INTRODUCTION TO QUANTUM METAMECHANICS (QMM)

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ABSTRACT: Solutions for problems arising at the limits of science and philosophy require ontological grounding. Quantum Mechanics (QM) is increasingly called upon as a source of insight regarding such problems, but is not itself well-understood. The fact that QM has many conflicting interpretations for which ontological status is claimed demands a "post-quantum" theory which clarifies its meaning, settles the differences among its interpretations, and facilitates the analysis and solution of otherwise intractable problems. Herein described as *Quantum Metamechanics* (QMM), this theory is a "meta-interpretative" mapping of QM and its various interpretations into a supertautological description of reality, the CTMU Metaformal System. By incorporating the CTMU, a true ontic identity supporting the self-identification and self-existence of reality, QMM provides QM with a valid ontology in terms of which its various interpretations can be evaluated and synergized.

KEYWORDS: CTMU; Cognitive-Theoretic Model of the Universe; Quantum Mechanics; Quantum Metamechanics; QM; QMM; Ontology; Quantum Ontology; Metaformalization; Formal Quantization; Metacausation; Retrocausation; Interpretation of Quantum Mechanics

I. INTRODUCTION

As never before, scientists and philosophers are trying to solve "big questions" having to do with such imponderable concerns as the nature and extent of reality, the origin and nature of life, the nature of mind and consciousness, the origin of the cosmos, the nature of space, time, and causality, the essence of human existence and spirituality, so-called paranormal phenomena, and other matters seemingly resistant to mechanical, material, or physical explanation. Accordingly, science and philosophy have been gravitating toward the broad and highly successful theory of quantum mechanics (QM) as a source of insight.

But despite its great theoretical and methodological utility, QM is as much a mystery as the questions themselves, and that of which the meaning is unclear is not itself a credible source of meaning. This has led to the search for a "post-QM" theory that properly explains QM itself and is thus better equipped to deal with metaphysical issues.

The purpose at hand is to identify the requirements of such a post-QM theory and then describe it in logical terms. Because this theory is necessarily a metatheory (or theoretical metalanguage) of QM, it is called **Quantum Metamechanics** or **QMM**. Its purpose is to map QM, along with any valid hypothetical correlates designed to obviate or accommodate its apparently problematical features, into the CTMU Metaformal System (Langan, 2018), a comprehensive high-level formulation of the structure of reality independent of QM itself, and then to explicate their relationship and thereby synergistically relate the microscopic and macroscopic scales of reality to each other. Because the Metaformal System is a supertautological (intrinsically valid) reflexive model of reality predicated on its manifest intelligibility, QMM can be described as a reflexive application of model theory which reliably locates QM within the theater of being.

Opinions to the contrary notwithstanding, QM itself is not an ontology. QM is a formal system standing apart from its universe, a mathematical apparatus incorporating such ingredients as linear algebra, Fourier analysis, and probability theory. Given the existence of certain measurements, QM merely yields statistical predictions of their outcomes. QM does not include definitions or attributions of being, existence, or reality. Assertions relating these concepts to QM reside elsewhere, usually in a more or less speculative interpretation of QM in an imperfect description of an incomplete set of observations labeled "physical reality".

That ontological status has nevertheless been claimed for various interpretations of QM – that they are called "quantum ontologies" - reflects a widespread misunderstanding of the word "ontology". In the minds of most scientists and philosophers, ontology consists of "claims about existence", e.g., the kinds of object, relation, operation, and process that exist in the world, and related epistemological claims about the nature and limits of knowledge, e.g., what kinds of knowledge are possible under what conditions. But insofar as anyone can make any claim at all about anything one likes, this is a trivialization. If existence can be meaningfully attributed to anything at all, then a valid ontological language must exist, and it must consist of actual knowledge rather than mere "claims".

Concisely, an *ontology* is a theoretical language that accounts for the nature and content of being (reality, existence) and logically supports its attribution on all scales and all levels of discourse. This carries certain requirements that QM cannot fulfill. *Being* is not an ordinary attribute, but the highest attribute of all; no lesser attribute can be meaningfully attributed to anything of which some kind or level of being, even if "purely conceptual", is not already a property. Moreover, just as QM suggests, ontology is intimately related to epistemology, which deals with the nature and limits of knowledge. Because something must *exist* in order to be known or identified, while that which exists must be *identifiable* as a value or instance of the attribute "existence", identifiability and existence must coincide.

While QM is considered by some to define the limits of physical measurement and thus of empirical identification, there are other things to be identified in the name of science – ideas, concepts, sensations, feelings, judgments, intentions, intuitions, and theories like QM itself, for example. It is simply not the case that abstract and subjective forms of existence and identity can be wholly supervened on "physical" objects and processes.

II. OVERVIEW OF QM

Informally, a *quantum* of X is the smallest particle or indivisible instance of X, while *mechanics* is the branch of physics dealing with the motion of bodies and the energy and forces producing motion, including statics, dynamics, and kinematics. It follows that *quantum mechanics* is the study of how energy and forces relate to the motion of particles. But this is a bit deceptive, as the elementary particles studied in physics do not actually "move" in the usual sense of moving bodies.

In fact, the elementary particles of physics are observed only when they are measured, and what they do between measurements is never witnessed. To call it "motion" in the usual sense is an assumption. Moreover, to measure them is to cause them to change state, which means that they are seen only in conjunction with state-transition events. Experimental data suggest that between these events, they become waves. This is the easiest conclusion to draw from (e.g.) the famous double-slit experiment, in which sending particles through a pair of slits in a partition produces a distinctly wavelike interference pattern on a screen.

The interference pattern produced in the double-slit experiment is considered strange because it occurs even when the particles are sent through the slits at widely spaced intervals. Thus, their respective "waves" cannot be interfering with each other in real time. The waves can only be interfering with each other in association with *each individual particle*, implying that each particle is somehow equivalent to coherent set of "probability waves" that superpose on and interfere with each other in association with it, influencing the motion of the particle if not actually guiding it to its point of impact. In other words, between the emission event and its impact on the screen, each particle behaves like a coherent superposition of waveforms. Accordingly, each particle or physical system capable of quantum coherence is associated with a "quantum wave function".

Why a wave, and why a function? First, we have the wavelike behavior of light, extended to particles of matter by de Broglie. Secondly, that only one of multiple possibilities is actualized as the outcome for a given quantum event requires a many-to-one function to select the one from the many (or, given the fact that quantum experiments can be formulated as yes-no questions, to select one of two possibilities). Thirdly, that we have an apparent superposition of possibilities means that we require something that obeys the superposition principle (or property), which says that for a linear function or system, the net output is the sum of the individual inputs. (That is, if input b produces output x and input c produces output y, then input b+c produces output x+y.) Although the world contains many nonlinear phenomena, its linear aspects are what make possible a reasonable notion of causality whereby cause and effect are "in proportion".

Linear systems include both wave media and vector spaces; a superposition of waves is just the sum of their amplitudes at each point, while a superposition of vectors is just a vector sum. Because (by Fourier's Theorem) any wave, classical or quantum, can be expressed as a unique sum of sine waves in superposition, and because the Hilbert space of quantum states is both a vector space and an inner product space in which vectors can be superposed, added together, multiplied by scalars, and multiplied by each other, the superposition of two possible states is again a state of the system. That is, if $|\psi_1\rangle$ and $|\psi_2\rangle$ are possible states of a system, then so is $|\psi\rangle = a_1|\psi_1\rangle + a_2|\psi_2\rangle$.

This can be interpreted to mean that the system is "in both states at once". When the system is in a superposition of possible states, its wave function is said to be *coherent*. On the other hand, when it is measured, its possible states suddenly decohere and its wave function "collapses", or at least *appears* to have collapsed, into a single definite state.

In classical mechanics, the state of a physical system consists of values for all of its observable attributes or "observables". In contrast, a quantum state consists of values for a "complete set of commuting observables" that can be measured one after another without disturbing the rest. The commutativity restriction owes to the fact that some observables are "conjugate" and therefore do not commute; measuring one can disrupt the other, putting it into a superposition of different possibilities and thus destroying the information available on it.

