Multi-folds for Entanglement and EPR

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Abstract:

This paper clarifies section 4.1 of the original paper on gravity emergence from entanglement, distinguishing between examples and actual expectation for EPR entanglement of isolated EPR entangled particles. In that paper we started from a hypothetical multi-fold universe U_MF, where the propagation of everything is slower or equal to the speed of light and where entanglement extends the set of paths available to Path Integrals. This multifold mechanism enables EPR (Einstein-Podolsky-Rosen) "spooky actions at distance" to result from local interactions in the resulting folds. It produces gravity-like attractive effective potentials in the spacetime, between entangled entities, that are caused by the curvature of the folds. When quantized, multi-folds correspond to gravitons and they are enablers of EPR entanglement. Gravity emerges non-perturbative and covariant from EPR entanglement between virtual particles surrounding an entity. In U_MF, we encounter mechanisms that predict gravity fluctuations when entanglement is present, including in macroscopic entanglements.

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1. Introduction

This paper provides an update to section 1 of the original paper [1] and its V3 update [143,144].

2. Updates to section 4.1: Entanglement and EPR

The following pages are section 4.1 as updated. References and equations numbers refer to [1,143,144]. Reference links are broken as a result.

… See [1,143,144].

4.1 Entanglement and EPR

Considering our initial motivation and intuition, it is logical that we start the discussion with **EPR** and Entanglement in general. Entanglement in quantum physics, is a key phenomenon that distinguishes quantum Physics from classical Physics, and it captures much of the mysteries of the quantum world. It is also the clearest example where Quantum Physics challenges our intuition and unambiguously tells us something about its deep connection to spacetime (e.g. locality or no locality, Lorentz invariance, or not e.g., faster than light signals or not), reality (is the wave function something real, are quantum states real), and the quantum state space (Are Hilbert spaces and variations and spacetime tied together besides configuration space or phase space representing subspaces, are there hidden variable or not-to be suitably phrased post confirmation of the violation of the Bell inequalities) [467, 466].
All that is without even discussing all the promises of Quantum information Theory, Quantum Cryptography and Quantum Computation built on Quantum entanglement. The formalism of entanglement is discussed in detail for example in [27], along with a mathematical model; in particular, in terms of entanglement entropy also known as von Neumann Entropy.
A simplified introduction can be found in [467]. Considerations and relationships with quantum coherence and correlations (which are different concepts and warrant care when sometimes mixing them together in **QFT** and statistical model) can be found for example in [252].
Let us now revisit the relevant aspects of the **EPR** paradox [4, 5, 95]. We use a particle model. We assume a conventional version of the paradox and so the background fold $\mathcal{R}_{BG}$ is flat. Note that it could also be a curved or twisted spacetime without changing much to the explanation of the **EPR** paradox or the use of Path Integrals [77, 96]).

