Introduction

General relativity (GR) altered the classical understanding of the concepts of space and time in a way which...is far from being fully understood yet. QM [quantum mechanics] challenged the classical account of matter and causality, to a degree which is still the subject of controversies. After the discovery of GR we are no longer sure of what is spacetime and after the discovery of QM we are no longer sure of what matter is. *The very distinction between space-time and matter is likely to be ill-founded*....I think it is fair to say that today we do not have a consistent picture of the physical world. [Rovelli, 1999, 227, italics added]

We agree with Rovelli and believe a current obstacle to unification[1] is the lack of a true marriage of spacetime with matter. That is, we believe one of the main obstacles to unification has been a form of 'spacetime-matter dualism' whereby the spacetime metric (hereafter simply "metric") is subject to quantization distinct from the matter and gauge fields. This view is carried over from quantum field theory (QFT) and GR. In QFT, although matter-energy fields are imagined to pervade space, the metric is independent of the matter-energy content of spacetime. And, although Weyl characterized GR as providing *RaumZeitMaterie* (Weyl, 1952), there are vacuum solutions in GR, i.e., spacetime regions where the stress-energy tensor is zero. Thus, neither QFT nor GR embody a true unity of "spacetimematter" and both employ a differentiable manifold structure for spacetime[2]. Herein we propose unification based on spacetimematter, finishing Einstein's dream so to speak. In order to accomplish this, we are proposing two changes to the standard view of fields – having them reside on a graph rather than a differentiable manifold and acknowledging that their dynamical attributes (energy, momentum, mass, etc.) necessarily entail a metric. Thus, we adopt lattice gauge theory's use of the term, i.e., a field is a map of scalars, spinors and/or gauge group elements to the graph. To illustrate this idea, we constructed a toy (scalar) model (see Technical Endnotes) whereby the partition function *Z* is produced using boundary operators on the graph so that the difference matrix and source vector of the discrete action satisfy a self-consistency criterion (SCC). *Z* then provides a distribution function for fields on the nodes and links, just as in standard quantum physics per lattice gauge theory (LGT). These fields account for both the metric and the matter-energy content of the graph, so we refer to them as "spacetimematter fields." We are therefore proposing that successful unification requires a modification and reinterpretation of *both* GR and QFT via their graphical instantiations, Regge calculus and LGT, respectively. Specifically, space, time and matter are co-constructed per a global constraint equation using path integrals over graphs in an attempt to derive matter and spacetime geometry 'at once' in an interdependent and background independent fashion from something underneath both GR and QFT. The use of an SCC implies physics is adynamical and acausal at the fundamental level, in stark contrast to the reigning paradigm of dynamism. However, our choice of an SCC results *statistically* in dynamical, causal physics. Essentially, our

[1] By "unification" we mean a theory that underwrites both the Standard Model of particle physics and GR, and accounts for situations where both spacetime curvature and quantum effects are relevant, e.g., the Big Bang and black holes.

[2] For an overview of problems associated with "the manifold conception of space and time" in quantum gravity see Butterfield & Isham (1999).

approach constitutes a form of modified LGT (MLGT) whose continuum limit yields quantum physics. Therefore, as will become clear, we expect the statistical limit will take the form of modified Regge calculus (MORC) with the continuum limit of MORC yielding a modified GR of sorts.

With these changes to the assumptions about fields, unification turns profoundly. Quantum gravity (QG) is no longer about quantizing GR and it cannot exist independently of the Standard Model, as is the case with Loop Quantum Gravity, for example. Unification is no longer about finding unique fundamental particles with intrinsic and essential properties that only exist at technologically unverifiable energy densities. A "particle" is not understood as a smoothly propagating perturbation of a continuous medium (field, as naively understood), but is simply a collection of detector hits forming a spacetime trajectory, which doesn't entail the existence of an entity with intrinsic properties, such as mass and charge, moving through the detector to cause the hits[3]. Rather, unification is about finding the unique fundamental fields of spacetimematter and these fields may form a denumerable, finite set. Indeed, the Standard Model may be very close to, if not actually constitute, this set. It may be that we essentially *have* unified GR and the Standard Model given MORC and MLGT (*a la* Technical Endnotes), but we don't see it because we're thinking about GR and the Standard Model dynamically. Furthermore, this graphical scheme for unification (Silberstein *et al*, 2012) has profound implications for foundational issues such as the interpretation of quantum mechanics (Silberstein *et al*, 2008; Stuckey *et al*, 2008) and issues in cosmology and astrophysics, e.g., an explanation of dark energy (Stuckey *et al*, 2012a & b).

Re-Thinking Dynamism

From very early on Western thinkers have generally assumed that everything can be explained. Perhaps the cosmological argument for the existence of God is the classic example of such thinking. In that argument Leibniz appeals to a version of the principle of sufficient reason (PSR) which states (Melamed & Lin, 2011) "no fact can be real or existing and no statement true without a sufficient reason for its being so and not otherwise." Leibniz uses the principle to argue that the sufficient reason for the "series of things comprehended in the universe of creatures must exist outside this series of contingencies and is found in a necessary being that we call God" (Melamed & Lin, 2011). While physics dispensed with appeals to God at some point, it did not jettison PSR, merely replacing God with fundamental dynamical laws, e.g., as anticipated for a Theory of Everything (TOE), and initial conditions (the Big Bang or some condition leading to it). In keeping with everyday experience a very early assumption of Western physics—reaching its apotheosis with Newtonian mechanics—is that the fundamental phenomena in need of explanation are *motion* and *change in time*, so explanation will involve dynamical laws most essentially.

