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Optical Neural Network and Reservoir Computing for Optical Fiber Communications

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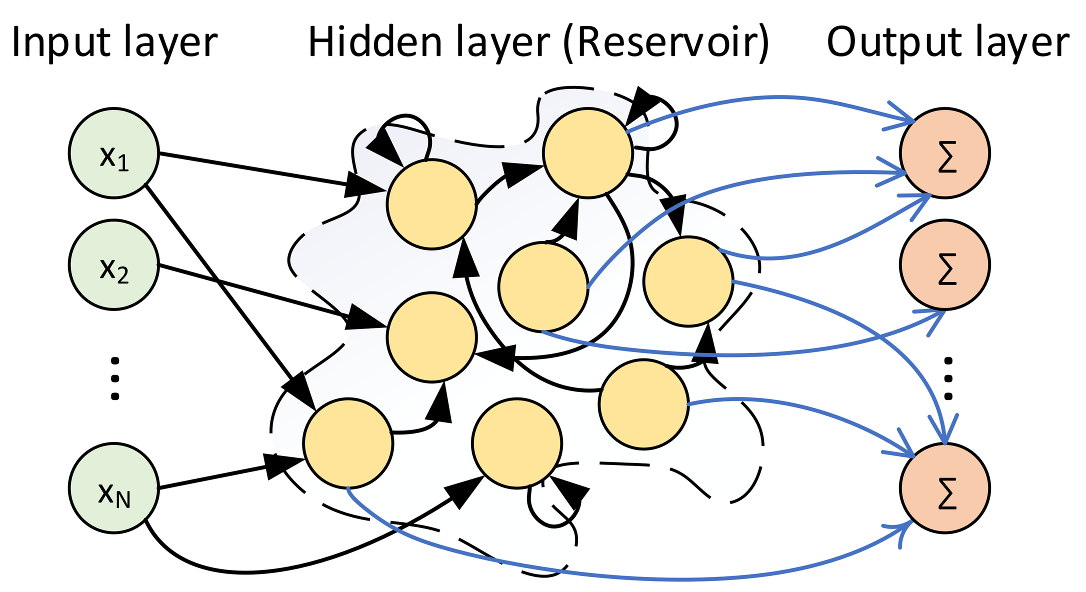
1. Introduction

- Nonlinear effects in optical fibers are one of the major limiting factor for optical communications [1].
- State of art for nonlinear mitigation:
  - Nonlinearity mitigation through digital signal processing [2]
  - Optical phase conjugation [1]
  - Nonlinear frequency division multiplexing [3]
    - **High implementation cost**
    - **Full knowledge of the optical parameters**
- Machine learning
  - Broad area of application
  - Very well-know for classification problems
  - Early stages for optical communications [4]
    - **Applications with central processing units are suboptimal in terms of speed and power efficiency [5]**
- Alternatively, optical neural network can be suitable to mitigate linear and nonlinear optical impairments
  - **Reservoir computing [6, 7]**
  - **Feedforward optical neural network (ONN) [5]**

2. Reservoir Computing

- Chromatic dispersion (CD) and nonlinearities induced by Kerr effect are time-dependent impairments.
  - **Challenging task to overcome in a common machine learning architecture where there no memory is considered (typically)**
- Recurrent neural networks mitigates time-dependent impairments with the aid of recurrent connections
  - Universal approximators [8]
  - **Difficulty to train**
- **In turn, reservoir computing simplifies the train process by leaving the hidden layer (reservoir) untrained.**

