The Role of Predictions in Joint Action

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Canada Research Chair in Machine Intelligence for Rehabilitation
Division of Physical Medicine and Rehabilitation, Dept. of Medicine

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UNIVERSITY OF ALBERTA
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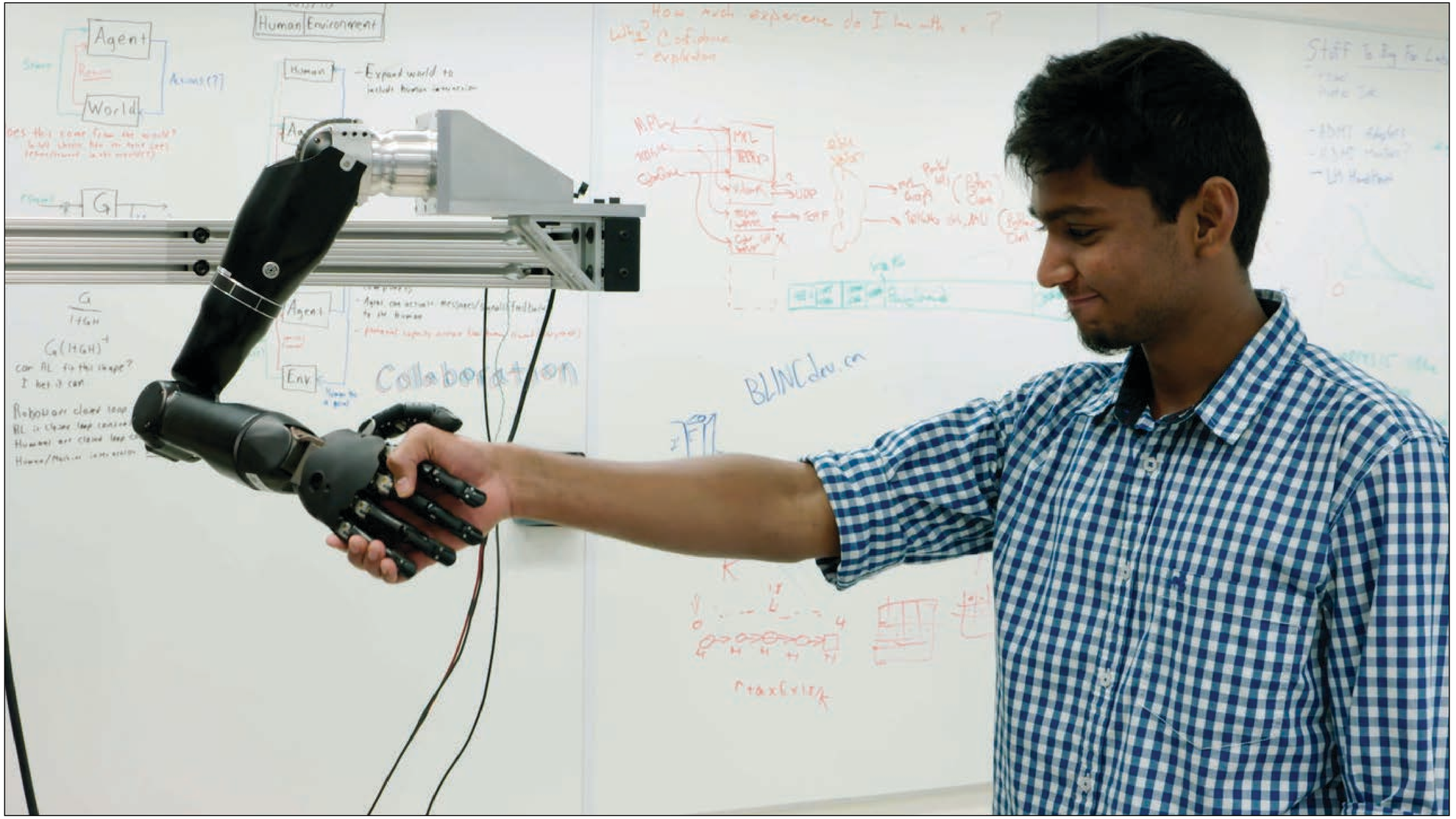
BLINC
BIONIC LIMBS FOR IMPROVED NATURAL CONTROL

SMART NETWORK
Sensory Motor Adaptive Rehabilitation Technology

amii



Joint Action?

Joint Action

Pesquita, Whitwell, and Enns, *Psychon Bull Rev* 25, 2018: “Predictive joint-action model: A hierarchical predictive approach to human cooperation”

JOINT ACTION

"a social interaction whereby two or more individuals coordinate their actions in space and time to bring about change in the environment"

Sebanz et al. (2006). Joint action: Bodies and minds moving together. *Trends. Cogn. Sci.* 10(2), 70–76.

Representation of shared **goal** and individual contributions to the shared goal.

Pesquita, Whitwell, and Enns, *Psychon Bull Rev* 25, 2018: “Predictive joint-action model: A hierarchical predictive approach to human cooperation”
Vesper et al., *Neural Networks* 23, 2010: “A minimal architecture for joint action”

Representation of shared **goal** and individual contributions to the shared goal.

Monitoring and prediction of partner actions.

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Representation of shared **goal** and individual contributions to the shared goal.

Monitoring and prediction of partner actions.

Continuous coordination via **continuous improvement of predictions** about a partner's actions.

Pesquita, Whitwell, and Enns, *Psychon Bull Rev* 25, 2018: "Predictive joint-action model: A hierarchical predictive approach to human cooperation"
Vesper et al., *Neural Networks* 23, 2010: "A minimal architecture for joint action"

PREDICTIONS

Momentary.
(e.g., classification decision)

S. Micera, J. Carpaneto, and S. Raspopovic, "Control of hand prostheses using peripheral information," *IEEE Rev. Biomed. Eng.*, 2010.

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Temporally extended.
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Sutton et al., "Horde: A Scalable Real-time Architecture for Learning Knowledge from Unsupervised Sensorimotor Interaction," *Proc. of 10th International Conference on Autonomous Agents and Multiagent Systems (AAMAS)*, 2011.

PREDICTIONS

Momentary.
(e.g., classification decision)

Temporally extended.
(e.g., expected return)

Can be acquired or updated in batches or in real time.

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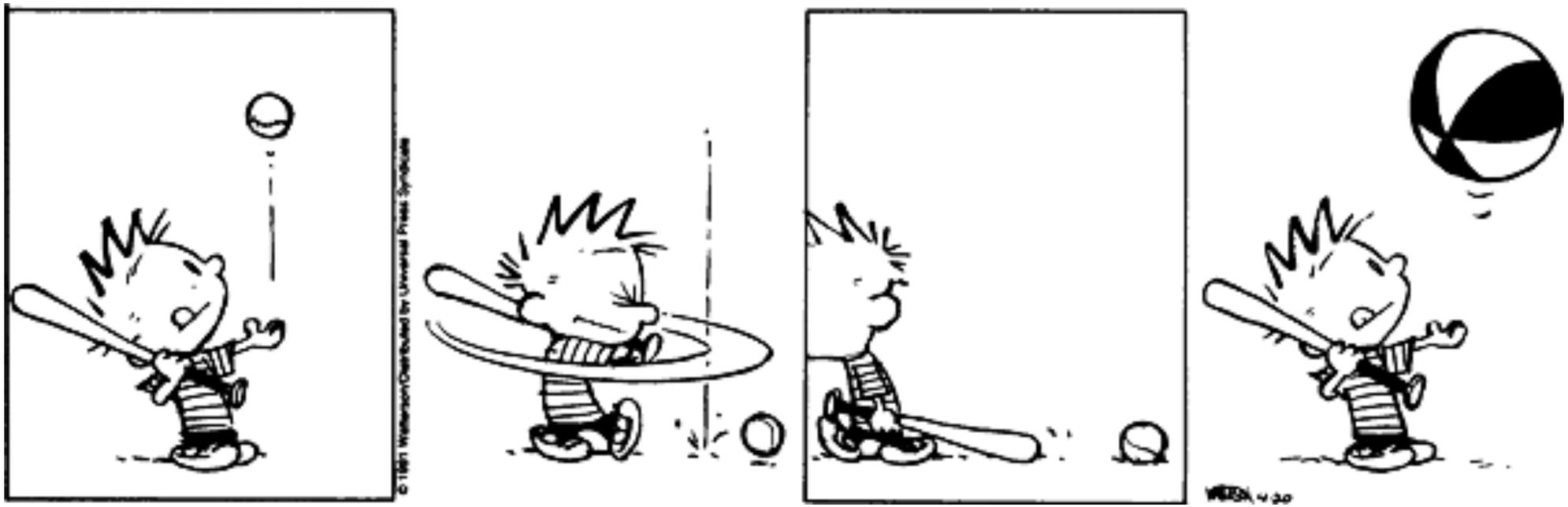
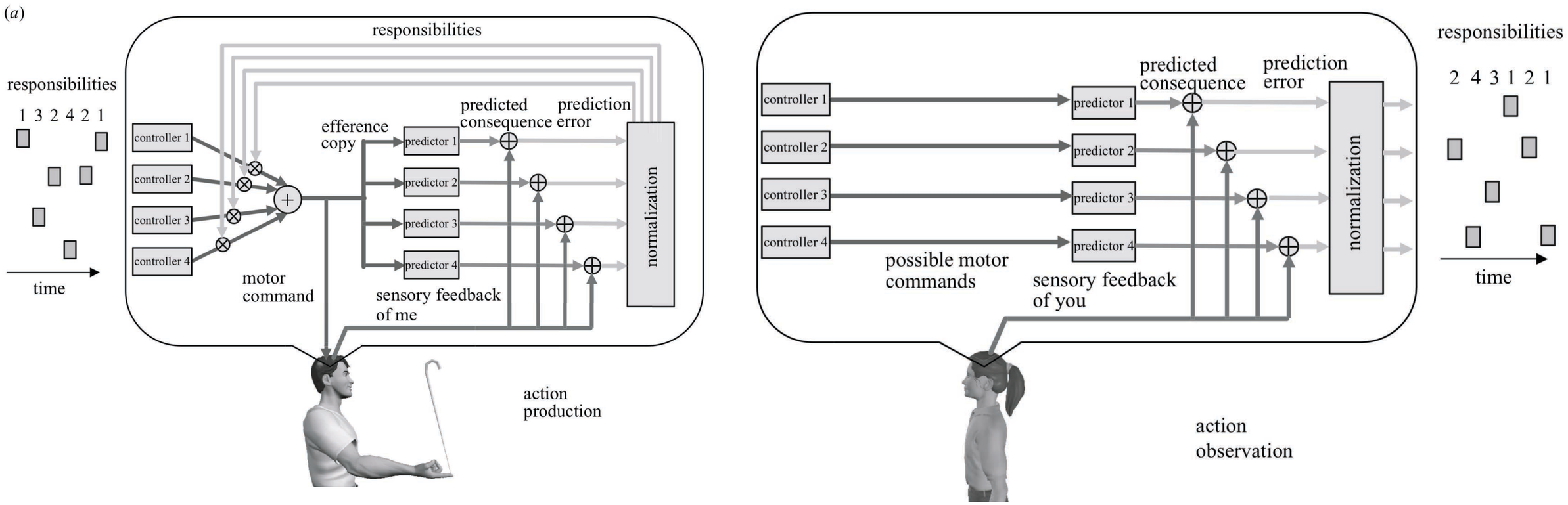
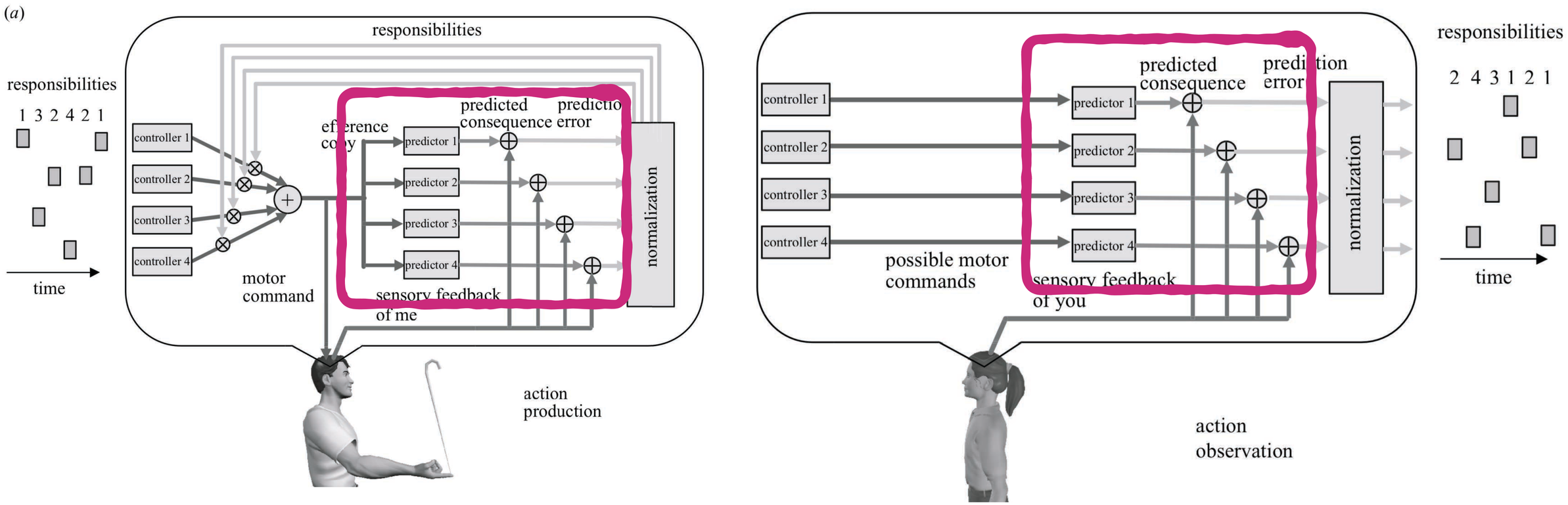


