氏　　名	池田　裕章
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学 位 論 文 題 目	Improvement of the massive overlap fermion action on the lattice
論 文 審 査 委 員	主　　査　　准教授　西村　淳 教授　　橋本　省二 教授　　磯　　暁 教授　　岡田　安弘 准教授　太田　滋生 准教授　石塚　成人　筑波大学

論文内容の要旨

Strong interaction, that governs the dynamics of quarks and gluons, is described by the Quantum Chromodynamics (QCD), the Non-abelian gauge theory based on SU(3) gauge group. Because of its asymptotic freedom, some non-perturbative methods are required to analyze the long distance physics based on QCD. Lattice QCD is a mathematically well-defined formalism of QCD that defines the gauge theory on four-dimensional hypercube, and enables a direct numerical calculation in the non-perturbative regime. It has been successfully applied for the studies of low energy dynamics of QCD, such as the quark confinement, hadron mass and decay constants, hadron structure and so on.

In the lattice calculation, the most significant source of systematic error is the discretization effects, which is due to finite lattice spacing a. Theoretically, it can be reduced by adding irrelevant operators to the lattice action so that they cancel the discretization effect in the long distance correlation functions. This, so-called improvement program, was originally considered by Symanzik and is widely used in present lattice calculations; the best known example is the removal of the $O(a)$ effect in the Wilson fermion formulation. In this work, we construct an improved lattice action which does not contain $O(a^2)$ effects at least at the tree level.

Our starting point is the overlap fermion formulation, which has manifest flavor and chiral symmetry at finite lattice spacings, in contrast to other fermion formulations such as those of Wilson or staggered. Because of this chiral symmetry on the lattice the discretization effects of $O(a)$ and $O(a^3)$ are absent, and we can concentrate on the improvement of the $O(a^2)$ effects to achieve a highly improved lattice formulation. If it is applied for heavy quark, the effect of improvement would be substantial because the leading error becomes $O((ma)^4)$ rather than $O((ma)^2)$ for the heavy quark mass \$m\$ not too small compared to the lattice spacing $1/a$.

We first improve the so-called kernel operator of the overlap fermion, and then add dimension-six operators to the action, so that it maintains the chiral symmetry. We

check that the tree-level quark dispersion relation and propagator are actually improved for both massless and massive case, and that the rotational-symmetry violating effects are largely removed.

We minimize the numerical cost for applying the improved operator in practical calculations by introducing an improved iterative solver algorithm. The resulting numerical cost for the new operator is only factor of two larger than the original overlap operator. We show some numerical test of the new overlap operator and propose a method to non-perturbatively tune the parameters in the operator.

博士論文の審査結果の要旨

池田裕章氏の博士論文「Improvement of the massive overlap fermion action on the lattice」は、格子ゲージ理論の数値計算において問題となる系統誤差のうち、最大の要因である格子化による誤差を、格子フェルミオン作用を改良して$O(a^2)$の項を消すことで大幅に削減する手法を提案したものである。格子上で厳密なカイラル対称性を実現するオーバーラップ・フェルミオンに基づく改良を考えることによって、通常の格子作用の改良よりも大幅に単純化した定式化を作ることが可能となる。また、作用の改良に伴う計算量の増大を最小限にとどめる数値計算の手法も同時に開発しており、将来の格子量子色力学の数値シミュレーションにおいて適用可能な、有望な定式化を与えたものと考えられる。

論文の内容は、現在の最先端の研究で問題になっている格子計算の誤差の問題に対して、これまでに行われた研究を消化した上でそこに新たなアイデアを加えることで顕著な進歩を実現するもので、博士論文で必要とされる新規性と独自性を十分に含むものになっている。本論文の内容は未だ学術誌に発表されていないが、近い将来に発表する計画をもっている。

以上の理由により、本審査委員会としては、本論文が博士論文にふさわしいものと認める。