Getting Something Out of Nothing:

Implications of a Future Information Theory Based on Vacuum Microtopology

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Abstract

Contemporary theoretical physicists H. S. Green and David R. Finkelstein have recently advanced theories which depict spacetime as a singular limit, or condensate, formed out of fundamentally quantum microtopological units of information, or process (denoted respectively by 'qubits,' or 'chronons.') H. S. Green (2000) characterizes the manifold of spacetime as a parafermionic statistical algebra generated fundamentally by qubits. "The quantum mechanics of systems with large numbers of interacting particles…can be formulat[ed] in terms of elements…represented by fermions or parafermions, and thus in terms of qubits." (108) David Finkelstein (2004a-c) models the spacetime manifold as singular limit of a regular structure represented by a Clifford algebra, whose generatorsrepresent 'chronons,' i.e., elementary quantum processes.

Both of these theories are in principle experimentally testable. Green, for example, writes that his parafermionic embeddings "hav[e] an important advantage over their classical counterparts [in] that they have a direct physical interpretation and their parameters are in principle observable." (166) David Finkelstein discusses in systematic detail unique empirical ramifications of his theory in (2004b) which among other things most notably include the removal of usual quantum field-theoretic divergences.

I will discuss the ramifications of the above theories, which share the ontological intuition of conceiving spacetime itself as fundamentally generated or derived from an underlying microtopology of fundamental quantum processes of information. The empirical tests discussed by Green and Finkelstein raise compelling questions for future information-based technologies. Since the work of Shannon and Hawking in the fifties and sixties, compelling associations among entropy, information, and gravity emerged in the study of Hawking radiation. Nowadays, however, the theories of Green and Finkelstein together suggest that the study of spacetime may not end at the edge of a black hole's event horizon, but begin in the development of technologies better able to probe its microtopology in controlled laboratory conditions.

H. S. Green (2000)

- **Defn. (Generalized Qubit)** For any $M \in$ **C×C = C²**:

(a) $M^2 = M$ and (b) $\mathrm{tr}[M] = 1$.

Or expressed component-wise:

(a) $$\sum_{k=1}^{N} M_{ik} M_{kj} = M_{ij}$$

(b) $$\sum_{k=1}^{N} M_{kk} = 1$$

where $N = \dim(M) \geq 2$

H.S. Green (2000) (2)

The solutions to constraints (a) & (b) in the above definition partition **C^2** into three equivalence classes: Hermitian[1] matrices, pseudo-Hermitian[2] matrices, and real-valued matrices[3]. **These three classes represent three different kinds of qubits, (a) characterized by the representation of information in ordinary QM (in the inertial frame of the observer), (b) the representation of information adopted in other inertial frames, (c) the representation of information derived from distant sources, respectively.**

- [1] I.e., any matrix A where: $A_{jk}^* = A_{kj}$ (the complex conjugate of A = the transpose of A.)
- [2] I.e., any matrix A such that, corresponding to A is another (Hermitian) matrix C which is idempotent (C^2 = Id) and CA is Hermitian.
- [3] I.e., $A \in \mathbf{R}^2$.

H.S. Green (2000) (*cont.*) (3)

- **(Hermitian)** $Q(\xi) = {}^1/_2\{\mathrm{Id} + \boldsymbol{\xi}\bullet\boldsymbol{\sigma}\}$ where: Id is the 2×2 identity matrix, ξ is a 3D spatial vector of unit norm, and $\boldsymbol{\xi}\bullet\boldsymbol{\sigma}$ is its expansion in the Pauli matrix basis. Since the relativity group of standard QM is Galilean, $Q(\xi)$ represents the information in the observer's 'proper' inertial frame of reference (IFR).
- **(Pseudo- Hermitian)** $Q(\omega) = {}^1/_2\{\mathrm{Id} + \boldsymbol{\omega}\bullet\boldsymbol{\rho}\}$ where:
  $\boldsymbol{\omega}\bullet\boldsymbol{\rho} = \omega_0\rho_0 - \omega_1\rho_1 - \omega_2\rho_2$ and $\omega_0^2 - \omega_1^2 - \omega_2^2 = 1$ and the matrices ρ_1, ρ_2 are anti-Hermitian. In locally flat spacetime, the Lorentz Group describes best how two or more IFRs transform, hence $Q(\omega)$ represents information adopted on different

  IFRs from that of the observer.