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In **EPR**, two quantum particles are produced and emitted in opposite directions (e.g. to preserve momentum) in entanglement. We say that particles or systems are entangled when their quantum state (e.g. opposite polarization for photons or opposite spin direction for electrons-again imposed by conservation considerations) cannot be described independently of the state of the other(s), even when they are separated by a large distance. In this paper we speak of **EPR** entangled particles when they are such Bell states, i.e., maximally entangled. We are not detailing or reviewing the importance of the Bell inequalities and their experimental violation validations and implications. Some details can be found at [466, 257, 258, 5, 265] as well as some generalization like for example: [466, 259, 196].
In a typical setup of an **EPR** experiment, a system emits two particles of opposite spins or polarizations and we do not know which particle is in what spin or polarization. Bell showed that they are a superposition of both states until one particle is measured [467]. Each particles motion may be described (at least when far enough from each other) by Schrödinger, Klein Gordon or Dirac[42] or other relativistic or non-relativistic equations of motion, for example derived from the Lagrangian that applies to it [77, 322].
The combined wave function (of the two particles) is similarly described by the Path Integral of the wave functions with creation and destruction operators, which is again the **QFT** approach. As explained in [5, 467], we know that observing, later, the quantum state of one of the particles, implies immediately that the corresponding quantum state of the other is fully determined. Hence the paradox: how can this happen as the particles have moved far apart, if the particles states were undetermined until the first measurement? Yet that determination is instantaneous after the local measurement of one of the particles[43].
In the most widely accepted understanding of U_{real}, Bell inequalities demonstrates (or validate) the nonlocality of Quantum Physics in $\mathcal{R}_{BG}$ by showing that Quantum Physics violates them. The resulting Bell Theorem forbids the possibility of "local" hidden-variable theories, i.e. theories which either supplement Quantum Physics with additional variables or new theories: the assumption of a certain kind of locality is a sufficient condition to derive the inequalities, and experiments validated that Quantum Physics violate this inequality [5, 99].
Non-local hidden variables remain possible [467, 466]. The **EPR** and the Bell theorem have been the sources of many controversies on their implications or understanding of measurement experiments. Some have tried to explain non locality in terms of a hidden variable contributed by space-time and showed that it amounts to adding a "quantum potential" to the particle motions [101, 102, 100, 103]. Others have argued entanglement of the measurement system to disprove non-locality (by satisfying Bells inequalities) but moving the problem to the experimental setup or creating many worlds [104] (à la Path Integral) where different states of experimental system exist in different worlds with only one encountered by observation [104, 105]. It is also worth reading on the complex answer to **EPR**, as provided by Bohr [107], and the analysis in [106]. Transactional quantum mechanics does not address, in our view, the **EPR** paradox if measurement occurrence is not predictable, i.e., we do not know that a measurement will take place and which measurement it will be (and of what): nonlocality is still needed.
So, in all these cases, there is still a need for suitable way to convincingly explain **EPR**, unless of course if we just want to shut up and compute without wondering, as suggested by the Copenhagen interpretation. Let us note the analysis [108], that uses the sum of histories with Path Integrals to reproduce the Bell inequalities results and with non-locality captured in all the past histories. Using Path Integral to discuss **EPR** has been done before in U_{real}.
However, we have forbidden supra luminous paths in our multi-fold universe U_{MF}. With no supra luminous interactions, the analysis of [108, 261, 340] is only valid if all considered paths are associated to speed lower than c. This restriction prevents using the model to explain **EPR** entanglement in general when the entangled particles have moved far away from each other.
Considering the above, the experimental corroboration of non-locality and violation by **QM** of Bell's inequalities and the examples like the successful quantum teleportation in U_{real} [109, 110, 466], we accept that quantum Physics indeed appears non-local in $\mathcal{R}_{BG}$.
This paper provides mechanisms to allow **EPR** entanglement and **QM** nonlocality without the paradoxes, and without supra luminosity. The onset of the **EPR** entanglement is considered to be a triggering event at x_0^μ. We propose that corresponding folds $F(for{:}\, x_0^\mu, t)$[44] are activated so that if measurements take place at x_f^μ on one of the two **EPR** entangled particles, the mapped path for the two **EPR** entangled particles can[45] meet at the antipode of the mapping of $x_f^\mu : y_f^\nu$.
Figure 2 illustrates a possible $F(x_0^\mu)$[46] as the surface (i.e., a 2-D space) of a 3-D (Spatial) sphere, outside spacetime and tangential to the momentum axis of the particles. At any time $t \leq f$, the mapping $M(x_t^\mu)$ to the sphere maps the segment $[x_0^\mu, x_t^\mu]$ to the equator going from $x_0^\mu = y_0^\nu$ to $y_0^\nu = M(x_t^\mu)$ so that the motion of the entangled particle can support a grand circle of the sphere of same perimeters as the distance between the particles as they move away. With the hard-partitioned tenancy of one instance per particle, interaction between the two entangled particles is allowed only at $y_t^\nu = M(x_t^\mu)$. As time passes, the folds evolve, and the sphere radius grows as a function of the momentum and time. It also evolves with the center of mass of the two **EPR** entangled particles that it tracks[47]. Note that figure 3 illustrates a center of mass that is not moving as we are in its referential. So $x_0^\mu = x_{CM}^\mu$. The intuitive smoothness of the mapping mentioned before, occurs in the spacetime region between the particles. Smoothness for paths encountering the support domain of the mapping will be discussed below with different possible mapping support domains. The shape, kinematics and dynamics of the proposed folds results directly from the symmetries of the folds as well as the need to ensure that the fold mechanisms ensure that paths meet at y_f^ν, at all time, but not that they become the source of additional new and non-observed physics due to creation or annihilation of particles in the folds with curvature itself changing with time, or disappearance of conserved quantities in the folds.

