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Experimental Quantum Error Correction

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Introduction

While it is clear that some form of error correction will be necessary to implement any type of scalable quantum computing, the literature on error correcting codes for adiabatic quantum computing is sparse. The most well-known of these codes requires physically improbable four-body interactions to protect against a general quantum error. We take a more practical approach, motivated by the tools at hand.

Equipment

USC has a D-Wave One adiabatic quantum optimization processor installed at the Information Sciences Institute in Marina Del Rey. While this device does not implement universal quantum computation, it does solve a special class of quadratic binary optimization problems. The computation is performed by initializing the system in the easily preparable ground state of an initial Hamiltonian H_I and slowly changing the control parameters of the system until the ground state of the final Hamiltonian H_F embodies the solution to the problem.

$$H(t) = \underbrace{\sum_i \Delta(t)\sigma_x^i}_{H_I} + \underbrace{\sum_i h_i \sigma_z^i + \sum_{i,j} J_{ij}\sigma_z^i \sigma_z^j}_{H_F}$$

$$\Delta(0) >> h_i, J_{ij} \longrightarrow \Delta(T) << h_i, J_{ij}$$

Error Correcting Code

We implement a four-qubit repetition code in the computational basis. Within each logical group, three "data" qubits carry the couplings from the original problem and one "ancilla" qubits mediates stabilizer terms throughout the logical group, providing a penalty for violating equality amongst the four qubits. We encode only the final Hamiltonian; in fact, we are not able to change H_I.

Unencoded: $$H_F = \sum_i h_i \sigma_z^i + \sum_{i,j} J_{ij}\sigma_z^i \sigma_z^j$$

Encoded: $$\overline{H}_F = \sum_i h_i \overline{\sigma_z^i} + \sum_{i,j} J_{ij}\overline{\sigma_z^i}\,\overline{\sigma_z^j} + H_{\text{penalty}}$$

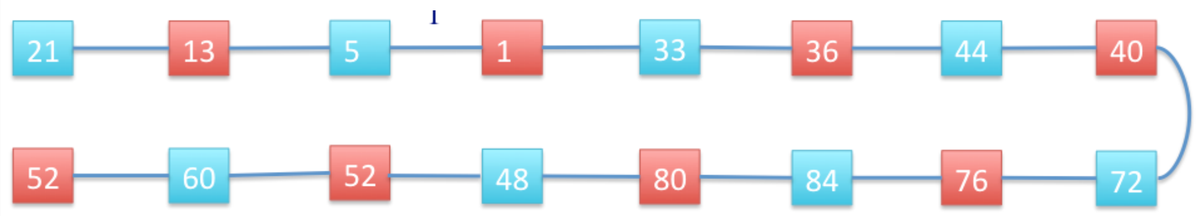
$$\overline{\sigma_z^i} = \sigma_z^{i,1} I_{i,2} I_{i,3} + I_{i,1}\sigma_z^{i,2} I_{i,3} + I_{i,1} I_{i,2}\sigma_z^{i,3}$$

Penalty:

