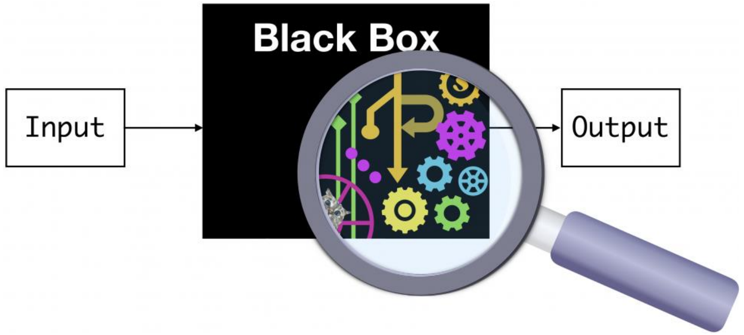
Towards Transparency in Coreference Resolution: A Quantum-Inspired Approach

Hadi Wazni and Mehrnoosh Sadrzadeh

https://arxiv.org/abs/2312.00688

CRAC 2023, the Sixth Workshop on Computational Models of Reference, Anaphora and Coreference, EMNLP 2023

Motivation



- Large language models (LLMs), such as GPT-3 have achieved impressive results in various NLP tasks.
  - face criticism for being black boxes
- One way to enhance the transparency and interpretability of these models is to explicitly **integrate linguistic structure** into them.
- Distributional Compositional Categorical (DisCoCat) framework:
  - meaning (or semantics) of a sentence = grammatical (or syntactic) structure + distributional (or statistical) data
  - a symbolic model of grammar, the Lambek calculus, **L**
  - in need of large computational resources and has limited scalability

Mathematical Foundations for a Compositional Distributional Model of Meaning, https://arxiv.org/pdf/1003.4394

Lambek calculus

Functional word types

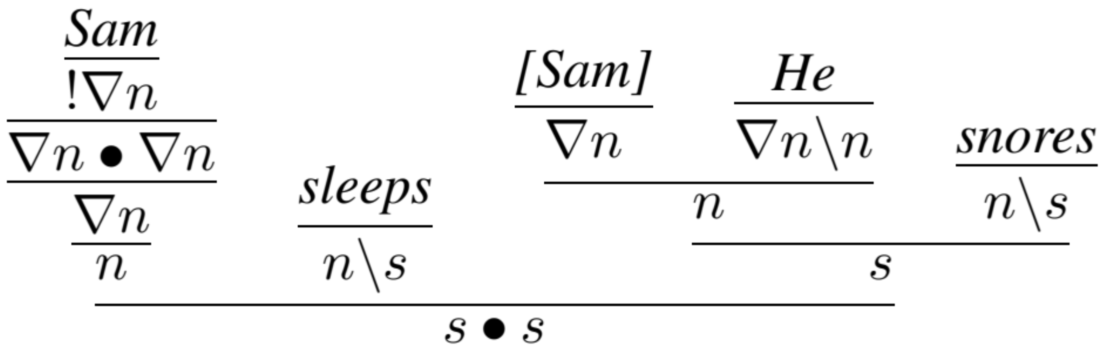
- Given a set of atomic types {n, s} :
  - generate L types using connectives \, • and /
  - *adjectives* take input nouns on the right, n/n
  - *verbs* take subjects on the left (and objects on the right) and return a sentence.
    - intransitive verb n\s, transitive verb n\s/n

