Adaptive actuation and control for bioinspired and biohybrid robots

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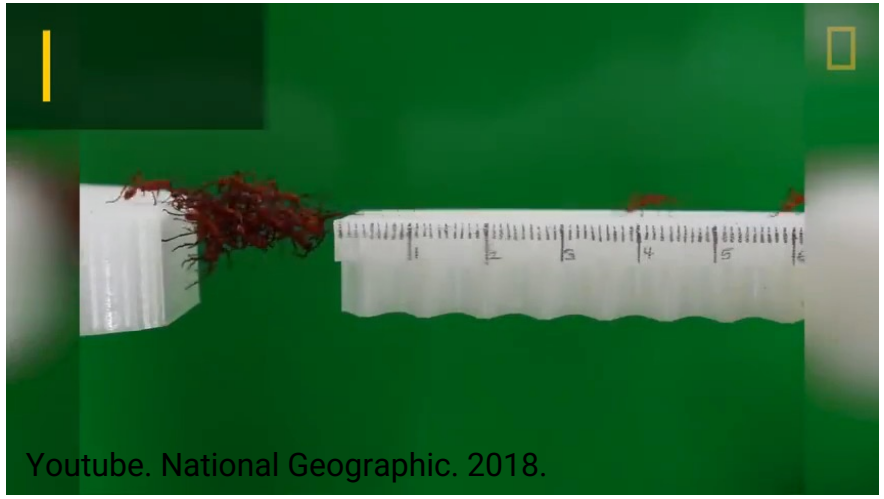
Assistant Professor, Mechanical Engineering
Carnegie Mellon University
NSF NRI-FRR PI Meeting, May 1-3, 2023

Animals are capable of tremendous feats of agility, adaptability, and problem solving


Youtube. Starry Sky. 2022.

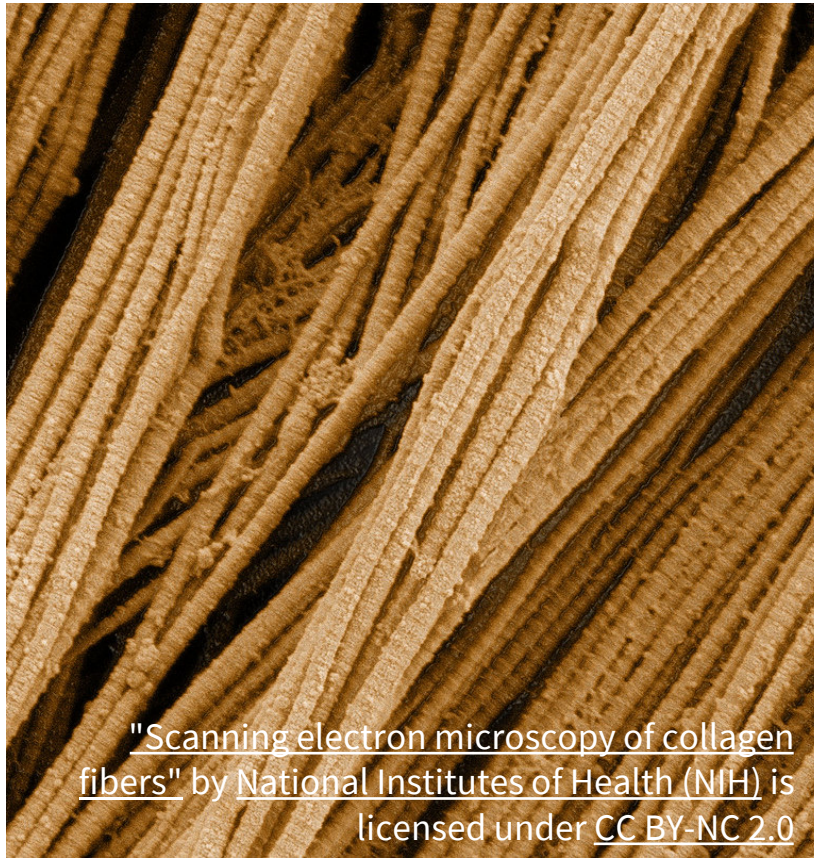

Youtube. BBC. 2016.


Youtube. Jon Bondy. 2009.

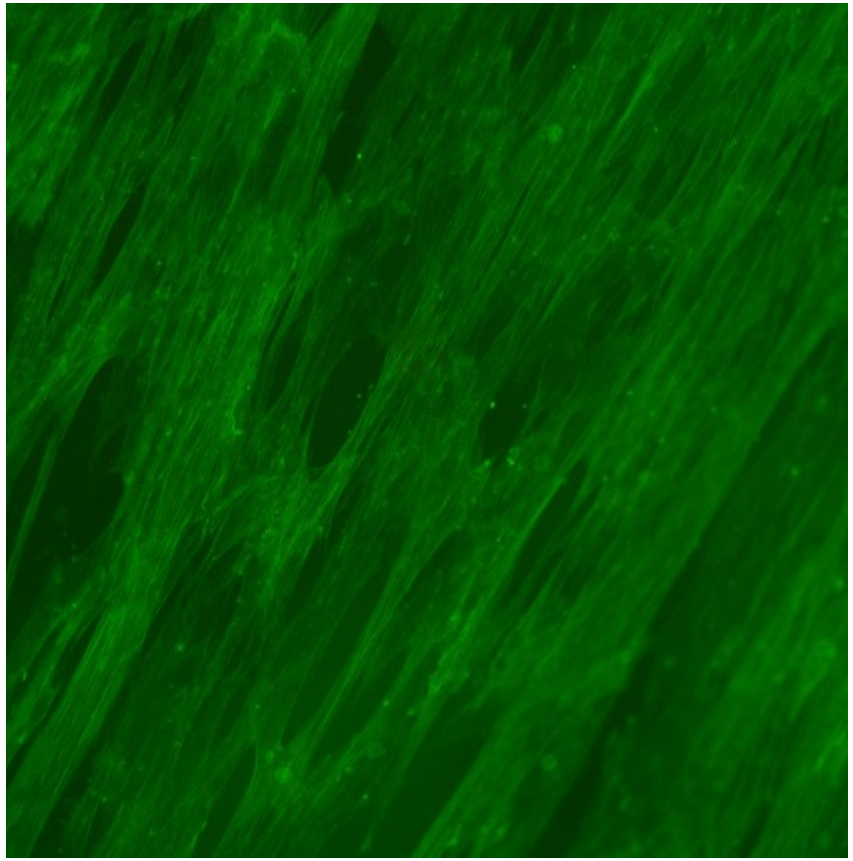

Youtube. National Geographic. 2018.

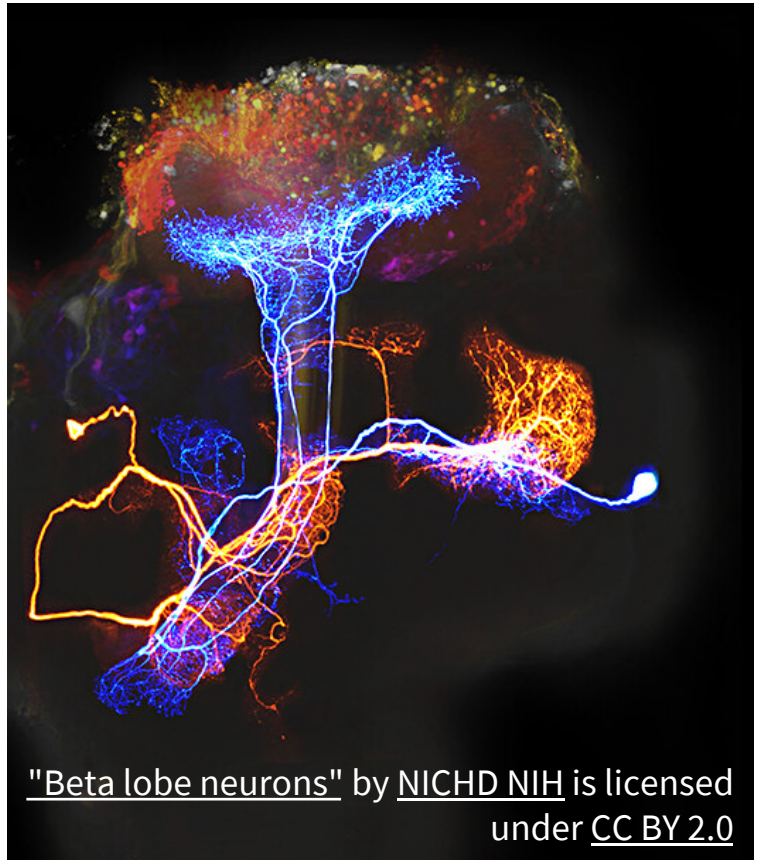

Youtube. PLOS Media. 2014.

Unlike many existing robots, biological systems are composed of dynamic, responsive materials



"Scanning electron microscopy of collagen fibers" by National Institutes of Health (NIH) is licensed under CC BY-NC 2.0





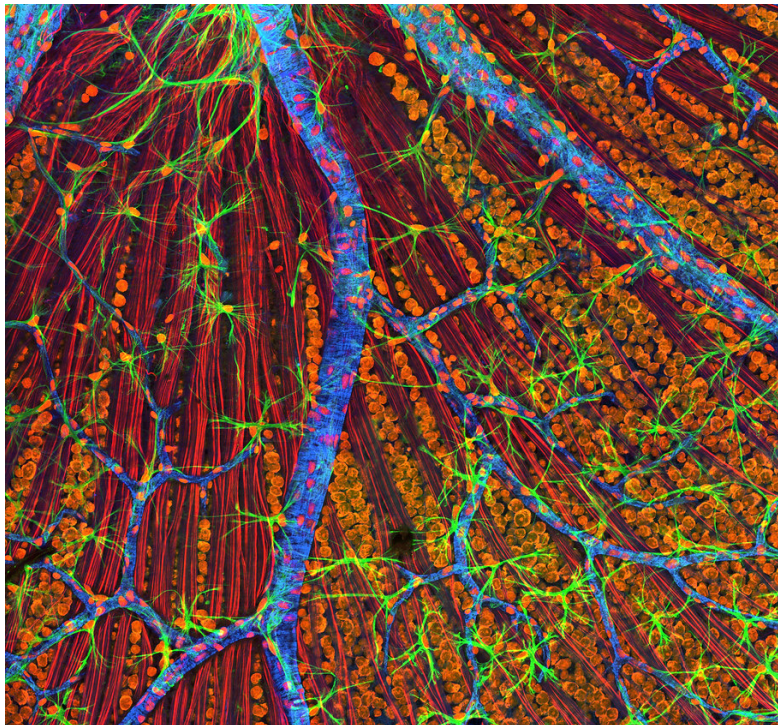
"Beta lobe neurons" by NICHD NIH is licensed under CC BY 2.0

Soft robots that capture the adaption, compliance, and multifunctionality of animals are needed

Agriculture

"strawberries picked at Rudd's Farm" by Scrap Pile is licensed under CC BY 2.0.

