Quantum Volume

计算QV基本过程

From qiskit textbook

https://github.com/Qiskit/textbook/blob/main/notebooks/quantum-hardware/measuring-quantum-volume.ipynb

Procedure:

1. Set `ncircuits` and `nshots`, sweep `depth`
2. Generate `ncircuits` random circuits with SU(4) gates -> ideal simulation
   `ideal_heavy_outputs` list of most likely 50% output states
3. For each random SU(4) `circuit`, transpile with the noise model.
   `real_counts` simulation outputs, formatted as (output state, counts)
4. If an `output state` is in `ideal_heavy_outputs`, then `N_heavy += counts`

Finally, $\mathrm{HOP} = N_{\mathrm{heavy}}/N_{\mathrm{shots}}N_{\mathrm{circs}}$

Standard deviation, $\sigma = \sqrt{\mathrm{HOP}(1-\mathrm{HOP})/N_{\mathrm{circs}}}$ (as defined in the textbook, no N_{shots} ?)

Criteria of success: $\mathrm{HOP} - 2\sigma > 2/3$

Benchmark results

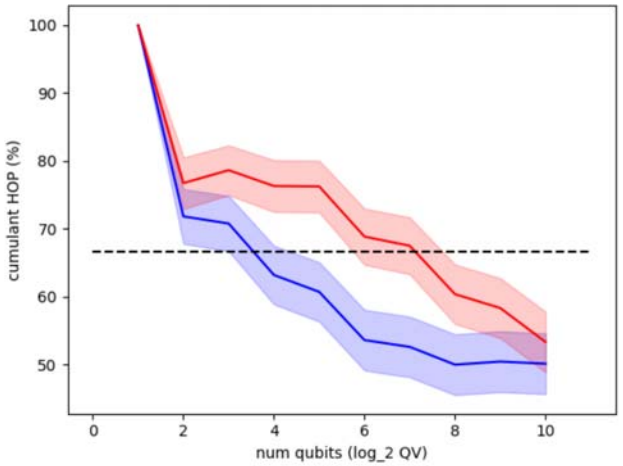
basis_gates = ['id', 'rx', 'ry', 'cz', 'reset']

FakeHuayi37

- num qubits = 37
- 1q-gate error ~= 0.5%
- 2q-gate error ~= 2% (d=1) 4% (d=2,3,4)
- readout error ~= 0.05%

FakeQuantinuumh2

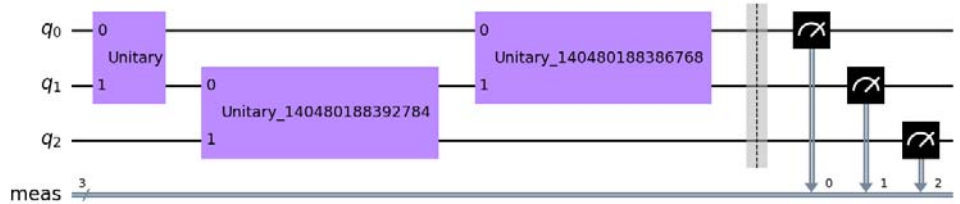
- num qubits = 32
- 1q-gate error ~= 0.15%
- 2q-gate error ~= 0.45% (d=1,2) 1% (d=3,4,5)
- readout error ~= 0.05%

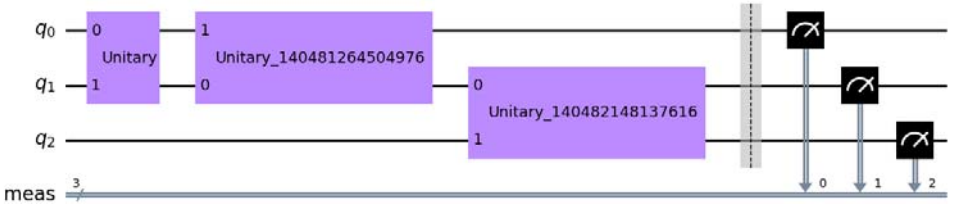


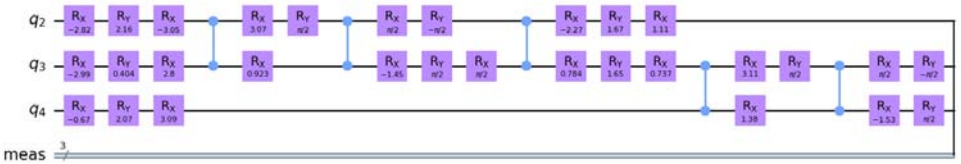
	backend	n_qubits	QV	HOP	success	n_circuits	n_shots	2sigma
0	fake_huayi37	1	2	99.942	True	500	100	0.215344
1	fake_huayi37	2	4	71.804	True	500	100	4.024510
2	fake_huayi37	3	8	70.756	True	500	100	4.068600
3	fake_huayi37	4	16	63.178	False	500	100	4.314015
4	fake_huayi37	5	32	60.690	False	500	100	4.368729
5	fake_huayi37	6	64	53.586	False	500	100	4.460619
6	fake_huayi37	7	128	52.586	False	500	100	4.466151
7	fake_huayi37	8	256	49.970	False	500	100	4.472135
8	fake_huayi37	9	512	50.418	False	500	100	4.471980
9	fake_huayi37	10	1024	50.108	False	500	100	4.472126

