Integrated Photonics for Neuromorphic Computing

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Artificial Intelligence (AI) is transforming the world around us in similar ways to how mechanical steam-powered machines started the industrial revolution. However, standard approaches to AI come at a significant hidden cost: the process of training only a single, common AI model in terms of energy consumption and emissions is exploding, and overall, the modern computing sector is overtaking other heavy-polluting industries. Smarter models and methods can reduce this cost, but the underlying problem is the hardware. Current AI is still not nearly as efficient as biological systems like the human brain.

Architectures that are inspired by neural networks (NN) found in biology try to mimic the large number of neurons and high connectivity while being highly energy-efficient. These neuromorphic computers take full advantage of recent developments in photonics, semiconductors, and superconductors. We aim to combine different technologies and make use of their individual advantages: quantum single-photon sources for signal generation, together with integrated photonic routing and superconducting single-photon detection. We specifically target the development of quantum neural networks using strong optical non-linearities.

Recently, there have been two cognate proposals from NIST [1] and MIT [2, 3] to use linear optics—either fixed or programmable photonic networks—to combine the inputs to a neuron, and fanout of the neuron outputs. Especially interesting is the proposal for a quantum optical neural network to perform various protocols for quantum optical state compression, reinforcement learning, black-box quantum simulation, and one-way quantum repeaters [3].

Our approach is to initially address the fanout problem with photonics for classical and quantum NN: we investigate the use of inverse design—a machine learning technique—to produce better optical interconnects, i.e., $1 \times N$ beam splitters. Comparing our results to state-of-the-art (e.g. [4]), we found 1-to-10 interconnects with 4× less loss, especially important for quantum networks, and a ∼50000× smaller footprint, enabling scaling. This shows the viability of our approach as a powerful tool in the design of compact low-loss nano-photonic devices and is a crucial step towards the scalability of classical and quantum neuromorphic systems.

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