Real physics from "unphysical" simulations

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The core of photonics and metamaterials computational design and modeling is a Maxwell solver: given sources (currents) as a function of time or frequency, calculate the resulting electromagnetic fields in a given geometry. A straightforward way to employ such a solver is to perform numerical experiments that directly mirror laboratory experiments, e.g. transmission or reflection calculations. Even extraction of effective-medium "metamaterial" parameters is commonly done by the direct analog of ellipsometry measurements. Although this approach is very useful, there are also way to exploit Maxwell solvers that have no direct experimental analogue, taking advantage of the extreme flexibility in sources and "measurements" provided by the computer. In this talk, we discuss some old and new analytical transformations that allow Maxwell solvers to be used in ways very different from experiments. "Standard" techniques that are not as well known as they should be include "adjoint" solves for sensitivity analysis and optimization. More recent ideas include ways to use "unphysical" complex-frequency solvers to extract results over a whole bandwidth simultaneously and laser modeling that skips time evolution of the gain medium to jump directly to the steady state. Often, the very thing that makes a problem seemingly intractable, e.g. the huge difference in timescales between the gain media and the optical frequencies, are what makes efficient computational solvers possible.