Building Communicative Capital during Human-Machine Collaboration

Patrick Pilarski and Richard Sutton
(with Kory Mathewson, Craig Sherstan, Adam Parker, Ann Edwards, and many others)

Division of Physical Medicine & Rehabilitation, BLINC Lab, Alberta Innovates Centre for Machine Learning, and Reinforcement Learning and Artificial Intelligence Laboratory

UNIVERSITY OF ALBERTA
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com·mu·ni·ca·tive

/kəˈmyo͞onəˌkādivˌkəˈmyo͞onikədiv/

(adj.) relating to the conveyance or exchange of information.

cap·i·tal

/ˈkapədl/

(noun) a valuable resource of a particular kind; wealth in the form of money or other assets owned by a person or organization or available or contributed for a particular purpose such as starting a company or investing.

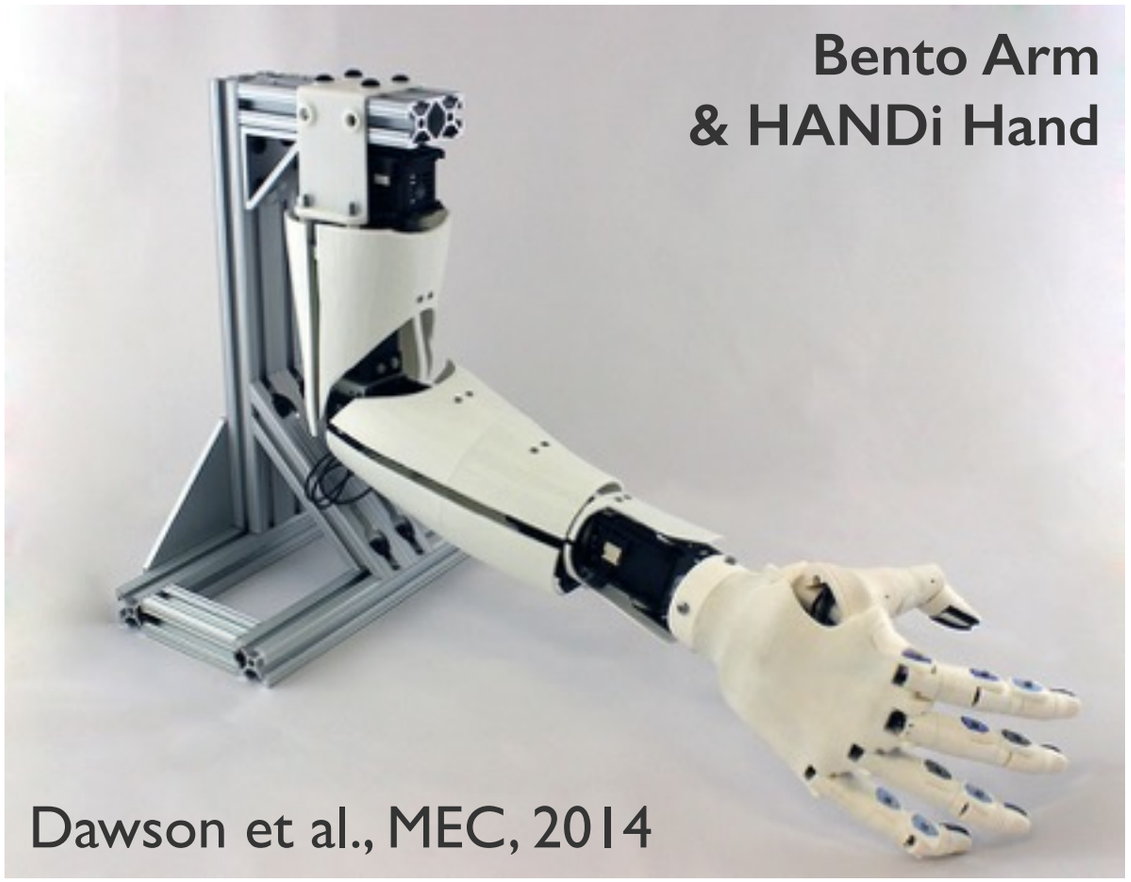
communicative capital

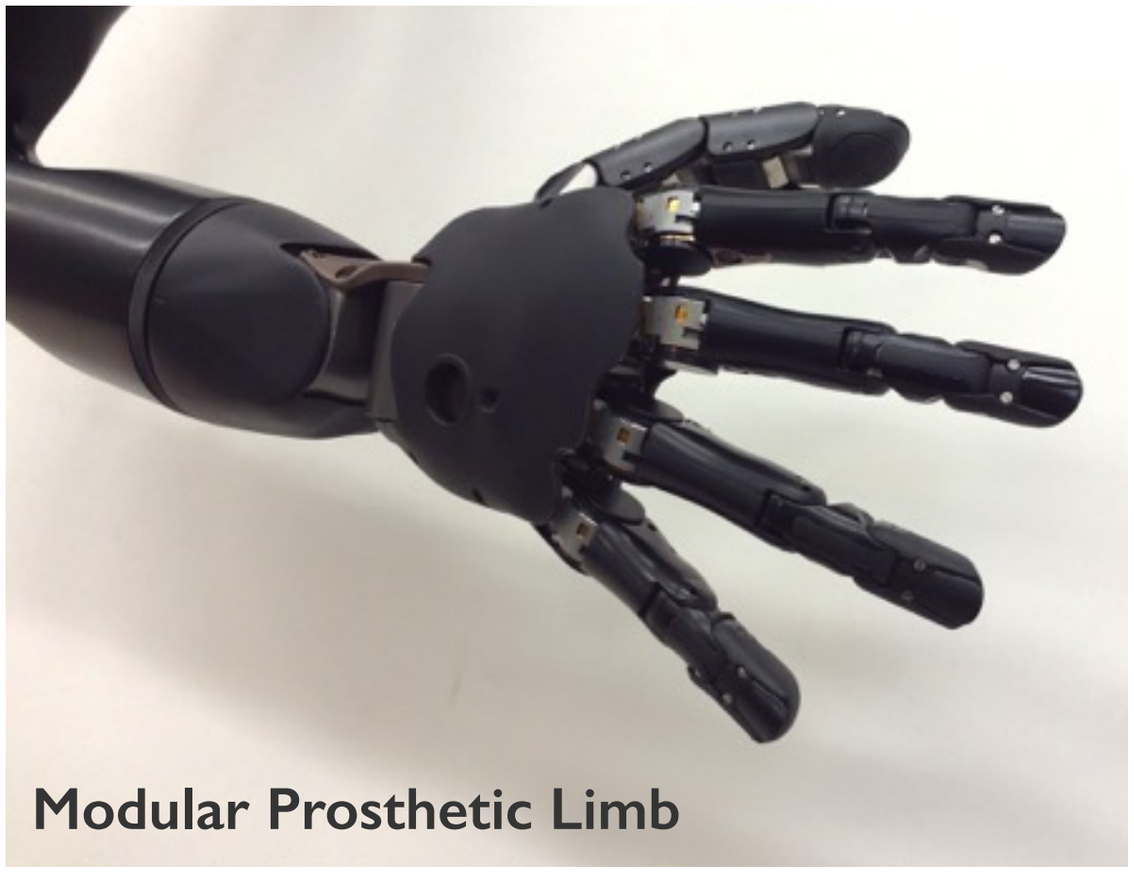
(noun) a valuable communication resource acquired through hard work that may or may not be in service of primary reward; an asset of shared understanding that facilitates the pursuance of a goal.

Outside. Pee outside.
Seriously: pee outside!

Whee! I can pee
on carpets!

Humans and machines doing things together (bff)


Bento Arm
& HANDi Hand
Dawson et al., MEC, 2014


Modular Prosthetic Limb


Targeted Reinnervation Surgery
Hebert et al., 2014

PROJECT DANIEL

NOT IMPOSSIBLE'S "PROJECT DANIEL" USES 3D PRINTERS TO MAKE PROSTHETIC ARMS FOR CHILDREN OF WAR IN SOUTH SUDAN

Photo: Not Impossible Labs

- Future prosthetic devices will receive an unprecedented density of data about a user, their needs, and their environment.

- This stream of data will need to be skillfully leveraged to enable the coordination of vast numbers of actuators and functions.

- Prostheses need to take an **active role** this process.

The **Gargoyles** from Neal Stephenson's cyberpunk dystopia novel *Snow Crash*.

Prostheses should have agency

- **Autonomous systems that have and seek goals.**

- Parts of an information processing system (e.g., both sides of a tightly coupled human-machine interface) are well thought of as each being full information-processing systems with goals.

WALL-E, from the Pixar film of the same name.

Agency

- **Hallmarks of agency include:** the ability to take actions, have sensation, persist over time, and improve with respect to a goal

- These hallmarks give rise to an agent's ability to predict, control, and represent / model its environment (including other agents).

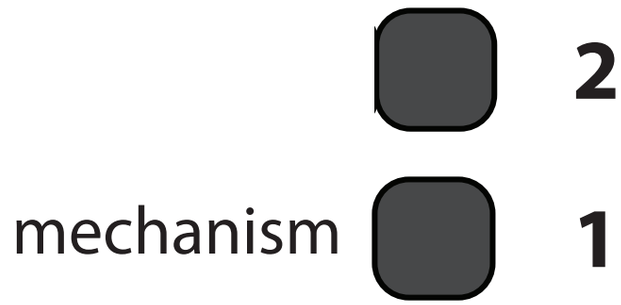
- Agency is not easily identified as present / absent.

- We attempt to identify one viable schema for thinking about agency in a prosthetic setting.

System 1 (Director)

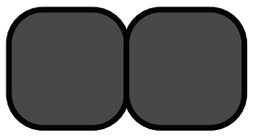
mechanism  **1**

System 1 (Director)



System 1 (Director)

adapts to assistant and environment

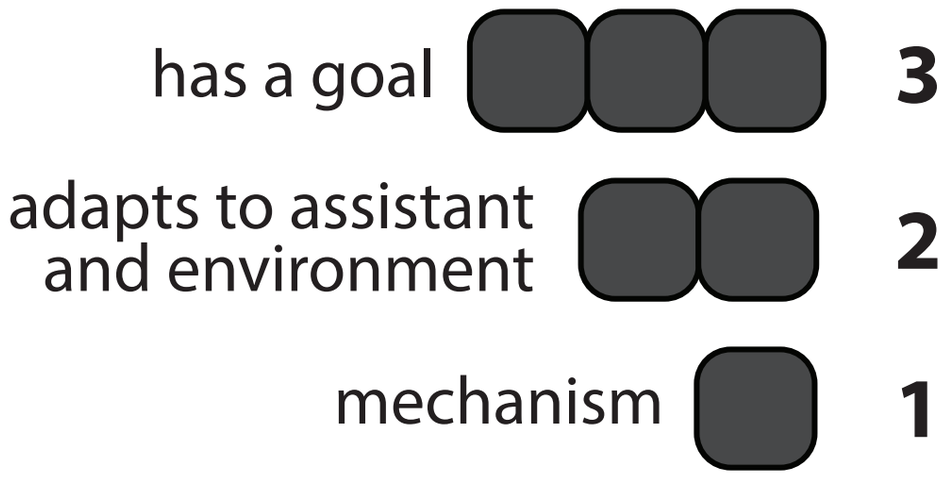


2

mechanism

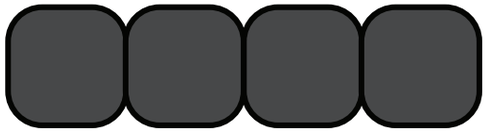
1

System 1 (Director)



