🔥FireFlow: Fast Inversion of Rectified Flow for Image Semantic Editing

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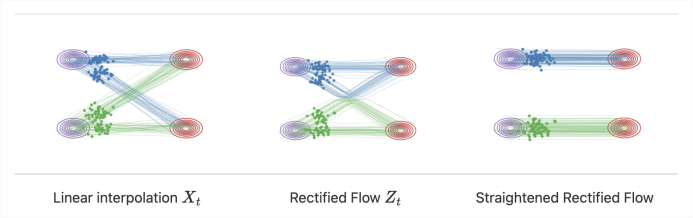
2025.6

Motivation



- Rectified Flow (ReFlow) enables fast ODE-based generation.
- **Inversion for real images is slow or inaccurate** (e.g., FLUX-dev).
- Existing solvers either trade speed for accuracy—or vice versa.
- We need **a simple, fast, training-free method for inversion and editing**.

Key Idea

Our Contribution: FireFlow

- A novel solver for ReFlow with **second-order accuracy** and **first-order cost**.
- Leverages near-constant velocity in well-trained ReFlows.
- Requires only **8 steps** with nearly **1 NFE/step**—no extra training or models.

Efficient ODE Solver:

First-Order Scheme: Euler

$$X_{t+\Delta t} = X_t + \Delta t \cdot v_\theta(X_t, t)$$

- Simple and fast: only one function evaluation per step.
- Local error: $\mathcal{O}(\Delta t^2)$, Global error: $\mathcal{O}(\Delta t)$.
- Often used in ReFlow, but suffers from accumulation of drift errors.
- Inefficient for high-fidelity inversion and editing tasks.

Efficient ODE Solver:

Second-Order Scheme: Midpoint

$$X_{t+\frac{\Delta t}{2}} = X_t + \frac{\Delta t}{2} \cdot v_\theta(X_t, t)$$

$$X_{t+\Delta t} = X_t + \Delta t \cdot v_\theta\left(X_{t+\frac{\Delta t}{2}}, t + \frac{\Delta t}{2}\right)$$

- **Two function evaluations** per step: at t and at $t + \frac{\Delta t}{2}$.
- **Global error:** $\mathcal{O}(\Delta t^2)$ — higher accuracy than Euler.
- Approximates v_θ using a central slope — better trajectory tracking.
- More accurate for inversion/editing, but incurs **2× NFE cost**.

Efficient ODE Solver:

Second-Order Scheme: FireFlow

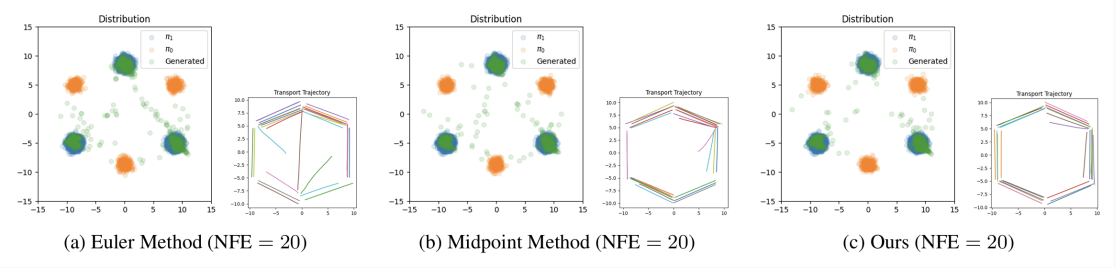
$$\hat{v}_\theta(X_t, t) = v_\theta\left(X_{(t-1)+\frac{\Delta t}{2}}, (t-1) + \frac{\Delta t}{2}\right) \qquad \text{(load } v_\theta \text{ from memory)}$$

$$\hat{X}_{t+\frac{\Delta t}{2}} = X_t + \frac{\Delta t}{2} \cdot \hat{v}_\theta(X_t, t) \qquad \text{(estimated midpoint)}$$

$$X_{t+1} = X_t + \Delta t \cdot v_\theta\left(\hat{X}_{t+\frac{\Delta t}{2}}, t + \frac{\Delta t}{2}\right) \qquad \text{(run \& save } v_\theta \text{ to memory)}$$

- **Only 1 NFE per step** — memory-efficient and fast.
- Retains $\mathcal{O}(\Delta t^2)$ global error like true midpoint.
- Enables accurate inversion/editing in as few as 8 steps.
- Leverages nearly constant drift in trained ReFlow models.

Results & Comparisons



(a) Euler Method (NFE $= 20$) (b) Midpoint Method (NFE $= 20$) (c) Ours (NFE $= 20$)

Figure 1: We evaluate the performance of 2-Rectified Flow using the Euler solver, midpoint solver, and our proposed approach on a 2D synthetic dataset. The source distribution π_0 (orange) and the target distribution π_1 (green) are parameterized as Gaussian mixture models.

Results & Comparisons

- **Inversion:** 2×–3× faster than baselines (RF-Solver, ReFlow-Inv.)
- **Reconstruction:** Lowest LPIPS, highest SSIM/PSNR at same cost.

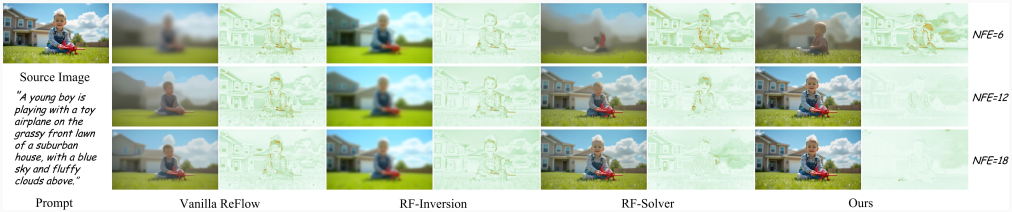


Figure 2: Reconstruction comparison across methods. [1]

[1] Difference images showing the pixel-wise variations between the source image and the reconstructed images are also provided.

Results & Comparisons

- **Inversion:** 2×–3× faster than baselines (RF-Solver, ReFlow-Inv.)
- **Editing:** Best CLIP similarity with fewer editing steps.

Figure 3: Editing comparison across methods.

Conclusion

- FireFlow enables efficient ReFlow inversion with strong editing fidelity.
- Matches 2nd-order accuracy with minimal cost.
- No training, no auxiliary models—ready to deploy.
- Code and supplementary available with submission.

Code Repository

Online Demo Page

ComfyUI Node Page

Thank You!