String Field Theory or: How I learned to stop worrying and love the tachyon

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Outline

History

What is string theory?
String spectrum
Super string theory

String Field Theory
Point particle
Open SFT
Sen's conjectures
Closed SFT

Summary

Historical background

What is string theory?

- String spectrum
- Super string theory

String Field Theory

- Point particle
- Open string field theory
- Sen's conjectures
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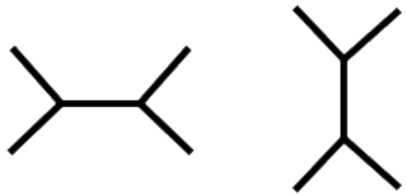
- Experimental Hadron physics
  - Mesons mass spectrum obeys the Regge trajectory

$$m^2 = \alpha_0 + \alpha_1 J$$

  - Four-point functions have an s/t duality



- The Veneziano amplitude has both properties
- String scattering gives the Veneziano amplitude
- There is only one free parameter – the string tension
- QCD turned out as a better model for hadronic physics
- Yet string theory "predicts" gravity

What is string theory?

- Strings are the fundamental objects (instead of point particles)
- Strings span a worldsheet (instead of a worldline)
- The string action is proportional to the worldsheet area

$$\mathcal{L} = \frac{1}{2\pi\alpha'} \int d\sigma^2 \sqrt{-h}\, h^{ab} g_{\mu\nu} \partial_a X^\mu \partial_b X^\nu$$

$$a, b = 0, 1 \qquad \mu, \nu = 0, \ldots, 25(D-1)$$

- String equation of motion

$$\Box X^\mu = \left(\frac{\partial^2}{\partial^2 \tau} - \frac{\partial^2}{\partial^2 \sigma} \right) X^\mu = 0$$

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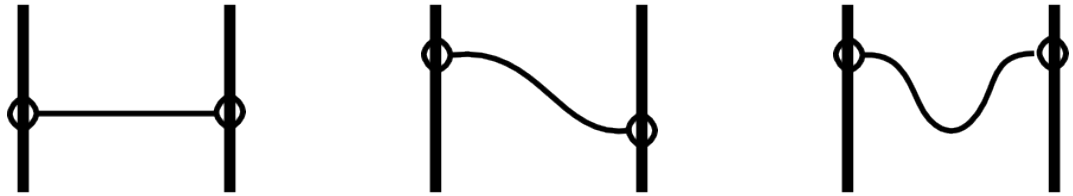
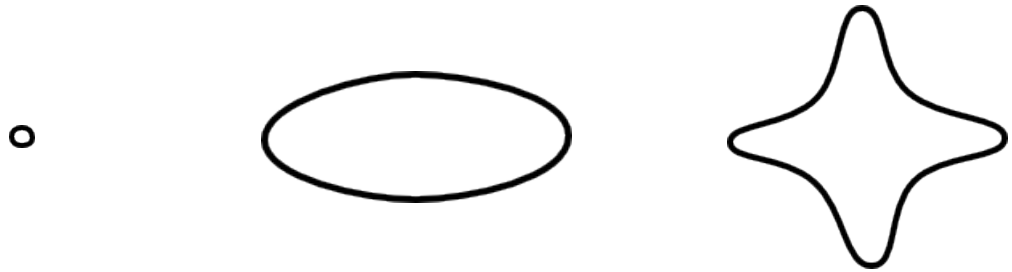
Classic relativistic massless strings

- Open string spectrum (Neuman boundary conditions)



p $\quad A_1^\mu, p$ $\quad A_2^\mu, p$

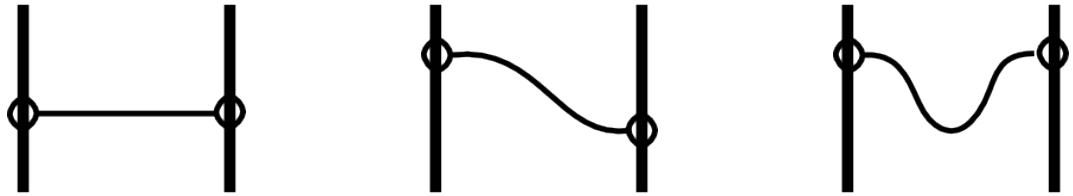
- Closed string spectrum (periodical boundary conditions)



