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Considerations on Super Poincaré Algebras and their Extensions to Simple Superalgebras

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Abstract

We consider simple superalgebras which are a supersymmetric extension of the spin algebra in the cases where the number of odd generators does not exceed 64. All of them contain a super Poincaré algebra as a contraction and another as a subalgebra. Because of the contraction property, some of these algebras can be interpreted as de Sitter or anti de Sitter superalgebras. However, the number of odd generators present in the contraction is not always minimal due to the different splitting properties of the spinor representations under a subalgebra. We consider the general case, with arbitrary dimension and signature, and examine in detail particular examples with physical implications in dimensions $d = 10$ and $d = 4$.

1 Introduction

Super Poincaré algebras [1] are non semisimple superalgebras [2, 3, 4]. (For a review see Ref.[5, 6]). They have in their even part an abelian ideal that contains the spacetime translation generators and a certain number of "central charges" (central with respect to the translation generators only, since they are in tensorial representations of the Lorentz group), whose physical interpretation is related to p-brane charges [7, 8].

Superconformal algebras are simple supersymmetric extensions of the conformal algebra. In Ref.[9] these extensions for $N = 1$ were studied for arbitrary dimension ($d = s + t$) and signature ($\rho = s - t$) and in Ref.[10] the case of extended supersymmetry was treated. There are in general two superconformal algebras, a maximal one which is always $\mathfrak{osp}(1|2Nn)$ ($2n$ is the dimension of the spinor representation of the odd generators) and a minimal one, whose bosonic part is the Spin(s,t)-algebra of the spinor representation. Only in dimensions $d = 3, 4, 5, 6$ it is possible to find a simple superalgebra with a bosonic part which factorizes as a direct sum of the orthogonal algebra $\mathfrak{so}(s,t)$ plus a simple R-symmetry algebra [11], as required by the Coleman-Mandula theorem [12]. The odd part of the superalgebra is a direct sum of fundamental representations of $\mathfrak{spin}(s,t)$ [13]. For higher dimensions, the bosonic part is also the direct sum of an R-symmetry subalgebra and a spacetime subalgebra, but the spacetime subalgebra is enlarged with extra generators.

In the web of connections between string theory and M -theory [14], or possible generalizations as F-theory [15] or S-theory [16], it is natural to investigate the role played by the simple superalgebra, even in the cases $d > 6$ [9, 10, 17, 18, 19, 20]. As in the purely bosonic case, the super Poincaré algebra with central charges can be obtained from simple superalgebras in two different ways. One is by contraction [21], the other as sub-superalgebra [17, 18].

Let spacetime be a manifold of dimension d with an (indefinite) metric of signature (s,t). The Poincaré group acts on flat spacetime, $\mathbb{R}^d \simeq \mathrm{ISO}(s,t)/\mathrm{SO}(s,t)$. Its Lie algebra, $\mathfrak{iso}(s,t)$, is a subalgebra the conformal algebra of $\mathbb{R}^d$, the simple algebra $\mathfrak{so}(s+1,t+1)$ [22]. Other possible backgrounds are the symmetric spaces $\mathrm{SO}(s+1,t)/\mathrm{SO}(s,t)$, with signature (s,t). There is a contraction of the isometry algebra $\mathfrak{so}(s+1,t)$ which gives the Poincaré algebra $\mathfrak{iso}(s,t)$. Interchanging the roles of s and t we have a different contraction, from $\mathfrak{so}(s,t+1)$. For physical signature the two spaces are the de Sitter space $\mathrm{SO}(d,1)/\mathrm{SO}(d-1,1)$ and the anti de Sitter one $\mathrm{SO}(d-1,2)/\mathrm{SO}(d-1,1)$. Unitary multiplets of the anti de Sitter superalgebra in dimension 11, $\mathfrak{osp}(1|32)$ where investigated in Ref.[23].

The super Poincaré algebra in dimension d is a subalgebra of the superconformal algebra in the same dimension, appearing with different number of "central charges", depending whether one looks at the minimal or the maximal superconformal algebra. Ref.[24] is an attempt to formulate M-theory as a spontaneously broken phase of its superconformal extension, where the symmetry under the superconformal algebra $\mathfrak{osp}(1|64)$ is broken to the super Poincaré subalgebra with 2 and 5-brane charges.

