Supergravity and Open Strings

(An attempt to give a non-perturbative formulation of closed superstring theories $\supset$ supergravity theories via open string theory)

Plan

1. Motivation

2. Proposal

3. Consistency Checks

Work with Gaiotto, Rastelli, Zwiebach

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Motivation

We have a more or less complete understanding of superstring perturbation theory in terms of sum over Riemann surfaces.

We also have a good understanding of strong coupling behaviour of superstring theories using duality symmetries.

However, there is no non-perturbative formulation of these theories from which perturbation theory can be derived systematically.

There have been attempts to give non-perturbative formulation of string theories in special backgrounds.

- Closed string field theory — Zwiebach, ...
- Matrix theory — Banks, Fischler, Shenker, Susskind
  ⋮
- Maldacena conjecture — Maldacena

In the last two approaches the fundamental degrees of freedom are open strings living on D-branes.

In Matrix theory the degrees of freedom are open strings living on D0-branes.

In Maldacena conjecture they are open strings living on D3-branes / other D-branes.

Since D-branes carry Ramond-Ramond charge, both cases describe string theory in the presence of charged branes.

Matrix theory : Infinite D0-brane charge

→ momentum in the 11th direction.

As a result it describes M-theory in the infinite momentum frame.

Maldacena conjecture: D3-brane charge

→ Flux of 5-form field strength

As a result we have string theory in the presence of background 5-form flux (and AdS geometry)

Q. Can we get rid of the D-brane charge and still use open string degrees of freedom to give a non-perturbative formulation of string theory?

Proposal: Use a system of branes with zero total charge.

e.g. brane-antibrane system or non-BPS D-branes.

Example: Type IIB string theory has space filling BPS D9-branes

Use a system of equal number of D9-$\bar{\mathrm{D}}$9 pairs

$\to$ carries no charge

In type IIA we can take a set of non-BPS D9-branes as our starting point.

Dynamics of these systems are described by 'open string field theories'.

A field theory with infinite number of fields ψ_1, ψ_2, ... with action

$$S(\{\psi_r\})$$

$\{\psi_r = 0\}$: describes the D9-$\bar{\text{D}}$9 brane configuration in IIB and non-BPS D9-brane configuration in IIA

Proposal: Take these open string field theories to be non-perturbative definitions of the full type IIB / IIA superstring theories.

Naively a natural starting point would be a closed string field theory since type IIB /IIA string theory is a theory of closed strings.

However, open string field theories are much better understood than closed string field theories.

Witten

Furthermore it is known that even if we start with an open string field theory, the S-matrix elements of the theory contain closed string poles

Freedman, Giddings, Shapiro, Thorn

→ closed strings arise as 'bound states' of open strings.

Also the experience with Matrix theory / Maldacena conjecture indicates that open strings are better suited for giving a non-perturbative formulation of theories with gravity.

However this proposal clearly raises many questions.

A brane-antibrane system / non-BPS D-brane carries energy density even if it does not carry charge.

→ cosmological constant. (STRING SCALE)

Furthermore typically such systems carry tachyonic mode.

(*i.e.* one or more of the infinite number of fields ψ_1, ψ_2, ... have negative mass^2.)

→ the system is unstable.

Fortunately, these two problems cancel each other.

The action $S(\{\psi_r\})$ has a stationary point $\{\psi_r^{(0)}\}$ (minimum of the tachyon potential) where the negative contribution from the potential energy exactly cancels the energy density of the original system, and there are no tachyons.

This has been tested numerically.

Kostelecky, Potting
A.S., Zwiebach
Moeller, Taylor
Berkovits,
Berkovits,
A.S., Zwiebach
Smet,
Raeymaekers
Iqbal, Naqvi
⋮

(There is another version of string field theory, – boundary string field theory, – in which this can be proved analytically.

Gerasimov, Shatashvili
Kutasov, Marino, Moore

However, the relation of boundary string field theory with the more standard string field theory that allows us to carry out perturbation expansion is not known.

It is believed that the two theories are related by field redefinition.)

Since at the stationary point there is no net charge or energy density, we can identify this as the usual superstring vacuum.

If $\{\psi_r = \psi_r^{(0)}\}$ describes this 'vacuum solution' then we can expand the string field theory around this new solution.

$$\phi_r \equiv \psi_r - \psi_r^{(0)}$$

$$S(\{\psi_r\}) = S(\{\psi_r^{(0)}\}) + \tilde{S}(\{\phi_r\})$$

$\tilde{S}(\{\phi_r\})$ describes string field theory expanded around the tachyon vacuum, *e.g.* the type IIB / IIA string theory without any D-branes.

