A compression-decompression framework for universal acceleration of photonic neuromorphic computing

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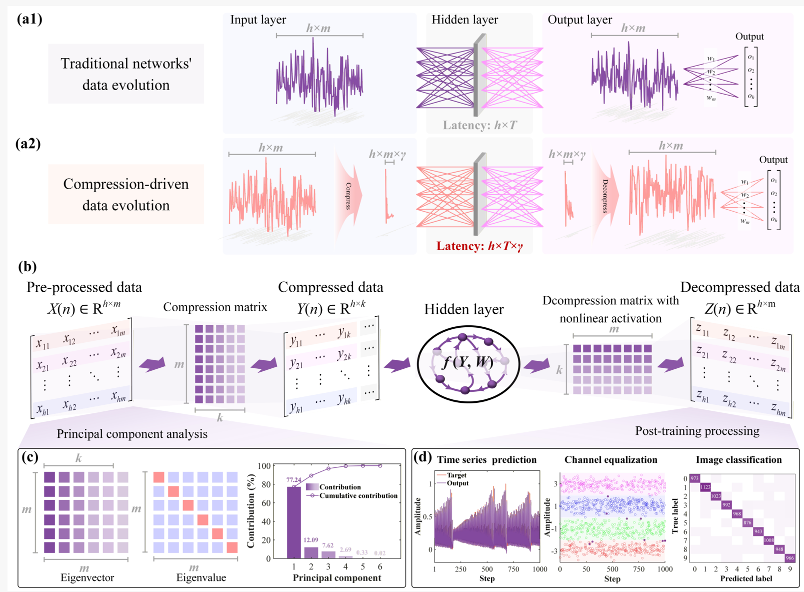

Figure 1. Schematic diagrams of compression strategy.

The rapid advancement of artificial intelligence, big data analytics, and scientific computing has imposed unprecedented demands on computational power, pushing traditional electronic architectures to their physical limits. The slowdown of Moore's Law and the escalating "memory wall" bottleneck have made it increasingly difficult for von Neumann-based processors to deliver the energy efficiency and throughput required by modern deep neural networks. In contrast, the human brain achieves exceptional computational efficiency and cognitive capability with remarkably low power consumption, inspiring the development of novel computing paradigms. Neuromorphic computing, which emulates the structure and information-processing principles of the brain, integrates interdisciplinary advances from neuroscience, computational neuroscience, and materials science, etc. aiming to achieve high-efficiency, low-latency computing systems.

Optical platforms, with their inherent advantages of broad bandwidth, low latency, high parallelism, and low power consumption, have emerged as a promising alternative in the post-Moore era, infusing new momentum into neuromorphic computing. By encoding information across multiple physical dimensions of light, e.g., wavelength, amplitude, phase, and polarization, optical systems can perform large-scale computations within a single time step. Photonic neuromorphic computing thus combines the architectural principles of neuromorphic computing with the intrinsic strengths of photonics, in order to realize high-speed, low-power, and highly integrable brain-inspired systems.

Despite notable progress, current photonic neuromorphic platforms still face limitations in achieving universal acceleration. On one hand, single optimization strategies lack adaptability across diverse hardware architectures. On the other hand, reducing samples in pursuit of computational speed often comes with a loss of accuracy, that is, an inherent trade-off between computational throughput and accuracy. Therefore, developing a solution that enables universal acceleration without sacrificing accuracy holds significant theoretical and practical importance, which will offer a pathway to overcome the rate-performance bottleneck and advance photonic neuromorphic computing toward practical and scalable applications.

The research group of Prof. Nianqiang Li and Yu Huang, from the School of Optoelectronic Science and Engineering at Soochow University, proposed a performance-compensated acceleration strategy based on a compression-decompression architecture, aiming to overcome the inherent limitations of conventional photonic neuromorphic computing in information processing speed and system scalability.

The core innovation of this framework lies in the construction of an adaptive, eigenvector-driven compression-decompression synergistic network. In the preprocessing stage, the compression process projects input data into a low-dimensional subspace highly relevant to the target task through eigenvector analysis, thereby significantly reducing the data volume processed by the hidden layer while preserving critical features. The decompression stage then effectively compensates for information loss incurred during compression to improve final performance.

To validate the generality and effectiveness of the proposed framework, the research group conducted experiments on two representative photonic neuromorphic platforms: a continuous-wave system based on commercial off-the-shelf lasers and a spiking system built on a specifically fabricated photonic neuro-synaptic chip. Experimental results demonstrate that the framework enables substantial speed improvements in photonic neuromorphic computing within the optical domain. The system achieves a recognition speed of 100 million images per second for image classification tasks and a processing throughput of 600 million data points per second for time-series tasks. Notably, while latency and hardware resource requirements are reduced by an order of magnitude, the proposed system's recognition accuracy and temporal processing capability can still be effectively restored to levels comparable to those of uncompressed architectures. These results confirm that the compression-decompression framework can achieve order-of-magnitude acceleration while effectively compensating for information loss introduced by compression, thereby breaking the inherent trade-off between speed and performance in conventional photonic neuromorphic computing. This work establishes a universal acceleration paradigm for high-throughput, low-power photonic neuromorphic chips and offers a novel pathway for software-hardware co-development.

Keywords: reservoir computing, compression-decompression framework, neuromorphic computing accelerator, semiconductor laser
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