

Quantifying Morphological Computation

ShanghAI Lecture, 23.11.2017

Keyan Ghazi-Zahedi

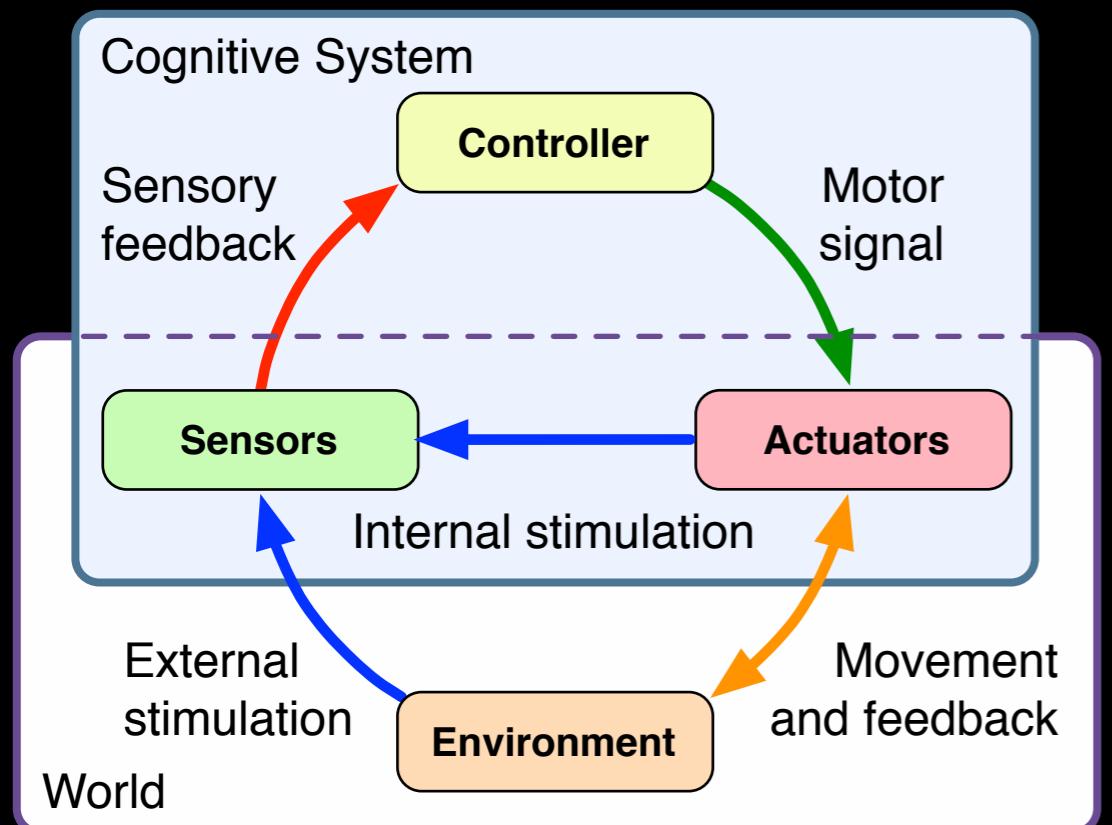
Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany

zahedi@mis.mpg.de

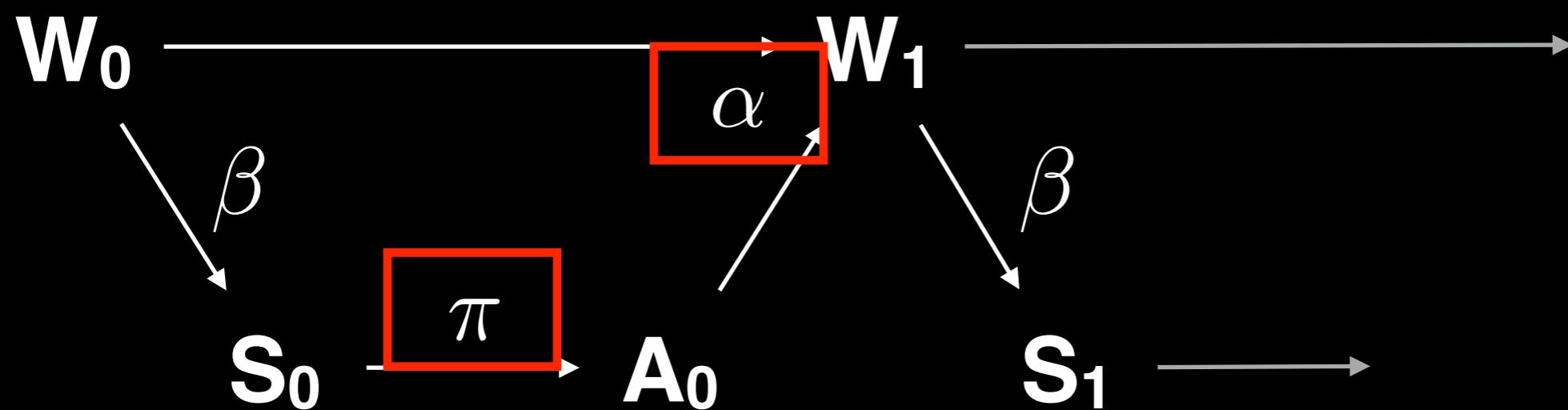


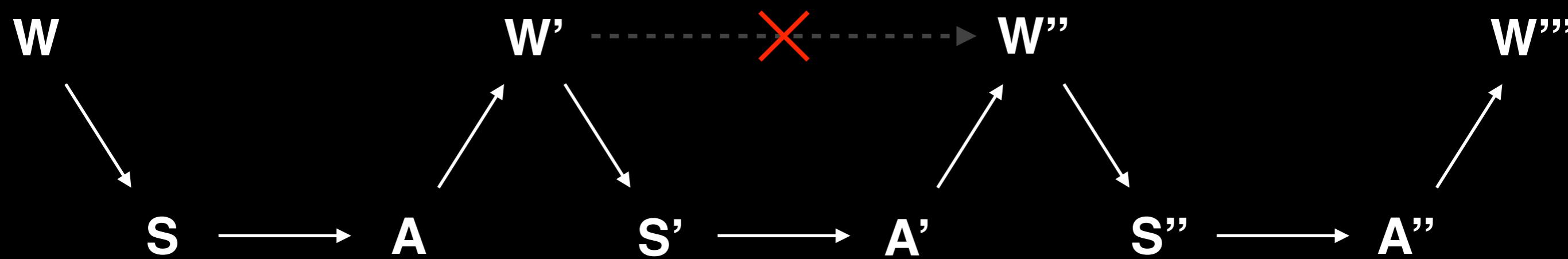
Kilian Jornet Burgada

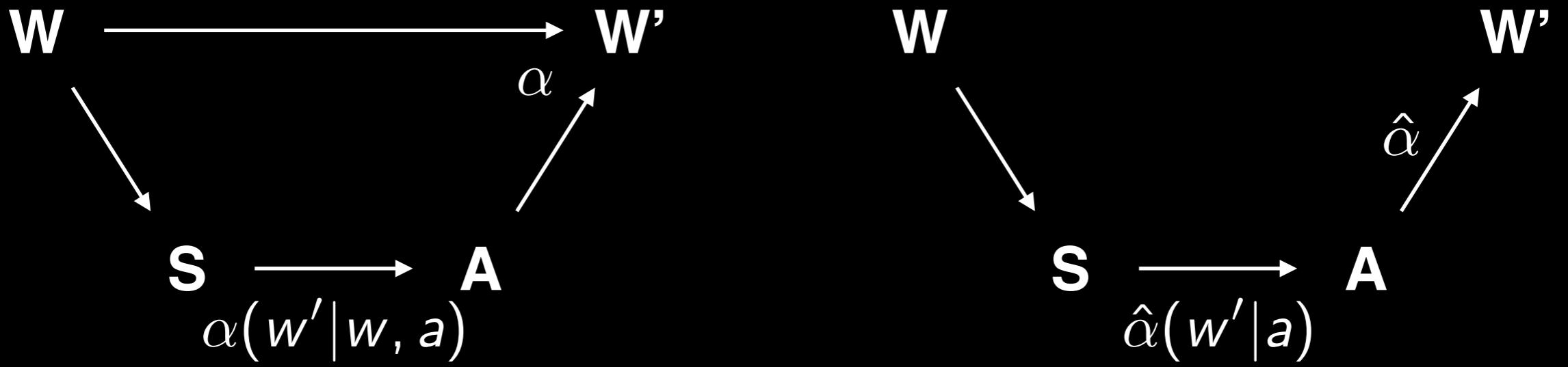
Morphological Computation:
Contribution of body-environment interactions to
the reduction of controller complexity



Bryce Harper, Source: Wolf Haley, YouTube







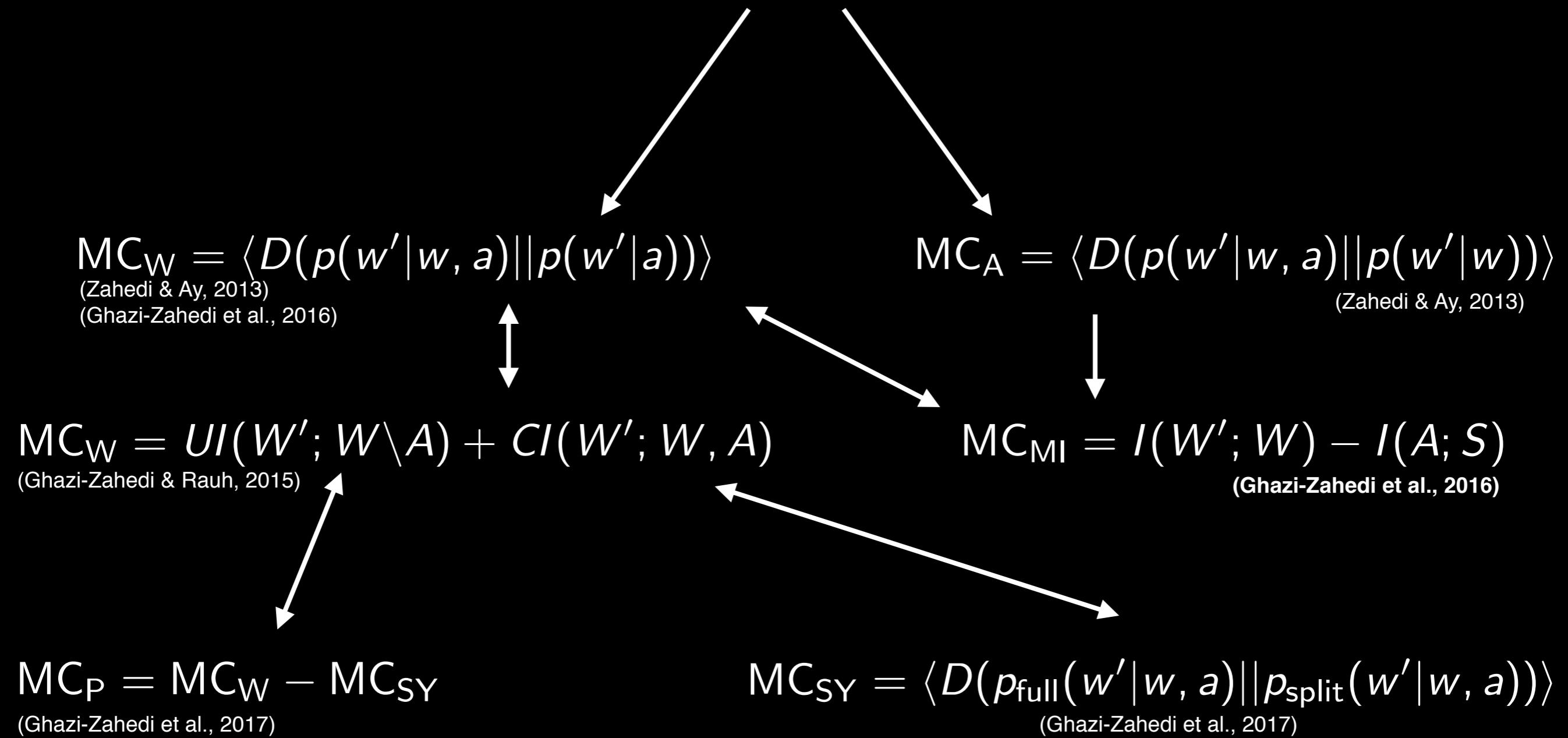
$$\text{MC}_W = \langle D(\alpha(w'|w, a) || \hat{\alpha}(w'|a)) \rangle$$

