

2025 Fall Diffusion Project

Exploring Latent-Space Posterior Sampling Strategies for Diffusion-Based Inverse Problems

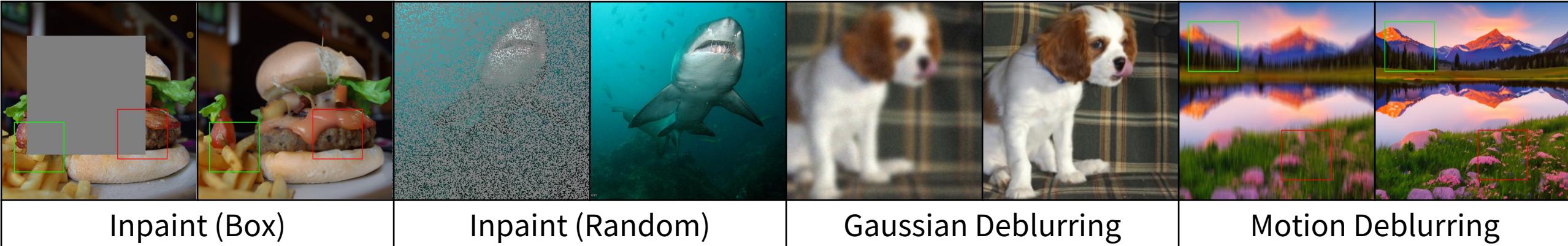
Yujin Kim

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- Motivation for Phase Retrieval Exploration
- Related Works for Phase Retrieval
- Exploration on Phase Retrieval
- Conclusion

Problem Setting

Inverse Problem: $y = A(x)$, $x = ?$

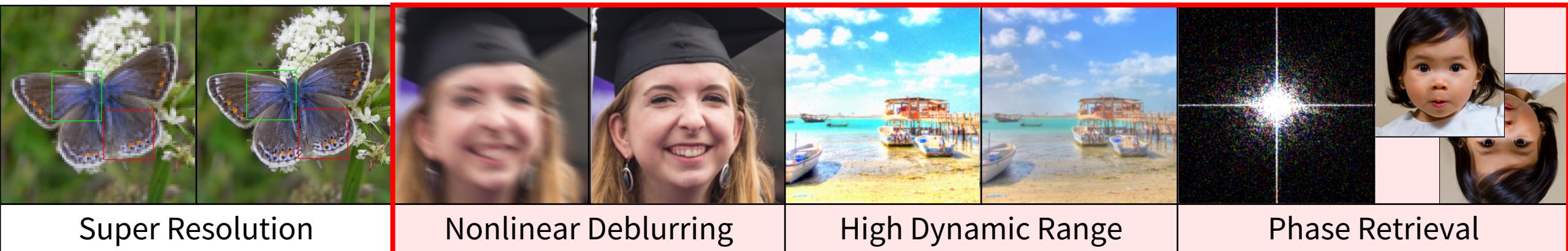


Inpaint (Box)

Inpaint (Random)

Gaussian Deblurring

Motion Deblurring



Super Resolution

Nonlinear Deblurring

High Dynamic Range

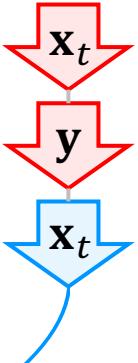
Phase Retrieval

Nonlinear

Related Works

ReSample (ICLR 2024)

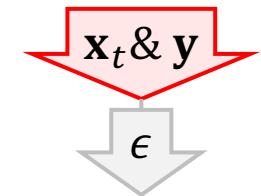
- At every timestep, predict \mathbf{x}_0 given \mathbf{x}_t by DDIM, and…
 - perform “Hard Data Consistency” optim. to force predicted \mathbf{x}_0 to match \mathbf{y} , and…
 - add noise to optimized \mathbf{x}_0 ~~with heuristic using DDIM denoised $\mathbf{x}_{t-\Delta t}$~~ for next step.
“stochastic resampling”
- (+) Measurement accuracy
 - (-) High optimization cost
 - (-) Coupling across consecutive timesteps



