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Quantum Cosmology Based on Discrete Feynman Paths

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Abstract

Although the rules for interpreting local quantum theory imply discretization of process, Lorentz covariance is usually regarded as precluding time quantization. Nevertheless a time-discretized quantum representation of *redshifting* spatially-homogeneous universe may be based on discrete-step Feynman paths carrying causal Lorentz-invariant action--paths that not only propagate the wave function but provide a phenomenologically-promising elementary-particle Hilbert-space basis. In a model under development, local path steps are at Planck scale while, at a much larger "wave-function scale", *global steps* separate successive wave-functions. Wave-function spacetime is but a tiny fraction of path spacetime.

Electromagnetic and gravitational actions are "at a distance" in Wheeler-Feynman sense while strong (color) and weak (isospin) actions, as well as action of particle motion, are "local" in a sense paralleling the action of local field theory. "Nonmaterial" path segments and "trivial events" collaborate to define energy and gravity.

Photons coupled to conserved electric charge enjoy privileged model status among elementary fermions and vector bosons. Although real path parameters provide no immediate meaning for "measurement", the *phase* of the complex wave function allows significance for "information" accumulated through "gentle" electromagnetic events involving charged matter and "soft" photons. Through its soft-photon content the wave function is an "information reservoir".

Introduction

Over the course of almost two decades I have been struggling to modify the framework of quantum mechanics so as to embed an essential role for electromagnetism. Because all measurements are electromagnetic and because the usual form of quantum theory interlocks with the concept of measurement, the Copenhagen basis that ignored electromagnetism seemed to me defective. Many forays failed, but they led to belief that Whitehead's idea of *discrete process*⁽¹⁾ might elucidate the persisting mystery of wave-function "collapse". Might quantum theory somehow be based on "events" where photons play a special role? Exploration of S-matrix theory during my youth exposed me (in complete ignorance of Whitehead's thinking) to Heisenberg's large-scale meaning for "event" in quantum mechanics. Today a much-smaller-scale complementary meaning will be explored.

Before coming to understand how process might underpin Hilbert space, I had stumbled, through string-inspired discrete-process *patterns* whose significance at that stage was unclear, onto a promising pair of discrete labels carried by chains of what I tentatively called "pre-events". One label was 2-valued and the other 3-valued. Stringlike pre-event patterns based on these labels--patterns that I associated with particle propagation and that I shall return to later in this talk--matched with astonishing fidelity the quantum numbers--spin, chirality, isospin, color, generation and electric charge--carried by the standard model's elementary particles. Even the Weinberg angle was matched. A process quantum theory based on pre-events bearing these two labels became for me irresistibly tempting.

I shall today describe the present status of an enterprise that has been assisted since inception by almost-daily conversations with Henry Stapp. Criticism from Henry and also from Jerry Finkelstein has been invaluable. Because the entire universe is involved, I call the enterprise “discrete-path quantum cosmology”--or DPQC.

I have difficulty choosing which of several different unusual DPQC facets to emphasize. The special role of electromagnetism I shall not today treat first. Two *other* DPQC facets compete in my assignment of priority. One is discretization of time; the other is a status for Feynman paths ⁽²⁾ more fundamental than that of Hilbert space. These two nonstandard DPQC aspects are related.

Discrete classical paths, whose causal Lorentz-invariant actions determine wave-function propagation, provide an elementary-particle DPQC basis for Hilbert space. A basis in fields that vary continuously with local time is not possible. I shall explain how a DPQC path-based wave function represents matter at a fixed “age”; discretization of wave-function age will be seen essential to consistent contact between paths and wave function. The model incorporates Whitehead’s idea that discrete process is more fundamental than matter by representing process as Feynman-path steps through a spacetime within which material-representing wave-functions occupy but a minuscule portion.

In usual quantum theory the wave function continuously changes with time. The action of standard-theory Feynman paths, occupying a continuous spacetime, is representable by classical fields that carry spacetime labels. Action is spacetime localized. Process, in standard physics, may be said to enjoy material underpinning. As

Whitehead appreciated almost a century ago, a converse relationship between matter and process is unrepresentable without discretizing process.

