Physics of creation

Symmetry breaking, (en)active inference, and unfolding statespaces

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Abstract

Physical explanation relies on the description of natural systems through the construct of "statespaces", i.e. mathematical representations of the space of their accessible states. By construction, a statespace representation must account for all determinants of the target system's evolution, and any change that it does not represent must be held as causally irrelevant. Therefore, although statespace representation appears necessary for formal tractability, it entails the reification of the physical symmetries underlying the target system.

This is unproblematic if we hold to the Platonic belief in an ordered, legible universe, whose activity is explained by well-defined "natural laws" imposing observable symmetries onto Nature. However, this idea relates poorly to the life sciences, where the organization that underlies system activity is clearly history-ladden and context-sensitive. More precisely, life and mind seem permeated by the phenomenon of *autopoiesis* (or self-creation), in which they create their own constitutive symmetries.

We discuss here the motivations of law-like explanation, and its intrinsic limitation to account for "creation" in life and mind. We then draft a formal account derived from the Free Energy Principle, rearticulated as a "statespace-free" theory of physical observation grounded in quantum information theory. Finally, we discuss the implication of this treatment for our role as agents in constructing physical reality.

“No phenomenon is a phenomenon, until it is an observed phenomenon.”

John Archibald Wheeler

“Nothing is true, everything is permitted.”

Hassan-i Sabbāh

Introduction

The self-organization that underlies the existence of life have been the subject of numerous investigations since the 20th century, beginning with Schrödinger's discussion of life's apparent ability to reverse the course of the second law of thermodynamics by maintaining themselves into existence (Schrodinger 1944). Informally, the second law states that any closed system can only (modulo infinitesimal quantum / thermal fluctuations) become more disorganized with time. In other words, they must therefore converge toward configuration of maximal entropy given their boundary conditions – *i.e.* configurations that are incompatible with the transient structure of life. The problem is dissolved by the realization that living systems are open systems, which happen to maintain their structure (*i.e.* maintain a high level of organization) by dissipating thermodynamic gradient in their environment. Perhaps dissipative structure exist precisely in virtue of their ability to dissipate gradients efficiently, and the existence of convection cells, reaction-diffusion processes, mind and life alike can be grounded in the principle of maximal entropy production (Nicolis and Prigogine 1977; Swenson and Turvey 1991).

However productive they may be, these thermodynamical approaches miss by far the target of explaining mind and life. Unlike the kind of systems typically studied by physicists, living/cognitive systems show an intricate, multiscale structure whose sensibility to context abstract away from general regularities (Mitchell 2003). Most importantly, they continuously redefine their own structure and the way they couple with the world through a process of self-creation (or *autopoiesis*) (Maturana and Varela 2012). In other words, they do not operate within a given space of possibilities, but instead actively define and realize a space of ***"adjacent possibles"*** entailed by their constitutive symmetries and their modes of environmental coupling (Kauffman 2019). It has been argued this feature makes them inaccessible to physical representation, which is on the contrary based on the articulation of a statespace - *i.e.* a predefined set of variables which is to account for the evolution of the target system (Longo and Montévil 2013; Longo, Montévil, and Kauffman 2012). In other words, the creative nature of life and cognition cannot be consistently represented in a given mathematical space, and much less explained in a lawful, physics-like manner.

The Free Energy Principle (FEP), a recent attempt to formalize the dynamics of life and cognition (Friston 2010, 2012, 2019), takes a complimentary view by focusing on the information-theoretic (rather than thermodynamic) properties of self-organizing systems. In the latest formulations at the date of writing (Da Costa et al. 2021; Friston 2019; Friston et al. 2022), the FEP boils down to a proof of existence of a synchronization manifold across any physical interface (formally, any Markov Blanket), which grounds a minimal notion of "active inference" where an agent's internal states tracks its environment's so as to bring about its favored sensorimotor states (*i.e.*, those coherent with its continued existence). This set of formal results affords a dual understanding of cognition as the dynamical anticipation of sensorimotor flow, and life as self-organization toward states that satisfy constitutive biological constraints. While some insist Active Inference provides a sufficient account of autopoiesis (M. Kirchhoff et al. 2018; Kiverstein, Kirchhoff, and Froese 2022), the FEP remains at the moment formulated in the same sort of closed statespaces as earlier thermodynamic principle, and is therefore structurally incapable to account for creative evolution.

Prima facie, this argument is the last nail in the coffin of the Free Energy Principle as a relevant framework to study mind and life. Indeed, previous arguments against the validity of the FEP as a framework to study mind and life only motivated the development of its mathematical formulation. For example, its argued lack of interactional asymmetry and applicability to linear edge cases (Aguilera et al. 2021) could be addressed by relaxing the Markov Blanket construct (Sakthivadivel 2022c), and the absence of historicity in its states formulation (Colombo and Palacios 2021; Di Paolo, Thompson, and Beer 2021) may be addressed in the near future by the development of its path-integral formulation (as proposed in Ramstead et al. (2022)). What in at stake in the present account is the very possibility of meaningfully representing living/cognitive systems within dynamical systems theory – or any other mathematical representation in a "closed" statespace. However, I suggest that the duality between informational and structural properties of complex systems which have recently been formalized in terms of an entropic and free-energy functional (Ramstead et al. 2022; Sakthivadivel 2022b) affords a mathematical theory of *statespace unfolding* as symmetry construction, understood as an expression of the target system's agency.

If this argument is warranted, the FEP provides a sufficient account of the grounding of autopoiesis in physical formalism. The process by which complex adaptive systems integrate and enact expectations about their perceived reality simply circles back to recreate the symmetries that constitute them. However, this result is not specific to biological and cognitive statespaces, and can arguably ground a *minimal cosmology* underlying the unfolding of physical symmetries more generally (in the line of Alexander et al. (2021) – which could be more accurately renamed "the Autopoietic Universe"). The postulated role of cognitive agency in statespace construction outlines a new *physics of creation*, conflicting radically with the Platonic intuition of a legible universe and with the corresponding "lawful" model of scientific explanation. In particular, this radical new approach commits us to a specific epistemological and ontological view named "participatory realism" (Froese 2022; Fuchs 2017), entailing that physical reality is constructed by the processes of observation by which it appears to observers (human or otherwise). Importantly, while this account originates from the discipline of cognitive science, it cannot be dismissed as a simple panpsychist or anthropomorphic projection as it emerges naturally from the role of the observer in cosmological evolution.

I first discuss the meaning of creation as symmetry unfolding/statespace construction, and its principled opposition to a cosmological belief in a legible universe. Then, I will expose the confusions underlying the attempt to account for creative dynamics in living/cognitive systems using lawful explanations, as exemplified by the Critical Brain/Life Hypothesis. I then show how the Free Energy Principle affords a conceptual understanding of symmetry unfolding in life and mind, while falling short of translating this understanding into formal results. I thereafter discuss the possibility of reformulating the Free Energy Principle as a sufficient and self-coherent account of creation in physics, in line with existing results in quantum physics and cosmological evolution. Finally, I expose the meaning of such a theory for our understanding of physical reality, life, mind, and – crucially – of our own knowledge. Those arguments will collectively bear doubt over the very coherence of the scientific enterprise, at least in the disembodied conception we have inherited from the modern era. They should nonetheless be considered, as they constitute a necessary first stone toward the articulation of a purely naturalistic and integrated understand of physical reality.

1 – Explaining creation away: scientific laws and unfolding symmetries

Our aim here is to define the target of the article by exposing in what sense "creation" is a key property of biological / cognitive systems, and to establish why the classical physicalist program of lawful explanation is structurally incapable of explaining (or even, as we will argue, of representing) it. Indeed, biological / cognitive systems are precisely defined by their ability for *self-creation*, which enables them to escape the framing of natural laws and closed mathematical representations. We argue that core features of mind and life are not accessible to the program of lawful explanation, which necessitates a shift in our approach to mathematical representation – what we call a *physics of creation*. We will reflect critically on the cognitive patterns that have shaped Western history to demonstrate why the framing of lawful explanation is prevalent in contemporary science, and why it is by construction inadequate for the purpose of formally accounting for creation in mind and life. This account will serve to ground the notion of "creation" that the present article aims to account for, as well as the basic epistemological framework in which this question is articulated.

What we hereby call "lawful explanation" is an consequence of a more fundamental belief in an ordered, legible cosmos. This dual system of belief and inference seems to have emerged in Ancient Greek societies, as an extension of the Indo-European cosmology (Lent 2017)). The core idea is that, if all natural phenomena exist in virtue of basic principles that underlie all things, then we can call upon "natural laws" to explain them. Trivially, defending or using lawful explanation entails two grounding positions without which the approach is entirely incoherent: 1) that there exist robust, acontextual, measurable regularities in nature that can be accounted for in terms of laws; 2) that the statement of those laws is genuinely explanatory of the observable facts entailed by the regularity. Both can be attacked independently: there could be no acontextual regularity to call upon for explaining natural phenomena (as was famously argued by Hume (Henderson 2020)), or those regularities can lack the relevant properties to be properly explanatory.

The generic category of lawful explanation has been formalized recently in the context of the logical empiricist movement as the "deductive-nomological" model of scientific explanation. It essentially reduces to the explanation of individual facts by deducing them from general laws (as inferred either from first principle or from the observation of aforementioned facts) (Woodward 2021). This is a good illustration of how the physical sciences generally operate. We look for guiding regularities in the organization of matter, we try to formulate them as natural laws in an unambiguous scientific language, and then we predict observable facts from those laws. It is critical to emphasize that this framework must conceive of laws as "natural facts" for them to be properly explanatory: they cannot reduce to simple heuristics, but need to be actual preexisting constraints in virtue of which observable phenomenon take the form they do. We are therefore supposed to revise them any time we observe some event that contradicts their predictions - unless we can conclude that our predictions were not, in fact, entailed by the relevant law (as discussed in the debates over falsification, see Chalmers (2013) for a contextualized discussion).

It is now generally accepted by epistemologist and practitioners alike that this model of explanation applies poorly to biological / cognitive systems. We do not expect to find any "law of eels" under which all eel behavior would fall. Instead, we study biological and cognitive mechanisms which can explain some regularities in eel behavior (Boone and Piccinini 2016). This strategy is developed under the umbrella of *structural-mechanistic explanation*, which attribute regularities in the activity of biological / cognitive systems to the particular structure that produces it in the specific context that it does (Bechtel 2009; Bechtel and Abrahamsen 2005) rather than to preexisting scientific laws (Mitchell 2003, chap. 5). For example, we do not explain the fact cognitive agents tend to follow course of actions that are statistically associated to reward by calling upon a "law of reinforcement" but by calling upon the integrated activity of brain dynamics (and most specifically of the Default Mode Network (Dohmatob, Dumas, and Bzdok 2020)). The question underlying scientific explanation therefore shifts from the articulation of laws held to meaningfully capture existing constraints to the discovery and cartography of the structure of the target system and of its context of activity (Bechtel 2008; Mitchell 2003).

