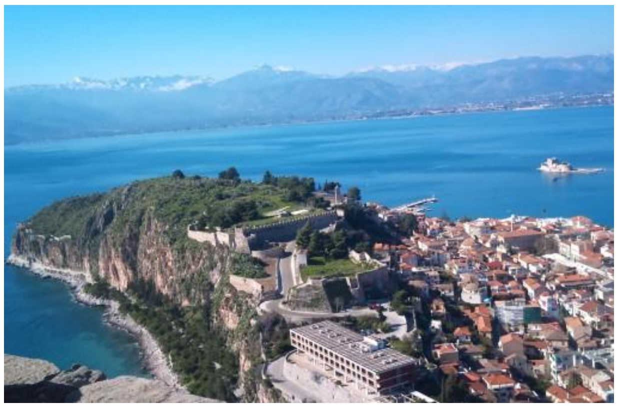
Rigid Holography and 6d N=(2,0) Theories on $AdS_5 x S^1$



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Outline

- Why study field theories on $AdS_p x M_q$?
- Rigid holography + simple examples.
- 6d A_{n-1} $\mathcal{N}=(2,0)$ SCFTs.
- How to study them on $AdS_5 x S^1$ using rigid holography ?
- Naïve analysis $\rightarrow$ a paradox $\rightarrow$ a surprising duality.
- Summary and open questions.

Field Theories on $AdS_p x M_q$ - why ?

- Field theories on curved space exhibit new features not visible in flat space.
- On AdS space have a new knob to turn : boundary conditions.
- Supersymmetric theories on $AdS_p x M_q$ can preserve (all) supersymmetry. Hope to compute many things exactly. Localization?
- Can hope to learn more about mysterious theories (such as 6d $\mathcal{N}$=(2,0) SCFTs).
- Can use AdS/CFT !

Standard AdS/CFT

- A quantum gravity theory on AdS_{d+1} is equivalent to a CFT_d. Symmetries match.
- Need boundary conditions to define. At weak bulk coupling, fields in bulk map to operators (“single-trace”) in the CFT_d. Non-normalizable modes (fixed) map to sources for operators, normalizable modes (fluctuating) to their VEVs.
- Graviton maps to EM tensor T_{mn}.
- Hilbert spaces identical.

Rigid holography

- A quantum field theory on AdS_{d+1} still has same symmetries as a CFT_d.
- Bulk fields still sit in same representations as local operators, can identify source and VEV. Correlators of these operators obey usual conditions (unitarity, crossing, etc.).
- However, no T_{mn}, so cannot be equivalent to a local CFT.
- Example – free field in bulk = single operator and its products = “generalized free field”. Decoupled subsector of CFT.

Rigid holography

- Can we realize interacting theories as decoupled sector in a CFT ? Need to have a limit of the CFT where all correlators $<\mathcal{O}_{QFT} \cdots \mathcal{O}_{QFT}\, \mathcal{O}_{other} \cdots \mathcal{O}_{other}>$ vanish, while some $<\mathcal{O}_{QFT} \cdots \mathcal{O}_{QFT}>$ remain finite.
- Vanishing of normalized $<\mathcal{O}_{QFT}\, \mathcal{O}_{QFT}\, T_{mn}>$ requires $c \rightarrow \infty$, as in large N limit.
- But usually all correlators vanish, so need to have also some other parameters scaling with N to retain finite correlators.

How to find examples ?

- Can sometimes embed a field theory on $AdS_p x M_q$ into string (M) theory on $AdS_m x M_n$ which is dual to an (m-1) dimensional CFT, and take a decoupling limit. So these QFTs are a subsector of (m-1) dimensional CFTs (though not full local CFTs by themselves).
- In flat space string (M) theory with branes / defects, decouple low-energy field theory by taking M_s, M_P to ∞ keeping energies and couplings (g_{YM}) fixed.

How to find examples ?

