The Emerging Role of Machine-Learned Feedback in Neuroprostheses

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Fellow and Board of Directors, Alberta Machine Intelligence Institute (Amii)
Research Scientist and Edmonton Office Co-Lead, DeepMind

SMART NETWORK
Sensory
Motor
Adaptive
Rehabilitation
Technology

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BLINC
BIONIC LIMBS FOR IMPROVED NATURAL CONTROL

DeepMind

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C.O.I. Disclosure

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

Other Industry Affiliations:

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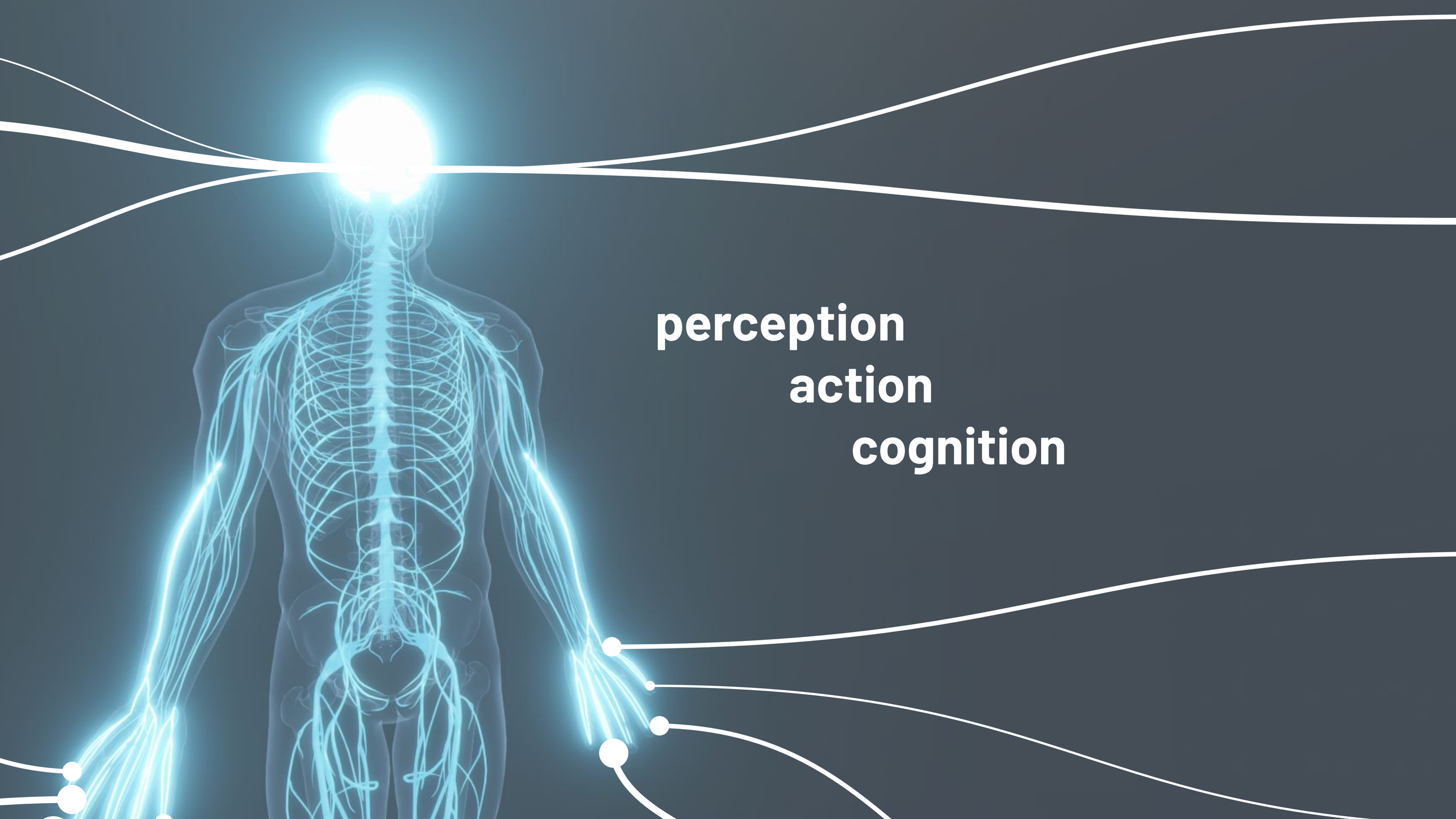
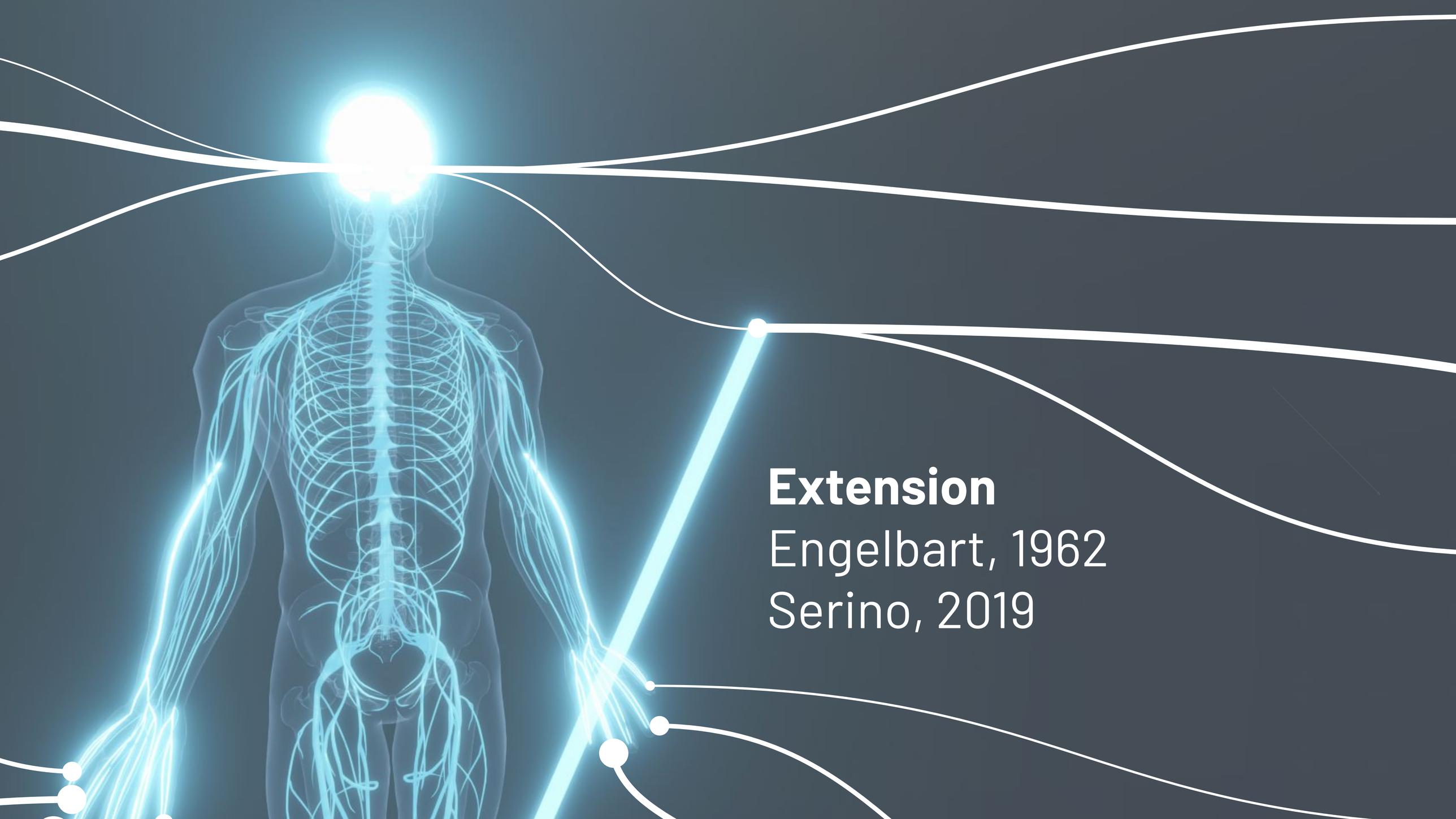
Board of Directors, *Alberta Machine Intelligence Institute*

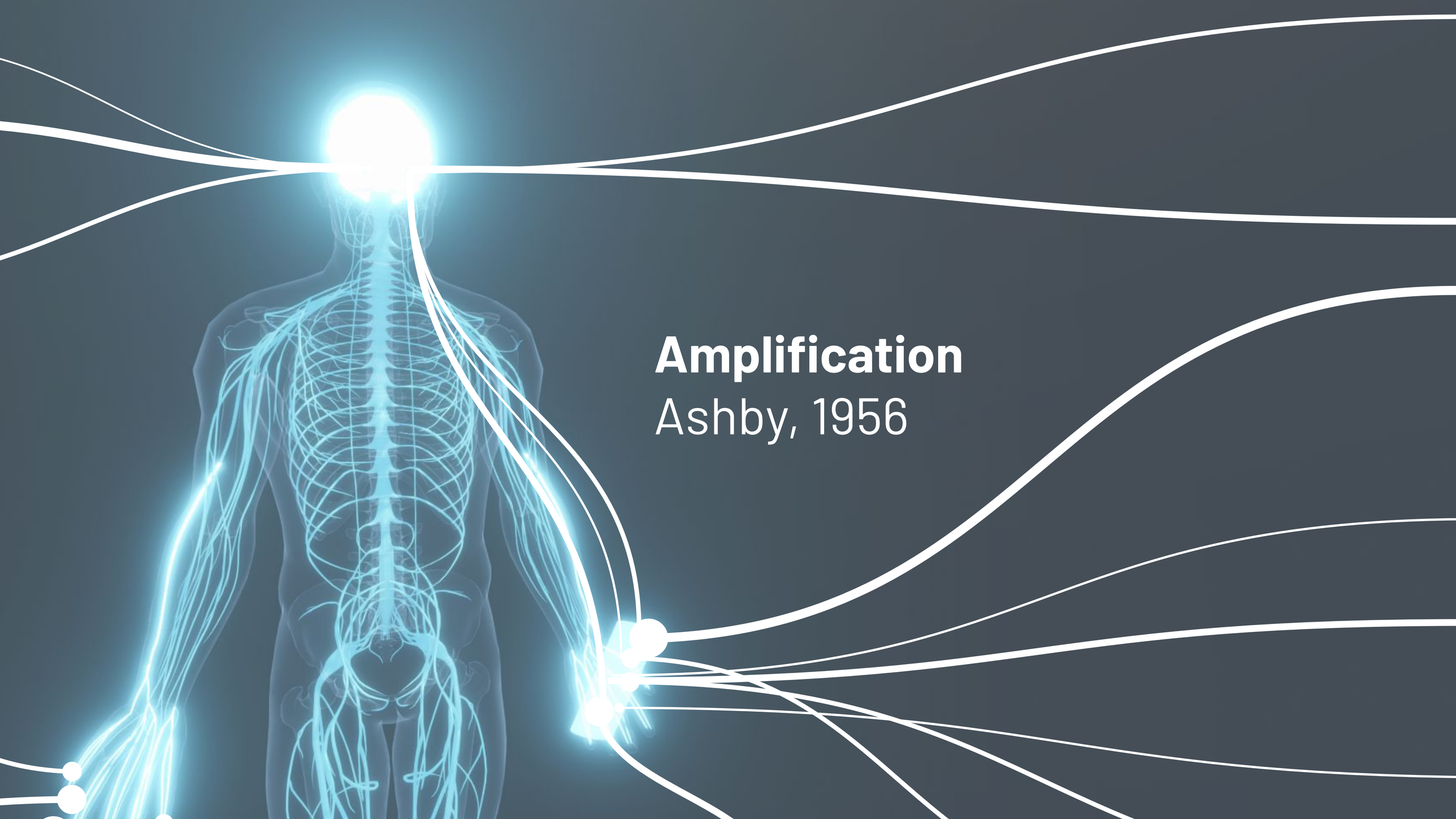
950BC - 700BC, The "Cairo Toe" (The University of Manchester), https://www.theatlantic.com/technology/archive/2013/11/the-perfect-3-000-year-old-toe-a-brief-history-of-prosthetic-limbs/281653/
Nerlich, *et al.*, *Lancet*, 356: 2176–79, 2000.

