OVERVIEW AND EXAMPLES OF PROMISING PHOTONIC SYSTEMS FOR DATA PROCESSING USE CASES

ELECTRICAL ENGINEERING ARTIFICIAL INTELLIGENCE DAY

2020, November 19th , 11:15-11:40

Information, Communications and Electronics (ICE), IP Paris, Telecom SudParis

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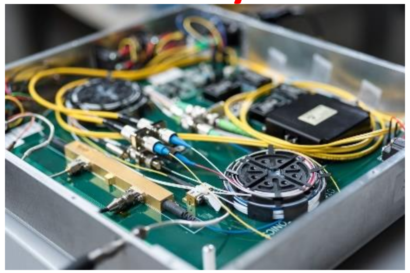
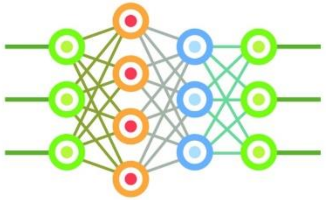
Institut Mines-Télécom

MAIN GOAL AND OUTLINE

Photonics systems



Machine Learning techniques



Outline

1. Context and objectives
2. Examples of promising photonic systems and use cases
3. One first research path explored in Télécom Sudparis on photonic Reservoir computing

Conclusions and perspectives

ENERGY EFFICIENCY FOR HIGH COMPUTATIONAL VOLUME

*HAO, Karen. **Training a single AI model can emit as much carbon as five cars in their lifetimes**. MIT Technology Review, 2019*

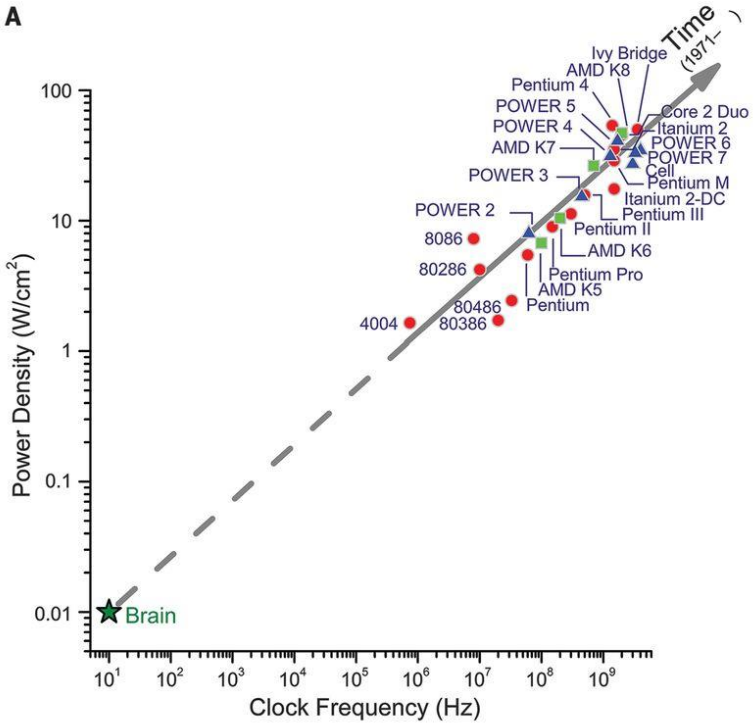
Human Brain

~ 38 PFLOPS

~ 20 W

Exceptional solving complex problems

Highly energy efficient



Merolla, Science 345, 6197 (2014)

Tianhe-2 supercalculator

~ 33 PFLOPS

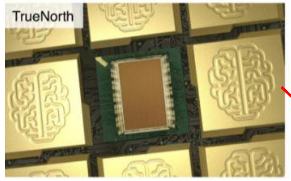
~ 18MW

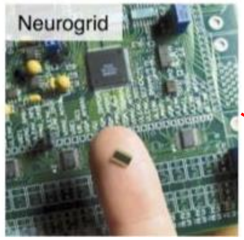
NEUROMORPHIC CHIPS

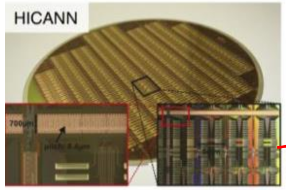
IN TERMS OF VELOCITY/SURFACE OR VELOCITY / ENERGY

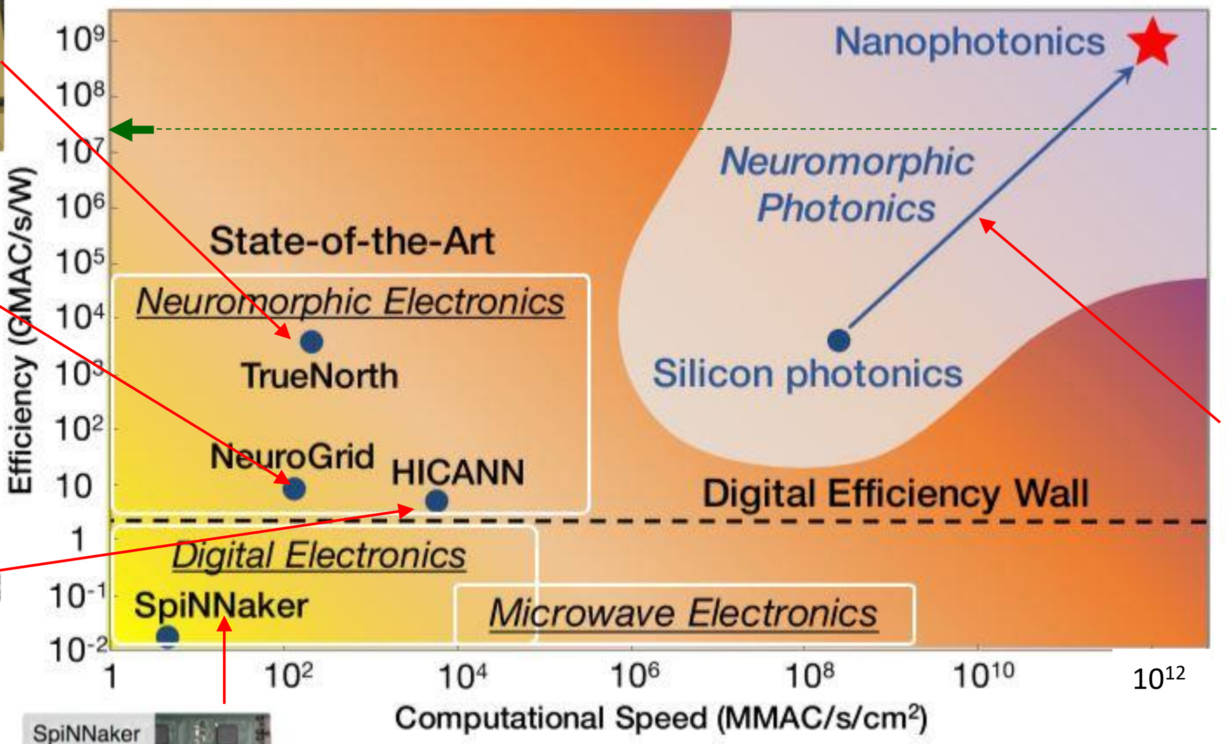
MAC : Multiply – Accumulate : $a \leftarrow a + b \times c$