Importantly, the dichotomy between deductive-nomological and structural-mechanistic explanation can be reframed in terms of the ontological status we grant to the relevant *physical symmetries*. Formally, symmetries are defined with regard to a transformation group. By construction, a transformation group is a set of transformation which contains the inverse of every member transformation, the chained composition of any series of components, and a neutral element that is the result of any transformation chained to its inverse. A physical or mathematical system is said to be symmetric relative to a given transformation group if and only if it is invariant under any transformation in this group. For example, Newton's laws of motion are symmetric under Galilean transformation - which means that their application gives the same trajectory in any set of reference frames that differ only by constant relative motion. Although this is an extension of the mathematical concept, biological structure entails invariance with regard to some transformation groups. Trivially, the relevant structure must be invariant throughout the time of the studied phenomenon, and the system trajectory must be invariant with regard to the set of transformation which conserve structure (e.g. permutation of functionally identical molecules).

Interestingly, Noether's theorem, a central result in physical mathematics, associates any continuous symmetry in a conservative system to a law of conservation for a given quantity. In other words, natural laws expressed in closed systems can in most cases be derived from the existence of an underlying symmetry group. For example, explanations calling onto conservation of energy implicitly call onto time invariance of their system's equations of motion, which underlies the conservation of energy. This allow us to relate the success of deductive-nomological explanation as an epistemic strategies to the existence of actual physical constraints. In the same way, explanations calling onto the structure of the ear drum implicitly call onto the invariance of its structure against time translations or transformations which do not affect said structure. Therefore, structural-mechanistic explanation also implicitly call upon the existence of underlying symmetries, although symmetries of a different kind. While physical symmetries are generally understood to preexist any singular instantiation, biological symmetries are clearly tied to the specific structure and history of the target system. In other words, while deductive-nomological explanation calls upon symmetries that are pre-physical universal facts, structural-mechanistic explanation calls onto symmetries that are constructed through a system's activity.

The structural-mechanistic kind of explanation is therefore essentially entailed by the nature of biological / cognitive systems. Physical explanation under the deductive-nomological model of explanation critically relies on a predefined "statespace" which encompasses all relevant variables for representing the system activity. This statespace enables the definition of physical symmetries as a mathematical construct, but also necessitates by construction that the target system be symmetric under any transformation that maintains the statespace representation. However, biological / cognitive systems are precisely characterized by the fact their constitutive symmetries (i.e. biological constraints) are continuously reconstructed by metabolic activity as canalized by the aforementioned symmetries themselves (Montévil and Mossio 2015; Moreno and Mossio 2015). In other words, life is defined by the phenomenon we have called "creation" – i.e. by the fact that it actively escapes from statespace representation, as its symmetries are continuously unfolding under its own activity. Because deductive-nomological explanations can only be articulated within a given statespace, the phenomenon of creation falls by construction outside its realm, which negates the possibility of explaining the specific properties of biological / cognitive systems under entailing laws (Kauffman 2019; Longo, Montévil, and Kauffman 2012).

Of course, it does not follow that there can be no universal regularities of biological / cognitive organization, or that general statements cannot have any explanatory value whatsoever. However, this explanatory value is essentially limited to constraining the space of structural-mechanistic possibilities (Green and Jones 2016), rather than directly entailing system activity as they are conceived to do under the physics-oriented deductive-nomological model of explanation. In systems that continuously redefine their own structure and the activity they produce, regularities are to be considered a target rather than a source of explanation. Most importantly, such constraining principles fall very short of explaining the key aspect of biological / cognitive systems, i.e. self-creation, for the very reasons exposed above. We will turn to illustrate this point in the example of the physical formalism of "criticality", under the banner of which some have tried to formalize the creative aspect of life and cognition under the (Aguilera and Bedia 2018; Bullmore and Sporns 2009; Hesse and Gross 2014; Longo and Montévil 2013; Safron, Klimaj, and Hipólito 2022; Shew and Plenz 2013) – a state of near-chaos that matter display near continuous phase transition.

2 – The Critical Brain Hypothesis: a case study

Let us first explain how "criticality", a concept emanating from the study of phase transitions in material science, came to a prominent role in biology and neurology. Phase transition is the process by which systems change their macroscopic organization as represented by an "order parameter" in response to a shift in a macroscopic variable known as "control parameter". The simplest, most analytically tractable case study of phase transition is the Ising model, meant to model the behavior of a ferromagnetic material. Below its so-called Curie temperature, the spins of a ferromagnetic material are aligned and it produces an observable electromagnetic field. Above that threshold, the spins are random, and their influence average out so that the material does not produce any field. Therefore, an order parameter (spin alignment) displays discontinuity in function of a control parameter (temperature) with observable macro manifestations (electromagnetic field production). The Ising model (as well as the ferromagnetism it aims to represent) is a case of continuous phase transition, *i.e.* one where free energy is continuous in function of the control parameter. This is in contrast to cases where a discrete amount of energy must be injected into the system at the transition threshold, as for example in water solidification / liquefaction at atmospheric pressure.

Near a continuous phase transition, physical systems display a set of features collectively known as "criticality". In short, criticality occurs when an ordering force (*e.g.* coupling) and a disordering force (*e.g.* thermal diffusion) are exactly balanced. In this regime, local fluctuations are not suppressed (as in the ordered case) or inconsequential (as in the disordered case), but they are amplified through system activity. This extreme susceptibility to (internal or external) perturbations causes massive switches in the system organization called "avalanches", which lead the system to organize into fractal substructures. As the typical mean-field (Landau) approach averages out local fluctuations, physicist had to develop the multi-scale renormalization group methodology to correctly predict the behavior of system near critical transitions (Wilson 1975, 1983). In particular, they noted that those displayed self-similar scaling (i.e. long range power-law patterns of temporal and spatial correlations, also know as fractality) with universal coefficient across large classes of system (Christensen and Moloney 2005; Stanley 1999). Consequently, physicist Per Bak and his colleagues proposed to explain the ubiquity of self-similar scaling in the universe by calling onto the self-organization of physical system toward critical phase transitions (Bak and Chen 1989, 1991; Bak, Tang, and Wiesenfeld 1987).

The paradigmatic example of self-organized criticality is the avalanche phenomenon (Christensen and Moloney 2005, chap. 3), where some potential is accumulated by the system and randomly dissipated through large (power-law distributed) fluctuations. In other words, avalanche models are dissipative systems displaying critical phase transition, whose control parameter is driven by an externally imposed potential flow and whose order parameter reflects the expected speed of potential dissipation. As near-zero dissipation below the criticality threshold allow potential to build up gradually and finite dissipation above this threshold drives it down quickly, such systems are trivially attracted toward their critical transition – hence the name of Self-Organized Criticality. Interestingly, this family of models include the stylized sandpile and forest fire model (where the control parameter is the number of elements within a set, and dissipation is driven by the density of set elements), but also relatively realist percolation model of brain activity with adaptive susceptibility. This enabled scientists to articulate Self-Organized Criticality as a candidate theory to explain the self-similar distribution of neuronal "avalanches" characteristic of brain activity (Beggs and Plenz 2003; D. R. Chialvo and Bak 1999; Dante R. Chialvo 2004, 2010; Stassinopoulos and Bak 1995). The Critical Brain Hypothesis was born.

Scientists began to suggest that criticality in the brain may not only explain the self-similar pattern of brain dynamics, but also their adaptive features themselves (Beggs 2008; Gautam et al. 2015; Kinouchi and Copelli 2006; Safron, Klimaj, and Hipólito 2022; Shew et al. 2009, 2011; Shew and Plenz 2013). Indeed, dynamical complexity and discriminative sensibility to stimuli are trivially maximized near a critical transition. Let us take a percolation model of brain activity, which models neuronal activity as binary states propagating from a given point. If the average number of neurons triggered by a given neuron firing is well below one, no patterns of activation can be triggered by small events or maintained through time. If it is well above one, all neurons fire all the time (in the limit of physiological constraints) regardless of stimuli. Therefore, the brain must maintain an average susceptibility close to one to be able to selectively respond to stimuli or maintain a given pattern of activity. Since percolation is an instance of continuous phase transition with regard to connection density, it must in other words remain poised in a critical regime.

Let us note that the complex phenomenology of critical systems affords a richer characterization in terms of unfolding symmetries. Both above and below a critical transition, system dynamics are symmetric with regard to the permutation of any component or regions. In the ordered case, all component or regions have the same spin; in the disordered case, the spin may vary at the individual scale but the average spin within any region remains 0 regardless of perturbation. But in the critical region, any permutation between components or regions that do strictly have the same makeup may lead to a catastrophic avalanche at any given scale. Therefore, the permutation symmetry holds only within coherent regions. In addition to this, the contour of coherent regions is contingent on the reorganization of the system during permutations or avalanches, and therefore the system's symmetry is itself contingent on its evolution. In other words, the critical system's symmetries are themselves defined by its endogenous fluctuations rather than being predefined. This pattern of multi-scale symmetry unfolding is the core motivation behind the renormalization methodology, which captures statistical invariants of the underlying process.

Some scholars noted that this enables the interpretation of criticality as a basic physical model for biological autopoiesis. Aguilera and Di Paolo (2021) insists for example that criticality "can capture cognitive relevant properties" such as agent-environment asymmetry, robust adaptiveness, and most importantly a high level of integrated information (a proposed measure of cognitive ability consciousness), and therefore bears a stronger relation with cognitive processes than a simple analogy. But some authors presented the even stronger argument that *biological organization was itself an instance of critical phenomenon* (Aguilera and Bedia 2018; Aguilera and Di Paolo 2021; Longo and Montévil 2013; Longo, Montévil, and Pocheville 2012). As Buiatti and Longo (2013) put it: "[An organism] is critical in the sense, in particular, that it continually changes symmetries by breaking existing symmetries and constructing new ones". As the citation illustrates, this literature generally redefines criticality as symmetry unfolding, then calls onto it as an *a priori* nomological explanation for all such instances (see e.g. (Aguilera and Di Paolo 2021; Longo and Montévil 2013; Mora and Bialek 2011; Muñoz 2018)).

