Simulating Quantum Systems:

Hamiltonian Simulations & Prospects for QML

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(Higher Order) Trotterization

- **Project: investigation of quantum algorithms**
- Created modular framework to construct high order trotterizations
- Preparation for benchmarking with Qubitization

$$\mathscr{S}_2(t) := e^{-i\frac{t}{2}H_1} \cdots e^{-i\frac{t}{2}H_\Gamma} e^{-i\frac{t}{2}H_\Gamma} \cdots e^{-i\frac{t}{2}H_1},$$
$$\mathscr{S}_{2k}(t) := \mathscr{S}_{2k-2}(u_k t)^2 \mathscr{S}_{2k-2}((1-4u_k)t) \mathscr{S}_{2k-2}(u_k t)^2,$$
$$\text{where } u_k := 1/\left(4 - 4^{1/(2k-1)}\right).$$

Figure 1 | Higher-order Suzuki formulas following Suzuki (1992); Childs et. al (2021)

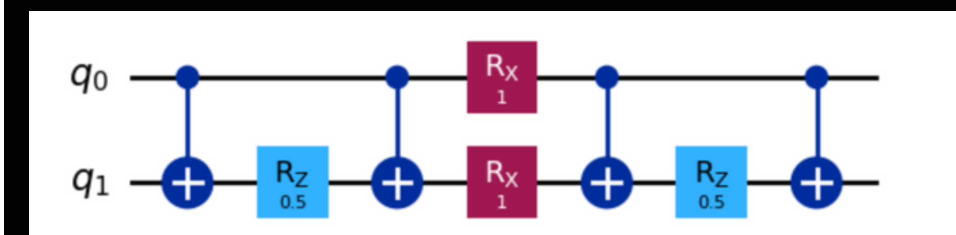


Figure 2 | Second order Trotter-Suzuki

(Higher Order) Trotterization

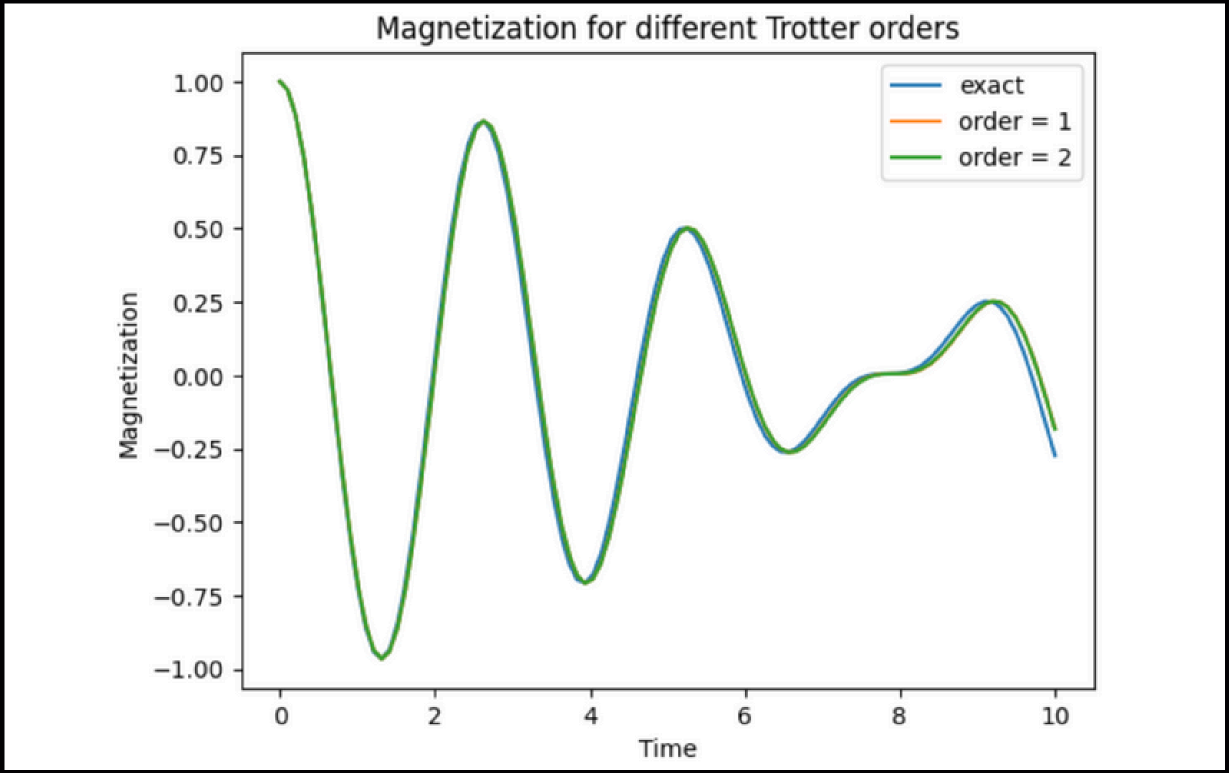


Figure 3 | Magnetization for different Trotter orders

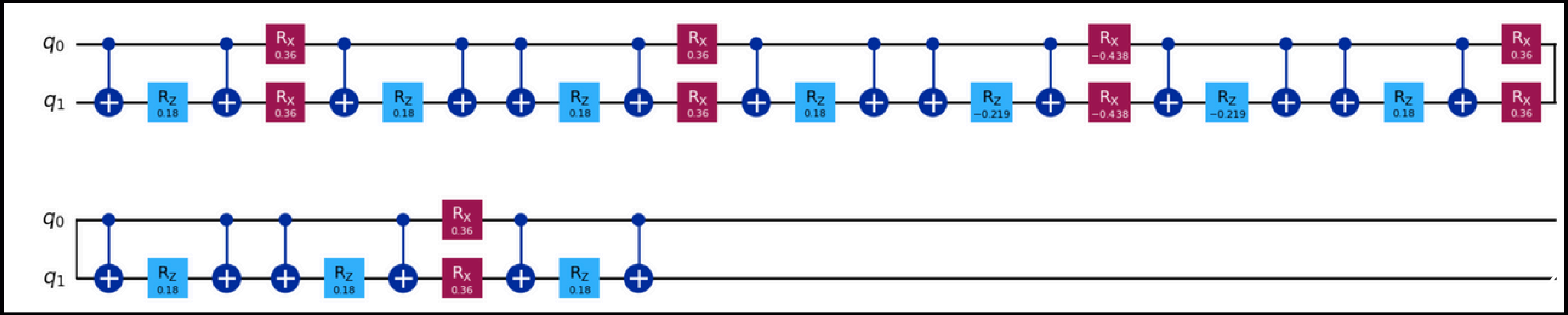


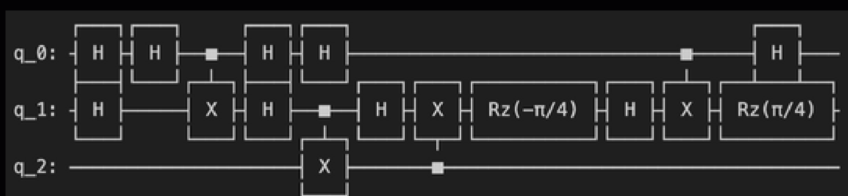
Figure 4 | Fourth order Trotter-Suzuki

(Higher Order) Trotterization

Order $2k$	Error Scaling $O(\Delta t^n)$	Number of Exponentials N
1st (Trotter)	$O(\Delta t^2)$	$O(1)$
2nd (Suzuki)	$O(\Delta t^4)$	3
4th	$O(\Delta t^6)$	7
6th	$O(\Delta t^8)$	19
8th	$O(\Delta t^{10})$	49
10th	$O(\Delta t^{12})$	123
$2k$th	$O(\Delta t^{2k+2})$	$O(5^k)$

Table 1 | Error scaling table, following Suzuki (1992)