« Principle of Neuromorphic Photonics », B.J. Shastri, …, P.R. Prucnal, Princetown, USA, 2018, ArXiv

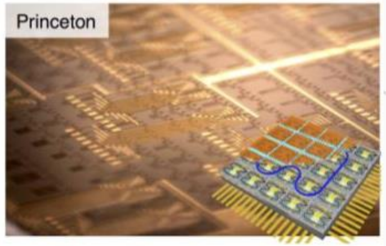








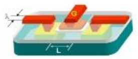
Human Brain :
10^{18} MAC/s
Pour 20W
1300 cm^3 et
1,5 kg

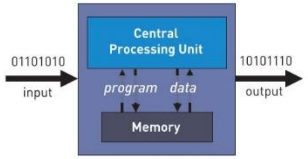


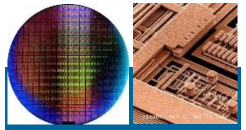
→ Photonic neuromorphic chips
High velocity, parallelism and low energy

JOIN COMPUTER SCIENCE AND COMMUNICATION PHOTONICS

sequential



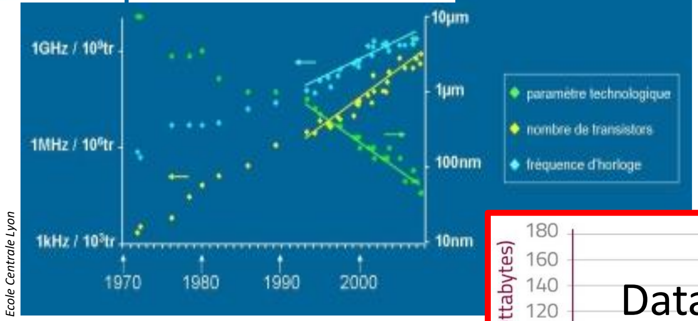


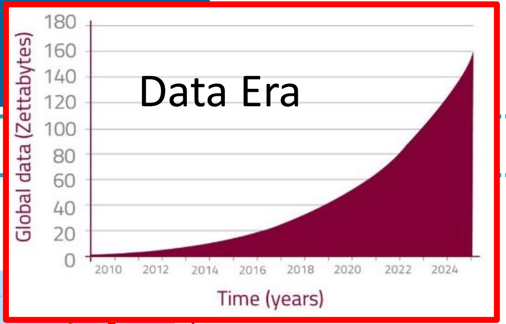


parallel

Electrons

Data processing

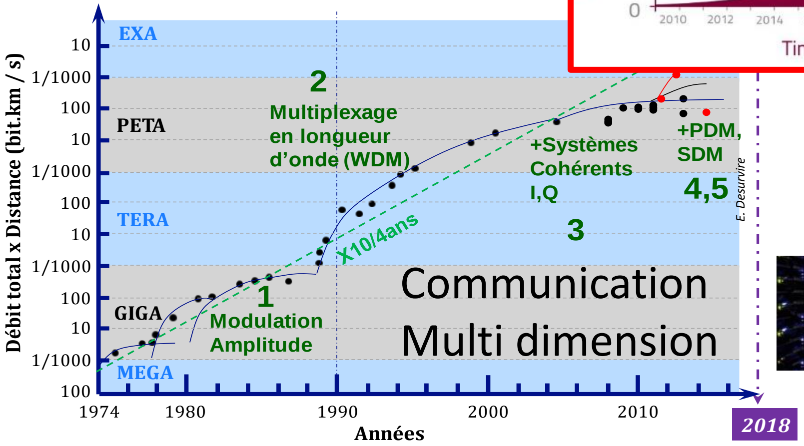




Era of computer science and communications

Photons

data transport

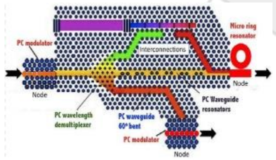


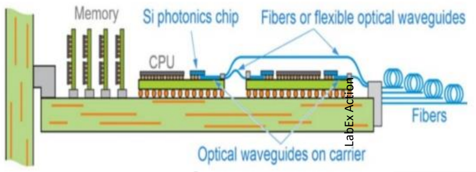
10 % world energy ?

Energy wall

(100 MW)

Hybridation
Elec / Photon ?





Neuromorphic?

Quantum computing ?

Examples of promising photonic systems and use cases

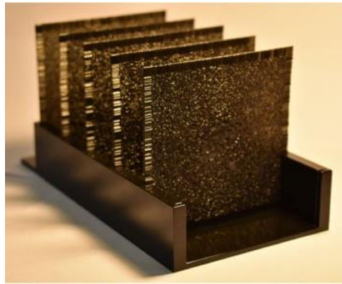
EXAMPLES OF OPTICS / AI

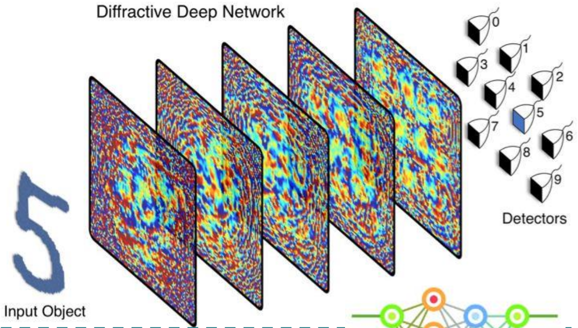
Scattering media→
Sparse random matrix
regularisation, SVM

Optical interference
Spatial light modulator →

Parallel
processing

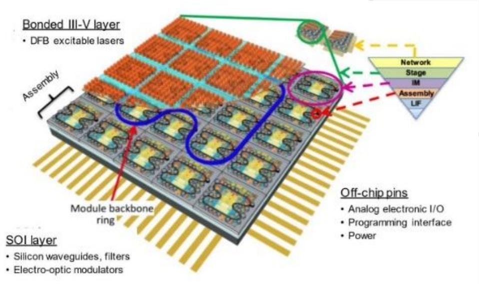
Diffractive media
(UCLA)

