Supplemental material to: "Line-graph qubit routing: from kagome to heavy-hex and more"

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Abstract

We showcase and benchmark line-graph qubit routing by routing random circuits (with fixed virtual graph) and circuits needed for the quantum simulation of the Heisenberg antiferromagnet on various graphs. The code implementing line-routing itself is found in `line_graph_routing.py` and maps Qiskit quantum circuits to Qiskit quantum circuits. (This can be altered to other circuit libraries with little effort.) We benchmark our results against other methods. The interactive version of this document is `line_graph_routing.ipynb`.

Contents

1 Requirements **2**

2 Kagome to heavy-hex **2**
2.1 Random . . . 2
2.2 Quantum simulation . . . 2

3 Complete graph to star graph **4**
3.1 Random . . . 4
3.2 Quantum simulation . . . 4

4 Shuriken to heavy square-octagon **5**
4.1 Random . . . 5
4.2 Quantum simulation . . . 5

5 Checkerboard to heavy-square **6**
5.1 Quantum simulation . . . 7

6 Random line graph to random heavy graph **7**
6.1 Random . . . 7
6.2 Quantum simulation . . . 8

7 Benchmarking **10**
7.0.1 Quantum simulation, kagome and shuriken, agianst SABRE . . . 10
7.0.2 Quantum simulation, checkerboard, agianst SABRE . . . 27
7.0.3 Random circuit, kagome and shuriken, against SABRE . . . 36
7.0.4 Random circuit, complete graph, against SABRE . . . 38
7.0.5 Against other routing methods . . . 40
7.0.6 Wall-clock time of line-graph routing . . . 42

1 Requirements

This notebook should typically run after installing the following packages with pip (or conda). In a terminal, run

```
pip install qiskit[visualization]
```

or

```
pip install 'qiskit[visualization]'
```

and

```
pip install netket networkx tabulate
```

Note Netket currently needs Python 3.9 (and SciPy >= 1.9.3). Netket is only used to generate patches of the kagome lattice as graphs and not for line-graph routing itself. This notebook was tested with a pip environment that can be recreated with `requirements.txt` by running `pip install -r requirements.txt` (after creating a new environment).

The file `line_graph_routing.py` should be placed in the same folder as the current notebook.

```
import line_graph_routing as lgr
import networkx as nx
```

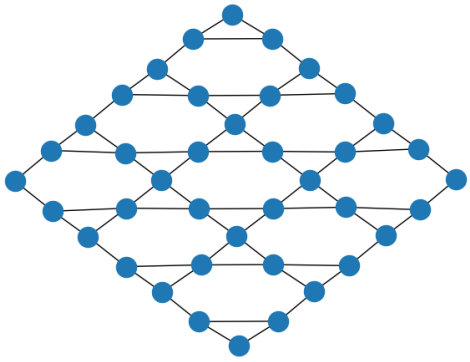
2 Kagome to heavy-hex

2.1 Random

Create a random circuit on a patch of the kagome lattice of 3×3 unit cells and show the circuit's coupling graph. With probability $2/5$, a CNOT is placed along an edge of the connectivity graph. With a probability $3/5$ a gate from {H,S,T} is chosen uniformly at random and placed at a random node.

```
lg = lgr.kagome(3, 3)
qc = lgr.random_circuit(lg, 10**4)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

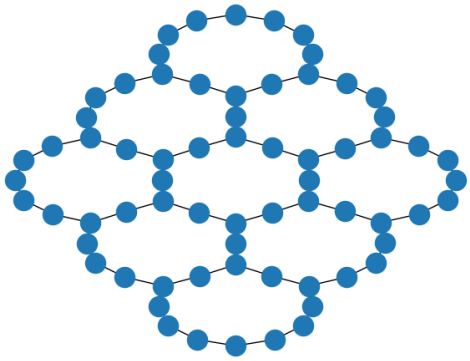
```
755
```



Route the circuit to a circuit with heavy-hex coupling graph.

```
qc = lgr.line_graph_route(qc)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

```
1337
```



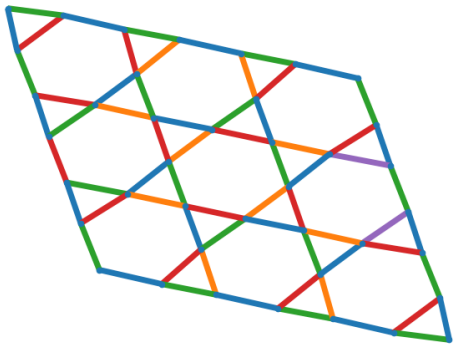
2.2 Quantum simulation

We base our circuits on edge colorings of the (kagome) lattice by identifying every color with a layer of HEIS gates. One of the colors (color '0') doubles as a color specifying the initial state by indicating along which edges singlet states are placed. The entire circuit is repeated p times, excluding initial state preparation. Every HEIS gets its own parameter. These parameters can later be bound to specific values to obtain circuits for dynamical quantum simulation or for simulated adiabatic state preparation.

First, create and show an edge coloring of the kagome lattice.

```
lg = lgr.edge_coloring(lg)
lgr.draw_edge_coloring(lg)
```

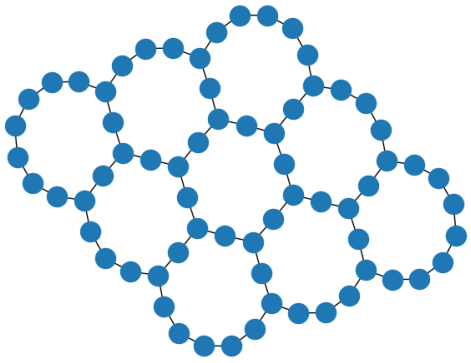
```
Matching is perfect
Edge coloring is not minimal
```



Create the associated circuit, route it to heavy-hex hardware and show the coupling graph of the routed circuit.

```
p = 1
qc = lgr.heis_circuit(lg, p)
print(qc.depth())
qc = lgr.line_graph_route(qc)
print(qc.depth())
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
```

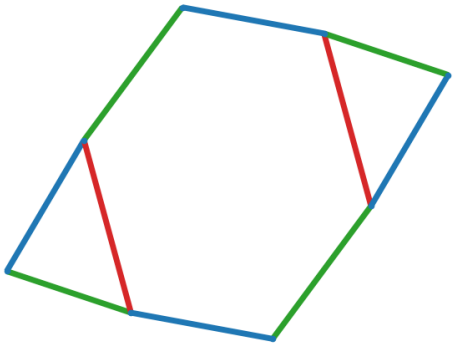
```
6
15
```



Since the above circuit has the connectivity of a 2D graph, the corresponding quantum circuit diagram will not be very insightful. However, for a single unit cell of the kagome lattice, the routed quantum circuit becomes a circuit on a circle, which allows for a clear representation as a quantum circuit diagram. We first create an edge coloring of the unit cell patch.

```
lg = lgr.kagome(1, 1)
lg = lgr.edge_coloring(lg)
lgr.draw_edge_coloring(lg)
```

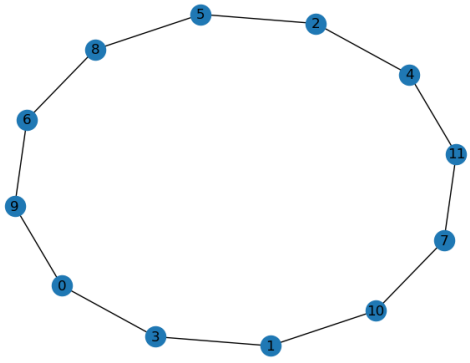
```
Matching is perfect
Edge coloring is not minimal
```



Create the HEIS circuit ased on this coloring, map it to heavy-hex hardware, and show the coupling graph of the routed circuit.

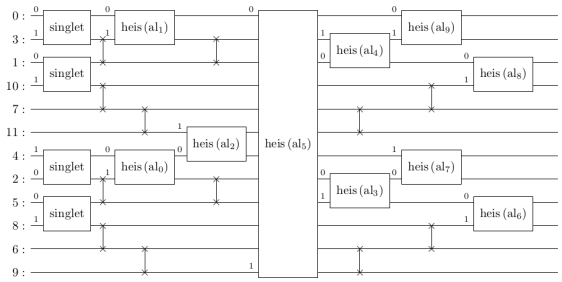
```
p = 1
qc = lgr.heis_circuit(lg, p)
print(qc.depth())
qc = lgr.line_graph_route(qc)
print(qc.depth())
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg, with_labels =␣
↪'true')
```

```
4
7
```



Show the circuit diagram of the routed circuit, with parameters `al_i`.

```
wo = [0, 3, 1, 10, 7, 11, 4, 2, 5, 8, 6,␣
↪9] # In the circuit diagram, place␣
↪qubits in this order.
qc.draw('latex', wire_order = wo)
```



The fircuit depth can be reduced further by replacement of the initial and final SWAP gates between qubits (10,7) and (8,6) by a relabeling of those qubits.

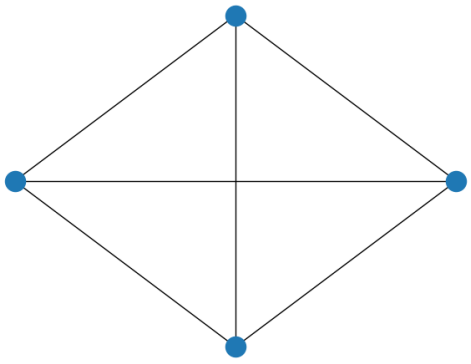
3 Complete graph to star graph

3.1 Random

Create a random circuit on the complete graph of four nodes and show the circuit's coupling graph.

```
n = 5
lg = nx.complete_graph(4)
qc = lgr.random_circuit(lg, 10**2)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

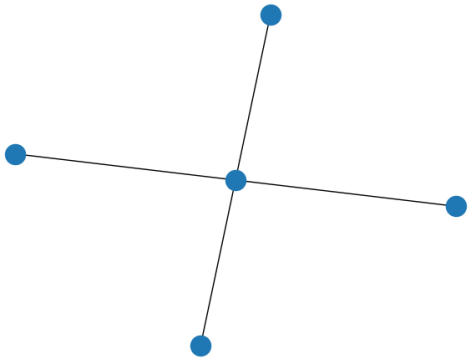
```
56
```



Route the circuit to a circuit with star-graph connectivity.

```
qc = lgr.line_graph_route(qc)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

```
108
```



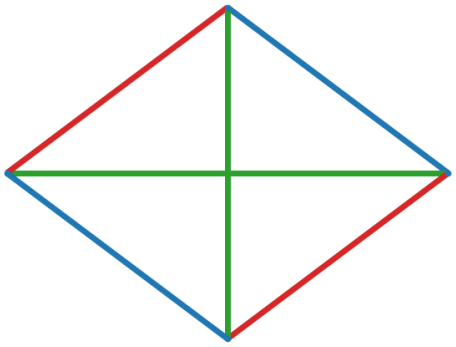
3.2 Quantum simulation

As before, circuits are defined by identifying every color with a layer of HEIS-gates. For more details, see the `kagome to heavy-hex` section.