However, even early proponents of the Critical Brain Hypothesis agree that criticality has a specific physical meaning distinct from critical-like phenomenology (Beggs and Timme 2012). Criticality is by construction a distinct phenomenon, produced by a continuous phase transition with well-defined control and order parameters. However, it is dubious whether we could identify an integrated control parameter in the form of coupling strength [1]. Critical-like susceptibility and scale-invariance [2] in the brain may be explained by multiple other mechanisms than critical transition (Marković and Gros 2014; Mitzenmacher 2004; Newman 2005; Stumpf and Porter 2012) - such as such as correlated noise, variants of rich-get-richer mechanisms (Barabàsi and Bonabeau 2003; Sornette 1998), structural constraints (Savage et al. 2004), scale separation (Proekt et al. 2012), uncorrelated chaos (Touboul and Destexhe 2017) or

1 Shew et al. (2009, 2011) does suggest a strong candidate for a control parameter by showing that brain activation could be manipulated through the balance of excitatory vs inhibitory connections. However, this hypothesis could not be meaningfully traduced within a computational model. See Muñoz (2018), sec. IV.A for a discussion of several interpretations of phase transitions in neural systems - most are informal and lack an association to a well-defined control parameter, in the image of Kauffman's reappropriation of the "edge of chaos".

2 Assuming that patterns of neuronal activations are indeed scale-invariant, which is itself debated (Beggs and Timme 2012; Marković and Gros 2014, sec. 5.2; Touboul and Destexhe 2010).

network optimization (Carlson and Doyle 1999, 2000; Marković and Gros 2014) (e.g. instantiated by Hebbian learning (Levina, Herrmann, and Geisel 2007, 2009; Uhlig et al. 2013)). Most importantly, activation density (the suggested order parameter for the brain) is not in itself the explanatory target, but is only a precondition to adaptive information processing. Therefore, criticality is at best a non-explanatory nomological account of symmetry unfolding in the brain, and only obscures its far-from-equilibrium, organized nature.

Indeed, unfolding symmetries in critical systems are a result of the contingent multiscale amplification of local perturbations. On the contrary, the complex fluctuations of living and cognitive systems participate to the active maintenance and (re)production of the system's structural identity. It is true that criticality theory provides a useful statistical model of symmetry unfolding, as well as the powerful renormalization group methodology to study this phenomenon analytically and empirically. However, it only predicts a very simple regularity: the wild patterns of fluctuations displayed by critical systems. Biological and cognitive systems do display such wild fluctuations, but unlike in critical systems those fluctuations are constrained by their underlying organization so as to preserve their existence. In other words, reproducing the wild statistical patterns of biological and cognitive systems in simpler models is not sufficient to explain symmetry unfolding in life and mind, we must also and above all study how they harness such patterns into maintaining their own organization - in other words, why is there *ordo ab chaos*. We will therefore turn to a theory that addresses just this question by formulating a formal account of the emergence of form and meaning in far-from-equilibrium dynamical systems: the Free Energy Principle.

3 – Of constraints and semantics: introducing the Free Energy Principle

The Free Energy Principle (FEP), and the related Active Inference Framework (ActInf), emerged recently from the study of the mechanisms of cognition and their underlying physics. Both stem from a variational method for approximate Bayesian inference, based on the minimization of Variational Free Energy (VFE) given a model of / constraint over the posterior distribution. It was postulated that the brain functions through a similar process of error minimization over prediction of the sensorimotor flow (Friston 2010), which motivated the development of a mechanical model of neurocognitive inference (ActInf) (Friston et al. 2016). ActInf formalists thereafter attempted to demonstrate from first principle that Active Inference is entailed by the physics of self-organization in any far-from-equilibrium dynamical system, leading to the development of the mathematical framework of the FEP (Friston 2012). More precisely, the FEP aims to describe how every single "thing" (understood as a system with a stable structure and interface) implicitly entails a variational model of its environment (Friston 2018), and therefore "creates meaning" through the statistics of the dynamical attractor of its coupled agent-environment dynamics.

Let us introduce two closed physical systems A and E, each characterized by a set of stochastic differential equations. Trivially, both admit attracting distributions $p_{A/E}$ in the form of solution to their respective Fokker-Planck equations, and $p_{A/E}$ is statistically independent with regard to $p_{E/A}$ - they are symmetric with regard to any operator affecting the other only. Let us now introduce B, a physical interface between A and E which mediate interaction between the two [3]. Given the interaction, both p_A and p_E remain statistically independent from each other, but as conditioned on p_B [4]. This introduces the concept of a *Markov blanket* as a "real" physical entity, as generally discussed in the FEP literature. Trivially, the introduction of a physical interface entails symmetry breaking as $p_{A/E}$ need remain symmetric only for transformations over $p_{E/A}$ that do not translate into changes in p_B. In the latest canonical treatment of the FEP to date, symmetry breaking was demonstrated to entail the emergence of a synchronization manifold which associate to each state in B the expected corresponding states in A/E (Da Costa et al. 2021).

3 It is not trivially adequate to postulate *a priori* the partition between A and E, as the FEP entails the emergence of the partition from patterns of statistical independence in a system's attracting distribution. However, it is most consistent with the interpretation of the FEP as a theory of physical observation developed in Fields et al. (2021), which will ground the discussion of statespace construction in part. 4.

4 Crucially, condition independence in this scenario is verified by attracting distribution, but not by individual states or trajectories. See (Parr et al. 2021).

This synchronization manifold and the underlying dynamics constitute the formal core of the FEP. Indeed, it underlies the emergence of an "information geometry" where every possible state of the agent meaningfully entails a statistical distribution over states of environment, which entail a Bayesian belief about the causes of their perceivable blanket states (Parr, Da Costa, and Friston 2020). More specifically, the states in A minimize an information-theoretic value known as "variational free-energy" (VFE) over states in B, hereby performing variational Bayesian inference (Da Costa et al. 2021). This entails a form of optimal (Bayesian) inference given approximations of the process underlying data generation, approximations which are generally understood to represent intrinsic limits in the agent's computational abilities. Partitioning further B states between sensory states (that are influenced only by states in E) and active states (that are influenced by states in A), it appears that the agent's internal states (A) and B's active states together minimize variational free energy over B's sensory states (Da Costa et al. 2021). This means that the agent does not passively infer probable causes over its sensory states, but actively samples sensory states in a way that enforces conformity with its expectations in a process described as "self-evidencing".

Crucially, this form of inference has little to do with the explicitly representational cognitivist model of inference, as it corresponds to the active demarch by the blanketed system to maintain a sensorimotor flow consistent with the expectations implicitly entailed by its structure (Bruineberg, Kiverstein, and Rietveld 2018; Inês Hipólito et al. 2021; Nave et al. 2020; Ramstead, Kirchhoff, and Friston 2020). More precisely, self-evidencing corresponds to the attraction of the coupled system toward the region of the synchronization manifold as a result of a dissipative gradient descent on variational free energy. Because the internal section of the manifold is equipped with an information metric, and since each internal state implicitly encodes a variational distribution over external states, states within the internal manifold can be interpreted as Bayesian belief over external states (Friston et al. 2022). This motivates a minimal theory of cognitive meaning grounded on biological normativity (Allen and Friston 2018; Constant, Clark, and Friston 2021; Kiverstein, Kirchhoff, and Froese 2022; Ramstead, Friston, and Hipólito 2020) – i.e. the ability of the blanketed system to regulate dynamical flows so as to maintain its constitutive identity (in the form of the validity of the expectations implicitly entailed by its structure).

To fully understand the meaning of this theory, we need to delve into its most recent formalization in Sakthivadivel (2022b, 2022a). To simplify, the FEP can be formalized as a least action principle in the sense that any modal trajectory of the coupled system must minimizes the integral of the VFE functional (Friston et al. 2022). This enables the formulation of a corrective "gauge" force (Ramstead et al. 2022; Sengupta et al. 2016), which appears to extrinsically enforce the intrinsic symmetries of the VFE within statespaces that do not account for those symmetries. This is similar, for example, to the way the electromagnetic force emerges as a corrective term in statespaces that do not translate local phase symmetry in Schrödinger's equation. This gauge force, by construction, traduces the effects of the "beliefs" (or expectations) entailed by the synchronization manifold and the information metric it is equipped with. Most interestingly, those forces can be mapped onto structural constraints over system viability, providing a natural grounding for earlier theorizations of the continuity between mind and life under the FEP (M. Kirchhoff et al. 2018; M. D. Kirchhoff and Froese 2017).

However impressive these results are, the debate on whether they constitute a meaningful grounding of cognitive meaning in biological autonomy is still alive and well. So far, most criticism has focused on the lack of historicity in the FEP (Di Paolo, Thompson, and Beer 2021), as well as as the adequacy of the Markov blanket construct to account for the coupling between biological / cognitive systems and their environment (Aguilera et al. 2021; Raja et al. 2021). However, this line of criticism could be addressed without any major problem by highlighting that the FEP also applies to system with historically contingent trajectories (Da Costa et al. 2021; Parr et al. 2021), and calling for the development of its path-integral formulation (as foreshadowed in Ramstead et al. (2022)). More problematic is the fact that the ActInf notion of meaning and biological autonomy are directly entailed by the properties of the attracting distributions, and therefore by the equations defining *a priori* the target dynamical system. Therefore, the FEP currently fails to account for the fact that biological constraints and cognitive meaning are not fixed by the system's structure, but continuously unfolding under its active (re)production of the underlying organization [5].

The debate over the adequacy of the FEP to formally account for the properties of biological autonomy and cognitive meaning has elicited an interesting answer in ActInf theorists. While a minority still holds that the FEP actually represents those phenomena (Kiverstein, Kirchhoff, and Froese 2022), most have retreated to some variant of a non-realist interpretation of the theory, in which the target system either does not actually follow the required conditions or does so only as an instrumental / *a posteriori* characterization of their behavior (Andrews 2020; Baltieri, Buckley, and Bruineberg 2020; Constant 2021; van Es 2020; van Es and Hipolito 2020; Friston, Wiese, and Hobson 2020; Ines Hipólito 2019; Ramstead, Friston, and Hipólito 2020). This body of work is characterized by the claim that systems behave *as if* minimizing VFE – see Ramstead, Sakthivadivel, and Friston (2022) for an articulation of the

5 Although this specific issue may very well be addressed by ongoing work on relaxing the Markov blanket construct (Sakthivadivel 2022c), the meaning we can represent remains constrained by the embedding statespace in which we represent the system. The underlying problem therefore applies, up to consideration that will be detailed part. 4.

state-of-the-art position. While easily defensible, this instrumentalist interpretation hardly ground the widespread claim that the FEP constitutes a meaningful explanation to the activity of living and cognitive systems – much less the mathematical proof of existence of an actual physical force. To some extent, the discussion is confused by the fact the FEP is not a model of any given physical system, but a first principle / physical imperative: much like the least action principle, it necessarily holds true – if we can identify an appropriate statespace to model the target system.

