

The Search for a New Equivalence Principle

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Abstract

The emerging quantum physics - quantum computing *conceptual bridge*, mandates a “grand unification” of space-time-matter *and* quantum information: an “all quantized” quantum digital world. The present article suggests an equivalence principle, to include *space-time* and *entropy* beyond Einstein’s matter-energy unification $E = mc^2$ with the “fixed” correlation with space-time from general relativity $G = \kappa T$. It requires tripling time, not more space dimensions as in String Theory, while complexifying the energy-momentum tensor to include *entropy*, and *finally unify space and time* by a *generalized Wick rotation*: an “external supersymmetry” which trades *parallel and sequential quantum computing* relative to a *space-time coordinate system*. The *Feynman Path Integral* algebraic formalism already has a place for this, when interpreting *entropy as a measure of symmetry*.

1 Introduction

Major breakthroughs in physics are based on a change in perspective regarding already existing mathematical models, due to new *unifying principles*.

The article reviews some fundamental questions and theoretical difficulties (“paradoxes”) which in the present author’s opinion should be solved as a result of a conceptual unification steaming from a new fundamental principle. At this stage, we are able to list what seem to be the major pieces of a “puzzle”: a theory including the benefits of, and built with the technology of the present quantum theories (Quantum Mechanics/Quantum Field Theory, Quantum Gravity etc.) while resolving the “conceptual tension” of the measurement paradox. In my opinion, we do not always need express contradictions between experiment and theory. Especially since nowadays, what theory predicts, say String Theory for instance, may lie “safely” outside the experimental range.

The understanding may come from a new way of looking at the same “technical tools” (e.g. Special Relativity - see §3.1).

2 Models, models, models!

Recall that we *model* reality and we do not know what reality *is*; many books have been written on the subject, so I will only mention a few relevant names: Kant, Mach, Einstein etc. and revisit briefly a few relevant aspects.

2.1 What do we mean by “What is *time*?”?

Implicitly we refer to a concept within a theory (framework/context etc.) which usually belongs to a specific community or person’s knowledge, linked via a tag like Newton, Einstein, Heisenberg, Feynman etc.. Or, when asking “What is an Electron?”, the answer ... depends on some “hidden variables”: the theory we implicitly have in mind when we ask that question. “Electron” may refer to the corresponding particle in Lorentz’s theory, or the de Broglie’s wave, Dirac’s spinor etc. Even worse still, it can be quite misleading when “explaining” quantum mechanics, and in the same statement

making use of the term “electron” to refer to the quantum description and then to ponder in classical terms about it ...

In this sense, there are many meanings behind what we call “time” or “space” etc., within various theories; so one has to be careful about the implied context.

2.2 “Is it a particle or a wave?”

The “electron” for instance, is very well modeled as a particle by a few theories, when it comes to a certain range of experiments, yet there is a need for other theories modeling the “electron” as a wave because of another class of experiments ... Overall quantum theory has a unified explanation for “all” experiments (of a certain kind, of course) and the *Complementarity Principle* may be thought of as a “Two classical charts atlas of Quantum Mechanics”.

2.3 Interpretations of quantum mechanics

Why do we need to “interpret the result” of a quantum mechanics computation in classical terms?

Classical mechanics is contained within quantum mechanics (⁴, p.12), and it is not just a “limit” (*Correspondence principle*). Indeed, the measurement process involves a quantum probe (microsystem, elementary particle etc.), *interacting* with the measuring apparatus (usually a macrosystem) and the result of the experiment itself is modeled, or at least used by the experimental physicist (or processed by some software!), in classical terms. *We* acknowledge only macroscopical events: dots on a screen, beeps in a counter, bobbles in a chamber etc.. Even a Stern-Gerlach experiment (i.e. involving “internal states”) involves the interaction of a quantum probe (the electron) with a magnetic field (macrosystem!) AND a detector: beeps on 2 counters, providing the input to a classical gate/computation. So, in a way Quantum Mechanics is a phenomenological theory! (beyond the Kantian statement of the type “we only model phenomena ...”), and the reduction from a quantum computation to a classical computation mandates the collapse of the wave function: content lost in “translation”.

