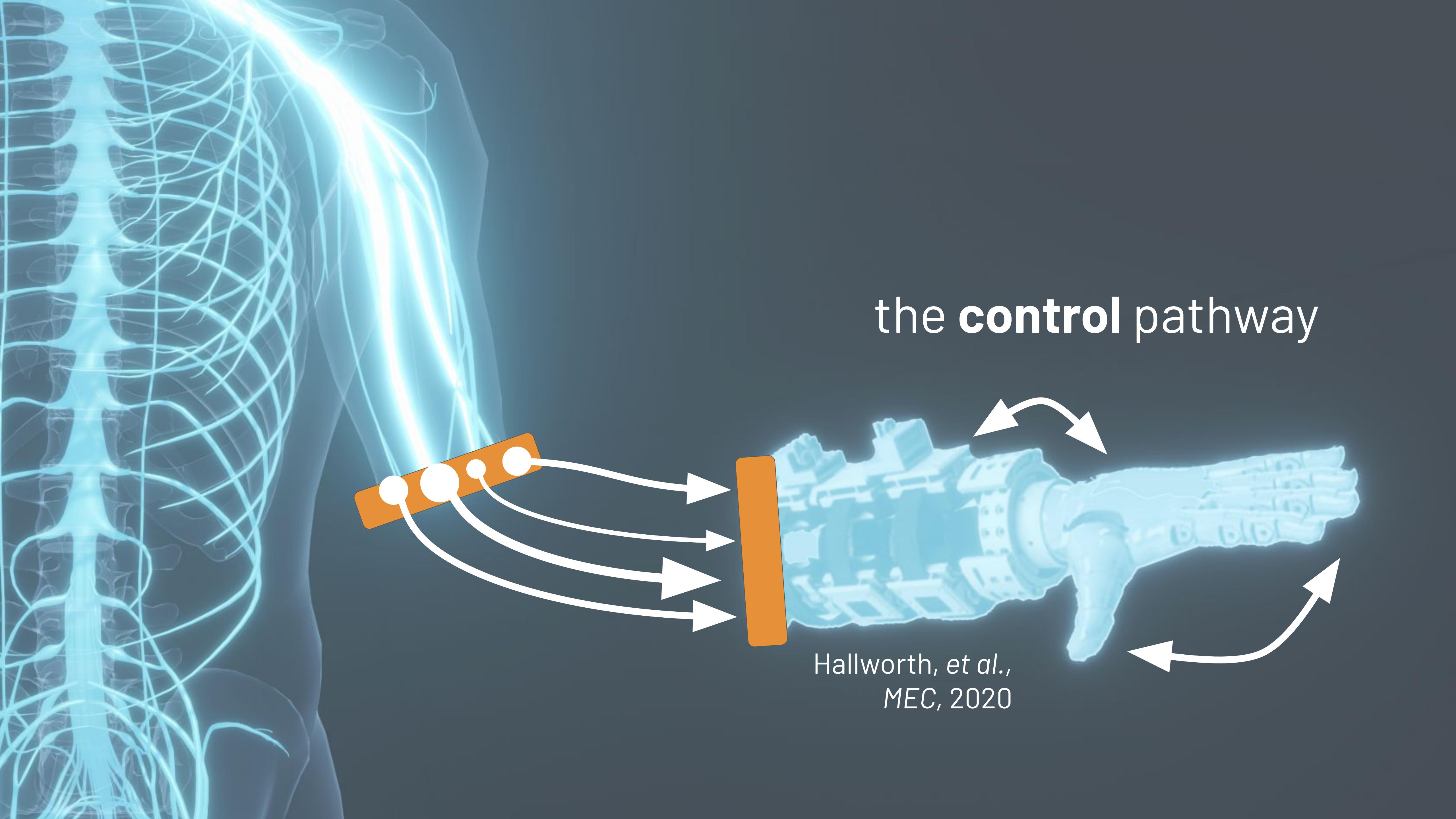
the **control** pathway

Hallworth, *et al.*,
MEC, 2020

machine intelligence
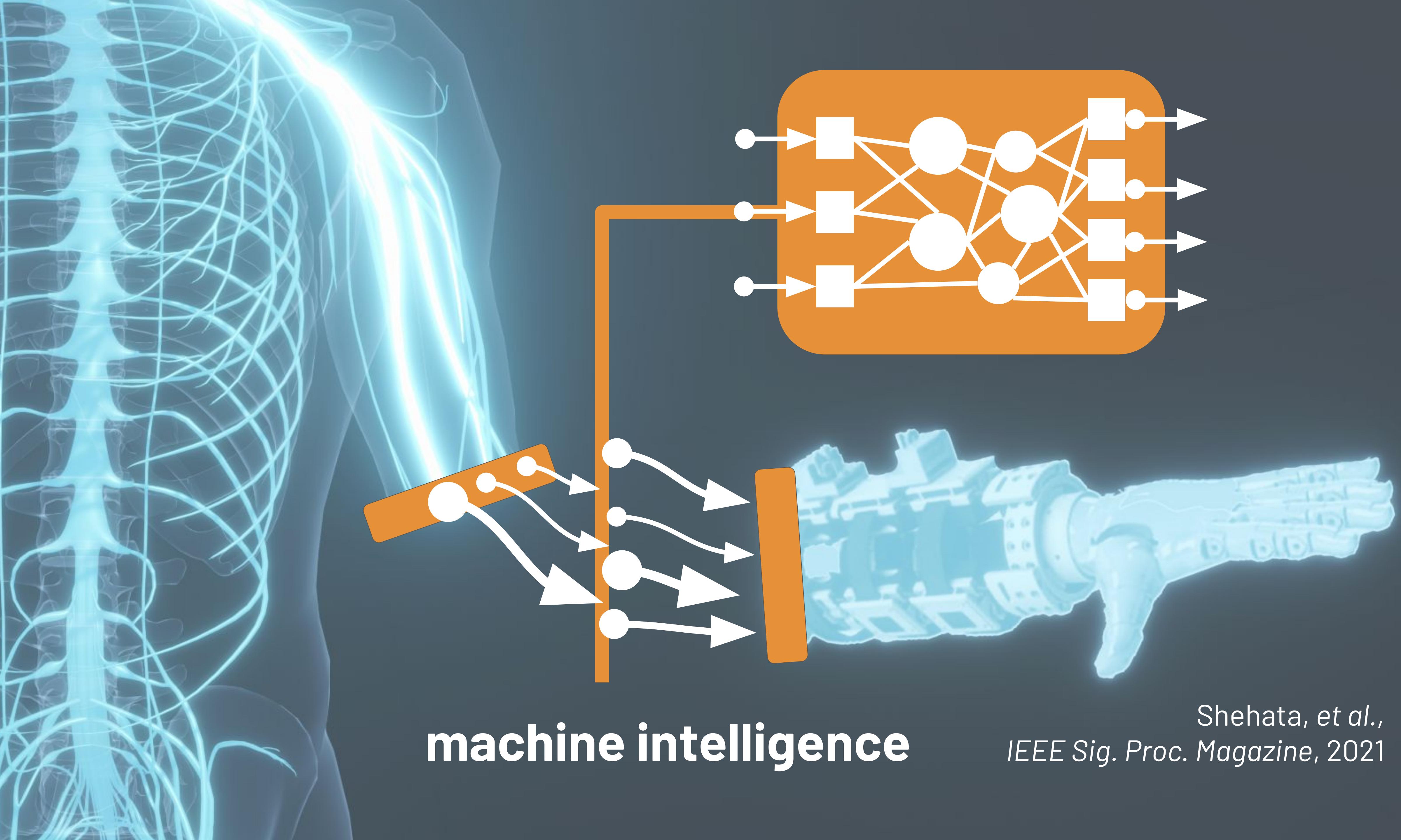
Shehata, *et al.*,