- In string(M) theory on $AdS_m x M_n$ with branes / defects filling $AdS_p x M_q$, again take M_s and M_P to ∞, but now need to keep R_{AdS} fixed. In dual CFT means taking $M_P\ R_{AdS} \sim N^\alpha$ to ∞.
- Would like to keep QFT couplings fixed – may or may not be possible.
- Naturally keep SUSY.
- So field theory on $AdS_p x M_q$ (with specific boundary conditions) = a subsector of the (m-1) dimensional CFT. **Rigid Holography**

Caveats

- Is it an exact equivalence ? The dual subsector captures the response of the QFT on $AdS_p x M_q$ to sources on the boundary.
- But this QFT also has local correlators in $AdS_p x M_q$. Are these uniquely determined by the response to boundary sources ? (Are local QFT correlators in flat space determined by S-matrix ?)
- Get specific boundary conditions, not clear how to generalize.

Examples in IIB on AdS_5xS^5

- NS5-branes on AdS_4xS^2 (6d SYM, LST) : $M_P R_{AdS} \rightarrow \infty$ requires $N \rightarrow \infty$. $g_6^2 \sim \alpha'$. Can take $M_s \rightarrow \infty$, get free 6d SYM on AdS_4xS^2. Or can keep M_s fixed ($g_s \sim 1/N$), and get UV completion : $\mathcal{N}=(1,1)$ LST on AdS_4xS^2 (non-local non-conformal example).
- D1-branes on AdS_2 (2d SYM) : Again need $N \rightarrow \infty$. Now $g_2^2 R_{AdS}^2 \sim (N g_s^3)^{1/2}$. So can take $g_s \sim 1/N$ and get free 2d SYM, or can keep $N g_s^3$ fixed and get interacting 2d SYM.

Our main example

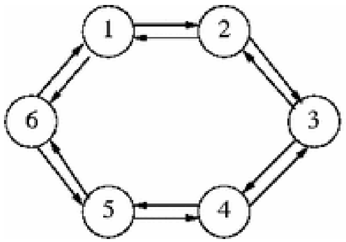
- 6d A_{n-1} $\mathcal{N}=(2,0)$ SCFT on $AdS_5 x S^1$.
- It arises as the low-energy theory on n overlapping IIA NS5/M5-branes.
- The same theory arises in type IIB on a C^2/Z_n orbifold, at its singular point (related by string dualities).
- For a single M5-brane, low-energy theory is a free $\mathcal{N}=(2,0)$ tensor multiplet, containing 5 scalars (transverse motion), a self-dual 2-form ($dB=*dB$) and fermions.

Our main example

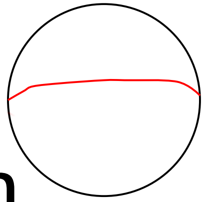
- For $n>1$ get an interacting CFT whose only parameter is n. (Dual for $n \to \infty$.)
- M theory realization implies moduli space is R^{5n}/S_n (removing the center of mass R^5). At generic points get ($n-1$) tensor multiplets.
- In IIB, it is realized by turning on blow-up modes for ($n-1$) 2-cycles localized at the orbifold fixed point (3 scalars each), and two 2-form fields (B_2, C_2) on each of the 2-cycles.
- On $R^5 x S^1$ at low energies get 5d $SU(n)$ SYM with $g_5^2 \sim R_{S^1}$, generally broken to $U(1)^{n-1}$.

$AdS_5 x S^1$ embedded in string theory

- Consider type IIB string theory on $AdS_5 x S^5/Z_n$ = near-horizon limit of K D3-branes on C^2/Z_n. Dual to 4d $\mathcal{N}$=2 $SU(K)^n$ elliptic quiver with bi-fundamental hypermultipets (Kachru-Silverstein).



- Fixed points : $AdS_5 x S^1$ in $AdS_5 x S^5/Z_n$, locally have a C^2/Z_n orbifold there.



- At orbifold point B_2 fields non-zero. When vanish get 6d $\mathcal{N}$=(2,0) A_{n-1} SCFT on $AdS_5 x S^1$ (coupled to rest of type IIB), with $R_{AdS}=R_S$ and specific boundary conditions.

