Quantum Natural Language Processing

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By Quantum Natural Language Processing (QNLP) we mean the canonical implementation of natural language on quantum hardware, where by canonical we mean that compositional language structure, including grammar, matches the manner in which quantum systems compose.

The Categorical Distributional Compositional (DisCoCat) model for natural language [8] enables such a canonical embedding. One instance of this is the perfect match of grammatical structure in terms of pregroups [15] and the compositional quantum structure of bipartite entanglement [1]. In fact, DisCoCat was directly inspired by teleportation-alike behaviours [5].

Besides vector spaces and inner-products, which are commonplace in modern Natural Language Processing (NLP), DisCoCat also employs several other quantum-theoretic features, such as projector spectra for representing meanings of adjectives, verbs and relative pronouns [17, 12, 13, 7], density matrices for representing linguistic ambiguity and lexical entailment [16, 2], and entanglement for representing correlated concepts [4], all of which 'exits' on quantum hardware. Therefore DisCoCat-QNLP deserves to be referred to as 'quantum-native'.

The first proposal to implement QNLP was put forward in [19]. A first major upshot of quantum implementation of DisCoCat is an exponential reduction of space resources as compared to implementations on classical hardware. Other initially mentioned upshots include the nativeness of density matrices, and the availability of quantum algorithms that provide an algorithmic quantum advantage for typical NLP tasks such as classification.

However, a 1st shortcoming in that proposal was the reliance on quantum RAM [11], which doesn't exist yet, and may never do. Also, one needs to provided hardware-dependent conversion of DisCoCat diagrams into, e.g. quantum circuits. These shortcoming are addressed in:

- A paper submitted to QPL by us:

  Quantum natural language processing on near-term quantum computers, 2020, arXiv:2005.04147.

Recently, we performed QNLP in the form of question-answering on IBM quantum hardware. In fact, this was the 1st time any form of NLP had been done on quantum hardware. The main two resources for our implementation are:

- A medium blog describing the implementation that we did:

  https://medium.com/cambridge-quantum-computing/quantum-natural-language-processing-748d6f27b31d

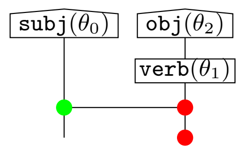
- A github repository containing the implementations:

  https://github.com/oxford-quantum-group/discopy/blob/ab2b356bd3cad1dfb55ca6606d6c4b4181fe590c/notebooks/qnlp-experiment.ipynb

This work makes use of tool box components presented in:

- Another ACT submission describing the DisCoPy toolbox in that stack [10].

One key change as compared to [19] is the use of variational quantum circuits [3] instead of qRAM. Here is such a parametrised quantum circuit that we used:



where the values of $\theta_0, \theta_1, \theta_2$ are learned using a small corpus. For reasons of simplicity, we used the verb structure that was studied in [14]. The task, rather than classification, is question answering [9], and we used a 1-dimensional sentence space. We made use of ZX-calculus [6] for easy translation between between DisCoCat diagrams and quantum circuits, and used CQC's t|ket> compiler and optimisation [18], which also relies on ZX-calculus.

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