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Summary of Previous Research Achievements

(I) Supersymmetry

(I–1) Formulation of Supersymmetric Lattice Theories and a No-Go Theorem

Nonperturbative analysis is indispensable for understanding supersymmetry, and lattice theory offers a powerful framework for this purpose. My contributions to supersymmetric lattice theories comprise the following: i) One of the earliest realizations of a subset of supersymmetry on the lattice. ii) A proof that the full supersymmetry algebra cannot be realized on the lattice. iii) The discovery of the cyclic Leibniz rule, which provides a key mechanism for implementing supersymmetry on the lattice.

(I–2) Discovery of a New Mechanism for Supersymmetry Breaking

If supersymmetry is realized in our universe, it must be spontaneously broken. We demonstrated that the presence of extra dimensions induces a new type of spontaneous supersymmetry breaking. This finding suggests that extending the supersymmetric Standard Model to higher dimensions may provide a viable mechanism for resolving the problem of supersymmetry breaking.

(II) Higher-Dimensional Theories

(II–1) Discovery of Properties Intrinsic to Higher-Dimensional Theories

Our work has uncovered several properties unique to higher-dimensional theories for the first time: i) the discovery of new mechanisms for supersymmetry and gauge-symmetry breaking; ii) the identification of nontrivial vacuum configurations arising from the breaking of translational and rotational symmetries; iii) the discovery of hidden quantum-mechanical supersymmetry underlying higher-dimensional gauge and gravitational theories; iv) the discovery of a new mechanism for generating chiral fermions in extra dimensions. These properties are expected to play a crucial role in constructing higher-dimensional models beyond the Standard Model.

(II–2) Phenomenological Higher-Dimensional Models Beyond the Standard Model

The Randall-Sundrum model, which gained worldwide attention as a mechanism for resolving the hierarchy problem, corresponds to a solution of the Einstein equations with two branes. We succeeded in extending this to solutions with an arbitrary number of branes. Combining this result with the findings in (II-1), we constructed the first phenomenological higher-dimensional model that provides a unified explanation —purely from the perspective of extra dimensions— of all flavor structures of quarks and leptons, including the origin of generations, mass hierarchies, generation mixing, and neutrino masses, which had remained mysteries within the Standard Model.

(III) Quantum Gravity

(III–1) Nonperturbative Formulation of Quantum Gravity

Attempts to quantize gravity have so far been unsuccessful due to severe divergences, and no mathematically well-defined formulation of quantum gravity has been achieved. Using the Wheeler-DeWitt equation —a nonperturbative representation of quantum gravity— and the heat kernel method, we succeeded in formulating this equation in a divergence-free manner. Our formalism was recently rediscovered by Horava and has attracted attention as a new quantum gravity theory at the Lifshitz critical point.

(IV) Superstring Theory

(IV–1) Formulation of String Theory on Orbifolds

As a phenomenologically promising class of superstring models, theories in which extra dimensions are compactified on orbifolds have been extensively studied. Among these, orbifolds based on non-Abelian groups were analyzed for the first time by us. Furthermore, by introducing antisymmetric background fields, we demonstrated the existence of a new class of string theories. These studies are expected to open up possibilities for new phenomenological superstring models.