DBMSolver: A Training-free Diffusion Bridge Sampler for High-Quality Image-to-Image Translation

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CODE AVAILABLE!

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code: github.com/snumprlab/dbmsolver

The Bottlenecks & The Insights

The Problem:

The Premise: Diffusion Bridge Models (DBMs) enable direct Image-to-Image (I2I) translation using arbitrary image priors.The Method

The Bottleneck: Current DBM samplers (e.g., Hybrid Heun) are prohibitively slow, requiring 100+ Network Function Evaluations (NFEs) to generate coherent outputs.

Why Do N2I Solvers Fail Here?

Sampler Type	Prior Distribution	Valid for I2I?
Standard N2I DDIM, DPMSolver)	$\boldsymbol{x}_T \sim \mathcal{N}(\mathbf{0}, \sigma_T^2 \mathbf{I})$	❌ Fails (Artifacts)
DBMSolver (Ours)	Arbitrary prior, $p_T(\boldsymbol{x})$	✅ Yes

The Core Insight

By rigorously analyzing the underlying reverse-time Diffusion Bridge equations, we uncovered an overlooked semi-linear structure.

The Bridge Probability Flow ODE can be rewritten as:

$$\frac{\mathrm{d}\boldsymbol{x}_t}{\mathrm{d}t} = \underbrace{L(t)\boldsymbol{x}_t}_{\text{Linear Term}} + \underbrace{N(\mathbf{D}_{\boldsymbol{\theta}}(\boldsymbol{x}_t), t, \boldsymbol{x}_T)}_{\text{Non-linear Term}}$$

Using Exponential Integrators (EI), we analytically derive exact, closed-form solutions for the linear terms, eliminating a major source of approximation error.

DBMSolver in just 6 NFEs — sharp eye contours, hairlines, and mask edges

The DBMSolver Algorithm

The Method:

Phase 1: Initial Stochastic Update

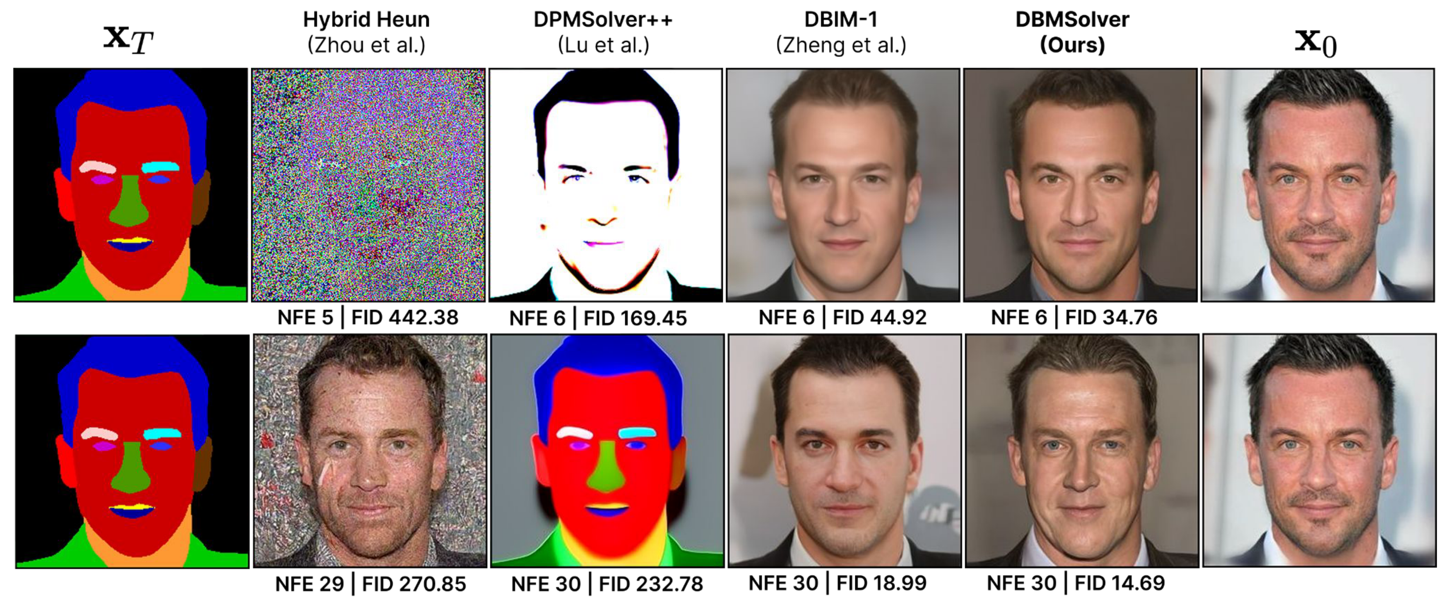
- Executes for the very first micro-step ($s = T$ to $t = T - \epsilon$).
- Uses a 1^{st}-order SDE solution (Euler-Maruyama) to prevent coefficient divergence.

