Information-Theoretic Interpretation of Metaoptic Frontends for Efficient Design and Implementation

Y Li[1,2], N A Behrens[1], and F Monticone[1]

[1] *Electrical and Computer Engineering, Cornell University, Ithaca NY, USA*
[2] *Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, 4 Place Jussieu, Laboratoire Kastler Brossel, Paris, France*
Contact Email: yandong.li@lkb.ens.fr

Optical frontends have demonstrated great potential for improving the efficiency of AI systems by preprocessing visual and imaging-domain input signals. Yet the role of metaoptics, such as metasurfaces and metamaterials, as optical frontends remains unclear. Here, we analyze metaoptic frontends from an information-theoretic perspective and show that well-designed optical preprocessing reshapes the statistical distribution of input data to benefit the downstream task. For hybrid systems composed of a metasurface frontend followed by a lightweight neural-network backend, we quantify how optical preprocessing enhances class separability and identify an upper bound on classification accuracy. Our results reveal that optimized optical frontends perform a role analogous to linear discriminant analysis: they promote inter-class separation while encouraging intra-class clustering. This interpretation suggests design pipelines different from end-to-end training, enabling optical frontends and electronic backends to be trained separately. It can be extended to broader AI tasks beyond classification, potentially reducing computational cost and leading to more resource-efficient implementations.