Bio-interfacing



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Environmental Deployment

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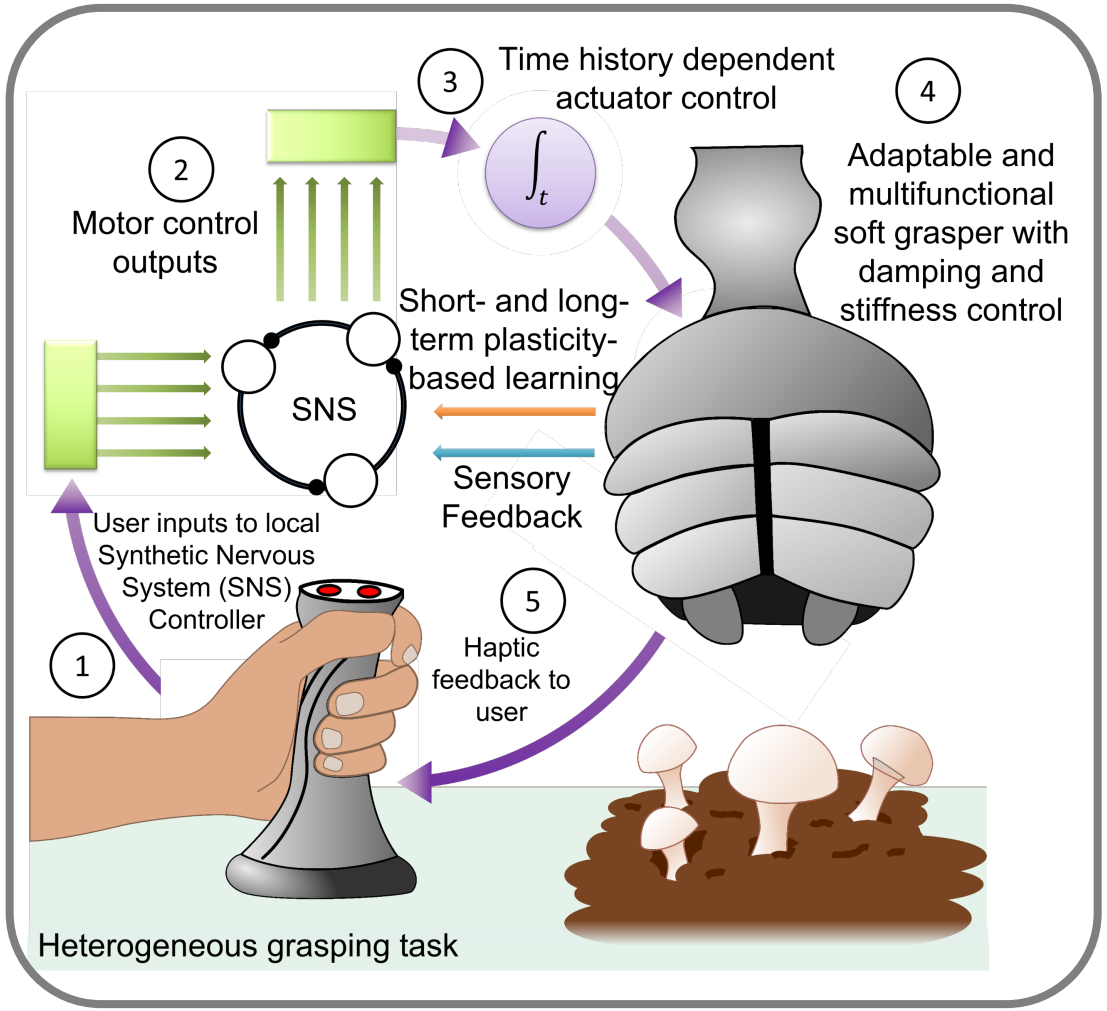
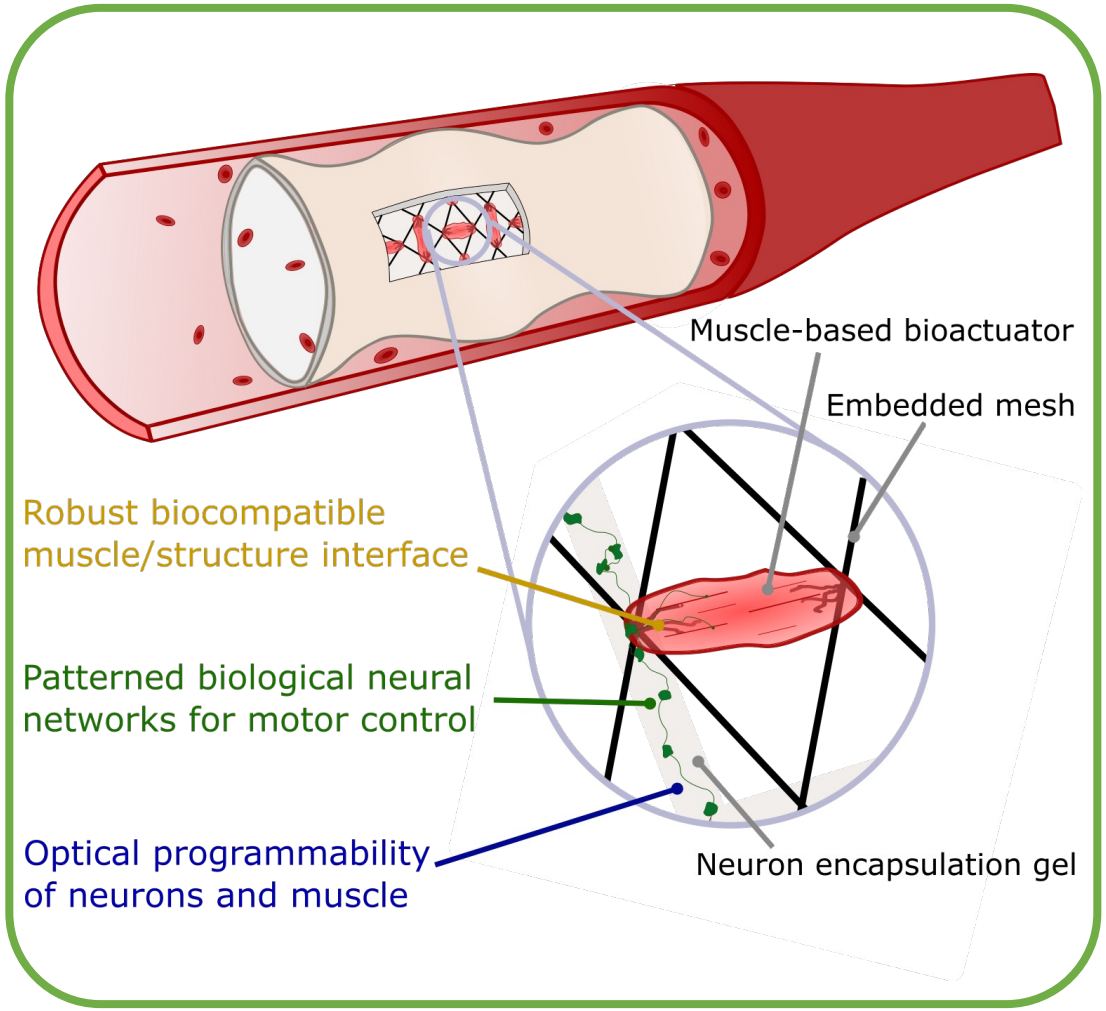
Abstraction of animal principles



Application of animal materials



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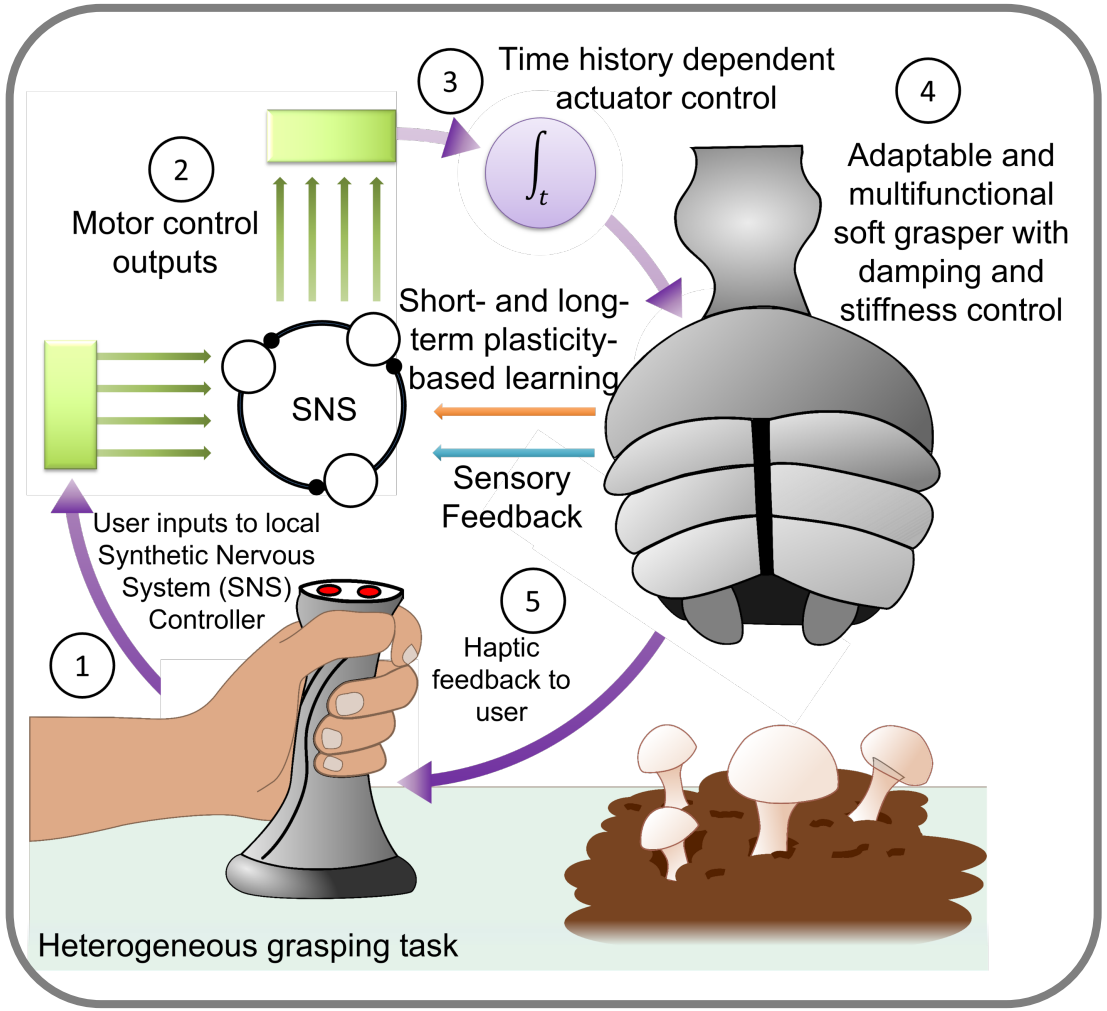

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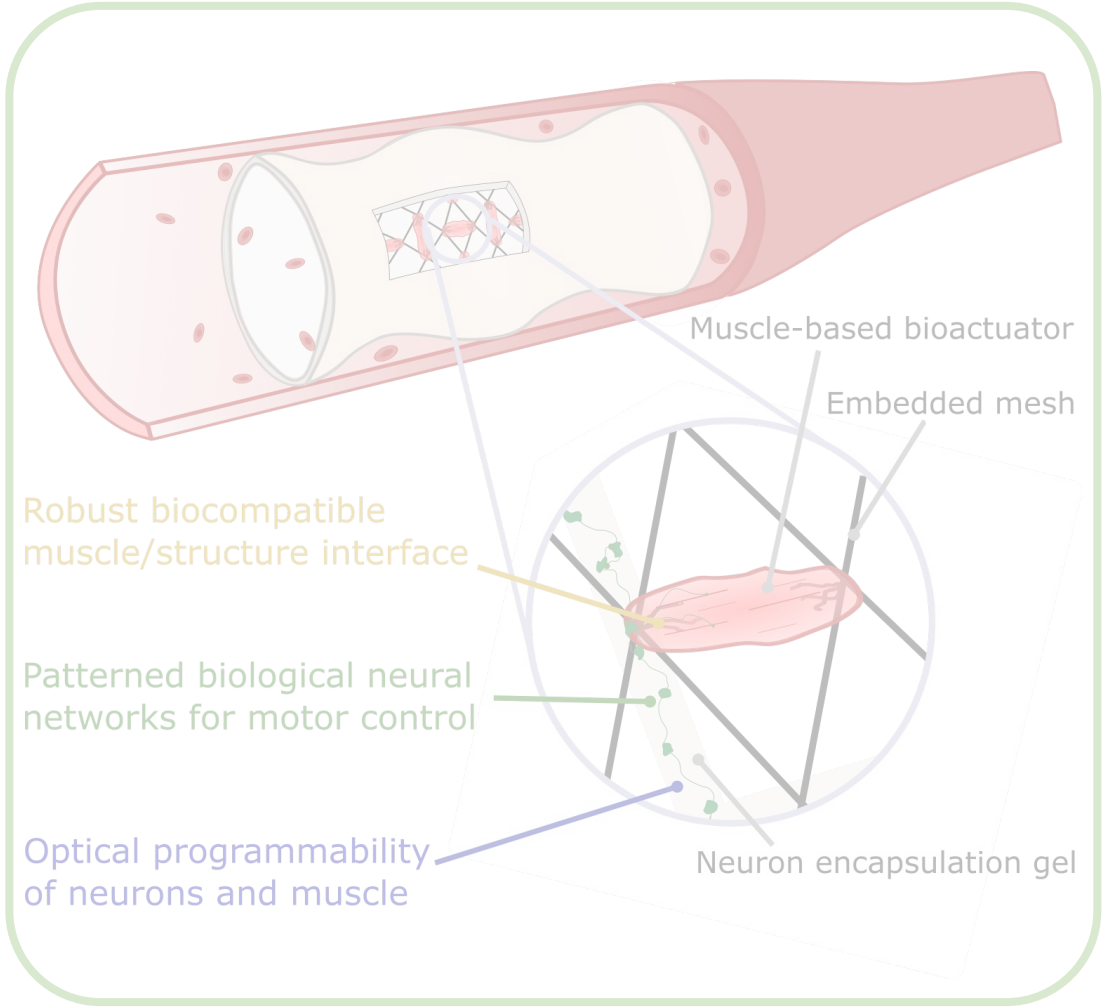
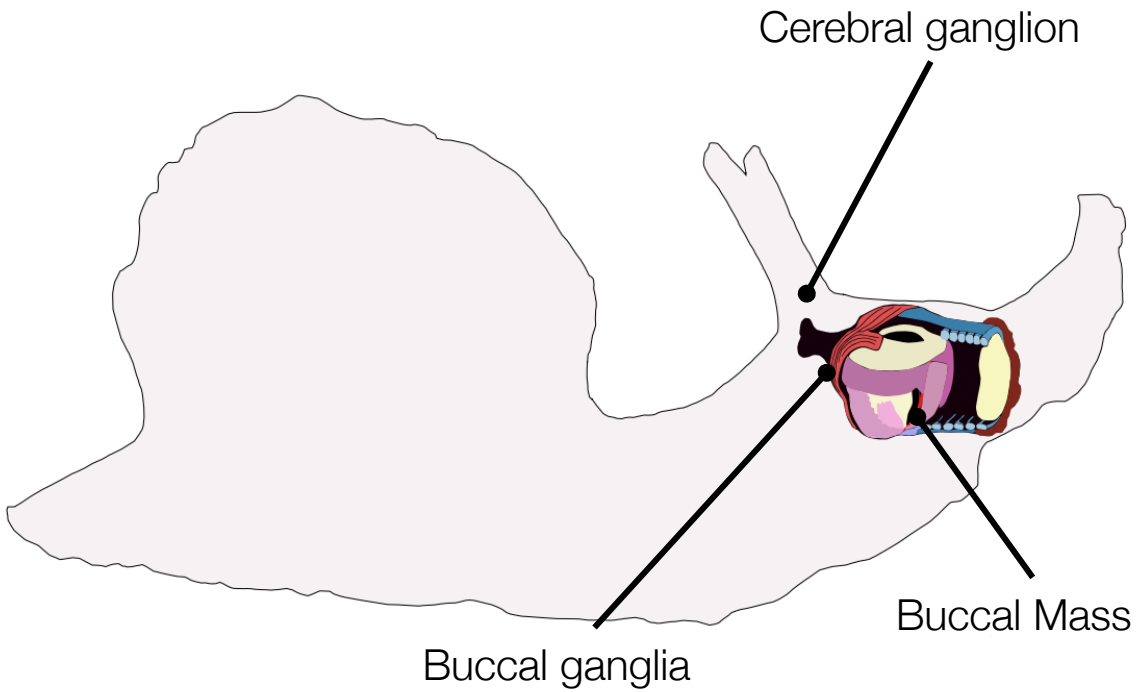


