Boğaziçi Math Seminar

Solving Geophysical PDEs with Generative AI: An Algorithm for Joint Inversion and Posterior Sampling

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Abstract:

Partial differential equations (PDEs) are a cornerstone of modern science, enabling us to predict future states of a system (the forward problem) and estimate underlying physical properties from state measurements (the inverse problem). In geophysics, the inverse problem is highly challenging and extremely ill-posed: we frequently know neither the PDE coefficients (the elastic constants of the rock media) nor the seismic source term in the PDE, yet we must solve the wave equation using only sparse surface displacement measurements from seismometers.

To solve these complex PDEs, researchers typically rely on classical numerical techniques such as the Finite Element Method (FEM). While versatile, these traditional solvers are computationally expensive and generally require fixing one unknown to make the problem tractable. Crucially, these solvers inherently map inputs to a single, deterministic point-estimate solution and often fail when applied to inverse problems with highly sparse, partial observations.

Recently, denoising diffusion models–a class of generative artificial intelligence (AI) algorithms that have achieved significant success in image generation–have emerged as a powerful alternative. Rather than learning a deterministic mapping, these AI models can be trained to learn the joint probability distribution of the PDE coefficients and their corresponding solution spaces, allowing the framework to simultaneously fill in missing information and solve the forward and inverse PDE problems concurrently.

In this talk, I will present how diffusion models can be leveraged to solve highly ill-posed geophysical inverse problems. After introducing the foundational principles of this AI algorithm in image generation, I will extend this concept to Bayesian posterior sampling for physical systems. I will show how the reverse stochastic differential equation (SDE) is guided simultaneously by sparse observational data and PDE mathematical constraints, generating a rich ensemble of valid Earth models rather than a single deterministic guess.

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Time: 13:30
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