An Introduction
to
Quantum Natural Language Processing
(QNLP)

Part 4 :

Quantum Natural Language Processing

Outline of the lecture

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❖ Introducing Quantum Natural Language Processing

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- ❖ Introducing Quantum Natural Language Processing
- ❖ Distributional Word Representation

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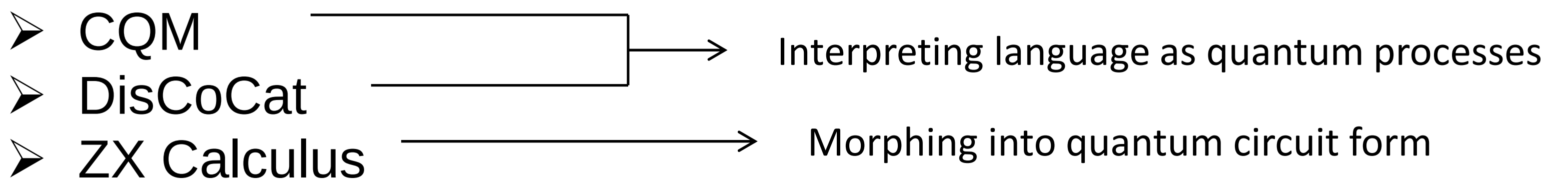

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Interpreting language as quantum processes

Morphing into quantum circuit form

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Introduction to QNLP Concludes

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- Inner product can be used to identify distances between different words which represents the closeness of meaning of the words

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- Diagrammatically, the composition is denoted by Cups & Caps, meaning that grammar compositionality is entanglement of words together!

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Adjective & Noun

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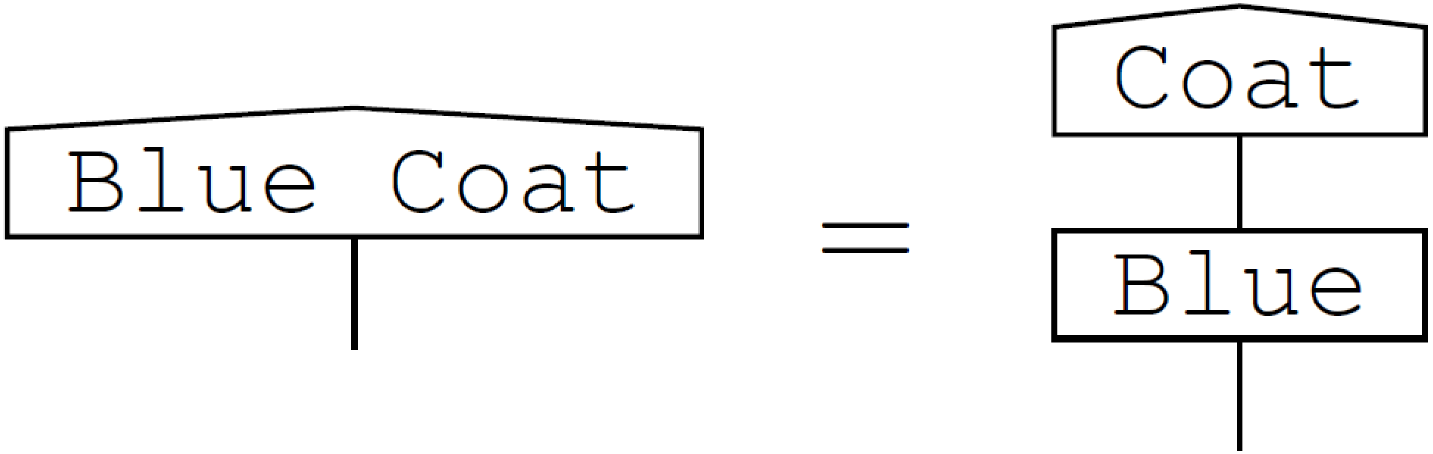

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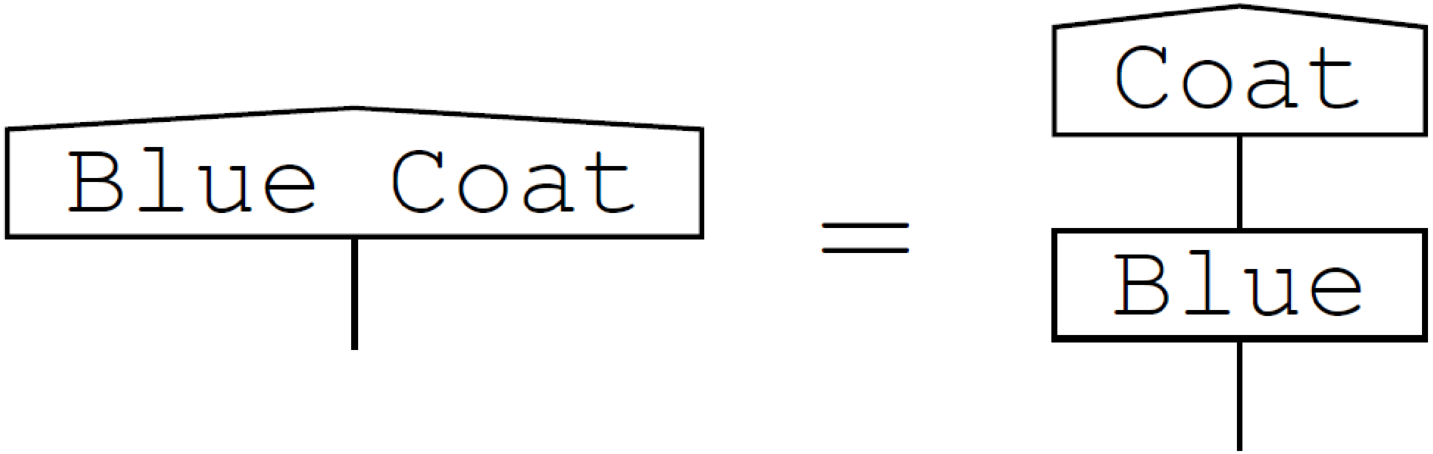

Applying an adjective ‘Blue’ to a noun ‘Coat’ is like applying a process to ‘Coat’

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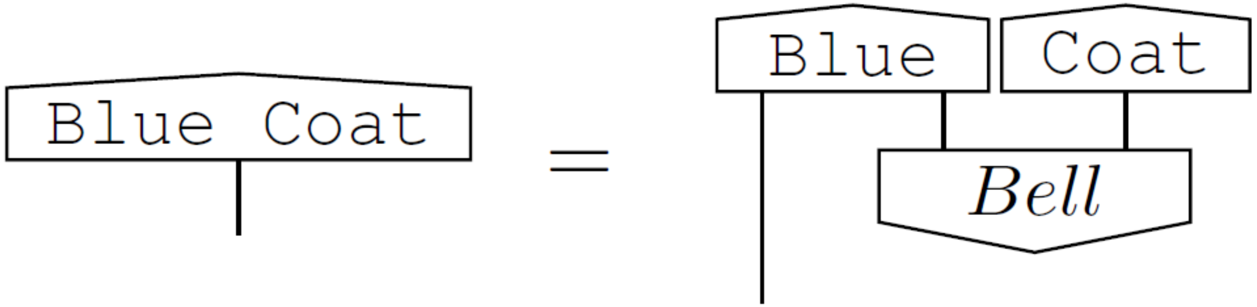

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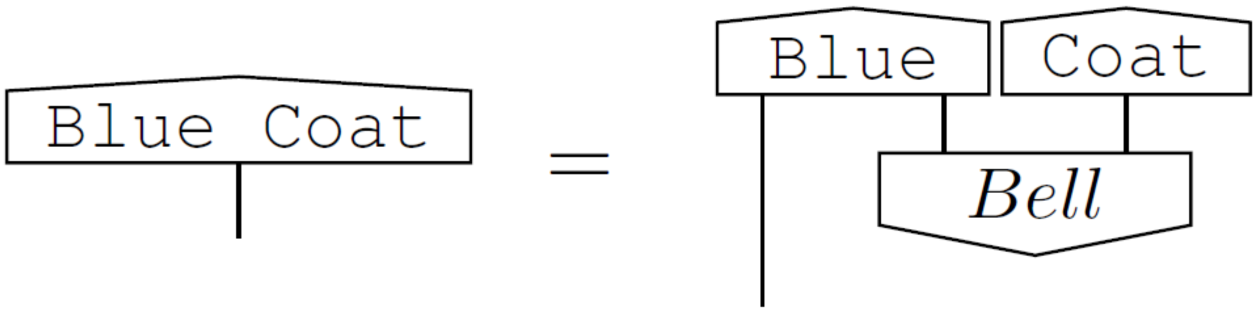

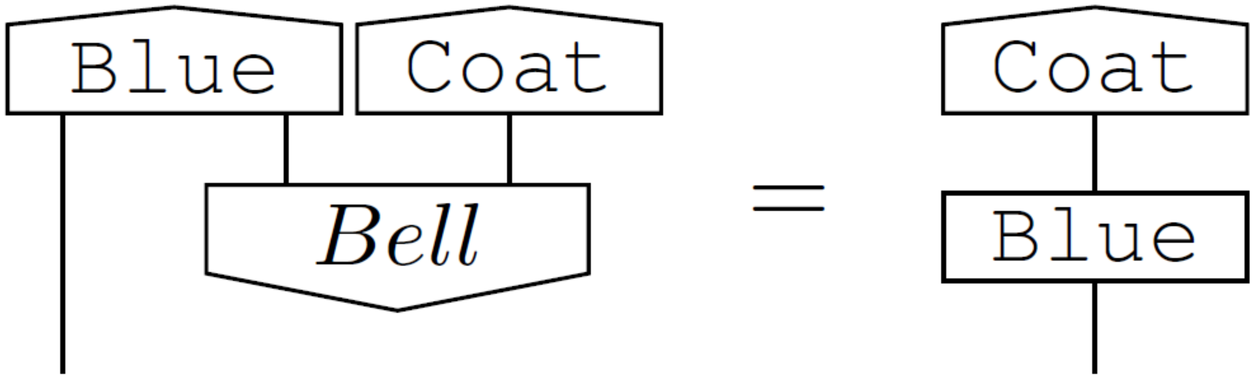

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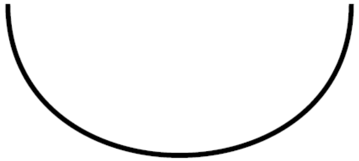

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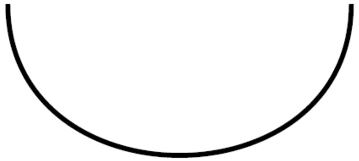
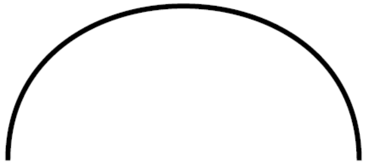
$\langle Bell| =$ 

$|Bell\rangle =$ 

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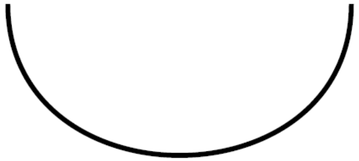
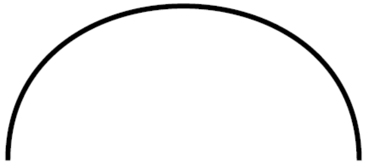
$\langle Bell| =$ 

$|Bell\rangle =$ 

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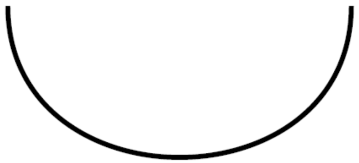
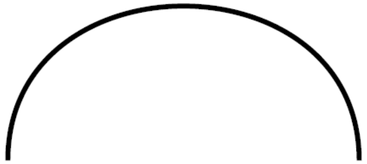
$\langle Bell| =$ 

$|Bell\rangle =$ 

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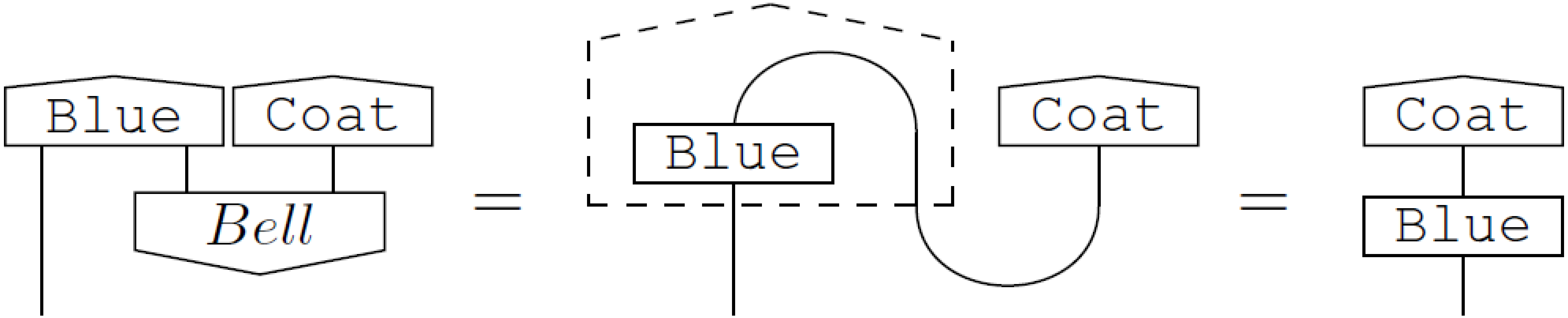

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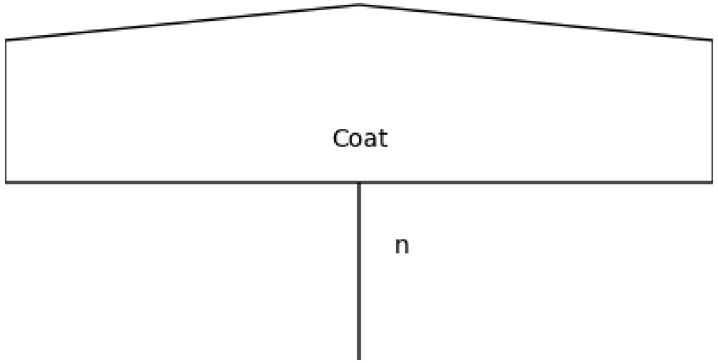

