Categorical Methods for Computational Linguistics on Quantum Hardware

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References

[1] Giovanni de Felice, Alexis Toumi, and Bob Coecke. "DisCoPy: Monoidal Categories in Python". In: *Proceedings ACT 2020*. EPTCS, 2021.

[2] Konstantinos Meichanetzidis et al. "Quantum Natural Language Processing on Near-Term Quantum Computers". In: *Quantum Physics and Logic (QPL)*. 2020. arXiv: 2005.04147.

[3] Alexis Toumi, Richie Yeung, and Giovanni de Felice. "Diagrammatic Differentiation for Quantum Machine Learning". In: *arXiv:2103.07960 [quant-ph]* (Mar. 2021). arXiv: 2103.07960 [quant-ph].