

Diffusion Models and Their Applications

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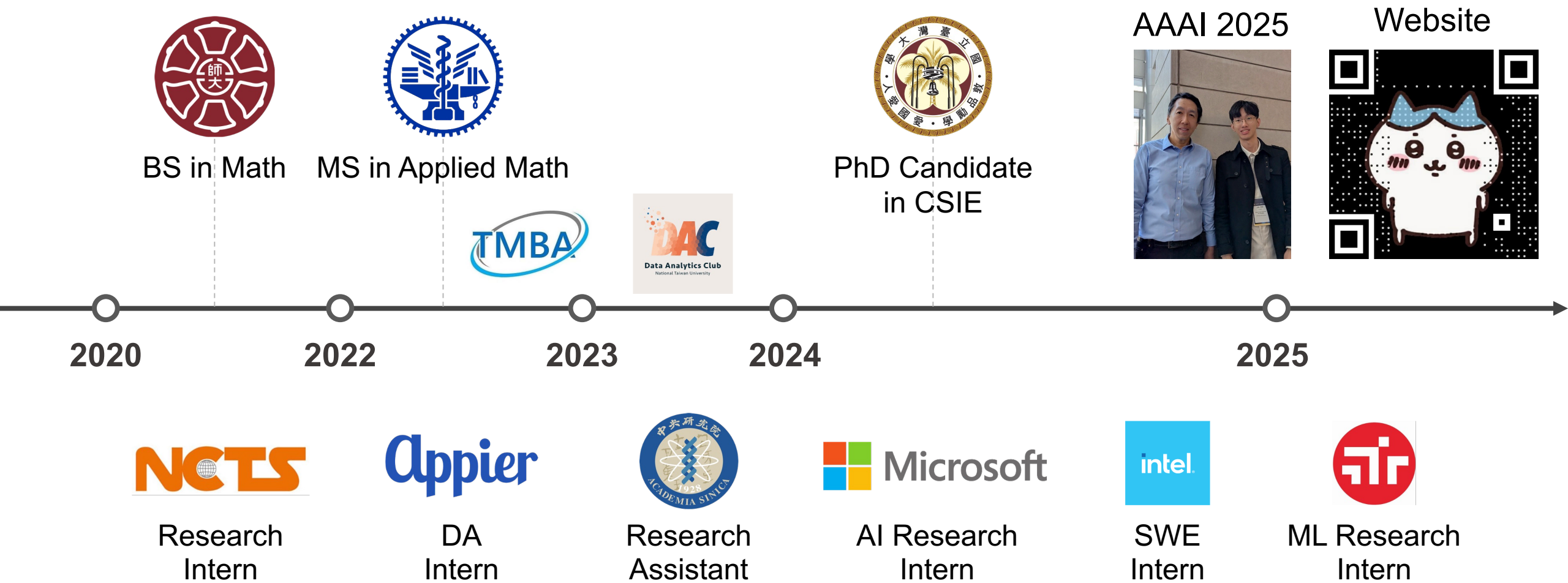
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[jwliao1209](https://www.instagram.com/jwliao1209)