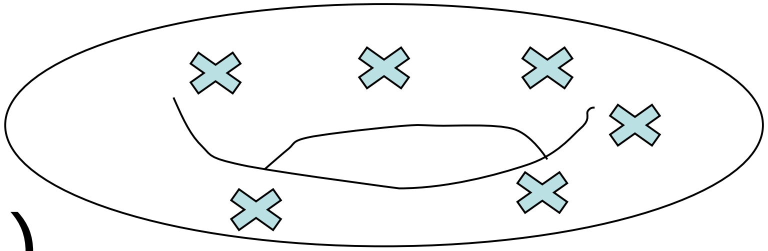
- 4d $\mathcal{N}$=2 SCFT has n exactly marginal deformations = complex gauge couplings.
- One maps to type IIB dilaton-axion.
- Other (n-1) map to B_2 and C_2 on 2-cycles of singularity. Other blow-up modes tachyonic.
- Near this point "moduli space" (space of SUSY vacua on AdS_5) is C^{n-1}/S_n with A_{n-1} (2,0) SCFT arising at the origin.
- Preserve 16 supercharges.
- At generic points on the "moduli space" have (n-1) 6d 2-forms $\rightarrow$ $U(1)^{n-1}$ gauge theory on AdS_5. Dual to $U(1)^n$ global symmetry of hypermultiplets (diagonal U(1) geometrical).

Naïve expectation

- At origin of "moduli space" expect $\mathcal{N}$=(2,0) theory on S^1 to give an SU(n) gauge theory on AdS_5. Would mean global symmetry of 4d $\mathcal{N}$=2 SCFT enhanced to SU(n).
- But can show from 4d $\mathcal{N}$=2 representations that global symmetries in 4d $\mathcal{N}$=2 SCFTs cannot be enhanced as a function of exactly marginal deformations (unlike in 4d $\mathcal{N}$=1), except at free points (high-spin currents).
- Consistent since W-bosons not BPS.
- What does happen in this 4d $\mathcal{N}$=2 SCFT ?

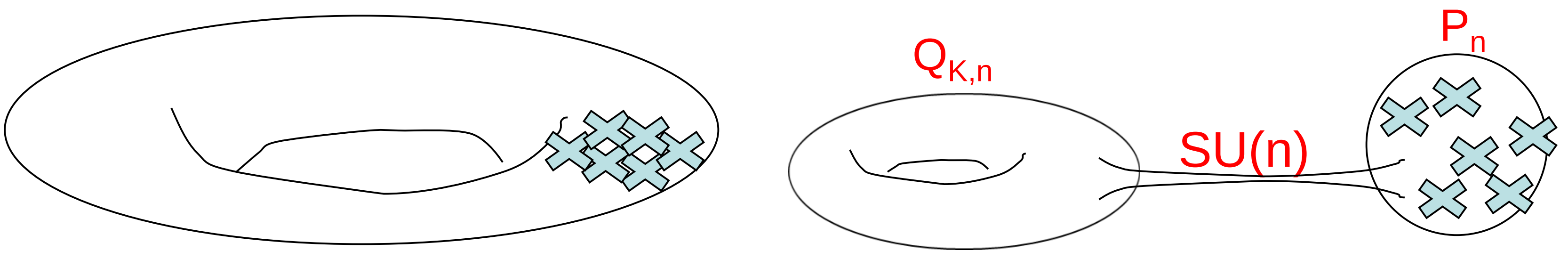
Singular limit in 4d $\mathcal{N}$=2 SCFT

- Space of couplings of $SU(K)^n$ quiver is the moduli space of n marked points on a torus (Witten). In Gaiotto language obtain this from A_{K-1} 6d (2,0) theory on a torus with n minimal (U(1)) punctures. Has a weakly coupled $SU(K)^n$ limit.
(Throats = weakly coupled 4d $\mathcal{N}$=2 theories.)



- Origin of “moduli space” : n punctures come together = (n-1) couplings go to infinity.

Singular limit in 4d $\mathcal{N}$=2 SCFT

- 

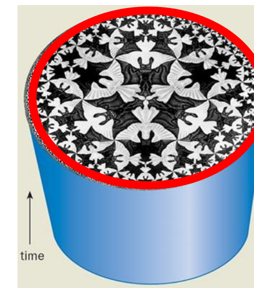
- Studied already (local on Riemann surface).
- Global symmetry not enhanced ☺, but get a weakly coupled SU(n) gauge theory, with $g_{SU(n)}$ going to zero at origin, coupled to two different 4d $\mathcal{N}$=2 SCFTs with SU(n) global symmetry : A_{K-1} on a torus with a single SU(n) puncture ($Q_{K,n}$) and a sphere with one SU(n) puncture and n U(1) punctures (P_n).