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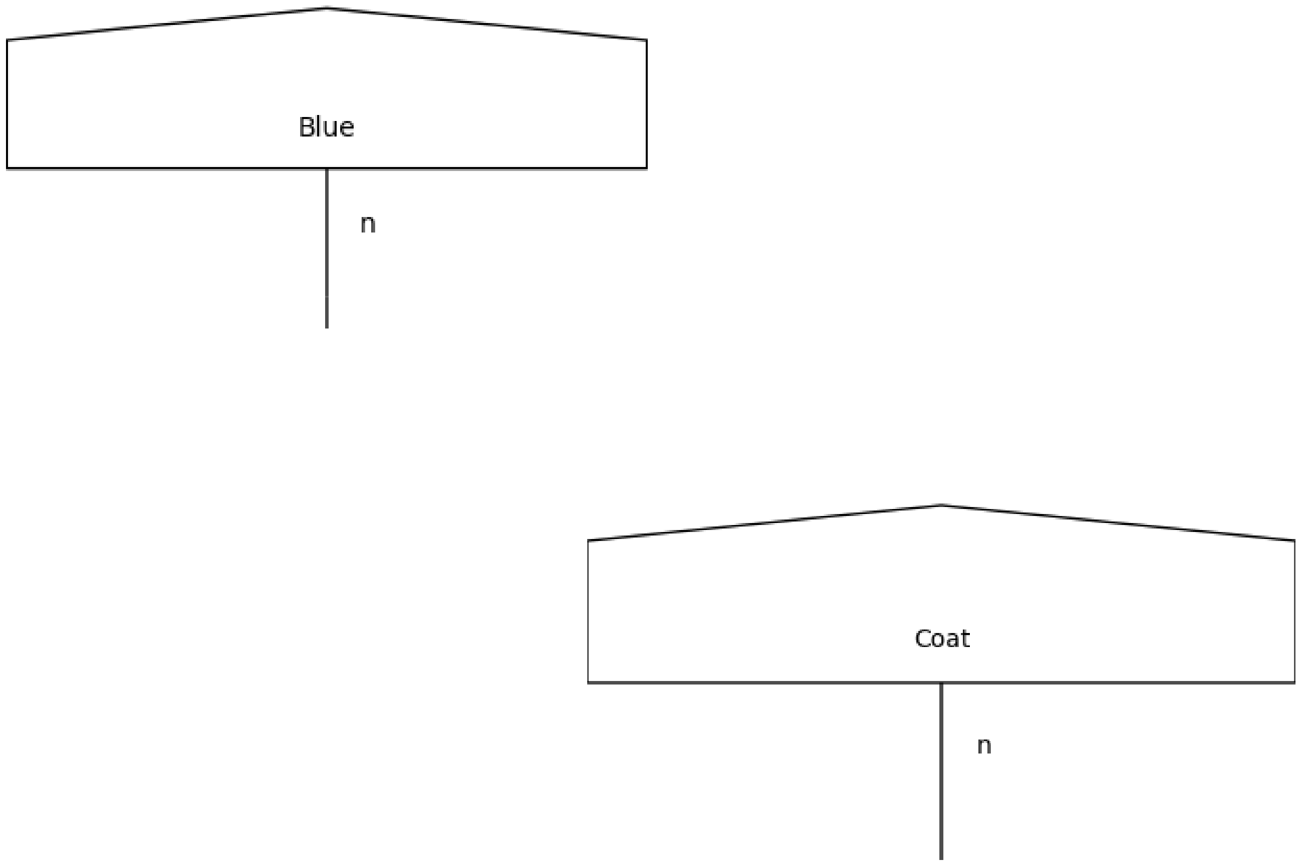

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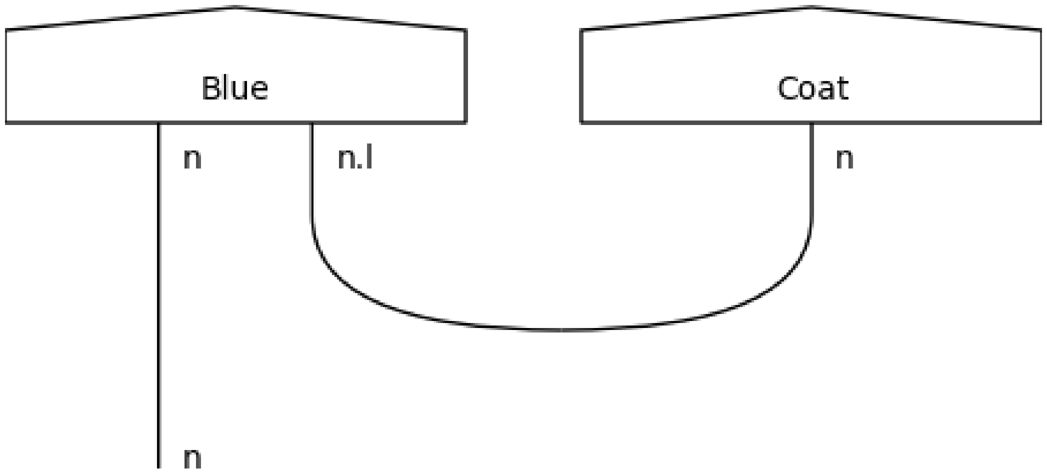

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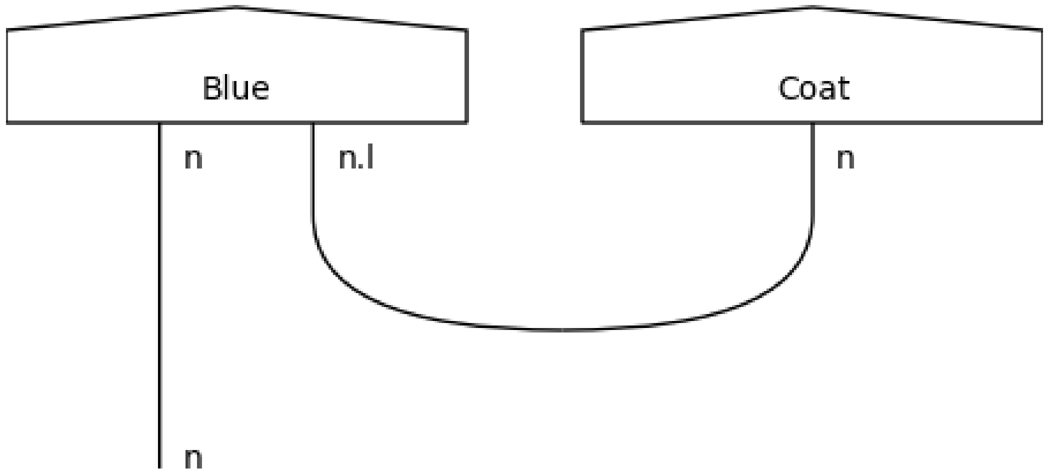

- ➢ For the noun ‘Coat’, the adjective ‘Blue’ is on the left, therefore, the cup connects n to n^l

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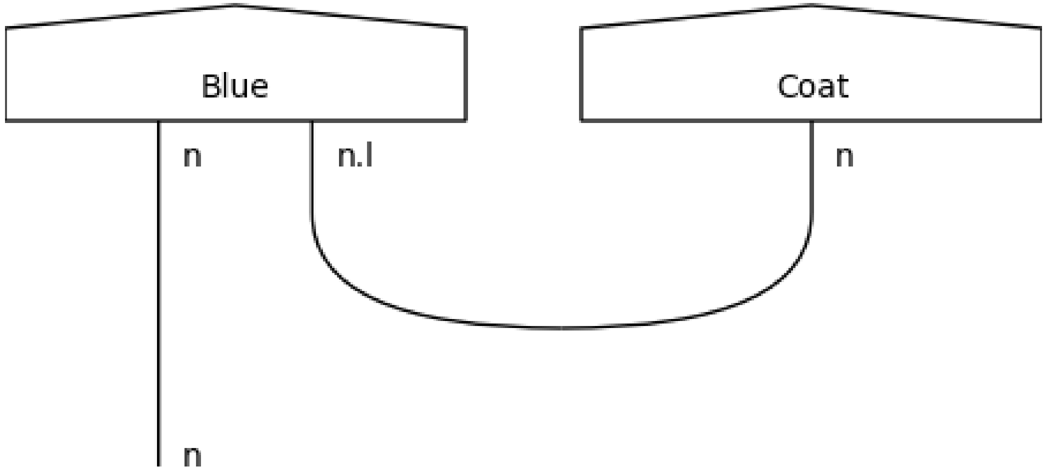

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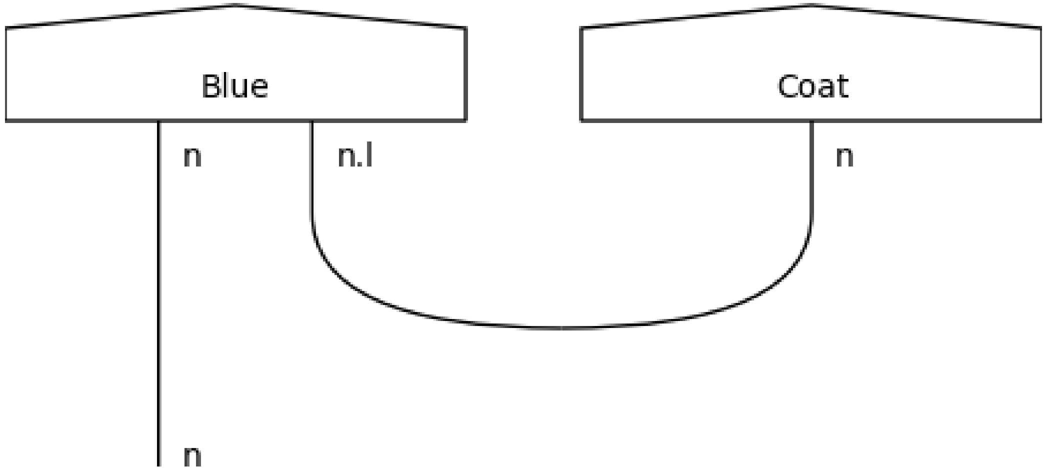

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QNLP Basics

Adjective & Noun

Adjective & Noun Concludes

Subject-Verb-Object Sentence

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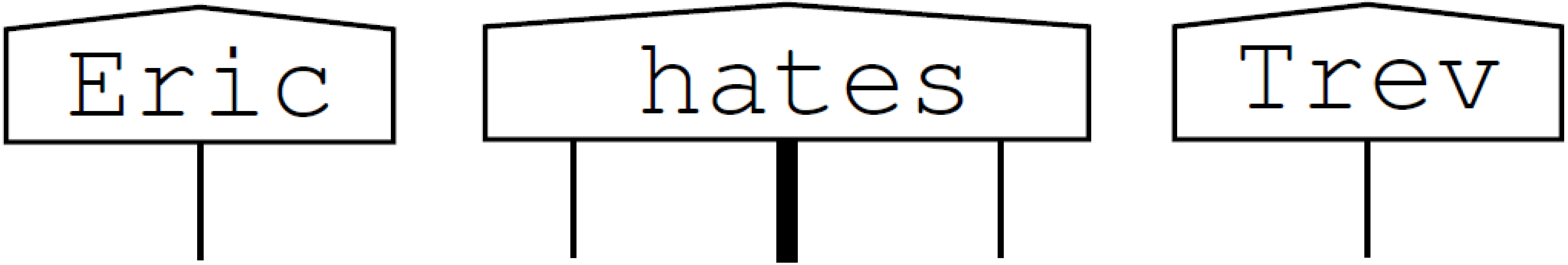

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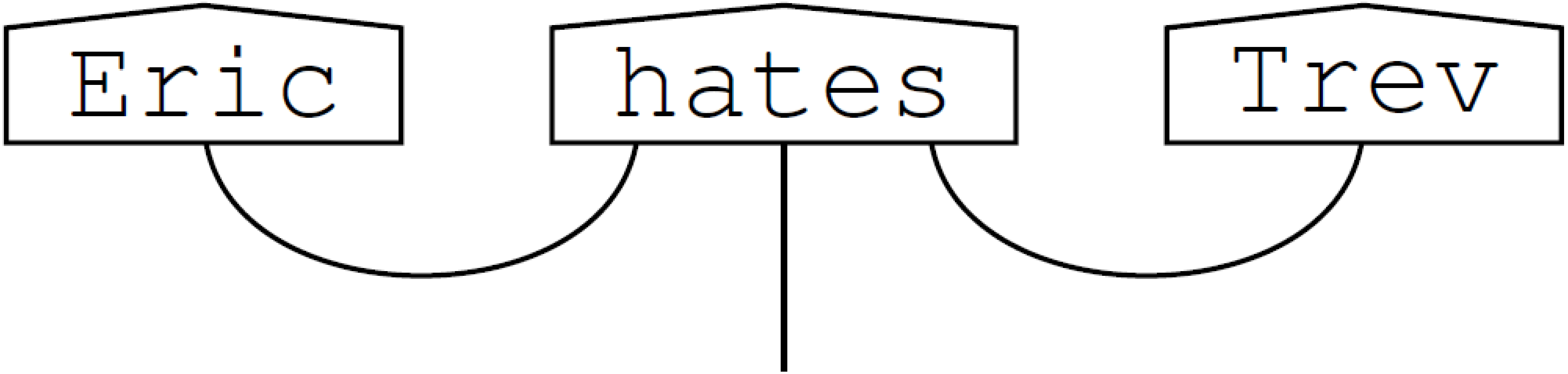

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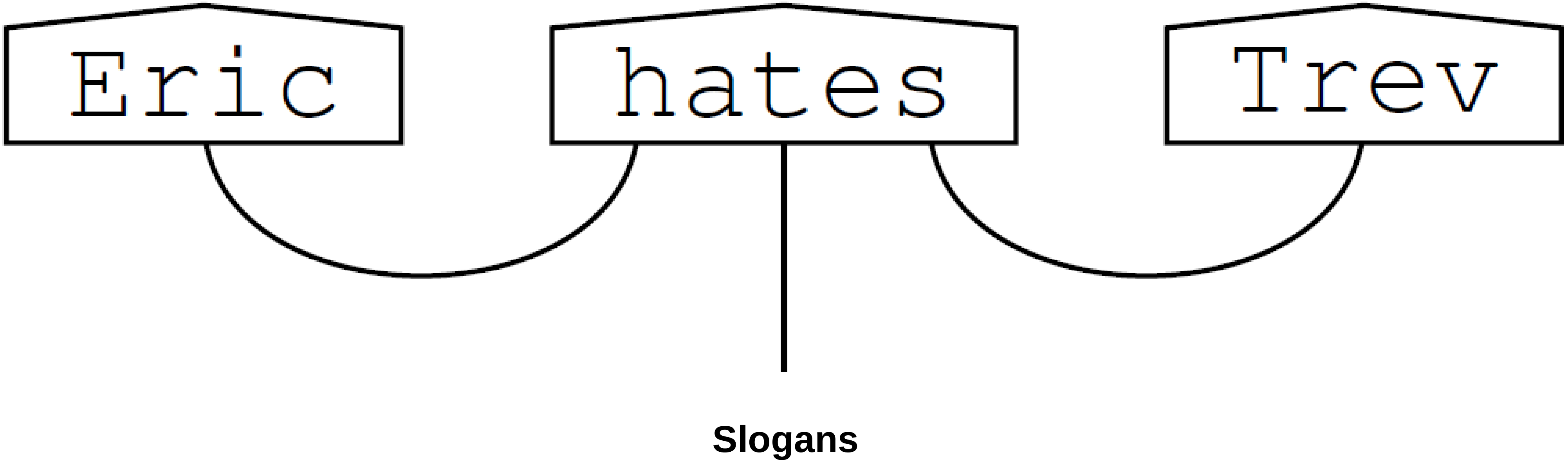