Create and show an edge coloring of the complete graph.

```
lg = lgr.edge_coloring(lg)
lgr.draw_edge_coloring(lg)
```

```
Matching is perfect
Edge coloring is not minimal
```

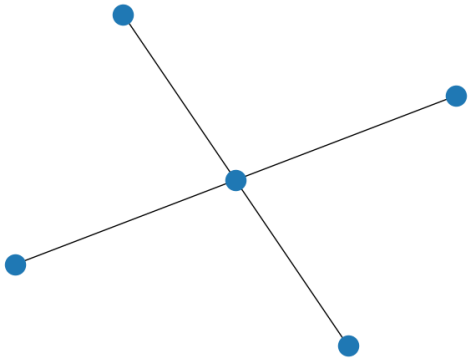


Create the associated circuit, route it to heavy-hex hardware, and show the coupling graph of the routed circuit.

```
p = 1
qc = lgr.heis_circuit(lg, p)
print(qc.depth())
qc = lgr.line_graph_route(qc)
```

```
print(qc.depth())
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
```

```
4
20
```



We do not show the circuit diagram in this case because the routed circuit is not a circuit on a line.

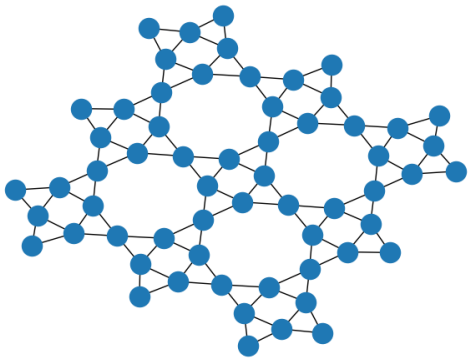
4 Shuriken to heavy square-octagon

4.1 Random

Create a random circuit on a patch of the shuriken lattice of 3×3 unit cells.

```
n = 5
lg = lgr.shuriken(3, 3)
qc = lgr.random_circuit(lg, 10**4)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

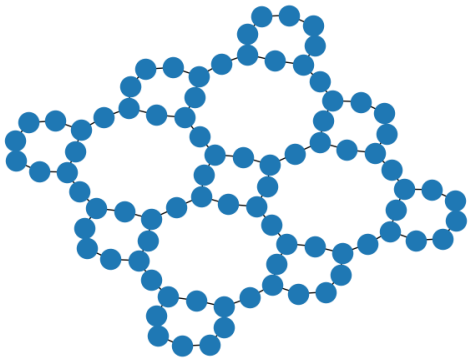
```
517
```



Route the circuit to a circuit with heavy-square-octagon connectivity.

```
qc = lgr.line_graph_route(qc)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

```
877
```



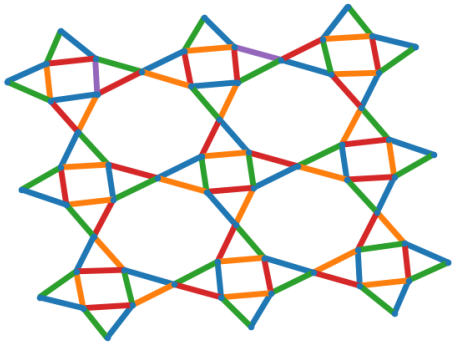
4.2 Quantum simulation

As before, circuits are defined by identifying every color with a layer of HEIS-gates. For more details, see the `kagome to heavy-hex` section.

Create and show an edge coloring of the shuriken lattice.

```
lg  =  lgr.edge_coloring(lg)
lgr.draw_edge_coloring(lg)
```

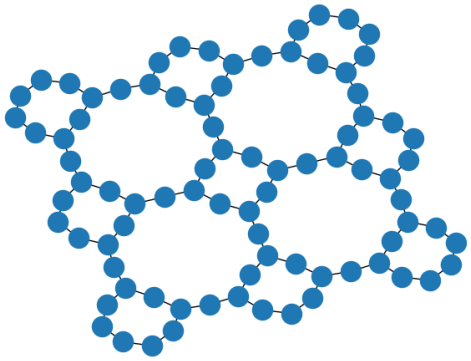
```
Matching is perfect
Edge coloring is not minimal
```



Create the associated circuit, route it to heavy-square-octagon hardware, and show the coupling graph of the routed circuit.

```
p = 1
qc = lgr.heis_circuit(lg, p)
print(qc.depth())
qc = lgr.line_graph_route(qc)
print(qc.depth())
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
```

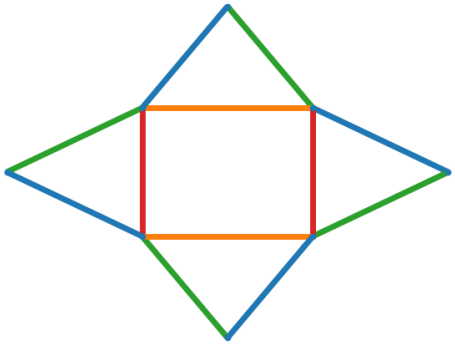
```
6
12
```



Again, the resulting circuit diagram will not be very insightful, but it will be for a single-unit cell patch of the shuriken lattice.

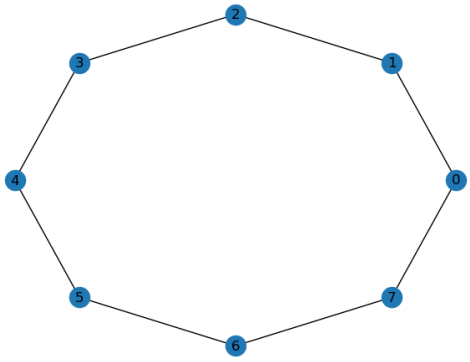
```
lg = lgr.shuriken(1, 1)
lg = lgr.edge_coloring(lg)
lgr.draw_edge_coloring(lg)
```

```
Matching is perfect
Edge coloring is minimal
```

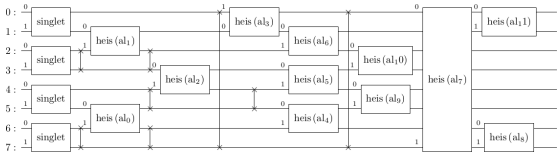


```
p = 1
qc = lgr.heis_circuit(lg, p)
print(qc.depth())
qc = lgr.line_graph_route(qc)
print(qc.depth())
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg, with_labels =␣
↪'true')
```

```
5
9
```



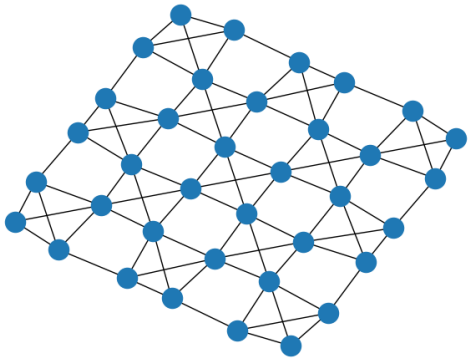

```
qc.draw('latex')
```

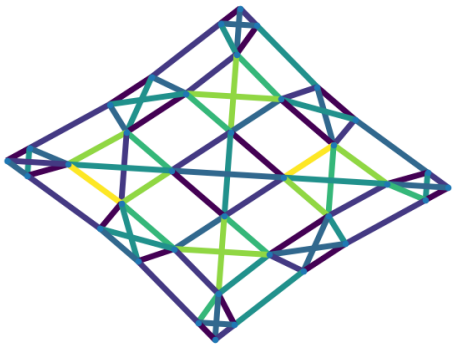


5 Checkerboard to heavy-square

```
m = 2.5 # For the checkerboard lattice,␣
↪specify dimentions in nodes by nodes.
lg = lgr.checkerboard(m, m)
qc = lgr.random_circuit(lg, 10**4)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

```
872
```

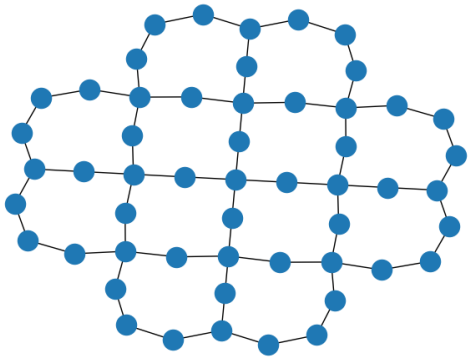




Route the circuit to a circuit with a heavy-square coupling graph.

```
qc = lgr.line_graph_route(qc)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

```
1622
```



5.1 Quantum simulation

As before, circuits are defined by identifying every color with a layer of HEIS-gates. For more details, see the `kagome to heavy-hex` section.

Create and show an edge coloring of the checkerboard lattice

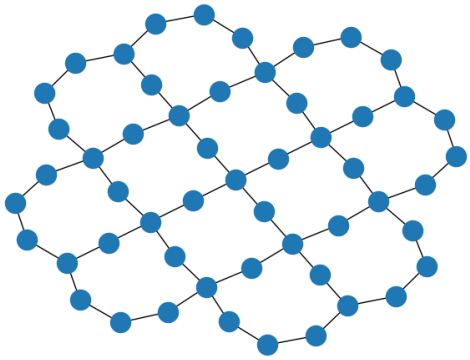
```
lg  =  lgr.edge_coloring(lg)
lgr.draw_edge_coloring(lg, spectral=True)␣
 ↪# Use spactral method to find location␣
 ↪of nodes.
```

```
Matching is perfect
Edge coloring is not minimal
```

Create the associated circuit, route it to heavy-square-octagon hardware, and show the coupling graph of the routed circuit.

```
p = 1
qc = lgr.heis_circuit(lg, p)
print(qc.depth())
qc = lgr.line_graph_route(qc)
print(qc.depth())
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
```

```
8
33
```



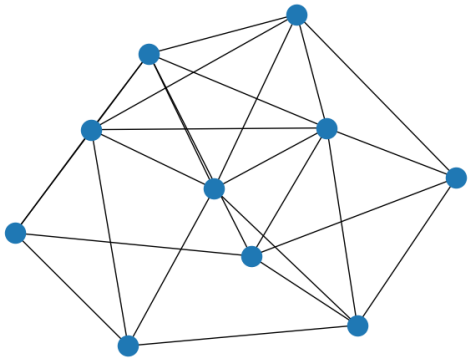
6 Random line graph to random heavy graph

6.1 Random

Create a random circuit on a random graph with 6 nodes and show the circuit's coupling graph. For details on `radom_line_graph` generation, see its function definition in `line_graph_routing.py`.

```
n = 6
lg = lgr.random_line_graph(6)
qc = lgr.random_circuit(lg, 10**3)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

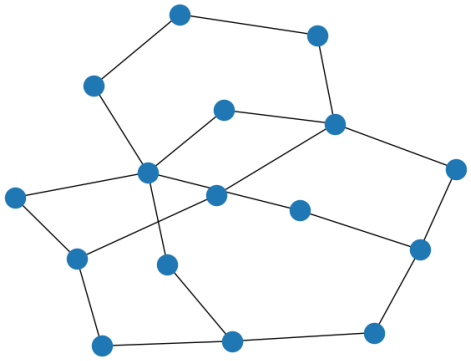
287



Route the circuit to a circuit with the associated heavy connectivity.

