The Universal Structure of Propagators in Open Superstring Field Theory

Shingo TORII (Univ. of Tokyo, Komaba)

• JHEP 04(2012)050 [arXiv:1201.1762]

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Background of this talk

An important problem in open String Field Theory (SFT)

• Can we describe closed strings in terms of FIELDS of open strings?

– Can we describe external closed strings in terms of open string fields?

How can we find a clue?

point: the open-closed duality

• It is natural to consider the quantization of open SFT.

– Can open SFT be consistently quantized? Is it anomalous?

A project on gauge fixing (of the WZW-type open SuperSFT)

• `JHEP 03(2012)030 [arXiv:1201.1761]`

Kroyter, Okawa, Schnabl, Zwiebach, S. T.

completed gauge fixing of the NS sector of free open SuperSFT and computed propagators in some gauges.

⇒ However, what type of gauge we should choose depends on what we would like to investigate. There will be no "almighty" gauge.

⇒ It is important to elucidate the universal structure of propagators.

Plan

1. Gauge Fixing of **Free** Bosonic SFT

2. The Structure of Propagators in Bosonic SFT

3. Gauge Fixing of **Free** SuperSFT (NS sector)

4. The Structure of Propagators in SuperSFT

5. Comment

1. Gauge Fixing of Free Bosonic SFT

action: $S_0 = -\frac{1}{2}\langle \Psi_1, Q\Psi_1 \rangle$ [Witten]

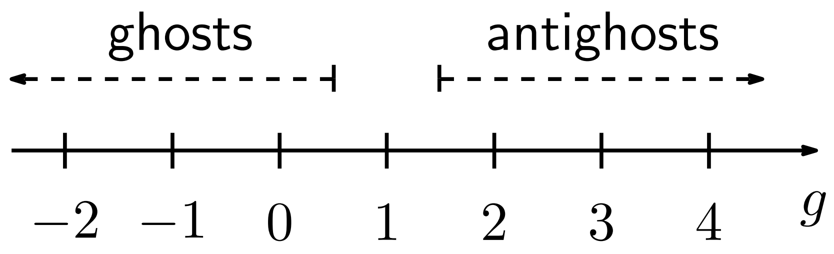
- Q: BRST charge in the 1st quantized theory
- Ψ_g: an open string field of world-sheet ghost number g
- $\langle A, B\rangle$: BPZ inner product of A and B.
- $\langle A, B\rangle = 0$ unless $g(A) + g(B) = 3$.
- gauge transf.: $\delta\Psi_1 = Q\Lambda_0$ $(Q^2 = 0)$

- Gauge fixing requires infinitely many ghosts and antighosts.

- However, we can obtain the gauge-fixed action simply by removing the constraint on the world-sheet ghost number:

$$S_0 = -\frac{1}{2}\langle \Psi_{\mathbf{1}}, Q\Psi_{\mathbf{1}} \rangle \quad \Longrightarrow \quad S = -\frac{1}{2}\langle \Psi, Q\Psi \rangle \ \text{ with constraints.}$$

$$\Psi := \sum_{n=-\infty}^{\infty} \Psi_n = \underbrace{\cdots + \Psi_{-1} + \Psi_0}_{\text{ghosts}} + \Psi_1 + \underbrace{\Psi_2 + \Psi_3 + \cdots}_{\text{antighosts}}$$



$$S = -\frac{1}{2}\langle \Psi, Q\Psi \rangle = -\frac{1}{2}\langle \Psi_1, Q\Psi_1 \rangle - \sum_{g \leq 0} \langle \Psi_{2-g}, Q\Psi_g \rangle$$

Let us consider the gauge $\mathcal{B}\,\Psi_{g(\leq 1)} = 0$, $\mathcal{B} = \sum_n v_n b_n$ (a linear combination of b_n).

- (Space-time) BRST invariance restricts the conditions on the antighosts $\Psi_{g(\geq 2)}$ (and they are automatically determined from the conditions on $\Psi_{g(\leq 1)}$).