2.4 The main “lesson”

from above is that there are implicit *channels of information* which are present, yet probably not correctly (or completely) modeled within the corresponding theory! The role of *observer* in classical physics is that of “user”, while in quantum physics is that of a “quantum programmer”. A crucial objective in classical physics is to have a *unique* description (“standard operating system” for the only hardware available) independent of observer (covariance; classical heritage). This is no longer tenable in quantum mechanics: “results” depend not only on “what” we observe (the quantum hardware the experimenter physicist prepares) but also on “how” we observe, which in turn depends on what do you intend to do with “the result” (the quantum software used to model the quantum computation). Nevertheless we are still looking for a “standard” in these proliferation of quantum “hardware-software” business.

A unifying point of view, as a “slogan”, if one has in mind the unification alluded to above (math-physics-computer science), is that “All is quantum computing” (see also “Feynman processor” ¹ etc.), i.e. any interaction, whether system-system (Einstein: “I like (!) to think I don’t have to look at the Moon for it to exist”), system-observer (quantum phenomenon), observer-observer (genuine communication, predominantly classical!) are of the same kind.

3 Three ... revolutions: returning to principles!

Let us consider Newton's simplifying picture of Kepler's Laws as a start for scientific modeling of (mechanical) phenomena. ¹

3.1 First revolution: Special Relativity

Special Relativity gave a new look at the technical tools already available at that time: Minkowski space, Lorentz contraction, conformal invariance of Maxwell's equations etc. Yet the *conceptual* breakthrough consists in "understanding" their "hidden" meaning: the unification of space and time. Technically speaking, this was already done by Lorentz and Poincare - see ³, p.25 - but ... "What is it that we are doing?" was probably the main question of the day. The unification was derived in an "axiomatic" manner from the fundamental principle $c = \text{constant}$, which mathematically corresponds to a constant Lorentz metric (conformal class). A probably more important fundamental principle is the equivalence between mass and energy:

$$\textit{Principle I} : \quad E = mc^2.$$

A "simple equation" yet with huge implications.

3.2 The second revolution: General Relativity (GR) or Quantum Mechanics (QM)?

In the author's opinion, QM is *The Revolution*, changing the way physics is done (see 2.4). *General Relativity* is a "jewel" amongst mathematical-physics theories, again starting from a fundamental principle, the equivalence between accelerations, gravitational or not, or in terms of masses: inertial or gravitational):

$$\textit{Principle II} : \quad m_g = m_a$$

General Relativity "upgrades" the Newtonian geometro-dynamic description "force of some kind = centripetal force":

$$\textit{Force} = \textit{Mass} \times \textit{Acceleration}$$

to a pure geometric description (space and time were already merged in special relativity) "matter tensor \sim geometry tensor":

$$\textit{Matter_Tensor} = \kappa \textit{Einstein_Tensor}.$$

Beyond the new "technical tools", e.g. semi-Riemannian spaces, Ricci curvature etc., this amounts to passing from a description of dynamics as "*curved* motion in *flat* (universal) space" to "*flat* motion (geodesics) in *curved* space(-time)".

In other words, taking a phenomenon (gravitational force for instance) from the left hand side (LHS) of Newton's principle and incorporating it into the RHS as Einstein's tensor, which is essentially the average curvature (κ denotes the gravitational constant). The "trick" proliferated: then came Kaluza-Klein, attempting the same maneuver with the electro-magnetic force. It did not work as well, since "internal degrees of freedom" could not be well accommodated as external degrees of freedom (i.e. dimensions of space-time). The alternative was to build degrees of freedom outside the "obvious" ones, leading to *Gauge Theory* (e.g. Yang-Mills theory etc.). Meanwhile the mathematics "technology" advanced and *String Theory* is capable of such feats, introducing "real" dimensions (for a grand total of 11? or 21? or ... etc.). Some of them, of course, need to be "hidden" from every-day "access" by

¹Or ... is it "a culminating point of the scientific revolution of the seventeenth century"? ², p.425

compactification, declaring them small enough not to contradict our experience. But they are just ... another model for space-time!