Qubitization



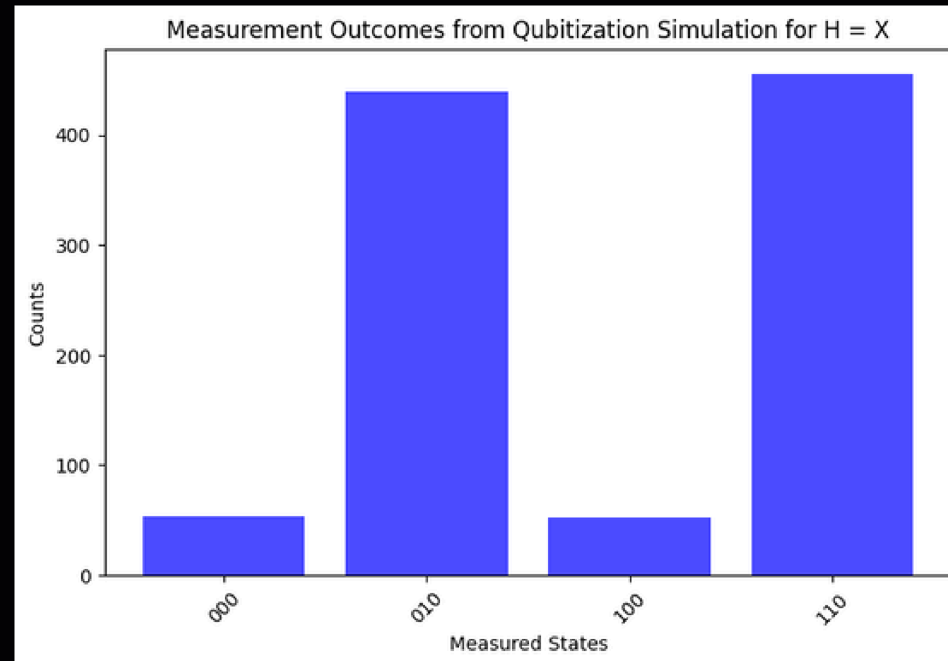


Figure 5 | Toy Model and Measurement Outcomes for H=X Hamiltonian Ising Qubitization

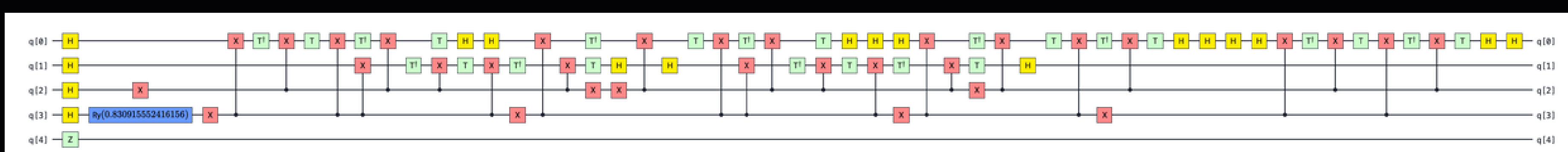


Figure 6 | Circuit diagram of Qubitization

Benchmarking

- Cross-validation of Trotterization and Qubitization methods
- As Trotterization depth increases:
    - circuit depth increases; **error decreases**
    - however, **execution time is higher** than Qubitization