- **(Real-valued)** $Q(\eta) = {}^1/_2\,\{Id + \boldsymbol{\eta}\bullet\boldsymbol{\tau}\}$ where: Id is the 2×2 identity matrix, where: $\boldsymbol{\eta}\bullet\boldsymbol{\tau} = -\eta_0\tau_0 + \eta_1\tau_1 + \eta_2\tau_2$ *and* $-\eta_0^2 + \eta_1^2 + \eta_2^2 = 1$ and the matrices τ_1, τ_2 are anti-Hermitian.

H.S. Green (2000) (4)

- DeSitter space is a topologically closed and spherically symmetric manifold which can be conveniently thought of in terms of a four-dimensional projective geometry. Its one-dimensional closed subspaces of rays of infinite extent describe timelike trajectories in the space, while its curved 3D subspaces are of finite radius R and describe the closure of set of all spacelike separated points. $Q(\eta)$ co-vary with respect to transports of points in such space-like 3D 'great circles', hence their space-like association. In the $R \rightarrow \infty$ limit deSitter space becomes the Minkowski space-time of special relativity. **Hence $Q(\eta)$ represents information derived from distant sources.**

H.S. Green (2000) (5)

- “ In quantum mechanics, the emphasis is on the microscopic events involving the creation and annihilation of particles which carry information from one point of space and time to another…**The qubit is the fundamental unit of information…** we have seen…examples of how the creation and annihilation of a single fermion and its spin, as well as some subspaces of physical space-time can be described in terms of these units…we shall go on to examine the different ways in which a pair of qubits can be combined. **By these means we shall obtain a complete representation of states of a fermion, in the coordinate and momentum representations, and also the spin angular momentum of spin one**.” (40-41)

H.S. Green (2000) (6)

"Quantal" (Paraferminionic) Embedding

- For Green, the impetus of constructing such a statistics is guided by his intuition that a spacetime point (x_μ) should be interpreted as an *event* wherein a neutral particle is emitted or absorbed (represented by parafermion elements ς_0, ς), while its geodesic path can be represented projectively by the join: $x_\mu(\varsigma_0) \vee x'_\mu(\varsigma)$ (where x, x' are the spacetime points corresponding to detection/absorption events) (147). Then, the manifold of spacetime itself may be characterized in terms of a parafermionic statistical algebra Σ fundamentally generated by qubits.

H.S. Green (2000) (7)

- The embedding of Riemmanian geometry into Σ wherein the metric, for example, takes on form:

$$g_{\mu\nu} \equiv \sum_{r=1}^{2s} \bar{\varsigma}_{\mu}^{(r)} \otimes \varsigma_{\nu}^{(r)}$$

where: $\bar{\varsigma}_{\mu}, \varsigma_{\nu} \in \Sigma$, dimΣ = 2s, and the bar superscript denotes the Majorana adjoint.

H.S. Green (2000) (8)

- The quantal embeddings "hav[e] an important advantage over their classical counterparts [in] that they have a direct physical interpretation **and their parameters are in principle observable**." (166) For instance, the geodesics $x_\mu(\varsigma_0)\vee x'_\mu(\varsigma)$ apply to the trajectories of *neutral* particle propagation, whether photons or neutrinos. Though both photons and neutrinos are neutral, "**it is not clear that a physical geometry constructed from the observation of neutrinos would be the same as that derived from the observation of light, but an informationally based theory could well provide some indication of differences which in the future could be detected experimentally**."(147)

- "As a consequence of quantization, a field is ultimately interpreted as providing a representation of the transmission of information through particles of the same type but possibly different momenta." (116)

David R Finkelstein (2004a,b)

- In the case of Finkelstein, the recent work discussed herein are the latest results representing the progression of a theory that had its origins in his "Space-Time Code" papers (I – IV) (1969 -1974) and earlier.
- In "Space-Time Code" papers an interpretation of spacetime as fundamentally constituted by "quantum computational" processes (.[1])

- [1] This, in turn, could be understood as a late twentieth century rendition of Isaac Newton's substantivilist view of space as a cosmic *Sensorium,* (lit. 'brain.'), private communication (1999)