p $\quad A_1^{(L)\mu}, A_1^{(R)\nu}, p$ $\quad A_2^{(L)\mu}, A_2^{(R)\nu}, p$

Quantum relativistic massless strings

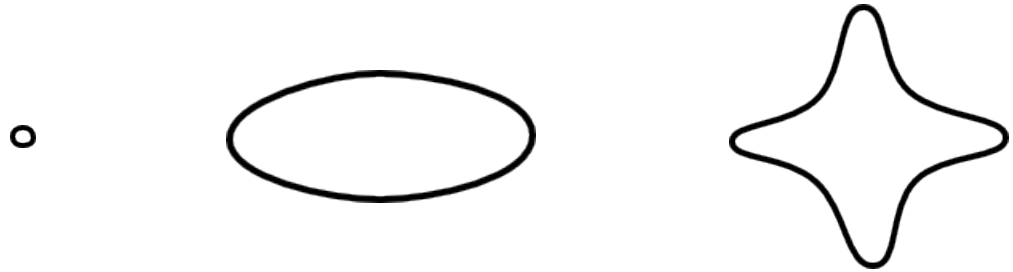
- Open string spectrum



$|0,p\rangle$ $\quad$ $a_1^{\dagger\mu}|0,p\rangle$ $\quad$ $a_2^{\dagger\mu}|0,p\rangle$

$m^2=-1$ $\quad$ $m^2=0$ $\quad$ $m^2=1$

- Closed string spectrum



$|0,p\rangle$ $\quad$ $a_1^{\dagger(L)\mu}a_1^{\dagger(R)\nu}|0,p\rangle$ $\quad$ $a_2^{\dagger(L)\mu}a_2^{\dagger(R)\nu}|0,p\rangle$

$m^2=-2$ $\quad$ $m^2=0$ $\quad$ $m^2=2$

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- Vacuum state

$$|0\rangle \equiv \prod_{n=1}^{\infty} \prod_{\mu=2}^{D-1} |0\rangle_n^{\mu}$$

- Vacuum energy

$$a \equiv \frac{1}{2}(D-2)\sum_{n=1}^{\infty} n = -\frac{D-2}{24} \overset{D=26}{\longrightarrow} -1$$

- Using zeta function regularization $\sum_{n=1}^{\infty} n = -\frac{1}{12}$
- Regge spectrum

$m^2 = a$	spin 0	$\|0\rangle$	1
$m^2 = a+1$	spin 1	$a_1^{\dagger\mu}\|0\rangle$	$(D-2)$
$m^2 = a+2$	spin 2	$a_1^{\dagger\mu}a_1^{\dagger\nu}\|0\rangle$	$\frac{1}{2}(D-2)(D-1)$
$m^2 = a+2$	spin 1	$a_2^{\dagger\mu}\|0\rangle$	$(D-2)$

- The last two sum-up to a spin-2 representation of $SO(D-1)$

Current inventory

- Meson spectrum, string tension related to Regge slope

$$T_s \equiv M_s^2 = M_{QCD}^2 \sim (100 MeV)^2$$

- Gravitons, string tension related to gravitational constant

$$G_N^{-1} = M_{\text{Planck}}^2 = g_s M_s^2 \sim (10^{19} GeV)^2$$

- Gauge bosons, string tension related to regularization scale

$$M_s^2 > M_{GUT}^2 \sim (10^{16} GeV)^2 \qquad g_s = g_{YM}^2 \sim 10^{-2}$$

- 26 dimensions
- No fermions
- A tachyon

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Super string theory

- Add supersymmetry to the string worldsheet
- Down to 10 dimension
- The tachyon is projected out
- Space-time fermions
- Consistent chiral models
- Space-time supersymmetry
- D-branes – mutli-dimensional non-perturbative objects

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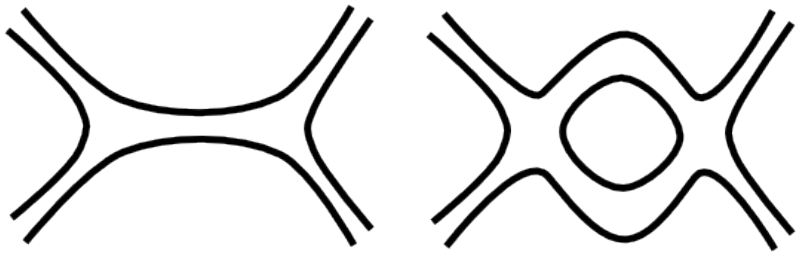
String Field Theory

- String theory is defined perturbatively



- The perturbative vacuum is not stable

- String Field Theory (SFT) is a non-perturbative formulation of String theory
- We need an action principle for the string field instead of the worldsheet action

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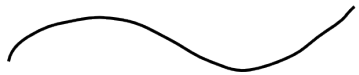
Point particle

