Simulations of Open LFT

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July 26, 2021

Quantum Algorithms for Open Lattice Field Theory. Jay Hubisz, Bharath Sambasivam and Judah Unmuth-Yockey. 2020. (2012.05257).

Quantum Simulation of Open Lattice Field Theory. Erik Gustafson, Michael Hite, Jay Hubisz, Bharath Sambasivam, and Judah Unmuth-Yockey. FUTURE PRINT.

Simulations

Consider the following Hamiltonian:

$$\hat{H} = -\sum_{\langle ij \rangle} \hat{\sigma}_i^z \hat{\sigma}_j^z - h_x \sum_i \hat{\sigma}_i^x + i\Theta \sum_i \hat{\sigma}_i^z. \quad (1)$$

Question: How does the system evolve?

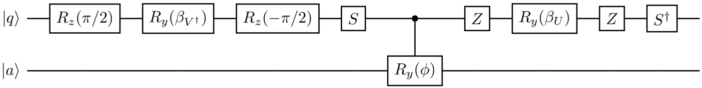
Exact Rotation

Damping Channel

Exact Rotation: 1 Site
$\hat{H} = -h_x \hat{\sigma}_1^x + i\Theta \hat{\sigma}_1^z$

Time Evolution Operator:

$$e^{-it\hat{H}} = U \Sigma V^\dagger \tag{2}$$



$$R_y(\beta) = \mathrm{Exp}\left(i\frac{\beta}{2}Y\right) \quad \text{and} \quad R_z(\alpha) = \mathrm{Exp}\left(i\frac{\alpha}{2}Z\right) \tag{3}$$

Exact Rotation: 1 Site

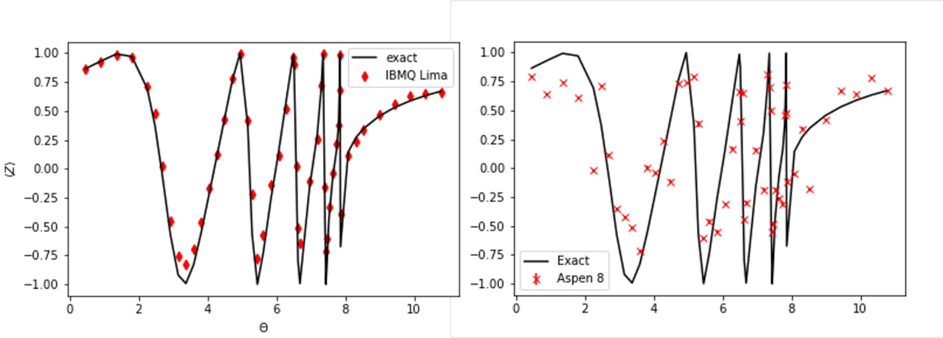


Figure 1: $h_x = 8, t = 2$

Exact Rotation: 2 Site
$\hat{H} = -\hat{\sigma}_1^z \hat{\sigma}_2^z - h_x(\hat{\sigma}_1^x + \hat{\sigma}_2^x) + i\Theta(\hat{\sigma}_1^z + \hat{\sigma}_2^z)$

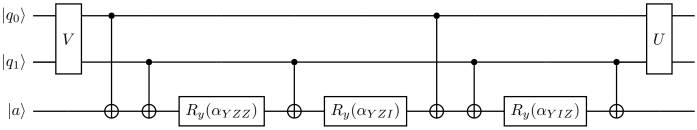


Figure 2: Complete circuit

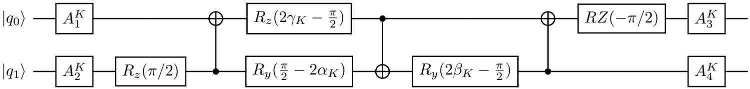


Figure 3: U,V Gate Decomposition

Exact Rotation: 2 Site

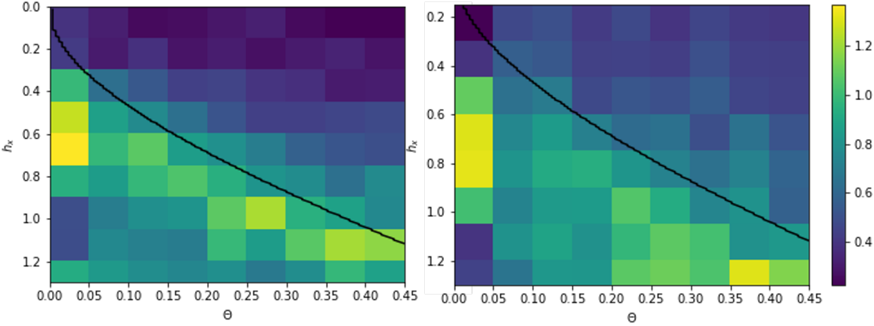


Figure 4: Run on IBMQ Lima and Yorktown. The observable $1 - \langle Z \rangle / 2$ is measured.