```
qc = lgr.line_graph_route(qc)
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
print(qc.depth())
```

576



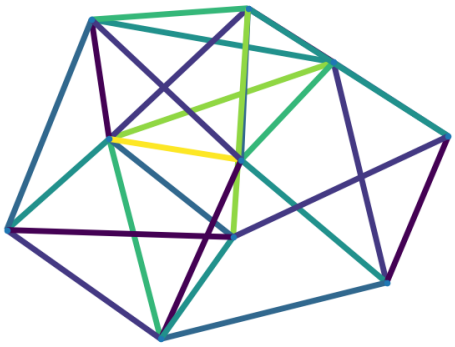
6.2 Quantum simulation

As before, circuits are defined by identifying every color with a layer of HEIS-gates. For more details, see the `kagome to heavy-hex` section.

Create and show an edge coloring of random graph. The method we use to find a perfect matching (needed for initial state preparation) is limited and may not find a perfect matching even if it exists. If a perfect matching is not found, try to create another random line graph (i.e., evaluate the two cells above) or use more sophisticated (or brute-force) methods to find a perfect matching.

```
lg = lgr.edge_coloring(lg)
lgr.draw_edge_coloring(lg)
```

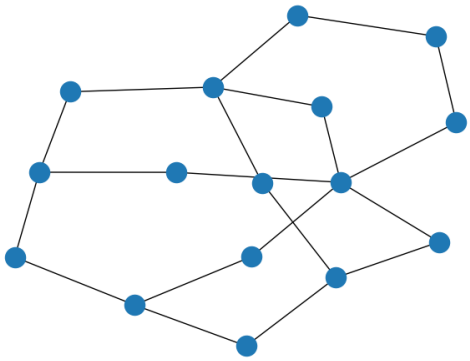
```
Matching is perfect
Edge coloring is not minimal
```



Create the associated circuit, route it to heavy-hex hardware and show the coupling graph of the routed circuit.

```
p = 1
qc = lgr.heis_circuit(lg, p)
print(qc.depth())
qc = lgr.line_graph_route(qc)
print(qc.depth())
cg = lgr.coupling_graph(qc)
nx.draw_kamada_kawai(cg)
```

8
32



We do not show the circuit diagram in this case because the routed circuit is not a circuit on a line.

7 Benchmarking

We benchmark line graph routing by performing the above routing tasks (but for larger unit cells) using both line-graph qubit routing and all methods available in qiskit. These methods are 'basic', 'lookahead', 'stochastic', and 'sabre' [1].

The benchmarking settings are specified by the following options: - `name` The name of the virtual graph, either `kagome`, `shuriken` or `complete`. - `size`. In case of `kagome` and `shuriken`: the size of the patch in unit cells by unit cells. In case of `complete`: the number of nodes of the complete graph. - `circuit type`. Either `quantum simulation` or `random`, as presented in this notebook. - `p` In case of `kagome` and `shuriken`: the number of cycles of the circuit. In case of `complete`: the number of random gates from the set `H,T,S,CNOT`. - `repetitions`. The number of runs for the methods `sabre` and `stochastic`. The methods `line-graph` and `basic` are deterministic and hence only run once. Correspondingly, the reported `total time` pertains to the time taken for this single run in case of the latter two methods. - `optimization_level`. Either 0, 1, 2, or 3. This specifies the optimization level used for the routing methods implemented in qiskit [2]. This parameter is passed directly to Qiskit's transpiler [1]. - `methods`. The methods to benchmark line graph transpilation against. Must be a list containing elements from `['sabre','basic','lookahead',stochastic]`. These methods are passed directly to Qiskit's transpiler [1].

The methods `sabre` and `stochastic` are probabilistic, achieving a different routing each time they are run, and hence achieve different performance characteristics with each run. We therefore run these methods *repetitions* times and report the average, confidence interval, and best performance out of these runs. Error bars on the data show the (symmetrized) 95% confidence interval and are obtained by bootstrapping the data. The error interval for `num_qubits` is sometimes given by `nan` because in those cases the number of qubits was equal for all runs. The routing methods`line-graph` and `basic` are deterministic and for these we enforce `repetitions=1`.

We consider the following performance characteristics. - `method` The routing method. - `av. n_swaps` The average number of swaps obtained among the `repetitions` runs of the routing method. - `min n_swap` The number of swaps of the run that achieved the lowest depth. - `av. depth` The average depth of the routed circuits among the `repetitions` runs of the routing method. We focus on the performance of routing so none of the gates in any of the routing methods are compiled into hardware native gates. That is, for the purposes of assessing routing performance, we assume the gate set `SWAP`, `HEIS`, `H`, `X`, `Z` `CNOT` for the quantum simulation circuits. For the random circuits we assume `SWAP`, `CNOT`, `H`, `S`, `T`. - `min depth` The minimum depth among the `repetitions` runs of the routing method. - `av. n_qubits` The average number obtained among the `repetitions` runs of the routing method. - `total time` The total wall clock time (in seconds) needed to perform all `repetitions` runs of the routing method. - `av. time` The average (minimum) wall clock time of the `repetitions` routing runs. - `min. time` The number wall clock run time of the run that achieved the lowest depth.

[1] Qiskit 0.43.0 documentation, https://qiskit.org/documentation/stubs/qiskit.compiler.transpile.html, accessed 11h May 2023.
[2] https://github.com/Qiskit/qiskit-terra/tree/main/qiskit/transpiler/preset_passmanagers

7.0.1 Quantum simulation, kagome and shuriken, agianst SABRE

```
import line_graph_routing as lgr # Loading these makes these cells stand-alone
import pickle

settings=[]
for name in ['kagome','shuriken']:
    for side in range(1,9,2):
        for p in [1,8,16]:
            for optimization_level in range(4):
                setting={'name':name,
                     'size': (side,side),
```

```
                    'circuit_type': 'quantum_simulation',
                    'p': p,
                    'repetitions' : 16,
                    'optimization_level' : optimization_level,
                    'methods' : ['sabre']
                   }
                settings.append(setting)

## Uncomment to rerun benchmarks. This takes a couple of hours.
#results=[]
#for setting in settings:
#    result=lgr.benchmark(**setting)
#    results.append(result)
#    lgr.print_benchmark(result)
#
#with open('benchmark_data/kagome_shuriken.pkl','wb') as f:
#    pickle.dump(results,f)

#Load previously obtained results from disk and show them.
import pickle
with open('benchmark_data/kagome_shuriken.pkl','rb') as f:
    results=pickle.load(f)