In the “phenomenological camp” the opposite tendency may be noticed (in the spirit of quantum mechanics; see 2.3): let the degrees of freedom (and states) be “internal” (abstract) ... and *Chiral algebras*, *Vertex Operator Algebras* etc. appeared!

So, where is the third revolution?

3.3 Space-Time: Is “motion” possible?

We do not need Zeno’s paradox (see ⁴, p.56) to claim that motion is not possible (⁵, p.14) ². Of course, we have to specify in which theory: in quantum mechanics, since otherwise classical mechanics deals great with motion/continuous evolution/dynamics (Poisson manifolds etc.), and we’ve learned not to talk about what reality *is*, but only modestly about our best model about it.

In quantum mechanics there are “states” and “transitions”, as in a sort of a “complexified” Markov process, where, amazingly, the possibility of having a result in two ways may cancel each other’s contribution (“indecision”!), rather than build up the probability! To model mathematically this feature, we choose *superposition* and *interference*, implemented as a linear theory over complex numbers.

The incompatibility between knowing the position *and* the momentum at the same time, for the same direction (Heisenberg’s uncertainty principle), conceptually refutes classical trajectories altogether, but still refers to classical concepts!

If we insist in adopting QM to investigate the motion process and still have a classical understanding of what the electron “does” in a two slit experiment we have to conclude that “it” goes through both holes simultaneously! This is in the “best approximating” classical statement for the quantum occasion ... So, “Is *motion* possible?” Well ... the answer is theory (and author) dependent.

3.4 What is an “Event”?

The differences in the approaches of modeling reality in *Classical Mechanics*, General Relativity, Quantum Mechanics, Quantum Field Theory (QFT) start with the concept of “event”⁷.

For Newton the “event” is a “particle”, (i.e. *existence* of matter), “somewhere in time”; these three concepts, existence, space and time, are “absolute”, i.e. independent of the observer and of each other.

For Einstein, “existence” is still “absolute”, although the “event” occurs in a (partially) unified space-time, yet still “absolute”, even after the advent of GR. After the QM lesson, we should agree that what we model are *correlations*: *A* interacting with *B* produces *C*, for example an *electron* in a *magnetic field* yielding a *beep* on the up or a down particle counter; ... and the observer? There is a missing aspect here in a parallel between quantum and classical computation⁸, to be explained elsewhere.

To implement “correlations” one needs to define the “states” and “transitions” (e.g. using categories: objects and morphisms). There is usually a “time-ordering” issue here: states first, then transitions ... This may be thought of as developing the theory starting from the “free case” (inertial reference frames and the free theory in the scattering method approach) and then adding “interactions” (all frames/scattering matrix etc). It is essentially the old Newton’s goal (and Descartes’ methodology) of representing functions as power series (or breaking down the theory in simpler steps).

In perturbative QFT the series is indexed by Feynman graphs, Riemann surfaces etc., i.e. building the “big processor” out of “microcomponents”.

²Zeno’s *Arrow* paradox seems to urge for Lorentzian contraction at least.

3.5 Quantum Field Theory (QFT)

In QFT we have a continuum of degrees of freedom (the values of the field) only because we strongly believe in a given space-time continuum. This is essentially the heritage of Newton and Leibnitz, preserved in the classical theory of Einstein.

Roughly speaking, QFT is an “upgrade” of QM as a complexified Markov Process, where the complete graph being *represented* (the transition matrix), is replaced with a class of graphs and the complex numbers as coefficients are replaced with operators (propagators).