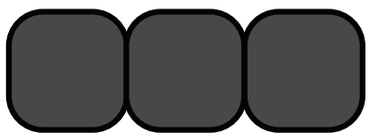
System 1 (Director)

models assistant as adapting



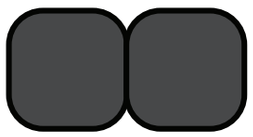
4

has a goal



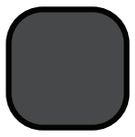
3

adapts to assistant and environment

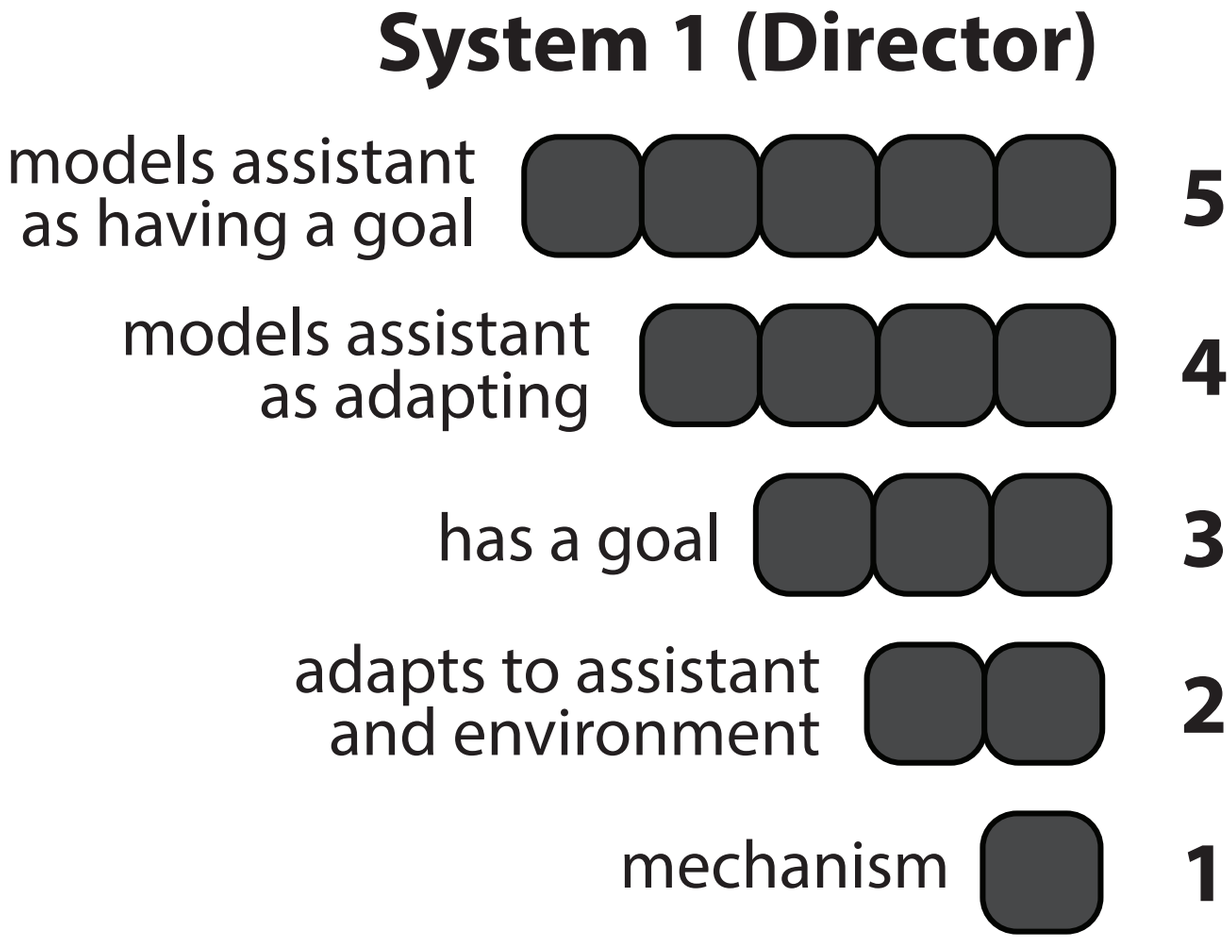


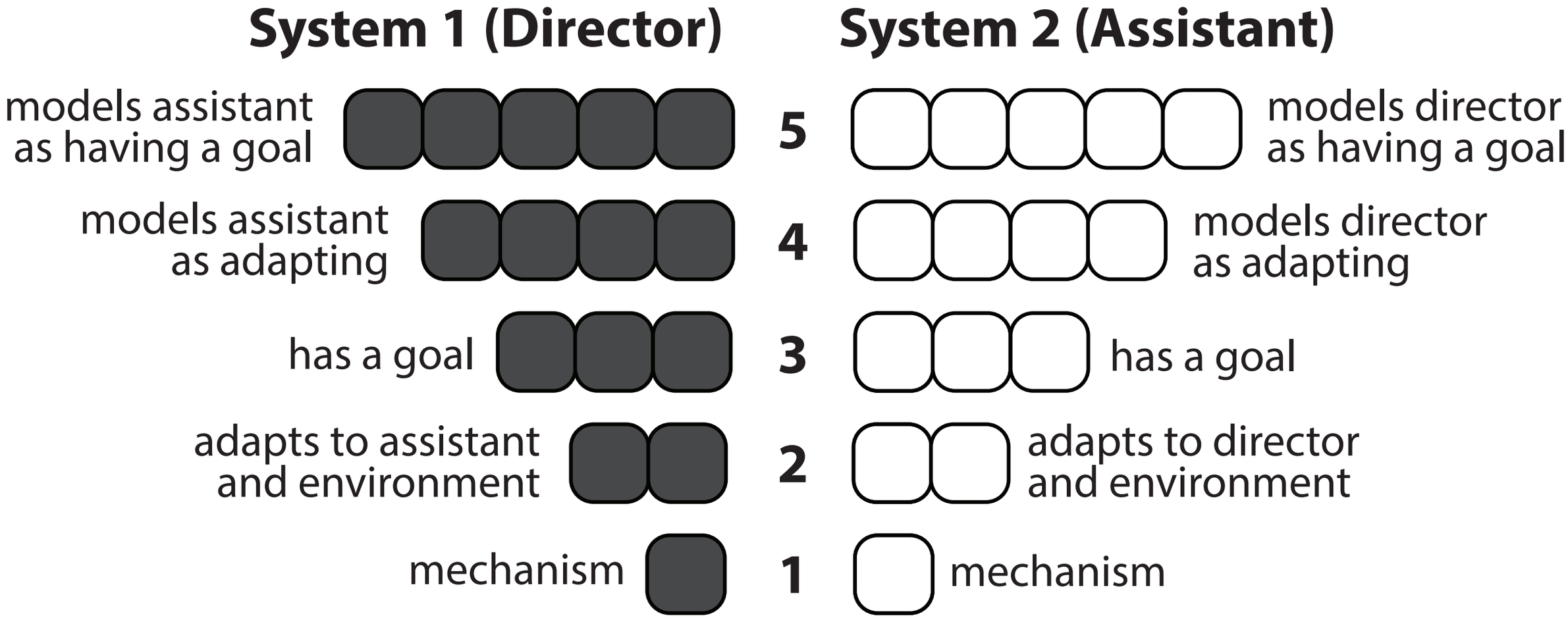
2

mechanism

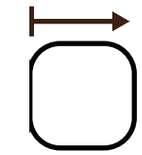


1


System 1 (Director)
models assistant as having a goal
5
models assistant as adapting
4
has a goal
3
adapts to assistant and environment
2
mechanism
1

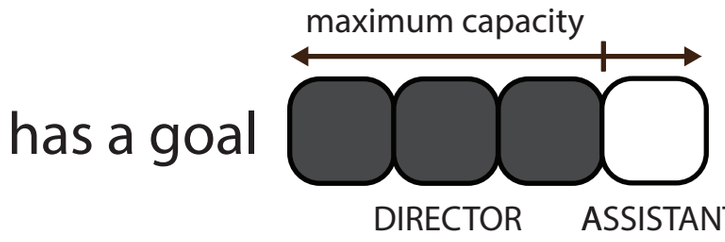

System 1 (Director)
System 2 (Assistant)
models assistant as having a goal
5
models director as having a goal
models assistant as adapting
4
models director as adapting
has a goal
3
has a goal
adapts to assistant and environment
2
adapts to director and environment
mechanism
1
mechanism

Combinations and Capacity



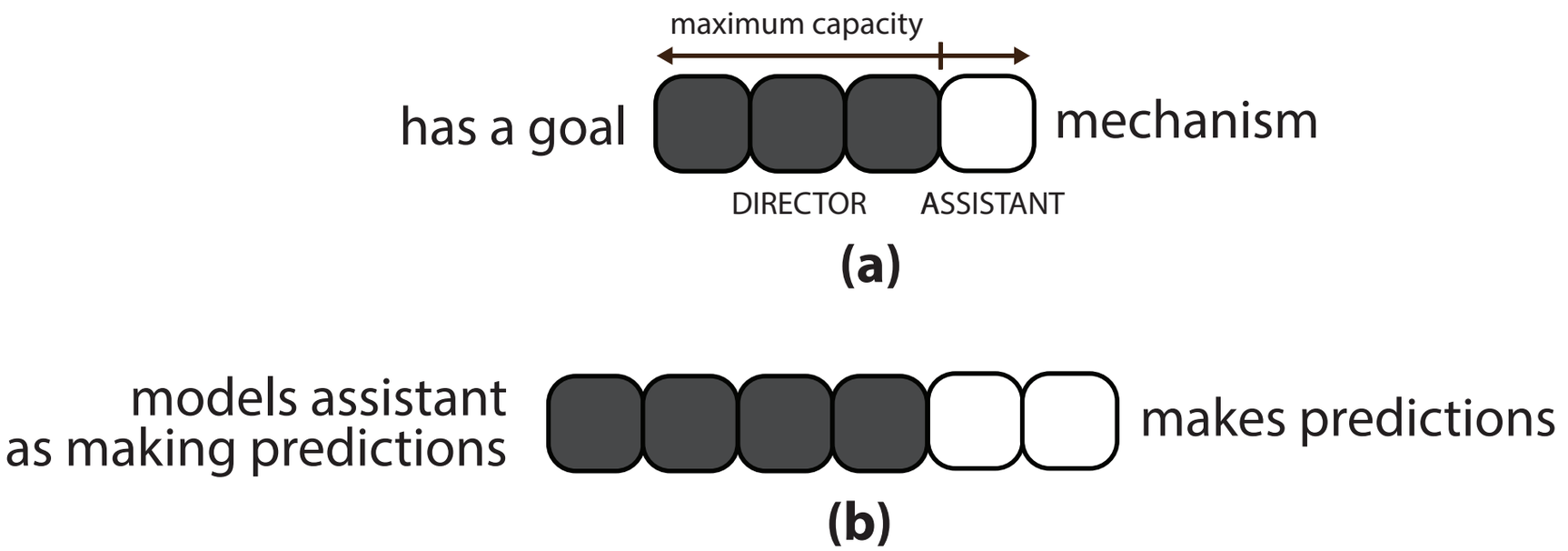
(a)

Combinations and Capacity

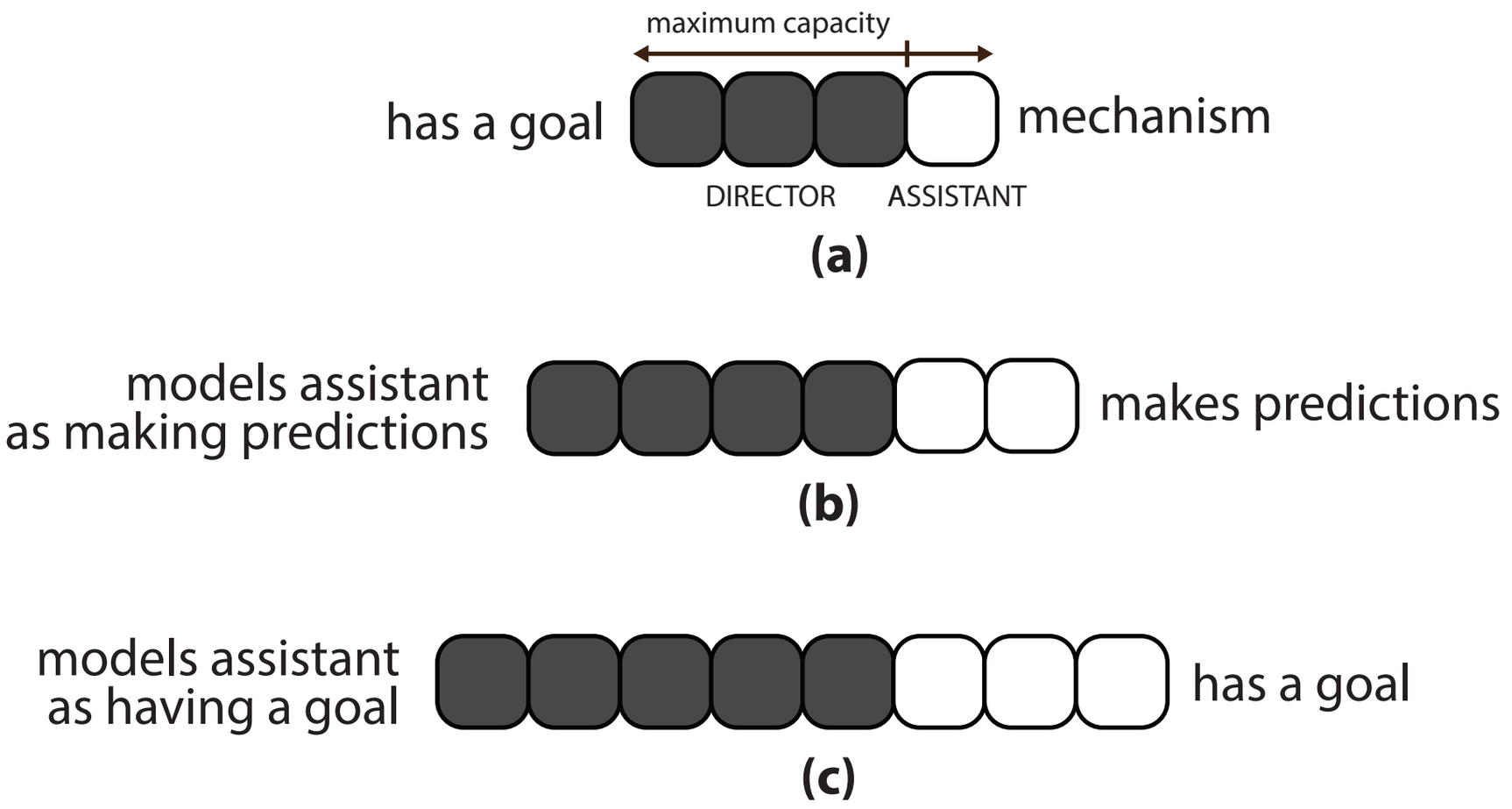


(a)