for result in results:
    lgr.print_benchmark(result)
```

```
--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  12 ± 0.0                  12  7 ± 0.0                  7  12 ± 0.0                   12              0.08  0.08 ± 0.0                 0.08
sabre       16 ± 2.06                  6  12.38 ± 2.09             6  10.25 ± 1.0                12              0.7   0.04 ± 0.06                0.02
--------------------------------------------------------------------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth      min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  -----------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  12 ± 0.0                  12  7 ± 0.0                 7  12 ± 0.0                   12              0.08  0.08 ± 0.0                 0.08
sabre       10 ± 0.81                  6  6.44 ± 0.34             6  8.75 ± 0.75                8              0.32  0.02 ± nan                 0.02
--------------------------------------------------------------------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2
method      av. n_swaps      min. n_swap  av. depth      min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  -----------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  12 ± 0.0                  12  7 ± 0.0                 7  12 ± 0.0                   12              0.08  0.08 ± 0.0                 0.08
sabre       6 ± nan                    6  6.0 ± nan               6  8.0 ± nan                  8              0.33  0.02 ± 0.0                 0.02
--------------------------------------------------------------------------------------------------------------------------------------------------------
```

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	12 ± 0.0	12	7 ± 0.0	7	12 ± 0.0	12	0.08	0.08 ± 0.0	0.08
sabre	6 ± nan	6	6.0 ± nan	6	8.0 ± nan	8	0.75	0.05 ± 0.02	0.04

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	96 ± 0.0	96	49 ± 0.0	49	12 ± 0.0	12	0.67	0.67 ± 0.0	0.67
sabre	99 ± 7.66	48	52.94 ± 5.28	41	11.5 ± 0.75	12	1.39	0.09 ± 0.02	0.08

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	96 ± 0.0	96	49 ± 0.0	49	12 ± 0.0	12	0.64	0.64 ± 0.0	0.64
sabre	48 ± 8.62	48	42.88 ± 3.28	41	8.5 ± 0.75	8	1.67	0.1 ± 0.02	0.09

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	96 ± 0.0	96	49 ± 0.0	49	12 ± 0.0	12	0.64	0.64 ± 0.0	0.64
sabre	48 ± 7.19	48	41.56 ± 1.41	41	8.25 ± 0.62	8	2.07	0.13 ± 0.02	0.11

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	96 ± 0.0	96	49 ± 0.0	49	12 ± 0.0	12	0.64	0.64 ± 0.0	0.64
sabre	48 ± nan	48	41.0 ± nan	41	8.0 ± nan	8	5.07	0.32 ± 0.02	0.29

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	192 ± 0.0	192	97 ± 0.0	97	12 ± 0.0	12	1.29	1.29 ± 0.0	1.29
sabre	100 ± 18.19	96	99.38 ± 9.69	81	11.25 ± 0.75	12	2.78	0.17 ± 0.02	0.15

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	192 ± 0.0	192	97 ± 0.0	97	12 ± 0.0	12	1.31	1.31 ± 0.0	1.31
sabre	96 ± 17.62	96	86.69 ± 8.53	81	8.5 ± 0.75	8	3.18	0.2 ± 0.03	0.17

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	192 ± 0.0	192	97 ± 0.0	97	12 ± 0.0	12	1.3	1.3 ± 0.0	1.3
sabre	96 ± nan	96	81.0 ± nan	81	8.0 ± nan	8	3.74	0.23 ± 0.02	0.21

name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	192 ± 0.0	192	97 ± 0.0	97	12 ± 0.0	12	1.29	1.29 ± 0.0	1.29
sabre	96 ± nan	96	81.0 ± nan	81	8.0 ± nan	8	10.26	0.64 ± 0.02	0.67

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	112 ± 0.0	112	15 ± 0.0	15	68 ± 0.0	68	0.6	0.6 ± 0.0	0.6
sabre	307 ± 3.44	286	72.62 ± 3.5	63	55.0 ± 1.66	55	1.83	0.11 ± 0.02	0.09

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	112 ± 0.0	112	15 ± 0.0	15	68 ± 0.0	68	0.6	0.6 ± 0.0	0.6
sabre	85 ± 3.56	85	27.38 ± 1.34	22	45.25 ± 1.66	52	1.8	0.11 ± 0.02	0.1

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	112 ± 0.0	112	15 ± 0.0	15	68 ± 0.0	68	0.6	0.6 ± 0.0	0.6
sabre	96 ± 4.19	82	26.81 ± 2.41	20	46.19 ± 1.12	47	2.62	0.16 ± 0.02	0.15

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	112 ± 0.0	112	15 ± 0.0	15	68 ± 0.0	68	0.5	0.5 ± 0.0	0.5
sabre	64 ± 2.34	67	21.44 ± 1.94	14	46.0 ± 1.75	47	7.77	0.49 ± 0.02	0.55

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	896 ± 0.0	896	113 ± 0.0	113	68 ± 0.0	68	4.25	4.25 ± 0.0	4.25
sabre	1361 ± 33.51	1203	312.5 ± 9.31	287	59.5 ± 1.75	51	10.83	0.68 ± 0.03	0.69

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	896 ± 0.0	896	113 ± 0.0	113	68 ± 0.0	68	4.39	4.39 ± 0.0	4.39
sabre	625 ± 19.67	613	192.38 ± 14.0	149	45.19 ± 1.28	44	10.99	0.69 ± 0.04	0.76

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	896 ± 0.0	896	113 ± 0.0	113	68 ± 0.0	68	4.42	4.42 ± 0.0	4.42
sabre	621 ± 9.75	621	182.06 ± 9.79	152	43.56 ± 1.4	44	14.53	0.91 ± 0.04	0.95

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	896 ± 0.0	896	113 ± 0.0	113	68 ± 0.0	68	4.23	4.23 ± 0.0	4.23
sabre	601 ± 10.06	555	176.25 ± 7.62	149	43.44 ± 0.72	43	45.11	2.82 ± 0.04	2.74

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1792 ± 0.0	1792	225 ± 0.0	225	68 ± 0.0	68	8.45	8.45 ± 0.0	8.45
sabre	2627 ± 55.91	2304	553.94 ± 12.78	509	60.94 ± 2.12	63	20.65	1.29 ± 0.05	1.29

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1792 ± 0.0	1792	225 ± 0.0	225	68 ± 0.0	68	8.87	8.87 ± 0.0	8.87
sabre	1213 ± 28.0	1213	388.12 ± 18.66	318	43.75 ± 1.16	44	20.66	1.29 ± 0.05	1.35

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1792 ± 0.0	1792	225 ± 0.0	225	68 ± 0.0	68	8.4	8.4 ± 0.0	8.4
sabre	1215 ± 14.41	1142	377.69 ± 19.52	311	44.06 ± 1.19	49	28.01	1.75 ± 0.01	1.79

name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1792 ± 0.0	1792	225 ± 0.0	225	68 ± 0.0	68	8.57	8.57 ± 0.0	8.57
sabre	1172 ± 15.38	1144	342.25 ± 13.38	290	43.56 ± 1.0	43	86.44	5.4 ± 0.05	5.53

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	270 ± 0.0	270	14 ± 0.0	14	164 ± 0.0	164	1.48	1.48 ± 0.0	1.48
sabre	1247 ± 9.78	1247	132.81 ± 3.09	123	128.31 ± 1.72	125	5.12	0.32 ± 0.03	0.37

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	270 ± 0.0	270	14 ± 0.0	14	164 ± 0.0	164	1.47	1.47 ± 0.0	1.47
sabre	338 ± 14.72	345	50.94 ± 3.44	38	110.69 ± 1.34	109	5.47	0.34 ± 0.02	0.3

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	270 ± 0.0	270	14 ± 0.0	14	164 ± 0.0	164	1.47	1.47 ± 0.0	1.47
sabre	364 ± 10.22	350	48.81 ± 4.88	38	110.19 ± 2.16	115	9.7	0.61 ± 0.03	0.56

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	270 ± 0.0	270	14 ± 0.0	14	164 ± 0.0	164	1.47	1.47 ± 0.0	1.47
sabre	274 ± 9.62	269	37.44 ± 3.25	30	106.25 ± 1.62	108	36.54	2.28 ± 0.03	2.33

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2160 ± 0.0	2160	98 ± 0.0	98	164 ± 0.0	164	10.96	10.96 ± 0.0	10.96
sabre	6068 ± 87.86	5579	557.62 ± 12.5	511	134.88 ± 2.03	134	27.49	1.72 ± 0.06	1.55

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2160 ± 0.0	2160	98 ± 0.0	98	164 ± 0.0	164	11.01	11.01 ± 0.0	11.01
sabre	2124 ± 45.1	2056	341.69 ± 14.66	286	106.5 ± 2.38	118	30.77	1.92 ± 0.05	1.98

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2160 ± 0.0	2160	98 ± 0.0	98	164 ± 0.0	164	10.93	10.93 ± 0.0	10.93
sabre	1894 ± 32.99	1953	324.31 ± 22.53	265	106.62 ± 2.47	118	44.89	2.81 ± 0.03	2.8

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2160 ± 0.0	2160	98 ± 0.0	98	164 ± 0.0	164	10.88	10.88 ± 0.0	10.88
sabre	1869 ± 23.79	1758	282.88 ± 13.62	236	104.12 ± 1.91	109	158.7	9.92 ± 0.08	9.89

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4320 ± 0.0	4320	194 ± 0.0	194	164 ± 0.0	164	21.85	21.85 ± 0.0	21.85
sabre	10420 ± 144.88	9561	979.94 ± 18.51	919	133.62 ± 2.94	124	56.99	3.56 ± 0.11	3.42

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4320 ± 0.0	4320	194 ± 0.0	194	164 ± 0.0	164	21.73	21.73 ± 0.0	21.73
sabre	4267 ± 109.67	4443	682.12 ± 23.85	627	107.31 ± 3.03	110	58.8	3.68 ± 0.11	3.58

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4320 ± 0.0	4320	194 ± 0.0	194	164 ± 0.0	164	21.86	21.86 ± 0.0	21.86
sabre	3972 ± 57.03	3804	628.44 ± 28.22	526	107.31 ± 2.53	109	85.09	5.32 ± 0.1	5.11

name = kagome, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4320 ± 0.0	4320	194 ± 0.0	194	164 ± 0.0	164	21.56	21.56 ± 0.0	21.56
sabre	3716 ± 30.9	3656	592.5 ± 13.72	562	104.94 ± 1.25	108	296.62	18.54 ± 0.15	18.2

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	498 ± 0.0	498	16 ± 0.0	16	300 ± 0.0	300	2.8	2.8 ± 0.0	2.8
sabre	3534 ± 31.01	3534	208.06 ± 8.72	175	238.75 ± 3.75	239	10.84	0.68 ± 0.03	0.71

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	498 ± 0.0	498	16 ± 0.0	16	300 ± 0.0	300	2.86	2.86 ± 0.0	2.86
sabre	1119 ± 28.5	1092	94.94 ± 7.28	70	202.19 ± 3.62	210	13.88	0.87 ± 0.03	0.8

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	498 ± 0.0	498	16 ± 0.0	16	300 ± 0.0	300	2.88	2.88 ± 0.0	2.88
sabre	994 ± 28.53	902	83.25 ± 4.84	68	200.81 ± 3.18	194	30.74	1.92 ± 0.04	1.95

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	498 ± 0.0	498	16 ± 0.0	16	300 ± 0.0	300	2.87	2.87 ± 0.0	2.87
sabre	868 ± 28.66	737	66.25 ± 3.94	53	194.75 ± 2.84	189	135.51	8.47 ± 0.05	8.39

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3984 ± 0.0	3984	114 ± 0.0	114	300 ± 0.0	300	21.51	21.51 ± 0.0	21.51
sabre	13056 ± 225.0	13056	766.81 ± 18.31	686	247.75 ± 2.97	251	61.25	3.83 ± 0.12	4.01

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3984 ± 0.0	3984	114 ± 0.0	114	300 ± 0.0	300	20.92	20.92 ± 0.0	20.92
sabre	5532 ± 133.17	4986	569.0 ± 30.89	426	199.12 ± 3.19	207	68.32	4.27 ± 0.11	4.14

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3984 ± 0.0	3984	114 ± 0.0	114	300 ± 0.0	300	20.7	20.7 ± 0.0	20.7
sabre	4758 ± 150.83	4644	511.88 ± 33.91	429	194.75 ± 3.38	199	118.43	7.4 ± 0.07	7.32

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3984 ± 0.0	3984	114 ± 0.0	114	300 ± 0.0	300	20.74	20.74 ± 0.0	20.74
sabre	4702 ± 106.77	4300	460.69 ± 27.72	375	191.88 ± 2.75	200	504.51	31.53 ± 0.21	31.37