Therefore, the FEP may provide a mathematically motivated theory of cognitive meaning, but the statespace problem still applies - much like it does for any nomological or structural-mechanistic explanation. Whether or not the FEP applies to life and mind, it may only explain the behavior states or trajectories within a given statespace. The way life and mind endogenously redefine their constitutive symmetries is at worst ignored and at best held to be entailed by the primordial statespace of the universe. Again, the problem is framed by presupposing a fixed landscape of possibilities, and creation is explained away. However, a key difference exists between the FEP and any other physical principle: its core construct (VFE) is not defined as a function of objective observables of the target system (such as their energy, position, or momentum), but of the meaning they project onto their reality. This property may be used directly to claim that the FEP grounds the notion of cognitive meaning, but it may also be turned on its head so as to ground statespace construction into the subjective experience of a physical agent. We will now follow this path to articulate the FEP as a candidate first principle for a new physics of creation.

4 – Toward a physics of creation: statespace unfolding under the Free Energy Principle

Although the formal content of the FEP does not account for the contingency of biological organization and cognitive meaning, it would be misleading to claim that it ignores symmetry unfolding. VFE minimization was initially introduced in neuroscience to help infer the causal structure underlying the notoriously wild brain dynamics. The most recent approach that FEP theorists have developed to address the transient structure of brain fluctuation, as discussed in K. J. Friston et al. (2020), explicitly borrows the renormalization methodology we discussed part. 2 in relation to criticality theory. Roughly speaking, the partition between particles equipped with internal and blanket states is inferred from patterns in endogenous brain fluctuations measured in experimental settings as well as prior knowledge in structural brain connections. The dynamical coupling within and between particles is then inferred. The operations are then reiterated with a renormalized statespace reduced to each particle and their dominant dynamical mode, until a given scale finally captures a dynamical structure capable to produce wild dynamics (here, positive Lyapunov coefficients) The dynamical structure hereby inferred is taken to be explanatory of the integrated behavior of the brain, and of associated biological / cognitive dynamics.

The key fact of relevance here is inferring the actual Markov blankets as defined in part. 3 would necessitate to measure the "actual" attracting distribution of brain dynamics, which agglomerates information about all their possible dynamical modes. However, since brain dynamics are transient, we can only infer the partition given the realization of a given dynamical mode (or set thereof) that happens to be enacted at the time of the experiment. This could easily be written off as a simple experimental limitation, that will progressively dissolve with the methodological development of fine-grained, long-term, *in eco* brain imagery (see Guénin--Carlut (2020) for further discussion). However, this would only displace the underlying problem. If Markov blankets are taken to be the physical interface enabling sensorimotor coupling in biological and cognitive systems, then they are constructed by the activity of the system itself rather than predefined by its structure. This naturally entails the condition of interactional asymmetry in agency, as well as the role of attention in modulating sensorimotor coupling so as to accommodate different tasks [6]. I argue hereby that Markov Blankets should accordingly be understood as the expression of transient dynamical modes, and that the underlying mathematics would allow us to draft a solution to the statespace problem.

6 See e.g. Parr and Friston (2019) for an active inference account of attention

Let us reframe the argument formally. If the posterior distribution q parametrized by the agent's internal states is held to formalize cognitive meaning, then it has to be defined over states the agent makes sense of (*i.e.* that it observes so as to decide of its course of action (Fields and Levin 2020)). Such observation entails by construction physical measurement, *i.e.* the transfer of information from external to internal states, and vice-versa. By Landauer's principle, it must therefore dissipate a given amount of free energy. In other words, for any given information to affect an agent's behavior, some other information must become unobservable as it is burned as fuel. Assuming we operate within a physically closed statespace, this means that the partition of states where q is defined (*i.e.* that can affect the agent's behavior) is constructed by the history of its interactions with the environment, and with it the synchronization manifold that underlies cognitive meaning. Assuming on the contrary that we operate within a statespace that is constructed to include cognitively relevant states only, then it is the statespace itself that must be constructed by the system's history.

This motivates a focus switch from the dynamics in an abstracted statespace to the physical process of measurement itself, as formalized in quantum information theory by Fields et al. (2021) [7]. Assuming an isolated quantum system that is partitioned between separable [8] subparts A and E, the physical interaction at the interface reduces to a sum of binary questions. Agent-environment asymmetry emerges here as a subsystem (say A)'s internal dynamics break the symmetry of the physical interface by dictating which boundary states drive meaningful information, which are burned as fuel, and which encode a coarse-grained classical memory – effectively dictating the terms of the interaction. Each question asked by A entails the preparation of the target states within a given quantum reference frame as conditioned by the agent's internal dynamics (*e.g.* by individuating the states it aims to measure). This progressively drives the alignment between A and E's reference frames, which therefore become mutually entangled. In this context, the FEP can be reframed as the statement that interacting quantum systems are driven toward mutual entanglement and therefore their disappearance as separable systems.

We must note here that there is a clear conflict with the classical formulation of the FEP, where separability (as entailed by MB coherence) is on the contrary a property of the attracting set of the system. But assuming that the FEP is self-standing account of physical measurement (understood here as the semantic embedding of physical interaction), the distinction dissolves immediately. Indeed, any observable states must then be encoded in the synchronization dynamics through a Markov Blanket (more precisely, within the information geometry of the synchronization manifold it entails).

7 See also Tegmark (2012) and Fields and Glazebrook (2020) for earlier treatments unrelated to the FEP.

8 "Separable" means here that they are not entangled, i.e. that their physical states can in principle be measured independently.

Therefore, all functionally significant states of a system are somehow entailed by the information available at its interface with the wider world (consistently with the holographic principle, see Fields et al. (2021) sec. 2.3). Therefore, the existence of individuated states or trajectories can be relaxed, and we fall back to the quantum information formulation. In this framework, the observable dynamics of the system depend on the reference frames/information geometry it develops in its coupling with the wider world. But as those are themselves constructed by the system's internal dynamics, we are left with only one possible basis to construct our physical ontology: the synchronization dynamic itself.

This substantiates a variant of Markov monism, as developed in (Friston, Wiese, and Hobson 2020), where generalized synchronization (as described by the FEP) grounds the construction of physical symmetries [9]. As systems synchronize across a given physical interface, entanglement/synchronization destroys their ability to observe states inconsistent with their shared information geometries. The states it entails then emerges as a proper physical observable with locally defined quantum fields, which topology and coupling with other observables are defined by the structure of observation itself. Crucially, this process grounds the emergence of subjective time as the system's entropy rises at each observation cycle and the agent progressively becomes unable to differentiate itself from its environment (Fields et al. 2021, sec. 2.2). Therefore, it constitutes a candidate explanation for the cosmological evolution of spacetime itself, in line with earlier work relating the physics of learning agents to the formalism of quantum gravity / gauge fields (Alexander et al. 2021; Tegmark 2012) [10]. We should note that the present approach shares with both established theories of quantum gravity a basic commitment of modeling spacetime as a discretized topology emerging from basic proto-physical processes [11].

9 Please note that the present account means relaxing the hypothesis of an embedding statespace, and instead explaining the existence of physical observable themselves as a consequence of the FEP. It is therefore much more radical than Friston's favored reductive physicalist interpretation. As observation is classically understood as a manifestation of consciousness, it is closer to what K. J. Friston, Wiese, and Hobson (2020) defines as panprotopsychism.

10 See also Lin, Tegmark, and Rolnick (2017) for a discussion of the structural analogy between neural networks and physical symmetries.

11 To be more specific, both major approaches to quantum gravity traduce different aspect of the FEP as presented here.
Indeed, string theory constitutes a derivation of the AdS/CFT correspondence, which reduces the geometry of gravitational field to this of lower dimensional, topologically Euclidian "slices" (Maldacena 1999; Witten 1998). It describes the emergence of spacetime as an holographic projection of the resonance between protophysical vibrational modes, which directly traduces the reductive physicalist interpretation of statespace emerging from synchronizing dynamical systems. Additionally, recent extensions shows that string theory affords a purely geometrical account of physical interaction (Arkani-Hamed and Trnka 2014), which is broadly consistent with the present geometrical account of physical symmetries.
On the other hand, loop quantum gravity theory posits that spacetime is constructed as a dynamical network of connections (a spin network) entailed by the representation of a background

Although articulating a formal account of the physics of creation is well beyond the scope of the present paper, we can define a general direction in which to orient the development of an adequate mathematical framework. The key focus of our approach is on the dynamical relation between an *intrinsic* and *extrinsic* information geometry (respectively probabilistic constraints over the internal states of the agent, and Bayesian belief over its external states) (Friston, Wiese, and Hobson 2020). Those information geometries need to be formalized as contingent modes of synchronization, which are mutually constructed through transient modes of coupling (*i.e.* Markov blankets, reformalized as reference frames). As their symmetries determine the states relevant for the system and their dynamical flow, their description can be leveraged to reconstruct an embedding statespace from the states imbued with meaning by the information geometry. The key difficulty of this treatment is formalizing how an agent's intrinsic information geometry determines its choice of Markov blanket / reference frames [12], and how the resulting extrinsic information geometry shapes in return its intrinsic geometry. Given such a formalism, we can model the construction of physical symmetries as observables emerge from the synchronization of learning proto-agents [13] - as outlined in Alexander et al. (2021).

Even assuming that the processes described above govern the construction of physical laws, one may remain unconvinced that they have anything to say about biological organization or cognition. The idea that psychological activity has anything to do with quantum processes is indeed considered with healthy skepticism, based on the argument that the brain is too hot and noisy to enable quantum coherence at the relevant timescales (in line with Tegmark (2000)). However, the same calculations corrected for an array of biological mechanisms appear to allow for quantum computation in the brain (Hagan, Hameroff, and Tuszyński 2002) [14], and most importantly the efficiency of biological computation appears simply too efficient to be explained by classical information processing alone (Fields and Levin 2021). The impossibility of quantum computation in biological systems is therefore anything but

independent gauge theory as a set of gauge invariant loop operators (the eponymous quantum loops) (Smolin 2004). This is most consistent with the panprotopsychist intuition of spacetime as an emergent topology, entailed by the information geometry resulting from the historical trajectory of mutual observation between basic proto-agents.

