Towards highly-sparse, autonomous imaging systems: high-resolution wavefield imaging for frontier exploration

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Can we image and monitor the internal ocean structure at global scales? Can we monitor in vast expanses of the Earth's cryosphere subsurface with meter-length resolution? Can we characterize the interior structures of asteroids and comets out in space efficiently and with high confidence? At the core of these questions lies the understanding and development of wave-based imaging systems, based on seismic or radar, that rely on highly-sparse, high-quality data, but whose output image quality is comparable to that of densely sampled, wide aperture array-based data. Traditionally, exploration seismology has long relied on wide aperture, dense data sets together with high-end imaging such as reverse-time migration and full-waveform inversion to produce high resolution subsurface models. Given the recent rise of drone-like, autonomous systems, in this talk, we present approaches that can take highly-sparse data as would be recorded by autonomous platforms, into accurate high-resolution images as if they had been acquired by densely-sampled, wide aperture source and receiver arrays. We demonstrate two approaches that could achieve this goal. The first is the use of sparse multicomponent sources and receivers capable of exciting/recording fields and their spatial gradients, together with a gradient-based wavefield reconstruction approach and subsequent imaging. The second approach relies on a new deep learning architecture, the so-called Recurrent Inference Machine, designed specifically for inverse problems – showing that it can surpass the capabilities of deterministic approaches to data reconstruction and imaging. We illustrate these approaches using a numerical model for oceanic turbulence, where we show the compressive sensing potential of these acquisition, reconstruction and imaging methods for acoustic imaging of the ocean's internal structure – overcoming current limitations in data acquisition and processing for seismic oceanography. Finally, we postulate that these approaches, though still in their early days, will pave the way in enabling breakthrough imaging systems at the frontiers of geo-imaging, e.g., for oceanography at global scales, in imaging the Earth's cryosphere or for planetary exploration.