Photonics and AI—a symphony of light and intelligence

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Artificial intelligence (AI), characterized by its capability in learning, comprehension, and problem solving, has emerged as a driving force in numerous fields, including photonics. The recent Nobel Prizes in physics and chemistry serve as a testament to AI's transformative capabilities, showcasing its ability to solve intricate problems and make significant discoveries. In the realm of photonics, AI has opened doors to unprecedented advancements, from the design of novel materials and devices to the optimization of imaging systems and the enhancement of sensing capabilities.

This means that the synergy between AI and photonics is indeed a two-way street. Photonics provides AI not only with the tools to sense and communicate more effectively, but also with the instruments to accelerate the inference speed. Moreover, AI offers photonics the intelligence to process, analyze, and interpret the sensed data, and also to solve a wide class of inverse problems in photonics design, imaging, and wavefront reconstruction in ways not possible before.

This joint theme issue of *Advanced Photonics* and *Advanced Photonics Nexus*, titled "Photonics and AI," showcases the latest research at the intersection of these two disciplines, highlighting their mutual enhancement and the potential to reshape our world. This collection includes one review article (with 2 more on the way) and 12 original research articles.

Lu et al.[1] present the latest advancements in applying machine learning to perovskite optoelectronic devices, covering perovskite active layers, transport layers, interface engineering, and mechanisms. They also offer a prospective outlook on future developments.

Wang and Lam[2] present a comprehensive and comparative analysis on the use of data-driven and physics-driven deep learning for phase retrieval, a subject that is widely encountered in different fields.

Mashiko, Naruse, and Horisaki[3] propose a new optical computation architecture called diffraction casting (DC) that utilizes a diffractive neural network for single instruction, multiple data (SIMD) operations. This approach allows for the alteration of logic operations simply by changing the illumination patterns and eliminates the need for encoding and decoding of the input and output, facilitating end-to-end all-optical computing. The authors numerically demonstrate DC by performing all 16 logic operations on two arbitrary 256-bit parallel binary inputs, showcasing the potential of DC for next-generation optical computing paradigms.

Chen et al.[4] discuss the development of an optical superoscillatory diffractive neural network (SODNN) that achieves superresolution imaging beyond the diffraction limit with superior optical performance. The SODNN is designed to create optical superoscillation effects in three-dimensional (3D) space, generating superresolved focal spots without sidelobes over a long depth of field and avoiding chromatic aberrations. The research demonstrates the potential of SODNNs to enhance intelligent optical instruments for imaging, sensing, and perception applications.

Shen et al.[5] present quantitative phase imaging (QPI) of a 3D stack of phase-only objects, using a wavelength-multiplexed diffractive optical processor.

The work by Unni, Yao, and Zheng[6] presents a nested deep transfer learning approach for modeling multilayer thin films, demonstrating the potential of AI to revolutionize the design process in nanophotonics. This research not only enhances the efficiency of material discovery but also paves the way for the development of more complex photonic devices.

Liu et al.[7] introduce a neural meta-camera that integrates an ultra-wide field of view (FOV) metalens with a CMOS image sensor, enhanced by a transformer-based neural network for color imaging. This innovative camera design corrects for chromatic aberrations, distortion, and central bright speckle, achieving high-quality, full-color images over an ultra-wide FOV. The compact, portable camera offers a promising alternative for applications such as micronavigation, microendoscopes, and on-chip devices, with the potential for real-time image processing.

Sun et al.[8] introduce a hybrid deep-learning and physics-based neural network for programmable illumination computational microscopy, underscoring the role of photonics in enhancing AI computational capabilities. This intersection is crucial for the advancement of neuromorphic computing, where light-based systems could outperform traditional electronic counterparts in speed and efficiency.

Wang et al.[9] introduce NeuPh, a deep learning framework based on local conditional neural fields for scalable and generalizable neural phase retrieval. NeuPh demonstrates its capabilities by solving the phase retrieval problem in multiplexed Fourier ptychographic microscopy, achieving continuous-domain resolution-enhanced phase reconstruction that outperforms existing methods in terms of scalability, robustness, accuracy, and generalizability. The framework's ability to generalize with limited training data and its potential for advancing deep-learning-based imaging techniques are also highlighted.

Zhu et al.[10] present innovative approaches to information security using event-based vision systems. These systems leverage the principles of neuromorphic computing to enhance the efficiency and effectiveness of visual data processing.

 [DOI: 10.1117/1.AP.6.5.050101]

Yang et al.[11] present a method for recognizing the pose and surface material of objects using a single time-of-flight (ToF) camera. The approach combines depth and active infrared intensity data, applies feature extraction, and employs lightweight machine-learning techniques to achieve high recognition accuracy, exceeding 94.8% in most cases. The proposed method is robust against ambient lighting changes and is applicable in various scenarios, including industrial production and autonomous driving, where accurate object surface information is crucial.

Wilson et al.[12] introduce an optical anti-counterfeiting detection method using a deep-learning approach known as RAPTOR (residual, attention-based processing of tampered optical response) to authenticate semiconductor devices. RAPTOR leverages the random pattern arrays of gold nanoparticles to identify adversarial tampering with high accuracy, outperforming traditional methods like Hausdorff, Procrustes, and average Hausdorff distance metrics. The method involves extracting nanoparticle positions and radii from dark-field images, applying semantic segmentation, and using RAPTOR to verify the authenticity of each pattern, offering a robust solution against counterfeit chips.

MacDonald, Yakovlev, and Pacheco-Peña[13] present a novel approach using waveguide-based metatronic networks to solve partial differential equations, specifically the Helmholtz wave equation. The proposed method leverages the analog computing capabilities of electromagnetic waves and has been demonstrated to effectively calculate solutions for both Dirichlet and open boundary value problems. The research opens up new possibilities for high-speed analog computing and the development of light-based processors capable of handling complex computational tasks.

For historic review and enrichment, we also offer an interview[14] with Prof. Demetri Psaltis, who has made profound contribution to the development of optical neural networks and learning-based computational imaging.

We hope this joint special issue will give the readers the impression that the fusion of photonics and AI represents not merely a scientific trend but a revolutionary leap forward in technology, which holds the promise of transforming multiple industries. We are excited to be at the forefront of this symphony of light and intelligence, where the collaboration between these two fields will undoubtedly lead to groundbreaking discoveries and applications that we can only begin to imagine.

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