HIGH-PERFORMANCE SIMULATIONS OF HIGHER REPRESENTATIONS OF WILSON FERMIONS

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Abstract

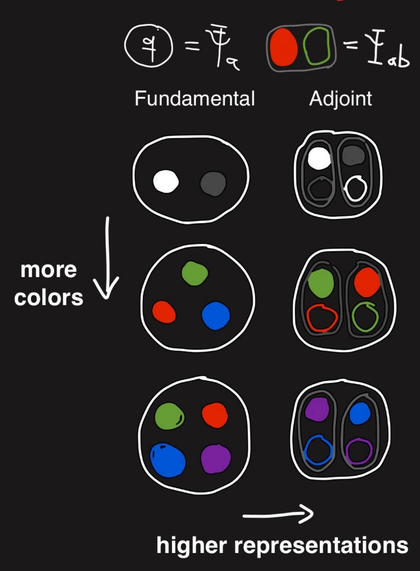
We present HiRep v2, an open-source software suite for high-performance **lattice field theory simulations** with dynamical Wilson fermions in **higher representations of SU(N) gauge groups**. This new version fully supports graphics processing unit (GPU) acceleration, optimizing both gauge configuration generation and measurements for NVIDIA and AMD GPUs. HiRep v2 integrates improved gauge and fermionic lattice actions, advanced inverters, and Monte Carlo algorithms, including the (Rational) Hybrid Monte Carlo ((R)HMC) with Hasenbusch acceleration. It exhibits **excellent scalability across multiple GPUs** and nodes with minimal efficiency loss, making it a robust tool for large-scale simulations in physics beyond the Standard Model.

Higher representations of fermions in beyond the Standard Model physics

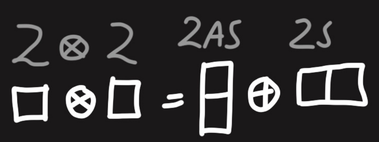
Different numbers of colors produce different patterns of chiral symmetry breaking, confinement or conformality.

Is one of these theories a model for a composite Higgs, Dark Matter or a Grand Unifying Theory?

This library can make non-perturbative predictions for particle masses and LECs that can help experimental searches and phenomenology.



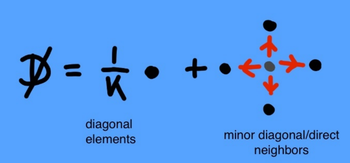
SU(2) Higher fermion representations

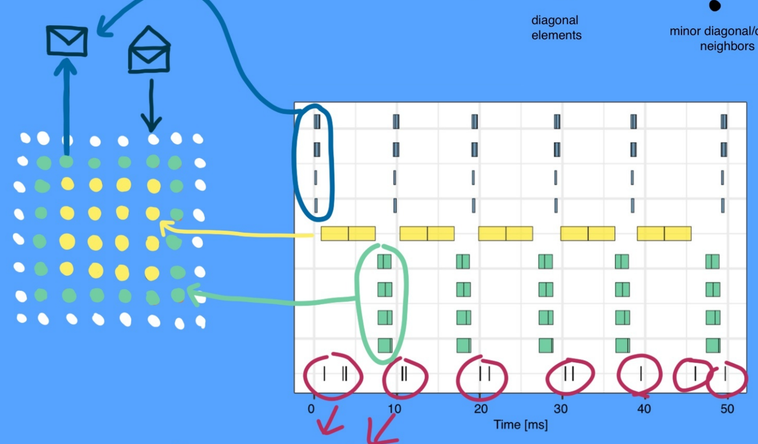


Scaling on GPUs

Bottleneck of lattice simulations with fermions: The Dirac operator. This is a minimally off-diagonal sparse matrix. Solve:

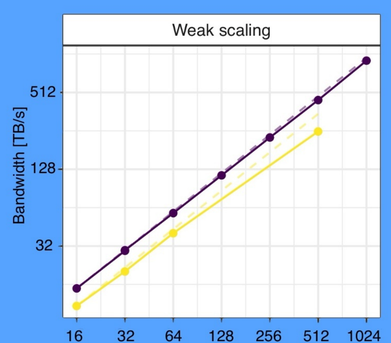
$$\not{D}\psi = \eta \quad \text{for } \psi$$



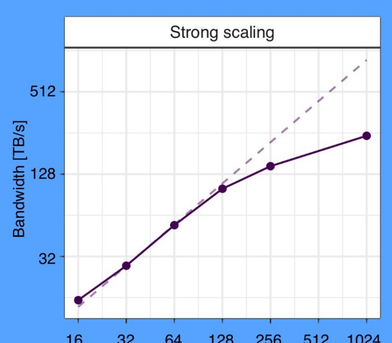


Here you can see that the communications between the GPUs are masked by the computations. This gives nearly ideal scaling

Can I simulate **twice the lattice size** with **twice the GPUs** in the same time? (Weak scaling)



Can I **speed up the simulation by a factor two** by using twice as many GPUs? (Strong scaling)



