Finding and counting channels with waves

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Increasingly, we need to find and count channels for waves. In nanophotonics, knowing how many optical channels can usefully enter or leave a small structure is critical for understanding what the structure can do and how to design it efficiently. Though conventional diffraction theory gives useful answers for large objects, for nanostructure on wavelength scales, there has been no clear picture. We show how understand such channels based on a concept of tunneling escape of waves from small volumes. We also show how to find the best coupled channels automatically through arbitrary optics, based on self-configuring photonic integrated circuit processors, which function as real-time optical analog processing systems.

Increasingly, we need to find and count channels for waves. Growing bandwidth demands require we exploit spatial channels more effectively. Information processing requires ever increasing numbers of channels that optics could provide. Numbers of strong channels can determine how much and what kind of information we can measure in sensing applications like microscopy or imaging.

One core question that has never had a simple answer is whether we can count how many different (i.e., orthogonal) waves or channels can propagate in and out of objects or volumes, especially on wavelength scales. We have not had any simple general model and intuition for important key behaviors: why do the coupling strengths tend to fall off rapidly past some number of well-coupled channels, and, indeed, just what defines that number? We show now [D. A. B. Miller, Z. Kuang, O. D. Miller, "Tunneling escape of waves," http://arxiv.org/abs/2311.02744] that there is a simple way of understanding these behaviors and deducing simple results. We exploit a tunneling behavior that has been somewhat hidden in waves from finite objects, and connects all the way from electromagnetic antennas and nanophotonics smoothly to evanescent waves in large optics.

A second question is how we can find such optimal, orthogonal channels, especially for communicating through unknown environments. We show that meshes of interferometers on either side of an arbitrary and unknown optical systems can automatically find the best orthogonal channels [S. SeyedinNavadeh et al., "Determining the optimal communication channels of arbitrary optical systems using integrated photonic processors," Nat. Photon. (published online 23 November 2023) https://doi.org/10.1038/s41566-023-01330-w], just by simple power maximization algorithms, and verify this by the low crosstalk of the resulting communication channels. Importantly, requires neither calibration nor external computation – the necessary settings are deduced by the optical system itself, giving a true real-time optical computation.