This relationship between conjugate observables defines an epistemological limit of QM. It is called the **Heisenberg Uncertainty Principle** (Messiah, 1999) and is written

$$\Delta x \, \Delta p \geq \text{hbar}/2 \,,$$

where the symbol Δ denotes the "spread" or loss of information on the associated variable. Here, the noncommuting observables are position x and momentum p. The principle could also be expressed, for example, in terms of energy E and time t as

$$\Delta E \, \Delta t \geq \text{hbar}/2$$

In the view of Bohr, Heisenberg, and others, the epistemological uncertainty principle has ontological bearing. According to Bohr's Quantum Postulate, reality is naturally quantized, or discretely partitioned into measurable stationary states with nothing intelligible inside or between them, and according to his Correspondence Principle, quantum mechanics must reproduce classical physics in the macroscopic limit of large quantum numbers. In other words, QM must "scale" from discrete microscopic to continuous macroscopic physics (Bohr, 1928).

Insofar as the focus of QM is the limiting scale of physical measurement on which classical mechanics breaks down, Bohr and Heisenberg saw QM as a terminal theory of reality of which classical physics is just the macroscopic limit. Yet at the same time, Bohr insisted that only the classical conceptual language of the macroscopic, fully observable physical domain be used to express knowledge of quantum objects and processes, and that all scientific investigation must rest on a concrete foundation.

> "[An] unambiguous communication of physical evidence demands that the experimental arrangement as well as the recording of the observations be expressed in common language, suitably refined by the vocabulary of classical physics. […] In all actual experimentation this demand is fulfilled by using as measuring instruments bodies like diaphragms, lenses and photographic plates so large and heavy that, notwithstanding the decisive role of the quantum of action for the stability and properties of such bodies, all quantum effects can be disregarded in the account of their position and motion." (Bohr, 1962, p. 91)

In short, QM not only characterizes the microscopic limits of measurement, but also marks the limits of reality. In a way reminiscent of Wittgenstein's observation that "the limits of my language are the limits of my world," the descriptive limits of QM also seem to limit reality itself, compelling the use of classical language to describe it. This, basically, is the theme of the Copenhagen Interpretation.

The Copenhagen Interpretation as "Quantum Ontology"

The Copenhagen interpretation originated in the mid-1920's as a product of expert collaboration involving Niels Bohr, Werner Heisenberg, and others (Herbert, 1985). Following close on the heels of QM itself, it is considered the original and paradigmatic interpretation of quantum mechanics. In keeping with the uncertainty principle, it asserts that physical systems lack definite properties prior to being measured, and that quantum mechanics can only predict the probability distribution of the possible results of a measurement. In effect, the measurement "collapses" the probability distribution to just one possible value, which did not previously exist but has come into existence due to the measurement (we will later refer to this property as "generativity"). In short, the real, physical state of the measured entity relies on measurement itself, which relies on those who do the measuring, and therefore cannot be separated from them. Because the probability distribution is described by a wave function, this is called the *reduction* or *collapse* of the wave function.

Because the Copenhagen interpretation asserts the *nonexistence* of physical properties, values, and states between measurement events, but asserts that they come into *existence* upon measurement, it has ontological bearing. Hence, it is widely considered the original "quantum ontology", a phrase which requires explanation. Conventionally, quantum ontology does not address the ontological or existential status of QM itself. Rather, it takes QM for granted and addresses its ontological implications for physical reality and sometimes reality in general. In this context, *reality* is synonymous with *being* or *existence*; if something is *real*, then it *exists* and has *being*. But as for the meaning of these synonyms, they are regarded as either primitive (i.e., associated with direct physical observation) or defined; and where they are deemed needful of definition, they are defined on either QM and the rest of physics (as in the Copenhagen Interpretation), or on the very interpretation of QM in question. In any case, it has become the height of fashion for anyone with an "interpretation of quantum mechanics" to declare it a self-contained "quantum ontology".

Unfortunately for such declarations, one cannot properly interpret a theory without having something definite to interpret, and something definite in which to interpret it; and one cannot have an ontology which fails to incorporate a metalanguage which is so defined as to support attributions of *reality, being,* and *existence* on all scales, from the quantum scale up to the entire cosmos. Quantum mechanics only partially meets only the first of these criteria, and makes no pretense of meeting the second. Aside from statements dealing specifically with physical measurements, most of it resists interpretation in concrete reality, and those interpretations of QM which receive the most attention do nothing to improve the situation. In fact, most of them are primarily concerned with getting around what many consider the biggest problem in quantum theory, the collapse of the wave function, and are thus reactions against Copenhagen.

III. THE MEASUREMENT (COLLAPSE) PROBLEM OF QM

The reduction of the wave function can be described as follows: the time evolution of a quantum state or wave function $|\psi\rangle$ is given by the nonrelativistic Schrodinger wave equation

$$i \text{ hbar } \partial/\partial t \; |\psi(t)\rangle = H(t) \; |\psi(t)\rangle,$$

where $i = \sqrt{-1}$, hbar is Planck's reduced constant $h/2\pi$, t is the time parameter with respect to which the wave function $|\psi(t)\rangle$ is differentiated, and H is the Hamiltonian operator representing the total energy of the system.

The Schrodinger Equation is linear in several important respects. For example, it can be simplified to unitary transformations which preserve inner products, and it has linear operators acting on a linear state vector (or wave function) in such a way that linearity holds among its solutions: if ψ_1 and ψ_2 are solutions, then so is $\psi = a_1\psi_1 + a_2\psi_2$. This restricts the entire description to linear spaces and linear geometry, excluding anything that cannot be expressed in a linear continuum. From the instant that $|\psi\rangle$ arises as a solution of the Schrodinger equation to its transformation into a new state, its dynamic is assumed (but not observed) to be both linear and wavelike.

Adapting the notion of linear causation to the quantum scale, QM drops the classical assumptions of determinacy and locality and makes the best of quantum uncertainty by replacing the notion of causal determinacy with inductive probability. Its success in describing microscopic reality thus comes at the cost of statistical de-resolution, a trade-off which reflects its inadequacy for describing the deep structure of reality. The best that QM can provide under these circumstances is a statistical approximation of acausal "wave function collapse".

Wave function collapse occurs as follows. At the point of measurement, $|\psi\rangle$ becomes a superposition of eigenstates of the quantity being measured and immediately collapses: $A|\psi\rangle \rightarrow a_n|\psi_n\rangle$. Mathematically, $|\psi\rangle$ has "expanded in" (been filtered or partitioned into) the eigenbasis of the operator (A) associated with the measured quantity or "observable", and then for all practical purposes instantaneously transformed from a superposition of many possible states into in a single eigenstate.

The essence of the measurement problem is that the projection postulate and its measurement-induced reduction (collapse) of the wave function conflicts with Schrodinger's equation, which prescribes the continuous deterministic unitary evolution of states rather than sudden, seemingly inexplicable punctuations. As mandated by the uncertainty principle, QM is probabilistic; between measurements, physical systems "exist" not as definite, directly observable states and state-transition events, but as undetectable and therefore unphysical superpositions of *possible* states.

These probabilistic superpositions, which are not even described by classical probability theory but require a "quantum" theory of probability all their own, must alternate with the definite outcomes of physical measurement events themselves. This implies that vast, spatially extended potentials coinciding with distant points of space, possible future states of a physical system which have not yet been actualized, are carried outward from quantum events at the speed of light only to be instantaneously confined to more or less precise locations.

This problem, which is connected to complementarity and wave-particle duality, is viewed as the central problem of QM. More than anything else, the measurement problem drives the "QM interpretation industry" of modern physics and philosophy, the successor of QM itself with respect to a considerable number of academic publications.

IV. THE QM INTERPRETATION PROBLEM

QM began as a mathematical theory of physical measurement. Considered in isolation, it is a rather skeletal affair consisting primarily of linear algebra along with other kinds of mathematics related to it by inspiration and convenience. Like all mathematics, its formal expression is abstract and symbolic. It can appear stark and intimidating when considered apart from the many experimental contexts to which it is applied, but for mathematics this can hardly be considered damning. The real problem has to do with the fact that it is difficult to motivate in terms of the small-scale measurements it describes. Such measurements require QM precisely because more intuitive macroscopic descriptions fail to work.