Anti de Sitter and de Sitter superalgebras play an important role in the framework of the AdS and dS/CFT duality [25, 26, 27, 28].

Also, it is possible to obtain the super Poincaré algebra as a contraction of a simple superalgebra. We have the de Sitter and anti de Sitter superalgebras (simple extensions of the de Sitter and anti de Sitter algebras respectively), although not always the contraction of an $N=1$ super algebra gives an $N=1$ super Poincaré algebra. In Ref.[19] the possibility of using some superalgebra gauge theory which gives M-theory as a particular low energy configuration (contraction) is explored.

Simple super algebras embedding ordinary spacetime supersymmetry algebras are also relevant to explore how the theories depend upon the signature of space-time and provide a clue on the existence of supergravity theories with non lorentzian spacetime signature, as conjectured in Ref.[29] on the basis of time like T duality, with the M, M' and M*-theories in eleven dimensions.

The paper is organized as follows. In Section 2 we enumerate all the (minimal) superconformal algebras with 64, 32, 16 and 8 spinor charges in dimensions $d=3,\dots 11$ and arbitrary signature. We observe that the same superalgebra may be obtained from spacetimes with different signatures ρ,ρ' if they are congruent mod 8, $\rho=\pm\rho'+8n$, which may suggest a duality of the physical theories. In Section 3 the de Sitter and anti de Sitter superalgebras in dimensions $d=3,\dots 12$ are considered and their contractions to super Poincaré algebras are studied. In Section 4 we consider physically interesting examples in $d=4$ and $d=10$.

2 Super conformal algebras in diverse dimensions

Superconformal algebras with up to 64 spinor real charges correspond to different real forms of complex superalgebras whose even part contains $\mathfrak{so}(s+1,t+1)$ and whose odd part is a direct sum of spinor representations of the same algebra. A spinor in dimension $d+2$, $d=s+t$, has complex dimension $2^{(d+1)/2}$ for d odd and $2^{d/2}$ for d even (chiral spinors). The dimension of the real representation depends on the reality condition (the same than the complex in the real case, twice the complex dimension in the quaternionic and complex case). In even dimension, when the superalgebra is of type $\mathfrak{sl}(m|n)$ $(d+2=2,6)$, it contains left and right spinors (non chiral algebra) while if the algebra is of type $\mathfrak{osp}(m|n)$ then it is chiral (in fact, the metric preserving condition halves the number of odd generators with respect to the linear superalgebra). For example, for $d=12$ the superconformal algebra is linear (or unitary) and for $N=1$ it has already 128 charges. So the maximal dimension that we can consider is $d=11$.

$d=11$**.** For $\rho=1,7$ mod 8 we have $\mathfrak{osp}(1|64)$ with 64 odd charges. It corresponds to spacetimes of type (10,1) (M-theory), (9,2) (M*-theory) and (6,5) (M'-theory) [29].

$d=10$**.** For $\rho=0$ mod 8, we have $\mathfrak{osp}(2-q,q|32)$, $(q=0,1)$ with 64 charges and $\mathfrak{osp}(1|32)$ with 32 charges. They correspond to spacetimes of type (5,5) and (9,1).

For $\rho=2,6$ mod 8 we have $\mathfrak{osp}(1|32,\mathbb{C})$ with 64 odd charges and spacetimes of type (6,4), (10,0) and (8,2).

For $\rho=4$ we have $\mathfrak{osp}(2^*|16,16)$ with 64 charges and spacetime (7,3).

These correspond to different forms of Type IIA, IIB and (1,0) theories studied in Ref.[29].

$d=9$**.** For $\rho=1,7$ mod 8 we have $\mathfrak{osp}(2-q,q|32)$ $(q=0,1)$ with 64 charges and $\mathfrak{osp}(1|32)$ with 32 charges. They correspond to spacetimes of type (9,0), (5,4), (8,1).

For $\rho=3,5$ we have $\mathfrak{osp}(2^*|16,16)$ with 64 charges and spacetimes of type (6,3) and (7,2).

