Emergent Geometry and String Field Theory

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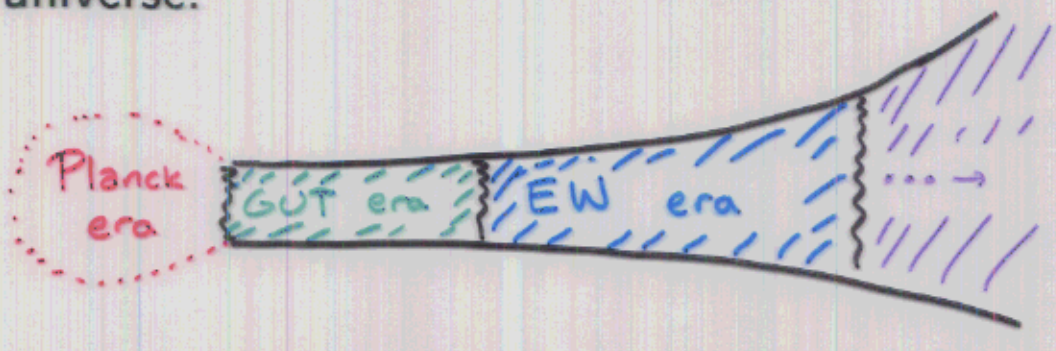
何の木の花とはしらず匂ひ哉

－芭蕉

How should geometry and topology be described in a fundamental theory?

- Early universe:



10^{-43}s 10^{-35}s 10^{-12}s

Planck era: $l < l_p$, geometry and topology undefined

Need a background independent (BI) framework

fundamental DOF $\Longrightarrow$ geometry + topology

"Emergent geometry"

- String landscape (Stanford group, etc.) (+ Bousso-Polchinski, Sethi-Wilczek, Acharya, Trivedi (KKLT), ...)

Need BI framework to describe full landscape, dynamics in terms of one set of DOF.

Background geometry in string theory

Perturbative String Theory

- Fixed space-time background.
- Only perturbative amplitudes between on-shell asymptotic states in fixed backgrounds are computed

M(atrix) Theory & AdS/CFT

- Fixed space-time background.
- Nonperturbative description given by D-brane quantum mechanics/field theory.
- Background DOF encoded in couplings of (nonrenorm.) operators in theory; cannot be changed within framework of quantum theory.
- Example: Background B field $\Longrightarrow$ NCYM

SFT

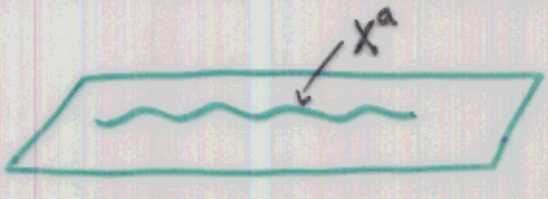
- Background choice (currently) needed to formulate theory.
- Theory is background-independent, but not manifestly.
- At solutions of EOM, DOF can reorganize to those of topologically and geometrically distinct vacua.

[Other approaches: LQG, causal sets, hol. cosmology, Mtx models, ...] { May have emergent geometry but not yet

Emergent brane geometry: examples from brane field theory

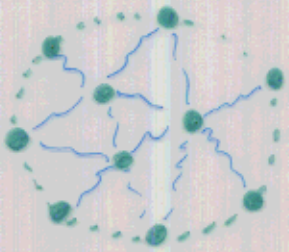
Transverse scalars on Dp-brane

Scalars X^a encode transverse fluctuations (simple geometry)



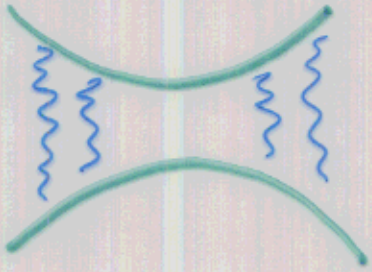
Higher-dimensional branes

Nonabelian X^a can encode D$(p+2n)$-brane matrix geometry



Strings between branes (talk by K. Hashimoto)

Combination of fields F_{0i} and nonabelian X^a can produce strings in space between branes.



Holography

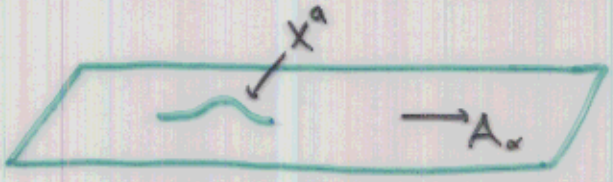
Scale-radius duality

- Generally, emergent geometry subtly encoded in original DOF.