In the quest to unify physics, it is the combination of PSR plus the dynamical perspective writ large (call it dynamism) that has in great part motivated the particular kind of unification being sought, i.e., the search for a TOE, QG and the like. Therefore, almost all attempts to unify relativity and quantum theory opt for dynamism as fundamental in some form or another. Such theories may deviate from the norm by

[3] Everything in nature is both a Source and a detector (sink), so this is not unique to experimental physics.

employing radical new fundamental dynamical entities (branes, loops, ordered sets, etc.), but the game is always dynamical, broadly construed (vibrating branes, geometrodynamics, sequential growth process, etc). However, it is important to note that from fairly early on in Western physics there have also been adynamical explanations that focused on the role of the future in explaining the past as well as the reverse, such as integral (as opposed to differential) calculus and various least action principles of the sort Richard Feynman generalized to produce the path integral approach to QM. And of course there are the various adynamical constraints in physics such as conservation laws and the symmetries underlying them that constrain if not determine the various equations of motion. But nonetheless, dynamism is still the reigning assumption in physics.

Dynamism encompasses three claims: (1) the world, just as appearances and the experience of time suggest, evolves or changes in time in some objective fashion, (2) the best explanation for (1) will be some dynamical law that "governs" the evolution of the system in question, and (3) the fundamental entities in a TOE will themselves be dynamical entities with intrinsic properties evolving in some space however abstract, e.g., Hilbert space. In spite of the presumption of dynamism, those who want fundamental explanation in physics to be dynamical and those who want a world that evolves in time in some objective fashion face well-known problems concerning: (1) the possible blockworld implications of relativity (both special and general) and (2) canonical QG, the quantization of a generally covariant classical theory, leading to "frozen time." As for whether relativity (both special and general) implies a blockworld, there is much debate (Savitt, 2011). Regarding special relativity (SR), many of us have argued (Peterson & Silberstein, 2010) that given certain widely held innocuous assumptions and the Minkoswski formulation, SR does indeed imply a blockworld. In addition there is the problem of time in canonical GR. That is, in a particular Hamiltonian formulation of GR the reparametrization of spacetime is a gauge symmetry. Therefore, all genuinely physical magnitudes are constants of motion, i.e., they don't change over time. In short, change is merely a redundancy of the representation.

Finally, the problem of frozen time in canonical QG is that if the canonical variables of the theory to be quantized transform as scalars under time reparametrizations, which is true in practice because they have a simple geometrical meaning, then "the Hamiltonian is (weakly) zero for a generally covariant system" (Henneaux & Teitelboim, 1992, 106). The result upon canonical quantization is the famous Wheeler-DeWitt equation, void of time evolution. While it is too strong to say a generally covariant theory must have $H = 0$, there is no well-developed theory of quantum gravity that has avoided it to date (Kiefer, 2011). It is supremely ironic that the dynamism and unificationism historically driving physics led us directly to blockworld and frozen time.

We believe that GR, QM, QFT, and the failures of unification are giving us clues that all the assumptions of dynamism might be false. In this essay we want to demonstrate how an alternative adynamical approach involving acausal global constraints as fundamental might help solve some longstanding problems. We are going to explore the possibility that integral-based and 4D-based explanations *a la* GR, are more fundamental than dynamical ones. In our block universe model neither dynamical laws nor dynamical entities are fundamental. Indeed, just as Rovelli suggested, there is no dualism remaining between spacetime and matter-energy, nor between fields and particles.

Re-Thinking Fields and Particles

QFT as currently practiced involves the quantization of a classical field (Wallace, 2006) when one would rather expect QFT to originate independently of classical field theory, the former typically understood as fundamental to the latter. As we outline in the Technical Endnotes, our approach provides a new fundamental origin for QFT independent of classical field theory. In this approach, the role of the field is very different than in QFT where it pervades otherwise empty, continuous space to mediate the exchange of matter-energy between sources. One obtains QFT results from LGT by letting the lattice spacing go to zero. In fact, one can understand QFT renormalization through this process of lattice regularization (‘t Hooft, 2007, 712). As it turns out, however, this limit does not always exist, so calculated values are necessarily obtained from small, but non-zero, lattice spacing (Roethe, 1992, 40). With this picture in mind, we can say simply what we are proposing: The lattice is fundamental, not its continuum limit. Once one accepts this premise, it’s merely a matter of degree to have sources connected by ‘large’ links (see Stuckey *et al*, 2009 and Stuckey *et al*, 2012a and b).

This severely undermines the dynamical picture of perturbations moving through a continuum medium (naive field) from source to source, i.e., it undermines the naive notion of a particle. In fact, the typical notion of a particle is associated with the global particle state of n-particle Fock space and “the notion of global particle state is ambiguous, ill defined, or completely impossible to define” (Colosi & Rovelli, 2009, 14). What we mean by “particle” is a collection of detector hits forming a spacetime trajectory (hereafter “Particle”) and doesn’t entail the existence of an entity with intrinsic properties, such as mass and charge, moving through the detector to cause the hits. In order to model discrete collections of detector outcomes, we propose a picture like that of MORC.

