

## Opinion

## On the Self-Organizing Origins of Agency

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The question of agency and directedness in living systems has puzzled philosophers and scientists for centuries. What principles and mechanisms underlie the emergence of agency? Analysis and dynamical modeling of experiments on human infants suggest that the birth of agency is due to a eureka-like, pattern-forming phase transition in which the infant suddenly realizes it can make things happen in the world. The main mechanism involves positive feedback: when the baby's initially spontaneous movements cause the world to change, their perceived consequences have a sudden and sustained amplifying effect on the baby's further actions. The baby discovers itself as a causal agent. Some implications of this theory are discussed.

## What Is this 'I'?

We humans tend to believe that we are agents, masters and mistresses of our fate, that our deeds and desires are our destiny. Yet, despite a sizeable literature on 'the sense of agency' and its behavioral and neuroimaging correlates (see [1,2] for recent reviews), the scientific basis of causal agency and how we come to experience ourselves as agents is lacking. Agency means action towards an end. When it comes to the behavior of living things, our inability to understand end-directedness forces us to posit (often implicitly) an intelligent agent residing somewhere inside the system that is responsible for the end-directed behavior we observe. The self as a causal agent remains a ghost in the machine awaiting exorcism, perhaps by new insights from the brain and cognitive sciences.

Charles Darwin, in *On the Origin of Species*, touched only briefly on the topic of agency, although he noted how 'admirably adapted' was the woodpecker to catch insects under the bark of trees and how mistletoe 'absolutely' required the agency of certain insects to bring pollen from one flower to another ([3] p.12). His later work on the habits of worms notwithstanding [4], Darwin admitted 'I must promise that I have nothing to do with the origin of the primary mental powers, any more than I have with life itself' ([3] p.189). In the introduction to his remarkable history of physiological psychology, Franklin Fearing [5] noted that 'Even before man speculated about the nature and source of his own experiences, he was probably curious about the agencies by which animal motion was effected' ([5] p.1). Life and motion, Fearing remarks, are almost synonymous terms.

In his famous book *What Is Life?*, Erwin Schrödinger [6], one of the chief architects of quantum mechanics and the author of the famous equation that bears his name, proposed an 'order from order' principle as the physical basis of life. Schrödinger speculated that this new kind of order took the form of an aperiodic crystal, later exposed as the beautiful double helical structure of the DNA molecule [7]. Not much more was said about Schrödinger's order from order principle or his call for 'new laws to be expected in the organism' (but see [8,9]). Still less truck was given to the question raised by Schrödinger in the final chapter of his small book. Each of us, says Schrödinger, has the indisputable impression that the sum total of our own experience and

## Trends

Over the past 30 years, higher-order principles of self-organizing dynamical systems have influenced our understanding of brain, cognition, and behavior.

They might also offer insights into age-old puzzles about the origins of agency and directedness in living things.

Experiments and observations of human infants combined with theoretical modeling suggest that the birth of agency corresponds to a eureka-like phase transition in a coupled dynamical system whose key variables span the interaction between the baby and its environment.

Analysis shows that the main mechanism underlying the emergence of agency is autocatalytic and involves positive feedback.

When the baby's initially spontaneous movements cause the world to change, their perceived consequences have a sudden and sustained amplifying effect on the baby's further actions. The prelinguistic baby realizes it can make things happen!

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memory is unitary and distinct from that of any other person. We humans, for example, have no doubt whatsoever that it is us, and us alone, who direct the motions of our own bodies and foresee its effects. *What is this 'I'?* (italics his) Schrödinger asks, like a voice crying out of the wilderness. Here I ask: where do agency and directedness come from? How does the self as a causal agent come about?

In this Opinion, insight into the origin of agency comes from an unusual and largely untapped source: experiments and observations of human babies. Stranger still is their interpretation in light of the principles and mechanisms of the science of coordination, coordination dynamics. Coordination dynamics [10–30] is a theoretical and empirical approach grounded in the concepts of self-organization in physics, chemistry, and biology and the mathematical tools of nonlinear dynamical systems [31–33]. A distinguishing aspect of coordination dynamics is that it is tailored specifically to handle the activities of animate, living things. The aim is to understand how functionally significant patterns of coordinated behavior emerge, persist, adapt, and change in a variety of different systems at multiple levels of description, from cells and their circuitry to brains and people. The behavioral, cognitive, and social processes studied in coordination dynamics include moving, perceiving, feeling, thinking, deciding, learning, remembering, developing, aging, and so on [10–30,34–38].

A main aspect of self-organizing dynamical systems [17] is that the emergence of pattern and pattern switching occur spontaneously, solely as a result of the dynamics of the system: no specific ordering influence from the outside and no homunculus-like agent or program inside is responsible for the behavior observed. Self-organizing systems are, it seems, selfless. They do not contain meaning or aspects that one would associate with meaning, such as agency, intention, will, or purpose. They can appear to be goal or end directed, but they are not organized around goals [39]. In fact, any hint of 'self' or agency is banished in physically based theories of self-organization [31,32,40]. Self-organization means that the system organizes itself, not that there is a self doing the organizing. So where does the self as a causal agent come from?

In an earlier work, I proposed that self-organizing processes in living things must (somehow) give rise to agency; that the most fundamental kind of consciousness, the awareness of self, must spring (somehow) from the ground of spontaneous self-organized activity [41,42]. We come into the world moving. We are never still. It is well known that the elementary spontaneous movements we are born with, whether we view them in terms of elementary reflexes or pattern generators, consist of a large repertoire of spontaneous movements, making a fist, kicking, sucking, and so forth. Coordination dynamics refers to the patterns that the system is capable of producing spontaneously at a given point in time along with the attractor landscape that defines the relative stability of these patterns as intrinsic dynamics [13]. Intrinsic dynamics is important to know because it influences what can be changed or modified by new experiences and how such change occurs (e.g., whether change is smooth or abrupt) [43,44]. The eminent philosopher and evolutionary biologist, Maxine Sheets-Johnstone, has repeatedly pointed to, and provided evidence for, the primacy of movement as 'the mother of all cognition', presaging every conscious mind that ever said 'I'. 'Spontaneous movement' argues Sheets-Johnstone [45] 'is the constitutive source of agency, of subjecthood, of selfhood, the dynamic core of ourselves as agents, subjects, selves'. In her elegantly chosen phrase, 'Movement forms the I that moves before the I that moves forms movement' ([45] p. 119). For Sheets-Johnstone, then, spontaneous movements and the kinesthetic feelings that accompany them are the foundation of first-person experience of agency.

So is this all there is to it? A critic might inquire by what mechanism something as meaningful as causal agency arises out of the (apparently meaningless) movements we are born with? How does our awareness of agency emerge from the electrical and chemical activity of the brain? Or

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