$$\frac{\dfrac{Sam}{n} \qquad \dfrac{sleeps}{n\backslash s}}{s}$$

Lambek calculus with soft subexponentials

SLLM

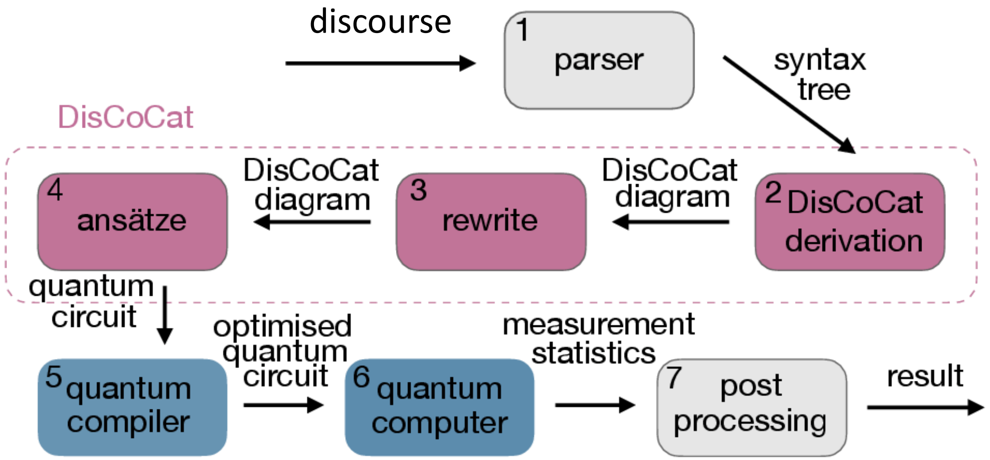
- SLLM has two modalities: one for copying !, one for moving ∇
  - referable words are typed !∇n,
    - *“Sam”* is copyable (!) and movable (∇)
  - referential words are typed ∇n\n
    - *“He”* looks for a copy of an ∇n type word on its left, and returns the copy



Anaphora and ellipsis in lambek calculus with a relevant modality: syntax and semantics, https://arxiv.org/pdf/2110.10641.pdf
Vector Space Semantics for Lambek Calculus with Soft Subexponentials, https://arxiv.org/abs/2111.11331

Methodology

Pipeline: parser



$$\textit{the students} :!\nabla n,\ \textit{read} : n\backslash s/n,\ \textit{the books} : n,\ \textit{They} : \nabla n\backslash n,\ \textit{were} : n\backslash s/(n/n),\ \textit{learning} : n/n,$$

$$\frac{\overline{n \longrightarrow n} \quad \overline{n \longrightarrow n}}{n/n, n \longrightarrow n}\ /_L$$

$$\frac{n/n, n \longrightarrow n}{n/n \longrightarrow n/n}\ /_R \qquad \frac{\overline{s \longrightarrow s} \quad \overline{s \longrightarrow s}}{s, s \longrightarrow s \cdot s}\ \cdot_R$$

$$\frac{n/n \longrightarrow n/n \quad s, s \longrightarrow s \cdot s}{s, s/(n/n), n/n \longrightarrow s \cdot s}$$

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$$\frac{\overline{n \longrightarrow n}}{\nabla n \longrightarrow \nabla n}\ \nabla_R \qquad \frac{n, n\backslash s/n, n, n, n\backslash s/(n/n), n/n \longrightarrow s \cdot s}{\nabla n, n\backslash s/n, n, n, n\backslash s/(n/n), n/n \longrightarrow s \cdot s}\ \nabla_L$$

$$\frac{\nabla n \longrightarrow \nabla n \quad \nabla n, n\backslash s/n, n, n, n\backslash s/(n/n), n/n \longrightarrow s \cdot s}{\nabla n, n\backslash s/n, n, \nabla n, \nabla n\backslash n, n\backslash s/(n/n), n/n \longrightarrow s \cdot s}\ \backslash_L$$

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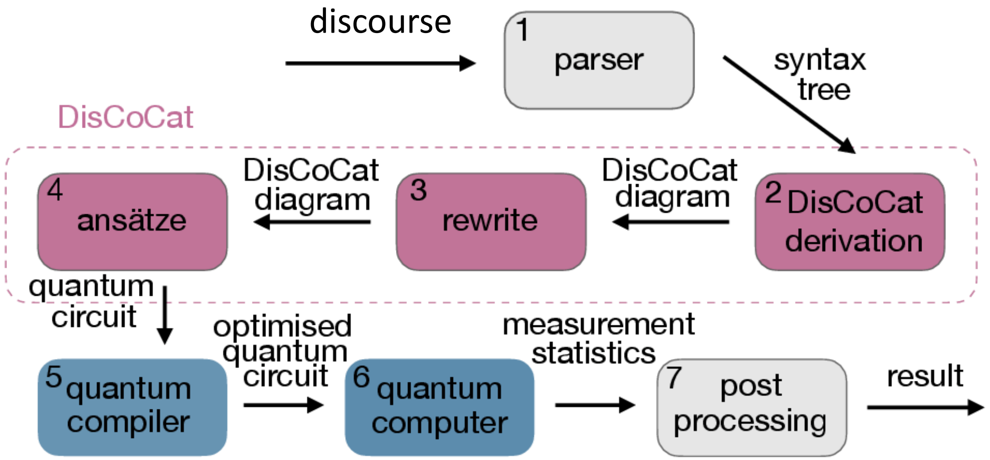
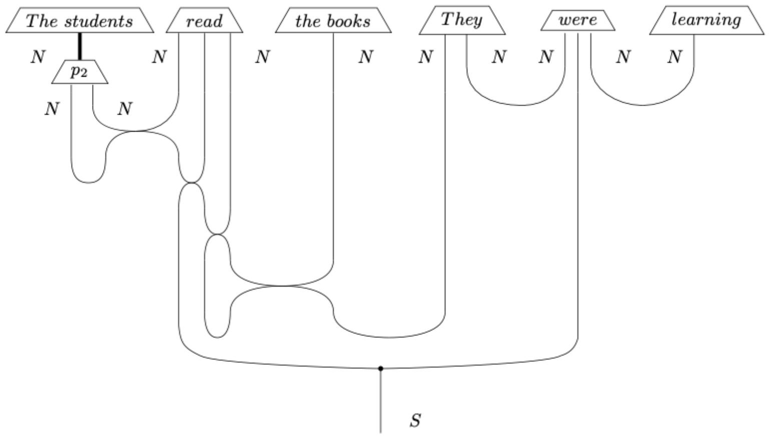
QNLP in Practice: Running Compositional Models of Meaning on a Quantum Computer, https://arxiv.org/abs/2102.12846

