Photonic Reservoir Computing: Principles, Architectures and Applications for Sensing and Information Processing

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Abstract: This presentation will describe the fundamental working principles of Photonic Reservoir Computing. It will elaborate on various photonic systems that implement the PhRC scheme, emphasizing their structure and functionality. Additionally, the potential applications of PhRC in sensing and information processing systems will be both described and demonstrated. This overview aims to provide a understanding of PhRC's capabilities and its transformative potential in the field of information photonics.

Artificial Intelligence (AI) drives the creation of future technologies that disrupt the way humans live and work, creating new solutions that change the way we approach tasks and activities. In many cases, AI has been an integral part of recent technological innovations, like self-driving cars, virtual assistants, smart devices. Currently, almost all AI processing is done in a cloud-server. This is because AI algorithms and models require a large amount of computational power, which traditional microelectronic digital processors are unable to provide. Recently, a new class of photonic system called Photonic Reservoir Computing (PhRC) has emerged as a potential candidate for the development of hardware capable of performing AI.

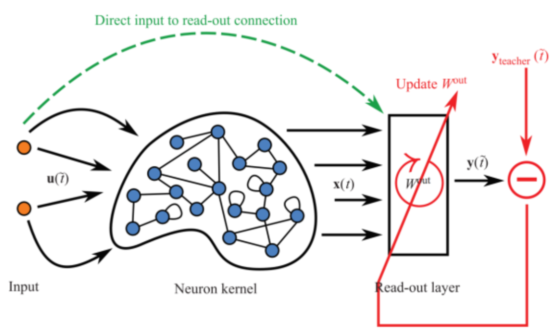

Figure 1. Schematic illustration of the Reservoir Computing machine learning scheme.

The Reservoir Computing machine learning algorithm, the foundation of PhRC, has a unique architecture compared to other neural network architectures. Unlike traditional feedforward neural networks, where the signal propagates in one direction (left-to-right) through layers of neural networks, Reservoir Computing is based on the 'kernel method' philosophy. This philosophy is based on the Cover's separability theorem of patterns, which states that a complex pattern classification problem, when transformed into a high-dimensional space, is more likely to be linearly separable than in the original lower-dimensional space [1]. This leads to a two-component architecture: a fixed nonlinear reservoir kernel and a programmable linear read-out (Fig. 1). The kernel nonlinearly transforms low-dimensional input $u(t)$ into a high-dimensional space, enabling the read-out to perform linear inference on these high-dimensional states—tasks that would be unfeasible in the original low-dimensional space. PhRC utilizes this

Reservoir Computing scheme in a photonic system, taking advantage of various optical systems that exhibit nonlinear high-dimensional dynamics, ranging from fiber-based setups to compact chip-scale devices.

In this invited talk, the principles behind the successful demonstration of PhRC will be discussed. Various architectures of PhRC will be reviewed, including electro-optic fiber-based PhRC [2-3], PhRC based on stochastic photonics [5-7], and stimulated Brillouin scattering PhRC [8], see Figure 2. Finally, potential applications for sensing and information processing will be highlighted.

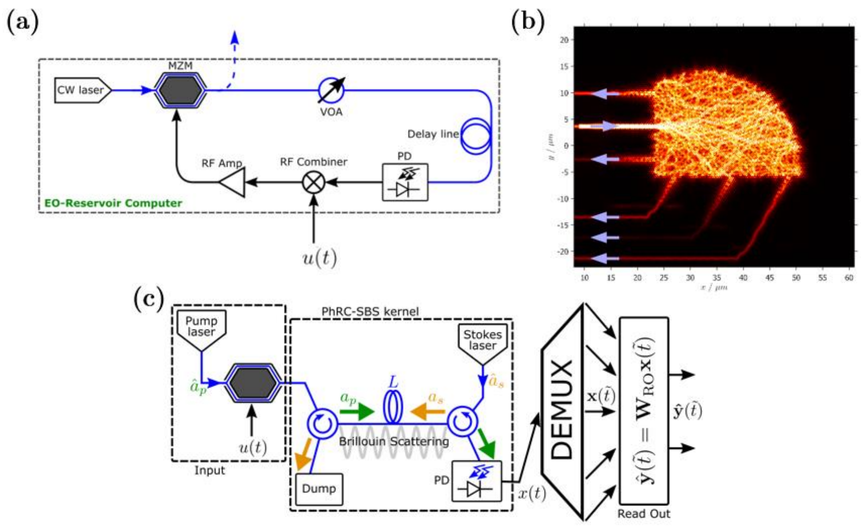

Figure 2. Schematic illustration of several PhRC architectures: (a) electro-optic PhRC, (b) PhRC stochastic photonics and (c) PhRC based on stimulated Brillouin scattering.

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