This suggests a sartorial analogy. On the bare-bones algebraic mannequin of QM, layer upon layer of clothing has been draped and piled by designers who differ strongly in their opinions of what looks good on it. To put it mildly, their visions clash with even less appeal than the underlying skeleton, tending to cancel each other. Consequently, even after their disorganized attempts to bury it under a mound of conceptual raiment, its bones poke through as starkly as ever, dangling and jutting like the girders and cranes of an unfinished skyscraper. Thus, while grudgingly praised for its spectacular empirical success, it continues to be roundly panned for its abominable aesthetics, prompting various efforts to "dress it up" in new interpretations that on close examination turn out to be equally counterintuitive and unappealing.

An interpretation of a theory is a "structure-preserving" correspondence or mapping between a theory regarded as the formal domain of the mapping, and a range or codomain consisting of a universe in which the theory is instantiated (i.e., in which it has instances consisting of specific objects, relationships, and processes that conform to it). The oxymoronic concept of "literal interpretation" notwithstanding, interpretation is a necessary stage in the recognition of any theory. No theory can be understood in terms of uninterpreted symbols, and the meanings of its constituents are dependent on the interpretative context in which it is defined. That such context must be provided in order to determine the "intrinsic structure" of a theory suggests that even when it is assumed that a given interpretative mapping will not change the theory to which it is applied, there is in fact a potential for theoretical structure to be changed.

The intrinsic structure of a theory can be at least partially clarified by *formalization*. A theory can be formalized by interpreting it in one or more well-defined structures including the language in which it is expressed along with any axioms and rules of inference supporting its descriptive or normative functionality. But while this definitely helps limit ambiguity, these formal structures - languages and axiomatic systems - may contain ambiguities of their own. Try as we might to nail everything down, theories do not always uniquely determine their universes, models, or interpretations, and universes do not always uniquely instantiate theories. (For purposes of orientation, the logical principles usually associated with interpretative variability include the *Lowenheim-Skolem theorem* and the *Duhem-Quine thesis*.)

Technically, interpretations of QM are correspondence mappings of which the formal domain is always the theory of QM, and the universe is always empirical or "physical" reality including the set of microscopic measurement events. As for the domain, QM is a theory that comes with principles and postulates that make it a formal system. However, like any formal system, it does not come packaged with a model, i.e., a valid correspondence between itself and any particular universe or set of instances. It merely refers generically to empirical reality, providing a general prescription for the execution and analysis of measurements of submicroscopic phenomena. Nevertheless, QM may be considered to intersect with empirical reality in precisely the measurement outcomes that it correctly (statistically) predicts.

The problem is that this intersection is only partial. Although the degree of correspondence between QM and the measurement events in which it is interpreted is often impressive, it is merely probabilistic; QM underdetermines its content and thus exhibits causal deficits. In particular, QM does not include the level of causation that predicts the occurrence of measurement events or determines their specific outcomes. Even worse, most of the complex mathematical apparatus of QM has nowhere to go; the empirical universe contains nothing that obviously corresponds to it and thus has "nowhere to put it". There appears to be nothing in empirical (observable) reality capable of supporting such things as probability waves and the equations that govern them.

In keeping with the scientific method, a scientific theory and its empirical universe absorb each other through their structural correspondence in an inevitable process of mutual contextualization and accommodation. Whereas a formal system isolates theory from universe, a theory cannot be isolated from any universe to which it is actually applied. This is especially true for any scientific theory intended to describe the empirical universe as it is progressively revealed to the human mind and senses. In establishing a "structure-preserving" correspondence between theory and universe, we are forced to deal with a joint structure that evolves as they feed back on each other as prescribed by the scientific method. For QM, this joint structure is limited to bare measurement events and their QM-predicted observable consequences; the rest of QM is either excluded, or empirical reality is interpretatively embellished with extra ingredients designed to accommodate it.

In other words, the description of the empirical universe changes as new observations are made, and the scientific method requires constant feedback between theory and universe in order to ensure a good descriptive / instantial fit. However, explanatory gaps and creative slack in this process of mutual accommodation can create holes through which one could drive a truck, so to speak. When this occurs, physicists are often completely unconstrained in making up new, empirically untestable "physical" structures and processes to which problematical QM ingredients can be mapped, and/or adding to or subtracting ingredients to/from QM in order to fit it to their preferred descriptions of the universe. (E.g., von Neumann implicitly adds to reality the physically undefined concepts of mind and consciousness in order to explain wave function collapse, Everett adds an unobservable cosmic wave function that generates countless totally unobservable alternate universes, de Broglie and Bohm add unobservable "pilot waves" that guide particles along linear localistic trajectories through nonlocal pilot fields, and so on.)

While QM is formulated in hard mathematical language, the empirical universe it describes is known strictly by direct observation and logical deduction. The only sure way to characterize the physical universe is by the minimal description of physical observations with no inferences but those obtained by plugging bare observational data into deductive logic. With respect to QM, this leads to a problem: there is no sure way to describe the physical universe that can fully accommodate QM, which contains ingredients of which the empirical universe appears to contain no observable instances. If there *were* such a description, then QM could be at least partially coupled with it in an appropriate language, pinning down both ends of the model-theoretic correspondence and thereby restricting the interpretation of QM.

V. FORMAL QUANTIZATION

Physics involves an operation called "quantization" which involves the division of physical properties and substances into their smallest possible discrete units or instances. For example, chemical compounds can be quantized in terms of molecules, molecules can be quantized as atoms, atoms can be quantized as protons, neutrons, and electrons, and the frequency of a standing wave like an atomic orbital can be quantized in terms of its ability to accommodate only a whole number of wavelengths without self-destructive interference. In quantum mechanics, the property which is quantized is called "action", defined as energy multiplied by time (making it both energetic and time-like) and roughly synonymous with "physical change". Many other physical properties can be quantized in terms of it.

However, quantization applies just as well to other kinds of property, including those which are purely mathematical. As physics is expressed in terms of various mathematical formalisms, it relies on the quantization of mathematical concepts well before it arrives at quantum mechanics. Of course, formal quantization is a well-recognized mathematical necessity. Sets are quantized as elements, topological spaces are quantized as points, geometry is quantized as lines, which are quantized as points and units of length, and angles, which are quantized as radians or degrees. More generally, any kind of formal system is quantized as symbols representing objects, relationships, functions, and operations. These symbolic "quanta" characterize the signature of the system; every symbol in the system must conform to one of these descriptors (including typographical symbols including empty spaces), and to each a degree of coherence is assigned.

The coherence of a symbol is what enables it to have a definite meaning and to be treated as a single unified entity. The coherence property is crucial; it means that anything possessing it can be treated as a unitary entity which behaves or transforms in a unified and regular way under certain mathematical or physical operations. Defined in terms of the coherence property, quantization means "division of a coherent identity into coherent subidentities which act as unitary entities and thus behave coherently." (This holds true in QM, where the coherence of a quantum wave function means that all of the possible states of the associated physical system cohere in mutual superposition and evolve in phase with each other.)

Unfortunately, there are problems with mathematical quantization, and they carry over into physics. This is easy to see in the case of a classical manifold, basically a space consisting of zero-dimensional (0D) points (real numbers, elements of the real continuum R^n) and equipped with a metric that is "locally Euclidean", permitting a reasonable in-frame notion of distance and locality. Immediately we detect a paradox: "of zero extent in a given space" means "nonexistent in that space" – existence in a space means taking up space in it - and we cannot assert the *existence* of a space consisting of *nonexistent* points that take up no space at all. Even if we could, there would be yet another problem associated with continuity, the *adjacency paradox*. An infinitesimal line element or increment of linear motion must relocate a point-object from one point to an adjacent point. But where points are zero-dimensional as continuity demands, adjacency or "being in mutual contact" effectively identifies them. Adjacent points simply merge, and no relocation can occur. Linear motion is out of the question.

