

What's Hot... in Evolutionary Computing?

by A.E. EIBEN (A.E.EIBEN@VU.NL), FACULTY OF SCIENCES, VU UNIVERSITY AMSTERDAM

Evolutionary Computing has received major exposure this year. Nature, the top dog of scientific journals, devoted a full-length review article to this field [7]. Evolutionary algorithms have been around for about three decades, but so far they did not manage to obtain such high profile coverage, so what changed?

In my view the new interest is based on a new role of artificial evolutionary systems. Traditionally, artificial evolution equals evolutionary problem solving, that is, using evolutionary algorithms as heuristic methods for solving optimization, design, and modeling tasks [8]. In this context, evolutionary algorithms are seen as a special type of generate-and-test search methods, distinguished by the use of a population, recombination of multiple candidate solutions, and stochastic selection operators that allow poor solutions to survive and reproduce, albeit with a relatively little probability. Evolutionary algorithms have proven successful in solving hard problems in the face of challenging characteristics like non-differentiability, discontinuities, multiple local optima, noise and nonlinear interactions among the variables. There is also substantial and well-documented evidence of evolutionary algorithms producing measurably human-competitive results [10]. The annual Humies competition (<http://www.genetic-programming.org/combined.php>), which rewards human-competitive results from evolutionary computation, highlights the great variety of hard problems for which evolutionary methods have delivered excellent solutions.

Developments over the last couple of years boosted a latent opportunity of employing artificial evolution far beyond (ab)using it as an optimizer. The punchiest way to explain this potential is through the following two statements.

Evolution can produce intelligence.

Artificial evolution can produce artificial intelligence.

The first statement is proven by our own intelligence that is a result of evolution on Earth. The second one, then, is a reasonable expectation, a plausible working hypothesis if you wish.

It could be argued that there is no such thing as *artificial* evolution. As noted by Dennett "If you have variation, heredity, and selection, then you must get evolution" [4]. From this perspective man-made evolutionary systems are not some inferior emulations of 'real' evolution, but a new form of evolution. The substrate in which evolution takes place is different –digital entities in software vs. physical entities in wetware– but the underlying principles are the same. In a certain context it may make sense to contrast the artificial and natural variants, for instance in the two statements above, but in general evolution is evolution.¹

To illuminate the new opportunities of utilizing evolution let me recall a fundamental relationship regarding artificial and natural agents, including robots, animals, and humans:

Environment + Body + Mind → Behavior

¹This is not to say that there are no significant differences between the actual mechanisms of natural evolutionary systems and evolutionary algorithms, cf. Table 1 in [7].

The quest for artificial intelligence started with a narrow focus on the Mind. The bold dream in the 20th century was to create thinking machines. This was reflected by the Grand Challenge of creating a computer program that can beat the world champion of chess. As we all know, this was successfully accomplished before the end of the century. The modern view on intelligence acknowledges the role of the body and considers the integrated Body + Mind as the source of intelligent behavior, cf. [13, 14]. Thus, the focus on thinking machines has widened and the bold dream of the 21st century is to create acting machines, commonly known as robots. The corresponding Grand Challenge of embodied intelligence is that of creating a team of robots that can beat the world champion of football.

This brings us back to the working hypothesis above that identifies evolution as a potential approach to achieving intelligent behavior in entities with a mind and a body, i.e., in robots. The related field is known as evolutionary robotics, cf. [1, 12], that “applies the selection, variation, and heredity principles of natural evolution to the design of robots with embodied intelligence” [5]. In particular, evolutionary robotics aims to evolve the controllers, the morphologies, or both, for real and simulated autonomous robots [15]. Considering the complexity of interactions between environment, morphology and controller, evolution may be not just one approach, but *the* approach to designing intelligent robots for a range of circumstances. However, forced by technical constraints the usual modus operandi in evolutionary robotics is quite limited: evolve robot controllers in simulation and transfer the outcome to real hardware afterwards. Thus, even though the final goal is to obtain physical robots with evolved intelligence, the evolutionary process is still digital, which leads to the notorious reality gap problem [9].

