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Vasiliki Vouloutsi · José Halloy
Anna Mura · Michael Mangan
Nathan Lepora · Tony J. Prescott
Paul F. M. J. Verschure (Eds.)

Biomimetic and Biohybrid Systems

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Editors
Vasiliki Vouloutsi
SPECS, Institute for Bioengineering of Catalonia
Barcelona
Spain

José Halloy
Laboratoire Interdisciplinaire des
Université Paris Diderot
Paris Cedex 13
France

Anna Mura
SPECS, Institute for Bioengineering of Catalonia
Barcelona
Spain

Michael Mangan
University of Sheffield
Sheffield
UK

Nathan Lepora
Bristol University
Bristol
UK

Tony J. Prescott
University of Sheffield
Sheffield
UK

Paul F. M. J. Verschure
SPECS, Institute for Bioengineering of Catalonia
Barcelona
Spain

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Preface

These proceedings contain the papers presented at Living Machines 2018: the 7th International Conference on Biomimetic and Biohybrid Systems, held in Paris, France, July 17–20, 2018. 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. More specifically, after the European Renaissance, we observe the usage of automata to imitate the functionality of both animals and humans. Such endeavors not only served to entertain but can also be considered as philosophical experiments that allowed for the reproduction of aspects of living organisms in machines, while revealing important information regarding their nature. What initially started as a philosophical idea turned into a mechanical revolution as most of the automata of the 18th century were not only imitating the external appearance of an organism but also simulated the organism's functionalities or behaviors. An example of linking human kinesiology and anatomy is Leonardo da Vinci's "Knight" in 1495, where an elaborate system of pulleys and cables moved the knight's armor to produce various human-like independent motions. This compelling artifact has endowed modern robotics with scaffolds for kinematics and structural design.

A way to appreciate the early simulation of living beings is the central idea of "moving anatomy" in the creations of Jacques de Vaucanson (1709–1782), a French inventor and artist. One of his first biomechanical automata was the "Flute Player," a life-sized wooden statue of a man who played the flute by emitting air through its mouth. This design resulted from the extensive study of human flute players and was used to validate Vaucanson's hypothesis that the consequent pitch of a note was

affected by the blowing pressure, aperture, and sounding length. Notably, his most famous creation was the "Digesting Duck" (1739) a mechanical artifact modeled upon thorough studies of real ducks that was conceptualized to teach the animal's anatomy. Both the "Flute Player" and the "Digesting Duck," although used for entertainment, are good examples that intended to approximate their biological counterparts.

Attention to anatomical, physiological, and behavioral simulations started with Vaucanson and climaxed with the creations of Pierre Jaquet-Droz (1721–1790). The father-and-son team of Pierre and Henri-Louis Jaquet-Droz produced three automata: "the Writer," "the Draughtsman," and "the Musician." Their hands were modeled after real human hands that later constituted the basis for constructing prosthetic limbs. The tendency of that period was to use mechanical artifacts to approximate nature and, through modeling, experimentation, and observation, draw conclusions about their biological counterparts. Nowadays, the study and modeling of biological systems has led to the acquisition of insights into a plethora of domains ranging from architecture to materials, sensors, and control systems and even robotics. Advances in each of these areas were presented in detail at the conference.

The main conference, July 18–20, 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: Jérôme Casas (University of Tours) on insect-inspired mechatronics; Metin Sitti (Max Planck Institute) on bio-inspired and bio-hybrid miniature mobile robots; Stéphane Viollet (Aix-Marseille University) on the application of insect perception models to robots; Simon Thorpe (University of Toulouse) on memory storage and retrieval in both humans and machines; and Pascal Brioist (University of Tours) on the machines of Leonardo Da Vinci. There were also 22 regular talks and one poster session and poster spotlight (featuring approximately 36 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 bio-robotics; collective and emergent behaviors in animals and robots; and bioinspired flight. The conference was complemented by workshops on July 17, 2018, held at the École Normale Superieure in Paris. More specifically, "Sapiens 5.0: Augmenting Humanity to Overcome the Challenges of the Anthropocene" was organized by professor Paul F. M. J. Verschure and Tony Prescott.

