MUPET Inference details

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For all experiments using DiffPIR, we used 1000 iterations and $\lambda = 1$ because this is the value that is most line with classical inverse problem solvers. We also used a batch-size of 32 and performed the tests on Nvidia A40 GPUs or slower. Per inverse problem considered, the tests took between one and two and a half hours to cover the whole data-set.

Tables 1, 2, 3 and 4 are hyper-parameter tests that were run on a single batch of 16 images from LSUN bedroom using the DiffPIR algorithm [1] in VE form as seen in Algorithm 1. Bold denotes the best performance per hyper-parameter pair, while the lowest LPIPS for each score-function is underlined. The hyper-parameters that produced the underlined results were used for the experiments in the main paper.

This means for pixel-wise completion, we used $\zeta = 0.6$ and $\sigma_T = 1$, for block-wise completion, we used $\zeta = 0.3$ and $\sigma_T = 10$, while for super-resolution we used $\zeta = 0.6$ and $\sigma_T = 0.1$ for the score-function obtained via MUPET, and $\zeta = 0.3$ and $\sigma_T = 0.01$ for the score-function obtained via DSM. For deblurring, we used $\zeta = 0.6$ and $\sigma_T = 0.1$ for the MUPET score and $\zeta = 0.3$ and $\sigma_T = 1$ for the DSM score.

The hyper-parameter tests suggest that larger selection of σ_T is advised when the inverse problem considered produces observations that are far away from the ground-truth image and neighboring pixels cannot make up for this missing information. Block-wise in-painting appears to be the most affected by this issue.

References

[1] Yuanzhi Zhu, Kai Zhang, Jingyun Liang, Jiezhang Cao, Bihan Wen, Radu Timofte, and Luc Van Gool. Denoising diffusion models for plug-and-play image restoration. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pages 1219–1229, 2023.

Data: Noisy $\boldsymbol{x}_T$, observation $\boldsymbol{y}$, noise-level σ_n, sequence of noise-levels $(\sigma)_i$ and degradation $\boldsymbol{A}$, steering parameter $\lambda > 0$, mixing parameter $\zeta \in [0, 1]$;

Result: Image drawn from the posterior $\boldsymbol{x}_0$;

for *i=T, ... , 1* **do**

$\rho_i \leftarrow \lambda \frac{\sigma_n}{\sigma_i}$;

$\boldsymbol{x}_0^{(i)} \leftarrow \boldsymbol{x}_i + \sigma_i^2 s_{\boldsymbol{\theta}}(\boldsymbol{x}_i, \sigma_i)$;

$\hat{\boldsymbol{x}}_0^{(i)} = \mathrm{argmin}_{\boldsymbol{x}} \|\boldsymbol{y} - \boldsymbol{A}\boldsymbol{x}\|_2^2 + \rho_i \|\boldsymbol{x} - \boldsymbol{x}_0^{(i)}\|_2^2$;

$\hat{\boldsymbol{\epsilon}}_i \leftarrow \boldsymbol{x}_i - \hat{\boldsymbol{x}}_0^{(i)}$;

$\boldsymbol{\epsilon}_i \sim \mathcal{N}(0, \boldsymbol{I})$;

$\boldsymbol{x}_{i-1} \leftarrow \hat{\boldsymbol{x}}_0^{(i)} + \sigma_{i-1}(\sqrt{1-\zeta}\hat{\boldsymbol{\epsilon}}_i + \sqrt{\zeta}\boldsymbol{\epsilon}_i)$;