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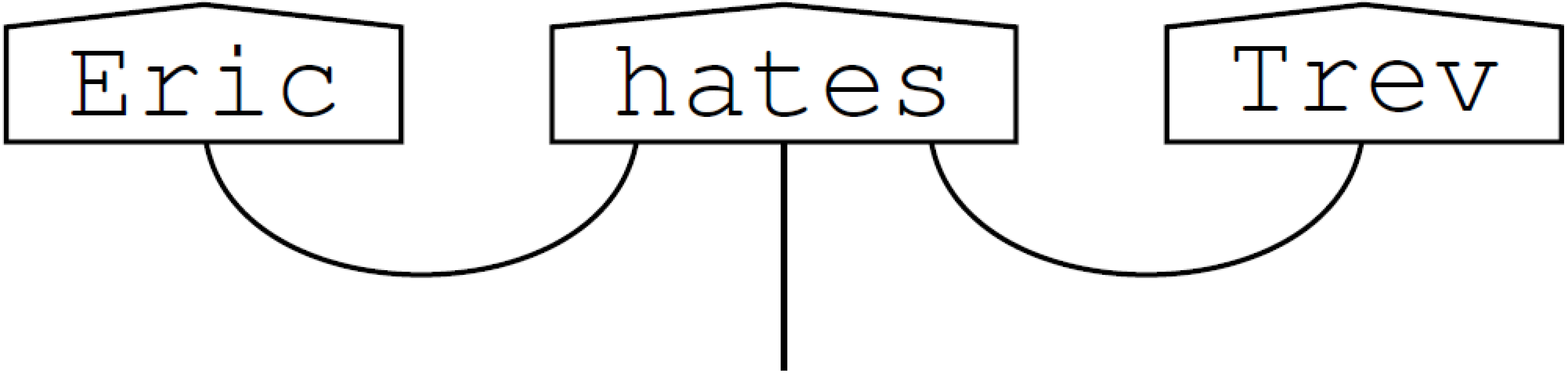

Slogans

A Sentence is a process which alters the meaning of its inhabitants (words)

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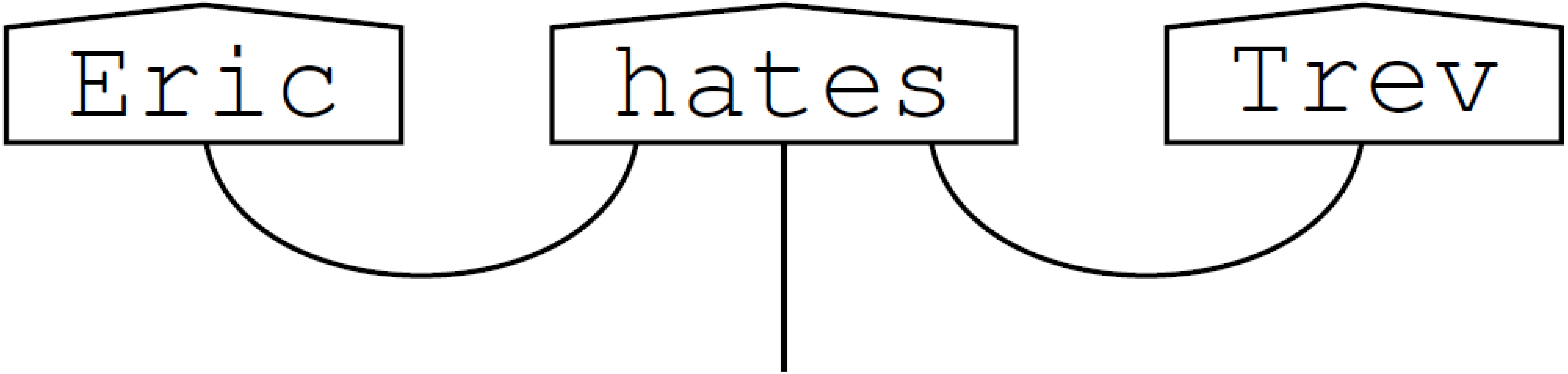

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Grammar is what mediates the flow of meanings between words

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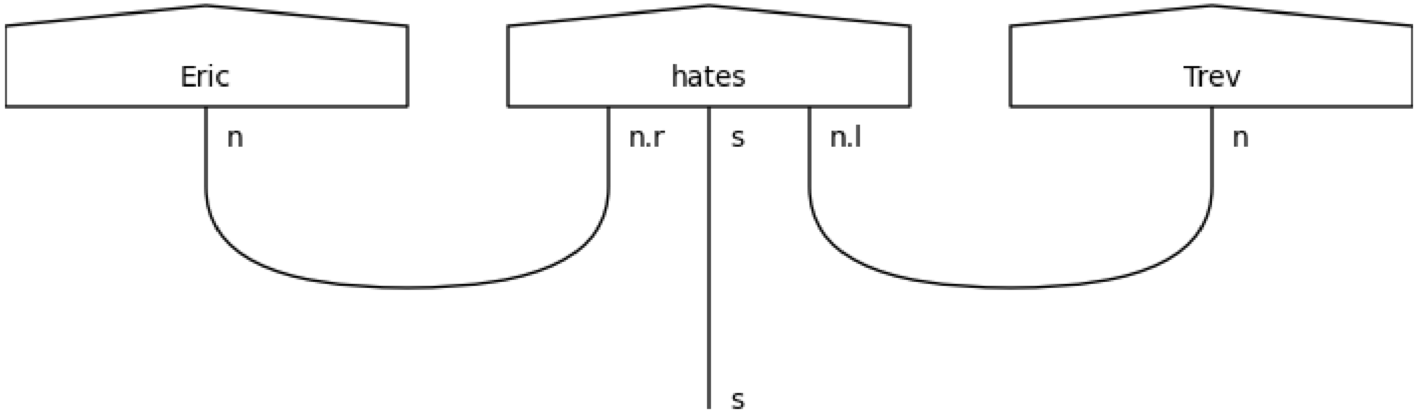

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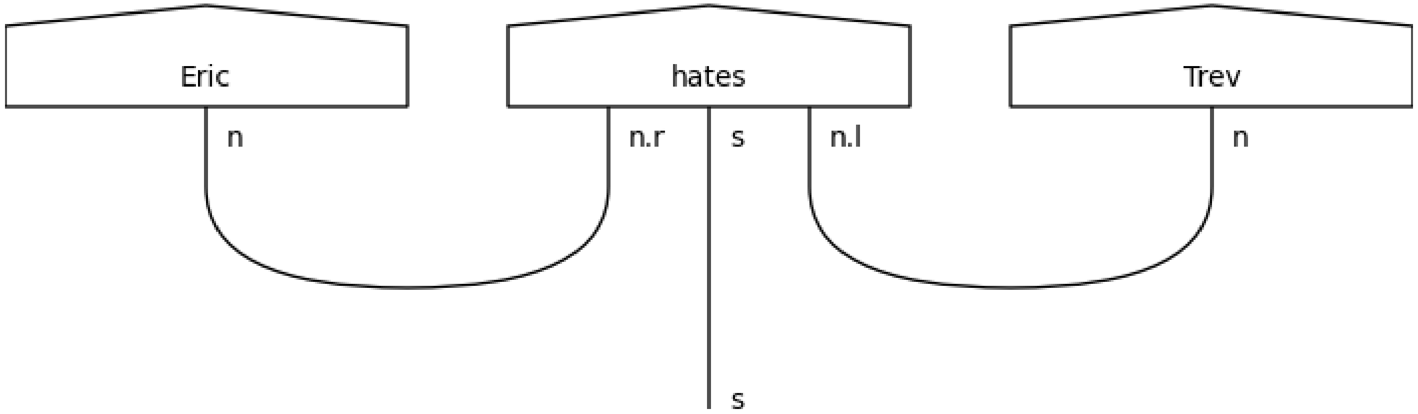

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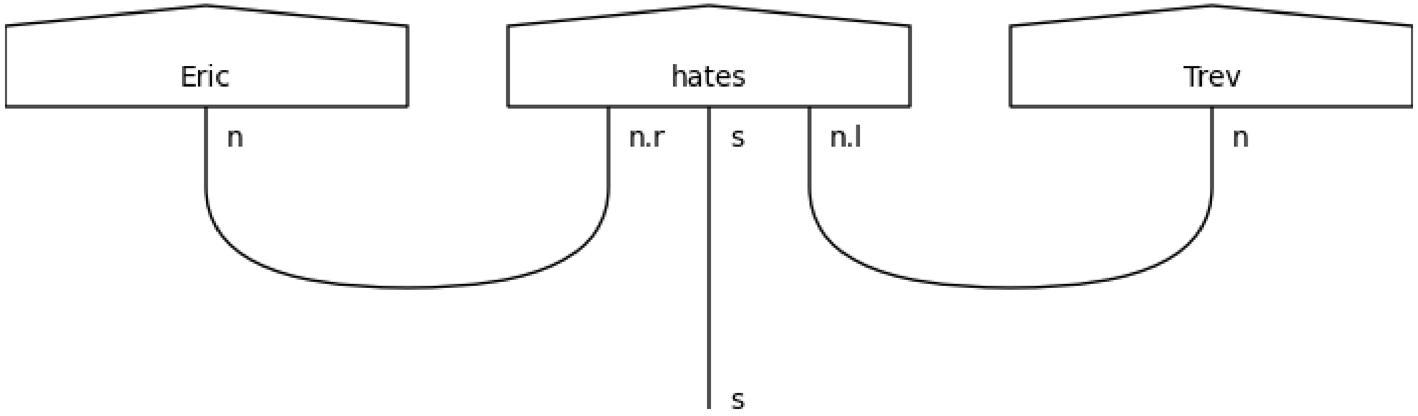

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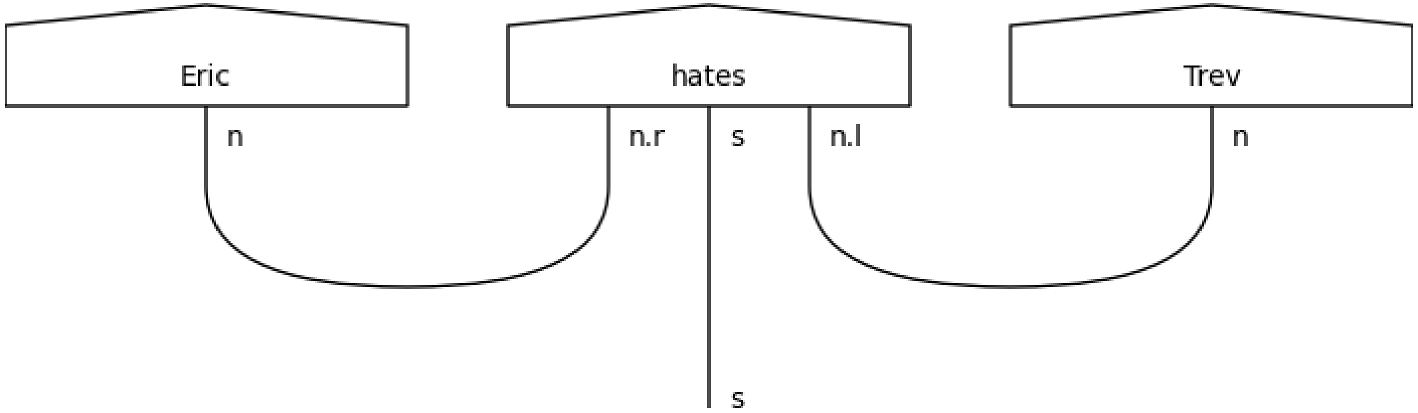

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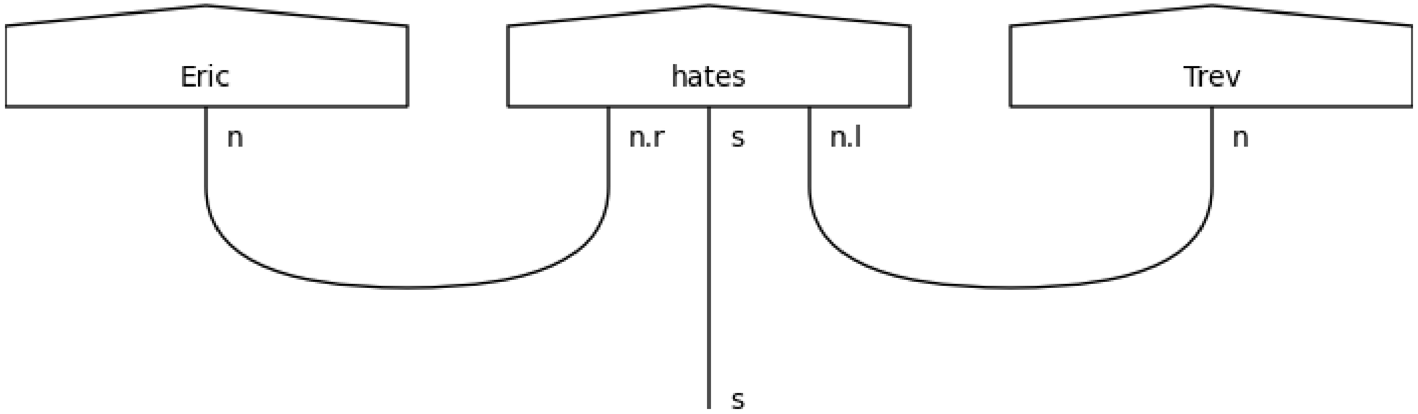

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Subject-Verb-Object Sentence Concludes