Methodology

Pipeline: DisCoCat diagram

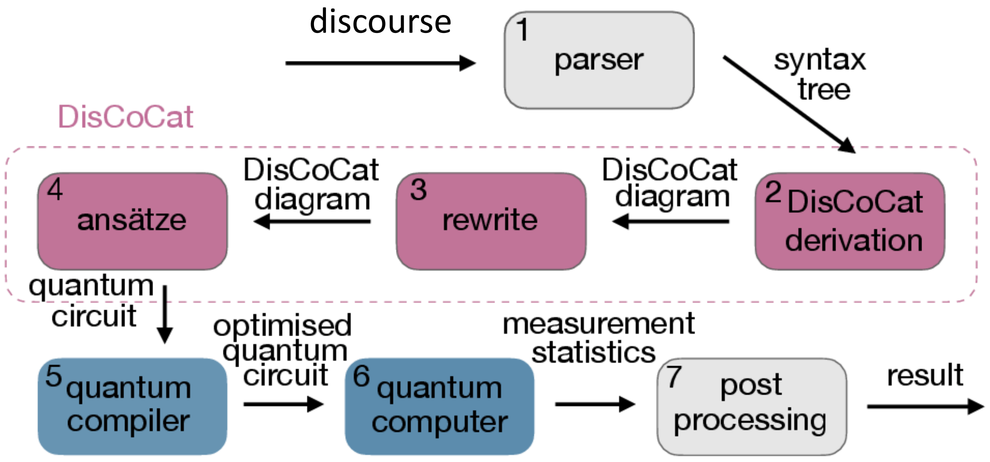


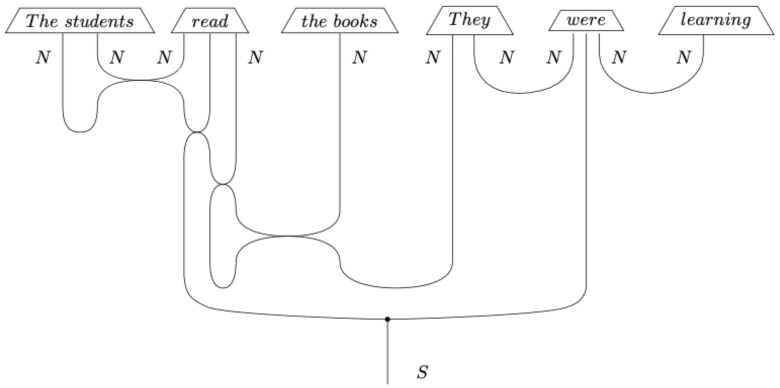


- An abstract representation of the sentence reflecting the relationships between the words