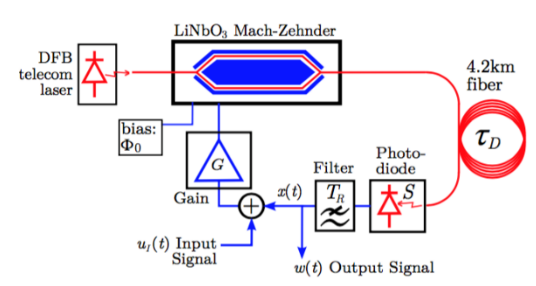




Nonlinear dynamic systems

Neuromorphic photonic
Reservoir computing

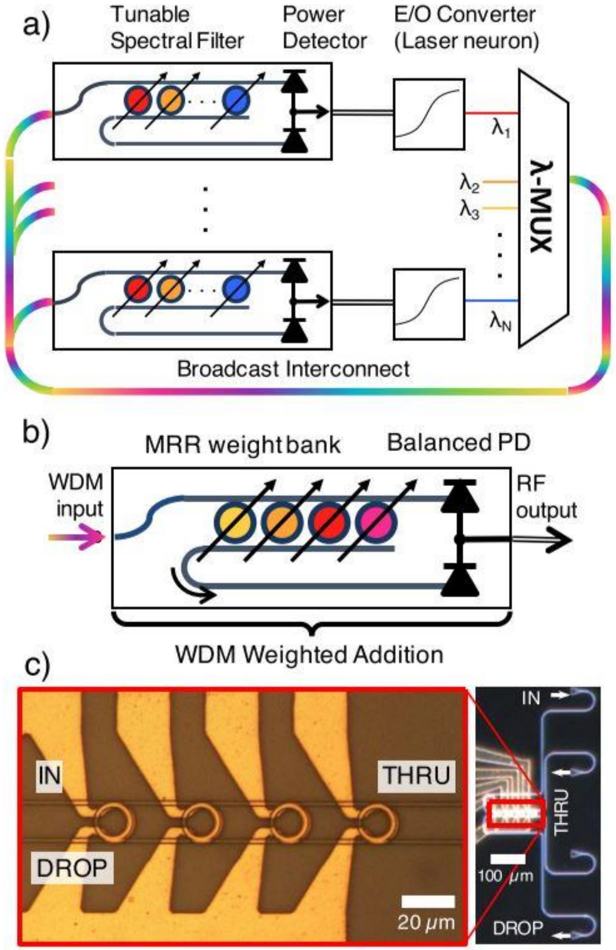


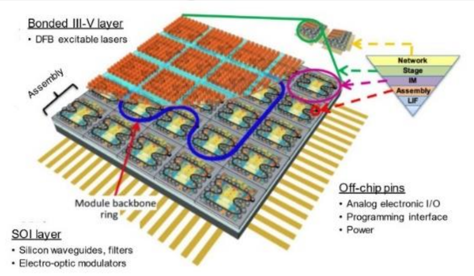


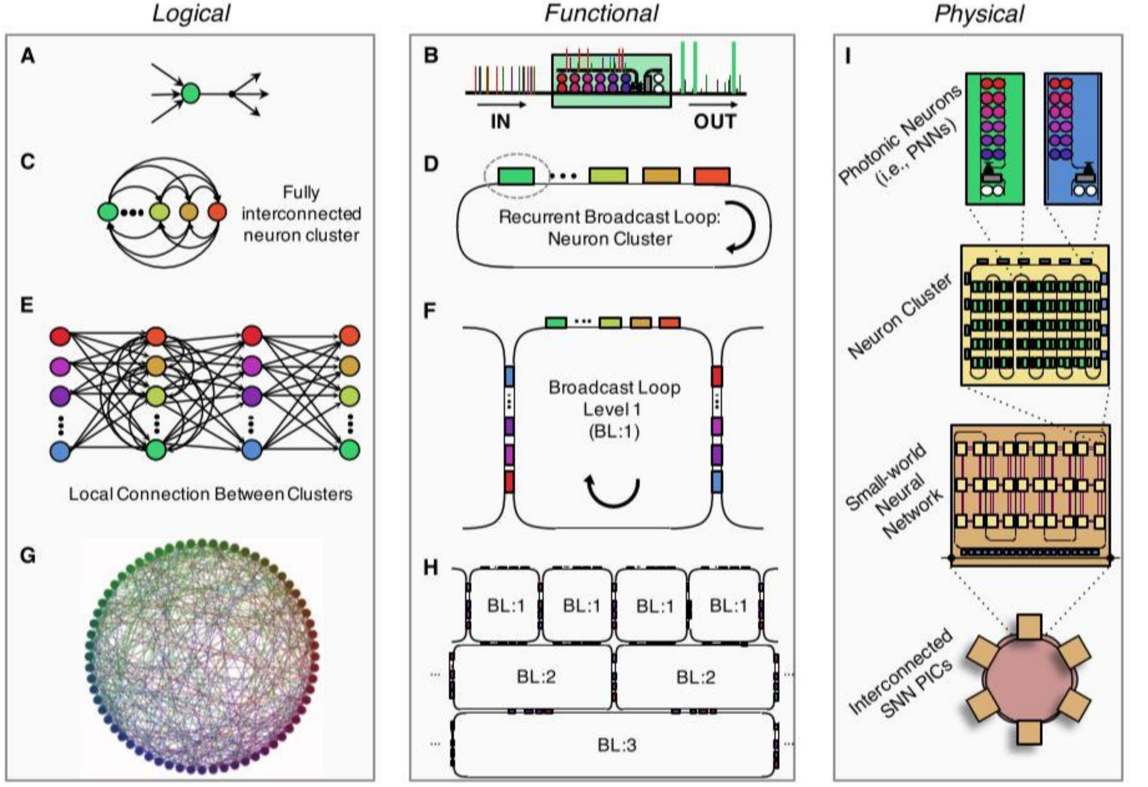
Princetown

FEMTO-ST

EXAMPLE OF PHOTONIC NEURAL NETWORKS



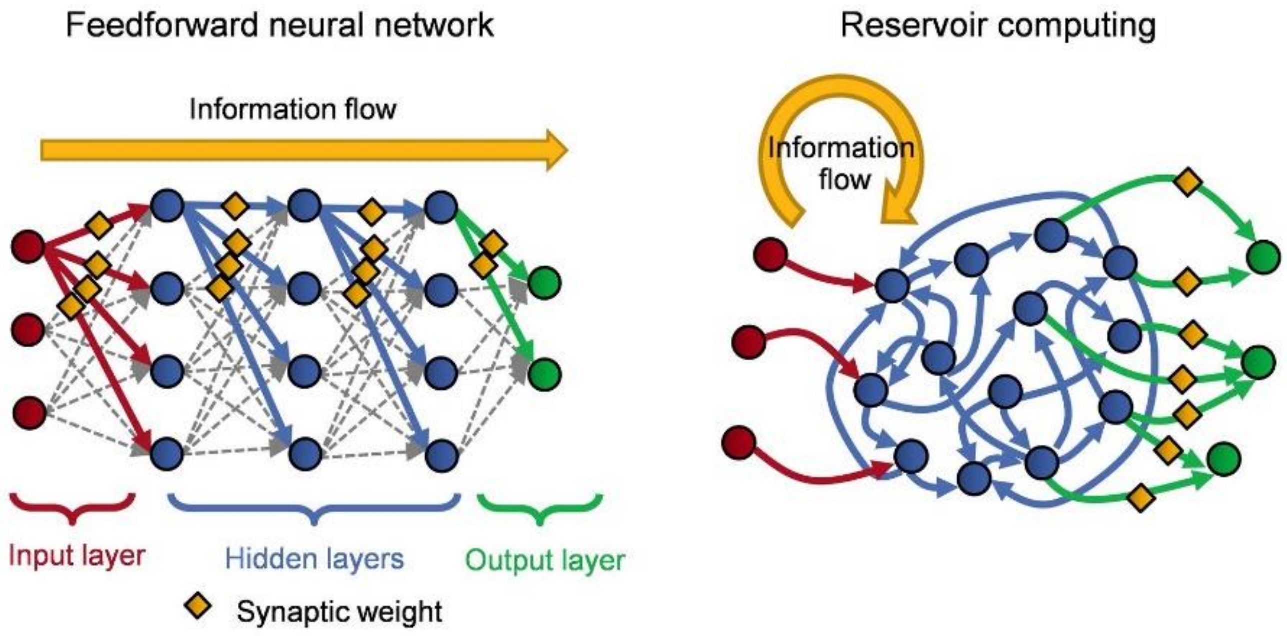


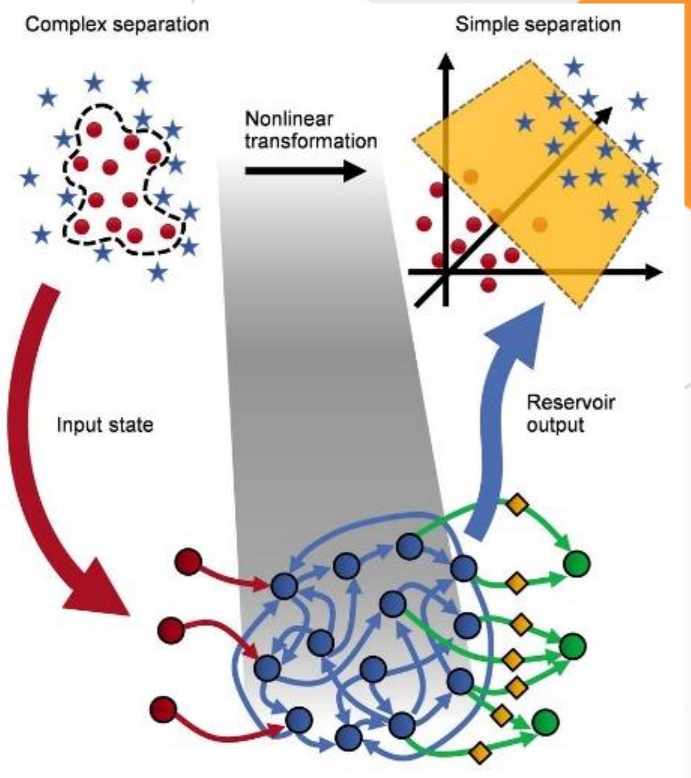


« Principle of Neuromorphic Photonics », B.J. Shastri, …, P.R. Prucnal, Princetown, USA, 2018, ArXiv

A GOOD STARTING CONCEPT : RESERVOIR COMPUTING

An interesting starting principle : Reservoir computing



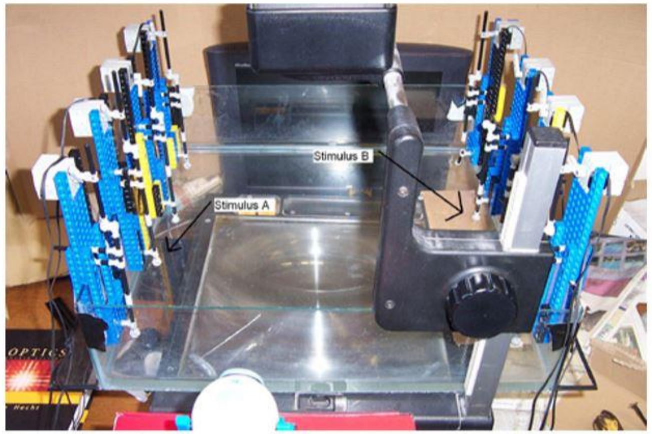


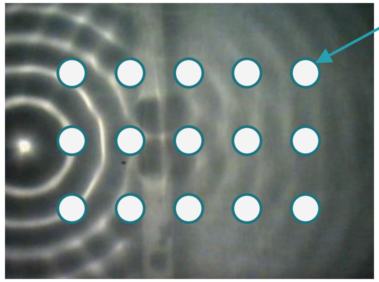
PHYSICAL SYSTEMS AS RESERVOIR COMPUTING

IMAGINATION IS THE UNIQUE LIMIT

Examples of promising photonic systems and use cases

Chrisantha Fernando et SampsaSojakka, « Pattern recognition in a bucket. », Proceedings of the 7th European Conference on Advances in Artificial Life, ECAL 2003, pages 588–597, 2003. 68, 69





Neurons state
