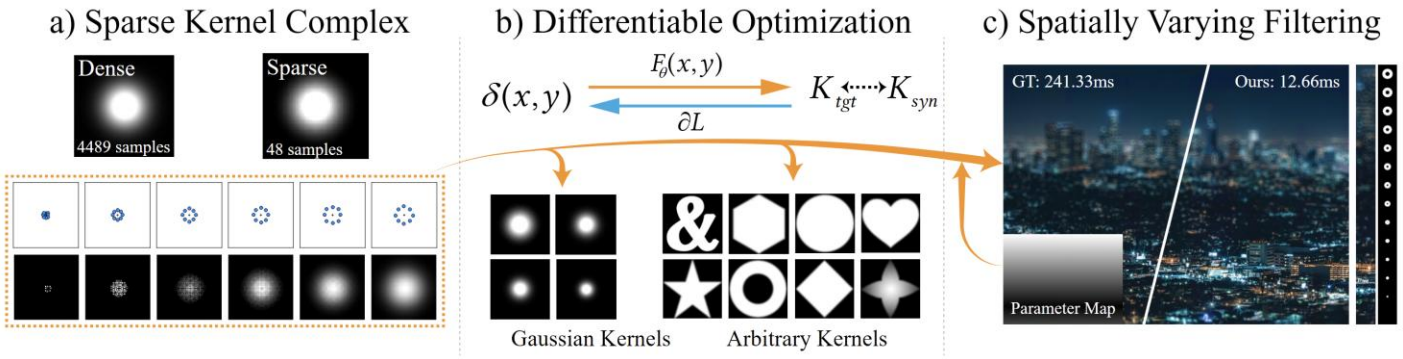

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DISK: Differentiable Sparse Kernel Complex for Efficient Spatially-Variant Convolution

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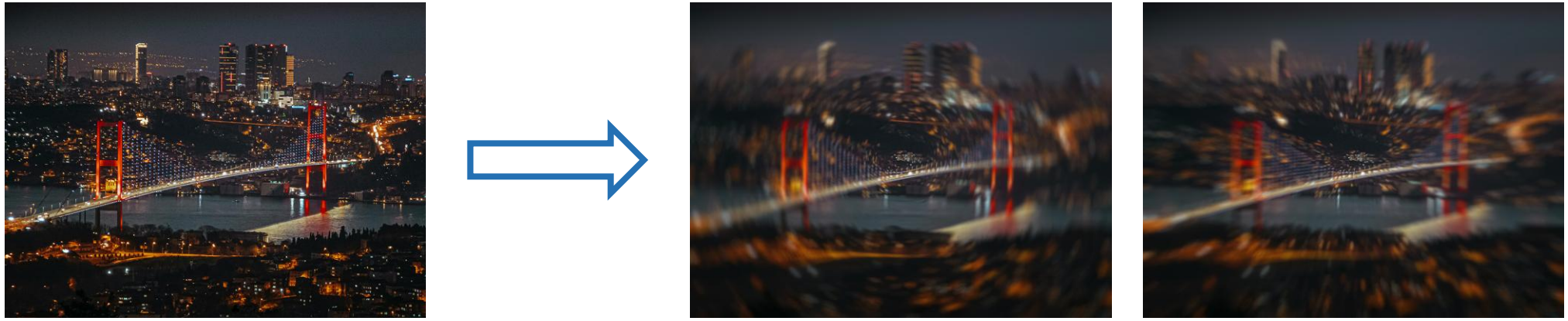
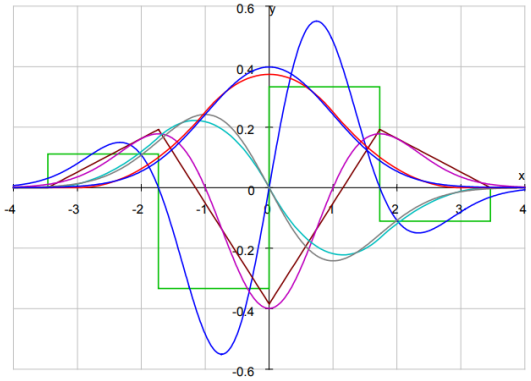
Problem

- Large kernels are useful, but dense filtering scales with kernel area
- Spatially varying kernels further increase runtime and storage cost
- Goal: keep dense-kernel expressiveness, but execute it sparsely