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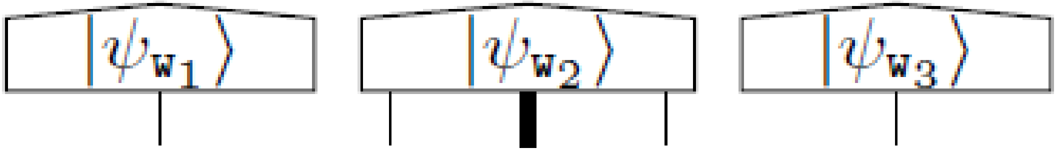

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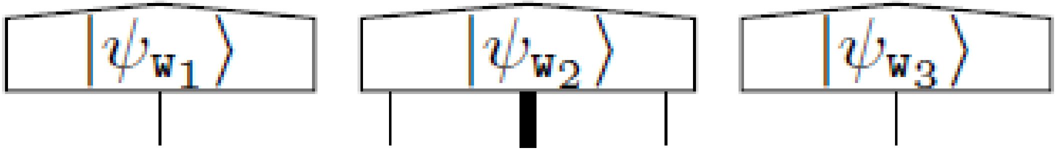

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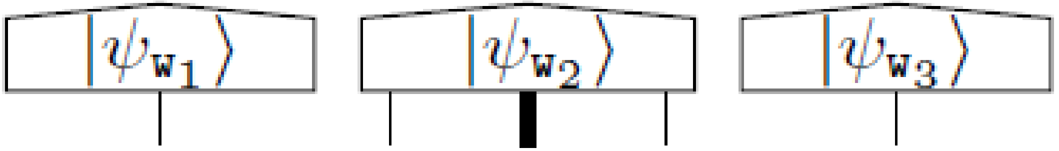

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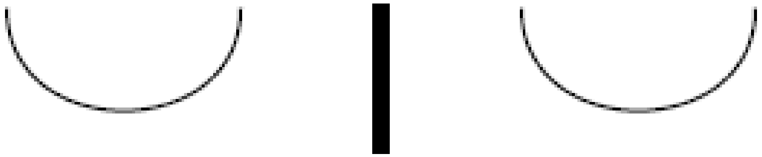

DisCoCat Algorithm

- Replace cups with bell states and all the straight wires with Identities

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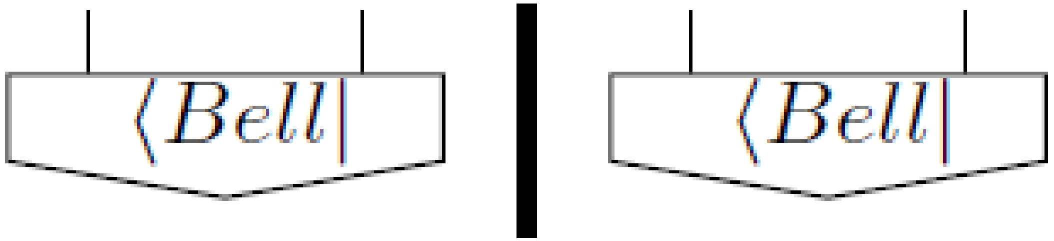

DisCoCat Algorithm

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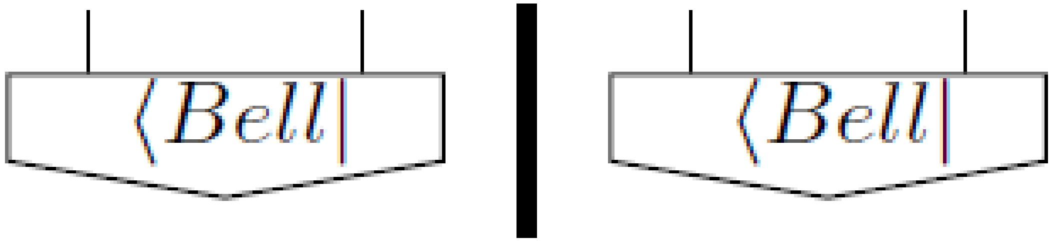

- ❖ Apply this quantum process to the meaning of the parts

DisCoCat Algorithm

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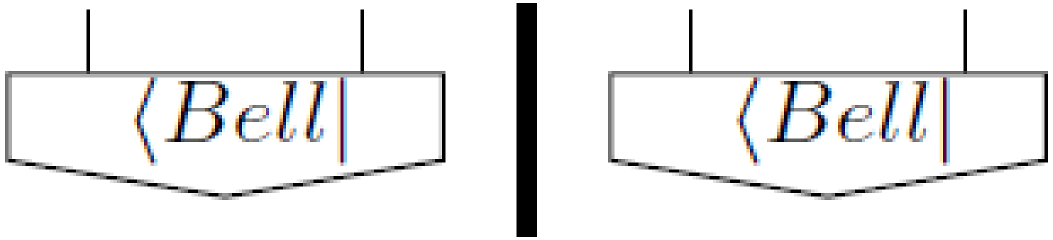

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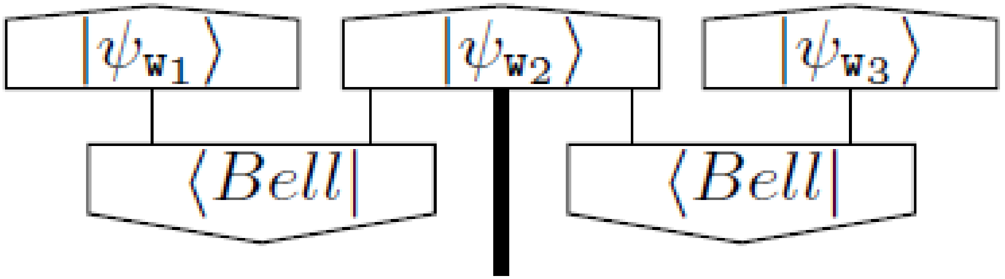

DisCoCat Algorithm

DisCoCat Algorithm Concludes

String Diagrams into ZX Quantum Circuits

String Diagrams into ZX Quantum Circuits

- String diagrams generated by the DisCoCat Algorithm needs to be converted into quantum circuit in order to run them on a quantum computer

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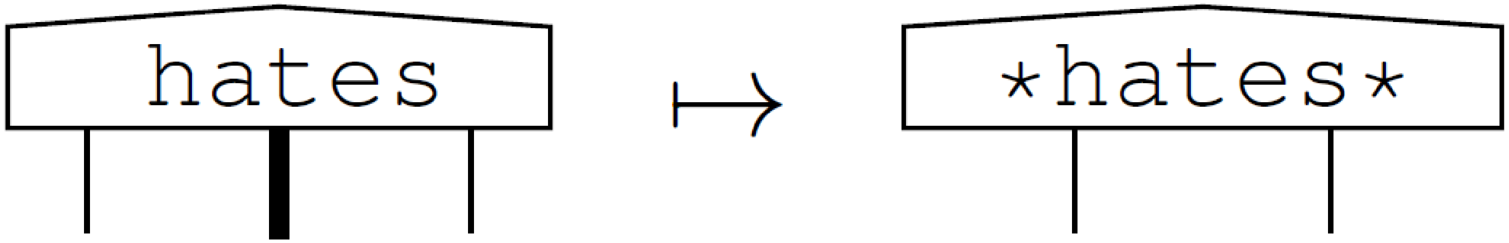

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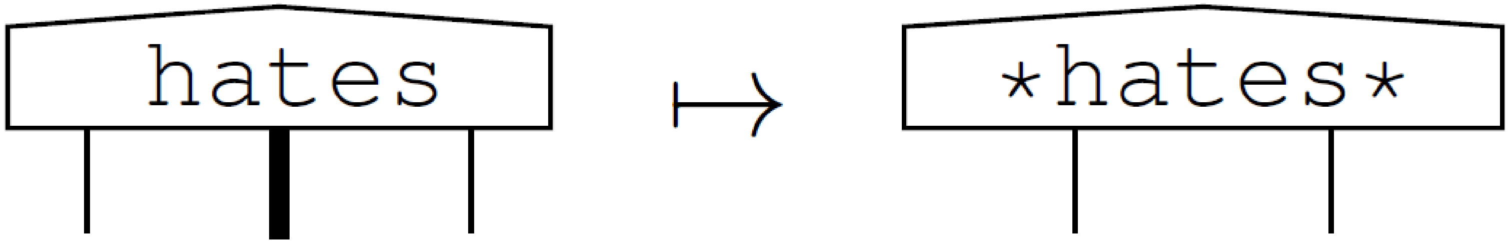

- ZX calculus and Spiders is used to modify the internal wiring of the system.

String Diagrams into ZX Quantum Circuits

- The internal wiring is shown in the following figure which has two Z spiders in them

String Diagrams into ZX Quantum Circuits

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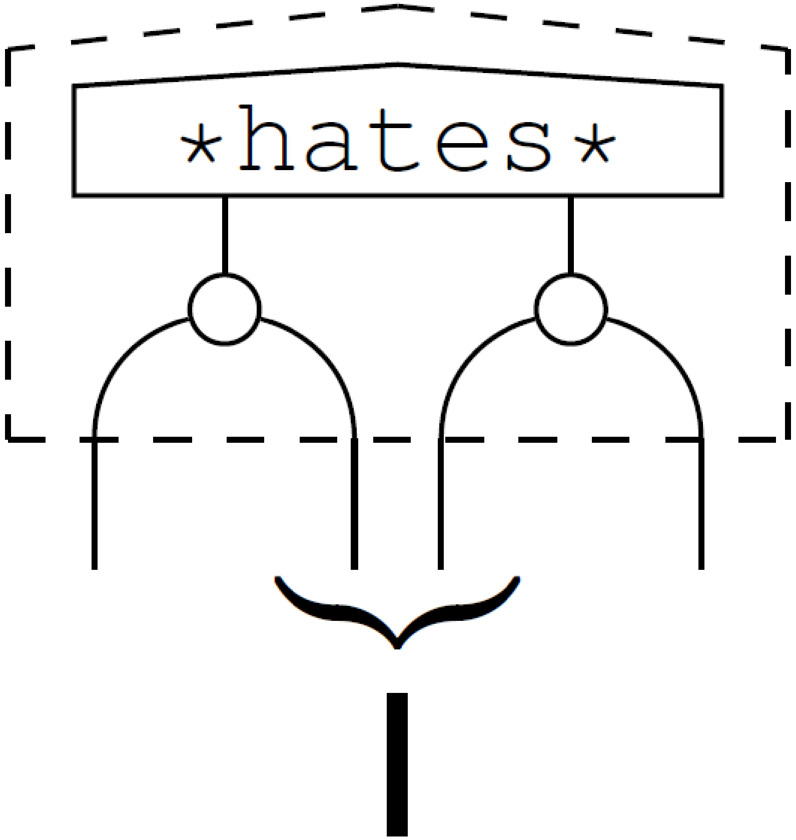

String Diagrams into ZX Quantum Circuits

- With the help of the internal wiring, we can start converting the string diagram into a ZX quantum circuit

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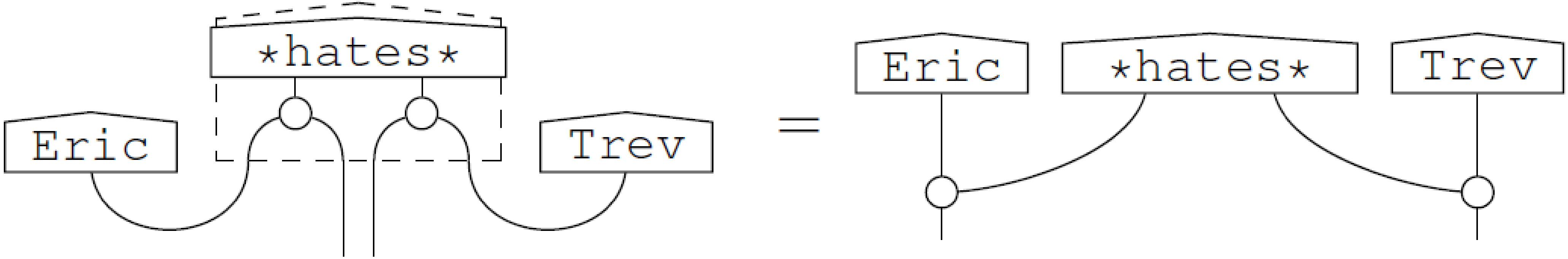

String Diagrams into ZX Quantum Circuits

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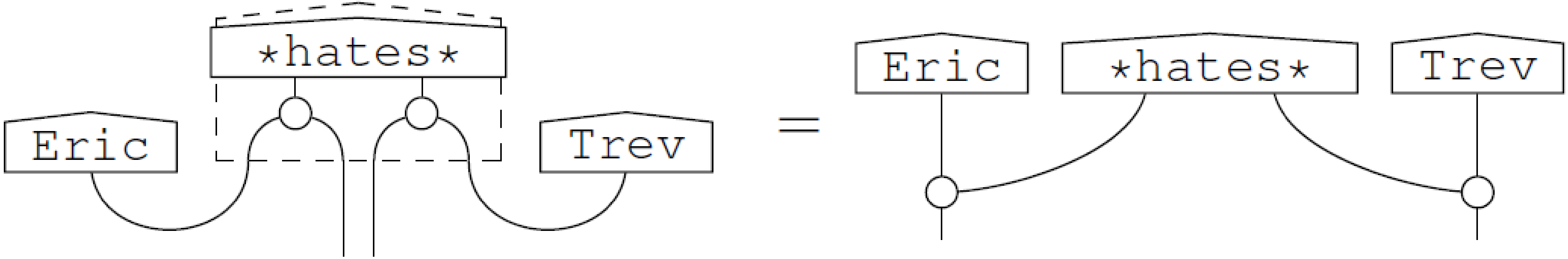

- The Z spiders are moved below the nouns – Eric & Trev and the extra wiring is removed

String Diagrams into ZX Quantum Circuits

- We can now use ZX calculus rewrite rules as shown below to convert the string diagram into a circuit

