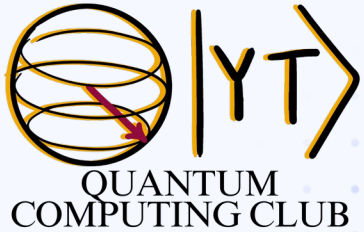
Quantum Cellular Automata for QEC

A Summer Research Experience

By Gabriel Balarezo



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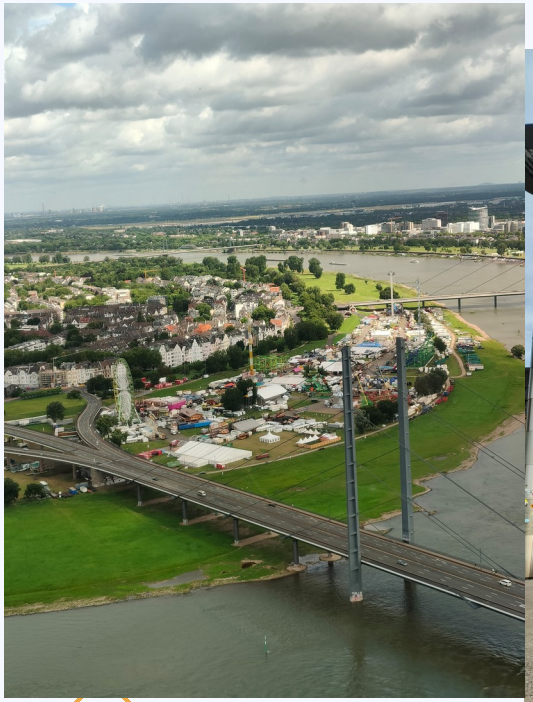
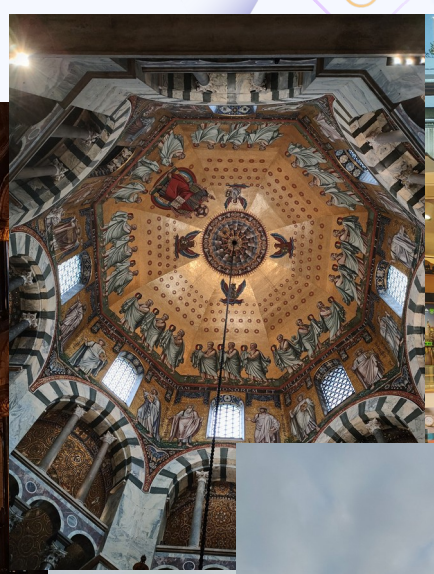
What is it like spending a summer in Germany?