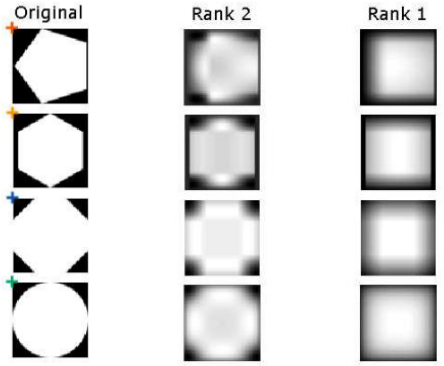


Prior Methods

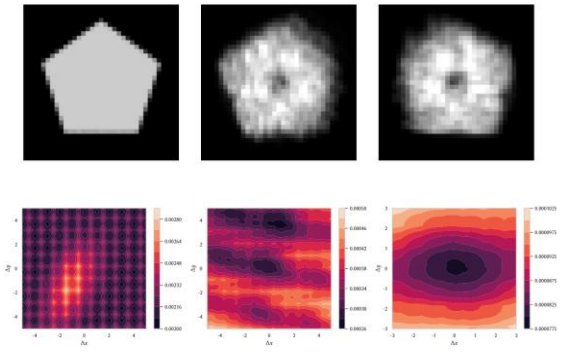
- **Gaussian-based**
  - fast ✅
  - kernel-specific ❗
  - limited flexibility ❗



- **Low-Rank**
  - more general ✅
  - still dense ❗
  - Blurry result ❗



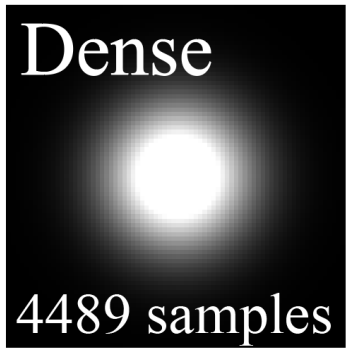
- **Parallel Simulated Tempering (PST)**
  - fast ✅
  - heuristic search
  - slow & unstable ❗



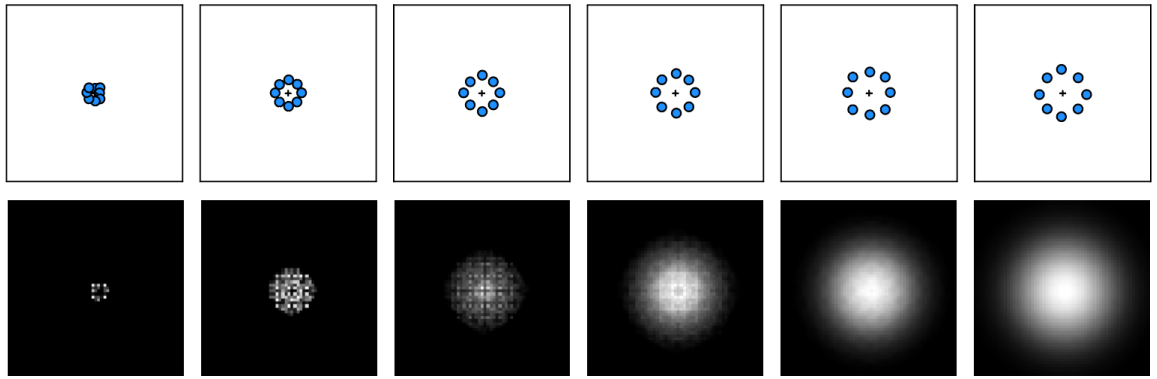
Our method: arbitrary kernels + sparse runtime + stable optimization

Sparse Kernel Complex

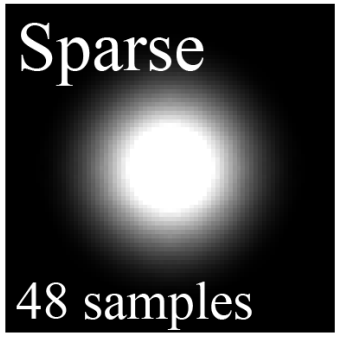
- Represent one dense kernel as a sequence of sparse layers
- Each layer contains samples with learnable offsets and weights
- Their composition forms the final effective kernel



Dense Target



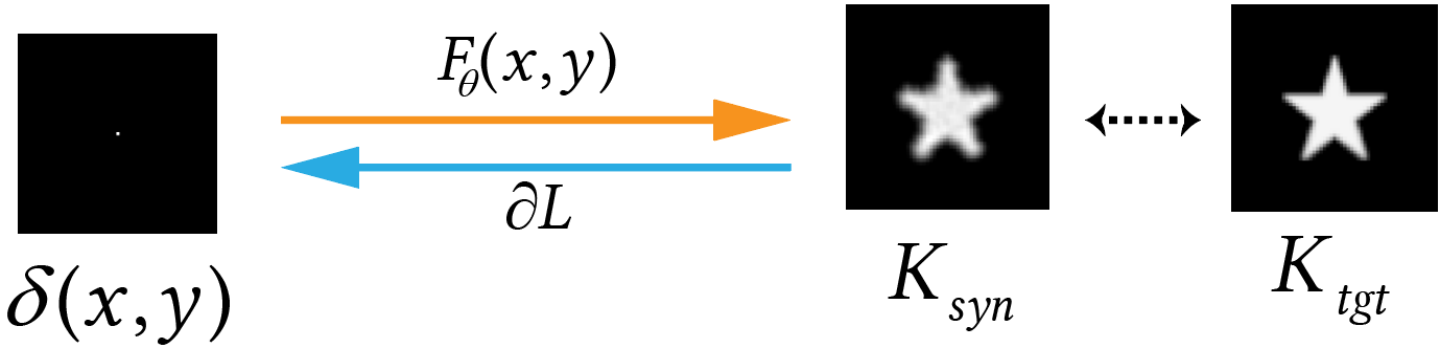
Sequential sparse layers (K1 -> K2 -> … K6)