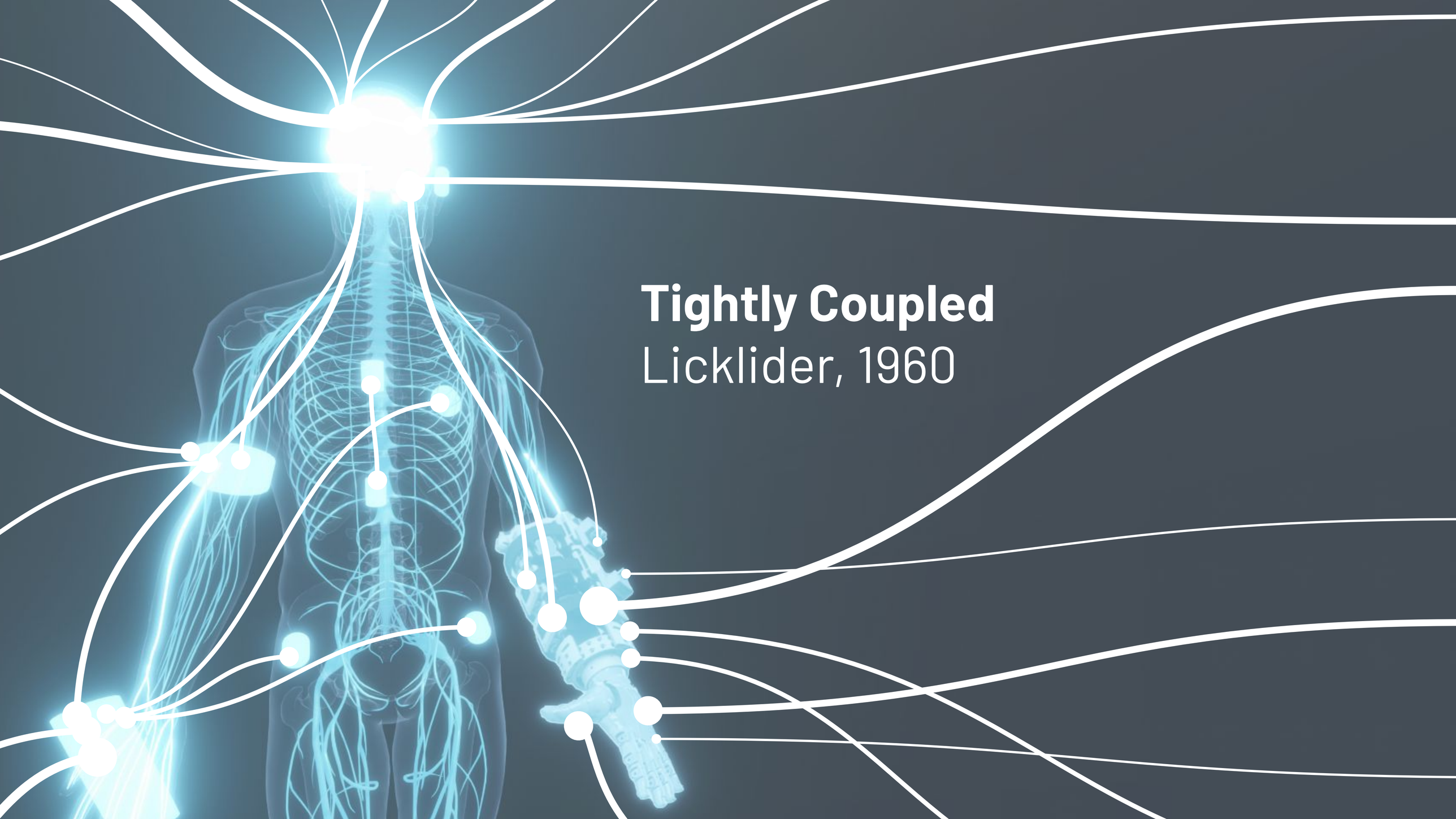
Video courtesy:
Amii / Chris Onciul

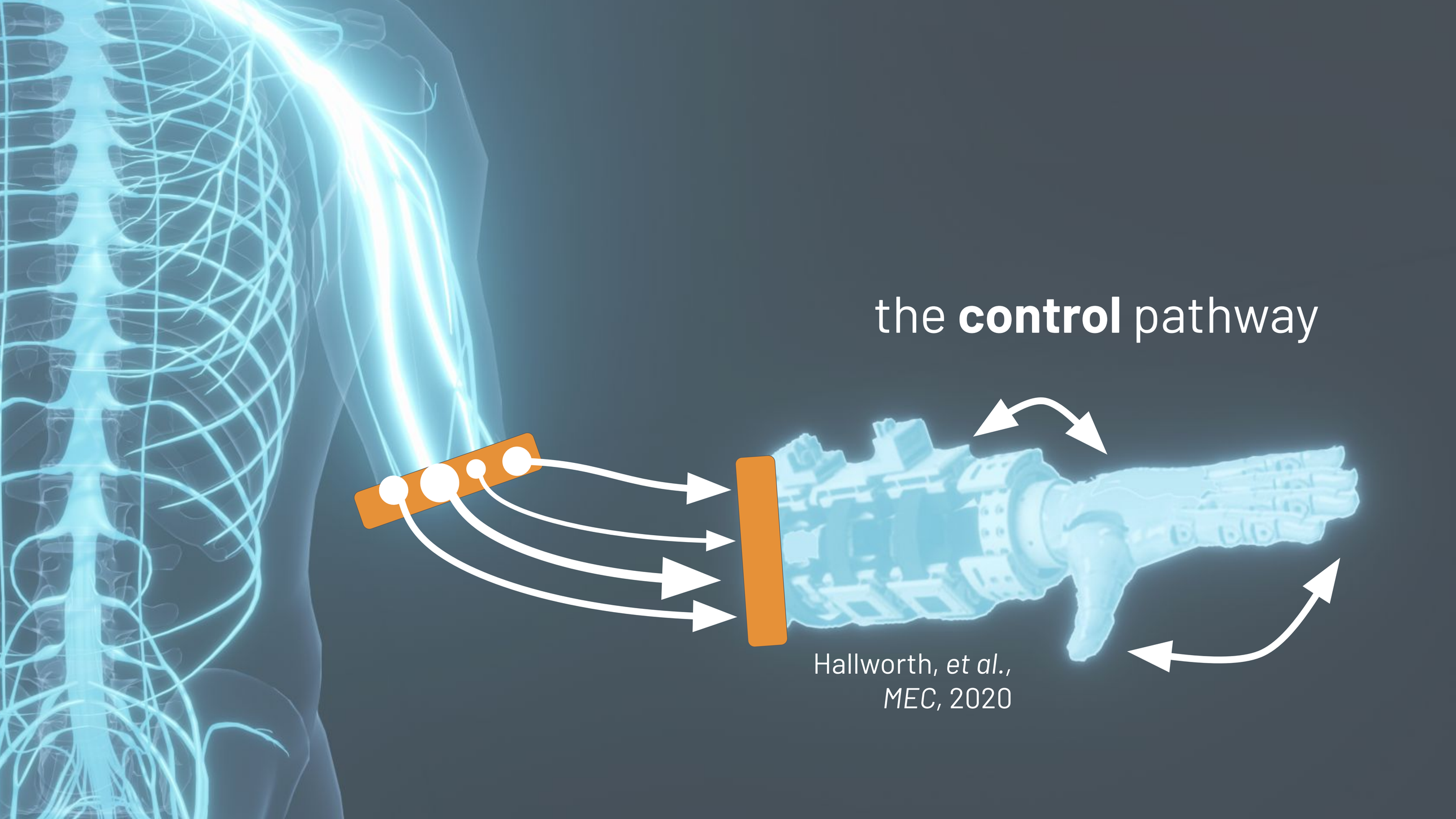

perception
action
cognition

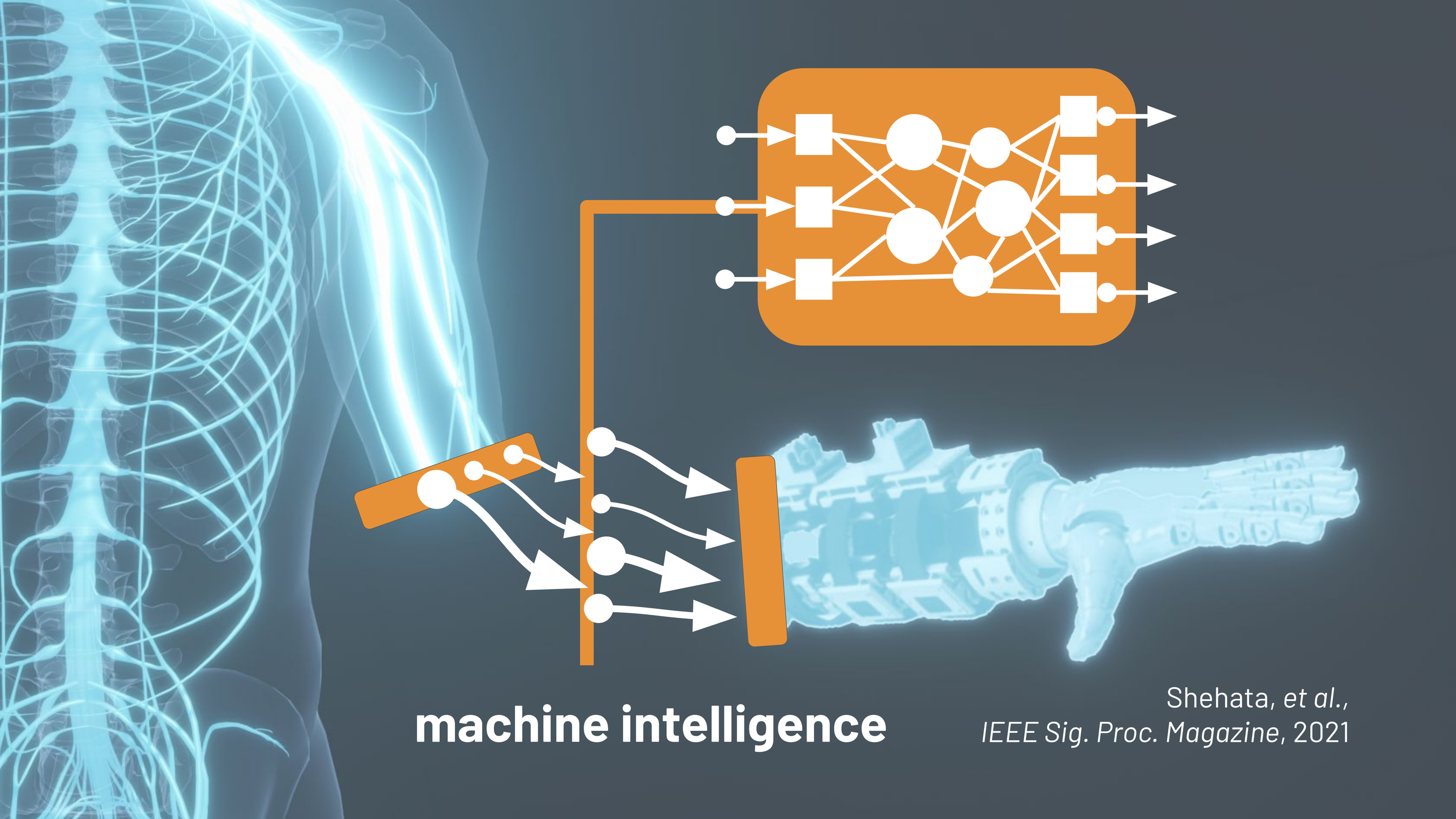


Extension
Engelbart, 1962
Serino, 2019


Amplification
Ashby, 1956

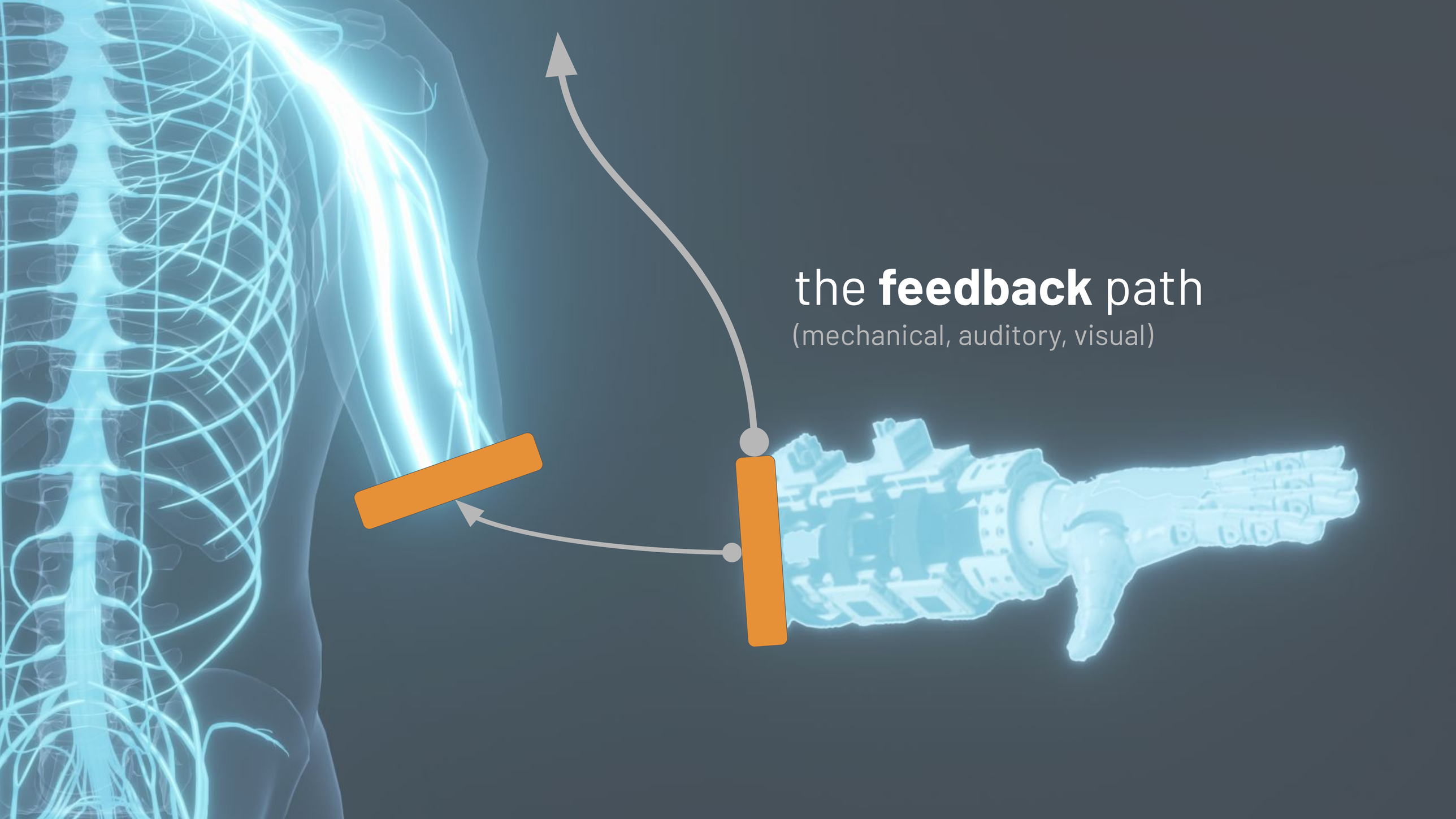

Tightly Coupled
Licklider, 1960