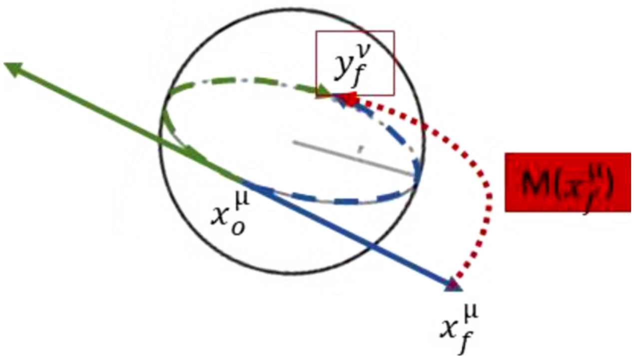

Figure 2: It illustrates a fold $F(\text{for}: x_0^\mu, f)$ at time f for two **EPR** entangled particles. The mapping is also illustrated for the segment $[x_0^\mu, x_f^\mu]$ to the equator going from $x_0^\mu = x_f^\nu$ to $y_f^\nu = M(x_f^\mu)$, for the closest particle (part1). A P-symmetric (i.e., a reflection) mapping exists for the symmetric segments associated to the other particle part2. Any entity meeting $[x_0^\mu, x_f^\mu\ (part\ 1)] \cup [x_0^\mu, x_f^\mu\ (part\ 2)]$ encounters the support domain of the mapping $\mathcal{D}(M)$ (the figure is for $\mathcal{D}_{tear}(M)$. This is one possible fold associated to $x_0^\mu(f)$. As the time, here noted f, changes, the fold also evolves to continue to match this figure: the fold grows proportionally to x_f^μ itself proportional to the elapsed time (if we assume constant momentum for each particle). With hard-partitioned fold instances per particle, interactions between the two entangled particles are allowed only at $y_T^\nu = M(x_t^\mu)$, besides the entry point. The fold grows as the particles move apart.

At any time before observation of one of the entangled quantum states, the Path Integral is therefore a sum of the Path Integral in the main background spacetime[48] plus the Path Integrals on the surface of all the different[49] possible spheres appropriately sized (i.e., to reflect the probability to take paths on any folds in $\mathcal{B}(x^\mu)$ versus on $\mathcal{R}_{BG}$).
With this construction, the two **EPR** entangled particles can always have allowed (and activated) paths that ensure that at t, a path can have $y_t^\nu(part_1) = y_t^\nu(part_2)$; therefore, allowing the wavefunction to communicate through their extensions in $F(for: x_0^\mu, t)$ [50].
Indeed, interaction between particles in the single tenant folds are allowed at that point. This explains how non-locality à la "Bell" occurs in **EPR** without requiring supra luminous communications, beyond what can reasonably be associated to the uncertainty principle. This mechanism achieves our principles and objectives. We postulate that this is what happened in U_{MF} when two particles are **EPR** entangled and we will investigate the consequences.
Let us now compute the contributions of $F(for: x_0^\mu, t)$ to the Path Integral $\mathcal{P}\boldsymbol{I}(\mathcal{S}, \psi)$ for a particle at x_t^μ. At time t, it is provided by the propagation of a particle with a relativistic or non-relativistic particle on the surface of a 3-D sphere with radius r, which is proportional by construction (the mapping) to the (spatial) distance between $x_0^\mu(t)$ and $x_f^\mu(t)$[51].

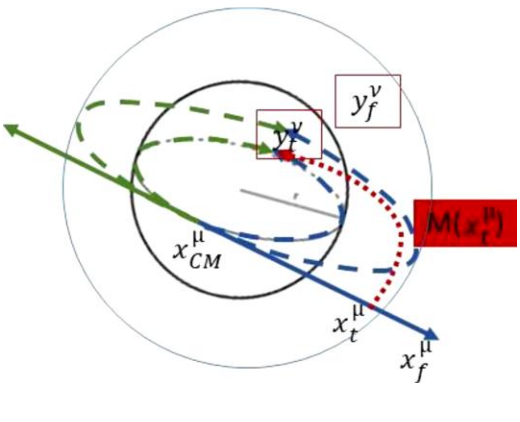

Figure 3: The contribution of $\boldsymbol{\mathcal{P}I}_{\mathcal{B}_{active}(for:\, x_{CM}^\mu, t)}(\boldsymbol{S}, \boldsymbol{\psi})|_{(part\ (t) \in \mathcal{D}(M)}$ may include integration over r. Here, we assume: $\mathcal{D}(M) = [x_{CM(t)}^\mu, x_t^\mu\ (part_1)] \cup [x_{CM(t)}^\mu, x_t^\mu\ (part_2)]$.

As discussed in section 10 of [77], and in [111], the contribution between $y_0^\nu(t)$ and $y_f^\nu(t)$ is in:

$$Int(t) = [x^\mu{}_{CM(t)}, x_t^\mu(part_1)] \cup [x^\mu{}_{CM(t)}, x_t^\mu(part_2)] \tag{6}$$

$$\boldsymbol{\mathcal{P}I}_{F(for: x_{CM}^\mu, t)}(\mathcal{S}, \psi)|_{part(t) \in Int} \propto \frac{1}{r^2} \tag{7}$$

$$\propto R \tag{8}$$

$$\propto m_{part(t)\,\in\,Int(t)} \tag{9}$$

$$\propto \kappa_{EPR}(\boldsymbol{F}(for\colon x_0^{\mu}, t), part(t)_{\in Int(t)}) \tag{10}$$

CM stands for center of mass between the two **EPR** entangled particles. Equation (8) shows that the contribution is proportional to the Ricci Curvature Scalar R of the sphere)[52]. These results hold for Euclidian or Minkowski metrics. We are only interested in the proportionality (and not the exact value) as we do not model in this work how contributions from activated folds are weighted versus the paths in $\mathcal{R}_{BG}$. Computations only involve the propagation Action; no interaction terms as already discussed. In (9), m_{part} designate the mass (or energy converted to mass) of the particle crossing at t the domain support $D(M)$ of the mapping.