Process discretization is possible in a spacetime related to that proposed by Milne during the thirties in order to connect Hubble's redshift to a principle of universe spatial homogeneity. ⁽³⁾ Milne attached a different Lorentz frame to each point in a 3-space; Lorentz invariance was equivalent to homogeneity of this 3-space. Milne's fourth dimension—that I call “age”—is frame independent and correspondingly may be discretized. Less than two years ago, it dawned on me that discrete process is naturally representable by Feynman paths, carrying Lorentz-invariant causal action, that take discrete steps forward or backward in age. Shortly thereafter I came to appreciate that such paths, together with *global* age steps between successive wave functions related by the path-action-determined Feynman propagator, would provide Hilbert-space basis *if* the wave function age step were an integral multiple of the path step.

My working hypothesis is that local path step is at Planck scale, $\sim 10^{-43}$ sec, while global wave-function step is at a hugely larger “wave-function scale”. The wave-function step is tentatively being guessed as near 10^{-5} sec (in “local” frame), above atomic scale but still below the scale of human consciousness, in a range allowing the wave function an S-matrix interpretation. Any theory that defines an S matrix is a form of “quantum mechanics”. (In the language of quantum field theory, the local step provides “ultraviolet cutoff”, while the global step provides “infrared cutoff”.)

The huge integral ratio ($\sim 10^{38}$) between local and global steps is presently accepted as a fundamental DPQC parameter, with a status like the scale interval spanned by inflation in “standard” cosmology. Eventually I hope number theory will point to a

precise *prime-integral* value for the ratio between wave-function step and path step. (An example of how number theory can pick out a special huge prime is provided by the Mersenne prime sequence, $2^2-1=3$, $2^3-1=7$, $2^7-1=127$, $2^{127}-1$, brought to my attention by Pierre Noyes and Herb Doughty.)

Age Discretization

Milne’s spacetime occupied the interior of a forward lightcone. DPQC ‘s “path spacetime” factorizes a forward-lightcone interior into the product of a curved 3-dimensional “boost space” and a 1-dimensional “age space”. Age--the Minkowski distance from lightcone vertex—is Lorentz invariant and may be quantized compatibly with Milne’s principle of equivalence for all locations in 3-space. DPQC applies Milne’s homogeneity principle not to matter but to process. Using the symbol τ for age and the 3-vector symbol β for (dimensionless) “boost”, infinitesimal displacements in ordinary 3-space and in boost space are related by $d\mathbf{x} = \tau d\beta$. Writing the boost symbol as $\beta\mathbf{u}$, where \mathbf{u} is a unit 3-vector, the curved metric of Milne’s continuous boost space is

$$d\beta^2 = d\beta^2 + \sinh^2 \beta d\mathbf{u}^2 .$$

Path spacetime is the set of hyperboloids whose age is an integral multiple of DPQC’s Planck-scale unit. Starting from one point on a hyperboloid, any other point on this hyperboloid may be reached by a boost. Choice of frame amounts to choosing, at specified age, a spatial location—to selection of a point in continuous boost space.

The lightcone boundary of Milne’s spacetime corresponds to a “big bang” from which age is measured. Redshift and universe homogeneity are correlated. However, when Milne supposed age *continuity* and interpreted his continuous spacetime materialistically (rather than through process), he encountered vanishing *4-dimensional*

curvature incompatible with Einstein’s classical general-relativistic representation of gravity. Milne’s approach, while widely recognized as interesting, became judged as nonviable. (It came to be called “kinematic cosmology”.)

The discreteness of DPQC renders spacetime curvature undefinable. Gravity is instead represented through the “action at a distance” concept uncovered by Wheeler and Feynman in their 1949 representation of classical electromagnetism without fields. ⁽⁴⁾ (The gravitational constant is determined in DPQC by the path step in age.) The large-scale meaning of classical *material* trajectories (*not* action-carrying Feynman paths) derives from stationary phase within wave-function propagation. We shall see that DPQC path action, which determines wave-function propagation, includes not only gravitational and electromagnetic action at a distance but “action of motion” through trivial events and, through nontrivial events, weak (isospin) and strong (color) local action. Action of motion underpins the meaning of “kinetic energy”.