$$= I(W'; W|A)$$

$$= \sum_{w', w, a} p(w', w, a) \log_2 \frac{p(w'|w, a)}{p(w'|a)}$$

$$= H(W'|A) - H(W'|W, A)$$

Quantifying Morphological Computation



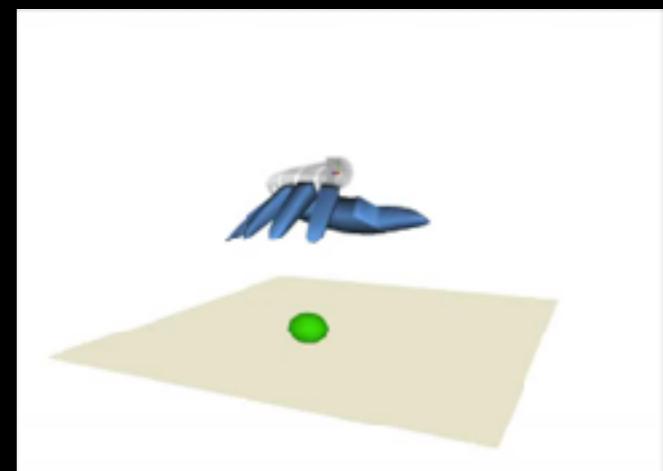
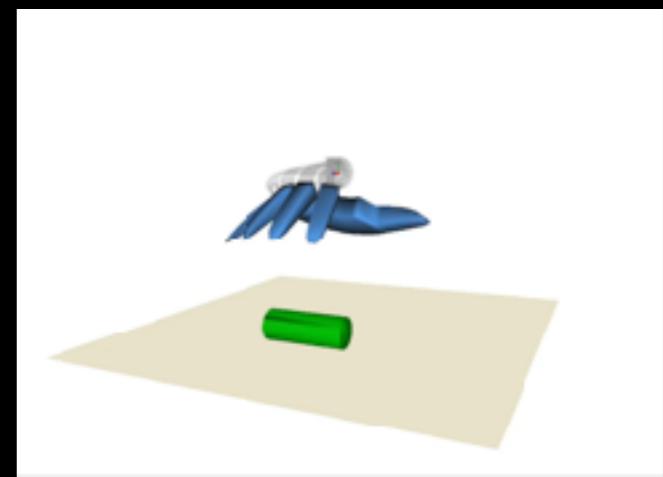
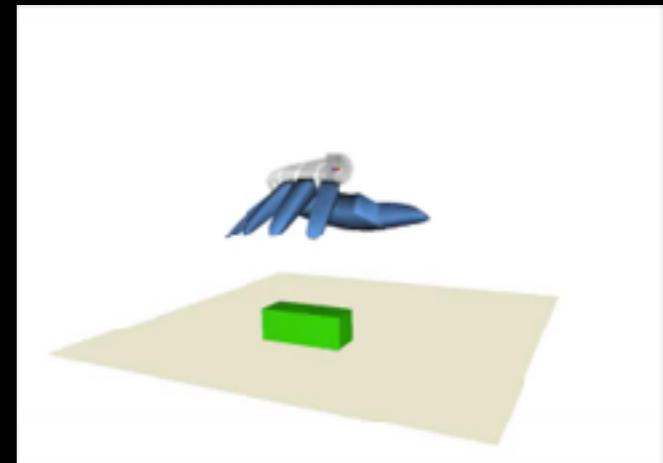
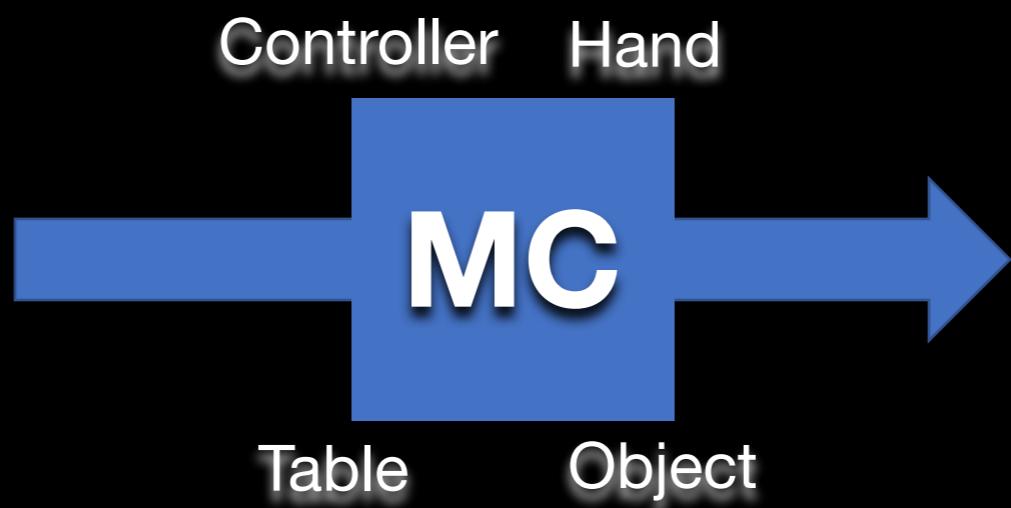
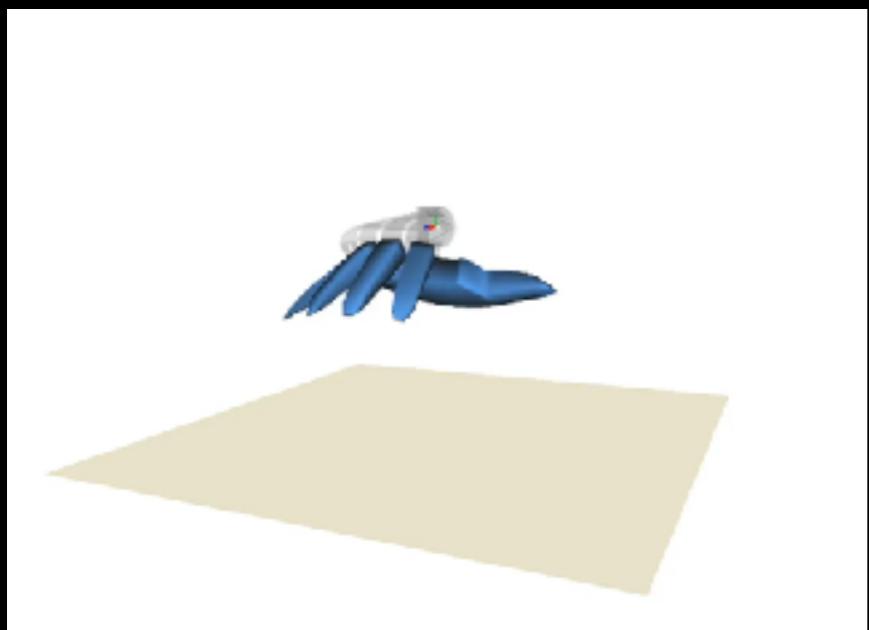
$$C_W = D(p(s'|s) || \hat{p}(s'|s))$$

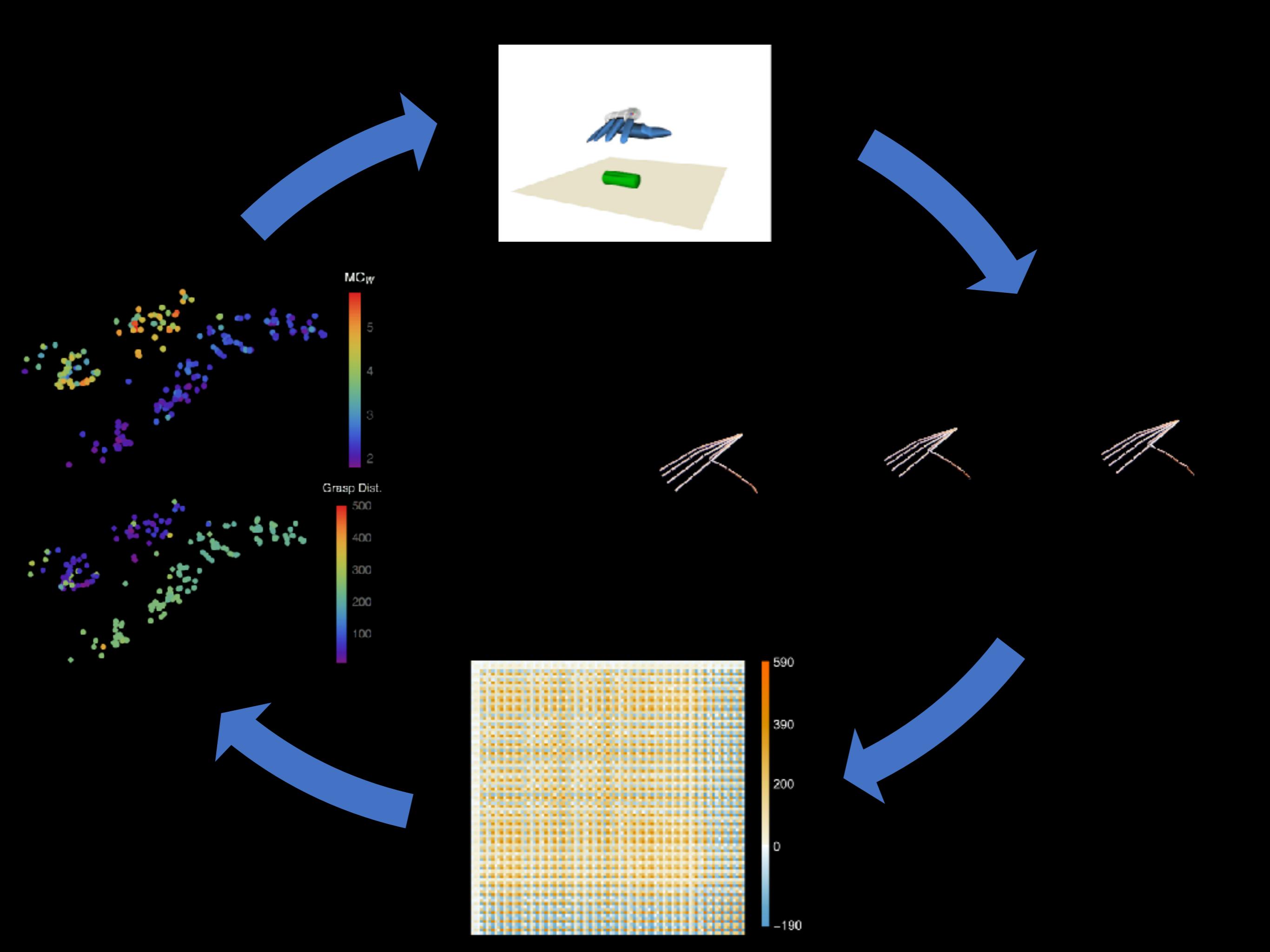
$$C_A = CIF(S \rightarrow S') - CIF(A \rightarrow S')$$

