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PRIX ANTONELLA KARLSON 2017

18 DÉCEMBRE 2017

Pour tout renseignement :

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PRIX ANTONELLA KARLSON

2017

Le Fonds de la Recherche Scientifique - FNRS accorde, tous les deux ans, depuis 2011, le "Prix Antonella Karlson" récompensant une thèse de doctorat dans un domaine des sciences exactes, incluant la physique, la chimie, les mathématiques, l'informatique et les sciences appliquées.
Ce Prix a été créé à la mémoire de Mme Antonella Karlson, physicienne d'origine bulgare établie en Belgique.

Antonella Karlson naquit en Bulgarie en 1960 et obtint un diplôme en physique de l'Université de Sofia avec une thèse intitulée "*SU(4) Unification of Electroweak Interaction in a Curved Space*".

Après une spécialisation en Quantum Field Theory, elle quitta la Bulgarie, alors sous régime communiste, et parti entreprendre un doctorat aux Etats-Unis. Le thème de sa thèse portait sur la "*Stabilization of Positronium by Laser Fields*". Elle vécut sept ans en Amérique ; donna des cours à l'université la journée et travailla de nuit comme House Manager et Security Coordinator pour payer sa chambre à l'International House.

En 1995, elle arriva en Belgique à l'ULB avec une bourse postdoctorale et s'installa à Bruxelles. En 2001, après différents travaux, elle entra en tant que Scientific Officer dans l'unité FET de la Commission européenne. Antonella Karlson coordonna l'initiative Quantum Information Processing and Communication et était très fière d'avoir réussi à rassembler les scientifiques européens autour de cette initiative.
En 2007, la malchance arriva sous la forme d'un cancer qui l'emporta en quelques mois.

Quand elle arriva aux Etats-Unis, elle avait seulement 24 dollars en poche. Mais pour Antonella Karlson, la physique et la science en général étaient, selon ses mots, "*une religion*" qui pouvait justifier tous les sacrifices.

C'est en se souvenant de cela que ses parents et son conjoint ont décidé de fonder le Prix Antonella Karlson : pour aider des jeunes chercheurs à avoir les ressources et le temps nécessaire pour trouver leur chemin.

PRIX ANTONELLA KARLSON

2017

› Le Prix 2017 a été attribué à :

Quentin VINCKIER

Docteur en Sciences de l'ingénieur et technologie - ULB
Chercheur Postdoctoral - NASA Jet Propulsion Laboratory, CalTech, USA

pour son travail :

Processeurs photoniques analogiques bio-inspirés basés sur le paradigme du reservoir computing.

For many challenging problems where the mathematical description is not explicitly defined, such as image classification or language processing, artificial intelligence (AI) appears to be much more robust compared to traditional algorithms. Such methods share the common property of learning from examples in order to "explore" the problem to solve. Then, they generalize these examples to new and unseen input signals.

The Reservoir Computing (RC) paradigm is a powerful AI approach which considerably reduces the implementation complexity compared to traditional AI methods. During my PhD research, I have designed and studied three original optical processors that physically implement the RC dynamics. On many hard nonlinear tasks, we have successfully demonstrated, both in simulation and experimentally, outstanding results that remain unsurpassed to our knowledge. Besides, the optical design of our systems may potentially lead to surpass electronic computers in speed and power consumption, paving the way towards the dream of high performance all-optical computing.

MEMBRES DU JURY 2017

DELAUDE Lionel	Professeur ULiège
FUSTIN Charles-André	Maître de recherches du F.R.S.-FNRS UCL
FÜZFA André	Professeur UNamur
LEEMANS Dimitri	Professeur ULB
MICHAUX Christian ***Président du Jury***	Professeur UMONS

* * *

FORTI Gian Luigi ***Observateur***	Représentant du mécène

Quentin VINCKIER
ULB

"Processeurs photoniques analogiques bio-inspirés basés sur le paradigme du reservoir computing."