$d = 8$. For $\rho = 0$ mod 8 we have $\mathfrak{sl}(16|2)$ with 64 charges and $\mathfrak{sl}(16|1)$ with 32 charges. They correspond to spacetimes of types (4,4) and (8,0).

For $\rho = 2, 6$ we have $\mathfrak{su}(8, 8|2-q, q)$ $(q = 0, 1)$ with 64 charges and $\mathfrak{su}(8, 8|1)$ with 32 charges. They correspond to spacetimes of type (5,3) and (7,1).

For $\rho = 4$ mod 8 we have $\mathfrak{su}^*(16|2)$ with 64 charges and spacetime of type (6,2).

$d = 7$. For $\rho = 1, 7$ we have $\mathfrak{osp}(8, 8|4)$ with 64 charges and $\mathfrak{osp}(8, 8|2)$ with 32 charges. They correspond to spacetimes of type (4,3) and (7,0).

For $\rho = 3, 5$ we have $\mathfrak{osp}(16^*|4 - 2q, 2q)$ $(q = 0, 1)$ with 64 charges and $\mathfrak{osp}(16^*|2)$ with 32 charges. They correspond to spacetimes of type (5,2) and (6,1).

$d = 6$. For $\rho = 0$ we have $\mathfrak{osp}(4, 4|8)$ with 64 charges, $\mathfrak{osp}(4, 4|4)$ with 32 charges and $\mathfrak{osp}(4, 4|2)$ with 16 charges. They correspond to spacetime of type (3,3).

For $\rho = 2, 6$ we have $\mathfrak{osp}(8|4, \mathbb{C})_{\mathbb{R}}$ with 64 charges and $\mathfrak{osp}(8|2, \mathbb{C})$ with 32 charges. They correspond to spacetimes of type (6,0), (4,2).

For $\rho = 4$ we have $\mathfrak{osp}(8^*|8 - 2q, 2q)$ $(q = 0, 1, 2)$ with 64 charges, $\mathfrak{osp}(8^*|4 - 2q, 2q)$ $(q = 0, 1, 2)$ with 32 charges and $\mathfrak{osp}(8^*|2)$ with 16 charges. They correspond to spacetime of type (5,1).

$d = 5$. For $\rho = 1$ we have $\mathfrak{osp}(4, 4|8)$ with 64 charges, $\mathfrak{osp}(4, 4|4)$ with 32 charges and $\mathfrak{osp}(4, 4|2)$ with 16 charges. They correspond to spacetime of type (3,2).

For $\rho = 3, 5$ we have $\mathfrak{osp}(8^*|8-2q, 2q)$ $(q = 0, 1, 2)$ with 64 charges, $\mathfrak{osp}(8^*|4-2q, 2q)$ $(q = 0, 1)$ with 32 charges and $\mathfrak{osp}(8^*|2)$ with 16 charges. They correspond to spacetimes of type (5,0) and (4,1).

For $d = 5$ there exists a smaller superalgebra, the exceptional superalgebra $\mathfrak{f}_4^p$. The integer number p denotes the real form of the complex superalgebra $\mathfrak{f}_4$, which depends on the signature of spacetime. For $\rho = 3, 5$ the even part of the superalgebra is $\mathfrak{spin}(7 - p, p) \oplus \mathfrak{su}(2)$ with $p = 2, 1$. In these signatures, the spinors are quaternionic (pseudoreal), so there exists a pseudoconjugation in the spinor space, which together with the pseudoconjugation in the fundamental of $\mathfrak{sl}(2, \mathbb{C})$ defining $\mathfrak{su}(2)$ gives a conjugation defining the real form of the superalgebra. For signatures $\rho = 1, 7$ we have an even part $\mathfrak{spin}(7-p,p)\oplus\mathfrak{sl}(2,\mathbb{R})$, with $p=3,0$. In these cases the spinors are real, so the conjugation defining the real form of the superalgebra is formed with the conjugation in the spinor space and the conjugation in the fundamental of $\mathfrak{sl}(2,\mathbb{C})$ defining $\mathfrak{sl}(2,\mathbb{R})$. The superalgebra has 16 charges. (For more on conjugations, pseudoconjugations and real forms see Ref.[9]. See also Ref.[30]

$d=4$. For $\rho=0$ we have $\mathfrak{sl}(4|8)$ with 64 charges, $\mathfrak{sl}(4|4)$ with 32 charges, $\mathfrak{sl}(4|2)$ with 16 charges and $\mathfrak{sl}(4|1)$ with 8 charges. They correspond to spacetime of type (2,2).