Feynman’s path integral picture introduced what we will call *The Automaton Picture*: states and transitions, whether these are paths in space-time (external DOF) or transitions in internal space (IDOF). This is a “popular picture” amongst physicists, and at the same time the most powerful quantization method (“Feynman brought QFT to the masses” ⁽⁹⁾, p.41).

We ultimately look for transition amplitudes of an interaction in the context of a framework based on the free case, which is classical in essence since we know how many particles go in, and what comes out, in classical terms. The amplitude is the sum of the amplitudes for all possible “scenarios”; the *correlation function* is a sum over Feynman diagrams or possible histories. This is a *basis* in the *transition space* (space of all “paths”).

The “problem” is, that if we believe “motion” is possible in a space-time continuum, then we end up with too many “paths”! This entails divergent integrals etc..

Physicists have learned quickly how not to step in quick sand, while mathematicians had a hard time building the bridge over the “swamp of infinities”, again due to the cherished inheritance of Newton and Leibnitz: the *analysis* (doubt now “hard analysis”). It is time to acknowledge that the paths themselves of a given model are irrelevant, forming the huge loop/path space of a Newtonian-Einsteinian version of a configuration space of classical-mechanistic events. Relevant is the homology/homotopy of the mode of interaction, viewed as a *network processing quantum information*, as it will be explained in detail elsewhere ²² (see also ²³).

3.6 External/Internal Degrees of Freedom: *The Automaton Picture*

The natural way to “solve” the problem of too many paths is to realize that all we need is a reasonable category of “paths” (transitions) and an action allowing to build a representation of this “Feynman category” ^{23,24} with suited coefficients corresponding to the internal degrees of freedom had in mind.

By now it appears that gravity is an organizational principle within the space-time description (GR), rather than an exchange interaction. Trying to push the beautiful particle-field picture (gauge theory) from scalar and vector fields to spin 2 tensor fields and incorporate gravity at all costs, could be the “take a bigger hammer” approach (like from string theory to ... M-theory too) to “crash the nutshell”, approach which looked so repelling to some (notably Grothendieck). It worked with Fermat’s Theorem, though, but, “What’s taking so long?” ¹⁰.

Alternatively, we could try to implement gravity as a pairing between the Feynman category and the coefficient category. The Feynman category captures the causality, since there is NO universal time at the micro scale, and we have to deal with the time ordered products and operator product expansions of QFT and renormalization. The “coefficient category” captures the macro-behavior (see §2.3) in an adjunction which trades additional external degrees of freedom (e.g. applying the homology differential, i.e. insertion of an edge¹¹) for additional internal degrees of freedom. In this article, we focus on the ideas and design of the theory, and therefore the technical details^{12,13,15}, should not clutter the picture at this point!

This should be done in conjunction with a model for the information flow (see §2.4), since there are several macrosystems involved, and an experiment, like a quantum computation, involves classical

read/write operations subject to classical logic/laws (see ¹⁴ for additional details).

No matter what the specific implementation will be (e.g. using graphs, networks, categories etc.), it will capture the idea of *automaton*: *states* and *transitions*, e.g. the *cellular automata* of^{16,17}). Yet the implementation will be written in one's favorite object-and-relations oriented high level language, in an "author dependent" fashion.

3.7 Is there a "time", after all?

Indeed "time" is THE delicate concept; or rather a plethora of interconnected concepts! We all like to ponder on the fundamental questions, trying to find new ways ... (see "Time's Up, Einstein", by Josh McHugh, Wired 06/2005, p.122). It was the analysis of what time is, that led Einstein to a clear picture unifying Newton's universal space with his universal time. Even at that stage, one could ponder on a hidden assumption Einstein implicitly made: transitivity of synchronization. It can indeed fail in GR, if there is no local time, i.e. if the orthogonal distribution to the Killing vector field is not integrable¹⁸. Instead of spending \$200,000 on a "Michelson-Morley experiment" trying to reintroduce the "ether" ¹⁹, one might rather test the above mentioned possibility, which definitely holds true at *some* level of accuracy.

