

BIOMIMETICS

A vision for future bioinspired and biohybrid robots

Barbara Mazzolai^{1*} and Cecilia Laschi^{2*}

Bioinspired and biohybrid robots can help respond to diverse, sustainable application needs.

In biology, a life cycle is a series of changes in form that an organism undergoes, returning to the starting state. The generation of a biological organism involves three tightly connected processes: growth (changes in mass), remodeling (changes in material properties), and morphogenesis (evolution of the shape) (1).

Similarly, robots could become bioinspired machines that can grow and adapt. They should be built with recyclable, biodegradable, or biohybrid materials, to return to a starting state. And they could find their (renewable) energy sources without weighing on Earth's energy balance. Robots of the future should be sustainable, unlike current technologies that are posing important problems given their energy needs and the waste produced at the end of their life cycle, which leaves behind "e-waste" (2) and a substantial CO₂ footprint. In diverse ecological niches, such bioinspired robots would develop purposive morphologies and abilities for negotiating their environments. We may think of robots in the forest growing and moving efficiently in dense vegetation and/or in the canopy, collecting and transmitting monitoring data, surviving on solar or wind energy, and decomposing at the end of their lifetime. Similarly, in the oceans, robots could swarm, populate the depths, and record data, with learned abilities and morphologies for walking or anchoring on the seafloor and programmed biodegradability for releasing traceable data storage devices. Even inside the human body, biohybrid devices with a life cycle can support monitoring and drug delivery, with safe biointegration, degradation, or disposal. This vision for robots of the future embraces the whole life cycle (see a pictorial view in Fig. 1).

The concept of a whole life cycle is a major principle that roboticists can take from nature. A bioinspired approach to robotics

cannot be limited to a copy of organisms proposed by nature but, rather, should rely on understanding and extracting principles. Living beings are complex, much more so than our robots. And they operate in a dynamic world that is considerably more complex than our robot-adapted structured environments. Such complexity is what provides living beings with effective and efficient sensory-motor behavior. A more global strategy and a multidisciplinary approach in bioinspired robotics have to be taken, aimed at identifying the key principles and transforming them in models that can be used for designing bioinspired robots. This way, robots will be able to face the complexity of the real world, without requiring simplifications to make the environment suitable for them. Similarly, they will not need to be simplified to make their behavior controllable: On the contrary, robots could be made as complex as needed to be effective and useful in real-world applications and to ultimately contribute to the goals set by the United Nations for sustainable progress (3). Yet, a

bioinspired approach, when based on a correct extraction and verification of biological principles, also serves the purpose of providing further tools for studying biology (4). Bioinspired robots turn particularly useful whenever it is practically impossible to investigate a biological question (in a nonsimulated way) by means of any living organism, because the scope is to study how the physical medium affects morphological adaptation (5); evolvability (6); or groups that are extinct (7), loosely defined, or even hypothetical.

We believe that this whole life cycle vision for the robots of the future will require a drastic rethinking of robot bodies, minds, and interactions with humans and the world. And this rethinking will have to be based on a close study of how intelligent behavior is achieved in living organisms. Natural intelligence is the result of a body and a brain interacting and evolving together. In robot design, the proposed scientific vision will lead to conceiving a robot as an integrated system, not as the assembly of components. The bodyware will be based on multifunctional

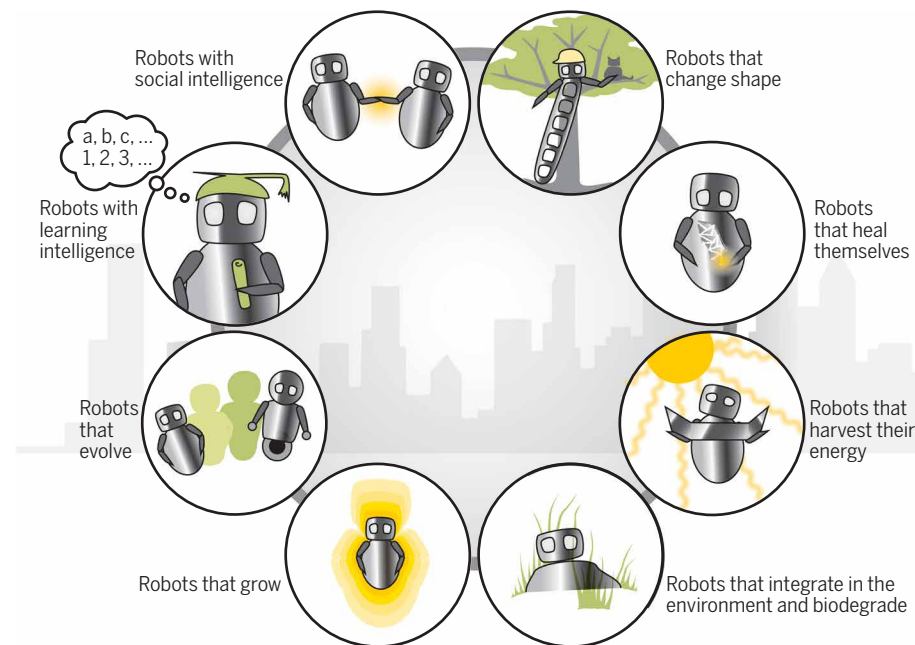


Fig. 1. The vision for robots with a whole life cycle.

¹Istituto Italiano di Tecnologia, Center for Micro-BioRobotics, Viale Rinaldo Piaggio, 34, 56025 Pontedera (Pisa), Italy.

²Scuola Superiore Sant'Anna, The BioRobotics Institute and Department of Excellence in Robotics & AI, Viale Rinaldo Piaggio, 34, 56025 Pontedera (Pisa), Italy.

*Corresponding author. Email: barbara.mazzolai@iit.it (B.M.); cecilia.laschi@santannapisa.it (C.L.)

materials (8, 9) and biohybrids (10) that interact with the environment and are fully integrated in natural ecosystems. Distributed sensors will provide robots with rich perception and understanding of complex world models (11), to move and act in a way that preserves living systems and the planet. Cognitive abilities will make them understand the environment and humans to behave meaningfully.

In line with recent trends in robotics research (12), future approaches will reverse the perspective on robot design. Going beyond soft robotics, bodyware of future robots will grow, regenerate, change shape to adapt to physical or task constraints, and biodegrade. Going beyond smart materials, biohybrids will ensure multifunctionality and biocompatibility. Going beyond current power sources, robot energy forms will be scavenged in the environment. Going beyond robot control, intelligence will develop together with a shape-shifting body. Going beyond evolutionary robotics, robot morphology will not only adapt to the task and the environment at the design stage but also improve with practice based on experience.

The integration of disciplines beyond the current widely adopted multidisciplinary approaches might help to guide research in these directions, pushing forward the pillars of knowledge that will contribute improving wellness and quality of life.

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10.1126/scirobotics.aba6893

Citation: B. Mazzolai, C. Laschi, A vision for future bioinspired and biohybrid robots. *Sci. Robot.* **5**, eaba6893 (2020).

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Sci. Robot. **5** (38), eaba6893. DOI: 10.1126/scirobotics.aba6893

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