Area Laws Between Multi-Fold Universes and AdS

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Abstract:

In a multi-fold universe, gravity emerges from Entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles that they be real or virtual. Long range, massless gravity results from entanglement of massless virtual particles. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales. Multi-folds mechanisms also result into 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. All these recover General relativity at large scales and semi-classical model remain valid till smaller scale than usually expected. Gravity can therefore be added to the Standard Model. This can contribute to resolving several open issues with the Standard Model.

In this paper, we discuss the area laws encountered in multi-fold universes as well as their implications to AdS tangent to the Multi-fold Universe and recover results from the AdS/CFT correspondence conjecture and associated holographic principles. Multi-fold mechanisms can provide hints of superstrings in AdS(5) (+ additional dimensions), their relationship to gravity and explain a AdS/CFT correspondence or holographic principle. As a result, with multi-fold mechanisms we find physical explanations for the Ryu–Takayanagi conjecture; not as a conjecture but as a fact. Doing so, we will also revisit the related work of Ted Jacobson, on entanglement thermodynamics equilibrium and General Relativity, and apply it to a multi-fold universe.

This analysis reinforces the positioning and understanding of superstrings with respect to multi-fold universes. We believe that it has strong implications for superstrings and M-theory.

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1. Introduction

The new preprint [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. 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 blackholes (Schwarzschild for photons and spacetime coordinates, and metrics between Reisner Nordstrom [2] and Kerr Newman [3] for massive and possibly charged particles – the latter being possibly

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extremal). Although surprising, [1] recovers results consistent with other like [4], while also being able to justify the initial assumptions of black holes from the gravity or entanglement model in a multi-fold universe. The resulting gravity model recovers General Relativity (GR) at larger scale, as a 4-D process, with massless gravity, but also with massive gravity components at very small scale that make gravity significant at these scales. Semi-classical models also turn out to work well till way smaller scales that usually expected.

In this paper, we remain at a high level of discussion of the analysis and references are generic for the subjects. It makes the points accessible to a wider audience and keeps the door open to further papers or discussions devoted to details of interest. Yet, it requires the reader to review [1], as we do not revisit here all the details of the multi-fold mechanisms or reconstruction of spacetime. More targeted references for all the material discussed here are compiled in [1].

2. AdS, Superstrings and Multi-fold Universe

With the multi-fold mechanisms described in [1], we discover that multi-folds can be considered as gravitons, massless and massive [13], in AdS(5) (+ additional dimensions for superstrings / M-theory). The relationship and dualities with multi-fold universes are compiled and summarized in [5,12].

In particular, [1,5] position AdS(5) around each spacetime point of the spacetime in a multi-fold universe; with multi-folds attached to entangled particles (real or virtual) evolving in AdS(5) and their effect reflected, via the mapping mechanisms, in spacetime as attractive effective potential or effective curvature contributions. This version of the (Multi-fold spacetime QFT)/AdS correspondence is a fact and along with multi-fold mappings it gives physical explanations to the holographic principles behind the conventional AdS/CFT correspondence conjecture.

Such analyses [1,5] have significant implications for superstrings, supersymmetries, Grand Unification Theories (GUTs) and Theories of Everything (ToE) [6].

3. Area Laws in Multi-fold Universe

[1] derived area laws and area related laws for multi-fold universe, including:

- Recovery of the Gauss theorem for massless gravity as well as a discussion of the impact for massive gravity or in presence of entanglement.
- Recovery of the Area law for blackholes and causal horizons in multi-fold universe spacetime.
- 2D processes associated to high energy (i.e. Planck scale) gravity processes as fractal random walks.

We will not repeat these analysis here and refer the reader to [1] for more details.

[1] also mentions area laws for entanglement, based on [7], as another hint of the link between gravity and entanglement in conventional physics. It is important as, after all, [1] focuses on showing how gravity emerges from entanglement among real particles (gravity like effects) or among virtual particles (emerging massive and massless gravity). We will provide a simple derivation of the structure of these laws (suitable in multi-fold universes and beyond) and therefore re-motivate ourselves the statements in [1]. Doing so, we will also revisit the work of Jacobson [8,9] in this domain.

[1] does not discuss another key conventional conjecture built on AdS/CFT correspondence conjecture and holography: the Ryu–Takayanagi conjecture [10]. We will do so and physically motivated it as factual in the following sections.

4. Area Laws for Entanglement in the Spacetime of Multi-fold Universe

In this section, we derive in a simple manner the area law (up to the proportionality factor) for entanglement in ways simpler than all the methods cited in [7,8,10].