Résumé

Research objectives

For many challenging problems where the mathematical description is not explicitly defined, artificial intelligence (i.e. bio-inspired) methods appear to be much more robust compared to traditional algorithms. Such methods share the common property of learning from examples in order to "explore" the problem to solve. Then, they generalize these examples to new and unseen input signals. The reservoir computing paradigm is a powerful bio-inspired approach drawn from the theory of artificial recurrent neural network (ARNN) to analogically process time-dependent signals. It was proposed almost simultaneously and independently by several research groups in the early 2000s [1,2]. Its low mathematical complexity compared to traditional artificial intelligence algorithms makes it a truly great candidate to solve hard nontrivial tasks more efficiently. These tasks include for instance grammar modeling, speech recognition, detection of epileptic seizures, robot control, time series prediction, brain-machine interfacing, power system monitoring, financial forecasting, or handwriting recognition.

Of course, reservoir computer (RC) algorithms can be programmed using modern electronic digital processors. But these electronic processors are better suited to digital processing, for which a lot of transistors continuously need to be switched on and off, leading to high power consumption. As we can intuitively understand, processors with hardware directly dedicated to RC operations – in other words analog bio-inspired processors – could be much more efficient regarding both speed and power consumption. Based on the same idea of high speed and low power consumption, the last few decades have seen an increasing use of coherent optics (i.e. laser light) in the transport of information thanks to its high speed and high power efficiency. This is the reason why a significant part of today's research is focused on all-optical processing. Another reason for which we need to switch gradually from electronics towards photonics technology is the cooling problem of electronic processors breaking the empirical Moore's law (the two-year doubling in the density of the transistors integrated on a silicon chip) [3]. Indeed, faster processors require a larger number of transistors per area unit, leading to an increase of the power consumption and the difficulty to cool the device. Photonics can play a key role in avoiding this problem by offering a large variety of passive devices. In order to address the future challenge of high performance, high speed and power efficient nontrivial computing, my research was devoted to the design and conception of photonic implementations of RCs using coherent light.

Reservoir computer principle

A standard reservoir computer is composed of three different layers. There is first the artificial neural network itself, called "reservoir", which consists of N internal variables $x_i(n)$ (also called "neurons") randomly interconnected together, where *n* is the discrete time variable. Through an input layer, the input signal(s) $u_k(n)$ is (are) injected into the reservoir. Then, in an output layer, the output signal(s) $y_p(n)$ is (are) computed by taking a linear combination of the $x_i(n)$. The mathematical description of a standard RC is given by

$$x_i(n) = F_{nl}\left[\sum_{j=0}^{N-1} \alpha a_{ij} x_j(n-1) + \sum_k \beta m_{ik} u_k(n) + \gamma\right], \quad (1)$$

$$y_p(n) = \sum_{i=0}^{N-1} w_{ip} x_i(n), \quad (2)$$

where F_{nl} is a nonlinear function which is essential to solve nonlinear tasks, a_{ij} is the interconnection matrix between the neurons, α is the feedback gain, m_{ik} is the input mask, β is the input gain, γ is a bias on the input signal, and w_{ik} are the readout weights. During a training phase, the first part of the input sequence $u_k(n)$ is used to optimize α, β, γ and w_{ip} by minimizing the mean square error $\langle [y_p{}^*(n) - y_p(n)]^2 \rangle_n$, where $y_p{}^*(n)$ is (are) the target signal(s). Then, during the test phase, the optimized α, β, γ and w_{ip} are kept fixed and the output signal(s) $y_p(n)$ is (are) computed using the rest of the input sequence. The principal novelty of the reservoir computing paradigm compared to traditional ARNNs is that a_{ij} and m_{ik} can be generated randomly, and only α, β, γ and w_{ip} need to be optimized. The architecture of a standard reservoir computer is illustrated in Fig. 1.