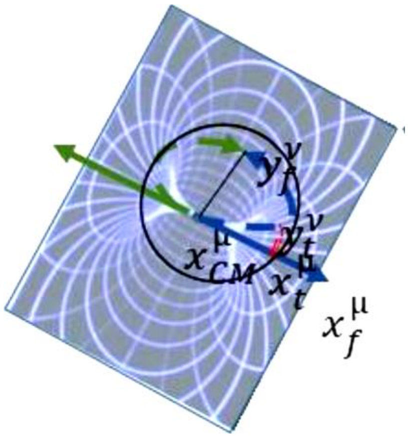

Figure 4: The contribution of $\mathcal{P}\boldsymbol{I}_{\mathcal{B}_{active}(for\colon x_{CM}^{\mu},\ t)}(S,\psi)\mid_{(part\ (t)\in\mathcal{D}(M))}$ includes integration over 2π. The bundles of fold are sets of tori. Here, we assume: $\mathcal{D}(M) = \left[x_{CM(t)}^{\mu}, x_t^{\mu}\ (part_1)\right] \cup \left[x_{CM(t)}^{\mu}, x_t^{\mu}\ (part_2)\right]$.

Here $\kappa_{EPR}(\boldsymbol{F}(for: x_0^\mu, t), part(t)_{\in Int})$ represents the weight that a path of $part(t) \in \left[x_{CM(t)}^\mu, x_t^\mu(part_1)\right] \cup \left[x_{CM(t)}^\mu, x_t^\mu(part_2)\right]$ in $F(for: x_0^\mu, t)$ carries versus a path in $\mathcal{R}_{BG}$which is weighted by $\kappa_{\boldsymbol{\mathcal{R}_{EPR}(BG)}}\kappa_{\boldsymbol{\mathcal{R}_{EPR}(BG)}}$. Physically, it can be viewed as the probability associated to having a contributing path from an activated fold associated to **EPR** entanglement. At this stage, we do not have ways to really quantify $\mathcal{K}_{\boldsymbol{EPR}}(F)$. We assume for the rest of the paper that these coupling constants are constant in $\mathcal{R}_{BG}$ for all entangled particles and folds: $\mathcal{K}_{\boldsymbol{EPR}}(F)$ and $\mathcal{K}_{\boldsymbol{EPR}}(\mathcal{R}_{BG})$.

$\mathcal{K}_{\boldsymbol{EPR}}(F)$ may also depend on a measure of the degree of entanglement (e.g. pure state entanglement vs. partial entanglement) [27].

Such analysis is for future works, but we provide some ideas in section 4.2. For now, we assume only pure state entanglement. Note that we have considered that the support domain of M for each fold is:

$$\mathcal{D}(M) = \mathcal{D}_{tear}(M) = Int(t) \tag{11}$$

This is an arbitrary proposal: without experimental guidance or a more detailed mathematical formalism, there is no way to decide at this stage. So, we just need a stake in the ground. To smooth a bit along the path of particles encountering the support domain we can rely on the uncertainty principle: we know that in this case (11) will be a wider region around the support domain $\mathcal{D}(M)$ defined in the equation (11):

$$\mathcal{D}(M) = \mathcal{D}_{\hbar+tear}(M) = \left[x_{CM(t)}^\mu, x_t^\mu(part_1)\right]^{\backsim\hbar} \cup \left[x_{CM(t)}^\mu, x_t^\mu(part_2)\right]^{\backsim\hbar} \tag{12}$$

In these equations, $\backsim \hbar$ designates the fuzziness that results from the uncertain principles and gives width and smoothness. It is also possible that the mapping extends beyond these regions (e.g. isotropic disk of radius r):

$$\mathcal{D}_{[\hbar]+disk}(M) = \mathcal{D}_{[\hbar]+disk}^{(1)}(M) \cup \mathcal{D}_{[\hbar]+disk}^{(2)}(M) \tag{13}$$

where:

$$\mathcal{D}_{[\hbar]+disk}^{(1)}(M) = disk\left(x_{CM(t)}^\mu, \quad d(x_{CM(t)}^\mu, x_t^\mu(part_1))\right)^{[\backsim\hbar]} \tag{14}$$

$$\mathcal{D}_{[\hbar]+disk}^{(2)}(M) = disk\left(x_{CM(t)}^\mu, \quad d(x_{CM(t)}^\mu, x_t^\mu(part_2))\right)^{[\backsim\hbar]} \tag{15}$$