Related Works

LatentDAPS (DAPS, CVPR 2025 Oral)

- At every timestep, predict $\mathbf{x}_{0|y}$ given \mathbf{x}_t and \mathbf{y} by posterior sampling via MCMC: $\mathbf{x}_{0|y} \sim p(\mathbf{x}_0 | \mathbf{x}_t, \mathbf{y}) \propto \frac{p(\mathbf{x}_0 | \mathbf{x}_t)}{\text{score term}} \frac{p(\mathbf{y} | \mathbf{x}_0)}{\text{measurement term}}$, and...
- add Gaussian noise to get $\mathbf{x}_{t-\Delta t} \sim N(\mathbf{x}_{0|y}, \sigma_{t-\Delta t}^2 \mathbf{I})$.



- MCMC methods:
 - Langevin dynamics (ULA)
 - Hamiltonian Monte Carlo (HMC)

(+) Decoupled latents across consecutive timesteps, leading to better exploration

(+) State-of-the-art performance in various tasks

- Even better with HMC – except in phase retrieval

(-) Phase retrieval metric is reported with multiple independent runs ()

8 images, equal measurement

Exploration

Experiment Setting

- Dataset: FFHQ & ImageNet
 - Validation set
 - 100 images
- Metrics
 - PSNR
 - SSIM
 - LPIPS
- Index regarding the hypothesis

	Improved 😊
Supporting evidence	Unchanged
	Degraded 😞
Contradictory evidence / Baseline	
Exception with notable tendency	

- Prior results from DAPS Table 1
 - LatentDAPS (ULA)
 - ReSample

Task	Method	FFHQ			ImageNet		
		PSNR (↑)	SSIM (↑)	LPIPS (↓)	PSNR (↑)	SSIM (↑)	LPIPS (↓)
Super Resolution 4×	LD_ULA	27.48	0.801	0.182	25.06	0.673	0.276
	ReSample	23.29	0.594	0.392	22.61	0.576	0.370
Inpaint (Box)	LD_ULA	23.99	0.802	0.194	17.19	0.624	0.340
	ReSample	20.06	0.749	0.184	18.29	0.631	0.262
Inpaint (Random)	LD_ULA	30.71	0.813	0.141	27.59	0.772	0.164
	ReSample	29.61	0.746	0.140	27.50	0.756	0.143
Gaussian Deblurring	LD_ULA	27.93	0.764	0.234	25.05	0.668	0.345
	ReSample	26.39	0.714	0.255	25.97	0.703	0.254
Motion Deblurring	LD_ULA	27.00	0.814	0.283	26.83	0.745	0.296
	ReSample	27.41	0.823	0.198	26.94	0.738	0.227
Phase Retrieval	LD_ULA	29.16 ± 3.55	0.796 ± 0.089	0.199 ± 0.078	20.54 ± 6.41	0.612 ± 0.114	0.361 ± 0.150
	ReSample	21.60 ± 8.10	0.648 ± 0.154	0.406 ± 0.224	19.24 ± 4.21	0.618 ± 0.146	0.403 ± 0.174
Nonlinear Deblur	LD_ULA	28.11 ± 1.75	0.713 ± 0.041	0.235 ± 0.049	25.34 ± 3.44	0.615 ± 0.057	0.314 ± 0.080
	ReSample	28.24 ± 1.69	0.742 ± 0.039	0.185 ± 0.039	26.20 ± 3.71	0.653 ± 0.064	0.206 ± 0.057
High Dynamic Range	LD_ULA	25.94 ± 2.87	0.751 ± 0.056	0.223 ± 0.080	23.64 ± 4.10	0.609 ± 0.053	0.269 ± 0.099
	ReSample	25.65 ± 3.57	0.732 ± 0.059	0.182 ± 0.085	25.11 ± 4.21	0.633 ± 0.049	0.198 ± 0.089

Exploration

LatentDAPS: ULA vs HMC

→ Among design choices on MCMC,
HMC, a more sophisticated approach,
showed better performance than **ULA** overall!
(Except in Phase Retrieval)