Wolpert et al., *Trends Cog Sci* 5(11), 2001: “Perspectives and problems in motor learning”
Flanagan et al., *Current Biology* 13(2), 2003: “Prediction precedes control in motor learning”
Desmurget et al., *Science* 324(5928), 2009: “Movement intention after parietal cortex stimulation in humans”



MOSAIC

Wolpert, Doya, and Kawato, *Phil Trans Royal Soc London B*, 358(1431), 2003: “[Motor control and social interaction]”



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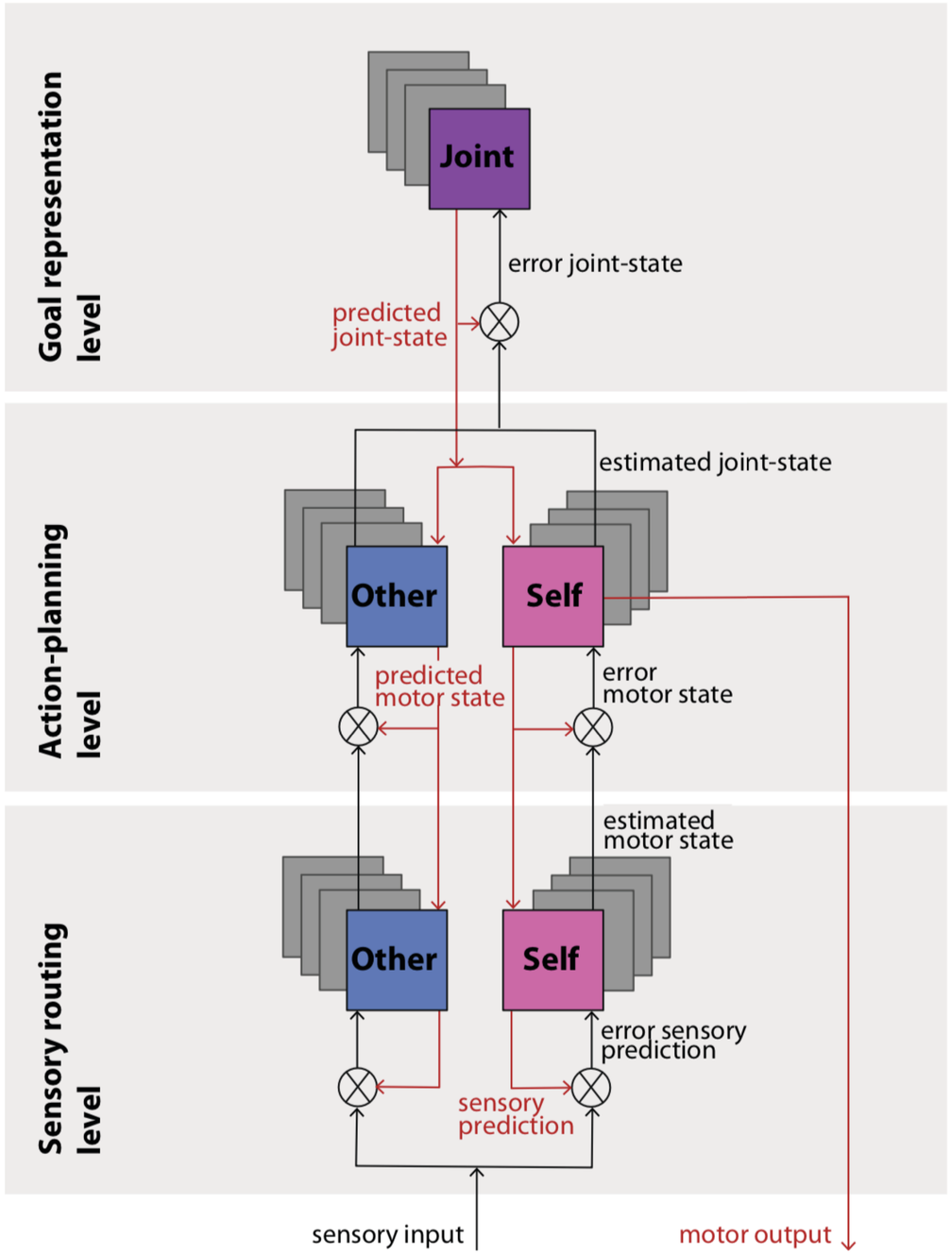

Predictive Joint-Action Model (PJAM)

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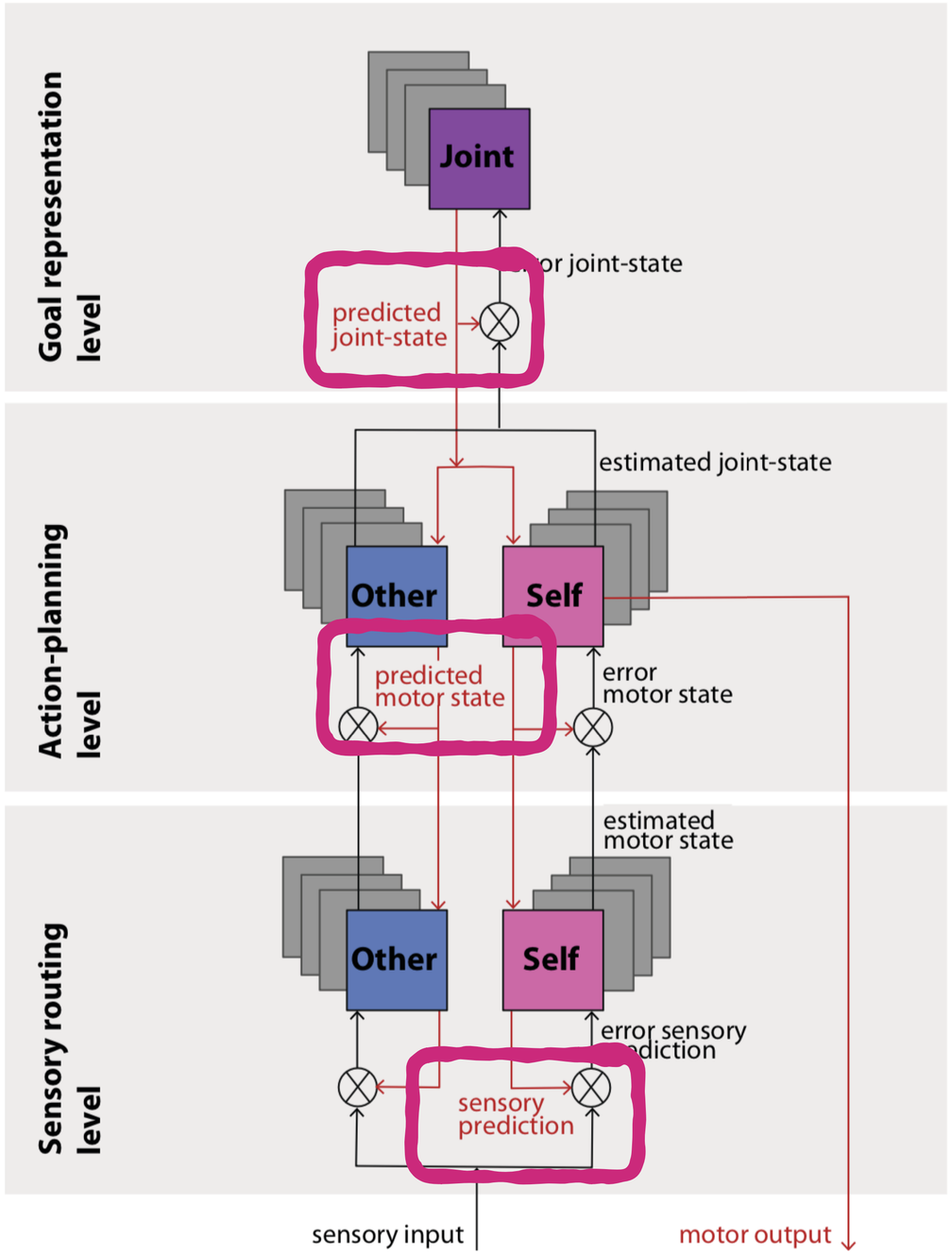

