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Sylvain Cussat-Blanc, Jordan Pollack

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Summary of “Cracking the Egg: Virtual Embryogenesis of Real Robots”

Sylvain Cussat-Blanc
DEMO Lab, Volen National Center for Complex
System - Brandeis University MS018
415 South street, Waltham, MA 02454, USA
cussat@brandeis.edu

Jordan Pollack
DEMO Lab, Volen National Center for Complex
System - Brandeis University MS018
415 South street, Waltham, MA 02454, USA
pollack@brandeis.edu

1. INTRODUCTION

Growing a robot from a single functional unit, in other words a cell, is one of the most exciting dreams for researchers in the modular robotics field. Recent works have allowed the development of bigger and more complex robots. Usually based on spheric or cubic units, they embed complex mechatronics that make them more accurate, more efficient and more diversified [6, 8, 1]. Some of these robots have a fixed morphology with an evolved controller and other, more complex, are self-reconfiguring robots. This last method generates a very interesting property: the robots are capable of self-healing, as multicellular organisms are.

On the other side, the history on virtual robots, commonly named artificial creatures, dates from the early nineties with Karl Sims' creatures. It took another six years before evolved robots took a step from virtual to reality [5]. Over the past few years, artificial Gene Regulatory Networks (GRN's) appear to be able to generate complex 2-D and 3-D morphologies when they control a developmental model [4, 3]. More recently, Schramm et al. were able to grow a digital aquatic worm that moves by oscillation generated by the same regulatory network used to grow it [7].

The main motivation of this work is to use a cell-based developmental system driven by a gene regulatory network to generate real robot morphologies. In our opinion, an evo-devo method is well suited for this range of problems because it is more biologically plausible than others quasi-developmental approaches and thus should scale up better. Using such a biologically plausible developmental model to produce robots could help us to inherently tackle crucial properties such as clustering, symmetry, regularity, robustness, complex self-organization into tissues and organs, etc. All these properties are necessary to produce the extremely complex machines that living systems are and would be extremely helpful in robotics.

Keywords

Modular robots, Cell-based developmental model, Gene regulatory network, Bodyplans

2. THE ROBOTIC BLOCKS

In this work, the design of our machines was inspired by living organisms. An organism is usually comprised of billions of functional units: the cells. Cells can have various functions (neural, muscular, etc.). Thus, our machine uses multiple block types that have different functions. The blocks must be easy to assemble so we can conceive an automatic assembly process using off-the-shelf robot arms and conveyor belts. When a machine is built, its morphology will not evolve anymore (as many grown living beings do not modify their morphology). With this constraint, the blocks do not need a dynamic linking and unlinking system: a simple dovetail latch is adequate. Finally, each block must be cheap to produce to keep the overall machine cost low. As presented in Figure 1, three different units are used in the work: a *noop* block is used to build the structure of the robots, a *hinge* block can rotate around a central axis and a *motor* block that actuate a hinge block connected through two plastic actuators.

3. THE DEVELOPMENTAL MODEL

We propose a novel approach to produce the robot morphology. It is based on a developmental model in which cells are controlled by a gene regulatory network coupled to a

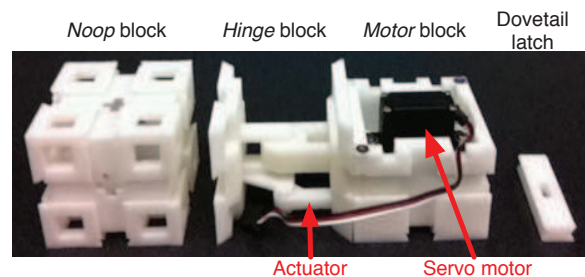


Figure 1: The robots are composed of three different blocks. Blocks are tied together by the use of dovetail latches inserted between the blocks.

novel non-linear morphogen production system. The developmental model is based on cells that act in a 3-D discrete environment. Two main types of cells are available: *stem* cells that can divide as much as they want to and *differentiated* cells, the final robotic blocks. At each time step of the simulation, the stem cells can either *divide symmetrically* to produce a new stem cell, *divide asymmetrically* to create a new differentiated *noop cell*, *differentiate* to become a *noop cell*, *rotate* to reorient its orientation vector, or commit a *special division* to produce functional hinge (*hinge cell* plus *motor cell*).

To select an action, cells are using a gene regulatory network (GRN). The GRN model used in this work is a simplified computational model of the real gene regulatory network that constantly control our own cells. It has been designed for computational purposes instead of simulating protein interactions. It is defined as a set of interacting proteins. Each of them has three tags (identifier, enhancer and inhibitor) and a type (input, output or regulatory). The tags are used to compute the affinity between the proteins for production enhancement and inhibition and, based on that affinities, all the network dynamics. At each step of the simulation, each cell executes its own regulatory network and selects the action corresponding to the maximum protein concentration associated to the cellular actions.

In our model, a non-linear morphogen production system generates the inputs to the GRN. The morphogen production profile of an input protein is coded by a Bézier's 3-D surface. It allows the generation of a surface by the mean of a given set of checkpoints. The surface determines the concentration of the input according to the current simulation step and the identifier of the cells. One surface is associated with the identifier of the input protein so that the GRN has a variety of morphogen production profiles.

4. RESULTS

To evaluate the morphologies generated, a virtual robot is grown before being dropped down in a 3-D simulated physics environment. In previous work [2], we already used interactive evolution to study the capacity of the GRN to inherently produce properties that other models usually include such as symmetry or regularity. In this paper, we have produced this robot in the real world and optimize new morphology from scratch with a standard genetic algorithm. In this second experiment, we have trained the robot for locomotion and obtained various morphologies. We built the best one

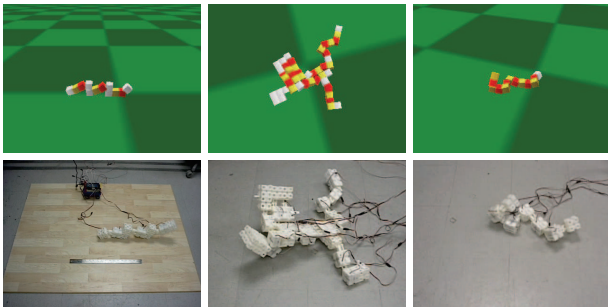


Figure 2: Robots obtained with genetic evolution, in simulation (top) and in reality (bottom).

in reality and obtained robots as the one given in example in figure 2.

5. CONCLUSION

This paper shows that a cell-based developmental model can produce the morphologies of modular robots and inherently induces symmetries and regularities. Self-repairing is another key property often desired in modular robots and many research teams proposed various algorithms to obtain this property. Developmental models are also known to inherently self-repair the developed structures, in other words to recover the function and/or morphology from a faulty cell. Having this feature inherently supported by the morphology design algorithm is a strong advantage of the approach. Because this model is based on the same principles, our developmental model should exhibit the same property.

Our current developmental model produces usable blueprints to assemble the robots, currently manually, but, in a long-term objective, machinery could be able to use these step-by-step blueprints to assemble and disassemble the robot automatically. The idea is to produce on-the-fly robots whose morphologies and behaviors are optimized for a given function and assemble them with an automatic process. Once assembled, the robots would perform their missions before coming back to the base and being disassembled or modified for another mission.

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