General unconstrained gauge-invariant Lagrangian formulations for arbitrary mixed-symmetry Higher Spin fields

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3) C.Burdik, A.R. J. Phys, Conf.Ser.C 2012;

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Basic aims to solve

1. Construction of GI Unconstrained & Constrained Lagrangians for the arbitrary free MS irreducible bosonic and fermionic HS fields subject to YT$(s_1, ..., s_k)$ on $\mathbb{R}^{1,d-1}$ on a base of BRST-BFV method;
2. Within this procedure construction of Verma Modules & its oscillator realization for $sp(2k)$ and generalized Verma Modules & its oscillator realization for $osp(k|2k)$ superalgebra underlying bosonic and fermionic HS fields on $\mathbb{R}^{1,d-1}$;
3. Derivation of the BV quantum action for obtained Lagrangians to formulate:
   1. Feynmann diagrammatic rules;
   2. construct by means of master BV action deformation vertexes of interacting HS theory.

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Outline

1. Motivations
   - HS formulations on $\mathbb{R}^{1,d-1}$ & (A)dS, SFT
   - BFV-BRST for direct& inverse problems of LF
2. Integer HS mixed-symmetry fields on $\mathbb{R}^{1,d-1}$
   - Integer HS symmetry algebra $\mathcal{A}(Y(k), \mathbb{R}^{1,d-1})$
   - Additive conversion: Verma module and osc.realization for $sp(2k) \subset A(Y(k), \mathbb{R}^{1,d-1})$
   - BRST for HS Symmetry algebra $\mathcal{A}_c(Y(k), \mathbb{R}^{1,d-1})$: Un &Constrained Lagrangian formulations
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HS formulations on $\mathbb{R}^{1,d-1}$ & (A)dS, SFT

Problems of HS field theory (M. Fierz, W. Pauli; L. Singh, C. Hagen; C. Fronsdal) have attracted significant attention ($k=1$ row in Young tableau (YT)), ($k>1$) $\mathbf{s}=(n_1+1/2, n_2+1/2, \ldots)$ $\mathbf{s}=(s_1, s_2, \ldots)$ (massive and massless:$m=0$) HS fields :

$$\Phi_{(\mu)_{s_1},(\nu)_{s_2},\ldots,(\rho)_{s_k}} \longleftrightarrow \begin{array}{|c|c|c|c|c|c|c|c|}\hline \mu_1 & \mu_2 & \cdot\ \ \cdot\ \ \cdot & \cdot & \cdot & \cdot & \cdot & \mu_{s_1} \\ \hline \nu_1 & \nu_2 & \cdot\ \ \cdot\ \ \cdot & \cdot & \cdot & \nu_{s_2} \\ \cline{1-6} \cdots & \cdots & \cdots\ \ \cdot\ \ \cdot & \cdot & \cdots \\ \cline{1-5} \end{array} = Y(s_1, \ldots, s_k)$$

in view of connection to SuperString Field Theory (SFT): (E. Witten (1986); C. Thorn(1989)) through special tensionless limit for intercept ($\alpha' \to 0$): (A. Sagnotti, M. Tsulaia, (2004)).

$\Longrightarrow$ SFT $\xrightarrow{\alpha'\to 0}$ $\{\infty\}$ set of HS fields in s/string spectrum

From cosmological research $\Longrightarrow$ an exceptional role of (Anti-)de-Sitter [(A)dS] space for consistent propagation of free (J. Fang, C. Fronsdal (1980); M. Vasiliev (1988)) and interacting (E. Fradkin, M. Vasiliev (1987, 2001), R. Metsaev (2005), E.Skvortsov, Yu.Zinoviev (2011)) HS fields due to:

- natural dimensional parameter – square inverse radius r of d-dimensional (A)dS space,
- connection of HS fields on AdS(d) space to AdS/CFT correspondence among $\mathcal{N}=4$ SYM and superstring theory on $AdS_5 \times S_5$ RR background,$k \leq \left[\frac{d-1}{2}\right] = 2$.

While LF for free HS fields subject to arbitrary $Y(s_1, ..., s_k)$ within constrained frame-like formulation (M. Vasiliev) was found (Yu. Zinoviev, Arxiv:0809.3287, Arxiv:0904.0549, E.Skvortsov NPB, 2009, 2011), the same problem in unconstrained metric-like formulation HAVE NOT BEEN SOLVED except for $YT(2)$ on $\mathbb{R}^{1,d-1}$.

