5d SCFTs from brane webs and O7-planes

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Overview

1. Introduction

- Generalities of 5d gauge theories

- String description using brane webs

- Superconformal index

2. Brane webs in the presence of O7^{-}

3. Brane webs in the presence of O7^{+}

4. Conclusions
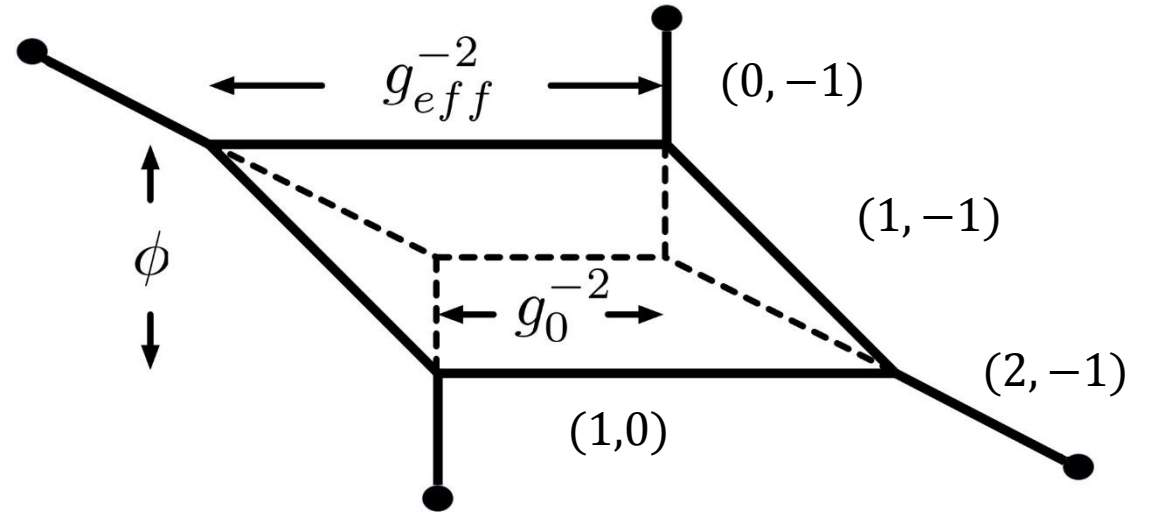
1. Introduction: 5d gauge theories

- 5d gauge theories are non-renormalizable.
- Example: N=2 SYM → 6d (2,0) theory.
- Yet, in the N=1 SUSY case a UV fixed point may exist.
- Exhibit interesting non-perturbative properties such as enhancement of symmetry and duality.

Enhancement of symmetry

- In 5d every simple non-abelian gauge group has a topologically conserved $U(1)$ current: $J \sim \; * Tr \; F \; \wedge \; F$.

- This current is carried by instatnon particles.

- These can provide additional conserved currents leading to an enhancement of symmetry.

- A classic example is an $SU(2) + N_F$, with $N_F < 8$, where instantons enhance the classical $U(1) \times SO(2N_F)$ global symmetry to E_{N_F+1}.

Brane webs

- Convenient way to represent 5d gauge theories.

- Parameters represented by position of external branes.

- Moduli represented by moving internal branes.

- Fixed point realized when all the 5-branes intersect at a point.