IEEE Sig. Proc. Magazine, 2021
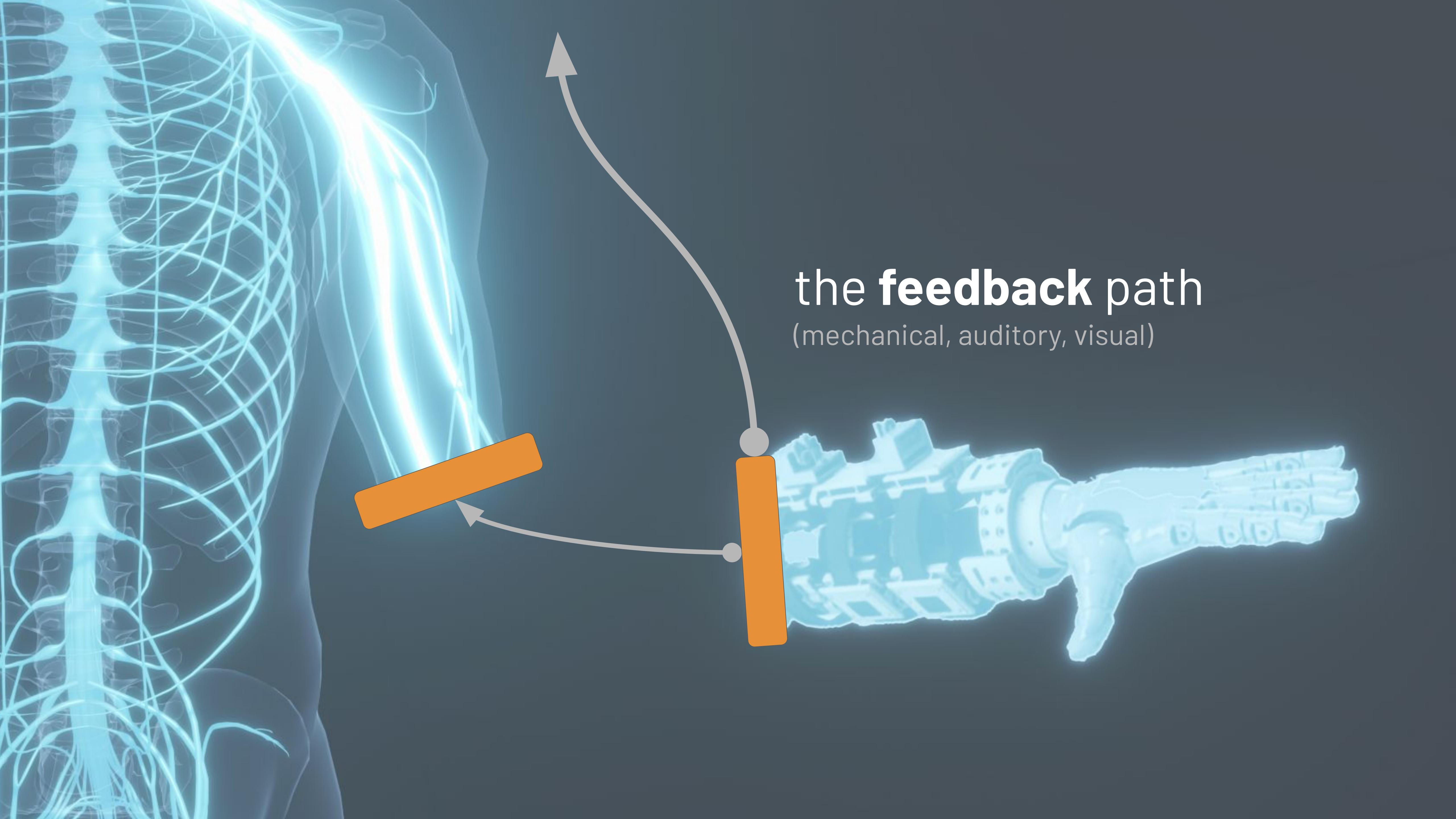
the **feedback** path
(mechanical, auditory, visual)
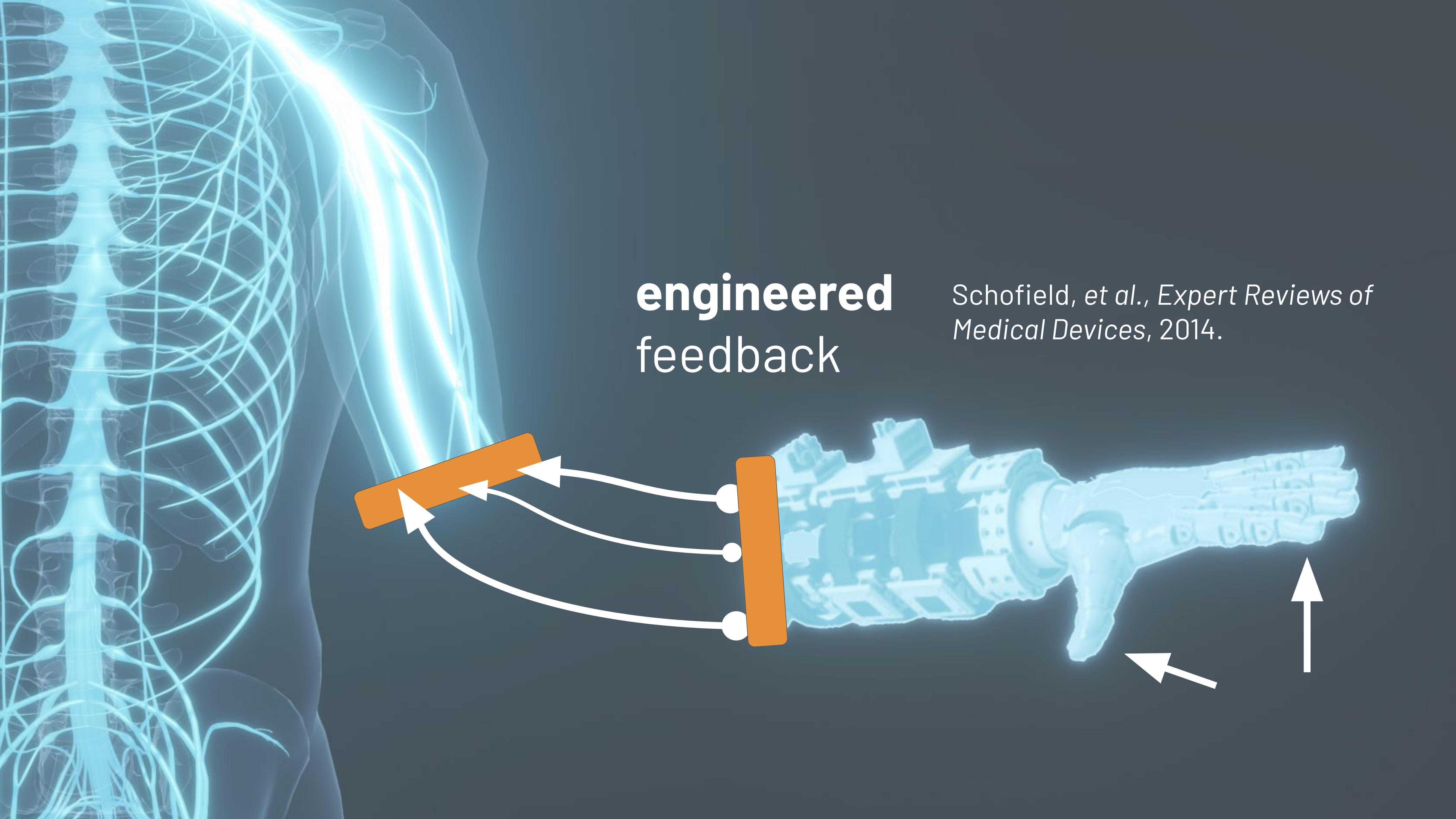
engineered feedback