Adaptive mechanics, learning and intelligent control improve soft robotic grasping

Award ID#: 2138923

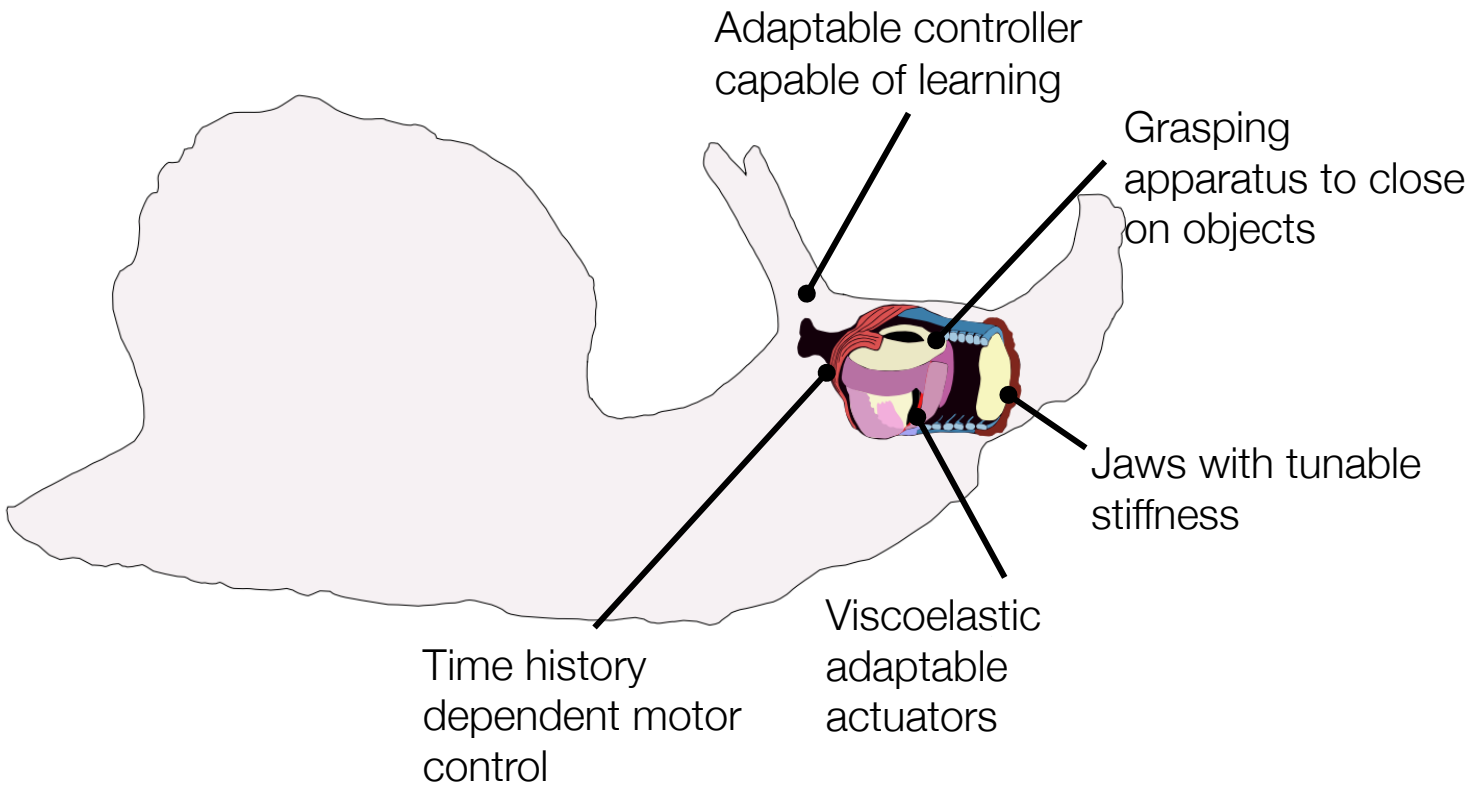
V.A. Webster-Wood, Carnegie Mellon University
R.D. Quinn, Case Western Reserve University
H.J. Chiel, Case Western Reserve University

Biological organisms can provide inspiration for soft grasping robots



K. Dai, R. Sukhnandan, M. Bennington et al, Living Machines, 2022.

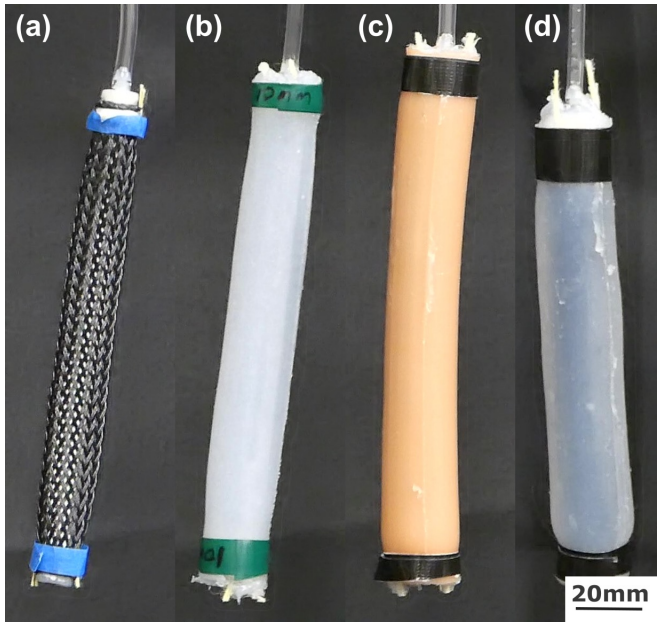
Biological organisms can provide inspiration for soft grasping robots

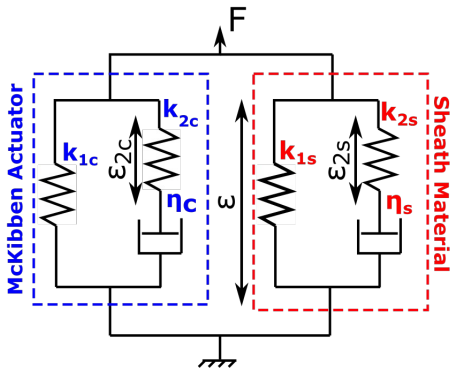


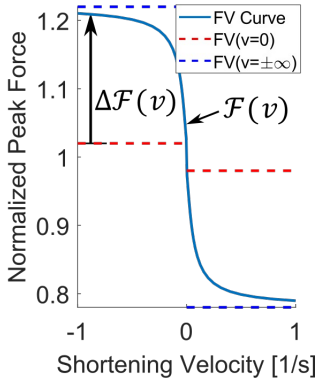
K. Dai, R. Sukhnandan, M. Bennington et al, Living Machines, 2022.

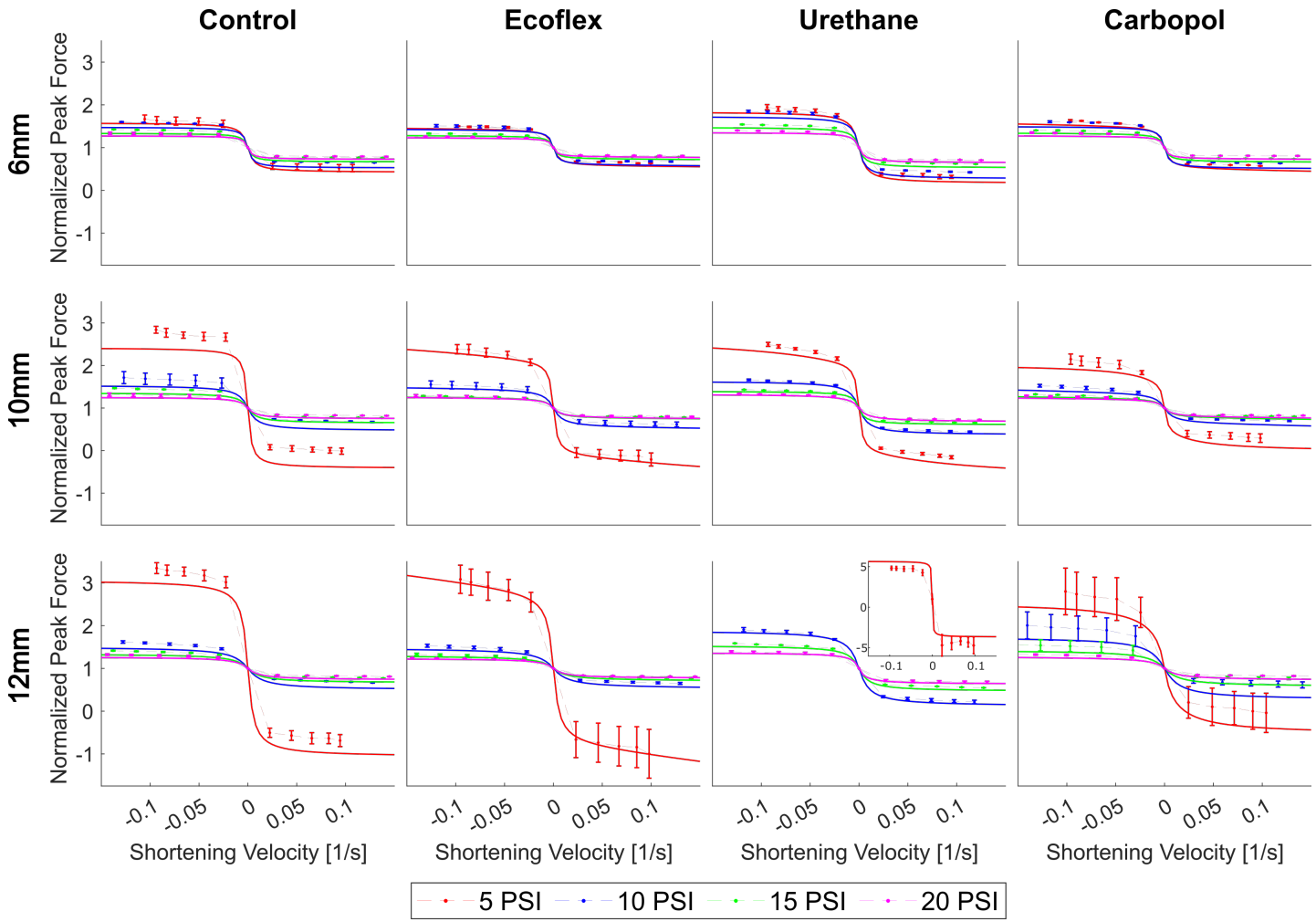
Tuning materials makes pneumatic muscles more biomimetic

