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Quantum Information and Computation JYU

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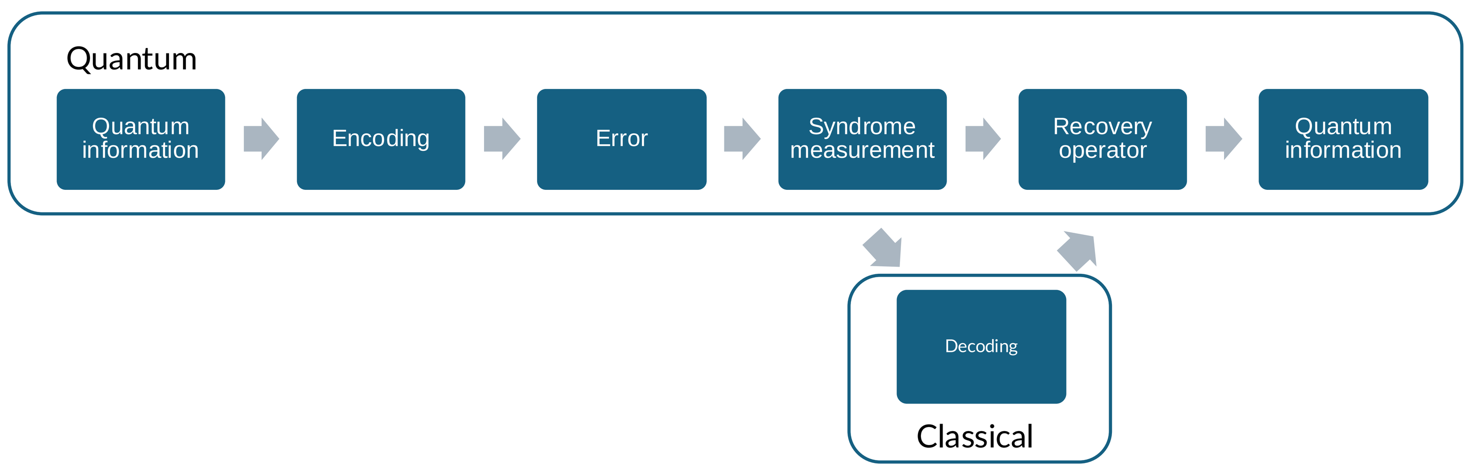
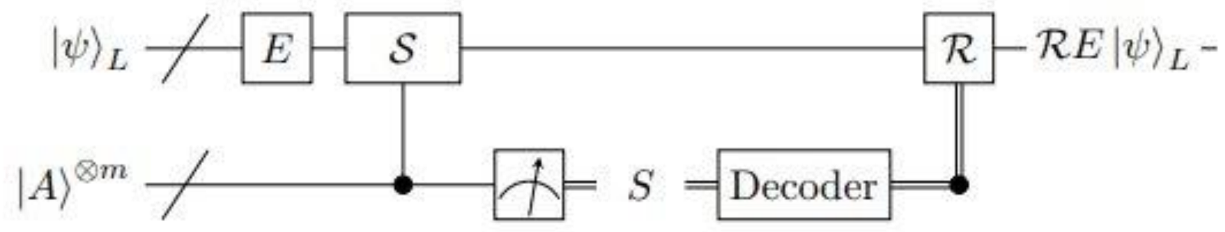
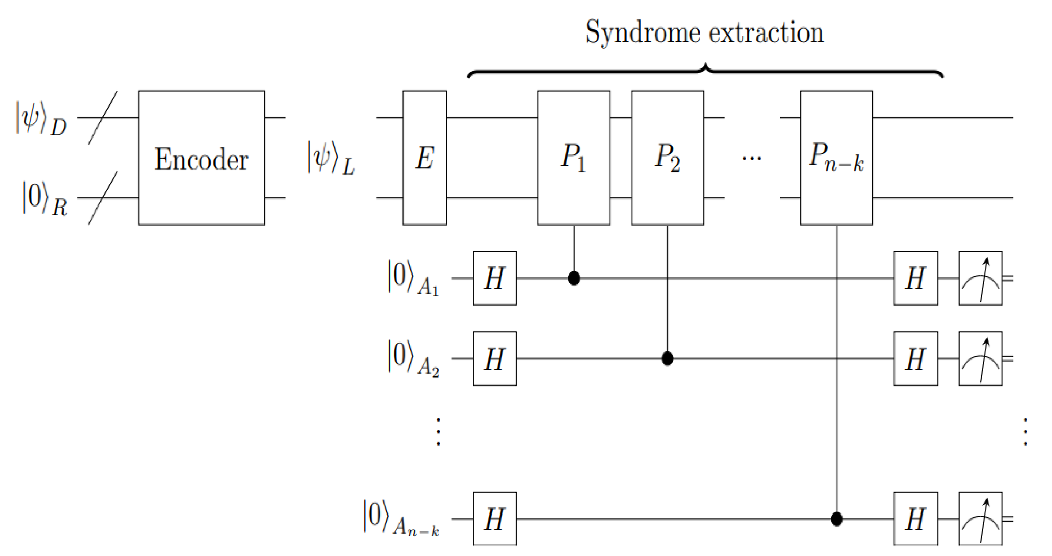
ML Approaches for Scalable and Efficient Quantum Error Correction