My AI Journey



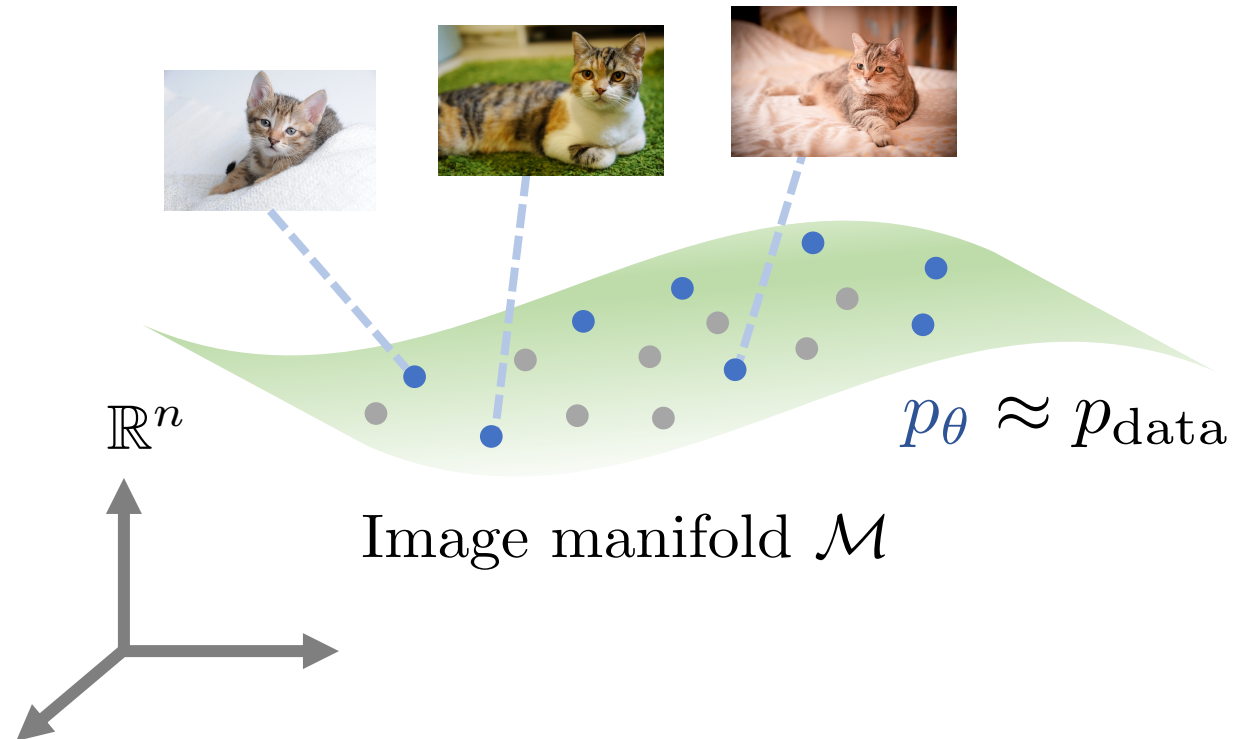
Outline

- Training and Sampling
- Controllability and Applications
- Aesthetic QR Code Generation
- Evasion Attack

What is Generative Model Learning?

Data Manifold Assumption

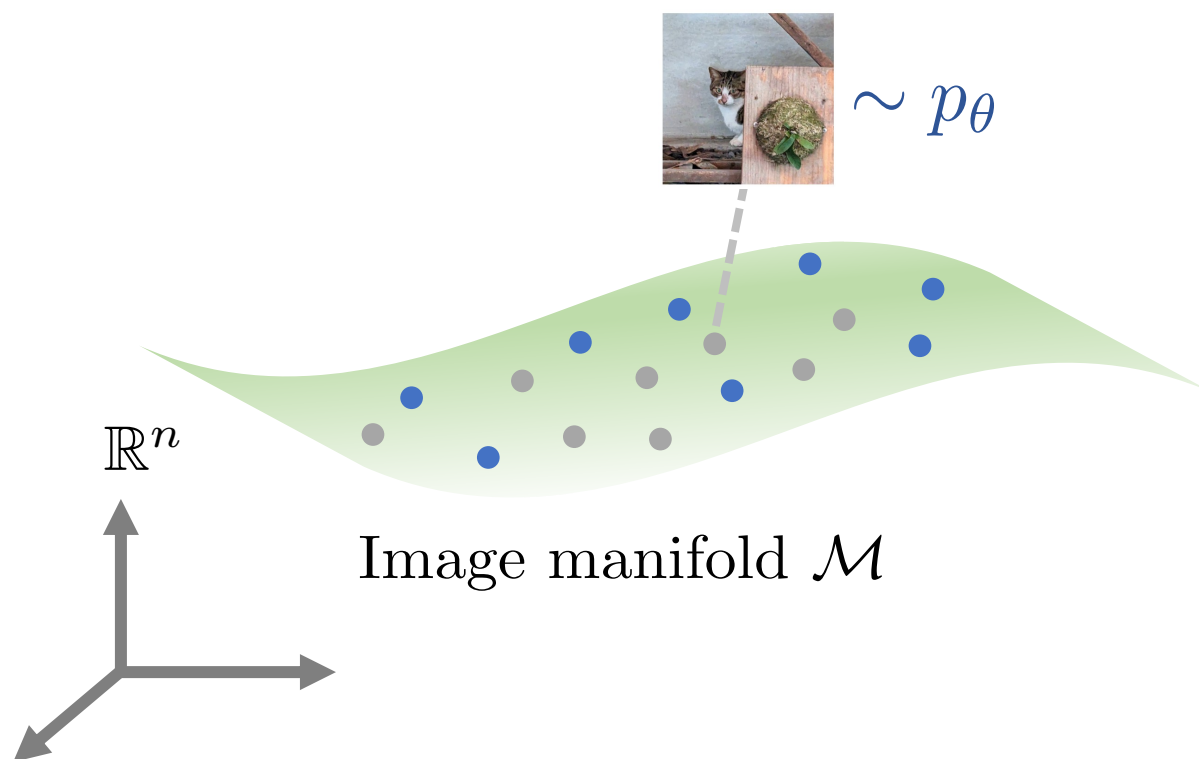
Natural high-dimensional data concentrate close to a non-linear low-dimensional hyper-surface