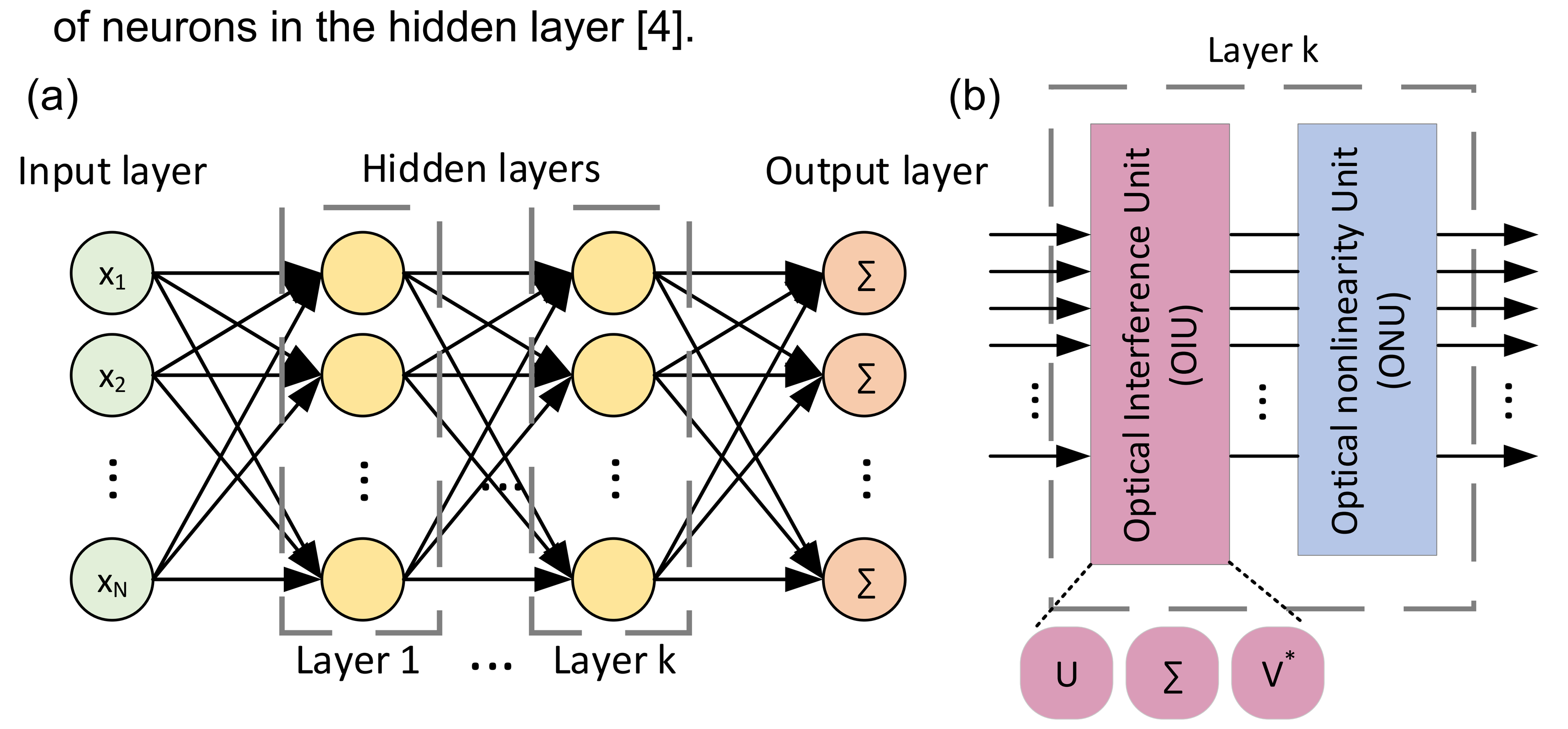


General schematic of a reservoir computing. The blue arrows are the only weights trained.

- By applying a nonlinear transformation, the input space will be mapped to a higher-dimensional space, resulting in a dimensionality expansion that might be linear separable.

3. Feedforward optical neural network

- Artificial neural network (ANN) with one hidden layer and linear output units can approximate arbitrary well any continuous function with sufficient number of neurons in the hidden layer [4].

