Reusability vs Morphological Space in Physical Robot Evolution

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ABSTRACT

Few evolved robots have been tested outside simulation due to real world experiments being resource and time expensive. In this paper, we discuss different approaches to physically implement evolved robots and propose a modular robot system with external automatic reconfiguration. While the morphological space is reduced, it provides us with a fast, reusable, fully autonomous system to evolve physical robots in reality.

CCS CONCEPTS

• **Computer systems organization → Evolutionary robotics**; **Robotic components**; *Robotic autonomy*;

KEYWORDS

Evolutionary Robotics, Modular Robots, Real Robots

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1 INTRODUCTION

Joint evolution of morphology and control for robots has been sought for some time [12]. However, only a few of the robot morphologies obtained by evolution are tested outside simulation. This is mainly due to real world experiments being expensive in terms of time and human resources. While some studies have strived to perform evolutionary robotics experiments completely on real settings or use a combination of simulation environments and real trials, this is still a challenge.

To overcome this difficulty, different techniques have been used to enable the testing of evolved robots in real world scenarios. Some of them employ reusable parts and therefore are faster to deploy, while others allow for higher shape variability. Figure 1 shows this trade off in a graphical way. In this paper, we will discuss these techniques and propose what we think is one of the most suitable approaches to evolve robots in reality.

2 EVOLVING PHYSICAL ROBOTS

The ability to test evolved robots with very varied shapes is a feature of 3D printing approaches. In the Golem project, Lipson et al. [6] use

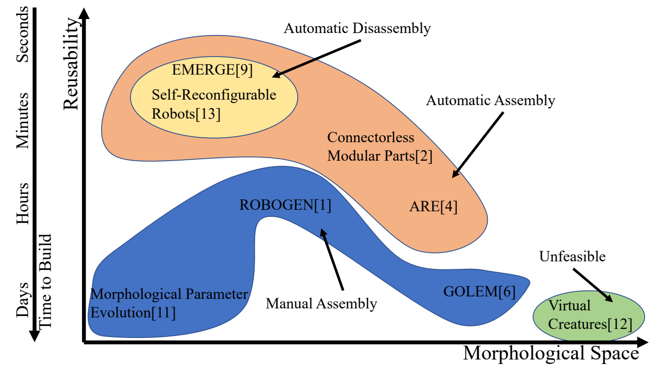

Figure 1: Comparison of real world robot evolution testing approaches.

3D printing to build robots made of cylindrical parts and one type of actuator (without sensors). First, robots are evolved in simulation and then all parts, with the exception of actuators, are printed, assembled and wired, for the robot to work properly. Samuelsen et al. [11] similarly transfer and test simulated robots, again without sensors, in the real world by 3D printing parts, but limit evolution to certain morphological parameters, like the length of limbs. 3D printing allows these robots to have a large morphological space, however printing can take hours depending on the part complexity, and days when accounting with wiring and assembly.

Moreover, as printed parts are different from each other, they can usually not be reused for building other robots. Auerbach et al. [1] attempts to solve this problem in the Robogen project. In this project, robots are designed to use standard cubic parts that can be attached to 3D printed spacers, which dimensions are modified by evolution. Standard parts include a control unit, two rotary actuators and three types of sensors. This system has been employed to demonstrate the feasibility of physically evolving robots in a proof of concept experiment [5]. However, the system parts must still be attached together manually, using screws and a significant amount of work.

Quicker methods for attaching parts have led to the automation of robot assembly. Hale et al. [4] use a robotic manipulator to insert pre-made *organs* (standard modular parts including actuators or sensors) into a previously evolved 3D printed frame with snap joints. The manipulator even wires components together. The result is a mix of the flexibility of 3D printing with automatic assembly. Nevertheless, at this point a human is still needed at some parts of the process and the disassembly of the *organs* to be reused has not been addressed yet.

Automatically joined modular parts, without sensors, are used also in Brodbeck et al. [2]. They speed up the robot assembly process by using only pre-made parts. These parts are joined together by a hot glue dispensing manipulator. This has the advantage of building and testing robots faster, compared to 3D printing approaches, but

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loses some shape variability. The parts can be reused, although somebody must manually separate them and eliminate the glue, after the robot has been tested.