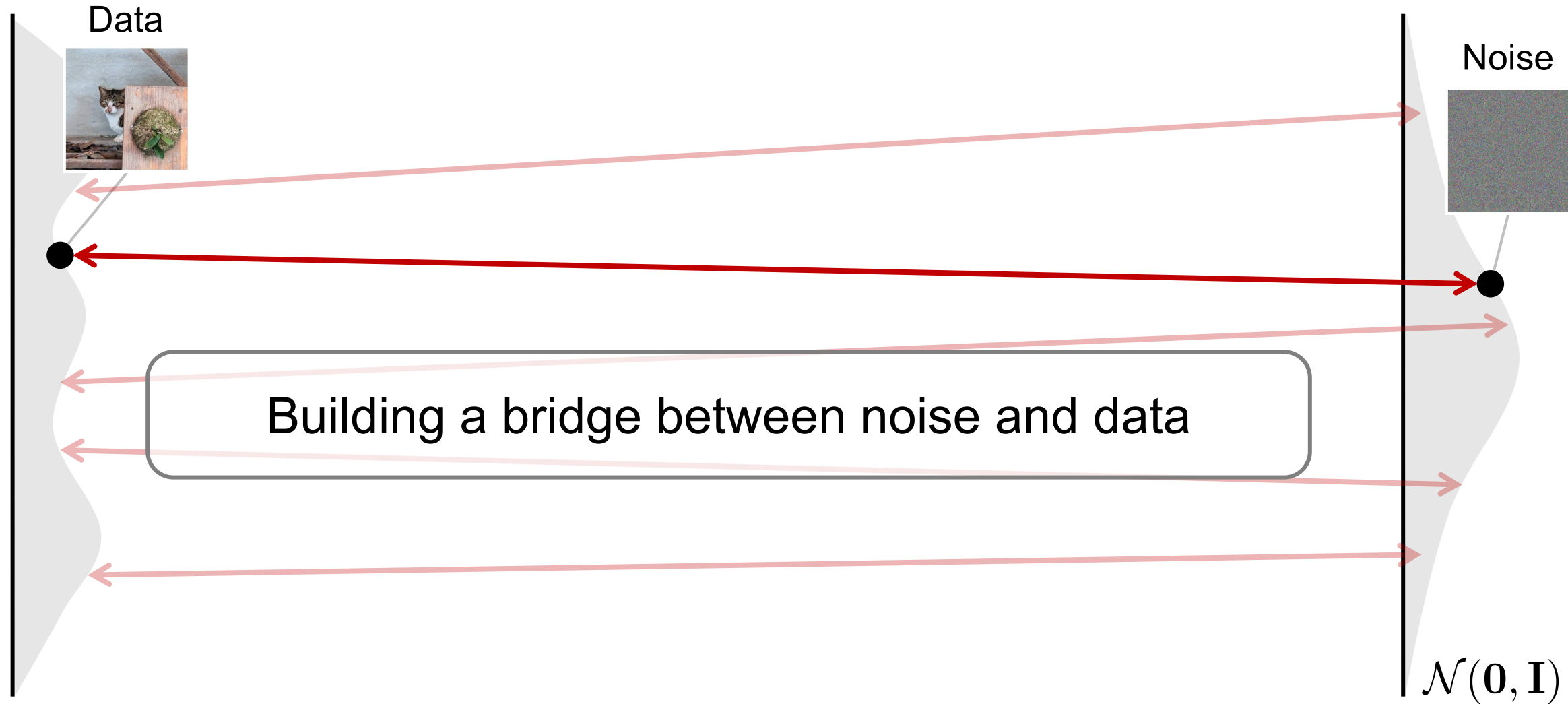
What is Generative Model Learning?

