Comment

Dynamics versus dualism

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Keywords: *free energy; information geometry; mental; neuronal.*

As someone who views the physics of life through the lens of Langevin dynamics and pullback attractors [1], the notion that temporo-spatial dynamics furnishes the "common currency" of neuronal and mental features sounds perfectly tenable. The heart of the matter is nicely summarised by Northoff et al [2], in their discussion of neuronal and mental relationships:

"*Mental features are here supposed to reflect the dynamics of time and space itself rather than a specific function like integration or access. In short neuronal dynamics are mental dynamics. No causal relationship is thus necessary anymore to connect neuronal and mental features – the dynamics of space and time provide an intrinsic and non-causal neuro-mental relationship."* p. 16

This is a splendidly monistic assertion; namely, that mental (i.e., Cartesian *res cogitans*) and neuronal (i.e., *res extensa*) processes are the same thing. In what follows, I try to substantiate this position under the banner of structural realism; namely, by specifying some ontological commitments that license the notion of a "common currency" [2].

I will assume that if neuronal and mental features inherit from the same dynamics, this dynamics must be equipped with two information geometries that can be plausibly associated with the mental and neuronal processes. An information geometry arises when manifolds are equipped with (Riemannian) metrics, which always exist in the form of Fisher information metrics for statistical manifolds [3-5]. A statistical manifold is simply some state or phase space in which each point can be associated with a probability distribution. I am assuming here that mental features are attributes of beliefs or representations, where one can associate (non-propositional) beliefs with probability distributions[1] [6]. This implies that mental processes live in the space of probability distributions, such that belief updating, decisions – and the like can – be formalised in terms of dynamics on statistical manifolds. In this setting, the degree of belief updating – or the amount that one has “changed one's mind” – is scored by distance moved in the space of probabilistic beliefs. This distance is supplied by an information length, which defines the implicit geometry [4]. Furthermore, probabilistic beliefs must have some support; namely, they have to be beliefs ‘about something’. In summary, to substantiate the notion that dynamics are the “common currency” that underwrites mental and neuronal processes, we need to establish that there are at least two information geometries that have dynamics in “common”. Happily, the dynamics of any states – that are internal to a system that exists in a particular sense – are necessarily equipped with two information geometries, which speak to distinct representational (mindful) and thermodynamic (neuronal) processes.

What follows is based upon a technical treatment of Bayesian mechanics in [7] – and a philosophical discussion of the implications in [8]. In brief, if the physics of living systems derives from the physics of (bounded) sets of states that possess a pullback attractor, then the states internal to that system have a dual-aspect information geometry. The argument is relatively straightforward and proceeds as follows: if something exists, in the sense that it can be distinguished from something else, then the thing (e.g., a particle or person) must possess a Markov blanket [9, 10]. A Markov blanket is a subset of states that render internal and external states independent, when conditioned upon blanket states: see Figure 1.

The existence of a Markov blanket implies a pullback attractor (i.e., an attracting set with characteristic measures) and an associated probability distribution over internal states; namely, the probability that any given internal state is sampled over time. This equips the internal state space with an information geometry that underwrites thermodynamics, as nicely articulated in [11]. However, in virtue of the Markov blanket, there will be most likely internal state and a posterior distribution over external states, when conditioned the blanket state (i.e., state of the Markov blanket). In other words, for every (expected) internal state there will be a probability density over external states, given a particular blanket state. This is quite important because it means that one can parameterise (posterior) beliefs about external states in terms of internal states; thereby equipping internal states with a second information geometry – an information geometry based upon probabilistic beliefs *about external states*.

[1] In the sense of Bayesian belief updating and belief propagation.