It follows that continuous motion requires finite termination or bounding of the interval in order to scale and sum infinitesimal increments, produce a definite integral, and assign a length to the interval. But this still leaves nonzero (albeit sub-finite) separations between each pair of successive points along a path or physical trajectory, and an object must "jump out of" the manifold or space in order to get from one point to the next. Motion then becomes a series of infinitesimal "quantum jumps" through hyperspace. This, of course, is not what mathematicians and physicists typically have in mind when they talk about "the continuous (differentiable, smooth) motion of objects or waves through the continuum". (We ignore for now the various workarounds that have been proposed for these problems, at least one of which – usually the Cauchy-Weierstrass epsilon-delta formalism based on infinite converging sequences – is generally invoked in introductory calculus courses in order to deflect the "problem / paradox of infinitesimals", which is never satisfactorily resolved with respect to the existence or nonexistence of 0D points and infinitesimal intervals between them.)

Naturally, this problem, being deeply rooted in the foundations of mathematics, was bound to emerge in the course of formulating and following mathematical procedures in physical calculations. Specifically, it was bound to emerge in connection with submicroscopic measurement procedures.

VI. QMM METAFORMALIZATION

Quantum Metamechanics or **QMM** is a "meta-mapping" that maps entire QM interpretations into the absolute structure of reality, and depending on their logical consistency, embeds them there. Only thus can the most valuable features of various QM interpretations be merged in a single coherent overall description of reality.

The formalization of a theory T amounts to the addition of axioms and rules of inference to a formal language L accommodating the expression and development of T, thus embedding T in L. Where the syntax and grammar of L amount to the "axioms and rules of inference" of L, the axioms and rules of T amount to an extension of the syntax and grammar of L, making T a special-purpose "sublanguage" of L. Where T = QMM and L = the supertautological Metaformal System (Langan 2018), this process amounts to "QMM Metaformalization". Because the intrinsic-language structure of the Metaformal System suffices to determine QMM, additional (QMM) axioms and rules of inference are unnecessary.

QMM metaformalization requires metaformalization of the generic QM-interpretative (QMI) mapping QMI:QM$\leftarrow\rightarrow$U, the domain and codomain of which are QM and empirical reality respectively. The problem with the generic QMI mapping is that thanks to the fertile imaginations of various scientists and philosophers, empirical reality has "overrun its buffers" in various conflicting ways and thus lacks a coherent formulation of its own, with the result that interpreters of QM are basically willing their preferred versions of reality into hypothetical existence as they please and calling it "ontological". No QM interpretation incorporating what may be an incoherent description of empirical reality can be judged trustworthy.

In contrast, QMM maps QM into empirical reality as represented by the CTMU. Thus, QMM is not just another interpretation of QM, but a metaformal extension of QM which specifies the absolute structure of its codomain and is itself embedded therein. Whereas ordinary QM interpretations speculatively modify the "reality" concept in order to solve or circumvent the measurement problem, QMM interprets QM in the supertautological Metaformal System.

Having itself been metaformalized, QMM can thus be described as the "metaformalization" of QM. This amounts to a true and inevitable extension of the QM formalism to incorporate a true metaformal ontology. It is in this extended structure that ordinary interpretations of QM, including their "ontological" claims, must themselves be interpreted.

The codomain and domain of QMM mapping may be described as follows.

Specifying the QMM Domain

Just as for ordinary QM interpretations, the formal domain of the higher-level QMM mapping includes QM. However, this requires a qualification: the codomain now consists of the CTMU supertautology, a metaformal ontic identity that equates existence to its own self-identification and thus couples ontology and epistemology. This affords a crucial advantage: being logically induced from the intelligibility of reality, the supertautology requires no additional proof and immediately qualifies the mapping as a true "quantum ontology". But it also comes with what may seem a disadvantage: the codomain can no longer unconditionally accommodate mere speculations, instead holding them in the domain along with QM. The domain now contains the entire QMI mapping, no extra features of which can accompany QM into the codomain unless they are consistent with the embedment of QM itself in the CTMU supertautology.

As for the usual formalism of QM, it can be described in terms of a variable axiomatic structure which is to some extent a matter of preference. But while the core concepts of QM can be differently organized, certain mathematical ingredients are indispensable. This allows us to describe the formal structure of QM with a set of postulates similar to the following:

1. The state (vector) of a quantum mechanical system, including all the information that can be known about it, is represented mathematically by a normalized ket $|\psi\rangle$. At each instant, this ket represents the state of a physical system in the space of states, a vector space called *Hilbert space*. Associated with the system is a *wave function* which, unlike a particle, extends throughout space and consists of possibilities in mutual superposition.

2. A physical observable is represented mathematically by an operator A that acts on kets. When operating on a wavefunction with a definite value an of that observable, it yields that value times the wavefunction: $A|\psi\rangle = a_n|\psi\rangle$

3. The only possible result of a measurement of an observable (physical) property is one of the eigenvalues a_n of the corresponding operator A.

4. The probability of obtaining the eigenvalue a_n in a measurement of the observable A on the system in the state $|\psi\rangle$ is $\mathrm{Prob}(a_n) = |\langle a_n|\psi\rangle|^2$, where $|a_n\rangle$

is the normalized eigenvector of A corresponding to the eigenvalue a_n.

5. After a measurement of A that yields the result (eigenvalue) a_n, the quantum system is in a new state that is the normalized projection of the original system ket onto the ket (or kets) corresponding to the result of the measurement: $|\psi'\rangle = P_n|\psi\rangle \,/\, \sqrt{(\langle\psi|P_n|\psi\rangle)}$. [This is a particular formulation of the *Projection Postulate*, which is central to the measurement problem.]

6. The time evolution of a quantum system is determined by the Hamiltonian or total energy operator H(t) through the time-dependent Schrödinger equation i hbar $\partial/\partial t\ |\psi(t)\rangle = H(t)\ |\psi(t)\rangle$.

Note that the mathematical definitions and formulae in these postulates are formal and "syntactic" in character, conforming to generic and often mathematical rules which exist in the cognitive-perceptual syntax of observers … the accepting syntax through which they recognize and absorb cognitive and observational input, supporting and constraining cognition and perception. As these rules are being projected on that part of physical reality consisting of submicroscopic events which would otherwise be unidentifiable as physical phenomena, they amount to features of the physical medium itself. Moreover, because physical reality exists on the limiting submicroscopic scale and all coarser scales, they are being ascribed to physical reality, and where physical reality is an aspect of reality at large, to reality as a whole.

Standard interpretations of QM are targeted on the same reality as that to which QM itself applies. Hence, their "extra" ingredients map to the same overall structure as does QM itself.

Specifying the QMM Codomain

Reality, the target of the partial interpretative mapping of QM which various interpretations supposedly "complete", has always been hard to define. From academically cloistered quasi-robotic gray men pushing symbols from equation to equation on dusty blackboards to Buddhist monks chanting together in their saffron robes, the vast majority who have tried have come up short. Reality displays immense complexity, and one tends to either become lost in the tangle or throw up one's hands in surrender. As much insight as QM brings to the reality-theoretic table, it is also very strongly affected by this problem. One cannot establish the true correspondence of QM with reality when, having used calculus and linear algebra and Fourier analysis to put the source of the mapping in the crosshairs, one still cannot positively identify the target.

Before QM can be used in the solution of metaphysical problems, it must be integrated with reality on the highest, most general, most inarguable level of structure and dynamics. For this to happen, reality must first be conclusively identified on the required level of description. Popular ignorance notwithstanding, this mission has been accomplished; reality has been succinctly described as a primal self-identification operator which reflexively identifies itself and thereby attributes existence to itself, functioning "trialically" as an object, a self-relationship, and a self-operation. In order to do this, the operator – herein denoted by the acronym G.O.D. or "Global Operator-Descriptor" – uses the most generic level of its own self-attributed being as ontic potential, generatively actualizing itself from that potential in the form required for existential self-identification and scientific intelligibility. Specifically, it takes the form of a supertautological intrinsic language which has been described in these Proceedings as the **Metaformal System**.