Water height at different surface points

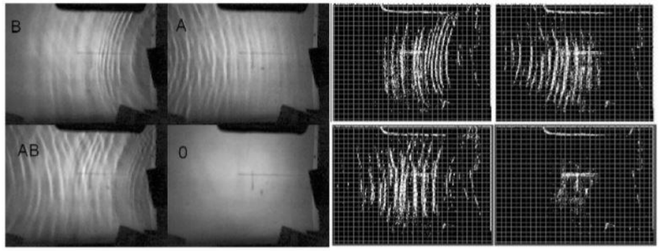
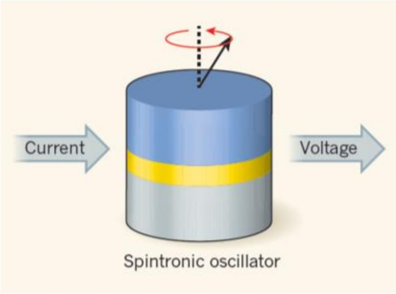


FIGURE 3.5 – Motif produit par les vagues pour la tâche "OU exclusif" avec le "Liquid Brain". (Gauche) Les images prises par la webcam pour différentes conditions d'activation des moteurs A et B. (Droite) Images traitées avec un filtre Sobel et seuillées correspondantes. Image provenant de [FS03].

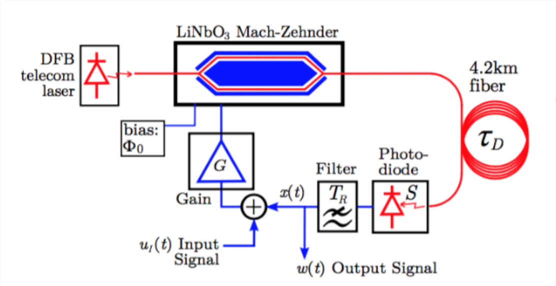
Spintronics



Spin-torque oscillator

Torrejon et al., Nature 547, 7664 (2017)
J. Grollier et al, Nature electronics (2020)

Photonics



Source: Photonic information processing beyond Turing: an optoelectronic implementation of reservoir computing
L. Larger et al

EXAMPLES OF PHOTONIC RESERVOIR

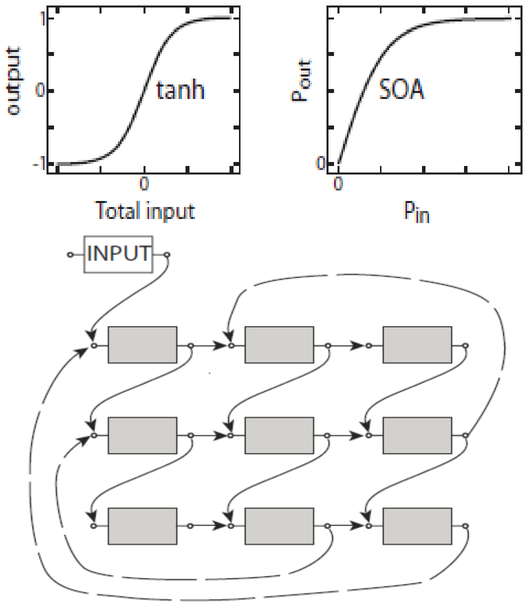
CLASSIFICATION

- Photonic reservoir computing
  - Spatially distributed
    - Chip silicon photonic
    - Diffractively coupled VCSEL
  - Delay based
    - Optoelectronic delay based
    - All optical delay based