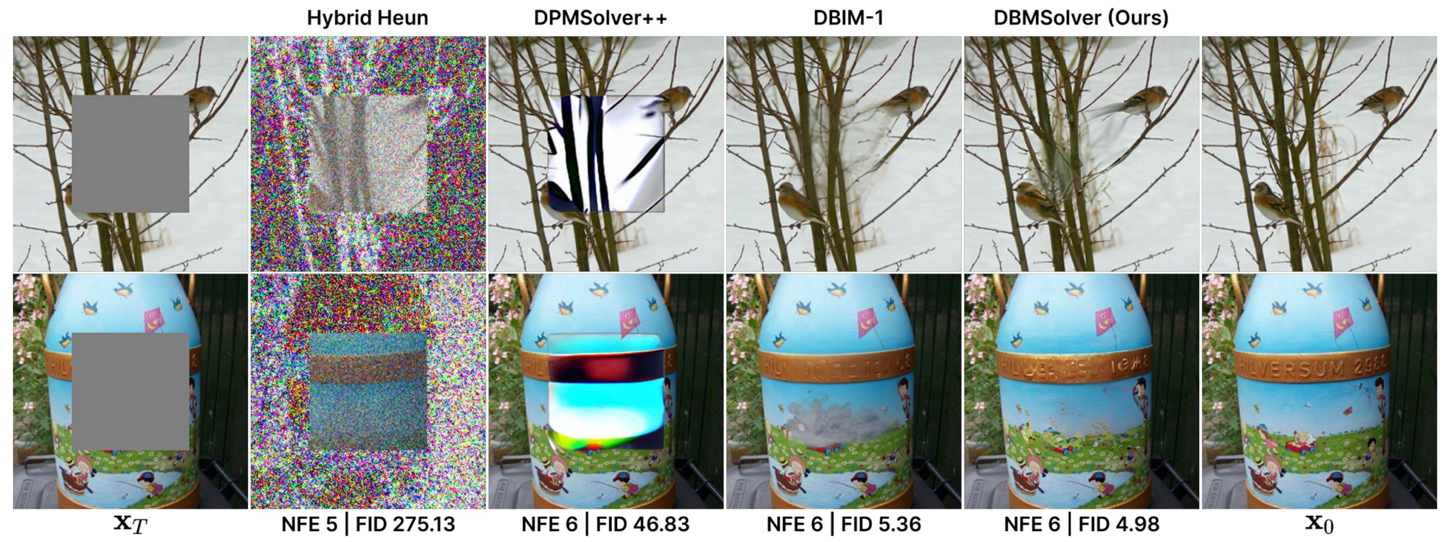
Phase 2: Deterministic Refinement

- Executes for all subsequent steps ($t < s \leq T - \epsilon$).
- Uses our exact, 2^{nd}-order ODE solution to rapidly denoise the sample.
- Concludes with a final Euler update to yield the translated image $\tilde{\boldsymbol{x}}_0$.

Order Selection: Why Stop at k = 2?