Dualities in 5d N=1 SUSY

$$SU(3)_0 + 2$$

mass deformation

S-duality + mass deformation

$$SU(2)_\pi \times SU(2)_\pi$$
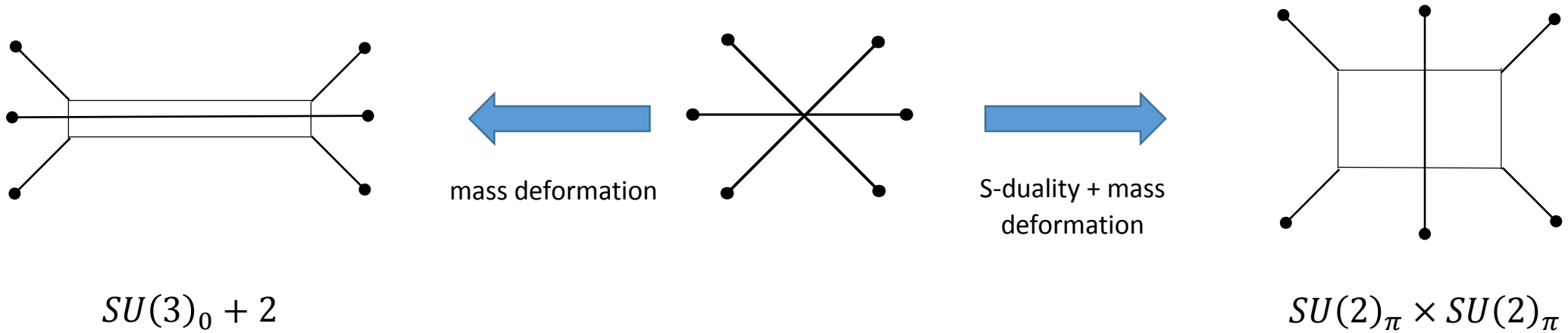
- A single fixed point can have more than one gauge theory deformation.

- This is called a 5d duality: two different gauge theories flowing to the same UV fixed point.

Superconformal index

- Useful tool to study 5d SCFT.

- It is a counting of the BPS operators of the SCFT and thus a protected quantity.

- Can be calculated exactly given a gauge theory description.

- The expression involves a perturbative and a non-perturbative part. The non-perturbative part given by the 5d Nekrasov partition function.

$$\mathcal{I} = \text{Tr} \, (-1)^F \, x^{2\,(j_1+R)} \, y^{2\,j_2} \, \mathfrak{q}^{\mathfrak{Q}}$$

$$\mathcal{I} = \int [d\alpha] PE[f_{perturbative}] |Z_{Nekrasov}|^2$$

Nekrasov partition function

- An important part in the calculation is evaluating the non-perturbative part: the Nekrasov partition function.

- Expressions for classical gauge groups with several types of matter content exist in the literature.

- Nevertheless, in some cases extraneous degrees of freedom must be removed by hand.

- Most conveniently done in string theory.

- In brane webs, these appear as D-strings stretched between parallel external $(q, 1)$ 5-branes.
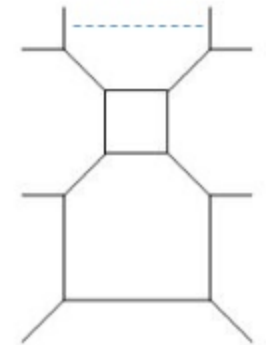
$SU(3)_1 + 4$

Introduction summary

- 5d gauge theories can go in the UV to a SCFT.

- Exhibit interesting behavior: symmetry enhancement and duality.

- Can be studied using string theory, for example: brane webs.

- Want to extend this to as many systems as possible. Particularly consider also SO and USp groups.

- This can be achieved by incorporating orientifolds.
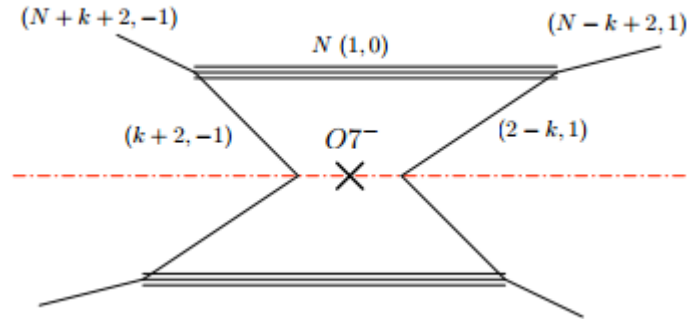
2. Webs with O7 planes

- Adding an O7 plane parallel to the D7-brane does not break supersymmetry.

- Effects of the O7 plane:

  ▪ Inversion symmetry.

  ▪ Monodromy.

