On Emergence of Relativistic Time from Quantum Phase

Lucian M. Ionescu

March 27, 2023

Abstract

Previously, an analysis of emergence of 3D-space from quark fields in the context of QCD suggested a similar analysis of the relation between quantum phase and relativistic time. As a follow-up, Einstein's synchronization analysis, in the context of quantum theory of EM leads to emergence of Minkovski Space-Time from quantum phase in the context of Scalar EM. An essential step in this direction was made by Kaluza-Klein approach to unification of gravity and electromagnetism.

This research program suggests that GR can be derived from the SM, via gauge theory, with Gravity from quantum origin, emerging macroscopically as geometry. In essence this is a "reverse engineering" of the historical development of modern theories from classical ones, taking the quantum level as primary, in order to derive the classical models we call "reality".

1 Introduction

Recall the goals of the research program to relate the Quantum Theory and Classical Theory:

1) To derive the later as emergent from the former, sketched in the previous works of the author:

	Standard Model	*Cartan Geometry*	*Tetrad Theory*
Quantum :	$SU(2) - Princ.\ Bundle$	*Frame bundle*	*Vierbeins Bundle*
	$\downarrow$	$\downarrow$	$\downarrow$
Classical :	$Space - Time$	$Space - Time$	*General Relativity.*

The idea is to use *soldering forms* to relate the EM and quark field connections of gauge theory of SM viewed as *Cartan connections* for the frame bundle (3D quark frame of baryons and lepton's quantum phase), at quantum level (baryons and leptons) to the emergent Space-Time metric (Lorentz transformations) [14].

2) Reformulate the Quantum Theory of Interactions as a QC in the *Network Model* generalizing Feynman / Quark Line Diagrams and String Theory / M-Theory in an intrinsic manner at Quantum Level. This may be viewed as a lattice of matter and interaction channels, intrinsically described at the bundle level and corresponding to an embedding in the "ambient Space-Time" as currently is when using FD, Riemann surfaces etc.

3) Since Gravity is already part of the Weak Nuclear Force [15, 17], if not neglected as is now in the SM, it will relate to the base Space-Time with GR, hence providing at the Quantum level a Quantization of GR.

4) Derive "weak force" decays as transitions from finite subgroups of symmetries, following the 3rd Quantization Principle: "Everything is quantized", including the qubit space and its symmetries $U(2) = U(1) \times SU(2)$ [18, 21, 5].

learning from Democritean vs. Platonic approaches [12], §2 and from modern Software Design Theory, our overall philosophy is that *Physics as an Expert System*, rather than axiomatic, is structured hierarchically in layers defined by interface and implementation, modeling *systems with interacting parts and structure, conceptual and mathematical* 3.5.

In this article we focus on how quantum phase, as local periodic quantized "time" relates with relativistic time of Special Relativity.

Relativistic Physics is based on the groundbreaking research of Einstein, starting from the analysis of what time is and the need for synchronization.

Reexamining Einstein's approach with knowledge of Quantum Physics allows to derive time from quantum phase, which in turn establishes the primary role of the EM vector potential, as part of the connection in the $U(1)$-bundle. The later can be interpreted as a collection of local periodic times, e.g. atoms.

We will show how the macroscopic relativistic time of Space-Time as a base manifold of EM principle bundle is associated to the quantum phase via the EM connection (vector potential), using the connection 1-form.

2 Quantum Phase and Relativistic Time

Scalar EM, as a $U(1)$-gauge theory, contains quantum, periodic proper time in disguise as quantum phase (change) [13]:

$$\Delta\phi = e/h \int \vec{A}d\vec{r}.$$

Locally an atomic clock establishes a linear time dimension. The Einstein synchronization transports this time at the origin of the coordinate system to a simply connected neighborhood.

The Feynman interpretation of the quantum phase of a particle provides the elation between quantum phase and relativistic proper time of a particle.

Indeed the Poincare-Liouville 1-form (symplectic potential) $\theta = Adr - \phi dt$ of an EM $U(1)$-connection over macroscopical Space-Time (e.g. $R^{3,1}$) relates time and quantum phase change (allows to define velocities and mass, in the symplectic formalism).