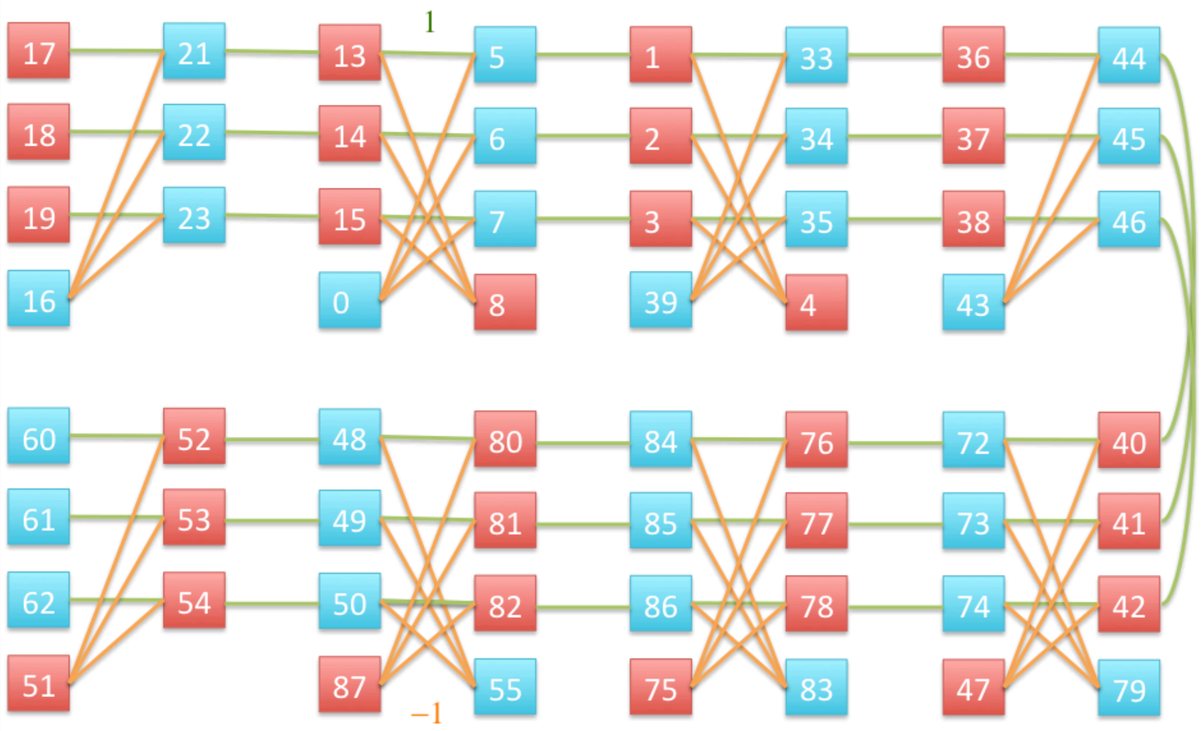
$$H_{penalty} = \sum_i -\left(\sigma_{i,1}^z I_{i,2} I_{i,3}\sigma_{i,a}^z + I_{i,1}\sigma_{i,2}^z I_{i,3}\sigma_{i,a}^z + I_{i,1} I_{i,2}\sigma_{i,3}^z \sigma_{i,a}^z\right)$$

Sample Problem: Antiferromagnetic Chain

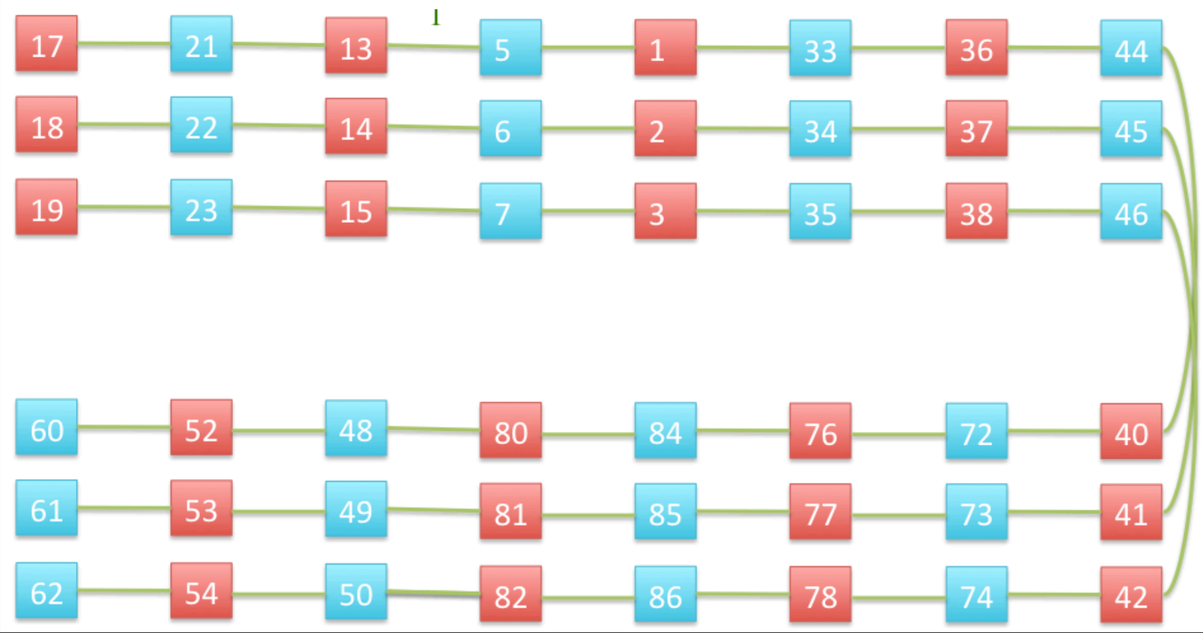
Unencoded:



