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# Biomimetic and Biohybrid Systems

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# Preface

These proceedings contain the papers presented at Living Machines: The 5th International Conference on Biomimetic and Biohybrid Systems, held in Edinburgh, UK, during July 19–22, 2016. 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."

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. The theme of the conference also encompasses biomimetic methods for manufacture, repair, and recycling inspired by natural processes such as reproduction, digestion, morphogenesis, and metamorphosis.

The following are some examples of *living machines* as featured at this and past conferences:

- Biomimetic robots and their component technologies (sensors, actuators, processors) that can intelligently interact with their environments
- Active biomimetic materials and structures that self-organize and self-repair
- Nature-inspired designs and manufacturing processes
- Biomimetic computers—neuromimetic emulations of the physiological basis for intelligent behavior
- Biohybrid brain–machine interfaces and neural implants
- Artificial organs and body parts including sensory organ–chip hybrids and intelligent prostheses
- Organism-level biohybrids such as robot–animal or robot–human systems

Five hundred years ago, Leonardo da Vinci designed a series of flying machines based on the wings of birds. These drawings are famous for their beautiful, lifelike designs, created centuries before the Wright brothers made their first flight. This inspiration from nature that Leonardo pioneered remains as crucial for technology today as it was many centuries ago.

Leonardo's inspiration was to imitate a successful biological design to solve a scientific problem. Today, this subject area is known as biomimetics. The American inventor Otto Schmitt first coined this term in the 1950s while trying to copy how nerve cells function in an artificial device. He put together the Greek words bios (life) and mimetic (copy) and the name caught on.

Why is nature so good at finding solutions to technological problems? The answer lies in Charles Darwin's theory of evolution. Life, by the process of natural selection, is a self-improving phenomenon that continually reinvents itself to solve problems in the natural world. These improvements have accumulated over hundreds of millions of years in plants and animals. As a result, there are a myriad natural design solutions around us, from the wings of insects and birds to the brains controlling our bodies.

Biomimetics and bio-inspiration has always been present in human technology, for example, making knives akin to the claws of animals. An exciting development, however, has been the dramatic expansion of the biomimetic sciences in the new millennium. The Convergent Science Network (CSN) of biomimetic and biohybrid systems, which organized the first Living Machines conference, has also completed a survey on *The State of the Art in Biomimetics* (Lepora, Verschure and Prescott, 2013). As part of the survey, we counted how much work on biomimetics is published each year. This revealed a surprising answer: from only tens of articles before the millennium, it has exploded since then to more than a thousand papers each year.

This huge investment in research inspired by nature is producing a wide variety of innovative technologies. Examples include artificial spider silk that is stronger than steel, super-tough synthetic materials based on the shells of molluscs, and adhesive patches mimicking the padded feet of geckos. Medical biomimetics is also leading to important benefits for maintaining health. These include bionic cochlear implants for hearing, fully functional artificial hearts, and modern prosthetic hands and limbs aimed at repairing the human body.

Looking to the future, one of the most revolutionary applications of biomimetics will likely be based on nature's most sophisticated creation: our brains. From our survey of biomimetic articles, we found that a main research theme is to take inspiration from how our brains control our bodies to design better ways of controlling robots. This is for a good reason. Engineers can build amazing robots that have seemingly human-like abilities. But so far, no existing robot comes close to copying the dexterity and adaptability of animal movements. The missing link is the controlling brain.

It is often said that future scientific discoveries are hard to predict. This is not the case in biomimetics. There are plenty of examples surrounding us in the natural world. The future will produce artificial devices with these abilities, from mass-produced flying micro devices based on insects to robotic manipulators based on the human hand to swimming robots based on fish. Less certain is what they will do to our society, economy, and way of life. Therefore the Living Machines conference also seeks to anticipate and understand the impacts of these technologies before they happen.

The main conference, during July 20–22, 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: Antonio Bicchi (University of Pisa) on robotics, haptics, and control systems; Frank Hirth (Kings College London, Institute of Psychiatry) on evolutionary neuroscience; Yoskiko Nakamura (University of Tokyo) on biomimetics in humanoids; Thomas Speck (Albert-Ludwigs-Universität, Freiburg) on plants and animals as concept generators for biomimetic materials and technologies; and Barbara Webb (University of Edinburgh) on perceptual systems and the control of behavior in insects and robots. There were also 20 regular talks and a poster session featuring approximately 40 posters. Session themes included: biomimetic robotics; biohybrid systems including biological-machine interfaces; neuromimetic systems; soft robot systems; active sensing in vision and touch; social robotics and the biomimetics of plants.

The conference was complemented with a further day of workshops and symposia, on July 19, covering a range of topics related to biomimetic and biohybrid systems: Our Future with Living Machines: Societal, Economic, and Ecological Impacts (Jose Halloy and Tony Prescott); Living Machines That Grow, Evolve, Self-Heal and Develop: How Robots Adapt Their Morphology to the Environment (Barbara Mazzolai and Cecilia Laschi); and The Emergence of Biological Architectures (Enrico Mastropaolo, Naomi Nakayama, Rowan Muir, Ross McLean, Cathal Cummins).

The main meeting was hosted at Edinburgh's Dynamic Earth, a five-star visitor attraction in the heart of Edinburgh's historic old town, next to the Scottish Parliament and Holyrood Palace. Dynamic Earth is a visitor experience that invites you to take a journey through time to witness the story of planet Earth through a series of interactive exhibits and state-of-the-art technology. Satellite events were held nearby at University of Edinburgh's School of Informatics in George Square. The Dynamics Earth experience, with its seamless integration of nature and technology, provided an ideal setting to host the 5th Living Machines Conference.

We wish to thank the many people that were involved in making LM2016 possible: Tony Prescott and Marc Desmulliez co-chaired the meeting; Nathan Lepora chaired the Program Committee and edited the conference proceedings; Paul Verschure chaired the international Steering Committee; Michael Mangan and Anna Mura co-chaired the workshop program; Anna Mura and Nathan Lepora co-organized the communications; Sytse Wierenga, Carme Buisan, and Mireia Mora provided additional administrative and technical support including organizing the website; and Katarzyna Przybcien and Lynn Smith 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 Programme 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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July 2016

Nathan F. Lepora
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