Path spacetime is the set of hyperboloids whose age is a positive-integral multiple of the path age step that I denote by the symbol δ . (The gravitational constant is δ^2 in units where $c = 1$.) Wave-function spacetime, on the other hand, is the relatively-tiny *subset* of these hyperboloids whose age is a multiple of the “global step” Δ , the ratio Δ/δ being the huge integer ($2^{127}-1$?) on which DPQC is founded.

Path Constraints

DPQC dynamical laws include *constraints* on its discrete paths—directed chains of pre-events. Paths, first of all, consist of directed *lightlike* “steps”—each step leading from one pre-event to a “following” pre-event. Along any connected portion of a path, successive pre-events are lightlike separated as well as being age-separated by $\pm\delta$. A path

comprises 6 closed directed correlated loops of steps within path spacetime, each loop carrying a different pair of the 2 labels to which I have earlier drawn attention.

Any loop consists of path “segments”, each segment being classifiable either as “enduring” or “tachyonic”. Inside an enduring segment, steps are monotonic in age—either increasing or decreasing. Inside a tachyonic segment, steps of increasing and decreasing age alternate. Whitehead used the adjective “enduring” to characterize materially interpretable process. ⁽¹⁾ My use of the adjective “tachyonic” stems from physics language describing a particle (so far, never observed) that moves faster than light. A tachyonic path segment has velocity hugely larger than light velocity.

Tachyonic path segments never enter wave-function spacetime, whereas certain enduring segments may cross a wave-function hyperboloid, on which exactly one pre-event along such a segment then locates. The tiny subset of labeled pre-events along a path (within enduring segments) that locate in wave-function spacetime provide a boost-space path-connected basis for wave functions housed by successive wave-function hyperboloids. Boost space plays a DPQC Hilbert-space role paralleling that of 3-space in nonrelativistic quantum mechanics. Precise definition of DPQC Hilbert space, however, depends on *further* path constraints that *correlate* the path’s 6 closed loops.

In formulating loop-correlation constraints I have been guided by the so-called “standard model” of particle physics and by the closed-string representation of an elementary particle. As detailed in the accompanying paper ⁽⁵⁾ the 3-dimensionality of space, supported by the standard-model collection of elementary particles and the string idea, indicates a constraint on enduring path segments that invariably clusters them into almost-parallel segment *quartets*. Each of the 4 segments within such a quartet may

belong to a different loop. Two segments within a quartet are age advancing and two are age retreating, with spatial spacing between segments fixed by the path age step.

Consistency of such an enduring pattern, which I call a “tower”, dovetails with space’s 3- dimensionality. One may loosely think of a tower as a “stack of tetrahedrons”. The precisely definable *central axis* of a tower is spatially straight and, for any age huge on Planck scale, almost lightlike. (“Our” age here and now is about 10^{60} in path-step units.)

DPQC Hilbert space is defined not by *individual* pre-events but by pre-event *quartets* in 3-dimensional patterns each corresponding to a fixed-age “slice” through a tower that passes through a wave-function-housing hyperboloid. There are 2 different patterns, each fixed by the path age-step δ . In a “fermionic tower” two segments of common “age direction” coincide in path spacetime while the other two segments are spatially separated from each other. In a “bosonic tower” the spatial separation between advancing segments equals that between retreating. The foregoing names for tower patterns have been chosen because, in the DPQC Hilbert space based on pre-event quartets, those quartets contacted by fermionic towers correspond to elementary spin- $1/2$ fermions while those contacted by bosonic towers correspond to elementary vector bosons.

Each tower has a precise “beginning” (earlier age) and “end” (later age) in path spacetime. The location in path spacetime of tower *center* at either beginning or end plays a role paralleling that of the spacetime label on a local field. Tower transverse orientation parallels the role of field spin labels. Apart from location and orientation in path spacetime, different fermionic (bosonic) towers differ only in the labels carried by

the 4 constituent segments. The 6 possible labelings of each segment lead in a wave function, with Pauli-like symmetry constraints internal to each quartet and a requirement that “photons couple to electric charge”, to a family of DPQC elementary particles that closely matches the standard-model fermions and vector bosons. ⁽⁵⁾ (The pair of labels carried by any path segment lead to 2 “observable” conserved quantum numbers carried by particles, one of these conserved quantities being electric charge.)