Our Result

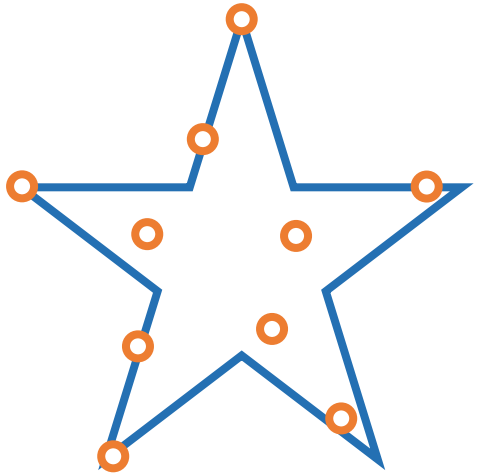
Differentiable Optimization

- A filter is characterized by its impulse response
- Apply the sparse complex to a delta impulse
- Optimize the synthesized kernel to match the target

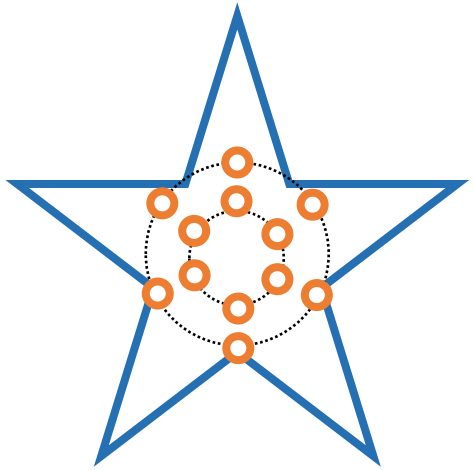


Initialization for Arbitrary Kernels

- **Sparse sampling initialization**
- sample on kernel support



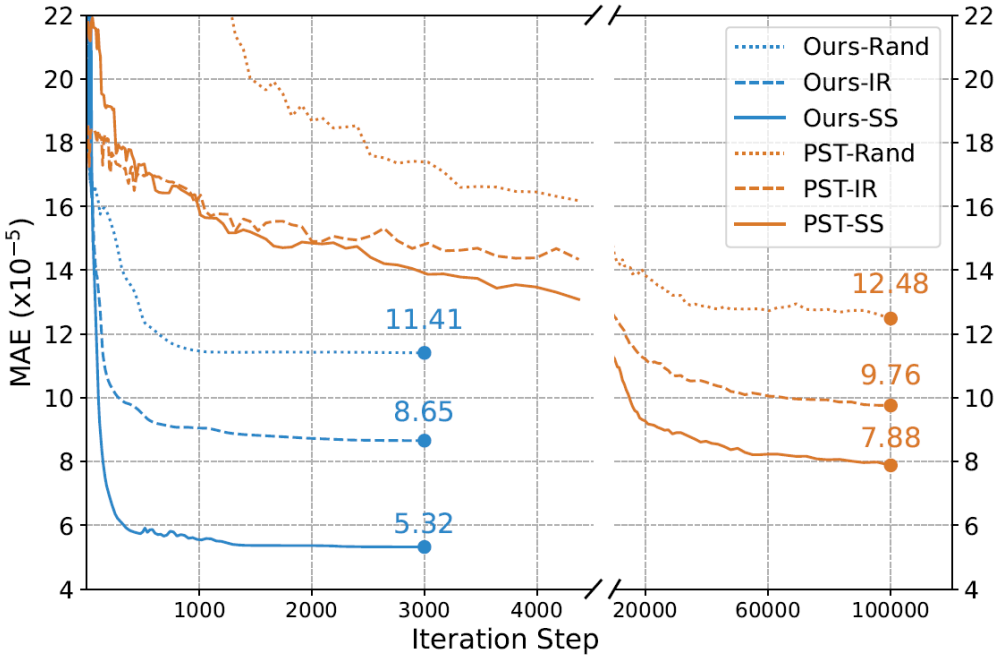
- **Increasing radial initialization**
- broad coverage across layers

