Dynamical symmetry breaking in nonperturbative string theory

Tsunehide Kuroki
(Division of String Theory and Mathematics, KMI)
@KMI Topics, 2013/7/10

String theory as quantum gravity

Fundamental requirements of string theory:

- quantum gravity:
  - consistent quantum (field) theory
  - determines space-time itself
  - reduced to the Einstein gravity

    → four-dimensional Minkowski space
    (including its signature?),
    standard model of universe
- unified theory:
  - standard model of particle physics

Perturbative string as a candidate

- includes both gauge boson (open string), and graviton (closed string)
- (perturbatively) consistent quantum theory
- nonrenormalizability of gravity
  → extended object

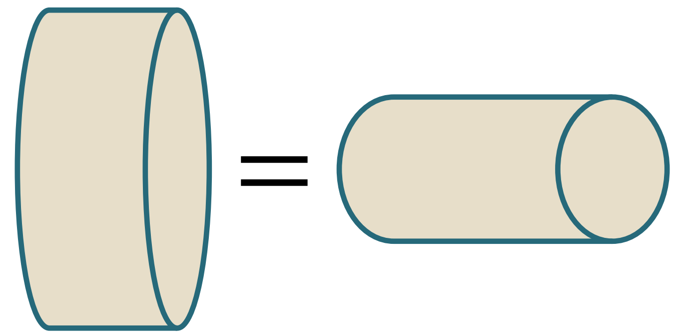
↓

(almost) unique ultimate theory respecting quantum theory (not Einstein gravity)

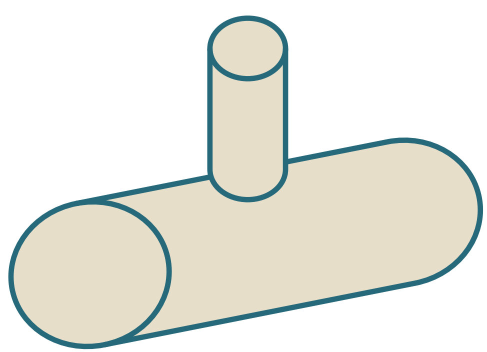
Virtues of perturbative string

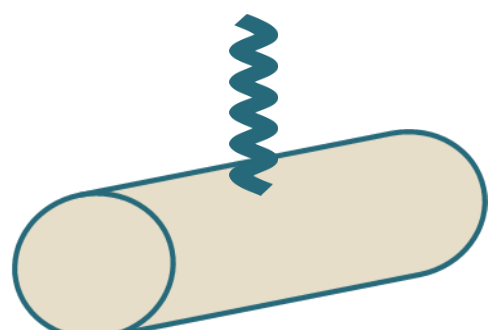
essence: local scale invariance on WS

- st–duality
  - UV–finiteness



- perturbative QG
  - graviton in the spectrum （cf. QCD string)
- unification of external field & spectrum
  - desirable as unified theory





Faults of perturbative string

- local scale invariance
  - background EOM (Einstein eq.)

$$S = -T \int d^2\sigma \sqrt{-h} h^{\alpha\beta} \partial_\alpha X^\mu \partial_\beta X^\nu G_{\mu\nu}(X)$$

→ essentially perturbation theory

on-shell (1st quantization)

  - anomaly → ten dimensions (critical dim.)
- infinite # of perturbative vacua
  - serious as quantum gravity

→ nonpert. formulation:

abandon local scale inv, even WS picture!

Nonpert. effect seen by perturbative string

- large order behavior

$$F(g_s^2) = \sum_{n=-1}^{\infty} C_n g_s^{2n}, \qquad C_n \sim (2n)! C^{-2n} \quad (n \to \infty)$$

cf. field theory: $C_n \sim n! C^{-2n} \quad (n \to \infty)$

suggests nonpert. effect $F \sim e^{-C/g_s}$

[Shenker 1991]

