Tachyon condensation in string field theory

Ted Erler

FZU, Prague

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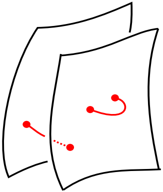
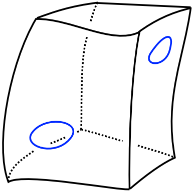
FORTE

What is string field theory?

String field theory is the field theory of fluctuations of a background in string theory.



Open string background (D-branes) $=$ matter+ghost boundary CFT $\longrightarrow$ Open SFT



Closed string background (spacetime) $=$ matter+ghost (bulk) CFT $\longrightarrow$ Closed SFT

The fluctuation field of a string background is a state in the worldsheet conformal field theory representing that background.

Open string on D-25 (bosonic string) :
$$\Psi = \int d^{26}k \Big[\underbrace{T(k)c_1}_{\text{Open string tachyon}} + \underbrace{A_\mu(k)\alpha^\mu_{-1}c_1}_{\text{Gauge field}} + \underbrace{\ \dots\ }_{\text{massive fields w/ higher spin}} \Big] e^{ik\cdot X}|0\rangle$$

Closed string in $D = 26$ Minkowski (bosonic string) :
$$\Phi = \int d^{26}k \Big[\underbrace{T(k)c_1\tilde{c}_1}_{\text{Closed string tachyon}} + \underbrace{h_{\mu\nu}(k)\alpha^\mu_{-1}\tilde{\alpha}^\nu_{-1}c_1\tilde{c}_1}_{\text{metric fluctuation +2-form+dilaton}} + \underbrace{\ \dots\ }_{\text{massive fields w/ higher spin}} \Big] e^{ik\cdot X}|0\rangle$$

What is SFT useful for?

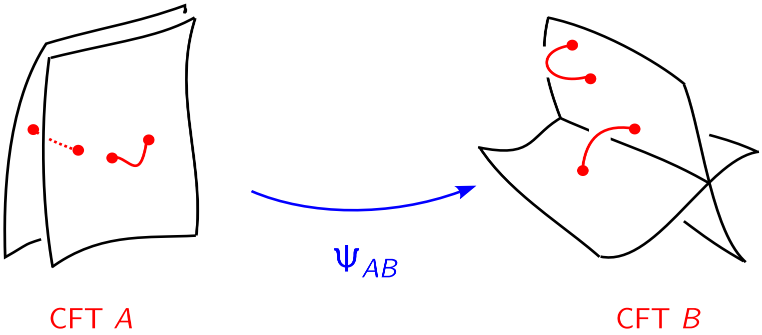
Recent focus:

SFT of a background $\mathcal{B}$ gives a complete and precise definition of perturbative string theory in the background $\mathcal{B}$.

See review segment by X. Yin.

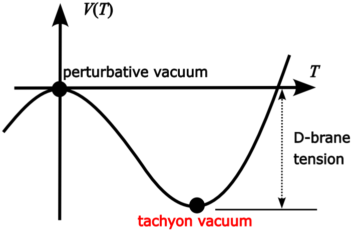
But is SFT useful nonperturbatively?

Most success: Vacuum structure of string theory



Open string tachyon condensation

Sen (1999): D-branes are solitons which emerge out of the open string tachyon condensate.



$\sim \frac{1}{2\pi^2 g^2}$

The open string tachyon has a potential.

There is a local minimum, called the tachyon vacuum.

It is a state where the unstable D-brane is annihilated.

Lower dimensional D-branes appear as “kinks” or “lumps” in this potential.

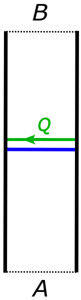
This picture can be made precise using open SFT.

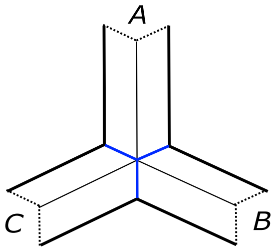
Witten's open bosonic SFT

$$S = \frac{1}{g^2}\left[-\frac{1}{2}\langle\Psi, {\color{green}Q}\Psi\rangle - \frac{1}{3}\langle\Psi, \Psi * \Psi\rangle\right]$$

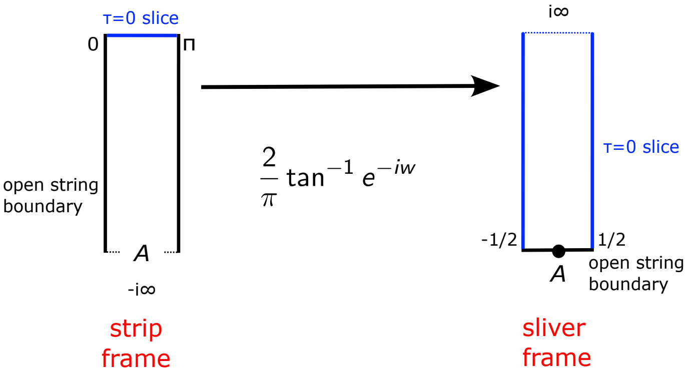
BRST operator

star product

$\langle A, {\color{green}Q}B\rangle =$ 

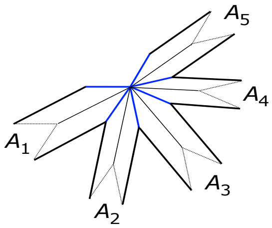
$\langle A, B * C\rangle =$ 

A change of conformal frame:

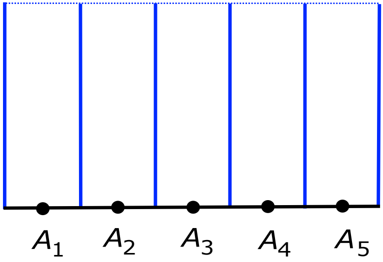


Interchanges open string boundary and $\tau = 0$ slice.

