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***Abstract*— The development of photonic system realizing advanced functionalities on-chip requires the careful integration of a large number of reliable and high-performance components. Novel approaches such as non-trivial geometries and metamaterials are required to achieve these targets. As a consequence, new design tools capable of handling a large number of correlated parameters are required. Moreover, multiple figures of merit must be considered simultaneously to evaluate the performance of the selected devices end unsure appropriate system integration. Here, we will discuss the potentiality offered by the combination of machine learning dimensionality reduction and optimization in tackling the multi-objective design of photonic devices as well as for the investigation of the effect of fabrication tolerances.**

Keywords—Machine learning, Dimensionality reduction, Optimization, Silicon photonics, Metamaterial Engineering

Photonics integration has steadily evolved in the last decades into a mature and reliable technology with applications ranging from telecommunication, to sensing and imaging. As such, photonic systems integrating on-chip a wide range of functionalities, including light generation and detection, coupling, routing, modulation, and filtering have become necessary. First, realizing such systems requires to properly combine many elementary building blocks taking care of parasitic effects, unwanted interactions, and non-uniform behaviors. Second, at a device level, high performance, scale of integration, and reliability become the primary focus to ensure the proper functionality of the system as a whole. Novel concepts need to be explored in order to fulfill all these requirements and the use of non-trivial geometries, integration of heterogeneous material, and extensive use of metamaterials and metasurfaces are attracting a large research interest [1]. Inevitably, this path toward complex photonic components and systems calls also for innovative design tools capable of supporting the development of such devices and their proper integration. In contrast with many traditional photonic building blocks that are realized using relatively simple geometries and are governed by a handful of parameters, novel components often require a large number of variables to be optimized at once. Even more importantly, multiple performance objectives and fabrication requirements need to be taken into account to ensure not only the device is highly performing but also adequate for integration into the larger system (e.g., low loss, wide bandwidth, low reflections, large features). Sweep of design parameters becomes computationally intractable or not applicable as parameters are often strongly correlated. Design trends and guidelines become difficult to extract, visualize or understand. As a result, machine–assisted design approaches such as optimization or machine-learning tools are now very often used to search efficiently in ever expanding design spaces designs with complex geometries simultaneously matching different performance requirements [2].

Here, we present our recent work on the use of machine learning dimensionality reduction and optimization tools to tackle some of the challenges in the analysis, design, and integration of multi-parameter, multi-objective photonic devices [3,4]. In particular, we discuss how dimensionality reduction allows to efficiently identify the small portion of the design space that holds all the design of interest starting from a handful of optimized devices with similar performance. Since the identified subspace can be described by a significantly reduced number of parameters, its exploration becomes much more efficient, enabling multi-objective optimization either by exhaustive mapping or by exploiting global optimizers. Lastly, we show how dimensionality reduction can be beneficial also in the analysis of the effect of fabrication tolerance in large photonic circuit. By reducing the number of random variables that needs to be considered, it enables the efficient use of stochastic surrogate models and a significant speedup compared to classical Monte Carlo analyses.

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