In these equations, [ ] designates options. The support domain could also just be:

$$\mathcal{D}(M) = \delta\left(x^\mu - x_{part_1}^\mu\right) + \delta\left(x^\mu - x_{part_2}^\mu\right)$$

$$\mathcal{D}_{[\hbar]+\delta}(M) = \left(\delta\left(x^\mu - x_{part_1}^\mu\right) + \delta\left(x^\mu - x_{part_2}^\mu\right)\right)^{[\backsim\hbar]} \tag{16}$$

If all remain active, the sphere as a fold in figure 2, is just one among many possible spheres. The bundle of activated folds $\mathcal{B}_{active}(x^\mu)$ includes all the spheres possible of radius $r' \le r$; a set of torus of small radius $r' \le r$, centered on the axis of the momentum of the two **EPR** entangled particles. It is shown in figure 3. As a result, we have several symmetries; the most important one from the point of a fold is the symmetry by rotation by 180^o for traditional **EPR** pairs. This means a fundamental "spin-2" type of symmetry[53]. The contributions of $\mathcal{B}_{active}\left(x_{CM}^\mu\right)$ to Path Integrals computed for all mapped spheres is therefore in:

$$\mathcal{D}_\alpha(t) = \mathcal{D}(M)\left(x^\mu_{CM(t)}, x^\mu_t(part_1), x^\mu_t(part_2)\right)$$

(17)

$$\mathcal{P}\boldsymbol{I}_{\mathcal{B}_{active}(for:\, x^\mu_{CM},\ t)}(S,\psi)\mid_{part\,(t)\in\mathcal{D}_\alpha(t)} \propto \left(\frac{1}{r}\right)$$

(18)

(by integrating the previous result over r and the 2π azimuth angle). The result can also be seen as:

$$\mathcal{P}\boldsymbol{I}_{\mathcal{B}_{active}(for:\, x^\mu_{CM},\ t)}(S,\psi)\mid_{part\,(t)\,\in\,\mathcal{D}_\alpha(t)} \propto \sqrt{|R|}$$

(19)

This is the result of integrating all the Ricci scalar curvature; which are indeed additive per [363, 364]; something that we will exploit in section 4.8. Otherwise it stays in r^{-2}.
Per the properties of the multi-fold mechanisms, particles stay on a fold; they do not jump from folds to other activated folds in U_{MF}), but follows the evolution (growth) with time within the same fold (no interaction is allowed that would support jumps). If it were not the case, we would no more be on folds with spherical symmetric spacetime of dimension $D = 2$, and, as a result, folds could create new particles [171]; something that does not match observation of **EPR** entanglement, nor address the purpose of the folds. We already know that on a 2-D surface gravity is purely topological without additional degrees of freedom of modifying the curvature and no interaction other than possibly at the entry and exit points. This is the reasoning that we mentioned earlier and that explains why we selected 2-D sphere surfaces for the form of the folds.
The entities affected by these phenomena are those that cross points on the axis between the two **EPR** entangled particles. The effect propagates relative to the center of mass at the speed of each **EPR** entangled particle. As computed in [77, 112], the effect amounts to introduce an anisotropic effective potential in the direction of x^μ_{CM}: (20b) is when only the current sphere is active as fold, which is the typical situation.

$$V_{eff} \propto \frac{1}{r} \qquad (20a), \qquad \text{or} \qquad V_{eff} \propto \frac{1}{r^2} \qquad (20b)$$