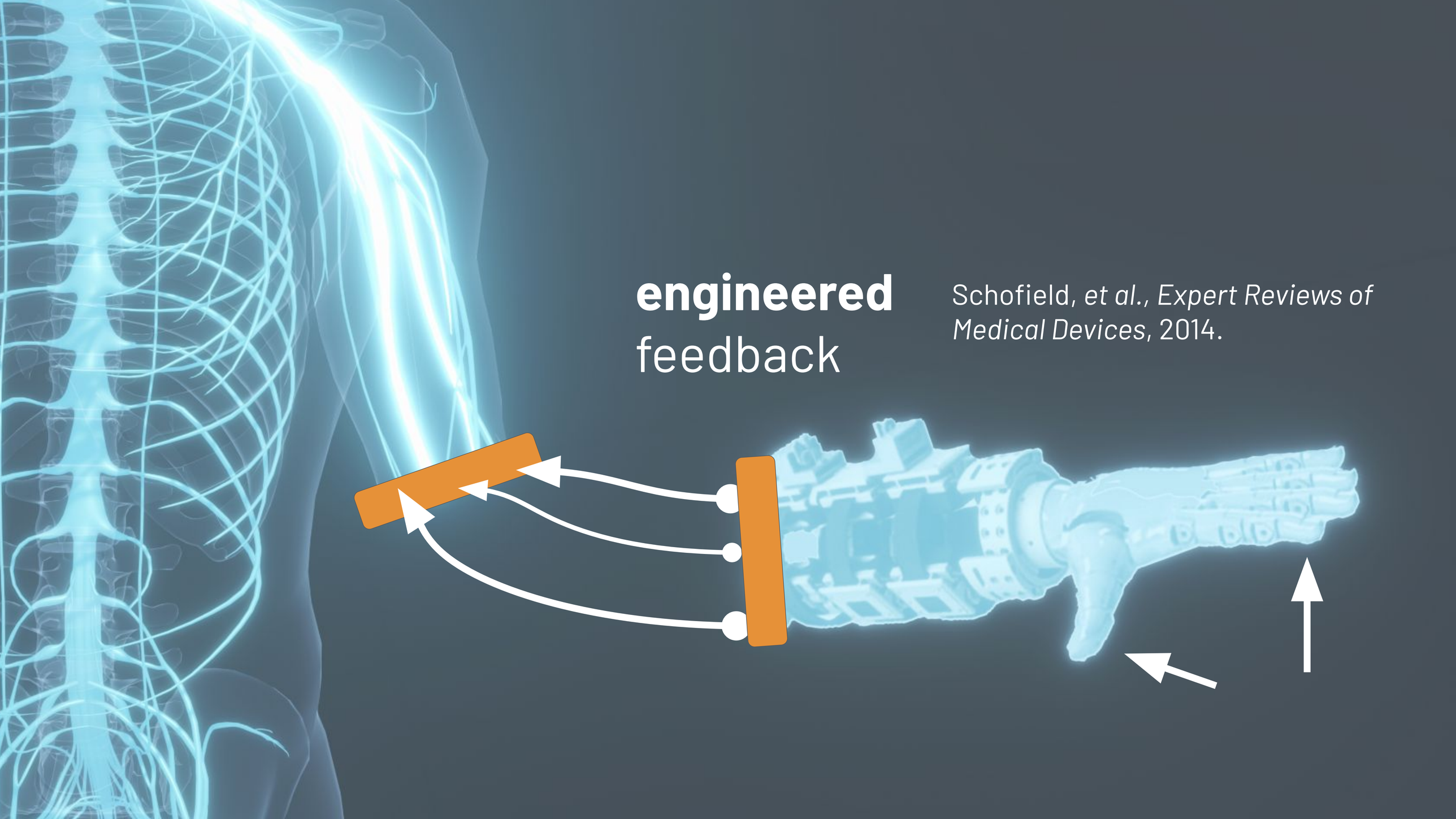

the **control** pathway
Hallworth, *et al.*,
MEC, 2020



machine intelligence

Shehata, *et al.*,
IEEE Sig. Proc. Magazine, 2021

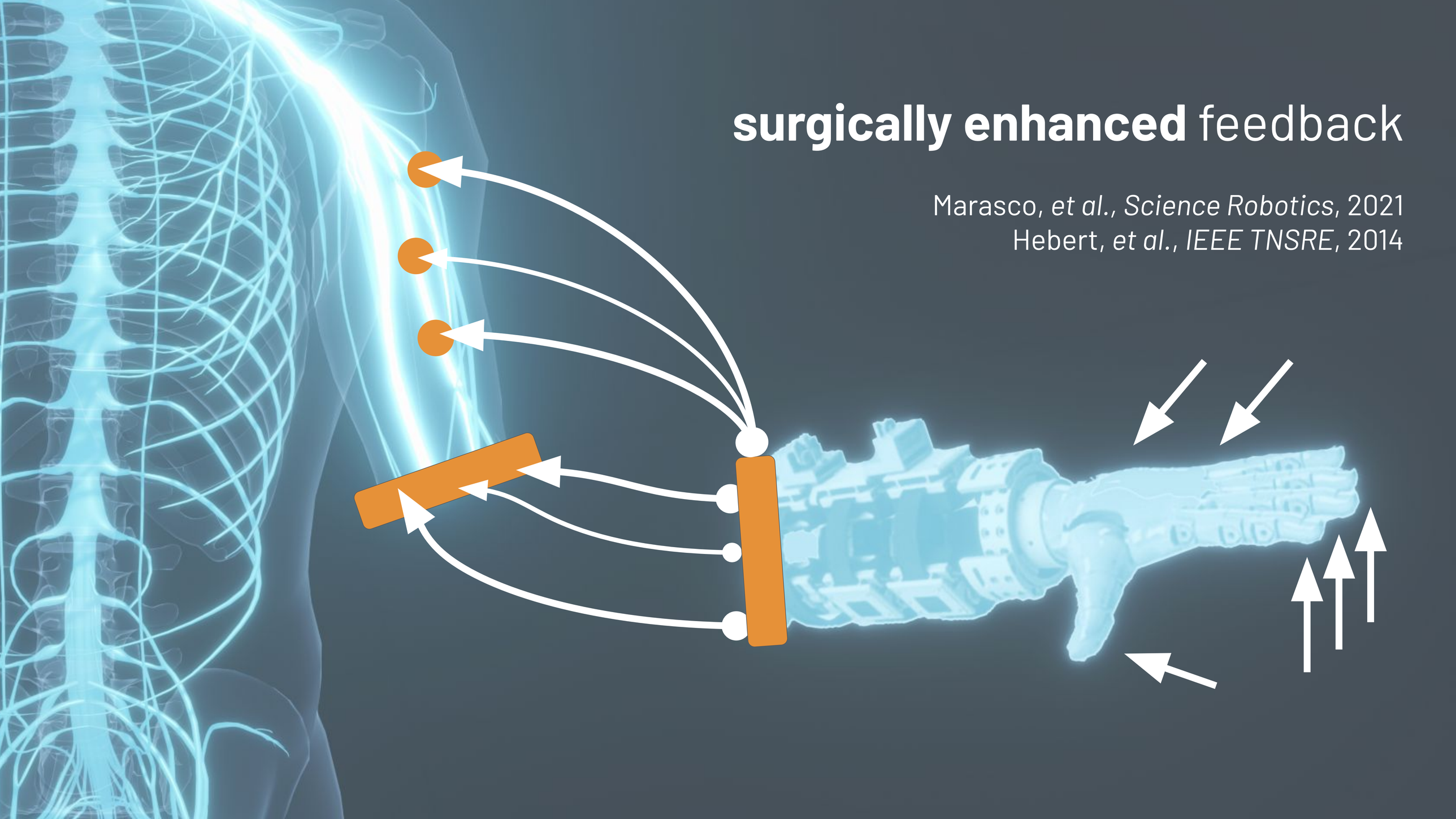

the **feedback** path
(mechanical, auditory, visual)

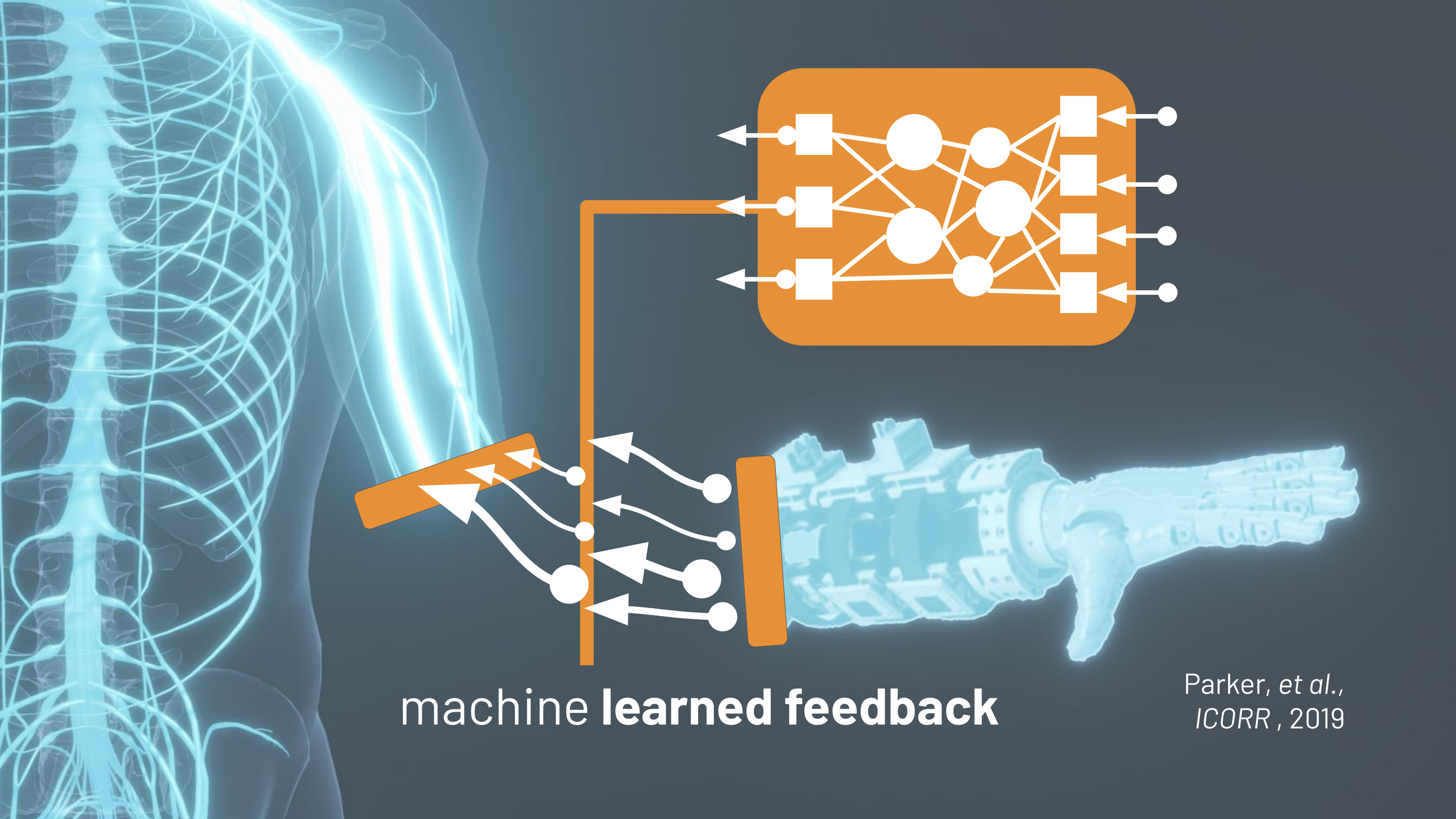


Schofield, *et al.*, *Expert Reviews of Medical Devices*, 2014.