If the electric field is null (no sources / divergence locally) then the electric potential (4th component of vector potential) is constant and Δt, the change in proper time, is proportional with the change in the quantum phase:

$$\Delta t = const.\ e/h \int \vec{A}d\vec{r}.$$

Even without electric and magnetic fields, we have quantum phase equipotential surfaces, orthogonal to the streamlines of the vector potential (connection form). This is relevant to, and in fact explains superconductivity and superfluidity (see later on).

2.1 The Electromagnetic Vector Potential

2.1.1 Emergent local Space-Time

EM modeled via a $U(1)$-connection defines outside sources (in vacuum) streamlines of the vector potential orthogonal (dual) to equipotential surfaces of quatum potential (space-like surfaces). Locally we have a distribution which when integrable (outside B-field / non-trivial monodromy) defines a natural space-time coordinate system, with proper time as parameter for the magnetic vector potential streamlines $\Delta\phi = e/h \int_{\gamma:A\to B} \vec{A}d\vec{r}$.

2.1.2 Change of gauge

A Lorentz choice of gauge allows to define a canonical space-like hypersurface in $M^{3,1}$ corresponding to the quantum phase defined time, as mentioned above.

A change of gauge $A \to A + grad(f)$ corresponds to a local change of origin of quantum phase and local time given by a quantum clock (periodic process).

The change of gauge should be related to a Lorentz transformation and monodromy measured by the corresponding, resulting magnetic field, to be addressed elsewhere.

2.1.3 Relation with other interpretations

Under such a gauge choice, the A-flow has a deeper meaning: see [6, 19, 13]. This point of view should be related with the emergence of *quantum time* from quantum phase[1].

2.2 Classical and Quantum Time

Quantum Time has a direction related to helicity (relative motion) and spin, but subject to CPT Theorem.

Macroscopic (relativistic) time as defined by recording the number of quantum phase rotations ($\int Adr$) is subject to an arrow due to our preparation-measurement I/O process and recording the order (classical information).

Maxwell's Demon observation inputs classical info into the system decreasing its entropy, relative to classical time. Our ordering of environment (creating classical structures / objects etc.) is a similar info based decrease of entropy, yet on the expense of debris and collateral increase of entropy. yet at quantum level (coherent quantum phase systems) the state may change but it is reversible.

2.3 On Time and Quantum Amplitudes

Quantum processes are modeled internally, at the level of Heisenberg Mechanics and Schrodinger equation as unitary processes, preserving quantum information and total probability (classical info).

At the level of Space-Time, classical models like EM or Feynman Path Integral in QFT the quantum amplitude of a process corresponds to an amplitwist of the Jacobian of a conformal transformation of the "dynamics flow". The scaling divergence reflects the spread/distribution of probability of a measurement outcome (interaction) and the rotation is a quantum phase reflecting proper time change, leading to constructive or destructive interference (relocation of the maximum corresponding to a Lorentz / conformal transformation).

2.4 Quantum Phase and Kozyrev Theory of Time

In other words we take the quantum phase holonomy as a primary concept defyining the relativistic time. The holonomy is due to the EM vector potential circulation and it is the origin of the magnetic field B (curl of A), which can be interpreted as a result of a Lorentz transformation applied to a coordinate system with a pure electric field (divergence), with its byproducts: contractions of space and dilation of time (as if EM force / curvature leads to a change of metric).

This is reminiscent of Kozyrev's work on the Theory of Time [24]. For example he claims ""Time possesses not only energy, but also a rotation (...) that it can transfer onto asystem" [25]. While reading his claims, one can establish a relation with quantum phase and the flow of the vector potential.

2.5 "Flow of Time" and Fine Structure Constant

The relation Kozyrev attributes to cause-effect velocity $c_2 = \alpha e^2/h$ and that of light $c_2/c_1 = \alpha$ can be rewritten in terms of quanta of electric charge $g_E = e/c$ and magnetic charge (fluxon) $g_M = h/e$ (loc. cit. p.179):

$$\alpha = g_E/g_M, \quad c_2/c_1 = \alpha.$$

These concepts, including the early attempts to identify an ether [26], relate in a consistent manner with the above model of time derived from quantum phase and vector potential of an EM connection.