SPATIAL RESERVOIR COMPUTERS

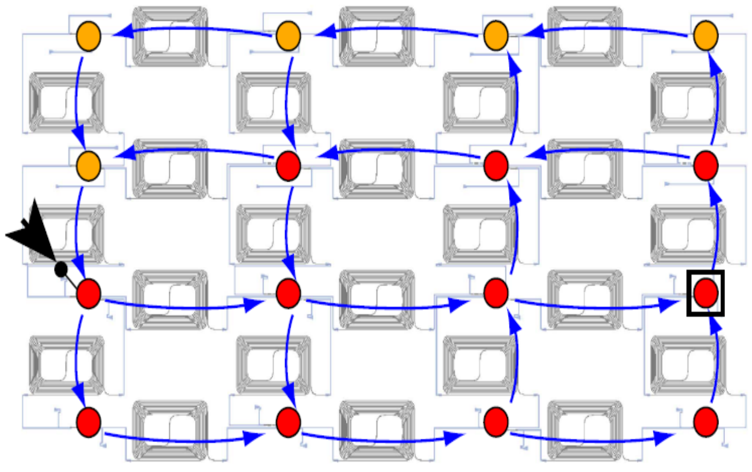
WITH DIFFERENT USE CASES

Source : Vandoorne K, Dierckx W, Schrauwen B, et al. Toward optical signal processing using photonic reservoir computing. Opt Express 2008;16:11182.



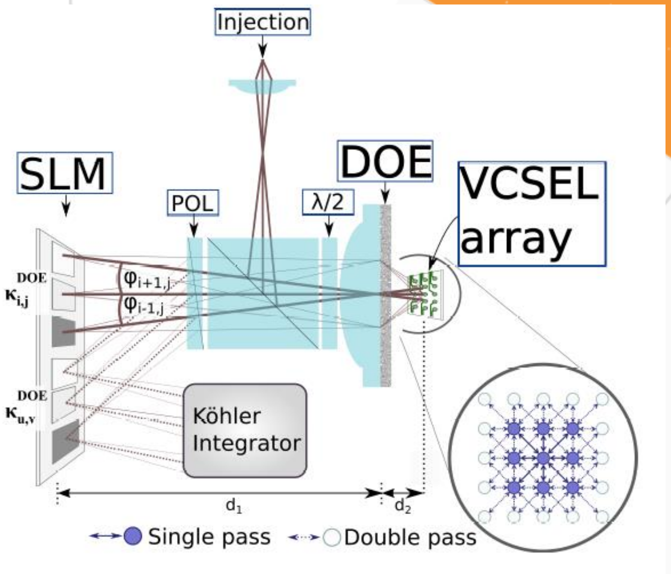
→ Applied to square signals recognitions

Source : Vandoorne K, Dambre J, Verstraeten D, Schrauwen B, Bienstman P. Parallel reservoir computing using optical amplifiers. IEEE Trans Neural Netw 2011;22:1469–81.



→ Applied to boolean operation and binary pattern recognition (header)

Source : Brunner D, Fischer I. Reconfigurable semiconductor laser networks based on diffractive coupling. Opt lett 2015;40:3854.

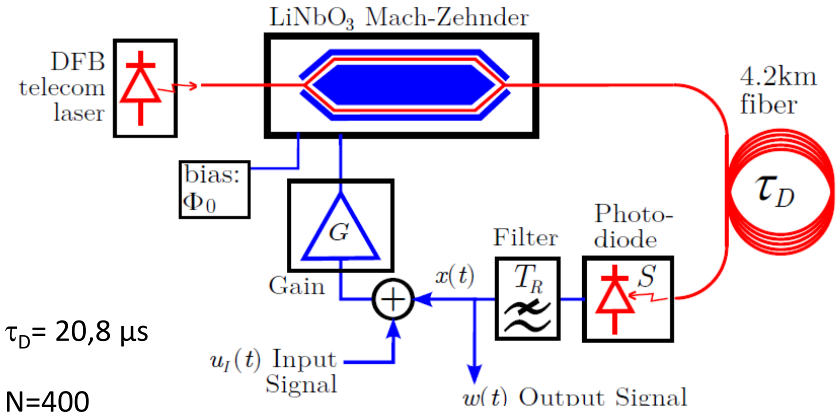


→ Applied to chaotic series prediction

PHOTONIC TIME-DELAYED RESERVOIR

Opto-electronic reservoir

Source: Photonic information processing beyond Turing: an optoelectronic implementation of reservoir computing
L. Larger, M. C. Soriano, D. Brunner, *L. Appeltant, J. M.* Gutierrez, L. Pesquera, C. R. Mirasso, and I. Fischer

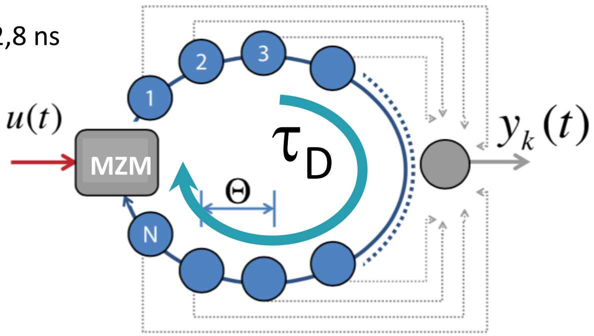


τ_D= 20,8 µs

N=400

θ= 20,8 µs / 400=52,8 ns

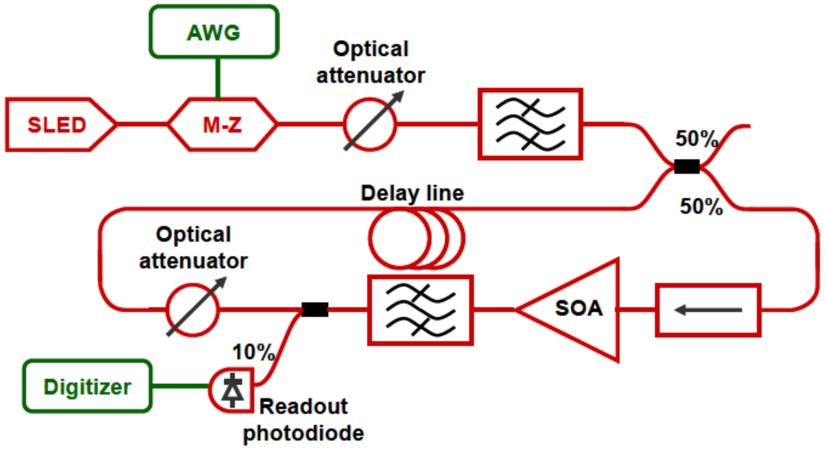
T_R= 240 ns



→ Applied to voice digit recognition

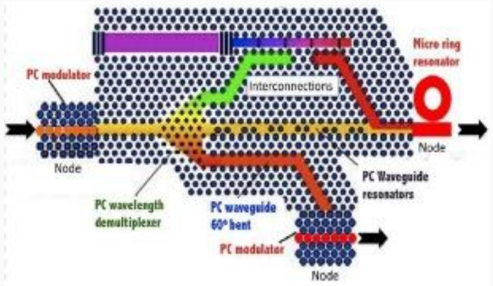
All optical reservoir

François Duport, Bendix Schneider, Anteo Smerieri, Marc Haelterman, and Serge Massar. All-optical reservoir computing. *Opt. Express, 20(20):22783–22795, Sep* 2012.