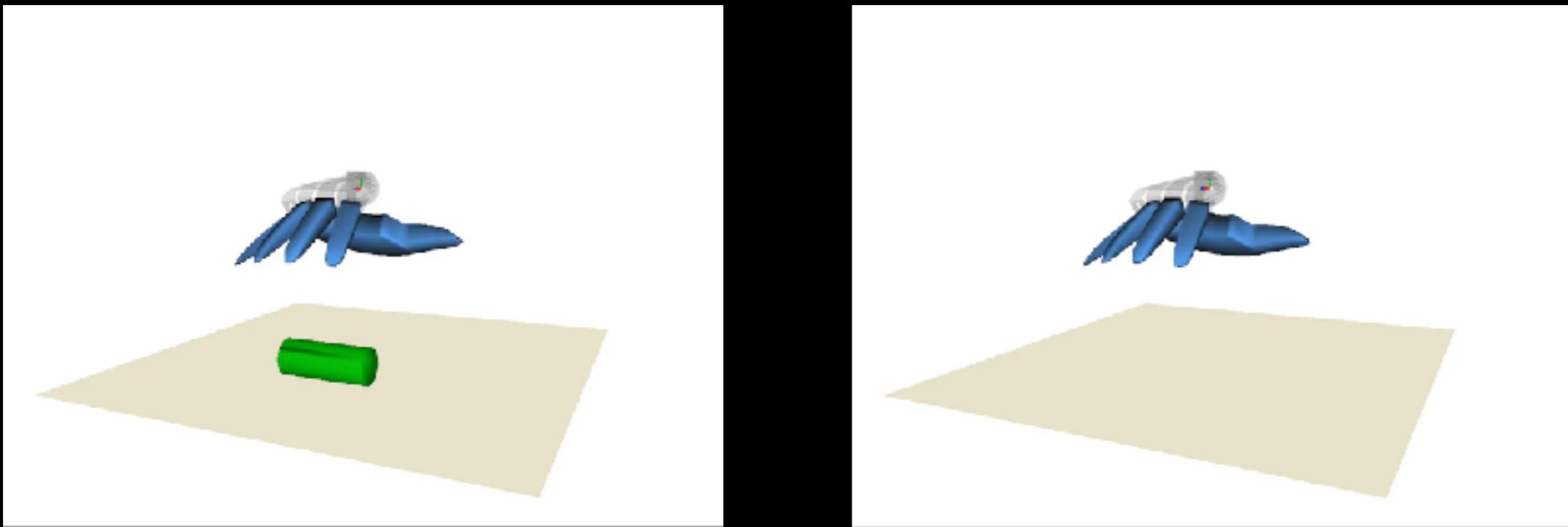
(Zahedi & Ay, 2013)

Application to Soft Robotics

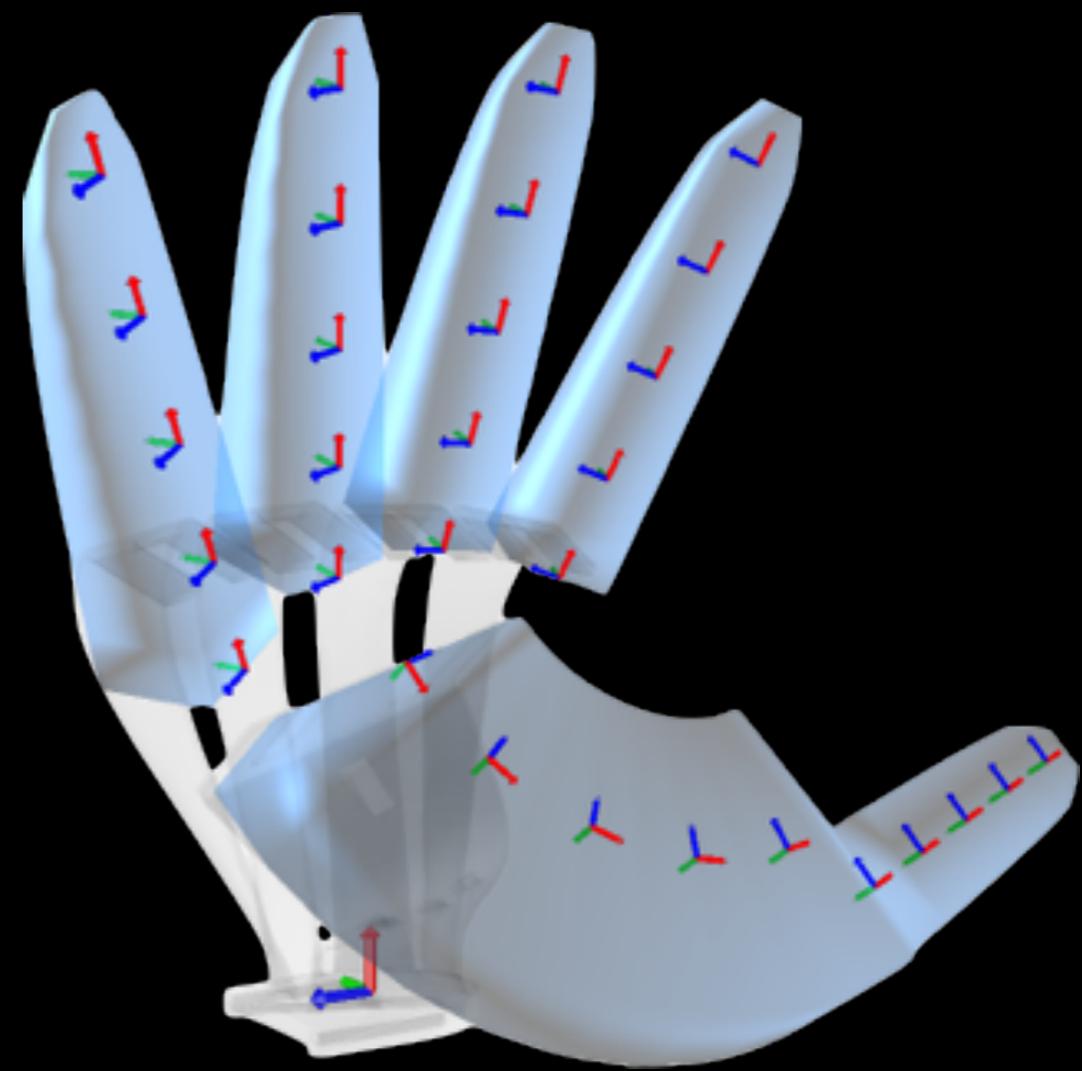
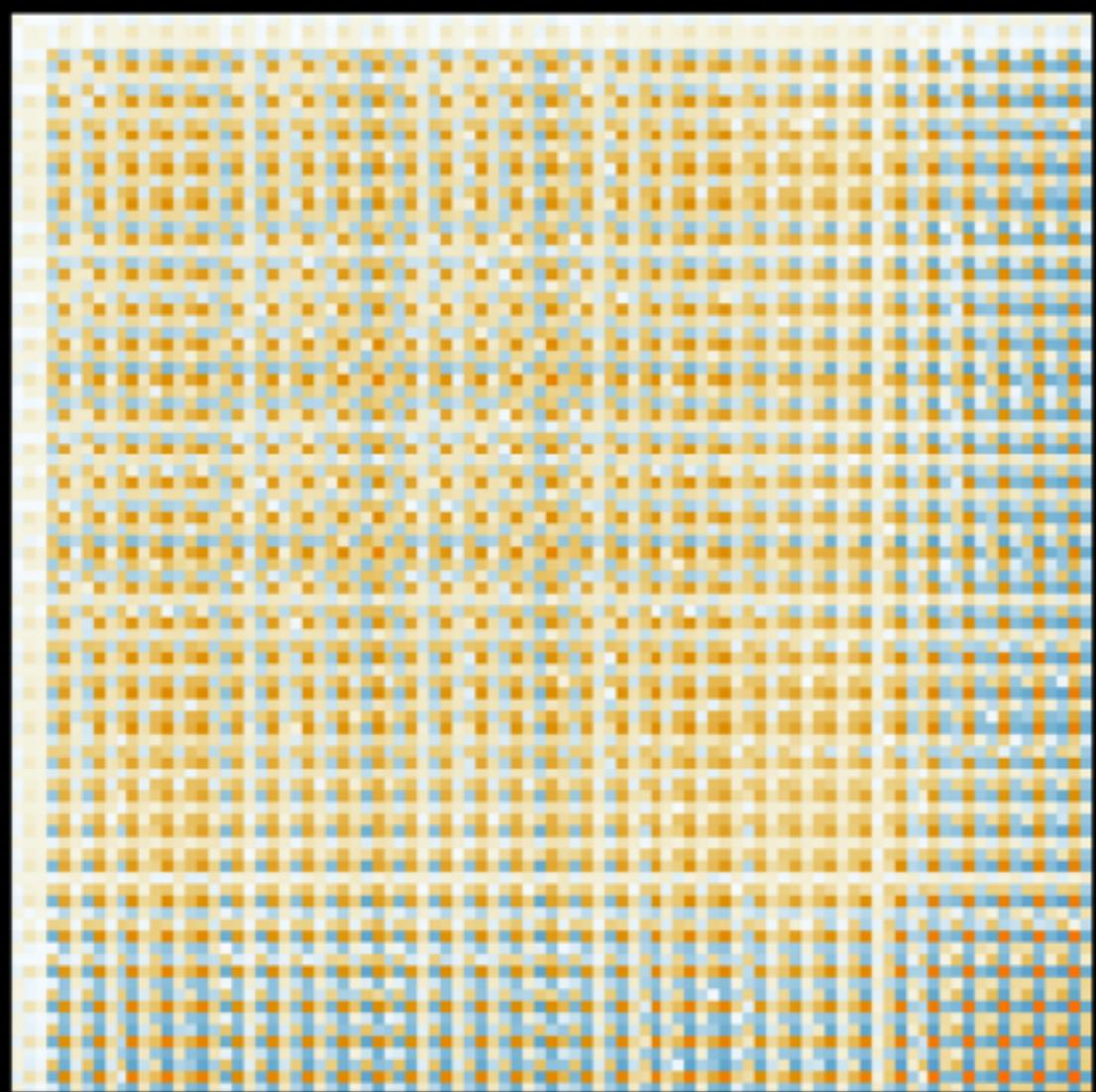


