From Quantum Relational Equivalence to Multi-folds Encounter in the Real Universe and Confirmation of the E/G conjecture

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Abstract

A recent popular science article proposed an intriguing model resulting from the combination of a few concepts and papers. The first one showed that exchanging quantum information between Alice and Bob creates reality, in particular 3D space, i.e. 4D spacetime with Lorentz symmetries. The second argues, with non-relativistic Quantum Mechanics (QM), that relational relativity between Quantum Reference Frames (QRFs) implies non-invariance of entanglement, quantum coherence and correlation; a result not aligned with relativistic QM, or multi-fold universes. Finally, the article argues that, as construction of a relative reality occurs by exchanging quantum information, uncertainty will remain between Bob and Alice due to the non-commutativity of spacetime.

Both in conventional relativistic QM, and in our multi-fold theory, entanglement is not relative. Correcting such outcome in the non-relativistic use cases above, and therefore disagreeing with the second paper, hints at multi-folds between entangled systems. Such result provides more consistent QFRs that ensure invariance of entanglement/coherence and correlation. It is a result of conventional Physics, not just multi-fold theory and a new original result.

Multi-fold spacetime is non-commutative, so one can recover the related results of the article. Spacetime can be reconstructed by exchanging quantum information. However, reality is now invariant with a minimum unresolvable uncertainty.

The exchange of quantum information associated with the reconstruction of reality, now invariant, seems to explain the fundamental relationship between spacetime and information theory, via information exchanges, and not just microscopically via entropy as is typically considered. It adds motivation for the activation of multi-fold when systems get locally entangled.

Interestingly the first paper indicates how important non-zero spin systems are to build reality via exchanges of quantum information. In our multi-fold model of the big bang and inflation, and small scales, with random walks of multi-fold massless Higgs particles, non-zero spins do not really exist until the Higgs field condensates into Qballs solitons with a superconducting skins that corresponds to microscopic black holes horizon and models other particles. Beyond fluctuations, this takes place at and after the multi-fold gravity electroweak symmetry breaking. This explains the seamless evolution, through spatial scales, of a discrete spacetime (2D regime) to a 3D then 4D spacetime that becomes from non-commutative to continuous. It is a unique new contribution of the paper and a significant consistency validation for the multi-fold theory.

Encountering multi-fold-like mechanisms in conventional physics is a milestones from the point of view of the multi-fold theory: if the real universe is governed by relational Quantum Physics, then ensuring invariance of entanglement, coherence and correlations, implies multi-fold-like mechanisms for entanglement, as well as something like the W-Type Multi-fold hypothesis. When combined with other results that we obtained recently, respectively encountering entanglement in gravity, when quantizing the Hilbert Einstein action, and no graviton as

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conventional virtual particles non-perturbatively subject to bootstrap and S-matrix, it looks like we have theoretically affirmed the E/G conjecture in our real universe: entanglement generates gravity like effects and gravity results from entanglement. These results are theoretical validations. Quantitative and experimental progress are still needed though.

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1. Introduction

We like to present the original thought process and its evolution from the analysis of a popular science article to a first theoretical encounter of multi-folds within our real universe.

This paper is structured as follows. We first present the outcome proposed by the initial popular science article [2], and the main references it relies on. Accordingly, reality, also identified as spacetime in these related papers, would be built by exchanging quantum information between Alice and Bob [3]. Also, a minimum uncertainty always persists in a non-commutative spacetime, and the constructed reality is not invariant between Alice and Bob, in the sense that quantum notions like entanglement, superposition, coherence or correlations are claimed to not be invariant across QRFs [4,5].

The first two notions are quite intriguing. We discuss their relevance to our multi-fold theory, and the resulting consistency for the multi-fold theory [1,37,*71,72*]. *(Throughout the paper Italic referenced were added on February 20, 2023).*

We object to the later statement (about non invariance of entanglement, or correlation) on the basis that correlation is clearly relational and invariant, as is entanglement, in relativistic QM [7-9,22][2]. Anyway, it is also not at all compatible with our proposed multi-fold mechanisms [1][3]. This leads to a correction to the proposal contained in [4,5] that enables us to conclude that the constructed reality is in fact invariant across QRFs.

Therefore, there is a need to amend the analysis provided in [4,5] to conclude invariance. In that paper, reasonings rely on non-relativistic QM. Such use cases must anyway be supported with the new explanation, that we propose. Doing so introduces new notions of QRFs that ensure invariance. Doing so has immediate implications on spacetime, resulting into the apparition of multi-fold-like mechanisms to support QRFs associated to entangled systems as in [1], and their wave functions extensions to support QRFs associated to systems in superposition, as for the W-type multi-fold hypothesis of [6].