Damping Channel: 1 Site
$\hat{H} = -h_x \hat{\sigma}_1^x + i\Theta \hat{\sigma}_1^z$

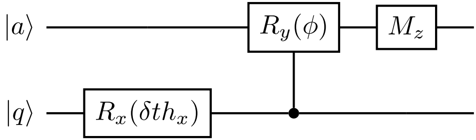


Figure 5: We store the measurements of the ancilla for each Trotter step. If they are all zero, then we know it is in the correct state.

Damping Channel: 1 Site

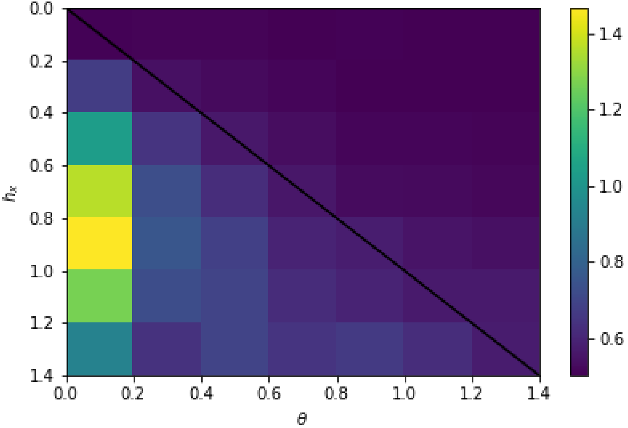


Figure 6: Four Trotter steps with $\delta t = 0.5$ on IBMQ Lima. We measure $1 - \langle Z \rangle / 2$.

Damping Channel: 2 Site
$\hat{H} = -\hat{\sigma}_1^z\hat{\sigma}_2^z - h_x(\hat{\sigma}_1^x + \hat{\sigma}_2^x) + i\Theta(\hat{\sigma}_1^z + \hat{\sigma}_2^z$

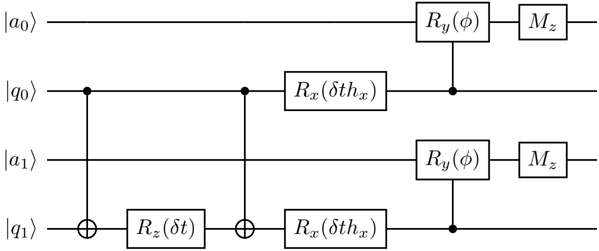


Figure 7: For a 2 site model the number of classical registers needed is 2 times the number of steps.

Damping Channel: 2 Site

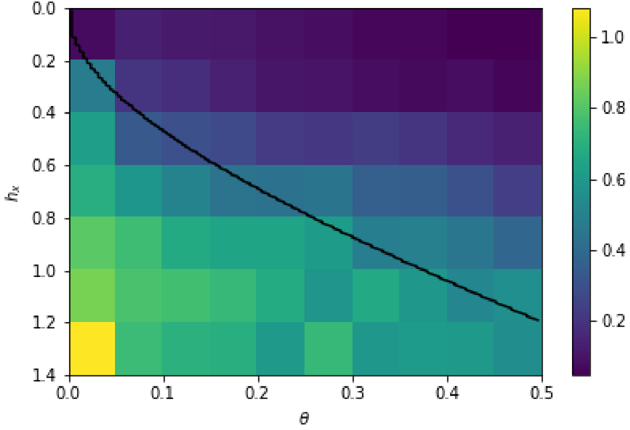


Figure 8: Four Trotter steps with $\delta t = 0.5$ on IBMQ Lima. We measure $1 - \langle Z \rangle / 2$.

Conclusion

Small non-Hermitian systems can be accurately simulated in the NISQ era.

Future Work:

- Consider other observables.
- Implement 3 and 4 site models for the damping channel approach (Rigetti, IonQ, etc.).
- Explore the thermodynamics of system's with complex β.
- Compare with the QITE algorithm.

Acknowledgments

This work was supported in part by the U.S. Department of Energy (DOE) under Award Number DE-SC0019139

Work funded by NSF award DMR-1747426

I would also like thank my advisor Yannick Meurice