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Super Resolution 4×	Ours - 5	28.06	0.733	0.247	25.61	0.669	0.284
	Ours - 30	-	-	-	24.12	0.548	0.342
	LD_ULA	27.48	0.801	0.182	25.06	0.673	0.276
	LD_HMC	29.73	0.838	0.183	26.14	0.708	0.272
	ReSample	23.29	0.594	0.392	22.61	0.576	0.370
Inpaint (Box)	Ours - 5	24.89	0.846	0.189	19.60	0.724	0.306
	LD_ULA	23.99	0.802	0.194	17.19	0.624	0.340
	LD_HMC	25.14	0.841	0.197	21.02	0.718	0.320
	ReSample	20.06	0.749	0.184	18.29	0.631	0.262
Inpaint (Random)	Ours - 5	33.18	0.919	0.109	28.57	0.821	0.171
	LD_ULA	30.71	0.813	0.141	27.59	0.772	0.164
	LD_HMC	33.14	0.916	0.123	28.60	0.818	0.183
	ReSample	29.61	0.746	0.140	27.50	0.756	0.143
Gaussian Deblurring	Ours - 5	30.12	0.850	0.194	26.09	0.697	0.292
	Ours - 15	-	-	-	26.14	0.700	0.288
	Ours - 30	-	-	-	26.25	0.705	0.282
	LD_ULA	27.93	0.764	0.234	25.05	0.668	0.345
	LD_HMC	29.81	0.842	0.203	25.96	0.691	0.301
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	ReSample	27.41	0.823	0.198	26.94	0.738	0.227
Phase Retrieval	Ours - 5	23.72 ± 6.66	0.675 ± 0.178	0.332 ± 0.150	15.32 ± 3.87	0.370 ± 0.198	0.563 ± 0.118
	Ours - 15	-	-	-	15.35 ± 3.92	0.364 ± 0.201	0.551 ± 0.119
	LD_ULA	29.16 ± 3.55	0.796 ± 0.089	0.199 ± 0.078	20.54 ± 6.41	0.612 ± 0.114	0.361 ± 0.150
	LD_HMC	23.04 ± 6.49	0.654 ± 0.179	0.351 ± 0.152	14.85 ± 4.34	0.358 ± 0.206	0.572 ± 0.124
	ReSample	21.60 ± 8.10	0.648 ± 0.154	0.406 ± 0.224	19.24 ± 4.21	0.618 ± 0.146	0.403 ± 0.174
Nonlinear Deblur	Ours - 5	30.16 ± 1.71	0.852 ± 0.040	0.188 ± 0.043	27.20 ± 3.82	0.753 ± 0.120	0.244 ± 0.074
	LD_ULA	28.11 ± 1.75	0.713 ± 0.041	0.235 ± 0.049	25.34 ± 3.44	0.615 ± 0.057	0.314 ± 0.080
	LD_HMC	30.03 ± 1.73	0.848 ± 0.043	0.196 ± 0.046	27.13 ± 3.76	0.750 ± 0.121	0.252 ± 0.076
	ReSample	28.24 ± 1.69	0.742 ± 0.039	0.185 ± 0.039	26.20 ± 3.71	0.653 ± 0.064	0.206 ± 0.057
High Dynamic Range	Ours - 5	27.44 ± 3.30	0.851 ± 0.081	0.197 ± 0.076	24.64 ± 3.82	0.757 ± 0.119	0.279 ± 0.094
	Ours - 15	-	-	-	24.99 ± 3.75	0.766 ± 0.118	0.261 ± 0.090
	Ours - 30	-	-	-	25.20 ± 4.03	0.783 ± 0.103	0.240 ± 0.093
	LD_ULA	25.94 ± 2.87	0.751 ± 0.056	0.223 ± 0.080	23.64 ± 4.10	0.609 ± 0.053	0.269 ± 0.099
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Exploration

(Codebase) LatentDAPS: ULA vs HMC

→ Among design choices on MCMC,
HMC, a more sophisticated approach,
showed better performance than ULA overall!
(Except in Phase Retrieval)

→ Competitive to **ReSample** in general!

