PROCEEDINGS OF SCIENCE

Thermodynamics using p4-improved staggered fermion action on QCDOC

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We present an exploratory study of the thermodynamics of $N_f = 3$ QCD with an improved staggered fermions using the QCDOC supercomputer. We use a p4 action with MILC-style smeared links (Fat 7). Some details of the implementation of the p4 action on QCDOC are discussed and performance benchmarks are given. We show preliminary results for the quark mass dependence of the pseudo-critical temperature T_c from several lattice volumes. We also make a comparison between p4fat7 and the old p4 action.

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1. Introduction

Lattice QCD is an important tool for the study of finite temperature QCD. Typically one is forced to use larger lattice spacing (a) for finite temperature quantities than zero temperature quantities. This is mainly because the temperature regime of interest $T_c = (N_\tau a)^{-1}$ (N_τ = 4 - 8) is about (1 fm)$^{-1}$, and simulations at several gauge couplings have to be performed to locate the transition temperature.

This makes improved staggered fermion formulations attractive for thermodynamics studies. Improvements of rotational symmetry via "knight's term" (p4 action) largely reduces the cut-off effects in the pressure and energy density at high temperatures [1]. Also, it is well known that staggered fermions break the flavor symmetry of continuum QCD and this effect can be largely reduced if fat links are used in the fermion action [2]. In this contribution we present an exploratory study of QCD phase diagram with a fermion action which combines the improvements in [1] and [2](p4fat7 action). A more detailed description of the action and simulation parameters are given in section 2. The phase transition for 3 degenerate flavors of p4fat7 quark is described in section 3. Comparison between p4fat7 and p4 action used in [3] is described in section 4.

2. Action and simulation parameters

For this study we use the tree-level improved Symanzik gauge action and p4fat7 action.

$$S(x) = \beta S_g(x) + S_f(x),$$
$$S_g(x) = \sum_{\mu>\nu}\left[\frac{5}{3}\left(1-\frac{1}{3}\mathrm{ReTr}[U_\mu(x)U_\nu(x+\hat{\mu})U_\mu^\dagger(x+\hat{\nu})U_\nu^\dagger(x)]\right)\right. \tag{2.1}$$
$$\left.-\frac{1}{6}\left(1-\frac{1}{6}\mathrm{ReTr}\left[U_\mu(x)U_\mu(x+\hat{\mu})U_\nu(x+2\hat{\mu})U_\mu^\dagger(x+\hat{\mu}+\hat{\nu})U_\mu^\dagger(x+\hat{\nu})U_\nu^\dagger(x)\right]-\frac{1}{6}\mathrm{ReTr}[\mu\leftrightarrow\nu]\right)\right].$$

The fermion part of the action (S_f) is shown in Fig. 1. The coefficient in the smeared link are chosen to cancel flavor symmetry breaking at order $\alpha_s a^2$ [2],

$$c_1 = \frac{1}{8}, \quad c_3 = \frac{1}{16}, \quad c_5 = \frac{1}{64}, \quad c_7 = \frac{1}{384}. \tag{2.2}$$

Here we use the above values of the fat7 coefficients without tadpole improvement. The effect of tadpole improvement on quenched configurations is studied in [4].

All the codes needed for dynamical gauge evolution (HMD R algorithm) is implemented for QCDOC in Columbia Physics System (CPS) and numerically checked against existing Asqtad and p4 action results. The "knight's move" term of p4 action is implemented without non-nearest communication by breaking the term into Parallel transport ($\psi'_\mu(x) = U_\mu(x)\psi(x+\hat{\mu})$) and recombination $\left(R_\mu(x) = \sum_{\nu\neq\mu}(\psi(x+\hat{\nu}) \pm \psi(x-\hat{\nu})\right)$, as illustrated in Fig. 2.

Inversion of p4fat7 Dirac operator, which is the dominating part of gauge evolution for small masses, is currently running at $\sim$ 31% of the peak for $4^3 \times 6$ local volume, which is the local

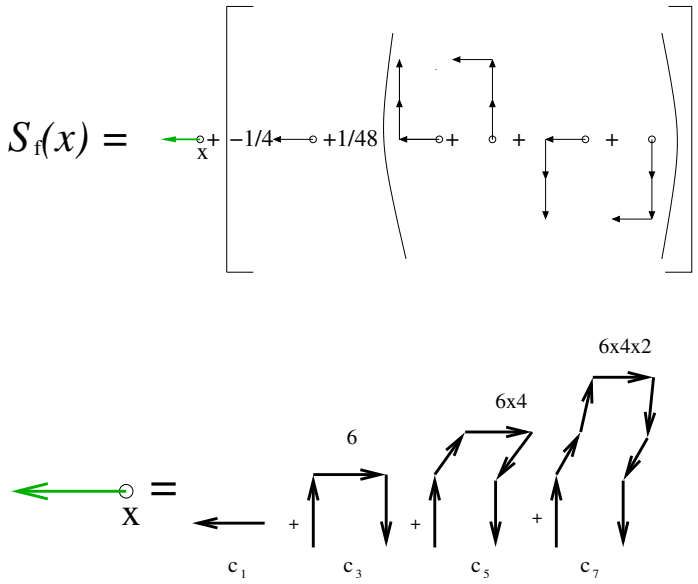

Figure 1: Diagram of p4fat7 action. The numbers above graphs denote the multiplicities of each graphs.

