Light travels in many ways through a scene, following multiple paths and bouncing several times on surfaces and inside materials. By injecting light into the scene, measuring what is returned, and reasoning about the complex propagation that takes place in-between, we should be able to recover rich information about the scene, even allowing vision systems to see around obstacles or inside volumes. However, despite decades of research on such inverse problems in multiple sciences, we can still reliably perform such inferences only in cases where we can severely constrain the complexity of photon trajectories. Given the growth of processing power and the accelerating advances in generalized optics, I argue that we now have the opportunity to solve these problems in much more general settings, by fundamentally rethinking: (1) the way that we measure light propagation; and (2) the way that we optimize for scene parameters that match these measurements.

To demonstrate this, in this talk I will be focusing on the problem of inverse scattering, where we seek to recover the material parameters controlling light propagation everywhere inside an object. Such material measurements are critical for applications ranging from diagnosing malignant tumors, to performing non-destructive industrial material inspection. I will describe progress we have made in both computation and imaging towards solving this extremely multi-path inverse problem: First, I will present an optimization framework that can solve for tens-of-thousands of variables that correspond to the point-wise scattering parameters inside of a heterogeneous turbid volume. Second, I will describe an acquisition system, based on optical interferometry, that can separately measure photons whose travel times differ by as little as one-trillionth of a second. Third, I will show how combining these two components into a computational imaging pipeline enables us to acquire scattering parameters for many types of materials, from everyday chemicals like waxes and soaps, to industrial coatings, and to deep tissues, which could not be accurately measured before.