  ▪ Two types of O7 planes:

$$O7^-, M_{O7-} = -T^{-4}$$
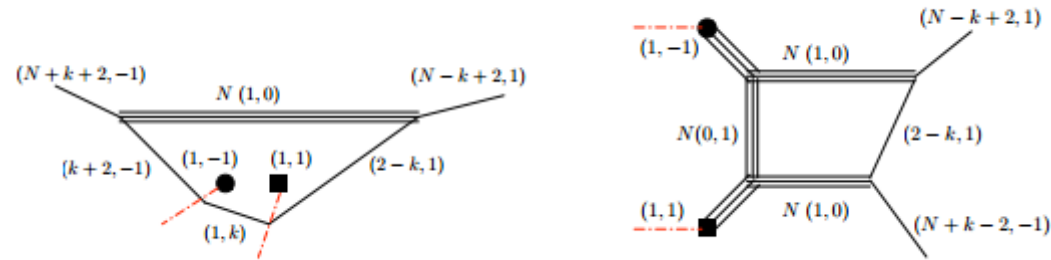
$$O7^+, M_{O7+} = -T^4$$

$$T = \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix}$$

$O7^-$

- Adding an $O7^-$ allows describing $USp(2N)$ gauge theories.
- Discontinuity due to the $O7^-$ monodromy.
- One more discrete parameter k - expected to map to the USp θ angle.
- However the $O7^-$ is T invariant.
- Possible resolution: $O7^-$ is only T^2 invariant.

$O7^-$: resolving the orientifold

- One can resolve the $O7^-$ plane.
- Map the description to one using ordinary brane webs.
- The USp θ angle depend on k and the choice of resolution: $\theta \sim k \bmod 2$.

$O7^-$: flavors 1

- Can generalize by adding flavor.
- Suggests enhancement of symmetry in the $N_f = 2N + 4$.
- There is a D-string state stretched between the two NS5-branes.
- Appears as a extraneous state in the Nekrasov partition function.
- The web description can then be used to understand the spectrum of such states.
- Adding more flavors results in external brane intersection: the $N_f \leq 2N + 4$ bound of Seiberg et. al.

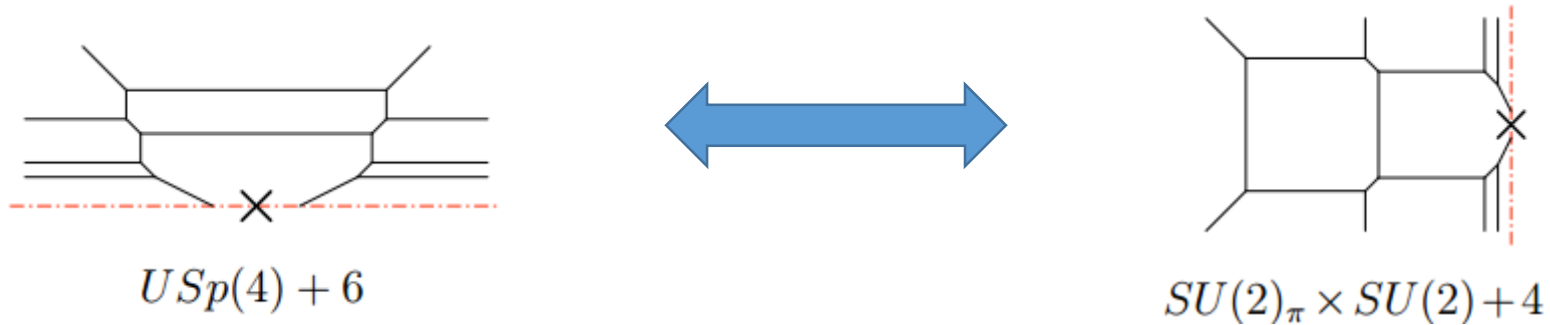
$$USp(2N) + (2N + 4)$$
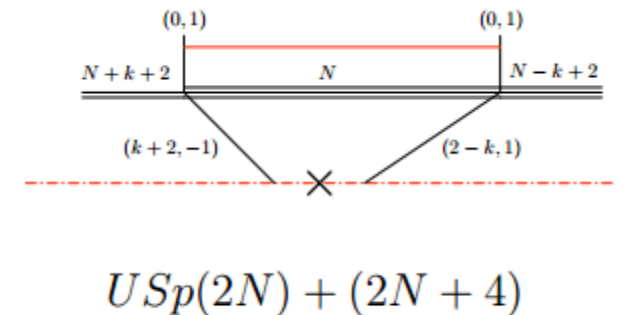
$O7^-$: flavors 2

- Can add one more flavor: intersection avoided by virtue of the S-rule.