Consider a field in spacetime. Consider a finite region spatial Σ with a (closed) surface $\partial\Sigma$ in spacetime and a field ψ of correlation length ξ. Consider a discrete spacetime as a lattice of cell minimum spatial dimension a. remember that [1] derives such a discrete spacetime. Let us call L the minimum length characterizing opposite sides of $\partial\Sigma$, V_Σ as volume of Σ and $A_{\partial\Sigma}$ as area of $\partial\Sigma$:

- If a << ξ << L, then the entanglement entropy of S(t, Σ) with respect to the rest of the spatial spacetime (for a given t) is given by: $\mathrm{S}(\mathrm{t},\Sigma) \propto \ln((\frac{\xi}{ka})^{3A_{\partial\Sigma}}) \propto 3A_{\partial\Sigma}\ln\left(\frac{\xi}{ka}\right)$ (1)
  where the proportionality term is independent of the Σ (only dependent on the field properties).
- Otherwise for ξ > L: $\mathrm{S}(\mathrm{t},\Sigma) \propto \ln((\frac{V_\Sigma}{k'a^3})^{A_{\partial\Sigma}}) \propto A_{\partial\Sigma}\ln(A_{\partial\Sigma}) + A_{\partial\Sigma}\,\mathrm{f}(\Sigma) + \cdots$ (2)

This is equivalent to the results in [7] and the analysis used by Jacobson in [8,9], for generic QFT fields, but not just CFTs (Conformant fields).

(1) and (2) simply rely on computing the entropy by enumerating the possible micro states: a region of coherence per surface element, hence (1). When the coherence length is larger than L(Σ), the characteristic dimension of Σ, the number of units in the whole V_Σ is what matters, hence (2).

5. Ryu–Takayanagi Equation in a Multi-fold Universe

We now consider $\partial U\big(MF(\Sigma)\big)$, the surface in AdS(5) wrapping (tangent) to all the multi-folds opposite grand circle to the entry point, i.e. the exit points with the mappings defined in [1]. Then by construction of the multi-fold mechanisms, that surface:

$$A_{\partial U(MF(\Sigma))} \propto A_{\partial\Sigma} \qquad (3)$$

This derivation of (3) is sketched in figure 1.

The field ψ is a QFT, not CFT; so equation (1) or (2) may apply but it remains:

$$\mathrm{S}(\mathrm{t},\Sigma) = c_1 A_{\partial\Sigma} + c_2\, A_{\partial\Sigma}\ln(A_{\partial\Sigma}) + \cdots \qquad (4)$$

Where c_i can be constant or functions of Σ depending on the type and properties of the field.

[10] showed that under the CFT case, with conventional AdS/CFT correspondence, c_1 is a constant and dominates. It matches the value of the entropy of black holes (Bekenstein-Hawking entropy).

As we do not depend on the AdS/CFT correspondence as a conjecture, (3) is factual in multi-fold universes. Also, in our model, gravity is present in the spacetime where entanglement is tracked (not just CFT without gravity).

The multi-fold mechanisms explain physically the choice of the minimal surface in [10], as a scaled version of the further away that the multi-folds, associated to all the possible entanglements within Σ, can reach. Entanglement beyond $\partial\Sigma$, introduces non-negligible additional contributions of the terms beyond the first term in (4).

Also, we know (see [1]) that, when $\partial\Sigma$ defines a causal horizon, the relationship is again involving only the first term in (4). With CFTs, and within the AdS/CFT correspondence conjecture, the Ryu–Takayanagi equation shows that only the first term in (4) is relevant.