Ordinary Regge calculus is a discrete approximation to GR where the discrete counterpart to Einstein’s equations is obtained from the least action principal on a 4D graph (Misner *et al*, 1973, 1166). This generates a rule for constructing a discrete approximation to the spacetime manifold of GR using small, contiguous 4D graphical ‘tetrahedra’ called “simplices.” The smaller the legs of the simplices, the better one may approximate a differentiable manifold via contiguous simplices (separability). Since on our view the graph, not its continuum limit, is fundamental, MORC obtains by simply allowing link lengths to be ‘large’ (Stuckey *et al*, 2012a). Obviously, we are proposing a very similar relationship between LGT and QFT, so we’re simply suggesting that LGT be modified as in our MORC. We will describe a consequence of MORC below for dark energy, but here we explore the implications of MLGT for particle physics.

Ironically, in the MLGT view, particle physics is clearly not about particles, at least as modeled by smoothly propagating perturbations of a continuous medium (naive field). We replace this dynamic picture of quantum physics with a 4D view of various distributions of spacetimematter fields on a topological graph representing the role of sources played by beam splitters, mirrors, Sources, detectors, etc., in the given experiment from initiation to termination (to include future boundary conditions such as measurement settings or outcomes). In ordinary Regge calculus, the graphical links play host to two fields, i.e., the stress-energy tensor and the metric, and there are vacuum solutions, so there can be links with a metric and no stress-energy tensor. We abandon this possibility in MLGT, i.e., the metric is not separate from spacetimematter. In fact, that the metric is ineluctably related to mass is already apparent in the two-point correlation function for a scalar field ϕ, i.e., $\langle \phi(x)\phi(y) \rangle \approx e^{-M|x-y|}$ (Rothe, 1992, 40). Thus, in order to obtain mass *M*, one needs a metric $|x-y|$. Conversely, one could use a definition of *M* to determine a metric, but of course the metric defined by the experimental context is preferred by default, i.e., *M* is contextual. The manner by which a gauge field on the links of a graph carries information about the metric can be seen in our analysis of the twin-slit experiment (Stuckey *et al*, 2009, section 3.4) and our explanation of dark energy (Stuckey *et al*, 2012a, outlined below).

So, we have jettisoned 'interacting particles' in favor of '4D field configurations'. The implications for this view on unification will be fleshed out below, but this implies the empirical goal at the fundamental level is to tell a unified story about detector events to include individual clicks/hits – how they are distributed in space (e.g., interference patterns, interferometer outcomes, spin measurements), how they are distributed in time (e.g., click rates, coincidence counts), how they are distributed in space and time (e.g., particle trajectories), and how they generate more complex phenomena (e.g., photoelectric effect, superconductivity). Thus in our model, particle physics per QFT is in the business of characterizing large sets of detector data, i.e., all the individual clicks.

As is eminently apparent from our graphical solution to the discrete scalar, two-source Gaussian amplitude (Stuckey *et al*, 2009, section 3.2), which gives *Z* for one Source and one sink (click), it is practically impossible to compute *Z* (in the fundamental theory) for all possible spatiotemporally relative click locations in a particle physics "event," which contains "approximately 100,000 individual measurements of either energy or spatial information" (Frish, 1993). However, we know from theory (Mott, 1929) and experiment (Fernow, 1986, sections 1.7.1-3) that with overwhelming probability detector clicks will trace classical paths, so it makes sense to partition large click distributions into individual trajectories and treat these as the fundamental constituents of high energy physics experiments. This is exactly what QFT does for particle physics according to our account. Since the individual trajectories are themselves continuous, QFT uses propagators in continuous spacetime which entails an indenumerably infinite number of locations for both clicks and interaction vertices. Thus, issues of regularization and renormalization are simply consequences of the continuum approximation necessary to deal with very large click distributions, having decided to parse the click distributions into continuum trajectories.

Essentially, we're saying a particle physics detector event is one giant interference pattern and the way to understand a particular pattern involving thousands of clicks can only realistically be accomplished by parsing an event into smaller subsets, and the choice of subsets is empirically obvious, i.e., spacetime trajectories. These trajectories are then characterized by mass, spin, and charge. The colliding beams in the accelerator 'create' a spatiotemporally small graphical field configuration, i.e., a Source, related to the hits in the surrounding detectors. The possible field configurations on the graph are used to compute *Z*, which is the basis for, among other things, the correlation function. In standard LGT → QFT the calculated outcomes are found by taking the limit as the lattice spacing goes to zero via renormalization, but in our model we needn't assume the spacing goes to zero, only that it's 'small' as defined by the experimental uncertainties. Likewise, assuming the Source and detector are sufficiently isolated during the brief period of data collection, the graph size is not infinite as in QFT.

Thus, our view of Particles agrees with Colosi & Rovelli (2009) in that particles are best modeled by local particle states rather than Fock n-particle states computed over infinite regions, squaring with the fact that particle detectors are finite in size. There are advantages of a local particle state over its global Fock counterpart. First, one can unambiguously define the notion of particles in curved spacetime as excitations in a local M4 region which makes it more compatible with QG (our brand of which is described below). Second, this theory of particles is much more compatible with the quantum notion of complementary observables in that every detector has its own Hamiltonian (different graph in our language), and therefore its own particle basis (unlike the unique basis of Fock space). Per Colosi & Rovelli (2009, 15), "In other words, we are in a genuine quantum mechanical situation in which distinct particle numbers are complementary observables. Different bases that diagonalize different H_R [Hamiltonian] operators have equal footing. Whether a particle exists or not depends on what I decide to measure." Thus, in our view, Particles simply describe how individual detectors (including those in nature) react to specific Sources, so one expects different Particles, i.e., different masses and charges[4], to appear in different detectors given the same Source, for example. In short, the 'essential' properties of Particles, such as mass and charge, are not intrinsic but relational or contextual. This implies a change in the current approach to unification.