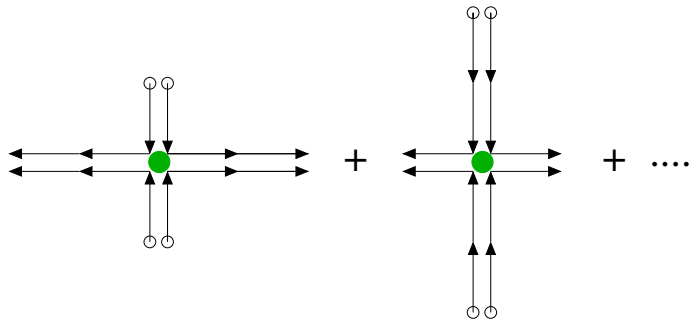

Figure 2: Illustration of implementation of p4 action. The arrows and circles denote the parallel transports and recombinations respectively.

volume for $32^3 \times 6$ on a 512-node QCDOC partition. Further optimization of the Dirac operator, especially at smaller volumes, is possible. Rational Hybrid Monte Carlo(RHMC)[5] implementation is also in progress. All the simulations were done with R algorithm[6] with the step size equal to 40% of the bare mass in lattice units.

3. $N_f = 3$ phase transition with p4fat7

Fig. 3 shows the coupling at the transition as a function of quark masses in lattice units. β_c are located by measuring susceptibilities in average plaquette, Polyakov loop and chiral condensate. The location of peaks coincide within errors. The use of tree-level coefficients enables the use of the reweighting procedure, which is used in locating the transition temperature. At β_c for each mass, separate measurements of heavy quark potential and spectrum calculations were done on $16^3 \times 32$ lattices for physical scale setting.

Volume	sites/node	CG(MFlops/node)	Smearing(MFlops/node)
$2^2 4^2$	64	173	271
4^4	256	207	313
$4^2 \times 6^2$	576	264	264
6^4	1296	231	164

Table 1: Performance of p4fat7 evolution codes on QCDOC, 420Mhz, 1024 nodes, MFlops/node

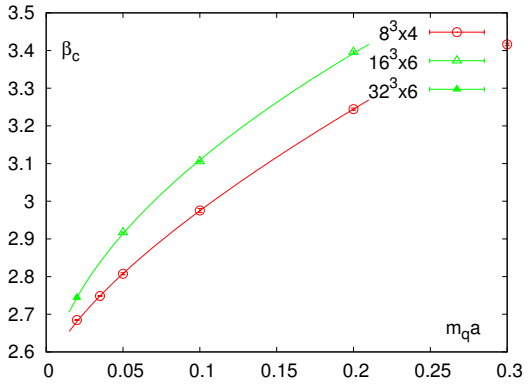

Figure 3: Transition coupling in lattice units (β_c) for 3 flavor p4fat7 action. The curves represent fits to $\beta_c(m_q) = A + B(m_q a)^C$. Red and green points denote $N_\tau = 4$ and $N_\tau = 6$ respectively.

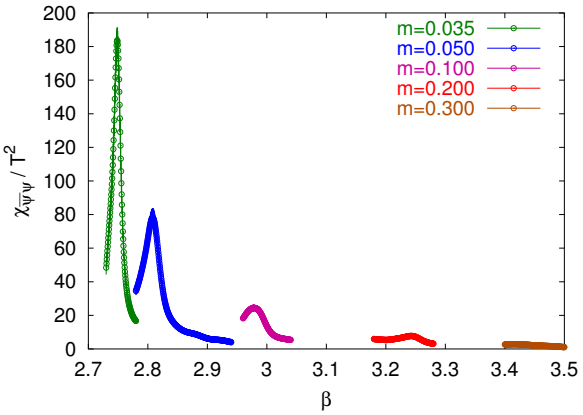

Figure 4: The susceptibility in chiral condensate for $8^3 \times 4$

It has been shown that staggered type fermions exhibits a transition from a rapid crossover to a 1st order transition in small masses. Initial studies suggest that the mass where the transition occurs for $N_\tau = 4$ may be larger than [3], as shown by the rapidly increasing peak in susceptibility in Fig. 4. This may indicate the additional smearing does not suppress finite lattice spacing error much. Further study is in progress.

