Isoqualitative Gauge Curvature at Multiple Scales: A Response to the Agnosticism of Quantum Cognitivism and Quantum Interaction

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ABSTRACT

Potential dualism lurks behind the metaphysical agnosticism of quantum cognitive and quantum interactionist models. This paper identifies and addresses two possible sources of such dualism: a) the theoretical distinction between canonically conjugate and other sets of observables, and b) the empirical issue of in vivo thermal decoherence threatening the integrity of any neural wavefunctions associated with quantum cognition. An isoqualitative distortion gauge structured like the q-boson has been proposed in previously published work by the author to address source a) and is now reviewed. A new construct, quantum auto-tunneling, analogous to the well-established classical notion of autocatalysis, is introduced in order to engage problematic aspects of source b).

Key Words: agnosticism, autocatalysis, decoherence, Fourier duality, fractal, Hard Problem, isoqualitative, photosynthesis, psychophysics, qualia, quantum cognition, quantum interaction, tunneling

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1. The Challenge of Quantum-Psychophysical Dualism

In their 2013 paper, "*Can Quantum Probability Provide a New Direction for Cognitive Modeling?*", Pothos and Busemeyer argued that quantum-formal models of cognition fit the bulk of existing data in the research literature with more empirical accuracy and more axiomatic parsimony than does standard modeling via non-quantum Bayesian probability (Pothos and Busemeyer, 2013). A case can indeed be made that greater empirical accuracy is achieved by quantum-formal models incorporating unitary time evolution, entanglement, superpositional interference, and order-dependent effects of sequentially assayed observables (Bruza *et al.,* 2015; Mender, 2013b; Pothos and Busemeyer, 2013). Enhanced axiomatic parsimony may also be gained through the fiber bundled mapping of classical Gibbsian phase spaces and their cognitively networked analogies into generalized quantum phase space (Bernstein and Phillips, 1981; Mender, 2010).

Views allied with those of Pothos and Busemeyer have been propounded elsewhere as well. Their approach represents an instance of more widespread ambitions, variously subsumed under disciplinary labels like "quantum cognition" and "quantum interaction," to capture mathematically the psychological properties of individual thinking and also of social processes

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through the considerable power of formal abstractions from quantum physics (Bruza *et al.,* 2015; Busemeyer *et al.,* 2015). Yet a deep problem arises in connection with this apparently promising agenda.

The fly in the ointment is a self-avowed quasi-metaphysical "agnosticism" among many quantum cognitivists and quantum interactionists concerning the question of a link between the abstractions of disembodied quantum formalisms and the concrete physicality of quantum mechanics. This retreat by such proponents of quantum cognition and quantum interaction from engagement with the gap between a quantized view of mentation and the physics of neural processes threatens to create a new form of metaphysical dualism, aggravating the difficulty of effectively addressing the ever-refractory "Hard Problem of Consciousness" (Chalmers, 1995; 1996). A possible quantum-dualistic breach may thereby be opened up between quantum mind and quantum brain along two distinct fault lines.

The first potential fault line is a theoretical discrepancy between, on one hand, great latitude permitted in relationships among the quantifiably qualitative observables posited by "agnostic" quantum cognition/interaction and, on the other hand, strict limits on allowed relationships among physical observables germane to neuroscientific measurement. In general, Pothos, Busemeyer, and allied theorists appear to have advocated the permissibility of modeling any pair of observables as algebraically non-commutative in order to account for order-dependency of empirical cognitive data. In contrast, quantum physics, which must undergird any physically plausible quantum neurodynamics, requires that certain pairs of quantifiable observables, such as energy and time or distance and momentum, but not others, such as energy and distance or quantified qualities farther afield like "sourness" and "bitterness," fail to commute multiplicatively. Order-dependent physical observables in the parlance of quantum mechanics are termed incompatible, while all others, including those in the domain of cognition and perception, are mutually "compatible."

The second potential fault line, an empirically based barrier, reflects contradictions between holistic quantum coherence, implied by quantum cognition/interaction for molar mental phenomena, and the thermally decohering effects of biological milieus on macroscopic brain states. Decoherence of quantum wavefunctions perturbed by demonstrably wet and warm conditions within the functioning brain has provided the basis of an influential critique mounted by Tegmark (2000) against non-trivially quantum accounts of cognitive neurophysics like the OrchOR model proposed by Penrose and Hameroff (Hagan *et al.,* 2002; Hameroff and Penrose, 1996) or the thermofield models propounded by Umezawa and his successors (Globus, 2003; Jibu and Yasue, 1994; Umezawa, 1993; Vitiello, 2001).

