Master in Photonics – "PHOTONICS BCN"
Master ERASMUS Mundus "EuroPhotonics"

MASTER THESIS PROPOSAL

Starting full time from April 2024
Presentation at the end of July or beginning of September 2024

Laboratory: Optoelectronics group (led by Prof. Valerio Pruneri)
Institution: ICFO – The Institute of Photonic Sciences
City, Country: Castelldefels (Barcelona), Spain

Title of the master thesis: Photonic neural network inference calculation using SPAD arrays

Name of the master thesis supervisor and co-supervisor:
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Keywords: optical neural network, single-photon detectors

Summary of the subject:

As Artificial Intelligence (AI) continues to gain prominence in diverse fields, spanning from healthcare to music and arts, experts are raising concerns about its environmental impact, advocating for a new 'green AI'. At the heart of many AI systems are Neural Networks (NNs), and here photonics offers a potential solution for the next generation of computing hardware. It promises not only exceptional speed but also unparalleled energy efficiency. Indeed, the computation can be executed 'on-the-fly' using light propagation within a programmable mesh. That is, due to the physical properties of light and photon detection, NN calculations can be evaluated "for free" without explicit encoding of all computational steps as it would be required in a digital electronic platform. One particularly intriguing application of photonic NNs are machine vision systems in which optics can be designed as a pre-processor capable of extracting relevant information from the image[1].

Until now, the conventional approach to AI-enabled computer vision has been to capture high-resolution images via sensors, digitize them through multiple Analog-to-Digital Converters (ADCs), and process them via NNs on digital processing units. This traditional workflow often leads to reduced imaging frame rates and consumes a substantial amount of energy. To overcome these limitations, various implementations of photonic NNs have been proposed, utilizing classical sensors such as photodiodes. However, to fully capitalize on the advantages of photonic NNs, such as parallelization, high-speed operation, and low power consumption, the magnitude of the implemented computation must still significantly increase[2].

The purpose of this project is to prove that employing Single-Photon Avalanche Diode (SPAD) arrays, serving as detectors and computation units, can significantly improve the performance of photonic NNs. SPADs eliminate the need for power-hungry and costly ADCs and will allow the design of a platform transversal to both classical and quantum imaging. By using a Spatial Light Modulator (SLM), we will map the incoming

images (i.e., objects we aim to classify) and the NN parameters onto a SPAD array. Thanks to the unique array architecture, computations will occur concurrently with detections without any additional time and power requirements.

In this project, the student will design and implement a novel photonic NN, based on single-photon detectors and SLMs. The student will form part of the Optoelectronics group at ICFO, led by Prof. Valerio Pruneri, working closely with members of the imaging team in order to take advantage of the group's expertise in machine learning, quantum imaging with correlated photon states, and single-photon detector technology.

References

[1] G. Wetzstein et al., "Inference in artificial intelligence with deep optics and photonics,"
doi: 10.1038/s41586-020-2973-6
[2] M. A. Nahmias et al., "Photonic Multiply-Accumulate Operations for Neural Networks,"
doi: 10.1109/JSTQE.2019.2941485.

Objectives:

- Introduction to methods in experimental optics – SPAD cameras, SLMs
- Data processing and analysis with image processing and machine learning in Python
- Design, implementation and testing of a photonic neural network

Required skills:

- Familiarity with programming using Python programming language (common scientific computing libraries such as NumPy etc)
- Previous experience with optics laboratory setups would be a bonus