Encoded:

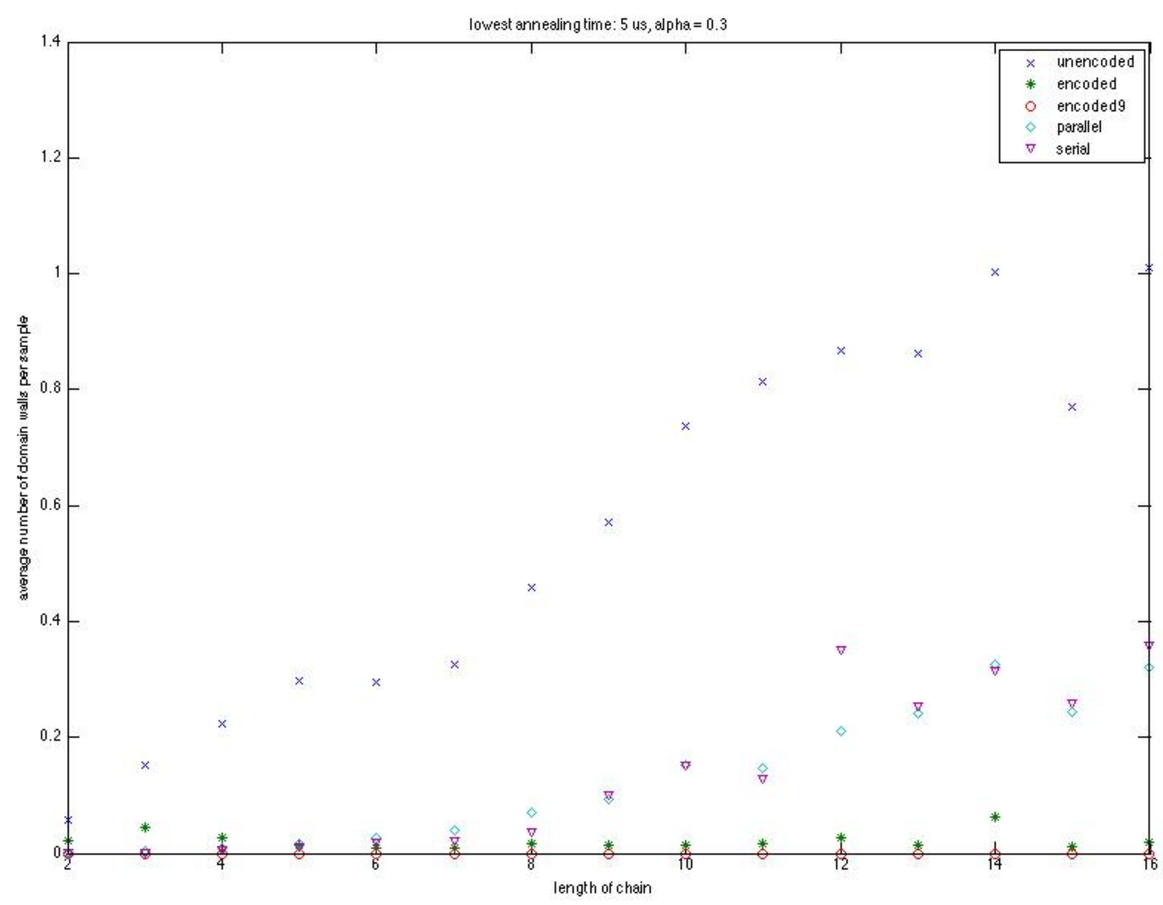


Parallel:



Results

Encoded chains exhibited fewer errors than their unencoded counterparts, even when classical decoding was used.



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