But since we aim at a deeper model, beyond the Standard Model or String Theory, where "events" are "pure correlations", the above issues are secondary. One lesson learned from Special Relativity is that there is a causal cone; events can be spatial separated (no causal correlation possible - we are not talking about entanglement yet ...), or if causally correlated, than they must be time-separated. Yes, a "proper time", is a different concept, representing "continuity of existence" and rather playing the role of a local parameter, as opposed to the experimenter's global "laboratory time" in quantum mechanics.

So, what we need is a *Causal Structure* and that is precisely what a *Feynman Category* provides!

$$\textit{Feynman Category} \implies \textit{Causal Structure}.$$

If a causality structure is given, then to benefit from the present and past theories one has to deal with embedding it in a classical $d = 4$ dimensional manifold (or is it $d = 11, 21?$), as some "background space"; or at least, after representing it in one way or another (e.g. decorating punctures on Riemann surfaces with operators, or implementing algebraically as vertex operator algebras etc.) one has to come up with an *Operator Product Expansion* (OPE) as a much more complicated issue than the usual 1-parameter group of unitary transformations capturing the dynamical evolution of a mechanical system as the "time flow".

Then, what is left of the idea of 4-coordinates as a "... starting point of the mathematical treatment" (³,p.24)? First of all, one should postpone the "mathematical treatment" until the "design" of the theory at a conceptual level is complete or at least satisfactory: the *application interface* as a set of "implementation specifications" of the physics model. Then let the implementation specialists ("math-programmers") to choose the appropriate tool box to implement the theory ... But this is another story! we would not have had QED a few decades ago, right? It had to be done fast, no time to wait for mathematicians to be pleased with a "rigorous", i.e. mathematical, implementation! What I am advocating here is to glance at the methodology of computer science, and *design* the theory with an "author independent" and "user friendly" *interface* between mathematical and physics models.

On the other hand, there are some holistic questions. There are 3-pairs of non-commuting observables representing external degrees of freedom (q_1, p_1 , etc.). Why are there three dimensions? Why are there three generations of elementary particles? etc.. These could be questions allowing to tell theories apart, but we feel there is much more to these questions than it meets the eye. They should be addressed as part of the quest for quantum gravity.

4 A New Equivalence Principle

Returning to General Relativity (GR), its importance still lies in the conceptual unification between space-time and matter. At a more technical level, perhaps the most important consequence beyond expansion of universe and Hubble's constant, is the *concept* of black hole. The unification of GR and quantum theory was initiated by S. Hawking as an extension of GR incorporating the black hole radiation. Since then, three laws have been identified (see ²⁰, p.92). In view of the above unification and the main characteristics of a black hole, namely the presence of an event horizon, we claim that the black hole of GR plays the role of the elementary particle from QFT: a "black-box" with internal degrees of freedom (DOF). Therefore the black-hole radiation laws are much more fundamental than presently acknowledged.

The first law relates *temperature*, as a measure of energy per DOF, with *acceleration* as a measure of the interaction (Newton's sense):

$$\text{Unruh's Law : } \quad \text{Temperature}/\hbar = \text{Acceleration}/c.$$

It expresses a principle, therefore in the simplest (physicist favorite) way, as a linear equation. Together with *Einstein's Equivalence Principle*, it suggests that there is an energy distribution for the 2-point gravitational correlation function (in some quantum discrete picture).

The second law:

$$\text{Bekstein's Law : } \quad \hbar \text{ Entropy} = \frac{1}{\kappa} \text{ Area}/(8\pi),$$

relates *entropy*, as a measure of the information needed to completely specify a state (the "quantum memory size") and *area*, which in a discrete geometric model should be thought of as a measure of the possible In/Out interactions ("quantum channel capacity"). Beyond the "global statement", adequate for stating an equivalence principle, there should be here a "local/discrete" version (Stokes Theorem at work).

