VRIJE UNIVERSITEIT BRUSSEL

The faculty of Engineering of the Vrije Universiteit Brussel invites you to attend the public defense leading to the degree of

DOCTOR OF ENGINEERING SCIENCES

of **Ali Mohammed Mohammed Al-Zawqari**

The public defense will take place on **Tuesday 22nd October 2024 at 4:00 pm** in room **D.2.01** (Building D, VUB Main Campus)

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ENHANCING GENERALIZATION AND FAIRNESS IN MACHINE LEARNING: INTEGRATIVE LEARNING APPROACHES FOR NANOPHOTONICS AND EDUCATIONAL DATA MINING

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Abstract of the PhD research

Artificial Intelligence (AI) has realized significant breakthroughs in fields ranging from healthcare and education to agriculture and environmental science, offering solutions that once seemed beyond reach. However, these advanced machine learning models face significant challenges. One key issue is their struggle to generalize effectively beyond the specific data they were trained on, which can lead to inaccurate outcomes. An example of this is a language model generating plausible but false information. Additionally, these models can inadvertently perpetuate or even exacerbate biases in their training data, leading to unfair outcomes in critical societal applications, such as skewed hiring practices. Given these challenges, this research focuses on developing new machine learning methodologies that enhance both AI systems' generalization capabilities and fairness.

The core contributions of this thesis include the development of novel models that optimize accuracy while ensuring fairness across diverse datasets. Specifically, we explore applications in two contrasting but increasingly data-driven fields: nanophotonics and educational data mining. The research leverages simulation data to refine predictive models—using physics information and a novel clustering algorithm—that more accurately account for the electromagnetic behavior of nanophotonic devices. This is particularly effective in improving accuracy for outliers. Methodologically, this work introduces innovative strategies that integrate different learning algorithms into models to handle the variability and complexities of the data in educational settings. The thesis also sheds light on the limitations of current debiasing methods. It introduces a new bias mitigation approach enhancing fairness under varied conditions of the awareness of protected attributes. Through a detailed analysis of these applications, this work advances our understanding of how machine learning can be adapted to better handle diversity in datasets and showcases practical implementations that could be adopted in other data-driven fields.