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“Hey! Look! (It’s not just for human-human dyads)

The Legend of Zelda: Ocarina of Time (1998)

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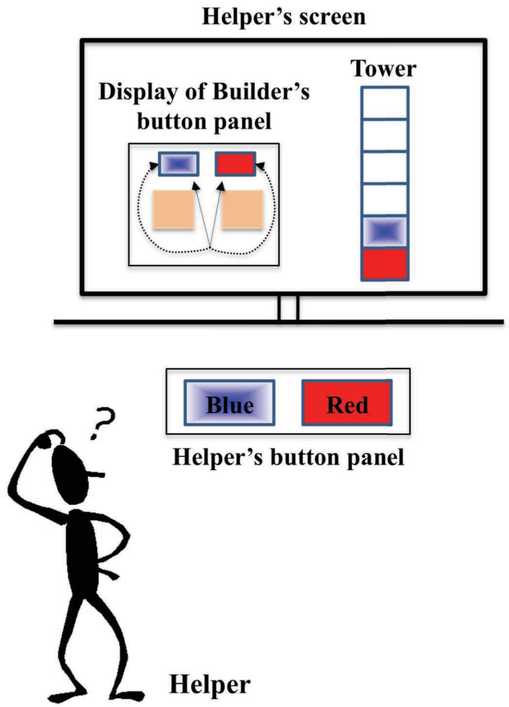

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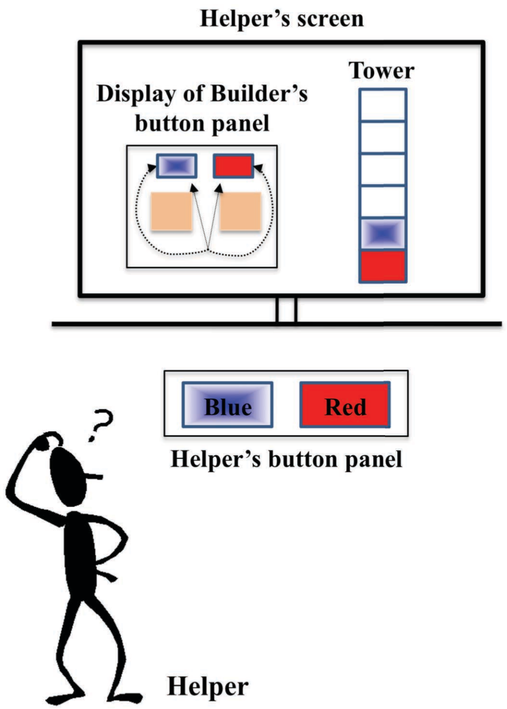

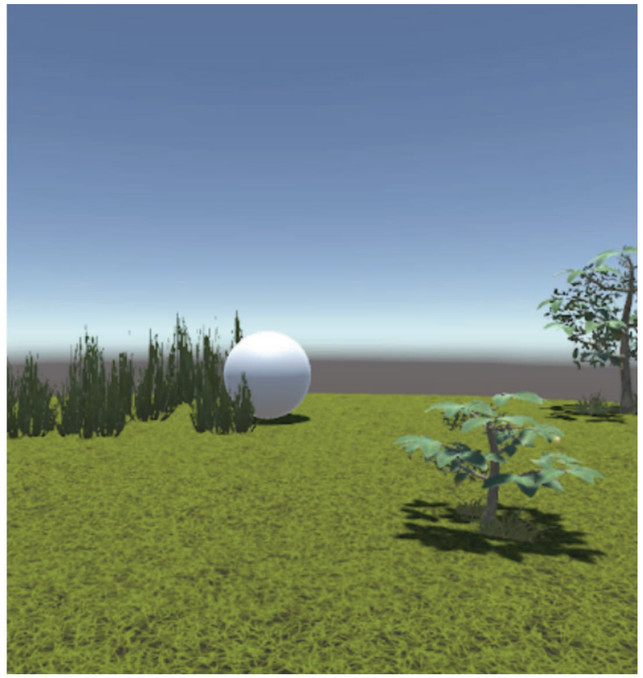

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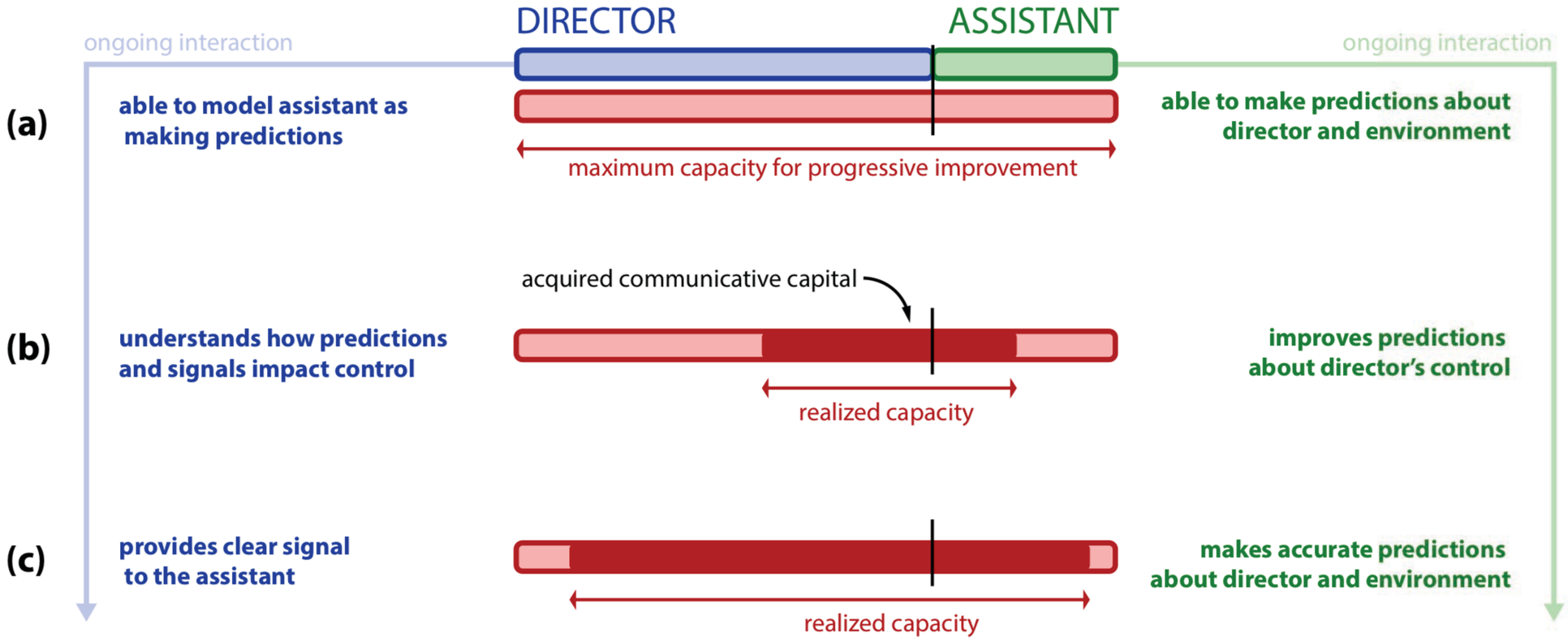
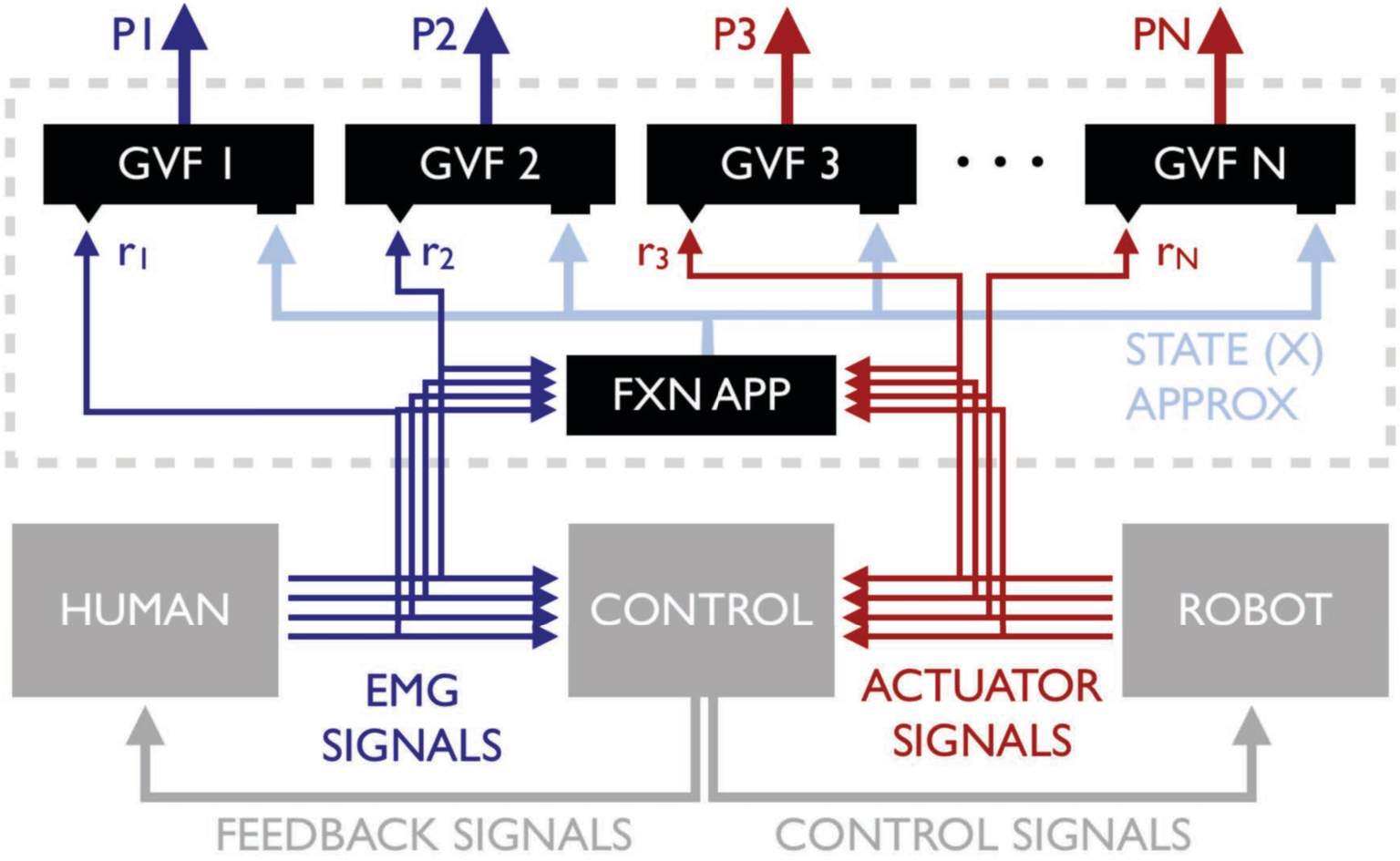
P. M. Pilarski, A. Butcher, M. Johanson, M. M. Botvinick, A. Bolt, A. S. R. Parker, “Learned human-agent decision-making, communication and joint action in a virtual reality environment,” *RLDM 2019 / arXiv:1905.02691* [cs.AI], 5 pages, 2019.