String Diagrams into ZX Quantum Circuits

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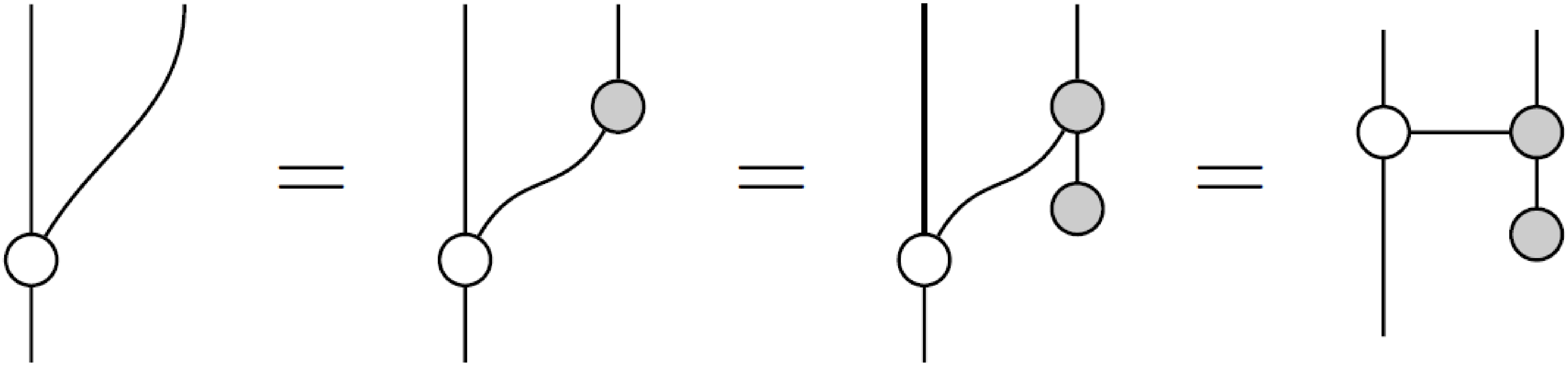

String Diagrams into ZX Quantum Circuits

- Two CNOT gates are being formed when the spiders are pulled out with ZX rules used and last two spiders (grey) are for post-selected measurement

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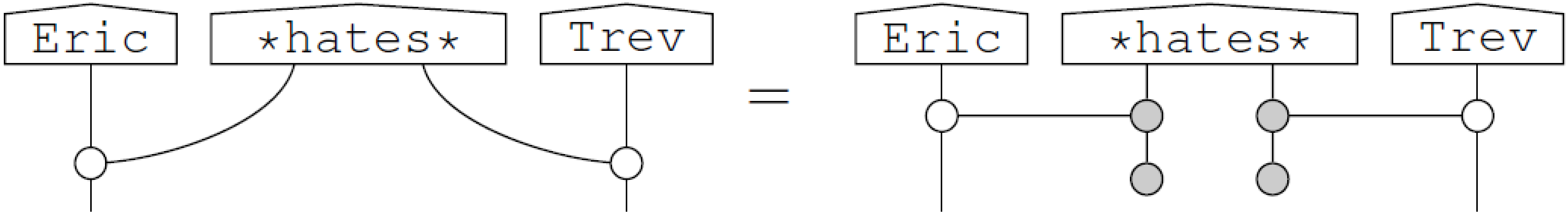

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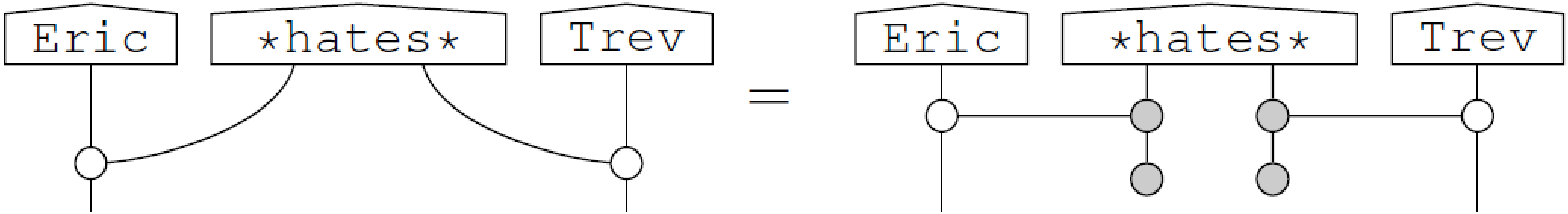

- For the complete quantum circuit between the subject and objects - Eric and Trev, the nouns are also converted into parameterized gates

String Diagrams into ZX Quantum Circuits

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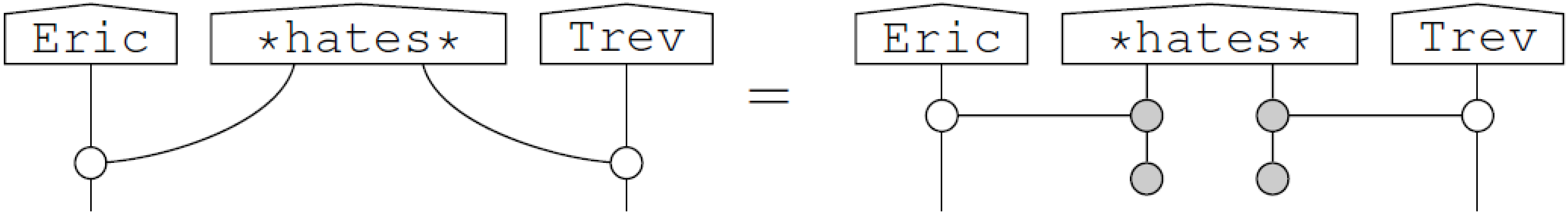
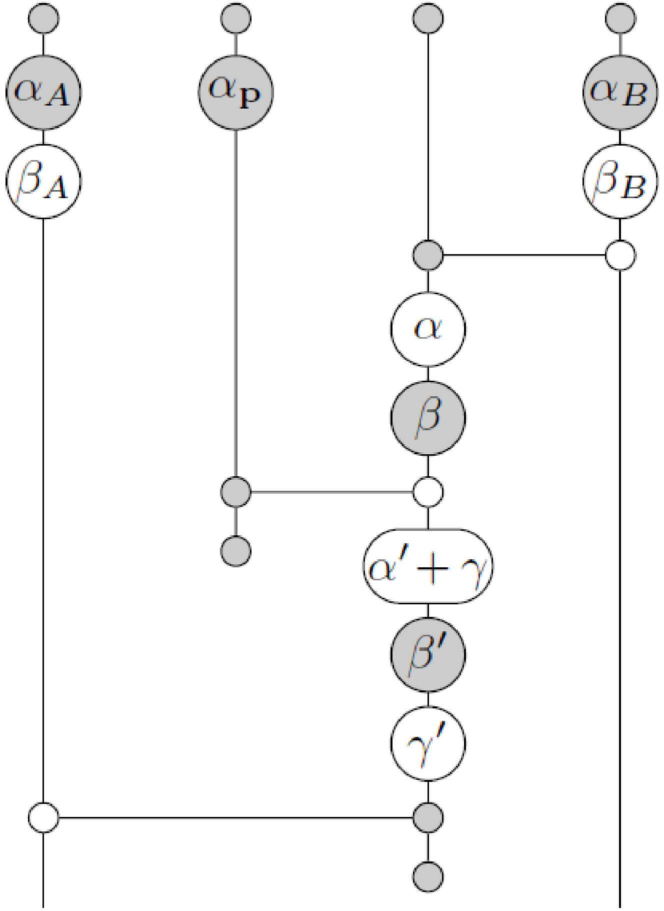


- ➢ For the complete quantum circuit between the subject and objects - Eric and Trev, the nouns are also converted into parameterized gates

- ➢ We represent verbs like ‘hates’ with ZX unitary gates and large space consisting of different verbs can be encoded by α, β, γ

String Diagrams into ZX Quantum Circuits



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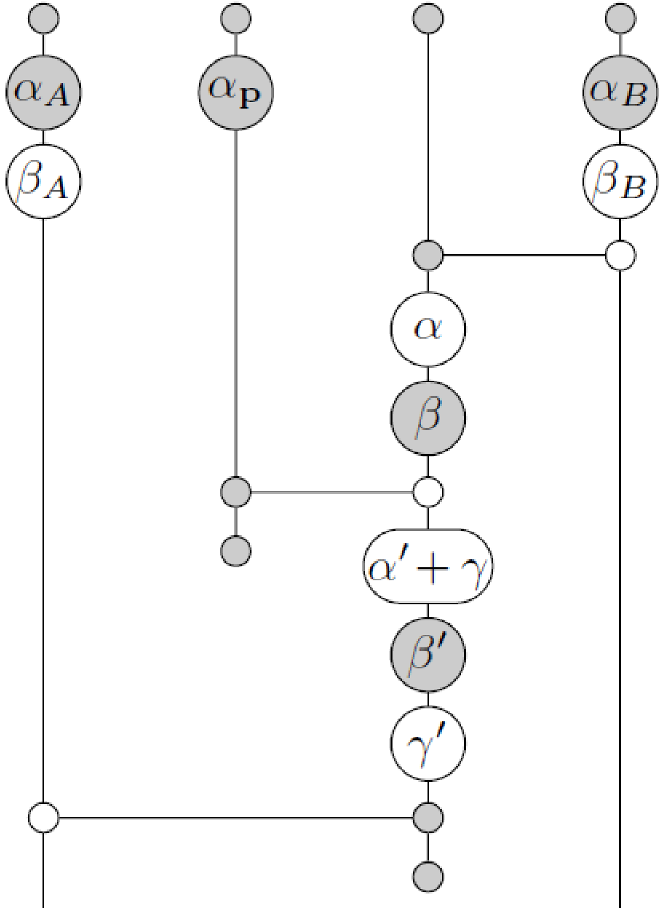
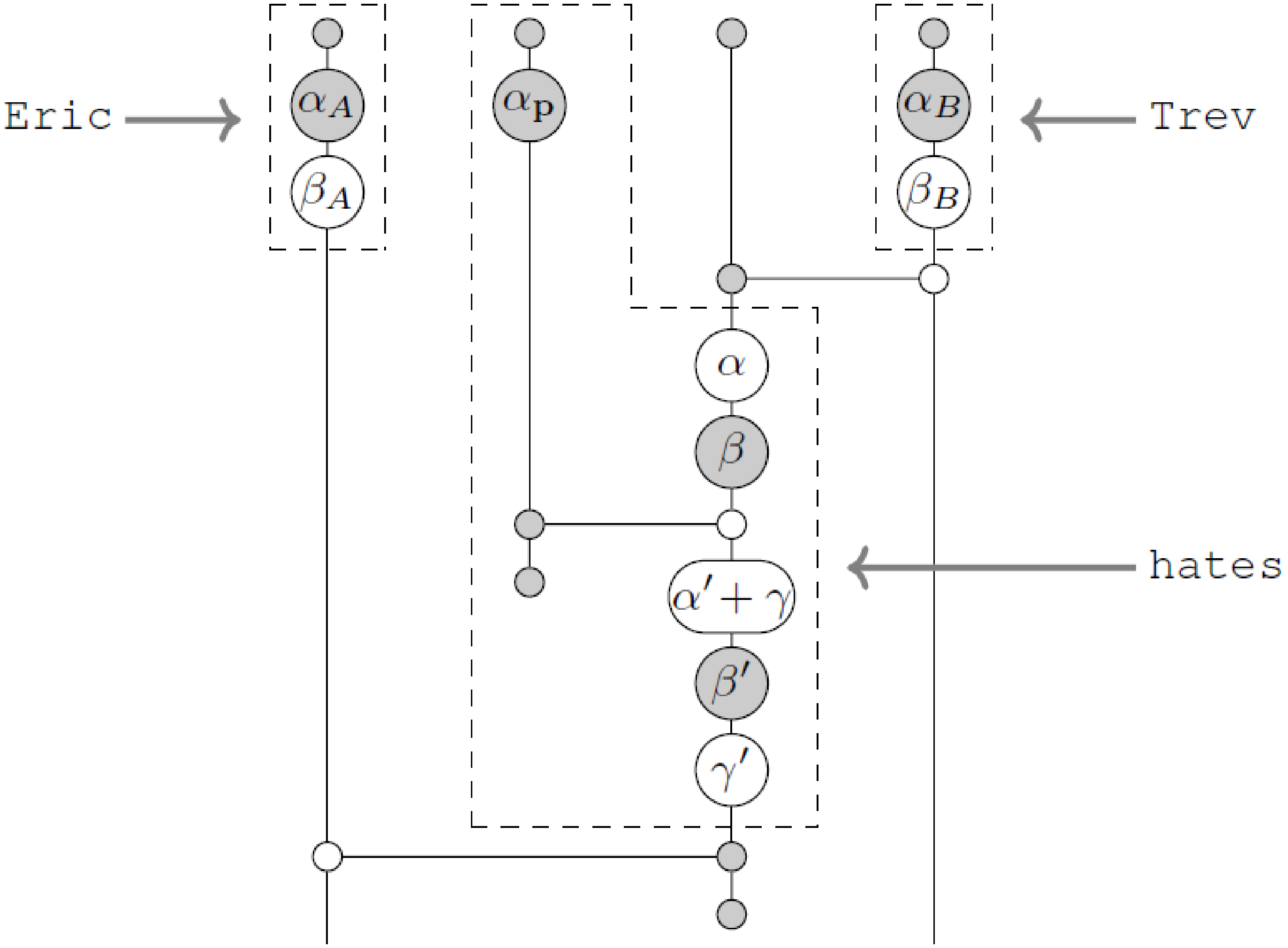


- ➢ We can depict different verbs by changing the values of α, β, γ

String Diagrams into ZX Quantum Circuits



String Diagrams into ZX Quantum Circuits

String Diagrams into ZX Quantum Circuits Concludes

Introducing λambeq & it’s Features

Introducing *λ*ambeq & it’s Features

- ❖ Released by Cambridge Quantum on October 13th, 2021

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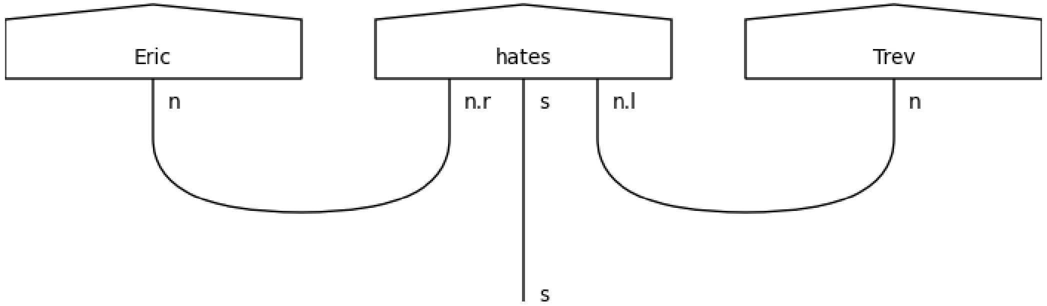