Data Manifold Assumption

Natural high-dimensional data concentrate close to a non-linear low-dimensional hyper-surface

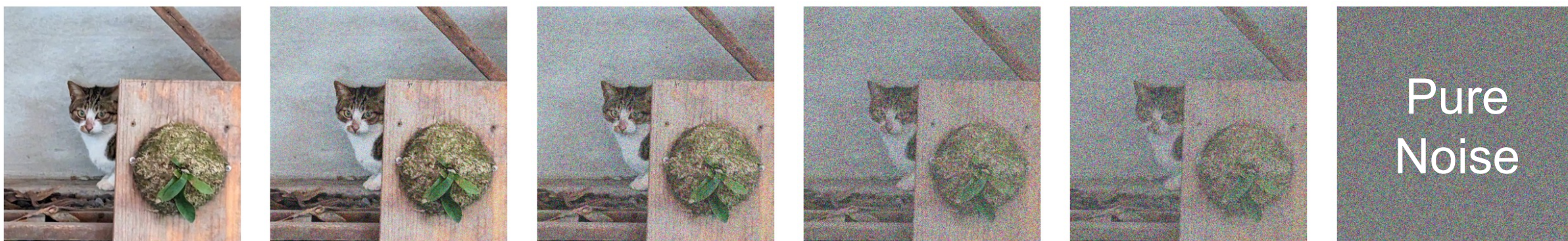


The Goal of Diffusion Models



What is Diffusion Model?

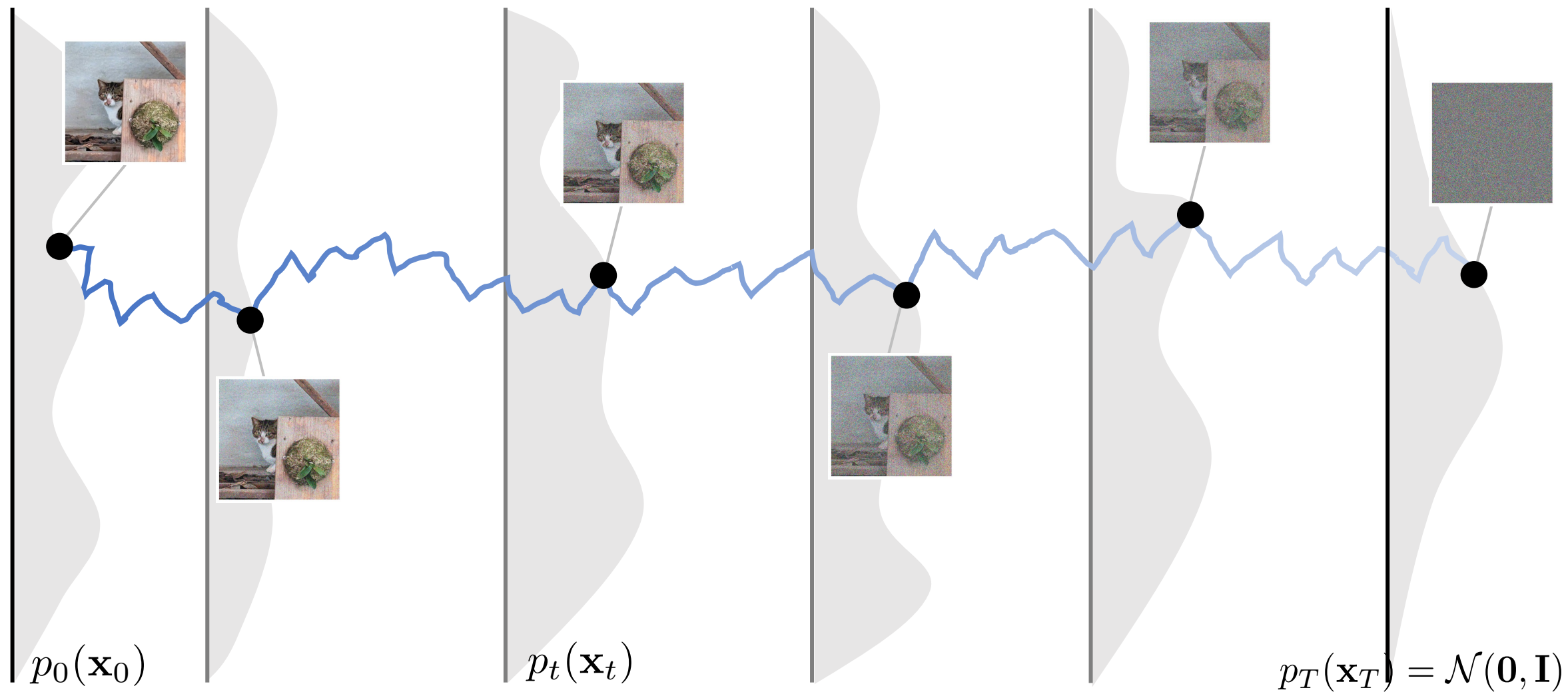
Forward Process: add noise step by step, from data to pure noise