- Suggests that a fixed point exist if $N_f < 2N + 6$.

- Suggests enhancement of the $SO(4N + 10)$ symmetry to $SO(4N + 12)$ in the $N_f = 2N + 5$ case.

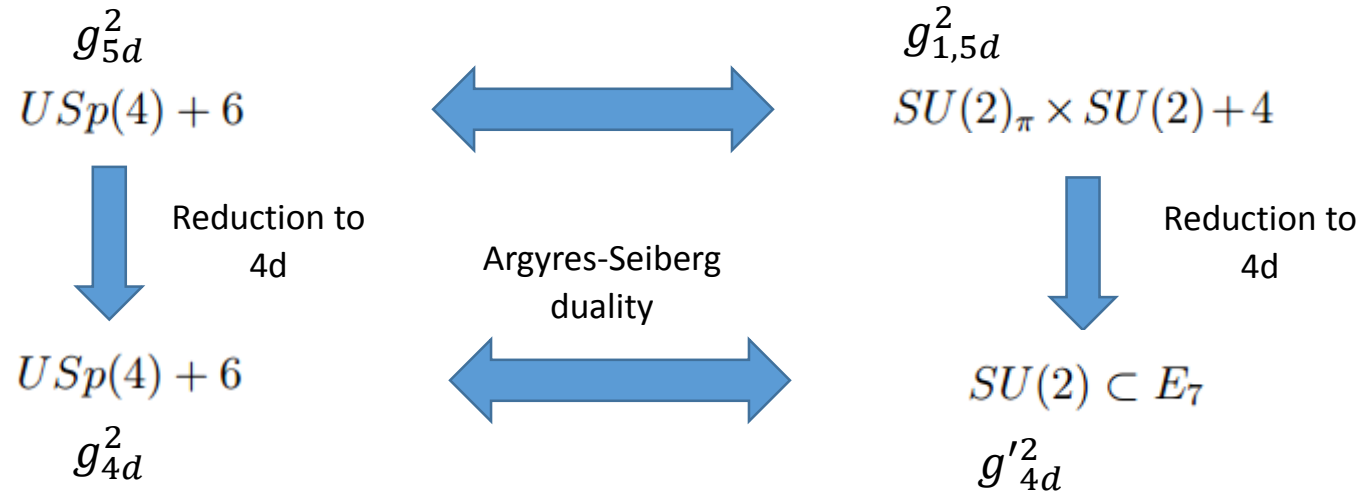- Allows determining the extraneous states spectrum also in this case.

$$USp(2N) + (2N + 5)$$
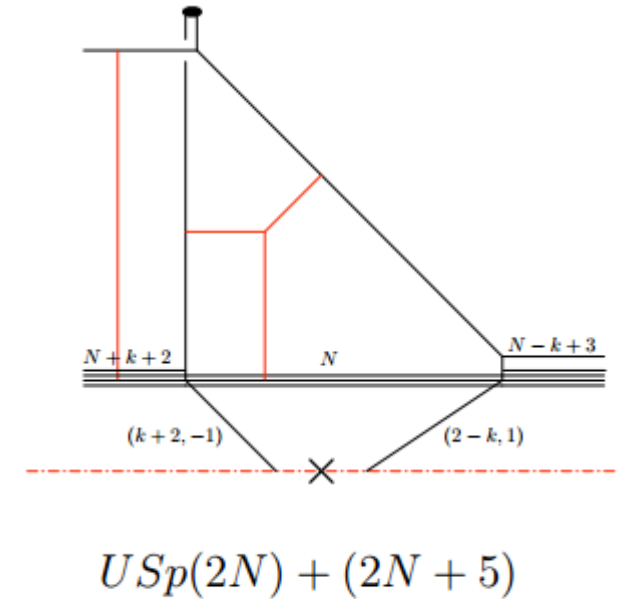
$O7^-$: duality 1