Schofield, *et al.*, *Expert Reviews of Medical Devices*, 2014.
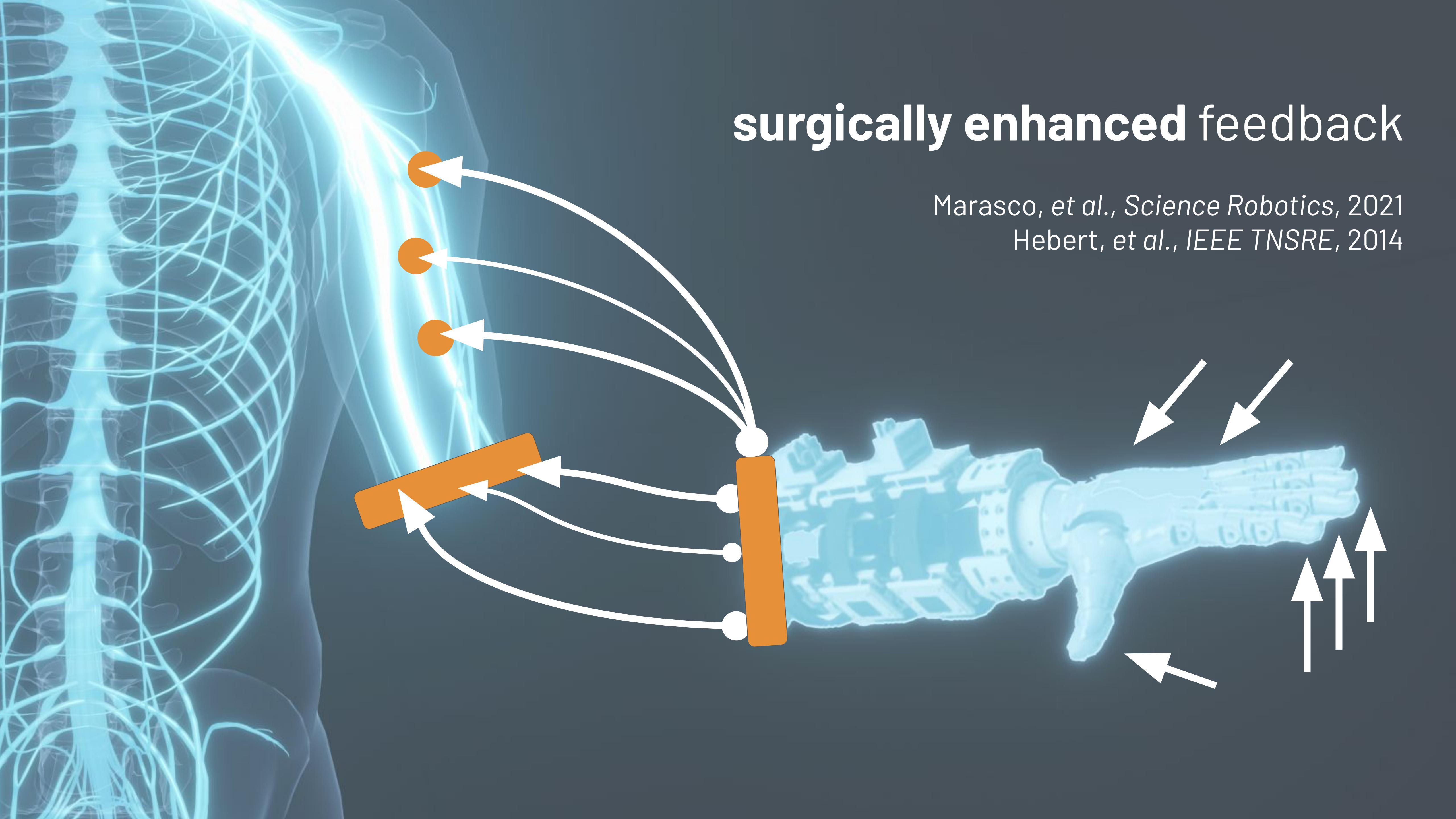
surgically enhanced feedback

