Quantum Natural Language Generation on Near-Term Devices
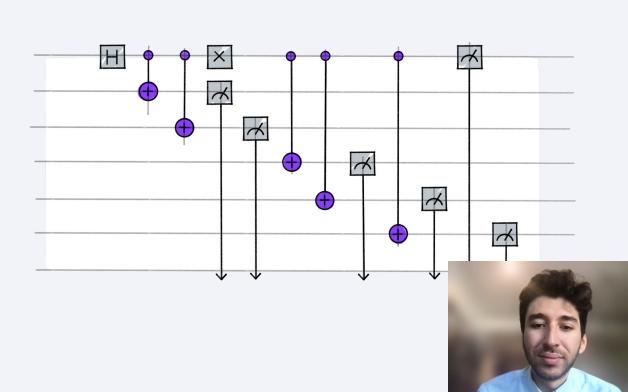
Amin Karamlou

IBM Quantum Community Team

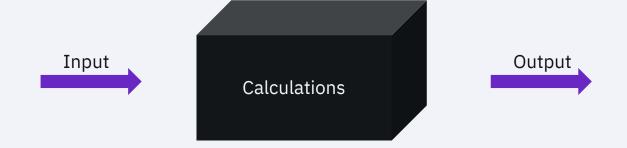**Collaborators:**

Marcel Pfaffhauser, IBM Quantum
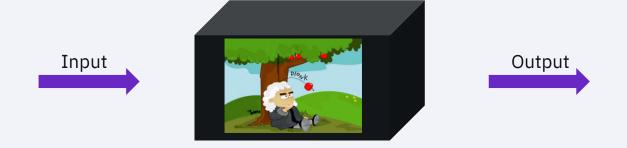
James Wootton, IBM Quantum

What is a computer?

Input

Calculations

Output

What is a classical computer?

Input

Output

What is a quantum computer?

Input
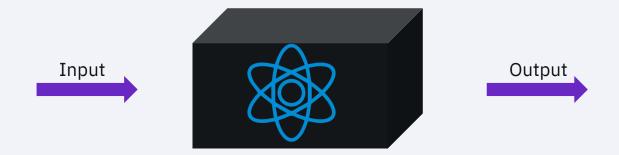
Output

- By using features of quantum mechanics that have no classical analogue quantum computers may be able to solve problems that classical computers are incapable of solving.
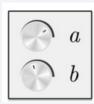
Qubits and Superposition

- Classical bits are always in one of two possible states, 0 or 1.

- Qubits on the other hand, can be in a linear combination of two states, $|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ or $|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$. This linear combination is known as a ***superposition***.

$$|\psi\rangle = a\,|0\rangle + b\,|1\rangle \; s.t.\, |a|^2 + |b|^2 = 1$$

Measurement

- We can **measure** a qubit in state $|\psi\rangle = a\,|0\rangle + b\,|1\rangle$. The result of a measurement is always 0 or 1. The result 0 is obtained with a probability of $|a|^2$, and the result 1 is obtained with a probability of $|b|^2$.

$$|\psi\rangle = \frac{1}{\sqrt{2}}\,|0\rangle + \frac{1}{\sqrt{2}}\,|1\rangle \longrightarrow$$

50% 0

50% 1

- After a measurement the state of a qubit **collapses** to $|0\rangle$ or $|1\rangle$ (whichever outcome was observed).

Quantum Logic Gates

- The state of a qubit can also be manipulated using **quantum logic gates**.

- Mathematically these are represented by unitary matrices. For example the Hadamard gate is represented as $H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$.