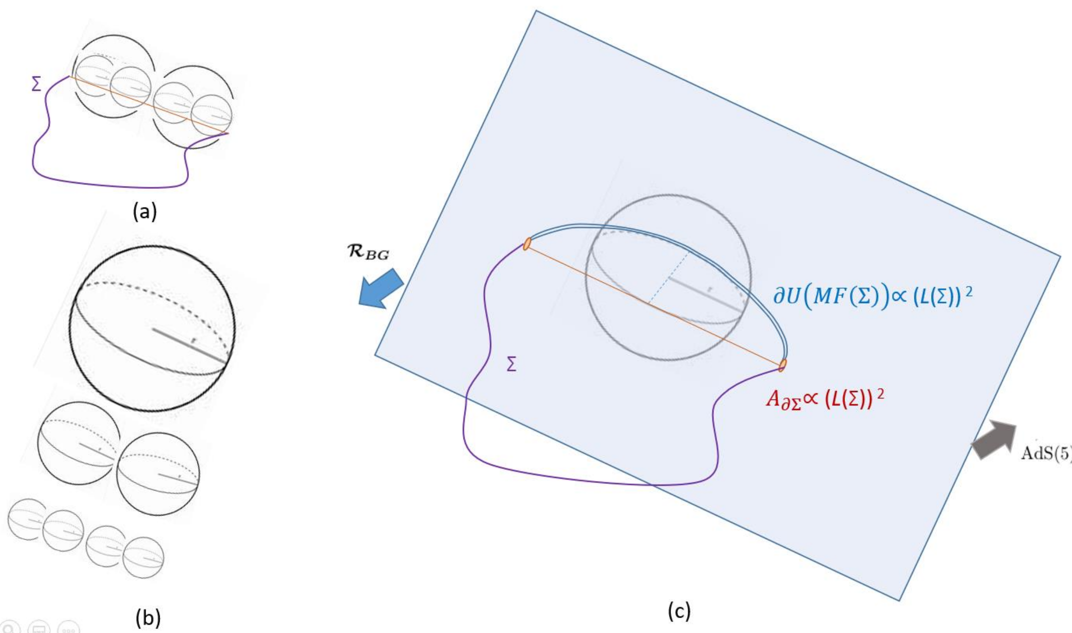

Figure 1: (a) Shows a set of folds, à la [1], for a ray through Σ. (b) explode the view of the folds at each point along the ray. (c) illustrates how the surface build against the opposite point of the grand circle for the largest fold for each point along the ray. It's contribution is depends on the length of the ray as does the contribution if the ray to the area of the boundary of Σ. Areas are compared by considering all the possible rays.

6. Non-holographic Considerations and Entanglement Equilibrium

[9] details holographic inspired models that do not use holography (but are inspired by the AdS/CFT correspondence conjecture) and cite [8] as a key example. Our derivation of (1) and (2) did not consider any holographic principle or inspiration. It was introduced later on to derive (4) and physically explain the results of [10].

Because we consider non-CFT and include gravity, we are in fact aligned with the analysis of [8]. All the reasoning presented in [8] for conventional physics can be repeated here for multi-fold universes.

However, we do want to comment on the derivation of GR. First of all, in [8], ψ is not attempting to model a quantum gravity field. Instead Jacobson relies on semi classical GR. He shows that as equilibrium of the entanglement implies no changes in the entanglement entropy, he recovers the GR equation for the energy of the field (and anything else). It is a powerful and intriguing derivation. Yet it was trivially the case the moment that [8] associated area deficit to the energy content of spacetime: it is an equivalent statements as imposing the Hilbert Einstein action (extremization). Here we show that the derivation is more generic: multi-fold mechanisms imply gravity and recover GR [1] as well as (1)-(4). No entanglement equilibrium is really needed for the derivation.

We also note that the model quantitative model of [8], allows to link directly short scale entanglement (e.g. vacuum) degree to gravity intensity: if much entanglement exist, then gravity is weaker. It makes sense also in a multi-fold universe: as entanglement create attractive potentials towards the center of mass and gravity is the result of entanglement between virtual particles: it is clear that if there is a lot of local entanglement everywhere, it will reduce / combat the gravity effect. It is analogous to some of the vacuum polarization effects to modify the gravity effects that we discussed in [1]. Indeed GR is an global and average effect that can't handle these effects other than by modifying the Newton gravitation that it uses.

6. Conclusions

Our analysis reviews area laws, for multi-fold universes, as defined in [1]. It provides non holographic area law for the entanglement entropy across an arbitrary space surface in spacetime (valid in multi-fold and non multi-fold universe) and it extend the result to a multi-fold equation analogous to the Ryu–Takayanagi conjecture, without the CFT limitation. This reinforces the analogies and dualities with superstring theories and the AdS/CFT correspondence conjecture discussed in [5].

We also showed the alignment with the work of Jacobson on Entanglement equilibrium and GR. Although, unfortunately, in our view, we do not see [8] as a derivation of GR from entanglement (it was derived from the area deficit that implies GR or Hilbert Einstein action), the result also reinforces the agreement with multi-fold approaches: it confirms indirectly and matches what [1] predicted in terms of vacuum polarization as a way to modify the total gravity effect in spacetime; something predicted in [1]. It is an additional validation option à la [11] for our multi-fold predictions.

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