12 While this dependence is a central element of the quantum information of the FEP described in Fields et al. (2021), it is not imbued with a generative model or even formally constrained.

13 Although no result can be derived prior to formalization, it is relevant to note that such an approach makes physical aberrations such time-reversal in antimatter (Ryder 1994) or spontaneous emergence of negative mass (Farnes 2018) *a priori* unproblematic as there is no reason that all physical observers couple to the same field in the same way. In other words, it dissolves the necessity for "natural laws" as defined in part. 1, as it considers physical phenomena as the result of contingent organization.

14 See also Hameroff and Penrose (2014) for a recent review of "Orch OR" theory. See also recent results showing unexpectedly large domains of quantum coherence in carbon (Lee et al. 2011) and water structure (Marchettini et al. 2010).

an established fact. A deeper problem of the present account is that it seems to negate entirely the possibility of objective knowledge, as the act of observation itself participates in constructing the observed phenomenon. As we will see, this is absolutely correct, but also entirely unproblematic and even necessary for the articulation of a radically naturalistic demarch.

5 – Science without laws: naturalistic explanation and participatory realism

In the discussion above, we have first highlighted the inadequacy of nomological-deductive explanations to account for the contingent, self-creative symmetries characteristic of living systems. By recreating a physical framework aimed to describe and explain such unfolding symmetries, we have however dissolved the core assumption underlying the very concept of nomological-deductive explanation: the idea of an order, legible cosmos. Indeed, if the existence of any physical symmetry is constructed by its very observation, we simply lack the kind of universal, entailing laws that physics typically supposes. The agency of observing systems, whether or not they are conceptualized as "mindful" or "biological", is simply what underlies the construction of physical statespaces – i.e. creation. On a cosmological level, this statement should only antagonize the most convinced Platonists: after all, if we agree the existence of woodlice and men is the contingent result of a specific cosmological history, the same can go for the scalar nature of the Higgs field or the structure of spacetime. But on an epistemological level, the key role we lend to observation in statespace construction negates the very existence of any natural fact prior to observation. Therefore, it dissolves the classical understanding of scientific explanation of natural phenomenon.

This understanding is thoroughly grounded in a naturalistic demarch, which does not correspond any specific philosophical position but can still be unambiguously tied to specific positions on explanation. Naturalism is usually defined as a broad movement sharing a general commitment to the ontological position of a causally integrated natural realm, and the methodological / epistemological demarch of grounding of science and philosophy in the entities that compose this realm (Papineau 2021). Therefore, a naturalistic explanation of a given phenomenon is one that is grounded on the natural structure that produces it, itself understood as a component of nature. This should recall the link we have drawn part. 1 between explanatory strategies and the actual nature of physical symmetries. In other words, naturalistic explanation entails a commitment to a specific causal ontology, aiming to reflect the actual organization of the target system (Sperber 2011)) – which is itself accessible to naturalistic explanation. Although naturalism is historically associated to the deductive-nomological model of explanation through the positivist and modal empiricist movements, we can observe a tension between the two: "natural laws" are understood to preexist to any given phenomenon, and are therefore removed from the realm of causal influence (i.e. nature).

A properly naturalized ontology should therefore disregard laws as a natural kind, and instead focus on the *underlying symmetries* as the locus of scientific explanation. The question of what kinds of explanation we can mobilize therefore reduces to what kinds of symmetries exist in nature, and where they come from. If there exist universal, embedding symmetries, then we can rearticulate the program of deductive-nomological explanation by simply switching the explanatory load from reified "natural laws" to the underlying symmetries. This should not pose any problem to the reader: indeed, we do not fall because we obey a universal "law of attraction", we fall because of the local curvature of space-time. Since laws cannot be the locus of naturalistic explanation to begin with, their dissolution need not change much our explanatory strategies. If the symmetries underlying a system's activity are contingent on a given context and a given cosmological, evolutionary or developmental history, then we have to acknowledge this contingency and investigate its determinants. In any case, we still have to formalize the symmetries embedded in our system of interest, and derive what kind of activity they entail.

The issue emerges when we become interested in how observation itself participate in constructing the symmetries underlying the physical universe. By construction, naturalism commits the scientist to some variant of structural realism, *i.e. to* the notion that scientific ontology must reflect the structure of natural entities (see Ladyman (2020) for a contextualized definition). This is *prima facie* inconsistent with the physics of creation, which entails that targets of scientific explanation lack a well-defined structure which is invariant with regard to observation. However, this apparent inconsistency dissolves under a closer investigation. Indeed, any given scientific explanation is intrinsically structural – it describes relations between the objects it postulates. Therefore, there is no need for a scientist to commit to the ground truth of its causal ontology, only to its coherence with background knowledge and empirical observation of the target system (Colombo, Hartmann, and van Iersel 2015). Therefore, a naturalist can insist that all there is to the world is structure, understood as the relations between natural entities (Ladyman 1998; Ladyman et al. 2007). Naturalistic explanation can therefore be abstracted away from the correspondence of their ontology to "natural entities" as such, and instead focus on the description of symmetries that are invariant with regard to observation.

Critically, similar considerations emerge from the study of the role of observers in quantum mechanics. Indeed, observation of a quantum system is demonstrably related to a loss of quantum coherence, where the apparent behavior of the system reduces to this of a pure (classical) state which corresponds to the outcome of the observation (Bacciagaluppi 2020). This phenomenon is classically understood as a "collapse" of an objective wavefunction which represents the real state of the system. This assumption entails an array of conceptual issues: How can wavefunction collapse propagate in space instantaneously (therefore faster than light)? How can system entropy spontaneously disappear? Most importantly, what kind of interactions entail wavefunction collapse in the first place? One way to solve (or more precisely, dissolve) the issue is the commitment to so-called "unitary" quantum mechanics, i.e. the view that decoherence is an outcome of quantum evolution under the Schrödinger equation rather than an objective wavefunction collapse. Observation is therefore understood as a physical process in which the observer becomes entangled with its target system, and therefore produce decoherence by constraining the outcomes of its future observations to states consistent with its history (Griffiths 2019).

Although it sustains a number of interpretations regarding what's actually out there (the most famous one being Everett's multiverse theory), unitary quantum mechanics can ground a consistently naturalistic and observer-centered cosmology. As per the development in part. 4, observation can be taken to entail the construction of physical symmetries. This construction does not alter, however, the "ground reality" from which it developed as the space of physical states that are in principle accessible (i.e. the embedding statespace) remains unaltered throughout the process. What is altered however is the physical states that are accessible to the observer, which is constrained by nature of the synchronization dynamic. In other words, the universe may evolve in a pure quantum state, while the world we agents live in (*i.e.* the states we can access) is constrained by our history of observations. The separation between those states that we observe and those that we discard enables an elegant explanation of why we seem to live in a well-structured universe (without calling onto intelligent design, or the necessity of such an universe for observer to exist in the first place): it just so happens that observation produces structure, and therefore constrain entropy for those states that we observe (Tegmark 2012).

The symmetries we produce through observation (or agentive engagement) are in this sense objective, observable parts of the universe. But they are at the same time subjective manifestations of situated belief systems. Physical statespaces are therefore understood as the embedding space of specific interactions, as structured by the gauge symmetries entailed by the agent's beliefs and/or structural constraints. This view seem to traduce one of the most extreme interpretation of unitary quantum mechanics: Quantum Bayesianism, or QBism. This approach holds quantum wavefunctions to traduce nothing more than subjective beliefs about outcomes of observations (Timpson 2008). Qbists' skepticism about any given statespace is not a negation of the actual existence of the natural world, and aims on the contrary to help us identify the actual invariants of physical theories (i.e. "reality", in a structural sense), and therefore the "ultimate building block" of physical reality. It just so happens that particular observers participate in defining the form adopted by these blocks, and therefore construct physical reality – hence the characterization of their position as «participatory realism» (Fuchs 2017). An important limitation to QBism as a physical theory appears quite straightforwardly: if agents can simply make up their own physical reality, what exactly constrains (or explains) cosmological evolution?

The formalism we have articulated here answers this question by relating QBism to another brand of participatory realism, emanating from cognitive science in the enactive tradition (Froese 2022). Let us think of the way humans understand their world: their coupling with their niche of ultra-collaborative hunters attuned our ancestors to each other's intentional states through both bodily synchronization and material cues (Shilton et al. 2020; Veissière et al. 2020). Because those intentions are directly perceived and acted upon, they are perceived as "real" by human agents. But as the collective abilities to represent the world expend (both through evolution of the cultural and material niche), aspects of the world we could not previously observe become understood and acted upon. This entire process is still constrained and constructed by our baseline cognition, although it undeniably entails the expansion of the space of our possibilities. A change in the Markov Blanket and/or the agent's internal dynamics (*i.e.* the mode and interface of the coupling) enables the unfolding of physical symmetries embedded in the agent-environment synchronization manifold, and therefore the construction of a new statespace. In others words, subjective perception by emerging agents entails the gauge forces which bring about, or «create», the structure of the universe.

Conclusion

The present work has related two problems underlying natural science: the program of lawful explanation which implicitly underlies it, and the difficulty of satisfyingly accounting for creation (*i.e.* open-ended evolution) in biological and cognitive systems. Quite straightforwardly, this is because lawful explanation relies on a reification of natural symmetries, while creation entails by construction the unfolding of such symmetries. Based on this statement, scientific explanation must to some extent recognize that the symmetries it relies on are historical and contextual products of system explanation. This is in no way problematic, as the program of structural-mechanistic shows that the description of biological and cognitive structure provides a satisfying ground for scientific explanation. We must simply relax the explanatory role of «natural laws», understood as systematic or statistical relations between observables, to focus instead on the physical symmetries which underlie such laws. This shift in focus is anyway required to articulate a naturalistic demarch, which is by definition grounded in the study and characterization of natural entities – "actual" physical objects which are object and subject to causal influence.

