D-branes and Closed String Field Theory

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Recent Developments in Strings and Fields
On the occasion of T.Yoneya's 60th birthday
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§1 Introduction

D-branes in string field theory

- D-branes can be realized as soliton solutions in open string field theory

A.Sen,……….
Okawa's talk

- D-branes in closed string field theory?

Hashimoto and Hata

HIKKO

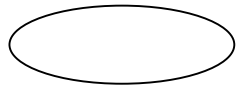
$$I = \Psi K \Psi + g\Psi^3 + \underline{c\langle B|\Psi\rangle}$$

♦A BRS invariant source term
♦c is arbitrary

D-branes in SFT for noncritical strings

SFT for c=0

Kawai and N.I., Jevicki and Rodrigues

String Field $\psi(l) \sim Tre^{lM} \sim$  l

String Field Theory∼Collective Field Theory in MM

$$\text{creation operator} \quad \bar{\psi}(l)$$

$$\text{annihilation operator} \quad \psi(l)$$

Jevicki and Sakita

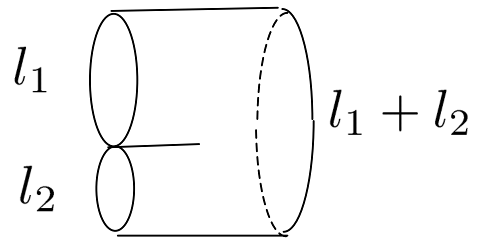
$$[\psi(l), \bar{\psi}(l')] = \delta(l - l')$$

$$\psi(l)|0\rangle = \langle 0|\psi^\dagger(l) = 0$$

t : fictitious time for stochastic quantization

H : Fokker – Planck Hamiltonian

$$H = \int_0^\infty dl_1 \int_0^\infty dl_2 (l_1 + l_2) \psi^\dagger(l_1 + l_2) \psi(l_1) \psi(l_2)$$
$$+ g_s^2 \int_0^\infty dl_1 \int_0^\infty dl_2 l_1 l_2 \psi^\dagger(l_1) \psi^\dagger(l_2) \psi(l_1 + l_2) + \int_0^\infty dl \rho(l) \psi^\dagger(l)$$



joining-splitting interactions

loop amplitudes

$$\langle w(l_1) \cdots w(l_n) \rangle = \langle 0 | \psi(l_1) \cdots \psi(l_n) | \Psi \rangle \quad (|\Psi\rangle = \lim_{t \to \infty} e^{-tH} |0\rangle)$$

Virasoro constraints FKN, DVV

$$T(l)|\Psi\rangle = 0$$

$$T(l) = \int_0^l dl' \psi(l') \psi(l - l') + g_s^2 \int_0^\infty dl' l' \bar{\psi}(l') \psi(l + l') + \rho(l)$$

Solitonic operators

Fukuma and Yahikozawa
Hanada, Hayakawa, Kawai, Kuroki, Matsuo, Tada and N.I.

$\int d\zeta \mathcal{V}_{\pm}(\zeta)$

$$\mathcal{V}_{\pm}(\zeta) = \exp\left(\pm g_s \int_0^{\infty} dl e^{-\zeta l} \bar{\psi}(l)\right) \exp\left(\mp \frac{2}{g_s} \int_0^{\infty} \frac{dl}{l} e^{\zeta l} \psi(l)\right)$$

$$[T(l), \mathcal{V}_{\pm}(\zeta)] = \partial_{\zeta}(\cdot) \longrightarrow T(l) \underline{\int d\zeta \mathcal{V}_{\pm}(\zeta)|\Psi\rangle} = 0$$

state with D(-1)-brane
ghost D-brane

these solitonic operators reproduce amplitudes with ZZ-branes

c.f.

$$\begin{aligned} T &\sim -\frac{1}{2}(\partial\varphi(\zeta))^2 \\ \mathcal{V}_{\pm}(\zeta) &\sim\ :e^{\pm\sqrt{2}i\varphi(\zeta)}: \end{aligned}$$

♦Can one construct such solitonic operators in SFT for critical strings?