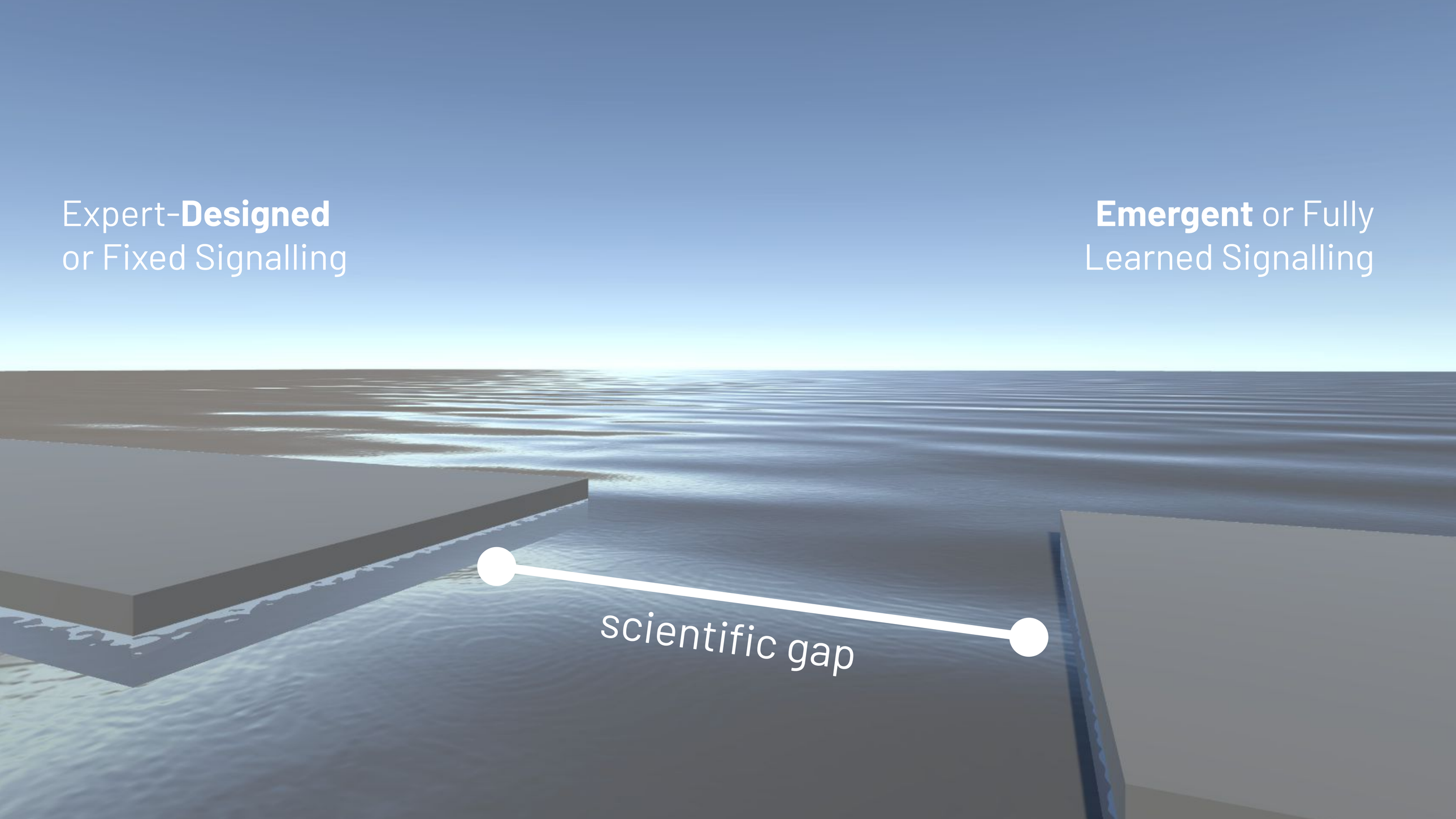
surgically enhanced feedback

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





Parker, *et al.*,
ICORR , 2019


Expert-**Designed**
or Fixed Signalling
Emergent or Fully
Learned Signalling
scientific gap

Crandall, *et al.*,
Nature Communications,
9:233, 2018.

Lazaridou and Baroni,
arXiv 2006.02419, 2020.

Jaques, *et al.*, *ICML*, 2019.

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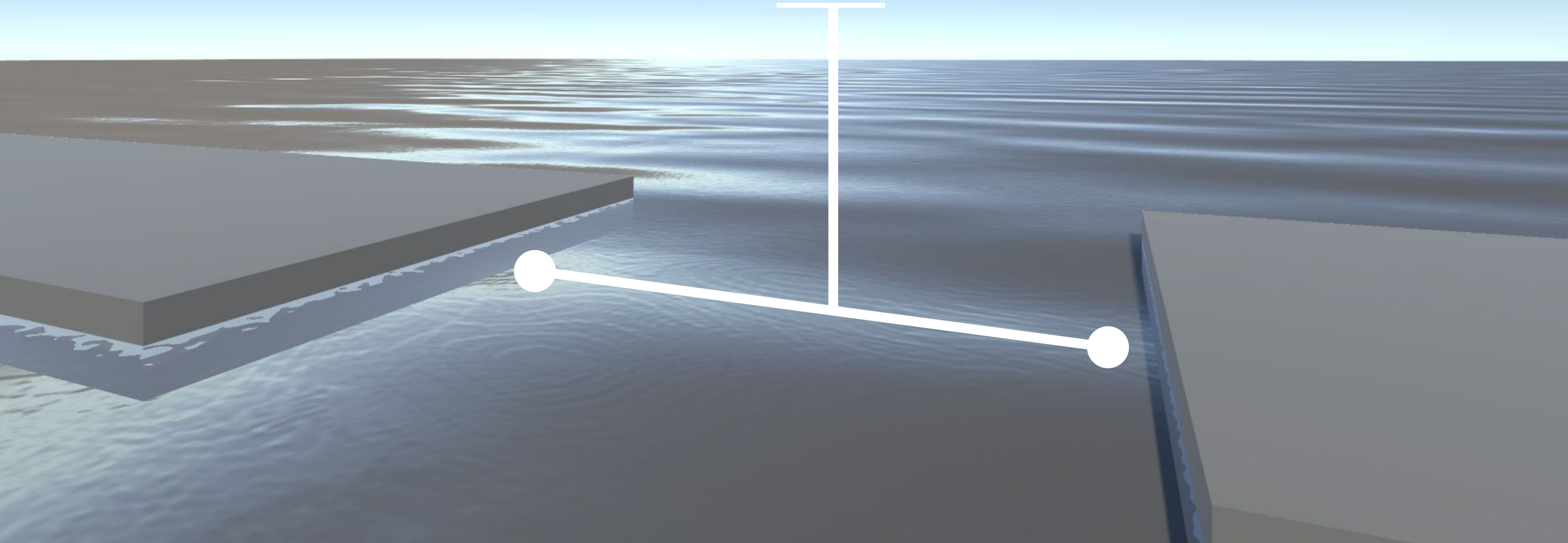

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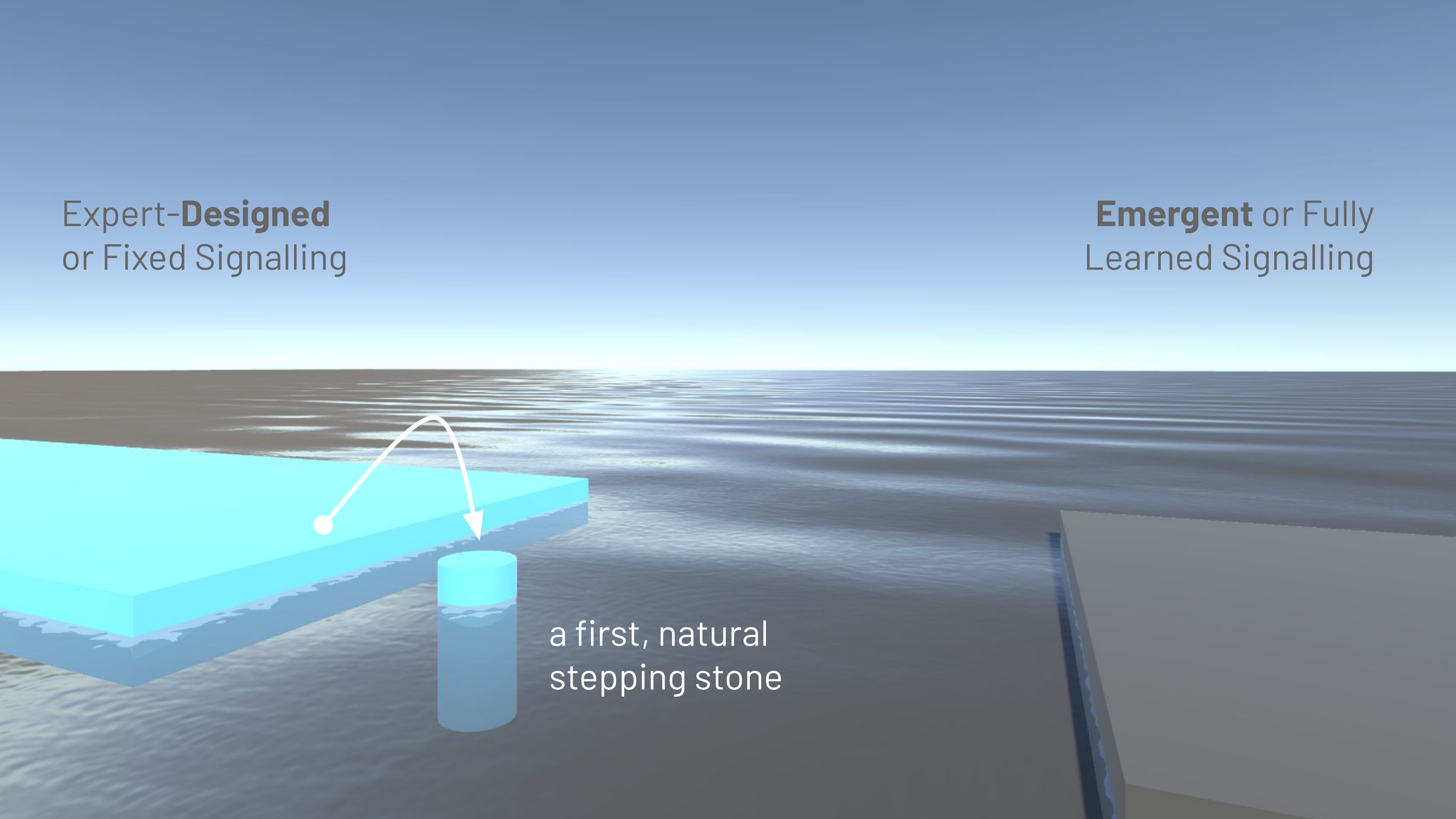


a first, natural
stepping stone

Pavlovian signalling

Butcher *et al.*, 2022; Brenneis *et al.*, 2022; Pilarski *et al.*, 2022.