For $\rho=2$ we have $\mathfrak{su}(2,2|8-q,q)$ $(q=0,\dots 4)$ with 64 charges, $\mathfrak{su}(2,2|4-q,q)$ $(q=0,1,2)$ with 32 charges, $\mathfrak{su}(2,2|2-q,q)$ $(q=0,1)$ with 16 charges and $\mathfrak{su}(2,2|1)$ with 8 charges. They correspond to spacetime of type (3,1).

For $\rho=4$ mod 8 we have $\mathfrak{su}^*(4|8)$ with 64 charges, $\mathfrak{su}^*(4|4)$ with 32 charges, $\mathfrak{su}^*(4|2)$ with 16 charges and spacetime of type (4,0).

$d=3$. For $\rho=1$ we have $\mathfrak{osp}(16-q,q|4)$ $(q=0,\dots 8)$ with 64 charges, $\mathfrak{osp}(8-q,q|4)$ $(q=0,\dots 4)$ with 32 charges, $\mathfrak{osp}(4-q,q|4)$ $(q=0,1,2)$ with 16 charges, $\mathfrak{osp}(2-q,q|4)$ $(q=0,1)$ with 8 charges and $\mathfrak{osp}(1|4)$ with 4 charges. They correspond to spacetime of type (2,1).

For $\rho=3$ we have $\mathfrak{osp}(16^*|2,2)$ with 64 charges, $\mathfrak{osp}(8^*|2,2)$ with 32 charges, $\mathfrak{osp}(4^*|2,2)$ with 16 charges and $\mathfrak{osp}(2^*|2,2)$ with 8 charges. They correspond to spacetime of type (3,0).

3 De Sitter and anti de Sitter superalgebras and their contractions

We write the simple superalgebras that are extensions of de Sitter ($\mathfrak{so}(d,1)$) and anti de Sitter ($\mathfrak{so}(d-1,2)$) algebras in physical signature $(d-1,1)$.

For $d=4,5,12$, the de Sitter superalgebra exists only with N even.

In $d=6$ and $d=10$ the de Sitter and anti de Sitter superalgebras coincide. This is because the signature $\pm\rho$ of the the $(d+1)$-dimensional spaces (where the de Sitter or anti de Sitter algebras are linearly realized) are congruent modulo 8 (3 and 5 for $d=6$, 1 and 7 for $d=10$). For anti de Sitter we have that the superalgebras of $d=6,7$ and $d=10,11$ coincide. For $d=6$ there exists a smaller subalgebra, the exceptional superalgebra $\mathfrak{f}_4$

d	de Sitter	odd	anti de Sitter	odd	odd SP
3	$\mathfrak{osp}(N\|2,\mathbb{C})_{\mathbb{R}}$	$4N$	$\mathfrak{osp}(N-q,q\|2)$	$2N$	$2N$
4	$\mathfrak{osp}(N^*\|2,2)$	$4N$	$\mathfrak{osp}(N-q,q\|4)$	$4N$	$4N$
5	$\mathfrak{su}^*(4\|N)$	$8N$	$\mathfrak{su}(2,2\|N-q,q)$	$8N$	$8N$
6	$\mathfrak{osp}(8^*\|2N-2q,2q)$	$16N$	$\mathfrak{osp}(8^*\|2N-2q,2q)$	$16N$	$8N$
7	$\mathfrak{osp}(8\|2N,\mathbb{C})$	$32N$	$\mathfrak{osp}(8^*\|2N-2q,2q)$	$16N$	$16N$
8	$\mathfrak{osp}(8,8\|2N)$	$32N$	$\mathfrak{osp}(16^*\|2N-2q,2q)$	$32N$	$16N$
9	$\mathfrak{sl}(16\|N)$	$32N$	$\mathfrak{su}(8,8\|N-q,q)$	$32N$	$16N$
10	$\mathfrak{osp}(N-q,q\|32)$	$32N$	$\mathfrak{osp}(N-q,q\|32)$	$32N$	$16N$
11	$\mathfrak{osp}(N\|32,\mathbb{C})_{\mathbb{R}}$	$64N$	$\mathfrak{osp}(N-q,q\|32)$	$32N$	$32N$
12	$\mathfrak{osp}(N^*\|32,32)$	$64N$	$\mathfrak{osp}(N-q,q\|64)$	$64N$	$64N$