Within stringy-inspired BRST-BFV approach (S. Ouvry, J. Stern, A. Bengtsson, A. Pashnev, M. Tsulaia, J. Buchbinder, V. Krykhtin, A.R.) this problem meets OBSTACLES in constructing:

1) Verma module for $sp(2k)$ in integer spin and for $osp(k|2k)$ in half-integer cases (in the framework of additive conversion);

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BFV-BRST for direct problem

Whereas, the direct BFV-BRST prescription to quantize an initial degenerate field theory given in LF

degenerate LF $(S(q^i), \delta q^i)$ $\xrightarrow{\text{Dirac-Bergmann}}$ t-local HF $(H_0, o_a)(t)$ $\{o_a, o_b\} = f^c_{ab}(q,p)o_c + \Delta_{ab}$

$\xrightarrow[\text{Batalin, Tyutin}]{\text{conversion}}$ converted HF$(H_0, O_a)(t)$ $\{O_a, O_b\} = F^c_{ab}(q,p,\zeta)O_c$

$\xrightarrow{\text{BFV method}}$ BFV-BRST charge $Q(t), Q^2 = 0$ $Q(t) = C^aO_a + \frac{1}{2}C^bC^aF^c_{ab}\mathcal{P}_c + \text{more}$

$\xrightarrow[\text{Kugo, Ojima}]{\text{quantization}}$ $|\Psi\rangle \in \mathcal{H}_{\text{phys}} : Q|\Psi\rangle = 0, \text{gh}(|\Psi\rangle) = 0$ gauge transfs: $|\Psi'\rangle = |\Psi\rangle + Q|\Lambda\rangle$

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BFV-BRST for inverse problem

CONSTRUCTION OF LF FOR HS FIELD WITH GIVEN (m,s)

Irreps conditions ISO(1,d-1), SO(2,d-1)	$\xrightarrow{\text{SFT}}$	(Super)algebra $\{o_I(x)\} : \mathcal{H}$ $[o_I, o_J\} = f_{IJ}^K(o)o_K + \Delta_{ab}(g_0)$

$\xrightarrow[\text{Burdik, Pashnev}]{\text{conversion}}$ $O_I = o_I + o'_I : \mathcal{H} \bigotimes \mathcal{H}'$, $[O_I, O_J\} = F_{IJ}^K(o', O)O_K$

$\xrightarrow[\text{Henneaux}]{\text{BFV}}$ BRST operator for $\{O_I\}$: $Q'(x)$, $Q' = C^I O_I + \frac{1}{2} C^I C^J F_{IJ}^K \mathcal{P}_K + \text{more}$

$\xrightarrow{\text{LF}}$ $Q' = Q + (g_0 + h + \text{more})C_g + \ldots : Q^2 = 0$
mass-shell $: Q|\Psi\rangle = 0, \text{gh}(|\Psi\rangle) = 0$
spin: $(g_0 + \text{more})(|\Psi\rangle, |\Lambda\rangle, \ldots) = -h(|\Psi\rangle, |\Lambda\rangle, \ldots)$
gauge transfs: $\delta|\Psi\rangle = Q|\Lambda\rangle, \delta|\Lambda\rangle = Q|\Lambda^1\rangle, \ldots$

At 2-3rd steps the Stuckelberg and gauge fields are appeared automatically to obtain GI LF for basic field

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Derivation of HS symmetry algebra $\mathcal{A}(Y(k),\mathbb{R}^{1,d-1})$

The m of g. spin $s=(s_1,...,s_k)$ $ISO(1,d-1)$ group irrep

$\Phi_{(\mu^1)_{s_1},(\mu^2)_{s_2},...,(\mu^k)_{s_k}} \longleftrightarrow$

μ^1_1	μ^1_2	$\cdot\ \cdot\ \cdot$	$\cdot$	$\cdot$	$\cdot$	$\cdot$	$\mu^1_{s_1}$
μ^2_1	μ^2_2	$\cdot\ \cdot\ \cdot$	$\cdot$	$\cdot$	$\mu^2_{s_2}$		
$\cdot$	$\cdot$	$\cdot\ \cdot\ \cdot$	$\cdot$	$\cdot$	$\cdot$		
μ^k_1	μ^k_2	$\cdot\ \cdot\ \cdot$	$\cdot$	$\mu^k_{s_k}$			

,

$$\left[\partial^2+m^2\right]\Phi_{(\mu^1)_{s_1},(\mu^2)_{s_2},...}=0, \qquad (1)$$

$$\partial^{\mu^i_{l_i}}\Phi_{(\mu^1)_{s_1},(\mu^2)_{s_2},...,(\mu^k)_{s_k}}=0,\quad i,j=1,...,k;\ l_i,m_i=1,...,s_i\,, \qquad (2)$$

$$\eta^{\mu^i_{l_i}\mu^i_{m_i}}\Phi_{(\mu^1)_{s_1},(\mu^2)_{s_2},...,(\mu^k)_{s_k}}=\eta^{\mu^i_{l_i}\mu^j_{m_j}}\Phi_{(\mu^1)_{s_1},(\mu^2)_{s_2},...,(\mu^k)_{s_k}}=0,\quad l_i<m_i, \qquad (3)$$

$$\Phi_{(\mu^1)_{s_1},...,\{(\mu^i)_{s_i}\underbrace{,...,\mu^j_1}\cdots\mu^j_{l_j}\}...\mu^j_{s_j},...(\mu^k)_{s_k}}=0,\quad i<j,\ 1\le l_j\le s_j, \qquad (4)$$

