Title: Gravity dual of Polchinski's theorem: forbidden landscape

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Abstract:

Gravity dual of Polchinski's theorem: forbidden landscape

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arxiv:0907.0227

My belief

Holography is one of the fundamental properties of quantum gravity

It is a good strategy to constrain candidates of quantum gravity from holography

Objective

- Show gravity dual of Polchinski's theorem in string/M-theory
- Discuss consistency/constraint of quantum gravity from holography
- String Landscape/ Swampland
  - Bad examples: spontaneous Lorentz symmetry breaking, ghost condensation

Theorem (Polchinski): the scale invariant theory is conformal (in 1+1 dimension)

↕ Gravity dual

Scale inv field configuration →
automatically conformal inv (AdS isometry)

Gravy dual of Polchinski's theorem

Theorem (Polchinski, 1988):
the scale invariant theory is
conformal (in 1+1 dimension)

IF

1. The theory is unitary
2. The theory is Poincare invariant
3. The spectrum is discrete

Scale inv vs conformal inv

- Scale invariance

$$x^\mu \to \lambda x^\mu$$

→ trace of EM tensor is total derivative

$$T^\mu_{\ \mu} = \partial^\mu A_\mu$$

- Special conformal invariance

$$x^\mu \to \frac{x^\mu + a^\mu x^2}{1 + 2a^\mu x_\mu + a^2 x^2}$$

→EM tensor is traceless (or A is total derivative)

$$T^\mu_{\ \mu} = 0 \ , A_\mu = \partial_\mu \lambda$$

Theorem (Polchinski):
the scale invariant theory is conformal (in 1+1 dimension)

Why 2D?

1. Tensor structure is simple
2. C-theorem
3. No counterexample in higher dim

Field theory proof

$$F(x^2) = z^2\langle T(x)T(0)\rangle$$
$$G(x^2) = z^3\bar{z}\langle \Theta(x)T(0)\rangle$$
$$H(x^2) = z^2\bar{z}^2\langle \Theta(x)\Theta(0)\rangle \ .$$

$$T \equiv T_{zz} \ , \quad \Theta \equiv T^{\mu}{}_{\mu}$$

$$\bar{\partial}T + 4\partial\Theta = 0$$

Following Zamolodchikov, we define

$$C = 2(F - \frac{1}{2}G - \frac{3}{16}H)$$

$$\dot{C} \equiv x^2\frac{d}{dx^2}C = -\frac{3}{4}H \leq 0$$ ← C-theorem!

At fixed point $\dot{C} = 0$ so $H = 0$

→ $\langle \Theta(x)\Theta(0)\rangle = 0 \iff \Theta = 0$

Gravity counterpart

Scale inv geometry → conformal inv (AdS)

Consider string/M-theory compactification

$$S_M = -\frac{1}{2\kappa^2}\int d^{11}x\sqrt{-g}\left(R - \frac{1}{2\cdot 4!}|F|^2\right) - \frac{1}{6}\int C_3 \wedge F_4 \wedge F_4$$

The following discussion applies to string theory as well….

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The following discussion applies to string theory as well….

Conjecture

Most general scale inv configuration:

$$ds_{11}^2 = f(\xi)\frac{dz^2}{z^2} + g(\xi)\frac{-dt^2+dx^2}{z^2} + 2h_i(\xi)\frac{dz d\xi^i}{z} + ds_8^2(\xi)$$

$$F_4 = A + \frac{dz}{z}\wedge B + \frac{dt\wedge dx}{z^2}\wedge C + \frac{dz\wedge dx\wedge dt}{z^3}\wedge D$$

$$z \to \lambda z\ ,\quad t\to\lambda t\ ,\quad x\to\lambda x$$

Claim: $f(\xi) = g(\xi)\ ,\quad h_i(\xi) = B = C = 0$

so that it is invariant under

$$\delta x_a = 2(\epsilon^a x_b)x_a - (z^2 + x^b x_b)\epsilon_a\ , \delta z = 2(\epsilon^b x_b)z$$

Proof

We impose gauge condition $h_i(\xi) = f(\xi)\partial_i\Lambda(\xi)$

$$z^2(f^2(\xi)R_{zz} + g^2(\xi)R_{tt}) = D^i J_i(\xi)$$

Null energy (weaker energy) condition

→ $$f^2(\xi)R_{zz} + g^2(\xi)R_{tt} \geq 0$$

Integrate over X_8

→ $$\int f^2(\xi)R_{zz} + g^2(\xi)R_{tt} = \int |B|^2 + |C|^2 = 0$$

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More generally

Nontrivial h gives additional terms:

$$z^2(R_{tt} + R_{zz}) = \tilde{h}_i \tilde{h}^i + (\partial_i \tilde{h}_j - \partial_j \tilde{h}_i)^2 - D^i j_i$$

Null energy condition gives positive definite in LHS…but non-trivial h can compensate.

Effective violation of null-energy condition?

→Most probably EOM for flux + other Einstein equations makes it vanish…

Should be true at least in (1+2) d.

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- Similar evidence can be presented in string theory (or any gravity theory with null/weaker energy condition)
- Does not depend on the dimension

→ Polchinski's theorem was only proved in 1+1 d.

(but no counterexamples…)

- Suggests higher dim generalization?

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Forbidden Landscape

So far so good

Question: is effective field theory consistent as quantum gravity?

