# Towards feasible virtual creatures by using modular robots

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***Abstract*— This paper deals with how to produce feasible robots obtaining their morphology and control through evolution. To this end, we propose using the components of a modular robotic architecture as the basic constructive elements for morphological evolution. This architecture presents a series of features to increase the evolvability of the system such as heterogeneous modules and a large number of connecting faces per module. Thus, useful robots can be deployed in a short time using only a few modules. In this paper, some examples of ad hoc configurations are shown to test the architecture and, finally, some evolved morphologies are built and tested in real experiments.**

## I. Introduction

Evolutionary robotics has been employed as a useful technique to achieve robust controllers for robots by exploiting the relation between the fixed morphology of the robots and their environment [1][2]. In fact, embodiment plays a key role in developing intelligent systems [3][4].

Similarly, some authors have used evolutionary algorithms to co-evolve the morphology and the control of the robot at the same time in order to obtain well-adapted robots for a task in a specific environment. This approach exploits the interrelations between the morphology, the control system and the environment for a task. Following this approach, Sims and other authors have evolved virtual creatures for walking, swimming, jumping or flying [5]-[7]. Nevertheless, these works are based on simulation without considering any physical constraints and their creatures cannot be built without an ad hoc adaptation. In contrast, only a few authors try to evolve robots that can be built using an automated technique [8].

On the other hand, other authors have studied how to obtain virtual creatures by evolving predefined parts, such as Lego bricks [9] or bars and circular sockets [10]. These works guarantee feasible robots that can be built, but they are only proof of concept to show that coevolution can generate real robots. This paper follows the same approach, but the main components to be used as basic elements for evolution are robotic modules: autonomous devices with some sensing, actuation, communications and computational capabilities. Different modular robots with different morphologies can be easily obtained by joining the modules.

Modular robots have shown a high level of versatility to build different robot configurations, but the morphology is usually selected by an external designer in most cases [11]-[13]. Some works try to automatically obtain the morphology of the robot for one task. In this sense, most are based on simulations and they ignore the control of the robot, evaluating only morphological features [14]-[16]. Only a few authors have coevolved modular robots that can be built [17][18].

While most simulated architectures present interesting properties to increase the evolvability of the system such as heterogeneity of the modules or large numbers of connecting faces per module, these are not present in the physical ones. On the other hand, the simulated architectures do not face the real operational issues such as power transmission, robustness, communications or computational capabilities.

This works seeks to fill this gap by designing a modular robotic architecture that can be employed as a basic component set to build robots through evolution. To this end, we have designed it taking into account the evolvability of the system and the real operational issues. Thus, useful robots, obtained through ad hoc design or by using evolution, can be deployed with a low number of modules and in a short time.

The following sections address the main features of the architecture and its implementation. Afterwards, some examples of ad hoc configurations are shown and, finally, some evolutionary morphologies are tested to display the possibilities of the architecture as a tool.

## II. Main Features of the modular robotic Architecture and implementation

The modular robotic architecture has to fulfil the following requirements in order to make the evolution and the operation of the robots easier:

- Evolvability: The predefined set of modules must generate enough morphological variation in the population and the morphological mutations should achieve well-adapted robots.
- Fast deployment: The modules should be assembled in a fast way to develop the selected morphology.
- Fault tolerance: If one module fails, it should not affect to other modules. So, its consequences can be minimized.
- Robustness: The robots must operate in real environments and should withstand the generated forces.
- Scalability: The number of modules of the robot should not affect its performance.
- Reduced cost: The cost of fabrication should be low.

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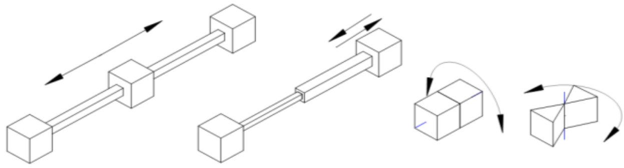

Figure 1. The four actuator modules: slider, telescopic, rotational and hinge.

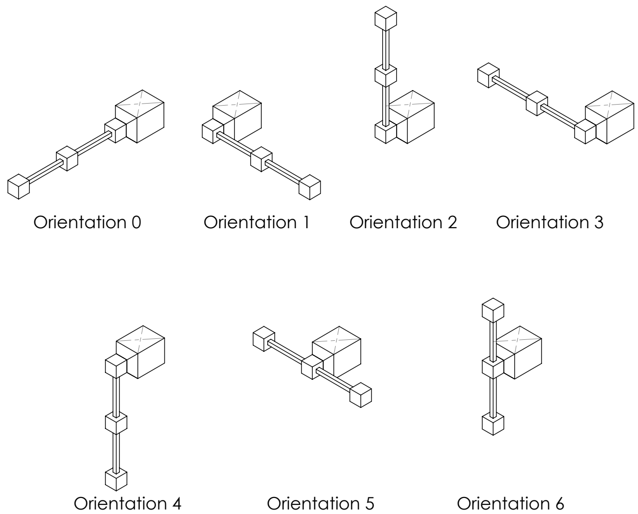


Figure 2. Different possibilities for attaching a slider module to a face.

