From the Berkovits formulation to the Witten formulation in open superstring field theory†

Y. Iimori,*1 T. Noumi,*2 Y. Okawa,*3 and S. Torii*2

Gauge invariance plays a fundamental role in the current formulation of covariant string field theory. In open bosonic string field theory,[1] behind the gauge invariance is the algebraic structure called the A_∞ structure,[2,3] which is closely related to the covering of the moduli space of Riemann surfaces. In open superstring field theory, we therefore expect that the structure underlying its gauge invariance be a supersymmetric extension of the A_∞ structure, which would be closely related to the covering of the supermoduli space of super-Riemann surfaces. However, there is very little understanding of gauge invariance, and some of the problems we are confronted with in open superstring field theory seem to be related to the lack of our understanding in this perspective.

For example, in the Witten formulation of open superstring field theory,[4] the gauge symmetry has proven to be singular because of the collision of picture-changing operators.[5] There are related divergences in tree-level amplitudes, which are also caused by the collision of picture-changing operators. It is possible that the source of these divergences is related to the singular covering of the supermoduli space of super-Riemann surfaces. At the moment, however, such understanding is negligible.

On the other hand, gauge transformation does not suffer from any singularity in the Berkovits formulation of open superstring field theory[6] in the Neveu-Schwarz sector. We do not, however, understand why it works well in the context of the covering of the supermoduli space of super-Riemann surfaces. In the Berkovits formulation, the action contains interaction vertices higher than cubic. We know that the bosonic moduli space of Riemann surfaces is covered by Feynman diagrams with cubic vertices alone, and the higher-order vertices do not contribute to the covering of the bosonic moduli space. Since gauge invariance requires the higher-order vertices, it is expected that these vertices play a role in the covering of the supermoduli space. At the moment, however, such understanding is missing.

In view of recent developments in the understanding of the supermoduli space,[7–10] the exploration of the relation between gauge invariance in open superstring field theory and the covering of the supermoduli space of super-Riemann surfaces can be crucially important for the profound question of whether open superstring field theory can be a consistent quantum theory by itself. In this report, as a first step towards this direction, we address the question of how the divergences in the Witten formulation can be resolved in the Berkovits formulation.

The Hilbert space of the string field in the Berkovits formulation is larger than that in the Witten formulation and, correspondingly, the gauge symmetry in the Berkovits formulation is larger than that in the Witten formulation. We perform partial gauge fixing in the Berkovits formulation to associate it with the Witten formulation. We introduce a one-parameter family of judicious gauge choices labeled by λ, and the cubic interaction in the Berkovits formulation reduces to that in the Witten formulation in the singular limit $\lambda \to 0$. We can think of the Berkovits formulation which is partially gauge fixed with finite λ as a regularization of the Witten formulation. We find that the divergence in the four-point amplitude as $\lambda \to 0$ is canceled by the quartic interaction. We also find that the divergence in the gauge variation of the action to the second order in the coupling constant as $\lambda \to 0$ is resolved by incorporating the quartic interaction. Our approach based on the one-parameter family of gauge choices enables us to discuss the nature of these divergences in a concrete and well-defined setting. Our next step will be to translate the mechanism of canceling the divergences into the language of the covering of the supermoduli space of super-Riemann surfaces, and our ultimate goal is to reveal a supersymmetric extension of the A_∞ structure underlying open superstring field theory.

References

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*1 Department of Physics, Nagoya University
*2 RIKEN Nishina Center
*3 Institute of Physics, The University of Tokyo