Where is the robot? Life as it could be

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The field of Evolutionary Robotics (ER) “aims to apply evolutionary computation techniques to evolve the overall design or controllers, or both, for real and simulated autonomous robots”, and dates back to the beginning of the 90s. ER is inspired by nature, under the assumption that if natural evolution created natural intelligence, then artificial evolution could create artificial intelligence. While today ER systems are hardly autonomous, the long-term view of ER foresees (autonomously) self-engineering robot systems. Importantly, despite the well-known fact that the environment is extremely determinant towards natural living forms, investigations regarding the environment are meager, especially when regarding environmental regulation of genetic material.

The main goal of this research was shedding light on the influences that the environment has on robot artificial life systems. To make this research possible, we developed a framework that allowed us to evolve populations of robots and measure the effects that different factors have on these robots. This framework included the design of *a)* a robot encoding method for morphology and controller, *b)* morphological descriptors, *c)* controller descriptors, *d)* behavioral descriptors, *e)* a set of environments presenting distinct environmental conditions, *f)* an Evolutionary Algorithm, *g)* a learning mechanism. Using this framework, we evolved populations of robots to perform the task of locomotion, so that their fitness was measured by their locomotion speed. Here we present results of multiple and extensive experiments with the evolution of morphologies and controllers of modular robots. In particular, we focus on the effects that different environmental conditions have on phenotypic and behavioral traits.

First, we explored our search space in different ways to demonstrate that our robot encoding is able to encode for high levels of diversity. This means many different types of morphological shapes were found by evolution. Several of these shapes presented multiple limbs, symmetrical structure, proportional morphology, etc. Among these robots there were some presenting animal-like morphological traits and locomotion gaits. For instance, we observed examples of robots that looked and locomoted like salamanders, turtles, penguins, insects, etc. Second, we demonstrated that in a flat floor environment there is a strong selection pressure for snake-shape robots (characterized mainly by having a single limb), whose principal lomocotion gait is rolling. Remarkably, these simple snake-shape robots were much faster than the other variety of shapes described before. Third, we demonstrated that by inclining the floor, a new selection pressure was created. In this case, the emergent robots had more limbs, were more proportional and smaller, and had their locomotion gait changed from rolling to rowing or dragging. Furthermore, in different experiments we tested changing the environmental conditions in two ways: across generations and during the robots lifetime. In the second case, naturally, because they disposed of one same morphology and controller, a trade-off happened. They managed to locomote in both environmental conditions (seasons), but their performance was worse than when they had evolved in each static environment separately. Finally, we designed a solution to mitigate this performance degradation caused by the trade-off described above. This solution is a novel robot encoding method called *Plasticoding*. This encoding gives the robots genotypes a capacity for *phenotypic plasticity*, meaning that one individual can develop different morphologies, controllers, and behavior according to environmental stimuli during its lifetime. Using *Plasticoding* we reduced the loss in performance for the flat environment. The results of *Plasticoding* increased the performance in 58% in comparison to our robot encoding when this plasticity capacity was not available (*Baseline*).

Because the environment is determinant to natural life forms, we believe this subject has a lot of potential to help to improve the quality of ER systems. Nevertheless, this subject was very scarcely explored in the literature. Therefore, our work is a fundamental step towards a long-term vision: succeeding in creating robot artificial life with complexity and adaptability comparable to what we see in nature.