Multiplication is simpler in sliver frame.



strip
frame



sliver
frame

Like lining books on the shelf of a library.

Tachyon condensation and level truncation

Ignore massive fields and write $\Psi = T c_1 |0\rangle$.

Evaluate action $= -$ tachyon potential:

$$V(T) = -S(T) = \frac{1}{g^2}\left[-\frac{1}{2}T^2 + \frac{27\sqrt{3}}{64}T^3\right]$$

Local minumum is first approximation to tachyon vacuum.

Improve with states at higher mass level.

Level truncation.

(Sen & Zwiebach 1999; Moeller & Taylor 2000; Gaiotto & Rastelli 2002; Kishimoto 2011, Kudrna & Schnabl 2018)

In Siegel gauge $b_0\Psi = 0$ tachyon vacuum has been computed out to level 30. (Kudrna & Schnabl 2018)

Some expectation values:

Level	State	Siegel gauge coefficient
Level 0 (tachyon)	$c_1\vert 0\rangle$	0.5405
Level 2	$c_{-1}\vert 0\rangle$	0.2248
	$L^m_{-2}c_1\vert 0\rangle$	0.05721
Level 4	$L^m_{-4}c_1\vert 0\rangle$	-0.005049
	$L^m_{-2}L^m_{-2}c_1\vert 0\rangle$	-0.0006812
	$L^m_{-2}c_{-1}\vert 0\rangle$	-0.008628
	$\vdots$	$\vdots$

Depth of the potential reproduces D-brane tension to better than 99.99 percent accuracy.

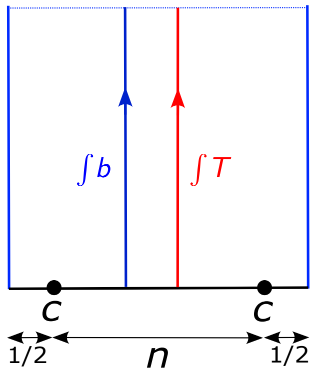
Lower dimensional D-branes may also be constructed by this method
(Moeller, Sen & Zwiebach 2000, Kudrna 2021)

Schnabl's solution (2005)

Schnabl gauge = Siegel gauge in sliver frame

Picture in the sliver frame (Okawa 2006)

tachyon vacuum $= \sum_{n \geq 0}$



$+$ phantom term

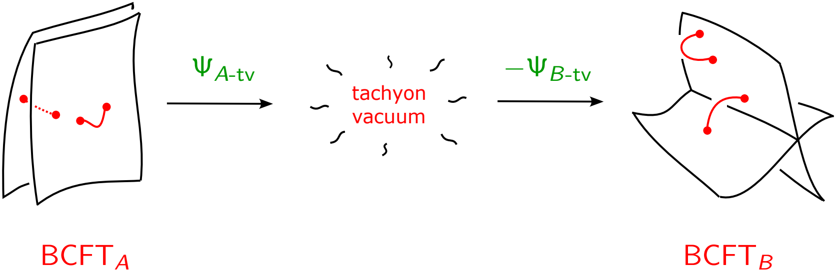
Some expectation values:

Level	State	Siegel gauge coefficient	Schnabl gauge coefficient
Level 0 (tachyon)	$c_1\|0\rangle$	0.5405	0.5535
Level 2	$c_{-1}\|0\rangle$	0.2248	0.4566
	$L^m_{-2}c_1\|0\rangle$	0.05721	0.1376
	$b_{-2}c_0c_1\|0\rangle$	0	-0.1442
Level 4	$L^m_{-4}c_1\|0\rangle$	-0.005049	-0.03028
	$L^m_{-2}L^m_{-2}c_1\|0\rangle$	-0.0006812	0.004581
	$L^m_{-2}c_{-1}\|0\rangle$	-0.008628	0.02275
	$\vdots$	$\vdots$	$\vdots$

Depth of the potential reproduces D-brane tension exactly (Schnabl 2005).

