Anomalous Dimensions @ Strong Coupling

Luca Mazzucato

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based on [Brenno Carlini Vallilo, LM, arXiv:1102.1219 [hep-th]]
for a pedagogical review, [LM, arXiv:1104.2604][hep-th]]

XI Workshop on Nonperturbative QCD, Paris

Outline

- Motivations: *conformal dimensions*
- *AdS/CFT* recap
- *@ Strong coupling* with string theory
- *Konishi* multiplet on the string worldsheet

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Motivations

What are anomalous dimensions in QFT?

- Take a local gauge invariant op $\mathcal{O}(x) = \mathrm{Tr}\,\phi^i(x)\phi^i(x)$
- In a CFT e.g. $\mathcal{N} = 4$ SYM: global symmetry $\supset$ *dilations* D

$$[D, \mathcal{O}(x)] = i\Delta\mathcal{O}(x)$$

- $\Delta \equiv$ *conformal dimension* $\leftrightarrow$ 2 pt functions

$$\langle\mathcal{O}(x)\mathcal{O}(y)\rangle \sim \frac{1}{|x-y|^{2\Delta}}$$

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What do we know about Δ?

hereafter: Planar limit $N \to \infty$

$\boxed{g_{YM} = 0 :}$ *classically* $\Delta = \Delta_0 \equiv$ "engineering dimension"

E.g. $\mathrm{Tr}\,\phi^i\phi^i$ has $\Delta_0 = 2$.

Turn on 't Hooft coupling $\lambda = g_{YM}^2 N \Rightarrow$ generate

anomalous dimensions $\equiv \Delta - \Delta_0 \neq 0$

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$\boxed{\lambda << 1}$: *weak coupling* planar loop expansion

$$\Delta - \Delta_0 = c_1 \lambda + c_2 \lambda^2 + \dots$$

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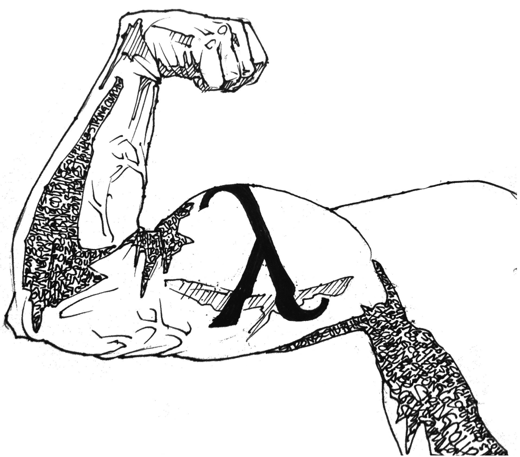

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@ Strong coupling? Use holography!

[Maldacena '97]

gauge		gravity
$\mathcal{N}=4$ SYM	$=$	IIB string theory on $AdS_5 \times S^5$
$\sqrt{\lambda}$	$=$	radius$^2/\alpha'$
$\lambda >> 1$	$=$	small curvature
strongly coupled CFT	$=$	perturbative string theory
CFT conformal dim. Δ	$=$	*E energy in AdS*

State of the Art: [Gromov et al. '09] conjectured a set of Y-system eqs. whose numerical solution gives $\Delta(\lambda)$ at any value of the coupling.

Problem: very hard coupled integral eqs.!

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AdS/CFT dictionary

BPS:	$\Delta - \Delta_0 =$	0	massless vertex op = SUGRA
short non-BPS:	$\Delta - \Delta_0 \sim$	$\sqrt[4]{\lambda} + \dots$	massive vertex op = quantum strings
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[Beisert et al. '10]

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Anomalous dimensions @ strong coupling

- $\Delta = E \quad \Rightarrow$ Compute the spectrum of *perturbative* string states in *AdS* in the near flat space limit

$$E \sim c_0 \sqrt[4]{\lambda} + c_1 + \frac{c_2}{\sqrt[4]{\lambda}} + \mathcal{O}(1/\sqrt{\lambda})$$

- Flat space is mass$\sim \sqrt{n/\alpha'}$

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Anomalous dimensions @ strong coupling: Konishi multiplet

- Simple string: sitting still at the center of AdS (with same quantum #s as SYM op. in the Konishi multiplet)
- Type IIB string σ model in $AdS_5 \times S^5$
- Compute worldsheet physical state condition (Virasoro) at 1-loop

$$T \sim \frac{E(E-4)}{\sqrt{\lambda}} + \text{quantum corrections} = 0$$

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[LM+Vallilo '11]