Unification and the Standard Model

Given MLGT and its implications, our approach to unification is necessarily novel. As regards the Standard Model viewed dynamically in terms of particles, the quarks and leptons of G = U(1) x SU(2) x SU(3) reside in a "motley collection of representations" (Zee, 2003, 391). Thus, in a dynamical understanding of reality based ultimately on interacting particles as described above, one seeks a gauge group subsuming G. However, as we stated above, Particles are not the fundamental ontological elements of reality. One finds as many different Particles as one creates different Source-detector combinations. Thus, the twenty or so free parameters of the Standard Model aren't evidence of a manifold fundamental ontology, but simply account for diverse possible outcomes associated with different Source-detector graphical configurations. The mystery[5] as to why elementary particles[6] of the Standard Model are described via irreducible positive energy representations of $\widetilde{P}_o \times G$ where $\widetilde{P}_o$ is the Poincaré group, is resolved not by understanding why there are elementary particles having the masses they do (dynamical paradigm), but by understanding why (or if) the fields used in the Standard Model are the

[4] Mass and charge are renormalized in the process of regularization in QFT. Since we propose non-zero lattice spacing and finite lattice size, we simply have different Particles for different lattice configurations. The localized and infinite particle states are convergent for high-energy particle physics (Colosi & Rovelli, 2009), so our approach to unification would suggest new experiments altogether.

[5] Baez and Lauda (2009, 17) write, "Though everyone would like to more deeply understand this curious choice of G, at present it is purely a matter of fitting the experimental data."

[6] These particles are the unique set associated with Fock space, and are obtained via localized particle states as shown in Colosi & Rovelli (2009).

fundamental building blocks of all possible spacetimematter field configurations on a graph. As it stands, the Gell-Mann matrices generating SU(3) are generalizations of the Pauli matrices generating SU(2) which are composed of complex numbers, and *i* is the generator of U(1). So, one could ask whether or not this in any way constitutes a 'complete set of fields'. Or, is it the case that this pattern extends to SU(5) or SO(10) (Zee, 2003, 391 & 405)? Or, does SU(3) need to be generalized per non-associativity, so as to constitute an octonionic gauge theory (Lassig & Joshi, 1996)? In that case U(1) → SU(2) → 'non-associative SU(3)' would parallel complex numbers → quaternions → octonions, which (with the reals) are the only unique, normed division algebras per Hurwitz's theorem (Baez, 2002). Thus, this might indicate the most fundamental collection of spacetimematter fields possible. In any case, it is obvious that the Standard Model is understood in a radically different fashion in our spacetimematter view.

Unification and General Relativity

As regards the "emergence" or derivation of GR from our fundamental theory, since we recover classical physics in terms of the "average spacetime geometry" over the graphical unity of spacetimematter, our discrete average/classical result is MORC as described above[7]. In MORC, simplices can be both large and non-contiguous (non-separable), and GR is its continuous, separable approximation. Accordingly, at the fundamental level, spacetime is not independent of matter-energy, i.e., the concept of a "vacuum solution" is meaningless, and spacetime cannot be modeled with a differentiable manifold, negating any talk of diffeomorphism invariant QG.

It seems to us that a glaring deviation from GR phenomena posed by our MORC would be found in the exchange of photons on cosmological scales in a matter-dominated GR cosmology. Therefore, we modified the Regge calculus approach to Einstein-deSitter cosmology (EdS) and fit the Union2 Compilation (Amanullah *et al*, 2010), i.e., distance moduli and redshifts for type Ia supernovae (Stuckey *et al*, 2012a). In addition to large simplices connecting photon emitter (supernova) and receiver (telescope), we modified the relationship between proper distance D_p and luminosity distance D_L to account for the fact that proper distance is computed using a matter-only stress-energy tensor while the luminosity distance is obtaining using photons, i.e., $D_L = (1+z)D_P$ → $D_L = (1+z)\sqrt{D_P \cdot D_P}$; per spacetimematter the metric is not independent of the gauge field (in this case the U(1) field) used to measure it. The specific form of $KQ = J$ that we used was borrowed from linearized gravity in the harmonic gauge, i.e., $\partial^2 h_{\alpha\beta} = -16\pi G\left(T_{\alpha\beta} - \frac{1}{2}\eta_{\alpha\phi}T\right)$. In this view, $h_{\alpha\beta}$ corrects the graphical inner product $\eta_{\alpha\beta}$ (of $D_P \cdot D_P$) in the simplex between the worldlines of photon emitter and receiver, where $\eta_{\alpha\beta}$ is obtained via a matter-only stress-energy tensor. The MORC, EdS and the concordance model (ΛCDM) fits of the Union2 data were compared. We found that MORC improves EdS as much as ΛCDM even though the MORC universe contains no dark energy is therefore always decelerating (see Data Fit). Thereby, it is quite possible that this data does not constitute "the discovery of the accelerating expansion of the

[7] The manner by which MORC obtains from MLGT is what we mean by QG.