Pavlovian signalling is a process wherein learned, temporally extended predictions

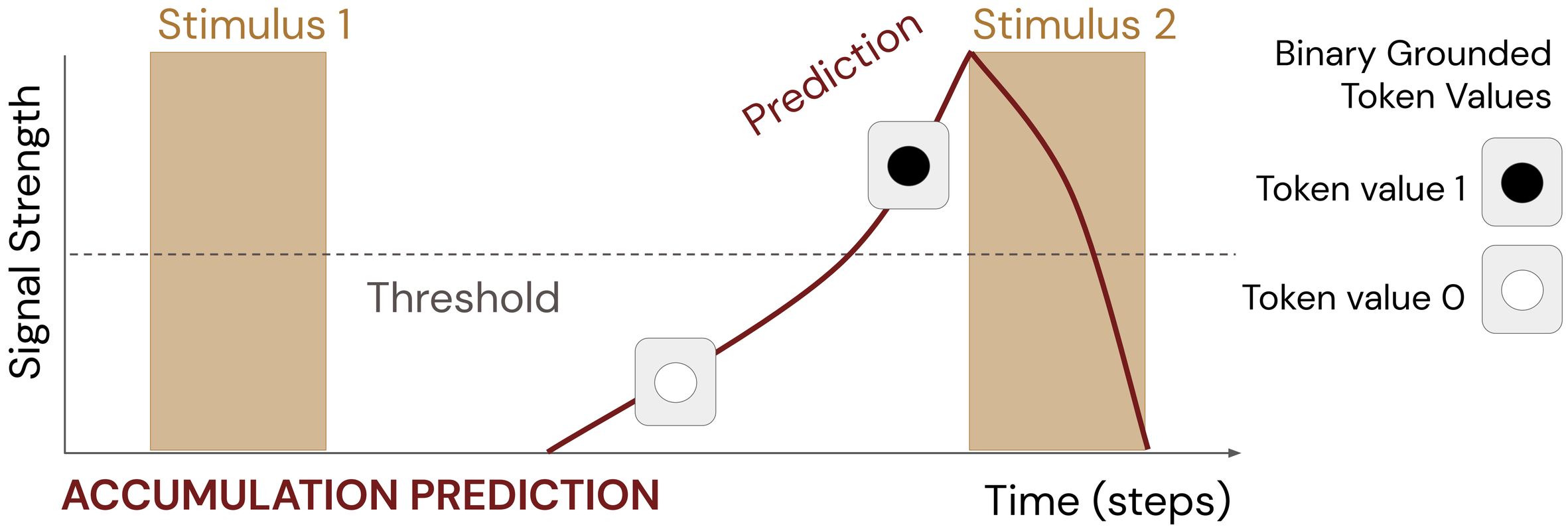
Butcher *et al.*, 2022; Brenneis *et al.*, 2022; Pilarski *et al.*, 2022.

Pavlovian signalling is a process wherein learned, temporally extended predictions are mapped in a defined way to signals intended for receipt by a decision-making agent

Butcher *et al.*, 2022; Brenneis *et al.*, 2022; Pilarski *et al.*, 2022.

Pavlovian signalling is a process wherein learned, temporally extended predictions are mapped in a defined way to signals intended for receipt by a decision-making agent, and where these signals are grounded for the sender in the definition of the predictive question and mapping approach that generated them.

Butcher *et al.*, 2022; Brenneis *et al.*, 2022; Pilarski *et al.*, 2022.



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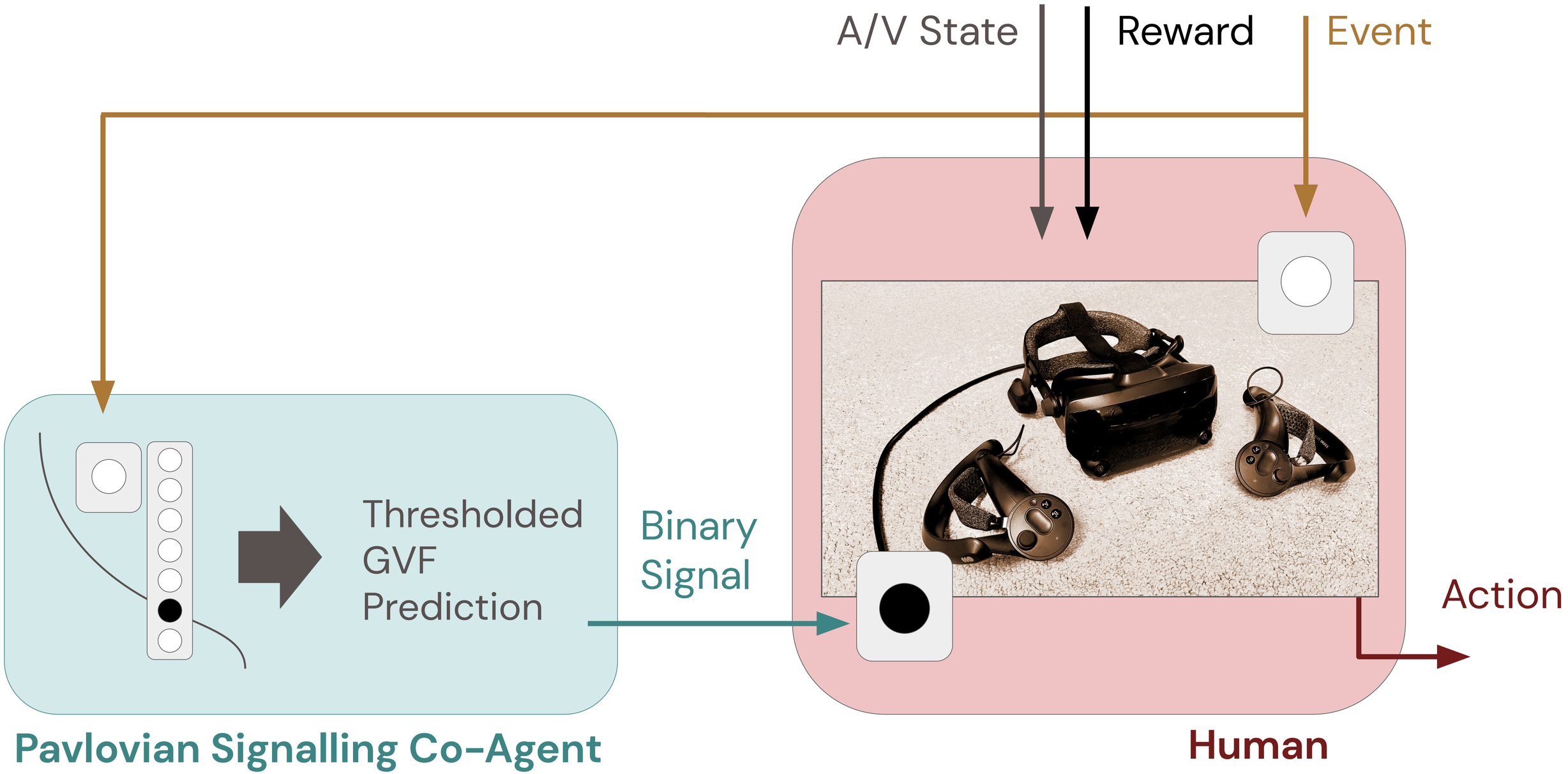
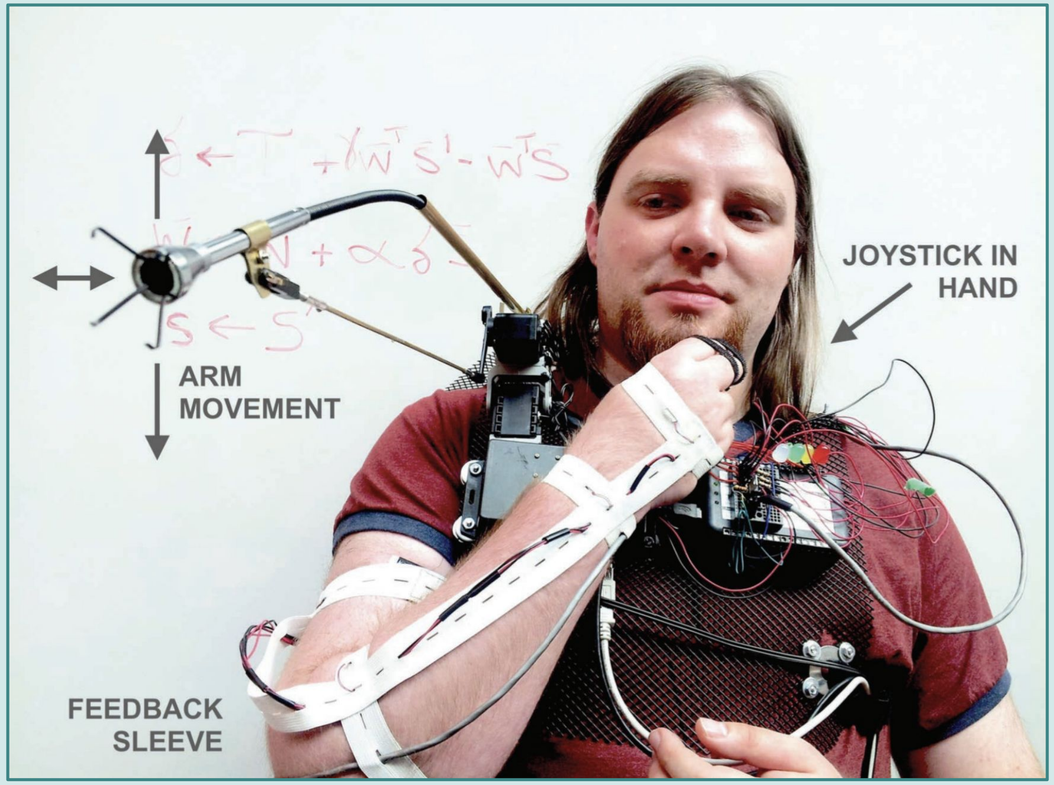


Butcher *et al.*, 2022; Brenneis *et al.*, 2022; Pilarski *et al.*, 2022.

The Frost Hollow Experiments

Brenneis, *et al.*, "**Assessing human interaction in virtual reality with continually learning prediction agents** based on reinforcement learning algorithms: A pilot study," *Adaptive and Learning Agents (ALA) Workshop, AAMAS* 2022.

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



Pavlovian signalling in **mode switching**.
Edwards *et al.*, *BioRob* 2016.

Switching-based **exoskeleton control**.
Faridi et al., *ICORR* 2022.

Emergent communication during navigation.
Kalinowska *et al.*, *CogSci* 2022;
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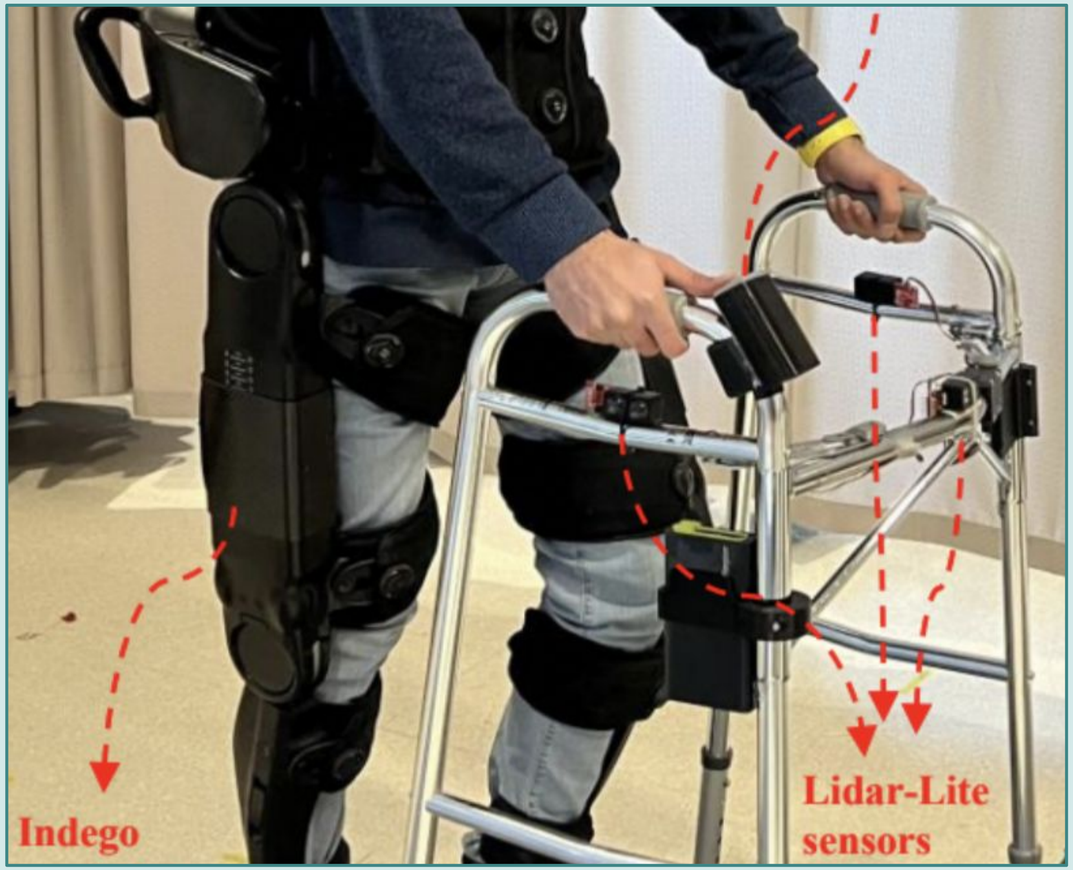