Methodology

Pipeline: rewrite

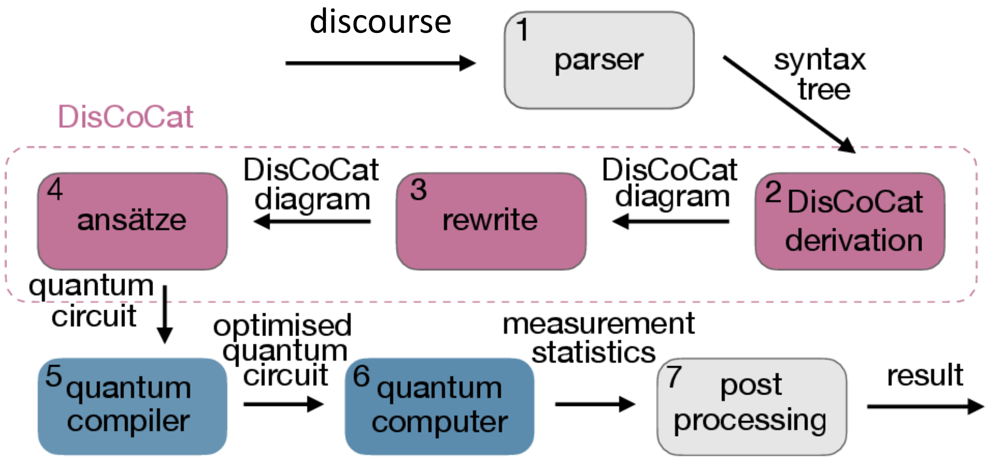


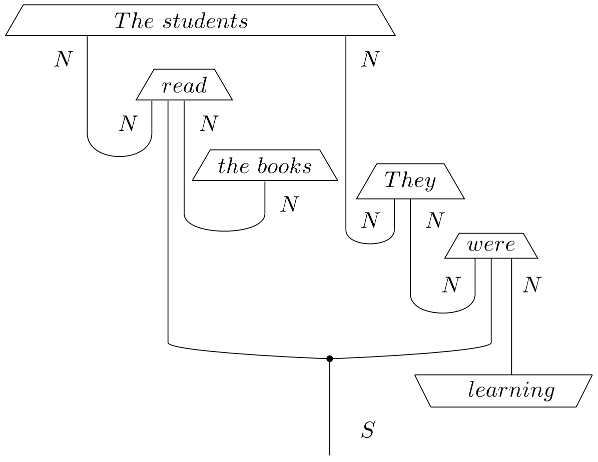


- The string diagram can be simplified: remove specific interactions between words that might be considered redundant to make the computation more amenable to implementation on a quantum processing unit

Methodology

Pipeline: rewrite





- The resulting string diagram can be converted into a concrete quantum circuit (or a tensor network in the case of a “classical” experiment), based on a specific parameterization scheme and concrete choices of ansätze.

Example 2
Object Anaphora

$$\textit{the students} : n,\ \textit{read} : n\backslash s/n,\ \textit{the books} : !\nabla n,\ \textit{They} : \nabla n\backslash n,\ \textit{were} : n\backslash s/(n/n),\ \textit{interesting} : n/n,$$

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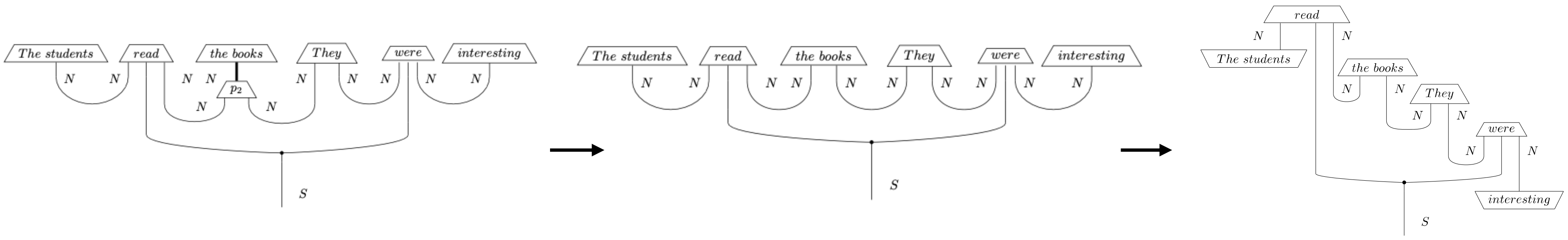
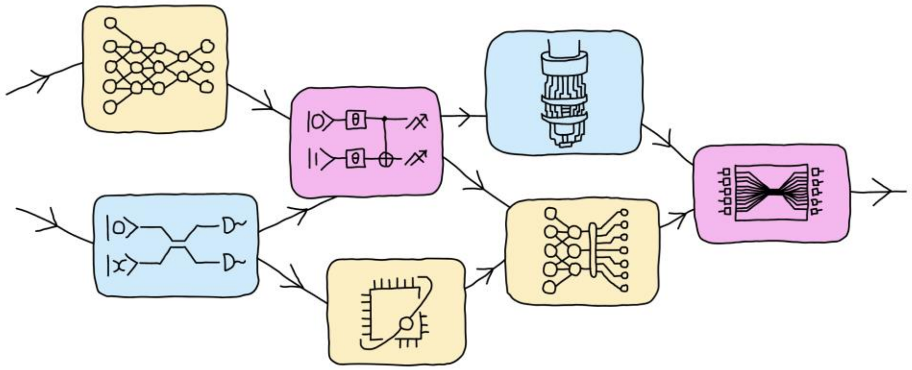