We want to find the LF for given HS field on $\mathcal{M}_{ext}$:

$\mathcal{S}_n:\mathcal{M}_{ext}=\{(\Phi_{(\mu)_{s_1},...,(\mu)_{s_k}},\Psi_{(\mu)_{s_1-1},...,(\nu)_{s_k}},\ldots)\}\to\mathbb{R},$

Primary constraints

$$\text{SFT} \quad \Longrightarrow \mathcal{H} : [a^i_\mu, a^{j+}_\nu] = -\eta_{\mu\nu}\delta^{ij},$$

An arbitrary "string-like" vector $|\Phi\rangle \in \mathcal{H}$

$$|\Phi\rangle = \sum_{s_1=0}^{\infty}\sum_{s_2=0}^{s_1}\cdots\sum_{s_k=0}^{s_{k-1}} \Phi_{(\mu^1)_{s_1},(\mu^2)_{s_2},\ldots,(\mu^k)_{s_k}}(x) \prod_{i=1}^{k}\prod_{l_i=1}^{s_i} a_i^{+\mu^i_{l_i}}|0\rangle,, \qquad (5)$$

permits to realize $\Longleftrightarrow$ Eqs. (1 - 4) as constraints on $|\Phi\rangle$.

Then the constraints

$$\boxed{(l_0, l_i, l_{ij}, t_{ij})|\Phi\rangle = \vec{0}} \Longleftrightarrow \texttt{irreps (1)- (4) for each } s_1, \ldots, s_k$$

All constraints, $sp(2k)$, $\mathcal{A}(Y(k), \mathbb{R}^{1,d-1})$

$$l_0 = \partial^2 + m^2, \; l_{ij} = \frac{1}{2} a_i^{\mu} a_{j\mu}\,, \quad l_i = -\imath a_i^{\mu} \partial_{\mu}, \; t_{ij} = a_i^{+\mu} a_{\mu j} \theta^{ji}, \theta^{ji} = 1(0), j > (<) i$$

which form together with $(l_i^+, l_{ij}^+, t_{i_1 j_1}^+, g_0^i)$ integer HS symmetry algebra $\mathcal{A}(Y(k), \mathbb{R}^{1,d-1})$ w.r.t. [,].

Subalgebra of operators

$$\{l^{ij}, t^{i_1 j_1}, g_0^i, l_{ij}^+, t_{i_1 j_1}^+\} \overset{\text{Howe duality}}{\simeq} sp(2k).$$

For $m = 0$ the only o_I from upper and lower triangular subalgebras in $sp(2k)$ compose an invertible matrix:

$\|[\theta_{\mathbf{a}}, \theta_{\mathbf{b}}]\| = \|\Delta_{\mathbf{ab}}(g_0^i)\| + (o_I)$,

for $m \neq 0$ its number k^2 increase on $2k$ items l^i, l_I^+

note on additive conversion procedure

To convert $\mathcal{A}(Y(k),\mathbb{R}^{1,d-1})$ with 2nd C.C. we have used the general procedure of additive conversion
$o_I \rightarrow O_I = o_I + o'_I : [o_I, o'_J] = 0$, so that $[O_I, O_J] \sim O_K$,
$\Rightarrow$ if $[o_I, o_J] = f^K_{IJ} o_K$, then $[o'_I, o'_J] = f^K_{IJ} o'_K$ & $[O_I, O_J] = f^K_{IJ} O_K$.
But, it's sufficient to convert only subalgebra $sp(2k)$ for $\{o_a\}$.
So that the algebra of O_I is the same $\mathcal{A}_c(Y(k),\mathbb{R}^{1,d-1})$ = $\mathcal{A}(Y(k),\mathbb{R}^{1,d-1})$ as for o_I, but for o'_I - $sp(2k)$.

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Verma module for $sp(2k)$

Cartan decomposition

$$sp(2k) = \{\overbrace{l'^{ij+}, t'^{+}_{nm}}\} \oplus \{\overbrace{g'^{i}_{0}}\} \oplus \{\overbrace{l'^{ij}, t'_{nm}}\} \equiv \mathcal{E}^{-}_{k} \oplus H_k \oplus \mathcal{E}^{+}_{k}$$

Requirement: boundary conditions for o'_I from Cartan subalgebra:

$$g^{i}_{0} \to g'^{i}_{0}(h^i) = h^i + \ldots,$$

So that, following the result by C.Burdik 1985 we start with highest weight vector $|0\rangle_V$ & construct following PBW theorem

$$V(sp(2k)) = U(\mathcal{E}^{-}_{k}) \otimes (|0\rangle_V) : \mathcal{E}^{+}_{k}|0\rangle_V = 0\,, g'^{i}_{0}|0\rangle_V = h^i|0\rangle_V\,,$$

to find $\{o'_I\} = \{o'_I(b_{ij}, b^{+}_{ij}, [b_i, b^{+}_{i}]\theta_{m0}, d_{ln}, d^{+}_{ln})\}$, $i,j,l,n = 1,\ldots,k; i \leq j, l < n : [b^{+}_{ij}, b_k, b^{+}_{k}, d_{ln}, d^{+}_{ln}] = [o_a]$: we use C.Burdik's results C. B., A. Pashnev, for $\mathcal{A}'_b(Y(1), AdS_d)$; A. Kuleshov, A. R. arXiv:0905.2705 for $\mathcal{A}'(Y(1), AdS_d)$;