2. The Structure of Propagators in Bosonic SFT

gauge-fixed action

$$S = -\frac{1}{2}\langle\Psi_1, Q\Psi_1\rangle - \sum_{g\le 0}\langle\Psi_{2-g}, Q\Psi_g\rangle \quad \text{with} \quad \mathcal{B}\Psi_g = 0.$$

Let us consider the Ψ_g-Ψ_{2-g} propagator Δ_g

$=$ the inverse of Q in the restricted subspace: $\Delta_g Q\Psi_g = \Psi_g$.

$$\Rightarrow \boxed{\Delta_g = \frac{1}{\mathcal{L}}\mathcal{B}}, \quad \mathcal{L} := \{\mathcal{B}, Q\}.$$

key relation $\underline{\frac{1}{\mathcal{L}}\mathcal{B}Q = 1 - \frac{1}{\mathcal{L}}Q\mathcal{B}} \Rightarrow \left(\frac{1}{\mathcal{L}}\mathcal{B}\right)Q\Psi_g = \Psi_g$

generalization

In the g-dependent gauges $\mathcal{B}_{(g)}\Psi_g = 0 \ (g \leq 0)$, we have

$$\boxed{\Delta_g = \frac{\mathcal{B}_{(g)}}{\mathcal{L}_{(g)}} Q \frac{\mathcal{B}_{(g+1)}}{\mathcal{L}_{(g+1)}}} \quad \text{with} \quad \mathcal{L}_{(g)} := \{Q, \mathcal{B}_{(g)}\}\,.$$

$\Rightarrow$ In bosonic SFT, it is manifest How the information about gauge-fixing conditions is reflected in the structure of propagators.

3. Gauge Fixing of Free SuperSFT

action: $S_0 = -\frac{\mathrm{i}}{2}\langle \Phi_{(0,0)}, Q\eta_0 \Phi_{(0,0)} \rangle$ [Berkovits]

$\Phi_{(g,p)}$: NS string field of world-sheet ghost number g and picture p.

- $Q^2 = \eta_0^2 = \{Q, \eta_0\} = 0$.
- formulated in the large Hilbert space.

$\Rightarrow$ $\langle A, B \rangle = 0$ unless $(g(A) + g(B),\ p(A) + p(B)) = (2, -1)$.

- $(g(Q), p(Q)) = (1, 0)$, $(g(\eta), p(\eta)) = (1, -1)$

Gauge Struct. $S_0 = -\frac{i}{2}\langle \Phi_{0,0}, Q\eta_0\Phi_{(0,0)}\rangle$ $(Q^2 = \eta_0^2 = \{Q, \eta_0\} = 0)$

1) $\delta\Phi_{(0,0)} = Q\Lambda_{(-1,0)} + \eta_0\Lambda_{(-1,1)} = \begin{bmatrix} Q & \eta_0 \end{bmatrix} \begin{bmatrix} \Lambda_{(-1,0)} \\ \Lambda_{(-1,1)} \end{bmatrix}$

(gauge transf.)

Gauge Struct. $S_0 = -\frac{\mathrm{i}}{2}\left\langle \Phi_{0,0}, Q\eta_0\Phi_{(0,0)}\right\rangle$ $\left(Q^2 = \eta_0^2 = \{Q, \eta_0\} = 0\right)$

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2) $\delta \begin{bmatrix} \Lambda_{(-1,0)} \\ \Lambda_{(-1,1)} \end{bmatrix} = \begin{bmatrix} Q & \eta_0 & 0 \\ 0 & Q & \eta_0 \end{bmatrix} \begin{bmatrix} \Lambda_{(-2,0)} \\ \Lambda_{(-2,1)} \\ \Lambda_{(-2,2)} \end{bmatrix}$ $\left(\begin{bmatrix} Q & \eta_0 \end{bmatrix} \begin{bmatrix} Q & \eta_0 & 0 \\ 0 & Q & \eta_0 \end{bmatrix} = 0 \right)$

(gauge transf. of gauge transf.)

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3) $\delta \begin{bmatrix} \Lambda_{(-2,0)} \\ \Lambda_{(-2,1)} \\ \Lambda_{(-2,2)} \end{bmatrix} = \begin{bmatrix} Q & \eta_0 & 0 & 0 \\ 0 & Q & \eta_0 & 0 \\ 0 & 0 & Q & \eta_0 \end{bmatrix} \begin{bmatrix} \Lambda_{(-3,0)} \\ \vdots \\ \Lambda_{(-3,3)} \end{bmatrix}$

$\cdots$ What does this mean? $\Rightarrow$ **ghosts, ghosts for ghosts, ...**

It is convenient to introduce the following matrices.