M. Bennington









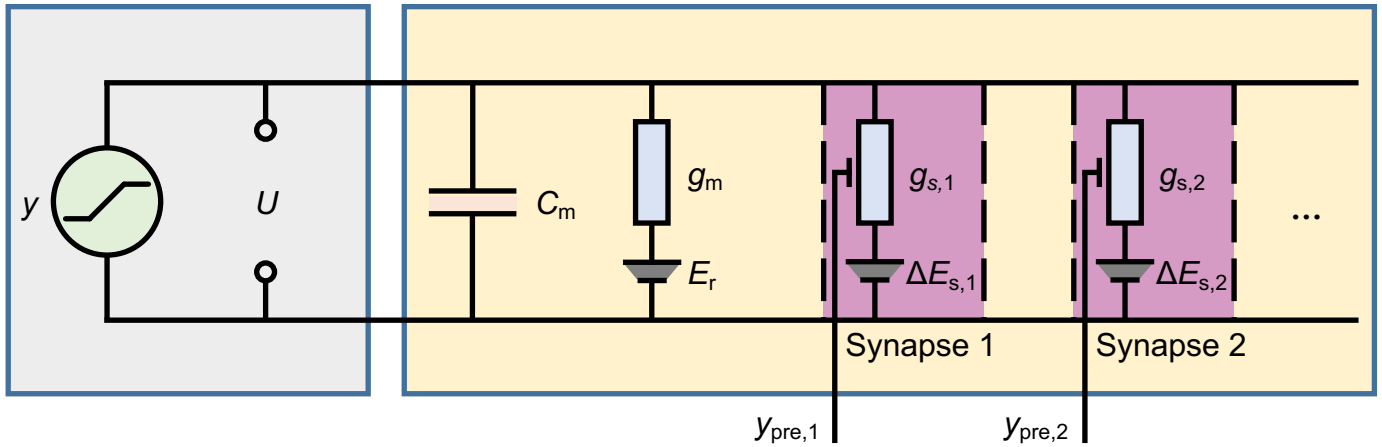
M. Bennington, et al. RoboSoft 2023

Synthetic Nervous Systems (SNSs) capture biologically inspired adaptability in conductance-based networks


H. Chiel


R. Quinn


Y. Li



U: Membrane potential

C_m: Membrane capacitance

g_m: Leak conductance

E_r: Resting potential

$g_{s,j}$: Maximal synaptic conductance

$\Delta E_{s,j}$: Reversal potential – resting potential

I: External stimuli and bias current

y_i: Neuronal activity

Y. Li, R. Sukhnandan, et al. ICRA 2023

SNS discretization allows backprop and parameter learning


H. Chiel


R. Quinn

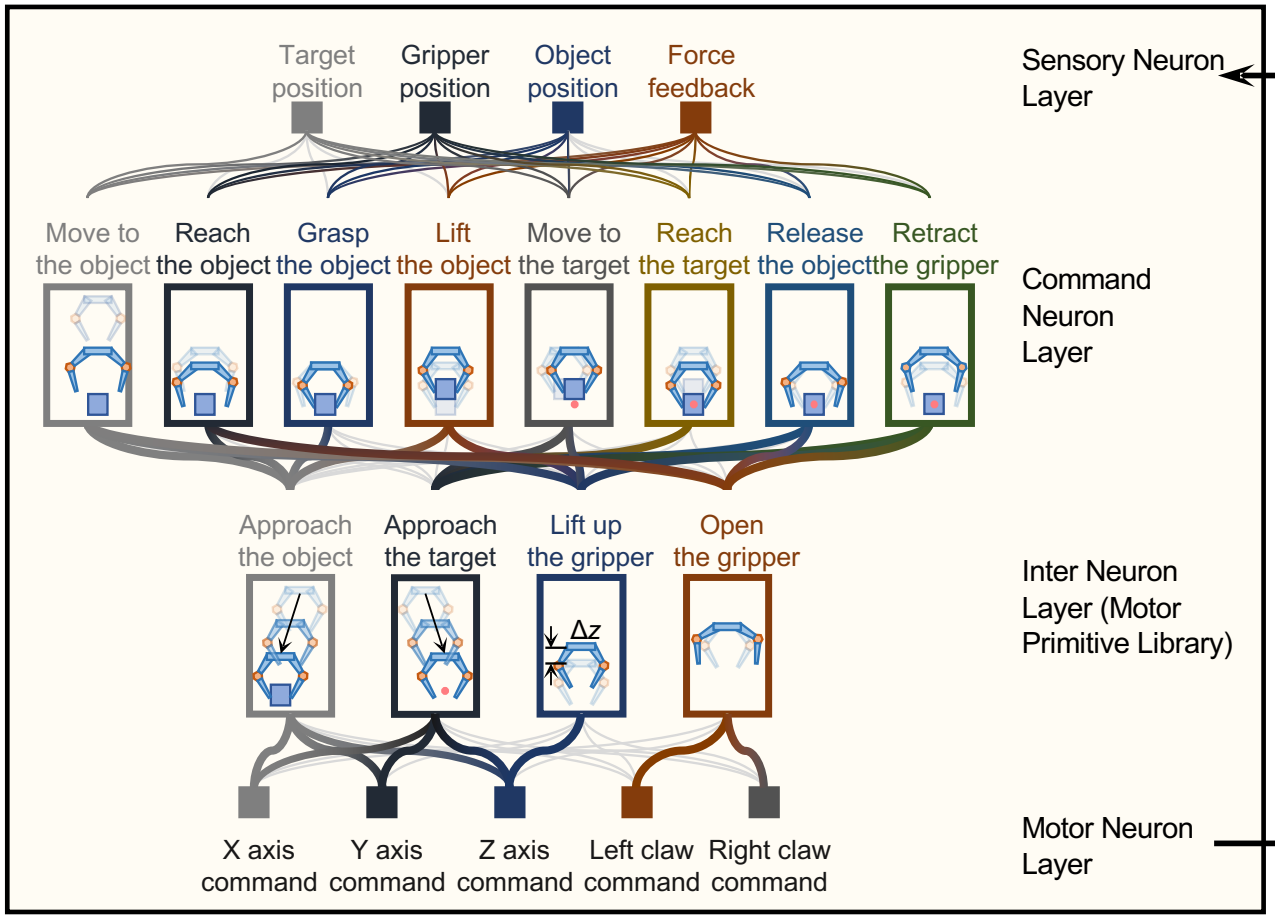

Y. Li

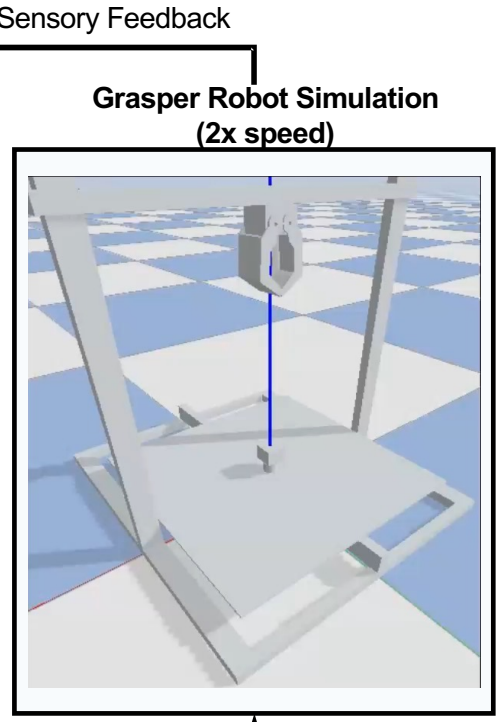
Y. Li, R. Sukhnandan, et al. ICRA 2023

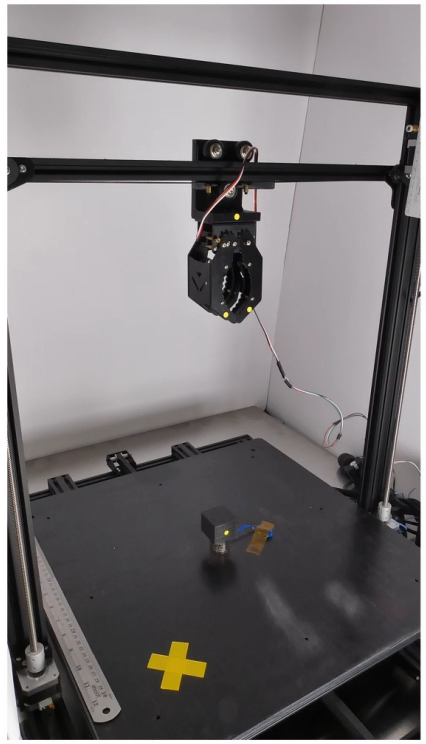
SNS control translates from sim-to-real with minimal tuning




R. Sukhnandan H. Chiel R. Quinn Y. Li







Y. Li, R. Sukhnandan, et al. ICRA 2023

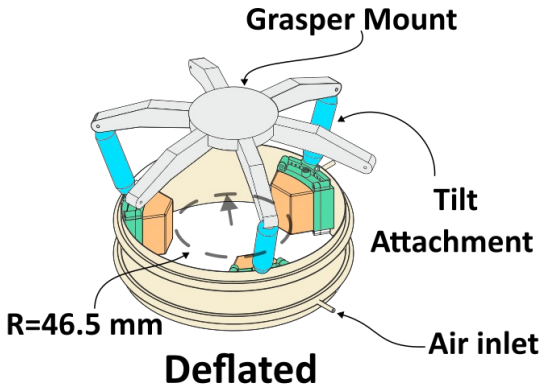
SNS control and tunable stiffness in soft grasping allows a range of objects to be pick-and-placed

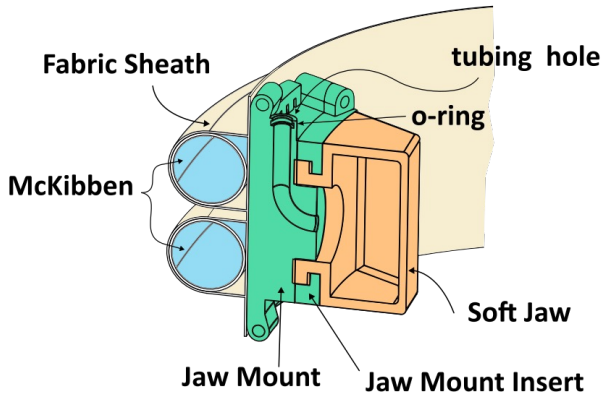

R. Sukhnandan

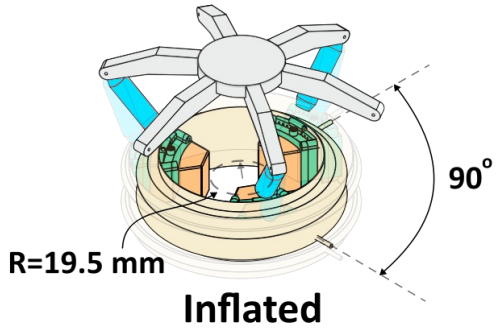

H. Chiel

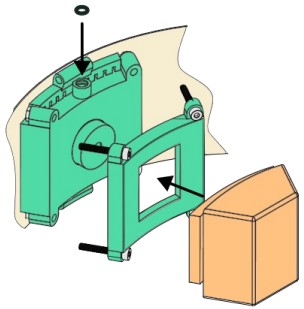

R. Quinn

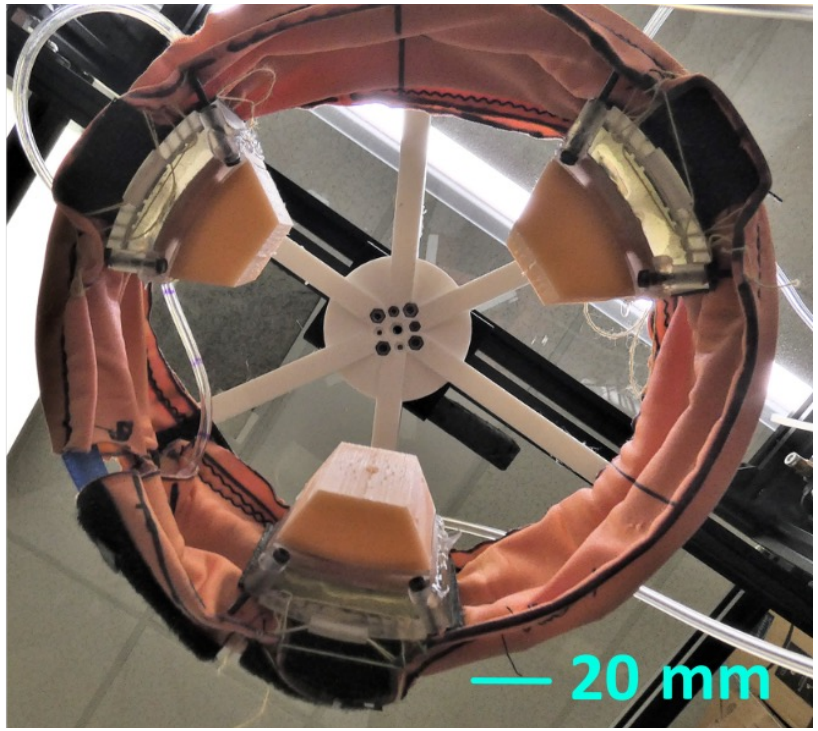

Y. Li











R. Sukhnandan, Y. Li, et al. Living Machines. 2023. Under Review.

SNS control and tunable stiffness in soft grasping allows a range of objects to be pick-and-placed