The Metaformal System $M = \{\Sigma(N,T), \Gamma\mu, S_\Sigma\}$ is a supertautological *intrinsic language* characterized by complete self-containment. That is, its self-dual signature Σ consists of a nonterminal metaphysical domain N and a physically emergent terminal domain T, and its generative grammar $\Gamma\mu$ controls the N|T relationship, producing the timelike strings (histories, paths, trajectories) S_Σ of T from the nonterminals of N. As an ontic identity language, M factors into dual *semilanguages* Ls and Lo which comprise its intensional and extensional aspects respectively. Although the definition of M strongly resembles that of an ordinary formal language with a signature, a grammar, and a set of linear "strings", it is a trialic metaformal language which evolves by modeling itself in its own intrinsic universe.

The fundamental objects of M are active signs called *telors* (telic identification operators), secondary quanta existing in N along with the primary quantum or G.O.D. representing the entire system, and *syntactors* (syntactic identification operators), including tertiary syntactors comprising the subatomic particles of the physical domain T, which depend on more complex but nonetheless coherent self-modeling telors for their regenerative existence.

Its μ-morphic grammar $\Gamma\mu$ is a self-identification operation which produces $S_\Sigma \supset T$, the set of terminal strings of M - the external states and linear trajectories of tertiary syntactors in the terminal domain T comprising the "surface structure" of M - by generating them in the pregeometric domain of N and projecting them onto physical timelines. Thus, M evolves by generatively identifying itself.

Conveniently enough for present purposes, the supertautology M is *self-quantizing*. It is an ontic identity - a coherent, intension | extension coupling formulated with respect to the attribution of being and identity - which naturally partitions and "multiplexes" itself by its intrinsic μ-morphic grammar $\Gamma\mu$ into coherent subidentities (active signs) that mirror its essential structure and can thus function coherently as its generative operators and/or physical content. Its self-quantization is both syntactic, applying to the formal level of being that controls identification, grammar, and orthography or well-formedness in T, and extensional or "semantic" (substantive, physical), forming meaningful configurations consistent with not just the syntax of intelligibility, i.e., the self-distributed rules of G.O.D. self-identification, but with the state of the external world. As a self-defining entity, the ontic identity must abut its logical complement *in situ*, permitting it to distinguish self from nonself.

The metaformal trialic self-quantization of the G.O.D. devolves to an *identity system* consisting of states coinciding with self-identification events that distinguish between self and nonself. The system generates at least three levels of identity: the primary or global level (the G.O.D.), the tertiary level (the level of ultimate and near-ultimate constituents of matter as already partially addressed by QM), and an intermediate level resolving the causal deficits of the primary and tertiary levels. This is the secondary mesoscopic level of identity, the classical scale occupied by various kinds and levels of secondary telor including human beings. Thus, just as the G.O.D. is the primary metaformal quantum of reality and elementary particles are tertiary quanta, human beings are "secondary quanta" with a combination of coherence and complexity that allows them to freely and meaningfully "self-model", configuring reality by configuring themselves. In other words, in the Metaformal System, life and consciousness are specifically quantized as innately coherent secondary telors whose coherent existence surpasses their physical emergence.

Like tertiary id-quanta – the submicroscopic, physically irreducible identities whose state transitions are quantized as action - secondary quanta are coherent identities mirroring the structure of the G.O.D.. But unlike tertiary quanta, which are detectably coordinated by nothing but localistic fundamental forces and are otherwise seemingly probabilistic, they have sufficient complexity and nonlocal integrity to generatively "self-model" on behalf of the larger reality they populate. Just as envisioned by theorists like von Neumann, Wheeler, and Stapp, the self-realizing "conscious minds" of secondary quanta play a crucial role in filling QM causal deficits. They are among the key missing ingredients of standard quantum mechanics … primitive elements of the Metaformal System directly and indirectly responsible for the coordination and collapse of quantum wave functions, and thus for completing physical identification processes that cannot be completed by QM alone.

This being understood, QMM maps QM directly into the structure and dynamics of the ontic identity in a most unequivocal way.

The QM ←→ Reality Correspondence

As a trialic intrinsic language, the CTMU Metaformal System M combines *language, universe,* and *model* to create a perfectly self-contained metaphysical identity. The intensional aspect of M is a self-configuring self-processing language, and the extensional aspect couples to this language as a pointwise distribution of its syntax which provides the language with instances. This intrinsic language is self-similar in the sense that it is generated within a formal identity to which every part of it is mapped as content; its initial form, or grammatical "start symbol" – herein discussed at various levels of resolution as the ontic identity, the G.O.D., and the Metaformal System - everywhere describes it on all scales. In this system, time, causation, and the spatial expansion of the cosmos as a function of time flow in both directions – inward and outward, forward and backward – in a dual formulation of causality characterizing a new conceptualization of nature embodied in a new kind of medium or "manifold".

The CTMU conspansive manifold, conceived as a joint medium for QM and General Relativity, differs from a classical manifold in important respects, several of which are geometrically transparent.

1. Whereas a classical manifold consists of points which exist independently of their transient (moving) content– the points are static parameters rather than the states they contain - the points of a conspansive manifold are trialic, which means that they *are* content. The state of a particle (tertiary syntactor) in the manifold "inner expands" to become an open potential which engenders and contains the next state. (Insofar as these syntactors are coupled in mutual state-transition events, the conspansive manifold superficially resembles the conventional pseudo-Riemannian spacetime manifold which has "events" as its points.)

2. The conspansive manifold contains three topologically nested levels of "point" corresponding to three levels of active sign in the signature of M: the primary telor, secondary telors, and tertiary syntactors, each instantiating its own level of metaformal quantization. Each kind of point has internal and external states. Points are rescalable by inner expansion and collapse.

3. Simplistically (nonrelativistically), the conspansive manifold can be "layered" in terms of the terminal and nonterminal subsignatures T and N of the signature Σ of M, consisting respectively of (a) current states, including those in T itself, which have occurred but have not yet been succeeded by newer states; and (b) past states deeper in N which have already been succeeded by newer states. The current layer includes the set of newly collapsed external states paired in mutual identification events that are occurring "right now / in the present" (ignoring for now the matter of simultaneity of events), and the set of "open" (still current) states which have not yet collapsed. The second, deeper layer consists of states which have already been replaced by newer states. Because states can never leave the overall manifold or primary point (as there is nowhere else for them to go), they remain in a state of *extended superposition* and are outwardly rescaled even after they have been replaced by new states and receded into the past, nesting and progressively interpenetrating as the manifold evolves (in contrast to the static extension of a "block world"). This "inner expansion" of the manifold, equating to the relative shrinkage of its content, is to be viewed in terms of rescaling morphisms rather than ordinary expansion and shrinkage. Thus, the entire manifold and its points are dynamically and in fact generatively coupled, changing in unison.

The generative dynamic of the conspansive manifold has primary and secondary stages. The primary stage consists of a self-dual n-ary (n-fold unary, n ≥ 2) operation, *conspansion*, with two alternating phases, *inner expansion* and *collapse*. Inner expansion *potentializes* the state transitions of the syntactors coupled in events – the points and events are brought into intersection by internal rescaling through the primary quantum (point) so that they "overlap" – while collapse re-actualizes the inner-expanded syntactors as compact objects in new interactions. Conspansion requires the progressive rescaling of points with respect to the manifold as a whole, leading to the apparent overall expansion of the manifold with respect to its content. The conspansive manifold thus evolves analogously to the physical cosmos, with intrinsic effects analogous to cosmic expansion, propagation of the wave function, and quantum wave function collapse.

The conspansive manifold evolves by way of generative information mappings that supersede standard physical causation occurring along timelike (or null) worldlines. Inner-expansive potentialization "opens" a tertiary identity or point of the manifold to N while collapsative actualization "closes" it in T; potentialization is null, while collapse is spacelike. Together, inner expansion and collapse comprise conspansive potentialization-actualization cycles which form self-dual information mappings, each of which initiates and actualizes a potential by restricting it to a specific outcome for a net gain of information. It is through these generative, metaphysical prereality-to-physical reality information mappings that the Metaformal System models and defines itself.

