Preface

These proceedings contain the papers presented at Living Machines: The 6th International Conference on Biomimetic and Biohybrid Systems, held at Stanford University, USA, during July 25–28, 2017. The international conferences in the Living Machines series are targeted at the intersection of research on novel life-like technologies inspired by the scientific investigation of biological systems, biomimetics, and research that seeks to interface biological and artificial systems to create biohybrid systems. The conference aim is to highlight the most exciting international research in both of these fields united by the theme of "Living Machines."

The Living Machines conference series was first organized by the Convergent Science Network (CSN) of biomimetic and biohybrid systems to provide a focal point for the gathering of world-leading researchers and the presentation and discussion of cutting-edge research in this rapidly emerging field. The modern definition of biomimetics is the development of novel technologies through the distillation of principles from the study of biological systems. The investigation of biomimetic systems can serve two complementary goals. First, a suitably designed and configured biomimetic artifact can be used to test theories about the natural system of interest. Second, biomimetic technologies can provide useful, elegant, and efficient solutions to unsolved challenges in science and engineering. Biohybrid systems are formed by combining at least one biological component — an existing living system — and at least one artificial, newly engineered component. By passing information in one or both directions, such a system forms a new hybrid bio-artificial entity.

Although one may consider this approach to be modern, the underlying principles are centuries old. For example, Leonardo Da Vinci took inspiration from the elegance and functionality he observed in the wings of birds when designing his famous flying machines in 15th-century Italy. Two centuries later, René Descartes, taking inspiration from the automatons he observed in Paris, postulated that the bodies of animals could be considered as nothing more than sophisticated machines. In contrast to Descartes, the mind is now commonly considered to be similarly machine-like allowing investigation through experimentation and replication. The logic of abstracting from nature for engineering purposes is clear in the light of evolutionary theory, which affirms that nature has had millions of years during which to hone biological systems to function robustly in their competitive and complex world.

One reason for the recent expansion and progress of the field of biomimetics is the availability of the necessary tools. For example, the observation of seemingly complex behaviors emerging from the interaction of animals with limited processing capabilities and their environment has been reported many times in nature. Social insects, with their ability to perform complex tasks such as nest building through simple stigmery methods being a foremost example. Building machines with similarly robust functionality governed by computationally cheap methods represents a defining goal for many researchers in this field. Such systems were famously explored by the

neuroscientist and cyberneticist Valentino Braitenberg, in his seminal book *Vehicles: Experiments in Synthetic Psychology*. Yet emergent systems by their very nature are notoriously hard to predict particularly when scaling to large integrated systems such as neural networks or collective robots. In this regard, modern computer simulation and embodied hypothesis in robots are now offering previously unfeasible insights into the functioning of many aspects of bio-inspired systems from morphological and neural computation, to sensing and control. Advances in each of these areas were presented in detail at the conference.

In addition, Living Machines 2017 provided an opportunity for researchers working on the next generation of tool-sets to present their work. Such approaches included novel materials for soft robots, next-generation biohybrid 3D printing methods, and bioinspired power systems. All of these offered a glimpse of the tools that may underpin future breakthroughs in the field.

With this installment of the Living Machines conference taking place in the USA for the first time we are reminded of the wonder upon which European explorers considered the boundless possibilities when discovering the Americas with Amerigo Vespucci coining the term "the New World" in 1503. This term appears newly appropriate in the context of the technological possibilities we face as demonstrated by the recent realization of fully automated cars, mind-controlled prosthetics, and AI systems capable of beating the best human Go players. As the relationship between man and artificial systems becomes increasingly intertwined, an enhanced understanding of the ethical, societal, and economic impacts of automated systems will be required. Such philosophical discussions have always been welcomed at Living Machines conferences and will only grow in their importance.

The main conference, during July 25–28, took the form of a three-day single-track oral and poster presentation program that included five plenary lectures from leading international researchers in biomimetic and biohybrid systems: Kwabena Boahen (Standford University, USA) on neuromorphic computing; Robert J. Full (Berkeley University, USA) on comparative biomechanics and physiology; Koh H. Hosoda (Osaka University, Japan) on the use of robots to explain adaptive intelligence of biological systems; Rebecca Kramer (Yale University, USA) on bioinspired manufacturing, materials and robotics; and Cecilia Laschi (Scuola Superiore Sant'Anna, Pisa, Italy) on soft robotics, humanoid robotics, and neurodevelopmental engineering. There were also 22 regular talks and two poster sessions featuring approximately 40 posters. Session themes included: advances in soft robotics; 3D-printed bio-machines; robots and society; biomimetic vision and control; utility and limits of deep learning for biorobotics; collective and emergent behaviors in animals and robots; and bioinspired flight.

The conference was complemented with a day of workshops on July 24, covering three prominent themes related to biomimetic and bioinsired systems: Bioinspired Aerial Vehicles (Alexis Lussier Desbiens, Mark Cutkosky and David Lentink); Evo Devo of Living Machines (Tony Prescott and Leah Krubitzer), and Control Architectures for Living Machines (Paul Verschure and John Doyle).

We would like to thank our hosts at Stanford University. Since its opening in 1891, Stanford University has grown to be one of the world's leading teaching and research universities. It is famed for its ability to take research from the laboratory to the market

and with its positioning at the at the heart of Silicon Valley provided an ideal setting for the conference.

We also wish to thank the many people that were involved in making LM 2017 possible: Tony Prescott and Paul Verschure co-chaired the meeting; Michael Mangan chaired the Program Committee and edited the conference proceedings; Paul Verschure chaired the international Steering Committee; Mark Cutkosky and Anna Mura co-chaired the workshop program; Anna Mura and Nathan Lepora co-organized the communications; Gosia Wojciechowska, Matthew Alfonso Estrada, and Amanda Kay Stowers provided administrative and local organizational support. We would also like to thank the authors and speakers who contributed their work, and the members of the Program Committee for their detailed and considered reviews. We are grateful to the five keynote speakers who shared with us their vision of the future.

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