Quantum cognitivists and quantum interactionists who prefer to remain "agnostic" about any nexus between abstract quantum formalisms as tools for modeling mind and corporeally realized quantum physics as instantiated within the brain's operations thus risk potential dualism on two levels. First, in the theoretical domain, the square peg of noncommutative observables representing order-dependent sets of quantized qualities such as "sourness and "bitterness" cannot be reconciled with the round hole of commutation to which the axioms of quantum physics applicable to the brain are compelled to assign such mutually compatible observables (Mender, 2013a; Mender, 2013b). Second, in the empirical domain, the holistic coherence celebrated by quantum cognitivists/interactionists modeling molar mental gestalts is shattered by thermal decoherence effects collapsing wavefunctions throughout living brains.

2. An Outline of Two Possible Paths Forward

Is there a way through these two potential explanatory gaps in quantum cognition/interaction, which threaten to exacerbate rather than illuminate the Hard Problem of Consciousness?

It has already been argued previously by this author that at least theoretical aspects of the germane issues can be addressed through formulation of a quantum cognitive analogy to the q-boson (Tuszynski, 1993) employed by physicists in second quantization. That is, in the theoretical realm, quantum cognitive adaptation of the "distortion" gauge mediated by q-bosons may serve to morph compatible sets of observables into the incompatible observables of quantum physics (Mender, 2013a). This morphing conveniently comports with second quantization's applicability to changes of state, in that the pertinent quantized qualities of perception and cognition may naturalistically be assumed to change via processes of habituation and dishabituation (Mender, 2015). Moreover, through an abstract geometry whose curvature is extrinsic to physical processes, the psychophysical distortion gauge happily can avoid the metaphysical pitfall of violating the causal completeness of physics, at least at a locally apparent scale (Mender, 2013a).

In the empirical realm, the author toward the end of this paper will make a new argument attempting to address the threat of a dualistic divide between disembodied quantum cognitive/interactionist holism and the physical decoherence problem. A key notion will entail the novel construct of auto-tunneling, a quantum-psychophysical analogy to autocatalysis, a classical idea originally conceived by Stuart Kauffman to explain nonlinear self-organization in biological systems (Hordijk, 2013). It will be argued that auto-tunneling can resolve scale-related tension between the molar coherence required by quantum cognition and the predicted decohering effects of thermal disruption on wavefunctions of the living brain. Auto-tunneling may accomplish this resolution by anticipating and incorporating crucially fractal properties of aerobic bioenergetics, extending across evolutionary time and ecological space, to enrich otherwise non-integrable "toy" models, whose physically extrinsic curvatures should thereby reprise themselves self-similarly across multiple scales. Auto-tunneling may hence provide a means of freeing quantum coherence, within the perturbative milieu of the brain, from the micro-constraints of Tegmark's concerns. The nontrivial relevance of quantization may thus expand via auto-tunneling to those macro-scales at which abstract quantum cognition and concrete neurophysics must intersect in an ontologically monistic yet causally self-consistent fashion.

3. Historical Contexts of Quantum Cognition/Interaction

As noted above, Pothos and Busemeyer, along with other proponents of quantum cognition/interaction, have recently raised the prospect of supplementing physical observables of quantum mechanics, such as distance, momentum, time, energy, and spin, with psychologically relevant "perceptual" observables, e. g. sweetness, pain, redness, itching, mustiness, etc. In fact, these latter sorts of cognitive "observables," akin to phenomenalist notions of "qualia" said to comprise conscious experience, were abstracted from human consciousness into schematized analogies with the classical dynamical observables of pre-quantum physics as early as the 19th century by the German psychophysicists Weber and Fechner (Mender, 2015).

Moreover, even before Weber and Fechner's quasi-scientific schematization, primitive qualia, prefiguring the physical observables of Newtonian and Hamiltonian paradigms, had long guided embodied sentient beings in coping with existential demands imposed by hostile natural environments. Intelligent ancestors of humans invented ever-improving gambits to secure food and oxygen. Human hunter-gatherers became viscerally canny protophysicists in their lifelong practical struggles to wrest survival from surrounding landscapes and embedding food chains. Aristotle followed hunter gatherers as a conceptual midwife for the mathematical formalizations of Newton and Hamilton. Einstein as the intuitive-scientific thought experimenter par excellence further refined classical dynamics. Quantum innovators took formal approaches to their current level of abstraction far beyond raw physical intuition (Mender, 2015).