Predictions as *Communicative Capital*

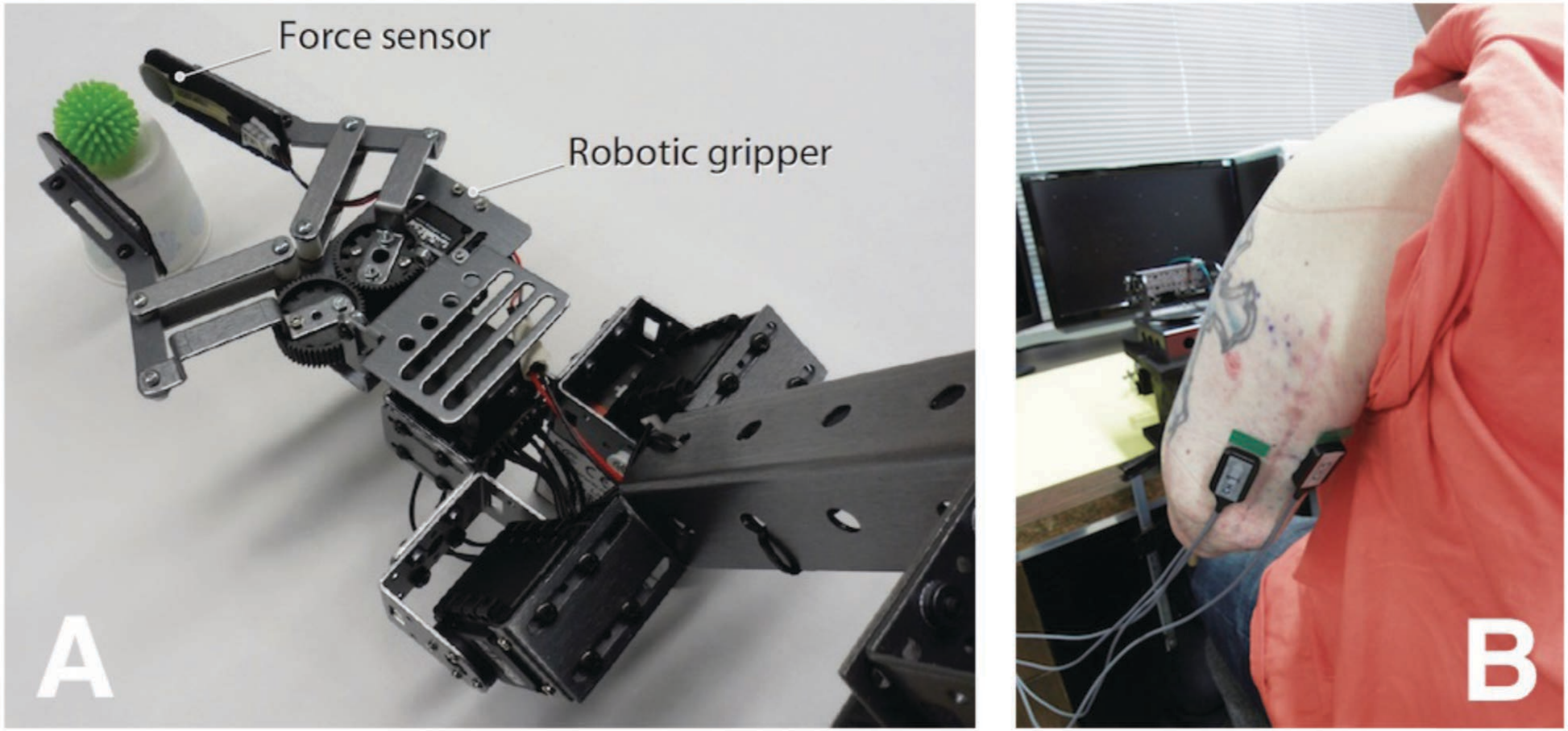


P. M. Pilarski, R. S. Sutton, K. W. Mathewson, C. Sherstan, A. S. R. Parker, A. L. Edwards, "Communicative Capital for Prosthetic Agents," arXiv:1711.03676 [cs.AI] (arXiv): 33 pages, 2017.

Commercially Deployed
Pattern Recognition for Prostheses



P.M. Pilarski, M.R. Dawson, T. Degris, J.P. Carey, K.M. Chan, J.S. Hebert, and R.S. Sutton, "Adaptive Artificial Limbs: A Real-time Approach to Prediction and Anticipation," *IEEE Robotics & Automation Magazine*, Vol. 20(1): 53–64, March 2013.



