Diffusion Models for Image Generation and Inversion

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Motivation

- Inverse problems in computational imaging arise when we want to recover a clean image x_o from degraded observations $y = Ax_0 + \eta, A \in R^{MxN}, \eta \sim N(0,\sigma^2 I)$
- This project explores fundamentals of diffusion models and their capabilities in two areas: **Image Generation** and **Image Restoration** via inpainting and deconvolution

Related Work

Forward Noising Process (VP):

$$x_t = \sqrt{\bar{\alpha}_t}x_0 + \sqrt{1-\bar{\alpha}_t}, for\ t = 1,2,\ldots,T$$

$$\alpha_t = 1-\beta_t, \bar{\alpha}_t = \prod_{i=0}^{t}\alpha_i, z \sim N(0,1)$$

Reverse Denoising Process (DDPM):

$$x_{t-1} = \frac{1}{\sqrt{\alpha_t}} * (x_t + (1-\alpha_t) * s_\theta,\ s_\theta = -\frac{e_\theta}{\sqrt{1-\bar{\alpha}_t}}$$

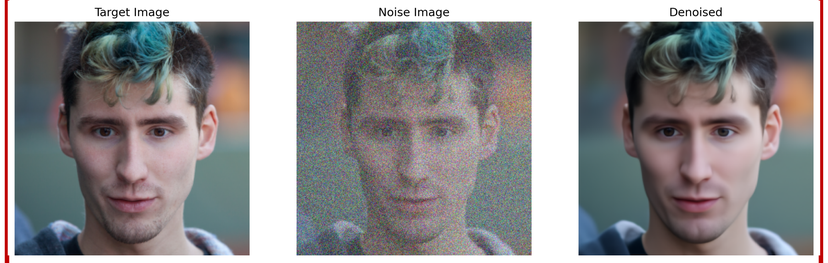
Image Restoration Methods:

- SDEdit: $x_{t*} = \sqrt{\bar{\alpha}_{t*}}y + \sqrt{1-\bar{\alpha}_{t*}}z, \quad z \sim N(0,I)$
- ScoreALD: $x_{t-1} \leftarrow x_{t-1} - \frac{\nabla_{x_t}\|A(x_t)-y\|^2}{2(\sigma^2+\gamma_t^2)}$
- DPS: $x_{t-1} \leftarrow x_{t-1} - \frac{\zeta}{\|\nabla\|A\hat{x}_0 - y\|^2\|} \cdot \nabla\|A\hat{x}_0 - y\|^2$

References

[1] Sohl-Dickstein et al., "Deep Unsupervised Learning using Nonequilibrium Thermodynamics," ICML, 2015.
[2] Ho et al., "Denoising Diffusion Probabilistic Models," NeurIPS, 2020.
[3] Song et al., "Score-Based Generative Modeling through Stochastic Differential Equations," ICLR, 2021.
[4] Meng et al., "SDEdit: Guided Image Synthesis and Editing with Stochastic Differential Equations," ICLR, 2022.
[5] Jalal et al., "Robust Compressed Sensing MRI with Deep Generative Priors," NeurIPS, 2021.
[6] Chung et al., "Diffusion Posterior Sampling for General Noisy Inverse Problems," ICLR, 2023.