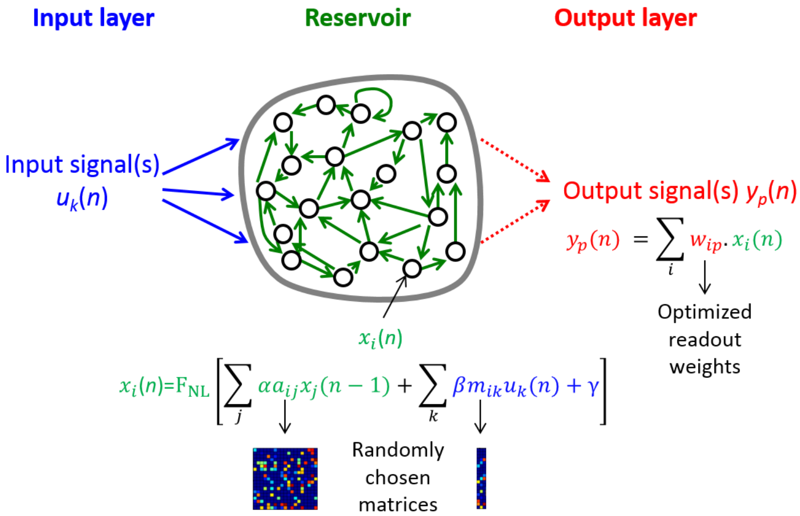

Figure 1 – Standard reservoir computer architecture

Optical implementations of reservoir computers

Recently, physical implementations of RCs have provided a breakthrough in information processing, especially in optical information processing. Several experiments with a reservoir based on active opto(electronic) components have been demonstrated prior to our research [4-8]. All these experiments encode signals in the intensity of the light and use a non-linearity provided by an active element (i.e. element that consumes power) in the reservoir layer.

During my PhD research, I have theoretically studied three original RC implementations on a wide range of hard nonlinear tasks by performing simulations on a computer, and I have successfully built two of these challenging optical processors using fiber optics components. Each of these RC implementations sequentially generates the neurons states given by Eq. (1). For the first time, we have demonstrated RC architectures based on a passive (rather than active) linear reservoir. The absence of active elements in the reservoir layer removes a major source of noise, therefore, improves performance. It also makes the system power efficient, as the reservoir itself does not consume any power. Actually, the total optical power injected in the neural network (0.57 mW peak power) is – to our knowledge – the lowest used so far. Another major novelty is that our RCs work with coherent light (laser light), thereby aiming to encode the signals in both the amplitude and the phase of the light rather than just in its intensity, as it was previously the case. These key features guarantee low error rates on a number of hard nonlinear tasks, and have led to performance that – to our knowledge – remain unequaled.

The first optical RC-based processor I have built has the particularity to implement a square non-linearity in the output layer with a fully linear reservoir layer, while all previous RC implementations use a standard nonlinear reservoir (see Eq. (1)) and linear output layer (see Eq. (2)) [9,10]. This original idea was first proposed by the University of Ghent with which our research group has collaborated. Because our system works with coherent light, the length of the optical fiber used to build the reservoir layer (which is actually a large ring optical interferometer) needs to be stabilized with an extreme precision against length fluctuations induced by ambient thermal, acoustic and vibrational noise. In order to address this huge experimental challenge, we have designed an isolation system and a fiber length controlling system to reach an impressing stabilization precision of ~ 4 nm (this is equal to 1 mm divided by 250 000!) over 230 m of optics fiber! Using 50 neurons, the output refresh rate of this processor is equal to 0.9 MHz and can be seen as the processing speed of our RC. In the future, smaller, possibly even integrated, reservoir may in principle enable far faster system and much simpler stabilization. On a wide variety of tasks, both in simulation and experimentally, our setup has demonstrated error rates which are – to our knowledge – still unsurpassed by other experiments [9,10]. This high performance is attributed among others to the use of a passive and thus less noisy linear reservoir, and a quadratic non-linearity in the output layer. As an example, we have performed a spoken digit recognition task over 500 digits without any miss-identified spoken digit using 50 neurons. In order to make the task more challenging, by using a signal-to-noise ratio of 3 dB on the input signal, we have obtained error rates as low as 0.8 % using 500 neurons.