in spite of closed SFT action

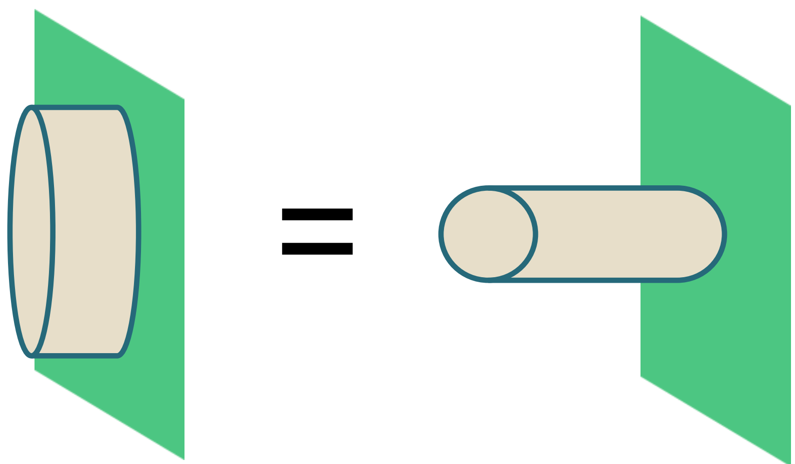
$$S[\Psi] = \frac{1}{g_s^2} \int (\Psi K \Psi + \Psi^3 + \Psi^4 \cdots)$$

cf. $S = -\frac{1}{4g^2} F_{\mu\nu} F^{\mu\nu} \quad \rightarrow \quad F_{\text{inst}} \sim e^{-C/g^2}$

D-branes as nonpert. effect (1)

- classical solution of closed SFT (soliton)
- black brane solution at low energy
- Dirichlet b.c. for open string
- st-duality

→ source of closed string

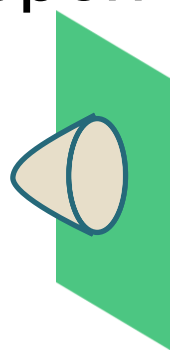


D-branes as nonpert. effect (2)

- dynamics: open string oscillation

[Polchinski 1995]

- action: open string disk amplitude



$$\sim \quad C/g_s$$

- tension $\sim \quad C/g_s$
- result of st-duality:

large order behavior, nonpert. effect.:

reflects difference from particle theory

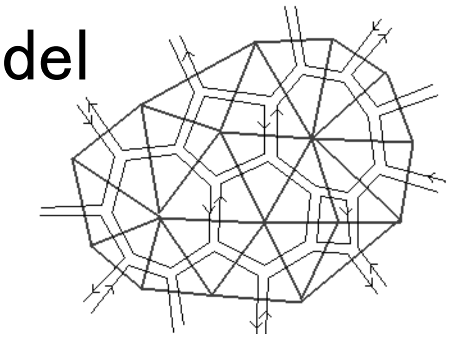
Toward nonpert. formulation

- nonpert. effect does not always suggest nonpert. formulation itself (D-brane: within perturbation theory)
- existence of D-particle, D-instanton
  - "quantization" of soliton
  - tractable thanks to st-duality: (a kind of) gauge theory (not BH dynamics)
- string duality:
  F-string ⇔ D-brane (as SG ⇔ MT)
  in some string theory,
  condensation of string ~ D-brane

[花早石川黒松多 2004]

Candidates so far

- discretization of WS → matrix model



$$S = N\mathrm{tr}\left(\frac{1}{2}\phi^2 + \frac{g}{4}\phi^4\right)$$

critical pt.: + large-N lim. (double scaling lim.)

→ smooth surface (ϕ : technical tool for WS)

- D-brane matrix model:

Yang-Mills type gauge theory (target sp. pic.)

$$S = \int d^{p+1}x \left(-\frac{1}{4g^2}\mathrm{tr}\left(F_{\mu\nu}F^{\mu\nu} + D_\mu\phi^i D^\mu\phi^i + \cdots\right)\right)$$

$A_\mu(x)$: gauge field on brane, $\phi^i(x)$: position

Virtues & faults: WS discretization

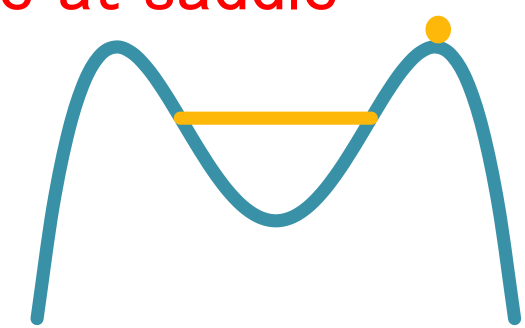
- virtues
  - reproduce all order perturbation theory
  - nonpert. effect ~ eigenvalue at saddle

    ~ tunneling of eigenvalue

    → WS boundary

    e^{-C/g_s}

    nonpert. exact free energy (Painlevé eq.)