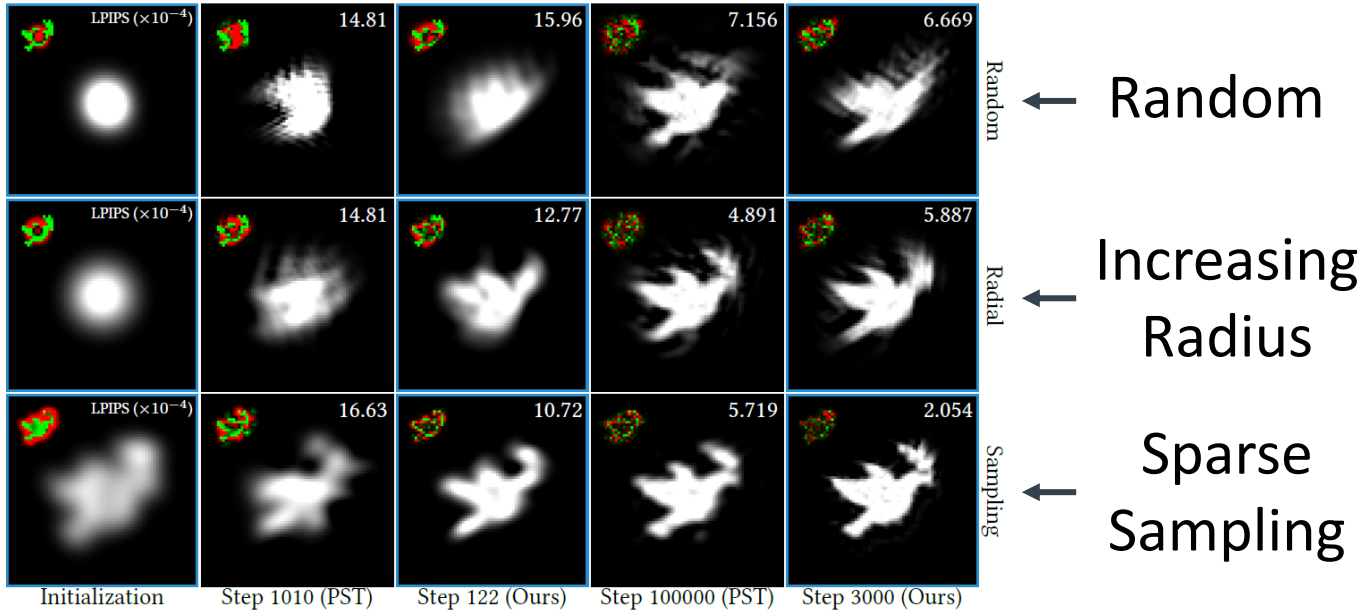


Initialization is critical for arbitrary kernel shapes

Ablation of Initialization Strategies

- **Ours-Step3k > PST-Step100k**





← Random

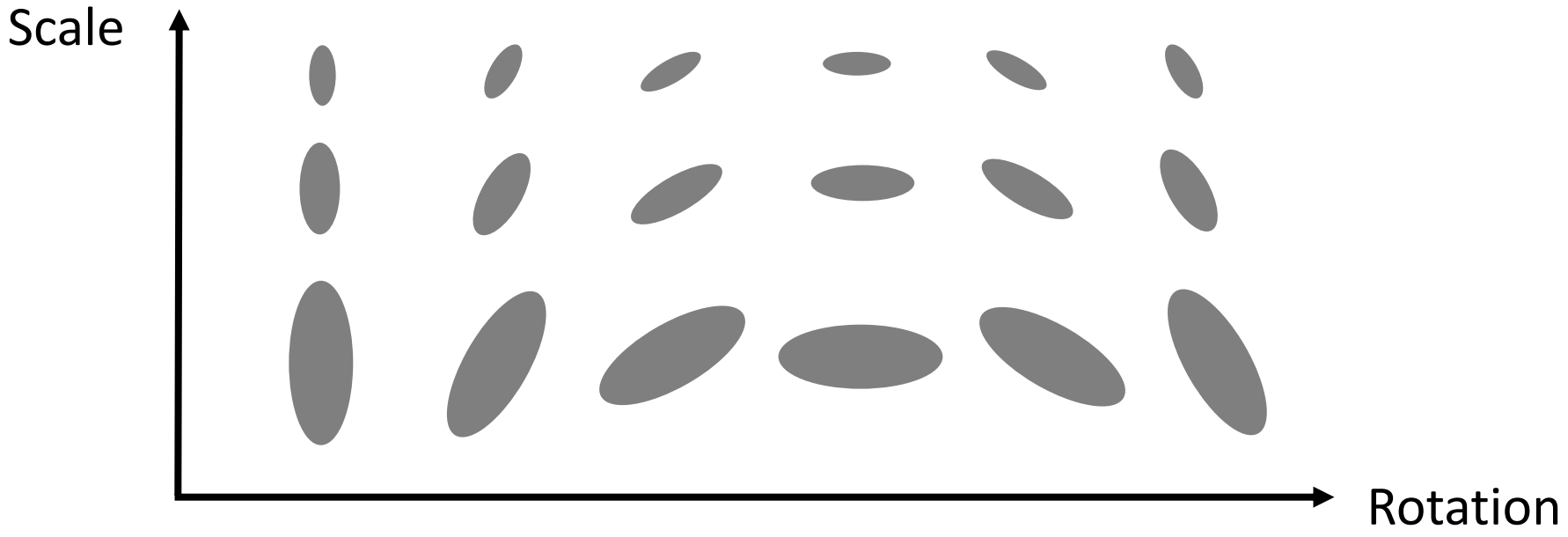
← Increasing Radius

← Sparse Sampling

Ours-SS > PST-SS > Ours-IR > PST-IR > Ours-Rand > PST-Rand