The exciting new opportunity is to have physically embedded evolutionary processes on real –not simulated– robots. One option is to evolve controllers on-the-fly in a population of real robots (with fixed morphologies). This has been demonstrated in a handful of studies, for instance [2]. Another one is to evolve robot morphologies in real hardware by manually constructing each individual of the next generation. The only example I know of is the work of John Long described in his book [11] and elegantly summarized in [3]. The ultimate goal is of course a system where robots can reproduce themselves and evolve in real space and real time. To date this may seem far fetched, but advances in 3D printing and automated assembly are bringing a robotic EvoSphere within reach quickly [6]. The Evolution of Things may be closer than it seems.

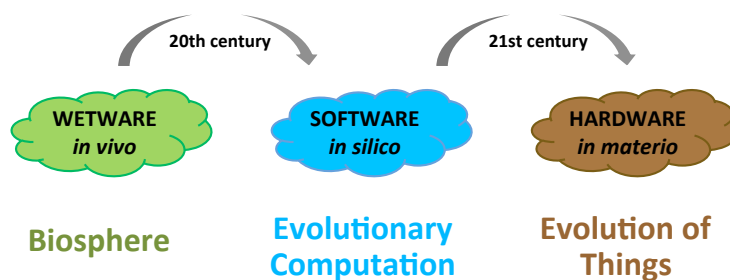


Figure 1: Illustration of the Evolution of Things after [6]. This picture shows two major transitions of evolutionary systems positioned from the perspective of the underlying substrate.

References

- [1] Josh Bongard. Evolutionary robotics. *Communications of the ACM*, 56(8):74–85, 2013.
- [2] N. Bredeche, J.-M. Montanier, W. Liu, and A.F.T. Winfield. Environment-driven distributed evolutionary adaptation in a population of autonomous robotic agents. *Mathematical and Computer Modelling of Dynamical Systems*, 18(1):101–129, 2012.
- [3] A Cho. The accidental roboticist. *Science*, 346(6206):192–194, October 2014.
- [4] D. C. Dennett. *Darwin’s Dangerous Idea*. Penguin, 1995.
- [5] S. Doncieux, N. Bredeche, J.-B. Mouret, and A.E. Eiben. Evolutionary robotics: what, why, and where to. *Frontiers in Robotics and AI*, 2(4), 2015.
- [6] A.E. Eiben. EvoSphere: The world of robot evolution. In A.-H. Dediu et al., editor, *Proc. of TPNC 2015*, volume 9477 of *LNCS*, pages 1–17. Springer, 2015. (to appear).
- [7] A.E. Eiben and J. Smith. From evolutionary computation to the evolution of things. *Nature*, 521(7553):476–482, May 2015.
- [8] A.E. Eiben and J.E. Smith. *Introduction to Evolutionary Computing*. Springer, 2nd edition, 2015.
- [9] N. Jakobi, P. Husbands, and I Harvey. Noise and the reality gap: The use of simulation in evolutionary robotics. In F. Moran et al., editors, *Advances in Artificial Life*, number 929 in *LNAI*, pages 704–720. Springer, 1995.
- [10] J.R. Koza. Human-competitive results produced by genetic programming. *Genetic Programming and Evolvable Machines*, 11(3):251–284, 2010.
- [11] John Long. *Darwin’s Devices: What Evolving Robots Can Teach Us About the History of Life and the Future of Technology*. Basic Books, 2012.
- [12] S. Nolfi and D. Floreano. *Evolutionary Robotics: The Biology, Intelligence, and Technology of Self-Organizing Machines*. MIT Press, Cambridge, MA, 2000.
- [13] R. Pfeifer and J. Bongard. *How the Body Shapes the Way We Think*. MIT Press, 2006.
- [14] R. Pfeifer and F. Iida. Embodied artificial intelligence: Trends and challenges. In F. Iida, R. Pfeifer, L. Steels, and Y. Kuniyoshi, editors, *Embodied Artificial Intelligence*, number 3139 in *LNAI*, pages 1–26. Springer, 2004.
- [15] P.A. Vargas, E.A. Di Paolo, I. Harvey, and P. Husbands, editors. *The Horizons of Evolutionary Robotics*. MIT Press, 2014.