Early Nervous Systems: Theoretical Background and a Preliminary Model of Neuronal Processes

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Extended Abstract

The evolution of the earliest nervous systems remains seriously under-researched. Within this small field, the focus has so far been mostly on the evolution of nerve cells, nervous system centralization and biomolecular precursors of nerve cells (Lichtneckert & Reichert, 2007). Another line of research concerns the geological and molecular evidence on ecological and morphological changes that may have contributed to the development of nervous systems in Precambrian life (Dzik, 2005; Peterson et al., 2005).

An important open question is how the very first nervous systems might have worked as a behavior producing system. The classic assumption, dating back to Parker's (1919), is that nerve cells evolved to connect pre-existing sensors and effectors, a proposal that was strongly influenced by Sherrington's exposition of the reflex-organization in vertebrates. Nervous systems are here a connecting device that gradually became more complex by adding feedback loops and cognitive extensions (Braitenberg, 1984).

However, this standard interpretation does not combine easily with other findings within this field. For example, many authors (e.g. Pantin, Passano, Horridge, Pavans de Ceccaty) claim that reflexes are a secondary development on top of a more primitive arrangement. The most basic examples of nervous systems are loosely connected nerve nets – skin brains (Holland, 2003) – spread out over the body without fast and specialized connections between specific sensors and effectors. A long neglected suggestion, going back to Pantin (1956), is that early nerve nets contributed foremost to the organization of patterns of muscle contractions in large multicellular animals. Coordinated muscle contractions allowed large animals to move about when earlier mechanisms, like ciliary crawling, became too inefficient. Under this interpretation, the key innovative function of early nervous systems is primarily to generate larger-scaled effectors rather than connecting sensors to some pre-existing 'effector'.

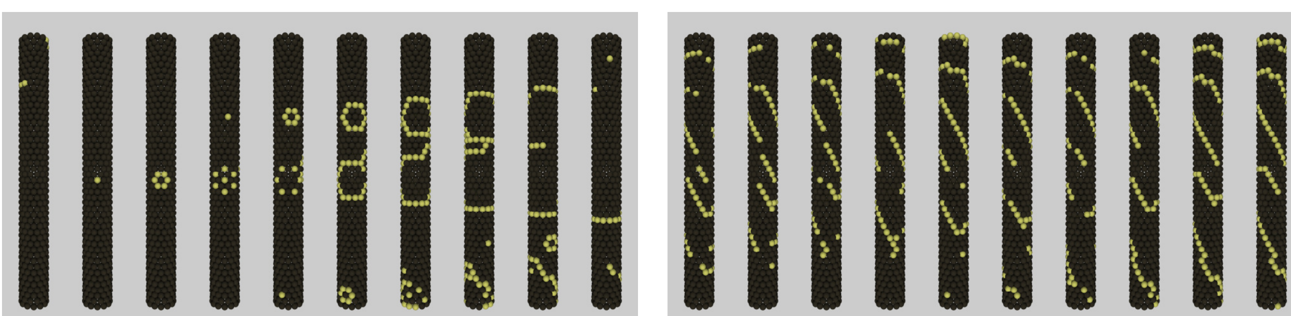

Figure: Emergent patterns on a simulated skin brain. Left: a simulation where every cell is connected to all six neighbors. Right: a simulation where every cell is connected to three, out of six, neighbors, forcing the spontaneous patterns to travel from bottom to top.

Our model investigates the transition from a non-neural conductive epithelium (Mackie, 1970) to a basic nerve net. A basic tube-like animal structure is approximated as a single sheet of cells that are both contractile and electrically conductive. Epithelial conduction produces spontaneous electrical activity on the bodily surface. We modelled the transition to nerve nets by varying three parameters: (a) Increasing the number of cells mimics increasing body-size. (b) Directionality of signalling, representing the evolution of synapses, makes cells in the model signal only in specific directions. (c) Formation and elongation of cell processes, representing the early evolution of axons and dendrites, allows cells to signal to non-neighbouring cells without influencing cells in between. The two last parameters represent key-aspects of neurons and the model provides a platform to investigate how these parameters modify global activity patterns at different body-sizes. The findings are relevant for a better understanding of the basic operation of nervous systems, early nervous system evolution and the problems encountered in the field of soft robotics.

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