As by now well accepted, the concept of qi / chi and associated experimental evidence is also due to the EM vector potential, with its derived fields E and B [28].

[1]The relation with the $U(1)$-quantum phase of the $SU(2)$-quark fields of EM-type, of a baryon, responsible for the emergence of Space, will be discussed elsewhere. In fact one may call (and unify) the RGB quark field triple as the baryon's quark field modeled as a Cartan Geometry connection for the "moving (spin) frame". Each quark field exhibits divergence and curl, responsible for "fractional electric charge" and magnetic poles, due to A_{Color}-flow, helicity / chirality and associated quantum phase.

2.6 ... and Space emergence

As mentioned earlier [14] the three quark fields for each color RGB in a baryon are of EM type (A_R, ϕ_R), representing an $U(1)$-connection for each of the basis vectors (quarks) of Cartan's "moving frame", with divergence (fractional electric charge) and curl (magnetic moment/spin), in the 3D-directions of a local frame.

How the RGB and T-connections relate, will be studied elsewhere. A connection with Kozyrev's "intuition" remains to be established.

3 Emergence of the Standard Model

The SM developed historically into three separate theories, as expected. Yet the assumptions which now should be challenged (mainly quarks as *particles* and *continuous* gauge groups) are still in place, since the 70s and should be reconsidered.

3.1 Theories of Electron and Nucleons: an analogy

As a general idea, the physics of $U(1)$ and $SU(2)$ bear useful analogies: Chemistry vs. Nuclear Physics [17].

The theory of electronic orbitals in an atom, with their geometry of type s,p,d, f... may be thought of as a shadow of the $SU(2)$-spinor theory of electron, for the Scalar EM as a $U(1)$-gauge theory. These orbitals type are flavors of electrons, associated to the principal quantum number n (energy level / Z/n Bohr frequency), analog to TOI Platonic symmetry groups corresponding to the flavor-geometry of nucleos; the isospin / weak charge corresponds to the Poincare duality of their modes of vibration (exchanging nodes with faces / 2-membranes).

The analogy relies on the idea of considering the electron as a 4-th color, time T, together with RGB colors which clearly represent the local generators of the state space $SU(2)$ (double of $SO(3)$) [20, 18], as a local model for the emergent Space via the quark field connections of EM type.

3.2 EWT and QCD

The Quantum Flavor Dynamics emerged from Fermi Theory of beta decay to model quark flavor transformations in baryon decays via mesonic bosons (consider baryons as nodes with quantum geometry and mesons as channels).

It introduced the W's and Z in th early 50s. Later it incorporated EM as Electroweak Theory (EWT).

QCD emerged from the hypothesis that quarks are elementary particles, hence needed to be kept together in a baryon by some unknown interaction. The idea of color as a quantum number became charge for this new interaction. Its range had to be restricted to the size of the baryon, since it was not observed experimentally outside it. Its main function was *confinement*.

Thus EWT modeled flavor aspects of particle physics and QCD the "other" aspects of states of the baryons, "color" related.

Their separation is artificial, by design. Their unification is straightforward: RGB corresponds to a baryon frame of $SU(2)$-transformations with associated quark fields; internal for resonant modes (QCD, but without need for confinement) and weak interaction for Klein geometry transformations (Platonic type).

The later is clearly proved by the derivation of CKM and PMNS matrices by F. Potter, also anticipated by the author on the general principle "Everything is discrete" (3rd quantization, of qubit state space in QC).

Then Klein geometry generalizes to Cartan Geometry of frames in the $SU(2)$-gauge bundle, where the "gauge theory" is in fact the Cartan Connection theory that allows to derive Space-Time from the quark and electron $SU(2)$-spinor fields (RGB and T).

3.3 Superconductivity

Note that the vector potential of EM defines the quantum phase (Einstein-Feynman proper time) and in superconductors gauge symmetry is broken, leading to a coherent macro Space-Time [19]. What is

physical in general is the EM-connection, with monodromy the B-field and A-fluxons the holonomy (quantum phase periods).

Quantum locking of superconductors in magnetic fields are due to locking in place at maxima of quantum phases interacton of the thwo A-flows.