Stabilizers:

- Signed tensor product of Pauli matrices that leaves a quantum state unchanged $M|\psi\rangle = |\psi\rangle$
- Stabilizer group $S = \{S_i \epsilon G_n \mid S_i|\psi\rangle_L \ \forall \ |\psi\rangle_L \wedge [S_i, S_j] = 0 \ \forall (i,j)\}$
- For each stabilizer, the syndrome extraction circuit maps the logical state as
- $E|\psi\rangle_L|0\rangle_{A_i} = \frac{1}{2}(I^{\otimes n} + P_i)E|\psi\rangle_L|0\rangle_{A_i} + \frac{1}{2}(I^{\otimes n} - P_i)E|\psi\rangle_L|1\rangle_{A_i}$



n = number of qubit
k = number of logical qubit encoded
d = distance of code

Fig:- [[n,k,d]] stabilizer code

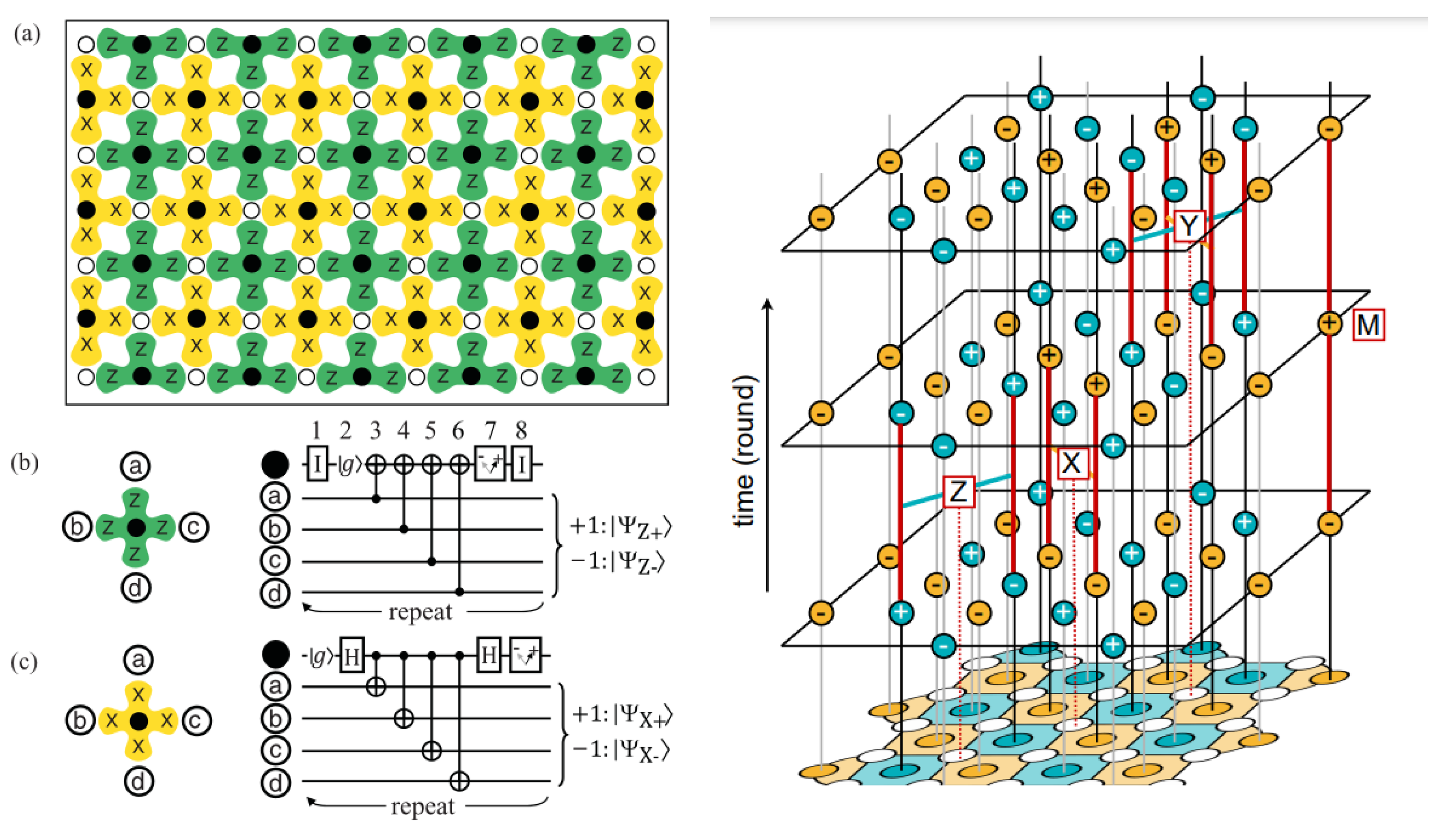
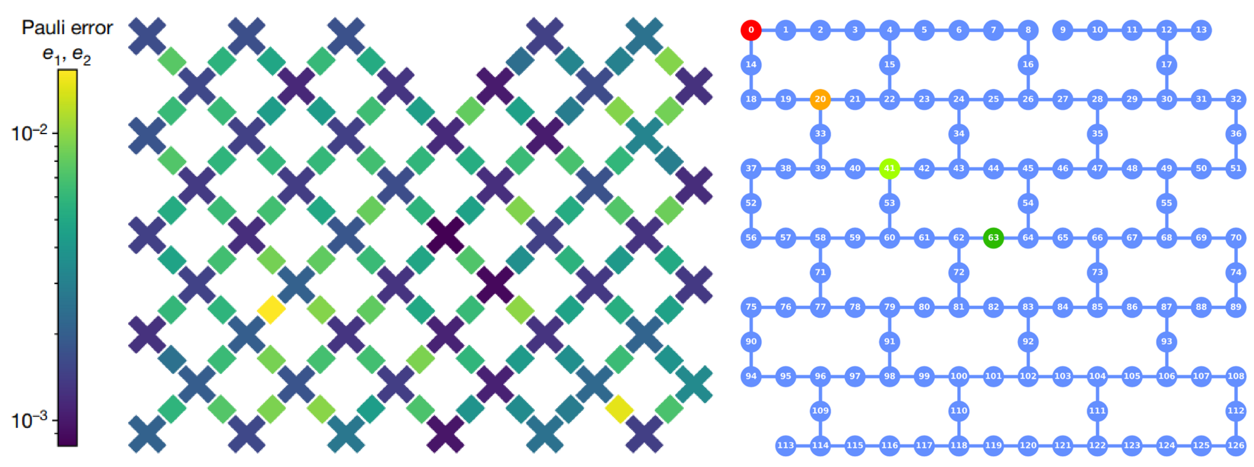