Motivation

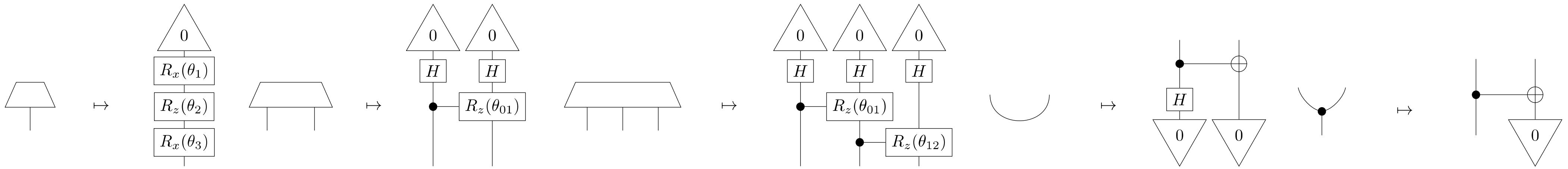
- Quantum Natural Language Processing (QNLP)
  - Categorical Quantum Mechanics + DisCoCat framework
  - String diagrams to translate from grammatical structure to quantum processes
  - Computes word embeddings using parameterized quantum circuits
    - sentence classification, music classification, translation, sentiment analysis..



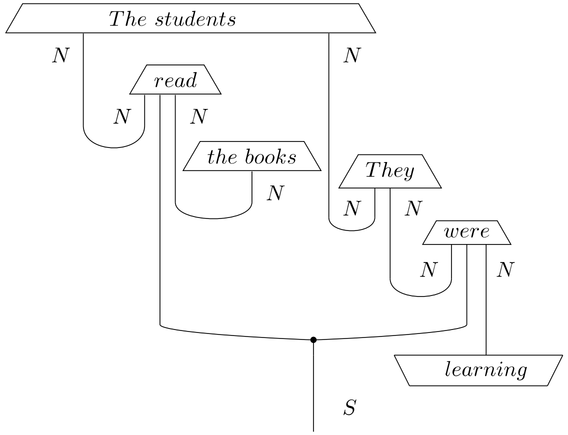
Quantum Algorithms for Compositional Natural Language Processing, https://arxiv.org/abs/1608.01406
Quantum Language Processing, https://arxiv.org/abs/1902.05162
Foundations for Near-Term Quantum Natural Language Processing, https://arxiv.org/abs/2012.03755