3.4 Gravity

Gravity emerges from the quark fields electric component (work capable), with quantum scalar potential discrete levels of energy, radially between two baryons (long range, due to A_C-fields for "colors" R, G, B) and spin orientation dependent.

In fact the One Boson Exchange Model of Nuclear Force (OBE), also called Weak Nuclear Force in the context of Quantum Flavor Dynamics, is the common ground where EWT and QCD meet (see author's previous work [14]). The flavor-mesons, e.g. $\pi = (u_R \bar{d}_G$ as nuclear bonds carry flavor (geometry/ symmetry) but also "color", as channels for gluon exchange (quark fields as Cartan connection). This is the Nuclear Physics analog of electronic bonds in Chemistry.

3.5 Emphasis on Processes, not Particles

A "Theory" should provide a framework for the processes involved (see §1): baryons and quark frame, geometry and mesonic bonds with gluonic exchanges (Elementary particle Physics); atoms with electronic orbitals and molecular bonds (Chemistry) etc.

Hence quarks and electrons are not "more elementary particles" but rather structure of the $SU(2)$-Theory of Quantum Space-Time. The three generations are not "other" particles, but rather geometries, like principal quantum number for electron (s,p,d,f ...) [14, 11].

3.5.1 On Titus-Bode Law

As an another example, consider the Planetary System and Titus-Bode Law, where the planets are structured at logarithmic distances from the Sun, reflecting a collective behaviour related to the emergence process. The Law is based on observation, is a model capable of prediction (detection of Ceres and asteroid belt in 1801 [9]). Such models in astronomy occupy rather a higher level in the hierarchy of Science Theories, but exemplify the main point: describing aspects of a collection of "particles" as parts of a system.

Other such "layers" implemented based on the theory of symmetry groups, as paradigms, are present in Chemistry and Nuclear Physics, Elementary Particle Physics [10]).

3.5.2 Role of and Lessons from Category Theory

Indeed, what is the "ID" of an mathematical object of a certain type (category)? ... Its group of automorphisms. Its "interaction properties" are defined by the relations with the other objects of the same type, modulo equivalences.

3.6 Quantum-Classical Physics Hierarchy

Gauge Theory bundle with Cartan connection (geometry) approach relates "quantum" from "classical" structures, e.g. QED and Scalar EM, EW/QCD unification and interactions on the base manifold (Space-Time: EM and GR).

3.7 Comparison with other models

3.7.1 Kaluza-Klein Theory

Kaluza-Klein Theory is an important step towards unifying G and EM, with a fith dimension essentially the quantum phase $U(1)$. throughing it internally as a principal bundle over GR could result in a more "natural" theory, since GR models effective Gravity, essentially Newton's Theory yet incorporating a few correction effects (bending of light, precession or perihelion etc.). GR has the much more important role of a model for the Universe, with new phenomena predicted (blackholes, expansion, Big-Bang etc.).

3.7.2 String Theory

KKT invited the circle to play a fundamental role: the String; yet String Theory adopts an approach of embedding RS in a product of Space-Time and Calabi-Yau manifold, instead of adopting the fibration models; hence the "landscape problem".

Similarly for M-Theory.

3.7.3 Feynman Diagrams etc.

FD are considered "pictorial tools" and bookkeeping devices, yet the progression to String Theory and Quark Line Diagrams shows the effectiveness of the idea of Network.

By now other "mysteries" of QM have justified the claim that quantum phenomena occur in a Quantum Network, without a material Space (nor Time), e.g. 2-slit experiment etc. [1].

Lattice models are considered an approximation, yet they go in the right direction: Network Model (Spin networks etc.).

3.8 Decays as Change of Phase / Symmetry Group

One relevant decay sequence is $\pi^- \to \mu^- \to e^-$, where the details are left aside (neutrinos). The point is the pion is a quark-antiquark pair, subject to $SU(2)$ symmetry (EWT as a flavor changing theory), but then it decays into masive muon, which by now we know it is an "electron with a different internal symmetry group (Cubic / Octahedral) which then decays to electron (which is a 1st generation lepton), hence must still have structure.