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Exploration

Adding Measurement Error Optimization to LD_HMC

- [15~45]: followed ReSample's intuition that optimization helped in latter 2/3 timesteps in entire denoising process.
- 5/15/30 iteration per timestep (fixed)
- Compared to our code baseline, LatentDAPS with HMC,
→ Largely, **PSNR** and/or **SSIM** were improved!
(Except in Super Resolution and ImageNet HDR)
→ In Super Resolution, all metrics degraded
and it got worse as iter. per timestep increase.
→ In Phase Retrieval, all metrics did improve; however,
the vanilla HMC performed uniquely poorly, and the
improvement was not sufficient to offset the gap with
ULA/ReSample.

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- 5/15/30 iteration per timestep (fixed)
- Compared to the target baseline, ReSample, largely,

→ **PSNR** and **SSIM** outperformed!

Except in Phase Retrieval

→ **LPIPS** didn't outperformed!

Except in Super Resolution

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High Dynamic Range	Ours - 5	27.44 ± 3.30	0.851 ± 0.081	0.197 ± 0.076	24.64 ± 3.82	0.757 ± 0.119	0.279 ± 0.094
	Ours - 15	-	-	-	24.99 ± 3.75	0.766 ± 0.118	0.261 ± 0.090
	Ours - 30	-	-	-	25.20 ± 4.03	0.783 ± 0.103	0.240 ± 0.093
	LD_ULA	25.94 ± 2.87	0.751 ± 0.056	0.223 ± 0.080	23.64 ± 4.10	0.609 ± 0.053	0.269 ± 0.099
	LD_HMC	27.19 ± 3.35	0.845 ± 0.086	0.203 ± 0.080	24.85 ± 3.84	0.758 ± 0.107	0.267 ± 0.092
	ReSample	25.65 ± 3.57	0.732 ± 0.059	0.182 ± 0.085	25.11 ± 4.21	0.633 ± 0.049	0.198 ± 0.089

Exploration

Adding Measurement Error Optimization to LD_HMC

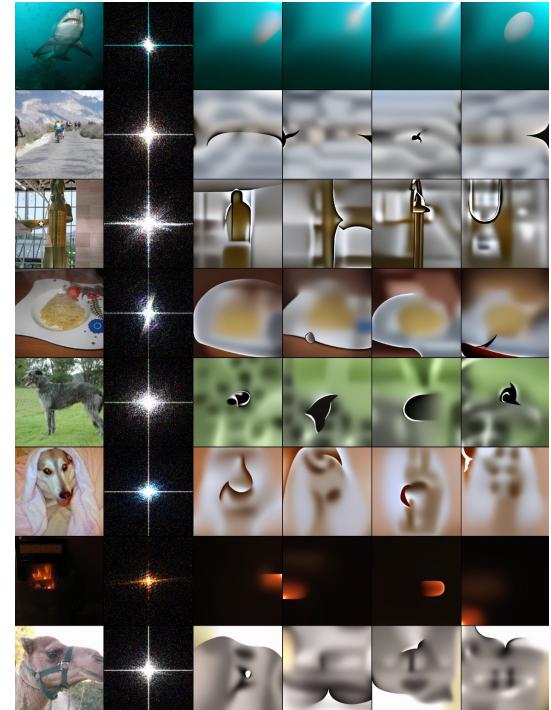
- [15~45]: followed ReSample's intuition that optimization helped in latter 2/3 timesteps in entire denoising process.
- 5/15/30 iteration per timestep (fixed)
- Effect on increasing iteration per timestep
→ Largely improved the metrics
Except in Super Resolution