Universe," (Nobel citation, 2011), i.e., there is no accelerating expansion, so there is no need of a cosmological constant or dark energy in any form (Stuckey *et al*, 2012b).

Our model has other possible implications for astrophysics and cosmology as well. Perhaps MORC's version of the Schwarzschild solution will negate the need for dark matter as its counterpart to EdS cosmology did with dark energy. What will MORC have to say about the event horizon and singularity in the Schwarzschild solution, i.e., black holes? Perhaps, the singularity will be avoided as in Regge calculus cosmology where backwards time evolution "stops" at a time determined by the choice of lattice spacing[8]. And, with our adynamical approach, cosmological explanation takes on an entirely new form. No longer is one seeking explanation in the form of a time-evolved spatial hypersurface of homogeneity – an explanation that cannot be satisfied with the Big Bang or even a non-singular "stop point" and results in contentious, misleading or unverifiable notions about "creation from nothing" (Carroll, 2012), the multiverse, etc. Rather, explanation via adynamical self-consistency writ large doesn't rest ultimately on the Big Bang or any other region of the graph. The reason the fields on node X and link Y have the values they do is required by the solution for the entire graph, i.e., it is required by the values of the fields on all the other nodes and links. No region of the spacetimematter graph is distinguished over any other in this explanatory scheme.

Overview of Unification

Mathematically, we summarize our approach as follows:

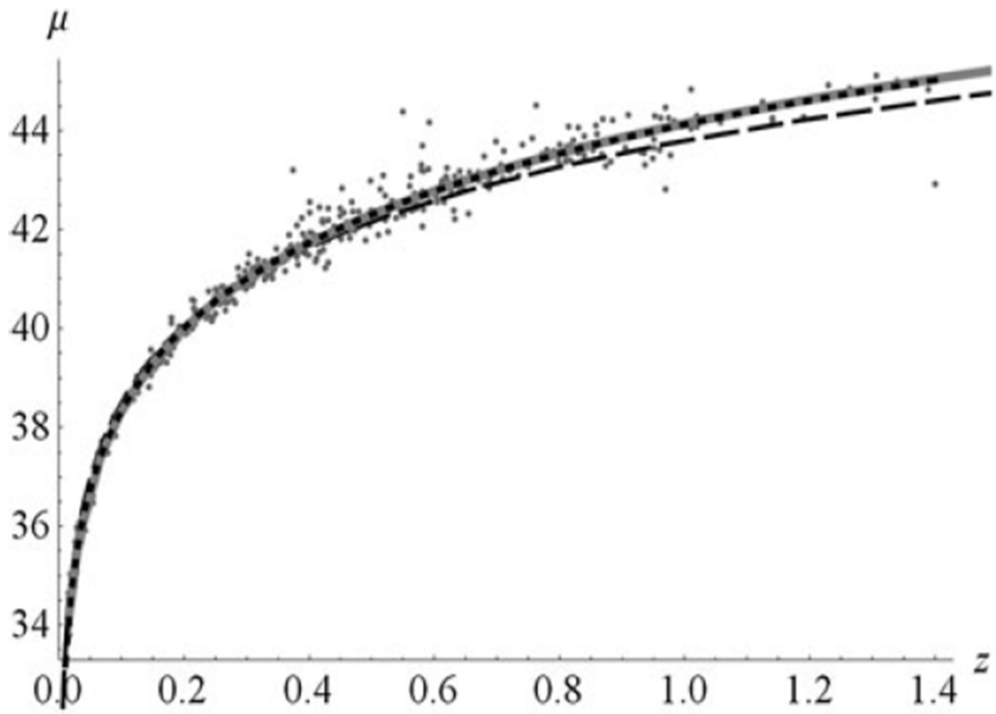
$$\vec{\vec{K}}\vec{v} \propto \vec{J} \rightarrow \frac{1}{2}\vec{\vec{K}} + \vec{J} \rightarrow Z \rightarrow \mathrm{P}\left(\widetilde{Q}_k = \widetilde{Q}_o\right) = \frac{Z\left(\widetilde{Q}_k = \widetilde{Q}_o\right)}{Z} \rightarrow \vec{\vec{K}} \cdot \vec{Q}_o = \vec{J}$$

(see Technical Endnotes). The first four steps are the basis for MLGT, i.e., LGT with non-zero lattice spacing (Figs. 1, 2 & 4). The last equation provides the most probable field values and those values are averaged over large collections of links and nodes to obtain classical Objects involved in processes (Fig. 3). This average produces the non-contiguous simplices of MORC, i.e., Regge calculus modified to include large link lengths and non-contiguous simplices. Thus, GR is understood as the continuous, separable (contiguous simplices) approximation to the statistical limit of MLGT. The mathematical representation of this approximation is the spacetime manifold, which is locally homeomorphic to R4. In contrast, geometric locality is not so clear cut on the underlying spacetimematter graph, since the simplices (local structures) are not contiguous but overlapping (think of tunneling, for example). GR's vacuum solutions represent the "spacetime + matter" approximation to the spacetimematter of MLGT, where the matter-energy content of the fields on the graph is not independent of the spacetime metric. Typically, a metric is chosen per the experimental configuration and that metric dictates the masses and charges of Particles. Thus, unification in our proposed view requires three things: (1) the most general SCC containing the topological basis for interaction terms in the action, (2) the fundamental spacetimematter fields of MLGT, and (3) the completion of MORC according to MLGT, i.e., our brand of QG. Per Colosi & Rovelli (2009, 15), "The world is far more subtle than a bunch of particles that interact."