It is reassuring to find out that Lee Smolin mentions implicitly such a "would-be" principle: "one pixel corresponds to four Plank areas"²⁰ (p.90), although it could rather be stated as "one *interaction qubit* corresponds to four Plank areas".

Later on (p.102), he derives some conceptual implications which are evaluated as not admissible, *IF* there is no theory to back them up (we have learned a lot from the old story: "Euclid's Parallels, axiom or not?"; let's derive the "unbelievable" consequences first, then decide how to build the theory!).

Finally the third law relating temperature and mass, but in an opposite way as the first law, is:

$$\text{Hawking's Law : } \quad \text{Temperature} = k/\text{Mass},$$

or alternatively:

$$\text{Mass} = k\beta$$

(with an eye on the entropy: Boltzmann's correspondence etc.).

It refers to the radiation capability of a black hole ("density of I/O-interactions"), rather than its energy distribution per DOF.

The situation is reminiscent of Newton's position when simplifying Kepler's laws ... so let's look for a new unifying principle, generalizing Einstein's Equivalence principle!

4.1 "Mind versus matter"

Recall that $E = mc^2$ (Principle I), in a sense, unifies energy and matter.

Quantizing energy and matter (Planck, Einstein, Bohr, de Broglie etc.):

$$\textit{Principle III:} \quad \textit{Energy} = \hbar \textit{ Frequency} \quad (E = \hbar\omega)$$

should correspond to *quantizing quantum information*. Then, since energy and matter determine space-time in GR, space-time should be equally quantized. Intuitively, quantum information (qubits) should be “stored” in quantum memory and processed by quantum gates and circuits. This is precisely the role of space-time as a causal structure. Loosely speaking, Feynman diagrams process quantum information residing on the boundary^{22,23,24}.

The new unifying *Equivalence Principle* will be labeled “Mind versus Matter” to convey its broad scope. It states a correspondence between matter-energy and space-time-information, both quantized, and therefore discrete:

$$\textit{New Equivalence Principle IV:} \quad \textit{qbit} \leftrightarrow \hbar \quad (S(\textit{qbit}) = \hbar).$$

The left hand side represents the quanta of information (entropy), and mathematically corresponds to a superposition of “Yes” and “No” with complex coefficients (probability amplitudes): elements of a 3D sphere S^3 . We prefer to identify qubits with $SU(2)$ rather than with quaternions, which exhibits the direct connection with *symmetry*, with its measure, the *entropy* (see¹⁴, pp.104, 134):

$$\textit{Entropy} < - > \textit{Symmetry:} \quad H = -\ln \textit{Aut}(\Gamma).$$

Here Γ represents the state space with its symmetries $\textit{Aut}(\Gamma)$.

The right hand side is the unit of action, the Plank’s constant as a suggestive symbol of quantum physics and quantization.

So far we aim not just to unify the “observer” and “observed” of quantum physics, and resolving the “measurement paradox”, but because the usual current resolutions of this paradox involve at some point the conscience, we also provide a possible interface between the “safe” science and the other “believe-it-or-not” areas of investigation (direct interactions between matter and mind).

The idea is that a transfer or fluctuation of a unit of energy should correspond to a quantum bit of information. An additional DOF (E/I) (internal, i.e. type of particle, or external (!), i.e. space-time “location”¹⁴) changes the partition function describing the distribution of amplitudes of probabilities in a way similar to a black hole “leaking” a qubit of information. The theory should naturally incorporate the black hole laws in the context of GR transmuted from its natural habitat (manifolds with a metric/Lagrangian) to the realm of *Feynman Processes* (representations of Feynman Categories: string/M-theory rephrased as background free theories, with a mass generation mechanism upgrading the Higgs breaking of symmetry).