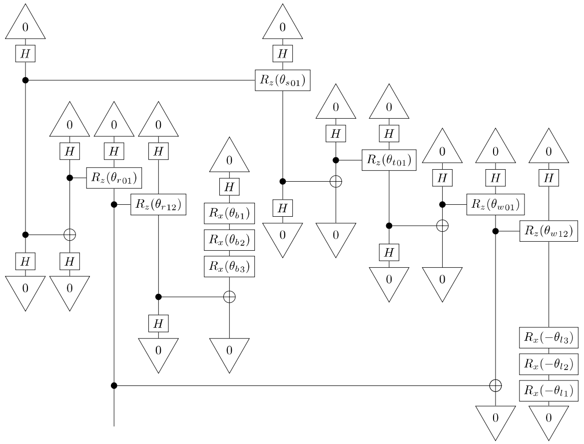
String Diagrams to PQCs

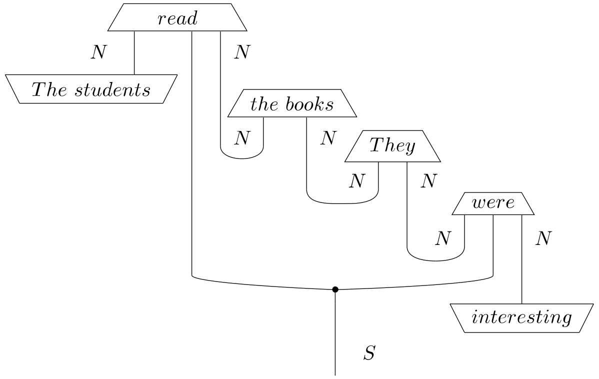
Pipeline: ansatze

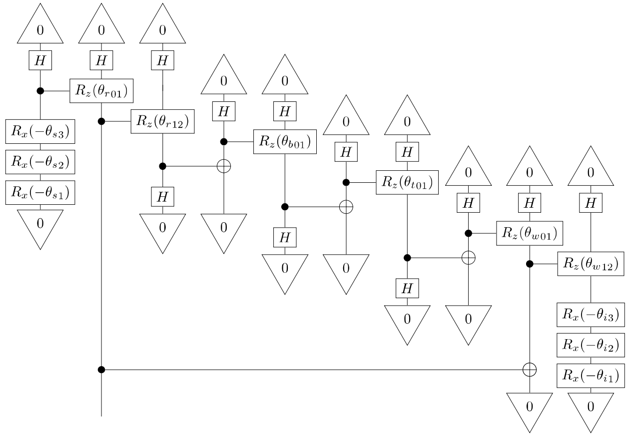


Translation from string diagrams to PQCs using a single-layer IQP ansatz, where each grammatical type is mapped to a 1-qubit space.









Data Collection

Generate Synthetic data

- We selected entries from the Definite Pronoun Resolution Dataset
  - excluded sentences containing proper nouns and negation
  - gave preference to shorter sentences
  - process resulted in a total of 10 entries

(1) The **students** read the **books**. **They** were learning.

(2) The **students** read the **books**. **They** were interesting.

(3) The **storm** delayed the **flight**. **It** was very dangerous.

(4) The **storm** delayed the **flight**. **It** was going over the ocean.

Resolving Complex Cases of Definite Pronouns: The Winograd Schema Challenge, https://aclanthology.org/D12-1071 (Rahman & Ng, EMNLP 2012)

Data Collection

Grammatical templates

(1) The **students** read the **books**. **They** were learning.

(2) The **students** read the **books**. **They** were interesting.

{verb, phrasal verb, verb phrase} {adjective, gerund phrase}

- The students **{verb, phrasal verb, verb phrase}** the books. They were **{adjective, gerund phrase}**.
- The **{adjective}** students **{verb, phrasal verb, verb phrase}** the books. They were **{adjective, gerund phrase}.**
- The students **{verb, phrasal verb, verb phrase}** the **{adjective}** books. They were **{adjective, gerund phrase}**.
- The **{adjective}** students **{verb, phrasal verb, verb phrase}** the **{adjective}** books. They were **{adjective, gerund phrase}**.

Prompt: Provide alternative sentences by replacing the words or phrases inside the brackets for each statement. Utilize different **verbs, phrasal verbs, verb phrases, adjectives, or gerund phrases** to create new sentences based on the given structure. Ensure that the pronoun '**they**' in the second sentence refers to '**students**' / Ensure that the pronoun '**they**' in the second sentence refers to '**books**'

Data Collection

Filtering

- We eliminated incorrect referent sentences, duplicate examples
  - kept well-formed sentences that have meaningful content
  - picked 300 to 400 examples for each entry
  - generated over 8 million diverse combinations
- 16,400 examples, 200,000 words, with 1,214 unique vocabulary.
  - 10,496 pairs (~60%) for training
  - 2,624 pairs (~20%) for validation
  - 3,280 pairs (~20%) for testing

- The **students** researched the **books**. **They** were seeking knowledge. **1**
- The ambitious **students** explored the **books**. **They** were boring. **0**
- The determined **students** read the humorous **books**. **They** were visually stunning. **1**
- The creative **students** discussed the ancient **books**. **They** were written by experts. **0**