Table 1: De Sitter and anti de Sitter superalgebras.

with two real forms, $\mathfrak{f}_4^1$ and $\mathfrak{f}_4^2$ whose bosonic parts are $\mathfrak{spin}(6,1)\oplus\mathfrak{su}(2)$ and $\mathfrak{spin}(5,2)\oplus\mathfrak{su}(2)$ respectively. $\mathfrak{f}_4$ has a non chiral odd part of type (1,1). They are the proper de Sitter and anti de Sitter superalgebras. For $d\leq 7$ one can find a simple superalgebra whose bosonic part has the de Sitter or anti de Sitter algebra as a factor. For higher dimensions this is not true, as one can check directly from Table 1.

The contractions of these algebras to Poincaré superalgebras where studied in detail in Ref.[9] for $N=1$. It is of interest to note that the contractions give super Poincaré algebras with a number of odd generators which is not, in general, the minimal one in super Poincaré. In Table 1 we have added the dimension of the odd part of the superalgebra ("odd") together with the dimension of the odd part of the N-extended super Poincaré algebra for a spacetime of type $(d-1,1)$ ("odd SP"). The de Sitter superalgebra gives the correct contraction for $d=4,5,12$. The anti de Sitter superalgebra gives the correct contraction for $d=4,5,7,11,12$. The remaining case give twice the number of odd generators. For $d=6,10$ one obtains by contraction a non chiral algebra (In both, de Sitter and anti de Sitter), and the same happens if one makes the contraction of $\mathfrak{f}_4$. Physically, in dimension $d\leq 7$ supergravity theories exist with both, Minkowski and anti de Sitter supersymmetric solutions.

4 Examples

We consider some examples in $d = 10$ and $d = 4$.

Spacetime of type (9,1). We have $d = 2 \bmod 8$ and $\rho = 0 \bmod 8$. The chiral spinor modules $S^{\pm}$ are real of dimension $2n = 16$. There is a chiral Poincaré superalgebra. The $N = 2$ chiral super Poincaré algebra is the IIB algebra. One can also construct a non chiral one with the odd generators in the direct sum $S^+ \oplus S^-$ and it is the IIA algebra. Both have 32 odd spinor charges.

The conformal algebra is $\mathfrak{so}(10, 2)$. Poincaré superalgebras are subalgebras of the conformal superalgebras. The chiral algebra of type (1,0) is a subalgebra of $\mathfrak{osp}(1|32)$, the embedding given by

$$\begin{array}{ccc} \mathfrak{sp}(32) & \xleftarrow{\supset} & \mathfrak{so}(10,2) \\ \mathbf{32} & \longrightarrow & S^+ = \mathbf{32} \end{array}$$

Type IIB algebra (type (2,0)) is a subalgebra of $\mathfrak{osp}(2-q, q|32)$, with $q = 0, 1$ and $q = 0$ for compact R-symmetry. It has 64 spinor charges. Finally, this superalgebra is embedded (not as a subalgebra) into another superalgebra with 64 spinor charges, $\mathfrak{osp}(1|64)$, which has the interpretation of the superconformal algebra of a spacetime of type $(10, 1)$ (that is, one dimension more).