Marasco, *et al., Science Robotics*, 2021
Hebert, *et al., IEEE TNSRE*, 2014

machine **learned feedback**
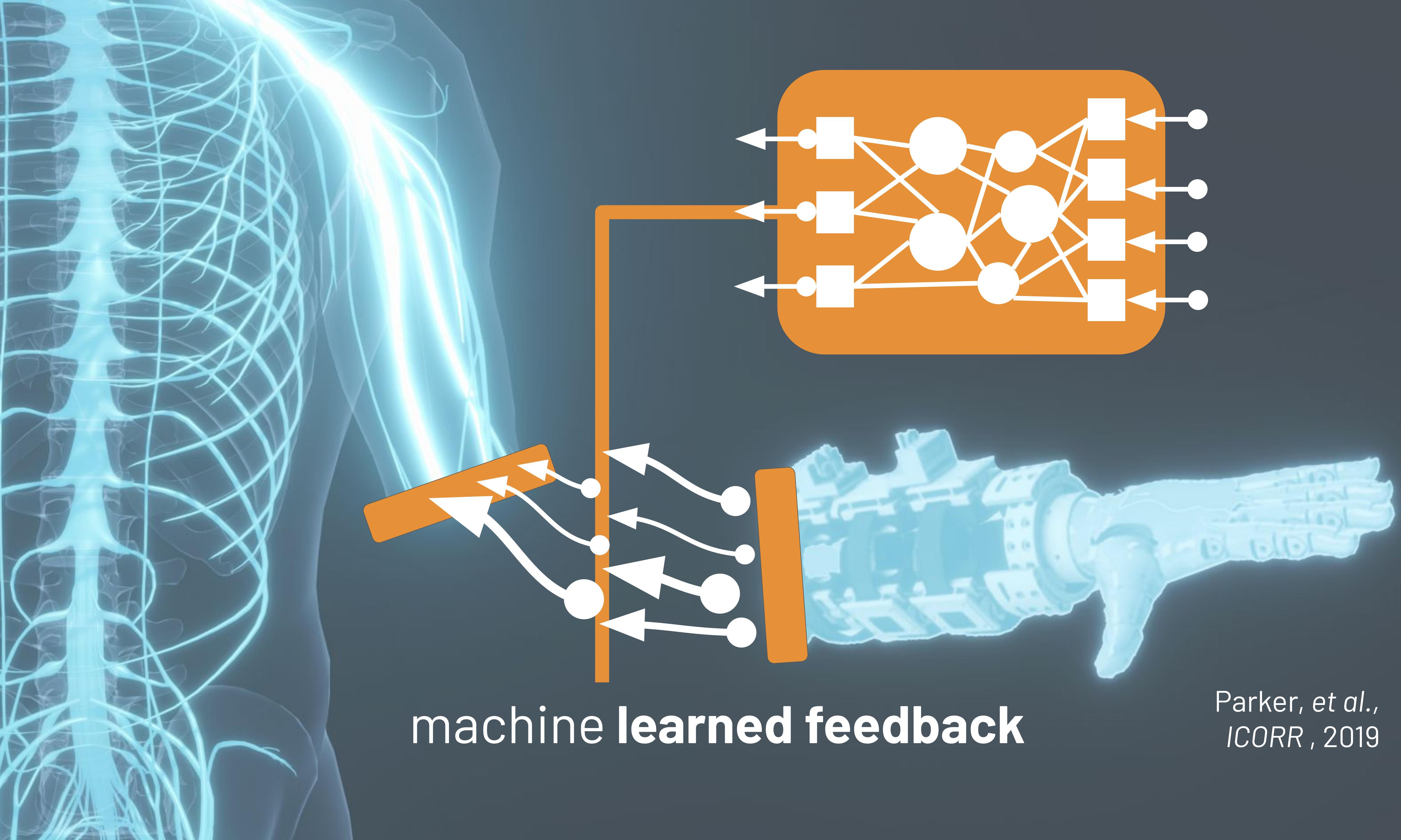
Parker, *et al.,*
ICORR , 2019
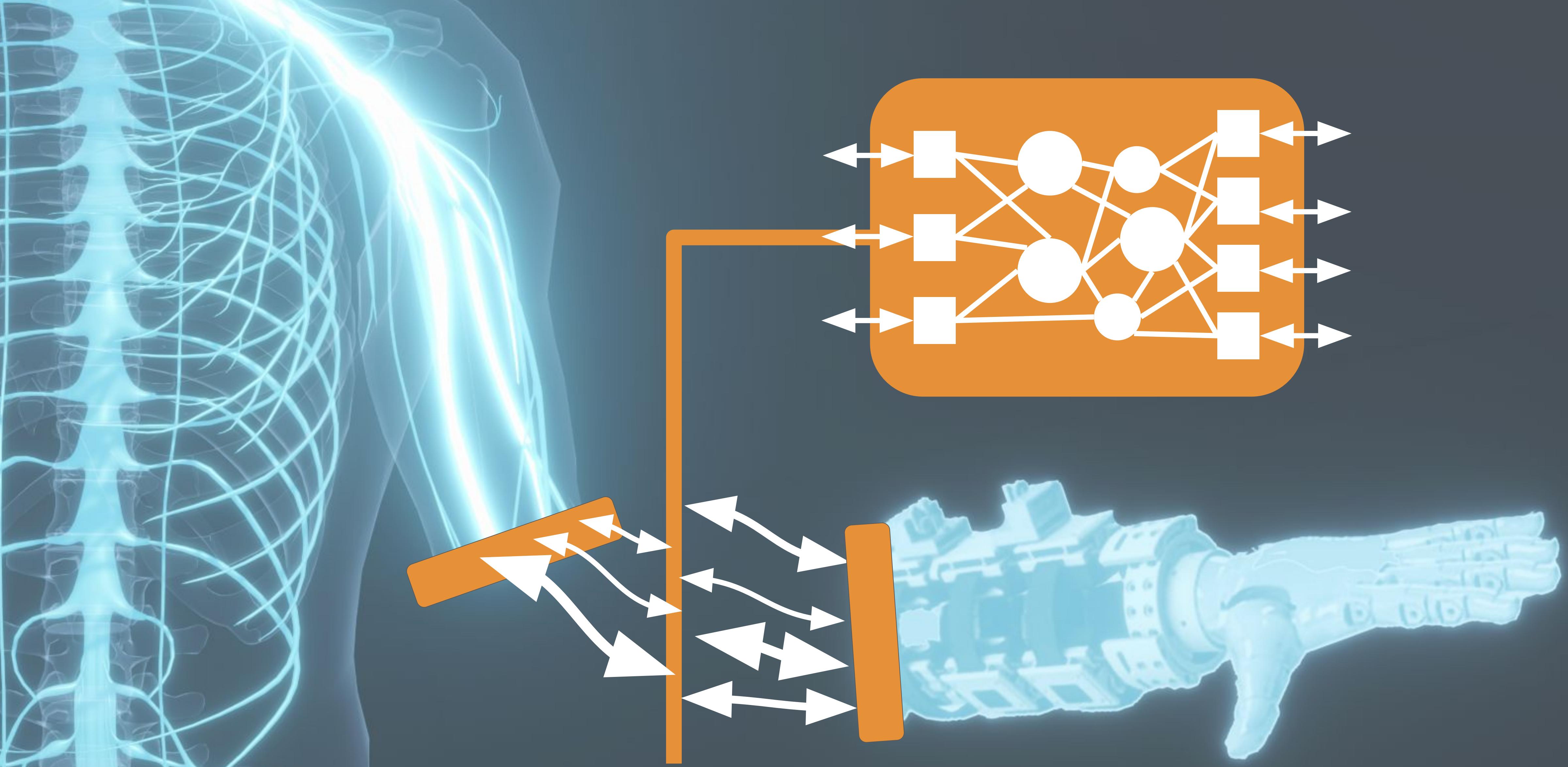
machine learned **bidirectional coordination**
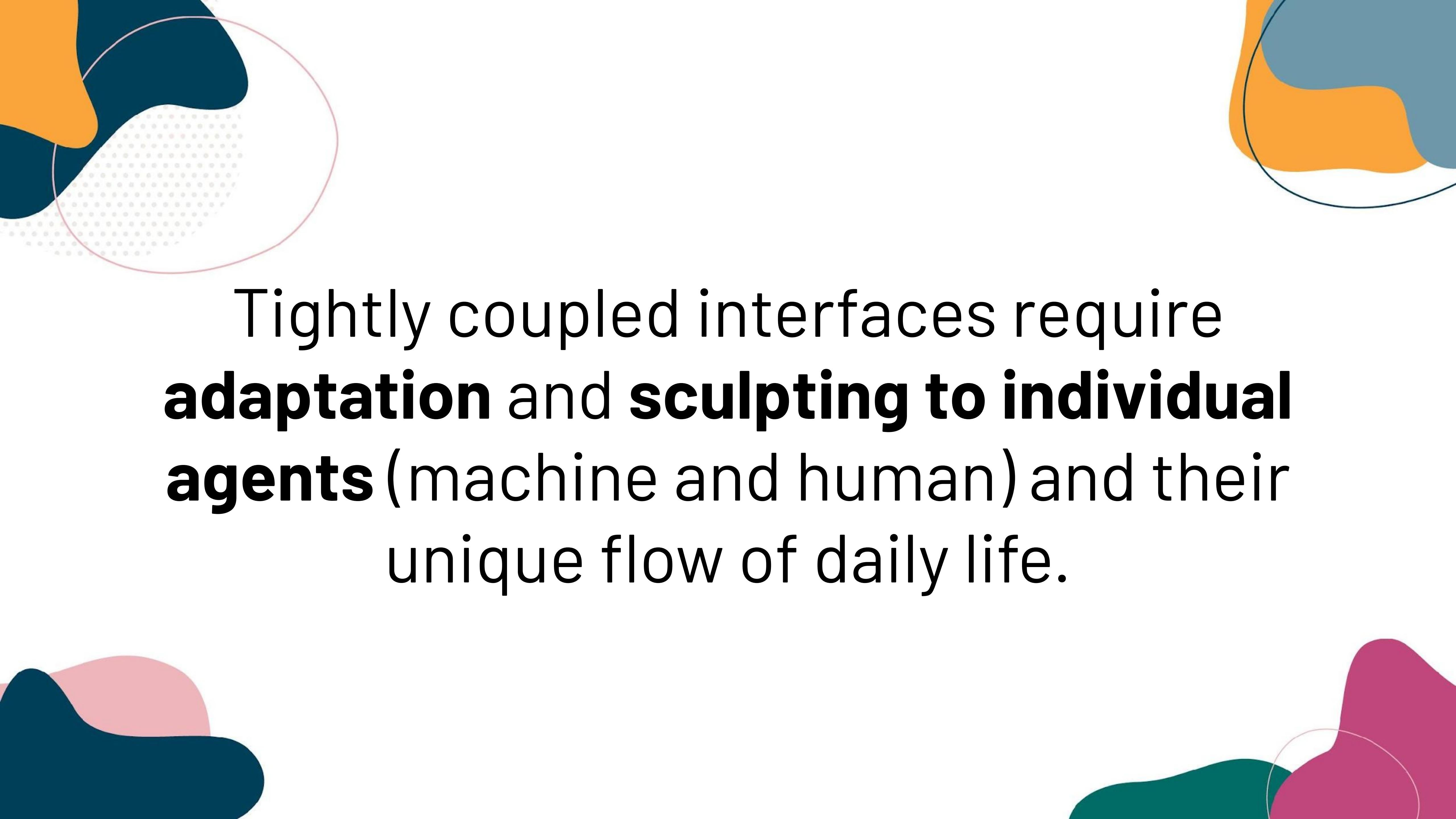