Bad examples

- Spontaneous Lorentz breaking
- Ghost condensation

Spontaneous Lorentz Symmetry breaking model

$$\mathcal{L} = F_{\mu\nu}F^{\mu\nu} - \sum_n \frac{g_n}{2n}(A_\mu A^\mu)^n$$

- EOM is solved by AdS_3 and the vector condensation

$$A = A^\mu dx_\mu = a\frac{dz}{z}$$

- EM tensor is proportional to $g_{\mu\nu}$

This solution is bad…

$$A = A^{\mu} dx_{\mu} = a\frac{dz}{z}$$

- Scale invariant but not conformal invariant

$$\delta x_a = 2x_a(\epsilon^b x_b) - (z^2 + x^2)\epsilon_a$$
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So,

spontaneous Lorentz symmetry breaking based on the action

is forbidden

in any consistent quantum theories of gravity

Ghost condensation model

$$\mathcal{L} = \sum \frac{h_n}{2n} (\partial^\mu \phi \partial_\mu \phi)^n$$

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$$\phi = c \log z$$

- $\phi(x) \sim \phi(x) + \Lambda$ so that scale inv is OK
- These scale inv but non-conformal field configurations are forbidden in quantum gravity (in 1+2D)

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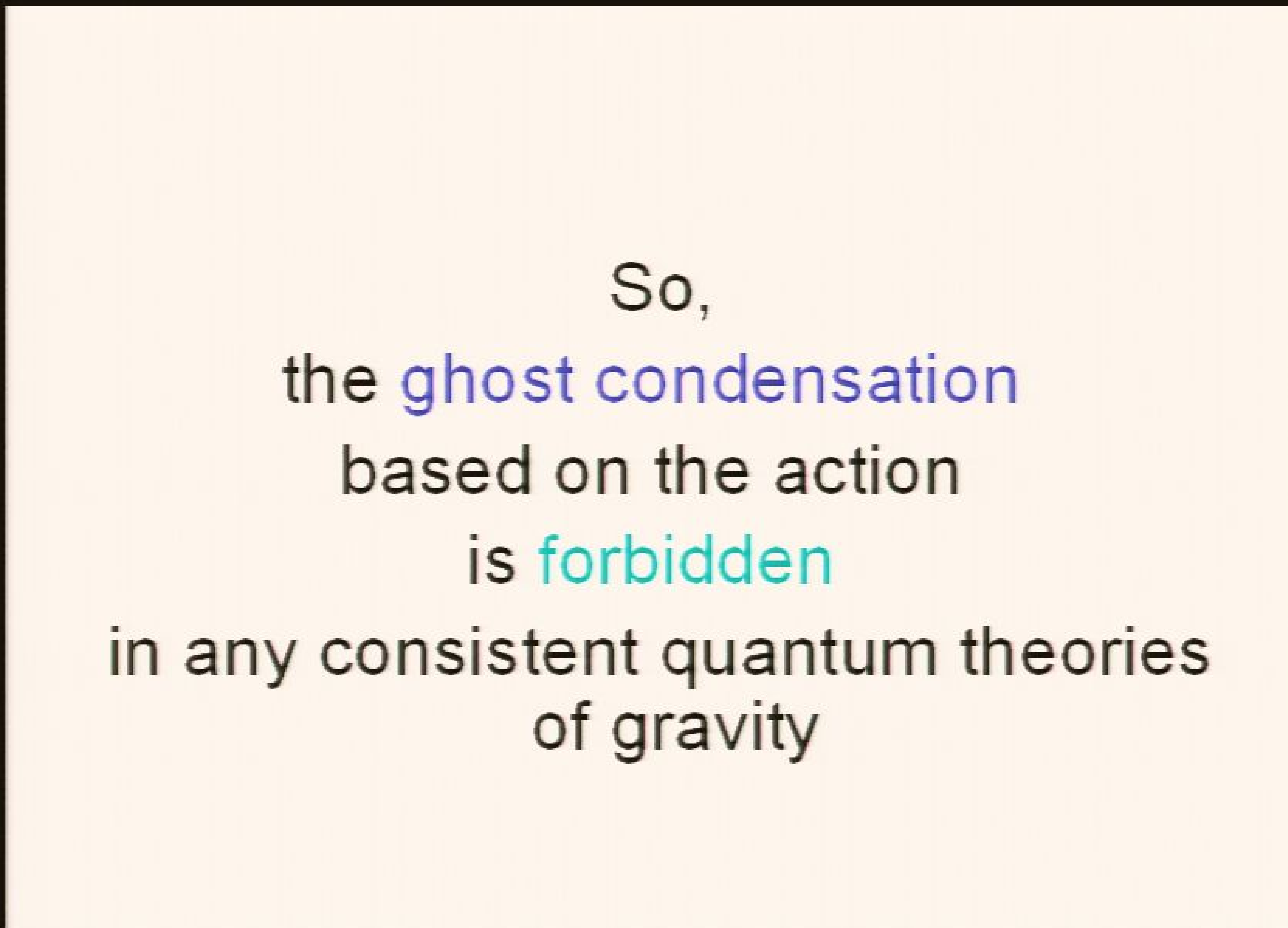
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Higher dimension

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- But Polchinski's theorem is only proved in (1+1) dimension
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Comparison to c-theorem

- Recall the proof of c-theorem and Pochinski's theorem is almost identical in (1+1) dim.
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- Deeper relation between them??
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