INFORMATION

Predicting Waves Mathematically

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Understanding the behavior of waves in complex environments holds the key to advances in a wide range of applications—from optical communications and computer technology to the prediction and detection of seismic, atmospheric, and oceanic phenomena. Wave phenomena are described using partial differential equations, which are a mathematical encoding of physical laws.

But significant challenges arise because phenomena are both multiscale—they derive from activity and interactions among very small spatial scales all the way up to very large scales—and nonlinear, which leads to waves that distort dramatically and "scatter" differently as their size is changed. These general features limit the solvability of problems on even the fastest computers.

Michael Weinstein develops hybrid analytical/computational approaches, which combine asymptotic mathematical analysis with computer simulation. Asymptotic analysis yields approximate, but fairly explicit and detailed information, on the very small-scale phenomena. With these degrees of freedom "solved for," the computer can then focus on the larger scales and efficiently give approximate, yet very accurate predictions.

Applying these approaches to the partial differential equations of optics, Weinstein has discerned how "soliton" light-pulses travel and interact within communications lines. This work has a wide range of practical applications: from determining the stability of optical pulses to ideas on how to robustly encode information in streams of optical pulses.

He has proposed designs of novel optical media to slow or even stop light pulses in micro-structured waveguides, and has proposed their application to optical buffering of information. A recent project exploits parallels between the equations of electromagnetics with those arising in the theory of shock waves in supersonic flight, to understand the generation of broadband, multi-colored light from laser light of a single color. Broadband light sources have applications ranging from communications to imaging science.

Other recent work he is addressing concerns metamaterials: specially engineered microstructures, which act as a macroscopic device, and achieve properties not possible using naturally occurring materials. One application studied by Weinstein is the attainability of the cloaking effect. Cloaking involves surrounding a region of space by an appropriate metamaterial. Anything in the surrounded region is undetectable by exterior sensors, and anything within the shielded region is isolated from the exterior world. Other application areas of metamaterials envisioned include improved solar energy cells, secure communications and sensors.

Weinstein is a fellow of the Society for Industrial and Applied Mathematics (SIAM), elected for his "contributions to the analysis and applications of nonlinear waves".

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