---

[8] This is the "stop point problem" of Regge calculus cosmology. Of course it's not a "problem" for our approach, but a "solution" to the existence otherwise of a singularity.

So, which of our basic physical assumptions are wrong? Answer: all those comprising dynamism.



Data Fit. Plot of Union2 data along with the best fits for EdS (*dashed*), ΛCDM (*gray*), and MORC (*dotted*). The MORC curve is terminated at $z = 1.4$ in this figure so that the ΛCDM curve is visible underneath**.** Per a sum-of-squares error analysis, the MORC fit is slightly better than the ΛCDM fit.

Technical Endnotes

According to our model, quantum physics is the continuous approximation of a more fundamental, discrete graph theory whereby the Wick-rotated transition amplitude *Z* is a partition function for spacetimematter field[9] configurations over a topological graph. To illustrate our proposed approach, we have constructed a toy (scalar) model whereby a topological graph is characterized by the difference matrix $\vec{\vec{K}}$ and source vector[10] $\vec{J}$ of the discrete graphical action for a 4D process, i.e., $Z\left[\frac{1}{2}\vec{\vec{K}}+\vec{J}\right]$ (Fig. 1). Adding spacetimematter fields to the topological graph one characterizes energy, momentum and mass transfer between sources, and these processes ineluctably include the metric[11] (Fig. 2). Essentially, this partition function *Z* provides a measure of the graph's ability to accommodate various spacetime geometries and matter-energy content for its unity of spacetimematter. Roughly speaking, the formal approach is LGT without the continuum limit; in fact the links can be as large as necessary to relate sources (see *3.4 The Twin-Slit Experiment* in Stuckey *et al*, 2009, and our explanation of dark energy in Stuckey *et al*, 2012a). Thus, in what follows, we adopt the language of LGT.

In our model, $\vec{\vec{K}}$ and $\vec{J}$ of *Z* are constructed from boundary operators ∂_1 and ∂_2 on the graph so as to satisfy an adynamical constraint equation we call the "self-consistency criterion" (SCC). Specifically, $\vec{\vec{K}}_m \propto \partial_1\partial_1^T$ for matter fields *Q* on the nodes, $\vec{\vec{K}}_g \propto \partial_2\partial_2^T$ for gauge fields *A* on the links, $\vec{J}_m \propto \partial_1\vec{e}$ for the matter sources, and $\vec{J}_g \propto \partial_2\vec{p}$ for the gauge sources. These relationships give SCC's of $\vec{\vec{K}}_m\vec{v} \propto \vec{J}_m$, and $\vec{\vec{K}}_g\vec{e} \propto \vec{J}_g$, where $\vec{p}$ is the vector of plaquettes, $\vec{e}$ is the vector of links, and $\vec{v}$ is the vector of nodes. The SCC so constructed is based on the boundary of a boundary principle on the graph ($\partial_1\partial_2 = 0$), a characteristic germane to physics (Misner *et al*, 1973, 364). $\vec{\vec{K}}_m$ so constructed has the same form as its counterpart for coupled harmonic oscillators (basis for Gaussian free field theory) and possesses a non-trivial null space, whence gauge invariance. $\vec{\vec{K}}_g$ so constructed contributes $F_{\alpha\beta}F^{\alpha\beta}$ to the action so that the gauge fields on links contribute $A(\partial_2\partial_2^T)A$ to the action, analogous to the matter fields on nodes contributing $Q(\partial_1\partial_1^T)Q$. $\vec{\vec{K}}_g$ also possesses a non-trivial null space. $\vec{J}$ so constructed is divergence-free and will reside in the row space of $\vec{\vec{K}}$ which provides a natural gauge fixing, i.e., restricting *Z* to the row space of $\vec{\vec{K}}$. The probability for a particular experimental outcome[12] (particular field value on a particular node or link) is given by

$$\mathrm{P}\left(\widetilde{Q}_k=\widetilde{Q}_o\right)=\frac{Z\left(\widetilde{Q}_k=\widetilde{Q}_o\right)}{Z}=\sqrt{\frac{a_k}{2\pi}}\exp\left[-\frac{1}{2}\widetilde{Q}_o^2a_k+\widetilde{J}_k\widetilde{Q}_o-\frac{\widetilde{J}_k^2}{2a_k}\right]$$

(same form for $\widetilde{A}_k=\widetilde{A}_o$, see Fig. 4).

The extremum of the probability gives $\delta\mathrm{P}\left(\widetilde{Q}_k=\widetilde{Q}_o\right)=0\Rightarrow\delta\left[-\frac{1}{2}\widetilde{Q}_o^2a_k+\widetilde{J}_k\widetilde{Q}_o-\frac{\widetilde{J}_k^2}{2a_k}\right]=0\Rightarrow a_k\widetilde{Q}_o=\widetilde{J}_k$ (same

---

[9] We use the word "field" as in lattice gauge theory (LGT), i.e., the map of a scalar or spinor to each node is the "matter field" and the map of an element of the gauge group to each link is the "gauge field."