Verma module for $sp(2k)$

Explicit obtaining of the $V(sp(2k))$ meet the technical obstacle because of not commuting of t'^{+}_{ln}, l'^{+}_{ij} with each other in $\mathcal{E}^{-}_{k}$.
The general $V(sp(2k))$ vector

$$|\vec{n}_{ij},\vec{p}_{rs}\rangle_V = |n_{11},\ldots,n_{1k},n_{22},\ldots,n_{2k},\ldots,n_{kk};p_{12},\ldots,p_{1k},p_{23},\ldots,p_{2k},\ldots,p_{k-1k}\rangle_V$$

$$|\vec{n}_{ij},\vec{p}_{rs}\rangle_V \equiv |\vec{N}\rangle_V \equiv \prod_{i\leq j}^{k}(l'^{+}_{ij})^{n_{ij}}\prod_{r,r<s}^{k}(t'^{+}_{lm})^{p_{rs}}|0\rangle_V, \qquad (6)$$

$$g'_{0i}|\vec{N}\rangle_V = \Big(\sum_{l}(1+\delta_{il})n_{il} - \sum_{s>i}p_{is} + \sum_{r<i}p_{ri} + h^i\Big)\Big|\vec{N}\rangle_V ,$$

$$t'^{+}_{r's'}|\vec{N}\rangle_V = |\vec{n}_{ij},\vec{p}_{rs}+\delta_{r's',rs}\rangle_V - \sum_{k'=1}^{r'-1}p_{k'r'}|\vec{n}_{ij},\vec{p}_{rs}-\delta_{k'r',rs}+\delta_{k's',rs}\rangle_V$$

$$-\sum_{k'=1}^{k}(1+\delta_{k'r'})n_{r'k'}\Big|\vec{N}-\delta_{r'k',ij}+\delta_{s'k',ij}\rangle_V ,$$

explicit construction of $V(sp(2k))$

$$l'^{+}_{i'j'}|\vec{N}\rangle_V = \Big|\vec{N} + \delta_{i'j',ij}\rangle_V \,, \qquad \texttt{for "-" root vectors} \in \mathcal{E}_k^-$$

$$\texttt{where } AB^n = \sum_{k=0}^{n} \frac{n!}{k!(n-k)!} B^{n-k} \mathrm{ad}_B^k A \,, \mathrm{ad}_B^k A = [[\ldots[A, \overbrace{B\}, \ldots], B}^{k \text{ times}}],$$

To get the action of E^{α_i} on $|\vec{N}\rangle_V$ we get the recurrent relation

$$t'_{l'm'}|\vec{0}_{ij}, \vec{p}_{rs}\rangle_V = \Big|C^{l'm'}_{\vec{p}_{rs}}\rangle_V - \sum_{n'=1}^{l'-1} p_{n'm'} \Big|\vec{0}_{ij}, \vec{p}_{rs} - \delta_{n'm',rs} + \delta_{n'l',rs}\rangle_V$$

$$+ \sum_{k'=l'+1}^{m'-1} p_{l'k'} \Big[\prod_{r'<l', s'>r'} \prod_{r'=l', m'>s'>r'} (t'^{+}_{r's'})^{p_{r's'} - \delta_{l'k',r's'}} \Big] t'_{k'm'} \Big|\vec{0}_{ij}, \vec{p}_{q't'}\rangle_V^{\vec{p}_{rs}>} \,,$$

The solution of the above Eq. exists, so that the explicit form of $t'_{l'm'}$ action on the vector $|\vec{N}\rangle_V$ has the final form

$$
\begin{aligned}
t'_{l'm'}|\vec{N}\rangle_V \quad = \quad & -\sum_{k'=1}^{k}(1+\delta_{k'm'})n_{k'm'}\big|\vec{n}_{ij}-\delta_{k'm',ij}+\delta_{k'l',ij},\vec{p}_{rs}\rangle_V \\
& + \sum_{p=0}^{m'-l'-1}\sum_{k'_1=l'+1}^{m'-1}\cdots\sum_{k'_p=l'+p}^{m'-1}\prod_{j=1}^{p}p_{k'_{j-1}k'_j}\Big|C^{k'_pm'}_{\vec{n}_{ij},\vec{p}_{rs}-\sum_{j=1}^{p}\delta_{k'_{j-1}k'_j,rs}}\rangle_V \\
& - \sum_{n'=1}^{l'-1}p_{n'm'}\,\big|\vec{n}_{ij},\vec{p}_{rs}-\delta_{n'm',rs}+\delta_{n'l',rs}\rangle_V \ .
\end{aligned}
$$