The evolution of the conspansive manifold is that of M itself. By way of conspansion, the generative grammar Γμ of M produces the extensional (physical, geometric, topological) semilanguage Lo from its dual intensional semilanguage Ls. As QMM maps QM into the conspansive manifold, it thus induces an extension of QM into Γμ and Ls. Driving Γμ is a secondary stage of evolution of the conspansive manifold associated with primary and secondary quanta (the coherent higher-order points of the manifold) and called *telic recursion*. By telic recursion, adaptive exploratory feedback between Ls and Lo generates the terminal expressions of M, coupling and collapsing syntactors in interactive mutual identification events including the measurement events of QM.

QM is thus mapped to the open top layer of the conspansive manifold, where inner expansion is approximated by the symmetric time-like propagation of the wave function according to the time-dependent Schrodinger equation (bearing in mind that $\Psi(x)$ and the Schrodinger equation must ultimately be formulated in terms of the point-structure and topological dynamic of the manifold), and conspansive collapse is thus analogous to wave function reduction (collapse, projection). The irreducible characterization of a QM measurement like $\langle\psi i|\psi\rangle$, in which a present (or prepared) state ψ "casts its shadow" on vectors representing possible next states, implies that collapse is just the conspansive rescaling of inner-expanded static potentials: $A|\psi\rangle \rightarrow a_i |\psi_i\rangle$. This reflects the topological dynamic of the conspansive manifold, in which both phases of conspansion regulate and transform its point-structure. Adding a metaphorical touch to the implicit anthropic coupling of observer and universe, one might observe that this causes the manifold to "breathe". The conspansive manifold thus mirrors quantum dynamics, rescaling, combining, and collapsing quantum wave functions along with its own points in a fully coordinated fashion.

Self-Modeling

Like M itself, the conspansive manifold evolves by "self-modeling", i.e., by letting active Ls semantic potentials "inside the points", their internal states, guide and coordinate wave function collapse to produce the physical content of Lo "outside the syntactors" as external states (this can be likened to a directed form of "decoherence" replacing the more familiar random kind). In terms of information: where the manifold is a pointwise distribution of M-syntax, collapse is a spacelike information mapping which achieves specificity by the semantic reduction of inner-expansive scope or extent. QM indeterminacy and probabilism allows this process the freedom required by its innate generativity.

In the conspansive manifold, the coordinated self-modeling of primary and secondary quanta flows "retrocausally" outward and pastward from the advanced semilanguage Ls into the retarded semilanguage Lo. The content of the flow is determined by the telic-recursive feedback of Ls, the dynamical semilanguage of M, and Lo, the "static" semilanguage of M which is already bound in the past and thus parameterizes Ls. But even as determinacy flows from future to past, the objects through which it flows are propelled along timelike gradients from past to future by retarded causation, a linearized approximation of the true metacausal dynamic. The true dynamic is not located in T at all; T is merely what the true dynamic produces as output, and reality can thus be described as a kind of "self-simulation".

The linear semimodel of T – the collapsed "pixels" of the terminal "display space" to which classical physics is confined – affords access to only a localistic, linearized correlate of true causation, a mere projection of the real metacausal dynamics of M. It is on this surficially displayed causal simulation, the M-subsignature $T\subset\Sigma$, that true quantum reality is projected from the nonterminal domain $N\subset\Sigma$, thereby literally casting the shadows which seem to move across the walls of Plato's dank and dimly lit cave.

Telesis

Strictly speaking, the "action" of $\Gamma\mu$ is not energetic, but telic and informational in nature; it effects the punctuated redistribution of energy as medium-content relationships are generatively redefined and emerge into the terminal domain T. Where energy is confined and conserved in T by definition, its longstanding function as the ultimate reduction of reality - a role it often fills in modern physics, and arguably in the history of physics as *vis viva* - requires some amount of adjustment, especially when moving away from T and deeper into the nonterminal domain. In the deep structure of M, the physical quantity *energy* must be reductively generalized to a protean "metasubstance", *telesis*, which intrinsically determines its own properties and composition by unbinding and binding itself in conspansive potentialization-actualization cycles, and of which physical energy is just the conservative orthogonal restriction to T.

Telesis, a metaphysical generalization of both energy and volition, can be described as "self-actualizing self-potential" which generates medium-content relationships. According to Heisenberg, quantum objects are not so much hard bits matter as "probabilistic tendencies" or *potentiae* which "stand in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality" (Heisenberg, 1958). By process of elimination, Heisenberg could only have been talking about telesis.

In CTMU terms, Heisenberg's quantum potentiae coincide with tertiary syntactors (point-quanta) of the conspansive manifold that are inner expanding due to the generative self-action of telesis while interfacing between the nonterminal and terminal domains N and T. Thus, their actualization, amounting to quantum wave function collapse, is the mechanism of emergence of T from N, and of Lo from Ls.

Generativity

The Metaformal System M is an identification system consisting of an ontic identity with many subidentities which all identify each other, passively recognizing and actively transforming each other. By definition, generativity characterizes the evolution of any identification system not governed by timelike laws of causation relating a preexisting array or background medium to its content. Law, medium, and content must all be determined together in order for identification to occur, and because this amounts to a determination of causation itself, the process is by definition "metacausal" in nature.

In classical mechanics, a closure principle is assumed under which causation must be defined on the medium and content of nature, with outside factors excluded. For example, (1) a fixed law is induced – e.g., Newton's second law F=ma – which is intended to capture some aspect of the generic medium-content relationship, (2) a specific distribution of content in the medium is fed to this law as input (the "cause"), and (3) the law converts the causal input to output (the "effect"). Classical mechanics is thus ruled by "causal efficacy", in which cause determines effect by timelike laws which relate the medium of nature to its physical content. (Although we have deliberately chosen a very simple example in F=ma, it characterizes physical reasoning in general.)

The CTMU replaces the classical closure assumption with an ontic closure principle (ARC, or Analytic Reality Closure) under which the entire relationship between medium and output is self-selected from unlimited possibilities in the self-potentialization of the ontic identity and its subidentities. Rather than merely relating cause and effect (causal input and output states) using a timelike law within a fixed array, metacausal functions relate entire medium-content relationships within the conspansive manifold. Not only are cause and effect coupled in mutual dependency, but so is the law by which their mutual determination emerges. This mirrors the intrinsic dynamic of the generative grammar of M (and for that matter generative grammar in general), wherein any given expression and its grammatical abbreviation, its "start symbol", must be determined before the grammatical derivation of the expression can proceed.

In generative evolution, the exact relationship between a fixed array and its content is fundamentally indeterminate precisely because there is no fixed medium independent of its content, and paths cannot be defined until the dependency relationship has been generated. Inner expansion turns terminal states in T into a "typographical array" in which the next states can be written (Langan, 2017, 2018), unbinding and opening the quantum metric. For each new event, the entire relationship must be regenerated along with the "law" describing that relationship before a trajectory can be determined. Such a relationship is called a *telon*, the self-configuration of an active sign of Σ called a *telor* (self-configurable telic identification operator), i.e., a secondary and/or the primary quantum of QMM. Thus, primary and secondary telic quanta are the true source of quantum dynamics.

Conspansive Duality: Distributed and Linear Morphisms

The inner expansion-collapse cycles of the conspansive manifold are "distributed endomorphic" and "distributed ectomorphic". A distributed endomorphism can be approximately visualized as a sphere collapsing to an interior point, while a distributed ectomorphism can be approximately visualized as a point expanding into a sphere. (Such morphisms are defined as "hological", preserving essential structure on all scales.) On the other hand, temporal sequences of the successive collapsed states of objects – the strings of S_Σ - are "linear ectomorphic" in both directions, with objects traveling along linear paths or trajectories. This is called the *linear ectomorphic semimodel* of the conspansive manifold, associated with "display space" T.