Tightly coupled interfaces require **adaptation** and **sculpting to individual agents** (machine and human) and their unique flow of daily life.
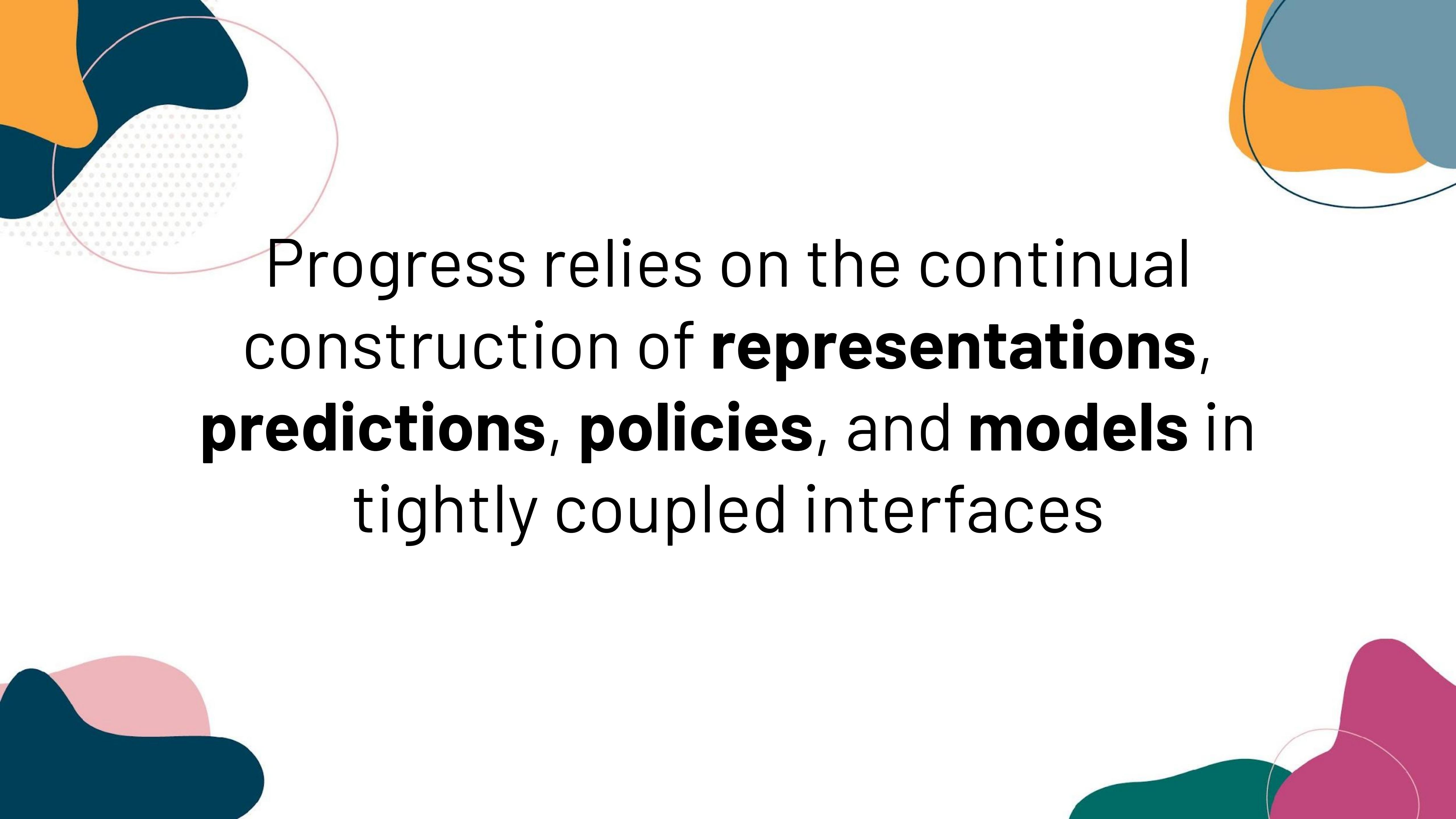
Progress relies on the continual construction of **representations**, **predictions**, **policies**, and **models** in tightly coupled interfaces