[10] We use the word "source" as in QFT, i.e., to mean "particle sources" or "particle sinks" (creation or annihilation events, respectively). When we want to specify "a source of particles" we will use "Source." It can also be understood in the LGT sense of generating functionals (see Rothe, 1992, 17).

[11] For example, the stress-energy tensor can be defined by the variation of the matter-energy Lagrangian with respect to the metric.

[12] Our discussion centers on experimental outcomes per the belief that experiments are designed to reveal specific characteristics of reality, so our description of experimental configurations and outcomes is applicable to nature in general.

form for $\tilde{A}_k = \tilde{A}_o$, see Fig. 3). Thus, the equations $\vec{\vec{K}}_g \cdot \vec{A}_o = \vec{J}_g$ and $\vec{\vec{K}}_m \cdot \vec{Q}_o = \vec{J}_m$ provide the most probable field values A_o and Q_o over links and nodes, respectively, and therefore underwrite classical physics (Fig. 3).

The SCC therefore provides an adynamical, global constraint that results in a self-consistent co-construction of space, time and matter that is *de facto* background independent. Accordingly, one has an acausal, adynamical unity of spacetimematter at the fundamental level that results statistically in the causal, dynamical "spacetime + matter" of classical physics. In summary: 4D topological graph → the SCC → partition function Z → distribution of spacetimematter fields → a classical process (Figs. 1 – 4).

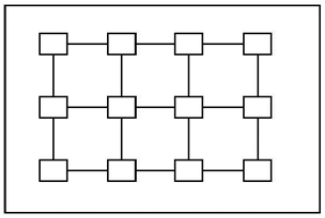


Figure 1. Topological Graph – The nodes of this graph are squares and the links are line segments connecting the nodes. $\frac{1}{2}\vec{\vec{K}} + \vec{J}$, such that $\vec{\vec{K}}_m \propto \partial_1 \partial_1^T$ for matter fields Q on the nodes, $\vec{\vec{K}}_g \propto \partial_2 \partial_2^T$ for gauge fields A on the links, $\vec{\vec{K}}_m \vec{v} \propto \vec{J}_m$, and $\vec{\vec{K}}_g \vec{e} \propto \vec{J}_g$, characterizes the graphical topology, which underwrites a partition function Z for the distribution of spacetimematter fields over the graph. The graph proper is merely topological, the spacetimematter fields contain the geometry.

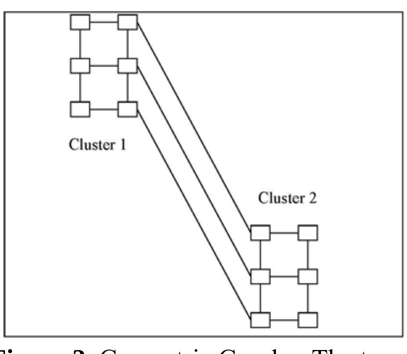


Figure 2. Geometric Graph – The topological graph of Figure 1 is endowed with a particular distribution of spacetimematter fields giving rise to a spacetime geometry in concert with the matter-energy distribution.

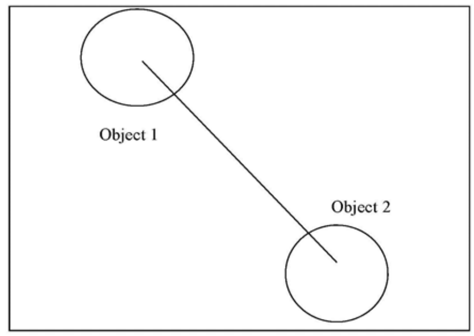


Figure 3. Classical Physics – Classical Objects and processes result when the most probable field values Q_o and/or A_o obtained from $\vec{\vec{K}}_m \cdot \vec{Q}_o = \vec{J}_m$ and/or $\vec{\vec{K}}_g \cdot \vec{A}_o = \vec{J}_g$ yield spatiotemporally localized Clusters 1 & 2 as in Figure 2. The lone link in this figure represents the average of the link lengths obtained via the most probable field values, so this is the origin of classical physics.

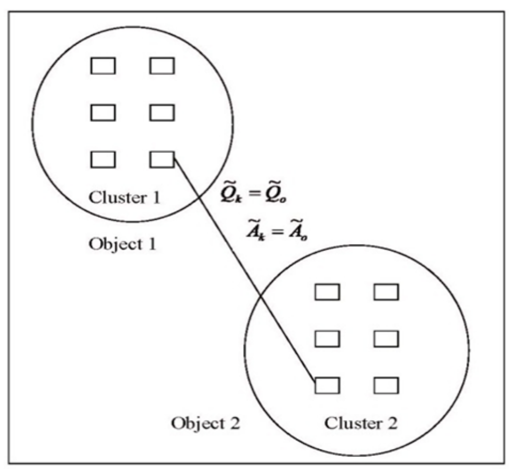


Figure 4. Quantum Physics – A particular outcome $\tilde{Q}_o$ and/or $\tilde{A}_o$ of a quantum physics experiment allows one to compute the spacetime geometry in the context of the classical Objects comprising the experiment, e.g., Source, beam splitters, mirrors, and detectors. See *3.4 The Twin-Slit Experiment* in Stuckey *et al*, 2009. The partition function Z provides the probability of this particular outcome.