→ Voice digit recognition, equalization, radar

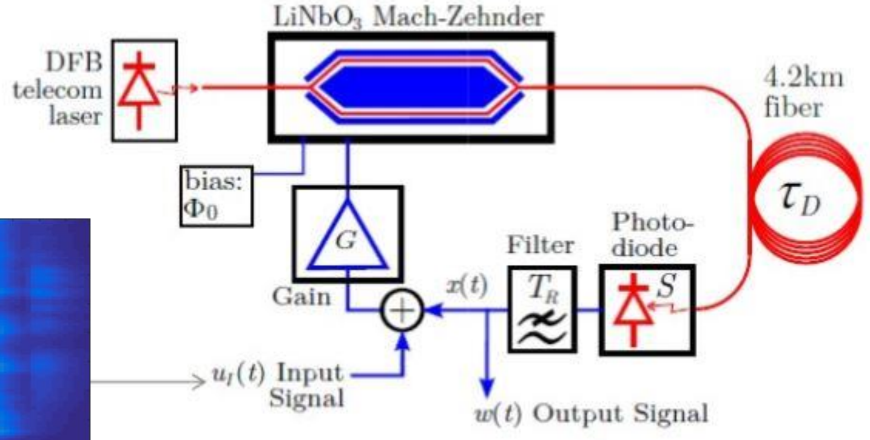
Nanophotonics

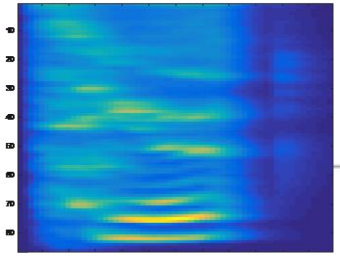


P. Bienstman, Ghent University
Photonic bandgap integrated circuits

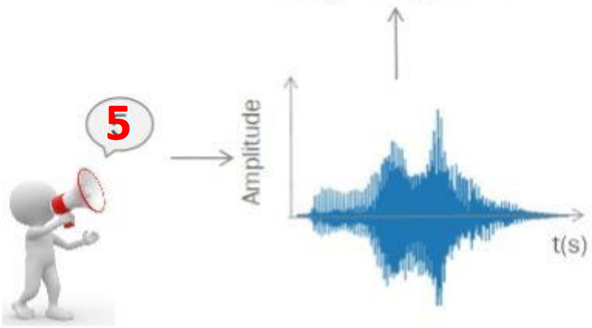
TIME-DELAYED RESERVOIR : EXAMPLE OF USE CASE

VOICE DIGIT RECOGNITION PRINCIPLE



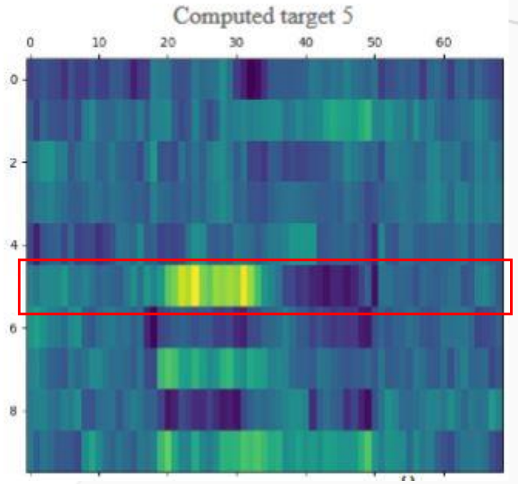


Time-frequency analysis



Transient response

Linear Regression



1 million words per second with 5% word error rate (WER) without fine tuning

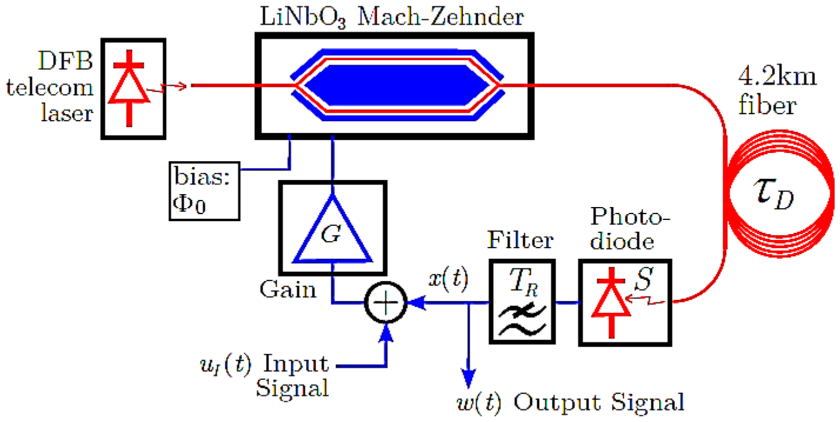
One first research path explored in Télécom Sudparis on photonic Reservoir computing

PHOTONIC RESERVOIR COMPUTING AT TELECOM SUDPARIS

PHD STUDENT : NICKSON MWAMSOJO

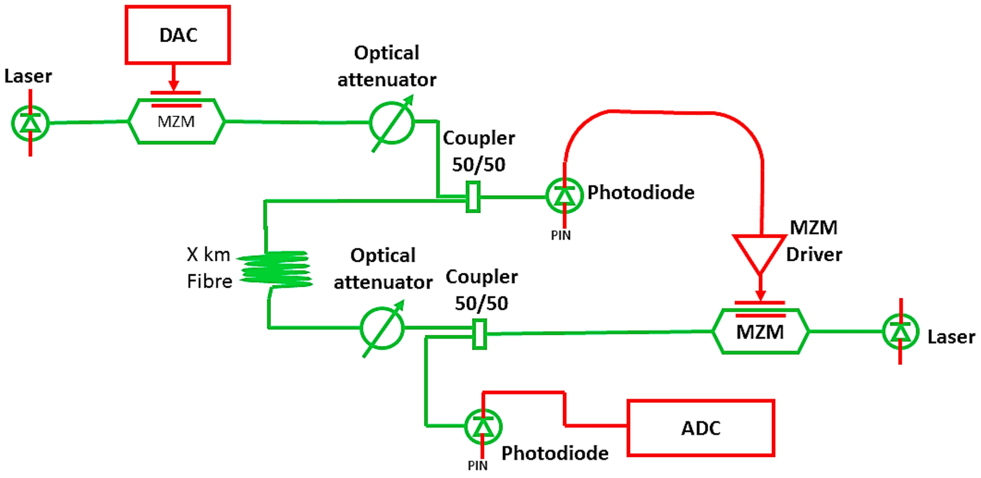
One first research path explored in Télécom Sudparis on photonic Reservoir computing