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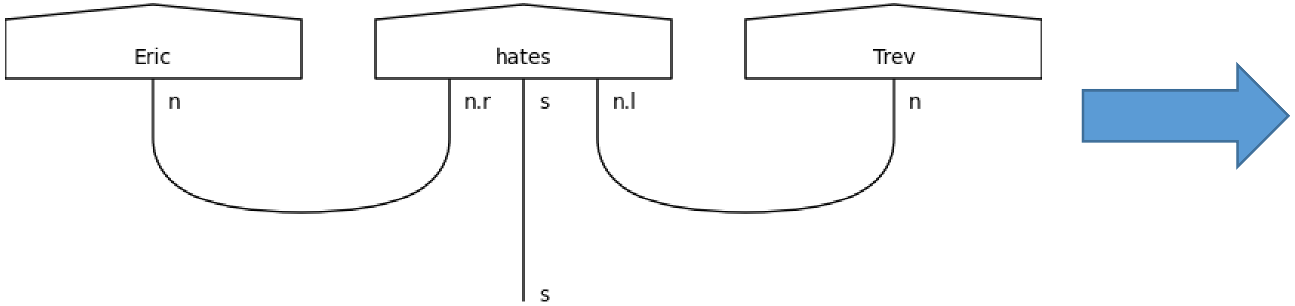

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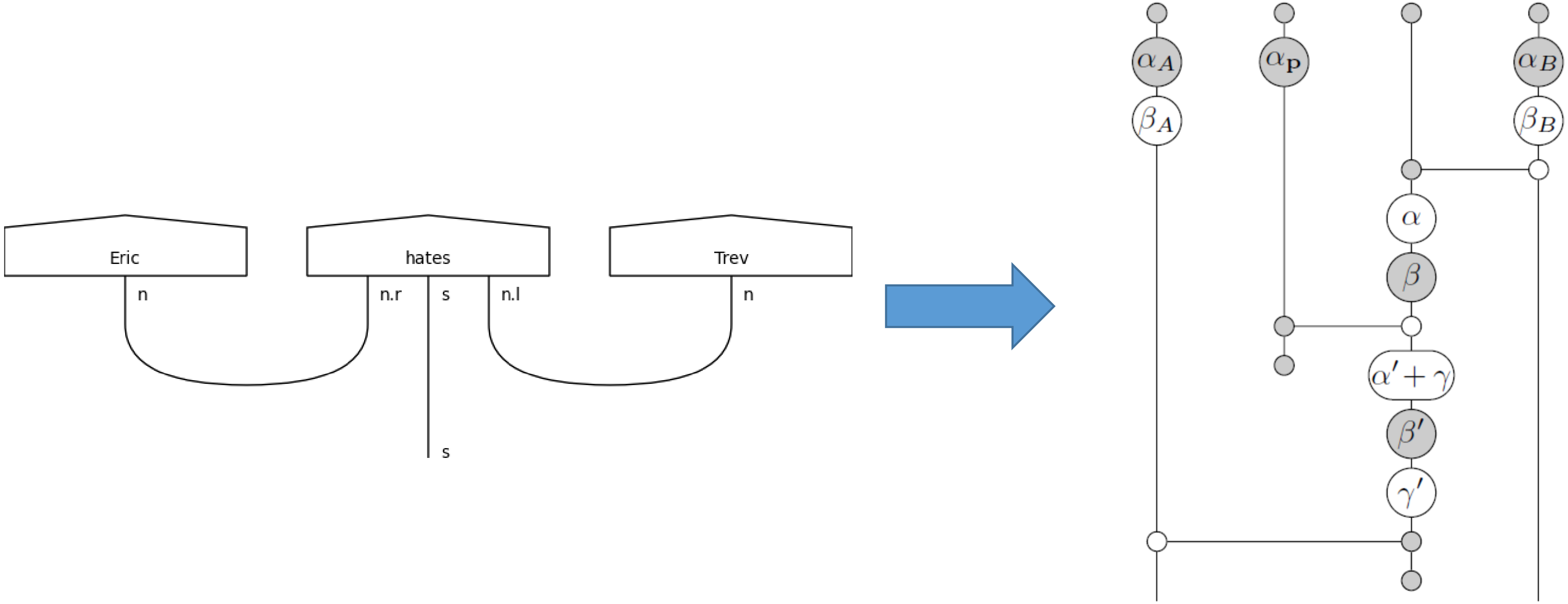

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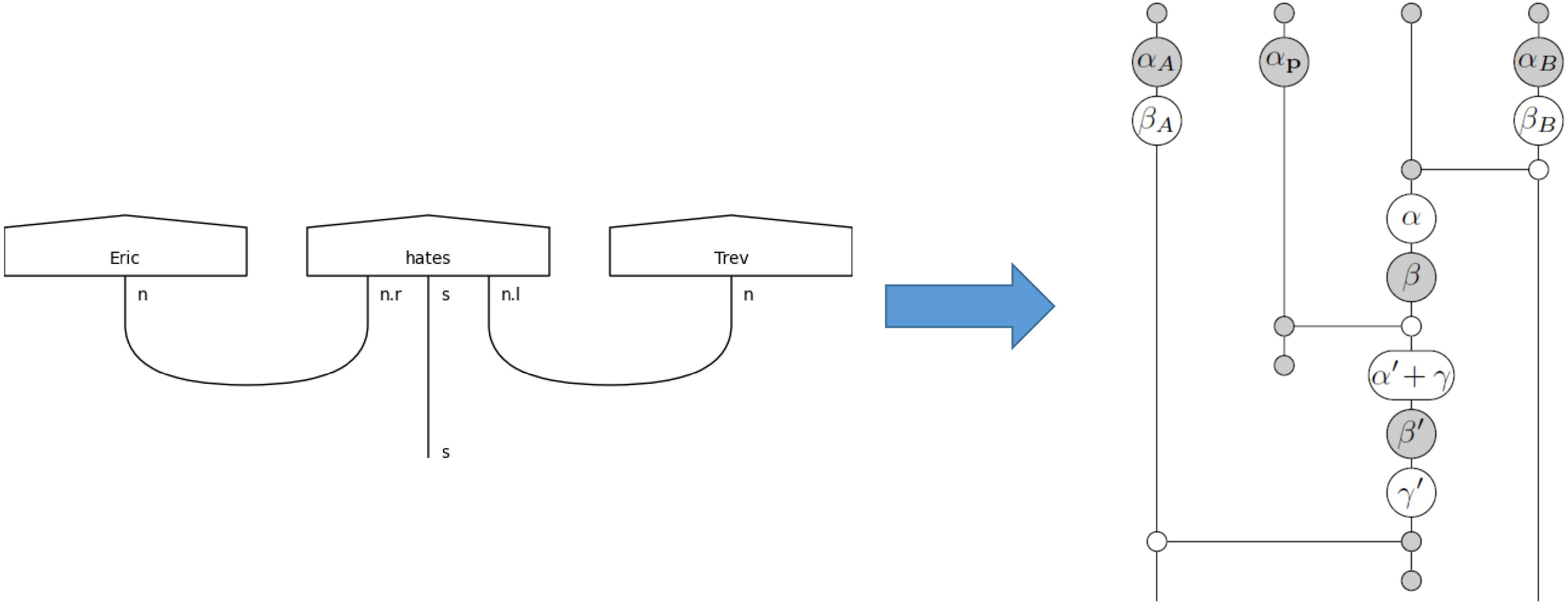

- ❖ Converts any sentence into quantum circuit based on compositional model (DisCoCat, Bag of Words & Word Sequence) and choices of ansatz (SpiderAnsatz, TensorAnsatz, IQPAnsatz)

Introducing *λ*ambeq & it’s Features

Features of *λ*ambeq

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- ❖ Modular – Independent modules providing flexibility

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- ❖ High level

Introducing λambeq & it’s Features

Features of λambeq

- ❖ Modular – Independent modules providing flexibility
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- ❖ High level
- ❖ Interoperability – Simple communication with other packages

Introducing λambeq & it’s Features

λambeq Architecture

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λambeq Architecture

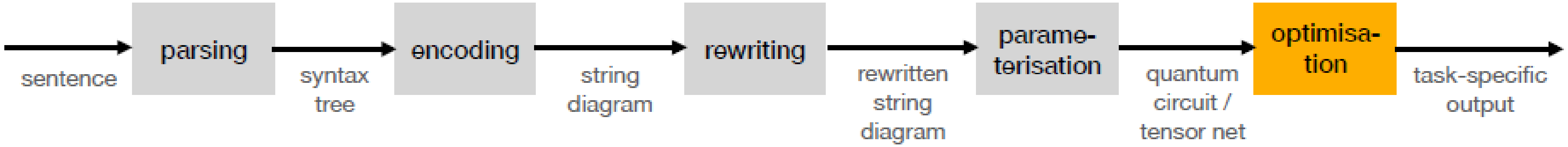
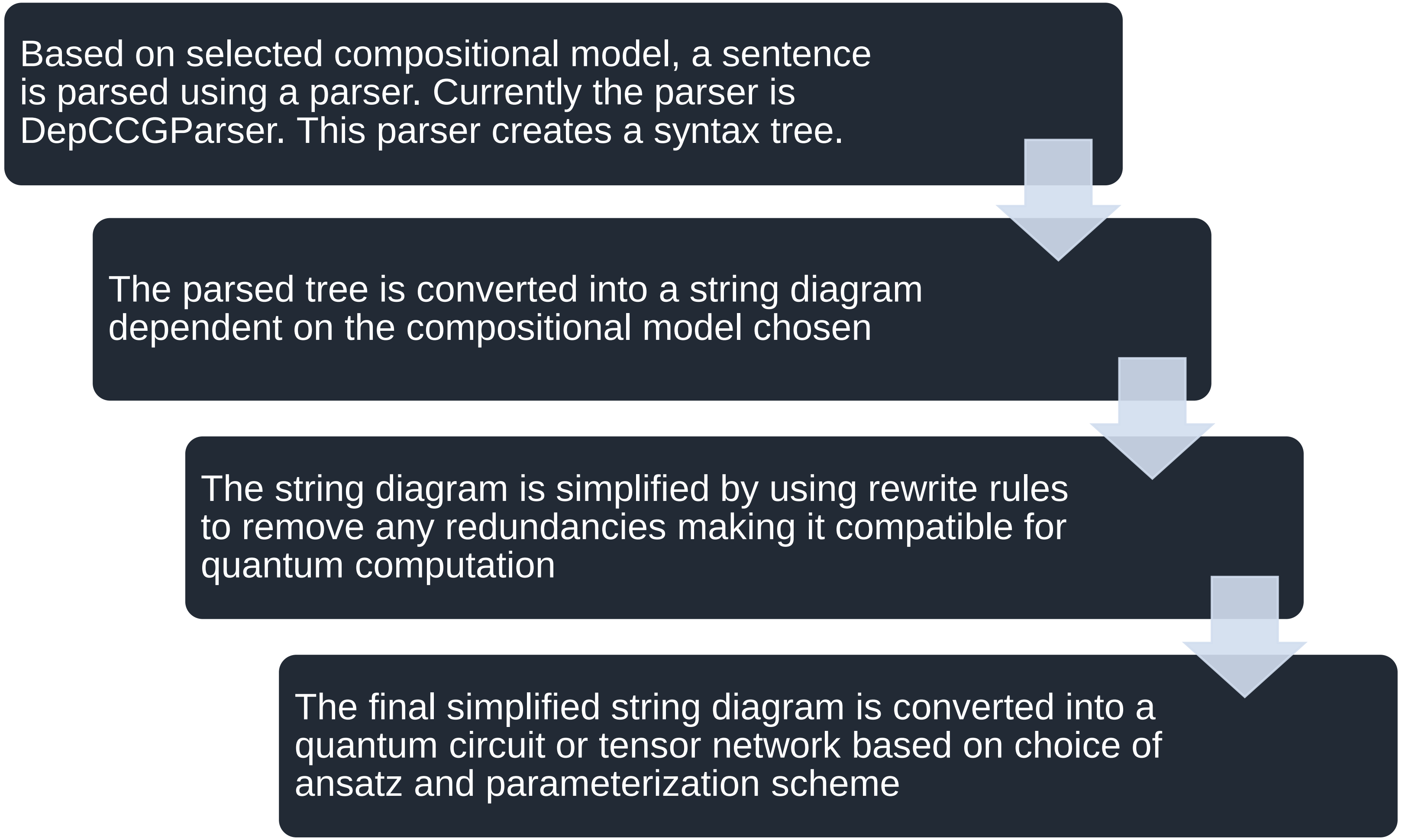


Image Source : lambeq: An Efficient High-Level Python Library for Quantum NLP

Introducing 𝜆ambeq & it’s Features

Working of lambeq :



Based on selected compositional model, a sentence is parsed using a parser. Currently the parser is DepCCGParser. This parser creates a syntax tree.