Fig - Surface Code[1]

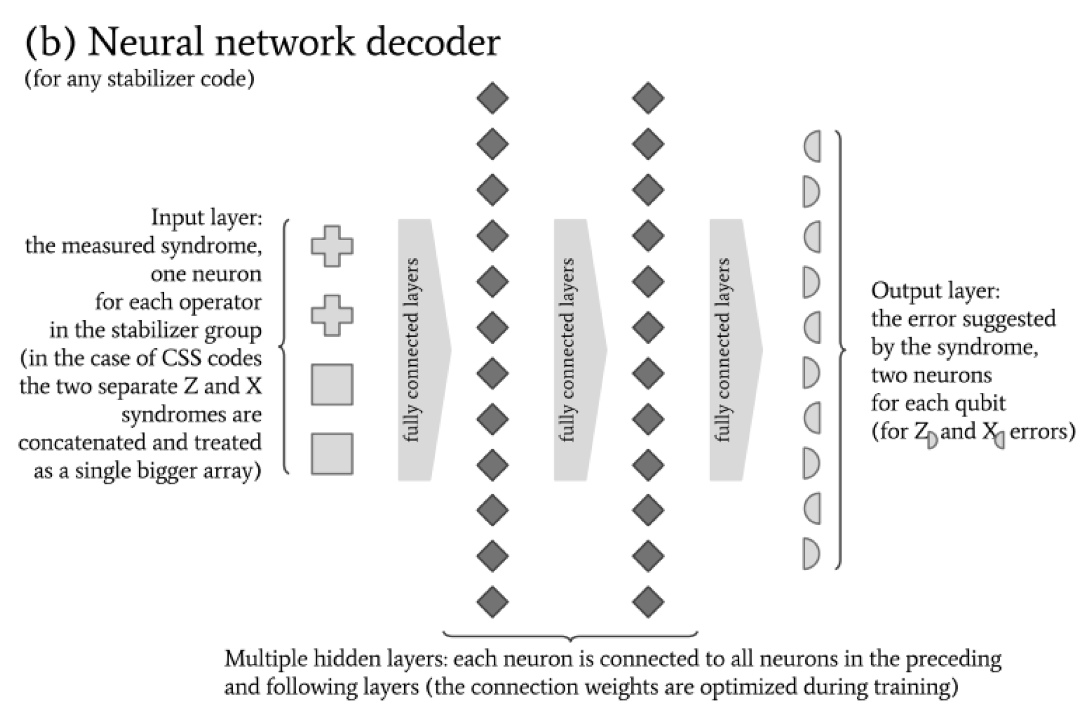
Challenges:

- Qubit Layout



- Scaling: $[[n = \lambda^2 + (\lambda - 1)^2, k = 1, d = \lambda]]$
  Ex – [[13,1,3]], [[41,1,5]]
- Number of Syndromes bits $m = n - k$
  Size of Syndrome table = 2^m
- Decoding: NP hard problem

Neural Network Decoder[2,3]:



References:
1. Austin G. Fowler et al. 2012, "Surface codes: Towards practical large-scale quantum computation", Phys. Rev. A **86**, 032324
2. Krastanov, S., Jiang, L. Deep Neural Network Probabilistic Decoder for Stabilizer Codes. *Sci Rep* **7**, 11003 (2017).
3. Bausch, J., Senior, A.W., Heras, F.J.H. *et al.* Learning high-accuracy error decoding for quantum processors. *Nature* **635**, 834–840 (2024)