At the more technical level of the Feynman Path Integral formalism, a conceptual “merger” between energy and entropy can be achieved with the price of *complexifying the action*¹⁴, p.224:

$$K(A, B) = \int_{\Gamma \in \textit{Hom}(A, B)} \frac{e^{iS(\Gamma)/\hbar}}{|\textit{Aut}(\Gamma)|} = \int_A^B \mathcal{D}\Gamma e^{H+iS(\Gamma)/\hbar}.$$

This is mandated by chiral theories anyway, where the Lagrangian contains complex coupling constants to account for charge-parity symmetry violations in particle physics interactions²⁵. Another reason for complexifying the action is the conclusion (¹², p.225) that it is *not* space in need of extra dimensions (11, 21 etc. as in “classical” String Theory), but rather *time* (st-symmetry in conformal field theory, Wick rotation to switch from Minkovskian to Euclidean QFT etc.). The new reason for enlarging the usual 1-dimensional time flow of mechanics to a 3-dimensional flow, is the interpretation of interactions

as communications of quantum information (qubits), towards a representation theory of a *non-abelian time*: $SU(2)$, instead of the classical 1-parameter *abelian time*: \mathfrak{R} . This will indeed *unify space and time* (ST), as playing the *dual role of parallel and sequential quantum computation coordinate system* in quantum networks admitting such a -time coordinate system (see²⁶ for additional details). The alternative for the mathematical implementation triples the number of time dimensions for a total of 3+3 ST-dimensions or doubles the ST ($2 \times (3+1)$).

At an elementary level (the physics interface), the equivalence between energy and matter is expressible in the well-known simple manner: $E = mc^2$; or rather $E = c^2m$, exhibiting the fundamental role of the “speed” of light, as a proportionality constant:

$$E^2 = c^2[p^2 + (m_0c)^2].$$

To unify with entropy/information, we include an entropy term, which renders an additional degree of symmetry of the above formula:

$$E^2 + \hbar^2 H^2 = c^2(p^2 + p_0^2). \quad (1)$$

The formula now reflects the *IE-duality* of the Quantum Dot Resolution (QDR), between external and internal DOFs¹⁴.

The further unification of matter-energy and space-time in Einstein’s GR can be suggested by the “simple” formula:

$$\textit{Geometry} \sim \textit{Energy} - \textit{Momentum} : \quad G = \chi T.$$

In a similar way, we simplify our Equation 1 by complexifying the framework, as needed by the many other reason stated above. Introduce the

$$\textit{Complex Energy and Momentum} : \quad \mathcal{E} = E + ik_B TH, \quad \mathcal{P} = p + icm_0,$$

where k_B denotes Boltzmann’s constant. The entropy H , or rather the extensive quantity TH of p.104, is related to a potential function Q ¹⁴, p.78:

$$H(\partial\Gamma) = Q(\Gamma) \quad (TH = dQ),$$

which may be related to the quantum potential of Bohmian mechanics¹⁴, p.192.

Then the above equality of moduli should be the shadow of a complex energy-momentum (tensor) equivalence, which expresses the equivalence between space and time coordinates at the level of the corresponding canonically conjugate variables:

$$\textbf{Generalized Wick Rotation} : \quad \mathcal{E} = \text{ci}\mathcal{P}.$$

It is consistent with Plank quantization $E = h\nu$ and de Broglie wave-particle duality $cp = h\nu$. Moreover, the complex energy-momentum tensor

$$\mathcal{E} = E + iQ, \quad \mathcal{P} = p_e + ip_i$$

provides a unified framework for the energy-momentum flow of external DOFs ($p = p_e$) and quantum information flow of internal DOFs ($p_i = cm_0$).

A detailed implementation is scheduled to appear in 2008²⁶.