end

Algorithm 1: Variance exploding version of DiffPIR used for evaluation

ζ	σ_T	Model	PSNR↑	SSIM↑	LPIPS↓
0.0	0.01	DSM	12.639	0.2609	1.0550
		MUPET	**12.655**	**0.2643**	**1.0517**
	0.1	DSM	12.745	0.2333	1.0752
		MUPET	**12.803**	**0.2399**	**1.0677**
	1.0	DSM	13.279	0.1977	1.1031
		MUPET	**13.386**	**0.2015**	**1.0912**
	10.0	DSM	**13.280**	0.1666	1.0542
		MUPET	13.264	**0.1667**	**1.0332**
0.3	0.01	DSM	12.813	0.2095	0.9659
		MUPET	**15.632**	**0.3750**	**0.7737**
	0.1	DSM	15.548	0.3917	0.6719
		MUPET	**17.850**	**0.4590**	**0.6026**
	1.0	DSM	**24.216**	**0.7513**	0.1854
		MUPET	24.090	0.7493	**0.1803**
	10.0	DSM	**23.899**	0.7345	0.2060
		MUPET	23.857	**0.7351**	**0.1986**
0.6	0.01	DSM	11.515	0.1535	0.9870
		MUPET	**17.939**	**0.4699**	**0.6221**
	0.1	DSM	19.022	0.5681	0.4005
		MUPET	**21.337**	**0.6378**	**0.3301**
	1.0	DSM	**25.059**	**0.7843**	<u>0.1775</u>
		MUPET	24.867	0.7770	**<u>0.1650</u>**
	10.0	DSM	**24.946**	**0.7782**	0.1843
		MUPET	24.861	0.7740	**0.1698**
1.0	0.01	DSM	9.2260	0.0762	1.0024
		MUPET	**20.180**	**0.5821**	**0.4838**
	0.1	DSM	24.018	0.7670	0.2073
		MUPET	**24.413**	**0.7729**	**0.1796**
	1.0	DSM	**25.284**	**0.7912**	0.1885
		MUPET	25.107	0.7836	**0.1797**
	10.0	DSM	**25.318**	**0.7885**	0.1983
		MUPET	25.201	0.7846	**0.1836**

Table 1: Hyper-parameter grid-search for 90% pixel-wise completion. Bold values indicate the highest MSE, highest SSIM, and lowest LPIPS in each pair of rows.

ζ	σ_T	Model	PSNR↑	SSIM↑	LPIPS↓
0.0	0.01	DSM	23.759	0.9312	**0.0764**
		MUPET	**23.762**	**0.9316**	**0.0764**
	0.1	DSM	**23.740**	0.9293	0.0757
		MUPET	23.740	**0.9296**	**0.0757**
	1.0	DSM	**23.623**	**0.9272**	**0.0719**
		MUPET	23.613	0.9269	0.0721
	10.0	DSM	**23.177**	0.9249	**0.0634**
		MUPET	23.125	**0.9247**	0.0647
0.3	0.01	DSM	23.805	0.9338	**0.0725**
		MUPET	**23.791**	**0.9341**	0.0732
	0.1	DSM	**23.856**	0.9351	**0.0692**
		MUPET	23.632	**0.9372**	0.0711
	1.0	DSM	25.203	0.9425	0.0513
		MUPET	**25.296**	**0.9455**	**0.0495**
	10.0	DSM	**28.016**	0.9507	**0.0330**
		MUPET	28.006	**0.9532**	0.0347
0.6	0.01	DSM	23.766	0.9338	**0.0728**
		MUPET	**23.663**	**0.9364**	0.0733
	0.1	DSM	**23.970**	0.9360	**0.0679**
		MUPET	23.404	**0.9369**	0.0720
	1.0	DSM	26.165	0.9505	**0.0478**
		MUPET	**26.304**	**0.9475**	0.0488
	10.0	DSM	28.232	0.9528	**0.0375**
		MUPET	**28.044**	**0.9546**	0.0380
1.0	0.01	DSM	23.654	**0.9366**	**0.0729**
		MUPET	**23.362**	0.9360	0.0737
	0.1	DSM	**24.119**	0.9400	**0.0668**
		MUPET	23.549	**0.9383**	0.0721
	1.0	DSM	27.680	0.9519	0.0457
		MUPET	**27.550**	**0.9549**	**0.0450**
	10.0	DSM	**28.586**	**0.9563**	**0.0422**
		MUPET	28.126	0.9556	0.0436

Table 2: Hyper-parameter search for block-wise inpainting with a 64×64 box of pixels missing. Bold values indicate the highest MSE, highest SSIM, and lowest LPIPS in each pair of rows.