Combinations and Capacity



Combinations and Capacity



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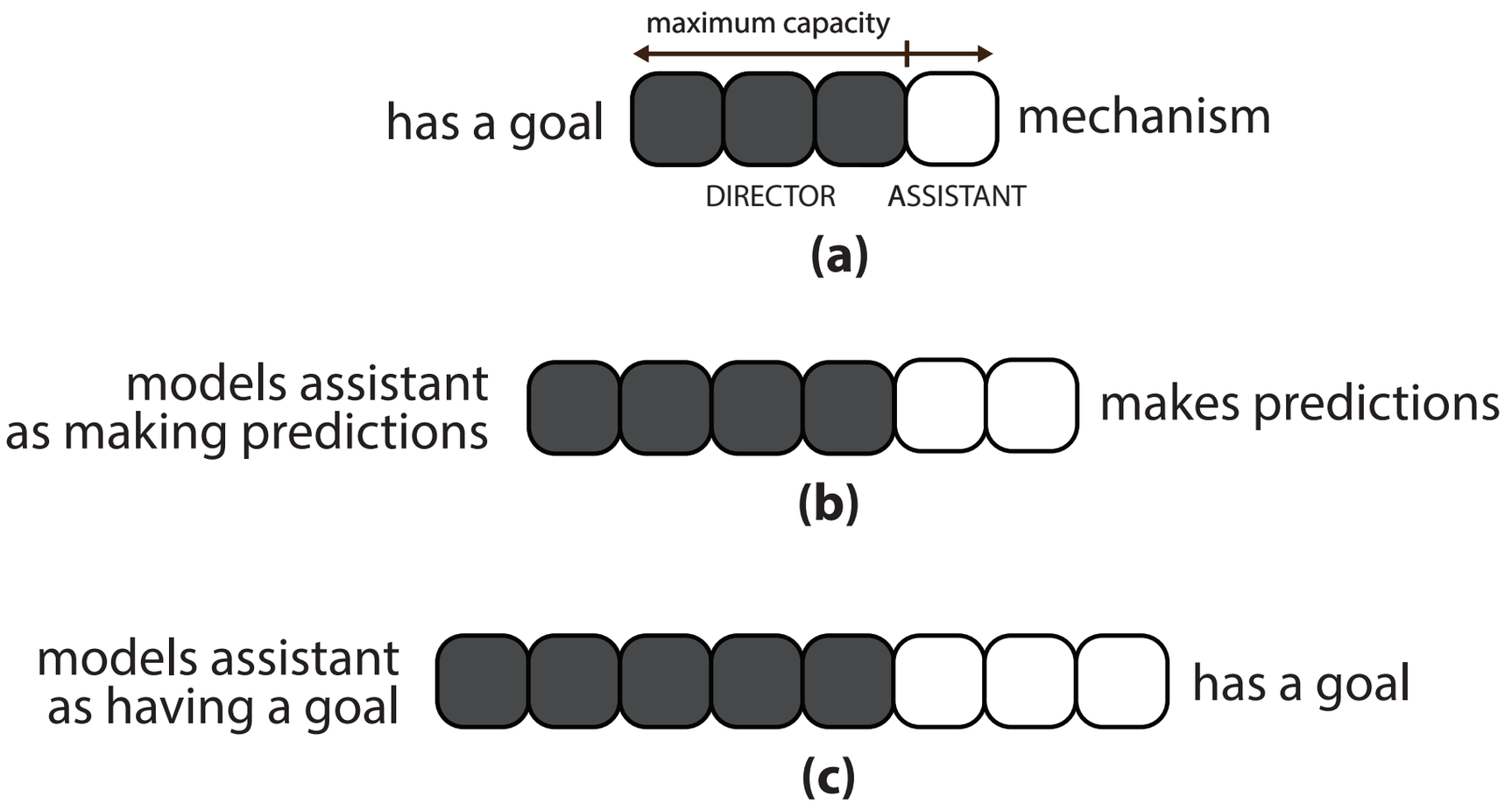
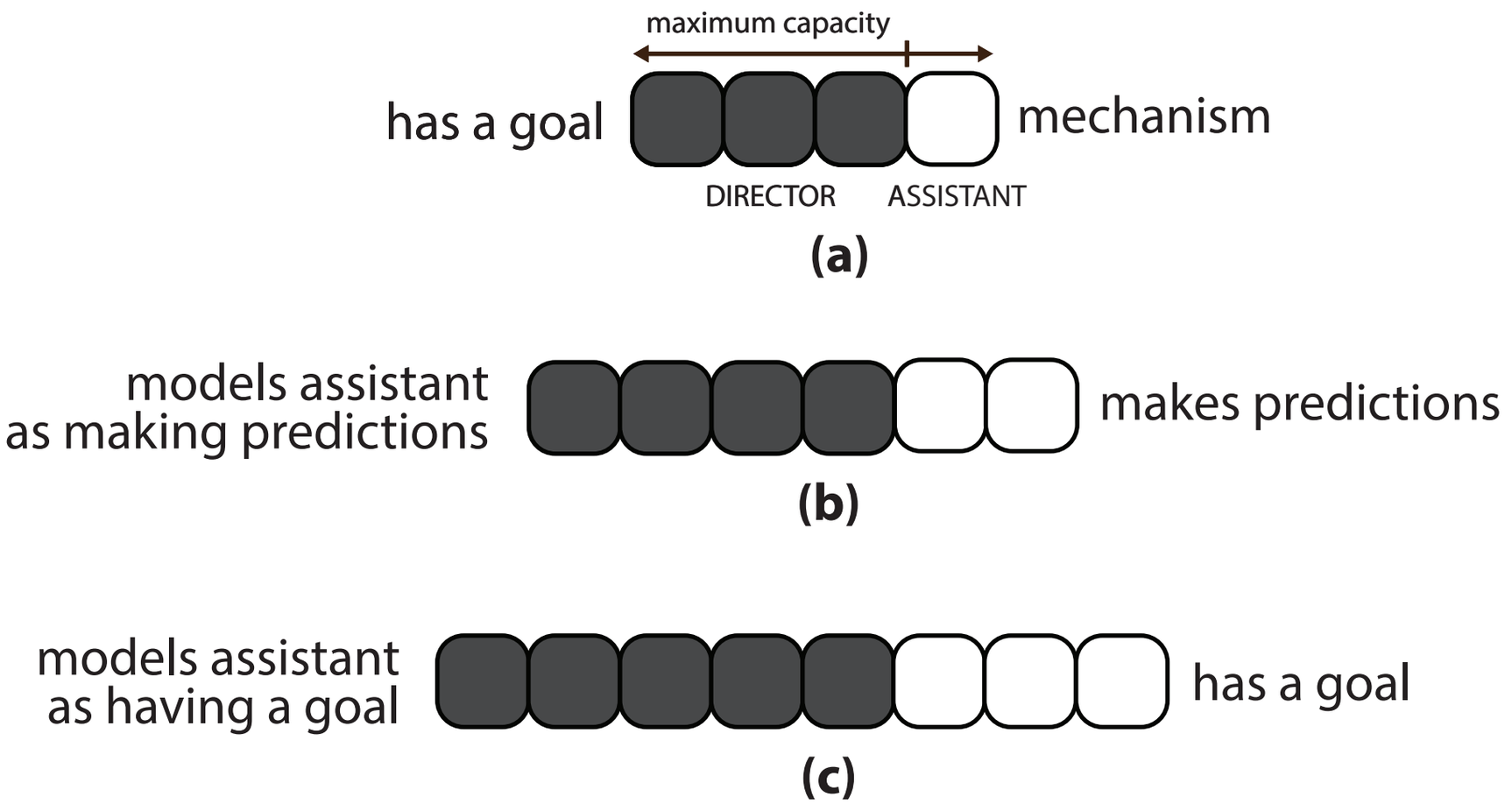
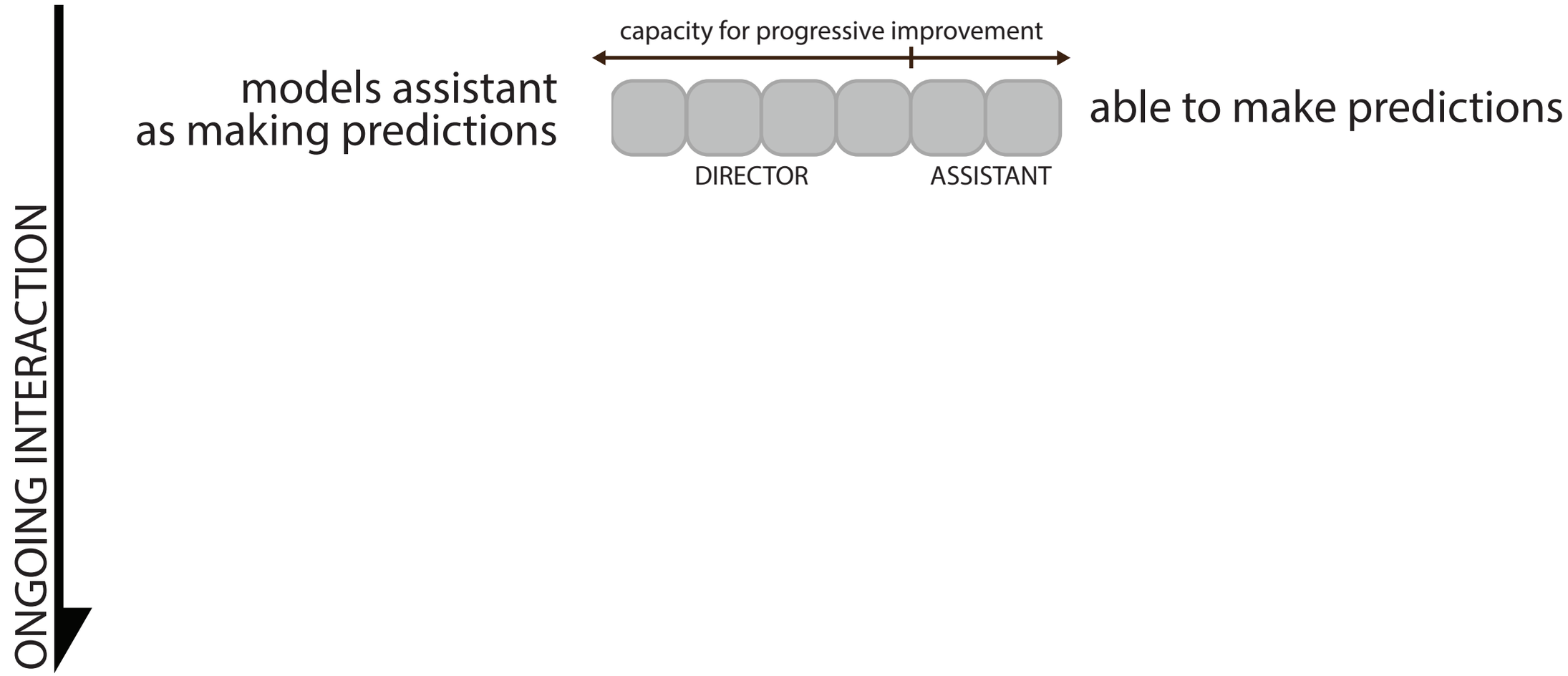


Combinations and Capacity



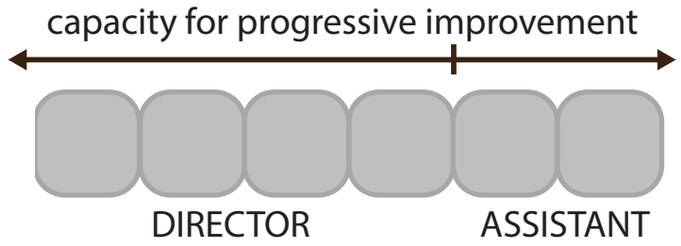
Improvement Through Interaction



Improvement Through Interaction

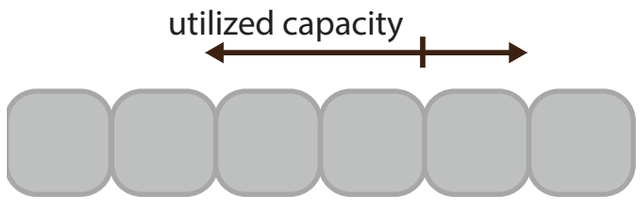
ONGOING INTERACTION

models assistant
as making predictions



able to make predictions

understands how
predictions and signals
impact control

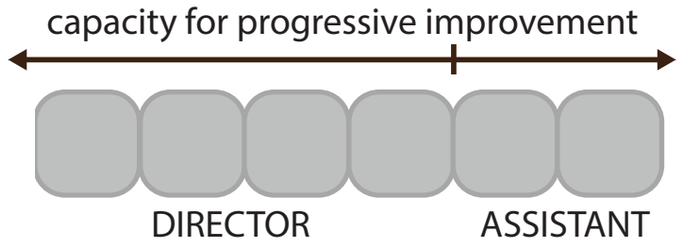


improves predictions

Improvement Through Interaction

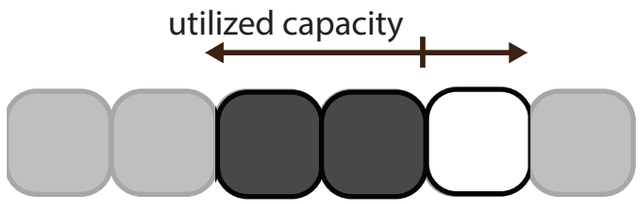
ONGOING INTERACTION

models assistant as making predictions



able to make predictions

understands how predictions and signals impact control

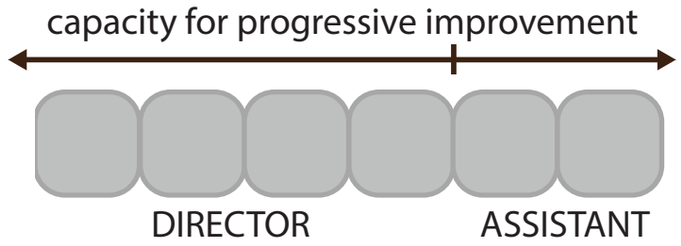


improves predictions

Improvement Through Interaction

ONGOING INTERACTION

models assistant as making predictions



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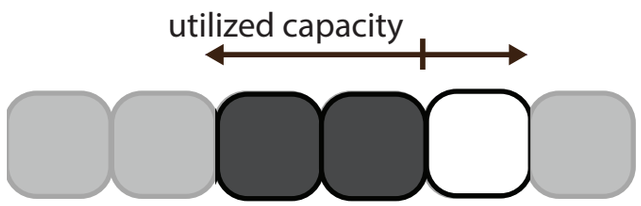
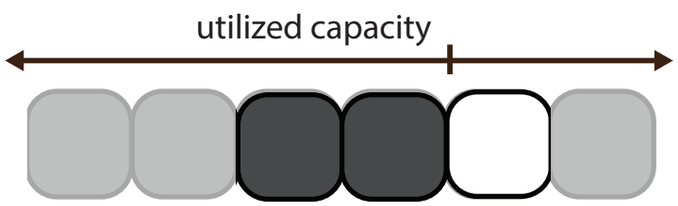