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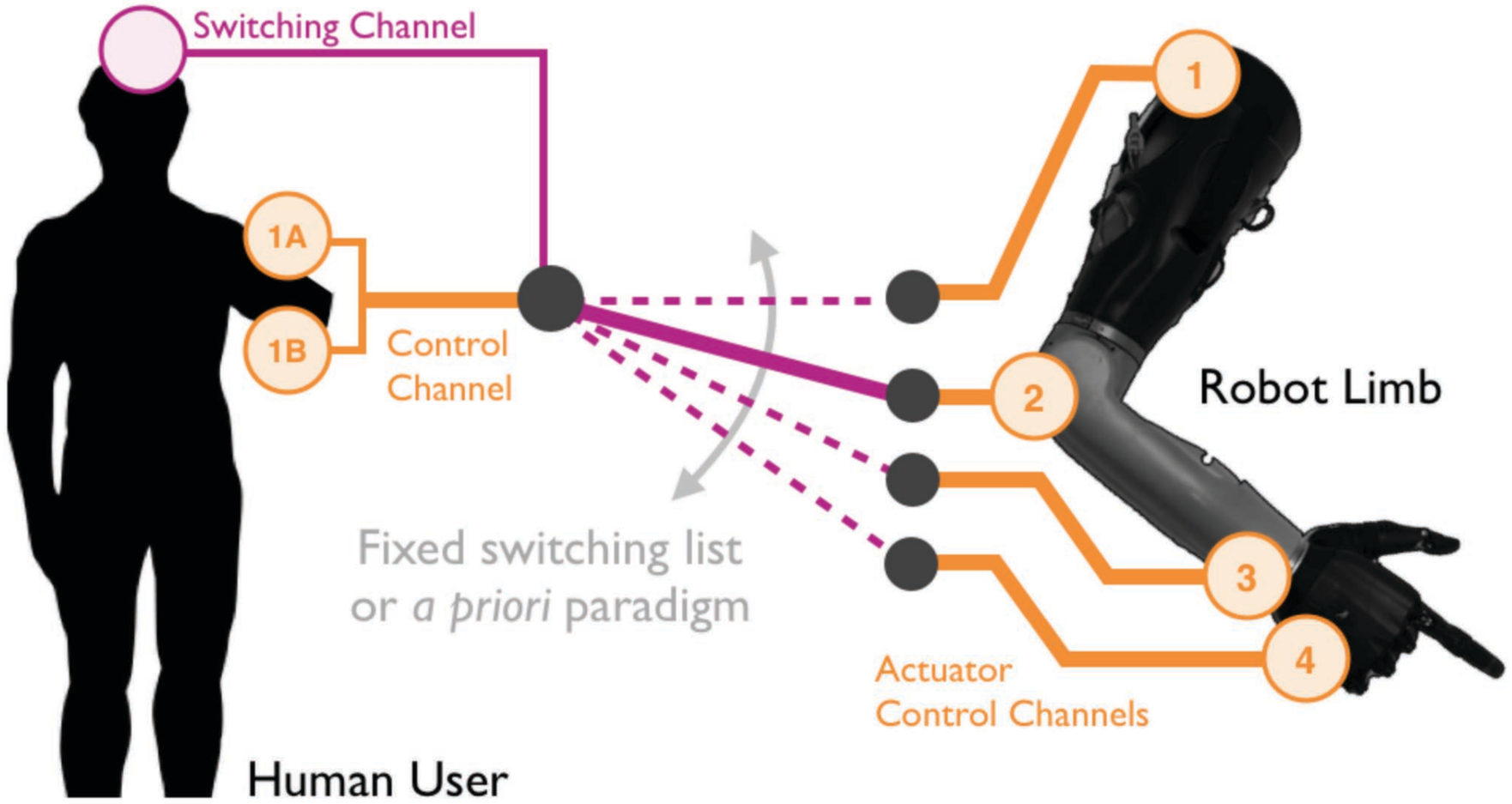
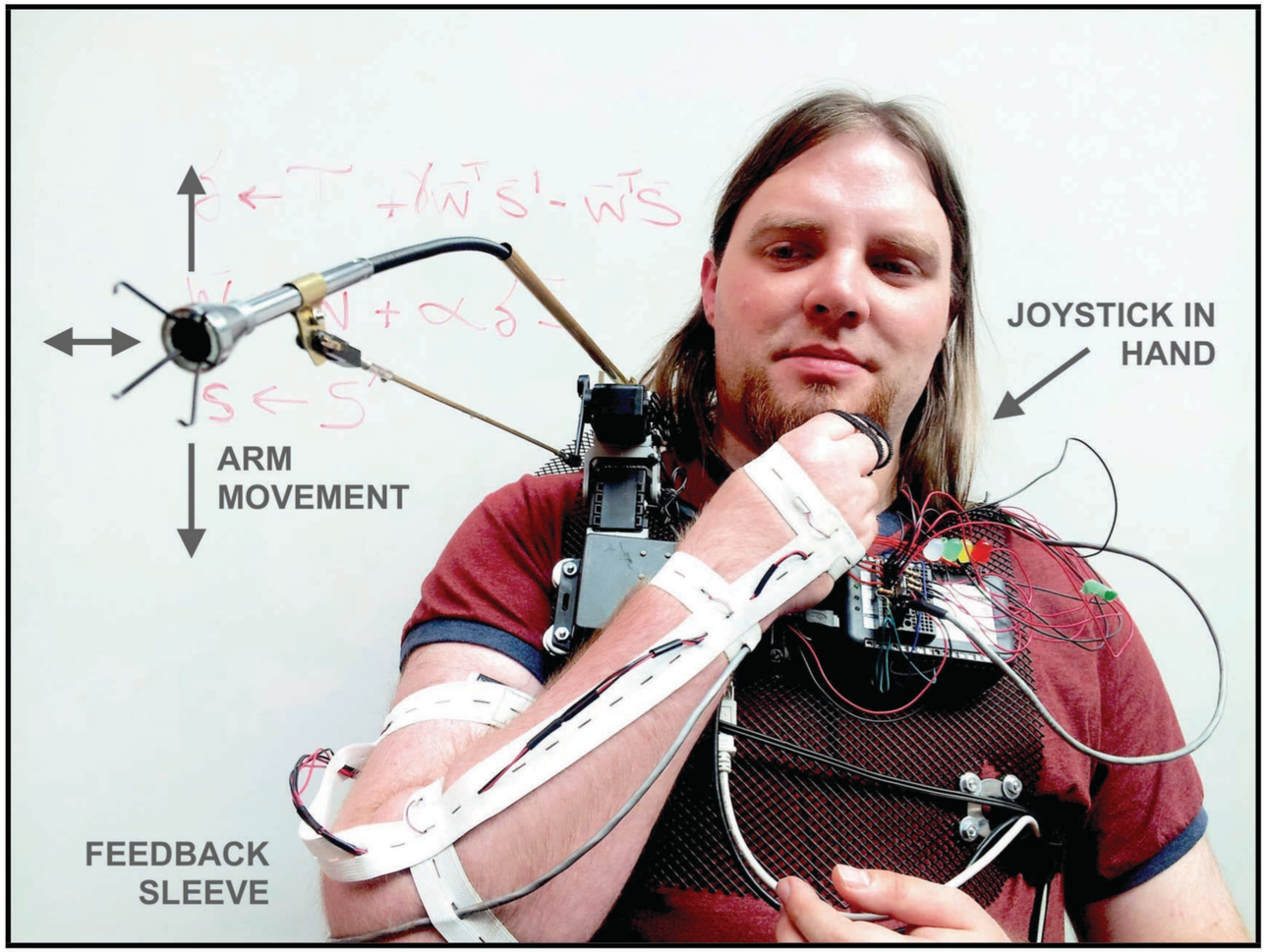


A. L. Edwards, "Adaptive and Autonomous Switching: Shared Control of Powered Prosthetic Arms Using Reinforcement Learning," MScRS Thesis, Faculty of Rehabilitation Medicine, University of Alberta, 2016.



A. S. R. Parker, A. L. Edwards, P. M. Pilarski, "Exploring the Impact of Machine-Learned Predictions on Feedback from an Artificial Limb," *2019 IEEE-RAS-EMBS International Conference on Rehabilitation Robotics (ICORR)*, 24-28 June, 2019, Toronto, 8 pages.

We have both the technology and model systems to study human-machine coordination as joint action.

C. Castellini at al., “Proceedings of the First Workshop on Peripheral Machine Interfaces: going beyond traditional surface electromyography,” *Frontiers in Neurorobotics*, vol. 8, no. 22, Aug. 2014.

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GVFs

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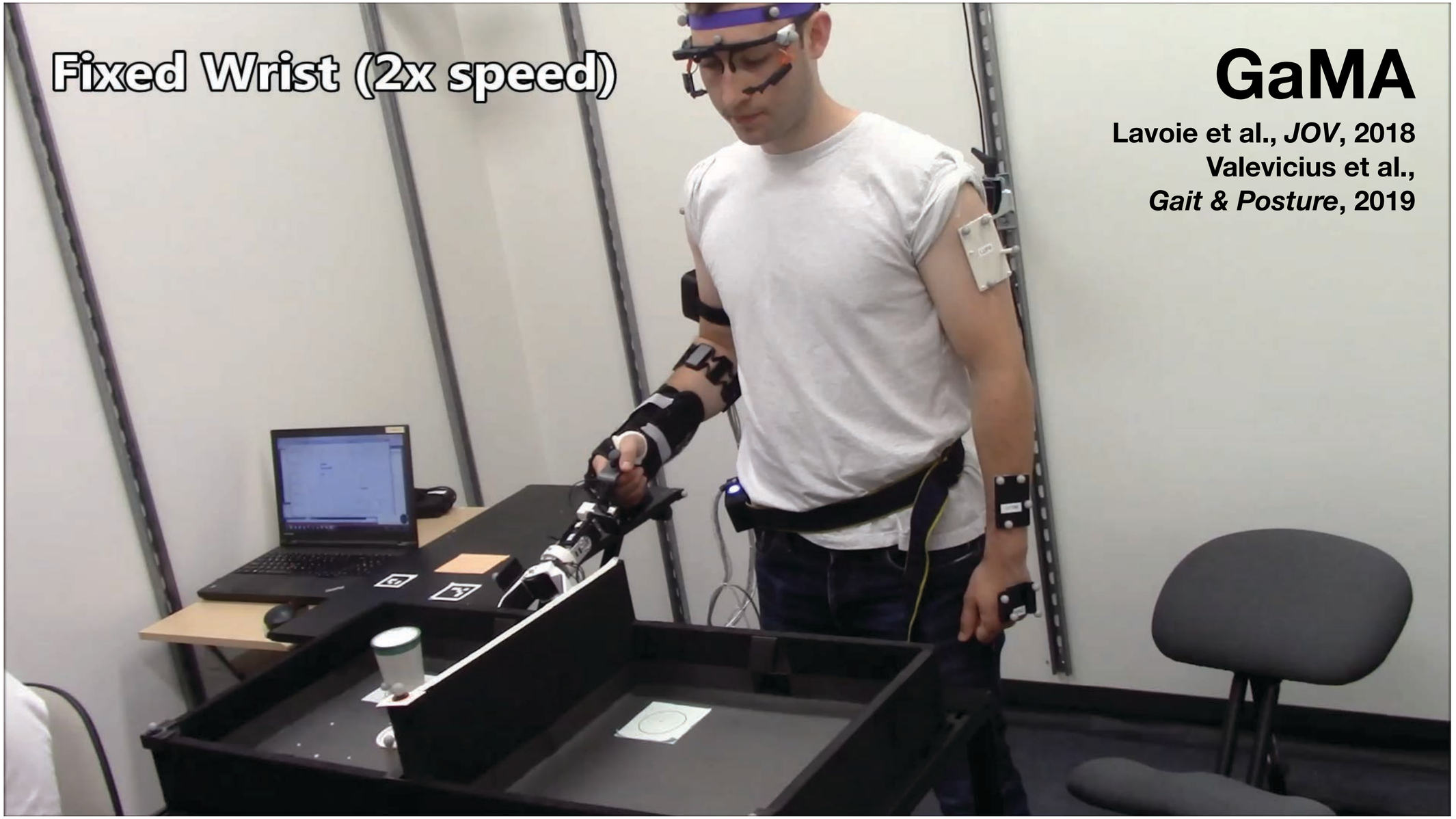
File photo by *The Canadian Press*/Amber Bracken, 2019



Brenneis et al., "The Effect of an Automatically Levelling Wrist Control System," *2019 IEEE-RAS-EMBS International Conference on Rehabilitation Robotics (ICORR)*, 24-28 June, 2019, Toronto, Canada, 8 pages

Both humans and machines can now represent goals, make and maintain predictions...

... can we gain utility by viewing human-prosthesis action as joint action?

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(Let's find out!)