Events; Material vs. Nonmaterial Towers

A tower begins and ends in a *junction* with either 2 or 3 other towers—a junction I call “event”. The *centers* of the ends (beginnings) of all towers coincide at the “event location” in path spacetime. An event *never* locates in wave-function spacetime.

Events may be either “trivial” or “nontrivial”. In a trivial event a terminating and a commencing tower share the same oriented central axis and the same labels, differing only in transverse orientation. A trivial event rotates a bosonic tower (discretely) by $\pi/2$ around its central axis while a fermionic tower is rotated by π .

The remaining 1 or 2 towers in a trivial event fall into a bosonic-tower category I call “nonmaterial”. A fermionic trivial event involves 1 nonmaterial tower while a bosonic trivial event involves 2. The labeling on the advancing half of any tower in the nonmaterial category is the *same* as the labeling on this tower’s retreating half, guaranteeing zero tower value for all quantum numbers. The role of the “emitted” or “absorbed” nonmaterial-towers in a trivial event resembles in some respects that of gravitons in quantum field theory.

A *material* tower may contact wave-function spacetime and thereby associate with an elementary particle. A nonmaterial tower owes its name to incapacity for crossing a wave-function hyperboloid. The wave function stores no nonmaterial information.

A nontrivial event is classifiable as either electromagnetic or nonelectromagnetic depending on whether or not it involves a special category of material bosonic tower called “*photonic*”—a tower that contacts a photon when crossing wave-function spacetime. A succession of photonic towers, with intervening trivial events, both begins and ends in an electromagnetic event. The special structure of an electromagnetic event (not here to be described) “*couples photons to electric-charge*”.

Path Action

Propagation of a hyperboloid-housed wave function to the wave function housed by the *succeeding* hyperboloid (of age larger by Δ) is determined, through an adaptation of Feynman’s prescription, ⁽²⁾ by the causal Lorentz-invariant actions of path portions located in the path spacetime *between* these two hyperboloids. Such a path portion I call a “*section*”. Although action rules are still under study, it has become apparent that any path section contains 3 different categories of action.

(a) Any *nonelectromagnetic* event inside the section supplies an increment of *local* action. The “*action of motion*” increment from a trivial event contributes $\pi/2$ to wave-function phase at fixed spatial location; for a nontrivial nonelectromagnetic event the increment is expected to be similar. Local nontrivial action corresponds to the strong color action and the weak isospin action of the standard model. (Nonelectromagnetic

DPQC event structure in path spacetime matches the algebraic structure of an SU(5) Yang-Mills Lagrangian.)

(b) Any charge-carrying (material) tower or portion thereof within a section carries an increment of *electromagnetic action at a distance* determined by a prescription paralleling that of the 1949 Wheeler-Feynman formulation of classical electrodynamics without fields. ⁽⁴⁾ An electromagnetic event, although not *carrying* local action, *affects* electromagnetic action by replacing a *single* charge-carrying tower with *two* joined towers of common labeling but differing orientation.

(c) Any tower succession (material or nonmaterial), with intervening trivial events, carries an increment of *gravitational action at a distance* whose prescription resembles that for electromagnetic action but with number of trivial events along the tower succession playing the role of electric charge times tower age extension.

Tower Reflection; Zitterbewegung

A velocity-reversing parity inversion about the plane perpendicular to tower central axis is called “tower reflection”. A reflection, like an event, never occurs in wave-function spacetime. A succession of material towers with intervening reflections and trivial events I call a “massive tower” because such a succession contacts a *parity-doubled* direct-sum wave function for a particle with rest mass—a wave function of the type discovered by Dirac for spin- $\frac{1}{2}$. Representation of sub-light velocity through a pair of oppositely-directed lightlike velocities was called by Schrödinger “zitterbewegung”. Stapp and I have found a Dirac-imitating direct-sum parity-doubled wave function for massive spin-1. ⁽⁶⁾

Although tower reflection appears at the very end of today's list of path features, universe self-awareness depends heavily on the rest mass carried by charged "observable" particles. Under investigation is the mechanism (plausibly related to field theory's "renormalization group") that determines observable rest masses. DPQC zitterbewegung requires much greater attention than so far received.