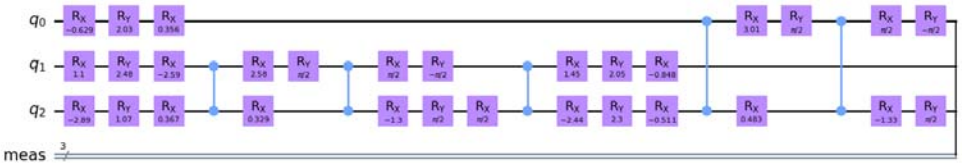
	backend	n_qubits	QV	HOP	success	n_circuits	n_shots	2sigma
0	fake_QuantinuumH2	1	2	99.954	True	500	100	0.191789
1	fake_QuantinuumH2	2	4	76.712	True	500	100	3.780443
2	fake_QuantinuumH2	3	8	78.610	True	500	100	3.667662
3	fake_QuantinuumH2	4	16	76.282	True	500	100	3.804478
4	fake_QuantinuumH2	5	32	76.222	True	500	100	3.807789
5	fake_QuantinuumH2	6	64	68.830	False	500	100	4.142879
6	fake_QuantinuumH2	7	128	67.480	False	500	100	4.189940
7	fake_QuantinuumH2	8	256	60.346	False	500	100	4.375349
8	fake_QuantinuumH2	9	512	58.306	False	500	100	4.409998
9	fake_QuantinuumH2	10	1024	53.308	False	500	100	4.462338

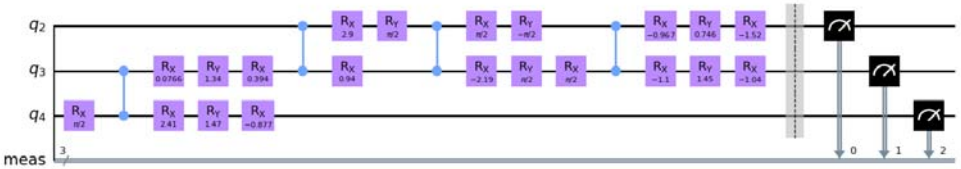
Random SU(4) circuits and transpiled circuits (coupling distance d=1 for Huayi, d=1,2 for Quantinuum)











Benchmark results

with lower error rates and different basis gates

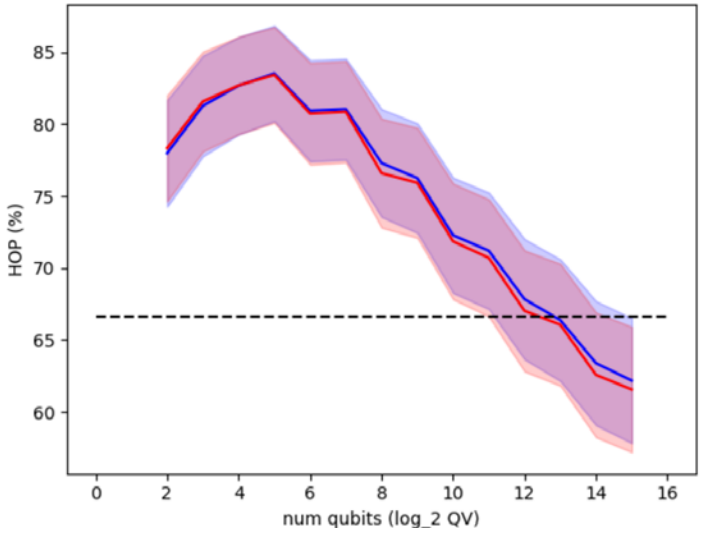
- num qubits = 32
- 1q-gate error ~= 0.003%
- 2q-gate error ~= 0.2% (d=1,2) 0.3% (d>2)
- readout error ~= 0.001%

FakeHuayi32_LE

basis_gates = ['id', 'rx', 'ry', 'cz', 'reset']