Hybrid Quantum-Classical Training

Supervised Binary Classification

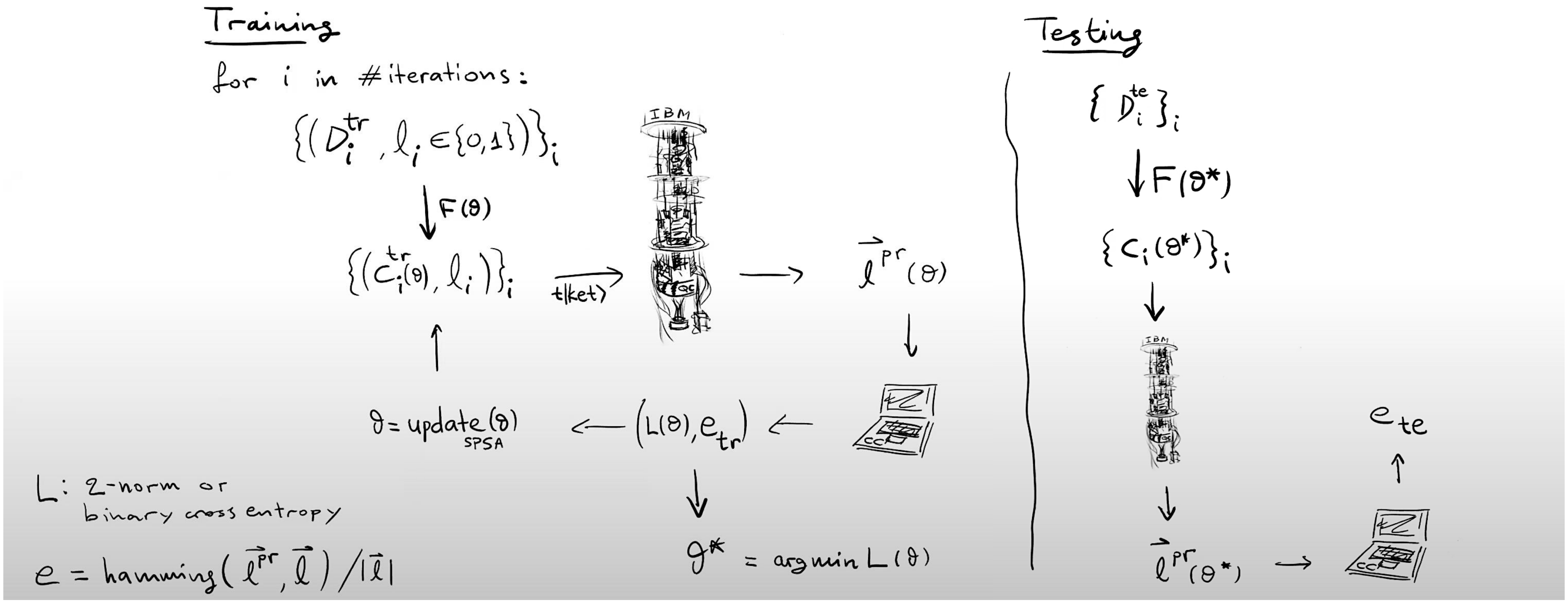
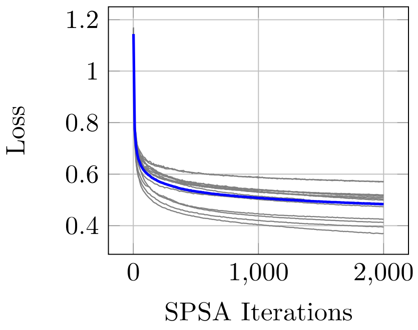


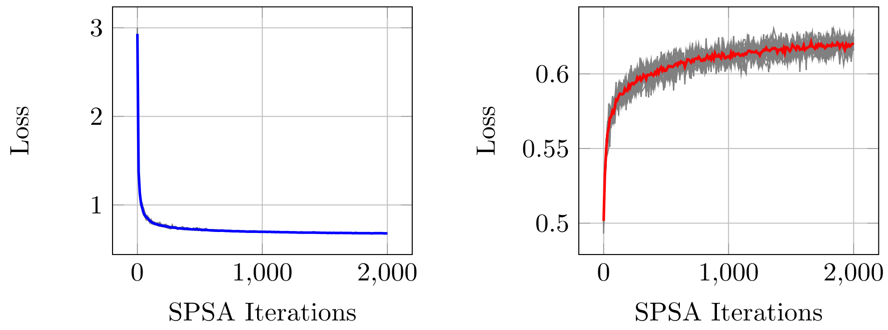
Image source: https://youtu.be/YskhOD_Gpvc

