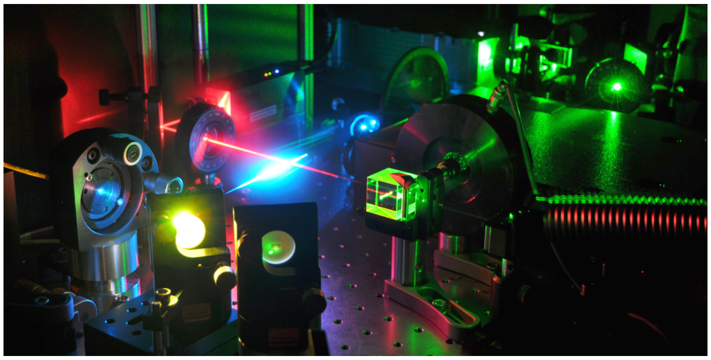
AI Designs Optics Hardware

A machine-learning algorithm rapidly generates designs that can be simpler than those developed by humans.

By **Mark Buchanan**

Researchers in optics and photonics rely on devices that interact with light in order to transport it, amplify it, or change its frequency, and designing these devices can be painstaking work requiring human ingenuity. Now a research team has demonstrated that the discovery of the core design concepts can be automated using machine learning, which can rapidly provide efficient designs for a wide range of uses [**1**]. The team hopes the approach will streamline research and development for scientists and engineers who work with optical, mechanical, or electrical waves, or with combinations of these wave types.

When a researcher needs a transducer, an amplifier, or a similar element in their experimental setup, they draw on design concepts tested and proven in earlier experiments. "There are literally hundreds of articles that describe ideas for the design of devices," says Florian Marquardt of the University of Erlangen-Nuremberg in Germany. Researchers often adapt an existing design to their specific needs. But there is no standard procedure to find the best design, and researchers could miss out on simpler designs that would be easier to implement.



No more DIY. The design of optics setups can be automated, according to new research results.
Credit: S. Mueller/Max Planck Institute for the Science of Light

Inspired by recent progress in applications of machine learning across the sciences, Marquardt and colleagues wondered if the design procedure could be improved. "Our aim was to find a way to search through the space of possible design concepts in some automated and efficient way," he says.

The researchers represented the possible design concepts as networks of interlinked "modes." A mode could be any kind of resonant cavity or structure able to trap microwaves, optical waves, or even mechanical vibrations. Examples include a microwave cavity in a superconducting chip or an optical cavity in an integrated photonic circuit. In the network representation, links between the modes represent physical interactions enabling one mode to influence another.

The team's network representation reflects the strengths of the connections by assigning a number to each link between modes. There are also some input modes, into which signals can be injected, and some output modes that can deliver the desired result. This representation allows machine learning to optimize the design for any input-to-output relationship. The algorithm the team developed simultaneously optimizes the network structure and the link strength parameters to find setups that yield the ideal behavior.

"The main challenge was to find an efficient way to go through the large space of possible designs," Marquardt says. "We found a way to drastically 'prune' the search by inferring, based on the first few tested networks, which ones would be automatically ruled out."

To test their scheme, Marquardt and colleagues employed it for several design tasks. For example, they used it to design an isolator—a device that provides perfect transmission with no loss of energy from the input to the output while also ensuring zero reverse transmission. Isolators have been developed for a wide range of wavelengths and applications. The algorithm quickly found the most efficient solution in a simple setup, one that had already been discovered by engineers using conventional techniques.

But in more challenging design cases, the researchers found that the machine-learning approach yielded superior results and new designs that had not been found previously. For example, they looked for schemes suitable for amplifying signals from a quantum computer. Here, the key measures of the complexity of the design are the number of modes and the number of interaction pathways required between the different modes. The best design known so far relies on four modes with six interaction pathways, but the automated procedure provided a design with the same behavior using only three modes with three interaction pathways. The team also described how to use the designs to build real hardware for waves of a wide range of wavelengths, from microwaves to visible light.

"This research is both exciting and timely," says Andreas Nunnenkamp, an expert in quantum control and many-body physics at the University of Vienna. "I imagine that this kind of automated scientific discovery will become an indispensable part of the toolbox for both experimentalists and theorists." In future work, the researchers plan to look into the automated design of periodic systems, where waves can propagate in spatially extended structures.

Mark Buchanan is a freelance science writer who splits his time between Abergavenny, UK, and Notre Dame de Courson, France.

REFERENCES

1. J. Landgraf *et al.*, "Automated discovery of coupled-mode setups," **Phys. Rev. X 15, 021038 (2025).**