The parsed tree is converted into a string diagram dependent on the compositional model chosen

The string diagram is simplified by using rewrite rules to remove any redundancies making it compatible for quantum computation

The final simplified string diagram is converted into a quantum circuit or tensor network based on choice of ansatz and parameterization scheme

Introducing λambeq & it’s Features

Qiskit Circuit of ‘Eric hates Trev’

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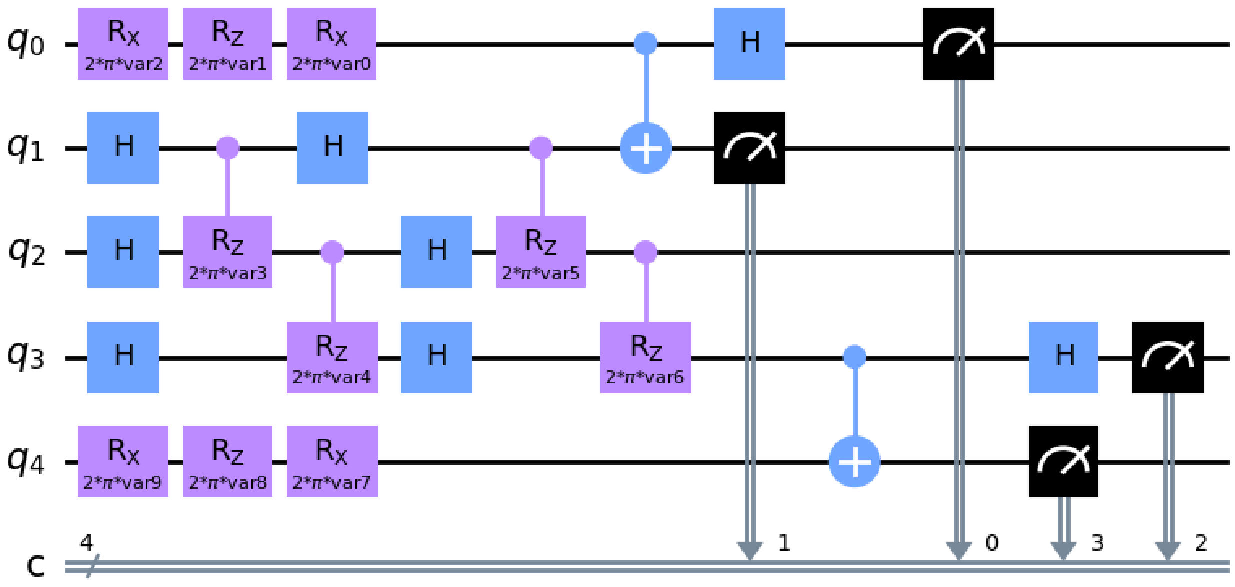


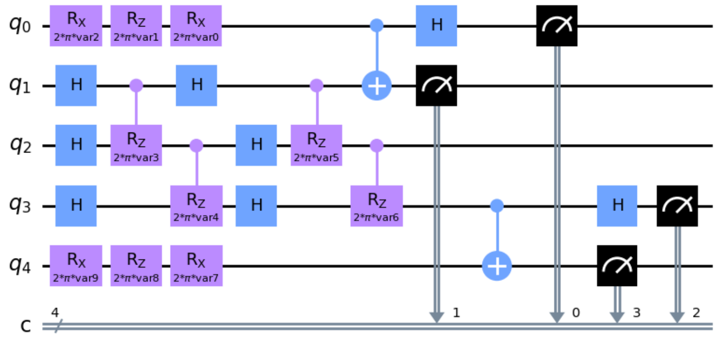
Diagram Generated using https://qnlp.cambridgequantum.com/generate.html

Introducing λambeq & it’s Features

Introducing λambeq & it’s Features Concludes

QNLP Training Process

QNLP Training Process



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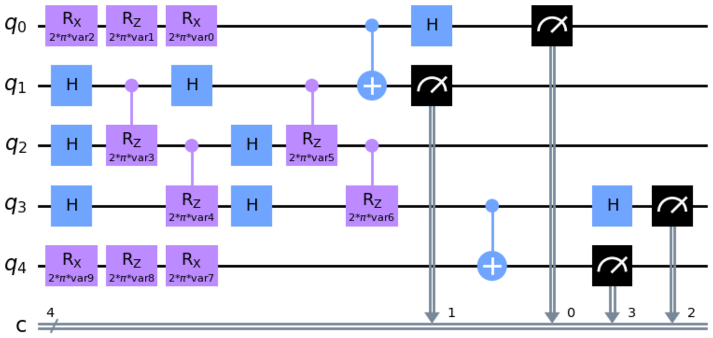

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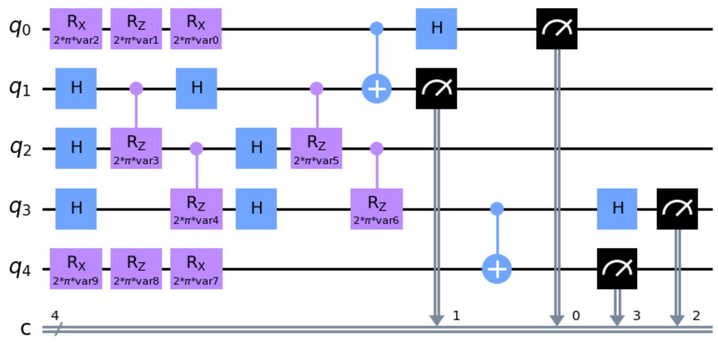

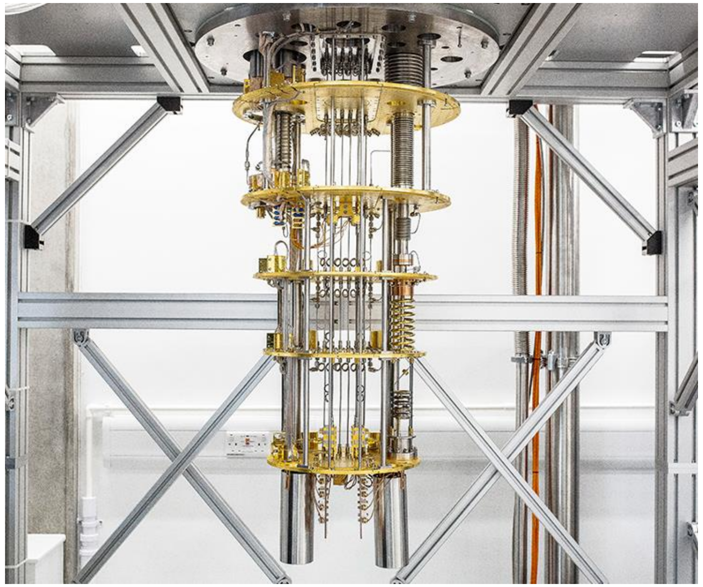

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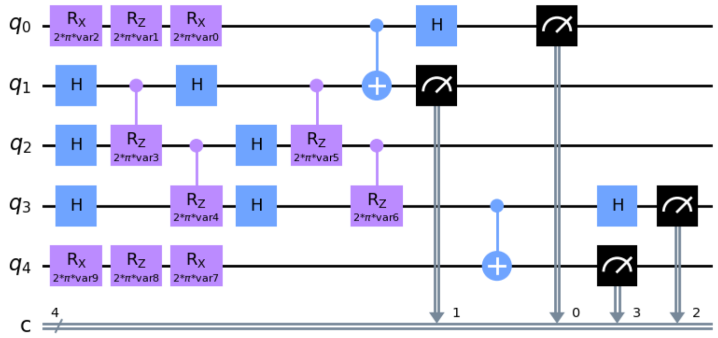

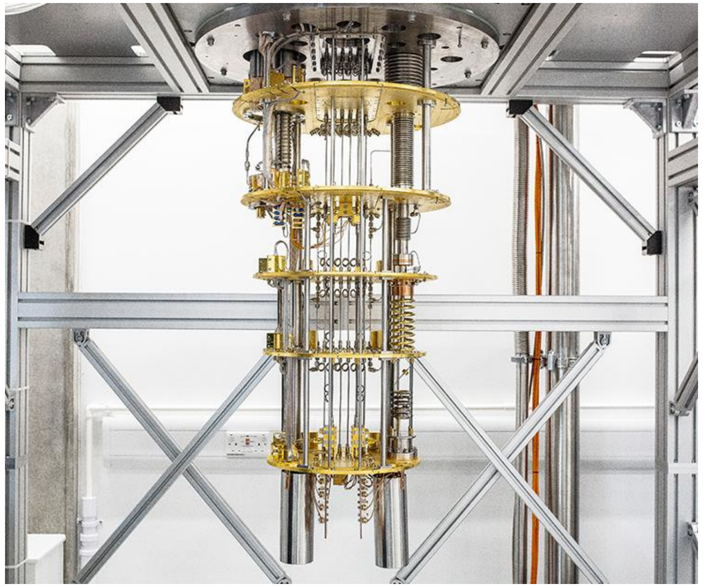

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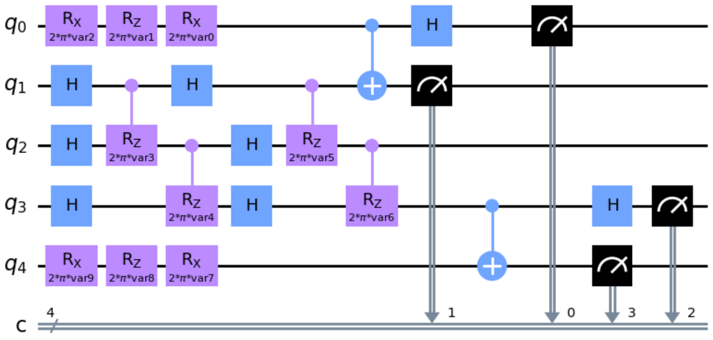

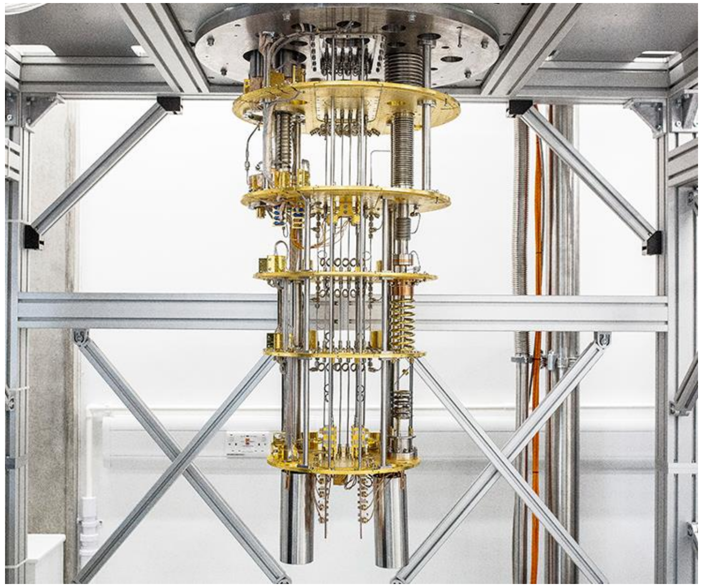

Does Eric hates Trev?

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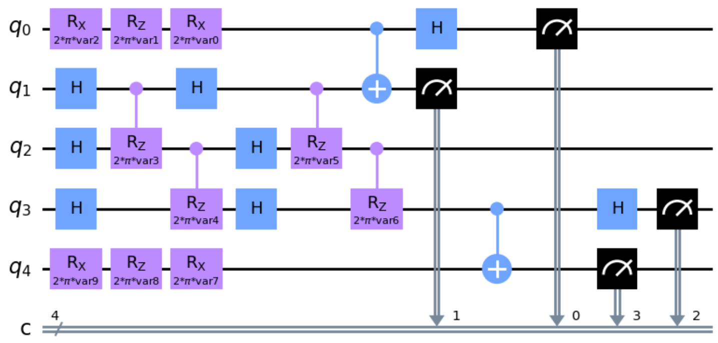

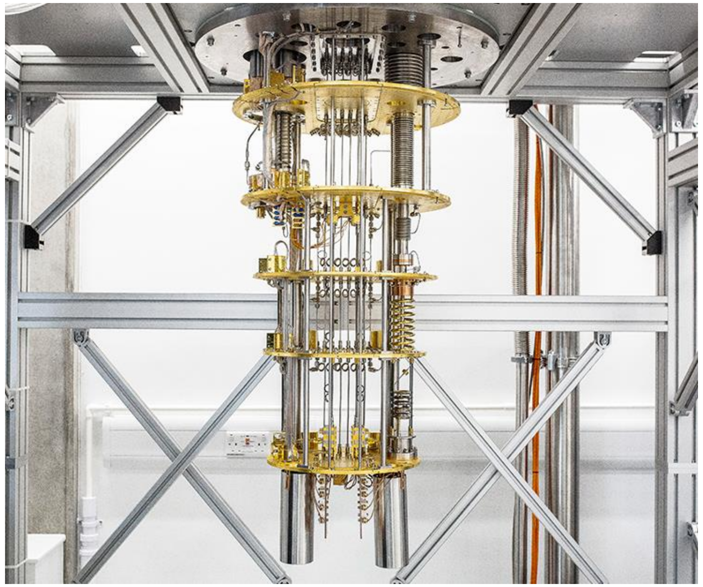

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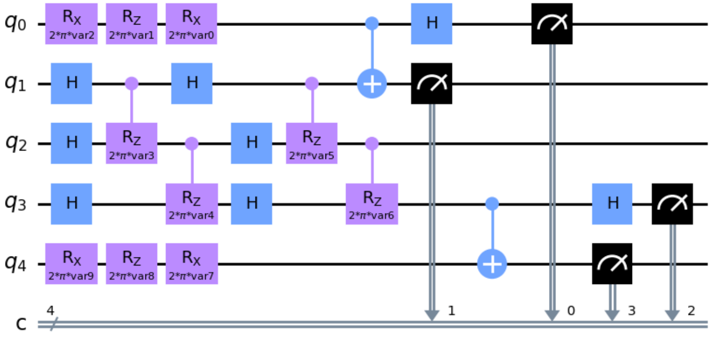
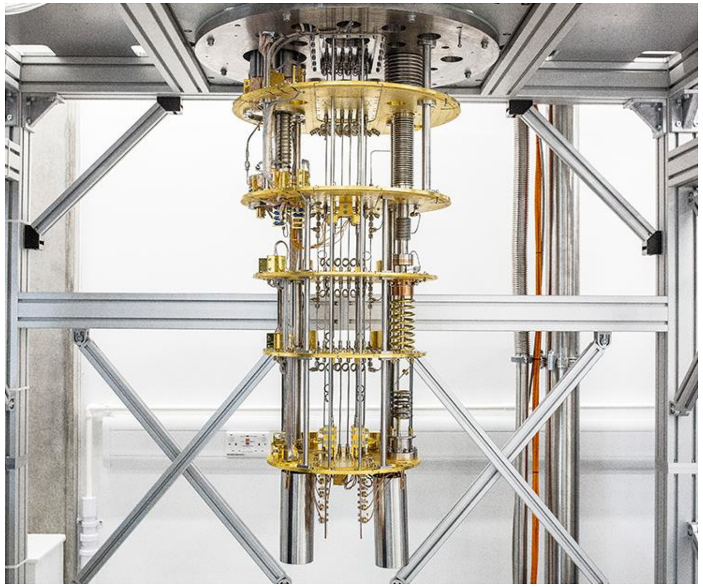




Does Eric hates Trev?

Yes!

