# Optoelectronic nonlinear transient computing with multiple delays

***R. Martinenghi, A. Baylón-Fuentes, F. Xiaole, M. Jacquot, Y. Chembo, L. Larger***

*University of Franche-Comté & FEMTO-ST/Optics Dpt., UMR CNRS 6174, 16 route de Gray, F-25030 Besançon, France*

Photonic nonlinear transient computing (NTC) [1,2,3] is a physical implementation, in optics, of a novel brain inspired computational paradigm, also referred as to *Echo State Network* (ESN[4]), or *Liquid State Machine* (LSM[5]) and *Reservoir Computing* (RC[6]) in the early literature. The particular approach which very recently led to the first photonic demonstrations[1,3], have been using the dynamical complexity developed by nonlinear delay optoelectronic oscillators, instead of that of a spatially extended network of dynamical nodes (as usual in neural network computing).

In this contribution, we report on a versatile electro-optic setup performing photonic nonlinear transient computing. The setup is making use of a hybrid analogue and digital architecture. A photonic part is ruling the dynamics, with a tunable nonlinear transformation performed by the operating point of a Mach-Zehnder modulator. An FPGA (Field Programmable Gate Array) is also used to emulate the delay (usually achieved via the time of flight of the light information in a fiber [1]), but also to emulate other specific and easily reconfigurable functionalities. The FPGA indeed allowed to design a multiple delayed feedback architecture as in [2], thus improving the connectivity of the virtual network of nodes emulated by the delay dynamics. We also implemented in-line processing features, such as the Readout processing which is usually performed off-line in most of the previous results.

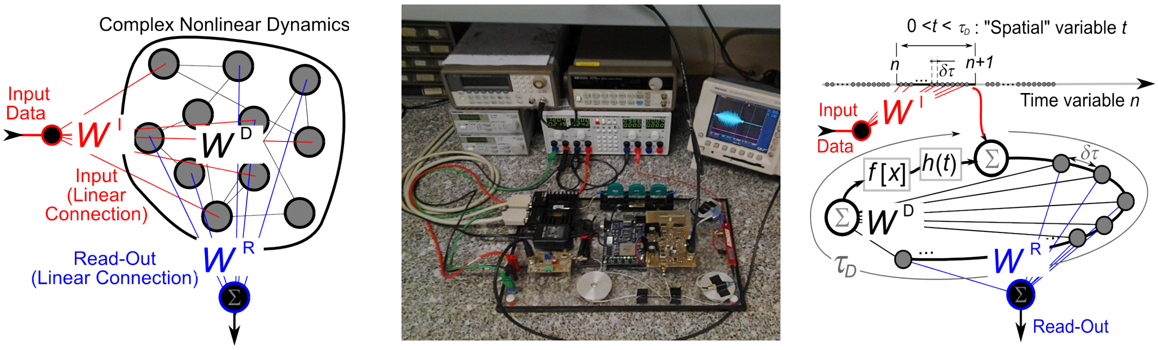


**Fig. 1** Left: principle of a reservoir computer with a network of nodes as the Reservoir; center: Experimental NTC, with hybrid photonic and programmable digital devices (FPGA); right: illustration of the network of dynamical nodes emulated by a delay dynamics (nodes -gray circles- are distributed along the delay line, and addressed at the input via time division multiplexing)

We will report on the computational capabilities measured while scanning the parameter space for the photonic nonlinear delay dynamics. Feedback gain, information weight, as well as shape of the nonlinearity have been investigated for their influence on the computational efficiency of the photonic NTC.

## References

[1] R. Martinenghi, S. Rybalko, M. Jacquot, L. Larger, “Photonic nonlinear transient computing with multiple-delay wavelength dynamics”, Phys. Rev. Lett., **108**, 244101 (2012).
[2] L. Larger, M. C. Soriano, D. Brunner, L. Appeltant, J. M. Gutierrez, L. Pesquera, C. R. Mirasso, and I. Fischer, “Photonic information processing beyond turing: an optoelectronic implementation of reservoir computing”. Opt. Express, **20**(3):3241–3249, (January 2012).
[3] Y. Paquot, F. Duport, A. Smerieri, J. Dambre, B. Schrauwen, M. Haelterman, and S. Massar, “Optoelectronic reservoir computing”, Scientific Reports, **2**:287, (February 2012).
[4] H. Jaeger, “The "echo state" approach to analyzing and training recurrent neural networks”, Technical Report GMD, 148, German National Research Center for Information Technology, (2001).
[5] W. Maass, T. Natschläger, H. Markram, “Real-Time Computing Without Stable States: A New Framework for Neural Computation Based on Perturbations”, Neural Comput., **14**, 2531 (2002).
[6] K. Vandoorne, W. Dierckx, B. Schrauwen, D. Verstraeten, R. Baets, P. Bienstman, and J. Campenhout. “Toward optical signal processing using photonic reservoir computing. Opt. Express”, **16**(15):11182–11192, 2008.

978-1-4799-0594-2/13/$31.00 ©2013 IEEE