Main Considerations & Starting Points

Train/test or continual learning?   **Continual learning**

Pre-trained or tabula rasa?   ~~**No**~~ **Minimize prior biases***

Relationship or a code channel?   **Evolving relationship**

Continual learning in **motor prediction**.
Parker *et al., IEEE SMC* 2022 (submitted);
Parker *et al., ICORR* 2019.
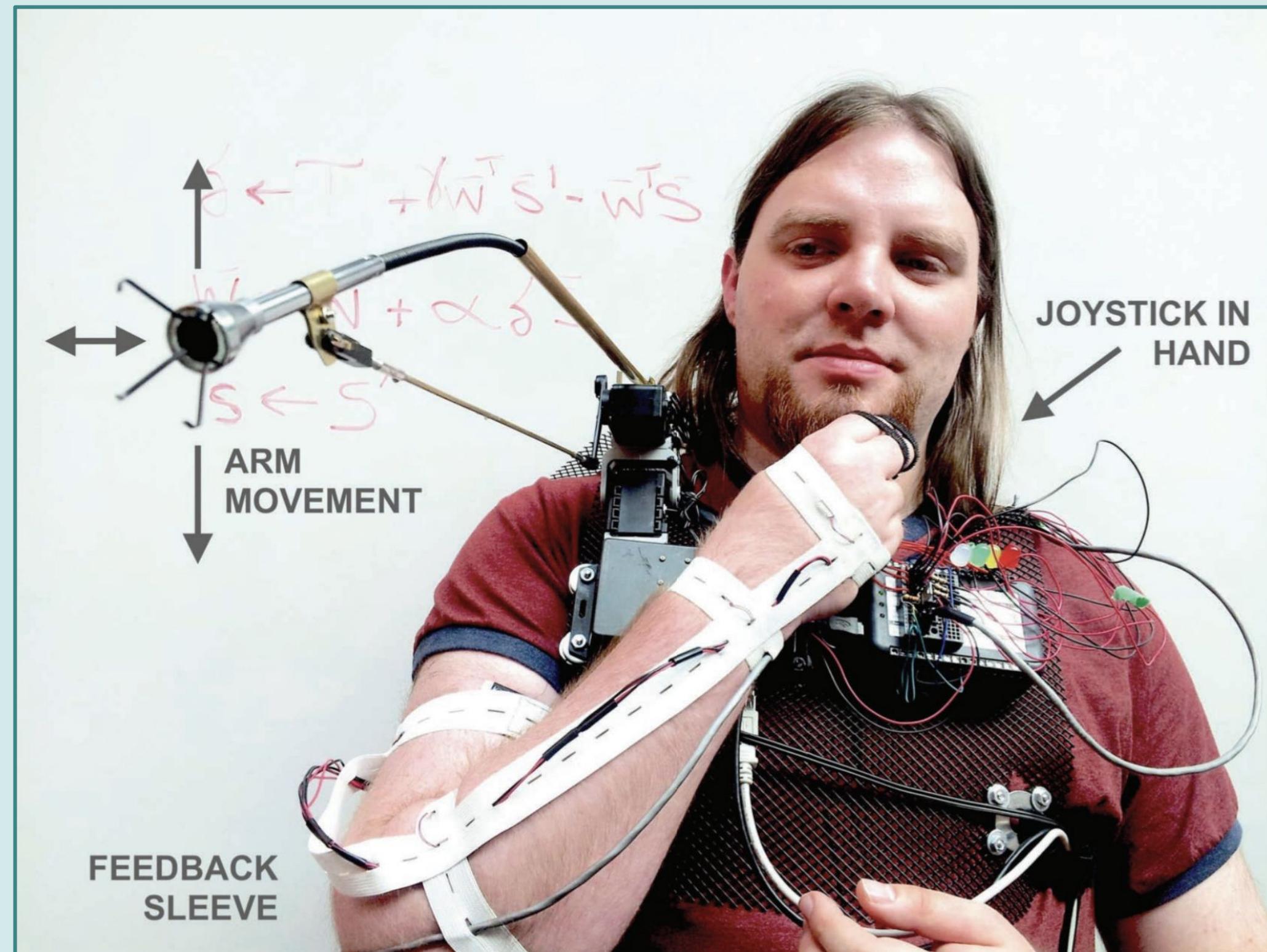
Continual learning in **exoskeleton control**.
Faridi et al., *ICORR* 2022.