Analogously, the action of the rest E^{α_i}: $l'_{l'm'}$ on $|\vec{N}\rangle_V$ is determined with help of the "basic-block" vector $\Big|C^{l'm'}_{\vec{p}_{rs}}\rangle_V$

$\Longrightarrow$ $V(sp(2k))$ **is explicitly found!** (J.B., A.R NPB 2012)

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Oscillator Realization for $V(sp(2k))$

Making use of the mapping (C. Burdik, 1985)

$$|\vec{n}_{ij},\vec{p}_{rs}\rangle_V \leftrightarrow |\vec{n}_{ij},\vec{n}_s\rangle = \prod_{i,j\geq i}^{k}(b^+_{ij})^{n_{ij}} \prod_{r,s,s>r}^{k}(d^+_{rs})^{p_{rs}}|0\rangle \in \mathcal{H}',$$

$$[b_k, b^+_l] \overset{m\neq 0}{=} \delta_{kl}, \quad [b_{ij}, b^+_{lk}] = \delta_{il}\delta_{jk},\ i\leq j, k\leq l, \qquad [d_{r_1s_1}, d^+_{r_2s_2}] = \delta_{r_1r_2}\delta_{s_1s_2},$$

Theorem

The polynomial oscillator realization for the $V(sp(2k))$ over Heisenberg-Weyl algebra $A_{k\times k}$ exists in the form

$$C(b_{ij}, b^+_{lk}, d_{r_1s_1}, d^+_{r_2s_2}), \quad C \in \{t'_{l'm'}, t'^+_{l'm'}, l'_{i'j'}, l'^+_{i'j'} g'^{i}_0\}. \qquad (7)$$

explicit form of **basic block** $C^{lm}(d^+, d) \to |C^{lm}_{\vec{p}rs}\rangle_V$

$$C^{lm}(d^+, d) \equiv \Big(h^l - h^m - \sum_{n=m}^{k}(d^+_{ln}d_{ln} + d^+_{mn}d_{mn}) + \sum_{n=l+1}^{m-1} d^+_{nm}d_{nm} - d^+_{lm}d_{lm}\Big)d_{lm}$$

$$- \sum_{n=l+1}^{m-1} d^+_{ln}d_{nm} + \sum_{n=m+1}^{k}\Big\{d^+_{mn} - \sum_{n'=1}^{m-1} d^+_{n'n}d_{n'm}\Big\}d_{ln}$$

so that, f.i. for t'_{lm}:

$$t'_{lm} = -\sum_{n=1}^{l-1} d^+_{nl}d_{nm} + \sum_{p=0}^{m-l-1}\sum_{k_1=l+1}^{m-1}\ldots\sum_{k_p=l+p}^{m-1} C^{k_p m}(d^+, d)\prod_{j=1}^{p} d_{k_{j-1}k_j}$$

$$-\sum_{n=1}^{k}(1+\delta_{nm})b^+_{nl}b_{nm}\,, \qquad k_0 \equiv l, \qquad (8)$$

. Thus, the additive conversion of o_I into the 1st class O_I is realized! (It completely applicable for massive HS fields by *dim.reduction* (J.B., A.R NPB 2012))

BRST operator for Lie algebra $\mathcal{A}(Y(k),\mathbb{R}^{1,d-1})$

The BRST operator Q' for Lie algebra $\mathcal{A}(Y(k),\mathbb{R}^{1,d-1})$ is constructed by the standard rules of BFV- method (without difficulties as in AdS(d) case J.B.,P.Lavrov 2007, A.R. arxiv:0812.2329, C.Burdik, A.R. 2012).

$$Q' = O_I\mathcal{C}^I + \frac{1}{2}\mathcal{C}^I\mathcal{C}^J f^K_{JI}\mathcal{P}_K, \quad Q'^2 = 0 \quad \texttt{where} \quad (\varepsilon, gh)Q' = (1,1), \qquad (9)$$

$\mathcal{C}^I = (\vartheta,\eta,\vartheta^+,\eta^+), \mathcal{P}_K$ - ghost coordinates and momenta with of opposite Grassmann parity to O_I with following non-vanishing C.R.

$$\{\vartheta_{rs},\lambda^+_{tu}\} = \{\lambda_{tu},\vartheta^+_{rs}\} = \delta_{rt}\delta_{su}, \qquad \{\eta_i,\mathcal{P}^+_j\} = \{\mathcal{P}_j,\eta^+_i\} = \delta_{ij}\,,$$
$$\{\eta_{lm},\mathcal{P}^+_{ij}\} = \{\mathcal{P}_{ij},\eta^+_{lm}\} = \delta_{li}\delta_{jm}\,, \qquad \{\eta_0,\mathcal{P}_0\} = \imath,\ \{\eta^i_{\mathcal{G}},\mathcal{P}^j_{\mathcal{G}}\} = \imath\delta^{ij}\,; \qquad (10)$$

and $gh(\mathcal{C}^I) = -gh(\mathcal{P}_I) = 1$.