From such a historical perspective, it may be instructive to inquire, as Thomas Nagel did in his qualia-oriented paper "What is it Like to be a Bat?" (Nagel, 1974), what it must have been like to struggle as a hunter-gatherer against the unforgiving ecologies of prehistory. Early homo sapiens while hunting and gathering had to trek from point A to point B (distance) employing muscular exertion (energy) to haul self and cargo (inertia linked to momentum) while steering clear of vertiginous (spinning) falls. With the coming of post-medieval physics, metrical distance mathematically abstracted the intuitive feeling of corporeal translation in space; momentum mathematically abstracted the feeling of bodily inertia whose shifts are mediated by vestibular signals to the brain; energy mathematically abstracted the feeling of muscular labor; angular momentum mathematically abstracted the feeling of vertigo; clock measurements of time mathematically abstracted the subjective feeling of temporal flow (Mender, 2015).

During the early 20th century, quantum approaches superseded the abstractions of classical physics, whose deterministic laws were contextualized in principle as a limiting case of more general "quantized" versions. A crucial aspect of quanitization entailed changing the mathematical expression of physical observables from a passive to an active form. Non-quantum observables in Newtonian and Hamiltonian physics had been represented by variables in equations. For instance, the observable 'momentum" appeared as the variable coordinates p_x, p_y, and p_z, which in specific cases would each then take on some definite quantitative numerical component value of the measurable "quality" understood to be momentum. Such pre-quantum observables were formulated to be "possessed" by their embedding equations and thereby served within those mathematical "sentences" as object-nouns. These classical nominative variables exerted no active verb-like influence shaping the quantitative results of empirical measurements but instead simply delineated in a passive manner the dimensionality of the germane qualitative observables. Quantum approaches, on the other hand, have come to represent observables not as noun-like variables, passively possessed by equations, but as operators, acting on those functions as symbolic agents of experimental measurement. The quantum operator imbues an operated function with that observable "quality" lying latent in the observable-verb's specific agency of empirical assay and may thereby pre-limit the expected set of possible quantitative readings (Margenau, 1977).

4. The Theoretical Trap

Although the quantum operator-verb configures the qualitative attributes of a pertinent observable measurement in the same way that the classically variable object-noun has done, the quantum operator-verb, unlike the classical object-noun, exhibits two singularly non-classical behaviors that constrain the quantitative results of measurement. First, quantum measurements "reduce" or "collapse" their targets, constituted through probability amplitudes as so-called wavefunctions acted upon by observable operators; the outcome is a distinctly quantitative yet also wholely random readout, non-deterministically preserving after reduction one element alone among the entire superposition of pre-collapse wavefunction components. Second, as briefly mentioned in the first section of this paper, combination of quantum observables into certain qualitatively defined kinds of sets leads to mutually "incompatible" sorts of reductions; i. e., if one of several incompatible observables is measured with a high degree of exactitude, then the precision with which other observables in that mutually incompatible set can be simultaneously assayed experimentally will be compromised. Both of the above uniquely post-classical effects exerted by operators on quantitative features of experimental observation build into the foundations of quantum measurement a fundamentally unavoidable element of uncertainty.

In algebraic terms, mutually incompatible observables interrelate "noncommutatively"; that is, switching the order in which operators A and B are mutlipled from AB to BA changes the magnitude of their product. For quantum physics, only some groupings of operators, such as those representing position and momentum or energy and time as experimental observables, but not others, such as such as those denoting position and time or energy and distance, demonstrate mutual incompatibility; compatible combinations of quantum observable operators, like all sets of classical observable variables but unlike sets of incompatible quantum observable operators, carry with them no limitations on the exactitude with which multiple observables in any grouping can be assayed.

