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# Extended string field theory for massless higher-spin fields

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**Abstract**

We propose a new gauge field theory which is an extension of ordinary string field theory by assembling multiple state spaces of the bosonic string. The theory includes higher-spin fields in its massless spectrum together with the infinite tower of massive fields. From the theory, we can easily extract the minimal gauge-invariant quadratic action for tensor fields with any symmetry. As examples, we explicitly derive the gauge-invariant actions for some simple mixed symmetric tensor fields. We also construct covariantly gauge-fixed action by extending the method developed for string field theory.


## 1. Introduction

String theory can be considered as an ultraviolet completion of spin-one gauge theory (open string) or spin-two gravity (closed string). Then a natural question is what is a UV completion of higher-spin gauge theory. Quantum consistency of the string theory requires the highest spin of the massless mode to be one for open string and two for closed string. Therefore we have to somehow extend the theory in order to adapt it to massless higher-spin fields with keeping the consistency of the theory. Constructing such a theory with interaction is not an easy task to complete in every detail. For a free theory level, however, we can systematically construct a class of theories which contain massless higher-spin fields as well as massive tower in their spectrum and are invariant under higher-spin gauge symmetry.

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The purpose of the present paper is to give an extended string-like field theory whose massless mode can have spin higher than two. Our main idea is to consider a multiple tensor product of open string Hilbert spaces as a basis of field space, just like the closed string field basis is a double. For example if we start from $n$ copies of open bosonic string Hilbert space with an appropriate set of conditions, then we obtain a bosonic extended string field theory with massless spin-$n$ fields and many other massive fields whose spin $J$ and mass $M$ satisfy the relation à la Regge behavior

$$J \leqslant \frac{n\ell^2}{2} M^2 + n, \tag{1}$$

where $\ell$ is a length parameter and is related to the open string slope parameter as $\alpha' = \ell^2/2$. The state density for each mass level is $\rho(M) \sim \exp(2\pi n \ell M \sqrt{\frac{D-2}{12}})$ in $D$ dimensions, which leads to Hagedorn temperature $T_H \sim \frac{1}{2\pi n \ell}\sqrt{\frac{12}{D-2}}$ in this model with $D = 26$. This suggests that the model may have a natural UV cutoff of order $1/\ell$ in the same way as string theory. To clarify this point more precisely, however, we have to incorporate with the interaction, which will be our next task. In the present paper, we only focus on the free theory as a first step.

The model is also useful for extracting the actions for higher-spin gauge fields. We can construct not only gauge-invariant free action but also gauge-fixed free action systematically utilizing the method developed previously for the open and closed string field theories. The minimal set of fields which describe a given representation of higher rank tensor is systematically identified in the extended string field level.

This paper is organized as follows. In the next section we construct an extended string field theory upon the state space of $n$-tensored version of those for open bosonic string field theory. Both gauge-invariant and covariantly gauge-fixed quadratic actions are given there in an analogous way to the string field theory [1,2]. Also minimal gauge-invariant set of fields [3] are given systematically in the extended string field level. In Section 3, we will focus on the massless sector of the model in detail. And some example higher-spin gauge field actions extracted from the general action are shown in Section 4. The final section will be devoted to the discussions. In Appendices A and B, we collect basic properties of the state space and define projection operators which are necessary for understanding the gauge fixing and the actions.

## 2. Extended string field theory

In this section, we formulate the new extended string field theory by assembling $n$ copies of state space of bosonic open string and give a class of gauge-fixed actions. We also give the minimal action which is obtained by eliminating the auxiliary fields part from the original action.

### 2.1. State space and inner product

We first provide $n$ copies of open string state space for momentum $p$ and take the direct product of them as

$$\mathcal{H}_n(p) = \mathcal{H}^{(1)}(p) \otimes \cdots \otimes \mathcal{H}^{(n)}(p). \tag{2}$$

Here each $\mathcal{H}^{(i)}(p)$ $(i = 1, \ldots, n)$ consists of $\alpha_{-l}^{\mu\,(i)}$ $(l \geqslant 1)$, $c_{-m}^{(i)}$ $(m \geqslant 0)$, and $b_{-n}^{(i)}$ $(n \geqslant 1)$ operated on the state