R. Sukhnandan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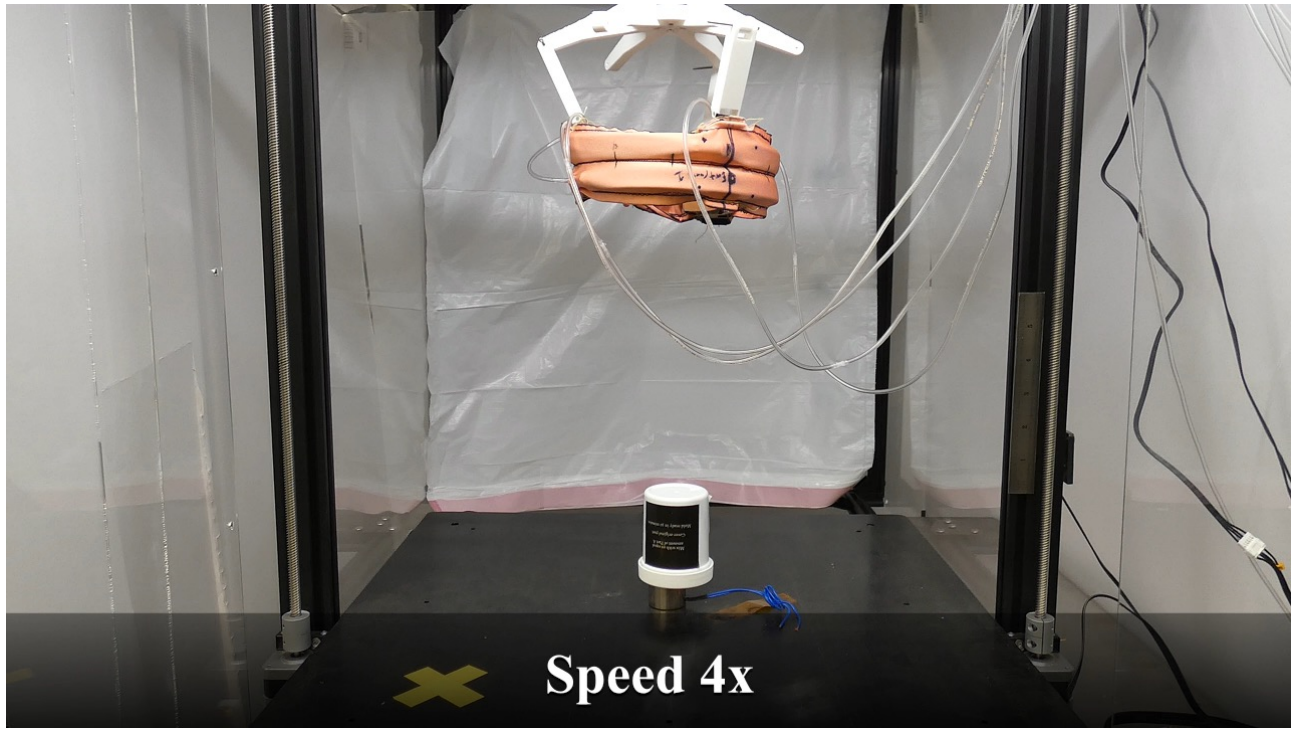
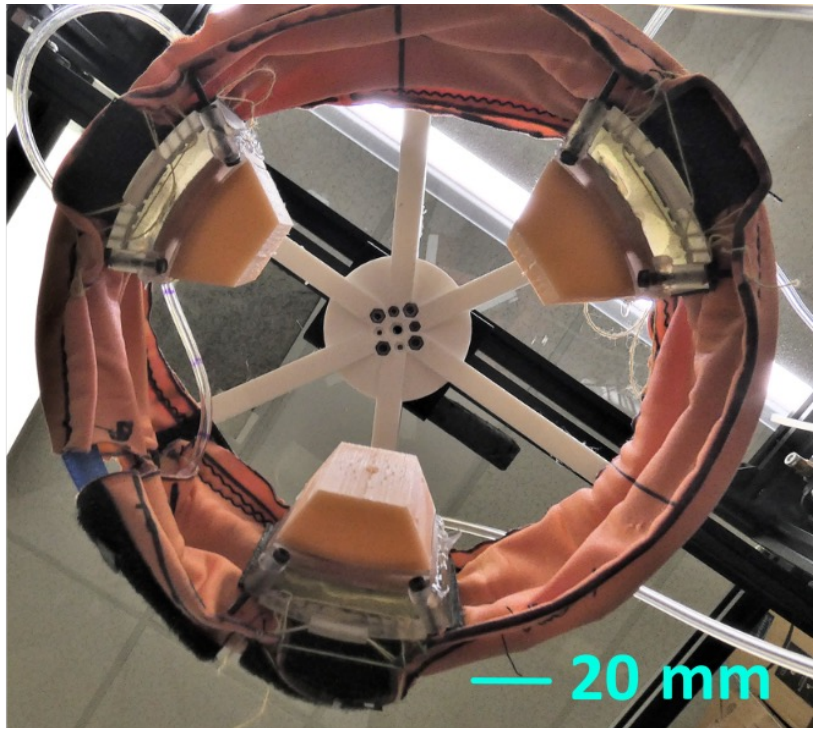
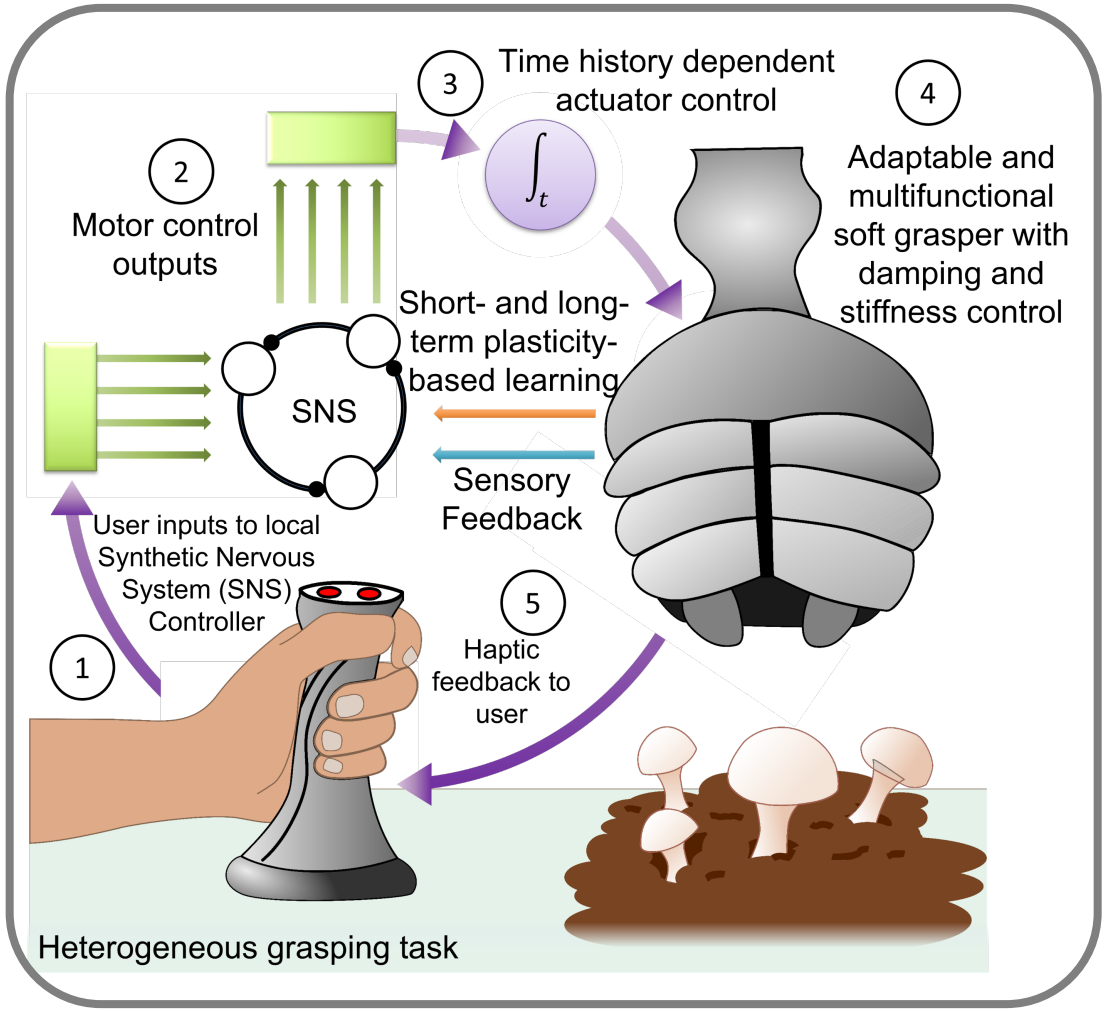




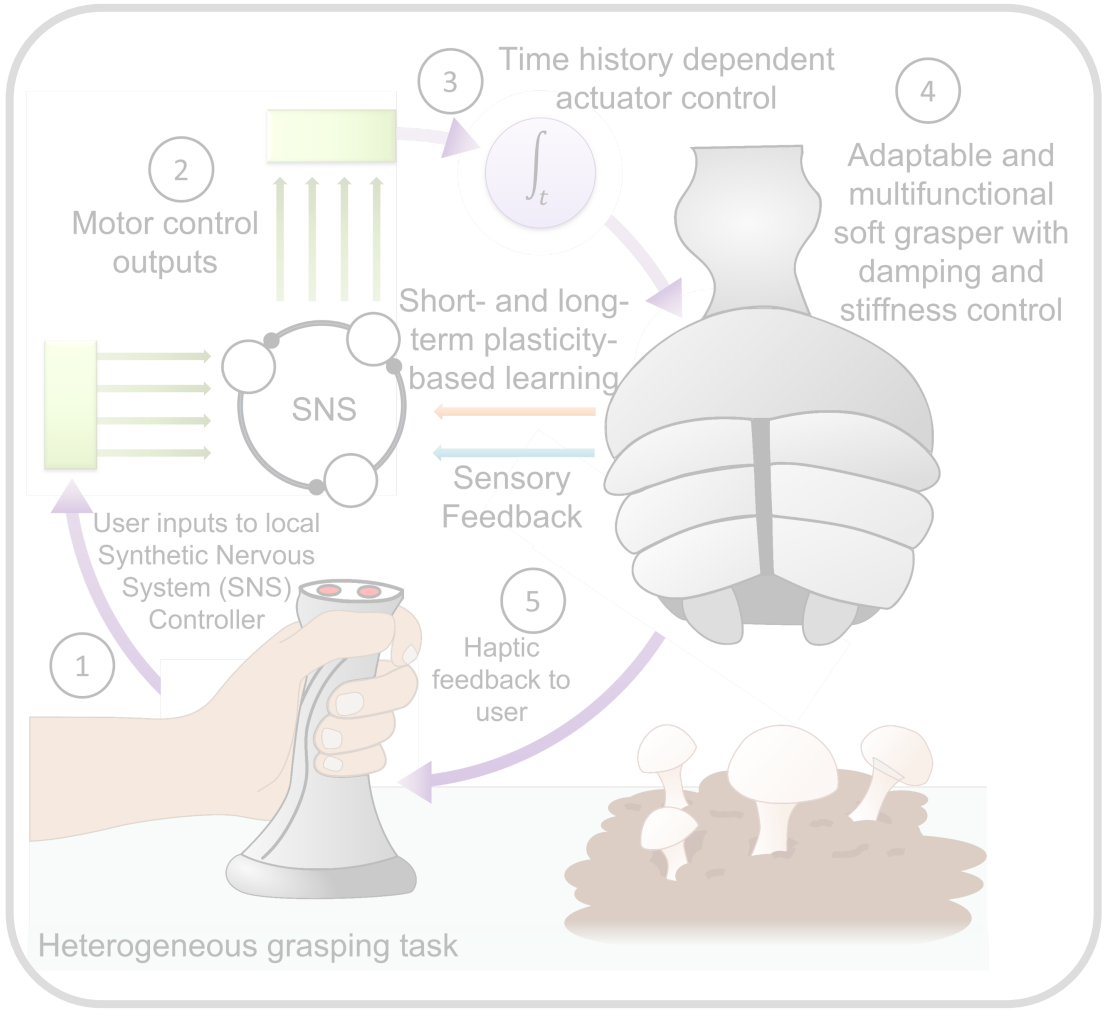
R. Sukhnandan, Y. Li, et al. Living Machines. 2023. Under Review.