- faults
  - available only in $D \leq 2$ (noncritical string)
  - no space–time SUSY

Virtues & faults: D–brane matrix model

- virtues
  - captures D–brane dynamics (@ low energy)

    many examples:

    force, scattering, decay, recombination···
  - concrete example as (classical) gravity:

    AdS/CFT: ∃region where closed string can be described by gauge theory (st–duality)
  - target sp. symm. (sometimes nontrivially)
- faults
  - F–string DOF, scattering amp., st–duality

Why D–brane MM can contain gravity

D–brane MM ← quantization of massless open string DOF → <u>should be valid only for D–brane dynamics @ low energy</u>

far from <u>full nonpert. closed</u> string theory

e.g.

IIB matrix model ··· D(−1)–brane (0d) [IKKT 1997]

Matrix theory ··· D0–brane (1d MQM) [BFSS 1997]

Matrix string th. ··· D–string (2d SYM) [DVV 1997]

AdS/CFT (strongest) ··· D3–brane (4d SYM) [Maldacena 1998]

Key: symmetries (1)

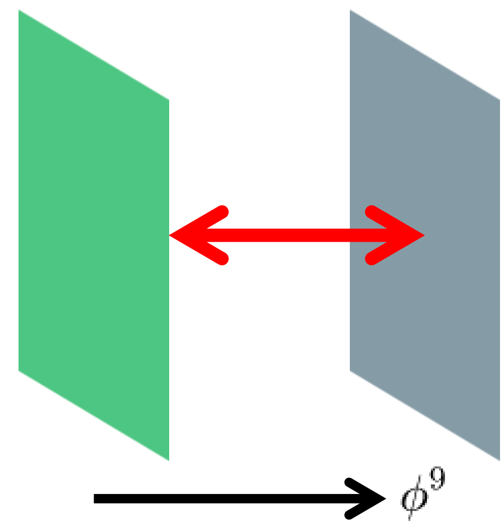
- SUSY

e.g. IIBMM

- ➢ maximal SUSY: graviton multiplet
- ➢ "emergent" 10d gravity (remnant of st-duality)

$$\phi^i = \left(\begin{array}{c|c} \blacksquare & \text{int} \\ \hline \text{int} & \blacksquare \end{array} \right)$$

$$\phi^9 = \left(\begin{array}{c|c} 0 & \text{int} \\ \hline \text{int} & r \end{array} \right)$$



one-loop in gauge th. in background $\rightarrow \dfrac{1}{r^6}$

Key: symmetries (2)

- isometry & conformal symmetry
  - AdS_5/CFT_4: SO(4,2)
  - other symm. ((broken) chiral symm. ···)

→ ensure validity low energy effective action (w/ small # of parameters)

(Note: even if symmetries do not agree, some quantities can be well described by their peculiarity (universality, BPS, ···))

usually, only very special closed string can be reproduced ···

(Maybe) Promising candidates

- IIBMM
  - D(−1)−brane low energy effective action
  - WS formulation of Schild gauge

$$S_n = -\int d^2\sigma\, e \left[\frac{1}{e^n} \left\{ -\frac{T^2}{2} \underbrace{\left(\epsilon^{\alpha\beta}\partial_\alpha X^\mu \partial_\beta X_\mu\right)^2}_{2\det_{\alpha\beta}(\partial_\alpha X^\mu \partial_\beta X_\mu)} \right\}^{\frac{n}{2}} + n - 1 \right]$$

$$n = 1: \quad \text{NG} \quad S = -m \int ds \sqrt{-\dot{X}^2}$$

$$n = 2: \quad \text{Schild} \quad S = -\frac{1}{2} \int ds \left(\frac{1}{e}(-m^2 \dot{X}^2) + e \right)$$

$$\text{gauge fix:} \quad \rightarrow S = -\frac{T^2}{2} \int d^2\sigma \, \{X^\mu, X^\nu\}^2$$

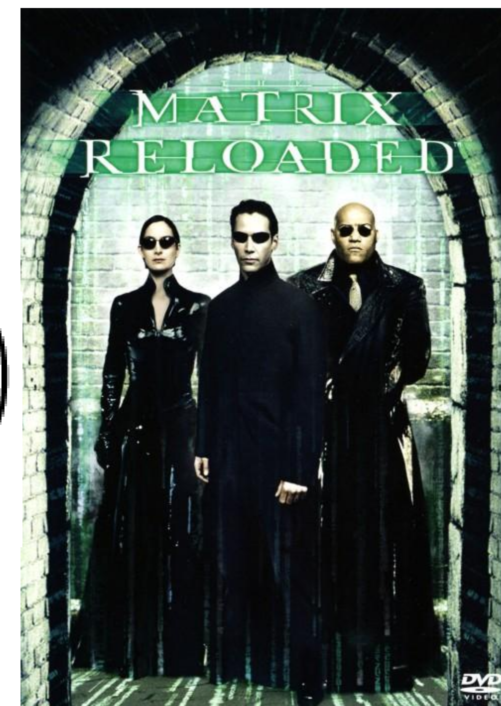
$$\rightarrow S = \beta \, \mathrm{tr}_N [A^\mu, A^\nu]^2 : \ \text{0d SYM}$$