Combining this with recent results that we obtained in terms of entanglement encountered in gravity [10] and the non-conventional aspects of gravitons [11], we deduct that the E/G conjecture [1,12,13] seems to be factual in our real universe, if one agrees that Physics must equivalently hold in any QRF, defined the right way.

2. Reality or spacetime creation across Bob and Alice by exchanging quantum information about non-zero spin systems.

[2] It is to be noted that the authors of [8] are partially overlapping with the authors of [4].
[3] Multi-fold mechanisms were motivated by a realist approach, and emphasized with the W-type multi-fold hypothesis [6], or even our digression on spin in [1,*73*].

[3] allows Alice and Bob to get details about each other quantum system by exchanging information about quantum details from each other's lab. Doing so they can reconstruct an understanding of each other's lab up to a scaling factor ambiguity. In [2,3], doing so to describe systems of non-zero spin implies that the reconstructed reality, or spacetime, is 4D, has Lorentz symmetries, and differs by Lorentz transformations between Alice and Bob.

2.1. Lorentz spacetime reconstruction

It creates a new perspective on spacetime reconstruction, as in [1,14-17,*74*]. A continuous Lorentz spacetime does not really exist in the initial phase till spatial scales are larger enough compared for spacetime to appear commutative, except for the sprinkling over Poisson distribution associated to random walk and inflation of essentially scalar massless particles (Higgs pre-multi-fold gravity electroweak symmetry breaking). As spacetime evolves from a mainly 2D process to a 3D then 4D processes and appear continuous, Lorentz invariance is established, across non-local regions [1,14,19,*75-77*], when stable massless particles with spin appear. Then, multi-fold electroweak symmetry breaking occurs with creation of many bosons and fermions, as result of Higgs condensations into microscopic black holes Qballs, and spacetime orientation [1,14-18,46,47,*75*], and as spacetime evolves from a mainly 2D process to a 3D then 4D processes and appear continuous, common spacetime orientation and Lorentz invariance is established, across non-local regions.

[14,19*,74*] show that related and consistent considerations can also apply to non-multi-fold universes.

2.2 Spacetime, gravity and quantum information

Furthermore the well-known relationships between information, spacetime entropy and gravity is motivated, from an information theory point of view, and not just microscopic and area law / holographic considerations, as in most of [1,47]. Such relationships are well known, and already discussed in a section of [1]. A good example is the black hole information paradox [1,49,*78,79*], or the fact that quantum computing and for example qubits is universal, and, therefore, considered to adequately model quantum gravity [1,20,21].

These points stand in multi-fold, and non-multi-fold theories.

2.3. Spacetime non-commutativity

As multi-fold spacetime reconstruction, as well as many other models, imply a non-commutative spacetime at small scales [1,16,74], the processes described in [3], imply unavoidable residual uncertainties in how reality can be shared from place to place. Many conventional physics models, and others, similarly result in non-commutative geometry. Some are mentioned in [1,16,*73*].

3. Invariance of quantum reality and QRFs equivalences

Inspired by [5] and based on the notions of QFRs introduced in [23,24], [4] concludes that reality (e.g. measures of entanglement in [5]) is not invariant across QRFs, but the sum (average) of such measures might be.

[5] is also not compatible with Einstein weak equivalence principle, at least at microscopic scales. So far, this has never been a too good sign so far in Physics.

In our view, this result is problematic because we know that in relativistic QM, entanglement measures, like the von Neumann entanglement entropy, are Lorentz invariant. Correlations, aka n-point functions, also are, and they are a key tool from QFT, as n-point functions, or n-point interacting Green's functions can completely characterize a field and its complete Green's function [50], just as moments. Granted, some of these models are not always formulated relationally; but that is not the issue. In fact, some of the authors in [4] have also reached the same conclusions as ours in other papers [8,22].

[4,5] rely on:

- Non-relativistic QM
- QFR definitions to be associated to systems in superposition or entanglement that are "unaware" of the states: they are QFR as in [23,24].

The latter point is potentially inconsistent with the reasoning so far, at least as we elaborate it. Indeed, if quantum information defines reality or spacetime, then such reality could or should be affected by entanglement. The violation of the weak equivalence principle can be seen as a clear hint that if reality is understood as spacetime and this kind of violation is encountered it could hint that additional gravity (or entanglement) effects have been missed or mischaracterized. As the multi-fold links entanglement and gravity via the E/G conjecture, which is factual in a multi-fold universe [1,12,13], we are surprised that the weak equivalence principle [51,52], and entanglement simultaneously hit bumps in the papers discussed in this section.

