

Dual design: Inferring structure from fundamental limits

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The recognition that the constraints implied by any set of linear differential equations can be reformulated to restate the optimization problems encountered in photonic inverse design as a quadratically constrained quadratic program (QCQP) and then convexified via Lagrange duality has proven to be a powerful means of determining fundamental performance limits. As soon as the constraints of total real and reactive power conservation are imposed, the subtle interplay between chosen material properties, device size, wave physics, and attainable objective values for basic scattering quantities is captured to a remarkable extent, including the onset of well-known asymptotics such as quasi-statics and geometric optics, and the possibility of creating resonances. More importantly, through the generalization of considering any number of local power conservation constraints, these convexification methods have been found to be remarkably predictive of what is possible for range of technologically relevant electromagnetic processes; limits coming within a factor of ten of topology optimized structures have been found for variety of basic absorption, scattering and field transformation functions as well as more complex objectives like surface-enhanced Raman scattering.

In this presentation, we demonstrate that the fields computed when calculating performance limits via duality can directly inform structural discovery through inverse design. Focusing on the exemplary problem of local density of states enhancement, we find that topology optimization initialized with structures derived from duality analysis consistently produces performance gains surpassing a factor of three, for sufficiently large design domains, relative to current methods. These results strongly suggest presently untapped potential in photonic inverse design, and highlight a number of open question concerning the mathematical structure of electromagnetic inverse design problems and related convexifications.

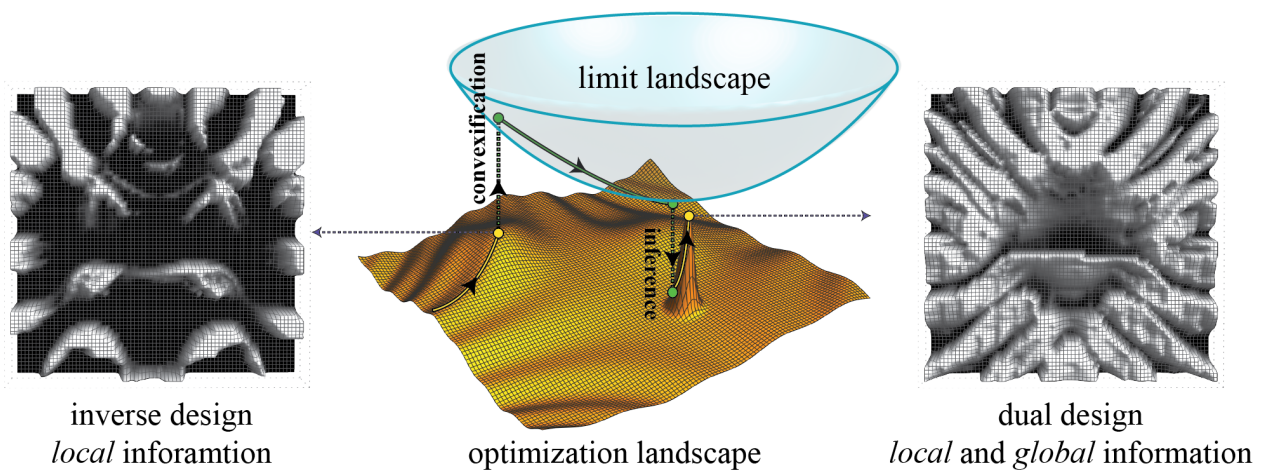


Figure 1: The general procedure we will describe follows the three steps outlined in the center of the figure. First, by solving the convexified optimization problem, an optimal limit field is obtained. Second, because this limit field will not generally correspond to a physical material realization, an inference step is performed to map the optimal limit field to a closely related structure capturing global (but not all local) optimality characteristics. Third, a (local) inverse design method is used to fine tune the material realization, resulting in improved performance.