ζ	σ_T	Model	PSNR↑	SSIM↑	LPIPS↓
0.0	0.01	DSM	24.440	0.7512	**0.3816**
		MUPET	**24.444**	**0.7518**	0.3881
	0.1	DSM	24.370	0.7327	0.3465
		MUPET	**24.389**	**0.7348**	**0.3409**
	1.0	DSM	**22.003**	**0.6032**	**0.3432**
		MUPET	21.924	0.5898	0.3448
	10.0	DSM	**19.218**	**0.4220**	**0.5565**
		MUPET	19.096	0.4000	0.5770
0.3	0.01	DSM	26.005	**0.7816**	0.2912
		MUPET	**26.056**	0.7783	**0.2887**
	0.1	DSM	26.136	0.7696	0.3173
		MUPET	**26.449**	**0.7722**	**0.2625**
	1.0	DSM	25.797	0.7437	0.3544
		MUPET	**25.897**	**0.7470**	**0.3230**
	10.0	DSM	25.239	0.7245	0.3762
		MUPET	**25.264**	**0.7263**	**0.3553**
0.6	0.01	DSM	25.421	0.7730	0.2915
		MUPET	**25.884**	**0.7750**	**0.2821**
	0.1	DSM	26.405	0.7796	0.2941
		MUPET	**26.529**	**0.7785**	**0.2381**
	1.0	DSM	26.420	0.7662	0.3254
		MUPET	**26.490**	**0.7705**	**0.2821**
	10.0	DSM	26.173	0.7555	0.3448
		MUPET	**26.218**	**0.7584**	**0.3089**
1.0	0.01	DSM	**23.004**	0.7316	0.3337
		MUPET	25.871	**0.7695**	**0.3039**
	0.1	DSM	**26.587**	**0.7794**	0.2927
		MUPET	26.348	0.7772	**0.2559**
	1.0	DSM	**26.535**	**0.7729**	0.3066
		MUPET	26.504	0.7728	**0.2825**
	10.0	DSM	26.475	**0.7696**	0.3215
		MUPET	**26.534**	0.7691	**0.2976**

Table 3: Comparison of DSM and MUPET models with different ζ and σ_T values for 3x super-resolution on LSUN bedroom. Bold values indicate the highest MSE, highest SSIM, and lowest LPIPS in each pair of rows.

ζ	σ_T	Model	PSNR↑	SSIM↑	LPIPS↓
0.0	0.01	DSM	24.699	0.7304	0.4517
		MUPET	**24.710**	**0.7324**	**0.4588**
	0.1	DSM	24.738	0.7231	**0.4148**
		MUPET	**24.777**	**0.7256**	0.4137
	1.0	DSM	**24.303**	**0.6799**	0.2905
		MUPET	24.270	0.6706	**0.2846**
	10.0	DSM	**23.530**	**0.6193**	0.3076
		MUPET	23.372	0.6080	**0.3113**
0.3	0.01	DSM	26.005	0.7800	0.3190
		MUPET	**26.288**	**0.7849**	**0.3002**
	0.1	DSM	26.445	0.7818	0.3015
		MUPET	**26.765**	**0.7866**	**0.2315**
	1.0	DSM	26.550	0.7785	<u>0.2757</u>
		MUPET	**26.641**	**0.7800**	**0.2338**
	10.0	DSM	26.529	0.7741	0.2850
		MUPET	**26.556**	**0.7757**	**0.2463**
0.6	0.01	DSM	25.487	0.7780	0.3150
		MUPET	**26.184**	**0.7860**	**0.2886**
	0.1	DSM	26.646	0.7902	0.2851
		MUPET	**26.864**	**0.7908**	**<u>0.2153</u>**
	1.0	DSM	26.705	0.7848	0.2823
		MUPET	**26.840**	**0.7889**	**0.2310**
	10.0	DSM	26.696	0.7819	0.2946
		MUPET	**26.800**	**0.7857**	**0.2500**
1.0	0.01	DSM	23.358	0.7591	0.3401
		MUPET	**26.026**	**0.7853**	**0.3021**
	0.1	DSM	26.379	0.7916	0.2885
		MUPET	**26.579**	**0.7877**	**0.2446**
	1.0	DSM	26.870	0.7896	0.2911
		MUPET	**26.924**	**0.7906**	**0.2587**
	10.0	DSM	26.822	0.7866	0.2992
		MUPET	**26.895**	**0.7887**	**0.2723**

Table 4: Comparison of DSM and MUPET models with different ζ and σ_T values for deblurring on LSUN bedroom (using a Gaussian blur-kernel with $\sigma_{\text{blur}} = 2$). Bold values indicate the highest PSNR, highest SSIM, and lowest LPIPS in each pair of rows.