4.2 Are black holes prototypical?

Again it is reassuring that the idea of the above unifying Equivalence Principle, in a form hinting towards the relation between space-time and information, is present in the remarkable book²⁰ (p.101): “There is something incomplete about a law which asserts a balance or an exchange between two very dissimilar things.”. Paying too much attention to its “draw backs” is not always a good idea (loc. cit. p.102). Yes, if one would just claim $E = mc^2$, would not be enough ... But again, a theory starts with an idea, a new principle (1% of inspiration), and then one designs the theory top-down (99% of the perspiration - T. A. Edison).

So, Lee Smolin is talking about a balance between “atoms” and “geometry”, which seems to him an unacceptable “mix” within the current theories (true!). But only in gauge theories on *manifolds* (or fixed lattices approximating them), there is a clear cut distinction between external DOF, modeled as a space-time, and internal DOF implementing the type of particle as a representation of a gauge group, to be “married” as a principle bundle etc.. Moreover, a distinction between “atoms” and “geometry” still leads back to an “absolute space-time” point of view.

This is no longer true in a *Feynman-Ionescu Theory* (FPI adapted to *Feynman Processes* as representations of *Feynman Categories* modeling causality and quantum information flow) where an insertion of a new graph should be thought of as “adding geometry” (and also as a change of scale!, i.e. *resolving* additional DOFs in the QDR multi-resolution analysis extending the fixed lattice point of view, e.g. LGT: Lattice Gauge Theory). Then, under the functorial adjunction (IE-duality), new internal DOFs are introduced: quantum information/qubits.

Now my “bet” regarding the two profound questions from²⁰, p.102, is:

(A) Yes, there is an “atomic structure” of the geometry of space-time, i.e. it leads to a better model (see 2), e.g. PROPs or LQG’s “grains of space-time”^{23,24} and also ²¹.

Our unifying *New Equivalence Principle* generalizes in a sense the idea behind Bekstein’s Law. Indeed, in a discrete *Feynman Category* model, “area” corresponds to the number of interactions, which from Unruh’s law, “carry” a certain energy. Roughly speaking a “space-time event” $A \rightarrow B$ has a double role of both *interaction channel* and *information channel*.

B) Yes, the *Digital World Theory*¹⁴ incorporating the theory of information (Shannon, quantum computing etc.) on top of a *Feynman Theory*, will have as natural consequences the black hole radiation laws, but in a different disguise (discrete of finite type).

How to switch from black holes, thought of as “prototypical” when it comes to “global” quantum aspects, to the general case, say in terms of Feynman graphs? It is too soon for “technicalities”! ... at least here, in this essay²⁶.

5 Conclusions

Let us review the main “evolutionary steps” of the fundamental concepts:

| | | | | |
|---|---|--------------------------|--------------------------|----------|
| Newton | Space | Time | Particle xor wave | N.A. |
| Einstein | Space-Time | | Particle xor wave | Observer |
| Heisenberg | Space | Time | Particle/Wave & Observer | |
| Dirac | Space-Time | Particle/Wave & Observer | | |
| Feynman | Path Integral Quantization | | | |
| Math.Ph.-Folklore | Representations of Feynman Categories | | | |
| <i>The DWT v 2.0</i> $\mathcal{E} = ic\mathcal{P}$ | Representations of Causal Structures with IE-duality: <i>Hodge-de Rham Quantum Dot Resolution.</i> | | | |

Here the “extended” *Causal Structure with IE-duality* refers to the incorporation of the concepts of entropy and information processing²², in order to unify the classical interactions “particle-particle” and “particle-observer” modeled by *Quantum Theory* with “observer-observer”, i.e. genuine communications. Besides the symmetry reasons, the author hopes that it would lead to a better understanding of “reality”, for example of the measurement paradox and of the “final frontier”: the *Mind-Matter Interface*.

How to put together all the above “design constraints” in a coherent theory, is another story²⁶. Its interface is *The Virtual Institute*²⁹, intended to stimulate the upbringing of *The Digital World Theory*¹⁴:

Reality is “The Quantum Matrix”!

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