improves predictions

provides clear signals to assistant

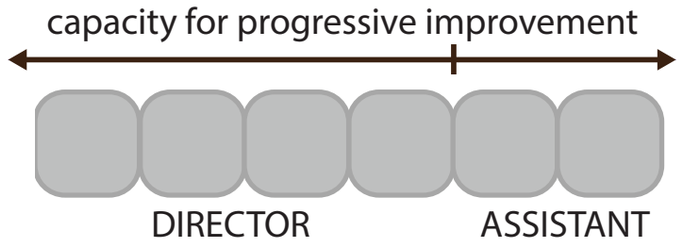


makes accurate predictions about director and environment

Improvement Through Interaction

ONGOING INTERACTION

models assistant as making predictions



able to make predictions

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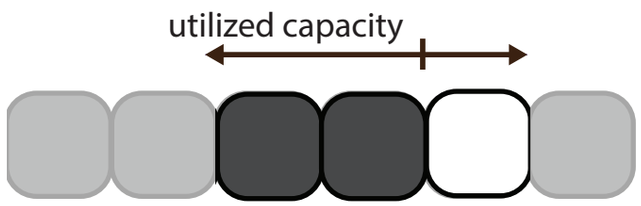
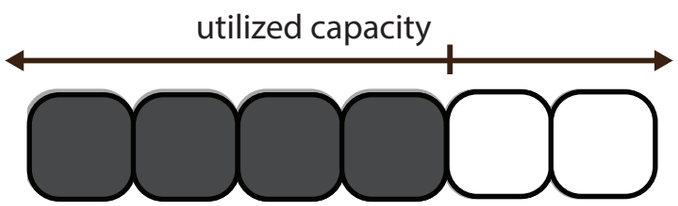


improves predictions

provides clear signals to assistant

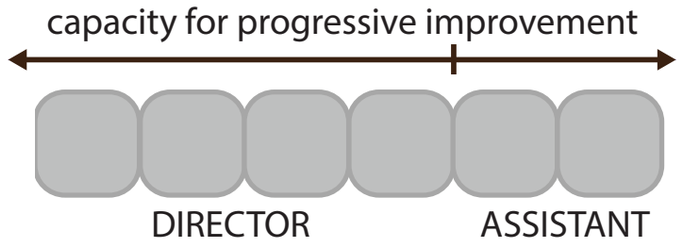


makes accurate predictions about director and environment

Improvement Through Interaction

ONGOING INTERACTION

models assistant as making predictions



able to make predictions

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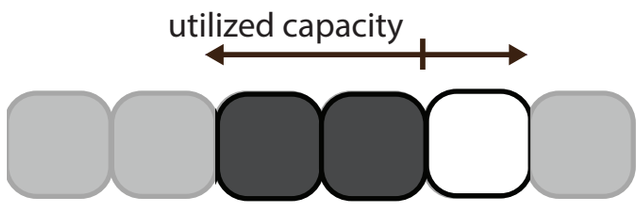
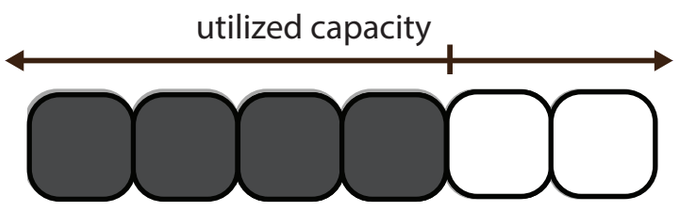


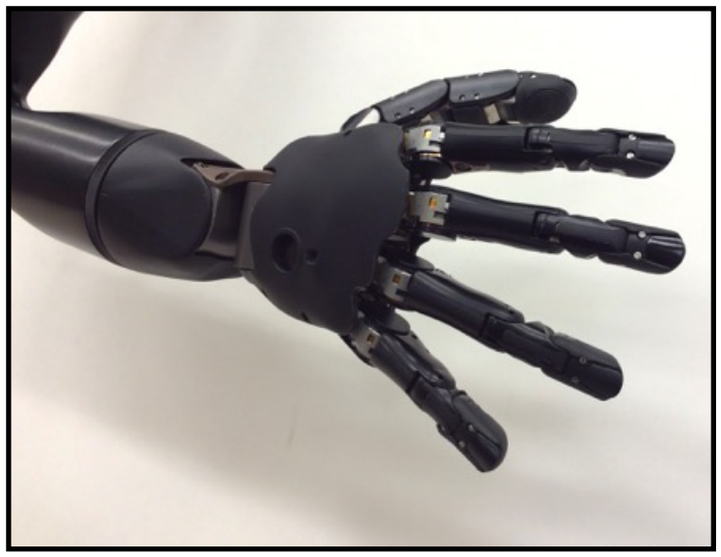
improves predictions

provides clear signals to assistant



makes accurate predictions about director and environment

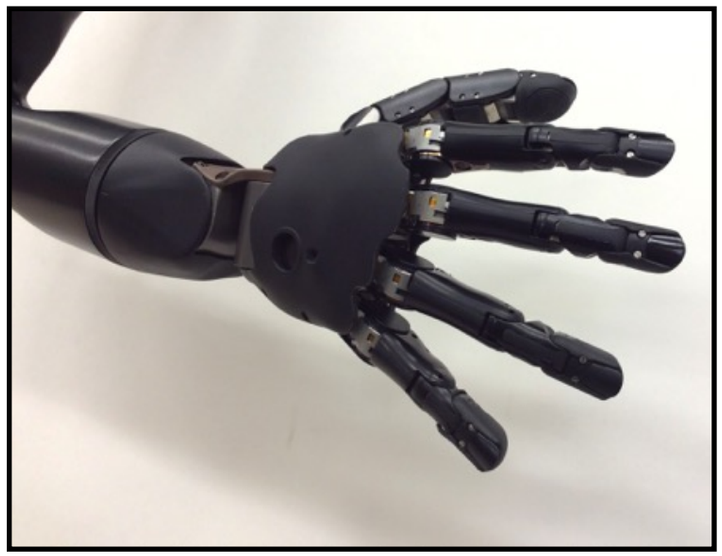
Building up *Communicative Capital*



System 1 (Director) **System 2 (Assistant)**

models assistant as having a goal		5	models director as having a goal
models assistant as adapting		4	models director as adapting
has a goal		3	has a goal
has a goal		2	adapts to director and environment
has a goal		1	mechanism

Pilarski et al., PNSMI, 2015



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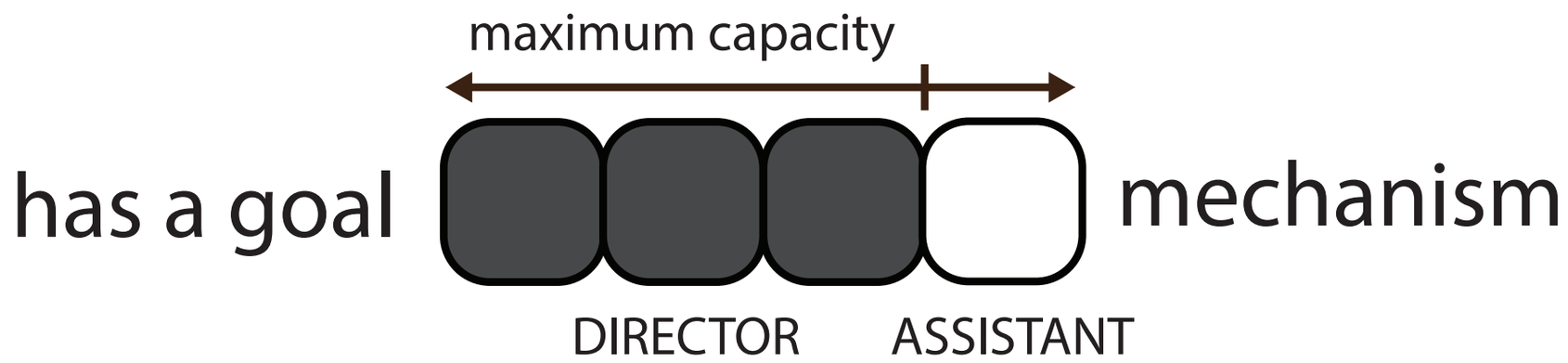
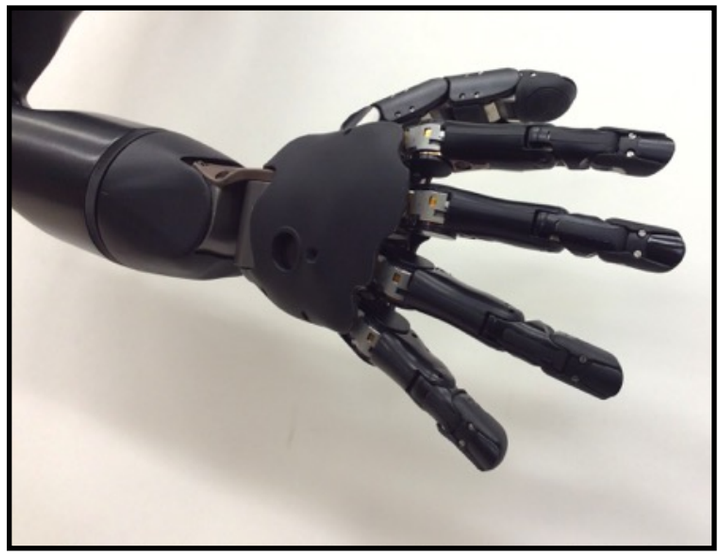
A. Mechanisms

Conventional Myoelectric Control


maximum capacity
has a goal
mechanism
DIRECTOR
ASSISTANT

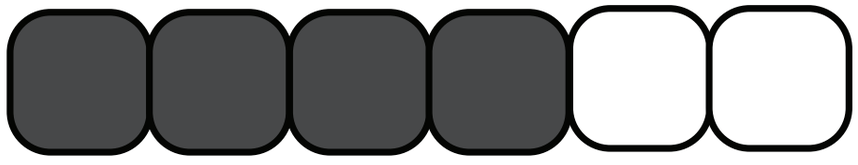
Sequential (Switched) Myoelectric Control



