Developmental Programs for Tensegrity Robots

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The Problem: Biologically inspired robots are often very rigid in their morphology, their controllers, and even their physical embodiment. In contrast, biological organisms can exhibit a wide range of robustness and adaptiveness in all of these areas. Robots are often constrained by imposing kinematics and dynamics that can be well understood from an engineering standpoint. The materials available for robot construction limit the physical embodiment of the machines to a rigid construction not unlike a bridge or an automobile. And most importantly, the controllers for these robots require hand design and hand tuning to obtain the desired performance. Our approach is to investigate methods for autonomous development of robots in order to provide them with the adaptability and robustness we witness in even simple biological organisms.

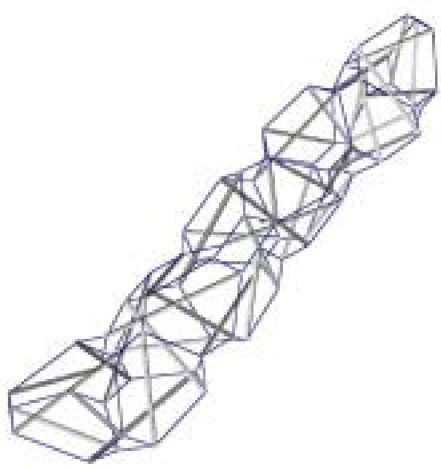

Figure 1: A model of a robotic tetrahelix tensegrity structure.

Motivation: A developmental approach to biologically inspired robots presumes that a higher level of adaptivity and robustness is possible if the robot has a program for ontogeny. We aim to design robots such that the robot phenotype progresses to maturation via a developmental program over time. These robots do not arrive in the world instantaneously and in fully developed form. Consequently, a repertoire of behaviors can develop and adapt appropriate to the environment in which the robot is situated.

Approach: Our approach is to investigate developmental programs that are in-vivo. These programs unfold in real-time and in the real-world, embodied in a robotic creature capable of basic sensing and action in the world. As the ontogeny progresses, the robot should progress from the simplest possible phenotype to one of greater complexity in morphology and behavior.

We are investigating genetic regulatory networks as the underlying mechanism that modulates and drives the developmental program. Notable previous work with regulatory networks and simulated robots has been done by Bongard [1]. In our work, we look to use regulatory networks to modulate expression of different body morphologies such that environmental influences can affect body plan. The regulatory networks also provide homeostatic control of neurogenisis and neural plasticity. In this manner, the neural topology could dynamically adapt as the robot matures and as the sensory patterns present in the world change. Importantly, the robot genotype specifies the rules by which the regulatory network guides the adapts the topology, not the network topology itself. This allows the environment to define the actual topology through a reinforcement signal. Our hope is that this will allow the robot to adapt to radical perturbations such as ad-hoc rewiring of its sensors and motors.

The robots being built for this purpose are based on the structural phenomena of tensegrity. Tensegrity structures, discovered in part by Buckminster Fuller and evident at multiple scales in biology [2], contain isolated compression beams seemingly floating in a sea of elastic tension provided by cables. The tensegrity robots under construction are to be highly compliant and driven by force-actuation. As such, they can provide rough models for organisms such as the leech and jellyfish.

Impact: The goal is to elucidate the basic organizational principles and essential mechanisms for the development of a robotic organism. Robots built on these principles should exhibit similarities, in robustness and adaptability, to real biological organisms. If we are successful, we will have expanded our understanding of how to better build living machines, and our understanding of the essential features of living organisms.

Future Work: This work is in a early phase of hardware construction. Future work will be centered on design of a developmental architecture for the robot.

References:

[1] J. C. Bongard. Evolving modular genetic regulatory networks. In *Proceedings of The IEEE 2002 Congress on Evolutionary Computation (CEC2002)*, pages 1872–1877. IEEE Press, August 2002.

[2] Donald Ingber. The architecture of life. *Scientific American*, 278:48–57, January 1998.