Among the groupings of quantum operators whose elements display mutual incompatibility is a subgrouping with unique properties. This very specific subset consists of the so-called canonically conjugate observables, interrelated through the attribute of Fourier duality. Fourier-dual observables are one another's Fourier transforms; such reciprocity constitutes a kind of invariance, termed antisymmetry or skew symmetry, in which interchanging a function's arguments flips the function's numerical value to its opposite (negative to positive or positive to negative) sign. Fourier duality between canonically conjugate observables can be traced to their classical origins in the "Poisson brackets," used by Hamilton and others, and the torque-oriented notation of Levi-Civita, generalizing the passively predicative coordinatization of Newtonian physics. However, quantized Fourier duality manifests a new and active post-classical role for observable operators through a

NeuroQuantology | December 2016 | Volume 14 | Issue 4 | Page 756-763 | doi: 10.14704/nq.2016.14.4.988
Mender D., Isoqualitative gauge curvature at multiple scales

specifically Fourier dual expression of quantum uncertainty in measured experimental results: for any two canonically conjugate quantum operators C and D, a sharply spiked statistical distribution of assayed outcomes for C leads necessarily to continuously sinusoidal oscillations of probability amplitudes for D, and vice versa.

It is problematic for "agnostic" quantum cognitivists/interactionists that the groups of observables definable as canonical conjugates are finite and small and by no means exhausts the endless varieties of possible qualia. Multiplying together the elements (e. g. energy X time, momentum X position) comprising any set of canonically conjugate observables must yield a product with the dimensionality of "action," i. e. of the classical Lagrangian and Planck's quantizing constant. In contrast to this qualitative limitation on the dimensionality of canonical conjugates, psychophysical observables may generally track any subjective "quale" from a pungent odor to a burning sensation to an angry sentiment. In principle all such ostensibly "non-physical" subjective "qualia" may be assigned quantitative values of experiential intensity according to the pre-quantum paradigm of Weber and Fechner; a probabilistically self-consistent take on the intensity of qualia may even be modeled mathematically by ersatz linear superpositions along "agnostic" lines proposed by Pothos, Busemeyer, and their allies. However, most sets of experienced qualia, which are not tracked by canonically conjugate quantum observables and hence do not yield products with the dimensionality of "action," cannot be assumed within the rubric of standard quantum physics to exhibit either noncommutative or Fourier-dual attributes (Mender, 2013a; Mender, 2013b).

5. Toy Monisms

It therefore seems apt to identify canonically conjugate quantum observables as the crucial point of attack in any attempt to transcend quantum interactionist/cognitivist "agnosticism" and thereby expand quantum psychophysics non-dualistically beyond standard quantum-physical limitations. A justification for this point of departure is that qualities formalized by canonically conjugate quantum observables, as previously discussed in the historical section of this paper and in contrast to other more purely quantitative operators, may be intuitively related to pre-quantum derivations from qualitative human experience. It will be argued below that a formal extension not yet considered either by standard physical approaches or by "agnostic" quantum/cognitivists can facilitate a true generalization of Fourier-dual skew symmetry to encompass psychophysical observables quantitatively linked with phenomenalistic "qualia." Such an agenda may be realized through a gauge-like distortion operator that opens up all possible sets of psychophysical observables to Fourier-dual noncommutativity by "warping" them into virtual "isoquality" with a product whose dimension is effectively "action." For this isoqualitative distortion gauge model, qualitative warping effects in one limiting case, entailing canonically conjugate observables themselves, must quantitatively vanish, while for other qualities warping must be non-negligible. The model also requires the relevant distortion gauge architecture to leave standard quantum physics, within the context of experimental designs customarily employed by quantum physicists, in conformity with the apparent causal completeness of conventional physical phenomena; this requirement constrains isoqualitative "warping" into a gauge curvature "extrinsic" to observables of a putatively "purely physical" character. All these specifications, requirements, and constraints aim at a self-consistent generalization of noncommutative Fourier duality, capturing within a new, synthetically monistic kind of quantum psychophysics not only physical observables but also psychologically germane "qualia" as well.

For purposes of visualization and further refinement of the above proposal, one may consider a "toy" geometrical model of the isoqualitative distortion gauge just described. Defects in the "toy" analogy will be heuristically identified and addressed in this paper's later section on auto-tunneling. Setting aside the issue of such defects for the moment, one can imagine that the antisymmetrical "space" of canonically conjugate Fourier duality is a flat plane. The plane may be attached as a tangent to any single point on a smoothly curved two-dimensional surface. The "curvature" of that latter surface may be either intrinsic or extrinsic to the curved surface's geometry. If relevant warping architecture bends the surface into a sphere, then the pertinent curvature will be evident intrinsically: triangulated "surveys" undertaken purely within the curved two-dimensional surface of the sphere without extension into a third dimension of "depth" will produce a measurably non-Euclidean vertex angle sum. However, if the curved architecture molds the surface into a cylinder, then the curvature will not be measurable by any intrinsic survey; triangulated surveys constrained within the surface itself will sum the angles of a triangle to 180 degrees, a value identical to that surveyed within any Euclidean tangent plane. Only from an extrinsic vantage point, i. e. extending out of the surface into the third dimension, will cylindrical curvature be detectable.