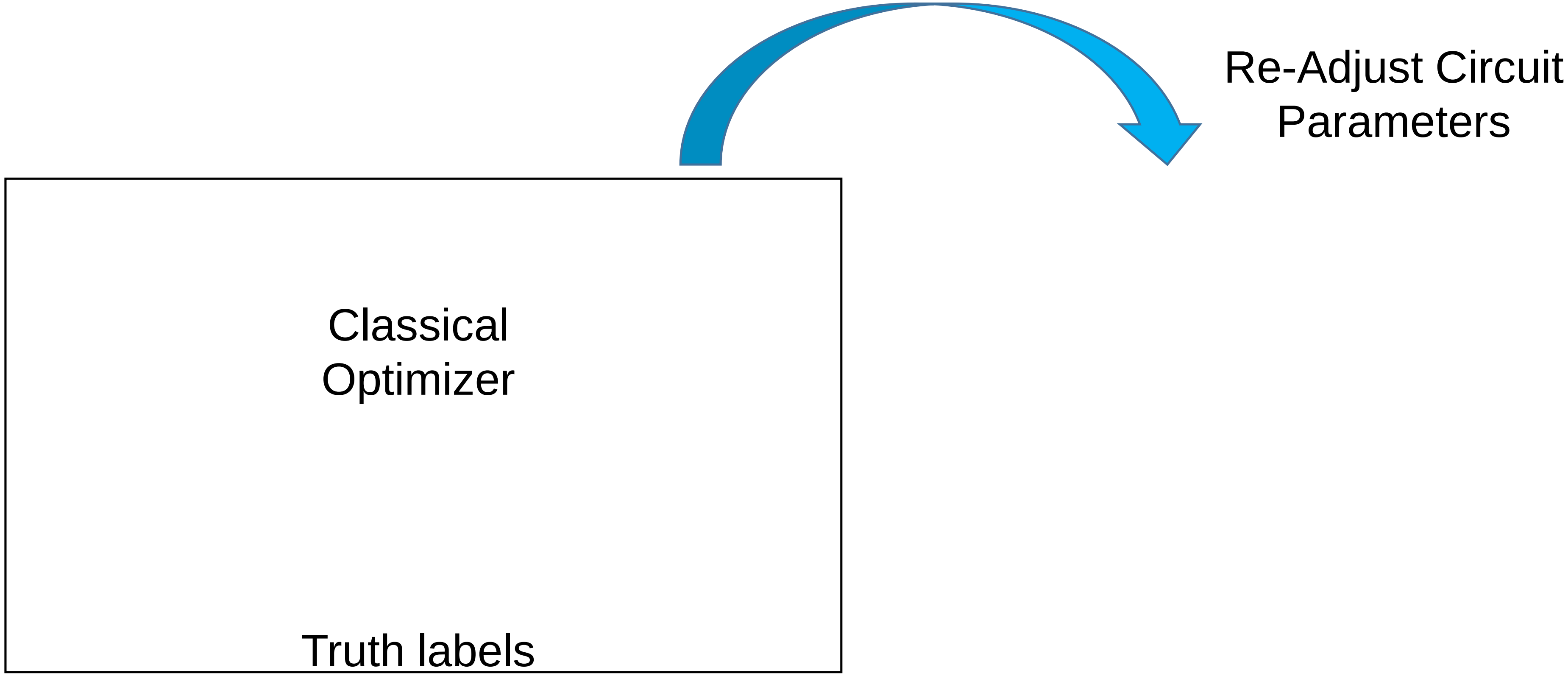
Diagram Generated using https://qnlp.cambridgequantum.com/generate.html Image from https://oxfordquantumcircuits.com/

QNLP Training Process

Classical
Optimizer

Truth labels

QNLP Training Process

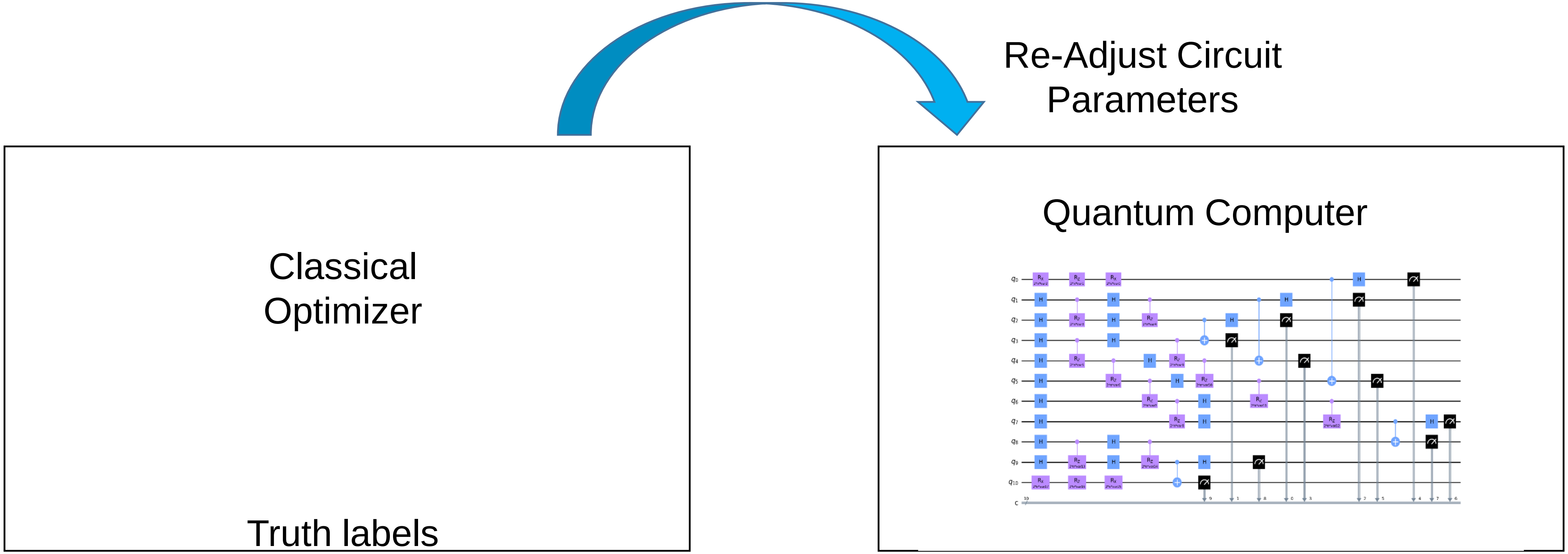


Re-Adjust Circuit Parameters

Classical Optimizer

Truth labels

QNLP Training Process



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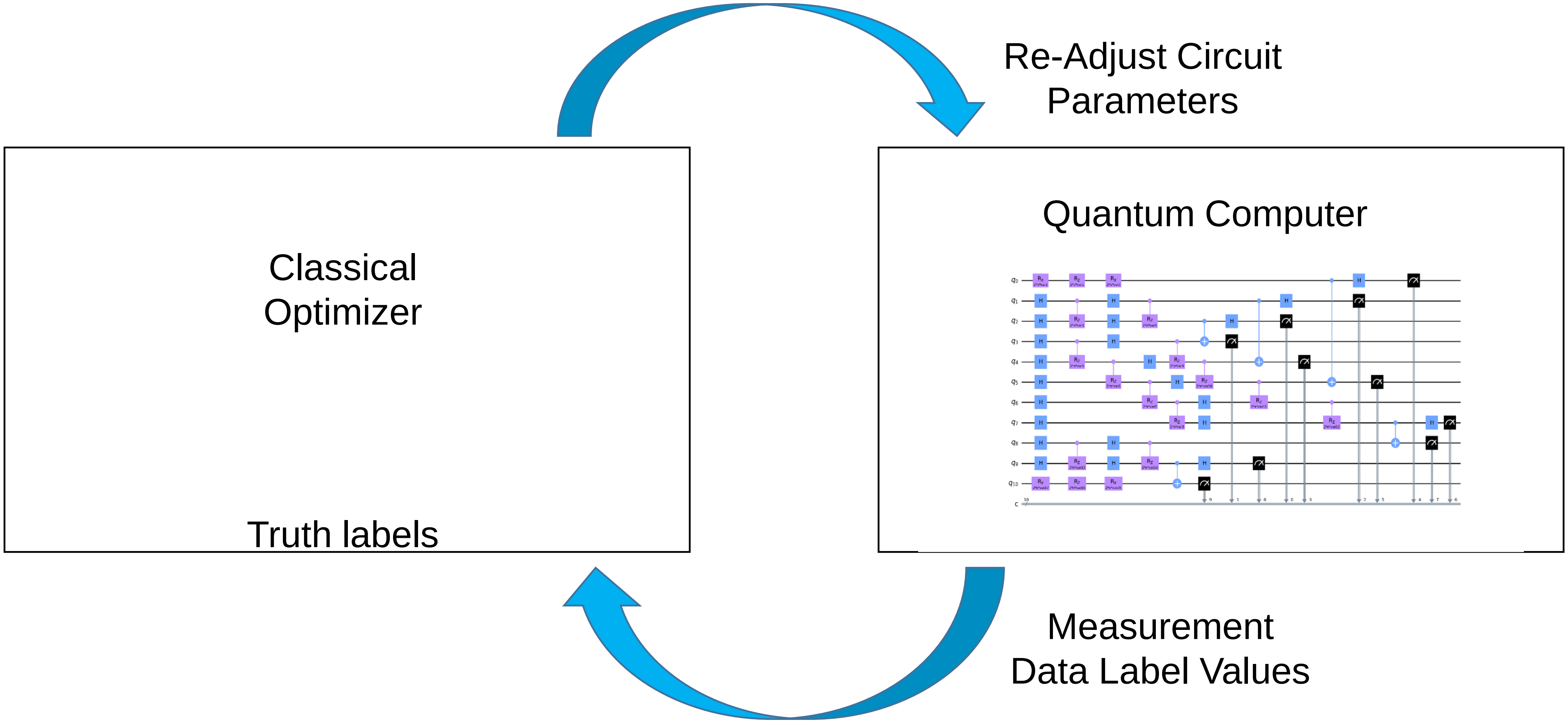
Quantum Computer

QNLP Training Process



Re-Adjust Circuit Parameters

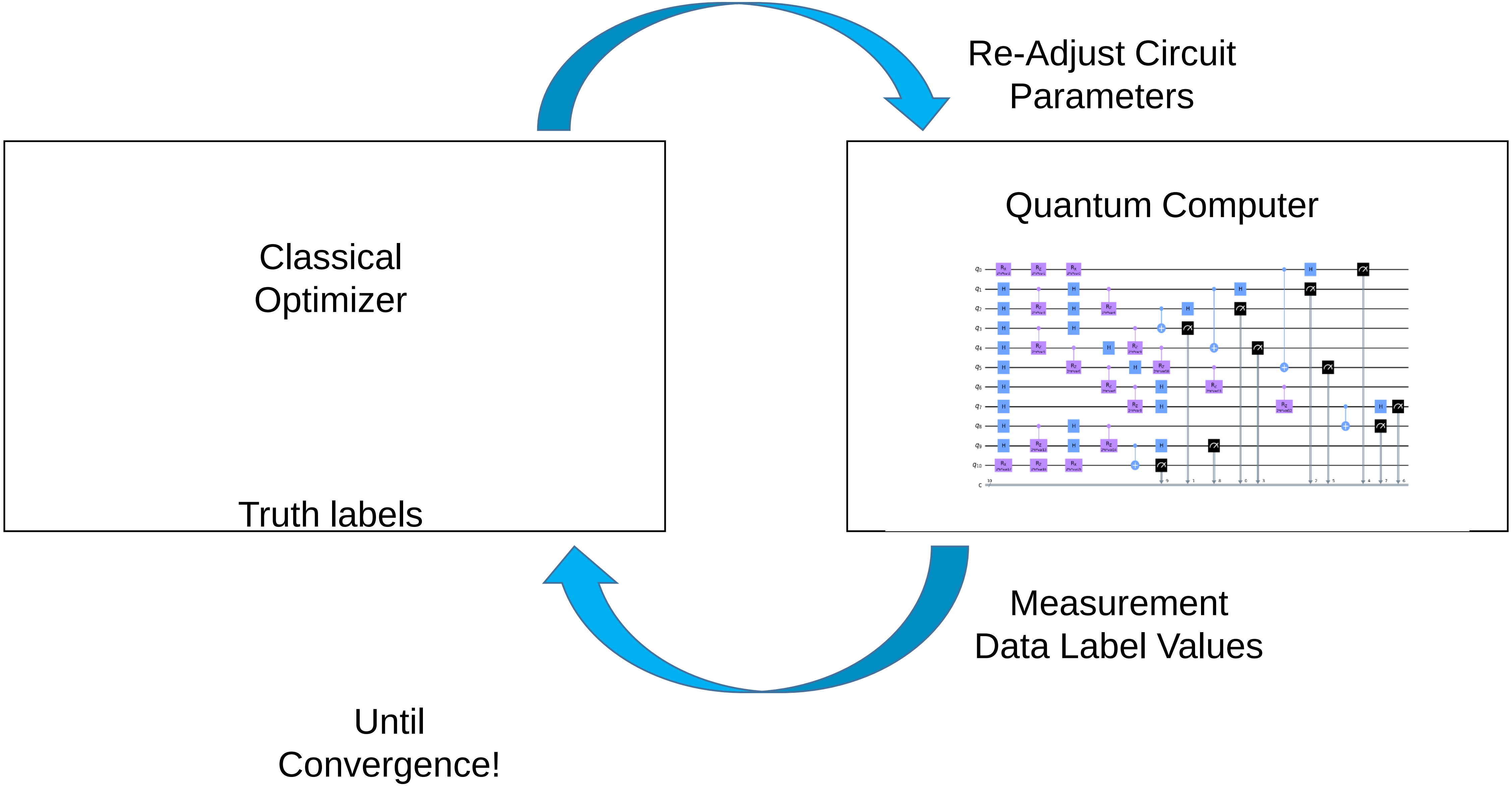
Quantum Computer

Classical Optimizer

Truth labels

Measurement Data Label Values

QNLP Training Process



Re-Adjust Circuit Parameters

Classical Optimizer

Truth labels

Quantum Computer

Measurement Data Label Values

Until Convergence!

QNLP Training Process

QNLP Training Process Concludes

Potential Use Cases/Applications of QNLP

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- ❖ Sentiment Classification

Potential Use Cases/Applications of QNLP

- ❖ Sentiment Classification
- ❖ Quantum Language Translation

Potential Use Cases/Applications of QNLP

- ❖ Sentiment Classification
- ❖ Quantum Language Translation
- ❖ Quantum Speech Recognition Systems

Potential Use Cases/Applications of QNLP

- Sentiment Classification
- Quantum Language Translation
- Quantum Speech Recognition Systems
- QNLP for Music Research

Potential Use Cases/Applications of QNLP

Potential Use Cases/Applications of QNLP Concludes

Future Directions for Research

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- ❖ Focusing on DisCoCirc algorithm to accommodate sentence to sentence grammatical structure

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- ❖ Focusing on DisCoCirc algorithm to accommodate sentence to sentence grammatical structure
- ❖ Longer term goal is to scale up and productionization of QNLP models with the help of Quantum DevOps

Future Directions for Research

Future Directions for Research Concludes

References

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Thank you so much!