Employing Complex Photonics for Neuro-inspired Information Processing

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We are currently witnessing a revolution in computing. For decades electronic computers, based on the concept of the von-Neumann machine, dominated computer hardware. The validity of Moore's law for more than five decades illustrates the enormously fast development. But the increasing demands on information processing, the physical limitations in transistor size and the power consumption of electronic computers call for alternative concepts and alternative hardware. Bringing together ideas from neuroscience, complex systems, machine learning and photonics is offering new fascinating opportunities to explore new concepts and to gain a new perspective on information processing. We deliberately choose a minimal design approach [1], allowing for the implementation of neuro-inspired computational concepts on different hardware platforms.

We present an architecture based on a nonlinear system, implemented by a nonlinear node with delayed feedback. Via time-multiplexing, we can emulate a complex nonlinear network using only a single or few nonlinear nodes [2]. By this reduction of the learning-based methods of Reservoir Computing and Extreme Learning to their bare essentials, we find that nonlinear transient responses of a simple dynamical system enable the processing of information with excellent performance. Our presented system employs a single mode telecommunication laser as nonlinear node. Delayed feedback is realized via a fiber loop mirror. Information can be injected optically by injecting the modulated intensity of a tunable laser. In recent years, we already demonstrated that with this approach we can tackle challenging tasks efficiently and at very high speed [3, 4].

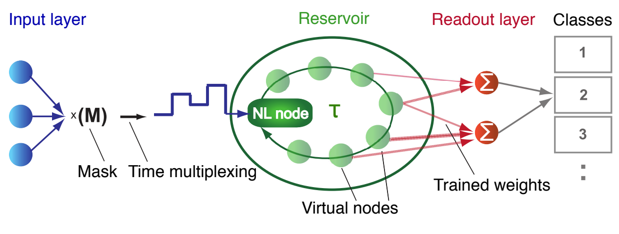

Figure 1: Reservoir computing scheme using a single nonlinear node with delayed feedback and time-multiplexing.

Building on these advances, we explore how this approach can be applied to real telecommunication tasks. To this end, we are investigating the influences of key parameters, including spectral detuning and power of the injected optical information, as well as the bias current of the information processing laser. These parameters affect two key properties, essential for the information processing: consistency and memory. Consistency is the property that the responses to multiple similar information inputs are sufficiently similar. Memory is the ability of the reservoir to keep information about previously injected inputs for a certain number of time steps. We show that both properties can be tuned via the operating conditions in the experiment. This offers perspectives to adapt the same reservoir computing system to different information processing requirements.

First we show that the system can be tuned to show good performance in a nonlinear prediction task. Moreover, we present how photonic reservoir computing can be employed to perform all-optical information recovery after optical transmission in Ethernet or long-haul transmission systems. We demonstrate processing at input data rates up to 20 Gigasamples per second. Since our system is designed to be compatible with telecommunication hardware, it represents a promising approach to avoid the optic to electronic bottleneck and to perform all-optical information processing. After training our photonic information processing system, we show improved bit error rates (BER) of the detected signal by one order of magnitude, compared to the same benchmark that excludes the reservoir. Simulated reservoirs with shorter time delays that employ optical feedback and utilize the reservoirs memory effects show a further improved performance, while speeding up the all-optical processing.

We discuss, how in the future the time-multiplexing of virtual nodes might be complemented by the implementation of parallel nodes in reconfigurable complex laser networks [5].

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