Reverse Process: generate data from pure noise by denoising

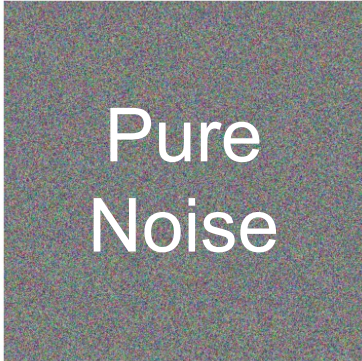
Creating noise from data is easy; creating data from noise is generative modeling – *Yang Song*

Diffusion Models



Mathematical Perspective of Adding Noise to Data

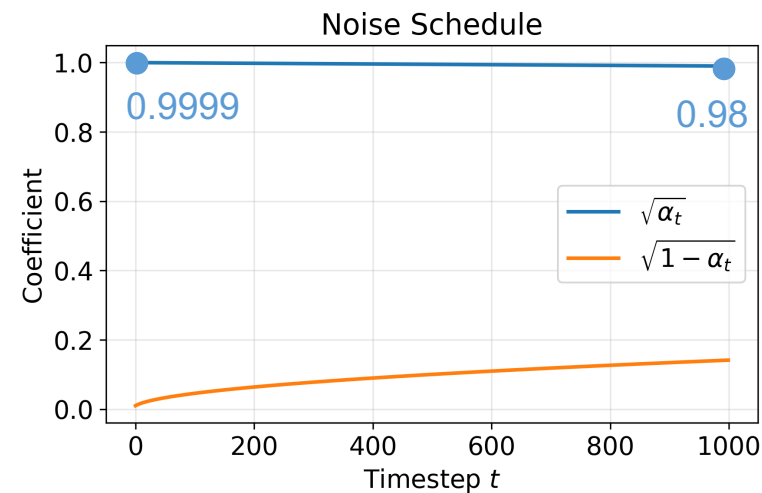
$$\sqrt{\alpha_1} \mathbf{x}_0 + \sqrt{1 - \alpha_1} \mathbf{n} = \mathbf{x}_1$$