To this end, a set of design features was selected for the architecture. First of all, the architecture is heterogeneous and each module has a high number of connecting faces. These two features permit building a large number of different morphologies by using only a few types of modules. They increase the evolvability of the system by favoring the preservation of a high morphological diversity in the population. Additionally, these features reduce the modules required for a task as now the architecture has specialized modules for each movement. Consider, as an example, the homogeneous architectures based on hinge actuators. They need to build a chain of two or more modules with a complex control to perform linear movements. While if you can employ linear modules, you only need one with a simpler control. Nevertheless, it is also important for evolvability that the architecture presents a reduced number of different modules. This preserves the advantages of modularity and, at the same time, it favors the feasibility of the system. Thus, the elements of the architecture have been classified into five different categories:

- Actuators: They have motors and generate the movement of the robots
- End-effectors: They have specialized tools like magnets, wheels or rubber legs.
- Expansion modules: Modules that increase the robot capabilities, like batteries, processing power, etc.
- Specialized sensors: Modules that carry specialized sensors like cameras or ultrasound sensors.
- Linkers: Modules used to join other modules.

All of these modules are autonomous units with computational and communications capabilities, power management and sensors. Therefore, an autonomous robot can be built using only actuator modules and the other modules are only used if they are required.

To select a small set of actuator modules, we have performed a top-down analysis based on typical tasks performed in real environments; this analysis can be consulted in [19]. Four different types of actuators were obtained: a slider, a telescopic, a rotational and a hinge module. The slider module and the telescopic one have prismatic joints, but the telescopic module varies its overall length while the slider module has a fixed length and a carriage slides over its structure. Similarly, two actuators have a revolution joint: a rotational module and a hinge module. These four actuators allow building robots with complex morphologies using a small number of modules as each kind of actuator implements a specific motion primitive. For example, the telescopic module can be used to build legs or the rotational one can be employed as a wheel. In addition, we must point out that all of them were selected with only one degree of freedom to simplify the mechanics and maintain the cost low.

A simplified sketch of the four actuator modules is shown in Figure 1. All of them, except the hinge actuator due to the lack of space, have cubic nodes at their extremes. These cubic nodes are connection bays that can permit joining modules at 90º orientations. As an example, the seven different possibilities to attach a slider module to a face are displayed in Figure 2. This design reduces the linkers in the robots and allows complex configurations like closed kinematic chains. Moreover, each attaching face has a small connector, manually operated, to join two modules mechanically in a few seconds. At the same time, the connector shares the energy and the communications between them.

Regarding communications, all the modules contain three different channels to share information. First, all the modules have a wireless channel based on a MiWi transceiver, which allows communications between different robots or modules that are not connected. Second, there is a CAN bus used as a main communications channel for all the modules in a configuration. And, finally, there is a local asynchronous

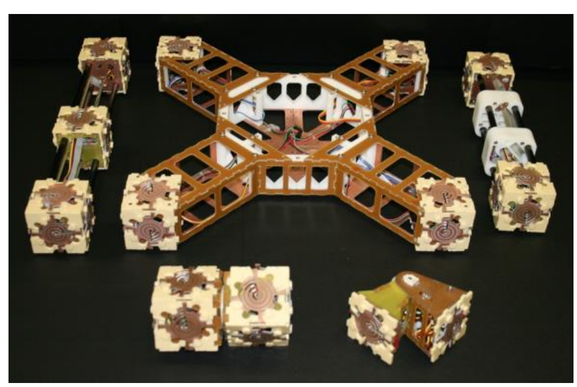

Figure 3. Implementation of the four actuator modules and a base module

communications line at each face. Thus, a module can know if there are modules connected to its faces and a robot can know its configuration using this information with the orientation of each module. These channels of communications increase the fault tolerance of the system, as they guarantee the communications even if a module is broken.

This architecture has been implemented using printed circuit boards, PCBs, joined with solder, resin parts and carbon fiber tubes as basic elements. Thus, very light weight and strong modules were obtained. Currently, we have implemented the four actuator modules, a base module (linker) and a magnetic module (end effector). These modules are shown in Figure 3. More information about the implementation of the modules can be found in [20].