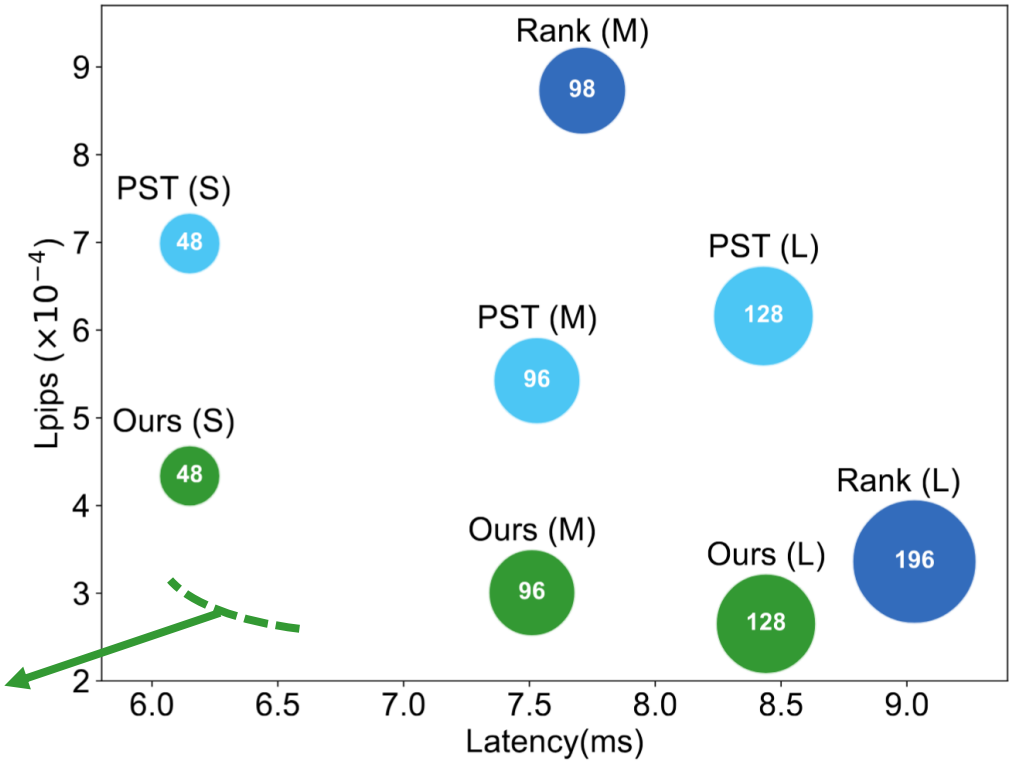
Kernel-Space Interpolation

- Offline: optimize a basis of sparse filters
- Runtime: Interpolate filters directly in kernel space
- Decouples kernel-generation cost from image resolution



Results: Single Kernel - Tradeoff

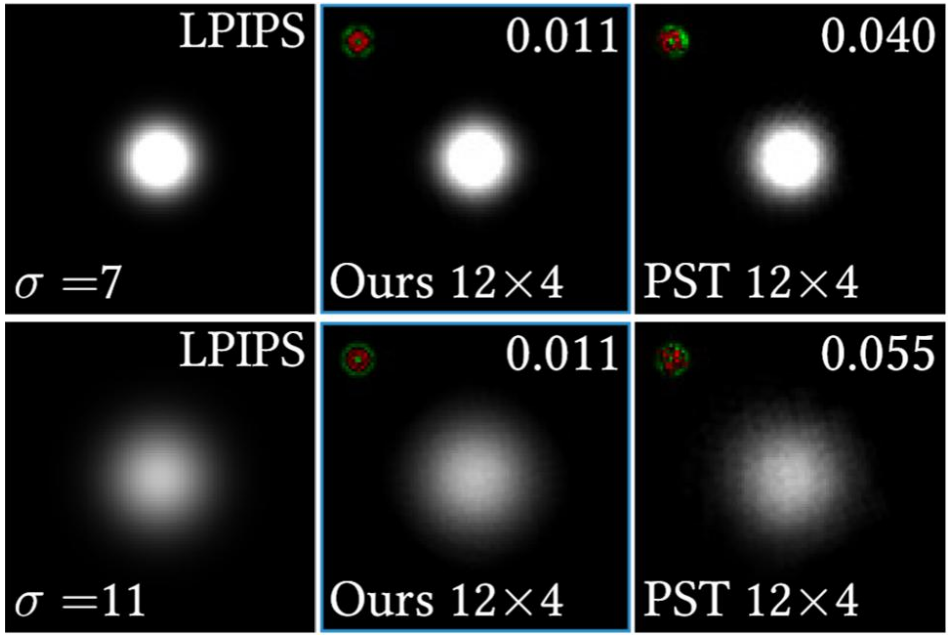
- Better quality-efficiency tradeoff than PST and Low-Rank