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Strings propagating in $AdS_5 \times S^5$ are described by a σ model on the

$$\text{supercoset} \qquad PSU(2,2|4)/SO(1,4) \times SO(5)$$

$$\text{coset representative}: \quad g(\sigma,\tau) \to \underbrace{g_0}_{global}\, g(\sigma,\tau)\, \underbrace{h(\sigma,\tau)}_{local}$$

[Metsaev+Tseytlin '98]

- σ model action in terms of $J = g^{-1}dg$ Maurer-Cartan one-forms $+$ appropriate ghosts (called pure spinors).
- Physical states:
  - $\#_{ghost} = (1,1)$ vertex operators V
  - in the BRST cohomology $QV = 0, \quad V \neq Q\Lambda$.
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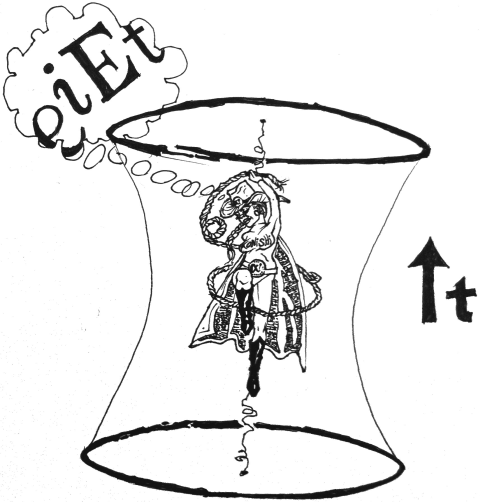

$\longrightarrow \quad \tilde{g}(\sigma,\tau) = \exp\left[-\tau E \mathbf{T}/\sqrt{\lambda}\right]$

- solves the worldsheet eoms
- vanishing BRST charge

- Quantize the σ model action in the background field method around $\tilde{g}(\sigma,\tau)$.
- Identify massive vertex operator
- Compute the 1-loop quantum corrections to Virasoro

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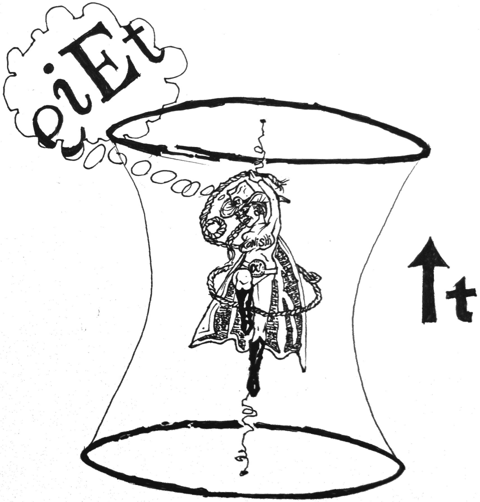

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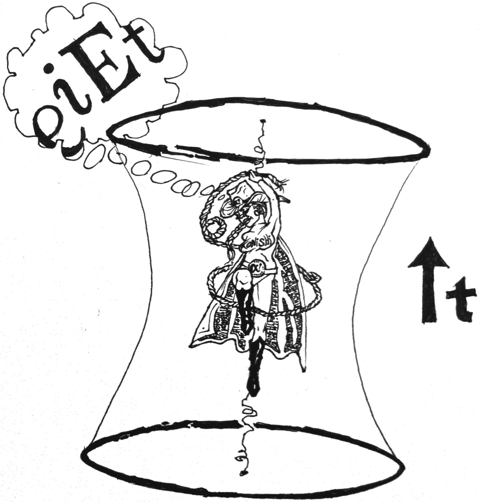

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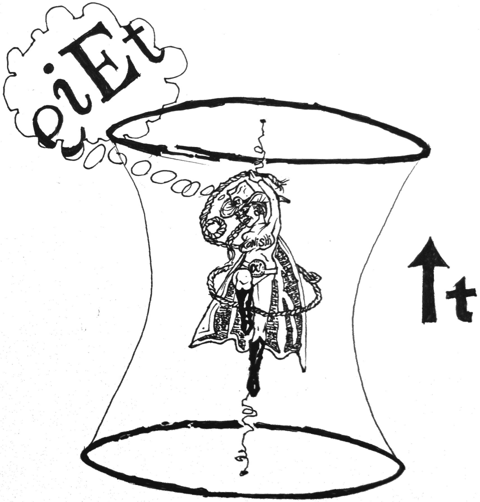