With thanks to many collaborators:
Dr. Richard Sutton
Dr. Jacqueline Hebert
Dr. Craig Chapman
Dr. Albert Vette
Michael Rory Dawson
Trainees past and present
Dept. CS and Dept. Medicine
Glenrose Rehabilitation Hospital
BLINC Lab, RLAI Lab, ACE Lab

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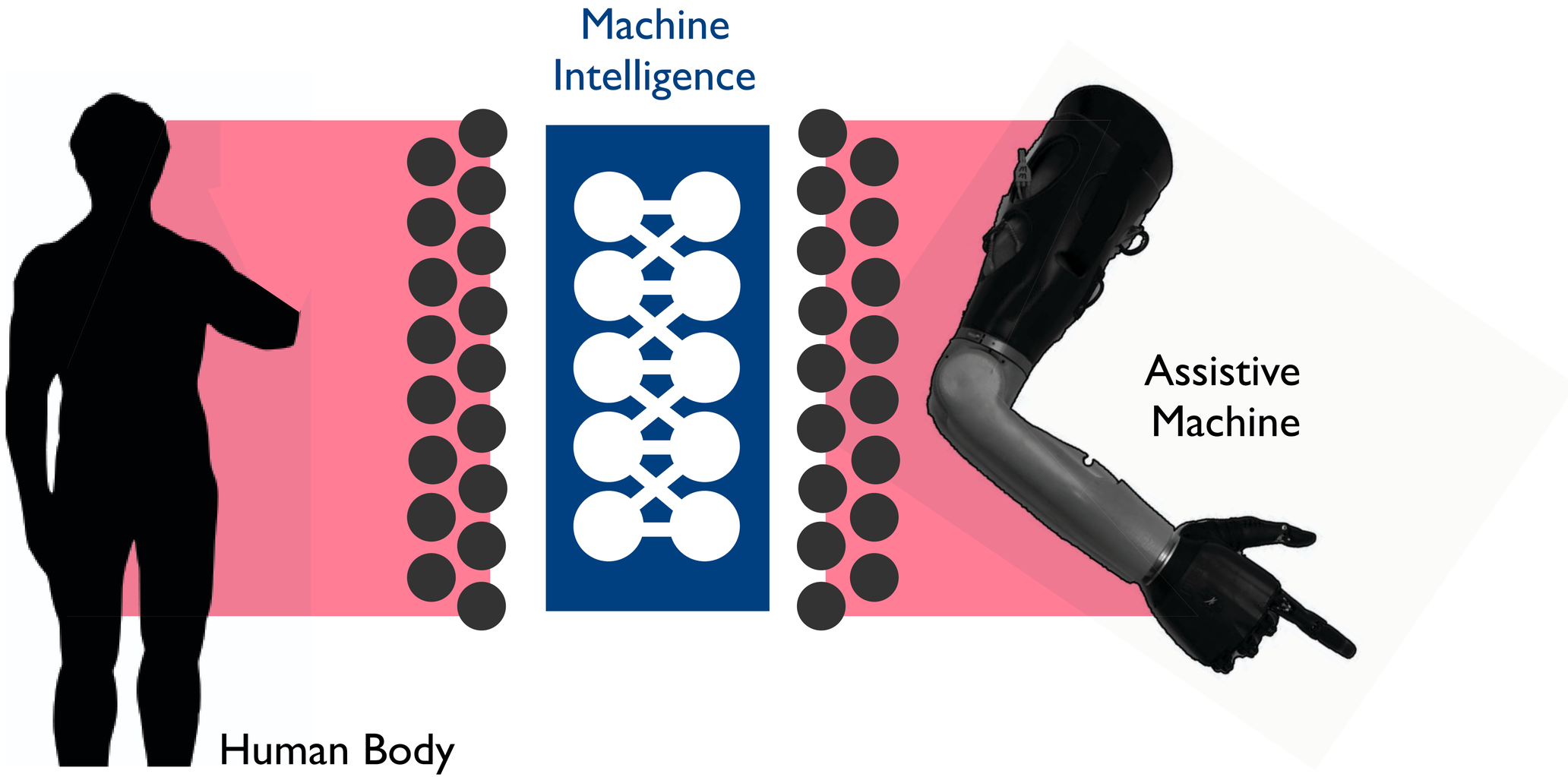
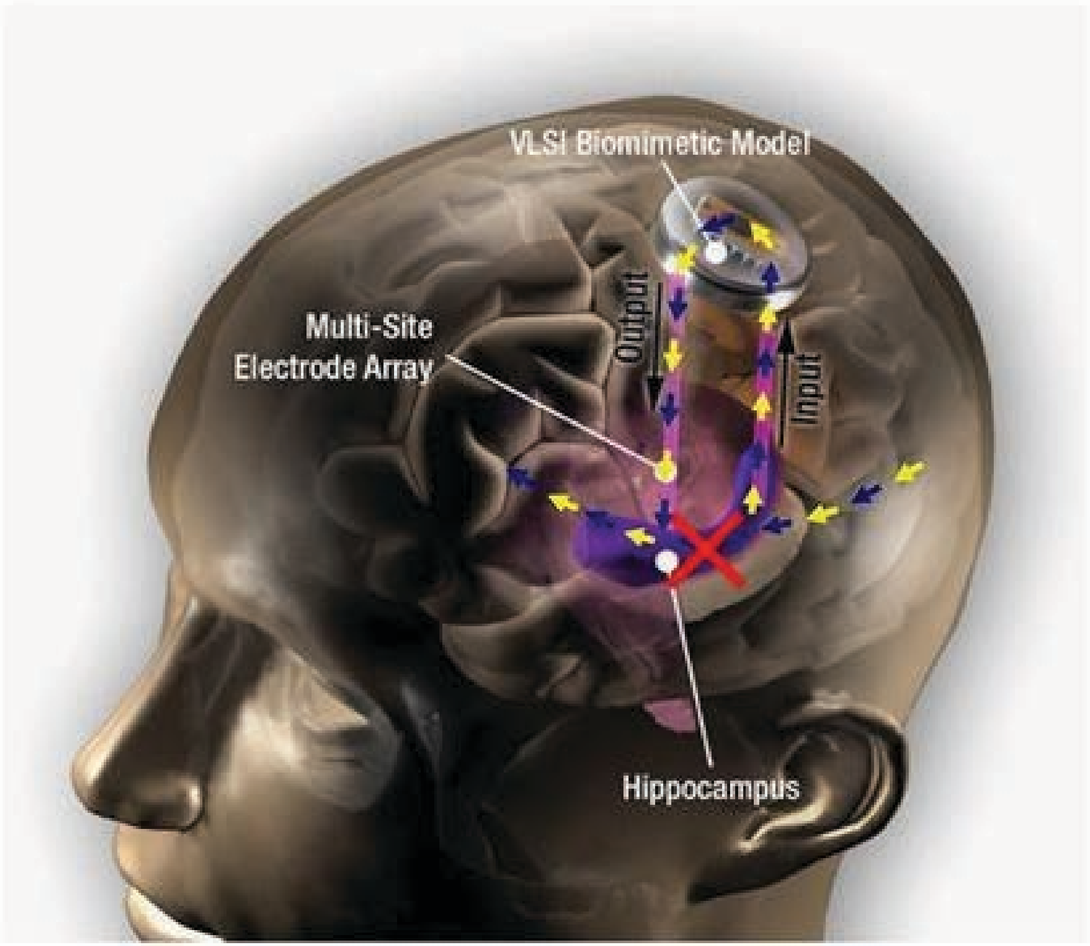
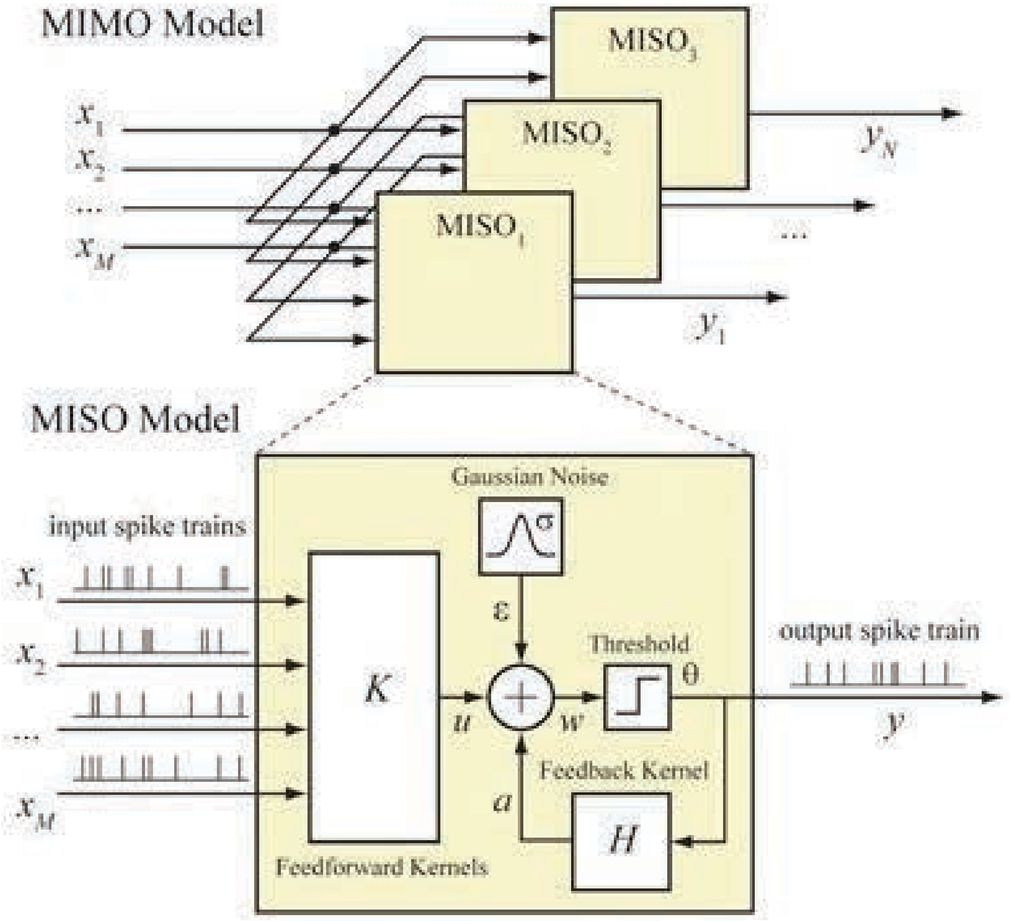
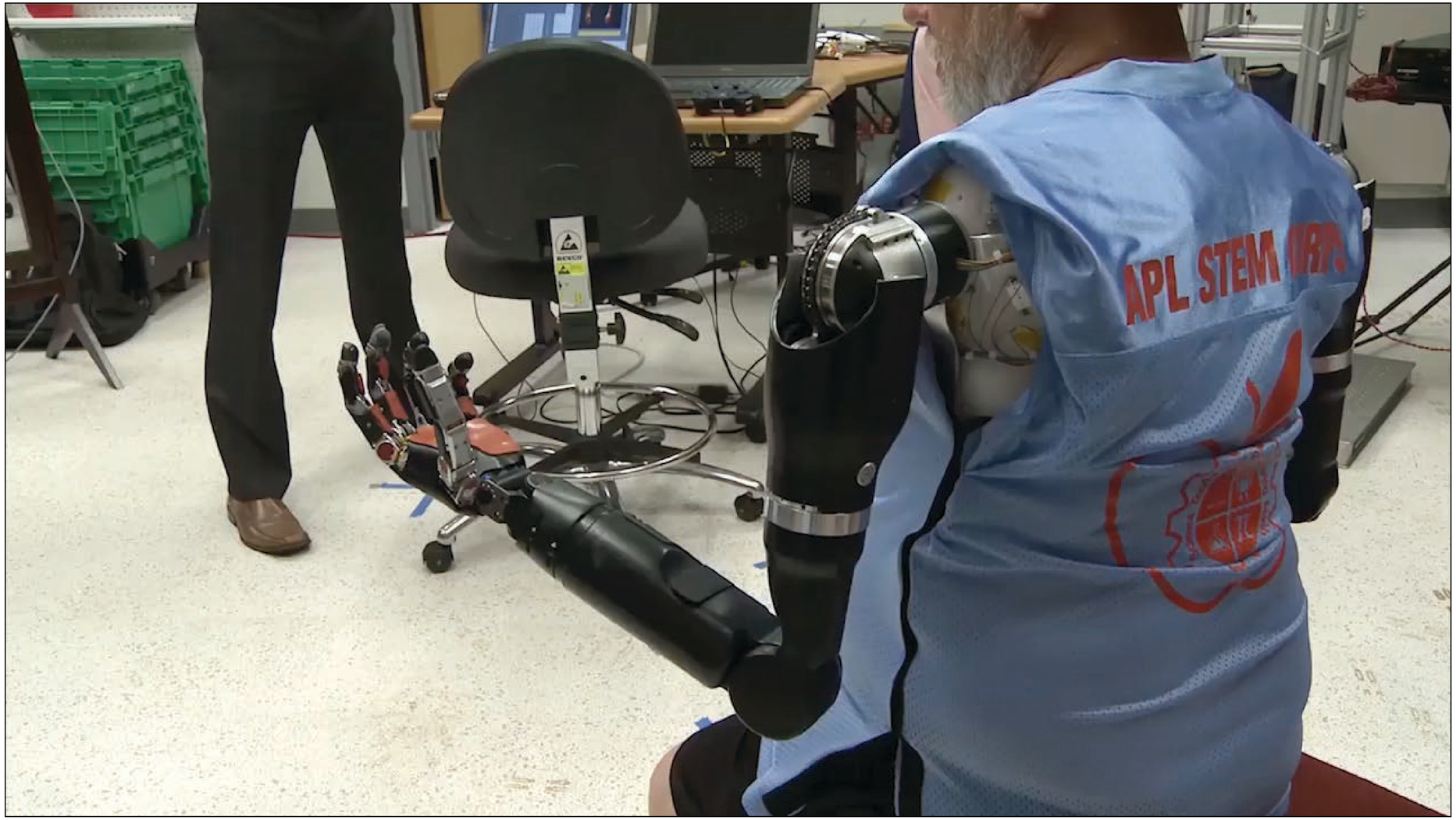