Emergent geometry in String Field Theory

1. Transverse Geometry

(Sen-Zwiebach/Coletti-Sigalov-WT)



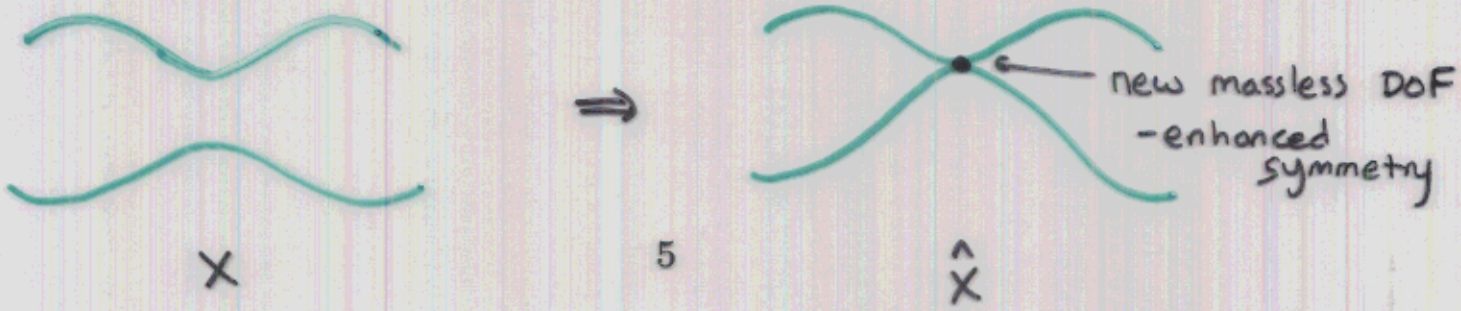
- SFT DOF contains A_α, X^a. BUT: differ from fields in perturbative framework by field redefinition. (a la Ghoshal-Sen, David)
- Sen-Zwiebach: zero-mode X^a only good to $l = \mathcal{O}(l_s)$

Field redefinition:

$$X = \hat{X} + g^2(\gamma \hat{X}^3 + \alpha \hat{X}^2 \partial^2 \hat{X} + \cdots) + \cdots$$

$$\gamma \approx -2.15, \quad \alpha \approx -2.96$$

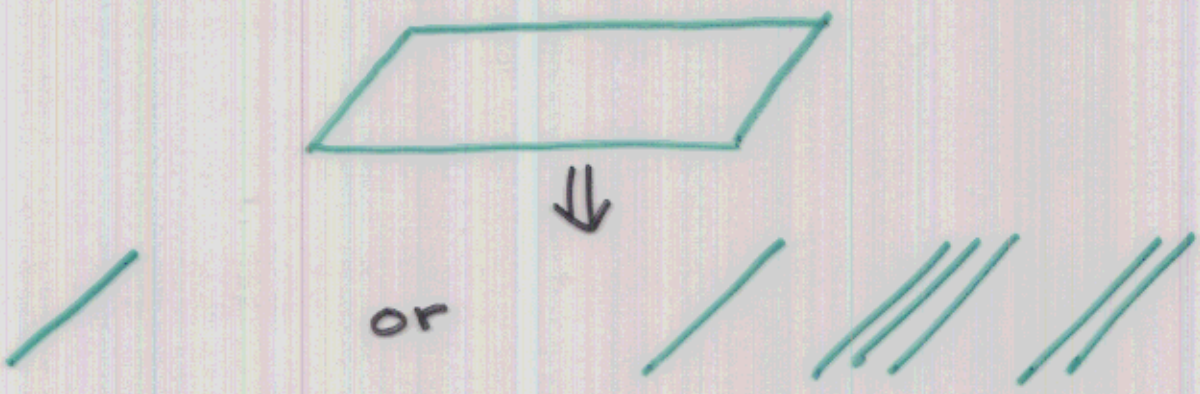
- Action $\Longrightarrow$ (nonabelian) Born-Infeld (including derivative corrections)
- $\hat{X}(X)$ only single-valued to $\mathcal{O}(l_s)$
- Appearance of derivatives obscures transverse locality



2. Lower-dimensional D$(p-k)$-branes

(Sen, Harvey-Kraus, de Mello Koch-Jevicki-Mihailescu-Tatar, Mateos-Sen-Zwiebach ...)

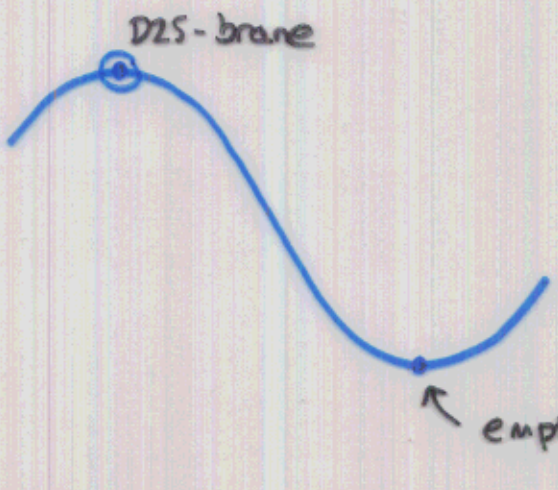
Multiple D$(p-k)$-branes as solutions of Witten's OSFT



$(p+1)$-dimensional U(1) SFT $\Longrightarrow$
$(p-k+1)$-dimensional U(N) SFT

- Original DOF rearrange to form DOF of new theory
- Classical open strings on $(p-k)$-brane emerge as complex composites of original (classical) DOF, localized around solution.
- Many possible vacua with different geometry and topology within a single framework.

