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# Biomimetic and Biohybrid Systems

First International Conference, Living Machines 2012
Barcelona, Spain, July 9-12, 2012
Proceedings

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# Preface

These proceedings contain the papers presented at *Living Machines: An International Conference on Biomimetic and Biohybrid Systems*, held in Barcelona, Spain, July 9–12, 2012. This new international conference is 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. We seek to highlight the most exciting international research in both of these fields united by the theme of "living machines."

## Conference Theme

The development of future real-world technologies will depend strongly on our understanding and harnessing of the principles underlying living systems and the flow of communication signals between living and artificial systems.

*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 artefact 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 development of either biomimetic or biohybrid systems requires a deep understanding of the operation of living systems, and the two fields are united under the theme of "living machines" — the idea that we can construct artefacts, such as robots, that not only mimic life but share the same fundamental principles; or build technologies that can be combined with a living body to restore or extend its functional capabilities.

Biomimetic and biohybrid technologies, from nano- to macro-scale, are expected to produce major societal and economical impacts in quality of life and health, information and communication technologies, robotics, prosthetics, brain–machine interfacing and nanotechnology. Such systems should also lead to significant advances in the biological and brain sciences that will help us to better understand ourselves and the natural world. The following are some examples:

- 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

- 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

A key focus of Living Machines 2012 was on complete behaving systems in the form of *biomimetic robots* that can operate in or on different substrates, sea, land, or air, and inspired by the different design plans found in the animal kingdom — plants, invertebrates, and vertebrates. A further central theme was the physiological basis for intelligent behavior as explored through *neuromimetics* — the modelling of neural systems. Exciting emerging topics within this field include the embodiment of neuromimetic controllers in hardware, termed *neuromorphics*, and within the control architectures of robots, sometimes termed *neurorobotics*. Contributions from biologists, neuroscientists, and theoreticians that are of direct relevance to the development of future biomimetic or biohybrid devices were also included. We invited both full papers and extended abstracts. All contributions were assessed by at least two expert referees with relevant background (see list below). Following the conference, the journal *Bioinspiration and Biomimetics* will publish extended and revised versions of some of the best papers presented at the meeting.

## A Brief History of Biomimetics

The ambition to mimic nature has been with us since ancient times. In the $4^{\text{th}}$ century B.C., Archytas of Tarentum is said to have built a steam-driven model of a dove that could fly. Leonardo Da Vinci's designs for machines, which included a humanoid robot, were largely inspired by nature, and by his own detailed observations of natural systems and mechanisms. By the middle of the $17^{\text{th}}$ century, Descartes was willing to assert that animals are complex automatons, and the extension of this radical idea to our own species came a century later with the book *L'Homme Machine* (1748), by Julien Offray de La Mettrie, which not only expanded Descarte's notion of the mechanistic nature of life to include the human species but also identified that machines — natural or otherwise — can be dynamic, autonomous, and purposive entities. In the $18^{\text{th}}$ century the famous automatons of the French inventor Jacques de Vaucanson, the "ancestors" of modern theme-park animatronics, were emblematic of this emerging view of man and of nature. It is easy to imagine that the term "living machine" was applied to many of these early and awe-inspiring life-like artefacts, at the same time that people were beginning to take seriously the possibility that we, ourselves, might operate according to similar principles.

With the rise of cybernetics in the 1940s, it became clear that there was the possibility to create inventions that would realize La Mettrie's vision of machines that were both autonomous and purposive. At the same time, interest in nature

as a source of inspiration was also gathering force. The term "biomimetics" was introduced by Otto Schmitt during the 1950s, and "bionics" by Jack Steel (popularized in Daniel Halacy's 1965 book *Bionics: the Science of "Living" Machines*) emerged as part of this growing movement in engineering that sought to build strong ties with the biological sciences and to make progress through "reverse engineering" natural systems. The biomimetic approach has since succeeded in overcoming many difficult challenges by exploiting natural design principles. Indeed, in the first decade of this century there has been an explosive growth in biomimetic research, with the number of published papers doubling every two to three years (see Lepora et al., this volume). The Living Machines conference sought to be a significant forum for this dialogue between nature and technology, and to be a place where people could discuss the biomimetic and biohybrid machines of tomorrow and what they might mean for understanding the biological machines of today.

## The Living Machines Conference in Barcelona

The main conference, July 10–12, took the form of a three-day single-track oral and poster presentation program that included six plenary lectures from leading international researchers in biomimetic and biohybrid systems: Joseph Ayers (Northeastern University) on synthetic neuroethology; Dieter Braun (Ludwig Maximilians University) on synthetic life, Peter Fromherz (Max Plank Institute) on neuroelectronic hybrids; Toshio Fukuda (Nagoya University) on micronano biomimetic and biohybrid devices; David Lentink (Stanford University) on the biofluiddynamics of flight; and Barry Trimmer (Tufts University) on soft, invertebrate-inspired robots. The meeting was hosted in *La Pedrera*, a building designed by the modernist, nature-inspired Catalan architect Antoni Gaudi. La Pedrera is a world heritage site, one of the best known buildings in Barcelona, and a very fitting setting for the first Living Machines conference. The conference also included an exhibition of working biomimetic and biohybrid systems including several autonomous biomimetic robotic systems.

## Organization and Sponsors

We take this opportunity to thank the many people that were involved in making LM 2012 possible. On the organizational side this included Carme Buisan, Mireia Mora, and Gill Ryder. Artwork was provided by Ian Gwilt. Organizers for the workshop program included Frank Grasso, Chiara Bartolozzi, Emri Neftci, and Stefano Vasanelli. We would also like to thank the authors and speakers who contributed their work, and the members of the International Program Committee for their detailed and considered reviews. We are grateful to the six keynote speakers who shared with us their vision of the future.

Finally, we wish to thank the sponsors of LM 2012: The *Convergence Science Network for Biomimetic and Biohybrid Systems* (CSN) (ICT-248986) which is funded by the European Union's Framework 7 (FP7) program in the area of *Future Emerging Technologies* (FET), the University of Pompeu Fabra in Barcelona, the University of Sheffield, and the Institució Catalana de Recerca i Estudis Avançats (ICREA). Additional support was provide by the FP7 FET Proactive Project BIOTACT (ICT-215910) and the ICT Challenge 2 project EFAA (ICT-270490).

July 2012

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