Internship subject

Laboratory: Centre de Nanosciences et de Nanotechnologies (UMR 9001)
Address : 10 Boulevard Thomas Gobert, 91120, Palaiseau

Contact: Daniele MELATI

phone number: +33 (0)1 70 27 06 16 // email: daniele.melati@universite-paris-saclay.fr
https://minaphot.c2n.universite-paris-saclay.fr/en/

Machine learning for the design of advanced photonic devices

The impressive development in nanofabrication technologies has opened the door to the possibility of **precisely controlling the behavior of light using nano-scale devices realized on chip**. In particular, **silicon-based photonics is widely considered the platform of choice for the realization of miniaturized devices** in a wide variety of application fields, including optical communications, sensors, machine learning computation, and imaging. Additionally, 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 and offers the unique potential for the seamless integration of photonic and microelectronic functionalities in a single chip.

Among some of the most recent technological advancements in the field of photonics, **the study and development of metamaterials – artificial materials consisting of designed building blocks arranged on a subwavelength scale – has represented a major breakthrough**. These structures allow to precisely control the interaction between light and matter, offering properties which cannot be obtained with classical materials. The tremendous progress in artificially engineered photonic structures also raised the problem of **developing appropriate design methodologies**. Classical procedures based on analytical modelling and numerical simulations largely rely on the past experience of the designer and known design patterns and are limited in the number of design parameter that can be handled, owing the constraints of computational resources available for simulation. For devices employing metamaterials, not only the number of design parameters vastly increase but often a multitude of figure of merits must be simultaneously evaluated, making this conventional approaches no longer applicable.

These challenges stimulated a large research effort in the direction of machine learning and data-driven methodologies which have been demonstrated as a viable solution to handle thousands of design variables simultaneously. Machine learning algorithms can build complex physical models directly from a set of training data, models that can then be used to very efficiently design novel photonic structures with desired properties. In this context, **our group has pioneered the use of dimensionality reduction techniques, demonstrating devices with unprecedented performance.**

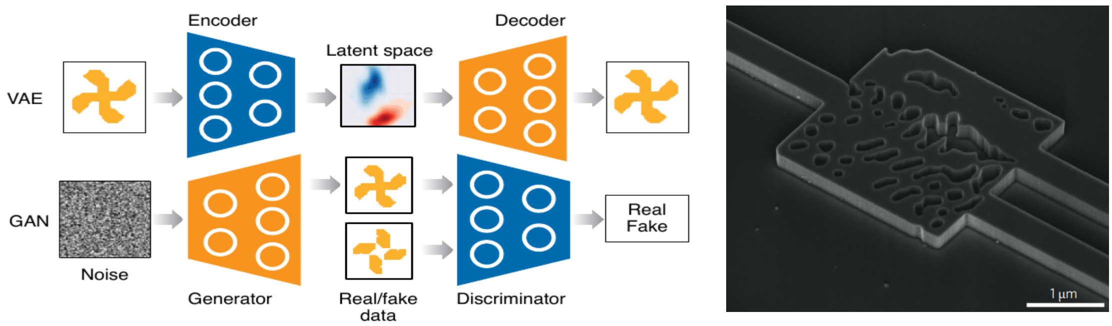

Fig.1: (left) Schematic representation of a Variational Autoencoder and a Generative Adversarial Neural Network [3]. (right) Metamaterial-based photonic device [4]

The goal of this internship is the exploration of machine learning algorithms for the development of silicon photonic devices with improved performance and advanced functionalities. Deep learning methodologies (e.g. variational autoencoders) will be combined with physics-based models, population-based optimization, and gradient descent techniques to both alleviate the large amount of input data required by classical algorithms and to efficiently optimize device designs.

The research activity will include:

- **Bibliography study** to familiarize with machine-learning-based algorithms, optimization techniques, their use in the field of integrated photonics, and unresolved challenges.

- **Set-up of machine learning models** linked to optical simulators (using available software and packages) capable of generating new device designs and evaluation of their performance compared to other available design techniques.

- **Comparison of expected performance and experimental measurements** of key performance metrics performed on fabricated devices (efficiency, bandwidth, reflections...) and integration of experimental data in the machine learning models.

During the internship, the student will be actively involved in the current research activity of the group, collaborating with PhD students, postdocs and researchers of different research backgrounds and nationalities. **This project can be continued and expanded as a PhD thesis within the framework of the project BEAMS funded by the European Research Council (ERC)** which focuses on the development of integrated photonic system for free-space optics and optical communications.

What we expect from you:

- 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.

Relevant bibliography

[1] P. R. Wiecha et al., 'Deep learning in nano-photonics: inverse design and beyond', Photon. Res., PRJ, vol. 9, no. 5, pp. B182–B200, May 2021, doi: 10.1364/PRJ.415960.

[2] Z. Liu et al., 'Tackling Photonic Inverse Design with Machine Learning', Advanced Science, vol. 8, no. 5, p. 2002923, 2021, doi: 10.1002/advs.202002923.

[3] W. Ma et al., 'Deep learning for the design of photonic structures', Nature Photonics, pp. 1–14, Oct. 2020, doi: 10.1038/s41566-020-0685-y.

[4] I. Staude and J. Schilling, 'Metamaterial-inspired silicon nanophotonics', Nature Photonics, vol. 11, no. 5, Art. no. 5, May 2017, doi: 10.1038/nphoton.2017.39

[5] D. Melati et al. 'Mapping the global design space of nanophotonic components using machine learning pattern recognition', Nat Commun, vol. 10, no. 1, pp. 1–9, Oct. 2019, doi: 10.1038/s41467-019-12698-1.

[6] D. Melati et al., 'Design of Compact and Efficient Silicon Photonic Micro Antennas with Perfectly Vertical Emission', IEEE J. Select. Topics Quantum Electron., vol. 27, no. 1, pp. 1–10, Jul. 2020, doi: 10.1109/JSTQE.2020.3013532.