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EDITORIAL

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# Foreword for the special issue on Lamprey and Salamander Robots and the Central Nervous System

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Animals are capable of fascinating motor skills, from the efficient and agile swimming of lamprey, the ability to switch between aquatic and terrestrial gaits in salamander, to the multiple and diverse activities of humans such as practicing sports or playing a musical instrument. All these skills require good coordination between the nervous system, the musculoskeletal system, and the environment. The control mechanisms underlying these skills are very complex because of the high number of degrees of freedom involved (large numbers of joints, muscles, and sensory channels), the highly nonlinear and complex dynamics of the musculoskeletal system, as well as uncertainties about the state of the environment.

Analyzing and understanding the underlying control principles is difficult because of the interplay of multiple components. To make progress here, we believe it is very useful to (i) choose simple animal models from which general principles can be learned, (ii) make comprehensive mathematical models that investigate the interplay of all involved components, and (iii) use robots to test hypotheses and validate the models.

This special issue constitutes a collection of articles at the intersection between robotics and neuroscience that illustrate such an approach. The articles result from the LAMPETRA Project, a collaborative project funded by the European Commission (FP7, EU contract no 216100). LAMPETRA stands for: *Life-like Artifacts for Motor-Postural Experiments and Development of new Control Technologies inspired by Rapid Animal locomotion*. During its course, the LAMPETRA project aimed at developing lamprey- and salamander-like bioinspired robots, with a twofold goal: to achieve new insight into and understanding of neuroscience and to find new engineering solutions for high-performance artificial locomotion in terms of fast response, adaptability, reliability, energy efficiency, and control. The main technological goal has been to develop autonomous artifacts that replicate living animal characteristics, from the neuronal level up to control and behavioral responses.

The choice of the lamprey and the salamander as animal models was motivated by their agile locomotion skills, their great importance from an evolutionary point of view, and by the fact that they are simple animals whose neuronal centers controlling locomotion have been studied in detail. The lamprey, an eel-like proto-vertebrate, swims with an anguilliform motion in which the body undulates with a traveling wave from head to tail. The salamander, a tetrapod amphibian, uses a similar swimming propulsion with limbs folded backward, and it can in addition switch to a slower stepping gait when on firm ground. By studying and comparing these animals, one can nicely investigate the basic principles of the vertebrate central nervous system and its reorganization during the transition from aquatic to terrestrial habitats during vertebrate evolution.

This special issue presents our current knowledge of lamprey and salamander locomotion in terms of neurophysiology and movement studies. It also presents numerical models of the underlying control circuits and explores how robots can be used as scientific tools in neuroscience. We believe that understanding locomotion control is a problem that fundamentally requires a comprehensive and interdisciplinary

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approach. As mentioned above, locomotion is a complex dynamic phenomenon that needs the interaction between the central and peripheral nervous systems, the musculoskeletal system, and the environment. Comprehensive approaches that take into account all components are required to understand the whole picture, e.g., to understand the feedback loops that are created through the physical interactions of the body with the environment and through the different neuronal centers involved in locomotion control.

In order to properly take into account the physical interactions of the body with the environment, it is both very interesting and highly relevant to use bioinspired robots, especially for situations like for the lamprey and the salamander where the interaction forces are difficult to simulate properly (e.g., hydrodynamic forces during swimming, or friction forces during stepping). The special issue presents two innovative lamprey- and salamander-like robots that are the state-of-the-art in biorobotics. The robots are capable of controlling their locomotion in goal-directed tasks, moving like real animals in their natural environments. The robots are unique tools to test our models in a closed loop and to investigate the neuronal principles underlying locomotion and goal-directed behaviors as observed in their biological counterparts. We are convinced that, in addition to numerical simulations, such types of robot will be used increasingly as scientific tools in neuroscience.

We hope that you will enjoy reading these articles as much as we have enjoyed our collaboration on these exciting topics.