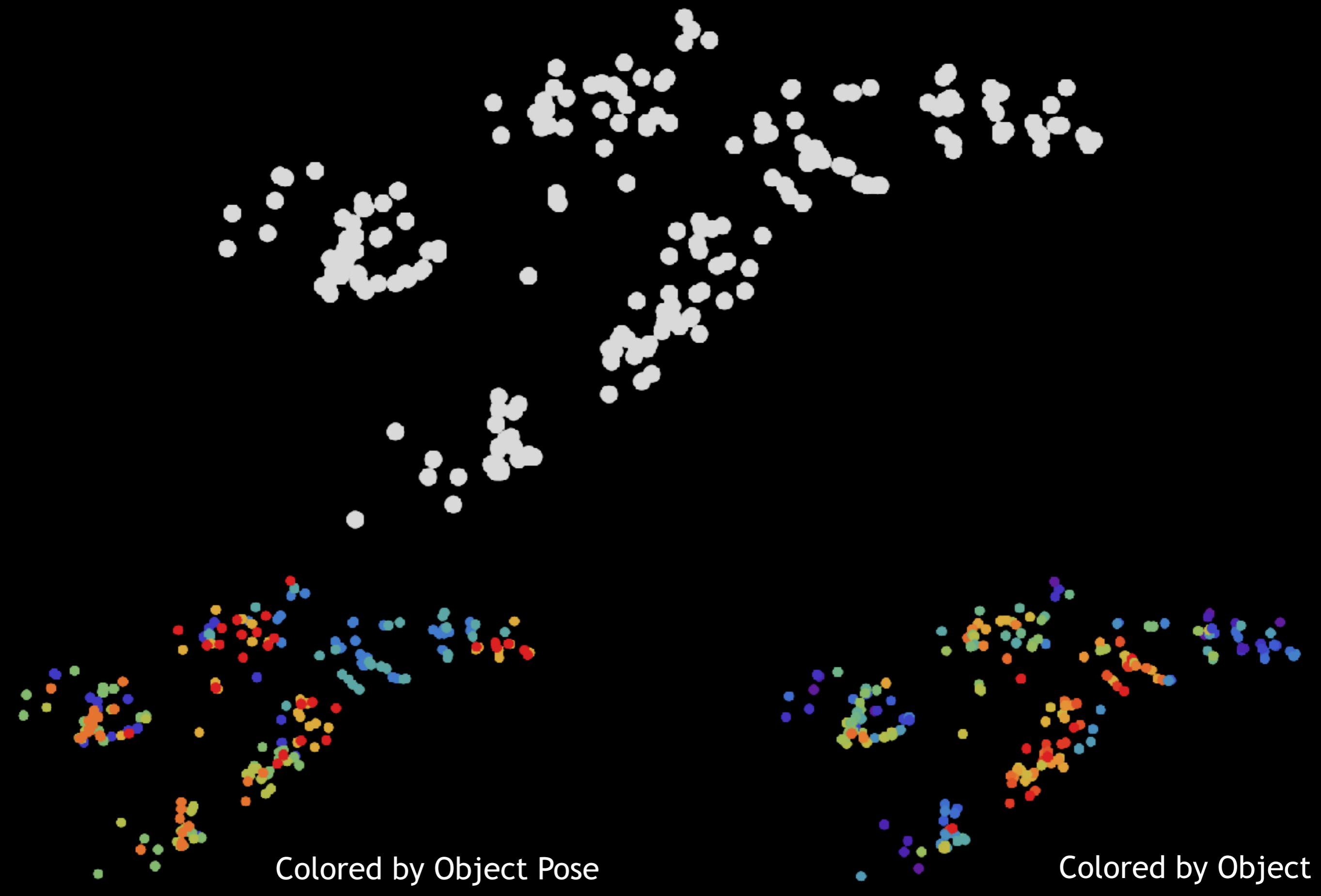


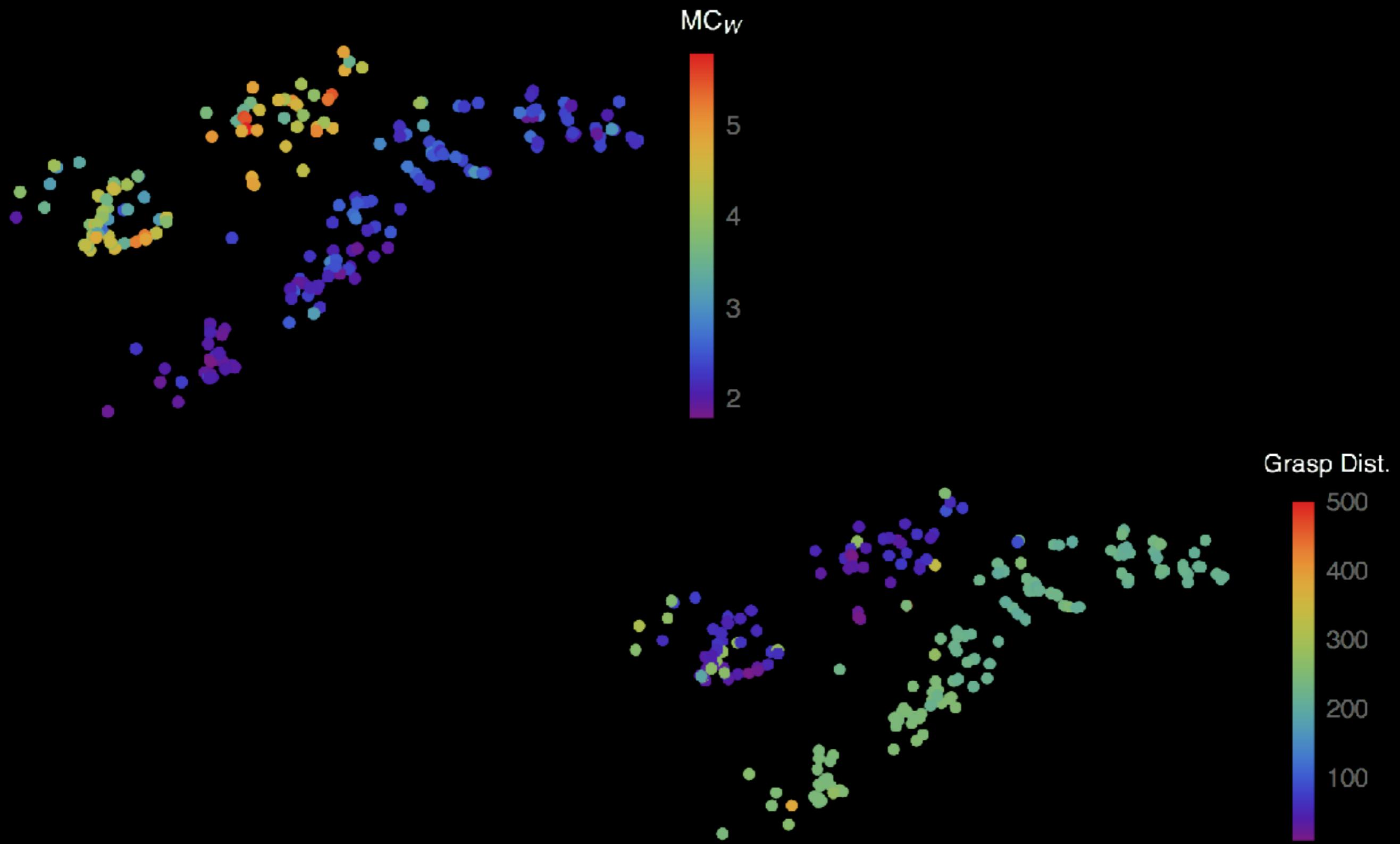


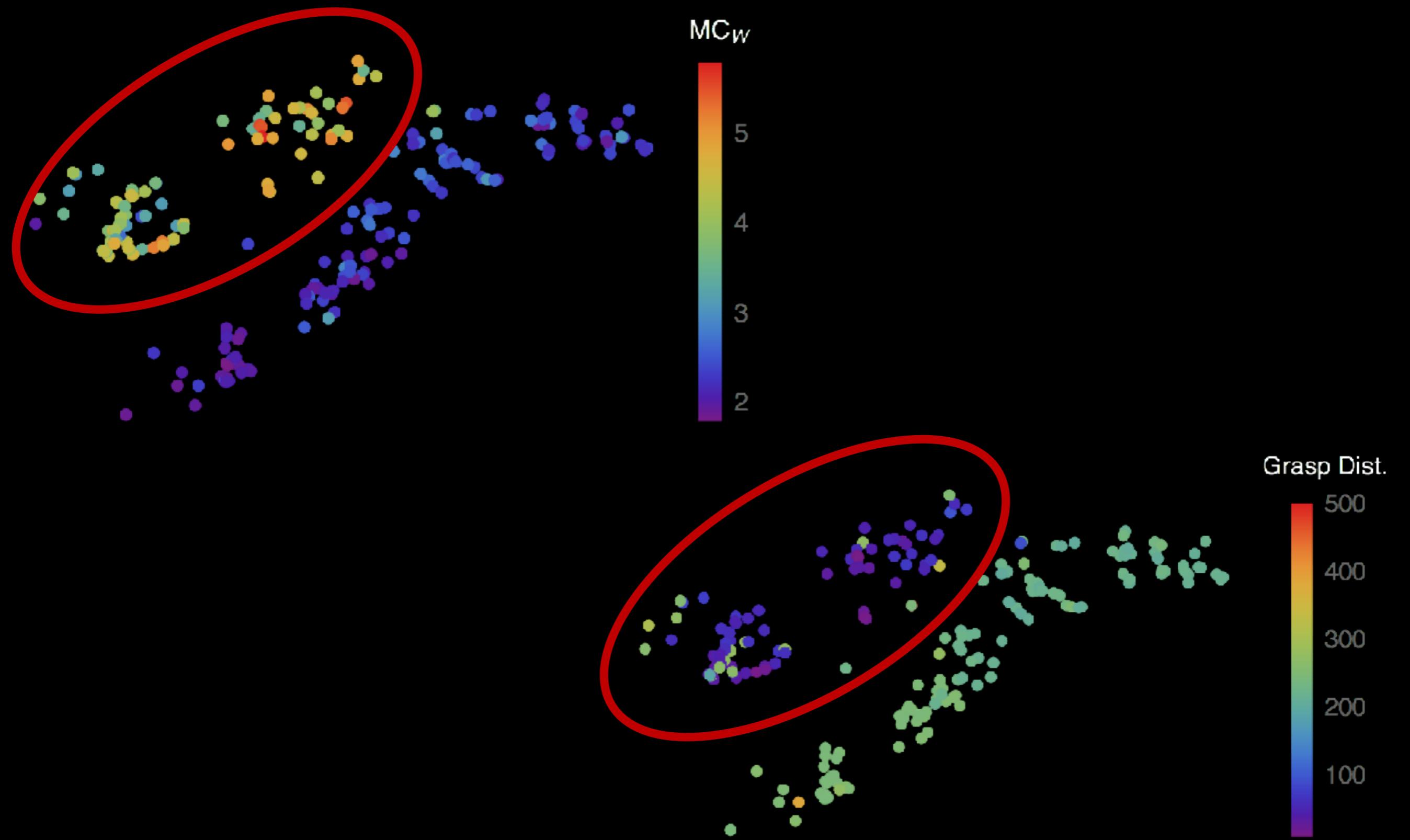


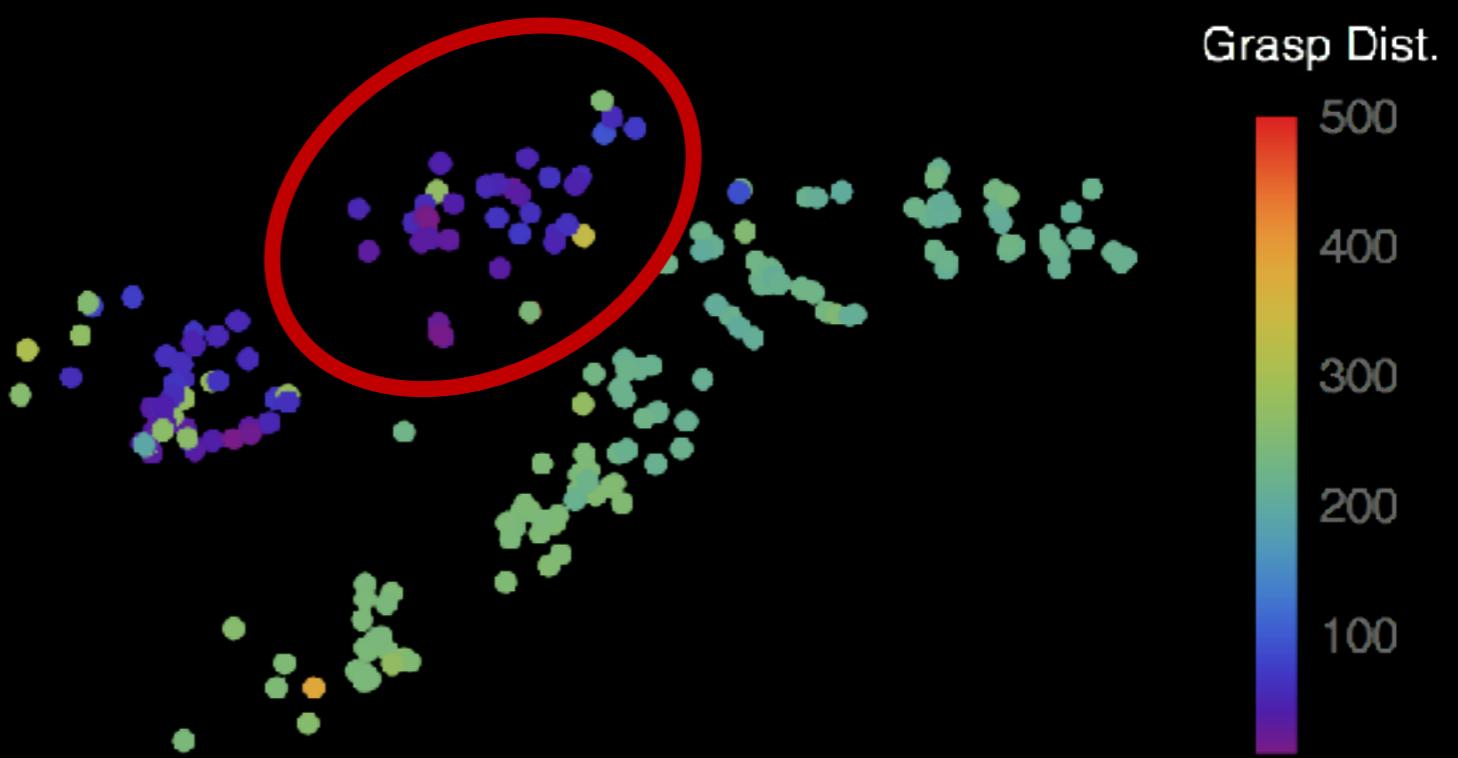