The first optical RC-based processor I have built needs an external computer in order to perform the weighted summation given by Eq. (2), partially canceling the main advantages of working with optics. The second optical RC-based processor I have built has highlighted for the first time the possibility of processing information autonomously and all-optically (i.e. the reservoir is fully optical; the output is also generated optically by the RC itself and not by an external computer as it was previously the case) [10,11]. This second architecture implements a sine nonlinearity on the input signal, whereas both the reservoir itself and the readout layer are kept linear. Using 50 neurons, the processing speed of this second system is equal to 0.58 MHz. Very promising experimental results were obtained on several tasks.

Conclusions and perspectives

The development of photonic reservoir computing is a very new, fast moving research area with high potential impact in future information processing technologies. To address tomorrow's nontrivial computing challenges, we have studied three original RC implementations on a wide range of hard nonlinear tasks, and we have successfully implemented two of these challenging systems in experiment. On several hard nonlinear tasks, our RCs perform outstanding results that – to our knowledge – remain unsurpassed. Such stunning improvements result from the very nature of the new algorithms implemented by our specific RC architectures. Besides, the passive nature of some of the optical components we have used and the scalable processing speed of our RC may potentially lead to surpass modern digital electronic processors both in speed and power consumption. Last but not least, our latest experiment constitutes the first autonomous reservoir computer able to process information all-optically without the need of any external computer connected to the system.

In the future, the next step would be to implement autonomous photonic RCs able to process the neuron states in parallel rather than sequentially, thus enhancing significant further speedup. This would constitute an essential milestone towards the development of ultrahigh speed photonic bio-inspired processors. Then, the integration of such systems on a chip may quickly turn these laboratory curiosities into real industrial applications, paving the way towards the dream of high performance all-optical ultrafast computing.

Bibliography

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[2] W. Maass, et al., Neural computation 14(11) (2002), pp. 2531–2560
[3] L. B. Kish, Physics Letters A 305(2) (2002), pp. 144–149
[4] F. Duport, et al., Optics express 20(20) (2012), pp. 22783–22795
[5] L. Appeltant et al., Nature communications 2.468 (2011)
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[10] Q. Vinckier, PhD thesis, Université libre de Bruxelles (2016)
[11] Q. Vinckier et al., CLEO: 2016. Optical Society of America, 2016, SF1F.1

Curriculum Vitae

PERSONAL INFORMATION

Quentin Vinckier

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POSITION

Postdoctoral associate at the NASA Jet Propulsion Laboratory

My grandmother likes to remind me that, when I was a child, I loved disassembling every machine that fell into my hands, which makes me think that I was born for Engineering Sciences. Growing up, my thirst for learning has never left me and I now aspire to contribute to tomorrow's technologies.

EMPLOYMENT

Nov. 2016

Postdoctoral associate at the NASA Jet Propulsion Laboratory

Caltech (California Institute of Technology) – NASA Jet Propulsion Laboratory – Geophysics and Planetary Geosciences Group – Pasadena (CA, USA)

- **System engineer, optical engineer and I&T engineer for the instrument of the Lunar Flashlight CubeSat mission**, whose goal is to map water ice in the permanently shadowed regions of the lunar south pole using an active multi-band reflectometer working in the 1-2 µm spectral range. I also provide support for the **instrument simulation model**.
- **Subcontract management.**
- **PhD student supervision** whose work is to assemble and calibrate a fully automated test bench that I personally designed to calibrate & characterize the optical receiver of the Lunar Flashlight mission (spectral calibration in a thermal vacuum chamber, point source transmittance characterization).

Sept. 2012 – Sept. 2016

PhD in Engineering Sciences and Technology (FRIA fellowship funded by FNRS)

ULB (Université Libre de Bruxelles) – OPERA photonics group – Brussels (Belgium)

- **PhD thesis** supervised by Prof. Marc Haelterman and Prof. Serge Massar: "Analog bio-inspired all-photonic processors based on reservoir computing paradigm". Description: Design and implementation of all-optical analogue "reservoir" computers to carry out nonlinear complex tasks in the field of information processing, using fibre-optics. This research activity is located at the intersection of two research areas: bio-inspired artificial intelligence transposed to "reservoir computing" learning system and dynamic optical systems.
- **Teaching assistant** for the Solvay Brussels School of Economics and Management. I supervised with other researchers the lab work of the theoretical course entitled "Physics of Information Technologies" (subjects: electronics and information theory).
- **Master thesis supervision** whose goal was to control a caterpillar robot with artificial intelligence based on reservoir computing paradigm (Sept. 2013 - May 2014). In particular, I designed all the electronic circuits to control the robot with a wireless connection using Matlab.