The embedding of the even parts and decompositions of the representations which are the odd part are as follows

$$\begin{array}{ccccc} \mathfrak{sp}(64) & \xleftarrow{\supset} & \mathfrak{so}(2) \oplus \mathfrak{sp}(32) & \xleftarrow{\supset} & \mathfrak{so}(2) \oplus \mathfrak{so}(10,2) \\ \mathbf{64} & \longrightarrow & (\mathbf{2}, \mathbf{32}) & \longrightarrow & (\mathbf{2}, S^+) = (\mathbf{2}, \mathbf{32}) \end{array}$$

Type IIA is also embedded into a superconformal algebra with 64 spinor charges, $\mathfrak{osp}(1, N2n) = \mathfrak{osp}(1|64)$. As before, we have

$$\begin{array}{ccccc} \mathfrak{sp}(64) & \xleftarrow{\supset} & \mathfrak{spin}(11,2) & \xleftarrow{\supset} & \mathfrak{so}(10,2) \\ \mathbf{64} & \longrightarrow & S = \mathbf{64} & \longrightarrow & S^+ \oplus S^- = \mathbf{32}^+ \oplus \mathbf{32}^-. \end{array}$$

The $d = 4$ case It is interesting to consider the case of dimension 4 with all possible signatures $\rho = 0, 2, 4$. For $\rho = 4$ (Euclidean case) the superalgebra is $\mathfrak{su}^*(4|2N)$, for $\rho = 2$ (Lorentzian case) the superalgebra is $\mathfrak{su}(2,2|N)$ and for $\rho = 0$ it is $\mathfrak{sl}(4|N)$.

The superalgebras with 32 charges are $\mathfrak{su}^*(4|4)$, $\mathfrak{su}(2,2|4)$ and $\mathfrak{sl}(4|4)$ (since $n = m$ these algebras have no $\mathfrak{u}(1)$ or $\mathfrak{o}(1,1)$ factor). They correspond to the underlying symmetries of $N = 4$ Euclidean Yang-Mills [31, 32], $N = 4$ ordinary Yang-Mills and $N = 4$ self dual Yang-Mills [33] considered in the literature. Only the latter two exist with eight charges, corresponding to $N = 1$ supersymmetry, $\mathfrak{su}(2,2|1)$ and $\mathfrak{sl}(4|1)$.

We note that these minimal superconformal algebras have a further extension into $\mathfrak{osp}(1|8)$ [9, 34], since $\mathfrak{sp}(8,\mathbb{R})$ contains both, $\mathfrak{su}(2,2) \oplus \mathfrak{u}(1)$ and $\mathfrak{sl}(4,\mathbb{R}) \oplus \mathbb{R}$. $\mathfrak{osp}(1|8)$ can also be viewed as an anti de Sitter super algebra in $d = 5$, so by contraction we get the five dimensional super Poincaré algebra with central charges. The central charges do not appear if we make the contraction from the minimal superalgebra $\mathfrak{su}(2,2|1)$.

It is interesting to note that the enlargement of $\mathfrak{su}(2,2) \oplus \mathfrak{u}(1)$ to $\mathfrak{sp}(8,\mathbb{R})$ does not change the rank of the algebra, so the number of quantum numbers that label an irreducible unitary representation would be the same.

$\mathfrak{osp}(1|8)$ has (as all superconformal algebras) an $\mathfrak{o}(1,1)$ grading

$$\mathfrak{osp}(1|8) = \mathcal{L}^{-1} \oplus \mathcal{Q}^{-1/2} \oplus \mathcal{L}^{0} \oplus \mathcal{Q}^{+1/2} \oplus \mathcal{L}^{+1},$$

with $\mathcal{L}^0 = \mathfrak{sl}(4,\mathbb{R}) \oplus \mathfrak{so}(1,1)$. Note that $\mathfrak{sl}(4,\mathbb{R}) = \mathfrak{spin}(3,3)$ and that we have

$$\mathfrak{so}(3,1) \oplus \mathfrak{so}(2) \in \mathfrak{so}(3,3), \qquad (\rho = 2)$$

with $\mathfrak{so}(2)$ being the R-symmetry of $\mathfrak{su}(2,2|1)$ and

$$\mathfrak{so}(2,2) \oplus \mathfrak{so}(1,1) \in \mathfrak{so}(3,3), \qquad (\rho = 0)$$

with $\mathfrak{so}(1,1)$ being the R-symmetry of $\mathfrak{sl}(4|1)$.

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