Communication, Coordination, and Control in a Quasistatic Neuromechanical System: *Aplysia* Feeding (IRG3)

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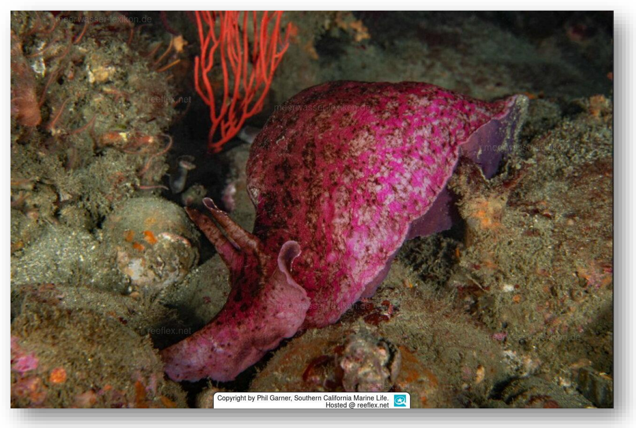
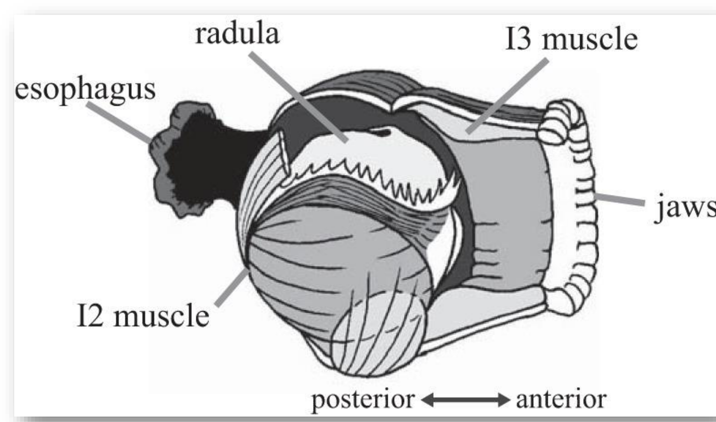
Aim 1: Modeling Neuromechanics

Model System: *Aplysia californica*



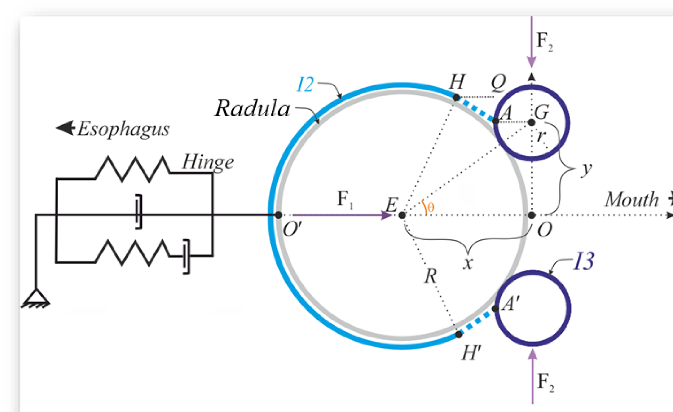
Aplysia's small size and slow movements make it an ideal system for studying control of quasi-static systems.

***Aplysia*'s feeding apparatus (the buccal mass)**



Within the feeding apparatus (the buccal mass), a central grasper (the radula) is moved by the musculature to transfer food from outside the animal to its esophagus.

Existing mechanical model

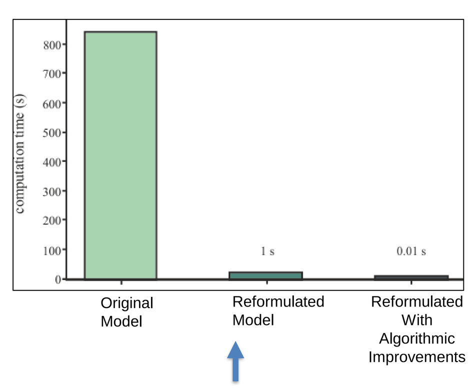


A mathematical model of the buccal mass has been constructed for simulated nervous systems to control. The model requires 800s of computer time to simulate 60s of behavior.