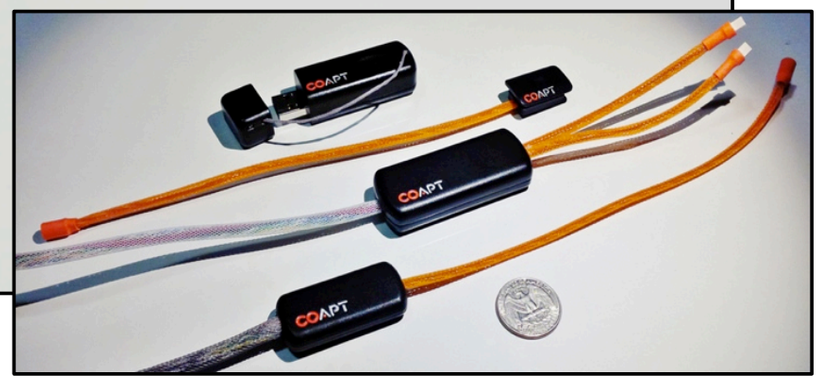
B. Learning

Predictively Enhanced Myoelectric Control

models assistant
as making predictions



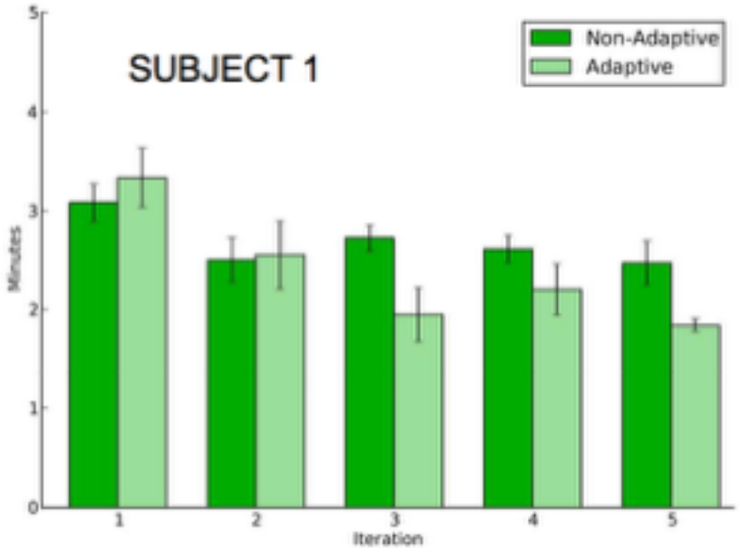
makes predictions

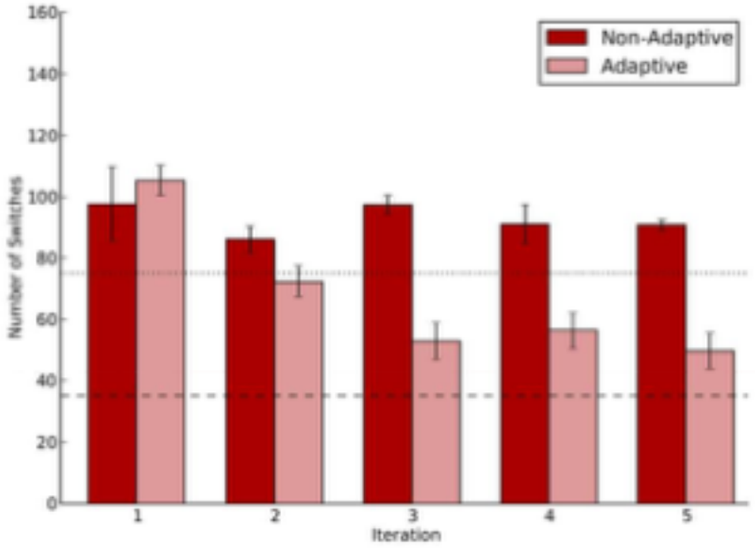


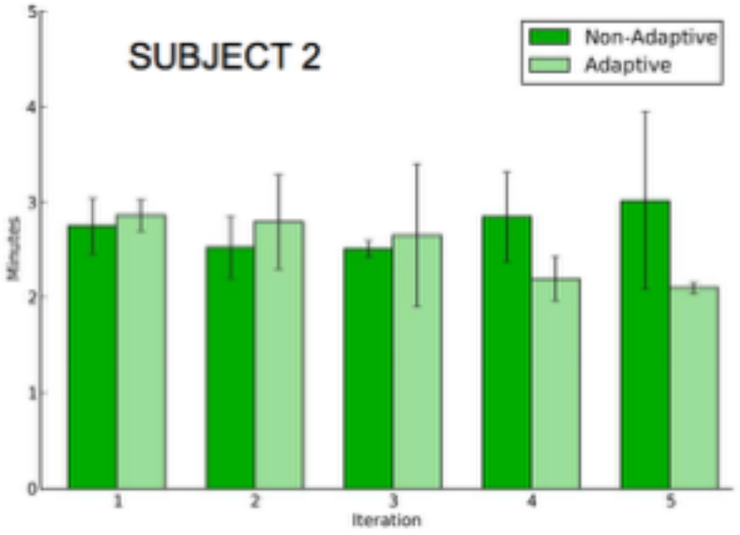
Commercially Deployed Pattern Recognition

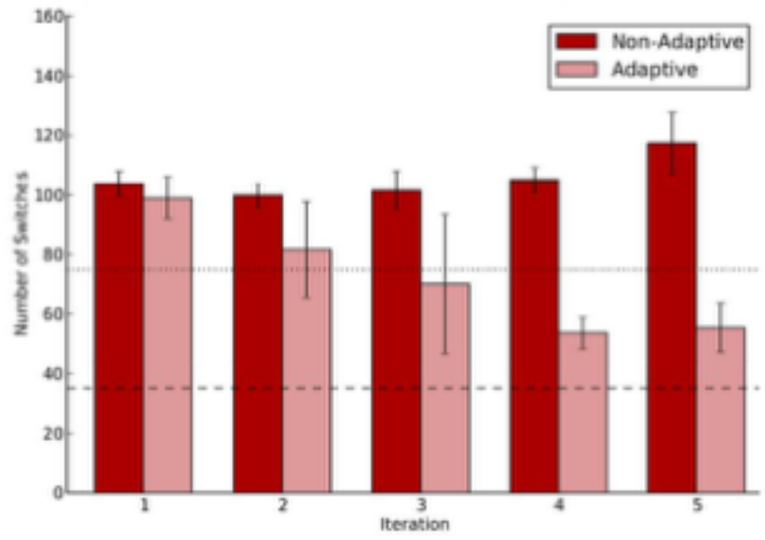
Adaptive Switching

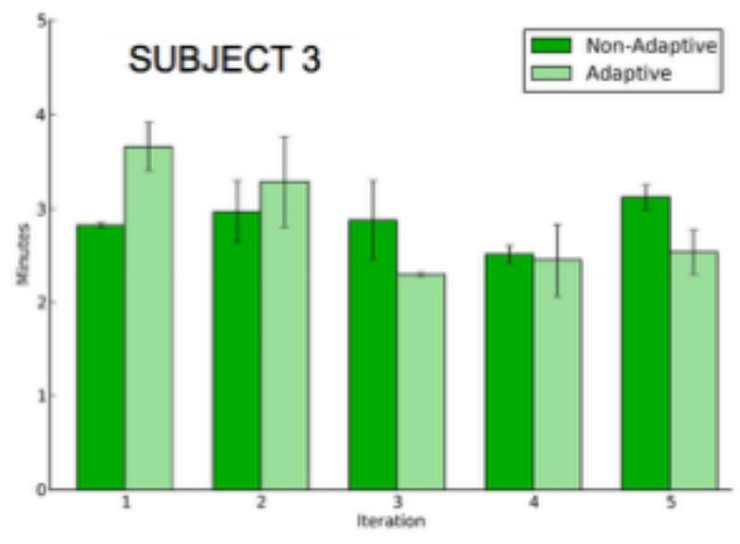
Edwards et al., *MEC*, 2014
Edwards et al., *Prosthetics Orthotics Int.*, 2015

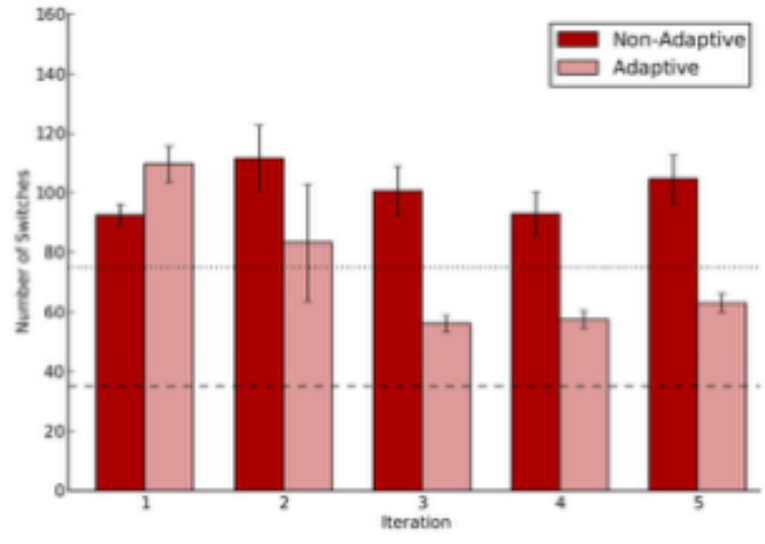




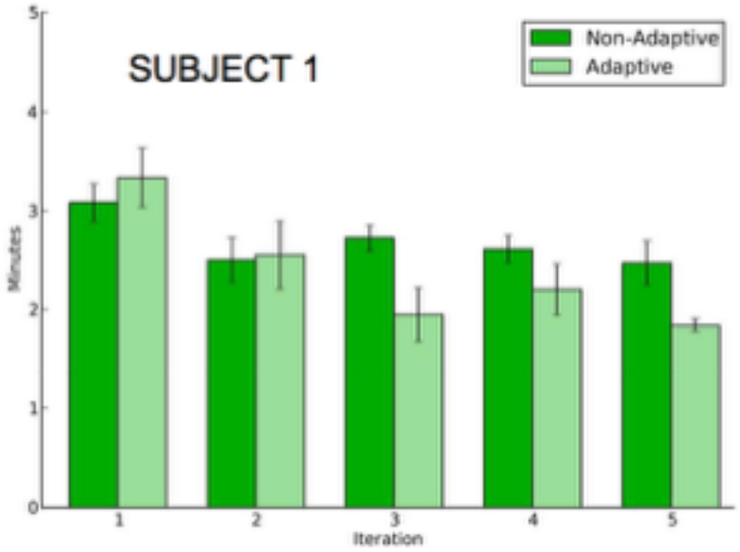


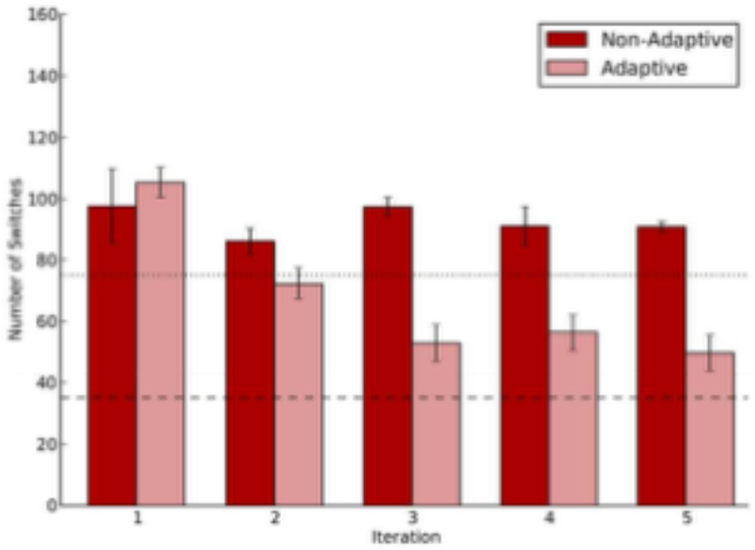


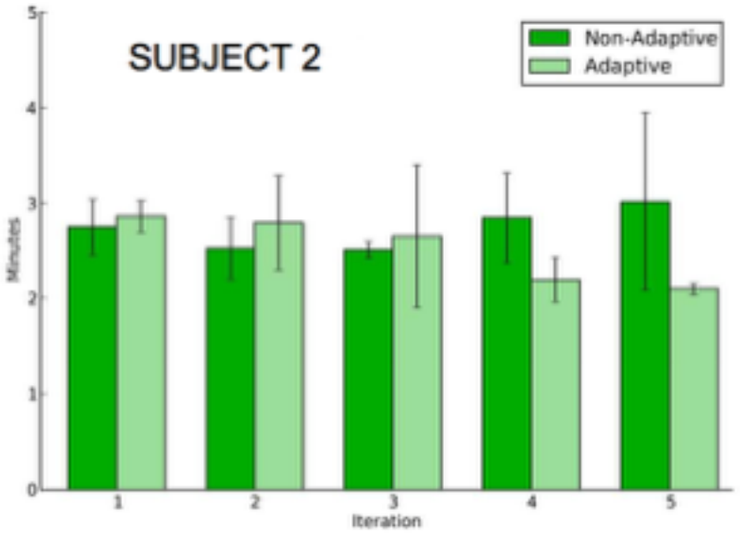


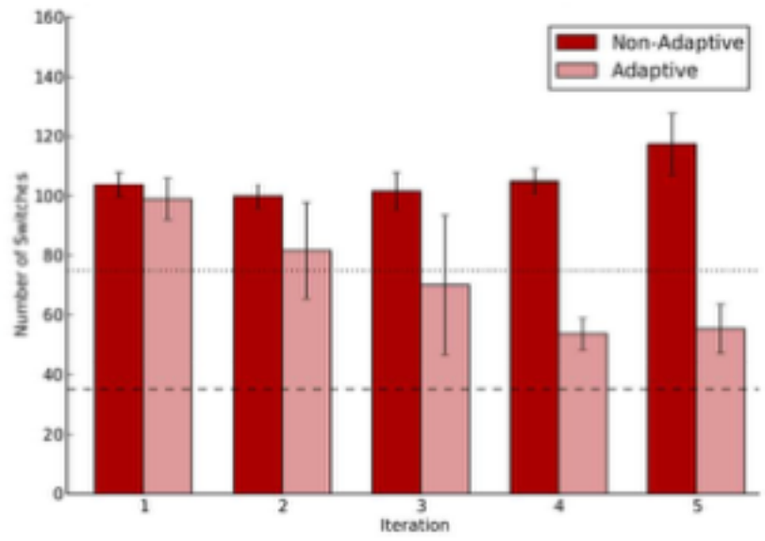


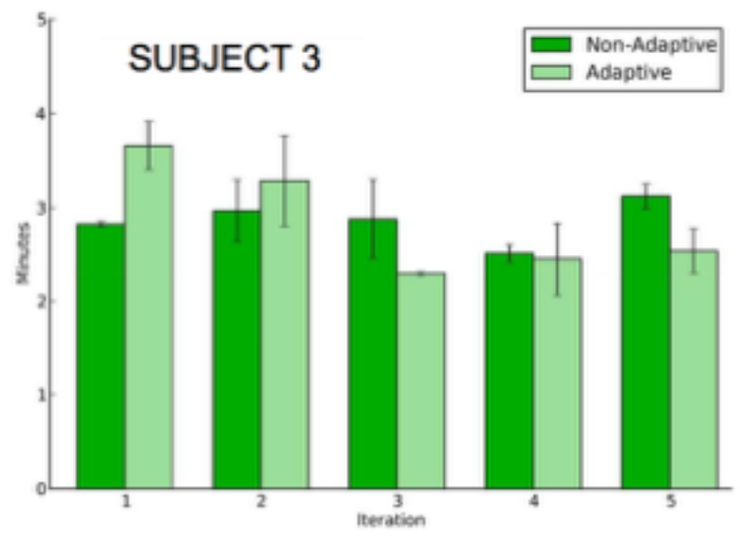
Edwards et al., *Prosthetics Orthotics Int.*, 2015

