Popular science abstract

The field of engineering makes use of biological concepts to develop smart solutions inspired by millions of years of evolution. In our work, we investigate the neural mechanisms underlying legged locomotion to gain further understanding of these networks and potentially improve the control of walking robots. The rhythmic movement observed during animal walking is generated through a combination of neural circuits producing oscillating output and sensory feedback capable of shaping that output. However, how the neurons are connected in a particular arrangement or “architecture” to create these circuits is not yet known. Our studies provide an informed guess about the potential architecture by simulating a neural network capable of driving coordinated, rhythmic movements. We approach this challenge in a novel way by incorporating two types of neurons in our network. Based on their prevalence in nature, we introduce the use of a non-spiking interneuron (NSI) to a spiking neural network (SNN). SNNs are composed of neurons that mimic how biological neurons communicate using spikes. We take SNNs one step further by adding NSIs that communicate through graded signals, thereby, adding to the functionality of the network. We find that NSIs provide two major benefits to the network. First, they are able to translate analog or spiking input to be sent onwards into the network and affect output. Second, they are able to separate network dynamics when connecting sub-networks of spiking neurons. This can be thought of as a neural equivalent to galvanic isolation in an electrical circuit. These results suggest that adding NSIs to SNNs is an important new research pathway that increases biological fidelity while providing a viable communication method for decentralized, distributed controllers. We argue that the advancement from pure SNNs to mixed neural networks introduces a new paradigm for adaptive controllers in robotics.

To ensure the network topology we develop is biologically plausible, we use insight from biological studies to design and constrain the network and finally compare the network output to experimental results. As our network does not use feedback, we must compare our results to a similar setup within biological studies. Biologists are able to study insect preparations deprived of sensory feedback through crushing or cutting the nerves of the animal. These preparations are then chemically-excited in order to record the motor neuron activity absent sensory feedback. This technique has shown that patterns of coordinated motor activity occur which resemble the step-phase transitions in an insect leg during walking. When an insect walks, the leg is either in the air, referred to as swing phase, or on the ground, referred to as stance phase. The switch from swing to stance and vice versa is defined as a step-phase transition. In our research, we recreate these patterns of activity by loosely coupling rhythm-generating neural circuits, confirming that our network topology can facilitate this type of coordinated motor activity. These results also highlight the limits of this type of feed-forward network, showing that feedback is necessary to inform the initiation of these step-phase transitions. In other words, the duration of the swing or stance phase may rely on sensory feedback. Our findings show that the mixed neural network topology we develop is able to reproduce coordinated motor activity of an analogous experiment conducted on an insect. This suggests that our network topology could be biologically plausible thus creating the possibility to test biological hypotheses about these networks in a controlled simulation environment.