Random Circuit Sampling

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What is RCS?

- **Random Circuit Sampling** (**RCS**)
  Sampling the probability distributions of randomly chosen quantum circuits
- Typically, the “random” choice is constrained to the abilities of the system
  - Operators directly implemented by HW
  - Entanglement with physical neighbors

Some Code for RCS

- The algorithm is something like:

```
for _ in range(depth):
    # First, apply random single-qubit gates to all qubits
    for qubit in qubits:
           circuit.append(random_single_qubit_gate(qubit))

    # Then, randomly apply two-qubit gates
    available_qubits = list(qubits)
    while len(available_qubits) >= 2 and random.random() < two_qubit_gate_prob:
           # Choose random pair of qubits
           q1 = random.choice(available_qubits)
           available_qubits.remove(q1)
           q2 = random.choice(available_qubits)
           available_qubits.remove(q2)

           # Apply random two-qubit gate
           if random.random() < 0.5:
               circuit.append(cirq.CNOT(q1, q2))
           else:
               circuit.append(cirq.ISWAP(q1, q2)) // |ab> where a!=b becomes i|ba>

  return circuit
```

- The above code came from:
  https://www.kaggle.com/code/peterbabulik/random-circuit-sampling

Why Care About RCS?

- RCS is a useful benchmark of quantum ability
- The idea is to test how uncorrelated noise is within the quantum system…
  basically providing a quality metric:
  total error approximately equals the sum of margin errors ⇒ noise is uncorrelated

Why Care About RCS?

- RCS is commonly used to claim quantum superiority, solving problems that no classical computer could reasonably solve
- Google has made claims based on RCS: *Quantum supremacy using a programmable superconducting processor*

  `https://www.nature.com/articles/s41586-019-1666-5`

- A nice summary of the reactions to that is:

  `https://www.the-innovation.org/article/id/686b587b8ae588673b3bf489`

I Don’t See Superiority Here

1. Is this a useful application?
2. Typical conventional simulations of quantum systems produce complete distributions that can be directly measured, not just sampled
3. An arbitrary sequence of quantum gates can be merged into a single 2^nx2^n unitary matrix and we only need real results (*i* isn’t sampled)
4. There are errors in the quantum computation

Merging Quantum Gates

- A single 2^nx2^n unitary matrix can represent any series of operations on *n* qubits†
  - Multiply unitary matricies in reverse order
  - Parallel gates G_a and G_b on qubit sets *a*, *b* produce the Kronecker product $G_a \otimes G_b$
  - Use identity matrix where no gate is applied
- Computation of result *i* components can be skipped because they are not measured

† Google's *n*=53, so this is still a huge matrix!