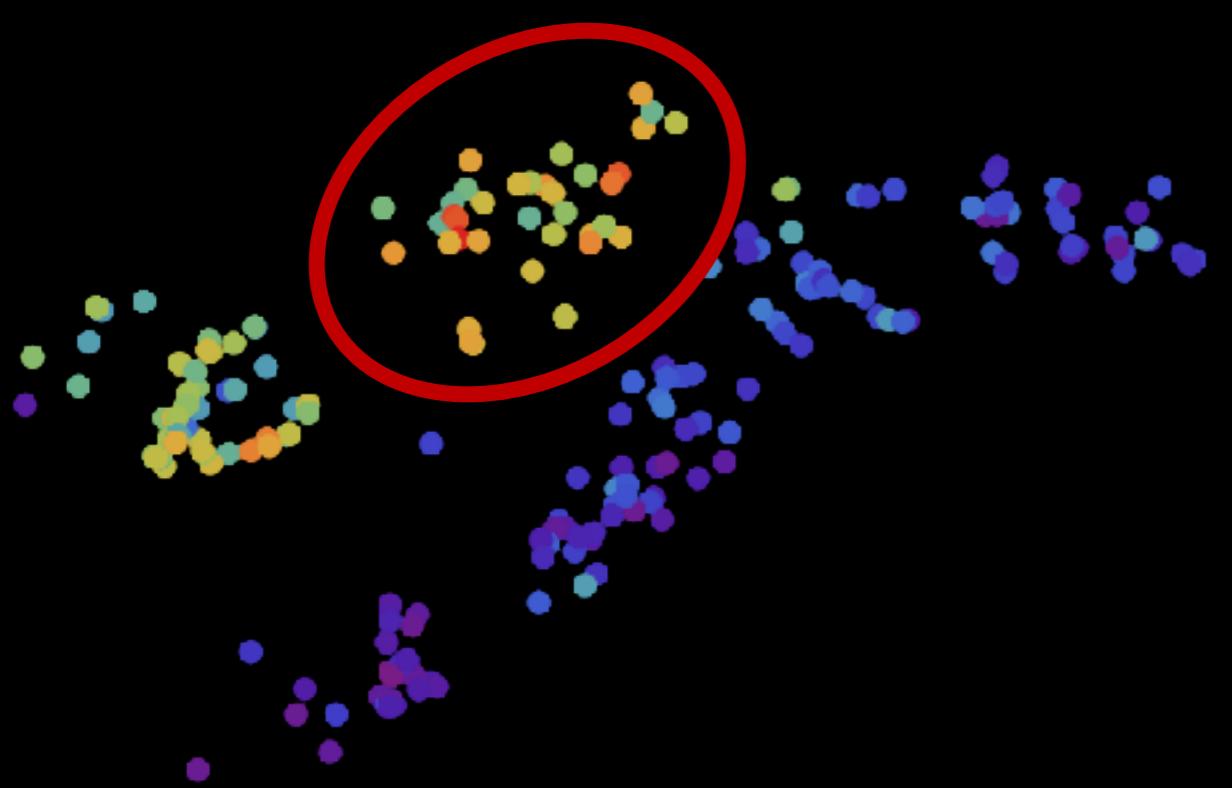
$$\begin{array}{c} \text{Diagram A} \\ - \\ \text{Diagram B} \\ = \\ \text{Diagram C} \end{array}$$