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	7968 ± 0.0	7968	226 ± 0.0	226	300 ± 0.0	300	41.85	41.85 ± 0.0	41.85
sabre	22309 ± 375.19	21499	1238.75 ± 23.39	1182	248.75 ± 2.74	242	116.84	7.3 ± 0.19	7.39

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	7968 ± 0.0	7968	226 ± 0.0	226	300 ± 0.0	300	41.09	41.09 ± 0.0	41.09
sabre	9497 ± 345.67	9370	1049.75 ± 55.28	888	194.06 ± 3.81	198	134.06	8.38 ± 0.28	8.61

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	7968 ± 0.0	7968	226 ± 0.0	226	300 ± 0.0	300	41.59	41.59 ± 0.0	41.59
sabre	9742 ± 181.92	9337	978.25 ± 31.91	856	197.69 ± 3.94	206	227.53	14.22 ± 0.41	15.89

name = kagome, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	7968 ± 0.0	7968	226 ± 0.0	226	300 ± 0.0	300	42.57	42.57 ± 0.0	42.57
sabre	8452 ± 100.74	8486	899.0 ± 24.78	790	192.25 ± 2.62	200	886.06	55.38 ± 1.31	60.71

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	8 ± 0.0	8	9 ± 0.0	9	8 ± 0.0	8	0.09	0.09 ± 0.0	0.09
sabre	8 ± nan	8	8.88 ± 0.19	8	8.0 ± nan	8	0.32	0.02 ± nan	0.02

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	8 ± 0.0	8	9 ± 0.0	9	8 ± 0.0	8	0.09	0.09 ± 0.0	0.09
sabre	6 ± nan	6	7.5 ± 0.25	7	8.0 ± nan	8	0.32	0.02 ± nan	0.02

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	8 ± 0.0	8	9 ± 0.0	9	8 ± 0.0	8	0.09	0.09 ± 0.0	0.09
sabre	6 ± nan	6	7.5 ± 0.25	7	8.0 ± nan	8	0.32	0.02 ± nan	0.02

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	8 ± 0.0	8	9 ± 0.0	9	8 ± 0.0	8	0.09	0.09 ± 0.0	0.09
sabre	6 ± nan	6	7.62 ± 0.22	7	8.0 ± nan	8	0.64	0.04 ± nan	0.04

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	64 ± 0.0	64	65 ± 0.0	65	8 ± 0.0	8	0.74	0.74 ± 0.0	0.74
sabre	74 ± 1.56	64	67.94 ± 2.31	61	8.0 ± nan	8	1.66	0.1 ± 0.02	0.09

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	64 ± 0.0	64	65 ± 0.0	65	8 ± 0.0	8	0.73	0.73 ± 0.0	0.73
sabre	62 ± nan	62	60.75 ± 0.53	59	8.0 ± nan	8	1.82	0.11 ± 0.02	0.1

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	64 ± 0.0	64	65 ± 0.0	65	8 ± 0.0	8	0.77	0.77 ± 0.0	0.77
sabre	62 ± nan	62	60.19 ± 0.69	58	8.0 ± nan	8	2.04	0.13 ± 0.02	0.13

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	64 ± 0.0	64	65 ± 0.0	65	8 ± 0.0	8	0.75	0.75 ± 0.0	0.75
sabre	62 ± nan	62	60.69 ± 0.66	58	8.0 ± nan	8	5.7	0.36 ± 0.03	0.41

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	128 ± 0.0	128	129 ± 0.0	129	8 ± 0.0	8	1.5	1.5 ± 0.0	1.5
sabre	138 ± 2.94	138	140.56 ± 3.66	128	8.0 ± nan	8	3.42	0.21 ± 0.03	0.18

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	128 ± 0.0	128	129 ± 0.0	129	8 ± 0.0	8	1.53	1.53 ± 0.0	1.53
sabre	126 ± nan	126	121.12 ± 1.06	119	8.0 ± nan	8	3.57	0.22 ± 0.02	0.2

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	128 ± 0.0	128	129 ± 0.0	129	8 ± 0.0	8	1.58	1.58 ± 0.0	1.58
sabre	126 ± nan	126	121.06 ± 0.88	118	8.0 ± nan	8	4.24	0.26 ± 0.03	0.24

name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	128 ± 0.0	128	129 ± 0.0	129	8 ± 0.0	8	1.5	1.5 ± 0.0	1.5
sabre	126 ± nan	126	120.81 ± 0.94	116	8.0 ± nan	8	11.06	0.69 ± 0.02	0.71

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	130 ± 0.0	130	12 ± 0.0	12	84 ± 0.0	84	1	1.0 ± 0.0	1
sabre	469 ± 8.24	460	67.94 ± 2.41	60	83.75 ± 0.22	84	2.68	0.17 ± 0.02	0.14

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	130 ± 0.0	130	12 ± 0.0	12	84 ± 0.0	84	0.89	0.89 ± 0.0	0.89
sabre	177 ± 6.53	187	34.5 ± 2.94	27	64.88 ± 1.19	67	2.79	0.17 ± 0.02	0.16

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	130 ± 0.0	130	12 ± 0.0	12	84 ± 0.0	84	0.89	0.89 ± 0.0	0.89
sabre	169 ± 7.66	123	34.5 ± 2.44	26	64.5 ± 1.0	63	4.43	0.28 ± 0.02	0.24

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	130 ± 0.0	130	12 ± 0.0	12	84 ± 0.0	84	1	1.0 ± 0.0	1
sabre	138 ± 6.41	94	29.44 ± 2.53	20	62.81 ± 0.84	63	14.29	0.89 ± 0.03	0.94

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1040 ± 0.0	1040	89 ± 0.0	89	84 ± 0.0	84	7.06	7.06 ± 0.0	7.06
sabre	2778 ± 36.62	2575	400.94 ± 8.12	362	83.81 ± 0.19	84	18.11	1.13 ± 0.03	1.16

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1040 ± 0.0	1040	89 ± 0.0	89	84 ± 0.0	84	6.92	6.92 ± 0.0	6.92
sabre	1268 ± 32.28	1039	254.25 ± 18.57	205	64.94 ± 1.41	63	16.06	1.0 ± 0.04	0.98

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1040 ± 0.0	1040	89 ± 0.0	89	84 ± 0.0	84	6.92	6.92 ± 0.0	6.92
sabre	1051 ± 26.45	926	215.75 ± 15.27	170	64.69 ± 1.41	65	22.5	1.41 ± 0.05	1.34

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1040 ± 0.0	1040	89 ± 0.0	89	84 ± 0.0	84	7.06	7.06 ± 0.0	7.06
sabre	966 ± 14.37	892	192.5 ± 13.59	145	64.44 ± 1.09	68	79.12	4.94 ± 0.07	5.05

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2080 ± 0.0	2080	177 ± 0.0	177	84 ± 0.0	84	13.7	13.7 ± 0.0	13.7
sabre	5067 ± 112.35	4490	774.94 ± 15.84	706	83.94 ± 0.16	84	31.53	1.97 ± 0.08	2.1

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2080 ± 0.0	2080	177 ± 0.0	177	84 ± 0.0	84	14.13	14.13 ± 0.0	14.13
sabre	2035 ± 50.28	1861	450.12 ± 38.78	302	65.19 ± 1.28	66	35.28	2.2 ± 0.06	2.19

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2080 ± 0.0	2080	177 ± 0.0	177	84 ± 0.0	84	13.71	13.71 ± 0.0	13.71
sabre	2080 ± 41.66	1890	398.25 ± 19.59	334	65.38 ± 0.94	63	44.87	2.8 ± 0.06	2.84

name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2080 ± 0.0	2080	177 ± 0.0	177	84 ± 0.0	84	13.89	13.89 ± 0.0	13.89
sabre	1826 ± 35.68	1703	373.75 ± 26.89	303	64.44 ± 1.53	61	150.75	9.42 ± 0.09	9.59

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	418 ± 0.0	418	14 ± 0.0	14	240 ± 0.0	240	2.76	2.76 ± 0.0	2.76
sabre	1722 ± 13.92	1706	117.56 ± 4.03	100	237.69 ± 0.81	239	7.59	0.47 ± 0.03	0.43

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	418 ± 0.0	418	14 ± 0.0	14	240 ± 0.0	240	2.61	2.61 ± 0.0	2.61
sabre	993 ± 25.43	918	85.12 ± 4.62	70	179.31 ± 2.32	182	11.16	0.7 ± 0.03	0.8

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	418 ± 0.0	418	14 ± 0.0	14	240 ± 0.0	240	2.58	2.58 ± 0.0	2.58
sabre	940 ± 25.45	830	83.06 ± 7.81	54	179.06 ± 3.62	194	25.23	1.58 ± 0.02	1.55

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	418 ± 0.0	418	14 ± 0.0	14	240 ± 0.0	240	2.6	2.6 ± 0.0	2.6
sabre	702 ± 15.83	712	66.81 ± 6.6	45	176.12 ± 2.69	183	105.59	6.6 ± 0.04	6.58

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3344 ± 0.0	3344	105 ± 0.0	105	240 ± 0.0	240	19.21	19.21 ± 0.0	19.21
sabre	10085 ± 62.18	10397	654.81 ± 12.53	619	238.31 ± 0.59	238	53.61	3.35 ± 0.12	3.66

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3344 ± 0.0	3344	105 ± 0.0	105	240 ± 0.0	240	19.42	19.42 ± 0.0	19.42
sabre	4949 ± 172.47	4147	581.88 ± 36.5	461	178.88 ± 2.91	173	60.32	3.77 ± 0.09	3.72

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3344 ± 0.0	3344	105 ± 0.0	105	240 ± 0.0	240	19.65	19.65 ± 0.0	19.65
sabre	4321 ± 153.74	3792	566.06 ± 43.95	414	173.81 ± 2.09	171	109.02	6.81 ± 0.22	7.04

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	3344 ± 0.0	3344	105 ± 0.0	105	240 ± 0.0	240	19.33	19.33 ± 0.0	19.33
sabre	3405 ± 65.66	3312	408.12 ± 21.62	343	170.62 ± 2.41	165	429.48	26.84 ± 0.98	25.93

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6688 ± 0.0	6688	209 ± 0.0	209	240 ± 0.0	240	38.44	38.44 ± 0.0	38.44
sabre	18976 ± 105.01	18874	1155.94 ± 14.25	1095	238.88 ± 0.38	238	108.03	6.75 ± 0.22	6.3

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6688 ± 0.0	6688	209 ± 0.0	209	240 ± 0.0	240	38.54	38.54 ± 0.0	38.54
sabre	8889 ± 336.48	6839	1004.38 ± 82.18	832	174.88 ± 2.72	176	111.6	6.98 ± 0.17	6.8

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6688 ± 0.0	6688	209 ± 0.0	209	240 ± 0.0	240	38.42	38.42 ± 0.0	38.42
sabre	6943 ± 155.17	6914	836.81 ± 46.97	673	173.06 ± 1.69	173	183.47	11.47 ± 0.2	12.22

name = shuriken, size = (5, 5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6688 ± 0.0	6688	209 ± 0.0	209	240 ± 0.0	240	38.14	38.14 ± 0.0	38.14
sabre	6644 ± 94.12	6326	667.75 ± 19.72	599	170.81 ± 2.19	165	693.94	43.37 ± 1.15	43.48

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	850 ± 0.0	850	14 ± 0.0	14	476 ± 0.0	476	5.19	5.19 ± 0.0	5.19
sabre	4169 ± 24.72	4173	143.25 ± 4.62	127	471.81 ± 1.22	474	16.26	1.02 ± 0.05	1.13

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	850 ± 0.0	850	14 ± 0.0	14	476 ± 0.0	476	5.2	5.2 ± 0.0	5.2
sabre	2783 ± 64.06	2792	196.44 ± 13.5	154	343.5 ± 3.28	349	48.94	3.06 ± 0.24	2.78

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	850 ± 0.0	850	14 ± 0.0	14	476 ± 0.0	476	5.31	5.31 ± 0.0	5.31
sabre	2665 ± 65.58	2535	170.75 ± 14.04	127	350.5 ± 5.34	352	132.45	8.28 ± 0.26	7.5

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	850 ± 0.0	850	14 ± 0.0	14	476 ± 0.0	476	5.22	5.22 ± 0.0	5.22
sabre	2079 ± 57.9	1891	124.12 ± 8.31	93	342.06 ± 3.19	354	628.32	39.27 ± 0.78	37.63

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6800 ± 0.0	6800	105 ± 0.0	105	476 ± 0.0	476	38.58	38.58 ± 0.0	38.58
sabre	25487 ± 146.92	25288	875.19 ± 21.34	785	474.06 ± 1.12	475	111.3	6.96 ± 0.17	6.82

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6800 ± 0.0	6800	105 ± 0.0	105	476 ± 0.0	476	38.22	38.22 ± 0.0	38.22
sabre	14038 ± 501.85	11572	1110.0 ± 72.38	836	349.44 ± 5.69	345	167.86	10.49 ± 0.26	10.87

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6800 ± 0.0	6800	105 ± 0.0	105	476 ± 0.0	476	37.94	37.94 ± 0.0	37.94
sabre	11889 ± 326.3	12192	1092.25 ± 51.37	922	343.62 ± 5.27	347	352.13	22.01 ± 0.34	20.89

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	6800 ± 0.0	6800	105 ± 0.0	105	476 ± 0.0	476	38.25	38.25 ± 0.0	38.25
sabre	9431 ± 295.31	9200	791.69 ± 50.65	589	336.75 ± 4.19	333	1612.88	100.8 ± 1.84	99.38

name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	13600 ± 0.0	13600	209 ± 0.0	209	476 ± 0.0	476	75.38	75.38 ± 0.0	75.38
sabre	45512 ± 312.53	44697	1457.12 ± 33.54	1343	473.31 ± 1.06	474	207.14	12.95 ± 0.2	13.88

