Sorting out light-space, the final frontier

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Optics is being implemented at progressively shorter distances to take over the communication of information in processing and switching machines. The high frequency of light offers high bandwidths and dense frequency division multiplexing; the short wavelength of light offers high connection densities; and the quantum nature of light offers lower energies because the photoelectric effect allows us to avoid charging the lines to the signal voltage. This set of potential advantages becomes particularly important and dominant at length scales beyond the size of the chip itself. Nanophotonics may offer further reductions in practical device energies and possibilities for optical interconnections even on chip.

Despite the high channel densities offered by optics, our desire for ever higher aggregate bandwidths in and out of ever smaller footprints means that even there we have to look at opportunities for yet more channels. We could, for example, run out of space to put even optical fibers. One possible solution is to explore using multiple spatial channels – or, equivalently, multiple different orthogonal beam shapes – in one fiber. Multimode optical fibers are, of course, used extensively, but mostly only as a convenience to relax alignment tolerances. The light in any specific mode of a multimode fiber typically mixes and scatters into all the other modes, so historically we have not attempted seriously to exploit the multiple different available modes as separate channels. We have long been able to separate polarizations and wavelengths, but the whole idea of trying to unscramble such arbitrary scattering to allow multiple separate orthogonal spatial channels has historically had no clear solution. Indeed, it was not even clear in principle that there was an optical solution to such problems, at least without incurring substantial losses. Even separating out well-defined but overlapping modes to different outputs without fundamental loss has proved very challenging.

Recently, however [1,2], we showed at least one method of designing and potentially making such unscrambling optics. This approach can be implemented in the rapidly developing silicon photonics technology. Remarkably, this approach can be entirely self-configuring in a simple progressive algorithm that requires no calculations at all. This also means we can contemplate self-aligning, self-configuring and self-stabilizing optical systems, potentially resolving many of the difficulties we face with complex optical systems, and offering a possible solution to using the full spatial channel density that optics can provide.

This work fits within a larger context of modern complex optical systems, such as those needed for quantum optics and possibly other areas such as imaging and security. The combination of such ideas with the growing opportunities in technologies like silicon photonics and nanophotonics is very promising for a new generation of highly functional optical systems, for communications and other areas.

1. D. A. B. Miller, "Designing linear optical components", *Optics Photonics News* (Dec. 2013), p. 38.
2. D. A. B. Miller, "Self-configuring universal linear optical component", *Photonics Res.* **1**, 1 (2013).