Towards a Roadmap for Living Machines

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Abstract. A roadmap is a plan that identifies short-term and long-term goals of a research area and suggests potential ways in which those goals can be met. This roadmap is based on collating answers from interview with experts in the field of biomimetics, and covers a broad range of specialties. Interviews were carried out at events organized by the Convergent Science Network, including a workshop on biomimetics and Living Machines 2012. We identified a number of areas of strategic importance, from biomimetic air and underwater vehicles, to robot designs based on animal bodies, to biomimetic technologies for sensing and perception.

Keywords: Biomimetics, roadmap, interviews, living machines.

A roadmap is a plan that identifies short-term and long-term goals of a research area and suggests potential ways in which those goals can be met. Developing a roadmap has three major uses. It helps reach a consensus about a set of goals and risks for a research area; it provides a mechanism to help forecast research developments and it provides a framework to help plan and coordinate research. The aim of this roadmap is to identify current trends relating to living machines together with their implications for future research.

We have been constructing a roadmap on living machines, by collating answers from interviews with experts in the field of biomimetics across a broad range of specialties. Interviews lasted about an hour each and were carried out at events organized by the Convergent Science Network [1]: (a) A Biomimetics week for the 2011 Barcelona Cognition, Brain and Technology Summer School (BCBT); (b) The 2012 Living Machines conference in La Pedrera, Barcelona [2].

From these interviews, we identified several areas of strategic importance where the biomimetics of living machines can either further our understanding of biological systems or could lead to new technologies in robotics and engineering. A complete description of the strategic goals and risks of these areas will be given in a full article to complement our recent paper *The state of the art in biomimetics* [3] published in the journal Bioinspiration and Biomimetics. For the time being, we summarize briefly these various areas concerning living machines.

Self-assembly, microstructures and micro-machines. Bio-inspired robotic systems, with features at microscopic length scales are at the forefront of current

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challenges and opportunities in robotic hardware. They have the potential to integrate nano-technology with macroscopic fabrication methods, and may lead to novel new methods of design and fabrication using bottom-up self-assembly rather than conventional top-down engineering approaches.

Biomimetic micro air vehicles (MAVs). Recently, a new class of MAVs are being developed that take inspiration from flying insects or birds to achieve unprecedented flight capabilities. Biological systems have inspired the application of unsteady aerodynamics to robots with flapping wings, while also motivating the use of other aspects of animal flight control such as distributed sensing.

Biomimetic autonomous underwater vehicles (AUVs). A new trend in the AUV community is to mimic designs found in nature. Although most are currently in their experimental stages, these biomimetic vehicles could be able to achieve higher degrees of efficiency in propulsion and maneuverability by copying successful designs in nature. A variety of sensors can be affixed to AUVs to measure the concentration of various elements or compounds, the absorption or reflection of light, and the presence of microscopic life.

Insect-based robotics. Insects are useful for biomimetic robotics because their morphologies and nervous systems are simpler than other animal species. Also, complex behaviors can be attributed to just a few neurons. Analysis of the walking behavior and neural architecture of insects can be used to improve robot locomotion. Alternatively, biologists can use insect-based robotics for testing biological hypotheses about the neurophysiological mechanisms involved in insects.

Soft and compliant robotics. The tentacles of squid, trunks of elephants, and tongues of mammals are examples of muscular hydrostats that inspire soft robots with the potential for dextrous manipulation in hazardous or unstructured environments. They are also a relatively safe technology to use around humans because of their compliant nature, making them ideal for the assistive or care applications, such as for the elderly.

Bipedal and quadrupedal robots. Types of bipedal movement include walking, running and hopping, while types of quadruped locomotion include trotting, pacing and bounding. Important principles include passive methods for un-powered walking, which has lead to novel designs for walking robots and furthered our understanding of the function of human and animal physiology. Legged robots have significant advantage over wheeled technologies in accessing areas currently unreachable.

Humanoid robotics. A humanoid design for a robot might be for functional purposes, such as interacting with human tools and environments, or for experimental purposes, such as the study of bipedal locomotion. Although the initial aim of humanoid research was to build better orthosis and prosthesis for human beings, knowledge has been transferred between both disciplines.

Social robotics and human-robot interaction. A social robot is an autonomous robot that interacts and communicates with humans or other social agents. A leading assumption is that social robots must develop a sense of self as to overcome the fundamental problem of social inference

Brain-based robotics. One goal of brain-based robotics is to use robots for embodying the principles underlying animal behavior. This can include using robots to study the neural mechanisms underlying movement control, perception and learning in animals, and in return to take inspiration from animals to design new control and sensing methods for robotics. Another important application is to test biological hypotheses that would be difficult or impossible otherwise.

Artificial olfaction and chemosensing. Devices that sense the existence of a particular chemical concentration in air or water is becoming an increasingly important requirement for modern robotics and automated systems. Applications include: quality control in food processing; detection and diagnosis in medicine; detection of drugs, explosives and dangerous or illegal substances; military and law enforcement; disaster response; and environmental monitoring.

Artificial audition and echolocation. Bats and cetaceans, such as whales and dolphins, use sound for perception and have far superior sensing capabilities than existing technologies. Applications include object localization in environments where vision is impaired, such as the dark, and even discriminating the material properties based on acoustic energy.

Artificial touch. Nature has provided examples of many different types of touch sensor to inspire artificial devices. Examples include the human fingertip, skin and tactile whiskers employed by animals such as rodents. Tactile sensors can be used to sense a diverse range of stimulus ranging from detecting whether an object has been grasped to a complete tactile image.

Grasping and manipulation with robot hands. An important application of tactile sensing is to help reproduce in some way the grasping and manipulation capabilities of humans. Even though many robotic devices have been developed, from very simple grippers to very complex anthropomorphic robotic hands, their usability and reliability still lags far behind human capabilities.

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