Machine
Intelligence
Assistive
Machine
Human Body

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



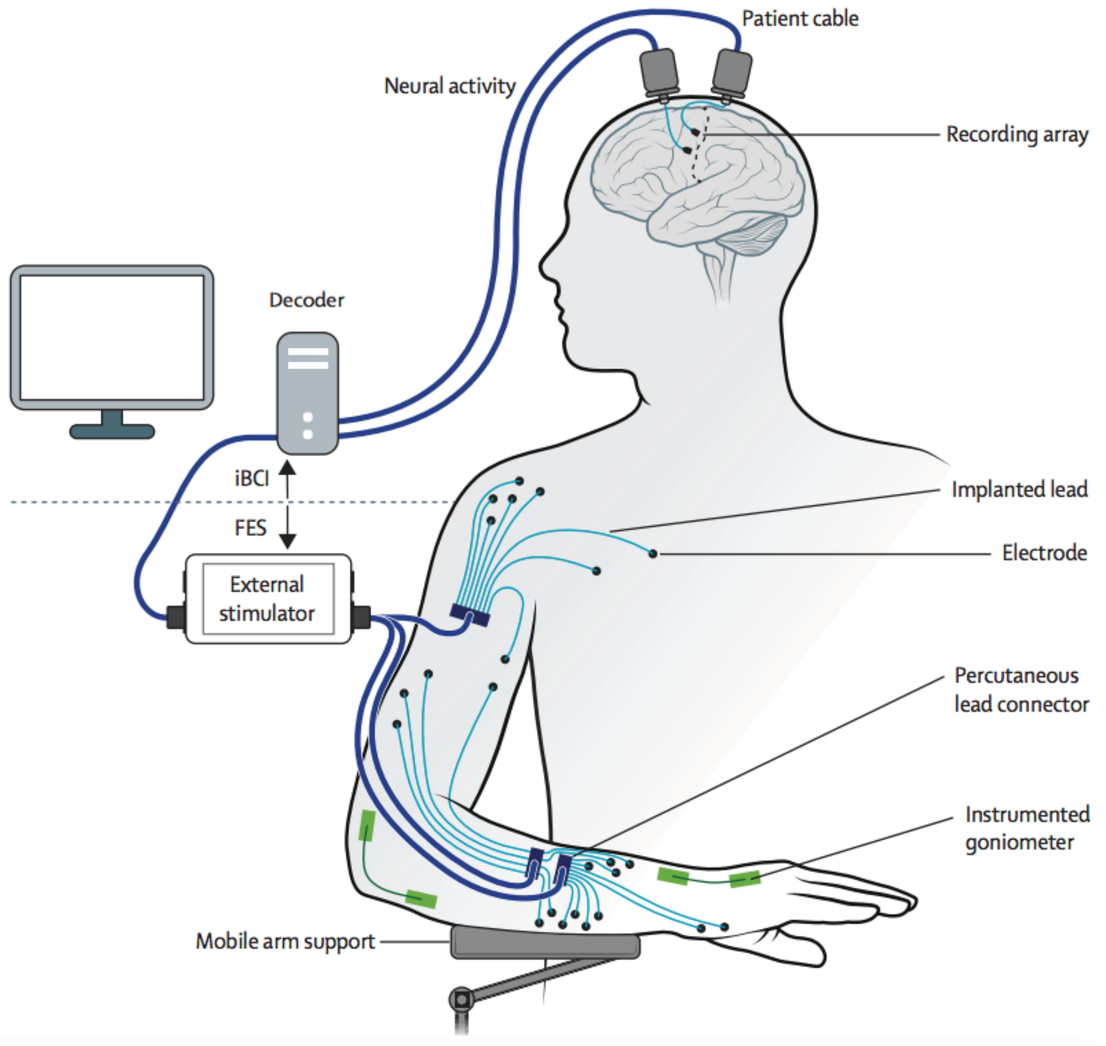


Direct brain-computer interfaces: *memory protheses* from the Center for Neural Engineering, Viterbi School of Engineering. https://cne.usc.edu/neural-prosthesis-for-hippocampal-memory-function/ and IEEE Trans Neural Syst Rehabil Eng. 2018, 26(2):272-280.

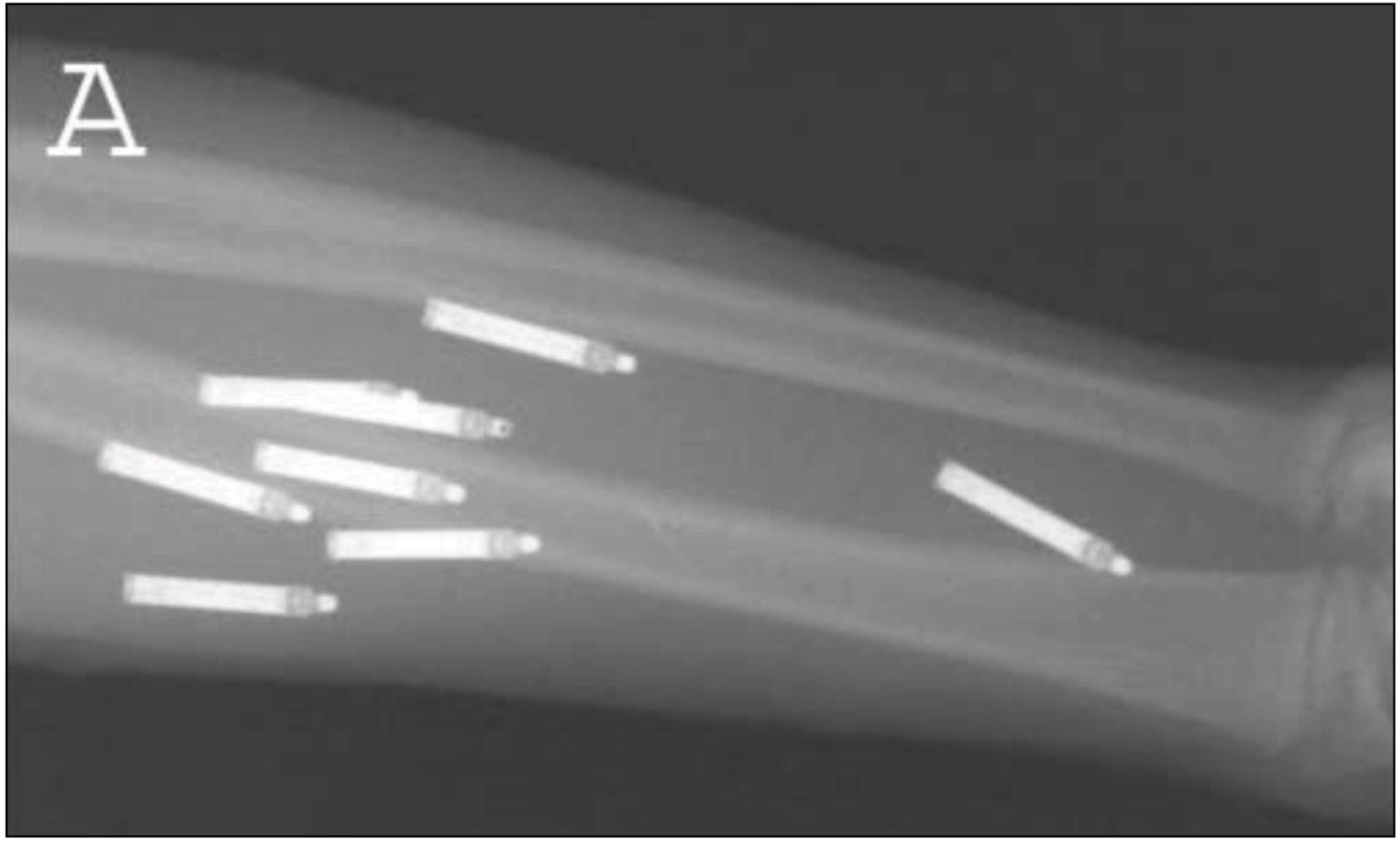


Brain-body-machine interfaces: “Amputee Makes History with APL’s Modular Prosthetic Limb” (JHU Applied Physics Laboratory); https://youtu.be/9NOncx2jU0Q