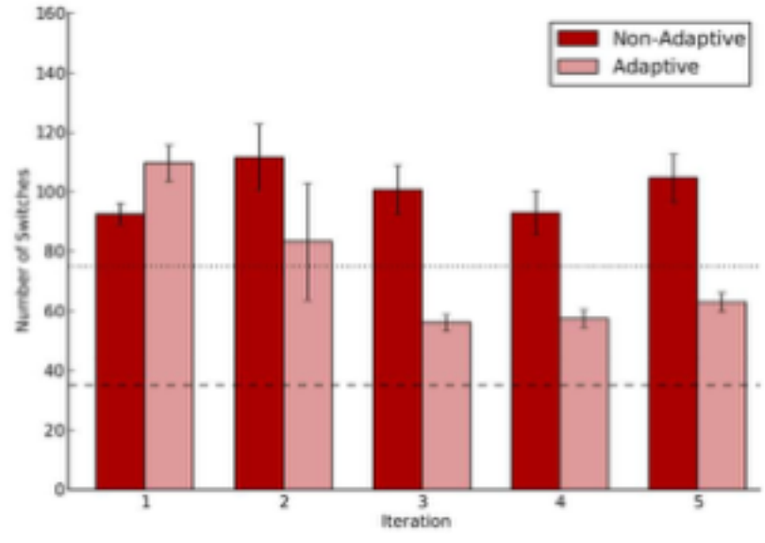




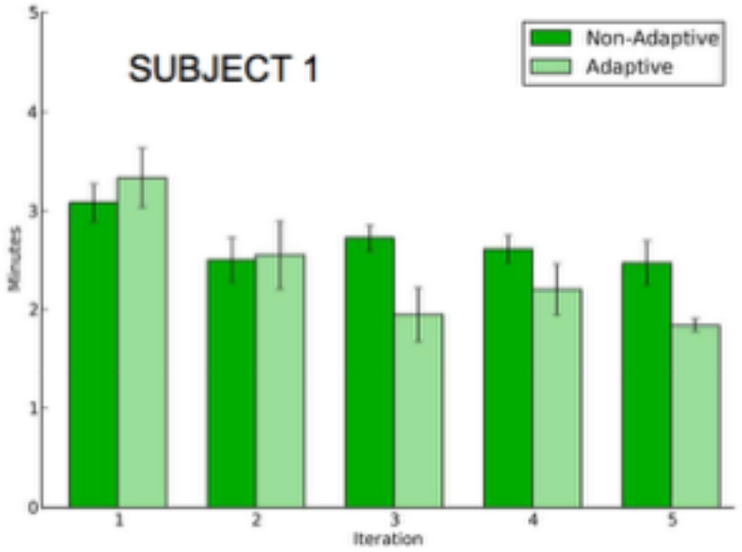


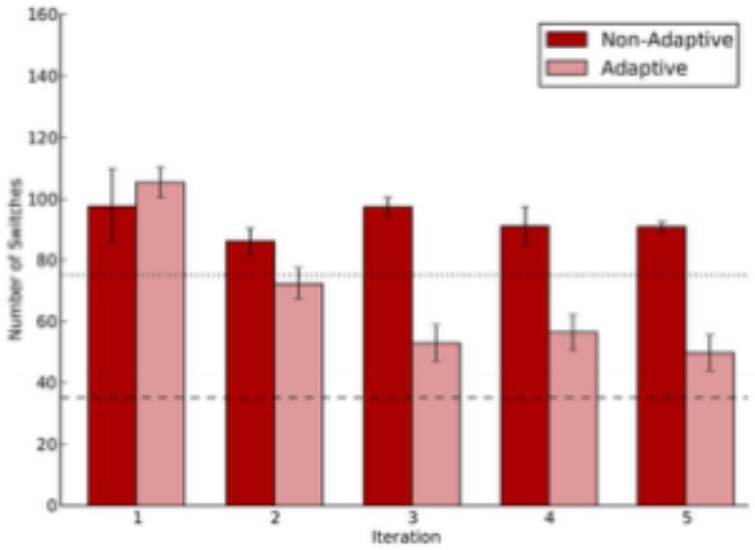


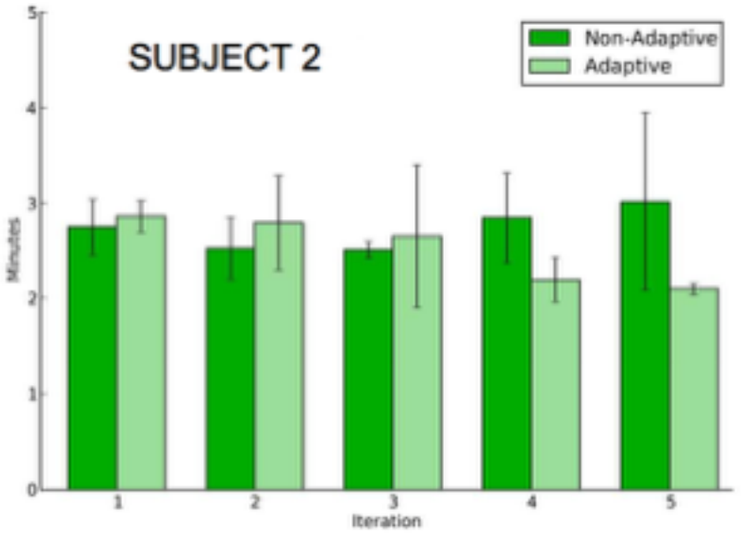


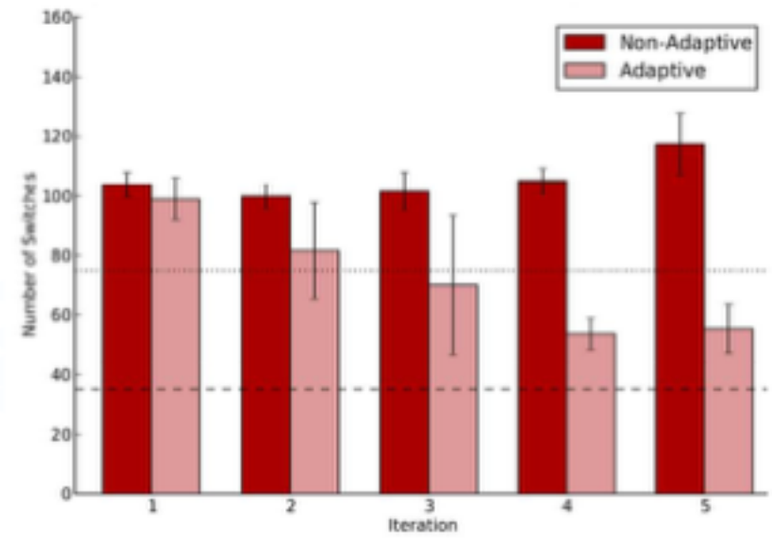


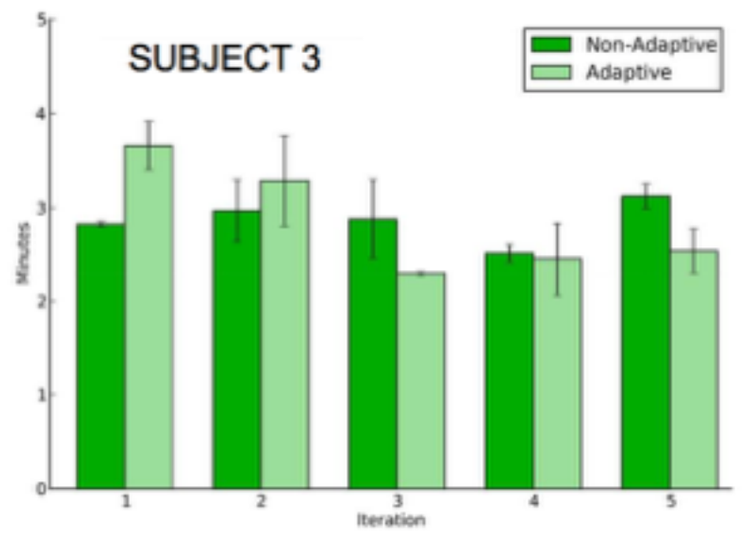
Edwards et al., *Prosthetics Orthotics Int.*, 2015