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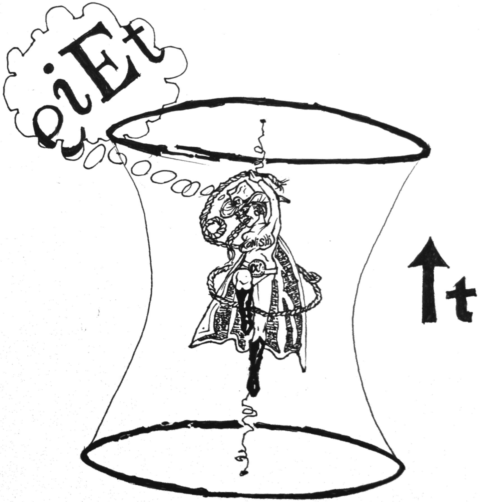

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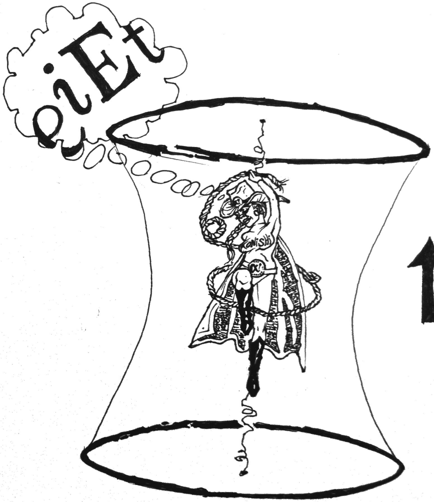

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- Konishi multiplet = Vertex operators at 1st massive level

$$V = X_{(-1)}\bar{X}_{(-1)}(L\bar{L}) \qquad \begin{array}{c}\text{Lorentz spin }(1,1)\\ SU(4)\text{ singlet}\\ \Delta_0 = 6\end{array}$$

- Virasoro constraint at 1-loop $T|V\rangle = 0$

$$\underbrace{-\frac{E(\overbrace{E}^{class.}\;\;\overbrace{-4}^{centr.\,charge})}{2\sqrt{\lambda}}}_{SO(2,4)\,Casimir} + \overbrace{2\sqrt{1+(E/\sqrt{\lambda})^2}}^{massive\ osc.}\;\overbrace{-\frac{2}{\sqrt{\lambda}}}^{quartic} = 0$$

$$\boxed{\textit{anomalous dim.}\ :\ \Delta - \Delta_0 = 2\sqrt[4]{\lambda} - 4 + \frac{2}{\sqrt[4]{\lambda}} + \mathcal{O}(1/\sqrt{\lambda})}$$

[LM&Vallilo '11]

[Gromov et al. '11]

[Roiban&Tseytlin '11]

Application: *Pomeron*

[Brower et al. '06]

- Leading Regge trajectory

$$\mathcal{O}_{string} \sim (\partial X \bar{\partial} X)^{j/2} e^{iEt} \longleftrightarrow \text{leading twist op's : Tr } F_{+\nu} D^{j-2} F_{+}^{\nu}$$

- Compute its energy at strong coupling

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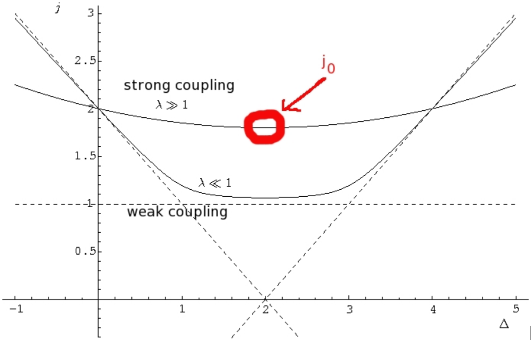
$$j_0 \equiv j(\Delta = 2) = 2 - \underbrace{\frac{2}{\sqrt{\lambda}}}_{[\text{Brower et al. '06}]} \pm \underbrace{\cdots}_{\text{loops @ strong coupl.}}$$

- Interpolating $j_0(\lambda)$ at finite λ using integrability?



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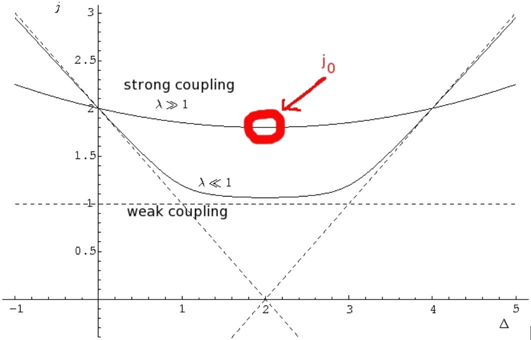

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THANK YOU!

Artwork courtesy of Miriam W. Carothers