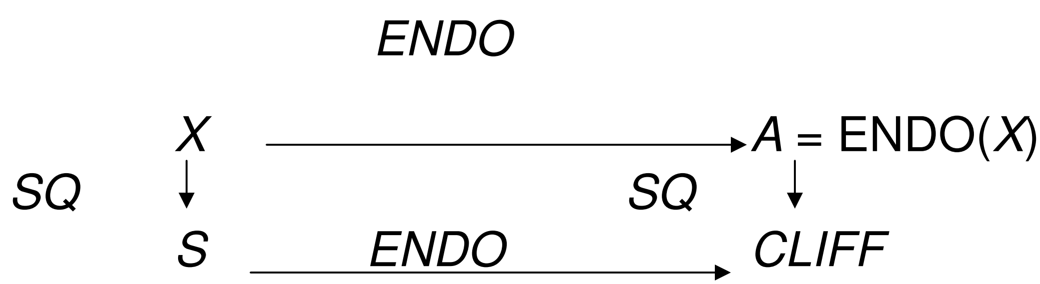
David R Finkelstein (2004a,b) (2)

- Spacetime as a singular limit, or condensate, formed out of fundamentally quantum microtopological units of information, or process (denoted respectively by ‘chronons,’ analogous to Green’s generalized qubits.)
- The spacetime manifold emerges as singular limit ([1]) of a regular structure represented by a Clifford algebra, whose generators γ^{α} represent the ‘chronons,’ i.e., the elementary quantum processes.

- [1] The framework for this procedure involves algebraic contractions/expansions, described in terms of the $\delta \to q \to c \to s$ procedure (1996)

David R Finkelstein (2004a,b) (3)

- Applying Clifford statistics to dynamics is achieved via the (category) functors ENDO, SQ which map the mode space[1] *X* of the chronon χ, to its operator algebra (the algebra of endomorphisms *A* on *X*) and to its spinor space *S* (the statistical composite of all chronons transpiring in some experimental region.) (2001, 10). The action of ENDO, SQ producing the Clifford algebra *CLIFF*, representing the global dynamics of the chronon ensemble is depicted in the following commutative diagram:



[1] The mode space is a kinematic notion, describing the set of all possible modes for a chronon χ, the way a state space describe the set of all possible states for a state φ in ordinary quantum mechanics.

David R Finkelstein (2004a,b) (4)

- Analogous to Green's embedding of the space-time geometry into a paraferminionic algebra of qubits, Finkelstein shows that a Clifford statistical ensemble of chronons can factor as a Maxwell-Boltzmann ensemble of Clifford subalgebras. This in turn becomes a Bose-Einstein aggregate in the $N \to \infty$ limit (where N is the number of factors.) This Bose-Einstein aggregate condenses into an 8-dimensional symplectic manifold M which is isomorphic to the tangent bundle of space-time. Moreover, M is a *Clifford manifold*, i.e. a manifold provided with a Clifford ring: (where: $C0(M)$, $C1(M)$,…,$CN(M)$ represent the scalars, vectors,…, N-vectors on the manifold.) For any tangent vectors $\gamma\mu(x)$, $\gamma\nu(x)$ on (Lie algebra dM) then:

$$\gamma^{\mu}(x) \circ \gamma^{\nu}(x) = g^{\mu\nu}(x)$$

  where: $\circ$ is the scalar product. (2004, 43) Hence the space-time manifold is a singular limit of the Clifford algebra representing the global dynamics of the chronons in an experimental region.

David R Finkelstein (2004a,b,c) (5)

- Empirical Testing

- David Finkelstein discusses in detail unique empirical ramifications of his theory in (2004b) which include the removal of usual quantum field-theoretic divergences.
- “[Our theory] freezes out zero-point energy of extreme hard or soft oscillators, like those responsible for the infrared or ultraviolet divergences of usual field theories…[and] in some extreme conditions [our unification and quantization of time, energy, space, and momentum] allows for the interconversion of time and energy of 10^{51} W, the Planck power.” (1)
- “[P]erhaps we have found a bottom to what continuum physics saw as a bottomless pit.” (2004a, 51.)

David R Finkelstein (2004a,b,c) (6)

- Such potentially observable extreme cases modifies high and low energy physics, as “the simplest regularization leads to interactions between the previously uncoupled excitation quanta of the oscillator…strongly attractive for soft or hard quanta.” (2004c, 19) Since the oscillator model quantizes and unifies time, energy, space, and momentum, on the scale of the Planck power (10^{51} W) time and energy can be interconverted.