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Explicit form of Q'

$$Q' = \tfrac{1}{2}\eta_0 L_0 + \eta_i^+ L^i + \sum_{l\leq m}\eta_{lm}^+ L^{lm} + \sum_{l<m}\vartheta_{lm}^+ T^{lm} + \tfrac{1}{2}\eta_G^i G_i + \tfrac{\imath}{2}\sum_l \eta_l^+\eta^l\mathcal{P}_0 \tag{11}$$

$$- \sum_{i<l<j}(\vartheta_{lj}^+\vartheta_i^{+l} - \vartheta_{il}^+\vartheta^{+l}{}_j)\lambda^{ij} - \tfrac{\imath}{2}\sum_{l<m}\vartheta_{lm}^+\vartheta^{lm}(\mathcal{P}_G^m - \mathcal{P}_G^l) - \sum_{l<m,n}\vartheta_{lm}^+\vartheta^l{}_n\lambda^{nm}$$

$$+ \sum_{n<l<m}\vartheta_{lm}^+\vartheta_n{}^m\lambda^{+nl} - \sum_{n,l<m}(1+\delta_{ln})\vartheta_{lm}^+\eta^{l+}{}_n\mathcal{P}^{mn} + \sum_{n,l<m}(1+\delta_{mn})\vartheta_{lm}^+\eta^m{}_n\mathcal{P}^{+ln}$$

$$+ \frac{\imath}{8}\sum_{l\leq m}(1+\delta_{lm})\eta_{lm}^+\eta^{lm}(\mathcal{P}_G^l + \mathcal{P}_G^m) + \sum_{l\leq m}(1+\delta_{lm})\eta_G^l\eta_{lm}^+\mathcal{P}^{lm}$$

$$+ \Big[\tfrac{1}{2}\sum_{n,l<m}\eta_{nm}^+\eta^n{}_l + \sum_{l<m}(\eta_G^m - \eta_G^l)\vartheta_{lm}^+\Big]\lambda^{lm}$$

$$- \Big[\tfrac{1}{2}\sum_{l\leq m}(1+\delta_{lm})\eta^m\eta_{lm}^+ + \sum_{l<m}\vartheta_{lm}\eta^{+m} + \sum_{m<l}\vartheta_{ml}^+\eta^{+m} + \sum_l \eta_G^l\eta_l^+\Big]\mathcal{P}^l + Herm.C.$$

$Q'^+K = KQ'$, in $\mathcal{H}_{tot} = \mathcal{H}\otimes\mathcal{H}'\otimes\mathcal{H}_{gh}$ due to $V(sp(2k))$ osc.realization

Unconstrained Lagrangian formulation

The obtaining of resulting LF takes standard character
As usual, we extract the spin operator from the Q':

$$\Longrightarrow Q' = Q + \eta^i_G(\sigma^i + h^i) + \mathcal{A}^i\mathcal{P}^i_G,$$

$$\sigma^i = G^i_0 - h^i - \eta_i\mathcal{P}^+_i + \eta^+_i\mathcal{P}_i + \sum_m(1+\delta_{im})(\eta^+_{im}\mathcal{P}^{im} - \eta_{im}\mathcal{P}^+_{im})$$

$$+ \sum_{l<i}[\vartheta^+_{li}\lambda^{li} - \vartheta^{li}\lambda^+_{li}] - \sum_{i<l}[\vartheta^+_{il}\lambda^{il} - \vartheta^{il}\lambda^+_{il}],$$

$$[Q, \sigma_i] = 0\,,.$$

The same applies to a scalar physical and gauge vectors $|\chi^0\rangle, |\chi^s\rangle \in \mathcal{H}_{tot}$ where $\partial(|\chi^0\rangle, |\chi^s\rangle)/\partial\eta^i_G = 0$: gh$(|\chi^0\rangle, |\chi^s\rangle) = (0, -s)$

$|\chi\rangle = |\Phi\rangle + |\Phi_A\rangle, |\Phi_A\rangle_{\{(b,b^+,d,d^+) = \mathcal{C} = \mathcal{P} = 0\}} = 0$ with $|\Phi\rangle$−basic HS f.

and with the use of the BFV–BRST EQUATION $Q'|\chi^0\rangle = 0$ that determines the physical states and a sequence of reducible GTrs, we get

$$Q|\chi\rangle = 0, \qquad (\sigma^i + h^i)|\chi\rangle = 0, \qquad (\varepsilon, gh)(|\chi\rangle) = (0,0), \tag{12}$$
$$\delta|\chi\rangle = Q|\chi^1\rangle, \qquad (\sigma^i + h^i)|\chi^1\rangle = 0, \qquad (\varepsilon, gh)(|\chi^1\rangle) = (1,-1), \tag{13}$$
$$\delta|\chi^1\rangle = Q|\chi^2\rangle, \qquad (\sigma^i + h^i)|\chi^2\rangle = 0, \qquad (\varepsilon, gh)(|\chi^2\rangle) = (0,-2), \tag{14}$$
$$\ldots \qquad \ldots \qquad \ldots$$
$$\delta|\chi^{s-1}\rangle = Q|\chi^{(s)}\rangle, (\sigma^i + h^i)|\chi^s\rangle = 0, \qquad (\varepsilon, gh)(|\chi^s\rangle) = ((s \, mod \, 2, -s). \tag{15}$$