Standard physics, including spacetime, is linear-ectomorphic. In a linear ectomorphism, an object leaves or enters a point of a manifold along a linear trajectory. (We have already seen that this leads directly to the adjacency paradox, forcing objects in motion to exit the manifold.) In the inner expansion-collapse cycles of the conspansive manifold, on the other hand, a telic point repeatedly "self-factorizes" into a self-nonself content-medium relationship under the guidance of one or more telons in such a way that an incremental linear displacement amounts to a conspansive cycle consisting of the inner-expansion of an initial state (the "medium") and collapse of its successor therein. Terminal content never leaves any point in its history, but merely *contracts within it*, projecting onto a timeline to define an ectomorphic interval.

Spacetime too is ectomorphic, consisting of points called "events" which are specified by four coordinates, three of space and one of time, that are separated by spacetime geodesics called *worldlines*. Spacetime can be overlaid on a continuously collapsed idealization of the terminal point-set T of the conspansive manifold, the points of which are fully collapsed tertiary syntactors already conveniently coupled in mutual identification events. Just "below" T, and interspersed with T, is the top level of N, in which inner-expanded but as-yet uncollapsed points of the manifold lie open, comprising what appears to be "empty space". This is where QM belongs, in the open states of the conspansive manifold. Below this open top stratum of N lies the deep structure of M including secondary quanta, the metacausal influence of which resolves the causal deficits associated with QM potentiae (open tertiary syntactors).

In short, spacetime is just a kind of "ectomorphic dual" of the conspansive manifold. Spacetime approximates T in the sense that objects "move" by skipping along timelike gradients like stones on the surface of a pond, their paths effectively interpolated between points generated on the surface. But unlike spacetime, the *surface itself* is regenerated with each skip of the "stone" or tertiary identity, and while spacetime can only confine its evolution to an ectomorphic scenario devoid of any extrinsic pregeometric background, T resides on an *intrinsic* background, the nonterminal domain N. T is thus adjoined to deeper structure supporting teleodynamics, which cannot reside on the surface of the manifold and is not actually supported there.

Due to these and other limitations of spacetime and the classical (Cartesian coordinate-space) model of classical physics from which spacetime evolved, QM cannot be fully modeled there, and its resulting homelessness has engendered various ontologically unsound interpretative modifications of empirical reality. QMM therefore maps potentiae to the open points of the top nonterminal stratum of the conspansive manifold, thus providing QM with a home at last.

VII. EXAMPLES OF QMM META-INTERPRETATION

Here we give a very brief account of the application of QMM to several well-known QM interpretations, particularly those which have been mentioned in the forum discussions of *Foundations of Mind*. Please bear in mind that all mainstream interpretations of quantum mechanics are confined to the linear semimodel of M and require adjustment in order to conform to the conspansive manifold. These interpretations will be treated as tersely described in Nick Herbert's respected and highly readable classic "Quantum Reality: Beyond the New Physics" (Herbert, 1985).

Copenhagen (Bohr and Heisenberg): *There is no deep reality*. While quantum indeterminacy leaves ample room for generativity, making use of it would require acknowledgement of the nonterminal (and non-physical) domain N and the deep structure of M, which this interpretation explicitly denies. This is unfortunate, as Heisenberg erred in placing his potentiae "between the idea of an event and the actual event, [in] a strange kind of *physical* reality just in the middle between possibility and reality" (Heisenberg 1958, page 41), thus explicitly calling ideas and possibilities "physical" even when they are *physically unrealized* and therefore *not* physically real. This, of course, is semantically inconsistent; if a phrase like "physically unrealized ideas and possibilities" has any content at all, it cannot be physical in nature. We may thus infer, for the sake of consistency, that potentiae are metaphysical, which means that QM is either metaphysical and thus reliant on the metaphysical structure of reality, or merely physical and therefore needful of augmentation by deep reality in order to explain how reality identifies itself. Mere probabilistic tendencies are by definition inadequate to determine individual state transitions, and even if they are included in QM, something more is required in order to account for the self-identification of reality. It follows that the statement "there is no deeper reality than QM itself" cannot be mapped into the supertautology, and must therefore be excluded from our understanding of reality.

Observer-Created Reality (John Wheeler): *Reality comes into being through the observations of observer-participants*. Reality corresponds to the metaformal supertautology (or to its physical domain $T \subset \Sigma$), creation is mapped to generative-grammatical production by $\Gamma\mu$, and observation is mapped to secondary and tertiary identification events (i.e., to quantum measurements, and generically, to bare tertiary interactions). To the extent of its description, Wheeler's interpretation meets the standards of QMM; reality can indeed be generated by teloric observers.

Consciousness-Dependent Reality (von Neumann-Wigner-Stapp): *Consciousness creates reality*. Insofar as the generic definition of "consciousness" overlaps with the self-identification of the ontic identity and its internal self-images, it passes the test of metaformal consistency for basically the same reasons as does Observer-Created Reality.

This approach merits additional explanation. Associated with the vNWS interpretation is a "process description" of quantum dynamics. Dirac originally noted that there are two ways in which a quantum system evolves: (1) the wave function deterministically explores all possible interactions as it propagates, and (2) a single possibility is randomly actualized. In his book *Mathematical Foundations of Quantum Mechanics* (1932), John von Neumann elaborated on these modes of evolution, observing that two distinct alternating processes are transpiring: Process 1, a non-causal, nondeterministic process in which a measured particle randomly assumes one of the possible eigenstates of an observable property determined by the relationship between the particle and a measuring apparatus, and Process 2, a causal, deterministic process in which the wave function evolves between measurements according to the Schrödinger wave equation.

Henry Stapp (2007) further develops this concept by defining four (4) processes as follows:

Process 0: "Some process that is not described by contemporary quantum theory, but that determines what the so-called free choice of the experimenter will actually be"

Process 1: "The basic probing action that partitions a potential continuum of physically described possibilities into a countable set of empirically recognizable alternative possibilities"

Process 2: "The orderly mechanically controlled evolution that occurs between interventions"

Process 3: "The process that selects the outcome, Yes or No, from the probing action"; "The choice of nature"

QMM maps Stapp Process 0 to a generative event associated with a secondary telor endowed with free will (generative capacity); Process 1 is mapped to the expansion of the measured system in an eigenbasis of the telonic observable (syntactic or semantic property) in the generative syntax of the telor, priming the system's wave function for collapse; Process 2 is mapped to the underlying telic-recursive process approximated by the Schrodinger equation under ectomorphic confinement to the surface of the conspansive manifold; and Process 3 is mapped to the combined action of the primary and secondary telors on the system, which triggers the collapse. In short, QMM maps all four of Stapp's processes into the conspansive manifold.

Bohmian Mechanics (early David Bohm*): Quantum particles are ordinary objects steered by guide waves in a nonlocal pilot field.* Bohmian mechanics is disallowed by QMM for the following reasons: (1) It is a so-called "realistic" interpretation of QM which holds that reality exists independently of the observer, precluding the crucial dynamical functionality of primary and secondary quanta (including conscious human telors); (2) It is deterministic, thus violating generativity; (3) it is fundamentally dualistic, holding the particle apart from its pilot wave (function) in such a way as to imply ontic inequivalence; and (4) It is often considered to violate the locality principle of classical physics (no superluminal influences) by requiring that the force on a point-particle instantaneously depend on the precise location of many other particles in the universe. Yet it is also widely considered to violate Bell's theorem by incorporating this nonlocal information as "hidden variables" which account for its determinism (d'Espagnat, 1979, 1989).

In the conspansive manifold, problem 4 is at least partially obviated by extended superposition, which distributes information on distant particles to every location within range of their wave functions (the scope of their inner-expanded states). Extended superposition means that no violation of locality is necessary. However, while the pilot field to some extent approximates the extended-superpositional structure of the conspansive manifold, it falsely objectivizes particles by turning them into ordinary objects which compactly persist between linear-ectomorphic state transitions, and thus commits to a form of dualism fundamentally separating medium (the pilot field) from content (the particle). Pilot waves supposedly guide particles, but in order to do so, must be determined in advance of the states of the particles themselves. Thus, field and particle are dynamically as well as structurally distinct. This is inconsistent with conspansion, whereby points of the conspansive manifold inner-expand to become their own media. Triality demands that the particle and its wave field coexist within a single identity in conspansive alternation.