Continual learning in **motor prediction**.
Parker *et al.*, *IEEE SMC* 2022 (submitted);
Parker *et al.*, *ICORR* 2019.

Predicted muscle fatigue in
wheelchair propulsion. Pilarski, *et al.*,
IFESS 2013.

Continual learning in **mode switching**.
Edwards *et al.*, *BioRob* 2016.

Continual learning in **exoskeleton control**.
Faridi et al., *ICORR* 2022.

Continual learning in **motor prediction**.
Parker *et al.*, *IEEE SMC* 2022 (submitted);
Parker *et al.*, *ICORR* 2019.

Continual learning in **mode switching**.
Edwards *et al.*, *BioRob* 2016.

Indego

Lidar-Lite sensors
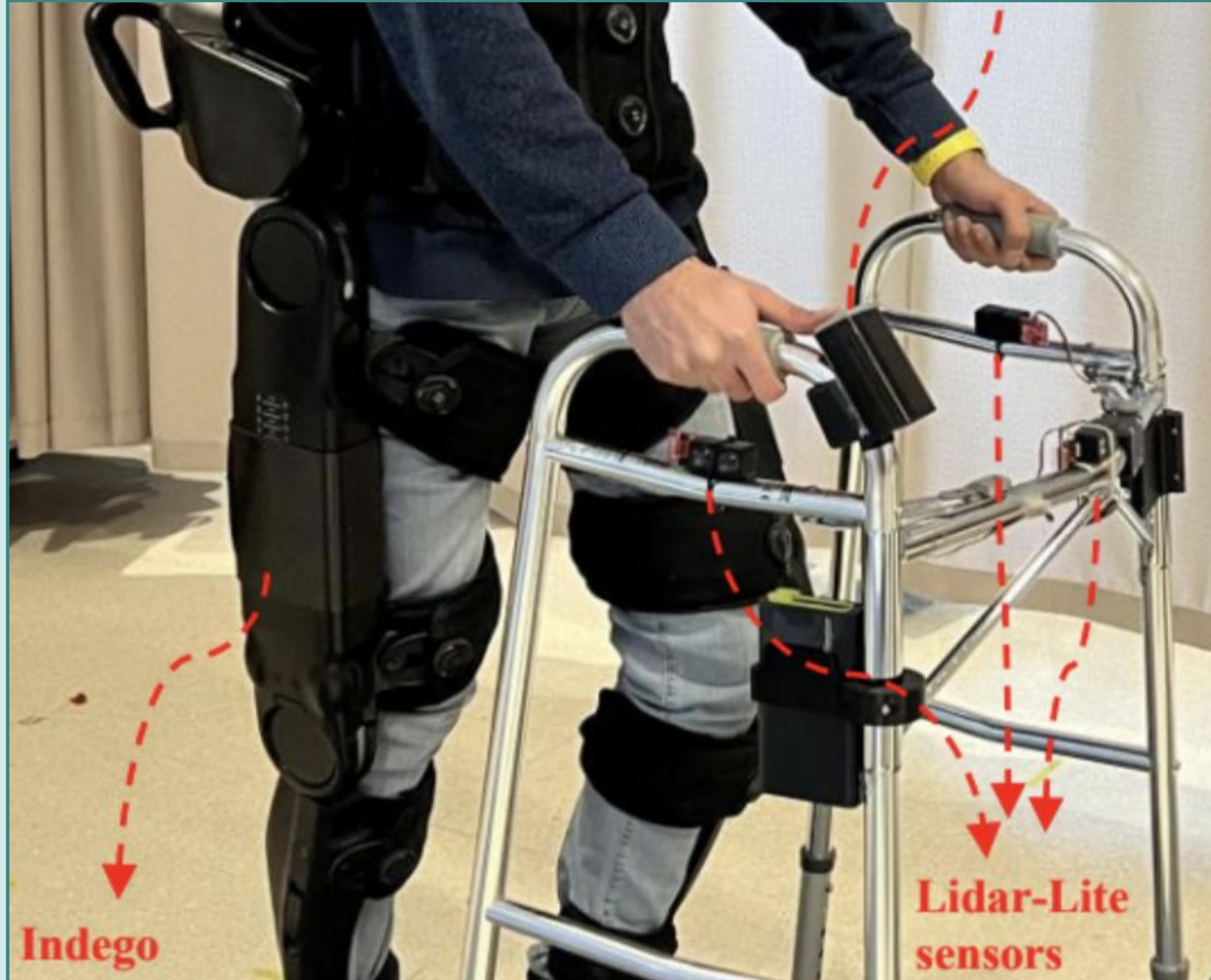
Continual learning in **exoskeleton control**.
Faridi et al., *ICORR* 2022.

Continual learning in **motor prediction**.
Parker *et al.*, *IEEE SMC* 2022 (submitted);
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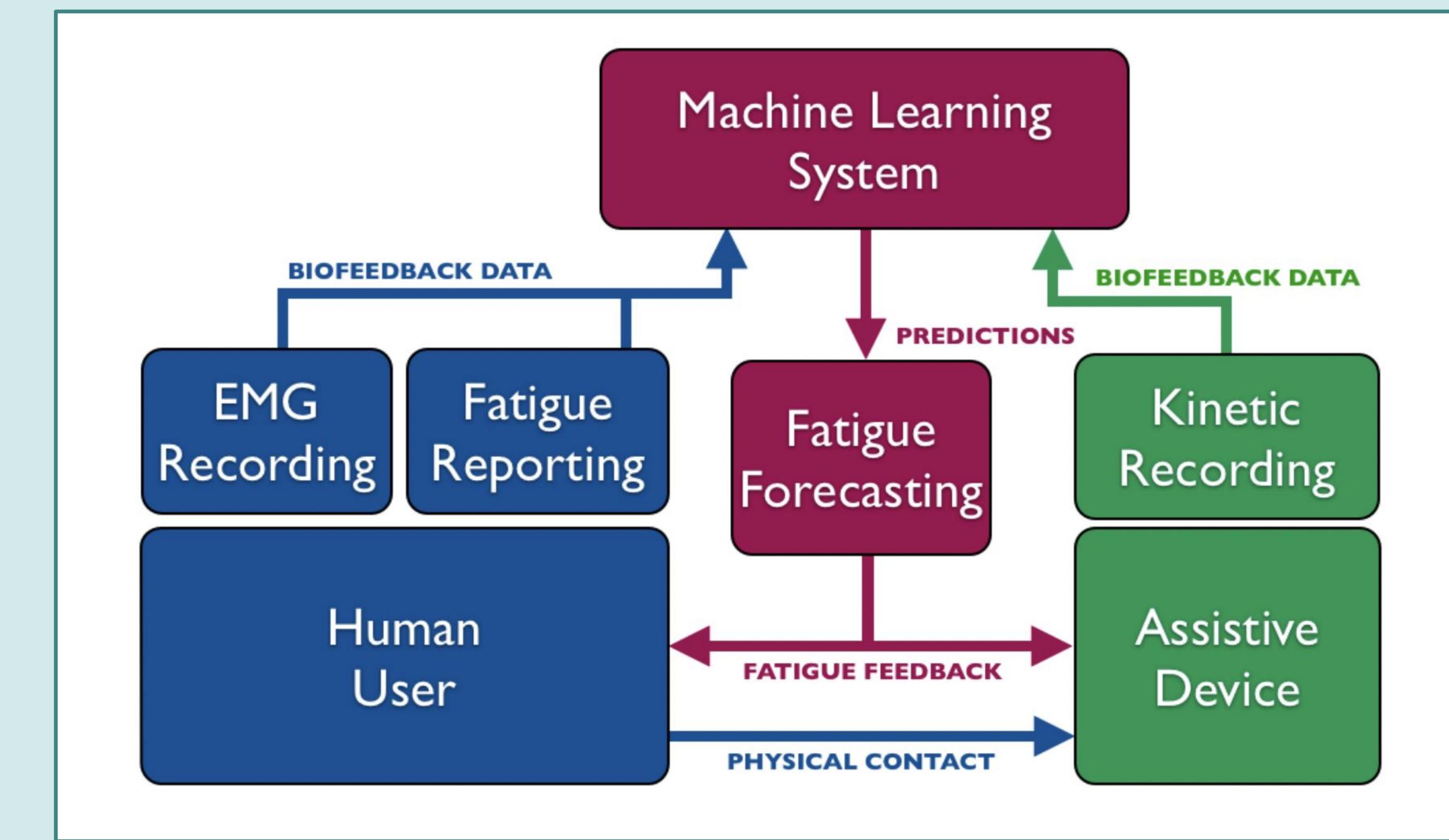
Continual learning in **exoskeleton control**.
Faridi et al., *ICORR* 2022.