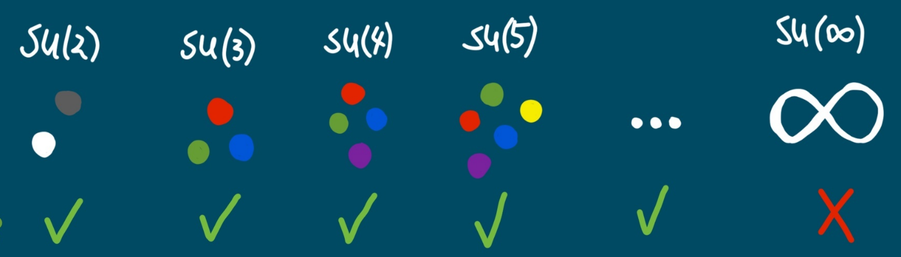
The large-number-of-colors limit

Strongly coupled gauge theories with fermions in different representations approximate SUSY and string theories in the limit of large N. You can use HiRep to compute physical observables and take the limit.

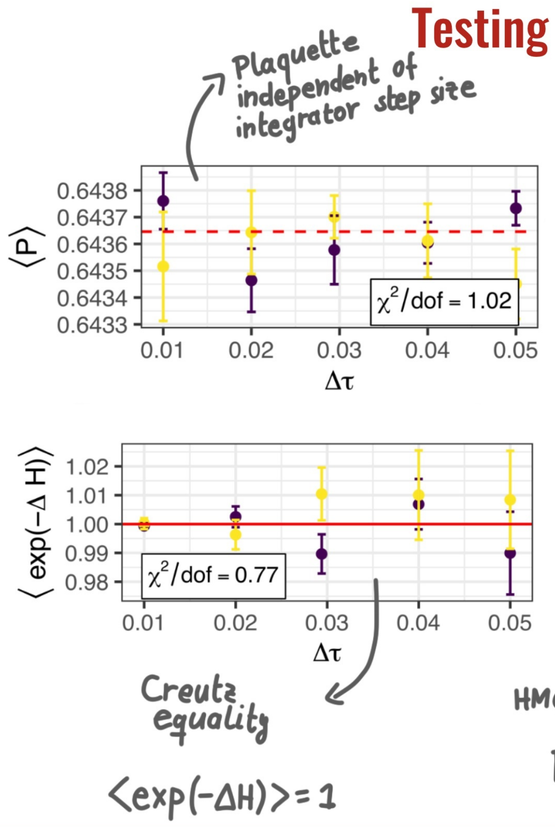
Above you can see an illustration inspired by 't Hooft on how strongly coupled gauge theories approach string theories.

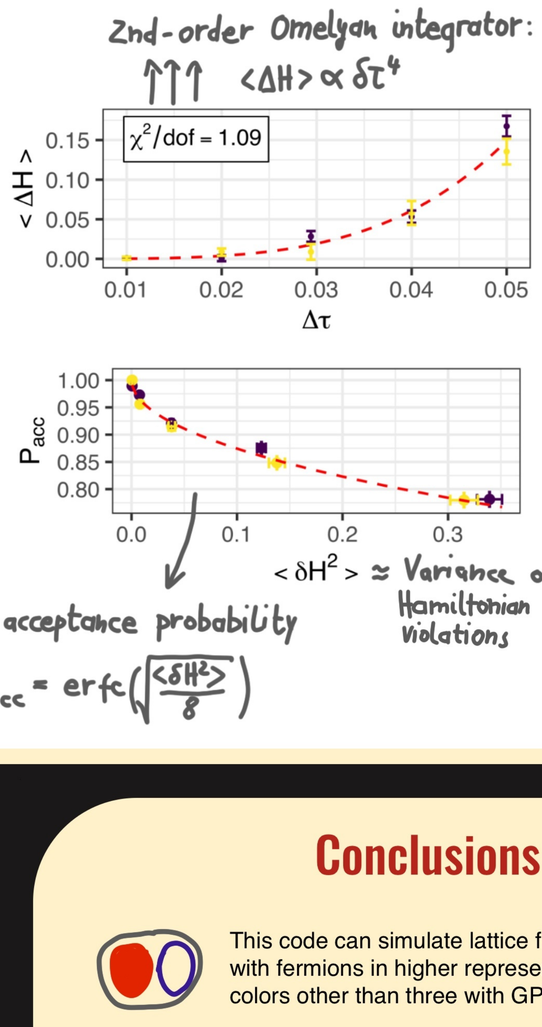
See [2].





Testing the algorithm [3-6]





Literature

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Use the code

Simulation code, benchmarks and tests

github.com/claudiopica/hirep

Conclusions

- This code can simulate lattice field theories with fermions in higher representations and colors other than three with GPU acceleration.
- Algorithmic tests show that the code displays the correct analytic behavior.
- The code exhibits excellent scalability in the bottleneck, the Dirac operator, where we can show scaling up to 1000 GPUs.