```
-------------------------------------------------------------------------------------------------------------------------------------------------------
name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method      av. n_swaps        min. n_swap  av. depth           min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ---------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  13600 ± 0.0              13600  209 ± 0.0                209  476 ± 0.0                476            75.82  75.82 ± 0.0               75.82
sabre       24677 ± 1008.11          19213  1943.62 ± 179.76        1252  342.62 ± 4.44            334           295.31  18.46 ± 0.33              19.18
-------------------------------------------------------------------------------------------------------------------------------------------------------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name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method      av. n_swaps        min. n_swap  av. depth           min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ---------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  13600 ± 0.0              13600  209 ± 0.0                209  476 ± 0.0                476            75.21  75.21 ± 0.0               75.21
sabre       22096 ± 699.86           19115  1676.12 ± 96.85         1293  348.44 ± 4.94            347           573.52  35.84 ± 0.93              38.88
-------------------------------------------------------------------------------------------------------------------------------------------------------


-------------------------------------------------------------------------------------------------------------------------------------------------------
name = shuriken, size = (7, 7), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method      av. n_swaps        min. n_swap  av. depth           min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ---------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  13600 ± 0.0              13600  209 ± 0.0                209  476 ± 0.0                476            76.74  76.74 ± 0.0               76.74
sabre       18148 ± 348.43           17064  1369.19 ± 66.21         1099  336.31 ± 4.62            323          2519.55  157.47 ± 3.75            146.54
-------------------------------------------------------------------------------------------------------------------------------------------------------
```

7.0.2 Quantum simulation, checkerboard, agianst SABRE

```
import line_graph_routing as lgr # Loading these makes these cells stand-alone
import pickle

settings=[]
for name in ['checkerboard']:
    for side in [i+0.5 for i in range(1,9,2)]:
        for p in [1,8,16]:
            for optimization_level in range(4):
                setting={'name':name,
                     'size': (side,side),
                     'circuit_type': 'quantum_simulation',
                     'p': p,
                     'repetitions' : 16,
                     'optimization_level' : optimization_level,
                     'methods' : ['sabre']
                    }
                settings.append(setting)

## Uncomment to rerun benchmarks. This takes a couple of hours.
#results=[]
#for setting in settings:
#    result=lgr.benchmark(**setting)
```

```
#     results.append(result)
#     lgr.print_benchmark(result)
#
#with open('benchmark_data/checkerboard.pkl','wb') as f:
#     pickle.dump(results,f)

#Load previously obtained results from disk and show them.
import pickle
with open('benchmark_data/checkerboard.pkl','rb') as f:
    results=pickle.load(f)

for result in results:
    lgr.print_benchmark(result)
```

```
-----------------------------------------------------------------------------------------------------------------------------------------------------------
name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  42 ± 0.0                  42  27 ± 0.0                27  21 ± 0.0                   21              0.17  0.17 ± 0.0                 0.17
sabre       45 ± 1.28                 47  32.44 ± 1.97            27  19.06 ± 0.66               21              0.99  0.06 ± 0.03                0.03
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name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth      min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  -----------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  42 ± 0.0                  42  27 ± 0.0               27  21 ± 0.0                   21              0.37  0.37 ± 0.0                 0.37
sabre       32 ± 1.44                 22  26.56 ± 2.0            19  17.69 ± 0.66               16              0.67  0.04 ± 0.03                0.03
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-----------------------------------------------------------------------------------------------------------------------------------------------------------
name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  42 ± 0.0                  42  27 ± 0.0                27  21 ± 0.0                   21              0.35  0.35 ± 0.0                 0.35
sabre       28 ± 0.84                 31  23.81 ± 1.81            19  17.94 ± 0.87               21              1.34  0.08 ± 0.04                0.04
-----------------------------------------------------------------------------------------------------------------------------------------------------------


-----------------------------------------------------------------------------------------------------------------------------------------------------------
name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  42 ± 0.0                  42  27 ± 0.0                27  21 ± 0.0                   21              0.17  0.17 ± 0.0                 0.17
sabre       28 ± 0.78                 25  25.31 ± 2.03            18  16.81 ± 0.41               18              2.56  0.16 ± 0.04                0.11
-----------------------------------------------------------------------------------------------------------------------------------------------------------
```

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	322 ± 0.0	322	188 ± 0.0	188	21 ± 0.0	21	1.89	1.89 ± 0.0	1.89
sabre	362 ± 7.38	343	235.0 ± 6.03	214	21.0 ± nan	21	4.87	0.3 ± 0.06	0.18

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	322 ± 0.0	322	188 ± 0.0	188	21 ± 0.0	21	1.98	1.98 ± 0.0	1.98
sabre	239 ± 3.71	240	197.25 ± 7.75	175	17.94 ± 0.84	16	4.99	0.31 ± 0.06	0.21

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	322 ± 0.0	322	188 ± 0.0	188	21 ± 0.0	21	1.94	1.94 ± 0.0	1.94
sabre	237 ± 2.75	227	183.5 ± 7.31	160	17.12 ± 0.5	16	5.84	0.36 ± 0.05	0.28

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	322 ± 0.0	322	188 ± 0.0	188	21 ± 0.0	21	1.95	1.95 ± 0.0	1.95
sabre	217 ± 2.41	221	187.5 ± 4.34	175	16.62 ± 0.44	16	17.58	1.1 ± 0.01	1.08

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	642 ± 0.0	642	372 ± 0.0	372	21 ± 0.0	21	3.85	3.85 ± 0.0	3.85
sabre	763 ± 20.84	657	485.38 ± 12.94	417	21.0 ± nan	21	8.07	0.5 ± 0.05	0.51

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	642 ± 0.0	642	372 ± 0.0	372	21 ± 0.0	21	3.18	3.18 ± 0.0	3.18
sabre	471 ± 9.91	469	379.56 ± 17.02	311	18.62 ± 0.88	21	7.55	0.47 ± 0.04	0.4

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	642 ± 0.0	642	372 ± 0.0	372	21 ± 0.0	21	3.22	3.22 ± 0.0	3.22
sabre	463 ± 5.31	466	376.0 ± 8.98	346	17.5 ± 0.81	21	10.29	0.64 ± 0.04	0.52

name = checkerboard, size = (1.5, 1.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	642 ± 0.0	642	372 ± 0.0	372	21 ± 0.0	21	3.23	3.23 ± 0.0	3.23
sabre	454 ± 2.81	447	353.69 ± 12.16	321	16.88 ± 0.5	16	29.5	1.84 ± 0.03	1.96

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	271 ± 0.0	271	30 ± 0.0	30	97 ± 0.0	97	0.92	0.92 ± 0.0	0.92
sabre	550 ± 9.03	548	104.56 ± 3.78	90	88.5 ± 1.56	92	2.56	0.16 ± 0.02	0.14

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	271 ± 0.0	271	30 ± 0.0	30	97 ± 0.0	97	1.01	1.01 ± 0.0	1.01
sabre	257 ± 7.69	233	63.81 ± 4.25	48	69.0 ± 1.38	68	3.03	0.19 ± 0.02	0.17

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	271 ± 0.0	271	30 ± 0.0	30	97 ± 0.0	97	1.01	1.01 ± 0.0	1.01
sabre	228 ± 6.72	234	57.94 ± 3.75	48	70.56 ± 1.25	71	4.87	0.3 ± 0.03	0.26

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	271 ± 0.0	271	30 ± 0.0	30	97 ± 0.0	97	1.04	1.04 ± 0.0	1.04
sabre	180 ± 2.97	187	45.44 ± 2.72	37	67.38 ± 0.97	70	16.94	1.06 ± 0.03	1.1

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2077 ± 0.0	2077	198 ± 0.0	198	97 ± 0.0	97	7.69	7.69 ± 0.0	7.69
sabre	3416 ± 49.08	3159	597.62 ± 15.12	544	92.62 ± 0.75	92	18.07	1.13 ± 0.05	1.19

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2077 ± 0.0	2077	198 ± 0.0	198	97 ± 0.0	97	7.68	7.68 ± 0.0	7.68
sabre	1870 ± 26.84	1894	481.25 ± 11.75	444	70.19 ± 1.84	68	20.33	1.27 ± 0.05	1.33

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2077 ± 0.0	2077	198 ± 0.0	198	97 ± 0.0	97	7.91	7.91 ± 0.0	7.91
sabre	1785 ± 15.44	1756	456.5 ± 14.31	404	69.56 ± 1.16	73	29.02	1.81 ± 0.05	1.86

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	2077 ± 0.0	2077	198 ± 0.0	198	97 ± 0.0	97	7.73	7.73 ± 0.0	7.73
sabre	1740 ± 16.03	1731	446.75 ± 14.74	387	69.12 ± 2.0	76	104.9	6.56 ± 0.05	6.48

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4141 ± 0.0	4141	390 ± 0.0	390	97 ± 0.0	97	14.99	14.99 ± 0.0	14.99
sabre	6142 ± 72.56	5875	1117.75 ± 21.0	1021	94.0 ± nan	94	36.66	2.29 ± 0.13	2.24

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4141 ± 0.0	4141	390 ± 0.0	390	97 ± 0.0	97	15.05	15.05 ± 0.0	15.05
sabre	3639 ± 29.19	3753	996.19 ± 20.97	934	70.0 ± 1.38	67	41.08	2.57 ± 0.09	2.48

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4141 ± 0.0	4141	390 ± 0.0	390	97 ± 0.0	97	15.66	15.66 ± 0.0	15.66
sabre	3684 ± 25.79	3608	949.5 ± 19.69	893	70.06 ± 2.69	71	57.58	3.6 ± 0.1	3.48

name = checkerboard, size = (3.5, 3.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	4141 ± 0.0	4141	390 ± 0.0	390	97 ± 0.0	97	15.64	15.64 ± 0.0	15.64
sabre	3580 ± 20.27	3621	924.56 ± 17.07	854	67.0 ± 1.47	65	207.53	12.97 ± 0.12	12.8

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	682 ± 0.0	682	34 ± 0.0	34	221 ± 0.0	221	2.48	2.48 ± 0.0	2.48
sabre	1770 ± 17.16	1791	138.56 ± 4.66	121	211.31 ± 1.47	213	6.81	0.43 ± 0.04	0.5

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	682 ± 0.0	682	34 ± 0.0	34	221 ± 0.0	221	2.45	2.45 ± 0.0	2.45
sabre	678 ± 30.68	678	107.06 ± 7.62	77	160.38 ± 1.34	160	9.63	0.6 ± 0.04	0.65

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	682 ± 0.0	682	34 ± 0.0	34	221 ± 0.0	221	2.47	2.47 ± 0.0	2.47
sabre	808 ± 21.59	773	102.81 ± 7.0	82	159.62 ± 2.76	160	18.67	1.17 ± 0.03	1.07

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	682 ± 0.0	682	34 ± 0.0	34	221 ± 0.0	221	2.41	2.41 ± 0.0	2.41
sabre	652 ± 19.28	608	83.75 ± 6.44	58	156.94 ± 1.84	158	80.01	5.0 ± 0.04	5.14

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	5148 ± 0.0	5148	223 ± 0.0	223	221 ± 0.0	221	18.16	18.16 ± 0.0	18.16
sabre	10367 ± 118.27	10404	823.12 ± 18.63	746	217.38 ± 0.62	219	46.53	2.91 ± 0.16	2.8

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	5148 ± 0.0	5148	223 ± 0.0	223	221 ± 0.0	221	18.72	18.72 ± 0.0	18.72
sabre	5644 ± 120.68	5373	800.31 ± 38.98	667	159.44 ± 2.66	166	52.7	3.29 ± 0.1	3.38

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	5148 ± 0.0	5148	223 ± 0.0	223	221 ± 0.0	221	18.19	18.19 ± 0.0	18.19
sabre	5241 ± 43.19	5091	734.25 ± 22.25	666	157.81 ± 3.06	171	89.44	5.59 ± 0.12	5.86

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	5148 ± 0.0	5148	223 ± 0.0	223	221 ± 0.0	221	18.3	18.3 ± 0.0	18.3
sabre	5054 ± 30.28	4839	723.25 ± 16.98	656	157.69 ± 2.69	159	363.83	22.74 ± 0.2	23.19

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	10252 ± 0.0	10252	439 ± 0.0	439	221 ± 0.0	221	36.56	36.56 ± 0.0	36.56
sabre	18950 ± 206.58	18281	1546.5 ± 24.0	1464	217.38 ± 0.78	218	98.11	6.13 ± 0.21	6.55

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	10252 ± 0.0	10252	439 ± 0.0	439	221 ± 0.0	221	36.48	36.48 ± 0.0	36.48
sabre	10695 ± 85.99	10470	1609.69 ± 39.03	1439	161.44 ± 2.88	158	113.03	7.06 ± 0.21	6.69

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	10252 ± 0.0	10252	439 ± 0.0	439	221 ± 0.0	221	36.69	36.69 ± 0.0	36.69
sabre	10265 ± 67.73	10411	1565.5 ± 31.69	1469	162.69 ± 4.19	163	171.93	10.75 ± 0.22	10.26

name = checkerboard, size = (5.5, 5.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	10252 ± 0.0	10252	439 ± 0.0	439	221 ± 0.0	221	37.43	37.43 ± 0.0	37.43
sabre	10373 ± 43.89	10384	1537.19 ± 30.88	1390	155.31 ± 2.59	158	681.17	42.57 ± 0.25	42.4

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1211 ± 0.0	1211	30 ± 0.0	30	393 ± 0.0	393	4.76	4.76 ± 0.0	4.76
sabre	4053 ± 23.25	4092	198.25 ± 3.97	187	350.88 ± 3.41	355	14.04	0.88 ± 0.04	0.91

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1211 ± 0.0	1211	30 ± 0.0	30	393 ± 0.0	393	4.49	4.49 ± 0.0	4.49
sabre	2459 ± 56.57	2107	186.38 ± 11.72	152	284.44 ± 2.91	289	25.29	1.58 ± 0.05	1.64

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1211 ± 0.0	1211	30 ± 0.0	30	393 ± 0.0	393	4.58	4.58 ± 0.0	4.58
sabre	2189 ± 48.72	1989	167.81 ± 10.59	138	286.19 ± 3.31	293	57.96	3.62 ± 0.05	3.58

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	1211 ± 0.0	1211	30 ± 0.0	30	393 ± 0.0	393	4.55	4.55 ± 0.0	4.55
sabre	1767 ± 37.66	1641	135.38 ± 6.47	105	279.06 ± 4.72	290	283.04	17.69 ± 0.12	17.6

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	9289 ± 0.0	9289	219 ± 0.0	219	393 ± 0.0	393	34.14	34.14 ± 0.0	34.14
sabre	22164 ± 192.21	21331	1027.31 ± 17.21	951	361.69 ± 3.69	377	93.75	5.86 ± 0.21	6.22

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	9289 ± 0.0	9289	219 ± 0.0	219	393 ± 0.0	393	34.49	34.49 ± 0.0	34.49
sabre	12118 ± 289.99	11694	1276.06 ± 66.48	1103	285.69 ± 3.28	293	118.35	7.4 ± 0.19	7.07

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 2

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	9289 ± 0.0	9289	219 ± 0.0	219	393 ± 0.0	393	33.66	33.66 ± 0.0	33.66
sabre	12194 ± 132.53	11396	1219.62 ± 31.86	1093	287.31 ± 3.31	286	222.24	13.89 ± 0.23	13.07

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 8, repetitions = 16, optimization_level = 3

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	9289 ± 0.0	9289	219 ± 0.0	219	393 ± 0.0	393	33.34	33.34 ± 0.0	33.34
sabre	11481 ± 103.84	11276	1151.81 ± 30.17	1052	279.0 ± 3.91	278	974.77	60.92 ± 0.4	61.4

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	18521 ± 0.0	18521	435 ± 0.0	435	393 ± 0.0	393	68.34	68.34 ± 0.0	68.34
sabre	39936 ± 352.99	38867	1884.31 ± 37.54	1805	359.75 ± 3.12	363	169.73	10.61 ± 0.29	10.02

name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	18521 ± 0.0	18521	435 ± 0.0	435	393 ± 0.0	393	67.22	67.22 ± 0.0	67.22
sabre	23853 ± 341.31	23359	2396.88 ± 96.2	2054	286.44 ± 3.78	299	222.73	13.92 ± 0.42	13.2