## III. AD HOC CONFIGURATIONS FOR USEFUL TASKS

This section is going to show a few examples of simple, but effective, robots that can be built with the architecture. The aim is to show that useful robots with only a few modules are possible. The tests were performed using an external power supply and a USB cable to connect the robot to a computer. A user sent the commands using the USB connection to a module which resent the commands to the specific module using the CAN bus.

The first example is a spherical manipulator, displayed in the top images of Figure 4. This morphology has been selected because manipulators are widely used to automate all kinds of tasks. Its configuration is a serial chain of three actuator modules: a rotational module, a hinge module and a telescopic module. In addition, there are two end effectors. The first one is a big magnet to fix the rotational module to the ground. The other is a small electromagnet in the extreme of the telescopic module. As can be seen, the robot is able to carry a small part from one place to another using the electromagnet.

The second example, middle images of Figure 4, is a snake configuration with only two hinge modules. This kind of morphology can be used to carry small sensors across narrow passages such as pipes. The direction and speed of the motion can be controlled by changing the control parameters of the modules (amplitude, angular velocity and offset).

The last configuration, bottom images of Figure 4, is a more complex walking robot, a biped morphology. This configuration allows walking over a ferromagnetic surface and overpassing obstacles. It is built with one rotational module, which has two branches of a hinge module connected to a magnetic module. The magnetic modules are permanent magnets with a coil inside. Thus, they can be fixed or unfixed to the ferromagnetic ground.

## IV. WALKING ROBOTS USING EVOLUTION

An evolutionary design system for heterogeneous modular robots, EDHMoR, was presented in [19]. The system is based on the coevolution of morphology and control using a direct tree encoding scheme, a constructive algorithm to deal with the high deceptiveness of the search space, a dynamic evaluation using a simulator and a methodology which uses a simple fitness function and guides the search adding restrictions to the environment. We used EDHMoR to design robots for carrying a payload over rugged ground. The payload is carried on the base module and if it falls, the