The Implicate Order (late David Bohm): *Reality is an undivided wholeness.* This interpretation is rather nebulous, but if held apart from the insupportable aspects of Bohmian Mechanics, it passes in several important respects. For example, it is explicitly generative; the implicate and explicate orders correspond to Ls and Lo respectively; its wave function entanglements mirror the extended-superpositional structure of the conspansive manifold; and the holomovement (Bohm, 1980) resembles the conspansive evolution of the manifold, including telic-recursive Ls|Lo feedback over a metaformal "semantic network" of wave function entanglements and the terminally restricted flow of advanced metacausal data from Ls to Lo. While it lacks an ontology of its own due to insufficient logical support for its conceptual ingredients, Bohm's "undivided wholeness" qualifies as a limited success by QMM standards (Bohm & Hiley,1993).

Many worlds (Everett): *Reality is a multiverse of many alternate universes.* In order to circumvent the reduction of the wave function, this interpretation reifies a higher-order wave function, the so-called *universal wave function*, and associates it with physical reality as a whole. Then it lets this vast "meta-quantum" evolve "deterministically", splitting into separate universes at each quantum event.

First, the good news: Everett racked up an impressive QMM score just by proposing the existence of a cosmic wave function. With some adjustment, QMM can map it to the primary quantum of the Metaformal System, i.e., to the ontic identity as a whole. But unfortunately, this is where the correspondence ends, for wave function collapse is a basic feature of the conspansive manifold and cannot be avoided. QMM maps wave functions in general to identities consisting of superpositions of the M-semilanguages Ls and Lo, and these are not merely optional. Secondly, the evolution of semilanguage superpositions is neither temporal nor deterministic but generative, and when it comes to generative events, there is no way for the cosmic superposition of possible universes to see them coming. It could only wait for them to occur and then pretend that elsewhere they didn't, splitting the metaverse into the universe where the event and its outcome have occurred, and an "alternate universe" where they have not. Moreover, it takes more than a cosmic wave function to make an ontology, and now that a proper ontology has been discovered, it is evident that there are ontological criteria that Everett failed to take into account. At the very least, the coming-into-existence of any given alternate universe depends on these neglected criteria.

Quantum field theory (**QFT**): While QFT is a complex and powerful extension of the formalism of QM, its inclusion here is justified by the fact that it incorporates QM and thus involves some amount of QM interpretation. Simplistically, QFT replaces particles and wave functions with quantum fields as primitive objects, defining the particles as "excitations" of the fields which emerge analogously to wave function collapse while permitting variation in particle numbers. This much is consistent with the structure of the conspansive manifold, at least where tertiary syntactors need persist only for the duration of a single state terminated by generative or annihilative events.

But as the conspansive manifold evolves by conspansive self-dualization in generative potentialization-actualization cycles terminating on interactions of its quantum point-identities, it symmetrically dualizes the relationship, making the field internal to the points just as the points are internal to the field. The quantum fields of QFT, like the elementary particles they replace as fundamental entities, are thereby identified with the points of the manifold, i.e., with tertiary syntactors, and thus equivalently reduced to pointwise syntactic distributions. But while both QM and QFT are confined to the open top layer of N and thus superficially excluded from the deep structure of M, they are now embedded in the conspansive manifold, a "quantum metafield" where physical systems superpose directly on deeper levels of metaphysical structure and dynamics.

Lastly, it is perhaps appropriate to mention the existence of a handful of interpretations involving Lagrangianism (e.g., the **Path Integral formalism** of Richard Feynman), advanced causation (e.g., the **Transactional**

Interpretation of John Cramer and its PTI variant by Ruth Kastner), or both at once.

The coupling of Lagrangianism and advanced causation may seem quite natural in the linear-ectomorphic spacetime "dynamic". While Lagrangian mechanics requires that the initial and final states of a moving object be determined before a definite linear path can be calculated using the stationary action principle, an advanced cause serves nicely as a final state. However, in the absence of determinism, it is given by assumption rather than any sort of explanation, and so for the initial state as well. This is no less true in the quantum realm, where classical determinism is out of the question; the initial and final states of a particle must be determined before its path can be determined and used for the ectomorphic transmission of causal influences. This is the case whether causation is considered to run forward or backward, and whether the initial or final point is designated as the cause or effect … i.e., whether determinacy is retarded or advanced. This spells trouble for retrocausal theories which rely on the linear-ectomorphic transmission of advanced influences along definite linear paths, even if this is wishfully attributed to, e.g., the "back-action" of mind on a pilot field. The first requisite is to establish a generative relationship between minds and fields, and this something that only the conspansive manifold can provide.

In the CTMU, determinacy in either direction of time is superseded by generative metacausation, in which the generative action of telic identity operators gives both the initial state and final state by projecting them onto a timeline from the depths of the conspansive manifold (and which, if desired, can be factored into advanced and retarded components in spacetime despite the inadequacy of spacetime alone for mental causation).

All QM interpretations are subject to this kind of analysis, some for better and others for worse. Because QMM stands on the CTMU Metaformal System and its logical-inductive groundwork, it is unconditionally validated by the intelligibility of reality and cannot be falsified by empirical induction. In short, just as with the Metaformal System itself, there is no way out of it.

VIII. SUMMARY

We have explained how QMM maps certain key concepts of the QM formalism, along with several popular interpretations of QM, into the supertautological CTMU Metaformal System, a true ontological metalanguage formulated in such a way as to logically support reflexive attributions of existence associated with the high-level self-identification of reality. By virtue of this mapping, QM itself, along with certain hypothetical ingredients attached to it by various interpretations dubiously claiming to provide it with an "ontology", finally have a true ontology against which they can be tested for relevance and consistency, and where those passing the standards of QMM may come to rest.

Concisely, the development can be described as follows. Any "interpretation" of A in B (or vice-versa) is a correspondence C between A and B: C:A←→B. Obviously, both A and B must be defined with some amount of coherence and precision before the correspondence C can be mapped. In any interpretation of QM, A = QM and B = reality as a whole. The problem has been that while the mathematical formalism of QM was well-defined, "reality as a whole" was not, in part because its description changes or has the potential to change with each new scientific theory or experiment. This is no longer the case; reality can now be unequivocally characterized as the supertautological and therefore rationally undeniable CTMU Metaformal System, and the true correspondence can therefore be established. By definition, QMM is that correspondence. All that remains is to apply QMM to the beasts of the quantum jungle, namely, the often strange and apparently wildly conflicting QM interpretations that have been freely proliferating at the frontier where physics meets metaphysics. It has just been demonstrated how this is done, with examples.

Nevertheless, let us explain once more *how* it was done in the clearest and briefest possible way. The CTMU Metaformal System is an intrinsic language, the involutional coupling of a language with a manifold whose points are the elements of the signature of the language, or in semiotic terminology, its "signs". This manifold is dynamic, with dual outward and inward gradients accounting for gravity and the relative linear motions of physical objects (the curvature of spacetime equates to the inner expansive gradient of the conspansive manifold, which is dual to the timelike collapse gradients of T). Its evolution can be described in terms of two operations, *conspansion* and *telic recursion*. By virtue of conspansion, the evolving manifold closely resembles the existing formalism of quantum mechanics; and by virtue of telic recursion, this formalism can be carried into the linguistic aspect of the manifold and the deep structure of the Metaformal System. (For now, we refrain from asserting that the Metaformal System is a "theory of quantum gravity", but this will no doubt eventually emerge.)

Thus, QMM is not to be confused with any mere interpretation of QM, examples of which relate to QMM as input. Rather, QMM is a "metamodel" which carries QM and its various prospective models (speculative interpretations) into the supertautological ontic identity. In short, QMM is what QM must become if it is ever to qualify as a truly reliable source of insight and authority regarding deep metaphysical questions of which the answers require certainty, generativity, and true ontological support.

Of course, there is much more to this story. But owing to space limitations, further details must be set aside for later presentation.

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