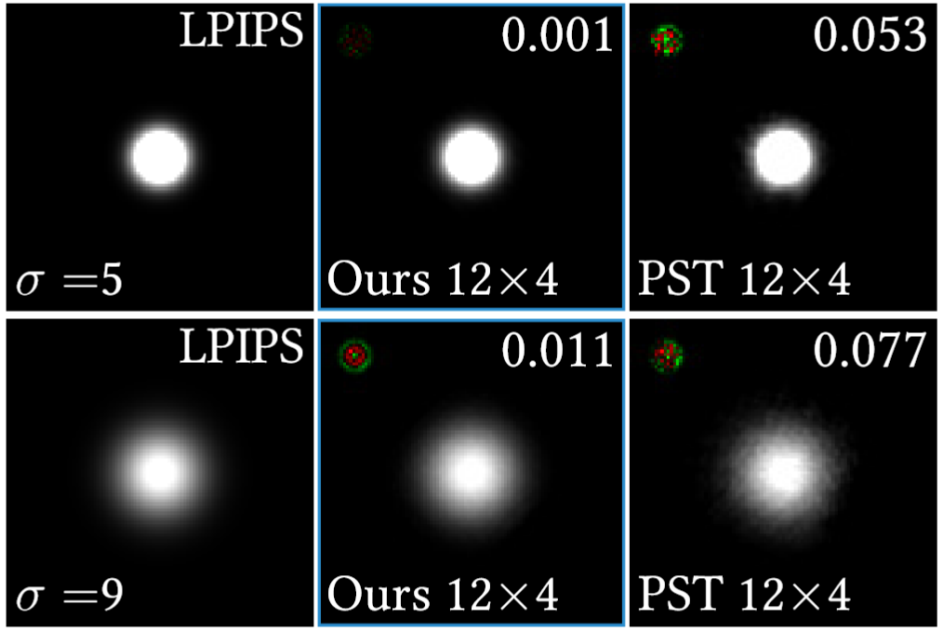


Left corner is better

Results: Single Kernel - Gaussian

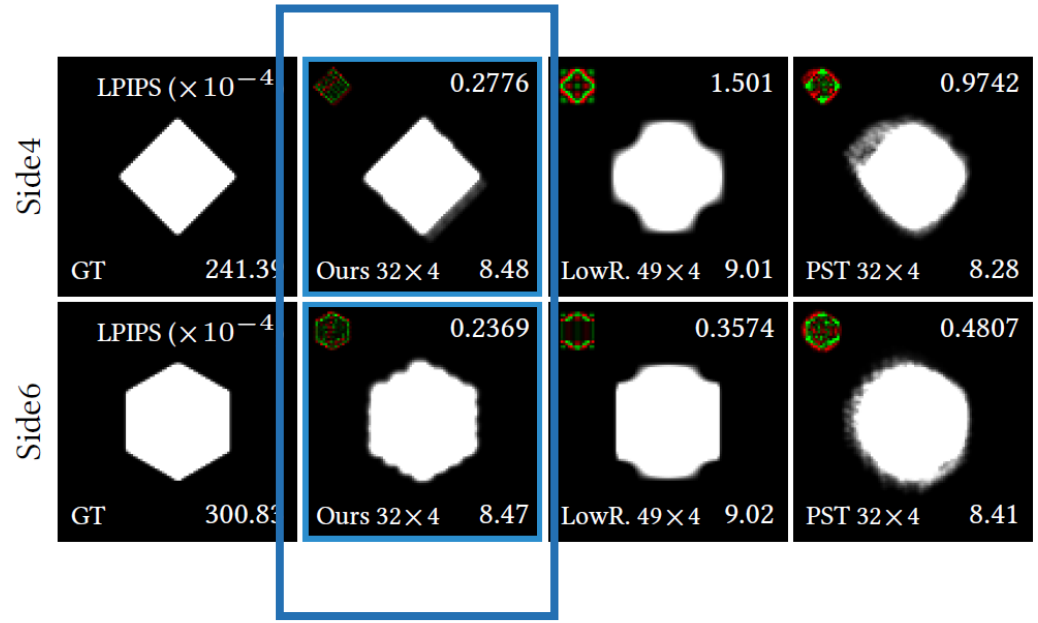
- Stable under sparse configurations
- The advantage becomes larger as σ increases