Examples: 2011-2021

Identifying patterns with TIDBD   Gunther 2020

GVF collections predicting surprise   Gunther 2018, Pilarski 2016

LfD from a contralateral limb   Vasan 2017, Vasan 2018

Learned feedback   Parker 2014, 2019

Learned joint synergies   Pilarski 2013, Sherstan 2015

RL policies from human reward   Pilarski 2011

Pavlovian control in SCI   Dalrymple 2020

Examples: 2011–2021

Constructed based on sensorimotor interactions with an individual and what they do, not an objective "task"

Identifying patterns with TIDBD

GVF collections predicting surprise

LfD from a contralateral limb

Learned feedback

Learned joint synergies

RL policies from human reward

Pavlovian control in SCI

Gunther 2020

Gunther 2018, Pilarski 2016

Vasan 2017, Vasan 2018

Parker 2014, 2019

Pilarski 2013, Sherstan 2015

Pilarski 2011

Dalrymple 2020

Situated & Assessable

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

Video courtesy:
Amii / Chris Onciul

Continual learning is important.
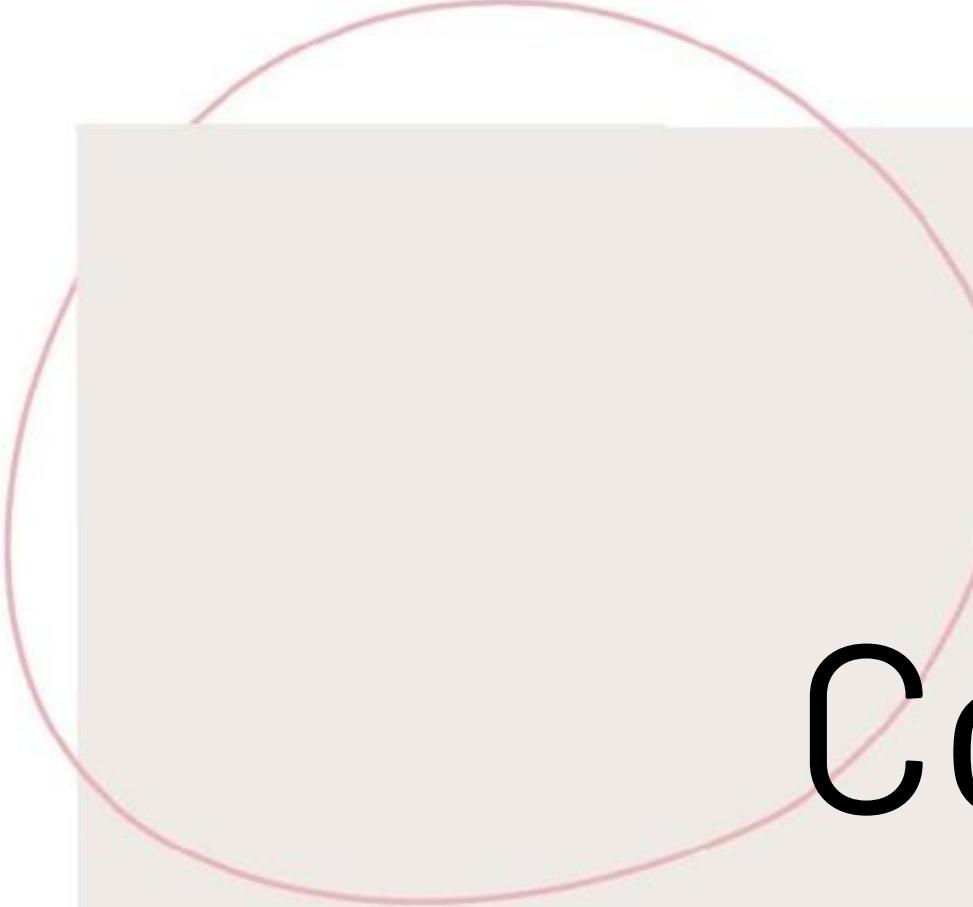
Constructing **representations**, **predictions**, **policies**, and **models** from ongoing experience lets tightly coupled interfaces **align & specialize** to individual human (or machine) agents and needs.
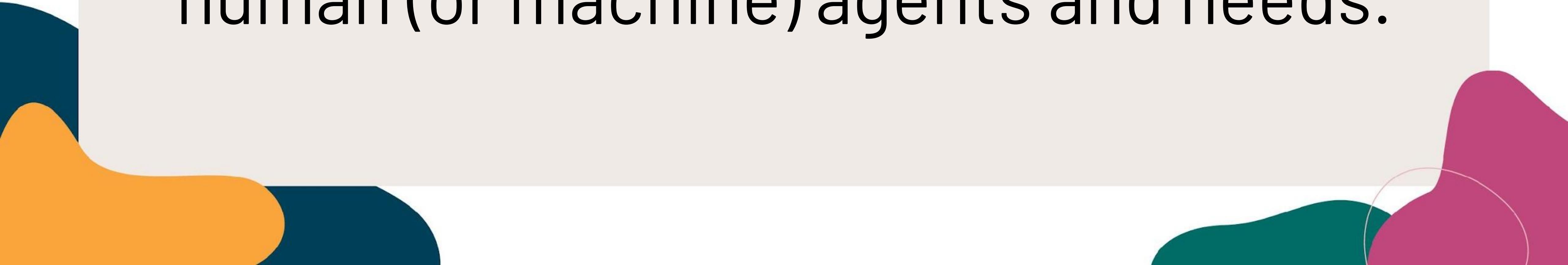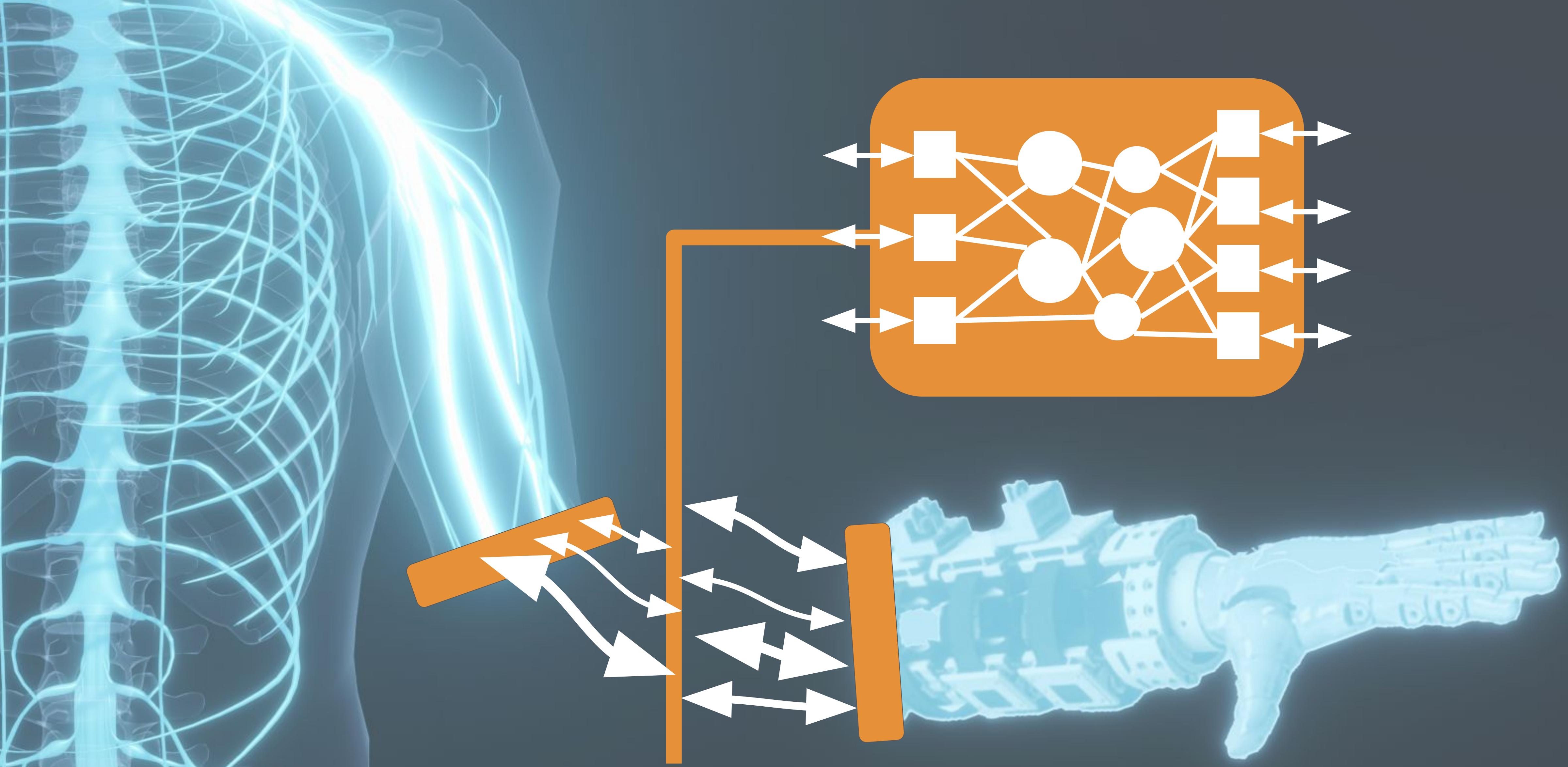
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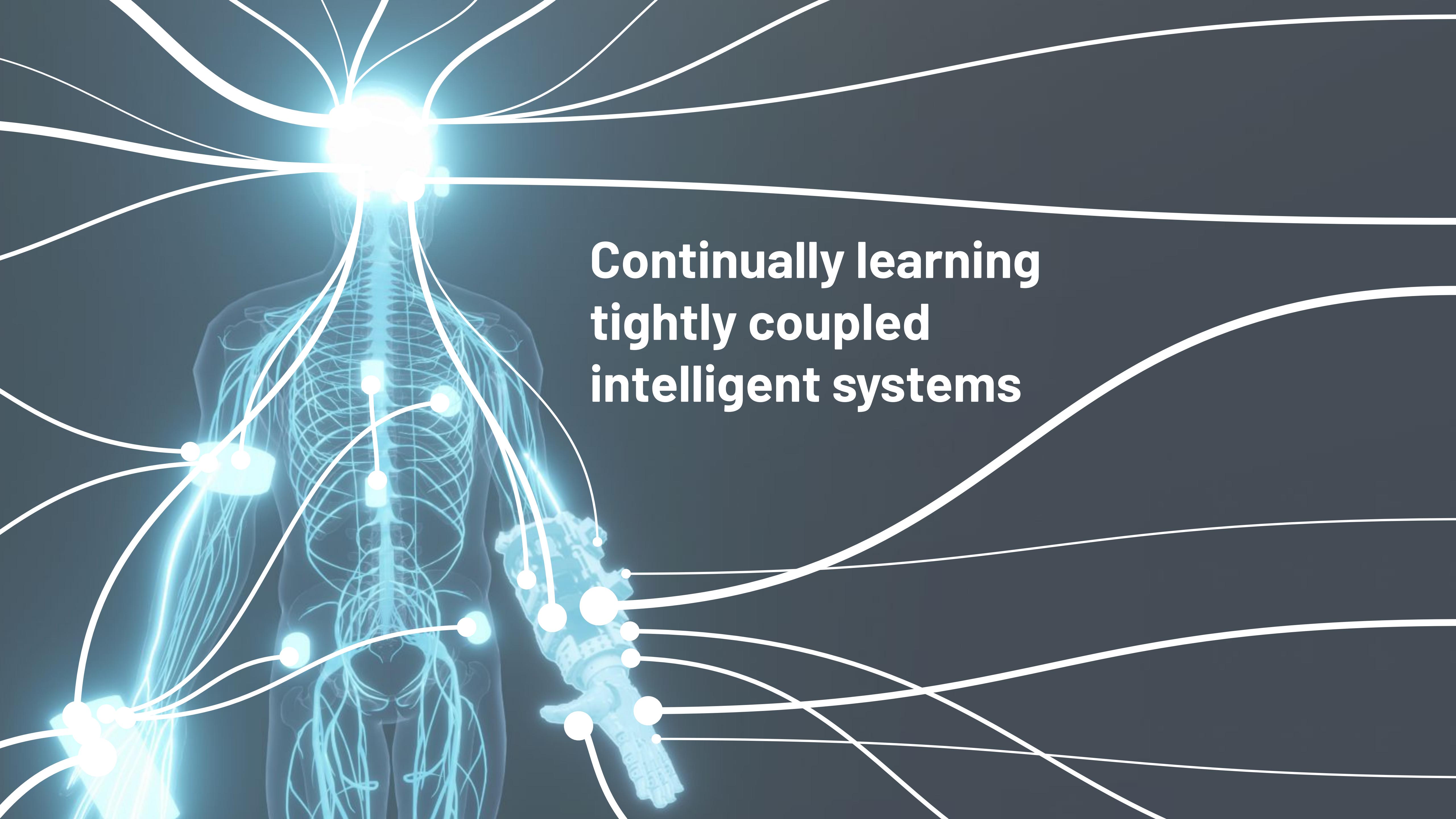
Continually learning
tightly coupled
intelligent systems

Post-surgery Osseointegration
Rehabilitation conducted at the
Glenrose Rehabilitation Hospital

Thank you and questions!

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Craig Chapman
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Liping Qi
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Roshan Shariff
Nathan Wispinski
Ben Hallworth

… and all the other members of our teams and labs advising or contributing to aspects the presented work.

amii

BLINC
BIONIC LIMBS FOR IMPROVED NATURAL CONTROL

DeepMind

UNIVERSITY OF ALBERTA
EDMONTON · ALBERTA · CANADA

SMART NETWORK
Sensory
Motor
Adaptive
Rehabilitation
Technology