Forward and Reverse Process

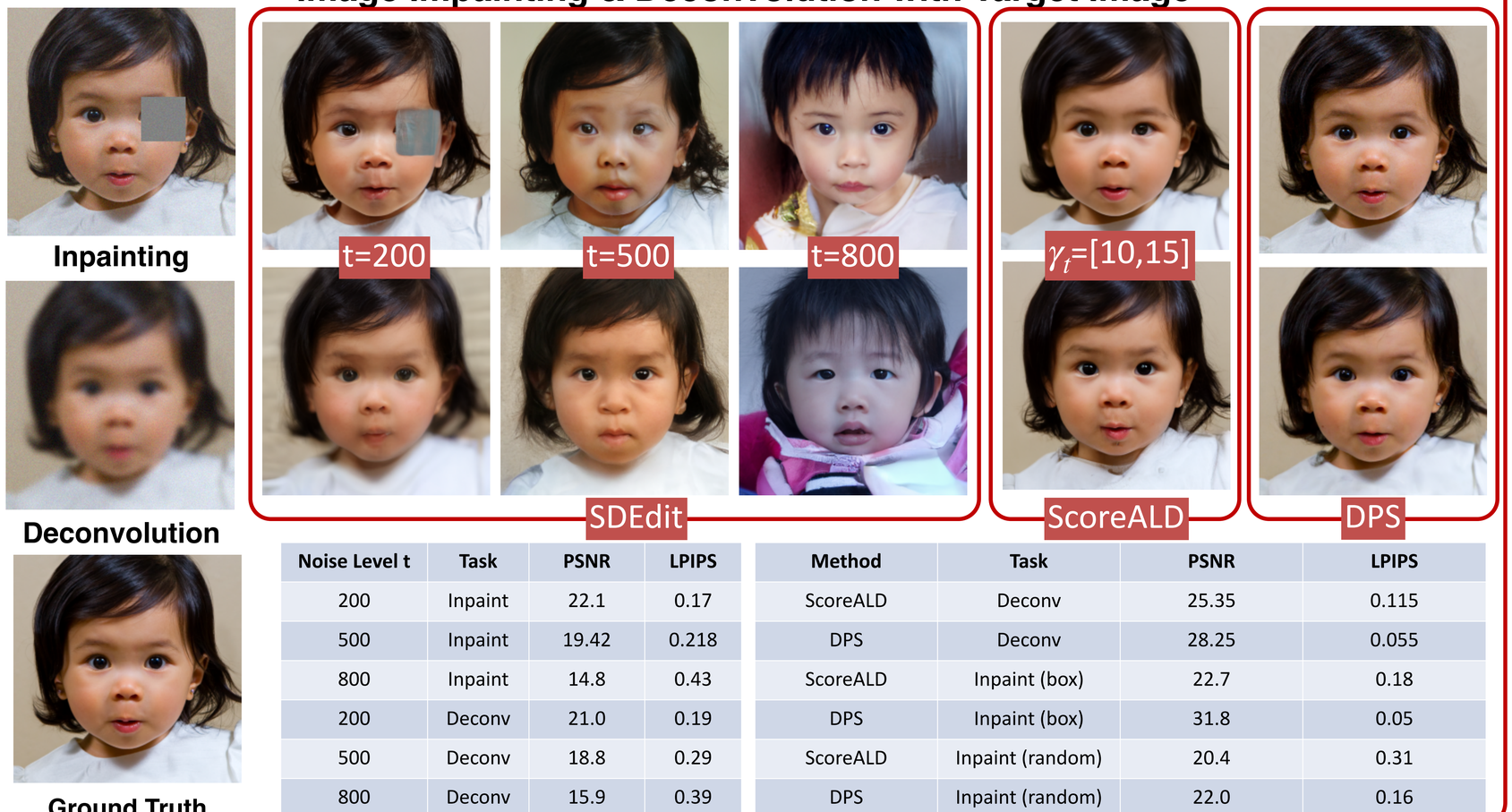


Noise level: t=100, **PSNR**: 32.7dB, **LPIPS**: 0.09

Image Generation using DDPM Method

Every random noise will create different set of "denoised image"

Image Impainting & Deconvolution with Target Image



Noise Level t	Task	PSNR	LPIPS
200	Inpaint	22.1	0.17
500	Inpaint	19.42	0.218
800	Inpaint	14.8	0.43
200	Deconv	21.0	0.19
500	Deconv	18.8	0.29
800	Deconv	15.9	0.39

Method	Task	PSNR	LPIPS
ScoreALD	Deconv	25.35	0.115
DPS	Deconv	28.25	0.055
ScoreALD	Inpaint (box)	22.7	0.18
DPS	Inpaint (box)	31.8	0.05
ScoreALD	Inpaint (random)	20.4	0.31
DPS	Inpaint (random)	22.0	0.16