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An Application of Trace2Trace Self-Supervised Deep Learning Framework for Seismic Deblending

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Abstract.

Simultaneous-source acquisition in seismic surveys has imposed constraints on traditional signal processing techniques due to the coherent interference arising from source blending. The deblending problem can be formulated as an ill-posed inverse problem where the objective is to recover individual source responses from composite seismic records corrupted by temporally overlapping energy. Formally, the recorded blended data $d(t,x)$ can be expressed as a summation of individual source responses $s_i(t,x)$, such that $d(t,x) = \sum_{i=1}^{N} \quad s_i(t - \tau_i(x), x)$, where $\tau_i(x)$ denotes the source-dependent time shift. The problem is severely ill-posed due to the absence of prior knowledge about $\tau_i(x)$ and the overlapping nature of $s_i(t,x)$.

Classical deblending techniques rely on transform-domain sparsity, low-rank structure, or predictive filtering. Methods based on sparse representations in the curvelet or seislet domains assume incoherence of blending noise and regularity of the signal. These priors often fail in high-interference or low-fold scenarios due to inadequate signal-noise separability. In addition, methods like f–x deblending or median filtering are limited by assumptions of trace-wise stationarity and lack robustness in the presence of aliased or strongly coherent noise.

Recent advancements in deep learning have introduced end-to-end data-driven models capable of learning complex mappings without explicit domain transforms. However, fully supervised training paradigms require access to clean seismic ground truth, which is infeasible in realistic acquisition settings. This constraint motivates the use of self-supervised learning paradigms tailored for geophysical inverse problems.

The Trace2Trace framework, originally inspired by the Noise2Noise paradigm for denoising, and used for the deblending task, provides a principled self-supervised approach for seismic data deblending by leveraging the statistical independence of blending noise and the spatial coherence of seismic signals. Specifically, it constructs training tuples from spatially adjacent traces x_i and x_{i+1} extracted from pseudodeblended common receiver or channel gathers. Given that both traces contain the same underlying reflectivity series perturbed by independent blending artifacts, the network learns to approximate the conditional expectation $E[x]$ via minimization of the expected loss $L = E_{x,y}|f_\theta(x) - y|^2$, where $x, y \sim D$, the empirical distribution of paired noisy traces.

The framework exploits the symmetry of the objective by training bidirectionally (i.e., f(x) → y and f(y) → x), enhancing generalization and stability. Furthermore, by using spatial sub-sampling (e.g., even and odd traces as complementary input-target sets), Trace2Trace effectively regularizes the learning process and avoids overfitting to localized noise patterns. The method is implemented using fully convolutional architectures, allowing scale invariance and translation equivariance, and is optimized using stochastic gradient descent over minibatches sampled from seismic shot gathers.

Empirical results demonstrate that Trace2Trace is a robust alternative to baseline model-based deblending methods, especially in low SNR regimes and under non-ideal source dithering conditions. Its self-supervised nature allows direct applicability to field data without the need for synthetically generated training labels, making it particularly suitable for deployment in operational seismic processing pipelines.

In this work, we present comparative results between the Trace2Trace framework and curvelet-based methods for self-supervised deblending. Additionally, we analyze empirical results that evaluate its performance relative to supervised deep learning approaches for seismic deblending.