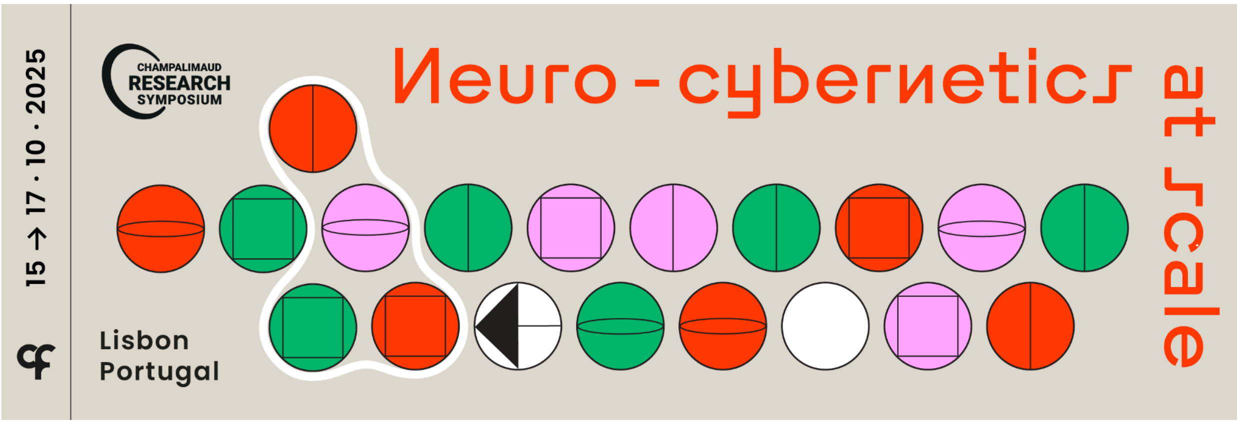

A Fully 3D Model of Jellyfish Swimming, Integrating Nerve Nets, Muscles, Body Biomechanics and Fluid-Structure Interaction

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Jellyfish are among the earliest freely swimming animals and their behaviors—including forward propulsion and evasive as well as approaching turning maneuvers—are generated by a comparatively simple, decentralized nervous system composed of neurons homologous to those of bilaterians [1]. It remains unclear, however, how the spatial structure and neural activity of jellyfish nerve nets give rise to both symmetric and asymmetric, tightly coordinated muscle contractions and, as a result, highly energy-efficient locomotion in water [2]. To address this, we develop a computational model of the scyphozoan jellyfish Aurelia aurita that integrates nerve nets, muscles, body biomechanics and fluid-structure interaction in—for the first time—three dimensions, to bridge the gap between neural activity and behavior.

To reduce computational cost, we introduce an abstract model of nerve net activity as signal transmission on a graph whose nodes correspond to synapses. This model captures the spatiotemporal propagation of neural signals and closely approximates the dynamics of a nerve net model of interconnected Hodgkin-Huxley-type neurons [3]. To simulate the interaction between the deformable jellyfish body and the surrounding fluid, we employ smoothed particle hydrodynamics, a particle-based method that models both the elastic body and the water in a unified framework and naturally handles large deformations.

Our model spans multiple domains, from nerve net architecture and dynamics to muscle activation and fluid-body interaction, providing a platform to study how behavior emerges from the interplay of nervous system, muscles, body and environment. In addition, it offers insights into the function of early nervous systems and the origins of autonomous movement.

computational neuroscience, jellyfish, locomotion, embodied behavior, fluid-structure interaction