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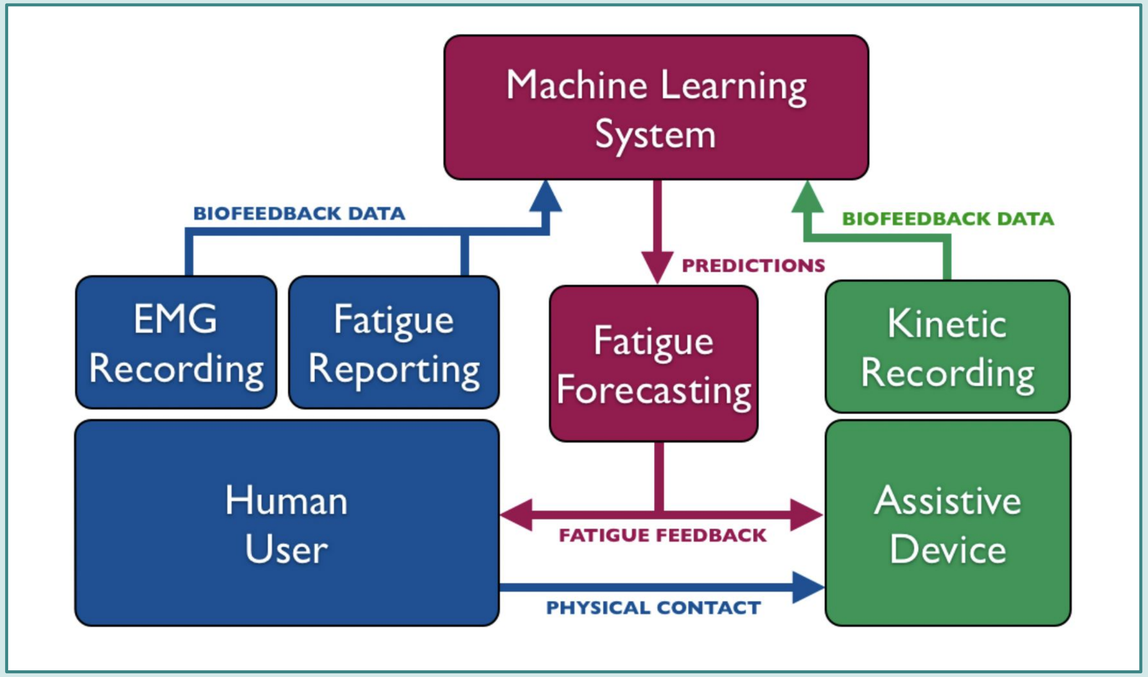

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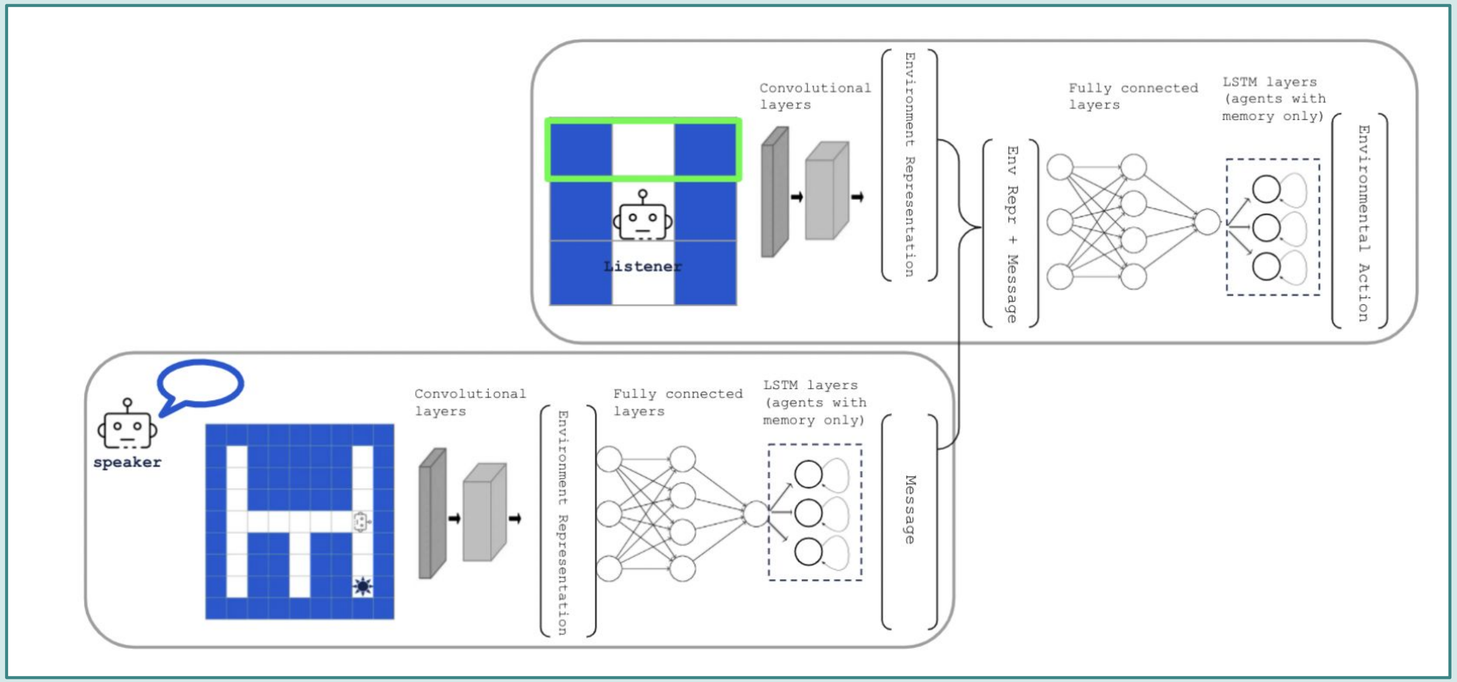

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Context

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

Video courtesy:
Amii / Chris Onciul

Interpretation

Dawson *et al.*, "**Joint Action** is a Framework for Understanding Partnerships Between Humans and Upper Limb Prostheses," in preparation, 2022.

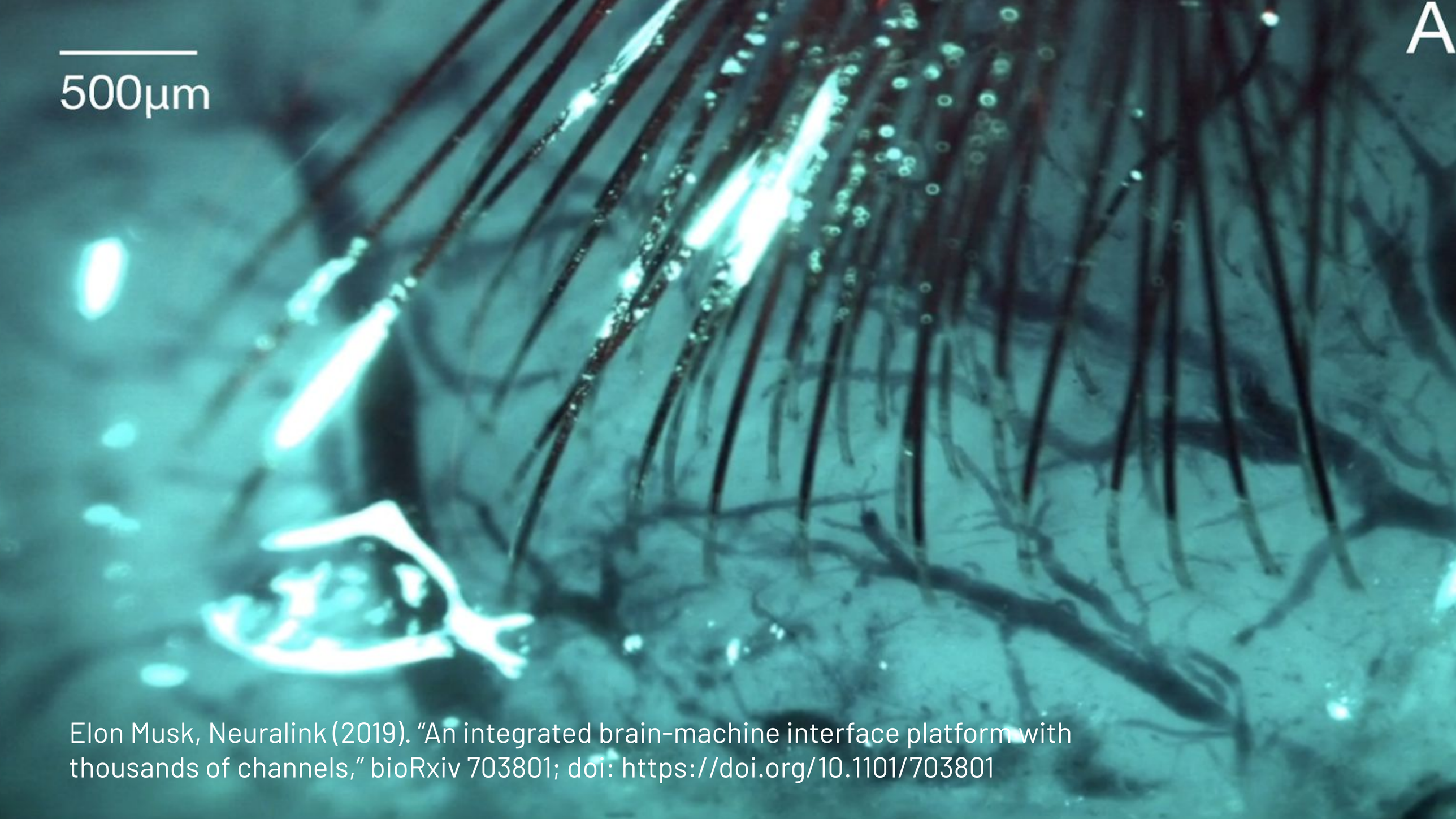
Mathewson *et al.*, "**Communicative Capital**: A Framework for Human-Machine Shared Agency and Collaborative Capacity,"*Neural Computing and Applications*, 2022 (submitted); also "Communicative Capital for Prosthetic Agents," arXiv:1711.03676 [cs.AI].

