Spiral autowaves as minimal, distributed gait controllers for soft-bodied animats

Michał Joachimczak, Rishemjit Kaur, Reiji Suzuki, Takaya Arita
Graduate School of Information Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
mjoach@alife.cs.is.nagoya-u.ac.jp

Abstract

Inspired by the self-organization of growing embryos and coordinated movement of multicellular assemblies such as the slime mold Dictyostelium, where each cell is controlled by the same controller (a DNA-encoded gene regulatory network), we evolve distributed gait control mechanisms for soft-bodied animats. The animats are made of compressible material, with each body region capable of independent actuation, controlled by a cell at its center. Each animat consists of hundreds of cells uniformly distributed throughout the body, each sharing the same artificial gene regulatory network and aware of the state of their local neighborhood. We found that one of the most common actuation patterns that emerged relied on cells synchronizing their oscillations in order to produce a rotating, spiral wave spanning throughout the body. We found this type of mechanism to emerge for a wide range of animat morphologies as well as in very different types of initial conditions. We investigate how the evolved controllers produce the pattern through local feedbacks and evaluate spiral stability when imperfect, noisy cells are used.

Introduction

Taking inspiration from distributed control mechanisms observed in nature, such as self-organization of a growing multicellular embryo and movement of multicellular assemblies of certain amoeba known as slime molds (e.g., Dictyostelium), we investigated the possibility of evolving distributed controllers for prespecified morphologies of soft-bodied robots that would produce gaits in a truly decentralized manner. By dividing animat bodies into hundreds of cells capable of communicating with their neighbors, we were expecting to observe the evolution of some form of autowaves organizing the gaits. Autowaves are a special type of nonlinear waves that are known to occur in active media and the main difference between autowaves and classical waves is that propagation of the former occurs at the expense of energy stored in the medium. The energy is used to trigger process into adjacent regions (Roska et al., 1995; Mangano et al., 1999). Autowaves occur in many biological phenomena, in particular they are essential to multicellular development, but are also central to processes such as propagation in nerve fibers or heart excitation.

The unexpected result of our evolutionary experiments was the predominant type of control mechanism that emerged. It was based on producing a very specific type of autowave: a rotating spiral known as a spiral autowave. Spiral autowaves are frequently observed in excitable media

Methods

We have employed the same approach to simulate soft-bodied animat locomotion as in our previous studies (see full description in Joachimczak et al., 2015), that is animats are two dimensional and are represented as a set of point masses (corresponding to cells) connected with springs. Unlike our earlier work, where we investigated co-evolution of bodies and brains, here we focused solely on the design of distributed controllers only. Hence, we assumed that morphology of an animat is specified at the beginning of an evolutionary run and does not change (other than the elastic changes during locomotion). Animat shapes were specified either as a drawing or a clip-art and then algorithmically triangulated to produce a mesh with a desired number of nodes. Locomotion was possible owing to the local, elastic changes to the body controlled by each cell.

During the evaluation, each cell of an animat is controlled by a copy of the same evolved artificial gene regulatory network (GRN) encoded in the genome (Fig. 1), with gene expression levels changing in a continuous manner. Despite the same controller, cells can differ in their behaviors, due to differences in environmental (input) signals ultimately producing different internal states of cells. The GRN topology was evolved using the NEAT (Stanley and Miikkulainen, 2002) algorithm, a state of the art technique for evolving network topologies. Fitness function promoted...
Results

We found that evolution, tasked with a problem of evolving distributed, local communication-driven controllers for soft animats repeatedly converged on a very simple and creative solution that relies on producing a rotating spiral autowave anchored in the center of the body or even multiple synchronized spirals in case of elongated individuals (Fig. 2). We also found that this simple control mechanism evolves for a wide range of tested animat morphologies and emerges both for morphologies that have a flat bottom as well as for morphologies supported by appendages.

Finally, we compared scenario in which cells can rely on a feedback of their own state with that of cells relying on the state of their neighbors and found that while the spiral autowaves emerged in each of the cases, different types of designs had very different robustness to noise. In particular, if we assumed that cells’ internal clocks are imperfect, only the experiments in which cells communicate with neighbors were able to produce sustainable spirals.

Conclusions

While the spiral autowaves are a common phenomenon in many physical and biological systems, we see their unexpected emergence in the context of evolving distributed gait controllers for soft-animats as an example of how artificial evolution can surprise us and suggest entirely new type of design, one that would be otherwise unlikely to be proposed by a human designer. Further study will reveal how robust is this type of design and how well it can apply to actual, 3-D soft-robots.

References