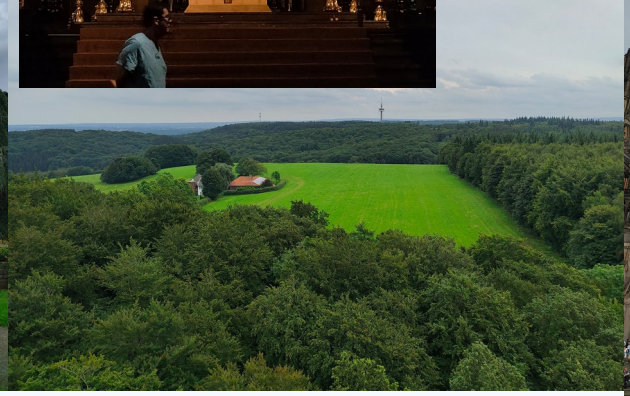
Introduction

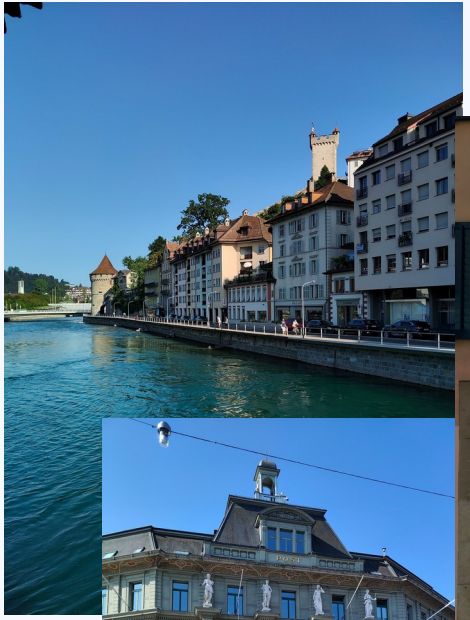


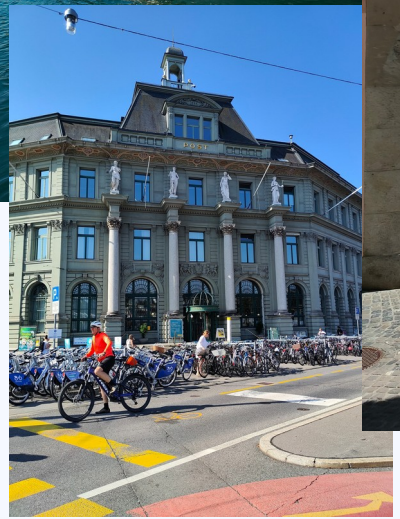


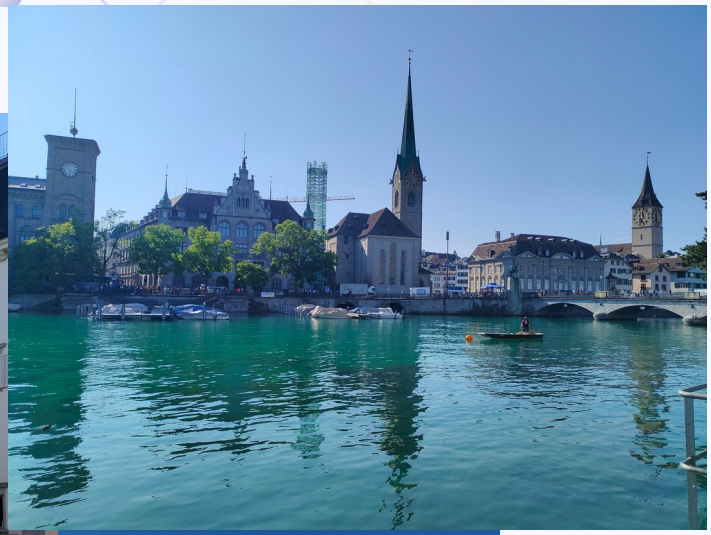


LPTURES
HOLZSCHNIT



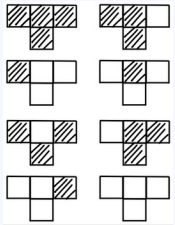


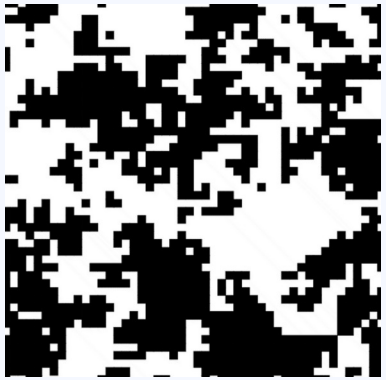


Cellular Automata

Simple rules, complex behaviour

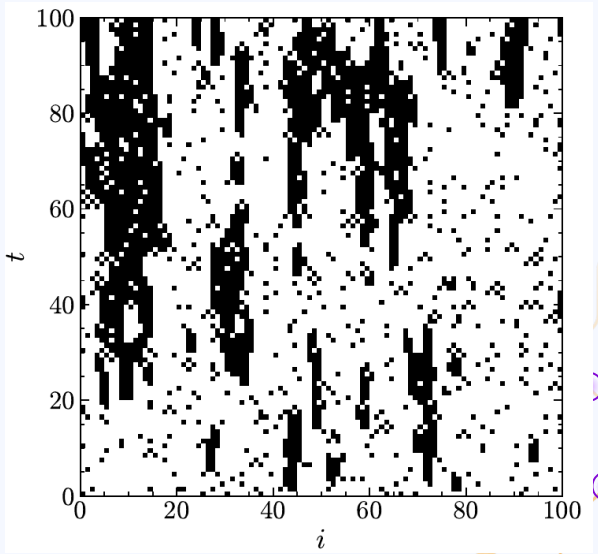
- Discrete dynamical systems.
- Finite lattice of cells, each in 0 or 1 state.
- Propagate information at finite speed, following a translation-invariant local rule.