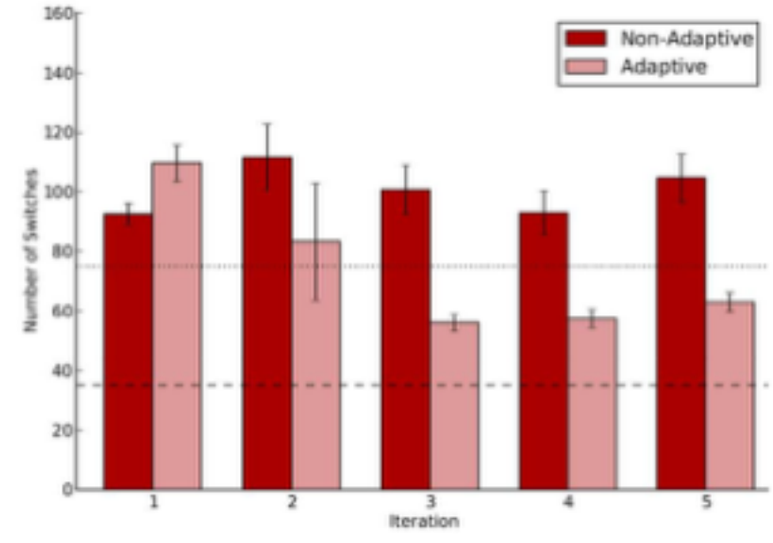




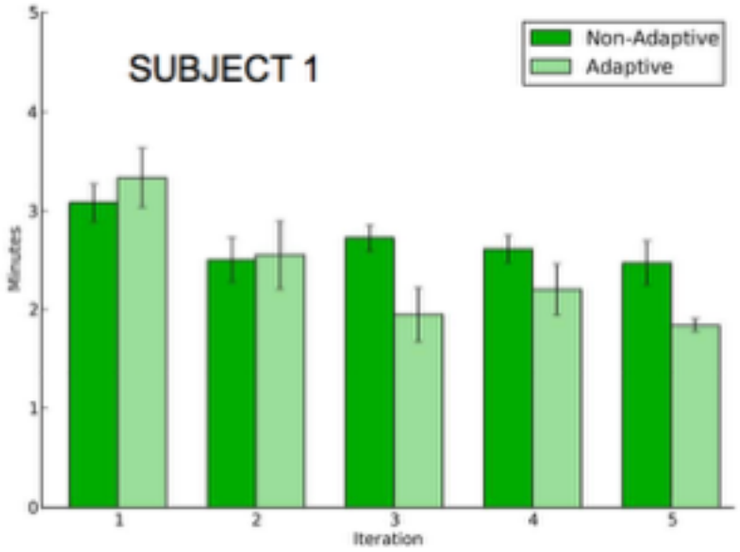


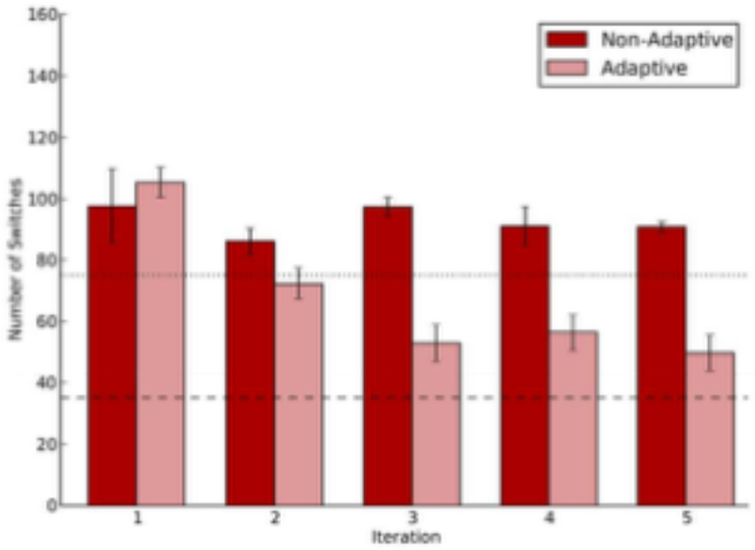


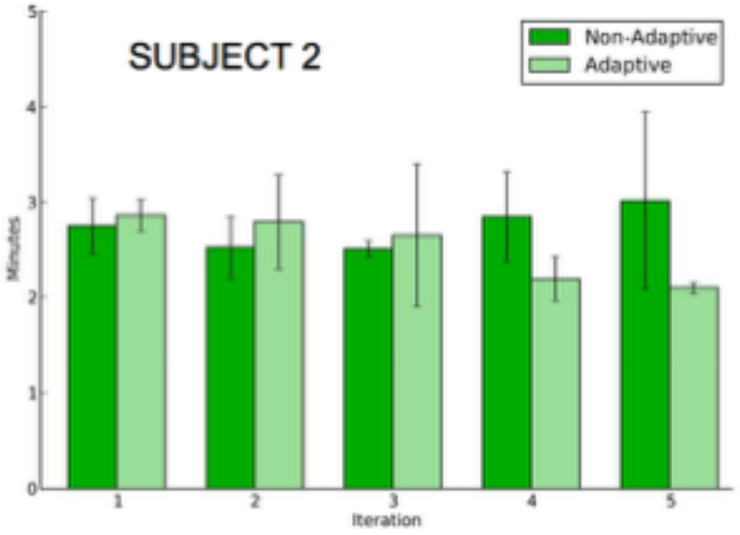


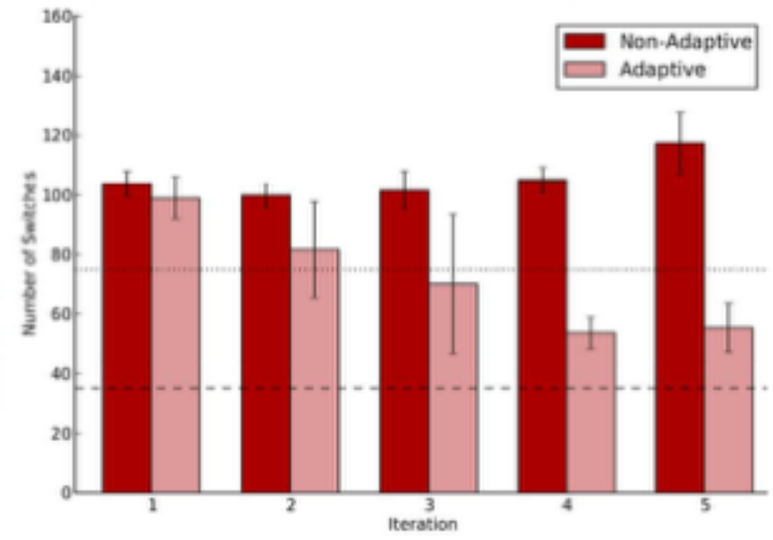


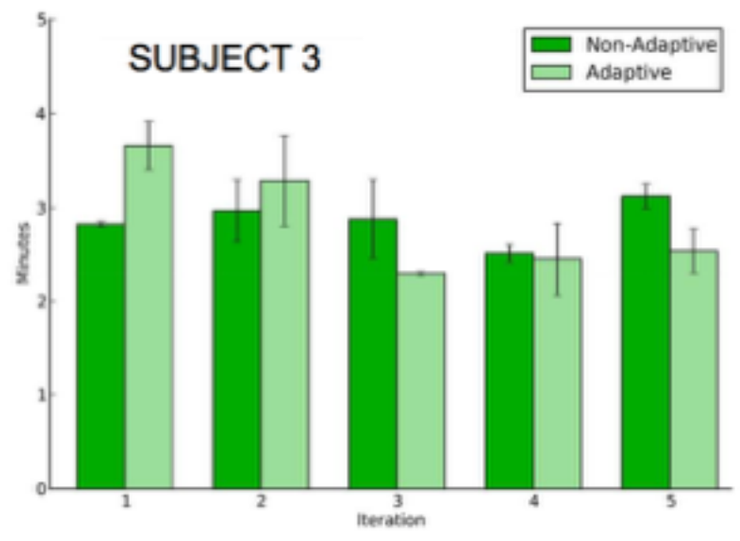
Edwards et al., *Prosthetics Orthotics Int.*, 2015

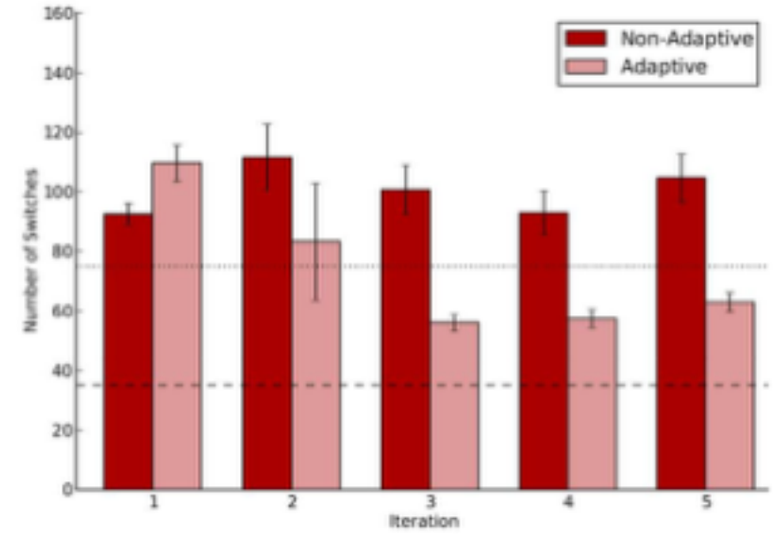


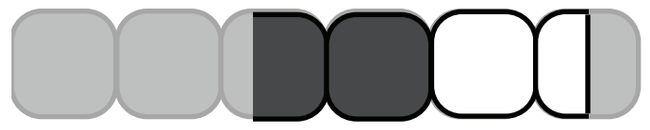










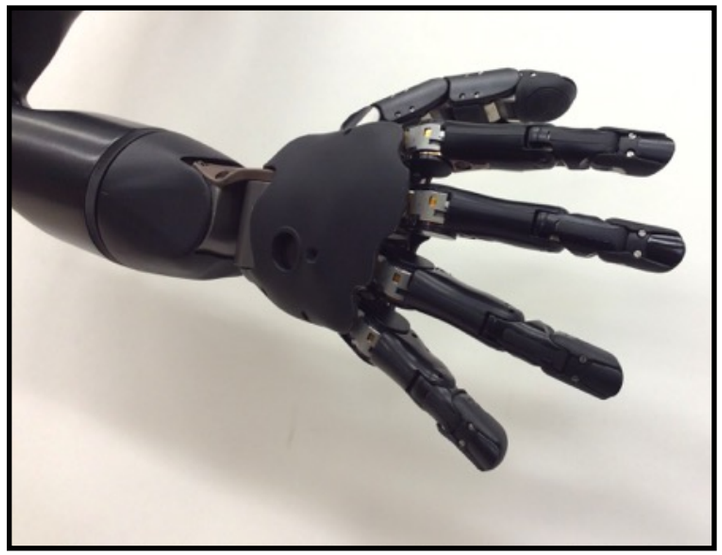


Edwards et al., *Prosthetics Orthotics Int.*, 2015

Autonomous Switching

Edwards et al., *BioRob*, submitted

(learning and unlearning automatic control actions)



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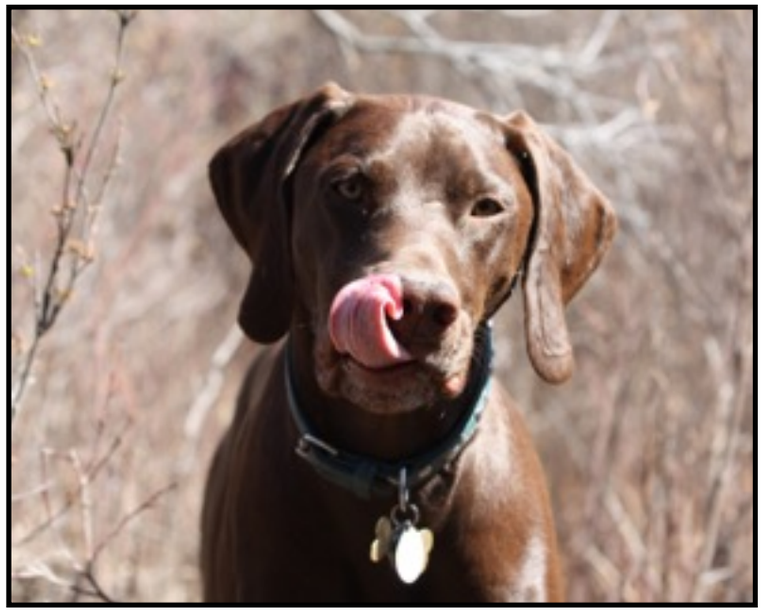
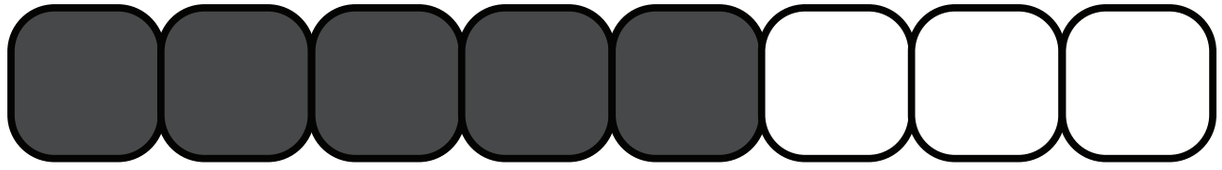


C. Goals

Reward-Based Myoelectric Control

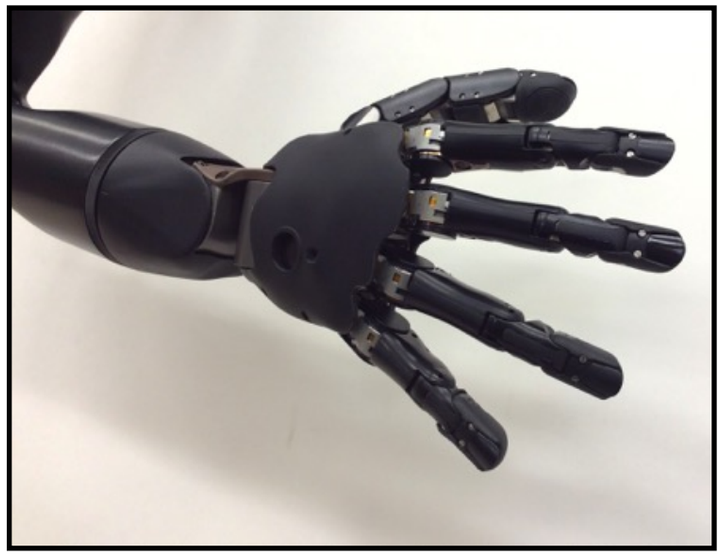
models assistant as having a goal



has a goal

Reward-based Training

Mathewson and Pilarski, *IJCAI-IML*, submitted



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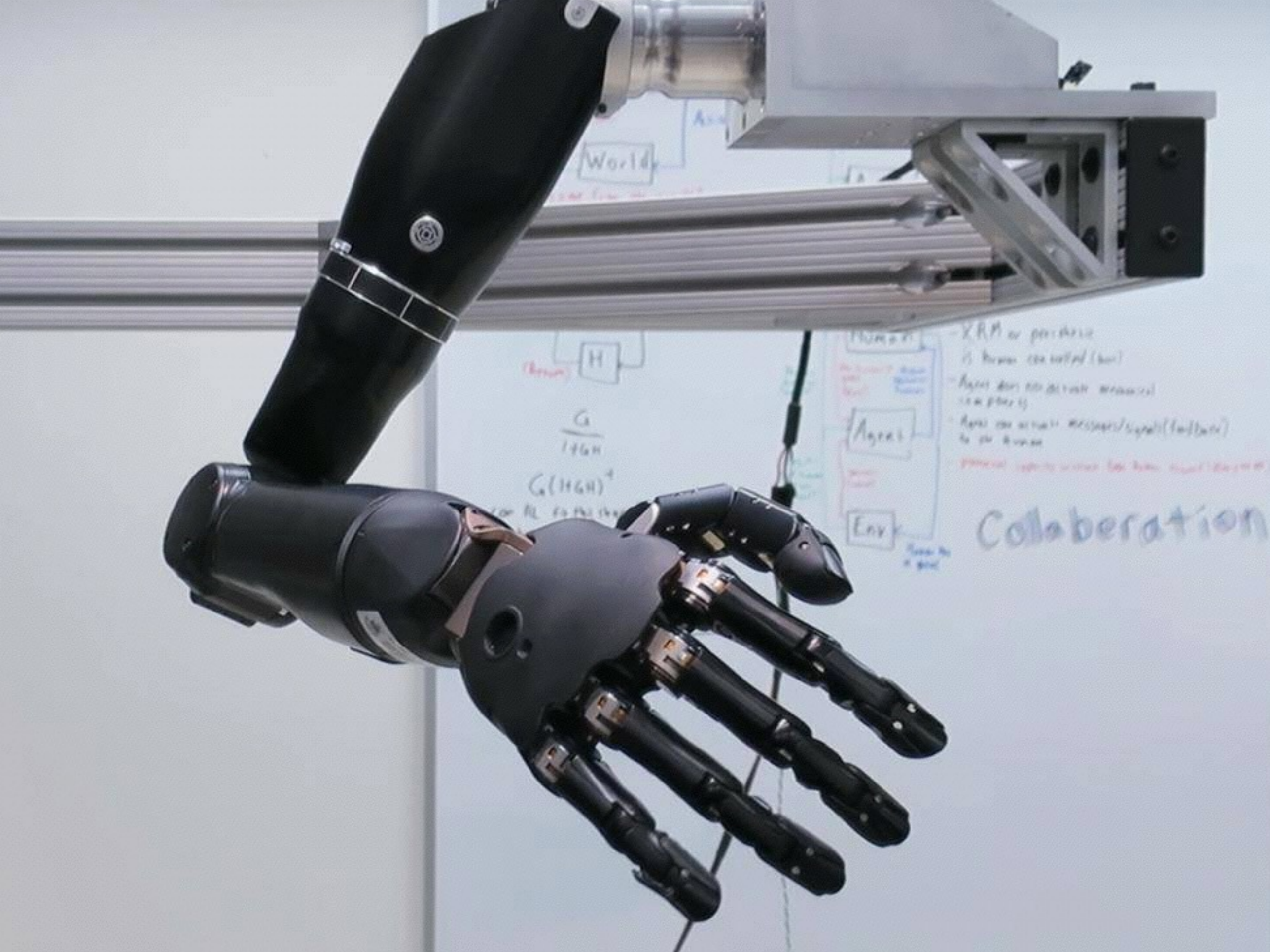
D. Models and Minds