Opto-electronic reservoir



Source: Photonic information processing beyond Turing: an optoelectronic implementation of reservoir computing
L. Larger, M. C. Soriano, D. Brunner, *L. Appeltant, J. M.* Gutierrez, L. Pesquera, C. R. Mirasso, and I. Fischer

All optical reservoir



PHOTONIC RESERVOIR COMPUTING AT TELECOM SUDPARIS

PHD STUDENT : NICKSON MWAMSOJO

Simulations of the two setups yielded the following results on a speech recognition benchmark task with Word Error Rate (WER) as a performance metric

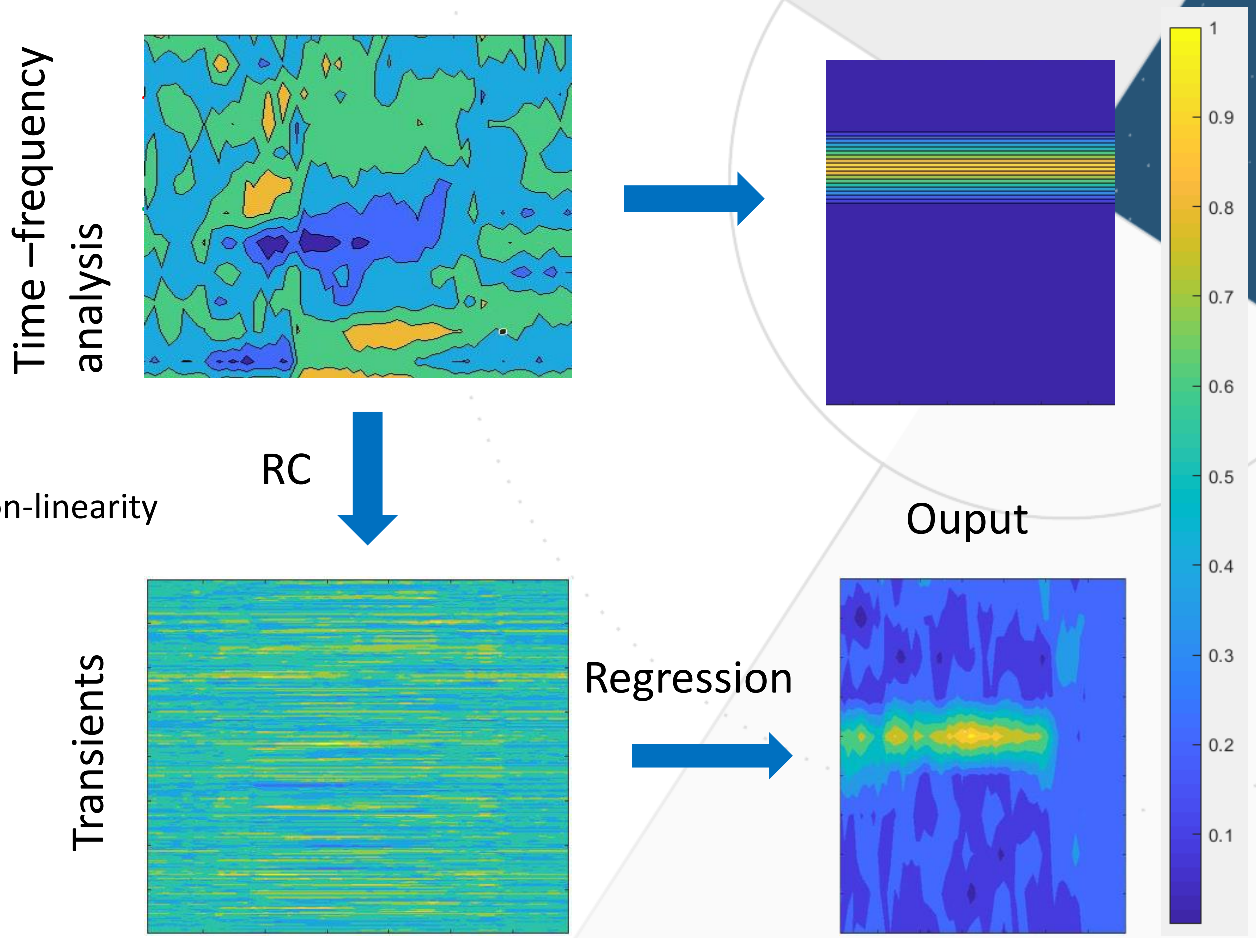
FOR LARGER'S SETUP

WER = 1,93% (400 neurons)

Demonstration of performance dependence on the non-linearity

FOR THE FULLY OPTICAL SETUP

WER = 1,4% (400 neurons)



One first research path explored in Télécom Sudparis on photonic Reservoir computing

PHOTONIC RESERVOIR COMPUTING AT TELECOM SUDPARIS

PHD STUDENT : NICKSON MWAMSOJO

One first research path explored in Télécom Sudparis on photonic Reservoir computing

Experimental realisation of these two setups yielded the following results

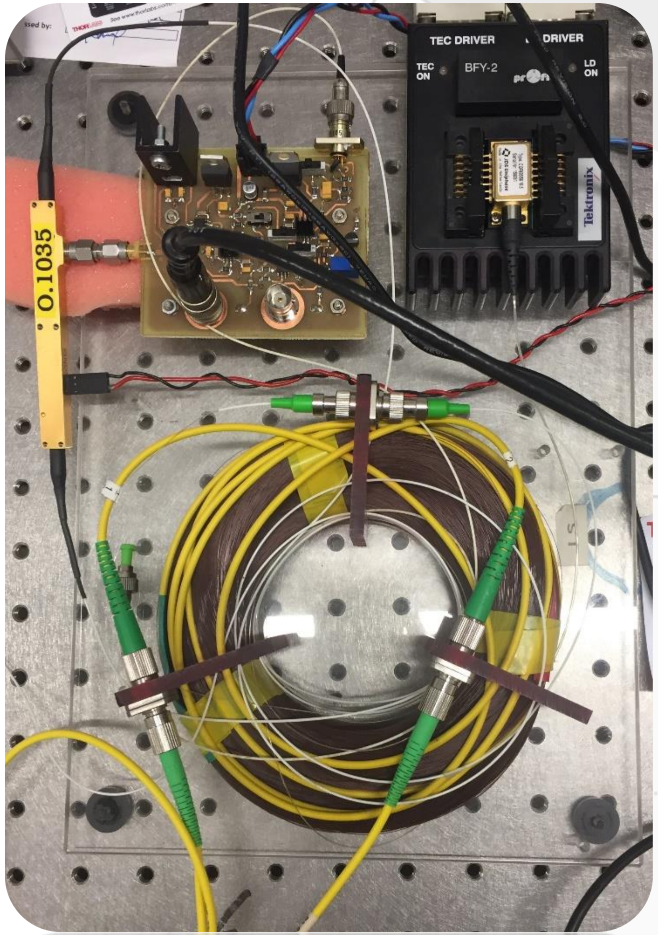
FOR LARGER'S SETUP

WER = 4.8% (400 neurons)