Task	Method	FFHQ			ImageNet		
		PSNR (↑)	SSIM (↑)	LPIPS (↓)	PSNR (↑)	SSIM (↑)	LPIPS (↓)
Super Resolution 4×	Ours - 5	28.06	0.733	0.247	25.61	0.669	0.284
	Ours - 30	-	-	-	24.12	0.548	0.342
	LD_ULA	27.48	0.801	0.182	25.06	0.673	0.276
	LD_HMC	29.73	0.838	0.183	26.14	0.708	0.272
	ReSample	23.29	0.594	0.392	22.61	0.576	0.370
Inpaint (Box)	Ours - 5	24.89	0.846	0.189	19.60	0.724	0.306
	LD_ULA	23.99	0.802	0.194	17.19	0.624	0.340
	LD_HMC	25.14	0.841	0.197	21.02	0.718	0.320
	ReSample	20.06	0.749	0.184	18.29	0.631	0.262
Inpaint (Random)	Ours - 5	33.18	0.919	0.109	28.57	0.821	0.171
	LD_ULA	30.71	0.813	0.141	27.59	0.772	0.164
	LD_HMC	33.14	0.916	0.123	28.60	0.818	0.183
	ReSample	29.61	0.746	0.140	27.50	0.756	0.143
Gaussian Deblurring	Ours - 5	30.12	0.850	0.194	26.09	0.697	0.292
	Ours - 15	-	-	-	26.14	0.700	0.288
	Ours - 30	-	-	-	26.25	0.705	0.282
	LD_ULA	27.93	0.764	0.234	25.05	0.668	0.345
	LD_HMC	29.81	0.842	0.203	25.96	0.691	0.301
	ReSample	26.39	0.714	0.255	25.97	0.703	0.254
Motion Deblurring	Ours - 5	31.22	0.870	0.167	27.11	0.738	0.271
	LD_ULA	27.00	0.814	0.283	26.83	0.745	0.296
	LD_HMC	31.17	0.869	0.168	27.05	0.735	0.274
	ReSample	27.41	0.823	0.198	26.94	0.738	0.227
Phase Retrieval	Ours - 5	23.72 ± 6.66	0.675 ± 0.178	0.332 ± 0.150	15.32 ± 3.87	0.370 ± 0.198	0.563 ± 0.118
	Ours - 15	-	-	-	15.35 ± 3.92	0.364 ± 0.201	0.551 ± 0.119
	LD_ULA	29.16 ± 3.55	0.796 ± 0.089	0.199 ± 0.078	20.54 ± 6.41	0.612 ± 0.114	0.361 ± 0.150
	LD_HMC	23.04 ± 6.49	0.654 ± 0.179	0.351 ± 0.152	14.85 ± 4.34	0.358 ± 0.206	0.572 ± 0.124
	ReSample	21.60 ± 8.10	0.648 ± 0.154	0.406 ± 0.224	19.24 ± 4.21	0.618 ± 0.146	0.403 ± 0.174
Nonlinear Deblur	Ours - 5	30.16 ± 1.71	0.852 ± 0.040	0.188 ± 0.043	27.20 ± 3.82	0.753 ± 0.120	0.244 ± 0.074
	LD_ULA	28.11 ± 1.75	0.713 ± 0.041	0.235 ± 0.049	25.34 ± 3.44	0.615 ± 0.057	0.314 ± 0.080
	LD_HMC	30.03 ± 1.73	0.848 ± 0.043	0.196 ± 0.046	27.13 ± 3.76	0.750 ± 0.121	0.252 ± 0.076
	ReSample	28.24 ± 1.69	0.742 ± 0.039	0.185 ± 0.039	26.20 ± 3.71	0.653 ± 0.064	0.206 ± 0.057
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	ReSample	25.65 ± 3.57	0.732 ± 0.059	0.182 ± 0.085	25.11 ± 4.21	0.633 ± 0.049	0.198 ± 0.089

Motivation for Phase Retrieval Exploration

Problem Setting

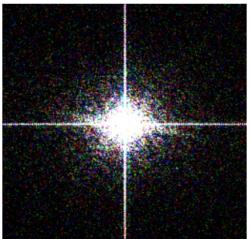
- Phase retrieval is unique that measurements is amplitude-only, $y = |\mathbf{Ax}|$
- In general, multiple image can have equal measurement: multimodal problem
- DAPS: oversampling_rate=2.0 setting \Rightarrow **2-mode problem: 0° and 180°**