Feb. – Sept. 2012

Engineer position in the field of nuclear waste treatment

ONDRAF/NIRAS – Brussels (Belgium)

Single point of contact for the radioactive waste producers (informing the producers: price, conditioning criteria before the waste care, treatment process, etc.; characterisation calculations; on-site measurements, etc.).

EDUCATION AND TRAINING

Sept. 2012 – Sept. 2016

PhD in Engineering Sciences and Technology

ULB (Université Libre de Bruxelles) – OPERA photonics group – Brussels (Belgium)

Sept. 2009 – June 2011

Master in Physics and Nuclear Engineering (Score: High honours)

ISIB (Institut Supérieur Industriel de Bruxelles) – Brussels (Belgium)

Principal subjects covered: Mathematics, nuclear physics, linear optics, general physics, radioprotection, materials physics, nuclear medicine, radiotherapy, radiology, chemistry, radio-chemistry, electronics, informatics, electricity, mechanics, risk analysis, project and quality management, entrepreneurial management.

Feb. – June 2011

Research student

ITN (Instituto Tecnológico e Nuclear) – Sacavém (Portugal)

Master thesis: "Neutron and gamma radiation effects on the behaviour of HEMT and MOSFET transistors". This work includes **theory**, **simulations** (Monte-Carlo simulations with MCNP coupled with SRIM simulations) and **experimental studies**.

Sept. 2006 - June 2009

Bachelor in Technological Engineering (Score: High honours)

ISIB (Institut Supérieur Industriel de Bruxelles) – Brussels (Belgium)

Principal subjects covered: Mathematics, nuclear physics, general physics, radiology, chemistry, electronics, automation, informatics, electricity, mechanics, electro-mechanics, materials science, graphic techniques, thermodynamics.

Feb. – June 2009

Student internship

Clinique Saint-Jean – Brussels (Belgium)

Dosimetry studies in conventional radiology and computed tomography.

PRIZES & AWARDS

2017 Antonella Karlson Prize

Fund for Scientific Research-FNRS (F.R.S.-FNRS) – Brussels (Belgium)

Prize awarded biennially for a doctoral thesis defended by candidates affiliated to a University of the Belgian Wallonia-Brussels Federation in a domain of exact sciences, including physics, chemistry, mathematics, IT and applied sciences.

PUBLICATIONS & CONFERENCES

Published papers in scientific journals

- **Q. Vinckier**, F. Duport, A. Smerieri, K. Vandoorne, P. Bienstman, M. Haelterman, and S. Massar, “High-performance photonic reservoir computer based on a coherently driven passive cavity,” Optica 2, 438-446 (2015).

Conference proceedings & articles (*peer-reviewed)

- **Q. Vinckier**, F. Duport, A. Smerieri, K. Vandoorne, P. Bienstman, M. Haelterman, and S. Massar, “Conception d’un ordinateur analogique tout optique de type "réservoir" à l’aide d’une cavité optique linéaire passive fonctionnant en lumière cohérente," in Journée Nationales de l’Optique Guidée (JNOG), (Société Française d'Optique, 2013) (**oral presentation**)*.
- **Q. Vinckier**, F. Duport, A. Smerieri, M. Haelterman, and S. Massar, “Information processing using a photonic reservoir computer based on a coherently driven passive cavity with an analog readout layer,” in 2015 European Conference on Lasers and Electro-Optics - European Quantum Electronics Conference, (Optical Society of America, 2015), paper CI_5_1 (**oral presentation**)*.