- Point particle's worldline action is its proper time

$$\mathcal{L} = \int ds = \int d\tau \sqrt{g_{\mu\nu} \dot{X}^\mu \dot{X}^\nu}$$



- Equation of motion

$$E^2 = p^2 + m^2$$

- First quantization gives the Klein-Gordon equation

$$\Box\Phi + m^2\Phi = 0$$

- This is a classical scalar field

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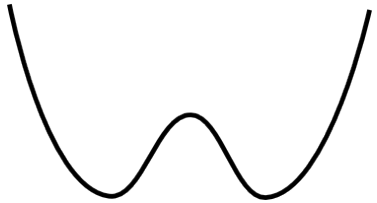
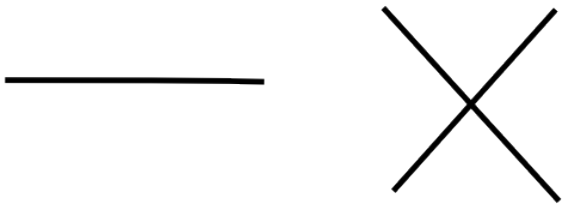
- Scalar field with Higgs-like potential example

$$\mathcal{L} = -\frac{1}{2}\partial_\mu \Phi \partial^\mu \Phi + \frac{1}{2}m^2\Phi^2 - \frac{1}{4}\lambda\Phi^4$$



- Feynman diagrams



- Equation of motion

$$\Box\Phi - m^2\Phi + \lambda\Phi^3 = 0$$

- Static solutions

$$\Box\Phi = 0 \quad \Rightarrow \quad \Phi = 0 \text{ or } \Phi = \pm\frac{m}{\sqrt{\lambda}}$$

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Open Bosonic Cubic String Field Theory

- The string field is a functional from the string configuration to a scalar value

$$\Psi[X^\mu(\sigma)]$$

- In mode-expansion we get

$$|\Psi\rangle = \int dp\, T(p)\,|0,p\rangle + A_\mu(p) a_1^\mu\,|0,p\rangle + \ldots$$

- The action is

$$S = \frac{1}{2}\langle\Psi|\,(p^2+m^2)\,|\Psi\rangle + \frac{g_s}{3}\langle\Psi^3\rangle$$

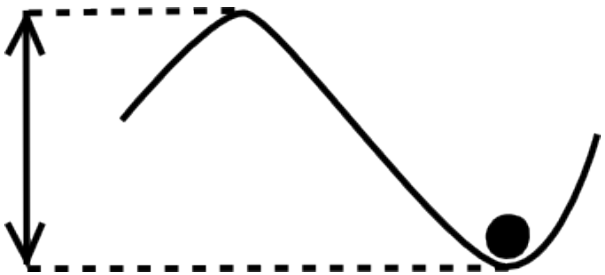
- Equation of motion

$$(p^2+m^2)\Psi + \Psi^2 = 0$$

Sen's conjectures

- Open strings must end on a D-brane
- Open SFT has a space-time filling D25-brane
- The tachyon signifies the instability of the D25-brane
- A solution to the E.O.M would correspond to annihilation of the D25-brane
- The potential height would be exactly the D25-brane energy

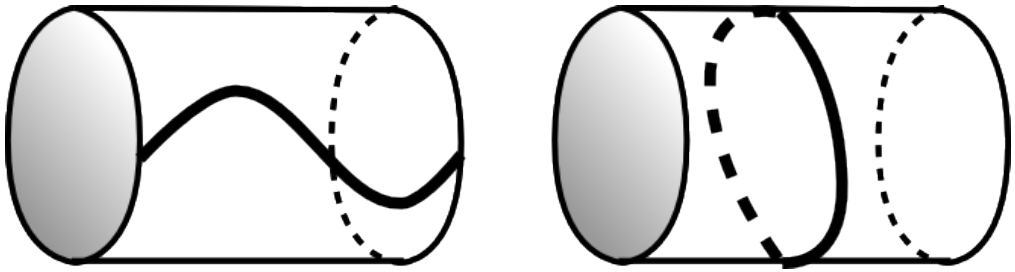
$$E = V_{25} T_{25}$$



- There would be no open-string degrees of freedom around the solution

Closed string field theory

- Seems redundant – open string field theory already contains closed strings at one-loop



- Seems necessarily because of the closed string tachyon
- No equivalent to Sen's conjectures

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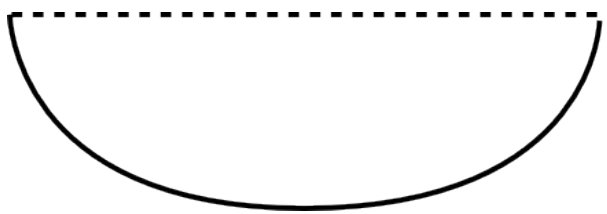
- Subjects not covered
  - Black hole entropy
  - Holography
  - AdS/CFT correspondence
  - Super String Field Theory
- Open questions
  - Is the tachyon related to the Higgs boson?
  - Is the tachyon related to the inflaton field?
  - Does string theory describe hadron physics after all?



  - Is string theory the theory of everything?

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