↓

Similar construction is possible for OSp invariant string field theory

Plan of the talk

§2 OSp invariant string field theory

§3 Idempotency equation

§4 Solitonic states

§5 Conclusion and discussion

§2 OSp invariant string field theory

light-cone gauge SFT (t, α, X^i) $(t = x^+,\ \alpha = 2p^+,\ i = 1, \cdots, 24)$

$$I = \int dt \left[\frac{1}{2} \int \langle \Phi | \left(i \frac{\partial}{\partial t} - H \right) | \Phi \rangle + \frac{2g}{3} \int \langle V_3(1,2,3) | \Phi \rangle_1 | \Phi \rangle_2 | \Phi \rangle_3 \right]$$

O(25,1) symmetry

↓

OSp invariant SFT =light−cone SFT with $(t, \alpha, X^i, X^{25}, X^{26}, C, \bar{C})$

Grassmann

Siegel, Uehara, Neveu, West,
Zwiebach, Kugo, ….

OSp(27,1|2) symmetry

$$X^{25}, X^{26}, C, \bar{C} \to c = 0$$

OSp theory ∽ covariant string theory with extra time and length

$$(t, \alpha, X^i, X^{25}, X^{26}, C, \bar{C}) \sim (t, \alpha, X^\mu, b, c, \tilde{b}, \tilde{c}) \qquad (\mu = 1, 2, \cdots, 26)$$

$$C(\tau,\sigma) = C_0 + 2i\pi_0\tau - i\sum_{n\neq 0}\frac{1}{n}\left(\gamma_n e^{-n(\tau+i\sigma)} + \tilde{\gamma}_n e^{-n(\tau-i\sigma)}\right)$$
$$\bar{C}(\tau,\sigma) = \bar{C}_0 - 2i\bar{\pi}_0\tau + i\sum_{n\neq 0}\frac{1}{n}\left(\bar{\gamma}_n e^{-n(\tau+i\sigma)} + \tilde{\bar{\gamma}}_n e^{-n(\tau-i\sigma)}\right)$$

$$\gamma_n = in\alpha c_n, \ \bar{\gamma}_n = \frac{1}{\alpha} b_n, \ \text{etc.}$$

BRS symmetry

$$\text{BRS transformation} \sim J^{C-} \in OSp$$

$$\delta_{\rm B}\Phi = M^{C-}\Phi + g\Phi * \Phi$$

$$M^{C-} \sim Q_{\rm B}^{st} - i\pi_0(\partial_\alpha + \frac{1}{\alpha})$$

the string field Hamiltonian is BRS exact

OSp theory $\backsim$ Parisi-Sourlas, stochastic quantization
Marinari-Parisi for c=0

Green's functions of BRS invariant observables = Green's functions in 26D

$\langle \mathcal{O}_1 \cdots \mathcal{O}_n \rangle$

↓

S-matrix elements in 26D

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S-matrix elements derived from the light-cone gauge SFT

<u>different from the usual formulation, but</u>

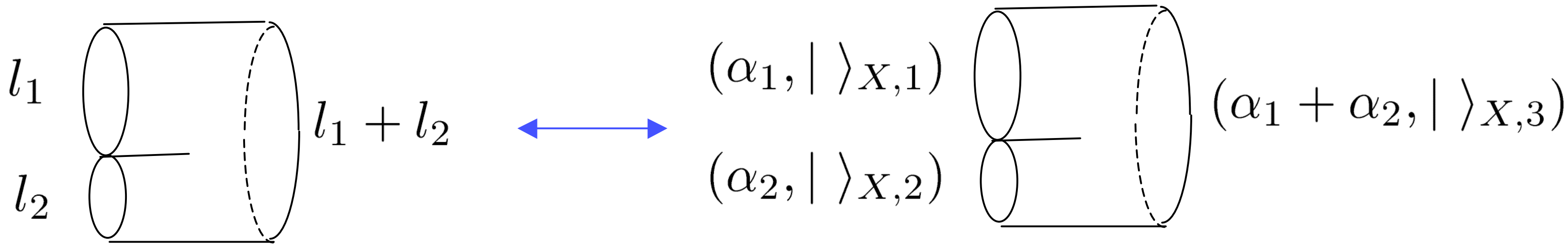
- string length
- joining-splitting interaction
- extra time variable

etc.