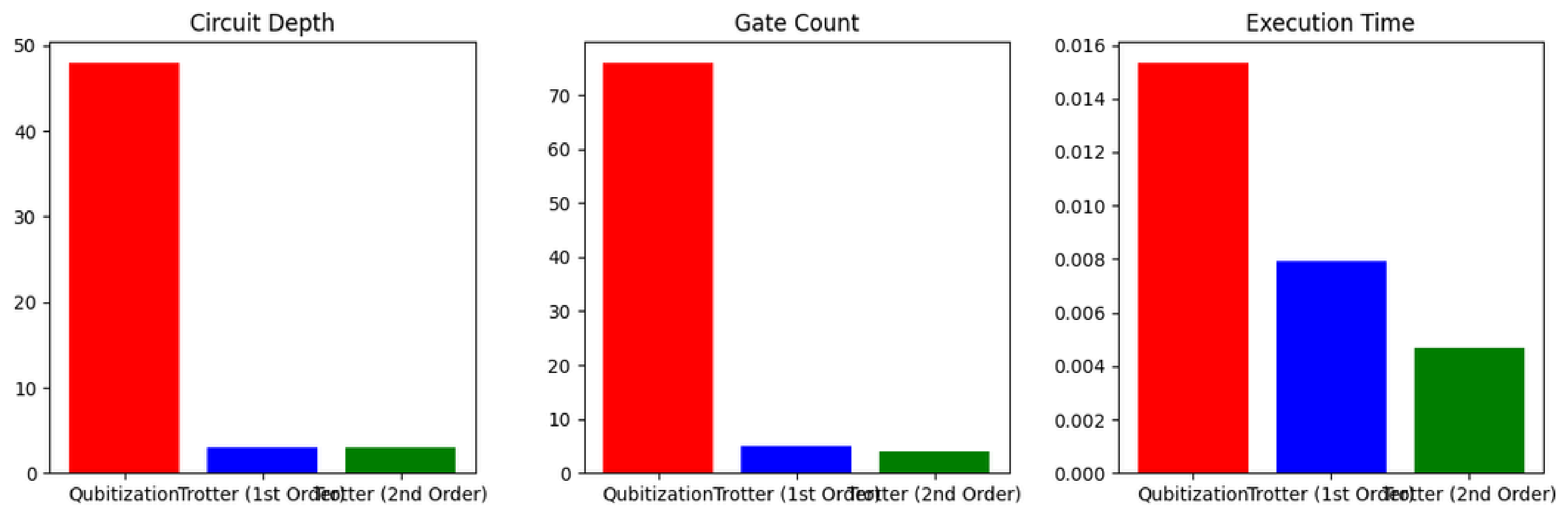


Figure 7 | Preliminary Benchmarking
(red) Qubitization; (blue) 1st Order Trotter; (green) 2nd Order Trotter

Real-World Applications:

- Quantum Algorithm for processing large-scale public health data
    - e.g. COVID-19 data from WHO and CDC
- System is assumed to follow Hamiltonian dynamics
- Hamiltonian is replaced by objective function

Toy Model:

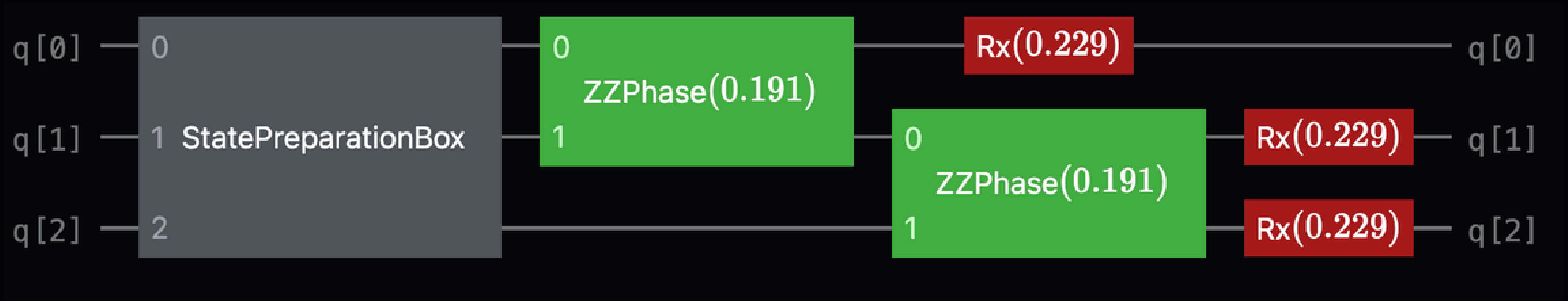


Figure 7 | State Preparation Box to process data

Conclusions

We have performed an investigation of quantum algorithms

- **Highly modular framework** to construct high order trotterizations
  - prescription for arbitrary Hamiltonian
- Construction of **Qubitization** for H=X Hamiltonian
- **Benchmarking** with Trotterization and Qubitization methods; preliminary results: latter performs faster
- Exploration of **feature selection** using quantum-inspired algorithm

Future Directions:

- Highly modular robust decomposition of arbitary Hamiltonians
- Benchmarking of additional algorithms
- Exploration of scalability

References

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GitHub Link: https://github.com/aanyabhandari3/Groobits-Quantinuum-2025