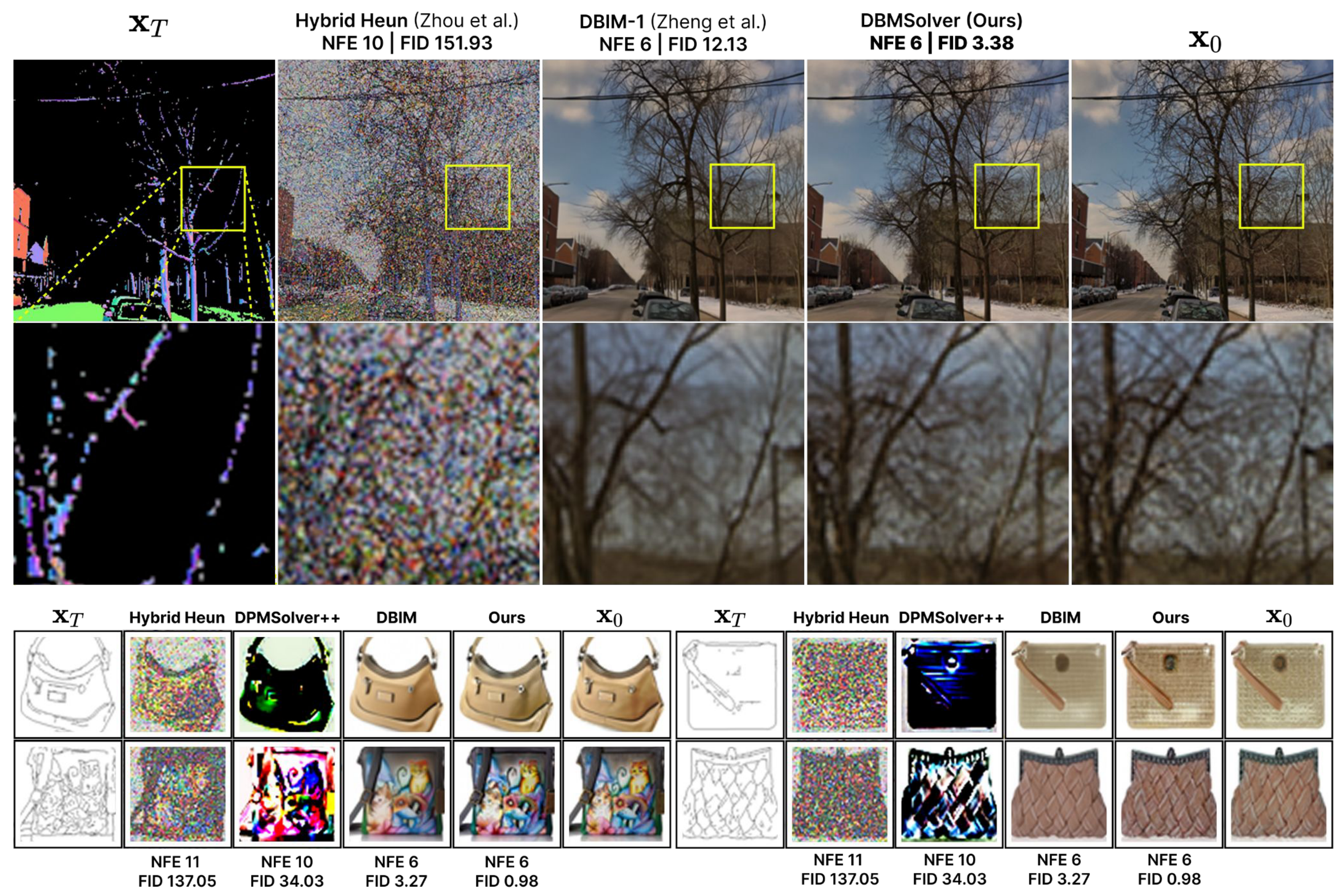
While 3^{rd}-order ($k = 3$) solutions for the Bridge ODE exist, they require non-elementary antiderivatives. Solving these requires numerical approximations (like linear multistep methods used in DBIM-2/3), which paradoxically increases error bounds. Our 2^{nd} -order solution remains analytically tractable, exact, and achieves superior FID scores.