⟶ similar to noncritical SFT

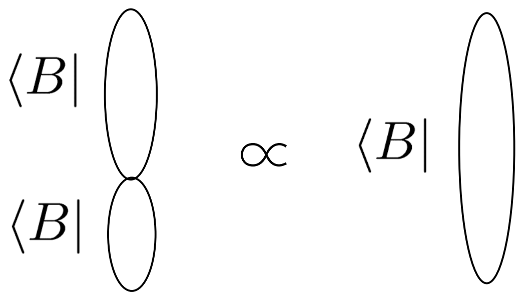
Can we construct solitonic operators?

§3 Idempotency equation



we need to consider boundary states

idempotency equation

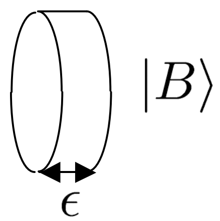


$$\langle V_3 | B \rangle | B \rangle \propto \frac{1}{\epsilon^\gamma} | B \rangle$$

Kishimoto, Matsuo, Watanabe

- regularization

$$|B\rangle \to e^{-\epsilon H} |B\rangle$$



Boundary states in OSp theory

$|B(l)\rangle$ the boundary state for a flat Dp-brane

$$P^\mu(\sigma)|B(l)\rangle = X^i(\sigma)|B(l)\rangle = C(\sigma)|B(l)\rangle = \bar{C}(\sigma)|B(l)\rangle = 0$$

$$\alpha|B(l)\rangle = l|B(l)\rangle$$

- BRS invariant regularization

$$|B(l)\rangle \rightarrow |B(l)\rangle^\epsilon = e^{-\frac{\epsilon}{|\alpha|}(L_0+\tilde{L}_0-2)}|B(l)\rangle$$

$$^\epsilon\langle B(l)|B(l')\rangle^\epsilon \sim l'\delta(l+l')e^{\frac{\pi^2}{\epsilon}|l|} \quad (\epsilon \sim 0)$$

- normalized state:

$$|n(l)\rangle = |B(l)\rangle^\epsilon \, e^{-\frac{\pi^2}{2\epsilon}|l|}$$

$$|\Phi\rangle = \int_0^\infty dl \left[|n(l)\rangle\, \phi(l) + |n(-l)\rangle\, \bar{\phi}(l) + \underline{\cdots} \right]$$

orthogonal to $|n(l)\rangle$

light-cone quantization

$$[\phi(l), \bar{\phi}(l')] = \frac{1}{l}\delta(l-l')$$

$$(\phi(l))^\dagger = \bar{\phi}(l)$$

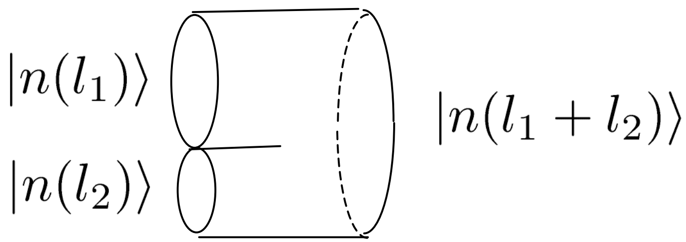
$$\phi(l)|0\rangle\rangle = \langle\langle 0|\bar{\phi}(l) = 0 \qquad |0\rangle\rangle \text{ : vacuum}$$