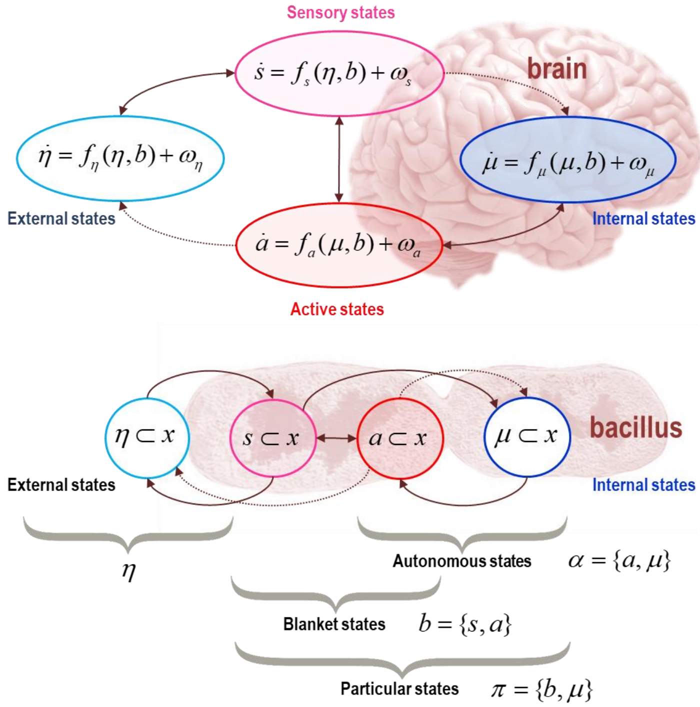

Figure 1 (*Markov blankets*): This schematic illustrates the partition of states (of a random dynamical system) into internal states (blue) and external states (cyan) that are separated by a Markov blanket – comprising sensory (magenta) and active states (red). The upper panel shows this partition as it would be applied to action and perception in the brain. The stochastic differential equations correspond to (Langevin) dynamics with random fluctuations (ω). The ensuing self-organisation of internal states then corresponds to perception, while action couples brain states back to external states. The lower panel shows the same dependencies but rearranged so that the internal states are associated with the intracellular states of a Bacillus, while the sensory states become the surface states or cell membrane overlying active states (e.g., the actin filaments of the cytoskeleton).

More formally, the internal state-space contains a statistical manifold, because the most likely internal state $\boldsymbol{\mu}(b) := \arg\max_\mu p(\mu \mid b)$ parameterises a posterior probability distribution $q_{\boldsymbol{\mu}}(\eta) = p(\eta \mid b)$ over external states. This means that the internal manifold acquires a dual aspect geometry. It has an information geometry in virtue of playing the role of a statistical manifold, while, at the same time, having its own geometry, endowed by its inherent information length [4]. We can express these two geometries in terms of their respective metric tensors g, where λ are the sufficient statistics of the density over internal states – that play the role of thermodynamic variables [11]:

$$\begin{aligned} g_\lambda &= \nabla_{\lambda'\lambda'} D_{KL}[p_{\lambda'}(\mu) \| p_\lambda(\mu)]|_{\lambda'=\lambda} \\ g_\mu &= \nabla_{\mu'\mu'} D_{KL}[q_{\mu'}(\eta) \| q_\mu(\eta)]|_{\mu'=\mu} \end{aligned} \quad (1$$

First, there is the information geometry inherent in the information length, based upon a time-dependent probability distribution over physical internal states. This geometry forms the basis of statistical mechanics [11]. At the same time, there is an information geometry in the space of internal states that parameterises belief distributions over external states. This geometry is conjugate to the first but measures distances between posterior beliefs. Both inherit from the same Langevin dynamics. Please see [7] for a full discussion and technical details. In terms of a common currency, Equation 1 shows that internal states – and their implicit dynamics – are common to both geometries. In the first (thermodynamic), the geometry rests on probability distributions *over internal states*, while the second (posterior) geometry rests on probability distributions *over external states*, parameterised *by* internal states.

In conclusion, the very existence of systems – e.g., creatures like ourselves – mandates a dual aspect information geometry. This geometry makes it look as if our internal (neuronal) states encode posterior beliefs about (external) states of affairs beyond our sensorium (i.e., beyond our Markov blanket). This means one can cast neuronal dynamics as performing some form of natural inference on the causes of sensory input while, at the same time, talk about the thermodynamics of neuronal activity. Put even more simply, there are two sorts of information geometry encoded by temporo-spatial dynamics in the brain. The first is of a mental sort and entails the updating of beliefs about something (i.e., external states), while the second is of a physical or thermodynamic sort that entails probability distributions over neuronal states *per se*. One might submit that this is the mathematical image of the "common currency" furnished by the dynamics of our embodied brains [2].

Acknowledgements: KF was funded by the Wellcome Trust (Ref: 203147/Z/16/Z).

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