The virtue of this "toy" analogy is its intuitively illustrative concretization of the epistemologically self-consistent way in which noncommutative Fourier duality can be extended from canonically conjugate quantum operators to all sets of qualia. Extrinsic properties of the curvature, representing a "toy" version of "psychological" qualities, evade detection by the "surveyor's" triangulations within the surface of the "cylinder," representing the intrinsic limits of a "purely" physical assay in apparent conformity with the causal completeness of standard physics.

Straightforward extrapolation beyond extrinsic curvature of the cylinder analogically conforming to the causal completeness of standard physics carries implications pointing toward more detailed "toy" elaborations. Comparing extrinsic curvature of a cylinder's surface with both the intrinsic curvature of the sphere's surface and the null curvature of the flat plane contrasts differently expressed symmetries of the three applicable geometries. The plane demonstrates global symmetry regarding invariant shapes whose constituent points are each moved a mutually identical distance and direction within that flat surface. The surface of the sphere demonstrates symmetry only to the degree that, once a "gauge" compensating for curvature is applied with locally variable flexibility to each particular point of a shifted shape, an identical invariance can be inferred for all points; this constitutes a local rather than a global symmetry. The symmetry demonstrated by the cylinder's surface seems similar to that of the plane, but this correspondence is not total: figures moved along a loop across the entire surface of the cylinder around the total "bend" of "extrinsic" curvature will be topologically "copied"; this directionally selective copying is an expression of global symmetry breaking. Further topological elaborations of the cylinder's surface and its symmetry breaking will be created by bending the cylinder's ends together into a donut shape, and then adding additional pretzel-like holes, i. e. increasing the "genus" of the manifold. Each integer-valued "genus" may be expected to model (as an elaborated though still "toy" topology) its own globally connective tier of psychophysical properties (Mender, 2013a).

6. The Empirical Span Across Scales

We must now turn to a crucial technical flaw in the above compendium of toy models, though this flaw has heuristic value. While it is true that a "flat" symmetrical vector space can be configured as an analogy to a "plane" that is "tangent" to some specifiable curved manifold (e. g. sphere, donut-like torus, or higher-genus pretzel-like structure), no antisymmetrical "flat limit" with the capability of serving such a "tangent" role can be defined. Instead, the "curved" manifold relevant to a hoped for antisymmetrical tangent considered "tangent" is non-differentiable; this issue relates to divergently non-integrable features (Penrose, 2005) imposing the constraints of chaos on the determinacy of the elusive tangent vector space's conformation.

That complication, however, points to dynamically fractal modes of redress. Such fractal dynamical constructs may allow non-linear, far-from equilibrium aspects of living systems, including the sentient brain in vivo, to be reconciled with Tegmark's empirical objection that thermal perturbations disrupt the linear coherence of would be holistic cognitive wavefunctions.

The pertinent biophysical phenomena to be captured by fractally geometrical refinements eclipsing "toy" models begin with quantum aspects of solar energy harvesting by photosynthesis, which can be viewed in terms of parallels between Heisenberg uncertainty and classical biochemical catalysis. Both green quantum photon capture and catalytic processes entailing enzymes in biomolecular systems accelerate applicable biological processes by breaching germane energy barriers between minimal states at the start and end of relevant reactions. Enzymes and other catalysts effect such acceleration by lowering selected energy barriers; quantum photosynthesis operates via tunneling through energy barriers to turbocharge the entry point for all eukaryotic energy flow.

