

2025 Fall Diffusion Project

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

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Contents

- Problem Setting
- Related Works
- Exploration

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

- Conclusion

Problem Setting

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

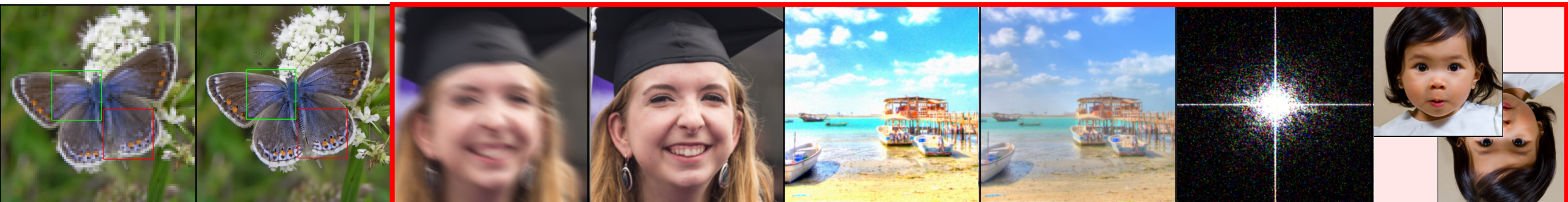


Inpaint (Box)

Inpaint (Random)

Gaussian Deblurring

Motion Deblurring



Super Resolution

Nonlinear Deblurring

High Dynamic Range

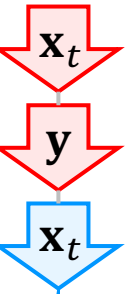
Phase Retrieval

Nonlinear

Related Works

ReSample (ICLR 2024)

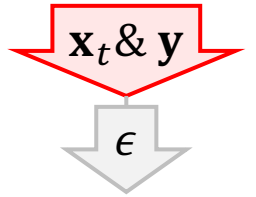
- At every timestep, predict \mathbf{x}_0 given \mathbf{x}_t by DDIM, and...
 - perform “Hard Data Consistency” optim. to force predicted \mathbf{x}_0 to match \mathbf{y} , and...
 - add noise to optimized \mathbf{x}_0 ~~with heuristic using DDIM denoised $\mathbf{x}_{t-\Delta t}$~~ for next step.
“stochastic 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: $\mathbf{x}_{0|y} \sim p(\mathbf{x}_0 | \mathbf{x}_t, \mathbf{y}) \propto \underbrace{p(\mathbf{x}_0 | \mathbf{x}_t)}_{\text{score term}} \underbrace{p(\mathbf{y} | \mathbf{x}_0)}_{\text{measurement term}}$, 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 regrading the hypothesis

| | |
|-----------------------------------|------------|
| Supporting evidence | Improved 😊 |
| | 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 4x | 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)

| Task | Method | FFHQ | | | ImageNet | | |
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| | | 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 |
| 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 |
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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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| | | PSNR (↑) | SSIM (↑) | LPIPS (↓) | PSNR (↑) | SSIM (↑) | LPIPS (↓) |
| Super Resolution 4× | Ours - 5 | 28.06 | 0.733 | 0.247 | 25.61 | 0.669 | 0.284 |
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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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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 the target baseline, ReSample, largely,

→ **PSNR** and **SSIM** outperformed!
Except in Phase Retrieval

→ **LPIPS** didn't outperformed!
Except in Super Resolution

| Task | Method | FFHQ | | | ImageNet | | |
|---------------------|-----------|-------------|-------------|--------------|------------|--------------|--------------|
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| 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 |
| | 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 |
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| | 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 |
| | 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 |

Motivation for Phase Retrieval Exploration

Problem Setting

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

LatentDAPS

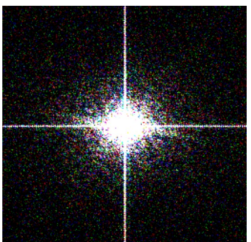
- Performs 4 independent runs to report 1 best metric
- The only task that performance in MCMC is **ULA** >> **HMC**



4 independent runs

2 modes:
 0° and 180°

Measurement



8 images, equal measurement



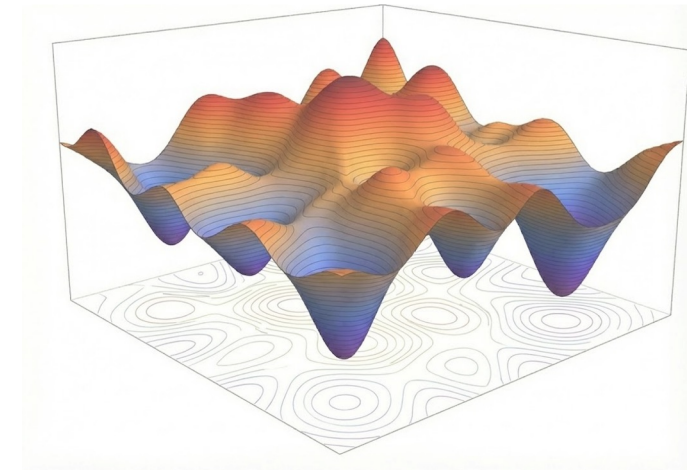
Related Works for Phase Retrieval

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

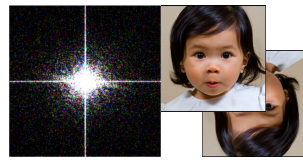
- Formulate diffusion-based inverse problems as variational posterior approximation (instead of explicit posterior sampling)
- Represent the posterior with an ensemble of interacting particles to capture multimodality
- Introduced **repulsive regularization**
 - to prevent particle collapse
 - to explicitly 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