- The state of a qubit $|\psi\rangle$ after the application of a quantum logic gate U is given by $U|\psi\rangle$
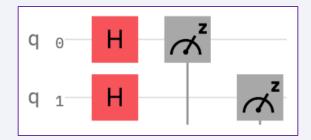
$$|\psi\rangle = 1|0\rangle \quad \longrightarrow \quad \boxed{H} \quad \longrightarrow \quad H|\psi\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

Quantum Circuits

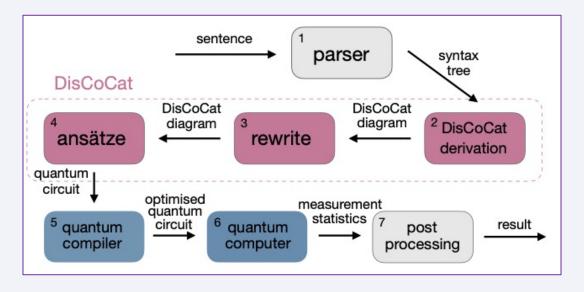- A quantum computation is nothing more than a series of **_quantum logic gates_** applied to some qubits, followed by a series of **_measurement_** operations.

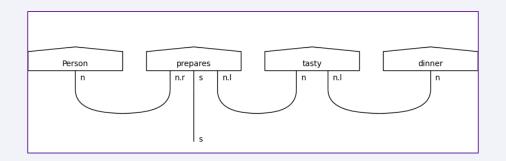- This process has a convenient representation as a **_quantum circuit_**.
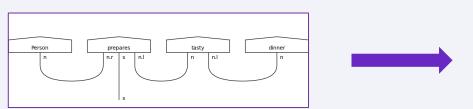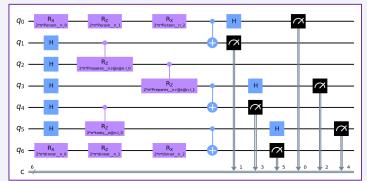
QNLP

Parsing and Diagram Creation
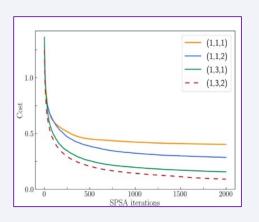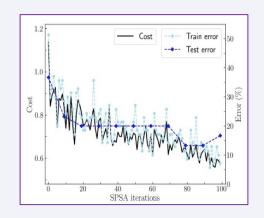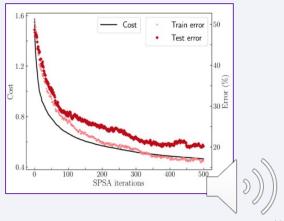
Circuit creation

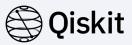# Binary Classification Examples

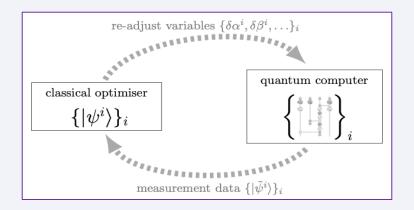Person prepares tasty dinner

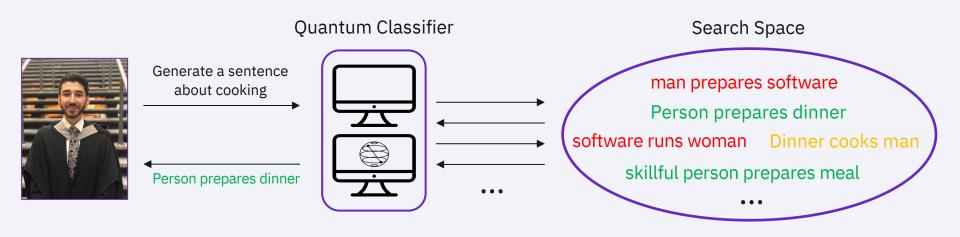Skillful programmer creates software

Training a Sentence Classifier

1. Start with a corpus of sentences, each belonging to one of several possible classes.

2. Create a parameterised quantum circuit for each sentence.

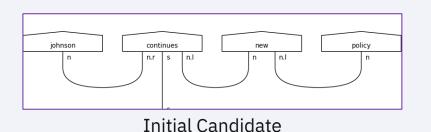3. Optimise the variables appearing in the circuits using a hybrid quantum classical algorithm.

re-adjust variables $\{\delta\alpha^i, \delta\beta^i, \ldots\}_i$

classical optimiser
$\{|\psi^i\rangle\}_i$

quantum computer
$\left\{ \begin{matrix} \end{matrix} \right\}_i$

measurement data $\{|\tilde{\psi}^i\rangle\}_i$

arXiv:2012.03755

Sentence Generation overview

Qiskit

Quantum Classifier

Search Space

Generate a sentence about cooking

Person prepares dinner

man prepares software

Person prepares dinner

software runs woman   Dinner cooks man

skillful person prepares meal

...