The middle Eqs. determines the spectrum of spin values for $|\chi\rangle$ and gauge pars. $|\chi^s\rangle$, $s = 1, ..., k(k+1)$, the corresponding proper eigenvalue and eigenvectors,

$$-h^i = n^i + \frac{d-2-4i}{2}, \quad i = 1,..,k, \quad n_1, ..., n_{k-1} \in \mathbb{Z}, n_k \in \mathbb{N}_0,, \ |\chi\rangle_{(s_1,...,s_k)}$$

where n_i must be associated with s_i from basic $|\Phi\rangle$: $n_i = s_i$.

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$\Longrightarrow$ The equations of motion and the sequence of reducible gauge transformations for the field with given $\mathbf{s}=(s)_k$:

$$Q_{(s)_k}|\chi^0\rangle_{(s)_k}=0, \delta|\chi^l\rangle_{(s)_k}=Q_{(s)_k}|\chi^{l+1}\rangle_{(s)_k},\ \delta|\chi^{k(k+1)}\rangle_{(s)_k}=0, l=0,...,k^2,$$

for $|\chi^0\rangle\equiv|\chi\rangle$, and can be obtained from the LAGRANGIAN

$$\mathcal{S}_{(s)_k}=\int d\eta_0\ {}_{(s)_k}\langle\chi^0|K_{(s)_k}Q_{(s)_k}|\chi^0\rangle_{(s)_k},\ K_{(s)_k}=K|_{-h^i=n^i+\frac{d-2-4i}{2}},$$

The corresponding LF of a bosonic field with a specific value of spin $\mathbf{s}$ subject to $Y(s_1,...,s_k)$ is an UNCONSTRAINED GTh OF MAXIMALLY $L=k(k+1)-1$-TH STAGE OF REDUCIBILITY
Corollary: the result contains as a particular case LF for bosonic HS subject to $Y(s_1), Y(s_1,s_2)$ (J.B, Krycktin, 2005; Burdik, Pashnev, Tsulaia, 2001), in (J.B., A.R. NPB, 2012) the new GI action was obtained for 4-th rank $\Phi_{\mu\nu,\rho,\sigma}$ with $Y(2,1,1)$ as 2-nd stage reducible GTh.

Constrained Lagrangian formulation

Key points of derivation from general Unconstrained LF:

1. $\mathcal{A}(Y(k),\mathbb{R}^{1,d-1}) \to \mathcal{A}_r(Y(k),\mathbb{R}^{1,d-1}) = \frac{\mathcal{A}(Y(k),\mathbb{R}^{1,d-1})}{sp(2k)} = \{l_0, l_i, l_j^+\}$,
2. there are no 2nd class constraints $\Longrightarrow$ no conversion,
3. to get within BRST-BFV approach cLF we reduce Q' (11) to $Q_r = \eta_0 l_0 + \sum_i(\eta_i l_i^+ + \eta_i^+ l_i + \imath\eta_i^+\eta^i\mathcal{P}_0)$, and have off-shell constraints $\mathcal{L}_{ij}, \mathcal{T}_{lm}$, and spin operator σ_r^i BRST extended by $\eta_i, \eta_i^+, \mathcal{P}^i, \mathcal{P}_i^+$ (as in K.Alkalaev, M.Grigoriev,I.Tipunin, 2009)::

$$\sigma_r^i = g_0^i - \eta_i\mathcal{P}_i^+ + \eta_i^+\mathcal{P}_i, : \quad [\mathcal{L}_{ij}, Q_r] = [\mathcal{T}_{lm}, Q_r] = [\sigma_r^i, Q_r] = 0, \tag{16}$$

$$Q|\chi_r\rangle=0,\qquad \sigma^i_r|\chi_r\rangle=(s^i+\frac{d}{2})|\chi_r\rangle,\qquad (\varepsilon,gh)\,(|\chi_r\rangle)=(0,0),\tag{17}$$

$$\delta|\chi_r\rangle=Q|\chi^1_r\rangle,\qquad \sigma^i_r|\chi^1_r\rangle=(s^i+\frac{d}{2})|\chi^1_r\rangle,\qquad (\varepsilon,gh)\,(|\chi^1_r\rangle)=(1,-1),\tag{18}$$

$$\delta|\chi^{s-1}_r\rangle=Q|\chi^{(s)}_r\rangle,\qquad \sigma^i_r|\chi^s_r\rangle=(s^i+\frac{d}{2})|\chi^s_r\rangle,\qquad \ldots,\tag{19}$$

$$\mathcal{L}_{ij}|\chi^p_r\rangle=0\qquad \mathcal{T}_{lm}|\chi^p_r\rangle=0,\qquad p=0,...,k.\tag{20}$$