this part of the theory looks quite similar to SFT for c=0

$$\frac{1}{l}\psi(l) \quad \sim \quad \phi(l)$$

$$\psi^\dagger(l) \quad \sim \quad \bar{\phi}(l)$$

Virasoro constraints $\sim$ BRS invariance



we may be able to construct solitonic operators

§4 Solitonic states

$$|D\rangle\rangle \equiv \int d\zeta\, \mathcal{V}(\zeta)|0\rangle\rangle$$ BRS invariant state

$$\mathcal{V}_\pm(\zeta) = \lambda \exp\left[\underline{\pm\sqrt{2}} \int_0^\infty dl\ e^{-\zeta l}\bar{\phi}(l)\right] \exp\left[\underline{\mp\sqrt{2}} \int_0^\infty dl'\, e^{\zeta l'}\phi(l')\right] e^{\pm\frac{C\epsilon^2}{\sqrt{2}g}\left(\zeta+\frac{\pi^2}{2\epsilon}\right)^2}$$

these coefficients are fixed by BRS invariance

$$\begin{aligned} \delta_\mathrm{B}|D\rangle\rangle &= \int d\zeta \delta_\mathrm{B}\mathcal{V}(\zeta)|0\rangle\rangle \\ &= \int d\zeta \partial_\zeta(\cdot)|0\rangle\rangle \\ &= 0 \end{aligned}$$

more generally

$$\left(\int d\zeta \mathcal{V}(\zeta)\right)^n|0\rangle\rangle$$ BRS invariant

amplitudes

$$\langle \mathcal{O}_1 \cdots \mathcal{O}_n \rangle = \langle\!\langle 0 | T \mathcal{O}_1 \cdots \mathcal{O}_n | 0 \rangle\!\rangle \longrightarrow$$ S-matrix elements

with D-branes $|0\rangle\!\rangle \to |D\rangle\!\rangle = \int d\zeta \, \mathcal{V}(\zeta) |0\rangle\!\rangle$

vacuum amplitude

$$\lim_{T\to\infty} \langle\!\langle D | e^{-iT\hat{H}} | D \rangle\!\rangle$$

perturbative calculation

$$\int d\zeta \mathcal{V}_\pm(\zeta) = \lambda \int d\zeta e^{\pm\sqrt{2}\int_0^\infty dl \; e^{-\zeta l}\bar{\phi}(l)} e^{\mp\sqrt{2}\int_0^\infty dl' \; e^{\zeta l'}\phi(l')} e^{\pm\frac{C\epsilon^2}{\sqrt{2}g}\left(\zeta + \frac{\pi^2}{2\epsilon}\right)^2}$$

saddle point approximation $\zeta = -\frac{\pi^2}{2\epsilon}$

$$|n(l)\rangle \, e^{-\frac{\pi^2}{2\epsilon}|l|} \to |B(l)\rangle^\epsilon$$

$$\langle\langle D|e^{-iT\hat{H}}|D\rangle\rangle \sim \exp[2^2 \times \text{cylinder amplitude for 1 D} - \text{brane}]$$

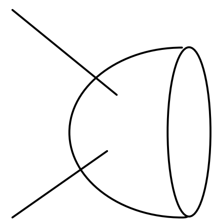
$|D\rangle\rangle$ should be identified with the state with two D-branes or ghost D-branes

(Okuda, Takayanagi)

- no T dependence
- $\zeta \sim$ constant open string tachyon background

$$e^{-\zeta l}|B\rangle$$

- disk amplitude



$$\mathcal{V}_+ \quad \rightarrow \quad \text{D} - \text{branes}$$

$$\mathcal{V}_- \quad \rightarrow \quad \text{ghost D} - \text{branes}$$

Baba, Murakami, N.I.
to appear

§5 Conclusion and discussion

♦D-brane ⟷ BRS invariant state in OSp invariant SFT

♦other amplitudes

♦similar construction for superstrings

we need to construct OSp SFT for superstrings first

♦1 D-brane ?

♦ghost D-branes ∼ annihilation operators for D-branes

?

2nd quantization Yoneya-san's talk