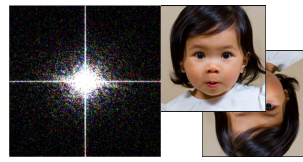
- LatentDAPS's posterior sampling jointly combines both phase and amplitude by score and measurement gradient term respectively via MCMC.

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

→ 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

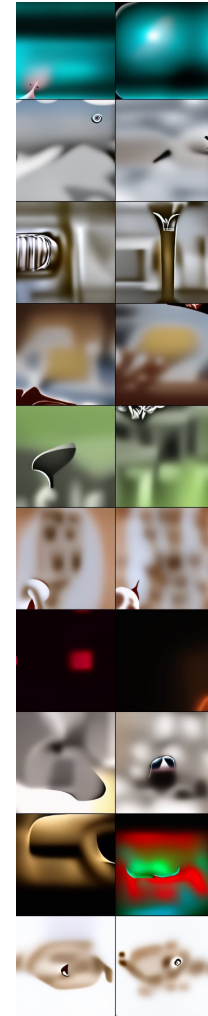
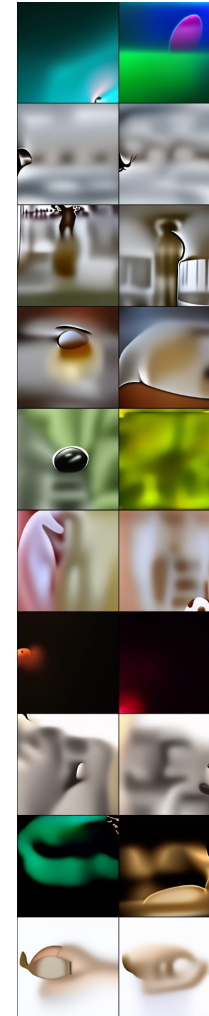
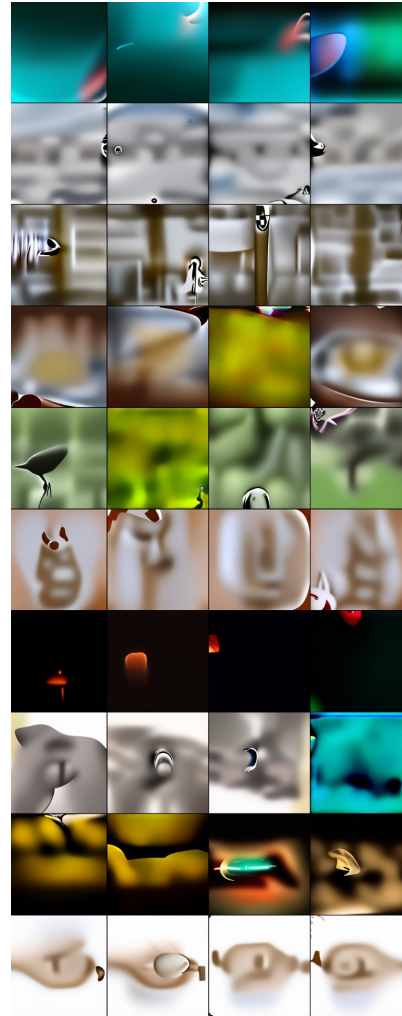
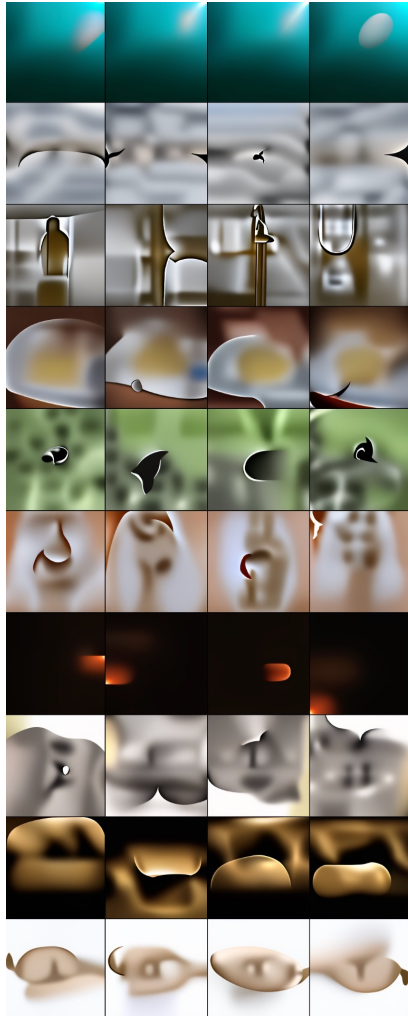
→ **Pruning** didn’t help:

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