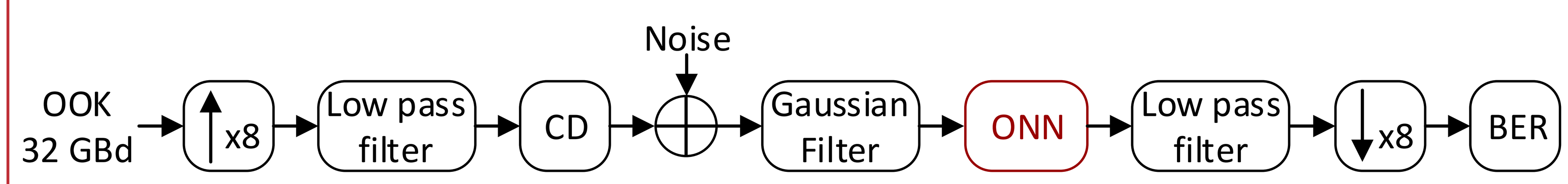


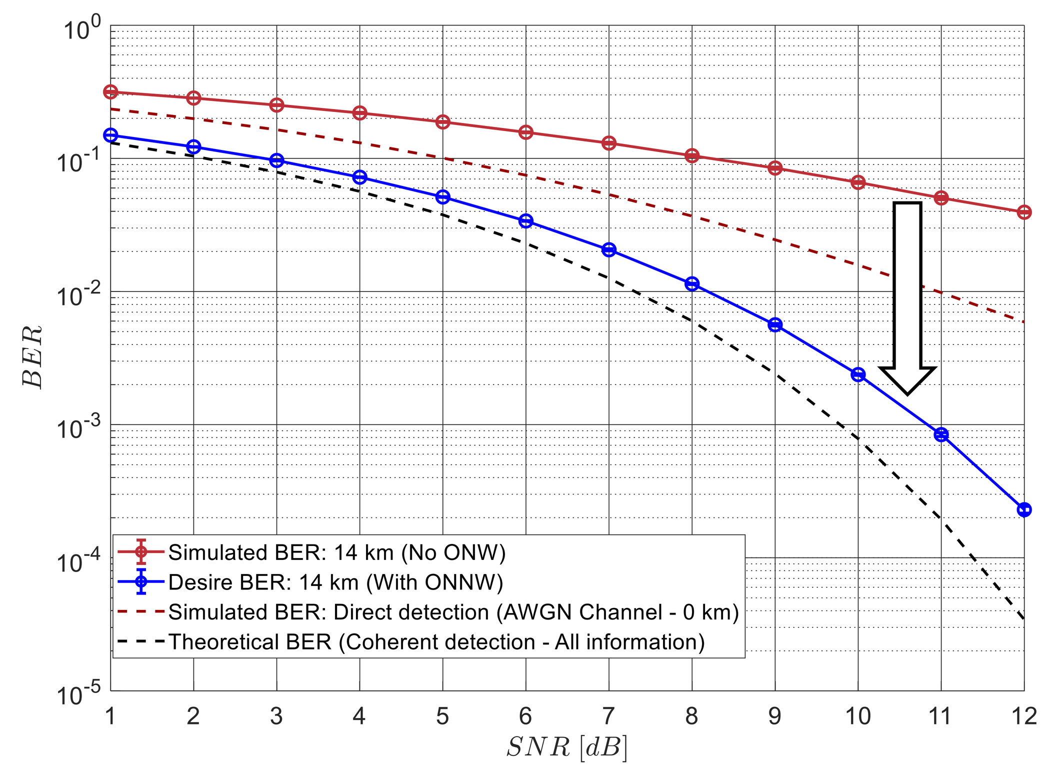
(a) General schematic of an ANN. (b) Building blocks for an ONN.

- In order to implement any ANN with optical components, two different structures are needed [5]:
  - optical nonlinear unit (ONU)
  - optical interference unit (OIU)
    - Any N x N unitary matrix can be implemented using optical beam splitters (variable reflectivity) or Mach-Zehnder interferometer [9].
    - Any matrix can be factorized using the singular-value decomposition:

Generic matrix ⟵ $A = U\,\Sigma\,V^*$ ⟶ Unitary matrices
Rectangular diagonal matrix with non-negative numbers (optical attenuators)

4. Simulations





5. Conclusions

- Reservoir computing: Leaving the reservoir untrained is a great benefit for hardware implementation [10]
- Forward optical neural network: Speed and power consumption can be significantly improved with an optical implementation of an ANN [5]

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