LatentDAPS

- Performs **4 independent runs** to report 1 best metric
- The only task that performance in MCMC is **ULA** >> **HMC**

Measurement



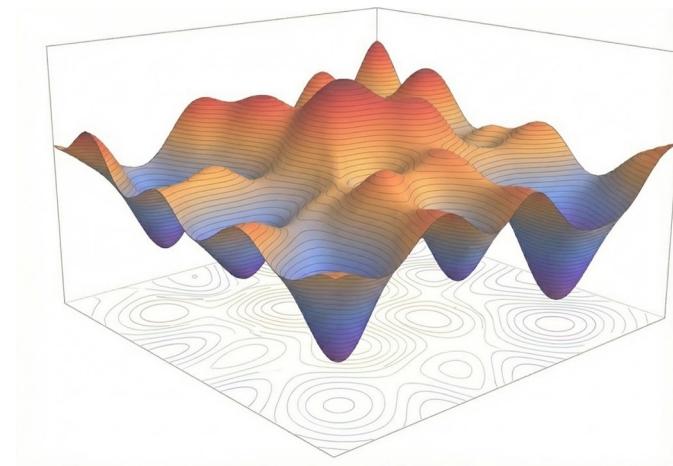
2 modes:
 0° and 180°



Related Works for Phase Retrieval

Repulsive Latent Score Distillation for Solving Inverse Problems (ICLR 2025)

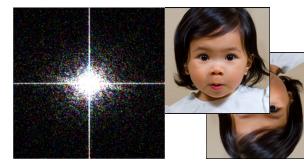
- Formulate diffusion-based inverse problems as variational posterior approximation (instead of explicit posterior sampling)
- Represent the posterior with an ensemble of interacting particles to capture multimodality
- Introduced **repulsive regularization**
 - to prevent particle collapse
 - to explicitly control diversity during optimization
 - exploiting **DINO-ViT feature distance** to gauge overall structure difference



Tree-Guided Diffusion Planner (NeurIPS 2025)

- Robotics planning domain (extends Diffuser, ICML 2022)
- Utilize **repulsion** to handle multimodality in non-convex objectives

Exploration on Phase Retrieval



Adding Measurement Error Optimization to LatentDAPS with ULA

- In timestep [50]: ensuring hard data consistency in the output without hindering LatentDAPS MCMC sampling

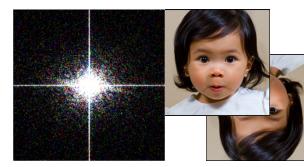
- LatentDAPS's posterior sampling jointly combines both phase and amplitude by score and measurement gradient term respectively via MCMC.

$$\mathbf{x}_0^{(j+1)} = \mathbf{x}_0^{(j)} + \eta \nabla_{\mathbf{x}_0^{(j)}} \log p(\mathbf{x}_0^{(j)} \mid \mathbf{x}_t) + \eta \nabla_{\mathbf{x}_0^{(j)}} \log p(\mathbf{y} \mid \mathbf{x}_0^{(j)}) + \sqrt{2\eta} \boldsymbol{\epsilon}_j$$

→ Degraded performance!

- Measurement is amplitude-only; measurement loss is blind to phase.
- Additional optimization yielded only marginal amplitude-error reduction while degrading phase alignment, suggesting that the measurement-loss landscape was (locally) flat.

Exploration on Phase Retrieval



Prior knowledge: phase retrieval with oversampling rate 2.0 has 2 modes

Adding Repulsion

- Hypothesis: “Compared to 4 independent runs in LatentDAPS, 4 dependent and repulsive runs would better cover phase retrieval’s 2 modes.”