The real difficulty begins when we try to account for the phenomenon of creation itself. By construction, the mathematical representation of any natural system relies on a "statespace", *i.e.* a predefined representation of all the possibilities accessible to the system. This construct makes it structurally impossible for the physicist to meaningfully account for open-ended evolution, or for the emergence of an "adjacent possible" (as described by Kauffman (2019)). More problematically, and in addition to the properties that could emerge of the postulated dynamics within the statespace, its definition implicitly entails a system-wide symmetry with regard to any transformation which leaves the statespace unchanged. This means not only that creation is in itself inaccessible to statespace representation, but also that creative systems (*i.e.* systems that redefine their constitutive symmetries) seem themselves beyond mathematical representation. This leaves us unable to account for the known creative aspect of mind and life, but also to thoroughly ground cosmological evolution in a naturalistic demarch. Indeed, in the absence of a physics of creation (i.e. a formal account of how new possibilities emerge in the natural world), we need to rely on a predefined embedding statespace which register all physical possibilities and whose structure is itself beyond causal influence.

We have hereby reviewed the two main candidate formalisms for representing creation: Self-Organized Criticality, and the Free Energy Principle. While both capture key aspects of creation, both the former and dominant formulations on the later ultimately fail to satisfyingly account for this process. Criticality theory is grounded in the physics of phase transition, where it describes the state of extreme susceptibility and fractal structure that emerges in continuous phase transition. While this does reproduce the wild phenomenology of brain dynamics, it fails to properly explain it or account for its role in the maintenance and construction of biological / cognitive organization. Ultimately, it is an adequate illustration of the inherent limitations of nomological explanation of mind and life. In conttrast, the FEP does account for how biological / cognitive systems construct new physical symmetries through the integrated activity entailed by their constitutive constraint, understood as synchronization across a physical interface. It is however limited by its mathematical formulation in dynamical systems theory, which constrains it to only describe systems with a predefined statespace and therefore overlook creation. But if we look at the foundations of the FEP, this limitation takes another nature: it is not clear whether the statespace in question is an embedding space predating the synchronization, or is itself constructed through cognitive activity.

Following the second road takes us a speculative but productive road to ground the physics of creation. Indeed, observation is by Landauer's principle an irreversible process, and the space of observable states (*i.e.* over which the belief distribution is defined) is therefore constructed by a system's history. The internal dynamics of the agent under study therefore construct not only dynamics within the postulated statespace, but also the statespace itself. In turn, the measurable parameters of the internal dynamics are themselves constrained by what can be observed by the environment. Physical measurement is therefore not a simple entailment of the intrinsic properties of either the agent or its environment, but should instead be understood as an autonomous, open process capable to ground statespace construction. To translate this understanding, we can reframe the FEP around the construct which stands in for the intrinsic geometry of measurement itself, *i.e.* the synchronization manifold, and try to reconstruct the embedding space from this ground. Although it constitutes an abstraction from a classical statespace formulation, it is a necessary step toward the formalization of the constructive role agency plays in the evolution of social systems, life, as well as the physical structure of the universe.

This framework has deep implications on what we understand of our universe, as well as on our reflexive attitude regarding our own knowledge. First, it opens up the mathematical possibility to represent unfolding statespaces, *i.e.* the creation of new physical possibilities by a system of interest. This creation is qualitatively understood as an entailment of the belief system of the agent, which affords a robust intuitive understanding of the subject. For example, we can take an interest in how the cognitive activity of States constrain the ecological information they can process, leading to the construction of legible landscapes and social systems alike (Guénin--Carlut 2021). In addition, by reduction, a theory of statespace unfolding would give us a mean to represent cosmological evolution without an embedding space (much like loop quantum gravity), or more precisely to represent the evolution of the embedding space itself. This enables the explanation of the most fundamental physical object, and therefore the grounding of a fully naturalistic picture of the universe. However, framing measurement itself as a core element of reality construction brings the observer to play an active role in the phenomenon it tries to observe, therefore dissolving the classical view of physical reality as an objective fact preexisting our attempts to navigate and understand it.

This statement ultimately does not threaten our basic commitment to naturalism, as there is no difficulty in admitting there exist a natural world and that we contribute to constructing it. Much like our activity constructs our cognitive and material niche by producing new structure from preexisting constraints, our observation of the physical world bring about new symmetries from the background of preexisting physical processes. Therefore, the challenges of the present approach are formal rather than conceptual in nature. We have shown that the physics of measurement enable in principle a mathematical account of symmetry construction / statespace unfolding, consistently with dynamical accounts of cognitive agency. However, the work presented here constitute an early, informal presentation of what would constitute a physics of creation and what are its implications. An actual formalization is yet to articulate, and it must address an array of open questions – most importantly, how to represent the geometry of measurement prior to the existence of an embedding space? As I have shown this question to be a central knot in the structure of physical theory, and it joins earlier lines of formalization in quantum loop and category theory, I am confident we will work toward a principled answer in the foreseeable future.

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The present article is the culmination of 6 years of research and reflections on how to formalize the basic intuition that a natural object or property must be observable in order to exist, properly speaking. If I were to acknowledge all the indirect contributions to this paper, this section would start looking like a detailed autobiography augmented with an history of the role of Buddhist philosophy in shaping contemporary quantum physics and cognitive science. Since the convention insists that the acknowledgment section must be shorter than the article, and since I wish not to spend an additional 6 years writing it, let us focus on direct contributions.

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Bibliography

Aguilera, Miguel, and Manuel G. Bedia. 2018. 'Adaptation to Criticality through Organizational Invariance in Embodied Agents'. *Scientific Reports* 8(1): 7723.

Aguilera, Miguel, and Ezequiel A. Di Paolo. 2021. 'Critical Integration in Neural and Cognitive Systems: Beyond Power-Law Scaling as the Hallmark of Soft Assembly'. *Neuroscience & Biobehavioral Reviews* 123: 230–37.

Aguilera, Miguel, Beren Millidge, Alexander Tschantz, and Christopher L. Buckley. 2021. 'How Particular Is the Physics of the Free Energy Principle?' *arXiv:2105.11203 [q-bio]*. http://arxiv.org/abs/2105.11203 (May 25, 2021).

Alexander, Stephon et al. 2021. 'The Autodidactic Universe'. *arXiv:2104.03902 [gr-qc, physics:hep-th, physics:physics, physics:quant-ph]*. http://arxiv.org/abs/2104.03902 (August 2, 2021).

Allen, Micah, and Karl Friston. 2018. 'From Cognitivism to Autopoiesis: Towards a Computational Framework for the Embodied Mind'. *Synthese* 195(6): 2459–82.

Andrews, Mel. 2020. 'The Math Is Not the Territory: Navigating the Free Energy Principle'. http://philsci-archive.pitt.edu/18315/ (January 13, 2021).

Arkani-Hamed, Nima, and Jaroslav Trnka. 2014. 'The Amplituhedron'. *Journal of High Energy Physics* 2014(10): 30.

Bacciagaluppi, Guido. 2020. 'The Role of Decoherence in Quantum Mechanics'. In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/fall2020/entries/qm-decoherence/ (October 3, 2021).

Bak, Per, and Kan Chen. 1989. 'The Physics of Fractals'.

———. 1991. 'Self-Organised Criticality'.

Bak, Per, Chao Tang, and Kurt Wiesenfeld. 1987. 'Self-Organized Criticality : An Explanation of 1/f Noise'.

Baltieri, Manuel, Christopher L. Buckley, and Jelle Bruineberg. 2020. 'Predictions in the Eye of the Beholder: An Active Inference Account of Watt Governors'. In *The 2020 Conference on Artificial Life*, , 121–29. http://arxiv.org/abs/2006.11495 (August 11, 2022).

Barabàsi, Albert-Làsilò, and Eric Bonabeau. 2003. 'Scale-Free Networks'. *Scientific American* 288(5): 60–69.

Bechtel, William. 2008. *Mental Mechanisms: Philosophical Perspectives on Cognitive Neuroscience*. Taylor & Francis.

———. 2009. 'Looking down, around, and up: Mechanistic Explanation in Psychology'. *Philosophical Psychology* 22(5): 543–64.

Bechtel, William, and Adele Abrahamsen. 2005. 'Explanation: A Mechanist Alternative'. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 36(2): 421–41.

Beggs, John M. 2008. 'The Criticality Hypothesis: How Local Cortical Networks Might Optimize Information Processing'. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 366(1864): 329–43.

Beggs, John M., and Dietmar Plenz. 2003. 'Neuronal Avalanches in Neocortical Circuits'. *Journal of Neuroscience* 23(35): 11167–77.

Beggs, John M., and Nicholas Timme. 2012. 'Being Critical of Criticality in the Brain'. *Frontiers in Physiology* 3. https://www.frontiersin.org/articles/10.3389/fphys.2012.00163/full (September 9, 2020).

Beni, Majid D. 2021. 'A Critical Analysis of Markovian Monism'. *Synthese*. https://doi.org/10.1007/s11229-021-03075-x (February 18, 2021).

Beni, Majid Davoody. 2017. 'Structural Realism, Metaphysical Unification, and the Ontology and Epistemology of Patterns'. *International Studies in the Philosophy of Science* 31(3): 285–300.

Boone, Worth, and Gualtiero Piccinini. 2016. 'The Cognitive Neuroscience Revolution'. *Synthese* 193(5): 1509–34.

Bruineberg, Jelle, Krzysztof Dolega, Joe Dewhurst, and Manuel Baltieri. 2021. 'The Emperor's New Markov Blankets'. *Behavioral and Brain Sciences*: 1–63.

Bruineberg, Jelle, Julian Kiverstein, and Erik Rietveld. 2018. 'The Anticipating Brain Is Not a Scientist: The Free-Energy Principle from an Ecological-Enactive Perspective'. *Synthese* 195(6): 2417–44.

Buiatti, Marcello, and Giuseppe Longo. 2013. 'Randomness and Multilevel Interactions in Biology'. *Theory in Biosciences* 132(3): 139–58.

Bullmore, Ed, and Olaf Sporns. 2009. 'Complex Brain Networks: Graph Theoretical Analysis of Structural and Functional Systems'. *Nature Reviews Neuroscience* 10(3): 186–98.

Carlson, J. M., and John Doyle. 1999. 'Highly Optimized Tolerance: A Mechanism for Power Laws in Designed Systems'. *Physical Review E* 60(2): 1412–27.

———. 2000. 'Highly Optimized Tolerance: Robustness and Design in Complex Systems'. *Physical Review Letters* 84(11): 2529–32.

Chalmers, Alan F. 2013. *What Is This Thing Called Science?* Hackett Publishing.

Chialvo, D. R., and P. Bak. 1999. 'Learning from Mistakes'. *Neuroscience* 90(4): 1137–48.