The same reasoning is true for non-relativistic and relativistic particles and computing the Path Integrals with Euclidean or Minkowski metrics [77, 112, 113]. Indeed, the apparition of a potential also appears in Klein Gordon (field) equation for Boson in a curved space (see chapter 5 in [345]) and in Dirac's equations for Fermions (see equation 5.23 in [345] is also always satisfied by spinors when taking the second order version of Dirac's equation which is of the form of Klein Gordon equation).
Again, the effective potential is proportional to the Ricci scalar of the sphere (for a fold) or to the square root of it after integration over all the involved folds and it is attractive towards the center of mass as the curvature of each sphere increases the potential on the sphere in ways that favor not moving away from x^μ_{CM} [346], further shows that are no differences of behavior / propagation between Bosons and Fermion in a 3D sphere (only the levels of energy differ due to the different spin statistics).
Other choices of $\mathcal{D}(M)\left(x^\mu_{CM(t)}, x^\mu_t(part_1), x^\mu_t(part_2)\right)$ lead to different V_{eff} .
In fact, $D_{[\hbar]+\delta}(M)$ keeps a $V_{eff} \propto \frac{1}{r^2}$. In all cases, in our multi-fold universe U_{MF} , **EPR** entanglement means that an emerging effective potential V_{eff} is felt by entities with a path in $\mathcal{D}(M)\left(x^\mu_{CM(t)}, x^\mu_t(part_1), x^\mu_t(part_2)\right)$.
It propagates a wave affecting x^μ_t at distances smaller or equal to the distance between $x^\mu_t\big|_{part_1\wedge part_2}$ from x^μ_{CM}, and always smaller that ct. Indeed, the spheres grow in radius at speed smaller than c: they grow at the speed of the **EPR**

entangled particles (with respect to their center of mass): the multi-fold effects are massive waves (unless if the entangled particles are massless and propagate at c, in which case the multi-fold effects are massless).

For $\mathcal{D}_{tear}(M)\left(x^{\mu}_{CM(t)}, x^{\mu}_{t}(part_1),\ x^{\mu}_{t}(part_2)\right)$, a gravity-like potential appears in between the **EPR** entangled particles and attractive towards their center of mass. For $\mathcal{D}_{\delta}(M)\left(x^{\mu}_{CM(t)}, x^{\mu}_{t}(part_1),\ x^{\mu}_{t}(part_2)\right)$, it is simply an attractive shock wave in $(1/r^2)$. The way that the folds follow the center of mass between the two particles may appear surprising: why and how would that happen? It turns out that analyses of **EPR** entanglement in phase spaces [246] show that **EPR** entanglement results into extra Wigner function correlations exactly around the center of mass of the two particles: **EPR** entanglement is a process that involves the center of mass of the entangled particles and there is a deeper relationship between Hilbert space/state space, configuration space and phase space.

When measurement or disentanglement takes place, the folds in $B_{activ}\left(x^{\mu}_{CM}\right)$ are deactivated. It is a deactivation event. It can be seen as if the folds "detach" from a state of being tangent to x^{μ}_{CM} and the mappings M are torn apart as a result.

For $\mathcal{D}_{[\hbar]+\delta}(M)\left(x^{\mu}_{CM(t)}, x^{\mu}_{t}(part_1),\ x^{\mu}_{t}(part_2)\right)$, it just ends being available to paths.

For $\mathcal{D}_{[\hbar]+tear}(M)\left(x^{\mu}_{CM(t)}, x^{\mu}_{t}(part_1),\ x^{\mu}_{t}(part_2)\right)$ a wave propagates back to $x^{\mu}_{CM(f)}$ as the tear of the mapping disappears.

As it is a spacetime change, connected to $\mathcal{R}_{BG}$, it seems logical to speculate that it propagates at c. In any case we avoid the paradoxes of wavefunction collapse with such a fold deactivation mechanism. For an interesting discussion of the relationship between disentanglement and wave function collapse, as well as looking at disentanglement as spontaneous symmetry breaking, see [490]. As fold kinematics and dynamics (and support domains), especially tear down, are pure speculation, it is hard to say more.

But it seems logical that an entity meeting $\mathcal{D}(M)\left(x^{\mu}_{CM(f)}, x^{\mu}_{f}(part_1),\ x^{\mu}_{f}(part_2)\right)$ would still feel an attractive potential towards $x^{\mu}_{CM(f)}$, until the mapping to the fold is deactivated at that point.

In all cases, the fold deactivation seems to indicate an irreversible process or, at least, away from equilibrium: it is not T symmetric. In U_{MF}, disentanglement appears as an irreversible process that violate T symmetry. At this stage, we cannot yet comment on other symmetry violations. We will add considerations throughout the paper as our model description and its analysis evolves. In our view, the fold activation and dynamics are probably also irreversible.

In U_{MF}, fold activation is the enabler of entanglement and its manifestation through the attachment of the folds to the entangled particles implemented by the mapping. The presence of multi-folds implements entanglement. Their deactivation coincides with its termination. So, while entanglement is not observable [87], its impact via V_{eff} (or curvature contributions) is observable and a sign and measure of entanglement. Multi-Folds exist outside $\mathcal{R}_{BG}$ and we cannot observe them either; but again, we measure their effect on $\mathcal{R}_{BG}$ via V_{eff} or the impact on an effective curvature.