→**Repulsion degrades performance: 4 independent runs > 4 repulsive runs!**

Adding Repulsion and Pruning

- Hypothesis: “There may be conservative pruning from 4 to 2 particles without performance loss.”
 - Criteria: measurement loss top 2

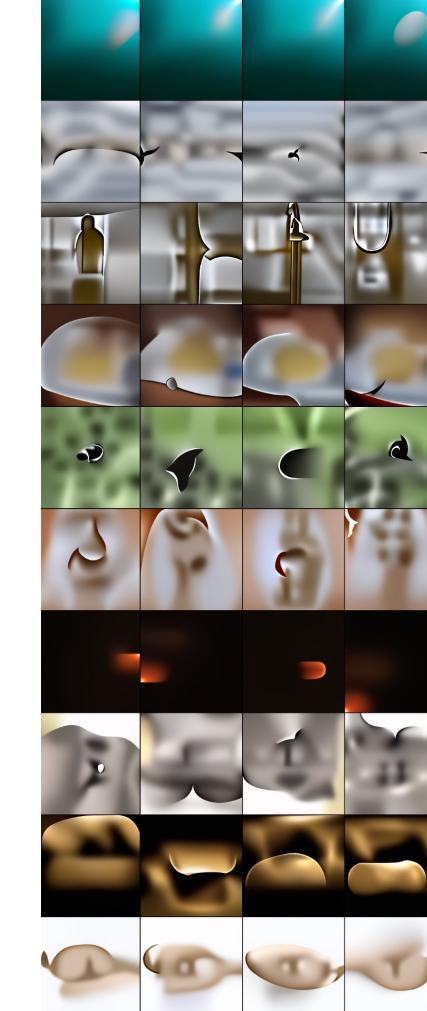
→**Pruning didn’t help:**

4 repulsive runs > 2 repulsive runs > 4→2 pruning at [29] w/ measurement loss!

→**Ranking of measurement loss at timestep [29] didn’t align with final PSNR.**

Exploration on Phase Retrieval

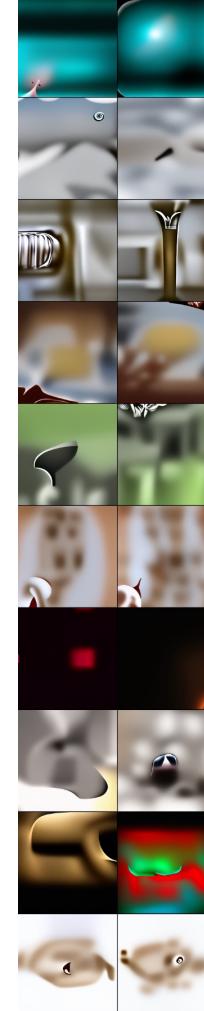
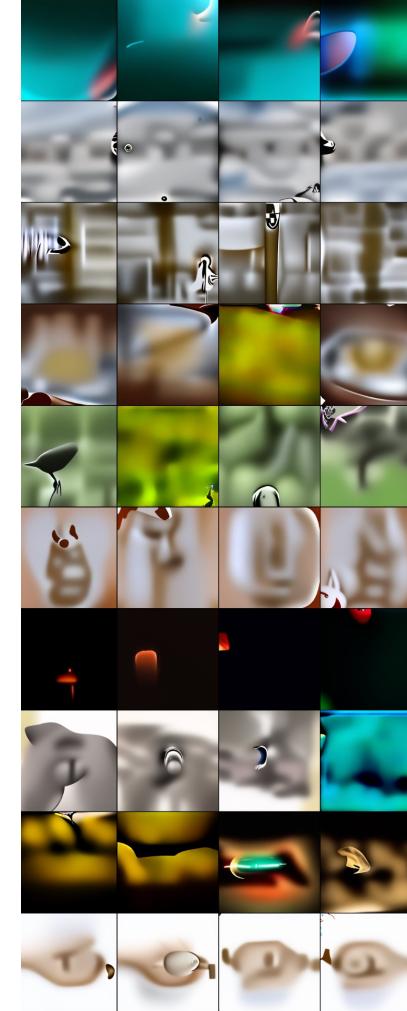
Data



4 independent runs

>

4 repulsive runs > 2 repulsive runs > 4→2 pruning at [29]



Thank you.

Exploring Latent-Space Posterior Sampling Strategies for Diffusion-Based Inverse Problems

Yujin Kim