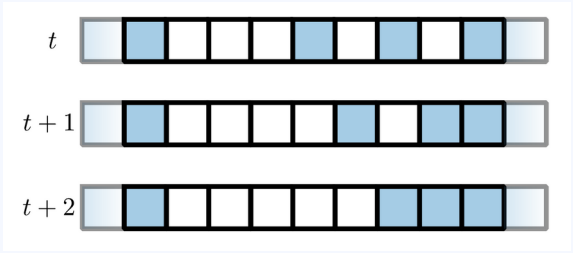


Wolfram's 232 rule (Local majority voting rule)

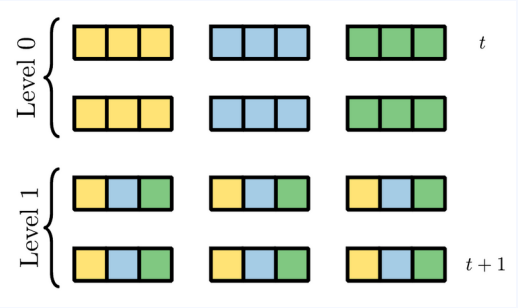
$$s_i^{t+1} = s_{i+1}^t s_{i-1}^t \oplus s_{i+1}^t s_i^t \oplus s_{i-1}^t s_i^t$$



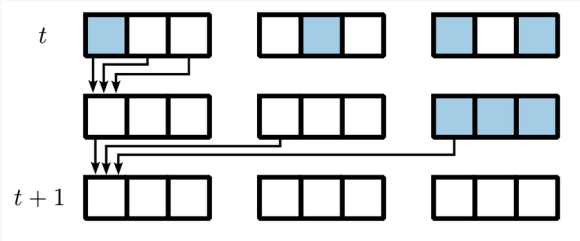
Non-concatenated CA



Concatenated CA

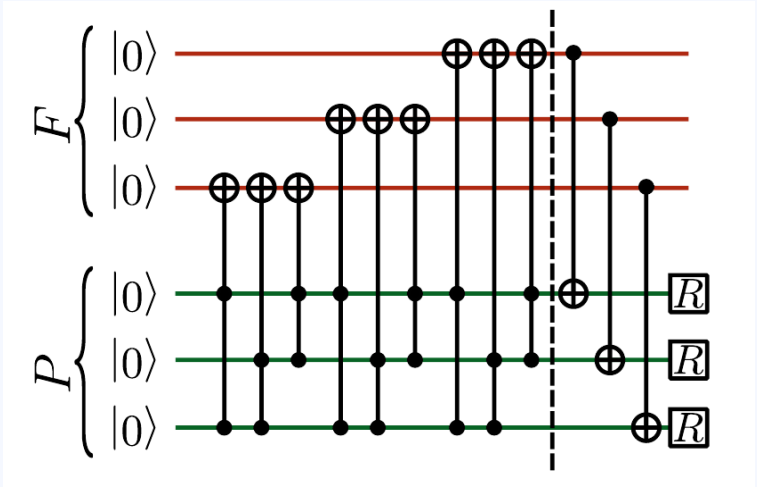


- Consider a 1D cellular automata, composed by N cells and periodic boundary conditions.
- The blue cells represent noise on a state, after 1 time step, concatenated CA successfully gets rid of the noise.



Quantum Cellular Automata

- Cells are now quantum systems (qubits)
- Use two registers: Present (P) and Future (F) to achieve reversible computation.
- Evolution from P to F is performed by quantum local majority voting (Q232) rule.



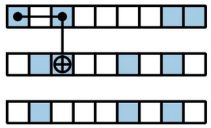
Non-concatenated CA

- Three Toffoli gates encode the majority amongst s^t_{i-1}, s^t_i and s^t_{i+1}.
- Traversal CNOT gates decouple P and F registers.