David R Finkelstein (2004a,b,c) (7)

- Moreover, in such extreme cases, equipartition and Heisenberg Uncertainty is violated. The uncertainty relation for the soft and hard oscillators read:

$$(\Delta L_1)^2(\Delta L_2)^2 \geq \frac{\hbar^2}{4}\langle L_3 \rangle^2_{|L_1 \approx 0\rangle} \approx 0 \Rightarrow \Delta p \Delta q << \frac{\hbar}{2}$$

$$(\Delta L_1)^2(\Delta L_2)^2 \geq \frac{\hbar^2}{4}\langle L_3 \rangle^2_{|L_{21} \approx 0\rangle} \approx 0 \Rightarrow \Delta p \Delta q << \frac{\hbar}{2}$$

Implications of a Future Information Theory

- Green and Finkelstein further the trend shared by the community of experimental and theoretical particle physicists to characterize the vacuum state as richly structured with internal and external dynamical symmetries([1])
- Moreover, their theories depict such a topological structure in terms of *discrete dynamical units*, fundamentally characterized in terms of information and process.
- Since the work of Shannon and Hawking in the fifties and sixties, for instance, compelling associations among entropy, information, and gravity emerged in the study of Hawking radiation, modeled in terms of vacuum pair-production occurring at the event horizon of a black hole singularity. Nowadays, however the theories of Green and Finkelstein together suggest that the study of spacetime as a "final information-theoretic frontier" may not end at the edge of a black hole's event horizon, but rather *begin* in the development of technologies better able to probe its microtopology in controlled laboratory conditions

- [1] Ref. Dirac's 'hole theory'

Implications of a Future Information Theory (2)

- Consider Finkelstein's finite harmonic oscillator. In the extreme cases where ordinary quantum field theory fails --in the infrared and ultraviolet cases--the 'hard' and 'soft' oscillators instead "cheat" the Heisenberg uncertainty relations. Hence, similar to the case of squeezed states of EM radiation,[1] manipulations of quanta on that scale in these cases can likewise be hypothetically performed with no theoretical bound to their accuracy. In addition, the energy required for such transactions could be provided by the time-energy conversion at the Planck power scale.

[1] I.e. coherent states $|\alpha, s\rangle$ with an additional degree of freedom (the 'squeezing' parameter s) resulting in violations of Heisenberg Uncertainty.

Implications of a Future Information Theory (3)

- In the case of H. S. Green, his extended qubits comprise the very essence of space-time. Recall that "an informationally based theory could well provide…indication of differences [between photon and neutrino-based physical geometries] which in the future could be detected experimentally." (2000,147) The question then becomes: if a field represents the transmission of information, how accessible is such information at the nanoscale?

Implications of a Future Information Theory (4)

- What form would this information theory take? Consider Asher Peres and Daniel Terno (2004) who work out the effective density matrix for a monochromatic signal consisting of a single photon.

- They derive the same Doppler factor derived by Jarrett & Cover (1981), *absent any specific physical model*, for the relativistic transformation of bit rate and noise intensity. ***"This remarkable agreement shows that information theory should properly be considered as a branch of physics***." (Peres & Terno (2004), 16)

Implications of a Future Information Theory (3)

- Ansatz1 The POVM formalism of Peres and Terno (2004) modelling photon detector-events should be extended to the graviton case discussed in H. S. Green.

- Ansatz2 The POVM formalism of Peres and Terno (2004) should be extended to the cases discussed in Finkelstein (2004b) involving the quantization of time and energy in the appropriately (high energy) nanoscale.

Implications of a Future Information Theory (4)

- Peres and Terno are also motivated by the belief in the **inseparability of the disciplines of relativity theory, quantum theory, and information theory**. (2004, 3) Peres and Terno work "bottom up" from a POVM[1] formalism modeling *actual experimental* processes of detector emission and absorption. They carry out their results with a fundamentally *algebraic* approach to field theory, as a means of solving some of the difficulties associated with the predictions depending upon specific methods of calculation, when working with different PVMs in curved space-time.[2] Hence, the theoretical entities in Green and Finkelstein's theories can be characterized in Peres and Terno, via respective algebraic homomorphisms. This constitutes the first step toward a future information theory of vacuum microtopology.

- [1] Positive operator valued measure

[2] "One of the difficulties of QFT in curved space-times is the absence of a unique (or preferred) Hilbert space…[since] different representations of canonical commutation or anticommutation relations lead to unitarily inequivalent representations." (Peres & Terno, 2004, p.24).

Conclusion

Ansatzen 1 & 2 together imply that a generalized and empirically based theory of quantum information and communication can arise from the domain of quantum topology, the way standard quantum optics and information theory arose from quantum electrodynamics. This presents the vacuum itself, characterized down to the Planck scale, as a potential resource and medium of information-exchange.

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