Photonic Neural Networks Applications

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***Abstract*—Integrated optical neural networks are much smaller (hundreds of neurons) than electronic implementations (tens of millions of neurons). However, the bandwidth and interconnect density in optics is significantly superior to that in electronics. This raises a question: what are the applications where sub-nanosecond latencies and energy efficiency trump the sheer size of processor? This talk will discuss of photonic neural networks in computing, communication, and signal processing.**

***Keywords*—Silicon photonics, neuromorphic computing, machine learning, optical neural networks, optical computing.**

Photonic technology has traditionally been used for long distance communication. However, modern bandwidth requirements and the standardization of silicon photonic integrated circuits (PICs) has led to the proliferation of shorter distance photonic links. For example, silicon photonic transceivers are now a pervasive component in datacenters. There has been growing interest in using silicon photonics as an enabling platform for unconventional computing [1-5]. This could result in a new class of ultrafast information processors for neuromorphic information and signal processing, machine learning, and HPC. Neuromorphic photonics [6] can enable new class of applications where low latency, high bandwidth, and low switching energies are paramount. These applications could include nonlinear programming (e.g. solving optimization problems and partial differential equations), scientific and high-performance computing (e.g. vector-matrix multiplications), machine learning acceleration (e.g. deep learning inference, and ultrafast and online learning), and intelligent signal processing (e.g. wideband RF signals, fiber transmission equalization, spectral mining).

Neuromorphic photonic processors are well suited for applications in which signals are in the analog and/or optical domain. This alleviates some of the I/O challenges associated with DACs. One such application is in fiber nonlinearity compensation in long-haul transmission systems. Artificial neural networks (ANNs) have been demonstrated for optical fiber communication, such as fiber nonlinearity compensation (NLC) in long-haul transmission systems [7]. Benefiting from the training and execution procedures of ANNs, ANN-NLC algorithms can create effective fiber transmission models from the received symbols without needing prior knowledge of transmission link parameters. Compared with the deterministic NLC approaches, such as digital back propagation [8], ANN-NLC provides comparable system performance with lower computational complexity. However, despite the reduced complexity with ANN-NLC, the hardware implementation of real-time ANN-NLC for high-speed optical transmission systems is still a challenge with conventional electronics (e.g., ASIC), considering the required computation speed and associated power consumption. The challenges in high circuit complexity, together with tight power budget, have prohibited implementing high-performance but computationally intensive DSP algorithms like ANNs in real time. So far, most efforts have been focused on developing new algorithms that requires compromises between transmission link performance and DSP complexity.

Applications such as ANN-NLC for optical communications demand for low-power and high-speed neural network implementation, and therefore necessitates the investigation of new hardware beyond purely electronic physics. Neuromorphic photonic processors are ideal for processing high-speed optical communication signals. Our prior research on PNN has revealed the analogy between the neural networks and WDM photonic hardware and demonstrated underlying on-chip devices that allow practical implementation on silicon photonic platforms [2,5,9,10]. The advances of silicon photonics enable integrations of optical devices and interconnects with sufficient density to perform computing tasks driven by real-world applications [6].

In OFC 2020 [11] demonstrated the experimental demonstration of a neuromorphic photonic processor (Fig. 2) to compensate for fiber nonlinearity over a 10,080 km trans-Pacific transmission link of 32 Gbaud PM-16QAM signals. By utilizing this photonic processor, we have achieved Q-factor improvement of 0.51 dB, which is only 0.06 dB lower than implementing the ANN with numerical simulation. The superior precision of photonic processor demonstrates the feasibility of using it for optical fiber transmission applications. Although the bandwidth of our current chip is limited, caused by the low extinction ratio of the modulator on chip, it can be realistically increased to accommodate the high-speed communication signals in future iterations [3]. Given such bandwidths, neuromorphic photonic processors could allow real-time ANN-enabled signal processing for high-speed communication signals with a single pipeline.

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2021 Photonics North (PN) | 978-1-6654-4483-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/PN52152.2021.9597894