$USp(4) + 6$

$SU(2)_\pi \times SU(2) + 4$

- The webs also allows us to study 5d dualities.
- Example: $USp(4) + 6 \leftrightarrow SU(2)_\pi \times SU(2) + 4$.
- Instantons of the right $SU(2)$ lead to an enhancement of $U(1) \times SU(2) \times SO(8) \to SO(12)$. This matches the $SO(12)$ on the $USp(4)$ side.
- The $USp(4)$ topological $U(1)$ is then mapped the left $SU(2)_\pi$ topological $U(1)$.

$O7^-$: duality 2

g_{5d}^2

$USp(4)+6$ ⟷ $g_{1,5d}^2$ $SU(2)_\pi \times SU(2)+4$

Reduction to 4d   Argyres-Seiberg duality   Reduction to 4d

$USp(4)+6$ ⟷ $SU(2) \subset E_7$

g_{4d}^2 g'^2_{4d}

- Interesting implications in the 4d reduction.
- To reduce the $USp(4)$ gauge theory from 5d to 4d, compactify on a circle of radius R, and take the limit: $R \to 0$, $g_{5d}^2 \to 0$ keeping $\frac{g_{5d}^2}{R} \to g_{4d}^2$ fixed.
- The mapping of symmetries implies that on the dual side the reduction is done as: $R \to 0$, $g_{1,5d}^2 \to 0$ keeping $\frac{g_{1,5d}^2}{R} \to g'^2_{4d}$ fixed.
- In 4d we get Argyres-Seiberg duality.

$O7^-$: with stuck NS5-brane

- Can generalize by adding a stuck NS5-brane.
- This describes an $SU(2N)_k$ gauge theory with one antisymmetric hypermultiplet.
- There is one discrete parameter that should map to the Chern-Simons level.
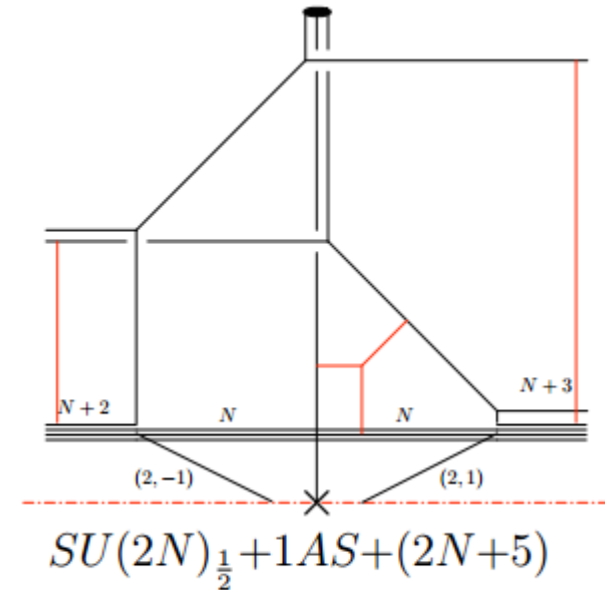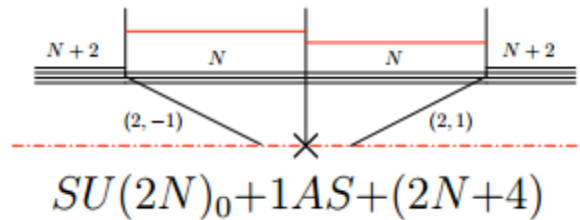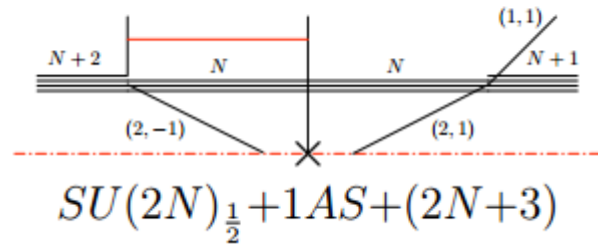- Can generalize to the $SU(2N+1)_k$ case by adding a stuck D5-brane.

