

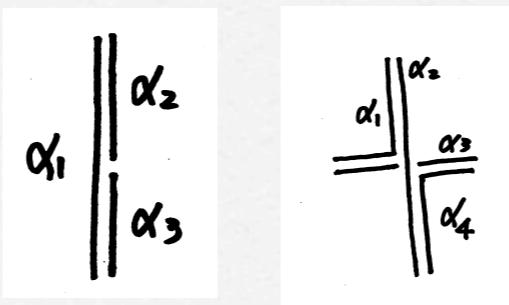
Present Status of String Field Theory

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Open Bosonic String

□ HIKKO (1986) (LC type)

$$S = \frac{1}{2} \Phi Q_B \Phi + \frac{g}{3} \Phi^3 + \frac{g^2}{4} \Phi^4$$



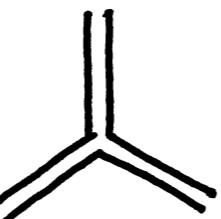
$$\begin{aligned}\delta\Phi &= Q_B \Lambda + g(\Phi * \Lambda - \Lambda * \Phi) \\ &\quad + g^2(\Phi \circ \Phi \circ \Lambda - \Phi \circ \Lambda \circ \Phi + \Lambda \circ \Phi \circ \Phi)\end{aligned}$$

- Intuitive joining-splitting (or recombining) interaction
- Unphysical length parameter α is needed.

□ Witten (1986) (cubic SFT)

cubic interaction

$$S = \frac{1}{2} \Phi Q_B \Phi + \frac{g}{3} \Phi^3$$



$$\delta\Phi = Q_B \Lambda + g(\Phi * \Lambda - \Lambda * \Phi)$$

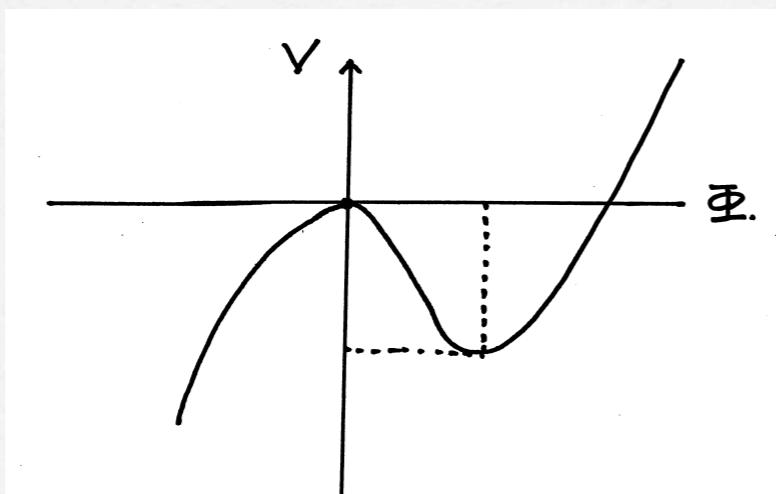
- Not intuitive but symmetric interaction
- It is more convenient and useful to study

□ Some important achievements

- Perturbative Amplitudes are reproduced (LC-type, CSFT).
- Analytic solutions are found (CSFT)

Tachyon Solution : Schnabl (2006)

No Open String Tachyon around it!

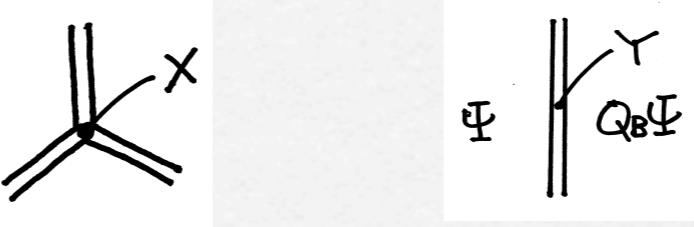


- Several technology is now developed to study CSFT.

