A Faster Objective Function for Making Quantum Circuits Nearest Neighbour Compliant

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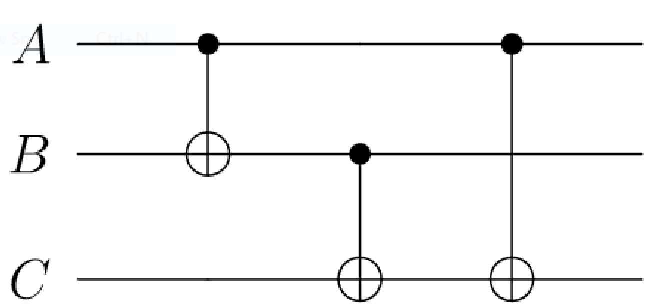

Fig 1. Example circuit

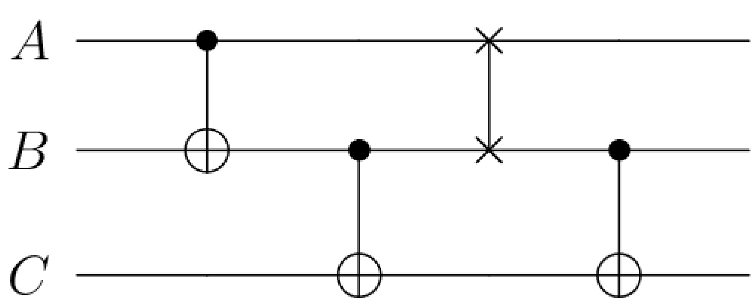

Fig 2. Circuit with swap inserted

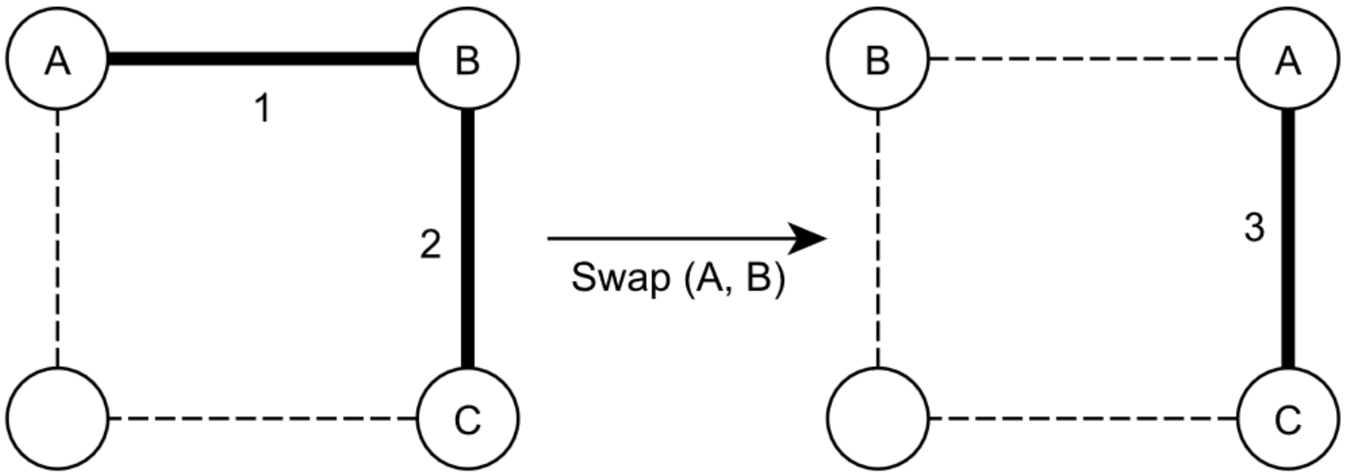

Fig 3. Qubit placement before and after swap

The optimal algorithm is intractable, so we use a heuristic:

$$Cost(P) = \sum_{i,j \in L} W(i,j) D(P(i), P(j))$$

Where P is the logical to physical mapping
L is the set of logical qubits
D is the distance between two physical qubits
W is the number of times two logical qubits interact

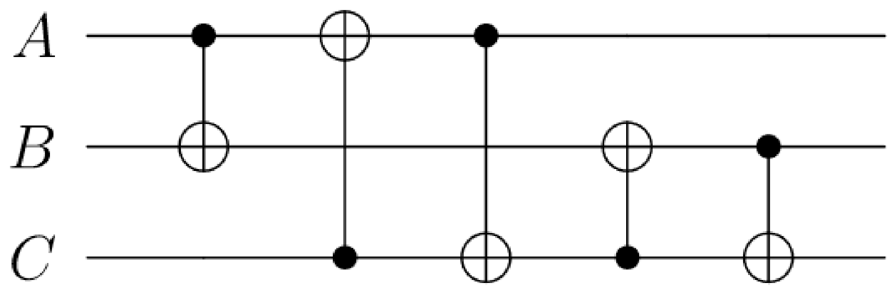

Figure 4: Example circuit

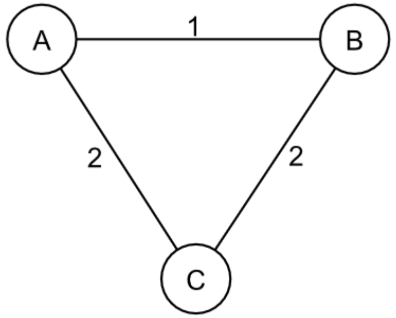

Figure 5: Weight function for circuit in Figure 4

However this weight function can insert unnecessary swaps:

