Cogn Neurodyn (2012) 6:199–202
DOI 10.1007/s11571-011-9187-4

BRIEF COMMUNICATION

From brain states to mental phenomena via phase space transitions and renormalization group transformation: proposal of a theory

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Received: 13 July 2011 / Revised: 10 October 2011 / Accepted: 26 December 2011 / Published online: 4 January 2012

Introduction and background

The comprehensive analysis of substantive and foundational issues in neurodynamics by Atmanspacher and Rotter (2008) provides one component of the conceptual background for this proposal, notably in regard to explicit clarification of ontic states and epistemic descriptions, and the cogency or their distinction and relationships: the former referring to ontic states ‘just as they are’, context independent, without any reference to an observer or knowledge; the latter designating the knowledge (generally incomplete) that can be obtained about an ontic state.

Brain State Dynamics and Complexity are the second constellation of background issues: Studying neural activity in terms of state space representations has proven of great heuristic value (Wackermann and Allefeld 2009) to account for the spatial and temporal dynamics of neural systems at micro-, meso- and macroscopic granularity. Its merit lies in making conceptual tools of statistical mechanics (Stanley 1971, 1999) available for neural data interpretation. Essentially, this entails associating a measure of neural activity with a point (or region) in a usually high dimensional space, and following the path taken under the control of dynamic evolution equations. It is crucially important for the topic of this communication that the dynamics of neural systems displays at all levels of organization the property of criticality. According to Critical Theory of Statistical Physics, a system’s dynamics can encounter singularities along its path through state space, which trigger sudden phase transitions to new macroscopic configurations with distinctly novel properties. The occurrence of such singularities in neural dynamics and associated phase transitions is by now amply established for all levels of neural system organization, and is documented in recent reviews by Chialvo (2010), Tagliazucchi and Chialvo (2011), and Werner (2010). Brain phase transitions between active-conscious and unconscious states are observed at critical values of anesthetic concentration (Steyn-Ross and Steyn-Ross 2010).

One important aspect of the system reconfiguration in phase transition consists of a change of the correlation function among its elements, which characterizes how the value at one point in state space correlates with the value at another point. While ordinarily extending only over short distances, correlation length increases with approach to the critical point of phase transition, establishing new patterns of collective interactions among the system’s components. In this process, the system loses all characteristic length scales for system specific variables: it becomes scale invariant, i.e. fractal (Stanley 1971, 1999). Applying this theoretical framework, Kitzbichler et al. (2009) compared phase synchronization and scaling in critical models with global synchronization in fMRI and MEG records from humans at rest, and found essential correspondence, suggesting that functional systems in brain exist in a state of endogenous criticality. Fraiman et al. (2009) determined brain correlation networks from fMRI voxel-to-voxel correlations under the same computational conditions, and arrived at the same conclusion: Comparing their human data with correlation networks of a computational model of magnetic spins (Ising model) showed close correspondence in all relevant respects, thus also supporting the conjecture of the human brain at rest functioning at or near a critical point. In addition, Expert et al. (2010) identified in human brain fMRI records the emergence of nontrivial collectives

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in a critical state. As noted before, they are evident as correlations between different points in space and at different times displaying spatial self-similarity, while the temporal patterns exhibit power-law (1/f) behavior of the power spectrum.

Concurrently with these developments, the focus of interest also extended to the nascent field of Complex Networks, situated at the intersection of graph theory and statistical physics (Costa et al. 2007). Their common features are inverse power-law statistical distributions, multiplicity of scales, manifestations of non-stationary, and non-ergodic statistical processes (West and Grigolini 2011; for review of neurobiological data, see: Werner 2010).

The following example of an elementary phase transition, and its implications, is intended to prepare the stage for introducing in the next Section the essential features of RNG. Consider water as a system which under changing temperature moves along a trajectory in state space to a critical point at which a phase transition to ice occurs. This consists on the molecular level in establishing new correlation patterns by coupling microscopic degrees of freedom to each other, making them effectively act as single entities which correlate with the previously referred scale invariance. Concurrently, certain numerical parameters (the 'critical exponents') characterize the system which are universal in the sense that they apply to entire classes of systems, comprising materials of very different microscopic constituents. In some sense, the system has 'forgotten' its earlier micro-configuration and joins a certain universality class whose members share some very general system properties, such as dimensionality and the length of range of interactions (see for instance: Wilson and Kogut 1974; Stanley 1971). The decisive issue for the purposes of the present proposal is the fact that the molecular rearrangement becomes at the macroscopic level manifest as a set of qualitatively new properties that could not be deduced from the microscopic state change, nor could it be anticipated from the prior macroscopic state. Thus, arises the opportunity of assigning new descriptors, for instance replacing 'fluidity' with 'solidity'. Herein lies one of the premises of this proposal: the change in the ontic state of the system's micro-configuration enabling a new macroscopic epistemics. In the next section, I turn to a RNG which establishes criteria for sequential application of this process.