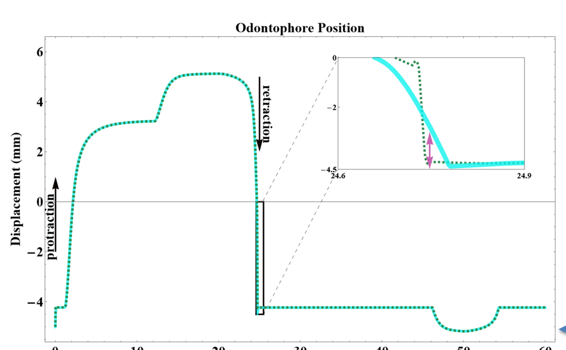
Algebraic reformulation of the model reduces computation time

$$(m\ddot{y} + F_2)cos(\theta) = (M\ddot{x} - F_1)sin(\theta)$$

$$F_2\ Cot(\theta) + F_1 = 0.$$

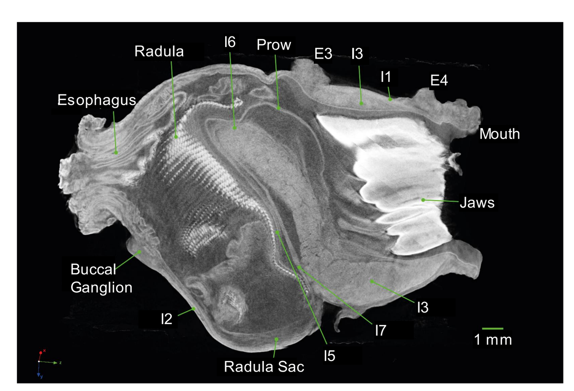


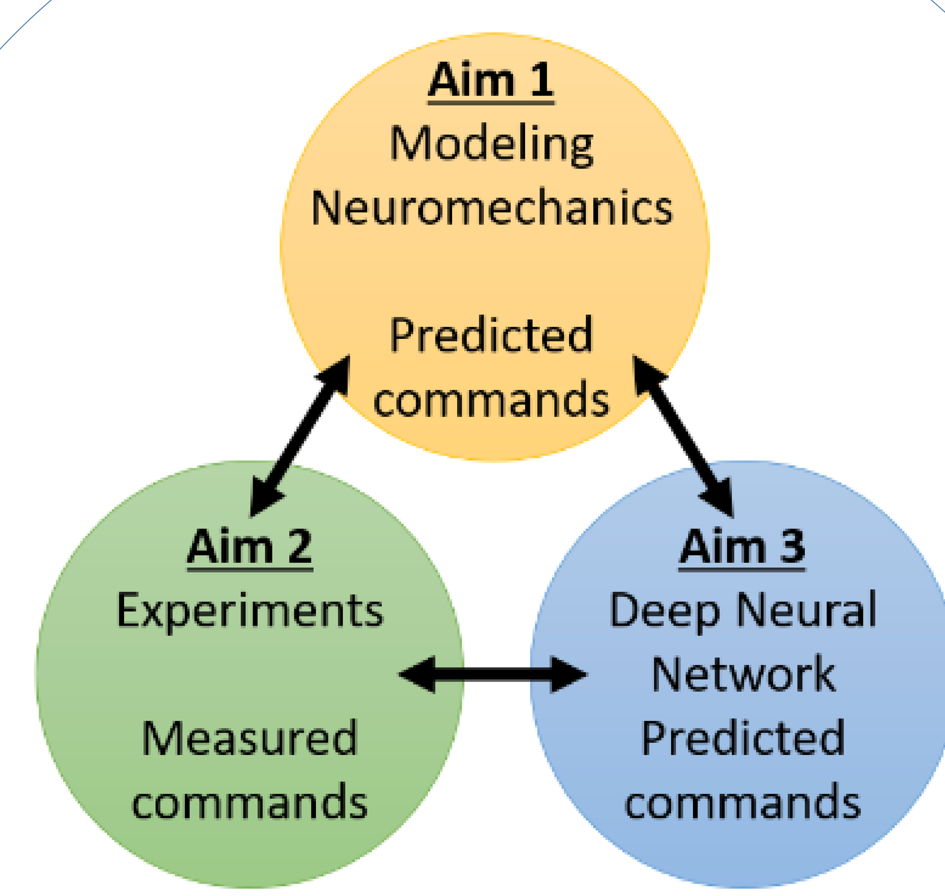
Reformulated model is more than two orders of magnitude faster to run than the original model



