# Growing Brains

Bryan Adams

Artificial Intelligence Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

http://www.ai.mit.edu

**The Problem:** The term "control structure" presumes that a controller should have a human-recognizable structure. However, for the most robust and effective controllers known, animal brains, researchers are still uncovering what, if any, structures are present. [3] The simple difficulty in locating and measuring the state of the tiny neurons that make up an animal brain present a daunting challenge, and measuring from large arrays of neurons is nearly impossible. This makes biological modelling of these structures imprecise and, to date, ineffective.

**Motivation:** Even some of the simplest animal brains allow creatures to exhibit a level of behavioral complexity that is unmatched in robotics today. A polyclad flatworm (figure 1), one of the most primitive encephalized creatures, is able to maintain its orientation, locomote, locate food, and avoid predators with roughly 2000 neurons in its central brain. [2]

Computational power can already allow for an effective simulation of these neurons. The missing piece is the organizational principles that allowed the brain to grow and function. If these principles could be even partially unearthed, they could hold the key to building robotic controllers that allow for more robust machine behavior.

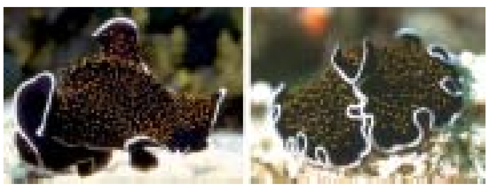

Figure 1: A polyclad flatworm

**Previous Work:** Neural nets, inspired by animal brains, have long been a foundation of AI. While they are appropriate for a variety of tasks, their limitations (in the most typical form) make them unsuitable for this task. Simply put, they are too removed from real neural nets to provide anything other than a starting point.

Many researchers have created more realistic simulations of biological brains [1] [4], most have suffered from a two dimensional and/or grid-like view of the world, creating very few neurons, and avoiding the issue of how chemistry affects development. Other research also neglects the role that development plays in the creation of a functioning brain.

**Approach:** This work will attempt to create a functional controller-generation mechanism that closely mimics the growth and development process of animal brains. By positioning the neurons in a three-dimensional world according to a set of rules for development (and based on chemical gradients secreted by the neurons themselves), this controller has mechanisms to self-organize. The axons, which are guided according to similar rules, allow for creative interconnection patterns. These neurons and axons also form a functional spiked neural network, which is then used to control a robot.

Artificial evolutionary techniques are used on a genome specifying the starting location and properties of each neuron's stem cell. As these properties are mutated over time, the resulting controllers are encouraged to create complex communication structures between a set of pre-defined sensory-motor neurons.

**Impact:** This work impacts two different areas. First, the understanding of neurological development from a biological perspective can benefit from this kind of full-bodied modelling. By creating a model that results in a functional control unit, theories about how the brain grows can be tested against resulting behaviors. Second, creating these virtual brains as machines can give insight into how robot controllers can be designed to be more robust and effective.

**Future Work:** Neural development is an endlessly rich and complex process, and greater detail can be added into the model as computational power allows. Phenomena such as neural growth and death, complex axon guidance, and sensory-motor intelligence can all be investigated and implemented into this model. New robotic platforms and tasks are also open to investigation.

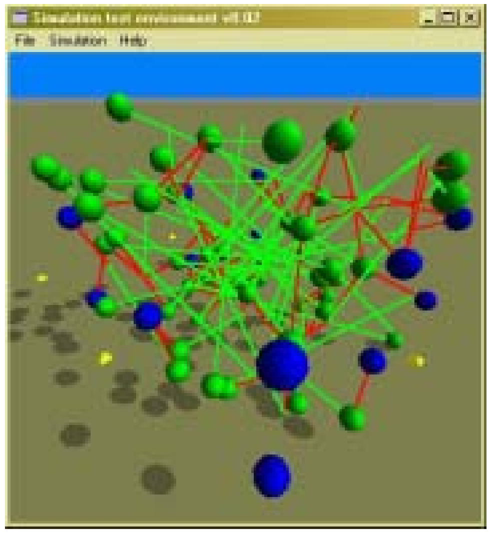


Figure 2: A simple visualization of an evolved brain.

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[1] J. C. Astor and C. Adami. A developmental model for the evolution of artificial neural networks. *Artificial Life*, 6:189–218, 2000.

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[4] A. Rust, R. Adams, S. George, and H. Bolouri. Activity-based pruning in developmental artificial neural networks. *Artificial Neural Networks, Proc. 4th European Conf. on Artificial Life (ECAL97)*, pages 224–233, 1997.