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Prior-Informed Neural Framework for Super-Resolution Reconstruction from Sparse Measurements

Researchers at Stanford have developed a general software framework that reconstructs high-resolution spatial fields from sparse, irregular, or noisy measurements. Many real-world systems (from medical imaging to sensor networks) only collect measurements at limited locations, which makes it difficult to recover fine details and reliably detect localized anomalies. Standard approaches such as interpolation or conventional reconstruction often smooth away sharp features or introduce artifacts when sampling is sparse.

This approach addresses these limitations by combining two information sources in a single reconstruction engine: (1) a physics- or model-based "prior" field (for example, a simulation output, planning calculation, or predicted map) and (2) the actual measured data, even when the measurements are sparse. The method represents the unknown field as a continuous function that can be sampled at any resolution, rather than as a fixed pixel or voxel grid. A two-stage optimization process first learns the prior field, then fine-tunes the representation to match measurements using a spatially weighted objective that prioritizes accuracy near measured points while preserving global consistency across the full field.

Initially demonstrated in radiotherapy dose verification, the framework is broadly applicable to any domain requiring sparse-to-dense reconstruction of 2D or 3D scalar or vector fields. A research-stage prototype has been implemented and validated on twelve clinical radiotherapy QA cases using sparse ArcCHECK measurements, showing accurate high-resolution dose reconstruction, recovery of delivery error patterns, and strong agreement with independent offset measurements.

Applications

- **Medical imaging reconstruction** (super-resolution MRI; sparse/low-dose CT; ultrasound field mapping)
- **Radiotherapy quality assurance** (high-resolution dose reconstruction and delivery error detection from sparse QA measurements)
- **Scientific imaging and tomography** (microscopy super-resolution; electron/optical reconstruction; limited angle/undersampled tomography)
- **Industrial sensing and metrology** (sparse sensor networks; structural health monitoring; laser scanning/optical metrology; non-destructive testing)
- **Geoscience and physical field mapping** (seismic reconstruction; weather/climate/pollution super-resolution; fluid/electromagnetic/plasma field diagnostics)

Advantages

- **High-fidelity super-resolution from sparse data** with fewer artifacts than interpolation/kriging and many sparse reconstruction methods
- **Prior-guided realism and global consistency** by anchoring reconstructions to physics/model-based priors (simulations, planning calculations, predicted maps)
- **Continuous field representation** (queryable at any resolution; not limited to pixels/voxels)
- **Robust performance with irregular and noisy sampling** (stable reconstructions even with uneven spacing and measurement noise)
- **Improved detection of localized anomalies** including between measurement locations, without requiring large training datasets

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