Conservation laws and unitarity are preserved for $\mathcal{D}_{\hbar+tear}(M)$ mappings: a path from any entity from any entity crossing $\mathcal{D}(M)$ can return to the entry point and let it be an exit point. Any infinitesimal wave function contribution can exit. The same argument exists for most other mappings: at any time after deactivation: the mapping points from any entity on (M) onto the fold can be met by paths on the fold that can be used to exit. Whatever is the process of deactivation, all conservations and unitarity can be maintained. Of course, in a model where mappings would not behave this way (variations on our proposal for a multi-fold universe U_{MF}), then it could introduce and explain conservation or unitarity[54] violations. In the rest of this paper, we assume a model with $\mathcal{D}_{\hbar+tear}(M)$ mappings (unless when discussing explicitly). This is for consistency with the virtual particle events discussed in section 4.4 and after.

… See [1,143,144].

3. Consistency

Of course, it is consistent with what we had published in [25]. (20) was only an example, but the typical expectation for the effect between isolated EPR entangled particles is (20b).

4. Review of the multi-fold theory, including beyond [1,143,144]

The multi-fold theory was introduced in [1]. Tutorials and overviews can be found at [8-10,22] while the latest developments, updates and discussions can be found at [8].

In a multi-fold universe [1,8-10,22], gravity emerges from entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles [1,24,25], whether they be real or virtual. Long range, massless gravity results from entanglement of massless virtual particles [1,25]. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales [1,26]. It is at the base of the E/G Conjecture [24], and the main characteristics of the multi-fold theory [22]. Multi-folds mechanisms also result in a spacetime that is discrete, with a random walk fractal structure and non-commutative geometry that is Lorentz invariant and where spacetime nodes and particles can be modeled with microscopic black holes [1,4,16,27-31]. All these recover General Relativity (GR) at large scales, and semi-classical model remain valid till smaller scale than usually expected. Gravity can therefore be added to the Standard Model (SM) resulting into what we define as SM_G: the SM with gravity effects non-negligible at its scales. This can contribute to resolving several open issues with the Standard Model without new Physics other than gravity. These considerations hint at an even stronger relationship between gravity and the Standard Model, as finally shown in [23].

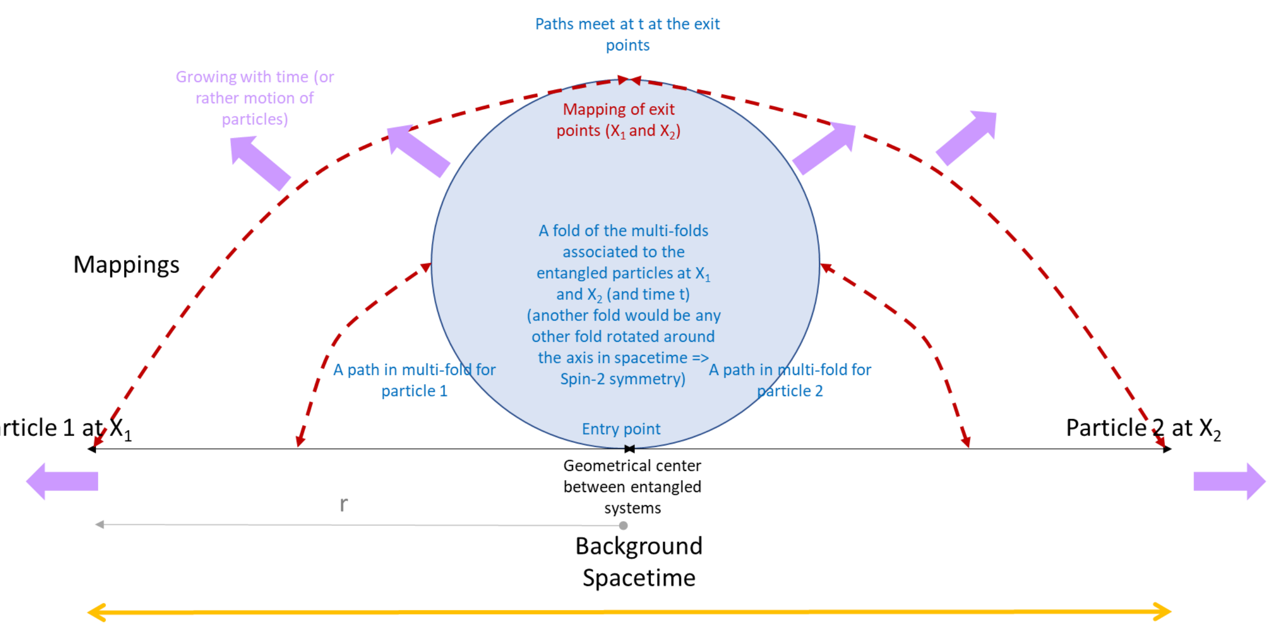

Figure 1 illustrates, in a simplified manner, the multi-folds, multi-fold mechanisms, their kinematics/dynamics and mappings for two entangled particles moving in opposite directions. From ([10])

Note that based on [142], the support domain defined in [1,143], is actually the historical path of the entangled particles, when the evolution is not linear. [1,76] also describe the dynamic effects of multi-folds. Justification of the multi-fold mechanisms and mappings as well as properties like tenancy, hierarchic entanglement and mappings have been presented in [1,8-10,22,23,29,63,86,90,101,136].