Chialvo, Dante R. 2004. 'Critical Brain Networks'. *Physica A: Statistical Mechanics and its Applications* 340(4): 756–65.

———. 2010. 'Emergent Complex Neural Dynamics'. *Nature Physics* 6(10): 744–50.

Christensen, Kim, and Nicholas R. Moloney. 2005. *Complexity and Criticality*. World Scientific Publishing Company.

Colombo, Matteo, Stephan Hartmann, and Robert van Iersel. 2015. 'Models, Mechanisms, and Coherence'. *The British Journal for the Philosophy of Science* 66(1): 181–212.

Colombo, Matteo, and Patricia Palacios. 2021. 'Non-Equilibrium Thermodynamics and the Free Energy Principle in Biology'. *Biology & Philosophy* 36(5): 41.

Constant, Axel. 2021. *The Free-Energy Principle: It's Not about What It Takes, It's about What Took You There.*

Constant, Axel, Andy Clark, and Karl Friston. 2021. 'Representation Wars: Enacting an Armistice Through Active Inference'. *Frontiers in Psychology* 11: 3798.

Da Costa, Lancelot, Karl Friston, Conor Heins, and Grigorios A. Pavliotis. 2021. 'Bayesian Mechanics for Stationary Processes'. *arXiv:2106.13830 [math-ph, physics:nlin, q-bio]*. http://arxiv.org/abs/2106.13830 (July 7, 2021).

Di Paolo, Ezequiel, Evan Thompson, and Randall D. Beer. 2021. 'Laying down a Forking Path: Incompatibilities between Enaction and the Free Energy Principle'. https://psyarxiv.com/d9v8f/ (April 19, 2021).

Dohmatob, Elvis, Guillaume Dumas, and Danilo Bzdok. 2020. 'Dark Control: The Default Mode Network as a Reinforcement Learning Agent'. *Human Brain Mapping* n/a(n/a). https://onlinelibrary.wiley.com/doi/full/10.1002/hbm.25019 (June 6, 2020).

van Es, Thomas. 2020. 'Living Models or Life Modelled? On the Use of Models in the Free Energy Principle'. *Adaptive Behavior*: 1059712320918678.

van Es, Thomas, and Ines Hipolito. 2020. 'Free-Energy Principle, Computationalism and Realism: A Tragedy'. http://philsci-archive.pitt.edu/18497/ (February 14, 2021).

Farnes, J. S. 2018. 'A Unifying Theory of Dark Energy and Dark Matter: Negative Masses and Matter Creation within a Modified ΛCDM Framework'. *Astronomy & Astrophysics* 620: A92.

Fields, Chris, Karl Friston, James F. Glazebrook, and Michael Levin. 2021. *A Free Energy Principle for Generic Quantum Systems*. arXiv. http://arxiv.org/abs/2112.15242 (June 4, 2022).

Fields, Chris, and James F. Glazebrook. 2020. 'Representing Measurement as a Thermodynamic Symmetry Breaking'. *Symmetry* 12(5): 810.

Fields, Chris, and Michael Levin. 2020. 'How Do Living Systems Create Meaning?' *Philosophies* 5(4): 36.

———. 2021. *Metabolic Limits on Classical Information Processing by Biological Cells*. arXiv. http://arxiv.org/abs/2103.17061 (June 9, 2022).

Friston, Karl. 2010. 'The Free-Energy Principle: A Unified Brain Theory?' *Nature Reviews Neuroscience* 11(2): 127–38.

———. 2012. 'A Free Energy Principle for Biological Systems'. *Entropy* 14(11): 2100–2121.

———. 2016. 'Active Inference: A Process Theory'. *Neural Computation* 29(1): 1–49.

———. 2018. 'Of Woodlice and Men: A Bayesian Account of Cognition, Life and Consciousness'. https://www.aliusresearch.org/bulletin02-fristoninterview.html (March 13, 2021).

———. 2019. 'A Free Energy Principle for a Particular Physics'. *arXiv:1906.10184 [q-bio]*. http://arxiv.org/abs/1906.10184 (April 22, 2021).

———. 2020. 'Parcels and Particles: Markov Blankets in the Brain'. *arXiv:2007.09704 [q-bio]*. http://arxiv.org/abs/2007.09704 (February 18, 2021).

———. 2022. 'The Free Energy Principle Made Simpler but Not Too Simple'. *arXiv:2201.06387 [cond-mat, physics:nlin, physics:physics, q-bio]*. http://arxiv.org/abs/2201.06387 (January 20, 2022).

Friston, Karl, Wanja Wiese, and J. Allan Hobson. 2020. 'Sentience and the Origins of Consciousness: From Cartesian Duality to Markovian Monism'. *Entropy* 22(5): 516.

Froese, Tom. 2022. 'Scientific Observation Is Socio-Materially Augmented Perception: Toward a Participatory Realism'. *Philosophies* 7(2): 37.

Fuchs, Christopher A. 2017. 'On Participatory Realism'. In *Information and Interaction: Eddington, Wheeler, and the Limits of Knowledge*, The Frontiers Collection, eds. Ian T. Durham and Dean Rickles. Cham: Springer International

Publishing, 113–34. https://doi.org/10.1007/978-3-319-43760-6_7 (June 13, 2022).

Gautam, Shree Hari et al. 2015. 'Maximizing Sensory Dynamic Range by Tuning the Cortical State to Criticality'. *PLOS Computational Biology* 11(12): e1004576.

Green, Sara, and Nicholaos Jones. 2016. 'Constraint-Based Reasoning for Search and Explanation: Strategies for Understanding Variation and Patterns in Biology'. *Dialectica* 70(3): 343–74.

Griffiths, Robert B. 2019. 'The Consistent Histories Approach to Quantum Mechanics'. In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/sum2019/entries/qm-consistent-histories/ (June 30, 2022).

Guénin--Carlut, Avel. 2020. 'Cognition in Eco & Cognition in Vitro : Can Cognitive Science Explain Ecological Behaviour ?' https://osf.io/ercz6/ (October 31, 2020).

———. 2021. 'Thinking like a State - Embodied Intelligence in the Deep History of Our Collective Minds'. https://osf.io/dxnzt/ (September 20, 2021).

Hagan, S., S. R. Hameroff, and J. A. Tuszyński. 2002. 'Quantum Computation in Brain Microtubules: Decoherence and Biological Feasibility'. *Physical Review E* 65(6): 061901.

Hameroff, Stuart, and Roger Penrose. 2014. 'Consciousness in the Universe: A Review of the "Orch OR" Theory'. *Physics of Life Reviews* 11(1): 39–78.

Henderson, Leah. 2020. 'The Problem of Induction'. In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2020/entries/induction-problem/ (August 11, 2022).

Hesse, Janina, and Thilo Gross. 2014. 'Self-Organized Criticality as a Fundamental Property of Neural Systems'. *Frontiers in Systems Neuroscience* 8. https://www.frontiersin.org/articles/10.3389/fnsys.2014.00166/full (September 9, 2020).

Hipólito, Ines. 2019. 'A Simple Theory of Every "Thing"'. *Physics of Life Reviews* 31: 79–85.

Hipólito, Inês, Manuel Baltieri, Karl Friston, and Maxwell James Ramstead. 2021. 'Embodied Skillful Performance: Where the Action Is'. *Synthese*. https://doi.org/10.1007/s11229-020-02986-5 (February 5, 2021).

John, Yohan. 2015. 'How Informative Is the Concept of Biological Information?' *3 Quarks Daily*. https://3quarksdaily.com/3quarksdaily/2015/05/how-informative-is-the-concept-of-biological-information.html (April 9, 2022).

Kauffman, Stuart A. 2019. *A World Beyond Physics: The Emergence and Evolution of Life*. Oxford University Press.

Kinouchi, Osame, and Mauro Copelli. 2006. 'Optimal Dynamical Range of Excitable Networks at Criticality'. *Nature Physics* 2(5): 348–51.

Kirchhoff, Michael et al. 2018. 'The Markov Blankets of Life: Autonomy, Active Inference and the Free Energy Principle'. *Journal of The Royal Society Interface* 15(138): 20170792.

Kirchhoff, Michael D., and Tom Froese. 2017. 'Where There Is Life There Is Mind: In Support of a Strong Life-Mind Continuity Thesis'. *Entropy* 19(4): 169.

Kiverstein, Julian, Michael D. Kirchhoff, and Tom Froese. 2022. 'The Problem of Meaning: The Free Energy Principle and Artificial Agency'. *Frontiers in Neurorobotics* 16. https://www.frontiersin.org/article/10.3389/fnbot.2022.844773 (June 24, 2022).

Ladyman, James. 1998. 'What Is Structural Realism?' *Studies in History and Philosophy of Science Part A* 29(3): 409–24.

———. 2007. *Every Thing Must Go: Metaphysics Naturalized*. Clarendon Press.

———. 2020. 'Structural Realism'. In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/win2020/entries/structural-realism/ (October 3, 2022).

Lee, K. C. et al. 2011. 'Entangling Macroscopic Diamonds at Room Temperature'. *Science* 334(6060): 1253–56.

Lent, Jeremy. 2017. *The Patterning Instinct: A Cultural History of Humanity's Search for Meaning*. Prometheus Books.

Levina, Anna, J. Michael Herrmann, and Theo Geisel. 2007. 'Dynamical Synapses Causing Self-Organized Criticality in Neural Networks'. *Nature Physics* 3(12): 857–60.

———. 2009. 'Phase Transitions towards Criticality in a Neural System with Adaptive Interactions'. *Physical Review Letters* 102(11): 118110.

Lin, Henry W., Max Tegmark, and David Rolnick. 2017. 'Why Does Deep and Cheap Learning Work so Well?' *Journal of Statistical Physics* 168(6): 1223–47.

Longo, Giuseppe, and Maël Montévil. 2013. 'Extended Criticality, Phase Spaces and Enablement in Biology'. *Chaos, Solitons & Fractals* 55: 64–79.

Longo, Giuseppe, Maël Montévil, and Stuart Kauffman. 2012. 'No Entailing Laws, but Enablement in the Evolution of the Biosphere'. In *Proceedings of the 14th Annual Conference Companion on Genetic and Evolutionary Computation*, GECCO '12, New York, NY, USA: Association for Computing Machinery, 1379–92. https://doi.org/10.1145/2330784.2330946 (March 8, 2021).

Longo, Giuseppe, Maël Régis Montévil, and Arnaud Pocheville. 2012. 'From Bottom-Up Approaches to Levels of Organization and Extended Critical Transitions'. *Frontiers in Physiology* 3. https://www.frontiersin.org/articles/10.3389/fphys.2012.00232/full (April 23, 2021).