Thinking of how an electronic orbital may change into another type, e.g. $f \to d$ (in an atom, with their geometry as a "flavor" / shape, suggests reinterpreting such a sequence as one channel through which the "particle" with internal geometry changes symmetry groups (reduction of structure group for connections). Intuitively, from a full RGB-"turbulent" flow to a laminar $U(1)$ flow[2]. It can be compared with a change of phase (like from gas to liquid to solid) but for gauge groups and moving frames (Cartan Geometry / principal connections), where due to the loss of energy via neutrinos some degrees of freedom in the moving frame reduces the group of symmetry ("freezes").

3.9 Phase Change as Reducing the Symmetry Group

An implementation of reduction of symmetry group is via monodromy of the connection, which defines points where the values of the curvature defines a Lie subalgebra [22], corresponding to a Lie subgroup of the "gauge group". Such a pair $H \to G$ is in fact a Klein geometry, as a local model for Cartan Geometry / principal connections approach to gauge theory and GR (vierbein models).

At such a point where the "Klein geometry" of the fiber changes a decay occurs, e.g. a pion decays into a muon, with an associated neutrino (not clear its Math role /meaning for the connection approach).

3.10 ... and Weak Force

This may be an alternative approach to using the Weak Force gauge paradigm as a separate interaction, "changing the theory" according to the group invoved, as needed.

Note that the role of W's and Z massive bosons are purely theoretical, as "imaginary particles" to serve the theory (remove the renormalization issues of Fermi 4-point effective theory). Indeed the measurement of W's mass is indirect, when resolving the 3-point observed beta decay into a Pauli model of a 4-point interaction with the unobserved neutrino, and "blowing-up" the 4-point singularity as a 3-3 Feynman interaction process (inserting a propagator).

The range of the W boson is smaller then the theoretical radius of a proton and hence not observable, nor compatible with QCD or other aspects of Quantum Physics: it is a virtual theoretical particle. yet "imaginary numbers" like i are powerful way of extending our math-models (algebra / geometry / number theory etc.).

This re-interpretation of decays via connection monodromy / change of phase of the "propagation flow" aims to unification of several types of particles as *one type of particle undergoing a process*; H_2O

[2]This will be explained elsewhere.

freezes from gas to liquid to ice, with some changes in its properties, but it is the "same" substance (underlying layer of modeling / description). Similarly the $SU(2)$-flavor meson (1st generation of quarks / Platonic geometry) "freezes" (at the level of the connection parallel transport of state) to an $SU(2)$-lepton (and geometry) which "looks-like" an $U(1)$-particle etc.

Such a change of phase model occurs in superconductibility and superfluidity, in solid state physics (see §3.3).

4 What is Mass?

Mass and velocity are not primary quantum invariants. For example the dynamics of a particle in EM field involves the generalized momentum $P = p + e/cA$; but baryons have three such fields of EM type (quark fields) and the electron comes with a forth.

A first step is to understand that position and momentum are not well defined at quantum level: symplectic geometry / Heisenberg Uncertainty Law.

4.1 Liouville form: from symplectic to cotangent framework

The separation between mass and velocity comes from the tautological one-form (Poincare-Liouville) and for the field, the connection 1-form $Adr - \phi dt$; this allows to translate the symplectic theory of QC (HyperKahler-Hodge structures) into a cotangent space framework T^*M, of a Space-Time experimentally defined (Einstein SR).

Quantum Phase relates to a global time (coordinate system dependent; e.g. Aharonov-Bohm effect: $\Phi = e/h \int_{path} \vec{A}d\vec{r}$).

4.2 On Mass of Leptons and Quarks

Then mass is due to magnetic / holonomy aspects of the RGBT connections. It should relate mathematically to classes of elliptic curves and modular functions ($SL_2(Z)$ invariant), leading to $j-invariant$ and representation theory of the Monster [23]: Platonic, Weyl groups, $E6-8$, Monster and VOAs.

While the lepton masses are well established experimentally, with the constants $1, 108, 1728$ in the invariant defined by Klein close to experimental values (loc. cit.), the quark masses are very much theory dependent (average/dynamic etc.).