Among the multi-fold SM_G discoveries, the apparition of an always-in-flight, and hence non-interacting, right-handed neutrinos, coupled to the Higgs boson is quite notable. It is supposedly always around right-handed neutrinos, due to chirality flips by gravity of the massless Weyl fermions, induced by 7D space time matter induction and scattering models, and hidden behind the Higgs boson or field at the entry points and exit points of the multi-folds. Massless Higgs bosons modeled as minimal microscopic black holes mark concretized spacetime locations. They can condensate into Dirac Kerr-Newman soliton Qballs to produce massive and charged particles [1,4], thereby providing a microscopic explanation for a Higgs driven inflation, the electroweak symmetry breaking, the Higgs mechanism, the mass acquisition and the chirality of fermions and spacetime; all resulting from the multi-fold gravity electroweak symmetry breaking. Massless particle on the other hand result from patterns of the random walks. The multi-fold theory has also concrete implications on New Physics like supersymmetry, superstrings, M-theory and Loop Quantum Gravity (LQG) [1,8-21].

The multi-fold paper [1] proposes contributions to several open problems in physics, like the reconciliation of General Relativity (GR) with Quantum Physics, explaining the origin of gravity proposed as emerging from quantum (EPR- Einstein Podolsky Rosen) entanglement between particles, detailing contributions to dark matter and dark energy, and explaining other Standard Model mysteries without requiring New Physics beyond the Standard Model other than the addition of gravity to the Standard Model Lagrangian [1,4-144]. All this is achieved in a multi-fold universe that may well model our real universe, which remains to be validated.

With the proposed model of [1], spacetime and Physics are modeled from Planck scales to quantum and macroscopic scales, and semi-classical approaches appear valid till very small scales. In [1], it is argued that spacetime is discrete, with a random walk-based fractal structure, fractional and noncommutative at, and above Planck scales (with a 2-D behavior and Lorentz invariance preserved by random walks till the early moments of the universe). Spacetime results from past random walks of particles. Spacetime locations and particles can be modeled as microscopic black holes (Schwarzschild for photons and concretized spacetime coordinates, and metrics between Reissner Nordström [2], and Kerr Newman [3] for massive, and possibly charged, particles – the latter being possibly extremal). Although possibly surprising, this recovers results consistent with others (see [4], and its references), while also being able to justify the initial assumptions of black holes from the models of gravity or entanglement in a multi-fold universe. The resulting gravity model recovers General Relativity at larger scale, as a 4D process, with massless gravity, but also with massive gravity components at very small scales, which make gravity non-negligible at these scales. Semi-classical models also turn out to work well till way smaller scales than usually expected.

Multi-folds are encountered in GR at Planck scales [5,6] and in Quantum Mechanics (QM) if different suitable quantum reference frames (QRFs) are to be equivalent relatively to entangled, coherent or correlated systems [7]. This shows that GR and QM are different facets of something that they cannot well model: multi-folds.

We have also shown the power of 2D random walks as key to understanding much of physics including QFT [1,16,17,31,59,60,63,82,83,101,131,134,142].

Considering results as in [5-7,17,23,58,77,85,90,97,101], and our answers to so many open issues with the SM and the ΛCDM can be qualitatively explained with the SM_G and multi-fold mechanisms, as discussed for example in [1,4-144], we can then argue that these conclusions can probably apply to our real universe, especially considering how the multi-fold mechanisms recover GR [1,6], and can be encountered in GR at Planck scales, with the spacetime reconstruction [1,31], and with the top-down-up-and-upper derivation of the multi-fold theory [6]. At the risk of repeating ourselves, as a result spacetime is, at very scales sales, discrete, generated by random (Levy) walks, and therefore (multi-fractal), non-commutative and yet Lorentz symmetric [1,6,17,30,31,60,63,90,97,101].

5. Conclusions

The update clarifies what was published in [1] (v1 & v2), section 4.1, where the bundle of spheres as fold was presented as an example of dealing with fold bundles and integration over r, but not intended to imply that (20) in [1] v1&v2 would have been the effect (in 1/r) for EPR entanglement between two isolated particles, instead of the effect of a single fold (torus) active at any time (20b), as in this paper and [25].

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