0–dim. SYM can be regarded as

- D(−1)–brane low energy effective action
- matrix reg. of F–string in Schild gauge

- $c = 1$ matrix reloaded

[McGreevy Verlinde 2003]



- MQM: WS discretization of $D = 2$ string

$$S = \beta \int dt\, \mathrm{tr} \left(\frac{1}{2}\dot{U}(t)^2 - V(U(t)) \right)$$

$$\text{with} \quad \beta \to \beta_c, \quad N \to \infty$$

- LEEE of unstable D0–brane

PUPT-2083
hep-th/0304224

Strings from Tachyons:

The $c = 1$ Matrix Reloaded

John McGreevy and Herman Verlinde

Department of Physics, Princeton University, Princeton, NJ 08544

Abstract

We propose a new interpretation of the $c = 1$ matrix model as the world-line theory of N unstable D-particles, in which the hermitian matrix is provided by the non-abelian open string tachyon. For D-branes in 1+1-d string theory, we find a direct quantitative match between the closed string emission due to a rolling tachyon and that due to a rolling eigenvalue in the matrix model. We explain the origin of the double-scaling limit, and interpret it as an extreme representative of a large equivalence class of dual theories. Finally, we define a concrete decoupling limit of unstable D-particles in IIB string theory that reduces to the $c = 1$ matrix model, suggesting that 1+1-d string theory represents the near-horizon limit of an ultra-dense gas of IIB D-particles.

Should perturbative string be realized?

- D–brane MMs (SYMs): difficult to reproduce pert. string amplitude

→ they must realize F–string, st–duality?

they should contain 10d gravity?

recall def. of quantum gravity:

well–defined quantum th. + 4–dim. EH @ LE

(cf. LGT: allows weak coupling exp.)

desirable:

- $1/N$–expansion = perturbative exp. of F–string
- double scaling limit = nonperturbative string theory

(cf. noncritical string)

- SUSY DW MM ← new e.g. of "desirable" one

Dynamical symmetry breaking in nonpert. string theory

- in "desirable" scenario,
  - $1/N$−expansion: perturbative (w.r.t. g_s) exp.
    symm. (in particular SUSY) is inevitable
  - double scaling limit: nonpert. string theory
    → two standard models @ LE
    → no symmetries!

∴ MM or SYM with

symm. preserved @ all orders in $1/N$−exp.

but gets broken in the DSL

Examples of DSB (1)

- rotational symm. in IIBMM: 0-dim. SYM

$$S = \frac{1}{g^2}\mathrm{tr}\left(-\frac{1}{4}[A_\mu, A_\nu]^2 + \frac{1}{2}\bar{\psi}\Gamma^\mu[A_\mu, \psi]\right)$$

manifest SO(10) symm.

eigenvalues of A_μ : space-time pts

→ originally 10-dim. flat sp.

- mean field approx.

(adding $M_\mu \mathrm{tr}\,(A_\mu A_\mu)$)

[Nishimura Sugino 2001]
[川河黒松篠 2002]
[Kawai Aoyama 2006] etc.

→ $T_{\mu\nu} = \left\langle \frac{1}{N}\mathrm{tr}(A_\mu A_\nu) \right\rangle$: 10 eigenvalues

→ four-dim. space "emerges" dynamically

Example of DSB (2)

- SUSY DW MM:

[T.K. Sugino 2013]
[Endres T.K. Sugino Suzuki]

$$S = N\mathrm{tr}\left(\frac{1}{2}B^2 + iB(\phi^2 - \mu^2) + \bar{\psi}(\phi\psi + \psi\phi)\right)$$

w/ nilpotent SUSY's

we have recently shown that:

- in $N \to \infty$ this MM reproduces several types of tree level two-point functions of 2D type IIA superstring theory: reproduce perturbative string (although in 0-dim.!)
- SUSY's are broken in the DSL via an isolated eigenvalue as $\sim e^{-C/g_s}$

Virtues & faults of our model

- virtues
  - reproduces tree level string amplitude
    → expected st-duality
  - SUSY is preserved at all orders in $1/N$-exp.
  - first e.g. of dynamical & nonperturbative breaking of SUSY in string theory
- faults
  - loses both WS picture & D-brane picture
  - poor target space and fields
    breaking of nilpotent SUSY is significant?