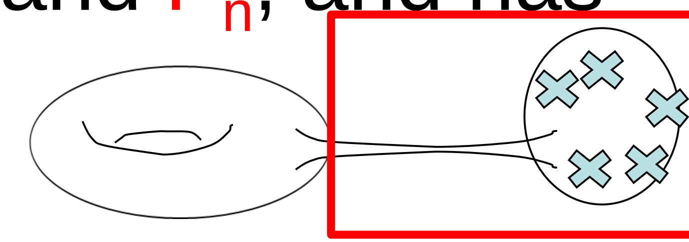
Singular limit in 4d $\mathcal{N}$=2 SCFT

- New SU(n) is strong-weak dual to original $SU(K)^n$; similar to Argyres-Seiberg.
- Implies that 4d $\mathcal{N}$=2 SCFT has at singular point an infinite number of conserved high-spin currents (instead of naïve expectation – new global SU(n)). These should somehow be part of $\mathcal{N}$=(2,0) theory on $AdS_5 x S^1$.
- Does this local field theory develop massless high-spin fields ? Not impossible on AdS_5, but very strange. Would like

Alternative description

- Can we get around inevitable conclusion ?
- We propose a simpler picture. The new 4d SU(n) and the P_n theory can live on the boundary of AdS_5; can have 4d $\mathcal{N}$=2 theories living there. The 4d SU(n) theory couples to both $Q_{K,n}$ and P_n, and has a vanishing beta function.





- Identify the bulk theory with the $Q_{K,n}$ theory. The 4d SU(n) gauge theory must couple to 5d SU(n) gauge fields on AdS_5, helping to cancel its beta function.

Alternative description features

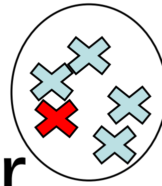
- Should be related by duality (extra AdS/CFT for $SU(n)xP_n$?) to the picture with high-spin fields in the bulk, but seems much simpler.
- Have SU(n) in AdS_5 but no global symmetry. Usually say unique boundary condition for G gauge fields on AdS_5 !? When have global symmetry G can always gauge it = couple to 4d G gauge fields on boundary. When bulk theory is weakly coupled, get large $(R_{AdS}/g_G{}^2)$ contribution to beta function of 4d G, inconsistent with conformal symmetry.

Alternative description consequences

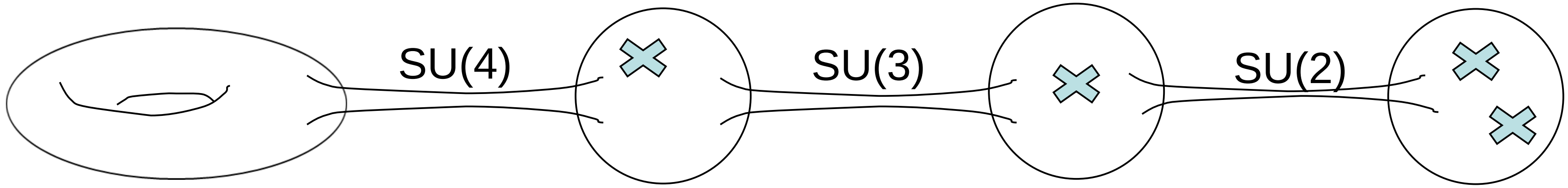
- In our case we know contribution to beta function. Implies bulk 5d SU(n) is strongly coupled at R_{AdS}. Thus, no contradiction with standard semi-classical analysis of allowed boundary conditions.
- On the "moduli space" 5d SU(n) behaves <u>very differently</u> from the naïve expectation: <u>not</u> broken to $U(1)^{n-1}$ (exactly marginal deformations described by changing couplings of SU(n) and P_n on boundary; $U(1)^{n-1}$ acts on boundary P_n theory).

Moduli space of (2,0) on AdS$_5$xS^1

- At origin of “moduli space” coupling constant of 4d SU(n) goes to zero – <u>infinitely far away</u> (in natural Zamolodchikov metric).
- Moreover, origin of “moduli space” is not just a point but an (n-2)-dimensional space – space of moduli of P_n theory = a sphere with (n+1) marked points. Big change…

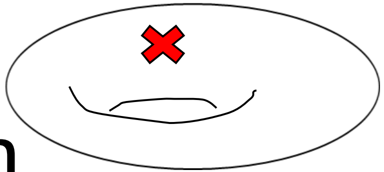


- The P_n theory has a region in its parameter space where it becomes a weakly coupled 4d SU(n-1)xSU(n-2)x…xSU(2) theory with bi-fundamental hypers + 1+n fundamentals.



