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Cellular gauge symmetry and the Li organization principle: General considerations

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Based on novel topological considerations, we postulate a gauge symmetry for living cells and proceed to interpret it from a consistent Eastern perspective: the *li* organization principle. In our framework, the reference system is the living cell, equipped with general symmetries and energetic constraints standing for the intertwined biochemical, metabolic and signaling pathways that allow the global homeostasis of the system. Environmental stimuli stand for forces able to locally break the symmetry of metabolic/signaling pathways, while the species-specific DNA is the gauge field that restores the global homeostasis after external perturbations. We apply the Borsuk-Ulam Theorem (BUT) to operationalize a methodology in terms of topology/gauge fields and subsequently inquire about the evolution from inorganic to organic structures and to the prokaryotic and eukaryotic modes of organization. We converge on the strategic role that second messengers have played regarding the emergence of a unitary gauge field with profound evolutionary implications. A new avenue for a deeper investigation of biological complexity looms. Philosophically, we might be reminded of the duality between two essential concepts proposed by the great Chinese synthesizer Zhu Xi (in the XIII Century). On the one side the *li* organization principle, equivalent to the dynamic interplay between symmetry and information; and on the other side the *qi* principle, equivalent to the energy participating in the process—both always interlinked with each other. In contemporary terms, it would mean the required interconnection between information and energy, and the necessity to revise essential principles of information philosophy.

Contents

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1. Introduction

The present paper is an attempt to extend a fundamental theory of modern physics, quite useful for the description of interactions between particles and fields, to the cellular dynamics of response to environmental signals and metabolites. Although a rigorous philosophical interpretation of this fresh and still tentative exploration of biological complexity cannot be properly framed yet (considering that the scientific exploration itself needs to be consolidated first), the work may provoke interesting philosophical-scientific and historical reflections as well—we will try to initiate them herein. Relevant names of modern physics have already made noticeable inroads about analogies between particle physics and Eastern thought: from Niels Bohr, to Werner Heisenberg, to Murray Gell-Mann. The arch famous book *The Tao of Physics* by Fritjof Capra (1975) popularized in the 1970's and 1980's a radical vision about that. But not many attempts have been made in biology or specifically in theoretical biology in that very direction. Finding a thinker of XIII Century in China who was proposing an explanatory framework which −arguably− is highly similar in abstract terms to the theoretical stance herein explored becomes rather surprising. But according to Joseph *Needham's* monumental work on *Science and Civilization in China* (1954–2015), we are in the forefront of the highest synthesizer, the truly Eastern equivalent to −and contemporary of− Thomas Aquinas' *Summa Theologicae* (cf. P. Kreeft, 2012). Indeed, the qualification of this work comes out far afield from the way of thinking that Western authors, both philosophers and scientists, were traditionally holding about the integration of life's processes, not to mention the "theories" during the medieval times or the mechanistic approaches during the scientific revolution (Chan, 1963). In another front, given that the gauge symmetry herein proposed implies a deep reconsideration of the informational dynamics of the living cell, putting it in a common framework with the basic gauge symmetry dynamics of the microphysical world, it would imply therefore rather complex information-symmetry-energy speculations that can be easily miscarried or misinterpreted because of their difficulty.

Therefore, in order to disentangle the different aspects involved, we will try to advance in a series of ordered discussion steps. Firstly, in the rest of this Introduction, we will attempt the direct presentation of gauge symmetry as based on new topological considerations, essentially the Borsuk-Ulam Theorem (BUT). Then, we will describe our theoretical construct of "topological cells", which will be based on a complexity index, energy considerations, and the interpretation of biomolecular pathways as "topological strings" (see below). Further, we will develop a more detailed gauge theory for these topological cells; we will discuss the results obtained and will extrapolate for the assessment of further biological complexity. We will see in the discussion that the mutual upholding between signals and mosaic gauge fields converged into the most robust dynamics via the emergence of second messengers, which really mark the transition from multiple proto-gauge fields to the genuine gauge field involving the response of the entire system. At the end of this technical presentation, we will retake the philosophical discussion, arguing that it is not just a matter of historical record, or an anecdotal comment about the *li* and the *qi* cleverly foreseen as organization principles many centuries ago; it is also an important concern in today's multidisciplinary dialogs around life, involving the relationships of information science (bioinformation in this case) and information philosophy (Wu, 1981, 2006, 2012; Brenner, 2011). Indeed, information appears as one of the main arenas where a new interpretation of life is nowadays attempted.

1.1. Introducing gauge symmetry and BUT

A gauge theory states that, in systems equipped with an internal symmetry and a preserved physical quantity, the local symmetry breaks due to external forces are counteracted by another force, called gauge field (Zeidler, 2011). Gauge theories, successfully developed in physics (Higgs, 1964), have been recently proposed for the evaluation of neuronal activities (Sengupta et al., 2016). Here we make an effort to operationalize a gauge theory also for cellular function. It is a very difficult task, because managing the astonishing numbers of molecular states and interactions continues to be a fundamental obstacle in building predictive models of biological systems (Sneddon et al., 2011); it is so despite pioneering works in bioenergetics and systems science which already obtained staggering figures for the minimal information describing the simplest cells (Morowitz, 1968; Riedl, 1978). Herein we will try to overtake the overwhelming complexity of cellular activity with the invaluable help of recently developed topological tools.

The Borsuk-Ulam theorem (BUT) states that, when a pair of opposite (antipodal) points on a 3D sphere are continuously mapped onto a 2D a circumference, their projections have matching description (Tozzi and Peters, 2016a). Recently developed BUT variants can be summarized as follows: a single feature embedded in a n dimensions M^n manifold maps to two features with matching description on a M^{n+1} manifold (Tozzi and Peters, 2016b; Peters and Tozzi, 2016; Peters, 2016). In case of convex manifolds, such as, e.g., disks and spheres, we will term them S^n and S^{n+1}. Single features may stand for physical or biological characteristics, such as points, lines, surfaces, functions, vectors, spatial or temporal patterns, movements, particle trajectories, thermodynamic features, signals and, above all, symmetries. The manifold M may be equipped with every kind of curvature: concave, flat or convex (Tozzi, 2016; Peters et al., 2016). The number n may stand for different kinds of dimensions, *e.g.*, spatial, temporal, complexity, and for different numbers, *e.g.*, natural, rational, irrational, imaginary. Matching features can be described as characteristics of paths or trajectories on abstract structures and allow system features commensurability. It looks like a transparent glass sphere between a light source and your eyes. You watch two lights on the sphere surface instead of one. But the two lights are not just images; they are also real. Matching features can be thus assessed at one level of

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