$$SU(2N)_k + 1AS$$
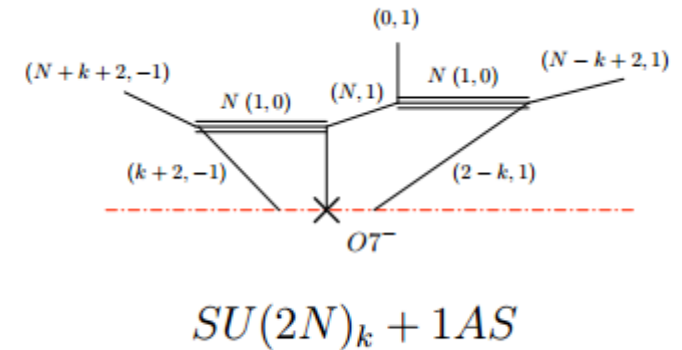
$O7^-$ +NS5-brane: resolution
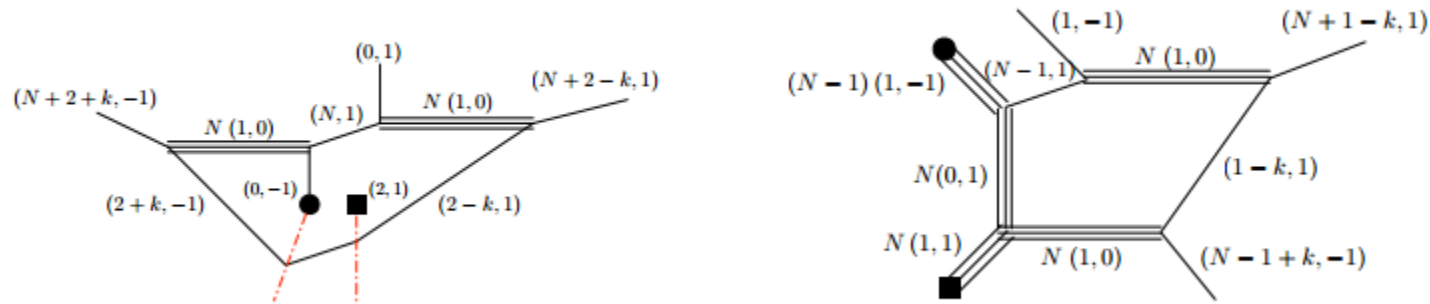
- Using the resolution of the $O7^-$, we conjecture the resolution also for the case with the stuck NS5-brane.

- We can then map the system to one of the ordinary brane webs.

$O7^-$+NS5-brane: flavors

$SU(2N)_{\frac{1}{2}}+1AS+(2N+3)$ $SU(2N)_0+1AS+(2N+4)$ $SU(2N)_{\frac{1}{2}}+1AS+(2N+5)$

- Can generalize by adding flavor. We find a good brane web as long as $N_f + 2|k| \leq 2N + 6, N_f \neq 2N + 6$.

- Very different from the $N_f + 2|k| \leq 8 - 2N$ of Seiberg et. al.

- The webs suggests enhancement of symmetry and can be used to remove extraneous states.

3. $O7^+$

$$SO(2N) \qquad\qquad SO(2N+1)$$
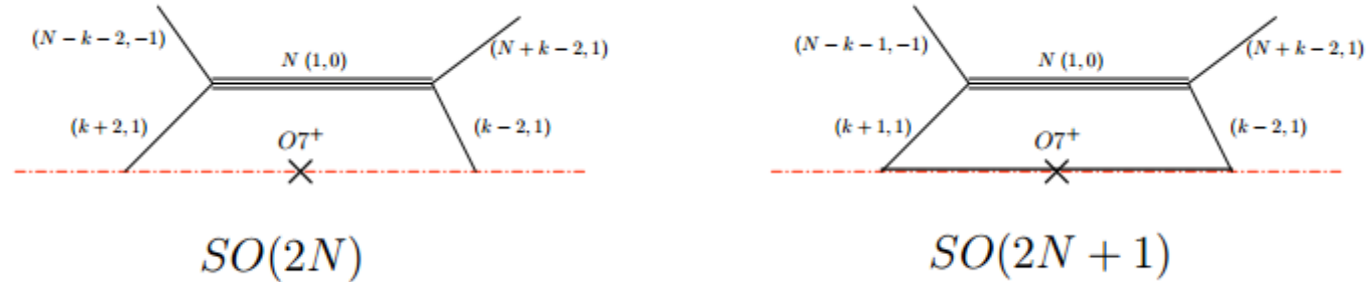
- Adding an $O7^+$ allows describing $SO(M)$ gauge theories.
- Again there is one more discrete parameter k.
- No analogue gauge theory parameter.
- Thus, it appears that $O7^+$, unlike $O7^-$, is T invariant.