...

Neighbouring Sentences

| Person | Prepares | Dinner | |

Insert Tasty

| Person | Prepares | Tasty | Dinner |

Substitute Person with Alice

| Alice | Prepares | Tasty | Dinner |

Delete Tasty

| Alice | Prepares | Dinner | |

Toy Example: Sports Headline Generation

Initial Candidate
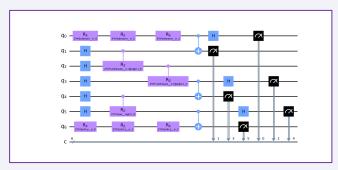
Run 100000 times

P(sport) = 5%

No.

P(sport) > 95% ?

P (Tech) = 10%
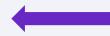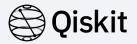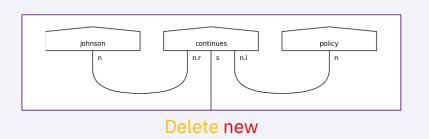
We need to generate a new candidate

P(Entertainment) = 3%

P(Politics) = 82%

Toy Example: Sports Headline Generation

Delete new
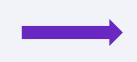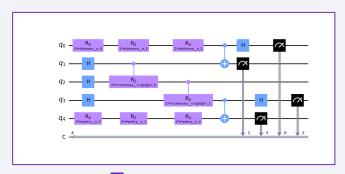
Run 100000 times

P(sport) = 7%

P (Tech) = 8%

P(Entertainment) = 3%

P(Politics) = 82%

P(sport) > 95% ?

Still No.

Let's generate another candidate.

Toy Example: Sports Headline Generation

Substitute Policy with Winning

Run 100000 times

P(sport) = 3%

Still No.

P(sport) > 95% ?

P (Tech) = 10%
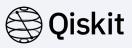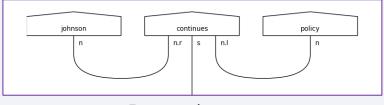
Things even got worse this time.

P(Entertainment) = 3%

P(Politics) = 84%

Toy Example: Sports Headline Generation
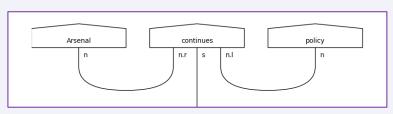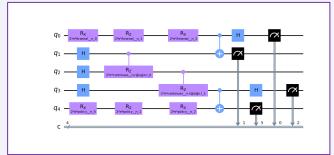
Revert changes
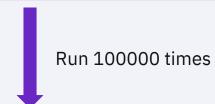
Substitute Johnson with Arsenal

Run 100000 times

P(sport) = 85%

P (Tech) = 3%

P(Entertainment) = 2%

P(Politics) = 10%

P(sport) > 95% ?
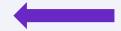
Still No.

But we're quite close now!
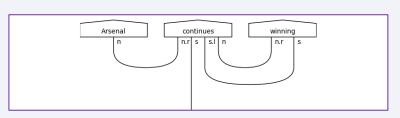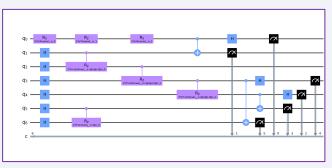
Toy Example: Sports Headline Generation

Substitute Policy with Winning

Run 100000 times

P(sport) = 97%

Yes!

P(sport) > 95% ?

P (Tech) = 1%

Output this sentence.
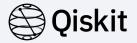
P(Entertainment) = 1%

P(Politics) = 1%

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Thank you