$$\boldsymbol{Q_{n,n+1}} = \underbrace{\begin{bmatrix} Q & \eta_0 & & \text{\Huge 0} \\ & \ddots & \ddots & \\ \text{\Huge 0} & & Q & \eta_0 \end{bmatrix}}_{n+1} \Bigg\} n \,, \quad \boldsymbol{Q_{n,n+1} Q_{n+1,n+2}} = 0. \quad \text{cf.)} \; Q^2 = 0.$$

$$\boldsymbol{\Lambda_{-n}} = \begin{bmatrix} \Lambda_{(-n,\,0)} \\ \vdots \\ \Lambda_{(-n,\,n)} \end{bmatrix} \Bigg\} n+1, \; \boldsymbol{\Phi_{-n}} = \begin{bmatrix} \Phi_{(-n,\,0)} \\ \vdots \\ \Phi_{(-n,\,n)} \end{bmatrix} \Bigg\} n+1, \; \boldsymbol{\Phi_{n+1}} = \begin{bmatrix} \Phi_{(n+1,\,-1)} \\ \vdots \\ \Phi_{(n+1,\,-n)} \end{bmatrix} \Bigg\} n$$

1) $\delta \boldsymbol{\Phi_0} = \boldsymbol{Q_{1,2}} \, \boldsymbol{\Lambda_{-1}}$

2) $\delta \boldsymbol{\Lambda_{-1}} = \boldsymbol{Q_{2,3}} \, \boldsymbol{\Lambda_{-2}}$

3) $\delta \boldsymbol{\Lambda_{-2}} = \boldsymbol{Q_{3,4}} \, \boldsymbol{\Lambda_{-3}}$

$\cdots$

$$\boldsymbol{Q_{n,n+1}} = \underbrace{\begin{bmatrix} Q & \eta_0 & & \text{\Huge 0} \\ & \ddots & \ddots & \\ \text{\Huge 0} & & Q & \eta_0 \end{bmatrix}}_{n+1} \Bigg\} n \,, \quad \boldsymbol{Q_{n,n+1} Q_{n+1,n+2}} = 0. \quad \text{cf.) } Q^2 = 0.$$

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1) $\delta\boldsymbol{\Phi_0} = \boldsymbol{Q_{1,2}}\,\boldsymbol{\Lambda_{-1}} \quad \Rightarrow \quad S_1 = -\left\langle \boldsymbol{\Phi_2}, \boldsymbol{Q_{1,2}\Phi_{-1}} \right\rangle$

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2) $\delta\boldsymbol{\Phi_{-1}} = \boldsymbol{Q_{2,3}}\,\boldsymbol{\Lambda_{-2}} \quad \Rightarrow \quad S_2 = -\left\langle \boldsymbol{\Phi_3}, \boldsymbol{Q_{2,3}\Phi_{-2}} \right\rangle$

3) $\delta\boldsymbol{\Lambda_{-2}} = \boldsymbol{Q_{3,4}}\,\boldsymbol{\Lambda_{-3}}$

$\cdots$

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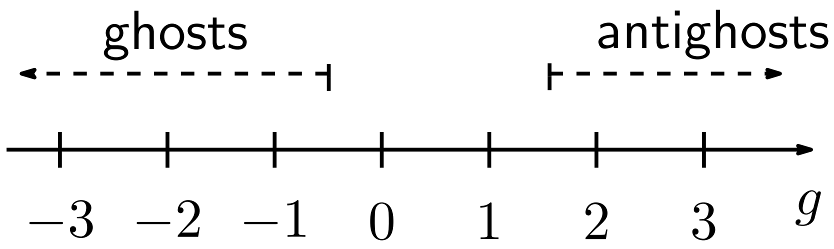
3) $\delta \boldsymbol{\Phi_{-2}} = \boldsymbol{Q_{3,4}}\, \boldsymbol{\Lambda_{-3}} \quad \Rightarrow \quad S_3 = -\langle \boldsymbol{\Phi_4}, \boldsymbol{Q_{3,4}} \boldsymbol{\Phi_{-3}} \rangle$

$\cdots$

$$S = \sum_{n=0}^{\infty} S_n = -\frac{\mathrm{i}}{2}\langle \boldsymbol{\Phi_0}, Q\eta_0 \boldsymbol{\Phi_0}\rangle - \sum_{n=1}^{\infty}\langle \boldsymbol{\Phi_{n+1}}, \boldsymbol{Q_{n,n+1}}\boldsymbol{\Phi_{-n}}\rangle$$



We can consider gauge-fixing conditions of the form

$\boldsymbol{B_{n+2,n+1}}\boldsymbol{\Phi_{-n}} = 0 \quad (n \geq 0)$.