The main conference was hosted at the Muséum national d'Histoire Naturelle, MNHN (Paris, France), a place built initially for medicinal and educational purposes. Surrounded by the botanical garden and next to the Seine, for more than four centuries, the MNHN hosted revolutionary discoveries in the field of natural sciences held by prodigious minds, such as Buffon, Lamarck, or Cuvier. Today, the MNHN is one of the most highly considered places in Europe with regard to scientific dissemination, education, and integration of multiple areas of expertise, ranging from molecular biology to applied technology. Hosting the Living Machines conference in such a place reinforces the aim of MNHN in the exploration and promotion of nature to protect it and understand it. This year, Living Machines was held in Paris after successful previous editions in Stanford, USA in 2017; Edinburgh, UK in 2016; Barcelona, Spain in 2015; Milan Italy in 2014; London, UK in 2013; and Barcelona, Spain in 2012.

We would like to thank our hosts at the National History Museum of Paris, Emmanuelle Pouydebat DR CNRS, and Vincent Bels, our hosts for the poster session

that was held at the Pierre and Marie Curie University, on the Jussieu Campus, in collaboration with Stéphane Doncieux UMPC, ISIR, and Benoît Girard DR CNRS, UPMC, ISIR.

We also wish to thank the many people that were involved in making the seventh edition of Living Machines possible: José Halloy and Paul Verschure co-chaired the meeting; Vasiliki Vouloutsi and Michael Mangan chaired the Program Committee and edited the conference proceedings; Tony Prescott chaired the international Steering Committee; Nathan Lepora was involved in the conference communication; Anna Mura was the general organization chair and also coordinated the website and communications; José Halloy and his group provided administrative and local organizational support in Paris. We are grateful to the SPECS lab and the Communication Unit at the Institute for Bioengineering of Catalonia (IBEC) in Barcelona for the assistance in the organization and for technical 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.

Finally, we wish to thank the organizers and sponsors of LM 2018: The Convergence Science Network for Biomimetic and Neurotechnology (CSNII; ICT-601167); the Institute for Bioengineering of Catalonia IBEC, and the Catalan Institution for Research and Advanced Studies (ICREA). Additional support was also provided by Springer. Living Machines 2018 was further supported by: the IOP physics journal *Bioinspiration & Biomimetics*, which will publish a special issue of articles based on the best conference papers, and *Biomimetics*, an Open Access journal, which will publish a special issue of articles based on the best conference posters, and by Eodyne SL (neuro-rehabilitation solutions) with an award for best paper with a social impact.

July 2018

Vasiliki Vouloutsi
José Halloy
Anna Mura
Michael Mangan
Nathan Lepora
Tony J. Prescott
Paul F. M. J. Verschure

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Tony J. Prescott	University of Sheffield, UK
Paul F. M. J. Verschure	Institute for Bioengineering of Catalonia (IBEC), Barcelona Institute of Science and Technology (BIST), Catalan Institution for Research and Advanced Studies (ICREA), Barcelona, Spain

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Vasiliki Vouloutsi	Institute for Bioengineering of Catalonia (IBEC), Barcelona Institute of Science and Technology (BIST), Barcelona, Spain
Michael Mangan	University of Lincoln, UK

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Emmanuelle Pouydebat	DR CNRS, Muséum d'Histoire Naturelle, France
Vincent Bels	Muséum d'Histoire Naturelle, France

Communications

Anna Mura	Institute for Bioengineering of Catalonia (IBEC), Barcelona Institute of Science and Technology (BIST), Barcelona, Spain
Nathan Lepora	University of Bristol, UK

Conference Website

Anna Mura	Institute for Bioengineering of Catalonia (IBEC), Barcelona Institute of Science and Technology (BIST), Barcelona, Spain

Workshop Organizers

Tony J. Prescott	University of Sheffield, UK
Paul F. M. J. Verschure	Institute for Bioengineering of Catalonia (IBEC), Barcelona Institute of Science and Technology (BIST), Catalan Institution for Research and Advanced Studies (ICREA), Barcelona, Spain

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