A Photonic Implementation of Reservoir Computing

K. Vandoorne, P. Bienstman

Photonics Research Group, Ghent University (UGent)

Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium

Reservoir Computing[1] is a new approach to study and use Neural Networks, which try to mimic a brain-like intelligence. It uses memory and feedback in the reservoir to extract time correlated features and in this why it can solve complex classification and recognition tasks like speech processing[2]. This has already been realized using software but a hardware implementation needs yet to be realized. Photonics offers a good perspective to achieve this fast and economic.

Introduction

Neural Networks are networks that can be trained to solve complex classification and recognition problems. They mimic the nervous system in the brain, consisting of vertices which are interconnected end whereby every connection has a certain weight that can be adapted during the learning process. While feed forward neural networks (no feedback) are well studied and understood, they are unapt for solving problems with time dependence. Recurrent Neural Networks are better suited because they have memory due to the feedback loops, but they have been proven hard to train.

Recently a novel approach to these networks has been proposed: Reservoir Computing. The network is split up into two segments. The first one is the reservoir which is a RNN with random weights and which is further left untrained. The second one is the read-out function which will be trained to solve a specific problem. The idea is that by splitting up the functionality the read-out function can be kept simple and therefore easy to train, while the whole system keeps its interesting computational properties - like extracting time dependent features - thanks to the reservoir. This can be seen in figure 1.

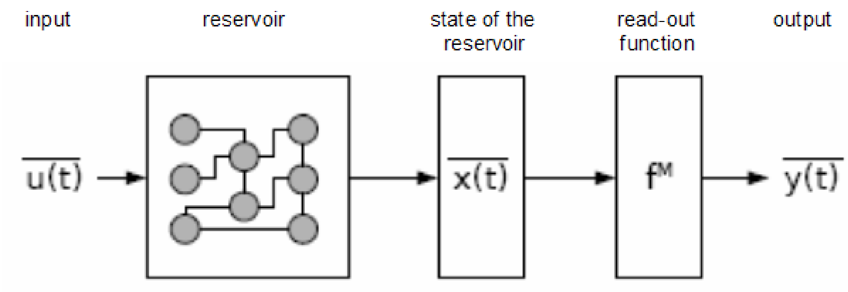

Figure 1: Reservoir computing

The implementation of Reservoirs has so far been restricted to software, so there is a need for a hardware implementation that performs in a power efficient way. Moreover the theory of Reservoir Computing doesn't limit the reservoirs to recurrent neural networks. Therefore a photonic implementation was proposed as a hardware implementation because it has properties which lead to a rich dynamical behaviour needed for reservoirs.

Photonics is the science which studies light and its interaction with materials. Nanophotonics tries to miniaturize the structures, needed to influence light, so that they would fit on a single chip. Given this it should be possible to develop a nanophotonic reservoir which is power efficient and very fast. It should be able to tacle all kinds of problems in an intelligent way, from the filtering of optical signals in telecom applications to speech recognition.

Implementation

The goal of this research is to develop a Reservoir based on nanophotonics. The reservoir will consist of different cavities which are interconnected. Inside the cavity non-linear effects will influence the properties of the resident light. These effects along with the degree of interconnection will determine the performance of the reservoir to solve complex problems. In a first stage the cavities will be studied until they are well understood. Different cavities will be evaluated like Photonic Crystal cavities (figure 2), Microdisklasers, SOA's,...
In the next stage they will be connected to form a reservoir. This reservoir will first be simulated and made into a hardware implemention to verify its computational potential.
The material system we are looking into is Silicon on Insulator (SOI) because it allows for compact designs and they can be made in collabaration with IMEC (Leuven). It will be necessary though to bond a layer of InP on the SOI[3] to enhance the non-linear effects, needed for a rich dynamic behaviour.

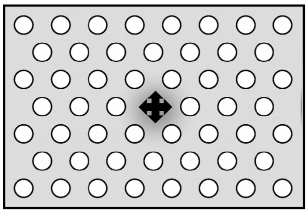

Figure 2: Photonic Crystal Cavity

Future work

In the near future the first reservoirs will be simulated and build to test their potential.

References

[1] W. Maass and T. Natschlger and H. Markram, "Real-time computing without stable states; a new framework for neural computation based on perturbations," *Neural Computation*, vol. 14, pp. 2531-2560, 2002.

[2] D. Verstraeten and B. Schrauwen and M. DH́aene and D. Stroobrandt, "Isolated word recognition with the liquid state machine: a case study", in *Information Processing Letters*, 2005, pp. 521-528.

[3] G. Roelkens and D. Van Thourhout and R. Baets, "Ultra-thin benzocyclobutene bonding of III-V dies onto SOI substrates",Electronics Letters, 2005. pp. 561-562.