Open Superstring

□ Prototype CSSFT (Witten (1986))

$$S = \frac{1}{2}\Phi Q_B \Phi + \frac{g}{3}X\Phi^3 + \frac{1}{2}\Psi Y Q_B \Psi + g\Psi\Phi\Psi$$



$$\delta\Phi = Q_B\Lambda + gX(\Phi * \Lambda - \Lambda * \Phi) + g(\Psi * \Xi + \Xi * \Psi)$$

$$\delta\Psi = Q_B\Xi + gX(\Psi * \Lambda - \Lambda * \Psi + \Phi * \Xi - \Xi * \Phi)$$

Φ : Boson, Ψ : Fermion,

X (Y) : (Inverse) Picture Changing Operator

- Based on RNS formulation
(Space-Time SUSY is not manifest.)
- There is a difficulty come from colliding X's.

□ Modified CSSFT (Preitschopf-Thorn-Yost (1990),
Arefeva-Medvedev-Zubarev (1990))

$$S = \frac{1}{2} A Y \bar{Y} Q_B A + \frac{g}{3} Y \bar{Y} A^3 + \frac{1}{2} \Psi Y Q_B \Psi + g Y \Psi A \Psi$$

$$\begin{aligned}\delta A &= Q_B \lambda + g(A * \lambda - \lambda * A) + g X (\Psi * \Xi + \Xi * \Psi) \\ \delta \Psi &= Q_B \Xi + g(\Psi * \lambda - \lambda * \Psi + A * \Xi - \Xi * A)\end{aligned}$$

$$A \sim X\Phi, \lambda \sim X\Lambda$$

- No colliding \times difficulty.
- Difficult to fix the gauge invariance.
 - ~ It is not clear to reproduce perturbative amplitudes.
(Kishimoto-Kohriki-Kugo-Kunitomo-Murata, work in progress)

□ WZW type SSFT (Berkovits (1995))

Action for boson

$$S = (e^{-\Phi}(Q_B e^\Phi))(e^{-\Phi}(\eta_0 e^\Phi)) + \int_0^1 dt (e^{-t\Phi}(\partial_t e^{t\Phi}))(e^{-t\Phi}(Q_B e^{t\Phi}))(e^{-t\Phi}(\eta_0 e^{t\Phi}))$$

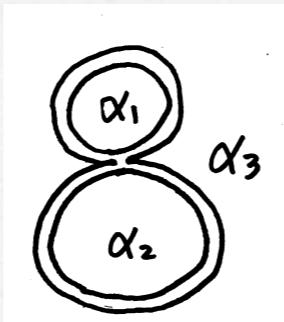
$$\delta e^\Phi = (Q_B \Lambda) e^\Phi + e^\Phi (\eta_0 \Omega)$$

- Based on extended RNS formulation with large Hilbert space.
- No picture changing operator
- Difficult to construct an action for fermion.

Closed Bosonic String

□ HIKKO (1986) (LC-type)

$$S = \frac{1}{2} \Phi Q_B \Phi + \frac{\kappa}{3!} \Phi^3$$



$$\delta\Phi = Q_B \Lambda + \kappa \Phi * \Lambda$$

- Intuitive recombining interaction.
- Unphysical parameter α is needed.

□ Non-polynomial SFT (Saadi-Zwiebach (1989),
Kugo-Kunitomo-Suehiro (1989))

$$S = \frac{1}{2}\Phi Q_B \Phi + \frac{\kappa}{3}\Phi^3 + \frac{\kappa^2}{3}\Phi^4 + \frac{\kappa^3}{4}\Phi^5 + \dots$$



$$\delta\Phi = Q_B \Lambda + \kappa \Phi * \Lambda + \frac{\kappa^2}{2} (\Phi^2 * \Lambda) + \frac{\kappa^2}{3!} (\Phi^3 * \lambda) + \dots$$

- Infinite types of interactions described polyhedra.
- Perturbative tree amplitudes are reproduced.
- With some modifications, we can construct the quantum action reproducing arbitrary loop amplitudes. (Zwiebach (1992))

Closed Superstring

- Heterotic SFT (Berkovits-Okawa-Zwiebach (2004))
 - For boson: WZW type with nonpolynomial CSFT
 - Action for fermion cannot be constructed.
- Type IIB SSFT
 - For NS-NS sector (including a half of bosons) :
Kugo-Kunitomo-Zwiebach, work in progress
 - For R-R sector ?
 - For NS-R (R-NS) [fermion] sector?