Fig. 5 shows the heavy quark potential and the lattice spacing, measured by r_0[7]. The error in each $T_c r_0$ includes the difference between 2 different spacial smearings.

4. Comparison with p4fat3 action

P4fat3 action, used in [3], has the knight's move term, 1-link term as well as 3-staple terms. In the notation in Fig. 1, the coefficients are

$$c_1 = \frac{3}{4}\frac{1}{1+6\omega}, \quad c_3 = \frac{3}{4}\frac{\omega}{1+6\omega}, \quad c_5 = c_7 = 0, \quad \omega = 0.2. \tag{4.1}$$

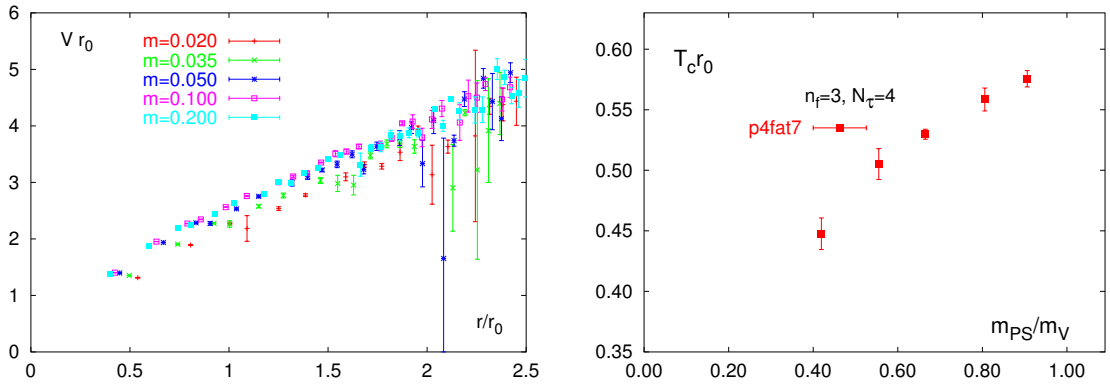

Figure 5: Scale from heavy quark potential for $8^3 \times 4$ p4fat7 lattices

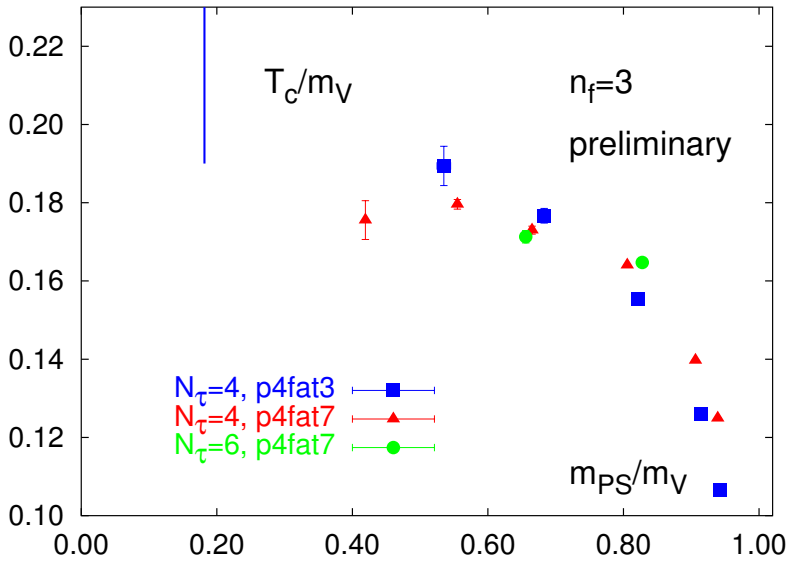

Figure 6: Comparison of T_c/m_V between p4fat7 and the p4fat3.

Fig. 6 shows the behavior of the transition temperature for the p4fat7 and p4fat3 actions. The transition temperature in units of vector meson mass shows a good agreement between the 2 actions. A further study will be needed for the continuum extrapolation.

5. Summary and Future plans

We studied the phase transition of p4fat7 action for 3 degenerate flavors of quarks. p4fat7 action exhibits the finite temperature phase transition and appears to be suitable for other studies such as Equation of States. Although the use of fat7 smearing shows the expected reduction of flavor symmetry breaking symmetry breaking in smaller lattice spacings[4], we do not see a large improvement in flavor symmetry breaking for the lattice spacing relevant for $N_\tau = 4$. More improvement

such as employing tadpole improvement may be needed. We also showed some preliminary results for $N_\tau = 6$ phase transition. More systematic study of $N_f = 3$ and 2+1 transition is in progress. Dirac operator and other routines needed for p4fat7 Hybrid Moleculardynamics are optimized for QCDOC and performing at $\sim 30\%$ for the volumes relevant for finite temperature studies. Implementation for RHMC is under way.

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