Abstraction of animal principles

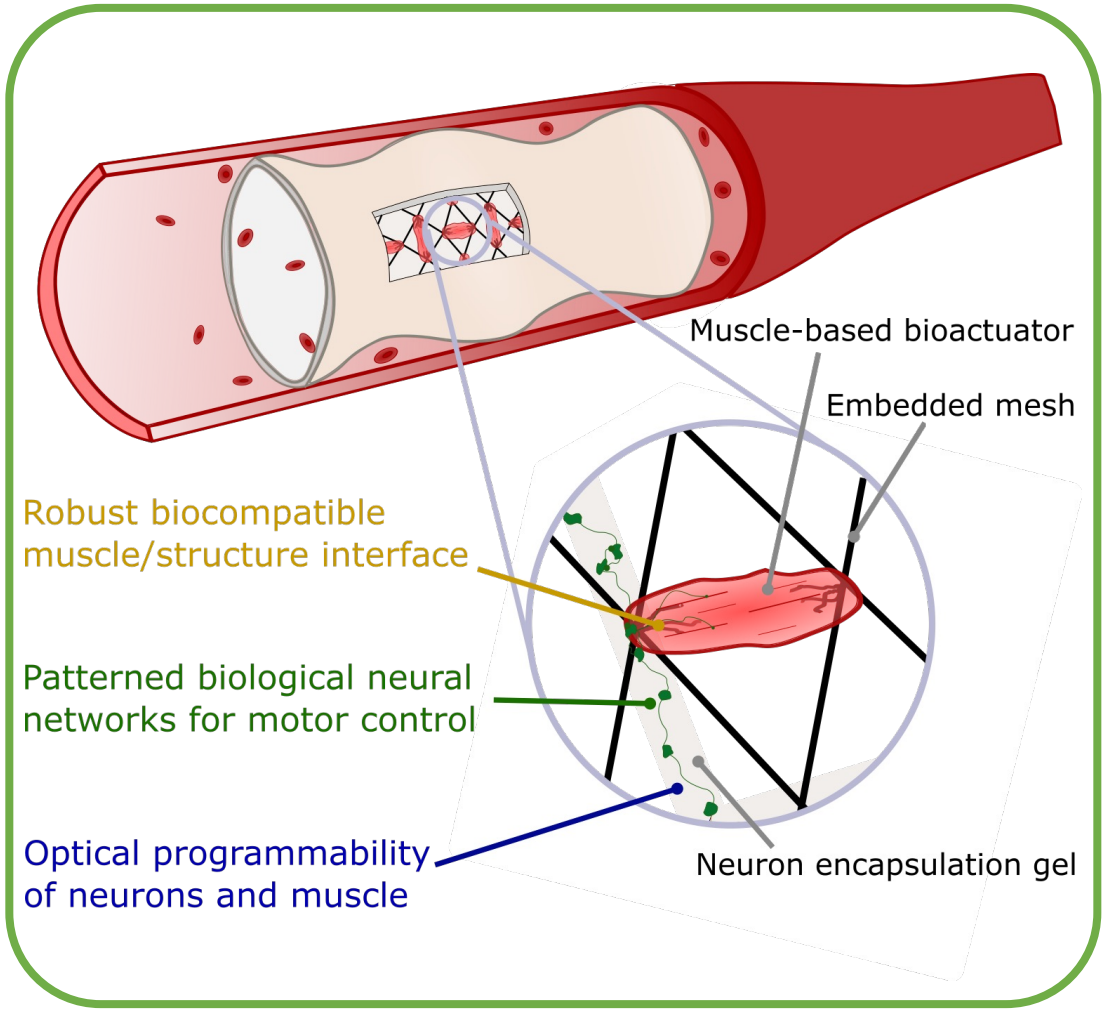


- Force-velocity properties of viscoelastic McKibben actuators can be tuned with an external sheath
- A novel soft grasper abstracted from general principles of sea slug grasping has been created
- An SNS controller was developed in simulation and transferred to the physical system with minimal tuning
- Emergent adaptability observed when the grasper fails to grasp an object and successfully regrasps

Abstraction of animal principles



Application of animal materials



Carnegie Mellon University

CAREER: Adaptive Actuation and Control in Embodied Biohybrid Robots

Award ID#: 2044785

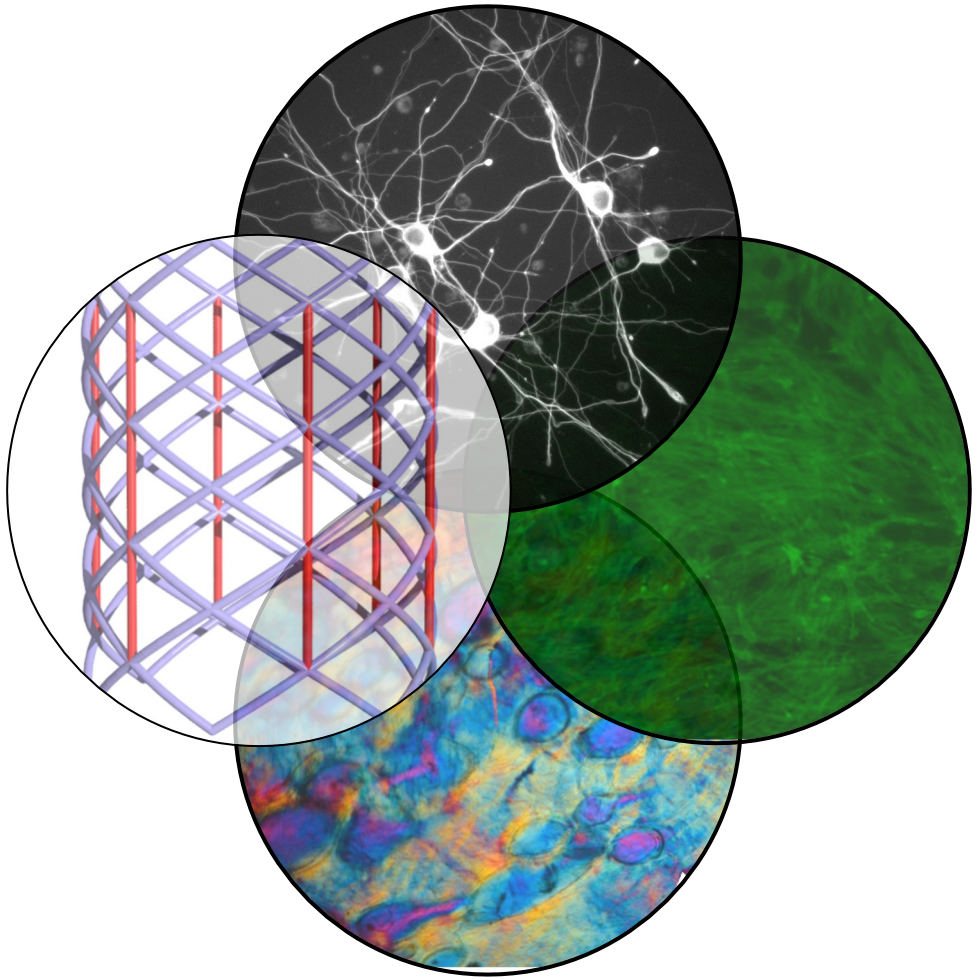
V.A. Webster-Wood, Carnegie Mellon University

Challenges and barriers limit current applications of Biohybrid Robots

(1) Current bioactuators are limited to interfacing with soft or small-scale substrates

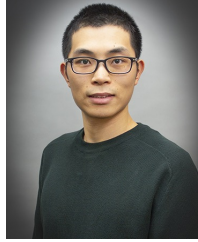
(2) Bioactuator stimulation often result in low actuation forces and muscle fatigue

(3) High barriers of entry for new biohybrid researchers due to lack of accessible modeling tools for biohybrid materials

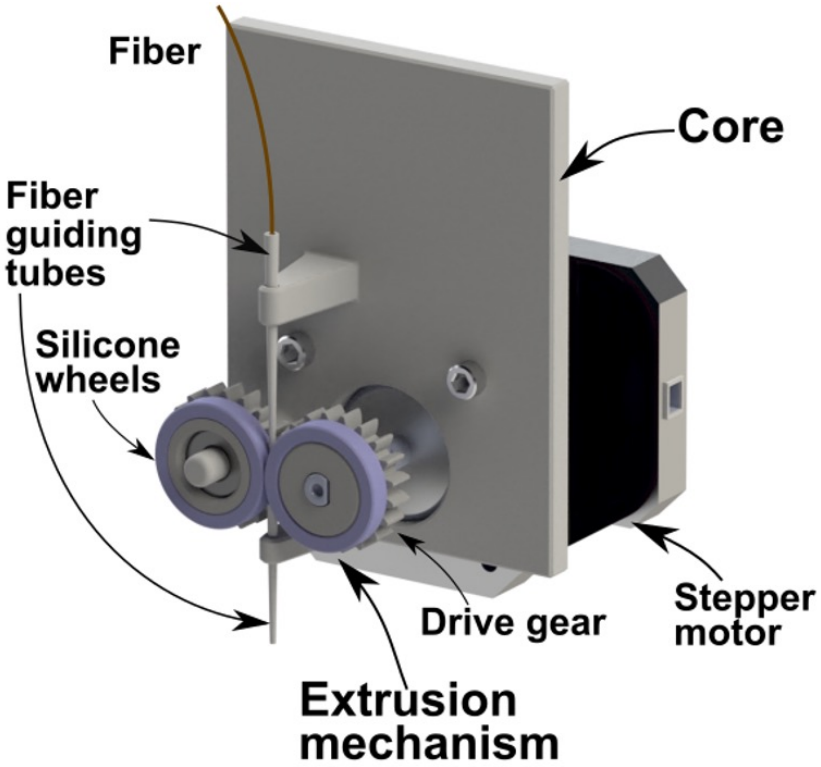


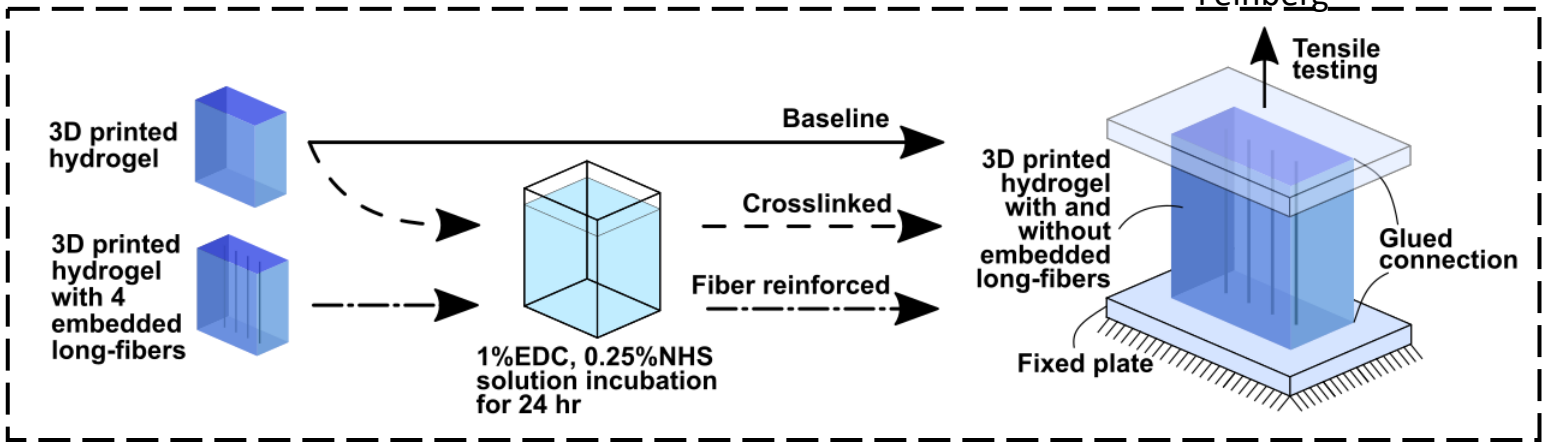
Long-fiber embedded FRESH (LFE-FRESH) printing improves hydrogel interfaces