Numerical simulation

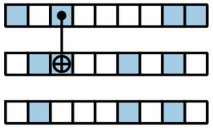
Toffoli(c_1, c_2, t)

- $r_t^{(1)} = r_t^{(1)} \oplus r_{c_1}^{(0)} r_{c_2}^{(0)}$

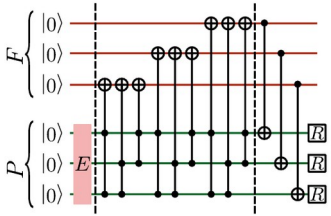


CNOT(c, t)

- $r_t^{(1)} = r_t^{(1)} \oplus r_c^{(0)}$

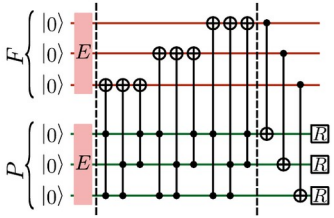


Noise in P register

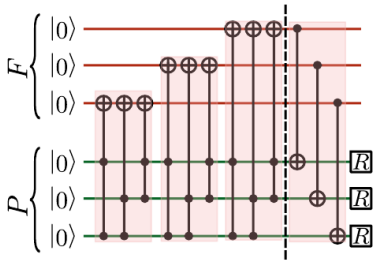


with probability p.