Denoting the solutions of the spin part of the above equations as $|\chi^p_r\rangle_{(s)_k}$ the Constrained LF for the bosonic HS field with $Y(s_1,...,s_k)$ will be determined by the LAGRANGIAN

$$\mathcal{S}_{(s)_k}=\int d\eta_0\;{}_{(s)_k}\langle\chi^0_r|Q|\chi^0_r\rangle_{(s)_k},\tag{21}$$

The corresponding LF of a bosonic field with a specific value of spin **s** subject to $Y(s_1,...,s_k)$ is an CONSTRAINED due to Eqs.(20) GTh OF MAXIMALLY $L=k-1$-TH STAGE OF REDUCIBILITY because of $|\chi^k_r\rangle=\prod_l^k\mathcal{P}^+_l|\Phi^k_r(a^+)\rangle\neq 0$.

on Derivation of HS symmetry superalgebra $\mathcal{A}^f(Y(k), \mathbb{R}^{1,d-1})$

The m of g. spin $s = (n_1 + 1/2, ..., n_k + 1/2)$ $ISO(1, d-1)$ group irrep

$$\Psi_{(\mu^1)_{n_1},(\mu^2)_{n_2},\ldots,(\mu^k)_{n_k}} \longleftrightarrow \begin{array}{|c|c|c|c|c|c|c|c|}\hline \mu^1_1 & \mu^1_2 & \cdot\ \ \cdot\ \ \cdot & \cdot & \cdot & \cdot & \cdot & \mu^1_{n_1} \\ \hline \mu^2_1 & \mu^2_2 & \cdot\ \ \cdot\ \ \cdot & \cdot & \cdot & \mu^2_{n_2} \\ \cline{1-6} \cdot & \cdot & \cdot\ \ \cdot\ \ \cdot & \cdot & \cdot & \cdot \\ \cline{1-6} \mu^k_1 & \mu^k_2 & \cdot\ \ \cdot\ \ \cdot & \cdot & \mu^k_{n_k} \\ \cline{1-5} \end{array},$$

$$\left[i\gamma^\mu\partial_\mu + m\right]\Psi_{(\mu^1)_{n_1},(\mu^2)_{n_2},\ldots} = 0, \quad \gamma^{\mu^i_{l_i}}\Psi_{(\mu^1)_{n_1},(\mu^2)_{n_2},\ldots,(\mu^k)_{n_k}} = 0\,,, \tag{22}$$

$$\Psi_{(\mu^1)_{n_1},\ldots,\{(\mu^i)_{n_i}\underbrace{,\ldots,\mu^j_1\ldots}\mu^j_{l_j}\}\ldots\mu^j_{n_j},\ldots(\mu^k)_{n_k}} = 0, \quad i<j,\ 1\le l_j\le n_j, \tag{23}$$

The analogous programm of LF construction is fulfilled in this case with only peculiarities of spin-tensor and fermionic nature.

peculiarities of LF construction for fermionic HS fields

1. $\mathcal{A}(Y(k), \mathbb{R}^{1,d-1}) \to$ superalgebra $\mathcal{A}^f(Y(k), \mathbb{R}^{1,d-1}) \supset \mathcal{A}(Y(k), \mathbb{R}^{1,d-1})$,
2. generalized V.M. construction for $osp(k|2k)$ of 2nd class constraints o_I in $\mathcal{A}^f(Y(k), \mathbb{R}^{1,d-1})$,
3. oscillator realization for $osp(k|2k)$ for o'_I in $O_I = o_I + o'_I$
4. imposing gauge conditions (A.Sagnotti, M.Tsulaia, 2004) extracting from the BRST obtained L.e.m. the terms proportional the 2nd order derivatives,
5. obtaining the Unconstrained (constrained) LF for the spin-tensor field $\Psi_{(\mu^1)_{n_1},(\mu^2)_{n_2},\ldots}$ subject to arbitrary $Y(n_1, ..., n_k)$, as for $Y(n_1, n_2)$ (P.Moshin, A.R, JHEP 2007)

Summary

- GI reducible unconstrained and constrained LFs for mixed-symmetry integer HS fields subject to $YT(k)$ in $\mathbb{R}^{1,d-1}$ space are developed;
- Verma and generalized Verma modules respectively for symplectic algebras $sp(2k)$ and orthosymplectic $\overset{\{o'_l\}}{osp(k|2k)}$ and theirs Fock space realizations are found;
- Equivalence of Lagrangian EoM with initial $ISO(1, d-1)$ group irreps on a base of Q-cohomological analysis is established.

Outlook

- construction of master BV action, first, for the developing diagrammatic technics with use of the oscillator formalism, second, to found GI vertexes of interacting HS theory.
- Transition of the above results within BRST-BFV approach onto HS fields in frame-like formalism.

Thank you for attention

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