Early Nervous Systems: Theoretical background and a preliminary model of neuronal processes

Ot de Wiljes[1], Ronald A.J. van Elburg[1], Michael Biehl[2] and Fred Keijzer[3]

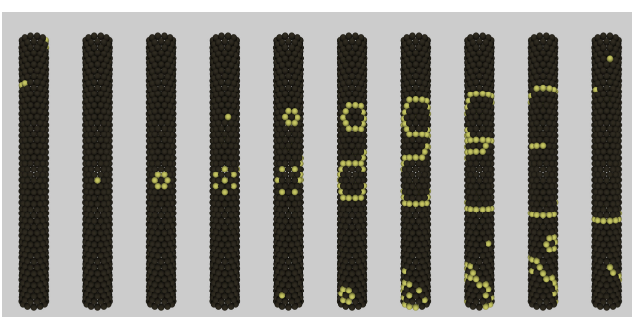
[1]Department of Artificial Intelligence, University of Groningen, The Netherlands
[2]Johann Bernouille Institute for Mathematics and Computer Science, University of Groningen, The Netherlands
[3]Department of Theoretical Philosophy, University of Groningen, The Netherlands
f.a.keijzer@rug.nl

Extended Abstract

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

One important open question here is how the very first nervous systems might have worked as a behavior producing system. The classic assumption, dating back to Parker's (1919) proposal, is that nerve cells evolved to connect pre-existing sensors and effectors. This proposal was strongly influenced by Sherrington's exposition of the reflex-organization in vertebrates and fits easily with the fundamental interpretation of nervous systems as basically a connecting device that later became equipped with complex feedback loops and cognitive extensions. Braitenberg's artificial vehicles provide a clear and influential illustration of this interpretation.

However, this classic 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 earliest nervous system must have been some form of loosely connected nerve net, spread out over the body, a *skin brain* as Holland (2003) called it, without fast and specialized connections between specific sensors and effectors. A plausible suggestion here, going back to Pantin (1956), is that early nerve nets may have contributed to the organization of patterns of muscle contractions in multicellular animals. Muscle contractions became important to move larger animal bodies about when more basic solutions like ciliary crawling become too inefficient. Under this interpretation, the key innovative function for early nervous systems is primarily to generate new larger-scaled effectors rather than connecting sensors to some pre-existing 'effector'.



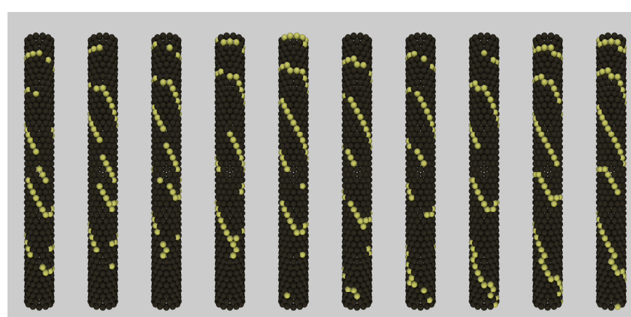


Figure: Emergent patterns on a simulated skin brain. On the left is a simulation where every cell is connected to all six neighbors. On the right is a simulation where every cell is connected to three, out of six, neighbors, forcing the spontaneous patterns from the bottom to the top.

Our model aims to investigate the transition from a conductive epithelium to a basic nerve net, as described by Mackie (1970). A basic tube-like animal structure is approximated as a single sheet of cells that are both contractile and electrically conductive. Epithelial conduction was represented as sustained and patterned spontaneous electrical activity on the bodily surface. We modelled the transition to nerve nets by varying three parameters: (a) Increasing the number of cells to mimic increased 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, for understanding early nervous system evolution and, in addition, for the field of soft robotics.

References

Braitenberg, V. (1984). *Vehicles: Experiments in synthetic psychology*. MIT Press, Cambridge, MA:.

Dzik, J. (2005). Behavioral and anatomical unity of the earliest burrowing animals and the cause of the "Cambrian explosion". *Paleobiology,* 31(3): 503-521.

Holland, N. (2003). Early central nervous system evolution: An era of skin brains? *Nature Reviews Neuroscience*, 4(8): 617-627.

Lichtneckert, R. & Reichert, H. (2007). Origin and evolution of the first nervous system. In Kaas, J.H., Striedter, G.F. and Rubinstein, J.L.R., editors, *Evolution of nervous systems, Vol. 1: Theories, development, invertebrates* , pages 289-315. Elsevier, Amsterdam.

Mackie, G.O. (1970). Neuroid conduction and the evolution of conducting tissues. *Quarterly Review of Biology*, 45: 319-332.

Pantin, C.F.A. (1956). The origin of the nervous system. *Pubblicazioni della Stazione Zoologica di Napoli,* 28: 171-181.

Parker, G. (1919). *The elementary nervous system*. Lippincott: Philadelphia.

Peterson, K. J., McPeek, M.A., & Evans, D.A.D. (2005). Tempo and mode of early animal evolution: Inferences from rocks, Hox, and molecular clocks. *Paleobiology*, 31(2): 36-55.