Proposition de SUJET DE STAGE M2R/Ingénieur-3A

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"Deep learning models for miniaturized silicon photonics sensors"

SCIENTIFIC PROJECT:

Lab-on-chip sensors are miniaturized circuits that integrate all key functionalities within a single chip, including target preparation, detection and data analysis [1]. Ideally, these devices should be compact, robust and low cost, allowing large-volume production. This would allow the widespread deployment of a wide range of high-impact applications such as invasive medical diagnostics, food quality control and air pollution monitoring. In addition, lab-on-chip sensors should comprise sophisticated and intelligence enough (data monitoring, processing and analysis) to be used by non-skilled personal.

Driven by the impressive development in nanofabrication technologies and nanoscale engineering, **silicon photonics is widely considered the platform of choice for the realization of high-performance on-chip miniaturized sensors**. Due to its compatibility with CMOS fabrication processes, silicon photonics holds the promise of providing ultra-compact devices that could be fabricated at large-volumes and low cost. Furthermore, Si has a unique potential for seamless integration of photonic and microelectronic functionalities in a single chip. This means, potential to integrate detection, processing and analysis capabilities. **One of the major limitations of Si photonics sensors today arises from the performance degradation in presence of small fabrication errors (e.g. 10 nm variation in waveguide width) or variations of the environmental conditions (temperature, humidity, …).** Thus, current Si sensors rely on complex forward models that simulate all device imperfections and environment variations to inverse the impairment effects and retrieve the original information. This approach requires accurate calibration processes, since any mismatch between the physical model and the actual measurement will degrade the sensor performance. This seriously limits the feasibility of these approaches in real-life scenarios.

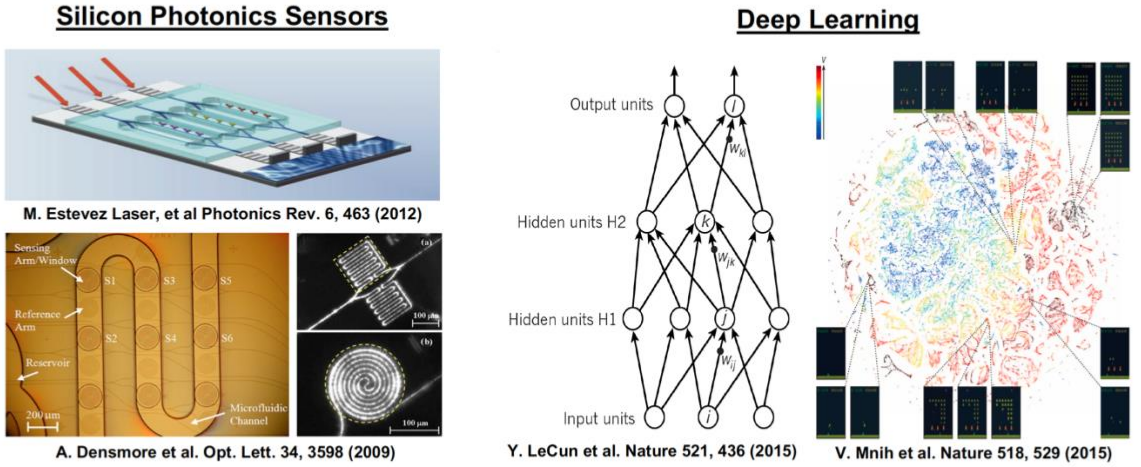

Fig. 1: Examples of miniaturized photonic biosensors (left panel) and deep learning models (right panel).

Deep learning methods rely on a training process and different abstraction levels to yield models able to automatically discover the representations needed for detection or classification [2]. **Deep learning models can perform precise detection regardless the changes in operation parameters within a training range, thus obviating the need for tight calibration processes.** The different abstraction levels are learned from data training, and not from engineering design. This provides deep learning methods with a unique flexibility and outstanding processing capabilities that are already being exploited in image [3] or speech recognition [4] or predicting DNA mutations [5]. **We experimentally demonstrate for the first time that the use of machine learning substantially improves the tolerances of on-chip SHFT spectrometers against temperature variations, thus opening a new route for their use in realistic applications outside the controlled laboratory environment** [6].

The goal of this internship will be to explore the use of deep learning algorithms to improve the performance, robustness and flexibility of miniaturized silicon photonics sensors. Simplified models of Si sensors and deep learning algorithms will be combined to alleviate performance degradations due to non-idealities and to develop advanced detection and processing functionalities.

The research activity developed during the internship can be extended into a PhD and will include theoretical study to understand the major limitations of current silicon photonics sensors and the basics of deep learning algorithms. Also, a modelling and simulation works will be carried out to develop simplified models of the sensors, generate meaningful training data and develop deep-learning models. The student will be also actively involved in the current research activities of the group, collaborating with PhD students, postdocs and researchers of different research backgrounds and nationalities.

METHODOLOGY OF THE STAGE

1) Bibliography study: Reading of a pre-selection of the main papers related to the topics of silicon photonics sensors and deep learning algorithms, e.g. [1] and [2].

2) Modelling of silicon photonics sensors: numerical simulations and constituent equations will be used to develop simplified model of silicon photonic sensors that allows fast analysis and generation of meaningful datasets to train deep learning algorithms.

3) Simulation of deep learning algorithms: deep learning models will be developed and trained to allow detection and classification of data provided by the simplified model of Si photonic sensor.

VALUED QUALITIES IN THE STUDENT

- Curiosity for novel research experiences and fields.

- Creativity and pro-activity in the search for innovative solutions and approaches.

- Capability to communicate and share results in a multidisciplinary and multi-nationality environment.

BIBLIOGRAPHY RELATED TO THE TOPIC

[1] M.-C. Estevez, et al. "Integrated optical devices for lab-on-a-chip biosensing applications," *Laser Photonics Rev.* 6, 463–487 (2012). https://doi.org/10.1002/lpor.201100025

[2] Y. LeCun, et al. "Deep learning," *Nature* 521, 436–444 (2015). https://doi.org/10.1038/nphoton.2007.89

[3] J. Krizhevsky, et al. "ImageNet classification with deep convolutional neural networks," in *Proc. Advances in Neural Information Processing Systems* 25, 1090–1098 (2012).

[4] G. Hinton et al. "Deep neural networks for acoustic modeling in speech recognition," *IEEE Signal Processing Magazine* 29, 82–97 (2012). https://doi.org/10.1109/MSP.2012.2205597

[5] H. Y. Xiong et al. "The human splicing code reveals new insights into the genetic determinants of disease," *Science* 347**,** 6218- (2015). https://doi.org/10.1126/science.1254806

[6] A. Herrero-Bermello et al. "On-chip Fourier-transform spectrometers and machine learning: a new route to smart photonic sensors" (under review).