Summary and Conclusion

I have sketched a quantum cosmology designed to span all ages after big bang and all scales between that of Planck and that of Hubble. The wave function, representing matter, has its basis in process. Undiscussed has been the arbitrariness residing in the *initial* wave function at age Δ . The "size" of the material universe has not been considered in my remarks today, nor has the influence of initial condition on universe "self-knowability". The proposal, however, accords electromagnetism a distinguished status intended to enable universe self-awareness.

DPQC requires four ingredients: (1) A discretized *path spacetime* that includes a (smaller) *wave-function spacetime* allowing paths to provide the basis for Hilbert space. (2) Definition of "constrained path" that correlates with wave function. (3) Specification of the action that determines wave-function propagation. (4) Wave-function initial ("big bang") condition. The first three of these ingredients have been touched on today.

DPQC lifts a notion from Feynman *graphs* in order to define *paths*. Feynman paths and Feynman graphs are usually regarded as completely different notions. Graphs, however, by uncovering the idea that "positrons are like electrons moving backward in time", led Feynman to observe that a *single* "line" meandering backward and forward in time, as well as in space, might represent *all* the electrons and positrons in the universe.

DPQC seizes on this Feynman insight to find in *individual* classical paths a basis not only for all the matter in the universe but for “nonmaterial process” that fills the role of general relativity’s “spacetime curvature”. A single path, in fact, *further* includes tachyonic *global* process.

I would love to report today an understanding of the mystery dubbed “wave-function collapse” but can merely call attention to novel DPQC features that may bear on this puzzle. Despite resemblance to the standard model in its Hilbert space (a Fock space, see below) and localized action, the discrete paths whose actions determine wave-function propagation do more than *locally* propagate and collide particles. Following are examples of nonlocal path features:

- (a) Electromagnetic and gravitational actions at a distance provide long-range influences on a particle that preclude its isolation.
- (b) Nonmaterial tower successions, which through trivial events underpin action of motion and gravitational action, themselves carry these two categories of action. DPQC’s nonmaterial towers play the pervasive nonlinear role of general relativity’s spacetime curvature.
- (c) Elementary-particle rest mass in DPQC associates with tower reflection. Fermionic tower reflection is a chirality reversal that involves “emission and absorption” of “global tachyons”--such a tachyon connecting fermionic tower reflections at the same age but *arbitrary* spatial separation. Wave-function “collapse” *might* relate to successions of tachyonic fermion connections that close global loops at fixed age within path spacetime.

(d) Absence of local action in an electromagnetic event allows such events to be “gentle”—disturbing only slightly the propagation of charged matter while nevertheless “recording” the event in DPQC’s “information reservoir”—a wave function that includes “soft” photons—of period at the scale of wave-function age-step Δ and momentum correspondingly tiny compared to charged-particle rest mass. Enabled thereby is the miracle of information accumulated with negligible material disturbance.

An essential future step for DPQC is the development of approximation strategies that will allow the successes of continuous-time theories to be reproduced. Only the outlines of such strategies, based on the large ratios of Hubble scale to wave function scale and of the latter to Planck scale, have so far been conceived.

Underway in this respect is an effort to quantify the accuracy of “observation reproducibility”—the foundation of science even though *exact* reproducibility of any measurement is impossible in an expanding universe. Through “special relativity” Einstein enlarged the meaning of “reproducible observation” from observations related by the spacetime-displacement group to those related by the so-called “Poincaré group”. Understanding the accuracy of special relativity in DPQC will require understanding the meaning of an “isolated particle” whose movement is defined by a “sea” of nonmaterial process. Also required, of course, is a meaning for “measurement”.

The huge ratios explicitly recognized by DPQC reduce a variety of heretofore-sacrosanct physics principles (such as Poincaré invariance) to the status of extremely accurate approximations. Do *any* of our sacred principles survive? Undisturbed is Pauli’s symmetry that defines “identical particles”—a notion essential to any meaning for reproducible measurement. The DPQC Hilbert space is a Fock space.

A complete and consistent set of DPQC path constraints and action prescriptions cannot yet be asserted, nor can I report DPQC reproduction of the successes of previous theories. Let me nevertheless in conclusion express confidence that the twenty-first century will see a discrete-time process-based cosmological version of quantum theory, with a central electromagnetic role that gives meaning to information acquisition.

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