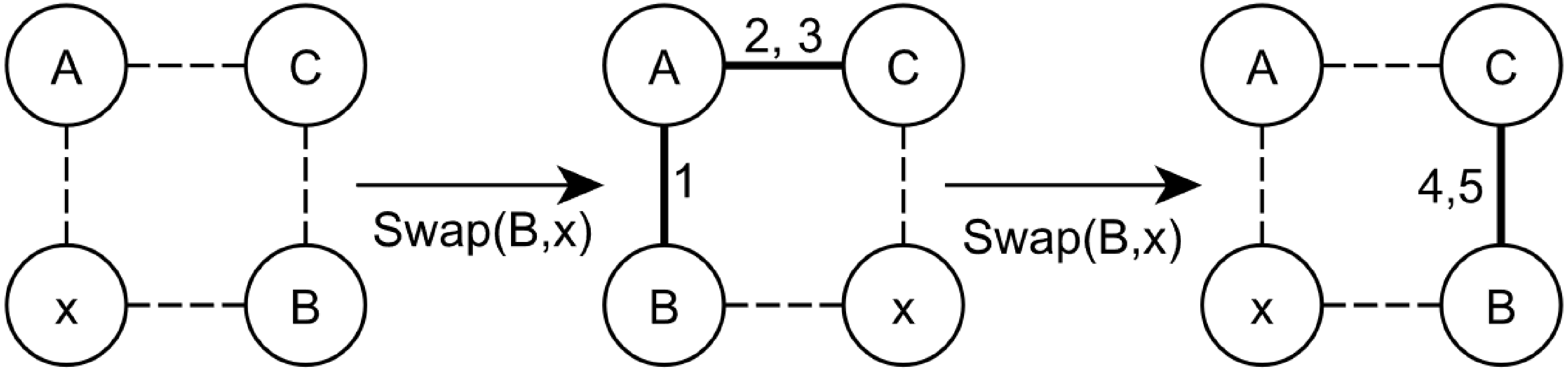

Figure 6: Placement and swap gates from minimising the objective function

[1] noted that the same situation would occur if the weight function does not satisfy the following criterion:

$$W(i,j) = \sum_{1 \le m \le N_g}^{N_g} P_m$$

$$P_m > \sum_{l=1}^{N_g - m} P_{m+l}$$

[1]: A. Kole, K. Datta, and I. Sengupta. A new heuristic for n-dimensional nearest neighbor realization of a quantum circuit. IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, 37(1):182–192, Jan 2018.

They proposed a weight function that weakly satisfies that criterion:

$$W'(i,j) = \sum_{1 \le m \le N_g}^{N_g} \frac{1}{T_m^k}$$

They compared k = 2, 3 and 4 for some circuits.

It was determined that there was little difference in swap cost, and used k = 2 for the whole benchmark suite. This is significantly better than the uniform function from the previous slide.

[2] found that strictly satisfying the criterion had no benefit compared to k = 2.

Therefore we tested the linearly decreasing weight function:

$$W_i(i,j) = \sum_{1 \le m \le N_g}^{N_g} \frac{1}{T_m}$$

Equivalent to k = 1

[2]: Rogers L., McAllister J. (2019) Comparison of Exponentially Decreasing Vs. Polynomially Decreasing Objective Functions for Making Quantum Circuits Nearest Neighbour Compliant. SAMOS 2019. Lecture Notes in Computer Science, vol 11733. Springer, Cham. https://doi.org/10.1007/978-3-030-27562-4_25

Results

	Uniform		Linear		Quadratic	
Dim	Swap	Time (s)	Swap	Time (s)	Swap	Time(s)
2×3	16423.98	2624.79	9937.52	1856.60	9672.88	2083.98
2×4	24621.36	3867.34	15778.40	2709.35	15408.06	3027.02
3×3	24581.84	7893.08	15490.36	6466.29	15124.82	6876.75

Table 1: Average results of 50 random circuits with 25,000 gates for each objective function

	Linear vs Uniform		Quadratic vs Linear	
Dim	Swap	Time	Swap	Time
2×3	39.49	29.27	2.66	-12.25
2×4	35.92	29.94	2.35	-11.72
3×3	36.98	18.08	2.36	-6.35
Average	37.46	25.76	2.46	-10.11

Table 2: Percentage difference between results in Table 1

Conclusions

- There is a trade-off between the performance and run-time
- The linearly decreasing weight function performs slightly worse than the quadratic, but is faster