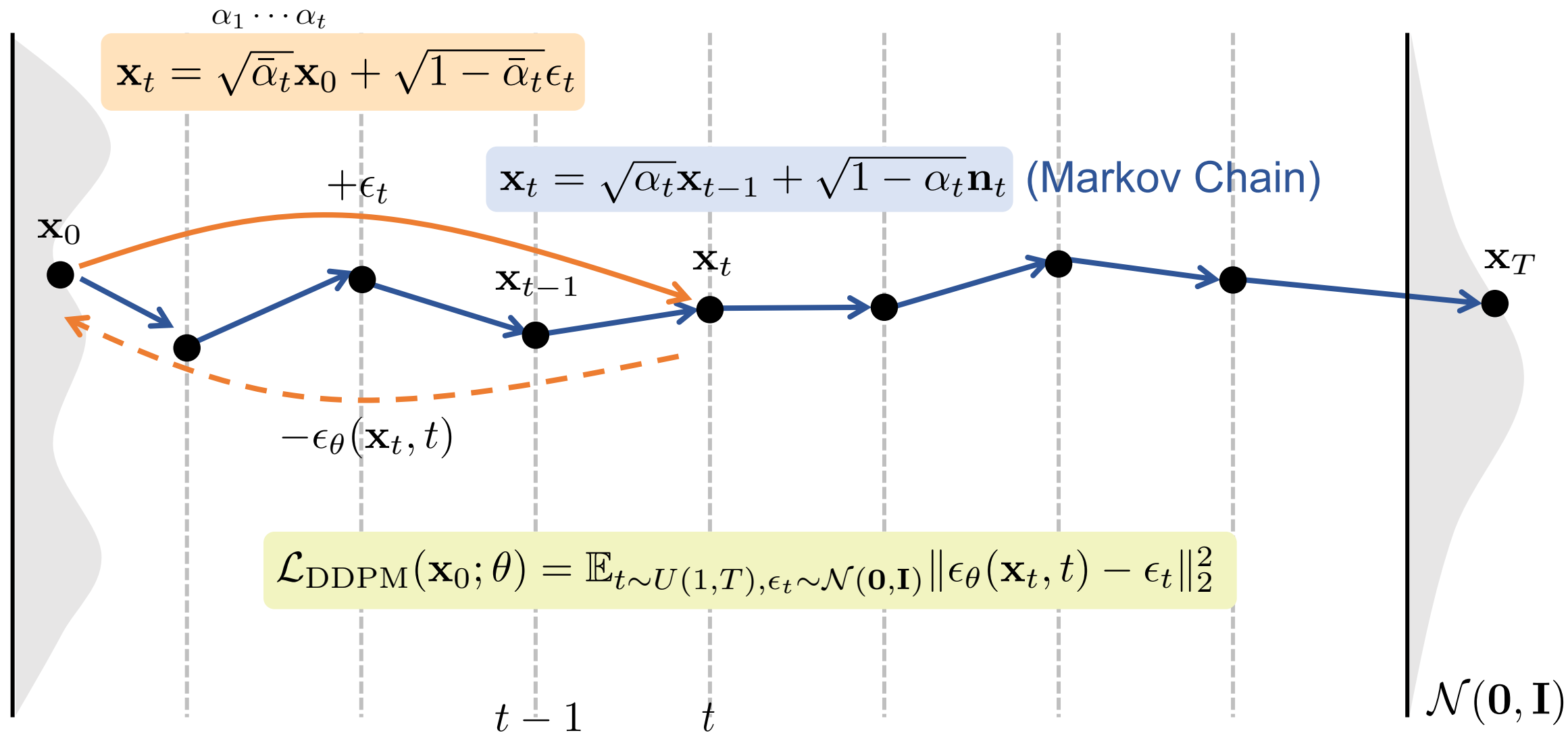
$\mathbf{x}_0$ $\mathbf{n}$ $\mathbf{x}_1$

- Distribution Form:**

$$p(\mathbf{x}_1 | \mathbf{x}_0) = \mathcal{N}(\mathbf{x}_0; \underbrace{\sqrt{\alpha_1} \mathbf{x}_0}_{\text{Mean}}, \underbrace{(1 - \alpha_1) \mathbf{I}}_{\text{Covariance}})$$



How Do We Train a DDPM?