Brain-body-machine interfaces: “APL’s Modular Prosthetic Limb Reaches New Levels of Operability” (JHU Applied Physics Laboratory); https://youtu.be/-0srXvOQlu0



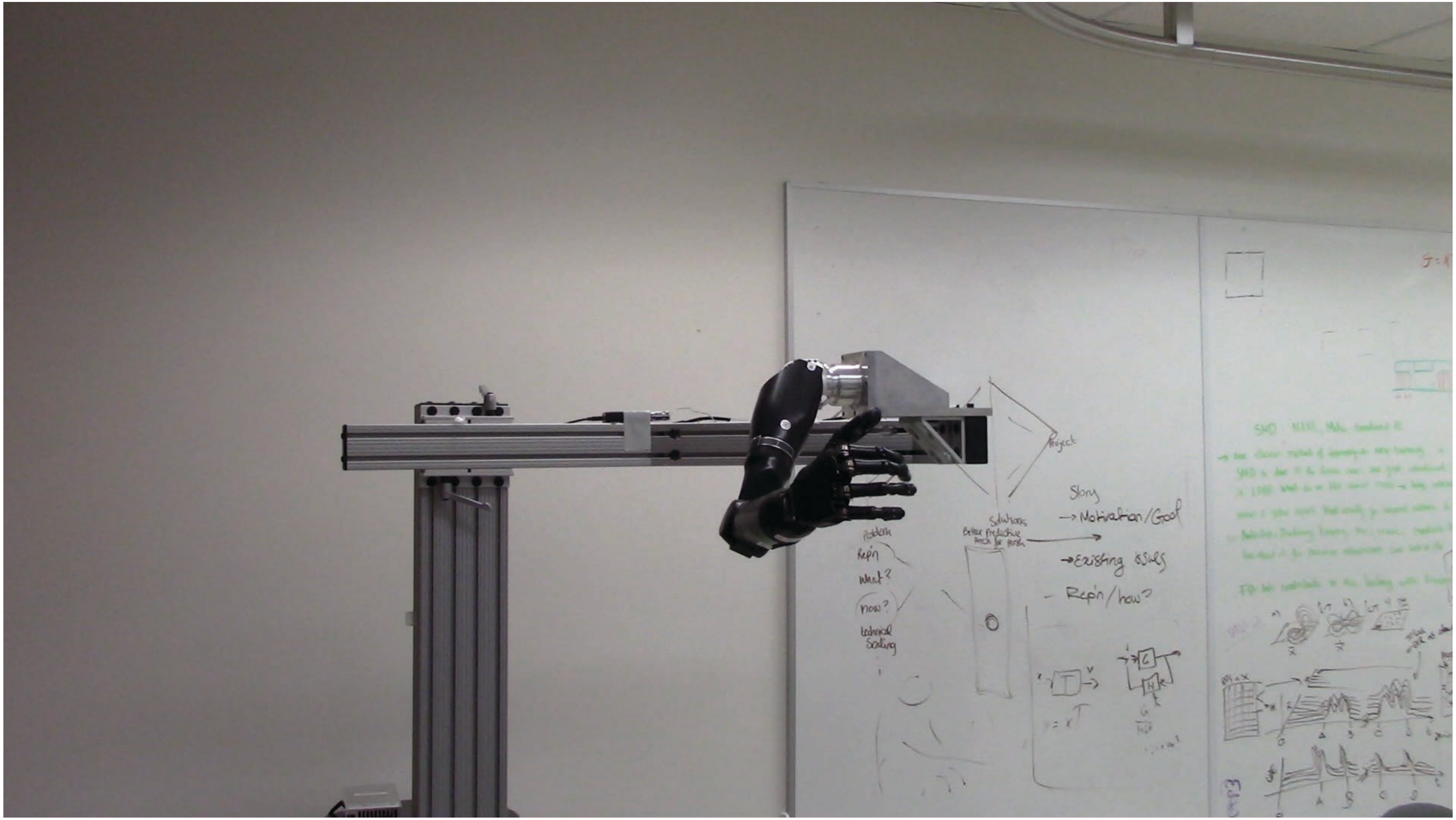
Brain-body-machine interfaces: "Restoration of reaching and grasping movements through brain-controlled muscle stimulation in a person with tetraplegia: a proof-of-concept demonstration" Ajiboye, A Bolu et al., *The Lancet*, Volume 389 , Issue 10081, 1821-1830, 2017.



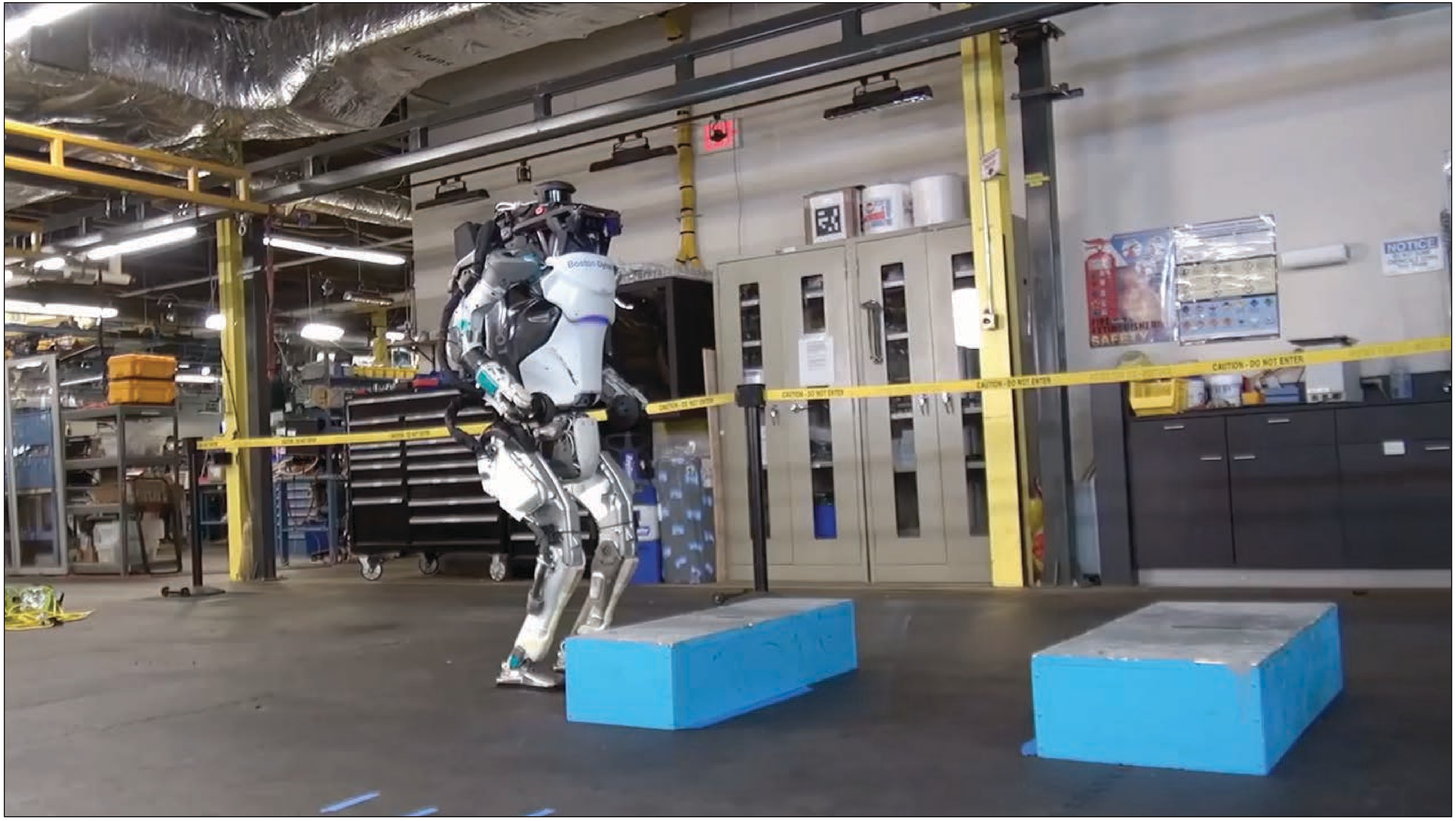
Brain-body-machine interfaces: Baker et al., “Continuous Detection and Decoding of Dexterous Finger Flexions With Implantable MyoElectric Sensors,” IEEE TNSRE 18(4):424-32, 2010.

Brain-body-machine interfaces: “Brain-Machine Interface @ EPFL- Wheelchair” (École polytechnique fédérale de Lausanne); https://youtu.be/0-1sdtnuqcE

University of Alberta: http://blinclab.ca



University of Alberta: http://blinclab.ca, https://www.smartnetworkcentre.ca/



And in case you were wondering what the robots are up to these days…

Atlas Robot (Boston Dynamics): https://youtu.be/fRj34o4hN4I

Exoskeletons: UC Berkeley spin-off suitX exoskeleton technology; https://www.youtube.com/watch?v=I3roYI3CB2Y