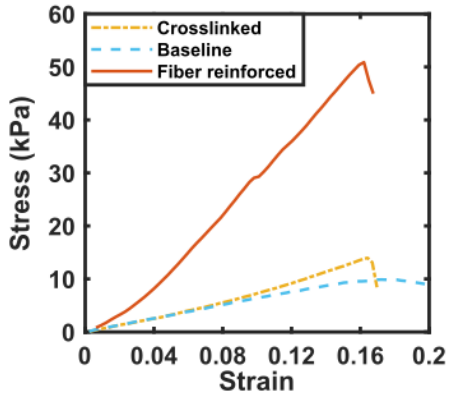

Dr. Adam Feinberg

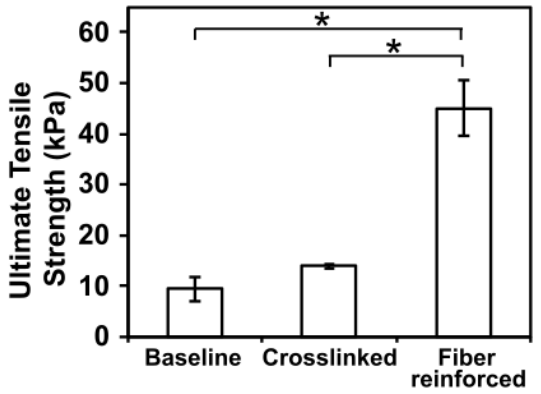

W. Sun

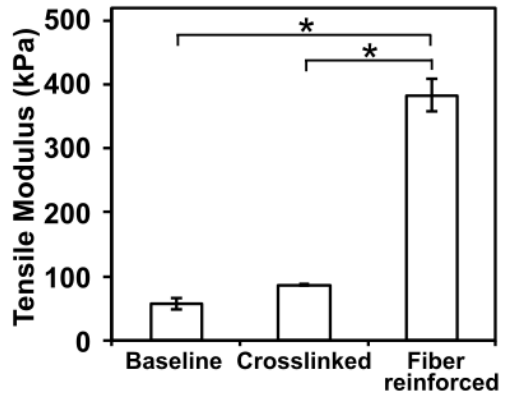
Custom-built Fiber Extruder









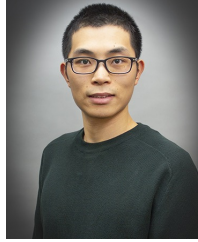


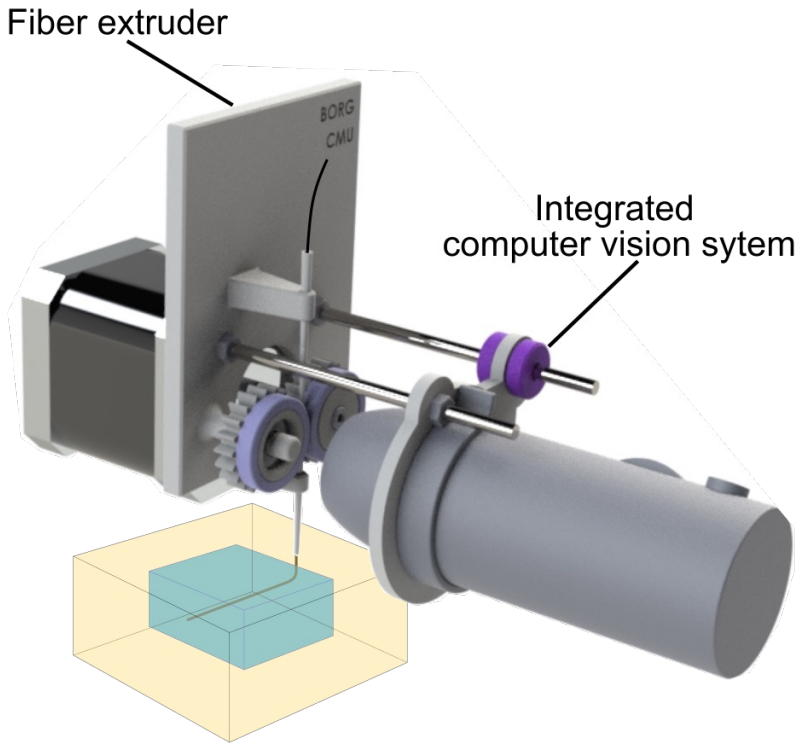
W. Sun, et al., HardwareX, 2022.

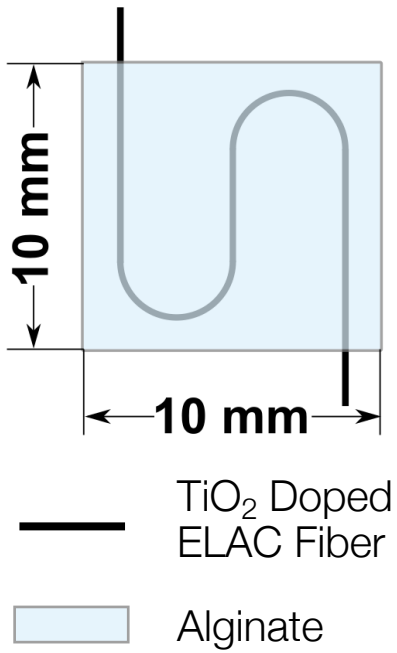
W. Sun, et al., ACS Biomaterials and Engineering, 2021.

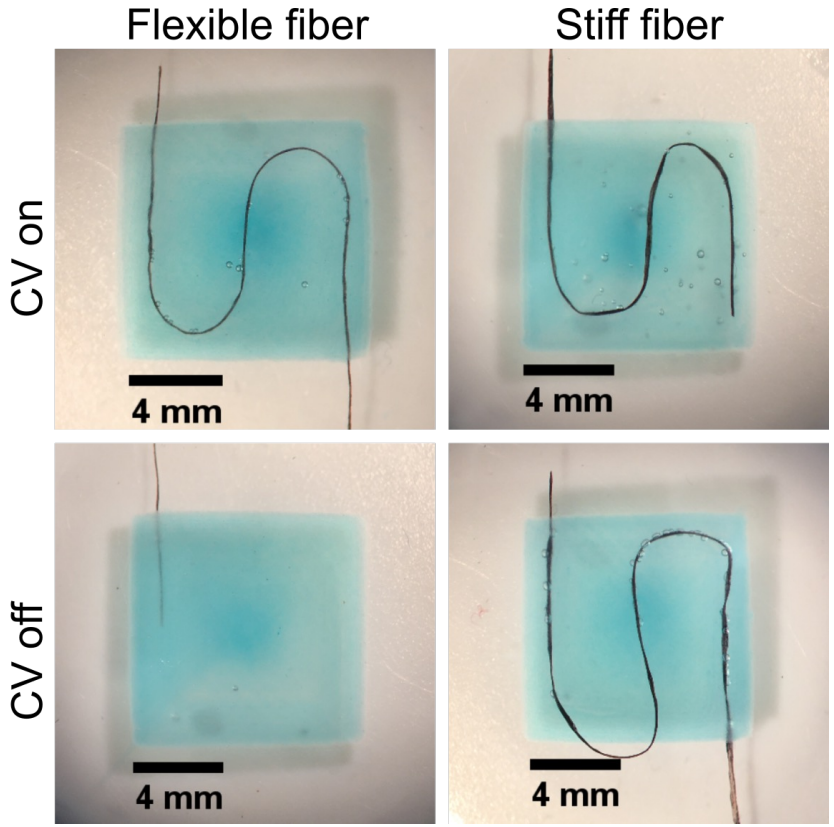
Closed-loop computer vision improves print fidelity in LFE-FRESH printing


Dr. Adam Feinberg


W. Sun

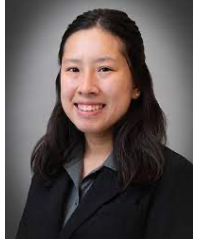


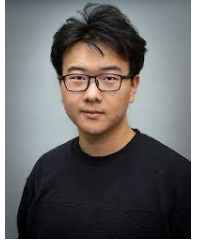




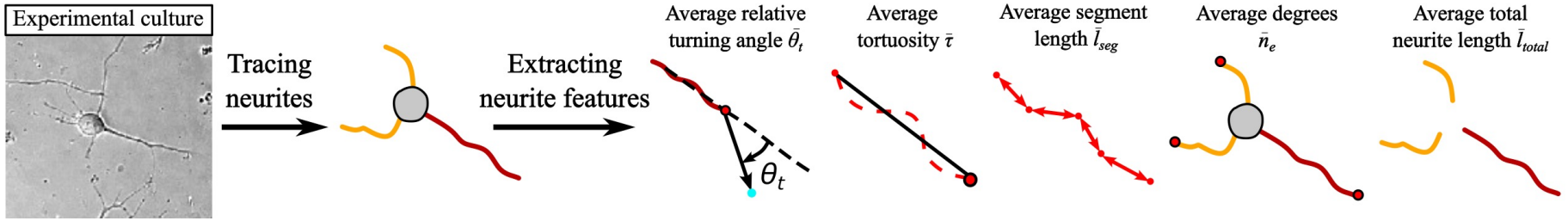
W. Sun, V. Webster-Wood. International Conference of Additive Manufacturing for a Better World, 2022.
W. Sun, et al., ACS Biomaterials and Engineering, 2021.

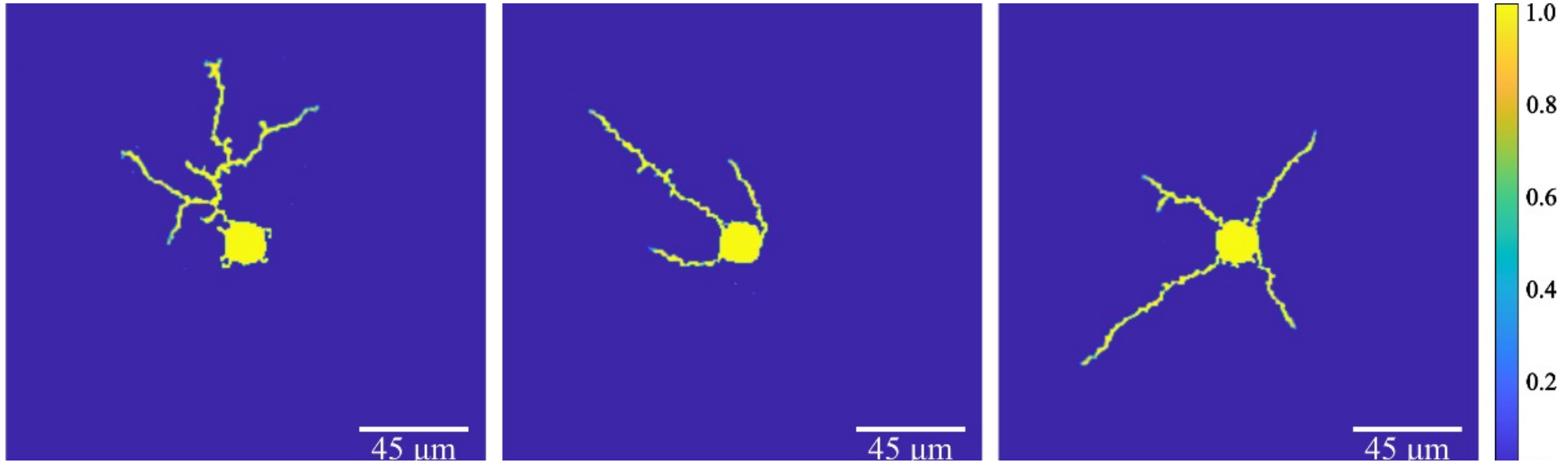
Quantitative experimental neuron growth metrics can be used to constrain neural growth models


A. Liao


K. Qian


Dr. Jessica Zhang



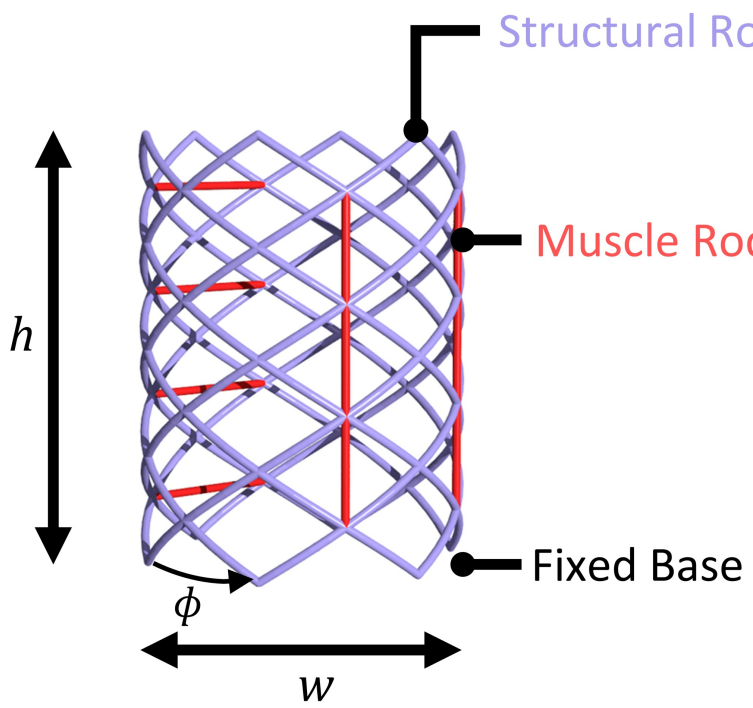


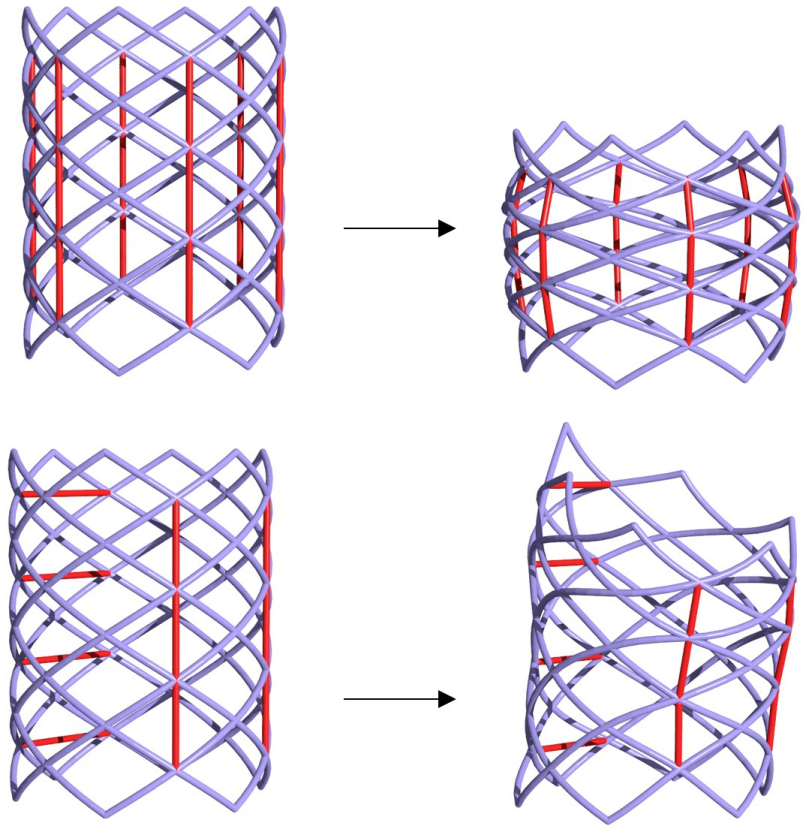
K. Qian, et al. arXiv. 2023.