Applying the renormalization group transformation (RNG)

Freeman and Cao (2008) sketched earlier some aspects of RNG in reference to perception, as did I (Werner 2009) in regard to cognition- and consciousness-related neural events. RNG is both a computational approach (Wilson 1971; Fisher 1998; Goldenfeld 1992) and a way of viewing reality Sokal and Bricmont 2004). In the former, the Renormalization Group Theory studies the dynamics of sequential phase transitions. This is understood as a mapping of a complex system space onto itself in the stepwise traversal of its basin of attraction (that is: its critical manifold) towards an ultimate critical fixed point (Sethna 2006). On consecutive steps of successive phase transitions, the system 'defines many different worlds', as Kadanoff (2011) aptly put it. The trajectory by which these consecutive 'worlds' originate is the subject of computational RNG, each step resulting in an increasing degree of correlations among system constituents. Metaphorically speaking, viewing the steps in the sequence of transformation as 'different worlds' is to highlight that each new correlation pattern of the system manifests itself at the macroscopic system level as qualitative novelty, obeying new laws and requiring new descriptors. Thus, the consecutive RNG transformations along a punctuated sequence of phase transitions transformations delimit levels of qualitatively different realities, each with its own scale and grain of resolution, and governed by its own laws and subject to new macroscopic descriptors.

The Renormalization Group view of reality elevates its computational theory to an epistemic principle: like a deck of cards, reality is considered a hierarchy of levels where, on each level, elements are collectively organized to structures with their intrinsic scales and configurations. In short: each level is an ontology, as such offering the opportunity for, and requiring the assignment of its own, distinct macroscopic description (i.e. their epistemics). Consecutive levels are related to each another by phase transitions. The relation works both ways: the transition from a lower to a higher level organizes the distinct objects of macroscopic levels of daily experience (Laughlin 2005); in the reverse order, epistemic access to new ontologies from phase transitions provide the opportunity for assigning new descriptors to the qualitative novelties the system dynamics has delivered.

Although unrelated to RNG, but for intuitive appreciation of this phenomenon consider the following historically notable illustration: when Anthony von Leuwenhoek in 1674 increased the magnification of his microscope to a certain (critical!) degree, he saw suddenly a populated world of protists, never previously expected to be part of the water drop he examined. In other words, he accessed the ontology of a new level of reality which needed to be described in new terms, i.e. required a new epistemology. Further improvement of optic resolution enabled subsequently access to still other features, say: mitochondria of individual cells, etc. In RNG terms, changing the magnification is equivalent to a step along a transformation trajectory associated with the change of the grain of observation; each new level requiring description in new terms, and discovery of new laws. This much for a stunning entries into new, previously unknown levels of Reality by changing the grain of resolution of observation. In RNG terms, changing the magnifications is equivalent to steps along a transformation trajectory associated with the change of the grain of observation; in this case to a finer grain.

Mental phenomena viewed in the framework of RNG

The objective of this essay, outlined in the Introduction, is to conceive the realm of subjective mental phenomena as an ontology whose epistemic access constitutes the features of experiential subjectivity. For a program of rationalizing subjectivity in Natural Science terms I suggest that the Renormalization world view is a useful and plausible conceptual platform. Specifically, I envision an ontology of Personhood which, in the format of a complex dynamical system, encompasses the body (somatic as well as autonomic), in association with the brain, and portions of the relevant (cognitive) environment (Werner 2011). Trajectories of Phase Transitions describe sequences of physical brain states, each providing the substrate for epistemic access as qualitative characterization of subjective mental states. Thus, the sequence of consecutive phase transitions would be associated with distinct kinds of mental phenomena, whereby each of the consecutive levels of the Renormalization process is at the ontic level a collective achievement with different granularity of resolution in details and different degrees of correlation of system components.

The trajectory of phase transitions forms in toto the path to a fixed point which would mark the fully conscious state. The density of correlation among the elements of a level reaches a maximum at the Fixed Point of RNG where it covers the total range of self-similar (fractal) scales, indicative of optimal integration of correlated activity. Note the difference to the more common and more intuitive view that Consciousness 'emerges' from neural mechanisms as a higher level of organization. The opposite is proposed here: The levels of subjectivity arise as ontologies in the phase transitions from the more encompassing (higher level) ontology of the world-body-brain Physics to subordinate levels; and can do so stepwise at consecutive levels of different resolution in details. This may be associated with the taxonomy of conscious, preconscious and subliminal processing which Dehaene (2009) describes.

Although drawn in crude brushstrokes, this sketch of applying the Renormalization view of the world to the subjectivity of mental phenomena is in principle amenable to testing its plausibility. This can be pursued by capitalizing in models on the computational assets of RNG. As starting points, the work of Song et al. (2005) and Radicchi et al. (2008) with RNG transformations of simple models of complex networks offers valuable clues.

As a final implication of Renormalization Group application, note that the forgoing speculations situate the problem of Brain Physiology in the parent domain of Condense Matter Physics (see for instance: Marder 2000). This suggests an interesting perspective: for the principle of Universality would permit identifying whether, and to what degree, other materials in Nature may possess features indicative of a form of consciousness, once it would have been possible to determine the Universality class of which the ontology of Personhood is a member.

Summary

On the premise of the ontology of personhood as a complex dynamical system, consisting of brain, body and the behaviorally relevant segment of environment, I suggest that the theory of Renormalization Group Transformation of Statistical Physics provides a conceptual framework that can account for subjective mental phenomena by enabling the epistemic access to physical brain states.

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