```
-------------------------------------------------------------------------------------------------------------------------------------------------------
name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 2
method      av. n_swaps       min. n_swap  av. depth          min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  ----------------  -----------  -----------------  ----------  ----------------  -------------  --------------  ----------------  --------------
line-graph  18521 ± 0.0             18521  435 ± 0.0                435  393 ± 0.0                 393          68.09  68.09 ± 0.0                68.09
sabre       23286 ± 127.03          22930  2395.75 ± 51.28         2243  288.56 ± 5.34             280         389.15  24.32 ± 0.38               24.34
-------------------------------------------------------------------------------------------------------------------------------------------------------


-------------------------------------------------------------------------------------------------------------------------------------------------------
name = checkerboard, size = (7.5, 7.5), circuit_type = quantum_simulation, p = 16, repetitions = 16, optimization_level = 3
method      av. n_swaps       min. n_swap  av. depth          min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  ----------------  -----------  -----------------  ----------  ----------------  -------------  --------------  ----------------  --------------
line-graph  18521 ± 0.0             18521  435 ± 0.0                435  393 ± 0.0                 393           67.2  67.2 ± 0.0                 67.2
sabre       22170 ± 140.89          23060  2352.75 ± 72.43         2121  281.62 ± 4.06             282         1750.38  109.4 ± 0.67              109.23
-------------------------------------------------------------------------------------------------------------------------------------------------------
```

7.0.3 Random circuit, kagome and shuriken, against SABRE

```
import line_graph_routing as lgr # Loading these makes these cells stand-alone
import pickle

settings=[]
for name in ['kagome','shuriken']:
    for side in range(1,7,2):
        for p in [side**2*500]:
            for optimization_level in [1]:
                setting={'name':name,
                     'size': (side,side),
                     'circuit_type': 'random',
                     'p': p,
                     'repetitions' : 16,
                     'optimization_level' : optimization_level,
                     'methods' : ['sabre']
                    }
                settings.append(setting)

## Uncomment to rerun benchmarks.
#results=[]
#for setting in settings:
#    result=lgr.benchmark(**setting)
#    results.append(result)
#    lgr.print_benchmark(result)
#
#with open('benchmark_data/random.pkl','wb') as f:
#    pickle.dump(results,f)

#Load previously obtained results from disk and show them.
import pickle
with open('benchmark_data/random.pkl','rb') as f:
```

```
    results=pickle.load(f)

for result in results:
    lgr.print_benchmark(result)
```

```
--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (1, 1), circuit_type = random, p = 500, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  --------------
line-graph  200 ± 0.0                200  249 ± 0.0              249  12 ± 0.0                   12              0.37  0.37 ± 0.0                 0.37
sabre       96 ± 0.62                 96  207.5 ± 1.19           205  12.0 ± nan                 12              1.17  0.07 ± 0.03                0.06
--------------------------------------------------------------------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (3, 3), circuit_type = random, p = 4500, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth        min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  -------------  ------------  --------------  -------------  ----------------  --------------  --------------
line-graph  2611 ± 0.0               2611  568 ± 0.0               568  68 ± 0.0                   68              1.14  1.14 ± 0.0                 1.14
sabre       1444 ± 25.94             1450  838.88 ± 35.0           720  44.31 ± 1.75               54             10.24  0.64 ± 0.03                0.66
--------------------------------------------------------------------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (5, 5), circuit_type = random, p = 12500, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth          min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ---------------  ------------  --------------  -------------  ----------------  --------------  --------------
line-graph  7592 ± 0.0               7592  735 ± 0.0                735  164 ± 0.0                 164              3.02  3.02 ± 0.0                 3.02
sabre       5637 ± 82.31             5452  1774.44 ± 54.79         1590  108.69 ± 3.56             107             32.72  2.04 ± 0.04                2.03
--------------------------------------------------------------------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------------------------------------------------------------------------------
name = shuriken, size = (1, 1), circuit_type = random, p = 500, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  --------------
line-graph  122 ± 0.0                122  247 ± 0.0              247  8 ± 0.0                     8              0.07  0.07 ± 0.0                 0.07
sabre       85 ± nan                  85  231.12 ± 0.31          231  8.0 ± nan                   8              0.84  0.05 ± 0.0                 0.05
--------------------------------------------------------------------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------------------------------------------------------------------------------
name = shuriken, size = (3, 3), circuit_type = random, p = 4500, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth        min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  -------------  ------------  --------------  -------------  ----------------  --------------  --------------
line-graph  2262 ± 0.0               2262  415 ± 0.0               415  84 ± 0.0                   84              1.05  1.05 ± 0.0                 1.05
sabre       1662 ± 39.26             1447  667.12 ± 39.54          517  65.25 ± 1.38               69             10.53  0.66 ± 0.04                0.7
--------------------------------------------------------------------------------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------------------------------------------------------------------------
name = shuriken, size = (5, 5), circuit_type = random, p = 12500, repetitions = 16, optimization_level = 1
method      av. n_swaps      min. n_swap  av. depth          min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
---------  ------------  ------------  --------------  -----------  --------------  -------------  ----------------  --------------  --------------
line-graph  6828 ± 0.0             6828  405 ± 0.0                405  240 ± 0.0                240             2.83  2.83 ± 0.0                2.83
sabre       6811 ± 192.15          5969  1403.31 ± 94.74         1094  177.31 ± 2.94            176            38.36  2.4 ± 0.04                2.38
-------------------------------------------------------------------------------------------------------------------------------------------------------
```

7.0.4 Random circuit, complete graph, against SABRE