Intertwining solution

(Erler & Maccaferri 2013 & 2019; Kiermaier, Okawa, & Soler 2010; Ellwood 2009)

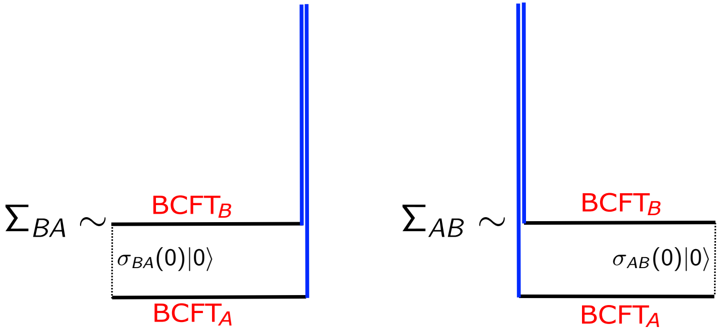


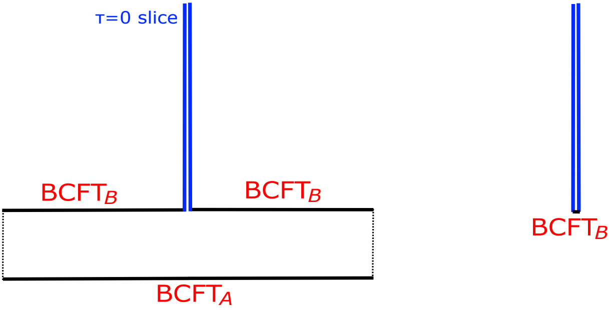
Solution: $\Psi_{AB} = \Psi_{A\text{-tv}} - \Sigma_{AB} * \Psi_{B\text{-tv}} * \Sigma_{BA}$

Intertwining fields

Assumes: $\Sigma_{BA} * \Sigma_{AB} = 1_B$ $\left(\begin{array}{c} *\text{-identity} \\ \text{of D-brane B} \end{array} \right)$

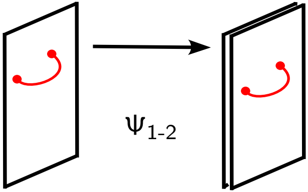
Intertwining fields



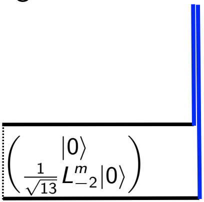


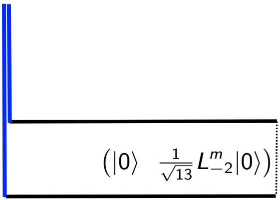
$$\Sigma_{BA} * \Sigma_{AB} \qquad = \qquad 1_B$$

Double D-brane solution



Intertwining fields:

$\Sigma_{2\text{-}1} \sim$ 

$\Sigma_{1\text{-}2} \sim$ 

$$\Sigma_{BA} * \Sigma_{AB} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Chan-Paton factors of the double brane are created!

Background independence

- Open SFT of D-brane A has a solution for any other D-brane B because any pair of D-branes systems always have stretched strings connecting them.

- Moreover, if the fluctuation fields of D-branes A and B are related by
$$\Psi^{(A)} = \Psi_{AB} + \Sigma_{AB}\Psi^{(B)}\Sigma_{BA}$$
their actions are equal
$$S(\Psi_{A\text{-tv}}) + S(\Psi^{(A)}) = S(\Psi_{B\text{-tv}}) + S(\Psi^{(B)})$$

- Further, the intertwining ansatz is gauge invariant. Therefore all solutions of open SFT are intertwining solutions!

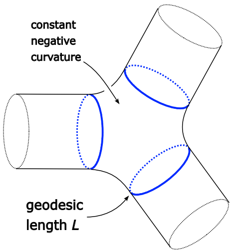
What about closed strings?

The situation is difficult.

- Closed string vertices are hard to compute.
- There are an infinite number of them.
- It is not clear what physics to look for.

Still there has been minor progress.

Closed string vertices



(1) Hyperbolic string vertices
(Pius & Moosavian 2017, Costello & Zwiebach 2019)

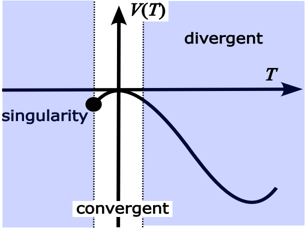
Consistent solution for all vertices
(Costello & Zwiebach 2019)

New analytic results
(Fırat 2021-23)

(2) New algorithms based on machine learning
(Erbin & Fırat 2022)

State of the art: quintic polyhedral vertex
(Moeller 2006)

Dealing with infinite number of vertices



Effective field theory models indicate that the closed string potential has a singularity in the vicinity of the perturbative vacuum. (Erler & Fırat 2023)

Closed SFT has at best finite radius of convergence.

Using Padé resummation, interesting things might be seen after computing vertices computed out to 8th order or higher.

Physics of closed string tachyon condensation.

On a compact target space, dilaton theorem implies that the action vanishes when evaluated on a solution.
(Erler 2022)

On a noncompact background the action might not vanish. However, the dilaton theorem requires that the action must be corrected by boundary terms which have not yet been constructed.

Could some analogue of the intertwining framework be viable for the closed string?

If there is a tachyon vacuum in closed SFT, probably yes.
(Erler, unpublished)

Is there a closed string version of the tachyon vacuum?

Maybe?
(Yang & Zweibach 2005)

Thank you!