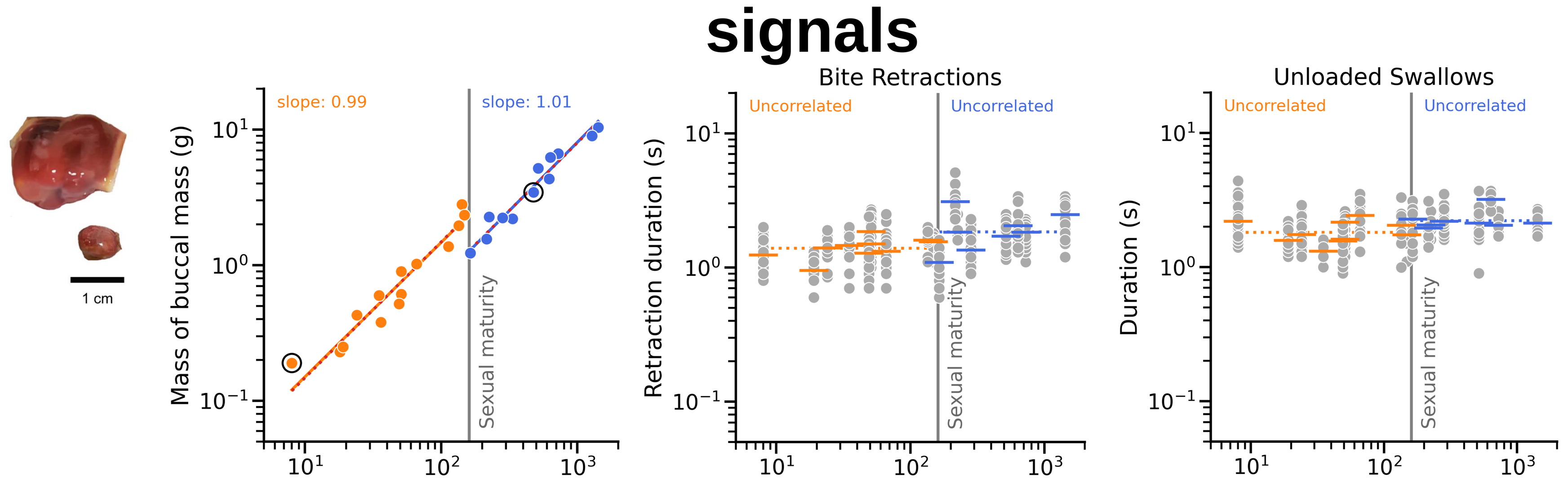
Reformulated model (dashed) returns extremely similar results to the original model (solid line) over a 60 s simulation of a behavior

MicroCT scanning will be used to refine the anatomy to improve the biomechanical model going forward