Noise in P and F registers

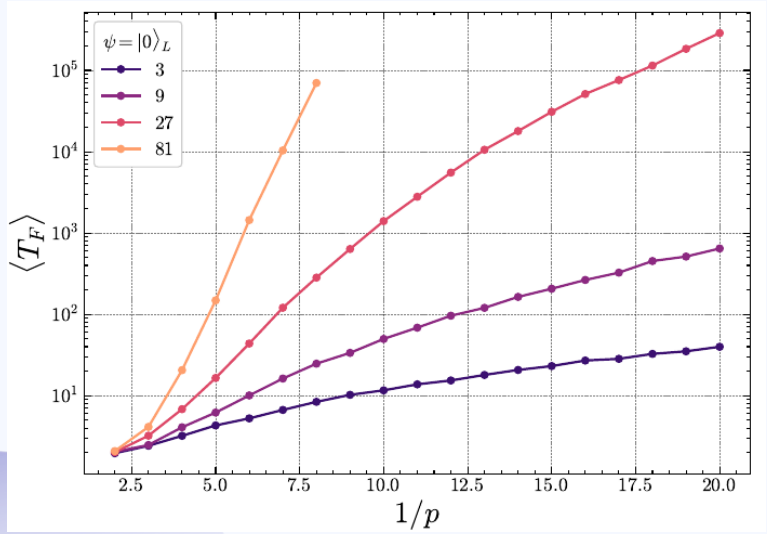


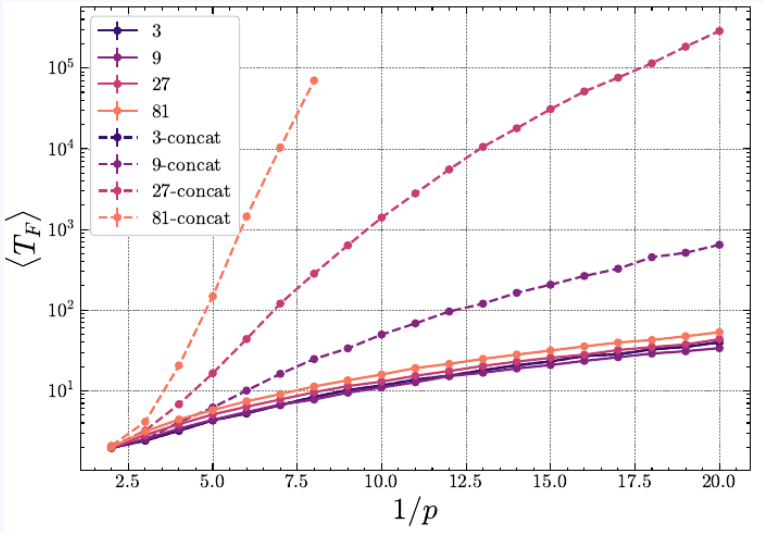
Circuit level noise



Results

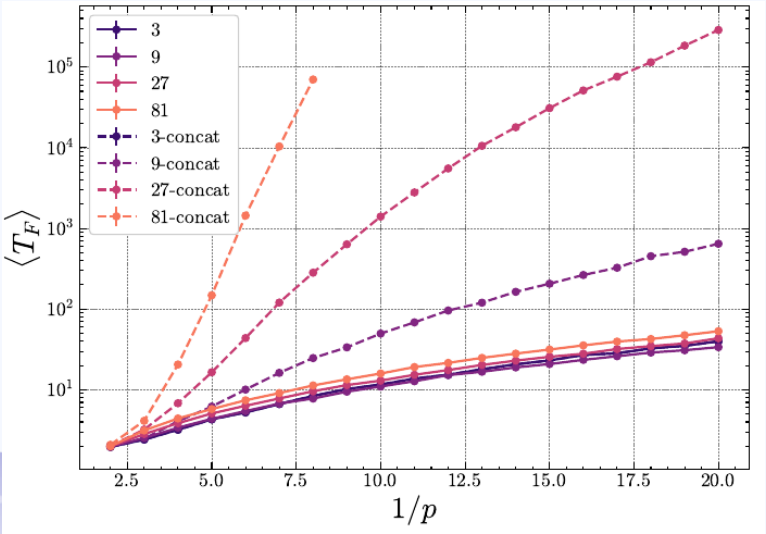
Noise in P and F registers

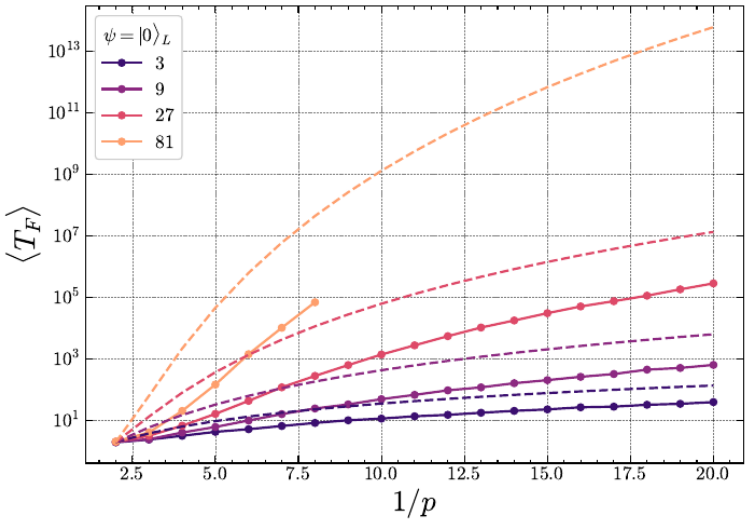




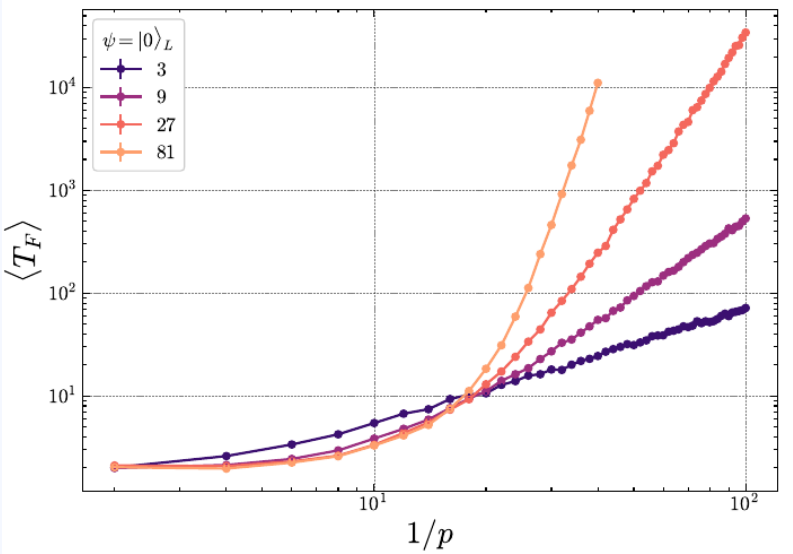
Results

Noise in P and F registers





Circuit level noise



- Circuit level noise reduces qubit's coherence time.
- A threshold was found about p=1/20

Conclusions

- **Concatenated QCA** with Quantum Local Majority Voting is a promising candidate for Measurement-Free Quantum Error Correction
- Threshold about p=1/20 for circuit level noise.
- Linear overhead in the number of qubits for the concatenated scheme
- Toffoli and CNOT gates are massively parallelisable given a platform that allows for this (e.g., neutral atoms)

Thanks!