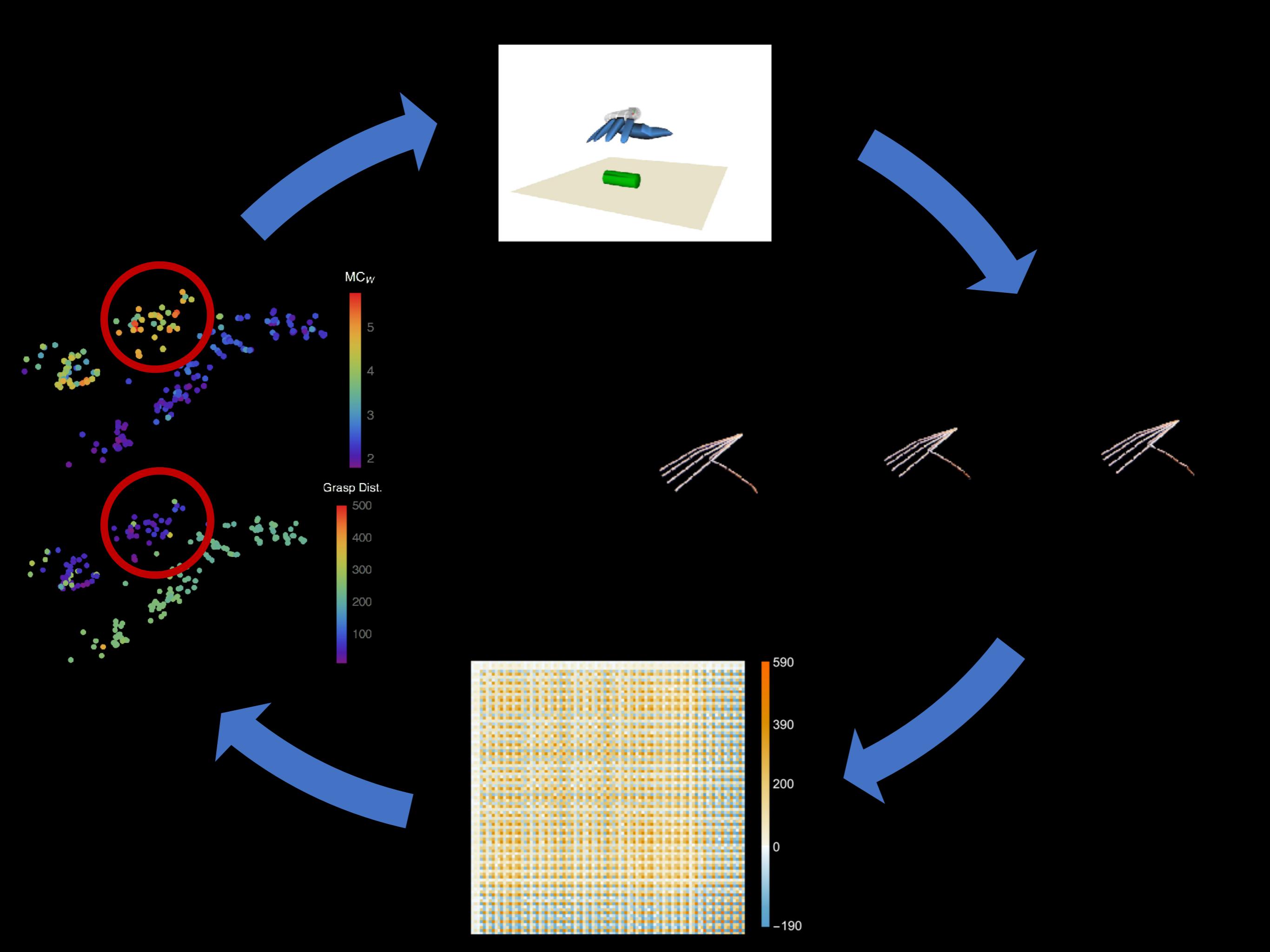






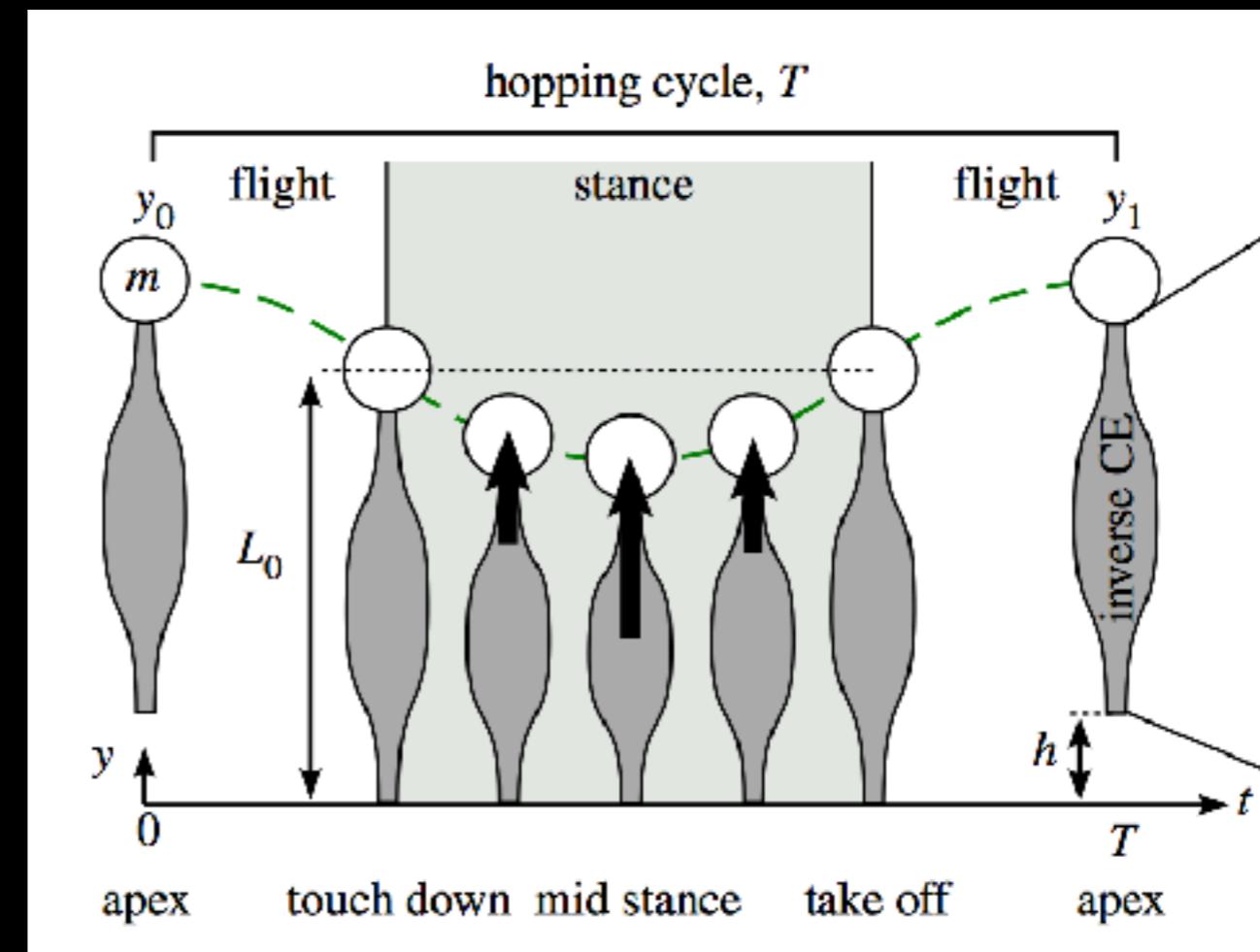
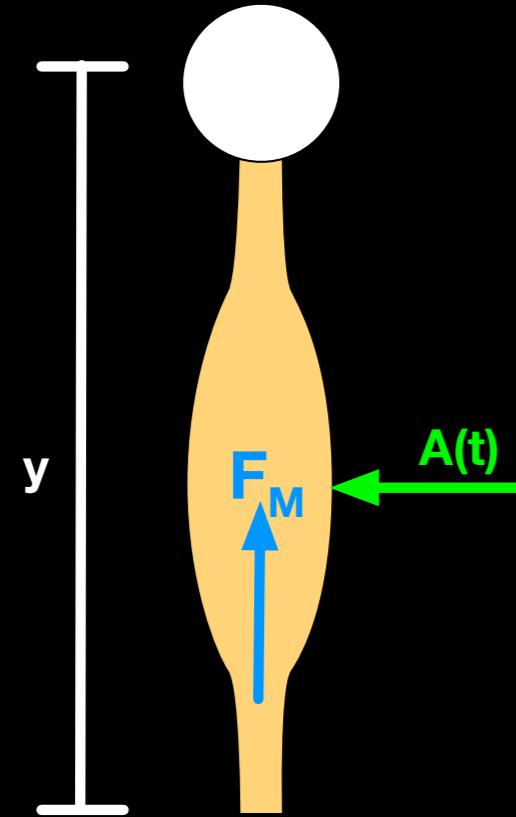