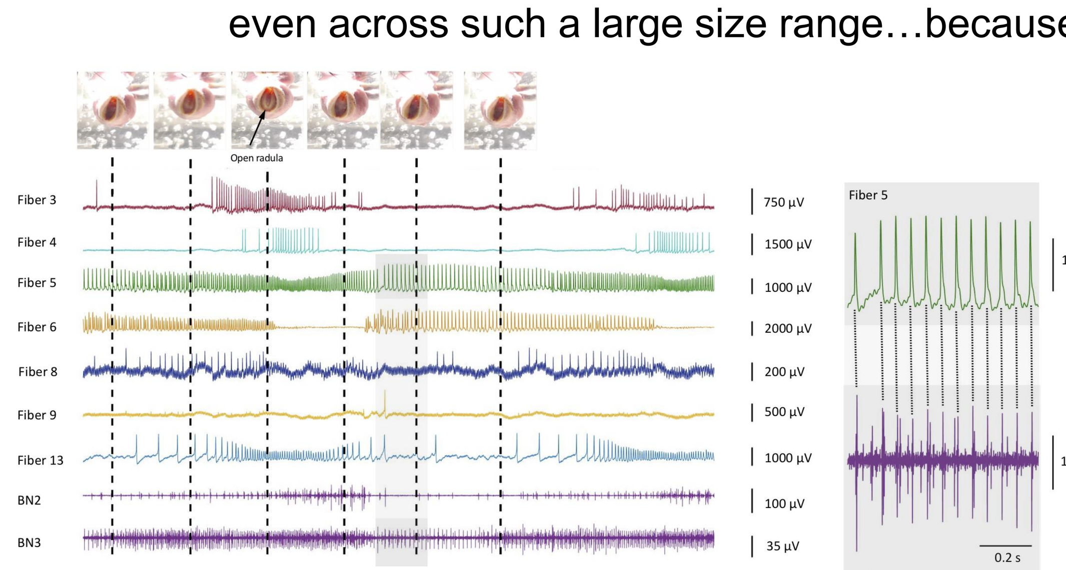


Aim 2: Scaling and measurements of control signals



Across the almost 3 orders of magnitude of mass range, buccal masses pre and post sexual maturity increased in size isometrically with mass

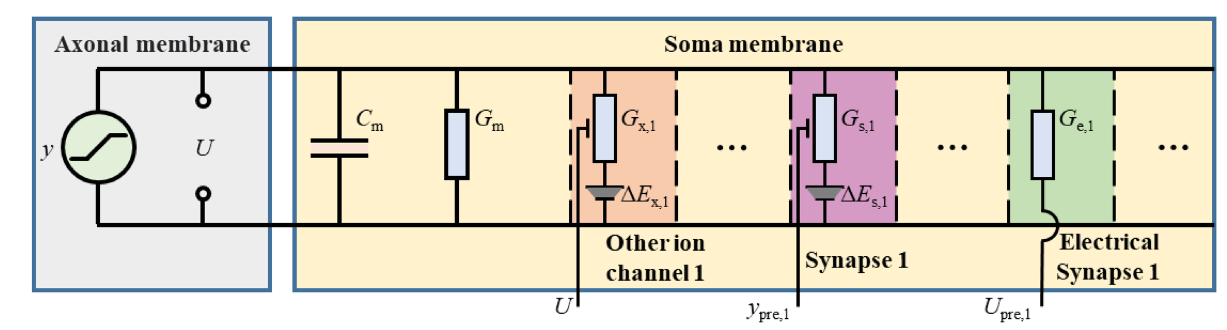
The mechanical model predicts that cycle time will be ***unaffected*** by animal mass, even across such a large size range…because of its quasi-static mechanics



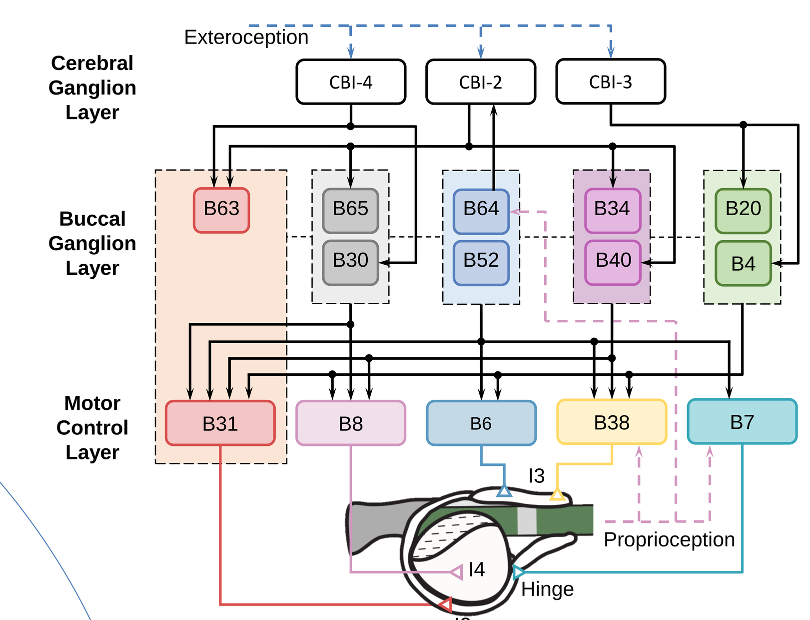
Using carbon fiber electrodes applied to the neurons of the buccal ganglion in a semi-intact feeding preparation, it is possible to record motor neuronal and interneuronal activity in the key neurons that control feeding behavior. The panel on the right, corresponding to the gray box in the panel on the left, shows intracellular (top, green) and extracellular (bottom, purple) recordings from identified multi action neuron B4/B5.