The former point is clearly an issue, but then again, low speed and energy use cases must be supported and non-relativistic QM should be good approximation of the relativistic model, with any additional effect modeled in the theory.

Therefore we will review the QRFs modeled and discussed in [4,5].

3.1 QRFs attached to systems in entanglement or superposition

Let us focus on Figure 3 in [4], and in particular figures 3(c) and 3(d).

3.1.1. Starting from 3(d) in [4]

We start from figure 3(d) in [4]. It is a better way to see the issues and proposed resolution.

The reasoning in figure 3(d) assumes that a QFR associated to A (note as QFR(A)) is clearly located at the position A. Hence the issues and non-invariance of entanglement (EPR) between QRFs associated to C and A. But [23,24] did not discuss these types of use cases. It is not clear at all that the QRF proposed in [4] is adequate.

In fact, if, instead, we want to impose invariance (equivalence) of EPR entanglement, one should state that QFR(A) is in fact entangled with QFR(B), or, at the same time, both. It is denoted QFR(A&$_{EPR}$B). With this notion, C in QRF(A) is at a certain distance of both entangled particles/systems (A and$_{EPR}$ B), which are entangled in this

QFR(A&$_{EPR}$B). The interpretation is immediate: spacetime locations A and B are now behaving as if entangled and QFRs are simultaneously in both positions, and both positions are equivalent. It is consistent with an EPR use cases where equivalent particles are now no longer distinguishable, state wise, when entangled.

Doing so, 3(d) (lower part) in [4] becomes as illustrated in figure 1.

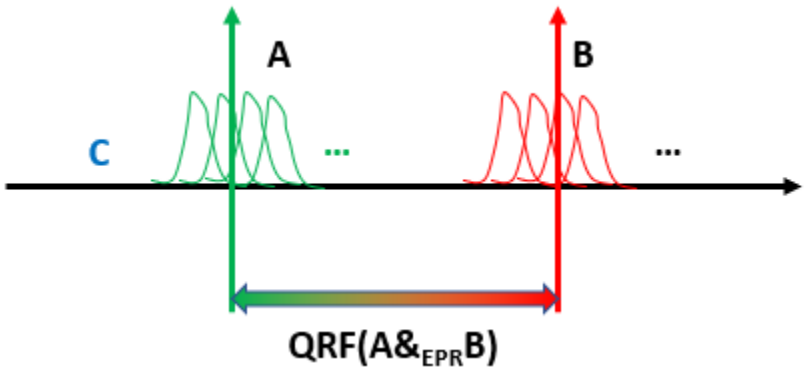

Figure 1: *Evolution of the lower part of Figure 3(d) in [4]. The QFR associated to A or equivalently to B amounts to having spacetime locations A and B exchangeable, which is consistent with the entangled system being undistinguishable (at least for EPR equivalent particles). The arrow amounts to identify the locations A and B.*

Such a QFR amounts to:

- Creating reality (think about the previous sections and spacetime) so that such spacetime location can be identified. How is of course to be defined.
- Multi-fold mechanisms, as in [1], provide a way to implement exactly such a reality. Many variations on the mechanisms, including mappings, could possibly be envisaged, but [1] provides a working one with the correct symmetries that recovers General Relativity (GR) at large enough scales [1,*74*]. You could think that, in figure 1, the bidirectional arrow establishes equivalence between spacetime location A and B as a result of the entanglement at A and B.
- Alternate mechanisms could encompass traversable wormholes[4] as discussed in [1,28,*74,78,80*], albeit equivalence may be slightly delayed though, by the traversal time; so not necessarily perfect.
- Another related idea was published in [27]. It introduce a Planck scale delay in a discrete spacetime.

3.1.2. Figure 3(c) in [4]

With this approach, the lower part of figure 3(c) in [4] can be transformed using the W-type multi-fold hypothesis [6], where the multi-folds now appear between spacetime locations within the wave function support. It can handle A and B as two entangled particles or as coherence in a wave function. The equivalence resolves any potential concerns.

[4] Note that we also know that under the right conditions, traversable wormholes could be a way to implement multifold mechanisms that would then live in an AdS(5), tangent dual to the multi-fold universe spacetime [1], and governed by GR [1,30,31]. This is somehow satisfactory to many, albeit not required by the multi-fold theory.

We leave the new figure 3(c) as exercise for the reader[5]. The reasoning is exactly the same as for figure 1, but includes also connection of spacetime locations in the support of the wave function(s).

Note added on February 20, 2023: The W-type multi-fold hypothesis may also be expanded or understood in terms of the paths in the path integral [81].

