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Comment

Physical model of qualitative cognition
Comment on "Physics of mind: Experimental confirmations of theoretical predictions" by F. Schoeller, L. Perlovsky and D. Arseniev

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The review of Schoeller, Perlovsky and Arseniev [1] encompasses and revisits several lives of dedicated and passionate work on a topic that concerns the heart of human beings: qualitative cognition, i.e. what makes us a subject. This rich review covers philosophical, logical, computational, biological, physiological, psychological, cognitive, physical, spiritual and artistic aspects of the subjective qualitative cognition. Remarkably, such a wide covering is achieved quite consistently and in a single framework, further justifying their statement about the "unity of the entire life experience" and the possible physical origin and handling of purely subjective qualities. To offer just a little taste of their work, one of the nice central propositions of their theory states that aesthetic emotion is the result of the satisfaction of the knowledge instinct: a Darwinian view. Providing a rational, computational and empirical coherent framework for such a basic statement is nothing but a scientific tour de force achieved here. This is just one example, but their review offers a rather complete inventory that structures the qualitative aspects of cognition, encompassing instincts, concepts, ideas, consciousness, altruism, emotions, perceptions, behavior, purpose, aesthetic, beauty, imagination and language: a methodically organized qualitative cosmogony of the subject where aesthetic emotions sit at the top of a vague-to-crisp cognitive hierarchy. The authors present an original psychophysical study of chills that corroborates the construction and prediction of their model.

The spectrum of the review is broad and mainly focuses on previous work from the authors corresponding to the successive stages of the construction of their theory. In what follows, we can only propose to open some perspectives about possible future lines of research opened by their work, and some possible relations with other theories proposed in the various investigated topics.

Finite dynamic logic The fundamental statement of the review is rooted in logic. Most of the reasoning about logic of the review is motivated and justified by the statement that "computational complexity has been shown to be equivalent to Gödelian incompleteness of logic", which could be further expressed in more formal statements, as developed below. This statement justifies the claim that AI and machine learning failed: "The various attempts in artificial intelligence (AI) to develop recognition systems by matching sensory images to memories took many years and

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resulted in failures". However, one could reasonably argue that these domains started to be efficiently implemented with non-negligible success due democratization and availability of computational power. The authors also support the idea that the dynamic logic model does not rely ultimately on classical logic (p. 7), although it is implemented on usual computers relying on standard logic as any Turing machine. As proposed by the authors originally in [2,3], cognition, brain computation and their simulations rely essentially on finite models, which behave very differently with respect to the infinite case: "most of the classical theorems of logic fail for finite structures" [4]. In the strictly finite context [2,3], Trakhtenbrot established that the completeness theorem does not hold [5], as reviewed in the work of Libkin [6]. In this finite context, using Trakhtenbrot's theorem, Fagin established the equality between the NP class and existential second-order logic [4], opening some new methods to tackle problems such as the $P = NP$ conjecture. This beautiful characterization of complexity classes within logic, related to the lack of completeness, arises from "classical" logic in a very restricted sense. It would be fairly interesting to determine whether the dynamic logic and its interpretations could be settled using such a finite model framework.

Toward a constructive logic of intuition and philosophy of mind From the philosophical point of view, the review [1] tackles the major problem of avoiding Plato's dichotomic object–subject dualism in cognition [2], as this approach hardly agrees with the purpose of empirical, computational and mathematical investigations of cognition, simply because the object of such studies is the subject. As Plato's view inherently relies on the opposition between metaphysic and physic, it imposes the inaccessibility of the world of ideas to empirical investigations. Aristotle may be opposed to Plato not so much on the relevance of logic for cognition or biological organization, but on the logical methods to achieve such a means. Where Plato defended a systematic dichotomic method (combinatorially in 2^n), Aristotle defended a constructive polytomic method, without excluded third (combinatorially in 3^n, 5^n...) that he applied to the classification of species [7]. The absence of excluded third is the signature of constructive or intuitionistic logic [8], which is also called "non-classical" and is a generalization of Boolean algebras to Heyting algebras. The requirement of finite models in this context is non-trivial, and implies a multiplicity of logics because there is no single finite Heyting algebra that satisfies Soundness and Completeness [9] (but they are sufficient to preserve the semantics as stated in theorem 2.4.8 of Sorensen and Urzyczyn [9]). It is hence tempting to pursue the formalization of intuition proposed by Schoeller et and colleagues [1] on the constructive–intuitionistic road. Could the proposed Kantian model correspond to infinite Heyting setting; could aesthetic be constructive?

Monadic synthesis of reflexive and qualitative consciousness Concerning psychological theories, a remarkable consequence of avoiding such a dualism is to allow the authors to propose a unified theory of consciousness where previous studies led unavoidably to a separation between reflexive and qualitative consciousness as expressed by Chalmers [10] (or conscious access and self-representation in Tononi and Edelman's work [11,12]): the "easy" (cybernetic – feedback) and "Hard" (qualia – spiritual) problems. Such an equivalence is the basis of the monads of Leibniz: could their model be understood as a formalization of psychological monads?

Probability, measure, beliefs and multi-level propagation of emotions In a first step, the model of dynamic logic consists in two interconnected layers. The first equation (1) is reminiscent of Bayes theorem, while the second (2) is reminiscent of a Bernoulli law. An interesting perspective would therefore consist in analytically investigating this model. Moreover a direct formulation in usual probabilistic or measure theoretic terms, which only appears more explicitly in section 4, could allow to further improve the usual Bayesian interpretations of cognition and neuronal computation [13]. Then the knowledge instinct, which is implemented by a learning task, maximizes a similarity function (eq. (3)) between the bottom and the top representation-layer. This function is reminiscent of the belief propagation algorithms developed notably by Pearl [14], and reminds among other examples the similarity functions used by Frey for message passing [15]. To maximize this high-dimensional similarity function, the descent algorithm (eq. (4)) follows the expectation of the gradient of log-likelihood, which in terms of information geometry (see the book of Amari and Nagaoka for review [16]) should correspond to finding the extrema of the Fisher metric. The parameters are initialized as the equidistributed distribution (maximum entropy, no prior), and the authors provide a cognitively meaningful and interesting interpretation of this initial state as a "vague representation". Computationally, it would be also interesting to systematically investigate the dependence of the object recognition capacity on the number of objects and situations. The second step of the model relies on a generalization to a multi-level hierarchy of interconnected layers, formalizing a sequential abstraction process. As the resulting framework relies on the

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