Maldacena, Juan M. 1999. 'The Large N Limit of Superconformal Field Theories and Supergravity'. *International Journal of Theoretical Physics* 38(4): 1113–33.

Marchettini, Nadia, Emilio Del Giudice, Vladimir Voeikov, and Enzo Tiezzi. 2010. 'Water: A Medium Where Dissipative Structures Are Produced by a Coherent Dynamics'. *Journal of Theoretical Biology* 265(4): 511–16.

Marković, Dimitrije, and Claudius Gros. 2014. 'Power Laws and Self-Organized Criticality in Theory and Nature'. *Physics Reports* 536(2): 41–74.

Maturana, H. R., and F. J. Varela. 2012. *Autopoiesis and Cognition: The Realization of the Living*. Springer Science & Business Media.

Mitchell, Sandra D. 2003. *Biological Complexity and Integrative Pluralism*. Cambridge University Press.

Mitzenmacher, Michael. 2004. 'A Brief History of Generative Models for Power Law and Lognormal Distributions'. *Internet Mathematics* 1(2): 226–51.

Montévil, Maël, and Matteo Mossio. 2015. 'Biological Organisation as Closure of Constraints'. *Journal of Theoretical Biology* 372: 179–91.

Mora, Thierry, and William Bialek. 2011. 'Are Biological Systems Poised at Criticality?' *Journal of Statistical Physics* 144(2): 268–302.

Moreno, Alvaro, and Matteo Mossio. 2015. 'Biological Autonomy. A Philosophical and Theoretical Enquiry'. https://www.academia.edu/12363315/Biological_Autonomy_A_Philosophical_and_Theoretical_Enquiry (November 25, 2020).

Muñoz, Miguel A. 2018. 'Colloquium: Criticality and Dynamical Scaling in Living Systems'. *Reviews of Modern Physics* 90(3): 031001.

Nave, Kathryn, George Deane, Mark Miller, and Andy Clark. 2020. 'Wilding the Predictive Brain'. *WIREs Cognitive Science* 11(6): e1542.

Newman, MEJ. 2005. 'Power Laws, Pareto Distributions and Zipf's Law'. *Contemporary Physics* 46(5): 323–51.

Nicolis, Grégoire, and Ilya Prigogine. 1977. 'Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations'.

Papineau, David. 2021. 'Naturalism'. In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/sum2021/entries/naturalism/ (October 1, 2022).

Parr, Thomas et al. 2021. 'Memory and Markov Blankets'. *Entropy* 23(9): 1105.

Parr, Thomas, Lancelot Da Costa, and Karl Friston. 2020. 'Markov Blankets, Information Geometry and Stochastic Thermodynamics'. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 378(2164): 20190159.

Parr, Thomas, and Karl Friston. 2019. 'Attention or Salience?' *Current Opinion in Psychology* 29: 1–5.

Proekt, Alex, Jayanth R. Banavar, Amos Maritan, and Donald W. Pfaff. 2012. 'Scale Invariance in the Dynamics of Spontaneous Behavior'. *Proceedings of the National Academy of Sciences* 109(26): 10564–69.

Raja, Vicente et al. 2021. 'The Markov Blanket Trick: On the Scope of the Free Energy Principle and Active Inference'. *Physics of Life Reviews* 39: 49–72.

Ramstead, Maxwell James et al. 2022. *On Bayesian Mechanics: A Physics of and by Beliefs*. arXiv. http://arxiv.org/abs/2205.11543 (June 2, 2022).

Ramstead, Maxwell James, Karl Friston, and Inês Hipólito. 2020. 'Is the Free-Energy Principle a Formal Theory of Semantics? From Variational Density Dynamics to Neural and Phenotypic Representations'. *Entropy* 22(8): 889.

Ramstead, Maxwell James, Michael D Kirchhoff, and Karl Friston. 2020. 'A Tale of Two Densities: Active Inference Is Enactive Inference'. *Adaptive Behavior* 28(4): 225–39.

Ramstead, Maxwell James, Dalton A. R. Sakthivadivel, and Karl Friston. 2022. 'On the Map-Territory Fallacy Fallacy'. http://arxiv.org/abs/2208.06924 (August 31, 2022).

Ryder, Lewis H. 1994. 'Matter-Antimatter Asymmetry in the Early Universe and Violation of Time Reversal Symmetry'. *Contemporary Physics* 35(3): 151–63.

Safron, Adam, Victoria Klimaj, and Inês Hipólito. 2022. 'On the Importance of Being Flexible: Dynamic Brain Networks and Their Potential Functional Significances'. *Frontiers in Systems Neuroscience* 15. https://www.frontiersin.org/article/10.3389/fnsys.2021.688424 (June 11, 2022).

Sakthivadivel, Dalton A. R. 2022a. 'A Constraint Geometry for Inference and Integration'. *arXiv:2203.08119 [cond-mat, physics:math-ph]*. http://arxiv.org/abs/2203.08119 (March 16, 2022).

———. 2022b. 'Towards a Geometry and Analysis for Bayesian Mechanics'. *arXiv:2204.11900 [cond-mat, physics:math-ph, physics:nlin, physics:physics]*. http://arxiv.org/abs/2204.11900 (May 1, 2022).

———. 2022c. 'Weak Markov Blankets in High-Dimensional, Sparsely-Coupled Random Dynamical Systems'. https://arxiv.org/abs/2207.07620v1 (July 19, 2022).

Savage, V. M. et al. 2004. 'The Predominance of Quarter-Power Scaling in Biology'. *Functional Ecology* 18(2): 257–82.

Schrodinger, Erwin. 1944. 'What Is Life'.

Sengupta, Biswa et al. 2016. 'Towards a Neuronal Gauge Theory'. *PLOS Biology* 14(3): e1002400.

Shew, Woodrow L. et al. 2009. 'Neuronal Avalanches Imply Maximum Dynamic Range in Cortical Networks at Criticality'. *Journal of Neuroscience* 29(49): 15595–600.

———. 2011. 'Information Capacity and Transmission Are Maximized in Balanced Cortical Networks with Neuronal Avalanches'. *Journal of Neuroscience* 31(1): 55–63.

Shew, Woodrow L., and Dietmar Plenz. 2013. 'The Functional Benefits of Criticality in the Cortex'. *The Neuroscientist* 19(1): 88–100.

Shilton, Dor, Mati Breski, Daniel Dor, and Eva Jablonka. 2020. 'Human Social Evolution: Self-Domestication or Self-Control?' *Frontiers in Psychology* 11. https://www.frontiersin.org/articles/10.3389/fpsyg.2020.00134/full?utm_source=F-AAE&utm_medium=EMLF&utm_campaign=MRK_1254058_69_Psycho_20200225_arts_A (July 23, 2020).

Smolin, Lee. 2004. 'An Invitation to Loop Quantum Gravity'. In *Quantum Theory and Symmetries*, WORLD SCIENTIFIC, 655–82. https://www.worldscientific.com/doi/abs/10.1142/9789812702340_0078 (July 13, 2022).

Sornette, Didier. 1998. 'Multiplicative Processes and Power Laws'. *Physical Review E* 57(4): 4811–13.

Sperber, Dan. 2011. 'A Naturalistic Ontology for Mechanistic Explanations in the Social Sciences'. *Analytical sociology and social mechanisms*: 64–77.

Stanley, H. Eugene. 1999. 'Scaling, Universality, and Renormalization: Three Pillars of Modern Critical Phenomena'. *Reviews of Modern Physics* 71(2): S358–66.

Stassinopoulos, Dimitris, and Per Bak. 1995. 'Democratic Reinforcement: A Principle for Brain Function'. *Physical Review E* 51(5): 5033–39.

Stumpf, Michael P. H., and Mason A. Porter. 2012. 'Critical Truths About Power Laws'. *Science* 335(6069): 665–66.

Swenson, R., and M.T. Turvey. 1991. 'Thermodynamic Reasons for Perception–Action Cycles'. *Ecological Psychology* 3(4): 317–48.

Tegmark, Max. 2000. 'Importance of Quantum Decoherence in Brain Processes'. *Physical Review E* 61(4): 4194–4206.

———. 2012. 'How Unitary Cosmology Generalizes Thermodynamics and Solves the Inflationary Entropy Problem'. *Physical Review D* 85(12): 123517.

Timpson, Christopher Gordon. 2008. 'Quantum Bayesianism: A Study'. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 39(3): 579–609.

Touboul, Jonathan, and Alain Destexhe. 2010. 'Can Power-Law Scaling and Neuronal Avalanches Arise from Stochastic Dynamics?' *PLOS ONE* 5(2): e8982.

———. 2017. 'Power-Law Statistics and Universal Scaling in the Absence of Criticality'. *Physical Review E* 95(1): 012413.

Tschacher, Wolfgang, and Hermann Haken. 2007. 'Intentionality in Non-Equilibrium Systems? The Functional Aspects of Self-Organized Pattern Formation'. *New Ideas in Psychology* 25(1): 1–15.

Turing, A. M. 1953. 'The Chemical Basis of Morphogenesis'. *Bulletin of Mathematical Biology* 52(1): 153–97.

Uhlig, Maximilian, Anna Levina, Theo Geisel, and J. Michael Herrmann. 2013. 'Critical Dynamics in Associative Memory Networks'. *Frontiers in Computational Neuroscience* 7. https://www.frontiersin.org/articles/10.3389/fncom.2013.00087/full (October 6, 2020).

Veissière, Samuel P. L. et al. 2020. 'Thinking through Other Minds: A Variational Approach to Cognition and Culture'. *Behavioral and Brain Sciences* 43.

https://www.cambridge.org/core/journals/behavioral-and-brain-sciences/article/thinking-through-other-minds-a-variational-approach-to-cognition-and-culture/9A10399BA85F428D5943DD847092C14A (October 7, 2020).

Wilson, Kenneth G. 1975. 'The Renormalization Group: Critical Phenomena and the Kondo Problem'. *Reviews of Modern Physics* 47(4): 773–840.

———. 1983. 'The Renormalization Group and Critical Phenomena'. *Reviews of Modern Physics* 55(3): 583–600.

Witten, Edward. 1998. 'Anti De Sitter Space And Holography'. http://arxiv.org/abs/hep-th/9802150 (September 12, 2022).

Woodward, James. 2021. 'Scientific Explanation'. In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2021/entries/scientific-explanation/ (March 31, 2021).