3.2. Analysis

Resolving the contradictions of invariant reality, and invariance of entanglement (measures) and coherence/superposition, or simply wave function support in different regions, amounts to suggesting:

- Quantum entanglement modifies spacetime. This encompasses correlations.
- Quantum wave functions modify spacetime. This encompasses coherence, or reasonable superposition.
- Both result in multi-fold mechanisms appearing between entangled particle and the W-type multifold hypothesis within a wave function support.
- Per [1], gravity like effects appear within entangled systems and within wave functions supports.

Also, it is probably worth mentioning that the developed QRFs for quantum systems do not contradict our previous analysis that no gravity or spacetime superposition, as proposed by Diósi and Penrose, is introduced, and so no associated induced wave function collapse as described in [29].

4. The real universe is a multi-fold universe

The original analysis was actually performed in conventional Physics i.e., without multi-fold assumptions, assumed to well, albeit partially, model our real universe.

The conclusion is therefore that:

> **Theorem*:*** *Conventional Physics, if we have a principle of QFR equivalence, i.e., well defined QFRs are equivalent to model reality, and invariance of entanglement, coherence and coherence (measures) across QFRs, implies that the universe that it models is multi-fold as well as with support of the W-type multi-fold hypothesis.*

In other words, the real universe, defined as where we live in, and what physics models, seems to be a multi-fold universe if conventional physics models it well and consistently.

As a result also, half of the E/G principle, factual in multi-fold universes, is now a theoretically verified E/G conjecture in our real universe [1,12,13,33]: entanglement (and wave functions) create gravity-like effects as consequence of [1].

We already proposed ways to validate experimentally this theoretical result by detecting fluctuations in entangled material [1,33] or confirming a dark matter contribution due to entanglement [1,34].

[5] It may be published in the future at [32] if it seems needed.

5. Going for a factual full E/G conjecture

In [10], we showed that quantization of the Hilbert Einstein action uncovers multi-folds-like terms implementing entanglement. That is in the context of Loop Quantum Gravity (LQG), yet not an endorsement of LQG. The LQG approach is mathematically rigorous, even if arguably incomplete [1,26,35,36], and aligned with multi-fold spacetime reconstruction [1,36,*74*], when correcting this way the related LQG challenges discussed in [26,35][6].

As such it is conventional physics, i.e. not multifold based. From that analysis we knew already that the other half of the E/G principle [1,12,13], factual in multi-fold universes, is also true in our real universe if well modeled by conventional physics: gravity involves entanglement.

We therefore have a corollary of the theorem in section 4:

Corollary: *In the real universe, the E/G conjecture is factual, if conventional physics models it well enough.*

It is aligned with [11], that also proved that in the real universe, graviton as conventional scattering non-perturbative particles do not exist. They are rather aligned with multi-fold ideas of quasi particles, attached to entangled real or virtual particles, and that do not follow, non-perturbatively, bootstrap / S-matrix models.

Note added on February 13, 2022: Note that there is an alternate way to confirm that the real universe and GR implies wormhole-like curvature at Planck scales, even if the authors again missed traversability to explain the gravity effect. See [45].

Note added on February 20, 2023: [45] is the base for [74] that further confirms these conclusions by encountering hints of multi-folds in GR, at Planck scales. It strongly suggests that our real universe is multi-fold.

This is further reinforced or consistent with results of the multi-fold theory that could contribute to address many open issues with the SM and the Standard cosmological model (Λ-CDM) [1,10,12,14-19,26,31-34,36-37,39-43,46,47,52,54-69,*71,72,74-76,80,83-95*].

6. Gravity involving or resulting from entanglement?

[1] discusses past work already hinting that gravity (-like effect(s)) results from entanglement. Multi-fold mechanisms showed how it can be modeled with entanglement of virtual particles and anti particle pairs. The model recovers GR at large enough scales [1,*74*]. Accordingly, gravitons are rather quasi particles attached to entangled particles as effects of the multi-folds, and associated attractive effective potential effects in spacetime [1,12,33,53].

Of course we admit that the model might be recovered with other approaches like explicit entangled graviton particles. Here, [1,11,38] help argue that it is not likely.

For example, [11] argued that only superstrings fit a suitable non-perturbative graviton as particle model. Any other consistent theory of quantum gravity implies that such graviton are quasi particles without scattering or non-

[6] Here, we do not claim that LQG is the model of gravity or quantum spacetime, far from that, see [1,10,26,35,36]. We just claim that it is pushing a proven process of quantization of the Hilbert Einstein action, inspired from Dirac quantization of constrained Hamiltonians.

perturbative physicality. Separately, [1,19,31,32,37-44,*77,83,84*] argued challenges to the physicality of superstrings.