Use $\tilde{S}(\{\phi_r\})$ as the starting point for the path integral description of the string field theory.

Around the tachyon vacuum ($\{\phi_r = 0\}$) there should be no physical open string states as the D-branes have disappeared

(Has been checked numerically) Ellwood, Taylor
Ellwood, Feng, He, Moeller

Since there are no perturbative physical states obtained by quantizing the open string fields, there is no perturbative S-matrix.

Q. What should we compute using this action?

There are of course still infinite number of off-shell string fields.

Look for gauge invariant operators involving these fields and compute their correlation functions.

It turns out that for every physical closed string vertex operator, there is a gauge invariant operator in the open string field theory.

Thus one would expect that the correlation function of these gauge invarint operators will be related to closed string amplitudes. Itzhaki, Hashimoto; Gaiotto, Rastelli, A.S.; Zwiebach

This still remains an open problem.

OTHER APPROACHES FOR GETTING CLOSED STRINGS:

Yi, A.S., Bergman, Hori, Yi; Gibbons, Hori, Yi; Gerasimov, Shatashvili

Besides closed strings, superstring theories also contain other objects.

- D-branes

- NS-5-branes

Can we find these objects in the open string field theory with action $\widetilde{S}(\{\phi_r\})$ described earlier?

It turns out that D-branes appear as regular solitons in this open string field theory.

→ Classical solutions satisfying the equation of motion

$$\boxed{\delta\widetilde{S}/\delta\phi_r = 0}$$

(Direct numerical checks as well as indirect analytical arguments using boundary string field theory)

Examples:

A 7-brane in IIB is a 'tachyonic vortex' solution.

$$T(\rho, \theta) = f(\rho) e^{i\theta}$$

$$f(\infty) = T_0, \qquad f(0) = 0$$

(ρ, θ): polar coordinates labelling directions transverse to the 7-brane.

Topological charge: $\pi^1(S^1)$

A 6-brane in IIA is a tachyonic hedge-hog configuration.

Topological charge: $\pi^2(S^2)$

A 5-brane in IIB carries topological charge associated with $\pi^3(S^3)$.

A general analysis leads to a more refined classification of D-brane charges based on K-theory.

Witten
Horava
⋮

Existence of D-brane solutions in this string field theory also gives another indirect evidence for the existence of closed strings in this theory.

Consider a classical solution describing a pair of D-branes separated by some distance.

Compute the one loop effective action in this background.

This one loop effetive interaction contains in it the closed string exchange interaction between D-branes (including graviton exchange forces).

(Follows from the result that closed strings appear as poles in S-matrix elements involving open strings)

Thus interaction between solitons in this string field theory does know about the closed string states.

What about the NS-5-branes?

Construction of NS 5-branes is part of a more general problem, in which we want to use the open string degrees of freedom to shift closed string background.

Since closed strings are bound states of open strings, this problem seems complicated and not much progress has been made on this front.

Clearly the success of this whole program depnds on how well we understand the open string field theory around the tachyon vacuum.

Unfortunately although the original string field theory action $S(\{\psi_r\})$ has a simple form, so far we do not have such a form available for the action $\widetilde{S}(\{\phi_r\})$

In order to derive this form we need to know the explicit form of the solution $\psi_r^{(0)}$ with which we shift the string field to go from $S(\{\psi_r\})$ to $\widetilde{S}(\{\phi_r\})$.

So far the explicit form of $\psi_r^{(0)}$ has only been found numerically.

In the absence of an analytic form of $\widetilde{S}(\{\phi_r\})$ that can be derived from the original string field theory action, we could try to guess the form of this action.

Useful guidelines:

- There should be no perturbative physical open string states.
- The equations of motion should have classical solutions describing the known D-brane solutions of the theory.

For bosonic open string field theory this has been carried out, although how to derive it from the original string field theory action is still unclear.

Gaiotto, Rastelli, A-S., Zwiebach

Gross & Taylor

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Summary

Open string field theory on the unstable brane system can provide a non-perturbative formulation of closed superstring theories.

Consistency check:

- At the minimum of the potential, the theory has zero energy density
- It does not contain any physical open string states.
- It contains all the D-branes as solitons.

Appearance of closed strings in the theory can be seen indirectly, but a more direct analysis should be possible.

Shifting closed string background (including construction of NS 5-branes) is a more challenging problem, which must be addressed.

If the program is successful, then we could in principle use this open string field theory to study non-perturbative questions in string theory, both analytically and numerically.