```
import line_graph_routing as lgr
import pickle

settings=[]
for name in ['complete']:
    for side in range(3,10,2):
        for p in [side*100]:
            for optimization_level in range(2):
                setting={'name':name,
                         'size': side,
                         'circuit_type': 'random',
                         'p': p,
                         'repetitions' : 16,
                         'optimization_level' : optimization_level,
                         'methods' : ['sabre']
                     }
                settings.append(setting)

## Uncomment to rerun benchmarks
#results=[]
#for setting in settings:
#    result=lgr.benchmark(**setting)
#    results.append(result)
#    lgr.print_benchmark(result)

#with open('benchmark_data/complete.pkl','wb') as f:
#    pickle.dump(results,f)

with open('benchmark_data/complete.pkl','rb') as f:
    results=pickle.load(f)

for result in results:
    lgr.print_benchmark(result)
```

name = complete, size = 3, circuit_type = random, p = 300, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	154 ± 0.0	154	334 ± 0.0	334	4 ± 0.0	4	0.12	0.12 ± 0.0	0.12
sabre	40 ± 0.97	37	267.88 ± 2.34	257	3.0 ± nan	3	1.01	0.06 ± 0.06	0.04

name = complete, size = 3, circuit_type = random, p = 300, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	140 ± 0.0	140	313 ± 0.0	313	4 ± 0.0	4	0.11	0.11 ± 0.0	0.11
sabre	34 ± nan	34	220.0 ± nan	220	3.0 ± nan	3	0.97	0.06 ± 0.0	0.07

name = complete, size = 5, circuit_type = random, p = 500, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	314 ± 0.0	314	548 ± 0.0	548	6 ± 0.0	6	0.19	0.19 ± 0.0	0.19
sabre	88 ± 1.25	84	458.06 ± 4.0	444	5.0 ± nan	5	0.96	0.06 ± nan	0.06

name = complete, size = 5, circuit_type = random, p = 500, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	286 ± 0.0	286	503 ± 0.0	503	6 ± 0.0	6	0.18	0.18 ± 0.0	0.18
sabre	72 ± nan	72	387.25 ± 0.31	386	5.0 ± nan	5	1.44	0.09 ± nan	0.09

name = complete, size = 7, circuit_type = random, p = 700, repetitions = 16, optimization_level = 0

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	436 ± 0.0	436	723 ± 0.0	723	8 ± 0.0	8	0.25	0.25 ± 0.0	0.25
sabre	115 ± 1.59	115	609.25 ± 6.01	586	7.0 ± nan	7	1.65	0.1 ± 0.02	0.09

name = complete, size = 7, circuit_type = random, p = 700, repetitions = 16, optimization_level = 1

method	av. n_swaps	min. n_swap	av. depth	min. depth	av. n_qubits	min. qubits	total time (s)	av. time (s)	min. time (s)
line-graph	478 ± 0.0	478	787 ± 0.0	787	8 ± 0.0	8	0.26	0.26 ± 0.0	0.26
sabre	118 ± 0.38	117	573.25 ± 1.66	567	7.0 ± nan	7	2.24	0.14 ± 0.01	0.13

```
-------------------------------------------------------------------------------------------------------------------------------------------------------------
name = complete, size = 9, circuit_type = random, p = 900, repetitions = 16, optimization_level = 0

method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  --------------
line-graph  593 ± 0.0                593  946 ± 0.0               946  10 ± 0.0                   10              0.43  0.43 ± 0.0                 0.43
sabre       151 ± 2.0                143  770.0 ± 6.84            730  9.0 ± nan                   9              1.6   0.1 ± nan                  0.1
-------------------------------------------------------------------------------------------------------------------------------------------------------------


-------------------------------------------------------------------------------------------------------------------------------------------------------------
name = complete, size = 9, circuit_type = random, p = 900, repetitions = 16, optimization_level = 1

method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  --------------
line-graph  650 ± 0.0                650  1036 ± 0.0             1036  10 ± 0.0                   10              0.33  0.33 ± 0.0                 0.33
sabre       149 ± 0.59               146  726.5 ± 1.59            720  9.0 ± nan                   9              2.74  0.17 ± 0.02                0.16
-------------------------------------------------------------------------------------------------------------------------------------------------------------
```

7.0.5 Against other routing methods

Above, we only ran SABRE because it outperforms the other methods available in Qiskit by default. The standard methods available are

```
from qiskit import transpiler
transpiler.preset_passmanagers.plugin.list_stage_plugins('routing')
```

```
['basic', 'lookahead', 'none', 'sabre', 'stochastic']
```

```
import line_graph_routing as lgr
import pickle

settings=[]
for name in ['kagome','shuriken']:
    for side in [1]:
        for p in [1]:
            for optimization_level in [3]:
                setting={'name':name,
                         'size': (side,side),
                         'circuit_type': 'quantum_simulation',
                         'p': p,
                         'repetitions' : 16,
                         'optimization_level' : optimization_level,
                         'methods' : ['basic', 'lookahead', 'sabre', 'stochastic']
                    }
                settings.append(setting)

## Uncomment to rerun benchmarks
#results=[]
#for setting in settings:
#    result=lgr.benchmark(**setting)
#    results.append(result)
#    lgr.print_benchmark(result)
```

```
#with open('benchmark_data/other_methods_1x1.pkl','wb') as f:
#    pickle.dump(results,f)

with open('benchmark_data/other_methods_1x1.pkl','rb') as f:
    results=pickle.load(f)

for result in results:
    lgr.print_benchmark(result)
```

```
--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3
method      av. n_swaps      min. n_swap  av. depth      min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  -----------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  12 ± 0.0                  12  7 ± 0.0                7  12 ± 0.0                  12              0.08  0.08 ± 0.0                 0.08
basic       14 ± 0.0                  14  17.0 ± 0.0            17  8.0 ± 0.0                  8              0.05  0.05 ± 0.0                 0.05
lookahead   8 ± nan                    8  8.81 ± 0.19            8  8.0 ± nan                  8             19.55  1.22 ± 0.04                1.26
sabre       6 ± nan                    6  6.0 ± nan              6  8.0 ± nan                  8              0.49  0.03 ± 0.0                 0.03
stochastic  6 ± 0.62                   6  6.06 ± 0.16            6  8.0 ± nan                  8              0.62  0.04 ± 0.0                 0.03
--------------------------------------------------------------------------------------------------------------------------------------------------------
```

```
--------------------------------------------------------------------------------------------------------------------------------------------------------
name = shuriken, size = (1, 1), circuit_type = quantum_simulation, p = 1, repetitions = 16, optimization_level = 3
method      av. n_swaps      min. n_swap  av. depth      min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  -----------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  8 ± 0.0                    8  9 ± 0.0                9  8 ± 0.0                    8              0.05  0.05 ± 0.0                 0.05
basic       16 ± 0.0                  16  19.0 ± 0.0            19  8.0 ± 0.0                  8              0.04  0.04 ± 0.0                 0.04
lookahead   6 ± nan                    6  8.0 ± nan              8  8.0 ± nan                  8             14.22  0.89 ± 0.01                0.88
sabre       6 ± nan                    6  7.62 ± 0.22            7  8.0 ± nan                  8              0.5   0.03 ± 0.0                 0.04
stochastic  6 ± nan                    6  7.0 ± nan              7  8.0 ± nan                  8              0.58  0.04 ± 0.0                 0.04
--------------------------------------------------------------------------------------------------------------------------------------------------------
```

The method 'lookahead' takes an impractical amount of time, so we exclude it when running benchmarks for larger/deeper circuits.

```
import line_graph_routing as lgr
import pickle

settings=[]
for name in ['kagome','shuriken']:
    for side in [3]:
        for p in [3]:
            for optimization_level in [3]:
                setting={'name':name,
                         'size': (side,side),
                         'circuit_type': 'quantum_simulation',
                         'p': p,
                         'repetitions' : 16,
                         'optimization_level' : optimization_level,
```

```
                        'methods' : ['basic', 'sabre', 'stochastic']
                    }
                settings.append(setting)

## Uncomment to rerun benchmarks
#results=[]
#for setting in settings:
#    result=lgr.benchmark(**setting)
#    results.append(result)
#    lgr.print_benchmark(result)
#
#with open('benchmark_data/other_methods_3x3.pkl','wb') as f:
#    pickle.dump(results,f)

with open('benchmark_data/other_methods_3x3.pkl','rb') as f:
    results=pickle.load(f)

for result in results:
    lgr.print_benchmark(result)
```

```
--------------------------------------------------------------------------------------------------------------------------------------------------------
name = kagome, size = (3, 3), circuit_type = quantum_simulation, p = 3, repetitions = 16, optimization_level = 3
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  336 ± 0.0                336  43 ± 0.0                43  68 ± 0.0                   68              1.33  1.33 ± 0.0                 1.33
basic       475 ± 0.0                475  287.0 ± 0.0            287  45.0 ± 0.0                 45              1.21  1.21 ± 0.0                 1.21
sabre       215 ± 3.56               203  63.25 ± 3.78            50  43.94 ± 0.97               45             12.37  0.77 ± 0.04                0.93
stochastic  410 ± 14.31              428  85.88 ± 4.12            71  46.44 ± 1.5                48             28.09  1.76 ± 0.07                1.46
--------------------------------------------------------------------------------------------------------------------------------------------------------
```

```
--------------------------------------------------------------------------------------------------------------------------------------------------------
name = shuriken, size = (3, 3), circuit_type = quantum_simulation, p = 3, repetitions = 16, optimization_level = 3
method      av. n_swaps      min. n_swap  av. depth       min. depth  av. n_qubits      min. qubits    total time (s)  av. time (s)      min. time (s)
----------  -------------  -------------  ------------  ------------  --------------  -------------  ----------------  --------------  ---------------
line-graph  390 ± 0.0                390  34 ± 0.0                34  84 ± 0.0                   84              1.81  1.81 ± 0.0                 1.81
basic       1195 ± 0.0              1195  491.0 ± 0.0            491  71.0 ± 0.0                 71              2.14  2.14 ± 0.0                 2.14
sabre       380 ± 10.03              344  78.19 ± 4.42            66  64.19 ± 0.94               67             24.94  1.56 ± 0.12                2.31
stochastic  813 ± 32.04              609  104.0 ± 7.88            76  66.56 ± 1.44               71             62.25  3.89 ± 0.09                3.76
--------------------------------------------------------------------------------------------------------------------------------------------------------
```

We see SABRE outperforms the other methods available by default in Qiskit, but not line-graph routing for the circuits considered.

7.0.6 Wall-clock time of line-graph routing

Create a random graph, construct the line graph, create a circuit on the line graph, and put this circuit into line-graph routing

```
from time import time
side=25
lg = lgr.kagome(side, side)
print('number of nodes =',lg.number_of_nodes())
```

```
La=10**5
print('number of gates =',La)
qc = lgr.random_circuit(lg, La)
begin=time()
qc = lgr.line_graph_route(qc)
end=time()
print('wall clock time =',end-begin,'(s)')
```

```
number of nodes = 1976
number of gates = 100000
wall clock time = 25.544434070587158 (s)
```