Hybrid Quantum-Classical Training

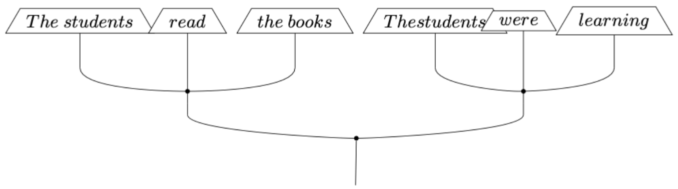
Results

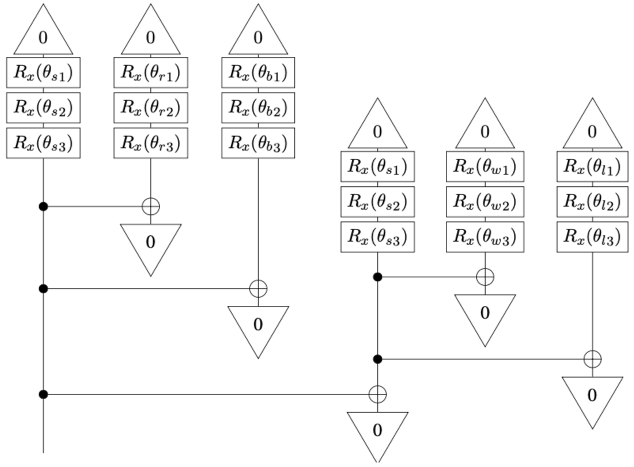


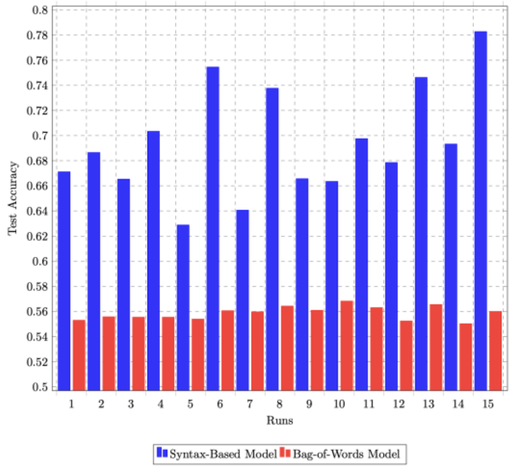
Syntax-Based Model



Bag-of-Words Model



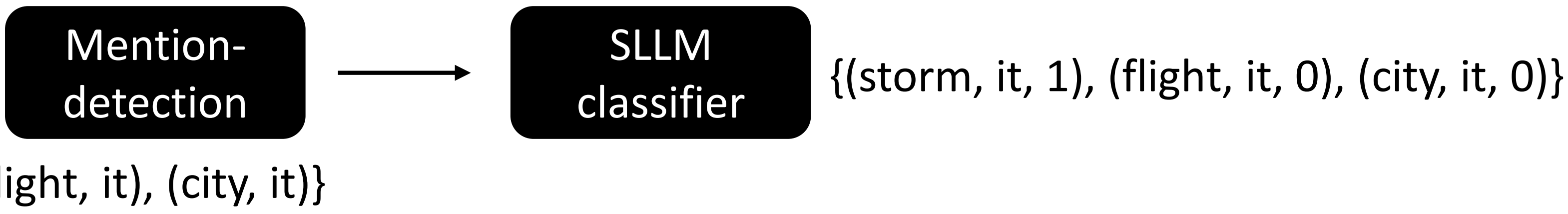




QuantumCoref

End-to-End System

Input: The destructive storm delayed the flight to the city. It was causing flash floods.



Model	F1 Score
SVM Full	0.914
SVM Add	0.821

Model	F1 Score
CoreNLP	0.563
Neural Coreference	0.585
SpanBERT	**0.927**
QuantumCoref	0.872

Model	F1 Score
CoreNLP + QuantumCoref	0.930
Neural Coreference + QuantumCoref	0.946
SpanBERT+ QuantumCoref	**0.986**

- Fine-tuned **SpanBERT**, unsurprisingly, it achieved an F1 score of **0.998**.
- Experiments were not specifically aimed at showcasing *quantum advantage* over classical systems.
- Our aim was to demonstrate the capabilities of our quantum-based approach, which also offers transparency.
- Fine-tuned **SpanBERT** = 366 million parameters > **QuantumCoref** = 2693 parameters.

Thank you !