FakeHuayi32_LE_RZZ

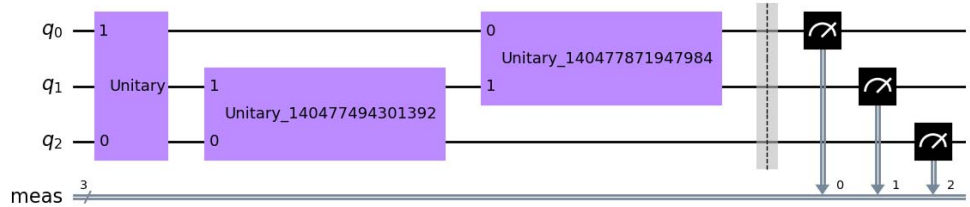
basis_gates = ['id', 'r', 'rz', 'rzz', 'reset']

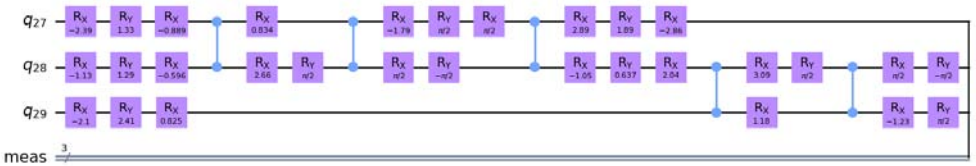


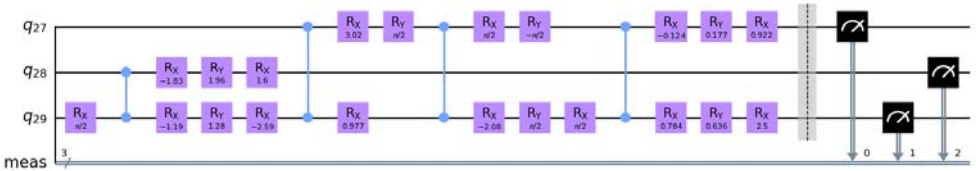
	backend	n_qubits	QV	HOP	success	n_circuits	n_shots	2sigma
0	FakeHuayi32_LE	2	4	77.976	True	500	100	3.706582
1	FakeHuayi32_LE	3	8	81.264	True	500	100	3.490057
2	FakeHuayi32_LE	4	16	82.670	True	500	100	3.385464
3	FakeHuayi32_LE	5	32	83.520	True	500	100	3.318324
4	FakeHuayi32_LE	6	64	80.930	True	500	100	3.513784
5	FakeHuayi32_LE	7	128	81.040	True	500	100	3.506016
6	FakeHuayi32_LE	8	256	77.298	True	500	100	3.746806
7	FakeHuayi32_LE	9	512	76.250	True	500	100	3.806245
8	FakeHuayi32_LE	10	1024	72.280	True	500	100	4.003600
9	FakeHuayi32_LE	11	2048	71.200	True	500	100	4.050244
10	FakeHuayi32_LE	12	4096	67.838	False	500	100	4.177852
11	FakeHuayi32_LE	13	8192	66.382	False	500	100	4.225286
12	FakeHuayi32_LE	14	16384	63.394	False	500	100	4.308690
13	FakeHuayi32_LE	15	32768	62.182	False	500	100	4.337371

	backend	n_qubits	QV	HOP	success	n_circuits	n_shots	2sigma
0	FakeHuayi32_LE_RZZ	2	4	78.328	True	500	100	3.685132
1	FakeHuayi32_LE_RZZ	3	8	81.570	True	500	100	3.467951
2	FakeHuayi32_LE_RZZ	4	16	82.688	True	500	100	3.384074
3	FakeHuayi32_LE_RZZ	5	32	83.418	True	500	100	3.326544
4	FakeHuayi32_LE_RZZ	6	64	80.726	True	500	100	3.528074
5	FakeHuayi32_LE_RZZ	7	128	80.856	True	500	100	3.518985
6	FakeHuayi32_LE_RZZ	8	256	76.592	True	500	100	3.787205
7	FakeHuayi32_LE_RZZ	9	512	75.922	True	500	100	3.824186
8	FakeHuayi32_LE_RZZ	10	1024	71.854	True	500	100	4.022340
9	FakeHuayi32_LE_RZZ	11	2048	70.704	False	500	100	4.070719
10	FakeHuayi32_LE_RZZ	12	4096	67.022	False	500	100	4.204998
11	FakeHuayi32_LE_RZZ	13	8192	66.064	False	500	100	4.235042
12	FakeHuayi32_LE_RZZ	14	16384	62.578	False	500	100	4.328320
13	FakeHuayi32_LE_RZZ	15	32768	61.566	False	500	100	4.350841

Basis gates: [id, rx, ry, cz]







Basis gates: [id, r, rz, rzz]