Topological properties of evolved robot brains

Christoph Adami[1], Nicolas Chaumont[1], Jeffrey Edlund[2] and Arend Hintze[1]

[1]Keck Graduate Institute
[2]California Institute of Technology
adami@kgi.edu

The topological structure of animal brains is likely to be interesting because the computational power of brains is thought to be almost entirely due to its wiring pattern and hierarchical organization. At the same time, this pattern is not at all well understood, and the information about the wiring pattern of the nematode C. elegans, for example, is unique in the literature. A promising direction for the study of network topology in the absence of detailed biological data is the Artificial Life approach, where functional networks are evolved that determine the survival of artificial organisms in an artificial chemistry and genetics. Recently, we used this approach to understand modularity in evolved artificial metabolic networks and developed new tools to dissect their topological and functional characteristics. Here, we apply some of these tools to the study of the brains of robots that have evolved to behave in a simulated world. The robots that are controlled by these brains are simulated versions of real robots (the ATRV Jr. of the iRobot Corporation) whose properties we tested in our laboratory. Both the robot and its environment are simulated in a three-dimensional world that implements realistic rigid body dynamics via the Open Dynamics Engine (ODE). As a consequence, evolved controllers could in principle be transplanted onto the simulated robots' real-world counterparts.

Neural computational tissues ("brains") are grown from genomes that implement neural network development and function based on a set of rules ("genes") that are conditionally executed, that is, regulated, by a set of simulated proteins produced by the cells in the tissue. This system ("Simnoesis") is based on the "Norgev" platform but was completely rewritten in order to be able to evolve complex tissues that process many temporally varying input signals. We evolve neural tissues on two-dimensional grids (of up to 15x15 neurons) that control a simulated ATRV Jr with 19 sensors (17 sonars, a compass, and a sensor relaying distance to goal), controlling two motors driven by two actuators for differential steering. The evolved tissues control complex robot behavior, such as wall-following, obstacle avoidance, and goal-finding, using a complex network structure reminiscent of the C. elegans connection graph. The fitness evaluation of a genome consists of growing the network, and evaluating the behavior of the robot in a 3D environment akin to the fitness evaluation in the work of Sims). Fitness evaluation and evolution via a Genetic Algorithm is implemented within the EVO software.

We analyze the properties of evolved neural networks using standard tools (such as edge-distribution, shortest-path length, and betweenness centrality), as well as new tools that reveal robustness and modularity via clustering methods and information theory. We find that the topological properties of evolved functional networks are very different from their randomized counterparts, and characterize the "rarity" of these networks with standard statistical tests. Finally, we compare the topological properties of our evolved networks to the connection graph of C. elegans.