REFERENCES

Amanullah, R., *et al* (The Supernova Cosmology Project). (2010). *Astrophysical Journal* **716**, 712–738.
Baez, J.C. (2002). *Bulletin of the American Mathematical Society* (N.S.), **39**(2), 145–205 (electronic).
Baez, J.C. & Lauda, A. (2009). A Prehistory of n-Categorical Physics. http://math.ucr.edu/home/baez/history.pdf
Butterfield, J. & Isham, C.J. (1999). Spacetime and the Philosophical Challenge of Quantum Gravity. http://arxiv.org/abs/gr-qc/9903072
Carroll, S. (2012). A Universe from Nothing? Discover Magazine Online http://blogs.discovermagazine.com/cosmicvariance/2012/04/28/a-universe-from-nothing/
Colosi, D. & Rovelli, R. (2009). What is a Particle? *Classical and Quantum Gravity* **26**, 025002. http://arxiv.org/abs/gr-qc/0409054.
Fernow, R.C. (1986). *Introduction to experimental particle physics*. Cambridge University Press, Cambridge.
Frisch, H.J. (1993). Pattern recognition at the Fermilab collider and Superconducting Supercollider. *Proceedings of the National Academy of Sciences* **90**, 9754-9757.
Henneaux, M. & Teitelboim, C. (1992). *Quantization of Gauge Systems*, Princeton University Press, Princeton.
Kiefer, C. (2011). Time in quantum gravity. In: Callender, C. (ed.) The Oxford Handbook of Philosophy of Time, p. 667. Oxford University Press, Oxford.
Lassig, C.C. & Joshi, G.C. (1996). An octonionic gauge theory. *Chaos Solitons Fractals* **7**, 769-775.
Melamed, Y. & Lin, M. (2011): Principle of sufficient reason. In: Zalta, E.N. (ed.) The Stanford Encyclopedia of Philosophy (Summer 2011 Edition). http://plato.stanford.edu/archives/sum2011/entries/sufficient-reason/
Misner, C.W., Thorne, K.S. and Wheeler, J.A. (1973). *Gravitation*, W.H. Freeman, San Francisco.
Mott, N. (1929). The wave mechanics of alpha-ray tracks. *Proceedings of the Royal Society* **A126**, 79-84.
Peterson, D. & Silberstein, M. (2010). In defense of eternalism: the relativity of simultaneity and block world. In: Petkov, V. (ed.) Space, Time, and Spacetime–Physical and Philosophical Implications of Minkowski's Unification of Space and Time, pp. 209–238. Springer, New York.
Rothe, H.J. (1992). *Lattice Gauge Theory: An Introduction*. World Scientific Press, Singapore.
Rovelli, C. (1999). Localization in quantum field theory: how much of QFT is compatible with what we know about space-time? In: Cao, T. (ed.) Conceptual Foundations of Quantum Field Theory, pp. 207-232. Cambridge University Press, Cambridge.
Savitt, S. (2011). Time in the special theory of relativity. In: Callender, C. (ed.) The Oxford Handbook of Philosophy of Time, pp. 546–570. Oxford University Press, Oxford.
Silberstein, M., Stuckey, W.M. & Cifone, M. (2008). Why Quantum Mechanics Favors Adynamical and Acausal Interpretations such as Relational Blockworld over Backwardly Causal and Time-Symmetric Rivals. *Studies in History & Philosophy of Modern Physics* **39**, No. 4, 736-751.
Silberstein, M., Stuckey, W.M. & McDevitt, T. (2012). Being, Becoming and the Undivided Universe: A Dialogue between Relational Blockworld and the Implicate Order Concerning the Unification of Relativity and Quantum Theory. To appear in *Foundations of Physics*, Online First: 4 May 2012. http://arxiv.org/abs/1108.2261.
Stuckey, W.M., Silberstein, M. & Cifone, M. (2008). Reconciling Spacetime and the Quantum: Relational Blockworld and the Quantum Liar Paradox. *Foundations of Physics* **38**, #4, 348-383. http://arxiv.org/abs/quant-ph/0510090.
Stuckey, W.M., Silberstein, M. & McDevitt, T. (2009). Relational Blockworld: A Path Integral Based Interpretation of Quantum Field Theory http://arxiv.org/abs/0908.4348
Stuckey, W.M., McDevitt, T. & Silberstein, M. (2012a). Modified Regge Calculus as an Explanation of Dark Energy. *Classical and Quantum Gravity* **29**, 055015 doi: 10.1088/0264-9381/29/5/055015. http://arxiv.org/abs/1110.3973.
Stuckey, W.M., McDevitt, T. & Silberstein, M. (2012b). Explaining the Supernova Data without Accelerating Expansion. Honorable Mention in the Gravity Research Foundation 2012 Awards for Essays on Gravitation. Submitted to *International Journal of Modern Physics D*, by invitation. http://users.etown.edu/s/STUCKEYM/GRFessay2012.pdf
't Hooft, G. (2007). The Conceptual Basis of Quantum Field Theory. In: Butterfield, J., Earman, J. (eds.) Philosophy of Physics Part A, pp. 661-729, North-Holland, Amsterdam. http://www.staff.science.uu.nl/~hooft101/lectures/basisqft.pdf
Wallace, D. (2006). In defence of naiveté: The conceptual status of Lagrangian quantum field theory. *Synthese* **151**, 33–80.
Weyl, H. (1952). *Space Time Matter*, Dover Publications, New York.
Zee, A. (2003). *Quantum Field Theory in a Nutshell*, Princeton University Press, Princeton.