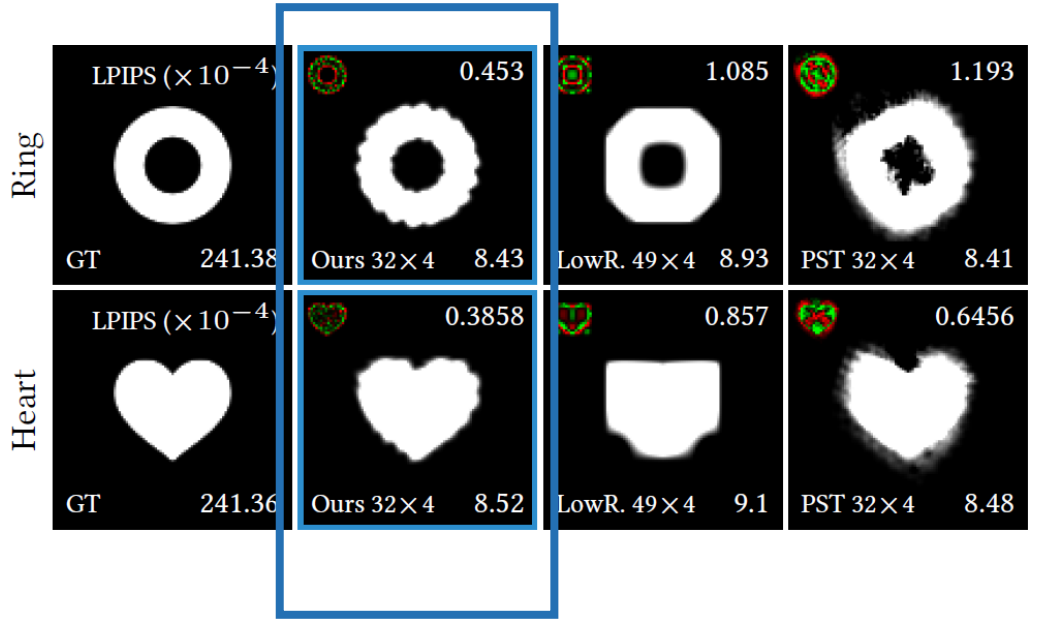


Results: Single Kernel - Arbitrary

- Our method better preserves sharp features on non-convex targets



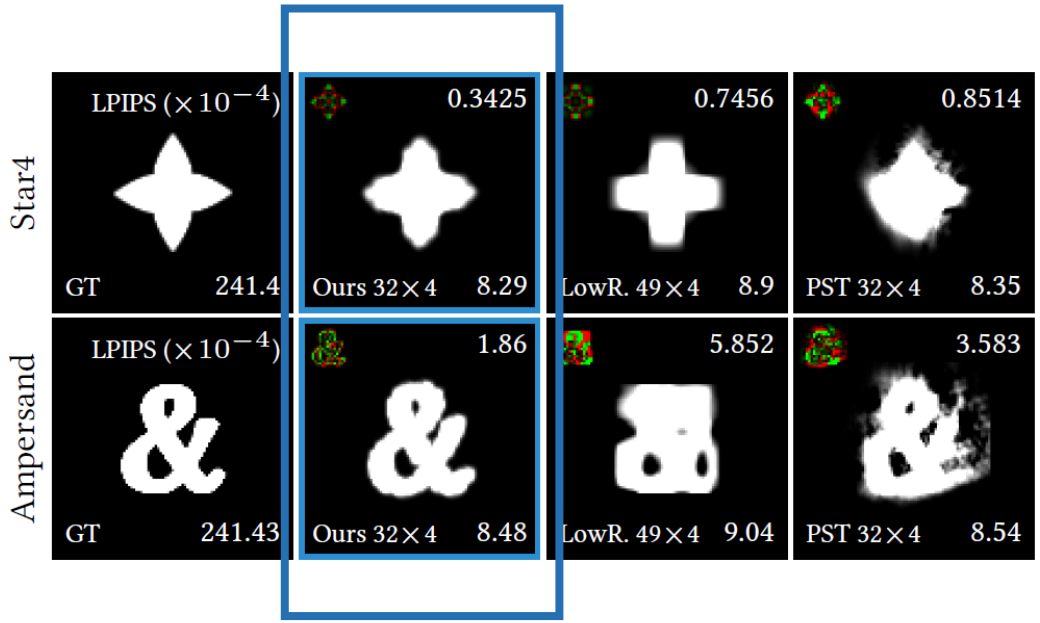
Ours

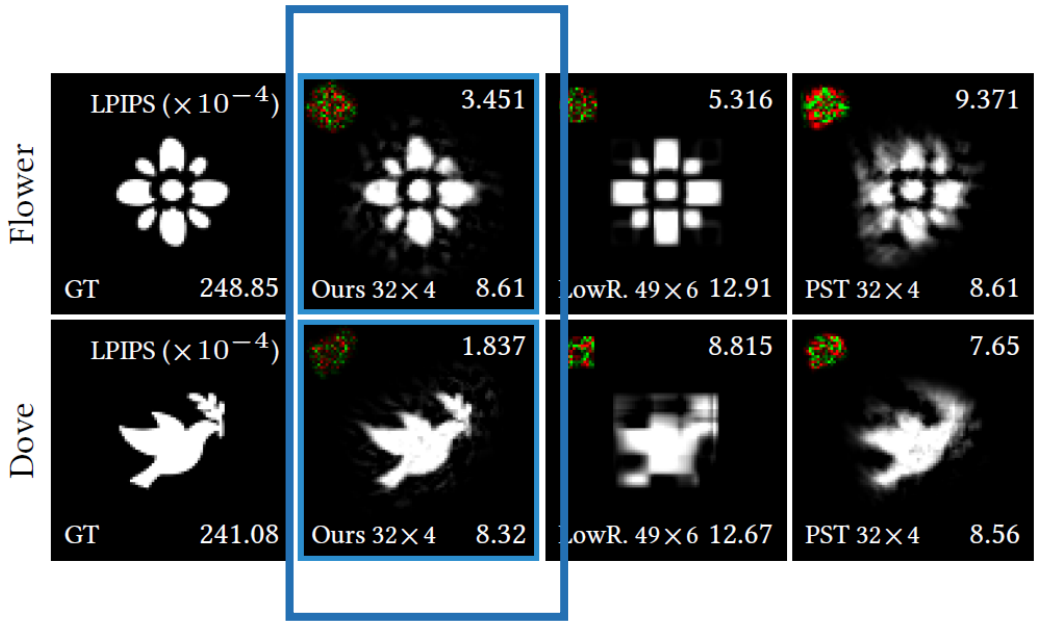


Ours

Results: Single Kernel - Arbitrary

- Generalizes to more complex shapes and optical PSFs





Results: 1D Spatially Varying

- 1D tilt-shift blur controlled by a per-pixel parameter map
- 19x speedup

39.27dB 32.49dB 33.22dB

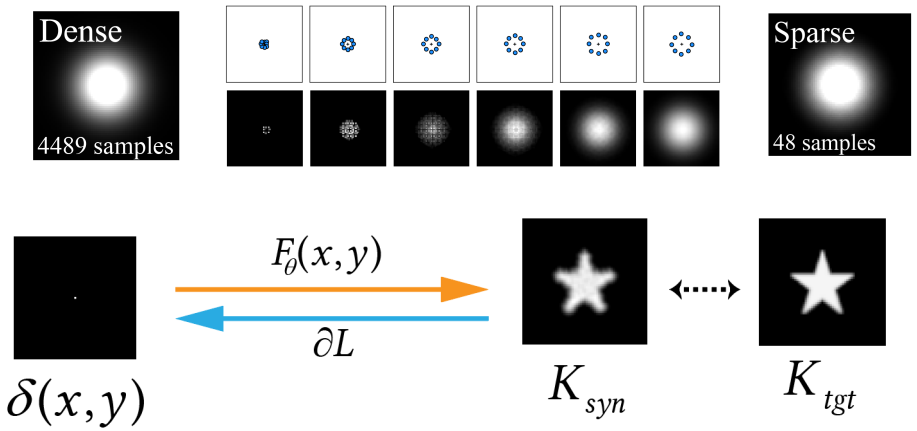
Results: 2D Spatially Varying

- 2D anisotropic effects: blur intensity + local blur angle