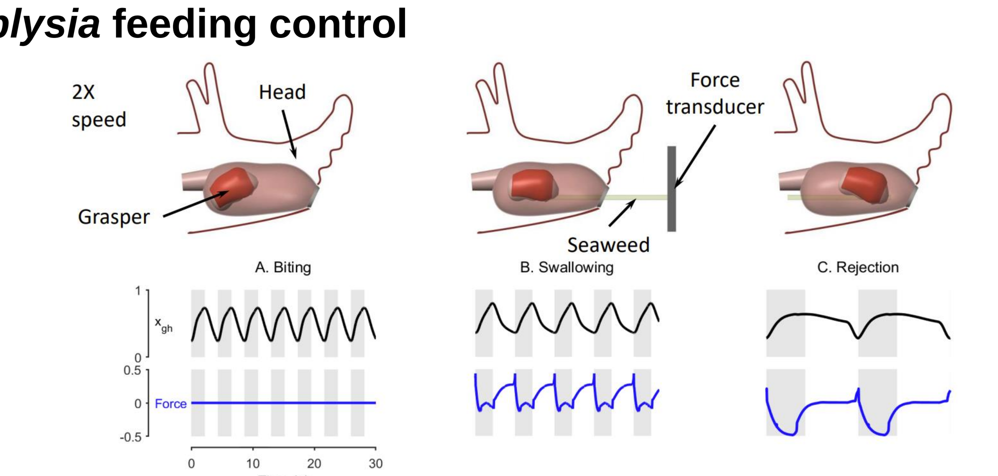
Aim 3: Comparison of machine learning and synthetic nervous system control

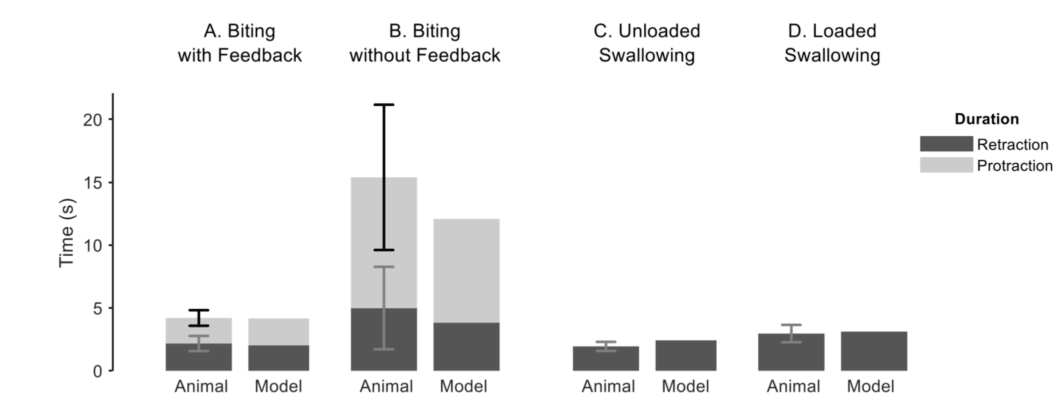
A Synthetic Nervous System model captures multifunctional *Aplysia* feeding control



We use Synthetic Nervous Systems (SNSs) to represent the neural dynamics (top). The SNS architecture takes into account the connectivity and dynamics of many key neurons (right).