Yet the Klein invariants from syzygy theory of Platonic groups TOI (and their doubles) should relate to mass in a simpler way. The context involves the lattices in $R^{3,1} = H = C \times C$ and corresponding groups (Modular, Mobius / Lorentz). Note the importance of Hodge structure in EM and theory of EC (lattice in C and higher tori, as Jacobian varieties of Riemann Surfaces / String Theory, related to Liouville angle-variables in Mechanis).

4.3 A Platonic M-Theory?

A different approach based on Riemann surfaces and Belyi maps having Platonic and Archimedean solids as *dessins d'enfant* (Grothendieck), will be presented elsewhere. Note that this approach is in the spirit of Membrane Theory and its modes of vibration (3D-cymatics). It is enticing that Belyi maps have at most three singular points, as many as quarks in a baryon (Riemann-Bloch sphere of the Hopf fibration): coincidence? [3]

4.4 SM, String Theory and Quantum Computing

The bigger framework, adopting the Network Model in Physics (Plato's interactive system point of view), suggests modeling such a QC interaction as a network of 3-punctured spheres as baryons (Hopf bundle is its unit tangent bundle, with marked points, related to $U(1)$ and fractional charges / quarks), related by String Theory's Riemann surfaces representing mesonic (Nuclear Force in nuclei as "quantum registers) / electronic (Chemistry / connectors in a molecule as a VLSI Q-circuit) channels of interaction.

[3] Einstein: "Coincidence is God's way of remaining anonymous".

4.5 Mass and Curvature

Interaction forces in the gauge theory model are in fact curvature of the corresponding connection; a geometric interpretation akin with Einstein's take on Gravity as curvature of Space-Time, or EM.

It is natural to investigate in what sense monodromy and holonomy impedes change of momentum and if this defines mass via the Poincare form / soldering.

5 Conclusions and Further Developments

The proposed program relates Quantum Models with Classical Models via bundle theory and connections.

5.1 Conclusions

Relativistic time emerges from a local quantum time defined by quantum phase, allowing to define an emergent Space-Time. A change of gauge of EM potential amounts to a change of origin.

A similar approach involving the RGB quark fields was sketched to obtain space, and hence Space-Time as emergent from the SM quantum description.

5.1.1 On the effectiveness of Mathematics

Several mathematicians and scientists have recognized the surprizing effectiveness of mathematics in describing the world of Physics (Wigner etc.); others, recently noticed the opposite: Weinstein, Sabine Hofenhelder etc. The change is due to a change of perspective: "Compute, don't think!" and "We need more data / digits " (ask Mother Nature instead) ...

The new developments, although at the level of ideas and as a research program have advanced our understanding regarding: 1) Gravity is of a quantum origin; 2) The EWT can accomodate QCD, incorporating Gravity; 3) Finite subgroups model quark and lepton generations; 4) How Time emerges from quantum phase via EM and Space emerges from quark fields (of EM type), using the Cartan Geometry / Connection approach and the SM.

5.2 Further Developments

Furthermore the three quark fields, each with divergence (electric source) and curl (magnetic source) forming the baryon field has the role of a product / coproduct for parallel transport when considering interactions. For example a Feynman 3-vertex interaction can be modeled as a tensor operation (product / coproduct) related with the geometric connection and gauge group.

The neutron as a more symmetric baryon ($Z/2$ / parity) unfolds as a hydrogen atom (beta decay plus electron capture by the proton), breaking the symmetry and separating divergence (radially) from rotations (curl). In this way conformal transformations (div and curl) emerge from the "neutral" (no divergence) QC maximally symmetric state of a neutron field.

The study of the baryon field from the QFT and tensor operations modeling such Feynman diagram interactions, will be dealt with elsewhere.

A further study of mass will take into account the Platonic Membrane Theory (in place of QCD approach to resonances), based on Riemann surfaces, Belyi maps and j-invariant [27].

Problems in Physics and Science, and even phenomena not yet clearly understood / recognized by the later, should not be solved, modeled, studied in isolation. Therefore we have included various aspects in this prospective account of how time (change / correlation parameter) emerges, in a non-self-contained manner, as a background for the main theme: EM potentials representing geometric connections, are essential to the understanding of fundamental physics. Several references were include as directions for further investigations.

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