Searching for the roots of experience: Early nervous systems and the origins of the animal sensorimotor organization

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Abstract. How did the earliest nervous systems evolve and how did the animal sensorimotor organization first take shape? The Skin Brain Thesis holds that nervous systems first arose not to connect sensors to effectors, but to generate a new kind of effector – *muscle* – and primarily functioned as a way to integrate whole body movement. Bodily sensitivity to self-induced motility subsequently provided a new sensing device that operated at a whole bodily scale. Such a skin brain organization can be contrasted to an input-output interpretation of both basic nervous systems and the animal sensorimotor organization. Close conceptual links can be drawn between early nervous systems and the animal sensorimotor organization, making it thinkable in a concrete way that nervous systems and the animal sensorimotor organization are not standard input-output devices on a par with current computers and robots. New options for redrawing the roots of the sensorimotor organization behind experience result.

How did the earliest nervous systems evolve and how did the animal sensorimotor organization (ASMO) first take shape? These two questions are intimately related. Nervous systems are closely tied to and even a necessary condition for the sensorimotor organization that is characteristic for animals. At the same time, animal abilities to move and sense are a necessary requirement for nervous systems to function. Both must have co-evolved from simple beginnings to the many different forms that currently exist. How did this co-evolution first occur?

While interesting in its own right, this question may seem far away from human experience and the human brain. Nevertheless, for sensorimotor accounts of experience this question is highly relevant as it targets the connection between neural systems and sensorimotor organization in its most basic biological form. While this remains far away from the human condition, it will help to clarify two basic questions: “What are nervous systems?” and “What is an animal sensorimotor system?” Having better answers to both questions will allow a better understanding of their relation and subsequently of the kind of organization on which human experience depends.

Early nervous systems stress a *biological* context for looking at basic nervous systems. This is an important switch as many cognitive and neuroscientists regularly use artificial cases as basic examples (e.g Braitenberg vehicles or robots). However, we should not simply assume a deep similarity between artificial control structures and nervous systems, nor between sensorimotor artifacts and the ASMO. Early nervous system evolution is a good biological test case where these standard preconceptions can be questioned.

These preconceptions can be described as a commitment to an input-output view for both nervous systems and for the ASMO: Nervous systems – usually cast as ‘the brain’ – are complex systems, only connected to the world through sensors and effectors – providing both input and output – while the relevant ASMO is constituted by these sensors and effectors. In addition, nervous systems are often interpreted as information processing devices, like computers, while the ASMO is cast as the animal version of a robotic device. While this general description may strike many as obviously correct in a rough and general sense, this description can actually be challenged when one turns to the early evolution of nervous systems.

This challenge comes in the form of the Skin Brain Thesis (SBT) (Keijzer, Van Duijn & Lyon, 2013). Following early work by Chris Pantin, the SBT holds that nervous systems first arose not to connect sensors to effectors, but to generate a new kind of effector: *muscle*. Muscle provided a much more powerful and large-scale source of motility than earlier cell-level means of locomotion, such as cilia. However, such contractions must be coordinated across the whole animal body in order to be effective and require dedicated forms of fast signaling: nervous systems. According to the SBT, early nervous systems did not merely connect sensors to effectors, they helped build up a new kind of effector. Early nervous systems enabled a switch to motility by coordinated multicellular body-contractions, which is a key evolutionary event for the animal sensorimotor organization.

According to this skin brain account, early nervous systems – diffusely connected nerve nets – evolved from contractile epithelia – ‘skin’ – in a step-wise process, first evolving synaptic transmissions to neighboring cells and later axodendritic processes that enabled transmission across longer distances. In both cases, the prime directive was to generate and control self-organized patterns of globally coherent activity across an organism’s contractile surface, integrating the dynamical motile aspects of the organism into a single unit that is sensitive to its own body-movements. For easy reference this process will be called *Pantin patterning*.

While the SBT initially targets the effector side of the ASMO, it has also repercussions for sensing, interpreted as detecting and using environmental features. First, a skin brain organization provides an important precondition for multicellular sensory arrays. Second and more fundamental, a skin brain organization turns the multicellular body itself into a sensing device that does not necessarily requires external sensors (Keijzer, 2014). Pantin patterning involves sensitivity to the configuration of the ongoing dynamical extension-contraction patterns within the animal body. Such sensitivity makes the dynamical movements

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of the body a variable that can be controlled by the organism. As bodily movements are themselves constrained by environmental features that either hinder or allow motility, bodily sensitivity alone allows the rudimentary sensing of the environment at this bodily scale. The result provides the outlines of a basic form of sensorimotor organization that is organized at and sensitive to environmental features at the level of a multicellular animal body.

The important issue here is that the SBT sketches how a basic multicellular organization can evolve that is tailored for sensorimotor interactions with bodily-scaled surface arrays in the environment. Instead of taking a high-level description of a sensing and acting organism in an environment as a precondition, a skin brain scenario specifies how such a complex sensorimotor organization can have come into being from a more basic set up. In this scenario, sensors and effectors are not basic, but derive from a fundamental skin brain organization.

While the SBT is tentative and limited to basic forms of nervous systems and the ASMO, the conceptual implications are important and immediate. First, the SBT provides an evolutionary account that draws necessary conceptual links between sensing and motility. Second, nervous systems themselves become conceptually linked to the ASMO. Third, the SBT makes it thinkable in a concrete way that nervous systems and the ASMO are not standard input-output devices on a par with current computers and robots.

REFERENCES

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