- 14x speedup

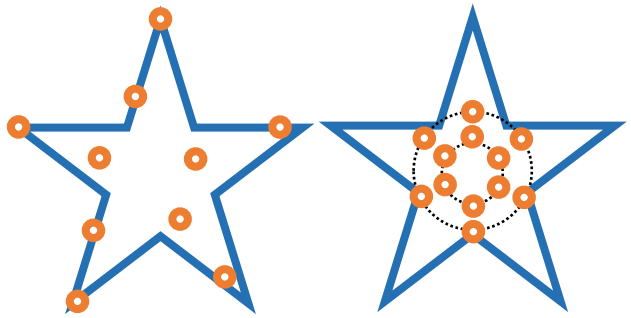
46.42dB 35.67dB 28.56dB

Conclusion

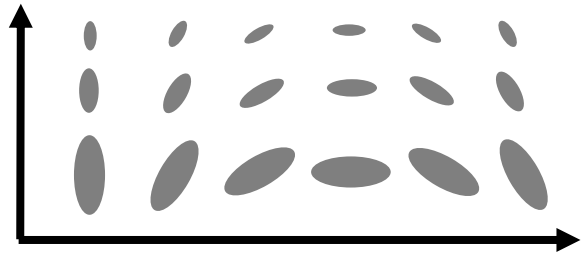
1. End-to-end **differentiable sparse-kernel** optimization
2. An initialization scheme with **Increasing Radial** and **Sparse Sampling**
3. **Kernel-space interpolation** for efficient spatially varying filtering



(1)



(2)



(3)

Thank you!

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Project page: https://wzz.ink/projects/differentiable-sparse-kernel/

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Code