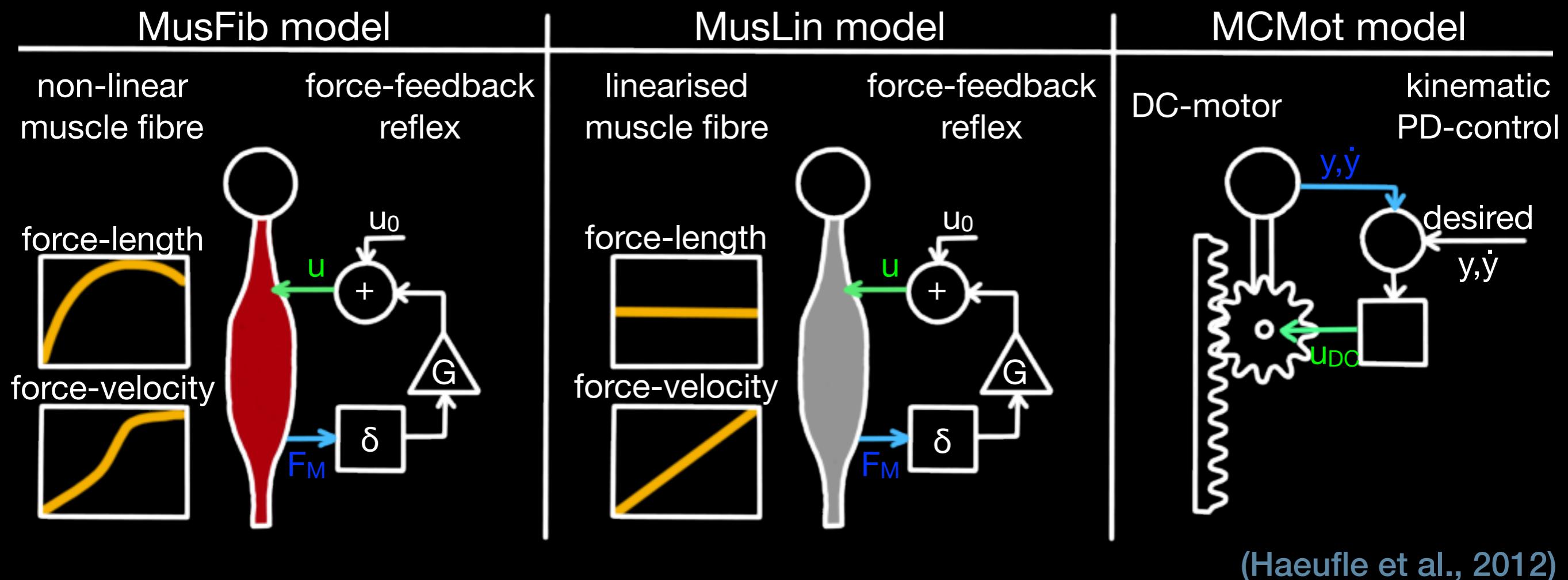




Application to Biomechanics

$$F_m = A(t) \, Fl(y) \, Fv(\dot{y}) \, F_{max}$$





7.219 bits

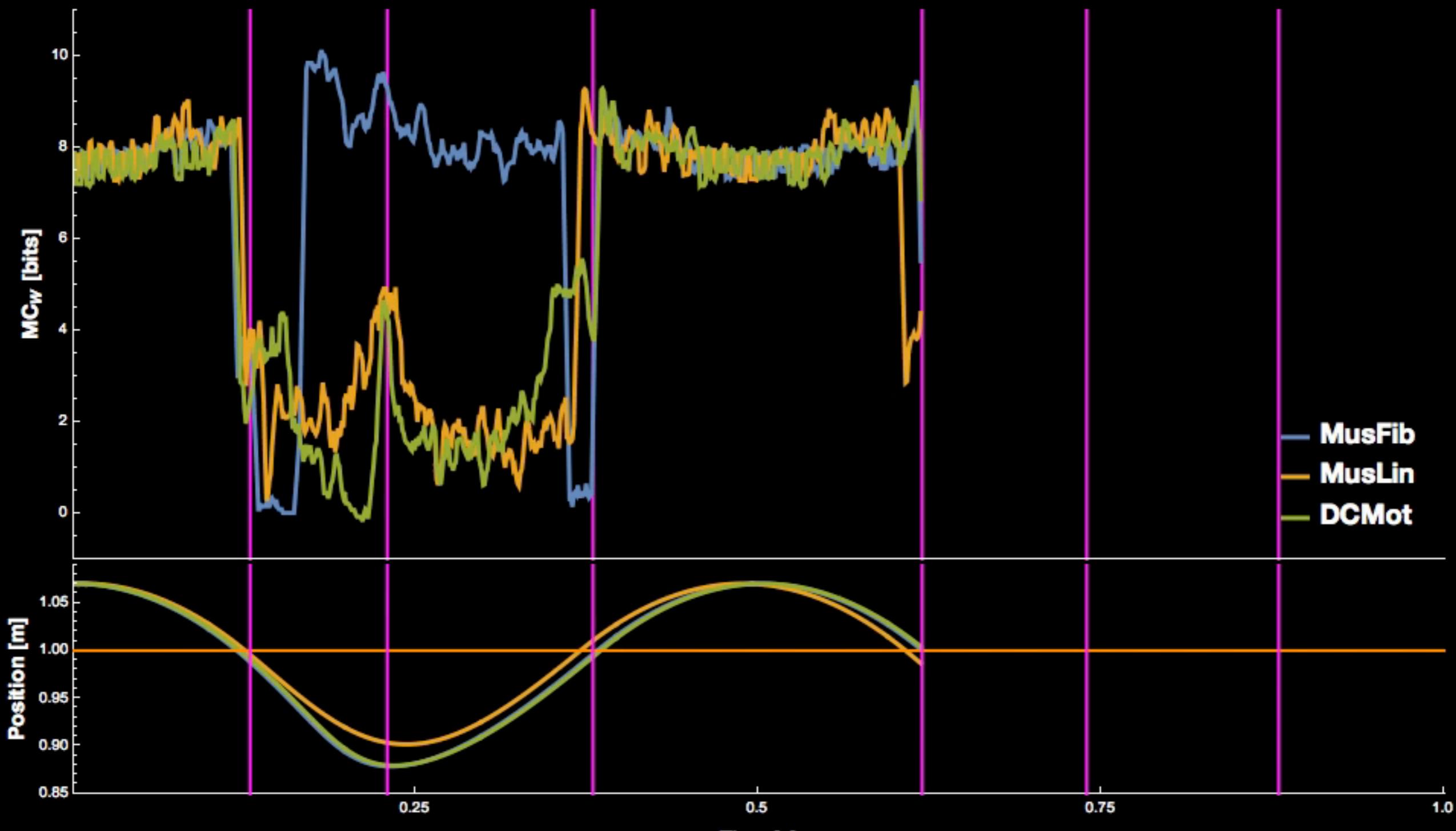
4.975 bits

4.960 bits

$$MC_W = D(p(w'|w, a) || p(w'|a))$$

(Ghazi-Zahedi et al., 2016)

Comparison of state-dependent MC_W



$$\log_2 \frac{p(w'|w, a)}{p(w'|a)}$$

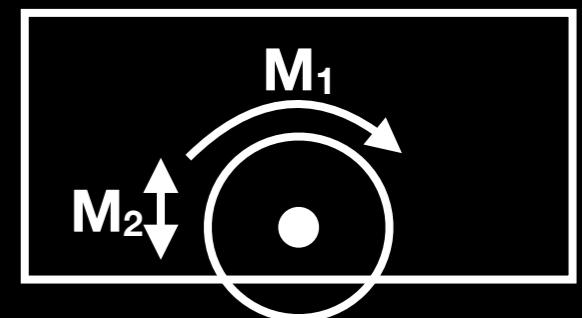
What is Morphological Computation?

How Morphology Contributes to Computation

- Morphological Computation
- Morphological Control
- Pre-processing (Sensors)
- Post-processing (Actuators)
- Brain layout
- Physical processes

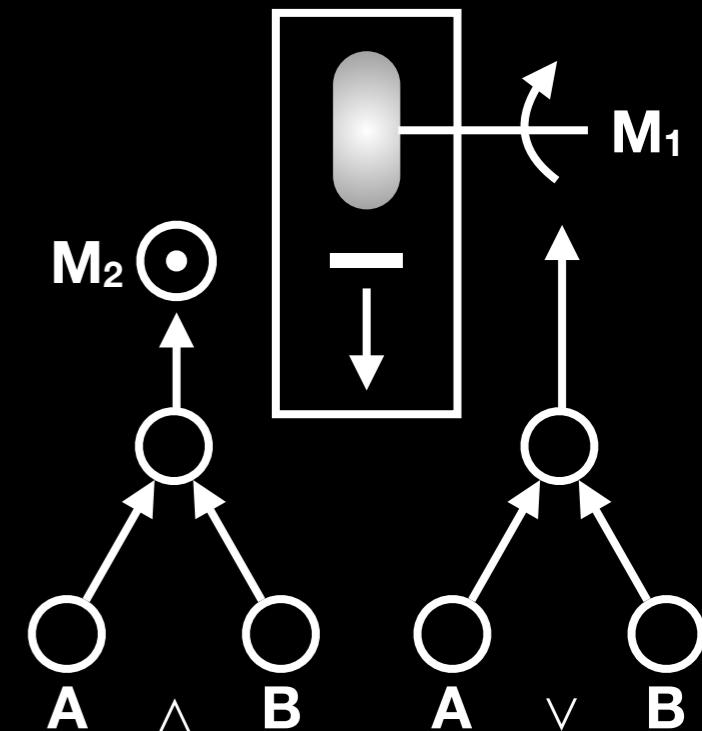
How morphology Contributes to Computation

- Morphological Computation



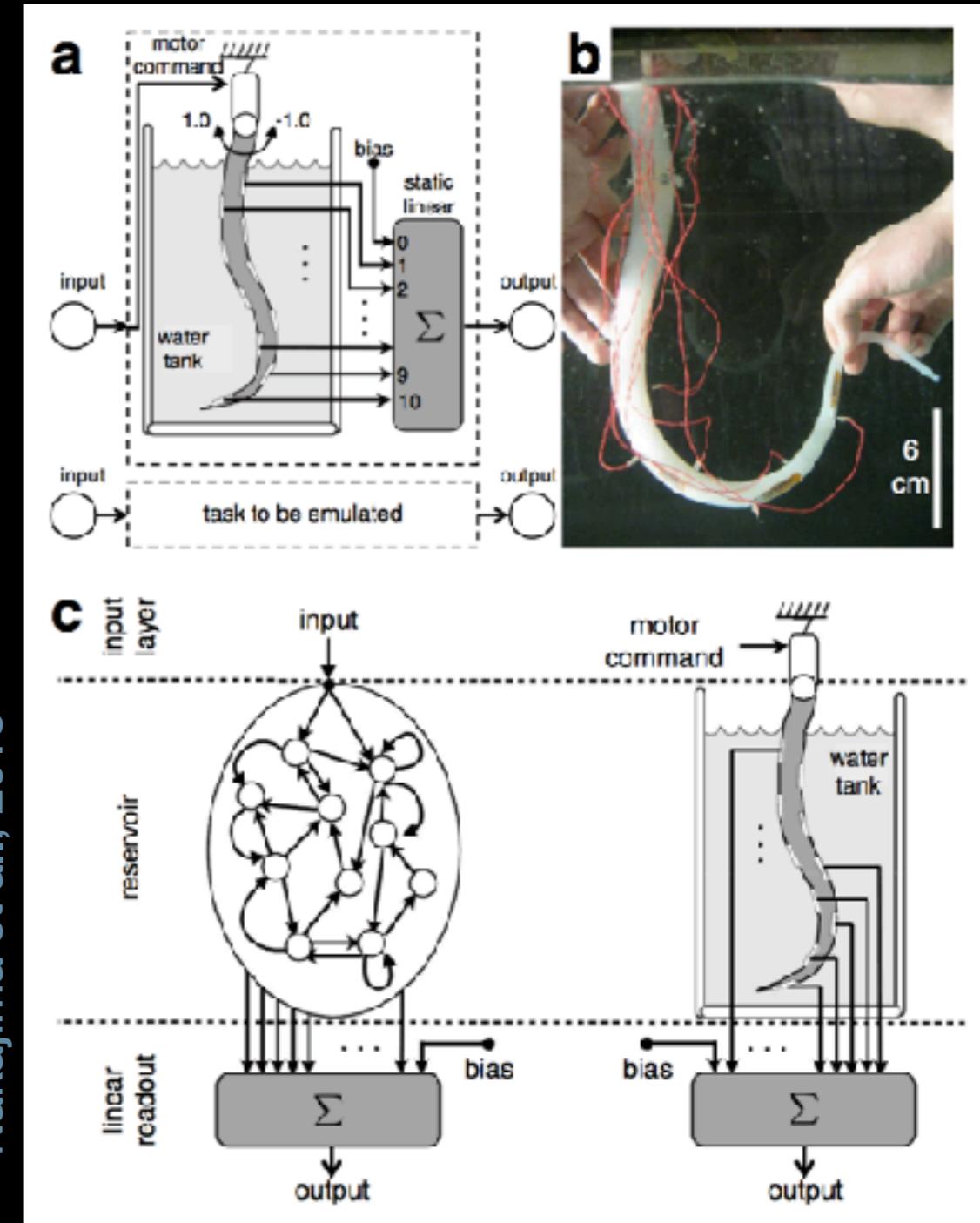
Example: XOR Robot

A	B	Wheel moves (M_1)	Wheel touches ground (M_2)	Robot moves
FALSE	FALSE	FALSE	TRUE	FALSE
FALSE	TRUE	TRUE	TRUE	TRUE
TRUE	FALSE	TRUE	TRUE	TRUE
TRUE	TRUE	TRUE	FALSE	FALSE