How Does DDPM Generate Samples?

$$\mathcal{N}(\mathbf{x}_t; \sqrt{\alpha_t} \mathbf{x}_{t-1}, (1 - \alpha_t) \mathbf{I})$$

$$\mathcal{N}(\mathbf{x}_{t-1}; \sqrt{\bar{\alpha}_{t-1}} \mathbf{x}_0, (1 - \bar{\alpha}_{t-1}) \mathbf{I})$$

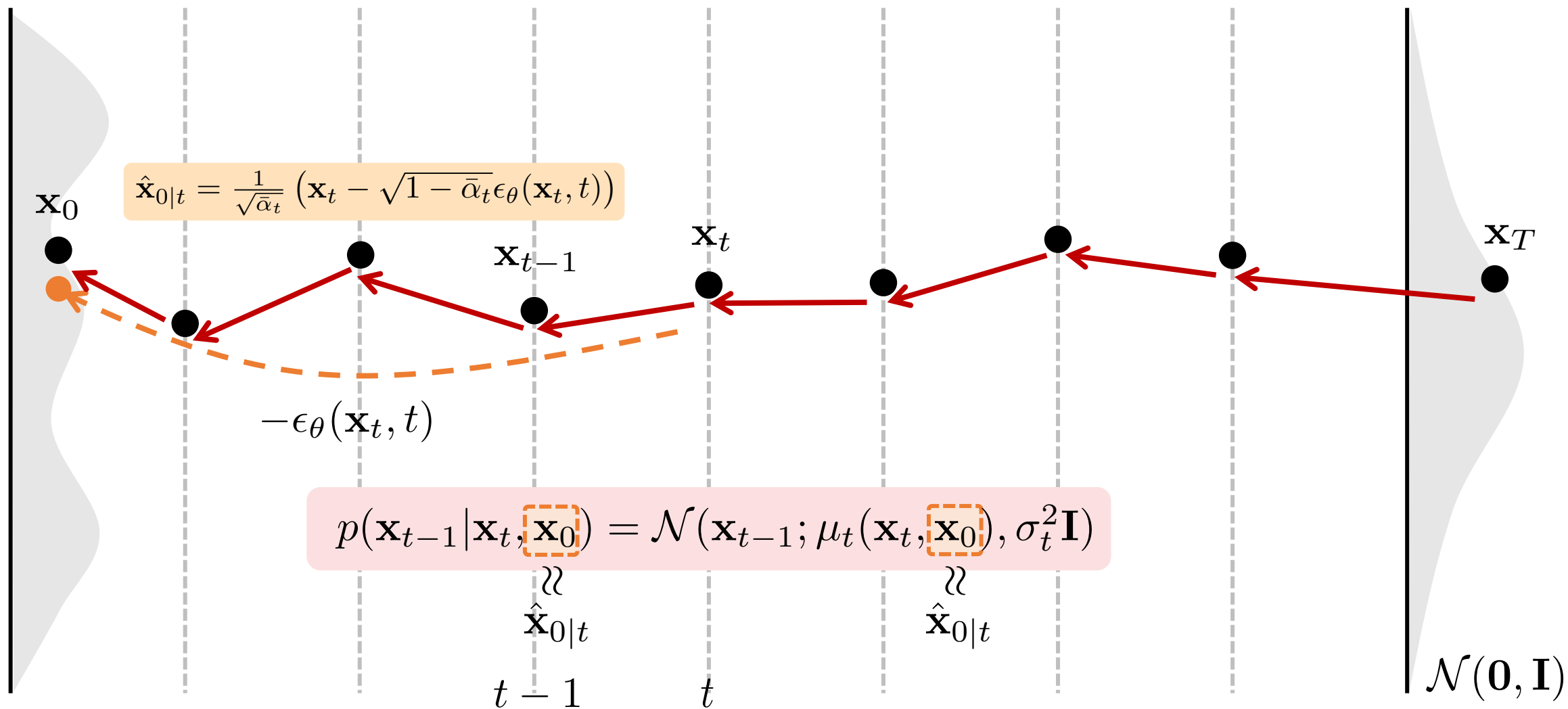
$$p(\mathbf{x}_{t-1} | \mathbf{x}_t, \mathbf{x}_0) = \frac{p(\mathbf{x}_t | \mathbf{x}_{t-1}, \mathbf{x}_0) p(\mathbf{x}_{t-1} | \mathbf{x}_0)}{p(\mathbf{x}_t | \mathbf{x}_0)}$$

$$\mathcal{N}(\mathbf{x}_t; \sqrt{\bar{\alpha}_t} \mathbf{x}_0, (1 - \bar{\alpha}_t) \mathbf{I})$$

