As we contemplate and design sophisticated nanophotonic structures, we want to know how best to think about them. We are also increasingly interested in understanding the numbers of spatial channels we might be able to use in communications, as in mode-division multiplexing, so we need a clear idea of how to count beams. Classic approaches like plane waves or specific mathematical families of beams may bear little relation to the behavior of complex devices, and may not offer clear answers on counting usable beams or channels. We would like a more appropriate and ideally efficient way of looking at and solving such problems.

Fortunately, both of these kinds of problems can be tackled by an approach based on singular-value decomposition (SVD). This defines and counts the best beams for given problems. For establishing and counting the best ways of communicating with waves, we can use “communications modes” [1], and for most economically describing the function of linear optical devices (including nanophotonics) we can use the “mode-converter basis sets” [2]. In both cases, this SVD approach gives us pairs of functions – the best source modes that couple to the best receiving modes in the communications problem, and the best input modes that convert to the best output modes in the linear device problem. The communications modes are provably better than standard beam families like orbital angular momentum modes, for example [3], for communicating through space, giving more channels with less (and even zero) cross-talk. The mode-converter basis sets allow us to deduce novel physical laws such as improved versions [4] of Kirchhoff’s radiation law, including laws that apply for arbitrary shapes and sizes of optical objects, and that work for beams and even for non-reciprocal optics. (The classic derivations did not include diffraction and were valid only for reciprocal optics.) This SVD approach to optics also allows us to construct arbitrary linear optical functions [5] based on meshes of interferometers, which can even set themselves up automatically [6] and “perfectly” [7]. Arguably, then, this new approach is both practically useful and fundamentally clarifying.