On the basis of the unphysicality of superstrings, we argue that a more conventional graviton model does not exist physically, and that the presence of multi-fold-like effects, associated to entanglement, theoretically confirms that gravity derives form entangled virtual particles emitted by a source of energy (mass), as proposed in [1].

7. Non-commutativity

Multi-fold universes are discrete, fractal and non-commutative [1,16,*73,76,77*]. Therefore, the proposal of [2], as hinted in section 1, applies: when exchanging quantum information to build reality across location, there is always inherent uncertainties that can't be eliminated.

At the risk of using some circular arguments, this can be a way to also justify why we encounter the uncertainty principle, also encountered in [1]. After all it is at the core of all Quantum Physics [*81*].

8. From 2D random walk to Multi-fold gravity electroweak symmetry breaking

[1,15-17,*73,76,77*] describe multi-fold spacetime reconstruction as a 2D discrete process of random walk resulting into a 2D then 3D then 4D spacetime, discrete, fractal, non-commutative and Lorentz invariant spacetime. Yet, one knows that even with the Poisson distribution and random sprinkling, at very early stage, Lorentz invariance is an ensemble property.

Interestingly, at very low (spatial) scale or very early on, the random walk were driven by massless Higgs, a scalar particle. It is responsible for the inflation or exponential growth phase, before encountering many other particles during slow roll, and reheating associated first to multi-fold gravity electroweak symmetry breaking [1,14-17]. These early phases, or spatial small scales, also correspond to the UU (Ultimate Unification) [1,38,*75,77,79*]. When scalar dominated, no no-zero spin related quantum information, except for fluctuations that may create temporarily particles with spin, is exchanged from location to location. Therefore, the findings of [3], as discussed and interpreted in section 2, imply that, to a large extent, Lorentz symmetry is not established globally or at least can be perturbed during these phases, until stable massless particles with spin appear. It exist only to the extent that random pairs of particles of higher spin are created and annihilated. Then as time passes or scale increases, energy levels drop, many particles have non-zero spin. As a result spacetime is realized from 2D to 4D and from discrete to continuous fully Lorentz invariant, no longer visible non-commutative.

Combining with [*81*], one can see the entanglement as the driver for interactions between entangled systems, which would also therefore allow creation of spacetime: the multi-folds, that could then also be seen as the dominant paths in a path integral that has spacetime, e.g. massless Higgs, fluctuations; starting from the moment of establishment of the entanglement between locally interacting systems [*81*]. That latter part is required to explain and follow the hierarchical principle of [1]. In other words activation of multi-folds results from the exchange of interactions between the entangled systems just like communications between parties would create Lorentz spacetime.

It is another appealing corroboration of the story told in [1,14-19,38,75,77,79]], and how it really addresses the concerns of many with a discrete spacetime and Lorentz symmetries. All the pieces fall in place to explain the seamless evolution across scales.

9. Conclusions

The paper provides a first theoretical derivation of multi-fold mechanisms and validation of the E/G conjecture in the real universe, on the basis that it would be well modeled by conventional Physics, even if such model may be incomplete. This is a significant result, but it still requires experimental validation as well as acceptance by the community of the equivalence principles as we introduced them to correct the papers that we discussed. For this the best candidates would be to detect gravity like fluctuations within or near entangled systems, especially macroscopic ones, or at cosmological scales with multi-fold dark matter effects. Of course, quantitative progress of the theory would also help a lot. In any case, after such a derivation, the multi-fold theory should probably be considered as an interesting approach.

Besides this groundbreaking result, definitively encouraging, the paper also provides an interesting resolution to the challenges encountered with prior QRF equivalence models: reality, especially entanglement / coherence / correlation measures, remains invariant, as we knew that it had to be, based on relativistic QM. Such a result is not limited to multi-fold universes.

We should also call out the consistency of the resulting multi-fold models with, in particular, the explanation of the information theory link to spacetime / reality, and how discrete, fractal and non-commutative, spacetime from 2D random walks, and particle creation, of massless Higgs can evolve through from Lorentz invariance as a Poisson random sprinkling to a continuous Lorentz symmetric spacetime. To our knowledge, such a result is also a first. It should be considered by all those concerned of incompatibilities between discrete spacetime at very smalls scales (2D random walk regime), and Lorentz symmetry at larger scales, eventually with a continuous 4D spacetime.

The link between Lorentz spacetime and information / interaction exchange provides also motivations for the apparition of multi-folds when two system become locally entangled.

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