$O7^+$: flavors

$$SO(2N) + (2N - 4)$$

$$SO(2N) + (2N - 3)$$
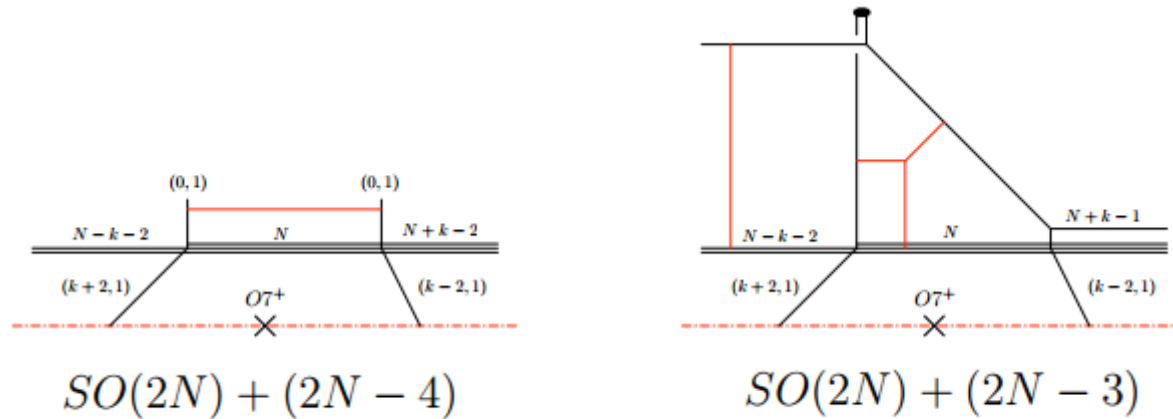
- Can generalize by adding flavor.
- Suggests that a fixed point exist if $N_f < M - 2$. This is one more than the bound of Seiberg et. al.
- Suggests enhancement of symmetry in the $N_f = M - 4$ and $N_f = M - 3$ cases.
- Allows determining the extraneous states spectrum.

$O7^+$ with stuck NS5-brane

$$SU(2N)_k + 1S$$
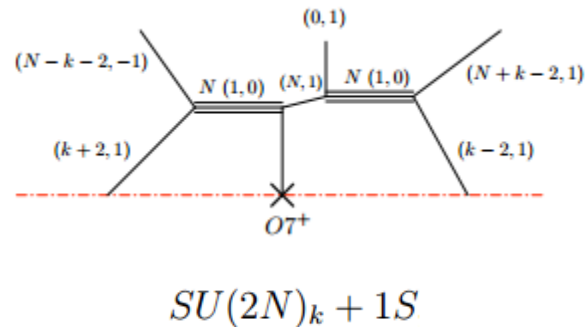
- Can also consider adding a stuck NS5-brane. This leads to an $SU(M)_k$ gauge theory with one symmetric hypermultiplet.

- These theories were ruled out by Seiberg et. al.

- This suggests that these theories do exist as 5d fixed points.

4. Conclusions

- One can extend the use of brane webs by considering orientifold planes.

- Useful for: new fixed points, motivating symmetry enhancement and dualities as well as assisting in index calculation.

Generalizations

- With O7: $SU(N)$ quivers with USp/SO or $SU(N) + S/AS$ ends.

- Can also consider O5 planes: $USp - SO$ quivers.

Thank you