Multiplet Recombination in Large N CFT and Holography

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based on work with V. Bashmakov, M. Bertolini and L. Di Pietro
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What is Multiplet recombination?

Example 1: $\lambda\phi^4$ theory in $4-\epsilon$ dim

- For $\lambda = 0$, the spectrum of primary operators contains $\phi, \phi^2, \phi^3, \ldots$. Since ϕ is free, multiplet of ϕ is short

$$\Box\phi = 0$$

- In the Wilson-Fisher fixed point, the spectrum of primary operator diminishes. ϕ^3 becomes a descendant of ϕ through the coupling λ

$$\Box\phi = \frac{\lambda_*}{3!}\phi^3$$

- ϕ acquires an anomalous dimension: $\gamma_\phi = \frac{1}{108}\epsilon^2$
- The conformal multiplets of ϕ and ϕ^3 merge into a single long multiplet at the Wilson-Fisher fixed point [Rychkov,Tan, 2015]

Example 2: $\mathcal{N} = 4$ SYM

- At zero gauge coupling, the theory contains an infinite tower of HS conserved currents
- For $g \neq 0$, all the higher spin currents are broken

$$\partial^{i_1} J_{i_1,i_2,\ldots,i_s} = g\mathcal{X}_{i_2,\ldots i_s}$$

- They all acquire anomalous dimension proportional to the gauge coupling
- The superconformal multiplets of $J_{i_1,\ldots i_s}$ and $\mathcal{X}_{i_2,\ldots i_s}$ merge

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- This phenomenon admits a holographic dual description in terms of Higgs mechanism for the infinite tower of HS gauge fields [Beisert, Bianchi, Morales, Samtleben, Heslop, Riccioni, 2003, 2004]

Multiplet Recombination

Consider two CFTs $\mathcal{P}_0$ and $\mathcal{P}_1$ which are assumed to be connected by either

- Relevant deformation (RG flow)
- Exactly marginal deformation (on a Conformal Manifold)

$$\underset{\text{(short multiplets)}}{\mathcal{P}_0} \xrightarrow{\lambda} \underset{\text{(long multiplets)}}{\mathcal{P}_1}$$

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In this talk, we will focus on scalar multiplet recombination triggered by a relevant double trace deformation in a CFT having a large N expansion parameter and address the problem from AdS/CFT perspective.

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In this talk, we will focus on scalar multiplet recombination triggered by a relevant double trace deformation in a CFT having a large N expansion parameter and address the problem from AdS/CFT perspective.

Motivation: Scalar counterpart of Higgs mechanism in AdS!

Field theory analysis at large N

Double-Trace flow

Double-trace deformation of a large N CFT

$$\int d^d x\, f\, O_1 O_2, \qquad \frac{d}{2} - 1 \le \Delta_1 < \Delta_2 < \frac{d}{2}$$

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Exactly solvable in the large N limit in auxiliary fields σ_1 and σ_2: $\sigma_1 = fO_2,\ \ \sigma_2 = fO_1$. Effective action for $\sigma_{1,2}$ at large N:

$$-\frac{1}{2}\int \left(\sigma_1(k) G_1(k) \sigma_1(-k) + \sigma_2(k) G_2(k) \sigma_2(-k) + \frac{2}{f} \sigma_1(k) \sigma_2(-k) \right)$$

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- σ_1 and σ_2 have IR correlators corresponding to operators with scaling dimension $d - \Delta_1$ and $d - \Delta_2$, respectively.
- No multiplet recombination.

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Holographic analysis

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$$\Phi_i(z,k) \underset{z\to 0}{\sim} (\Phi_i^-(k) z^{\Delta_i} + \Phi_i^+(k) z^{d-\Delta_i})(1+\mathcal{O}(z^2)), \quad i=1,2$$

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- The relevant double trace deformation $\int d^d x\ f\ O_1 O_2$ is implemented by imposing the following boundary condition [Witten, 2001]

$$J_1(k) \equiv (d-2\Delta_1)\Phi_1^+(k) + f\Phi_2^-(k)$$
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- The bulk geometry is still AdS (at least classically)

Holographic double-trace flow

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- The renormalized on-shell boundary action consistent with the boundary conditions

$$S = \frac{1}{2}\int \left((d-2\Delta_1)\Phi_1^+\Phi_1^- + (d-2\Delta_2)\Phi_2^+\Phi_2^- + 2f\Phi_1^-\Phi_2^-\right)$$

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- In AdS there is non-local relation between the Φ_i^+ and Φ_i^- modes

$$\Phi^-[J(k)] = G_i(k)(d-2\Delta)\Phi^+(k)$$

where

$$G_i(k) = -\frac{1}{2}\frac{\Gamma(\frac{d}{2}-\Delta_i)}{\Gamma(1-\frac{d}{2}+\Delta_i)}\left(\frac{k}{2}\right)^{2\Delta_i-d}$$

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- Solve for $(\Phi_1^-, \Phi_2^-, \Phi_1^+, \Phi_2^+)$ in terms of $(J_1, J_2) \rightarrow$ on-shell action explicitly in terms of the sources

Holographic double-trace flow

On-shell action

$$S[J_1, J_2] = \frac{1}{2}\int \frac{d^d k}{(2\pi)^d}\left(J_1(k)\frac{G_1}{1-f^2G_1G_2}J_1(-k) + J_2(k)\frac{G_2}{1-f^2G_1G_2}J_2(-k) - 2J_1(k)\frac{fG_1G_2}{1-f^2G_1G_2}J_2(-k)\right)$$

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$$\left. -2 J_1(k) \frac{f G_1 G_2}{1 - f^2 G_1 G_2} J_2(-k) \right)$$

This action for the sources J_1, J_2 is in exact agreement with the effective action for the fields σ_1, σ_2 obtained from the field theory analysis.

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No multiplet recombination yet!

Singleton Limit: $\Delta_1 \to \frac{d}{2} - 1$

Caveat: Unlike in the FT analysis we cannot simply substitute $\Delta_1 = \frac{d}{2} - 1$ in the on-shell action because the kernel vanishes

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We need to rescale the source as $J(k) = \frac{1}{\sqrt{2\eta}} \hat{J}(k)$, keeping $\hat{J}(k)$ finite in the limit. The resulting action is non-vanishing and gives the two point function of a free scalar.

Holographic multiplet recombination

On-shell action (after rescalings)

$$S = \frac{1}{2}\int \Bigg(\hat{J}_1(k)\frac{-k^{-2}}{1+\hat{f}^2k^{-2}G_2}\hat{J}_1(-k) + J_2(k)\frac{G_2}{1+\hat{f}^2k^{-2}G_2}J_2(-k) + 2\hat{J}_1(k)\frac{\hat{f}k^{-2}G_2}{1+\hat{f}^2k^{-2}G_2}J_2(-k)\Bigg); \quad \hat{J}_1 = \sqrt{2\eta}\,J_1, \hat{f} = \sqrt{2\eta}f$$

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Thank you for your attention!