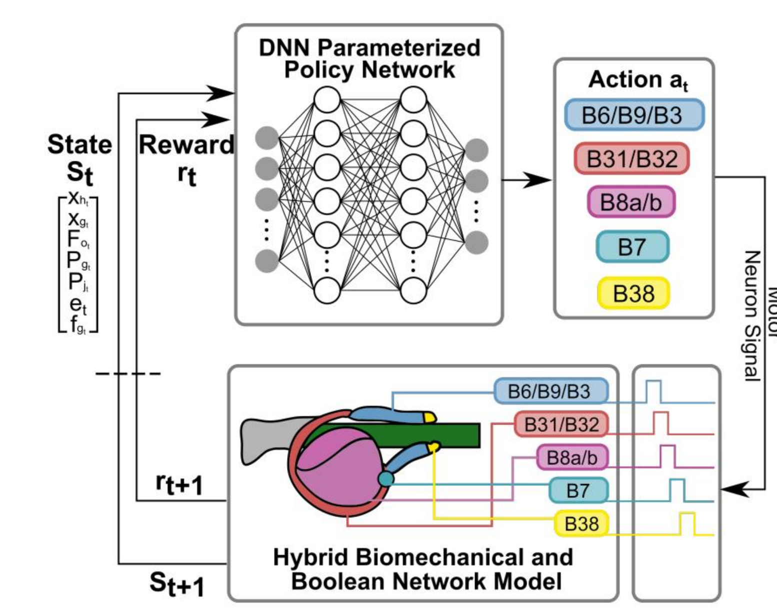


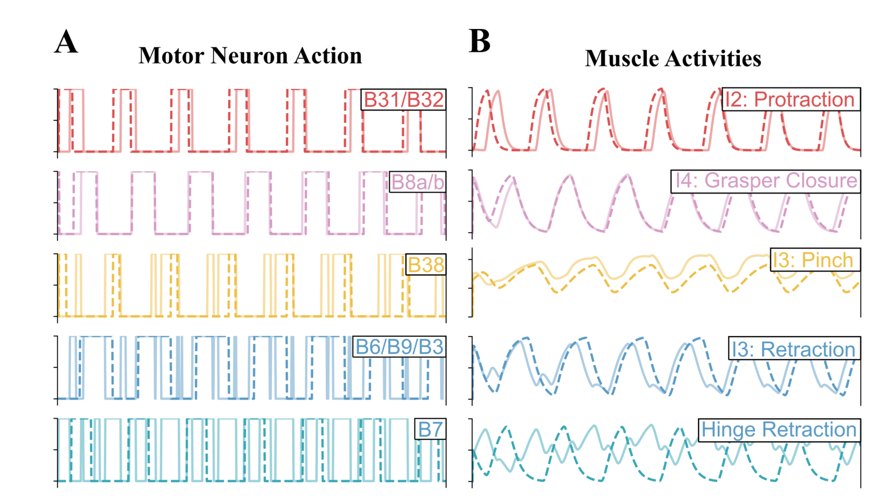




The model can reproduce multifunctional control of *Aplysia* feeding (top), and the responses of the model share similar features with animal data (bottom)

Reinforcement Learning for motor patterns generates similar, but not identical motor patterns





When DNN based reinforcement learning is used with an environment containing our simple *Aplysia* biomechanical model (left), the network learns to produce motor patterns to successfully ingest seaweed (right). Dashed lines: Our original Boolean model of *Aplysia* feeding circuitry. Solid lines: Learned motor commands.

Accomplishments & Next steps

Accomplishments

- 3D Refinement of feeding anatomy (buccal mass)
- 100-fold increase in simulation speed of biomechanical model
- Novel soft actuators and characterization of force-velocity properties in synthetic actuators
- Novel *Aplysia*-inspired soft grasping robot (SLUGBOT)
- Characterization of *Aplysia* musculature for robot model: I3 and I5
- Demonstration that a quasistatic system's response durations are independent of animal size
- Development of novel technology to monitor and manipulate individual identified neurons in a semi-intact *Aplysia* feeding preparation.
- SNS controller captures multifunctionality of feeding apparatus and neural dynamics
- A machine learning framework for comparisons between SNS control and reinforcement learning with standard ANNs has been developed

Next steps

- Use the biomechanics to determine "bottlenecks" and "don't care" regions for control
- Use the *in roboto* model to deepen our understanding of the *Aplysia* buccal mass and determine key control features
- Investigate the effect of synthetic actuator scale on key control features in the *in roboto* model
- Translate fiber orientations from 3D buccal mass reconstructions to actuator design
- Investigate neural activity in buccal and cerebral ganglia to understand higher and lower motor control and use it to refine our current SNS model
- Conduct head-to-head comparisons between machine learning-based modeling approaches and the SNS
- Use the SNS to control the *in roboto* model and compare kinematics to animal data