Courtesy: The Canadian Press / Amber Bracken

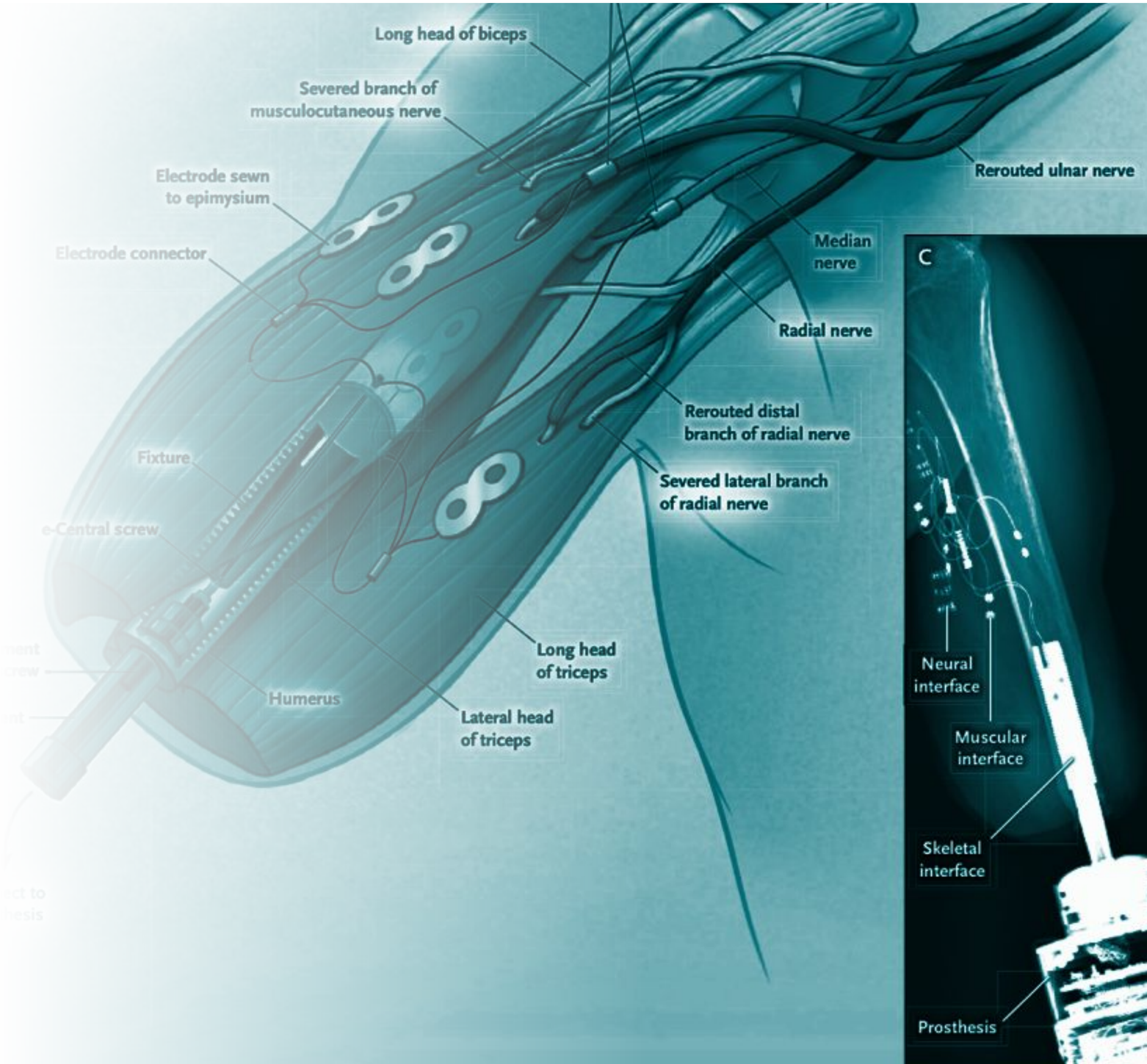
Assessment

H. E. Williams, C. S. Chapman, P. M. Pilarski, A. H. Vette, J. S. Hebert, "**Gaze and Movement Assessment (GaMA)**: Inter-site Validation of a Visuomotor Upper Limb Functional Protocol," *PLoS One*, 14(12), e0219333, 2019.

Video courtesy:
Amii / Chris Onciul



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

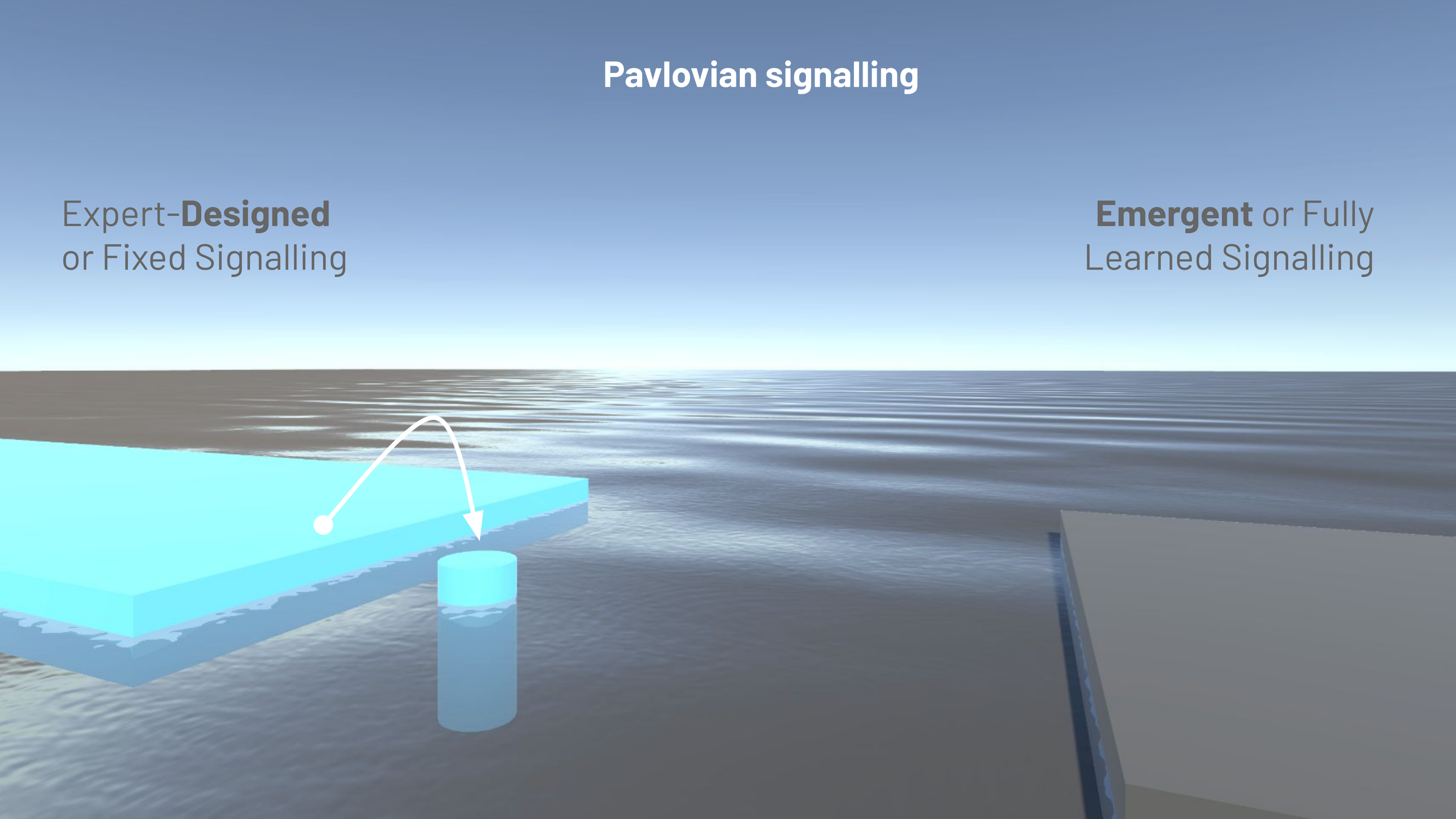


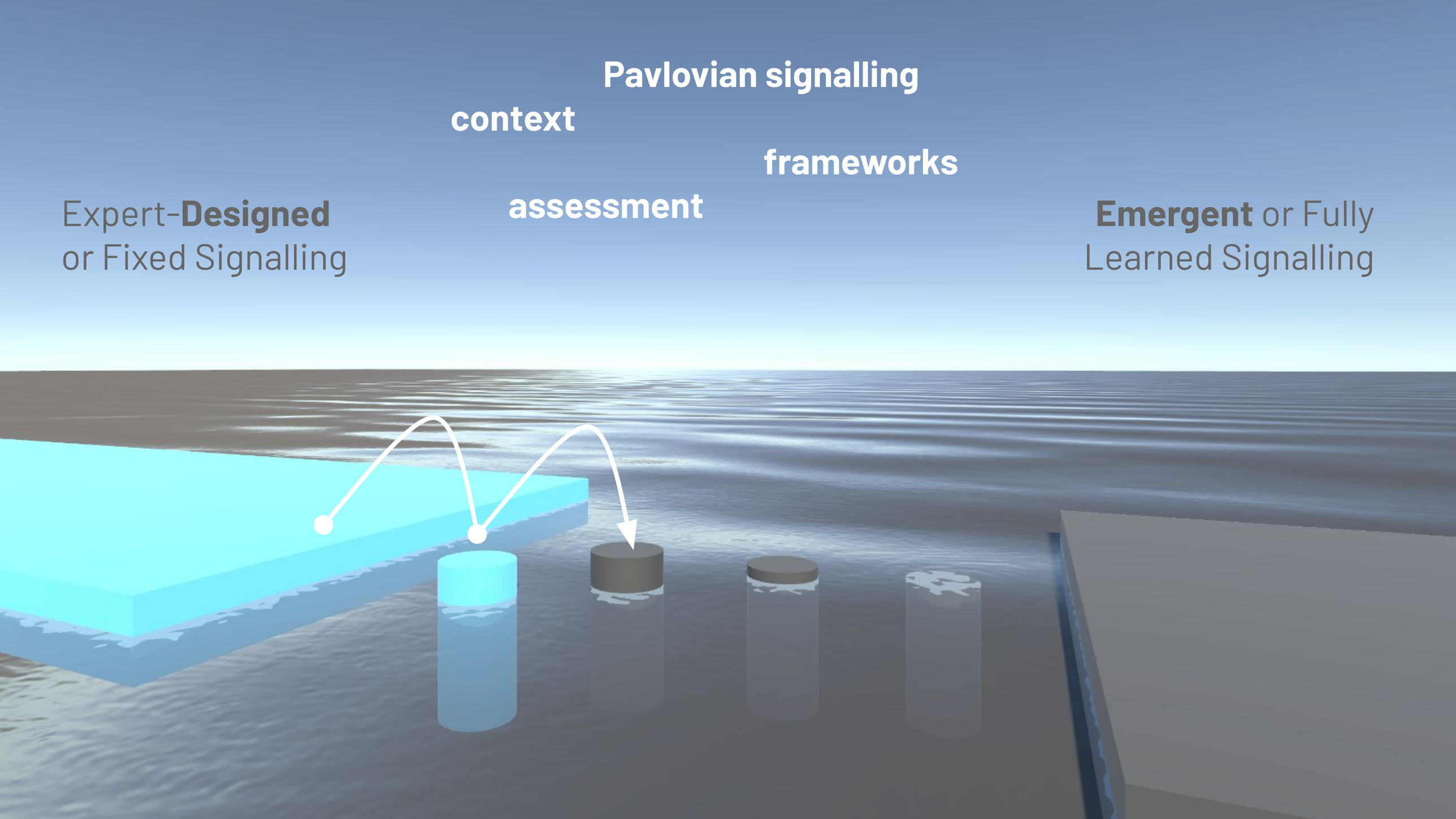
Ortiz-Catalan et al., *N Engl J Med* 2020; 382:1732-8.