3. The empty vacuum (Sen, ...)



- All open string DOF gone in stable vacuum
- Perturbative DOF: closed strings = quantum states in OSFT
- Bosonic quantum theory probably not well-defined.
  (etc., Ellwood-Shelton-WT)
- No known problems going from classical SUSY OSFT to quantum theory, although covariant SUSY OSFT not fully defined.

Multiple vacua from one set of DOF.

Stable vacuum is well-defined, apparently smooth, but:

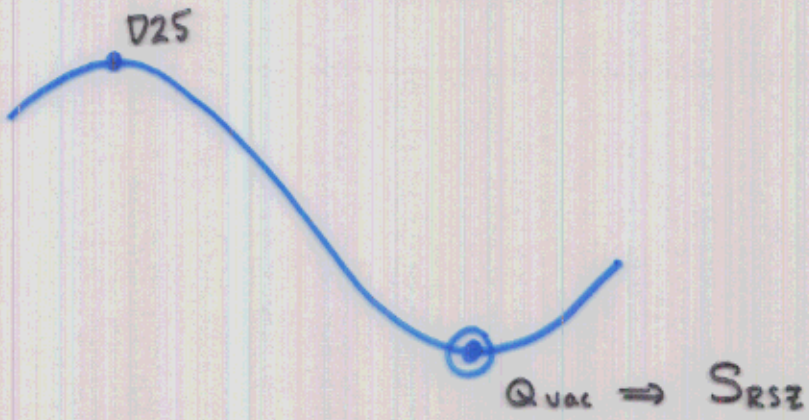
Can't compute analytically

Hard to understand quantum DOF

This is probably a generic situation in BI theories, without new tools.

4. RSZ Vacuum String Field Theory

(Rastelli-Sen-Zwiebach)



"Guess" pure ghost BRST operator Q in stable vacuum

Simpler theory $\Longrightarrow$

analytic solutions for multiple D-branes

(Hata-Kawano, Okawa)

Theory has singularities

But they can be tamed–reproduces D-brane tension (Okawa)

Again, multiple vacua from one set of DOF.

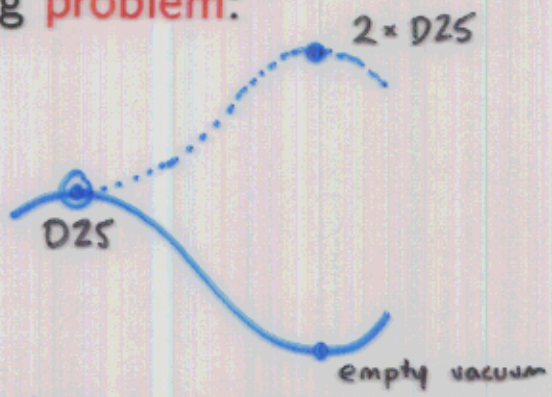
Summary of current situation:

Witten OSFT: Smooth solution, only known numerically

RSZ VSFT: Singular solutions, described analytically.

4. Open problem: multiple Dp-branes in Witten OSFT

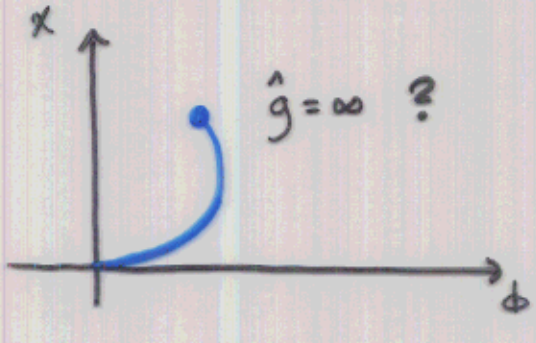
A serious outstanding problem:



Can we find two D25-branes in Witten's U(1) OSFT?

- Needed if theory is truly background invariant
- DOF would reorganize to give enhanced U(2) symmetry
- Not yet found despite some effort (Ellwood-WT)

5. Challenge: M-theory in OSFT/CSFT (?)



Is $g = \infty$ at a finite point in field space after field redefinition in CSFT/quantum OSFT?

Summary

- Witten's OSFT has solutions with different topology and geometry
- Geometry encoded in OSFT DOF in various hidden ways
- Need to generalize picture to include closed string backgrounds

Open questions/problems

- Analytic solution for stable vacuum?
- Find new solutions: $2 \times$ D25, M-theory?
- Develop tools to understand classical and quantum field redefinitions (analogous to NCFT)
- Complete definition of covariant super SFT (Berkovits?)
- Find background-independent description of closed string backgrounds
  - in OSFT?
  - in CSFT?
  - better background-independent theories?