Demonstration of performance dependence on the non-linearity

FOR THE FULLY OPTICAL SETUP

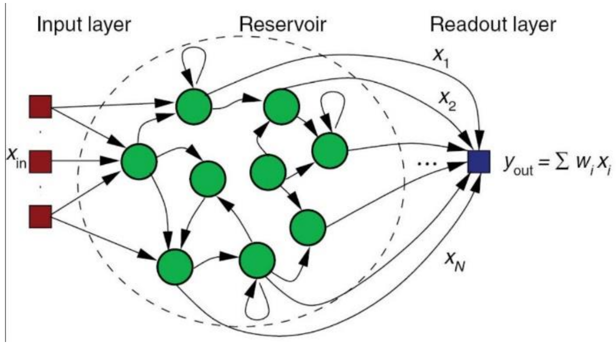
WER = 4.19% (400 neurons)

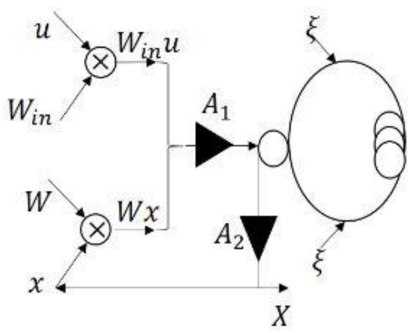


TIME DELAYED RESERVOIR

OTHER USE CASES

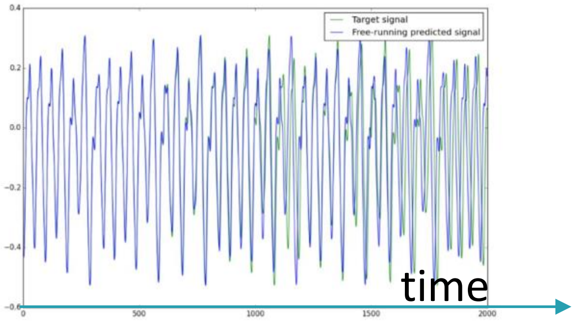
One first research path explored in Télécom Sudparis on photonic Reservoir computing

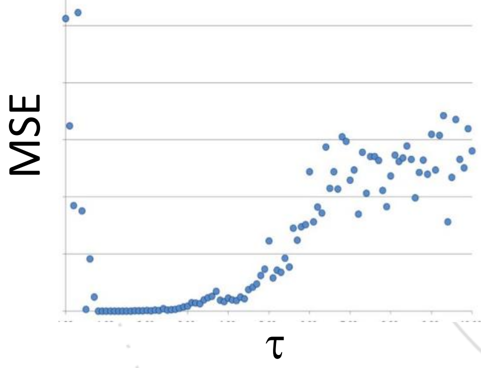




Source : Sorokina et al. , Aston university
ECOC 2018, Roma, Italy

Time series prediction : ex. Mackey-Glass





Optical communication signal equalization

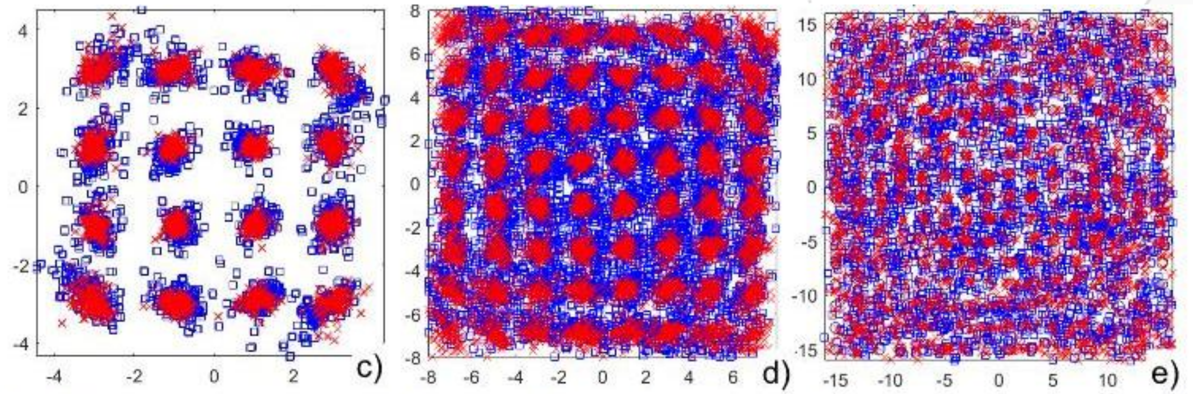


Fig. 2: Fiber reservoir computing for 16-,64-, and 256-QAM signal processing a) Q^2-improvement due to FORC-processing over linear equalization. The reservoir and signal parameters are the same as in Fig.1 with sampling rate 16. b) The corresponding BER. c) 16-, d) 64-, and e) 256-QAM modulated signal after linear equalization (blue) and FORC processing (red).

OVERVIEW AND EXAMPLES OF PROMISING PHOTONIC SYSTEMS FOR DATA PROCESSING USE CASES

ELECTRICAL ENGINEERING
ARTIFICIAL INTELLIGENCE DAY

Conclusions and perspectives

First very interesting starting examples

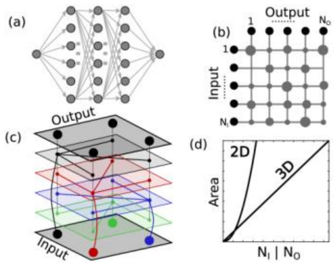
road to reach the velocity / energy objectives will be long

Photonic neural network mimics (or other physical hardware)

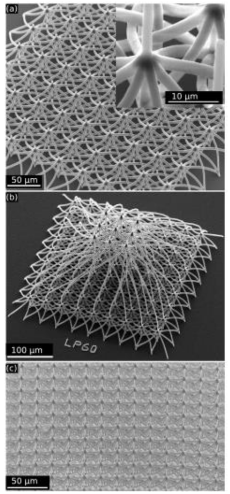
→ Mimic the brain adressing all directions : networks, neurons, memory, learning, noise

… From Daniel Brunner, FEMTO-ST

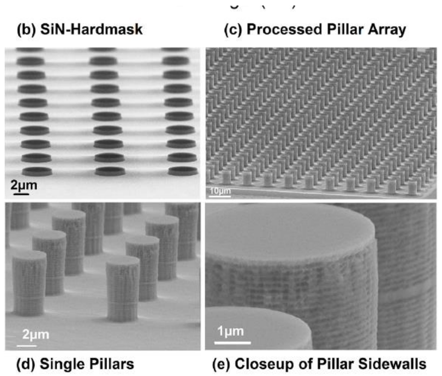
Networks



Moughames, et al. Optica 7, 640 (2020)



Photonic neurons



Heuser et al., J. Appl. Phys. 3, 116103 (2018)

Hardware-motivated learning

Bueno et al., Optica 5,756 (2015)