NeuroNex: Communication, Coordination, and Control in Neuromechanical Systems

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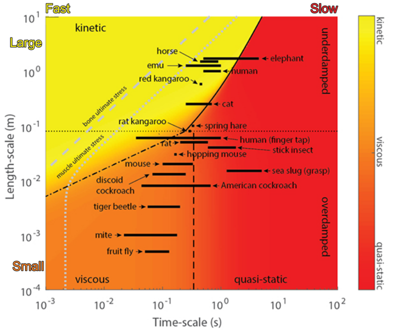
Abstract

How do biological nervous systems control and execute interactions with the environment? Animals of all sizes and speeds must solve this problem, whether during walking, grasping, feeding, or other behaviors. Our work focuses on **Communication, Coordination, and Control in Neuromechanical Systems (C³NS)** to develop comprehensive models of sensorimotor control with relationships to the environment, both within individual species, and across the phyla Arthropoda, Mollusca, and Chordata. Our Network seeks to **create a conceptual modeling framework that can predict control for organisms of different size and speed scales**. Through our inter-phylum experimental study of sensorimotor control, we will identify convergent or conserved principles to refine and inform this framework. Such a framework will have a tremendous effect on the ability to **interpret, and extend the impact of, experimental results across biology and robotics, with future applications to prosthetics**.

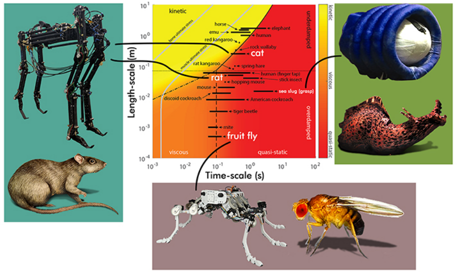
Interdisciplinary Research Group 1

R. Quinn (CWRU)
N. Szczecinski (WVU)
A. Hunt (PSU)
V. Webster-Wood (CMU)
G. Sutton (U. Lincoln, U.K.)
H. Chiel (CWRU)

IRG1's goal is to build a **scale-dependent model** of how neural control systems regulate motion in a dynamic environment.



The dynamic scale of a behavior can be predicted by the **length scale of the animal** and the **duration of the behavior**.



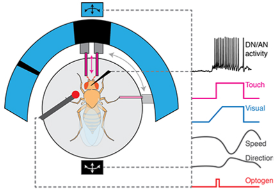
Our **model organisms and their robot models function in a unique behavioral regime**, depending on their size and the speed of their behaviors.

Interdisciplinary Research Group 2

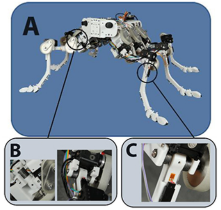
A. Büschges (U. Cologne)
A. Blanke (U. Bonn)
K. Ito (U. Cologne)
J. Ache (U. Würzburg)
N. Szczecinski (WVU)

IRG2 studies the **walking behavior of adult Drosophila melanogaster** (Arthropoda).

IRG2 is performing **high-throughput nano-CT scans of the legs** to investigate the effect of load sensors on the control of walking behaviors.



Multimodal closed-loop **VR setup for behavioral experiments** in combination with electrophysiological recordings or calcium imaging. Piezo motors will be coupled to the visual stimulus and the track-ball.



A) Photograph of Drosophibot. B) Torsional springs in parallel with the actuators **change the balance between elastic and inertial forces**, and therefore the dynamic scale. C) **Strain gauges on the tibia and trochanter** mimic the strain-sensing capabilities the animal

Optogenetic tools and automated behavioral assays will be used to study **how descending neurons promote or antagonize walking behavior**.

The dynamically-scaled robot **Drosophibot and its SNS controller** will be used as a substrate for integrating these results into a unified model.

Interdisciplinary Research Group 3

H. Chiel (CWRU)
V. Webster-Wood (CMU)
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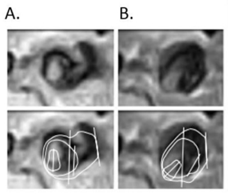
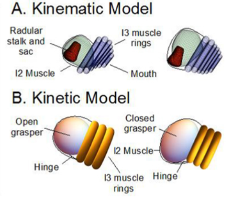
R. Quinn (CWRU)

IRG3 will study the **grasping and feeding behavior of sea slugs Aplysia californica** (Mollusca).

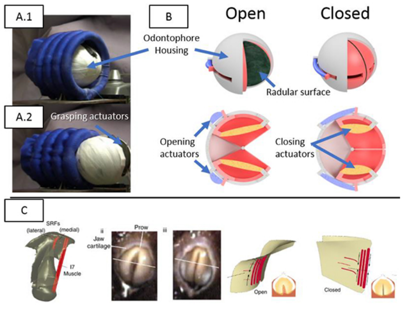
IRG3 will develop **multi-level neuromechanical models of grasping and feeding** to investigate how biomechanics and sensory feedback simplify neural communication. Experimental work will leverage the **MINT carbon fiber electrode (CFE)**, to record from different control centers.



MRI data captured during active feeding behavior in Aplysia. These MRI sequences have been segmented (lower panels) to identify **feeding apparatus structures during behavior.**



Segmented MRI data is used to construct **3D meshes for kinematic models** (A) which led to a kinetic model (B).



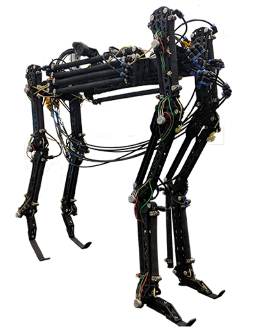
A) An initial grasper. B) Schematic of the **proposed bioinspired grasper with abstracted internal kinematic shape** changes showing open and closed configurations in oblique (top) and cross-sectional views (bottom). C) The final robotic grasper will be based on **solid models obtained from MRI data**. (Left) The grasper has a conformable surface (middle) and is capable of opening and **closing through actuation of the sub-surface fibers** and I7 muscles.

Interdisciplinary Research Group 4

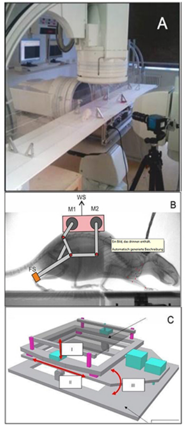
M. Tresch (Northwestern)
C.J. Heckman (Northwestern)
M. Perrault (Emory)
M. Fischer (Jena)
E. Andrada (Jena)
A. Hunt (PSU)
R. Quinn (CWRU)

IRG4 will study the **walking behavior of small mammals** (Chordata).

IRG4 will leverage their neuromechanical model and neurorobot, Muscle Mutt, to investigate how **small mammals control their interaction with the environment through posture and locomotion**.



Muscle Mutt is a planar robot modeled from limb segments in an adult dog (Whippet) with 3 degrees of freedom on each leg. The joints are controlled with artificial muscles attached to limbs via tendon-like strings. Muscle Mutt is controlled by a **synthetic nervous system and is capable of performing forward walking** on a controlled treadmill.



Experimental work will **quantify responses to perturbations via 3D X-ray video and EMG recording** of animals during posture and locomotion.

Extracellular recordings of **spinal interneurons will be recorded in response to these same perturbations** to understand how sensory information is integrated according to the dynamic scale of animals.

A) Biplanar X-ray system. B) Current methods **biplanar highspeed XROMM, force plate recordings and EMG recordings** during flat locomotion of rats (red point indicates identified tantalum beads and joints). We aim to add an **exoskeleton to perturb locomotion** of which a preliminary design is shown. C) Actuated perturbation platform (first design).

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