- **Q. Vinckier**, F. Duport, M. Haelterman, and S. Massar, "Information processing using an autonomous all-photonic reservoir computer based on coherently driven passive cavities," in Frontiers in Optics, OSA Technical Digest (online) (Optical Society of America, 2015), paper FTu3B.6 (**oral presentation**)*.
- **Q. Vinckier**, F. Duport, A. Smerieri, M. Haelterman, and S. Massar, "Autonomous bio-inspired photonic processor based on reservoir computing paradigm," in Photonics Society Summer Topical Meeting Series (SUM), (IEEE, 2016), pp. 183-184 (**oral presentation**)*.
- **Q. Vinckier**, A. Bouwens, M. Haelterman, and S. Massar, "Autonomous all-photonic processor based on reservoir computing paradigm," in CLEO: Science and Innovations, (Optical Society of America, 2016), paper SF1F-1 (**oral presentation**)*.
- M. Bauduin, **Q. Vinckier**, S. Massar, and F. Horlin, "High Performance Bio-Inspired Analog Equalizer for DVB-S2 Non-Linear Communication Channel," in Signal Processing Advances in Wireless Communications (SPAWC), (IEEE, 2016), pp. 1-5*.
- **Q. Vinckier**, K. Crabtree, C. G. Paine, P. O. Hayne, and G. R. Sellar, "Design and characterization of a low cost CubeSat multi-band optical receiver to map water ice on the lunar surface for the Lunar Flashlight mission," in Proc. SPIE 10403, Infrared Remote Sensing and Instrumentation XXV, (SPIE, 2017), paper 104030R (**oral presentation**).

Journal and conference papers in preparation

- A. Akrout, A. Bouwens, F. Duport, **Q. Vinckier**, M. Haelterman, and S. Massar, "Parallel photonic reservoir computing using frequency multiplexing of neurons," arXiv:1612.08606v1 (2016).
- P. O. Hayne, J. M. Martinez-Camacho, and **Q. Vinckier**, "Illumination and scattering for active reflectometry in the Moon's permanently shadowed regions: models for the Lunar Flashlight Mission," in preparation for *Space Sci. Rev.* (2018).
- **Q. Vinckier**, P. O. Hayne, J. M. Martiniez-Camacho, C. Paine, B. A. Cohen, U. J. Wehmeier, and R. G. Sellar, "System Performance Modeling of the Lunar Flashlight CubeSat Instrument," Submitted to the 49th Lunar and Planetary Science Conference (LPSC) (2018).
- **Q. Vinckier**, K. Crabtree, C. D. Smith, A. Dergevorkian, M. Gibson, V. Bach, U. J. Wehmeier, P. O. Hayne, and R. G. Sellar, "Optical and mechanical design of the multi-band SWIR receiver for the Lunar Flashlight CubeSat mission," in preparation for the SPIE Optical Systems Design conference (2018).

PERSONAL SKILLS

Mother tongue
French

Other languages
- English (professional working proficiency – C1 level).
- Dutch (limited working proficiency – A2 level).

Communication skills
- Sociability and rapid integration in a new environment.
- Ability to synthesize principal ideas of complex subjects in tight and rigorous presentations.

Organisational / managerial skills
- Team working ability combined with an aptitude to work with autonomy when necessary.
- Good sense of prioritization (multitasking abilities).
- Ability to keep to the time scheduled for the completion of my work.
- Proactive behaviour to anticipating, preventing, and solving problems.

Computer skills
- General programming languages: Matlab, C/C++, Java, Fortran, MySQL.
- Nuclear physics related simulation programming codes: MCNP, SRIM, ANISN, ORIGEN.
- Electronics related software: Keil, LabView, mplab.
- Microsoft Office, LaTeX.

Interests
- Reading (principally scientific literature) and theatre.
- Electronics, robotics and science in general.
- Music: I play electric and acoustic guitar, piano and drums.
- Running.

ADDITIONAL INFORMATION

Certifications

Class 2 expert in radiation protection

Delivered by ISIB (Institut Supérieur Industriel de Bruxelles) and IRE (Institut des Radioéléments) in January 2011 – Brussels (Belgium)

References

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Lauréats du Prix Antonella Karlson

- 2011 : Nathan GODLMAN, ULB
- 2013 : Quentin VAN OVERMEERE, UCL
- 2015 : Quentin MENET, UMONS
- 2017 : Quentin VINCKIER, ULB