4. The Structure of Propagators in SuperSFT

gauge-fixed action

$$S = -\frac{i}{2}\langle \boldsymbol{\Phi_0}, Q\eta_0\boldsymbol{\Phi_0}\rangle - \sum_{n=1}^{\infty}\langle \boldsymbol{\Phi_{n+1}}, \boldsymbol{Q_{n,n+1}}\boldsymbol{\Phi_{-n}}\rangle\ , \quad \boldsymbol{B_{n+2,n+1}}\boldsymbol{\Phi_{-n}} = 0.$$

- $\boldsymbol{\Phi_{-n}}$-$\boldsymbol{\Phi_{n+1}}$ propagator $\boldsymbol{\Delta_{n+1,n}}$: $\boldsymbol{\Delta_{n+1,n}}\,\boldsymbol{Q_{n,n+1}}\boldsymbol{\Phi_{-n}} = \boldsymbol{\Phi_{-n}}$

key in bosonic SFT

$$\frac{1}{\mathcal{L}}\mathcal{B}Q = 1 - \frac{1}{\mathcal{L}}Q\mathcal{B} \Rightarrow \left(\frac{1}{\mathcal{L}}\mathcal{B}\right)Q\Psi_g = \Psi_g$$

$\Longrightarrow$ In SuperSFT, we would like to find matrices $\boldsymbol{P}$ such that

$\boldsymbol{PBQ} = \boldsymbol{1} + \boldsymbol{MB}$. (Note: $\boldsymbol{\Delta}$ have to satisfy $\boldsymbol{\Delta Q} = \boldsymbol{1} + \boldsymbol{MB}$.)

Correspondence: $\boldsymbol{B} \leftrightarrow \mathcal{B}$, $\boldsymbol{P} \leftrightarrow \frac{1}{\mathcal{L}}$. propagator $\boldsymbol{\Delta} = \boldsymbol{PB}$?

Such $\boldsymbol{P}$ exists indeed:

$$\left(\boldsymbol{P}_{n+1,n+1}\boldsymbol{B}_{n+1,n}\right)\boldsymbol{Q}_{n,n+1} = \mathbf{1}_{n+1} + \boldsymbol{M}_{n+1,n+2}\boldsymbol{B}_{n+2,n+1}\,,$$

$\left(\boldsymbol{P}_{n+1,n+1}\boldsymbol{B}_{n+1,n}\right)$ is the inverse of $\boldsymbol{Q}_{n,n+1}$:

$$\left(\boldsymbol{P}_{n+1,n+1}\boldsymbol{B}_{n+1,n}\right)\boldsymbol{Q}_{n,n+1}\boldsymbol{\Phi}_{-n} = \boldsymbol{\Phi}_{-n}$$

$\Longrightarrow \boldsymbol{\Delta}_{n+1,n} = \boldsymbol{P}_{n+1,n+1}\boldsymbol{B}_{n+1,n}$ cf.) $\Delta_g = \dfrac{1}{\mathcal{L}}\mathcal{B}$

- In general we have

$$\boldsymbol{\Delta}_{n+1,n} = \left(\boldsymbol{P}_{n+1,n+1}\boldsymbol{B}_{n+1,n}\right)\boldsymbol{Q}_{n,n+1}\left(\boldsymbol{P}'_{n+1,n+1}\boldsymbol{B}'_{n+1,n}\right).$$

cf.) $\Delta_g = \dfrac{\mathcal{B}_{(g)}}{\mathcal{L}_{(g)}}\,Q\,\dfrac{\mathcal{B}_{(g+1)}}{\mathcal{L}_{(g+1)}}$

5. Comment

Important Property

$$\boldsymbol{\Delta_{n,n-1} Q_{n-1,n} + Q_{n,n+1} \Delta_{n+1,n} = 1_n} \quad \cdots (*)$$

cf.) $\dfrac{\mathcal{B}}{\mathcal{L}} Q + Q \dfrac{\mathcal{B}}{\mathcal{L}} = 1\,, \quad \Delta_g Q + Q \Delta_{g-1} = 1\,.$

In bosonic SFT, the above relations are crucial for the proof of the gauge independence of on-shell amplitudes. [Asano-Kato]

$\Longrightarrow$ $(*)$ will play the same role in SSFT.

Let's thank the organizers!