(or at least, in that general direction)


World
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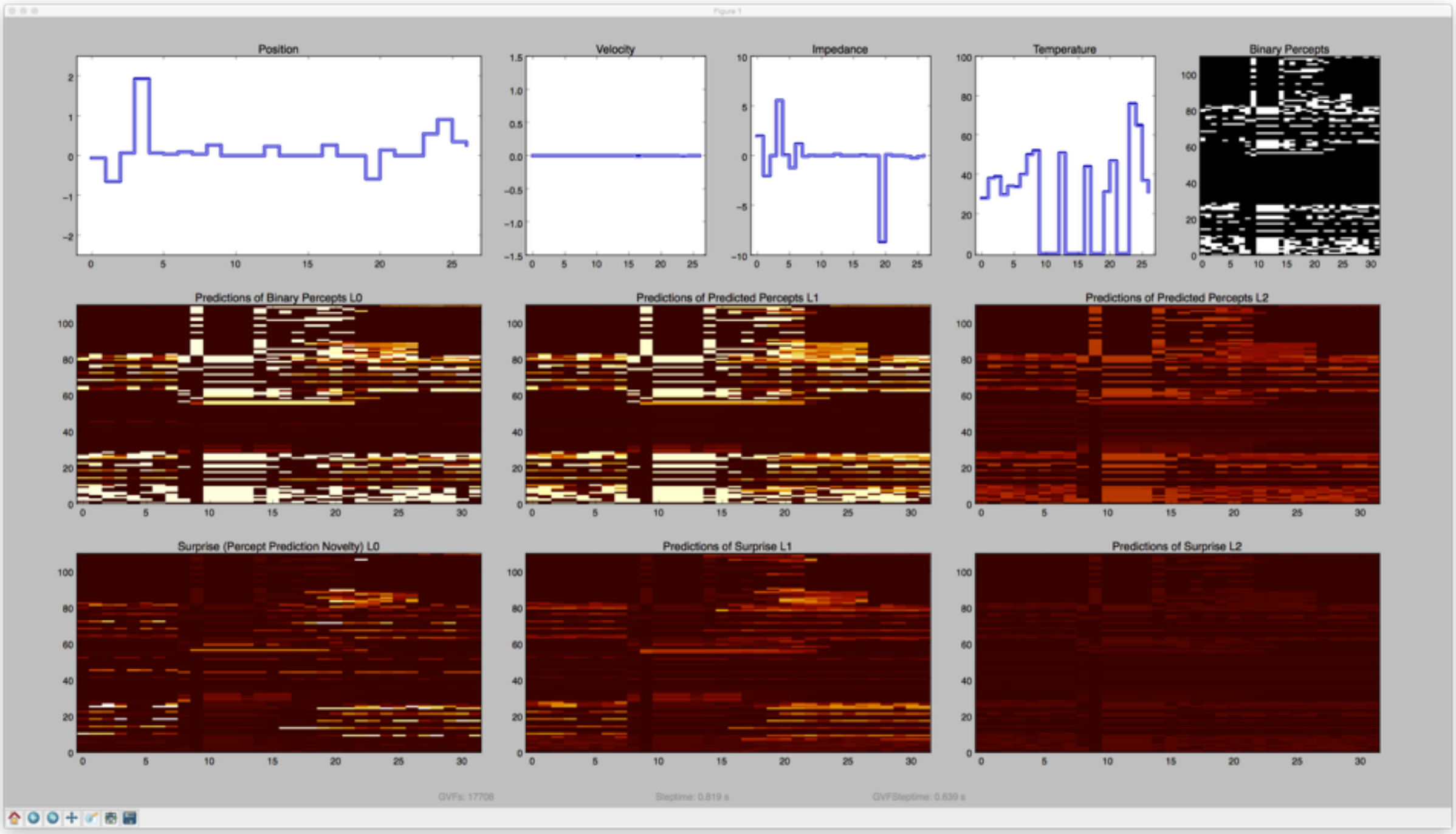
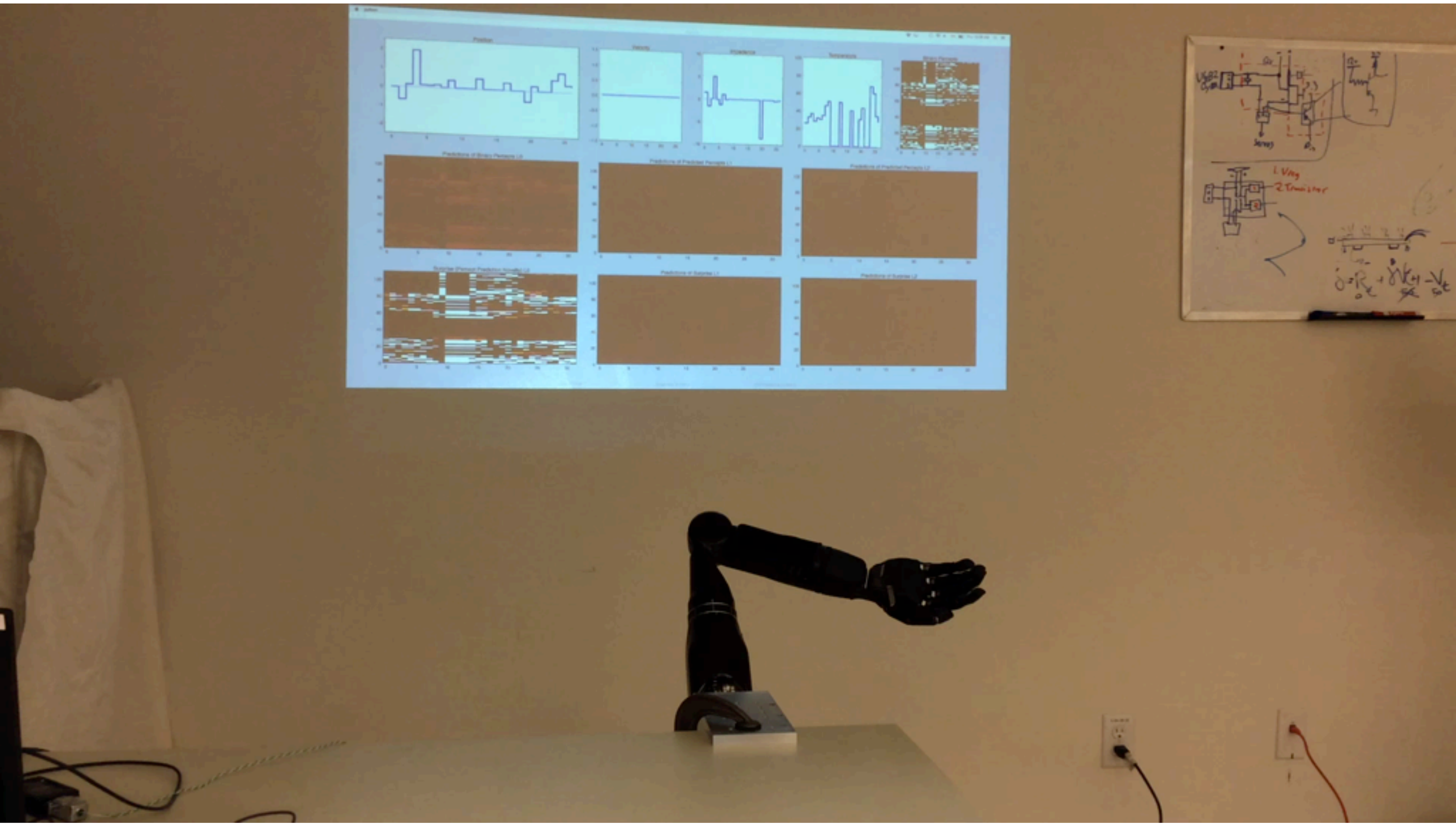
Collaboration



Communicative capital: work expended to build up knowledge about internal and external signals



Pilarski Lab, Feb. 25, 2016
(Pilarski and Sherstan, *BioRob*, submitted)

Things I Don't Know (or that remain less clear)

- **Scalability of methods.** I want a system to learn and compute 1 Billion GVF predictions per second.
- Where are things going to break? (real-time RL)
- How the heck do I use this GPGPU thing everyone keeps talking about?
- Can I prove that many predictions are useful, or am I just having fun with lots of hardware?

Things I Don't Know (or that remain less clear)

- **Knowledge topologies.** Step 1: get lots of primary predictions. Step 2: **????.** Step 3: Knowledge!

  - What is the right way to automatically build compositionally in a GVF architecture?

  - How do we kick-start learning with examples, demonstrations, and background information?

  - How do we measure learning progress? (happily, we now have good ways to measure human progress)

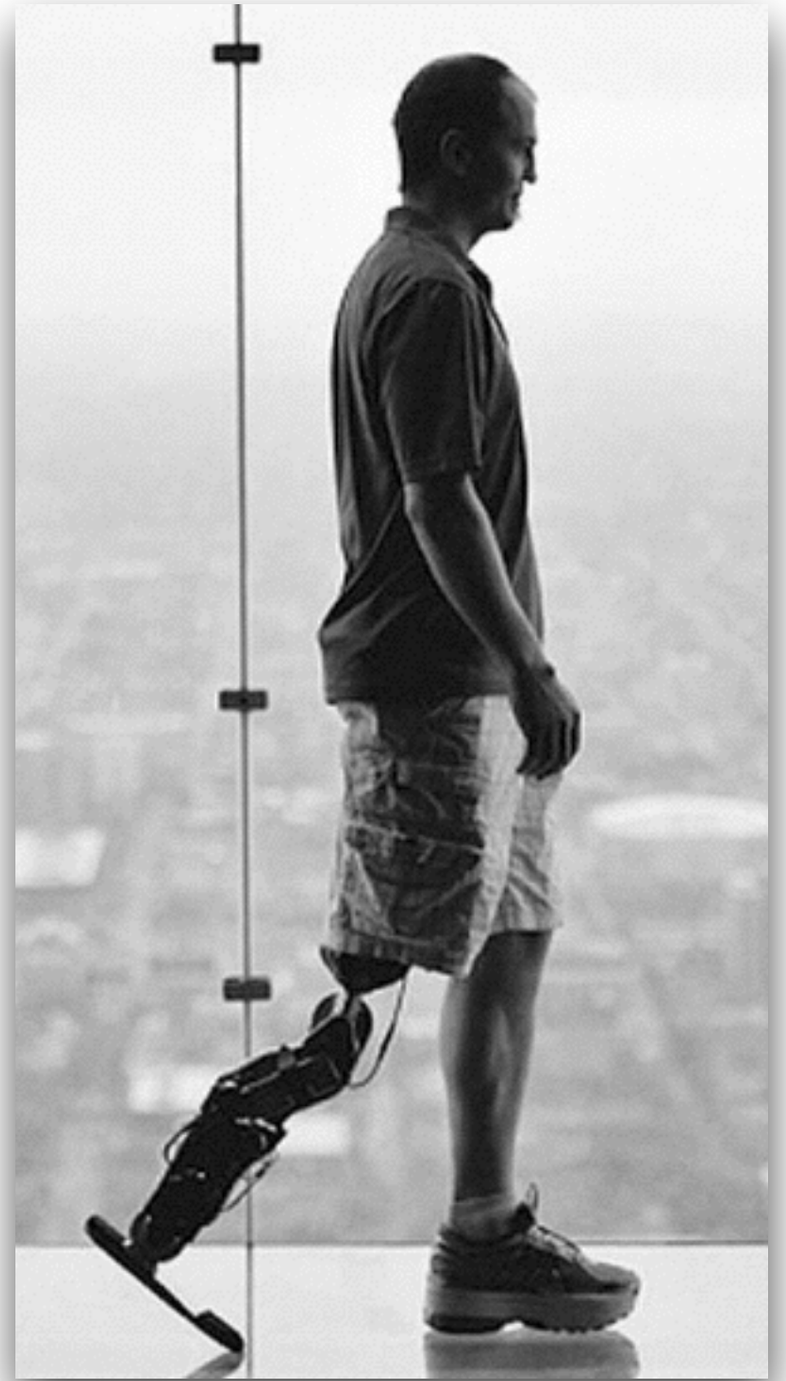
Concluding Remarks

- It is valuable to think of assistive technologies through the lens of autonomy and agency.

- We have presented one schema, with examples, to help explore this viewpoint.

- *Interfaces are all about communication and* ***communicative capital****.*

- **Posit:** mutual improvement (& capital) can best happen when both sides of an interface are full goal-seeking systems.



Zac Vawter at the top of the Willis Tower in Chicago (Photo: The Associated Press).

Funders and Collaborators

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Alberta Innovates Technology Futures

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UNIVERSITY OF ALBERTA FACULTY OF MEDICINE & DENTISTRY

UNIVERSITY OF ALBERTA FACULTY OF REHABILITATION MEDICINE

Thanks to: Richard Sutton, Kory Mathewson, Ann Edwards, Adam Parker, Craig Sherstan, Joseph Modayil, Thomas Degris, Jacqueline Hebert, K. Ming Chan, Michael Rory Dawson, and more!

Questions

... and thank you very much for your attention.

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