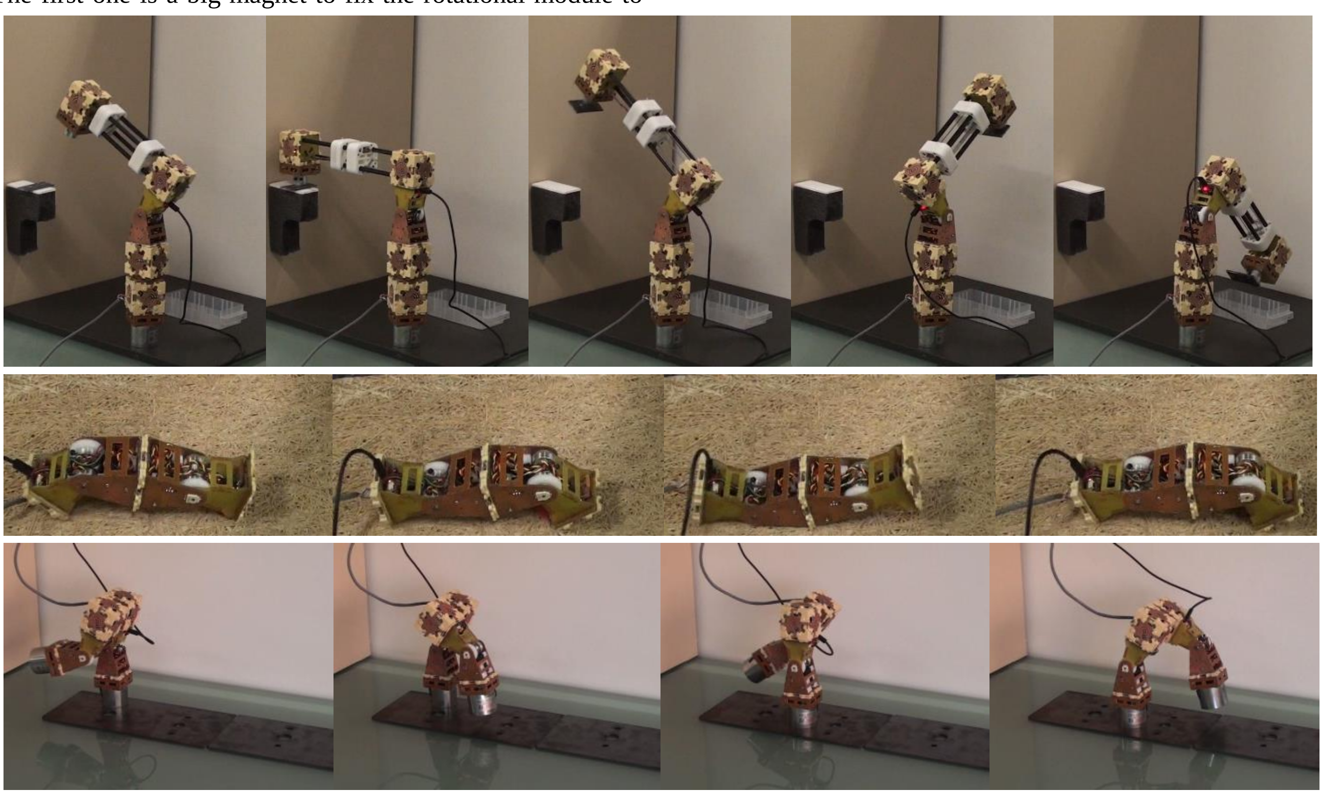

Figure 4. Some tests with three different morphologies: Spherical manipulator, snake and biped.

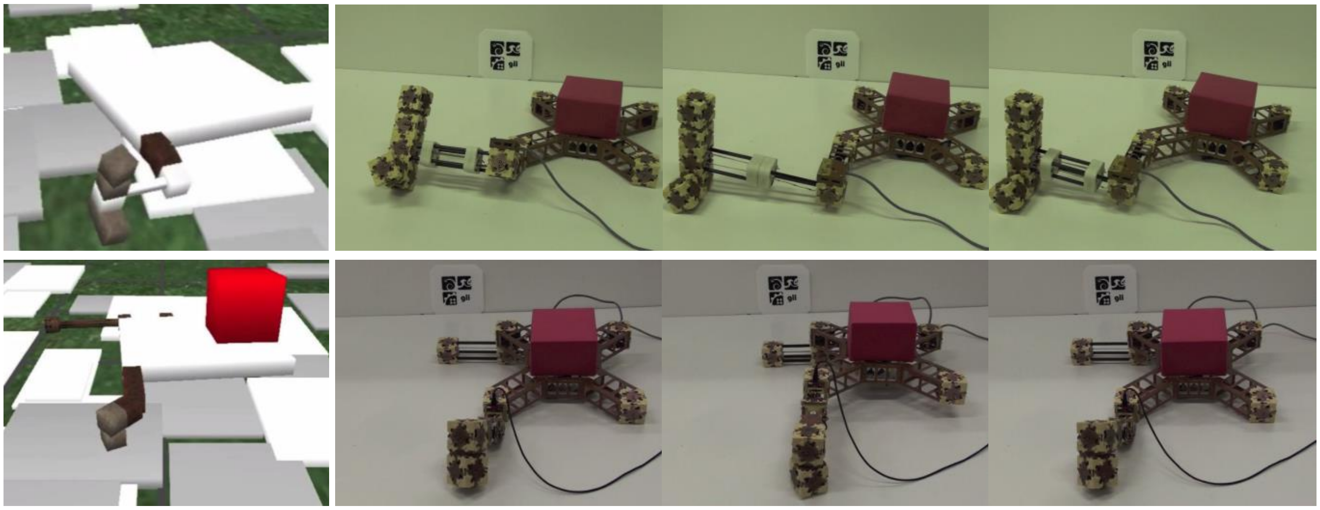

Figure 5. Some tests with coevolved morphologies. Left column: obtained robots in simulation. Other columns: operation of the built robot.

fitness is decreased. Using this setup, we have obtained different morphologies that carry the payload without problems. Two of these morphologies are shown in Figure 5. The left images correspond to the robots obtained in simulation with EDMHoR and the remaining to the robot constructed using the physical modules.

The first example (top images of Figure 5) is a robot composed of the base and four actuators. Specifically, a hinge module is connected between the base and a telescopic module. The telescopic module has at its other extreme two rotational modules. The second morphology, bottom images of Figure 5, has two branches. The first one is made up of a serial chain of two hinge and a rotational modules. And the other branch is only a slider module.

As can be seen in Figure 5, both robots are feasible and they can be easily built employing the base and the different actuator modules. Moreover, they are able to solve the designing task successfully, in this case carrying the payload without problems.

## V. Conclusion

The paper has presented a heterogeneous modular architecture with elements that present a large number of connection faces. This feature, among others, allows building a large number of different morphologies with only a few types of modules. The generated robots are deployed quickly and easily. Thus, the virtual creatures obtained by using evolution can be assembled and tested in real environments. To illustrate the advantages of the architecture, some real tests were performed considering ad hoc and evolved morphologies.

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