Modular robots using quick connectors provide also a way of building robots faster than with 3D printing approaches. As modules encapsulate functionality, like power, actuators and sensors, robots can be ready to be tested as soon as they are assembled. Additionally, modules can be reused as many times as needed. Nevertheless, connectors impose tougher restrictions to module positions in the structure, reducing the morphological space. In addition, the size of the robot is usually bigger than using a non modular approach, due to the connectors, and this can limit some tasks. Sensor placement is also restricted to certain positions inside the module. Modules of different shapes and sizes [3], are a practical way of mitigating these restrictions. A reduced search space can also speed up the finding of well performing robots, a desirable feature for real systems.

Some modular robots use connectors that should be joined manually, but others can be separated automatically as in self-reconfigurable robots [13]. However, the self-reconfiguration process can be very slow and complex, and the modules are heavier as they need actuators for the connectors. Using an external manipulator, as in the case of [2] and [4], opens a practical way for the possibility of eliminating humans completely from the process of testing robots in reality.

3 THE EMERGE SYSTEM

An example of a modular robot system already in use for evolutionary experiments is the EMERGE modular robot platform. The EMERGE platform uses modules with magnetic connectors that can be built using off-the-shelf components, and their design is open for anyone to use and modify [1].

EMERGE modules resemble a small cube with a central servo motor [9]. Attached to the central motor are 3D printed mating faces that contain magnets and proximity sensors. Faces maintain electrical and mechanical connection between modules and house Printed Circuit Boards (PCBs) to route communication and power inside the module. EMERGE robot morphologies can not only be assembled automatically by an external robotic manipulator but also disassembled. The process has been demonstrated with both an active gripper and a passive gripper [10]. Under the guidance of a visual positioning system, modules are assembled into planar morphologies, allowed to move and then rearranged without regard to their final location [2].

The use of a modular approach opens up a new question, what is the best module design to maximize the performance of the assembled robots? Modifications to the module design itself, and their impact on the performance of the resulting evolved robot morphologies for a locomotion task, have also been studied. Results show that increasing the length of the module, and thus the module weight, leads to robots having fewer modules and thinner shapes, and that longer modules are less effective than shorter ones [8]. Having different starting base modules also affects the resulting morphology.

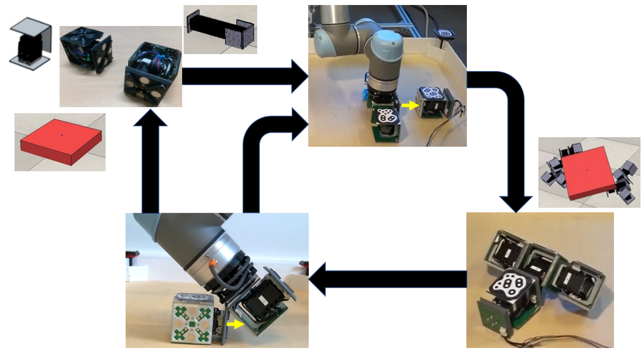

Figure 2: Real world evolutionary testing process using EMERGE modules and an external manipulator. Top-left shows different types of EMERGE modules that can be reused. Bottom-right shows the automatically assembled and tested morphologies.

Furthermore, limiting the number of faces other modules can connect to during evolution further reduces the search space making the search for fit locomotion movements even quicker[7].

Although these last studies have been performed mainly in simulation, our main goal is to carry out evolution of morphology and control with EMERGE modules in reality with the help of the automatic reconfiguration system (Figure 2). We are working on overcoming some limitations, like the ability to assemble 3D robot morphologies, ensuring modules are always powered despite changes in morphology and using a tracking system that does not interfere with robot assembly (currently, the markers are placed over connectors). Nevertheless, we are closer than ever to building a fast fully autonomous system, with reusable parts, for designing robots using real world evolutionary experiments.

[1] https://sites.google.com/view/emergemodular/home
[2] https://vimeo.com/292404982

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