It has recently been confirmed experimentally (Colloni *et al.,* 2010; Engel *et al.,* 2007) that solar energy input is captured and tunneled with a quantum "kick" into the general energy economy of eukaryotic cells. It is also well established that, thermodynamically downstream from quantum photosynthesis, a particular dissipative route both promotes the negentropy of intracellular biochemistry and helps to build the negentropy of electrical gradients across phospholipid bilayer membranes. This dual ordering process is mediated by photon-driven splitting of water into oxygen, protons, and electrons. The oxygen and protons are expelled from the cell, while the electrons are moved to intracellular NADP complexes. Spatial segregation of oppositely charged protons and electrons sets up a transmembrane electrical gradient. Finally, when ejected protons are at last permitted back into the cell and before they can combine as hydrogen ions into molecular hydrogen gas which might diffuse back out of the cell, the returning protons make renewed contact with sequestered electrons in the synthesis of highly negentropic carbon-based biomolecules from carbon dioxide. This synthesis traps and stores within the cell a biochemical potential energy reserve of very low entropy. Meanwhile, oxygen, having been extruded from the cell as an exothermically reactive "waste contaminant," accumulates in the ambient ecological milieu of the biosphere until aerobic respiration effects a deferred intracellular recapture of the oxygen followed in mitochondria by controlled combustive reactions with previously synthesized carbon-based biomolecules (Falkowski, 2015; Lane, 2015). The mitochondrial processes unleash ordered energy for use by neurons in creating transmembrane electrochemical differentials entailing cations larger than single protons. Specifically, monovalent sodium and potassium ion gradients mediate electrotonic and action potentials, while bivalent calcium ions subserve other membrane mechanisms and molecular messenger cascades. Such electrical fields, generated across membranes by ion differentials, transmit mechanistic "signals," stimulated by extracellular perturbations, to responsive components within cells, among which neurons further refine sub-categories of signaling phenomena. Particular architectonically varied spatiotemporal conformations of electrochemical ion gradients across neuronal membranes have been linked empirically with the nexus between mind and brain, engaging the "*easy problem*" of correlating neural and cognitive patterns. However, that kind of linkage, bypassing the "*hard problem of consiousness*," has not in itself offered any deep explanation of the mind-brain nexus in principle (Chalmers, 1995; 1996; Mender, 2015).

From Darwinian concepts it is possible to surmise positive coevolutionary feedback loops between, on one hand, fractal architectonics and fractal dynamical phase spaces, promoting inward diffusion of ambient oxygen required for aerobically fueled neural membrane potentials, and, on the other hand, emergence of conscious nervous systems "on the way to" the human brain. It seems energetically plausible that neurobiologically relevant evo-devo trajectories such as the randomizing symmetries of genetic variation, the relative stabilities of reduplicative homeosis in nonlinear attractor states, and other fractal architectures have arisen over the long haul through a dissipative informational ecology scaled up from the quantum-coherent microcosm (Mender, 2015).

The process of autocatalysis, a positive feedback loop whereby the end product of a chemical reaction catalyzes its own synthesis, is widely known to generate nonlinear dynamics, chaotic attractor states, and fractal phase space descriptors through germane enzyme action on biochemical systems in vivo. A more complicated generalization of such positive feedback loops, instantiated by the collectivity of autocatalytic sets, involves entire sequences of reactions whose aggregate intermediate products together with a final product catalyze a whole serial chemical process. Autocatalytic sets can themselves be nested into yet further metalevels of autocatalysis (Hordijk, 2013). One can invoke the above-mentioned parallel between tunneling and catalysis 1) to postulate auto-tunneling as positively fed-back facilitation of tunneled acceleration by products of tunneling itself and 2) to inferentially configure auto-tunneling and its collective manifestations in auto-tunneling sets as fractally self-similar breakouts from the previously described "toy" models.

These inferences offer a possible foundation for transforming the extrinsic curvature of a non-fractally oversimplified isoqualitative distortion gauge through an enriched mapping into the fully fractal architecture of auto-tunneling sets. Such a mapping might accomplish two important

NeuroQuantology | December 2016 | Volume 14 | Issue 4 | Page 756-763 | doi: 10.14704/nq.2016.14.4.988
Mender D., Isoqualitative gauge curvature at multiple scales

goals. First, the non-differentiability of Fourier-dual antisymmetry may be adequately captured by the fractal formalism of what becomes no longer merely a "toy" model. Second, fresh new visions of quantum-coherent neurophysics may, in a direct challenge to Tegmark, accommodate far-from-equilibrium perturbations beyond the microcosm and encompass not only the photosynthetic fountainhead of aerobic energy metabolism but also macroscopic contexts of evolution, ontogeny, anatomical structure, physiological function, and ecology relevant to the human brain. In these ways, a monistically isoqualitative psychophysics, prefigured to mesh with strictly physical observables while conforming to the causal completeness of standard physics, may be woven into open biophysical systems, including those involving the living brain, whose descriptive requirements span multiple scales (Vitiello, 2009).

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