State-of-the-Art Results

Unmatched Quality at 6 NFEs:



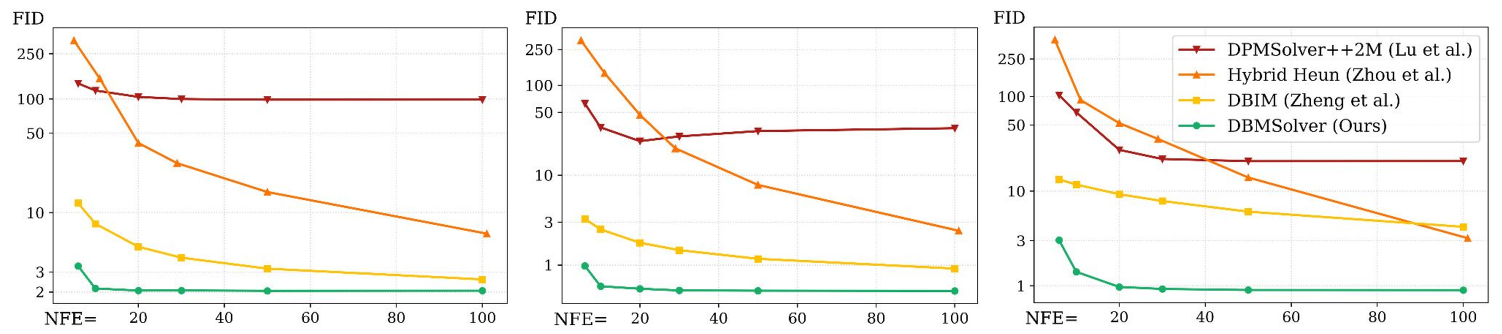
Visual Takeaways:

- DBMSolver flawlessly preserves delicate edge structures
  - e.g., tree branches, twigs, and handbag textures at just 6 NFEs.
- Baseline methods exhibit noticeable blurring and loss of detail at identical steps.

METHOD	NFE ↓	FID ↓	LPIPS ↓	MSE ↓
DIODE (256×256) — surface-normals → image				
Hybrid Heun	119	4.43	0.244	0.084
DBIM-1	20	4.99	0.201	0.017
DBIM-2	20	4.40	0.200	0.017
DBIM-3	20	4.23	0.201	0.017
ODES3	28	2.29	0.203	0.018
DBMSolver	6	3.38	**0.196**	**0.015**
DBMSolver	20	**2.06**	0.198	0.018
Face2Comics (256×256) — stylization				
BBDM	200	23.20	–	–
Hybrid Heun	119	2.36	–	–
DBIM-3	20	8.61	–	–
DBMSolver	6	3.04	–	–
DBMSolver	20	**0.96**	–	–

Training-Free Advantage & Conclusion

Efficiency Trends:



Metric Takeaways:

- DBMSolver curve drops faster and stabilizes earlier than all baselines.
- DIODE (256x256): 3.38 FID at 6 NFEs (vs. HH requiring 119 NFEs for 4.43 FID).

The "Training-Free" Value Proposition:

Recent distillation methods achieve fast sampling but require massive computational overhead to retrain the model. DBMSolver is a pure mathematical upgrade.

Method	NFE	DIODE FID	Training-Free?
CDBM	2	3.66	❌ (Requires retraining)
IBMD	1	4.07	❌ (Requires retraining)
DBMSolver	**6**	**3.38**	✅ **(Drop-in Replacement)**

Conclusion:

Recent distillation methods achieve fast sampling but require massive computational overhead to retrain the model. DBMSolver is a pure mathematical upgrade.

References & Contact:

1. Zhou et al., "Denoising Diffusion Bridge Models," ICLR 2024.
2. Zheng et al., "Diffusion Bridge Implicit Models," ICLR 2025.

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