Pavlovian signalling

Expert-**Designed**
or Fixed Signalling

Emergent or Fully
Learned Signalling




Pavlovian signalling
context
frameworks
assessment
Expert-**Designed**
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Emergent or Fully
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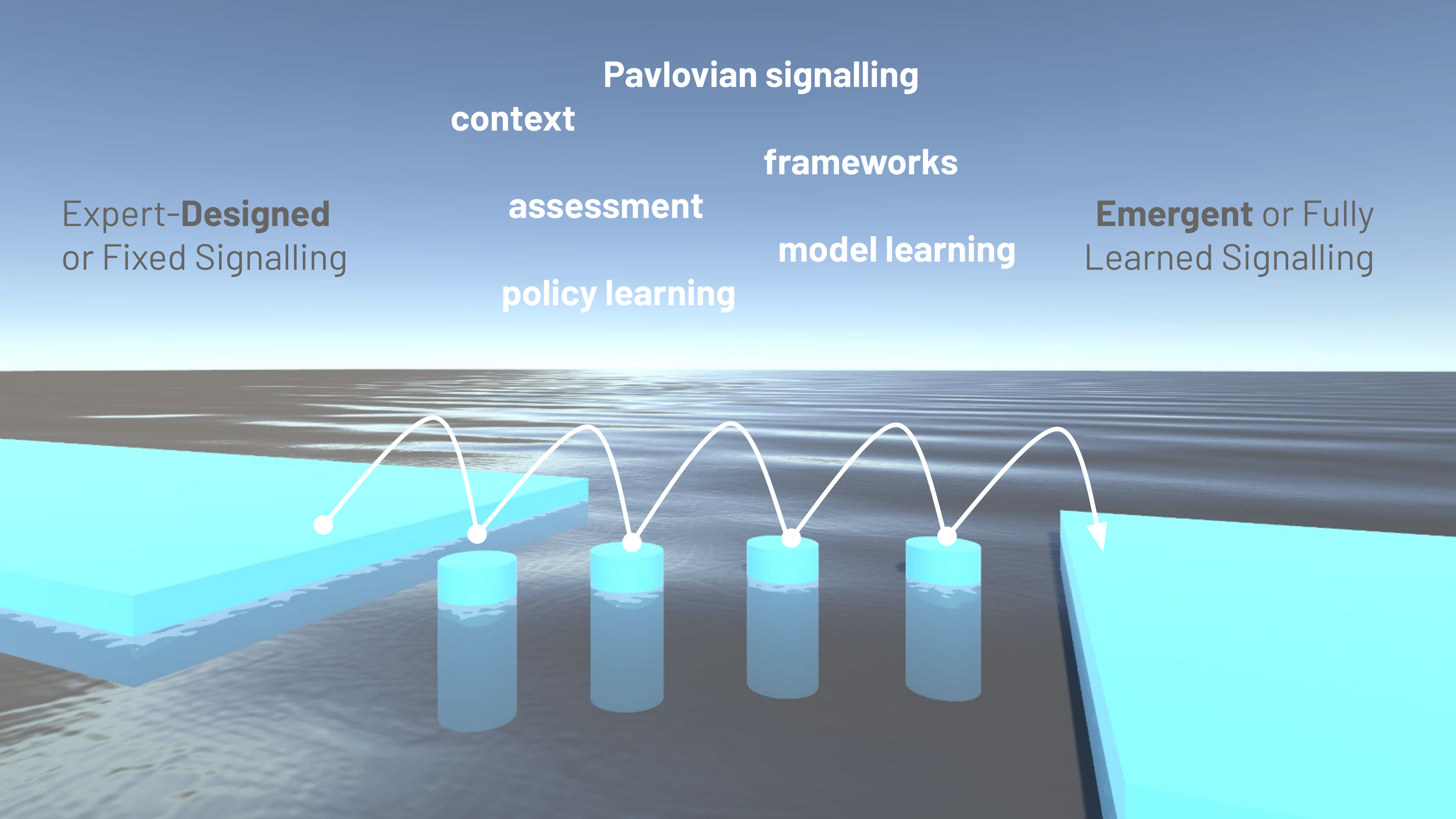
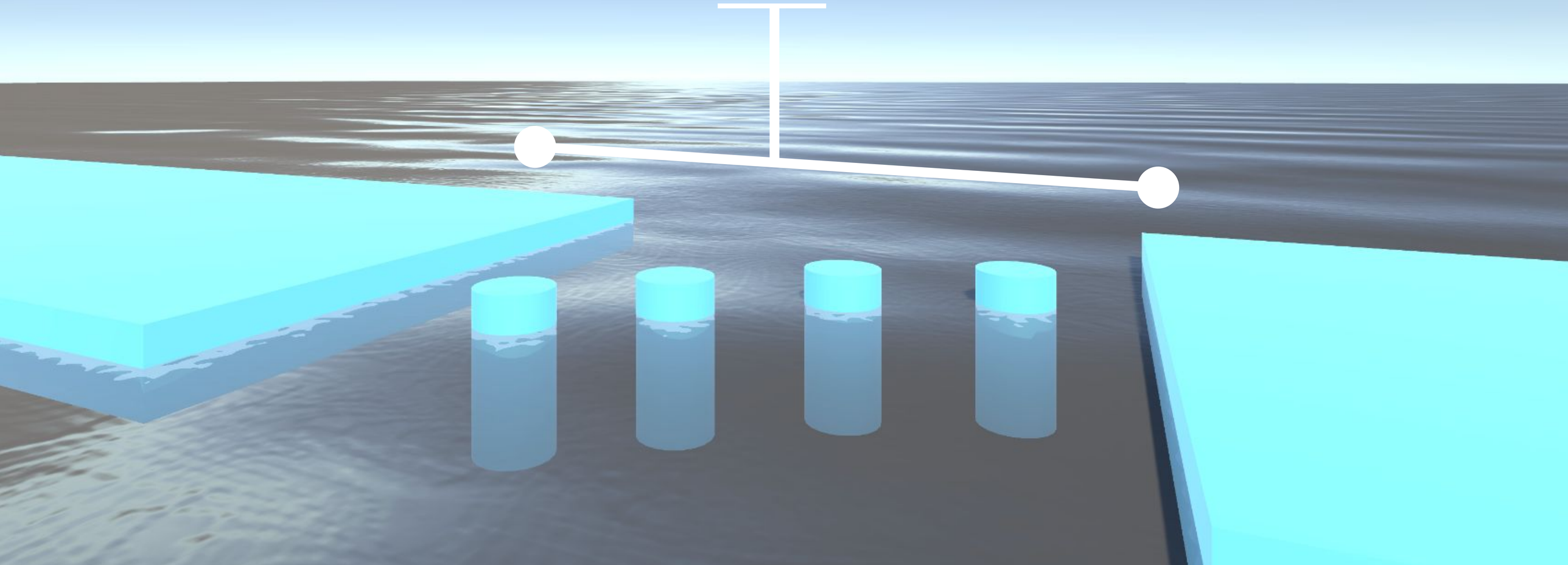

Pavlovian signalling
context
frameworks
assessment
model learning
policy learning
Expert-**Designed**
or Fixed Signalling
Emergent or Fully
Learned Signalling

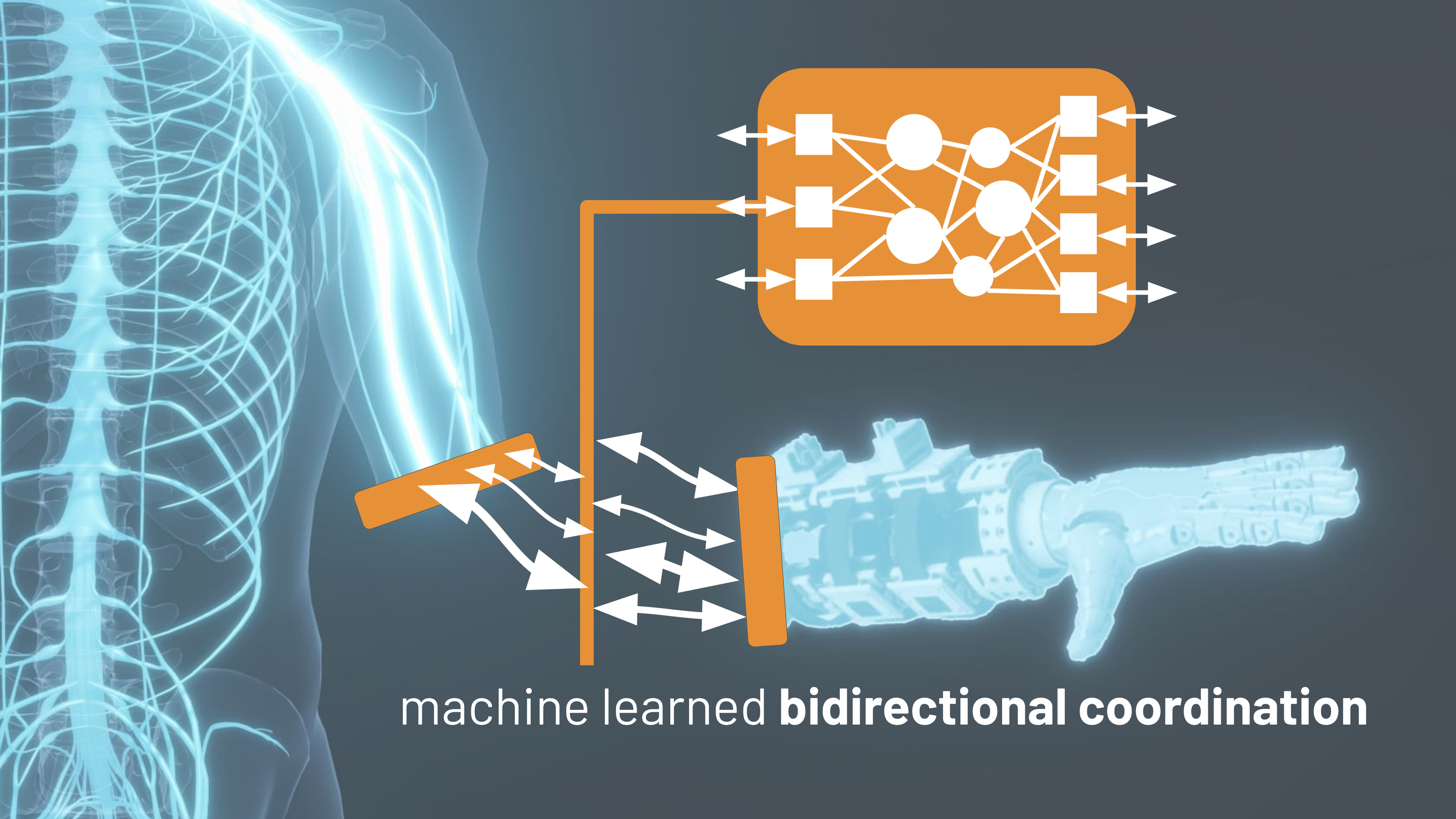
Ostensive-inferential Communication
Scott-Phillips, *Speaking our Minds*, 2014.

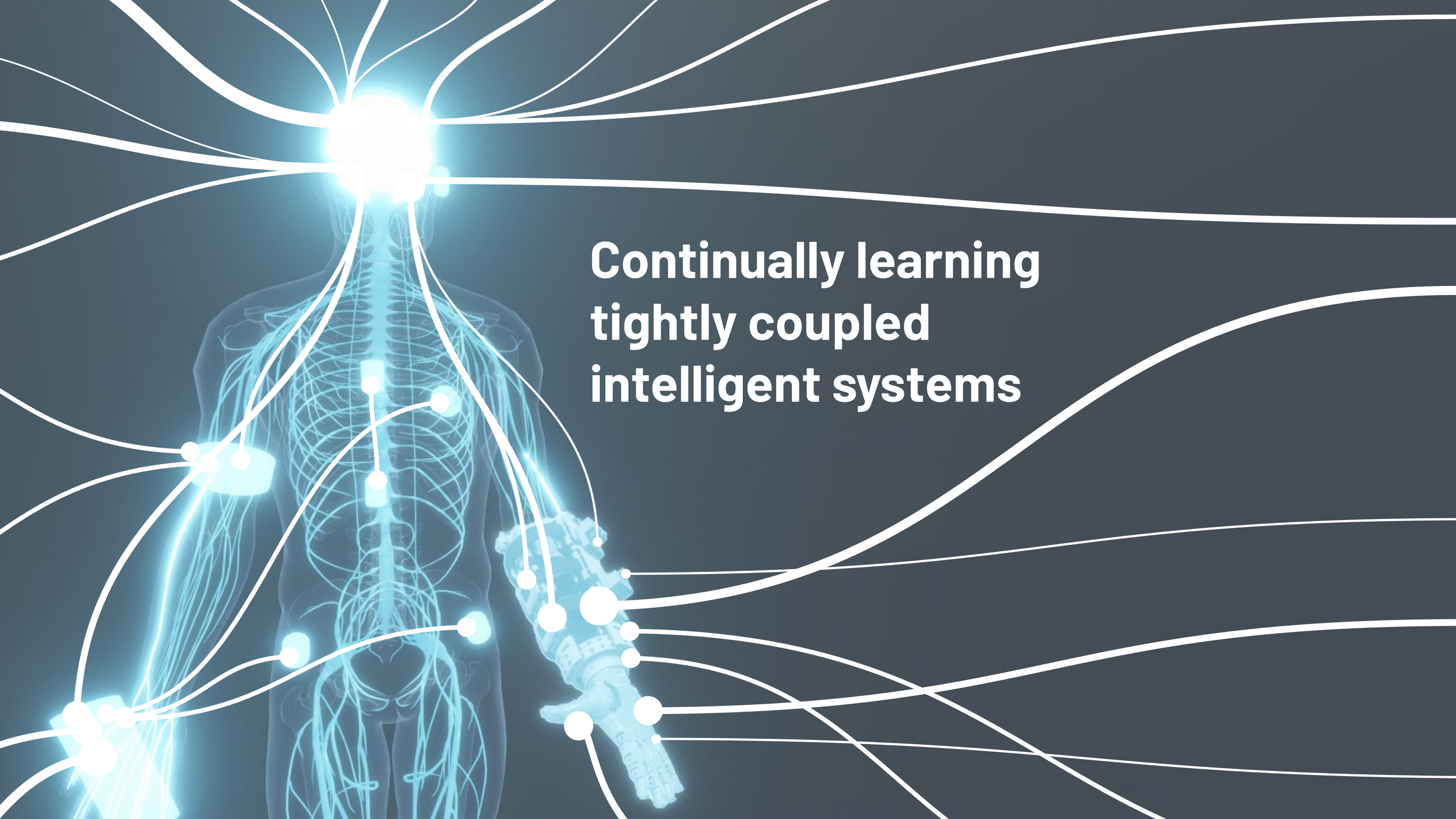
Expert-**Designed**
or Fixed Signalling

Joint Action
Sebanz, *et al.*, 2006.

Emergent or Fully
Learned Signalling




machine learned **bidirectional coordination**


Continually learning
tightly coupled
intelligent systems

GLENROSE
REHABILITATION HOSPITAL
FOUNDATION

University
Hospital
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Post-surgery Osseointegration
Rehabilitation conducted at the
Glenrose Rehabilitation Hospital

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Thomas Degris
Michael Johanson
Ahmed Shehata
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Glyn Murgatroyd
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SMART NETWORK
Sensory Motor Adaptive Rehabilitation Technology

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