How morphology Contributes to Computation

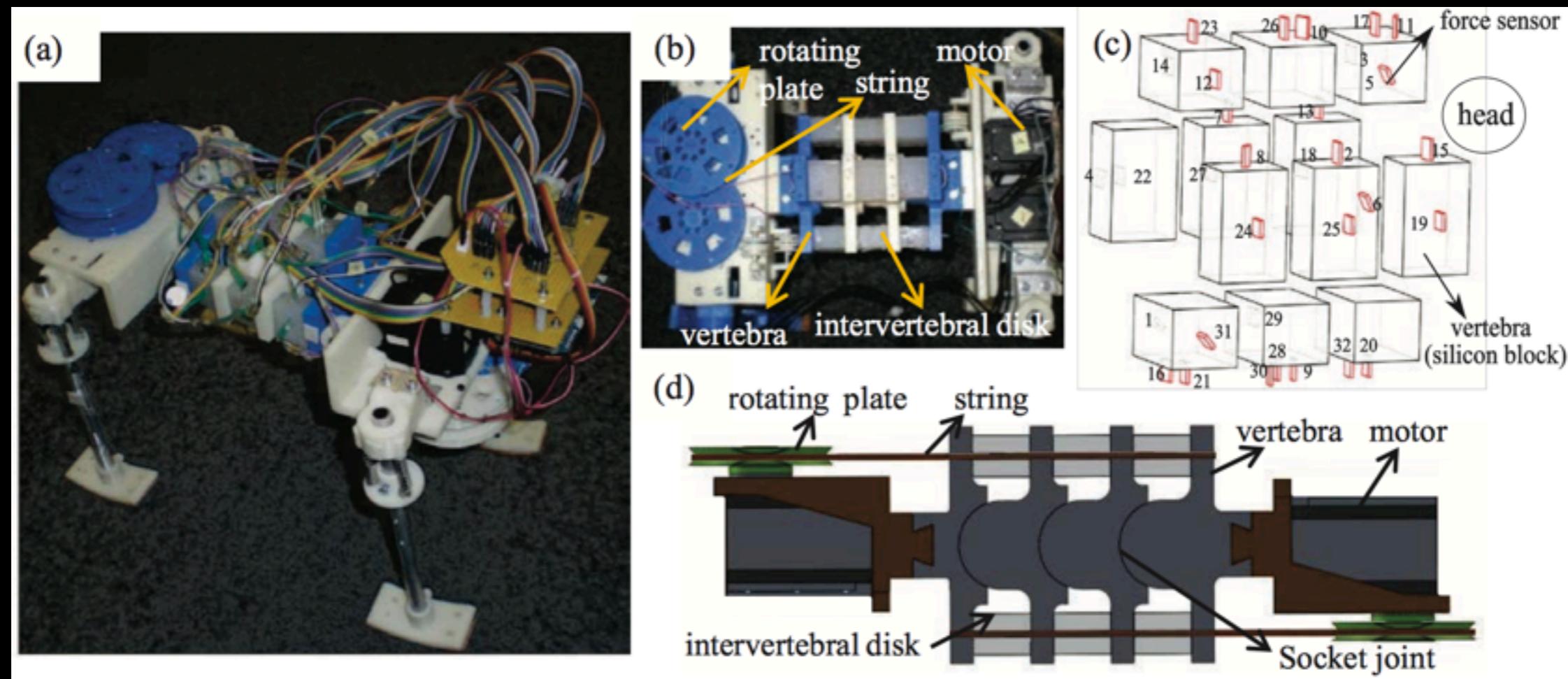
- Morphological Computation



Nakajima et al., 2015

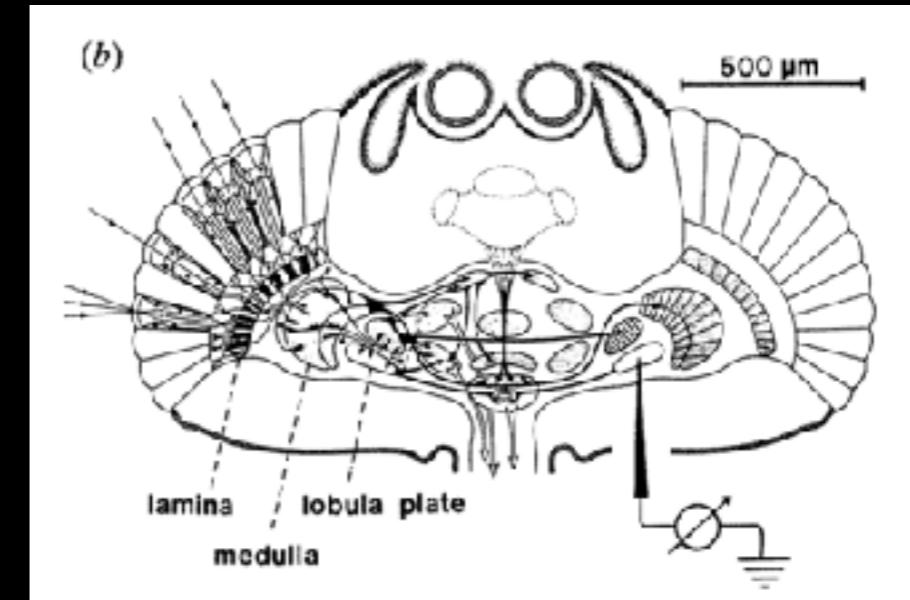
How morphology Contributes to Computation

- Morphological Computation
- Morphological Control



How morphology Contributes to Computation

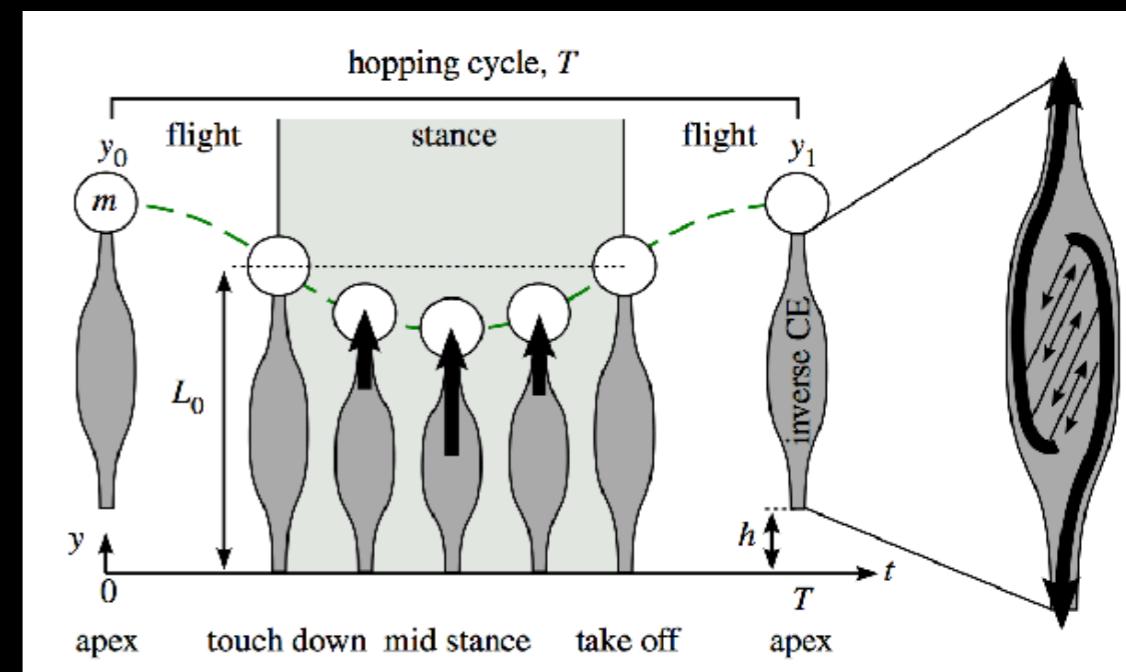
- Morphological Computation
- Morphological Control
- Pre-processing (Sensors)



Franceschini et al., 1992

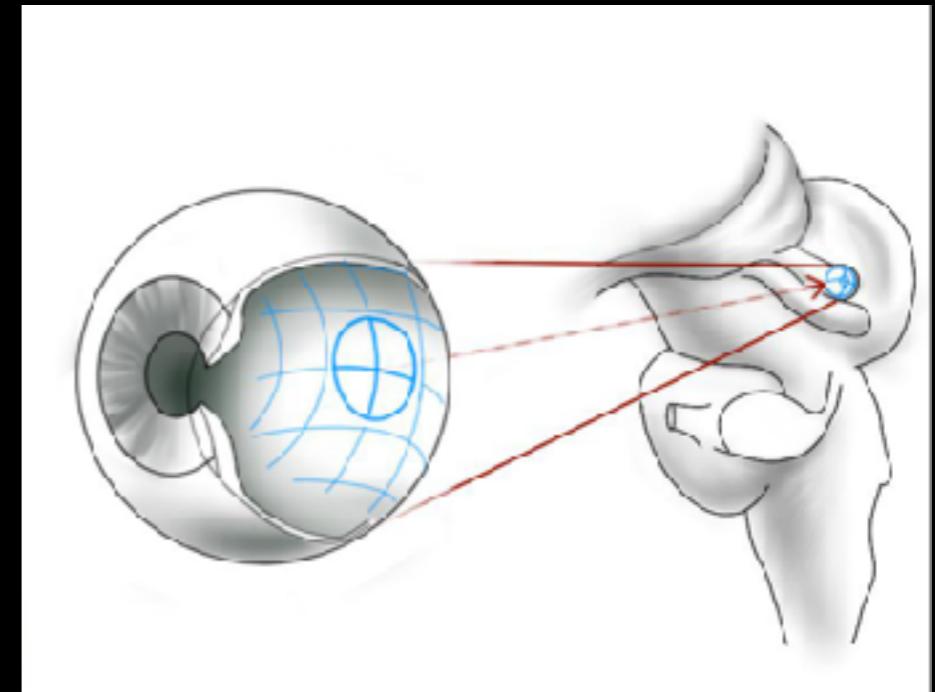
How morphology Contributes to Computation

- Morphological Computation
- Morphological Control
- Pre-processing (Sensors)
- Post-processing (Actuators)



How morphology Contributes to Computation

- Morphological Computation
- Morphological Control
- Pre-processing (Sensors)
- Post-processing (Actuators)
- Brain layout



„**Geometrical arrangement** of the **perceptive units** in the retina reflect the organization of the processing units into the Superior Colliculus, thus **simplifying the processing and the control** of eye movements”

How morphology Contributes to Computation

- Morphological Computation
- Morphological Control
- Pre-processing (Sensors)
- Post-processing (Actuators)
- Brain layout
- Physical processes



BBCWorldwide
<https://www.youtube.com/watch?v=NWH624jPW0w>

How morphology Contributes to Computation

- Morphological Computation
- Morphological Control
- Pre-processing (Sensors)
- Post-processing (Actuators)
- Brain layout
- Physical processes
- to be continued ...

Morphological Intelligence

Inspired by Krakauer's notion of intelligence

Morphological Intelligence describes the reduction of computational cost for the brain resulting from the morphology and its interaction with the environment.

- Morphological Computation
(XOR Robot)
- Morphological Control
(Physical Reservoir Computing)
- Pre-processing (Sensors)
- Post-processing (Actuators)
- Brain layout
- Physical processes



Nihat Ay
MPI MIS
SFI



Guido Montúfar
UCLA
MPI MIS



Daniel Häufle
University Tübingen
University Stuttgart



Syn Schmitt
University Stuttgart



Oliver Brock
TU Berlin



Raphael Deimel
TU Berlin



Vincent Wall
TU Berlin

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