- Note all beta functions in this chain vanish. $Q_{K,n}$ (5d bulk) contributes to beta function of SU(n) like (n+1) fundamental hypers.
- In this region it is easy to compute how many d.o.f. we are adding on the boundary (say in sense of conformal anomalies) : $O(n^3)$. Amusing since bulk 6d (2,0) theory also has $O(n^3)$ d.o.f. But no clear relation – for instance, 6d d.o.f. and 4d d.o.f. lead to a different density of states as a function of temperature / energy.

- This is all for the specific boundary condition that we get from type IIB. Can also take a "standard" boundary condition for 5d SU(n) gauge fields, and then the (2,0) theory is part of the gravitational dual to the $Q_{K,n}$ theory (which has an SU(n) global symmetry). In this case the (2,0) theory has no "moduli space". How is this dual related to the previous one ?



- To decouple should take $K \rightarrow \infty$ with couplings as above. Limit of 4d $\mathcal{N}=2$ SCFT contains a subsector dual to $\mathcal{N}=(2,0)$ theory on $AdS_5 x S^1$.

Summary

- Introduced "rigid holography", and used it to show that A_{n-1} (2,0) theories on AdS_5xS^1 with $R_{AdS}=R_S$ and specific b.c. are different from expected – "moduli space" is singular near origin, have SU(n) gauge fields on AdS_5 but with different behavior than in flat space.
- This theory appears as a decoupled sector in the large K, strong coupling limit of 4d $\mathcal{N}=2$ $SU(K)^n$. Can get same theory also from IIA backgrounds with n NS5-branes on AdS_5xS^1, dual to other 4d $\mathcal{N}=2$ quiver SCFTs.

Summary

- In retrospect, the behavior of the A_{n-1} (2,0) theories on $AdS_5 x S^1$ is not so surprising. They have a strongly coupled SU(n) gauge theory on AdS_5, as expected, and this theory does not have a "moduli space", presumably because its' scalars are tachyonic.
- Surprise is that when this theory is coupled to a 4d SU(n)xP_n theory on the boundary of AdS_5, have a very different dual description with $U(1)^{n-1}$ gauge fields in the bulk, and nothing on the boundary.

Further questions

- What can we compute (16 supercharges)? Localization in 4d $\mathcal{N}$=2 SCFT ? Directly on $AdS_5 x S^1$? (Work in progress)
- Gravity dual for (2,0) theory on $AdS_5 x S^1$?
- Are "boundary correlators" (computable in principle) enough to characterize A_{n-1} (2,0) theory on $AdS_5 x S^1$? (Is S-matrix enough?)
- Other boundary conditions? "Standard" with SU(n) global symmetry for any R_{AdS}/R_S, for specific R_{AdS}/R_S can couple to 4d $\mathcal{N}$=2 SU(n) theory on the boundary. Embed in string?

Further questions

- Far on “moduli space”, got a description with $U(1)^{n-1}$ and “moduli” coming from the bulk; near the origin, have a description where they come from the boundary. What is relation between them ? AdS/CFT ? Strong-weak duality (similar to Gaiotto-Witten) ?
- Do other sets of punctures coming together on a Riemann surface also correspond to (2,0) theories on $AdS_5 x S^1$ (b.c.) ? For a torus it seems so. Can we bring together punctures+handles ?

Further questions

- Many possible generalizations. Simple to get generalization to (2,0) LST on $AdS_5 x S^1$.
- Other D_n and E_n $\mathcal{N}$=(2,0) theories on $AdS_5 x S^1$ can be similarly studied using other orbifolds of type IIB on $AdS_5 x S^5$.
- Rigid holography should be useful for studying various $\mathcal{N}$=(2,0) theories on $AdS_4 x S^2$ and $AdS_3 x S^3$, 6d $\mathcal{N}$=(1,0) theories on $AdS_5 x S^1$ and other manifolds, 5d theories on $AdS_4 x S^1$, 4d $\mathcal{N}$=4 SYM on $AdS_3 x S^1$, etc.