We are developing modeling tools to lower barriers of entry to biohybrid robotics

S. Schaffer

- Parametric modeling pipeline for biohybrid lattice structures in PyElastica





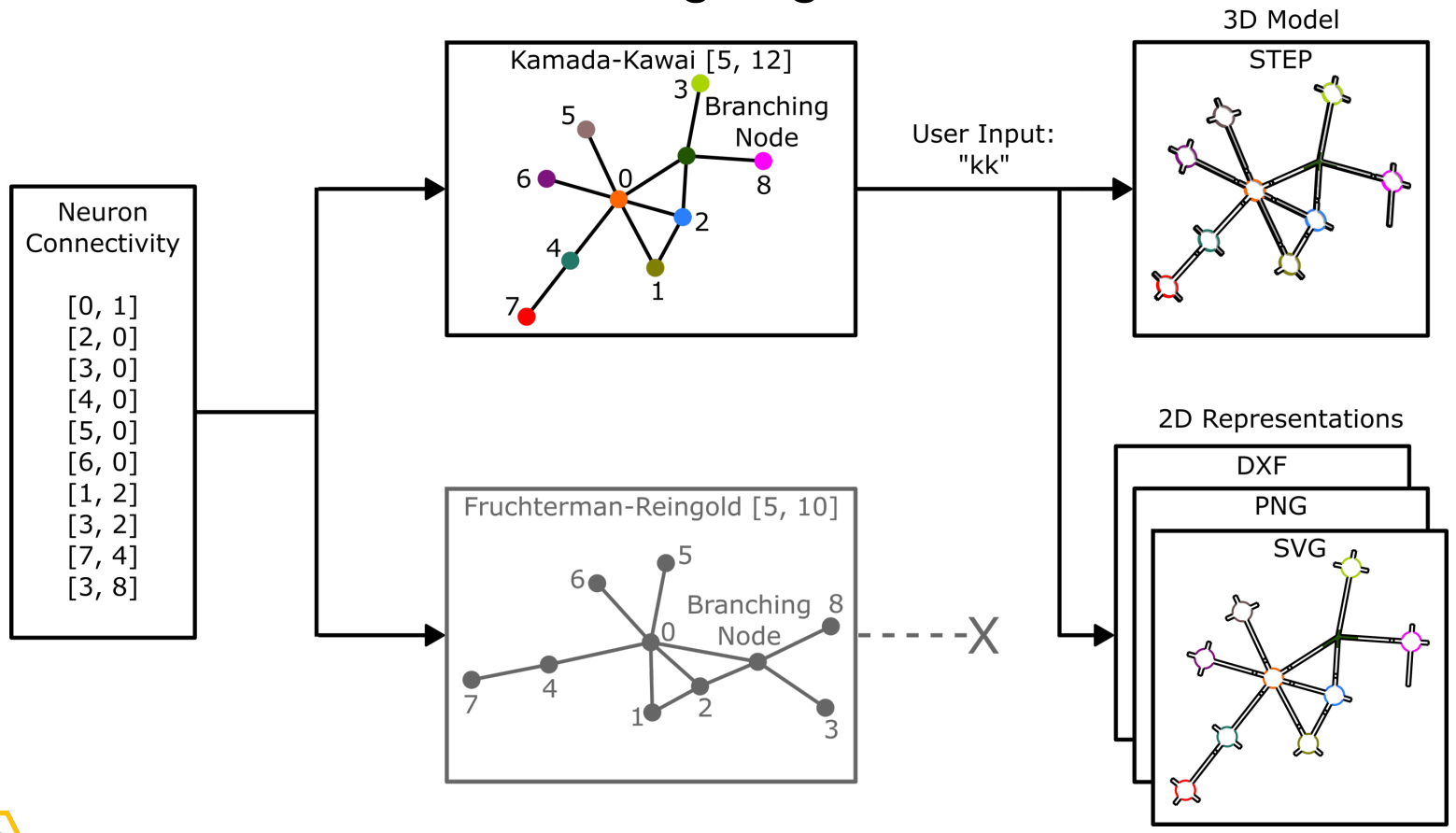
S. Schaffer et al. Living Machines 2023. Under Review.

We are developing modeling tools to lower barriers of entry to biohybrid robotics

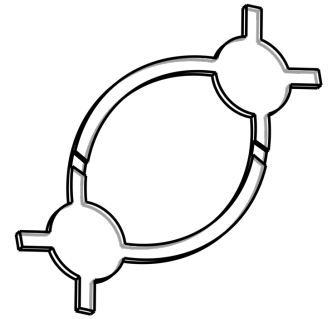

A. Liao


Dr. Jessica Zhang

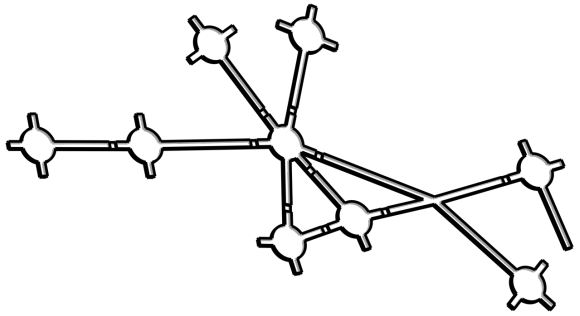
- GANGLIA: A tool for designing customized neuron circuit patterns



Half-Center Oscillator



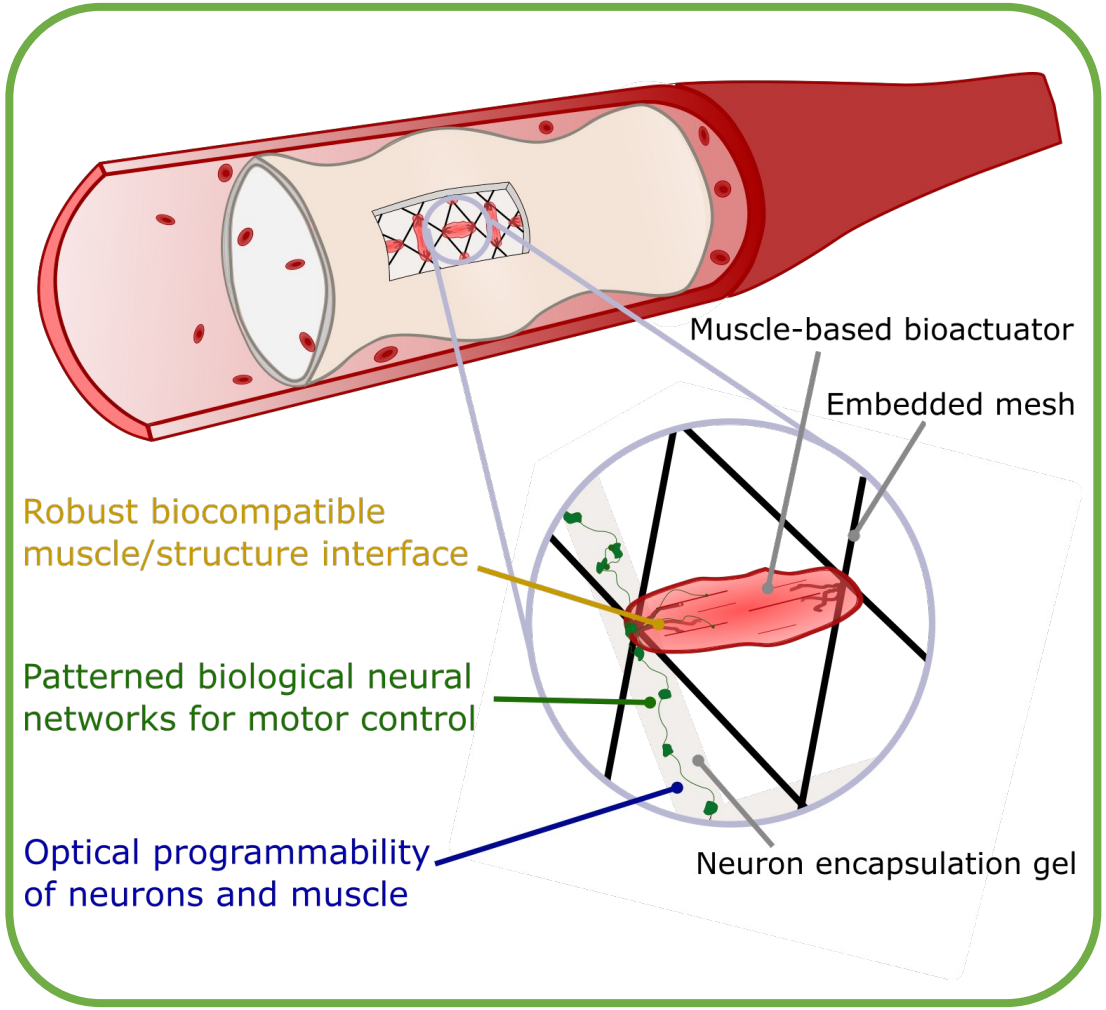
User-designed 9-cell Network



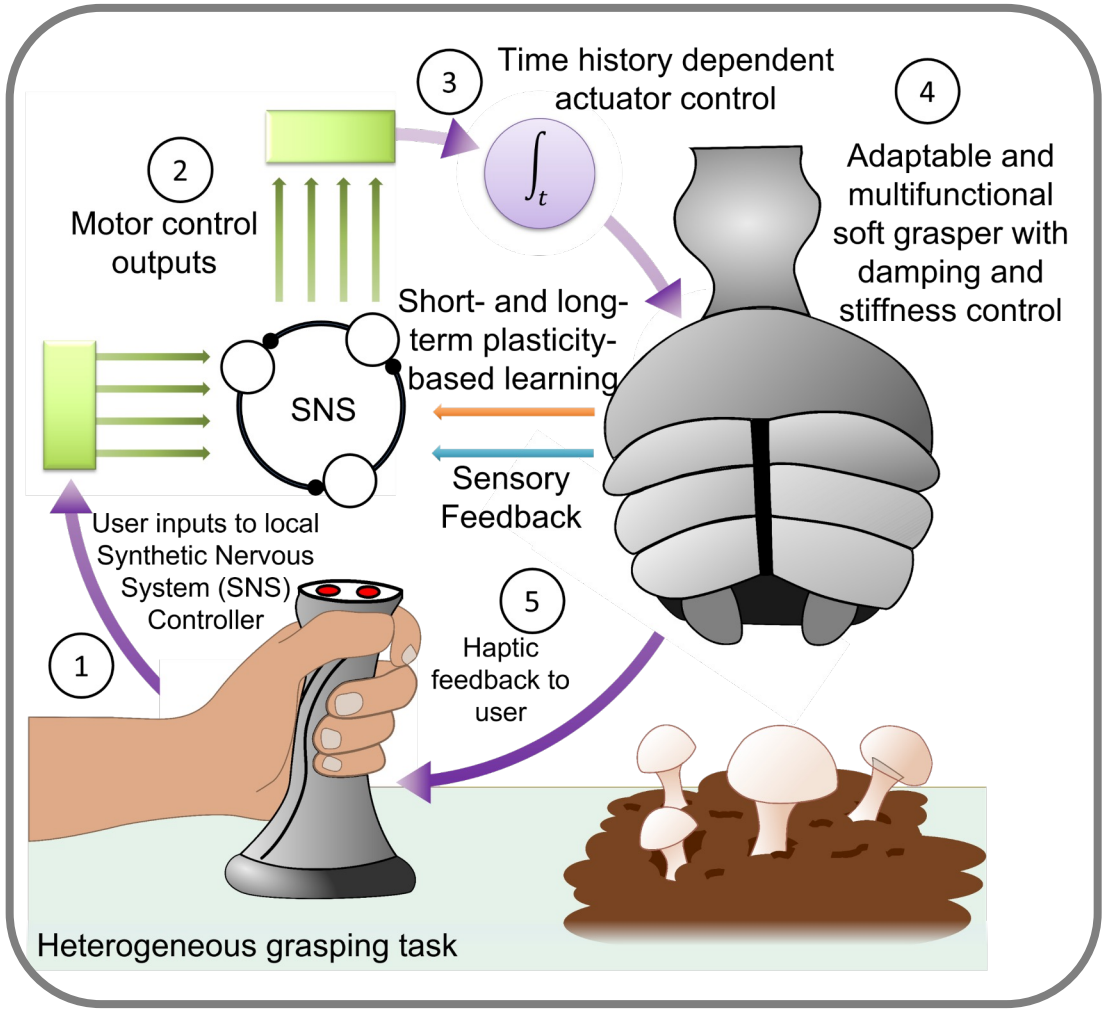
S. Schaffer et al. Living Machines 2023. Under Review.

Application of animal materials

- LFE-FRESH improves hydrogel mechanical properties
- Controlling extrusion based on fiber buckling improved LFE-FRESH outcomes
- A dataset of neuron growth *in vitro* has been developed and disseminated
- Metrics were identified to automatically identify growth stages
- New tools have been developed to lower barriers of entry to biohybrid robotics



Abstraction of animal principles



Application of animal materials