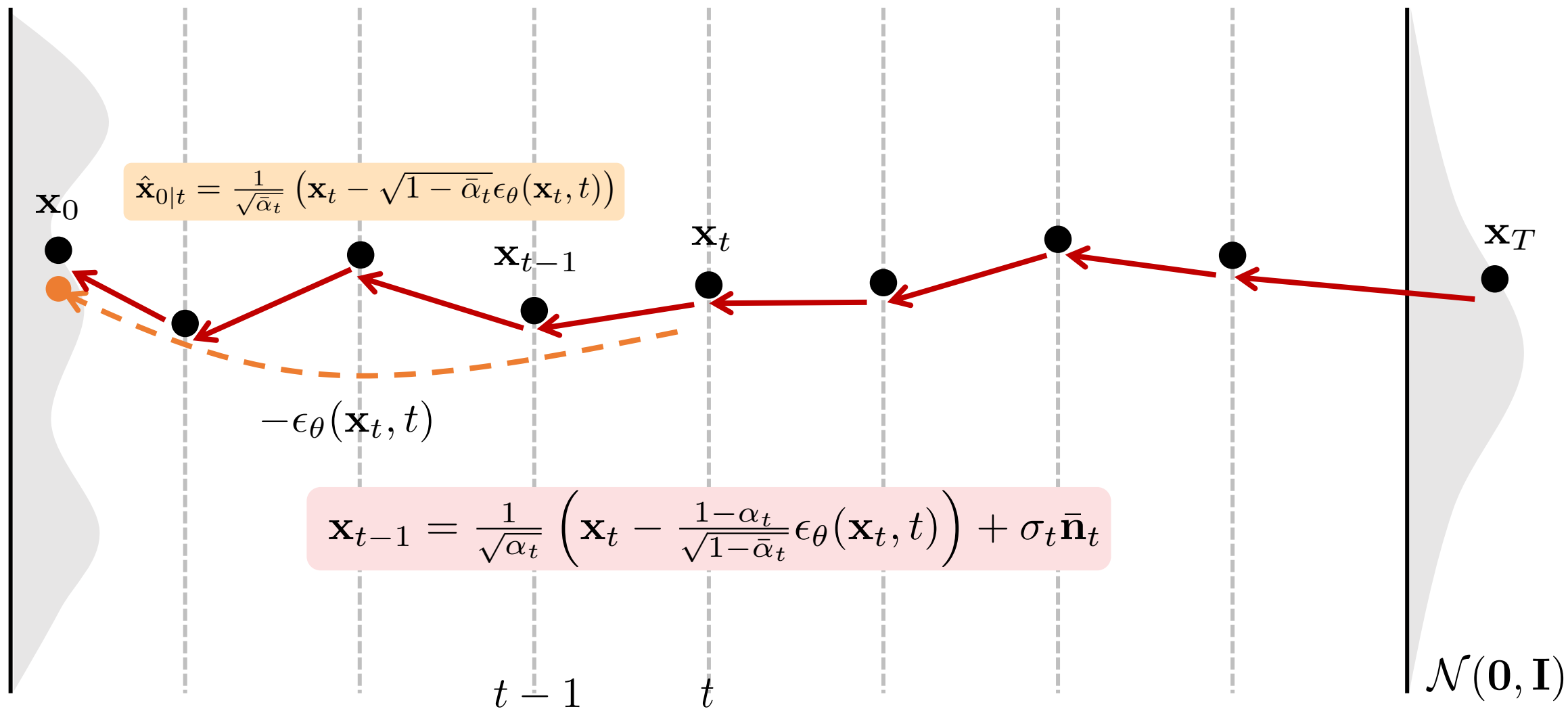
$$p(\mathbf{x}_{t-1} | \mathbf{x}_t, \mathbf{x}_0) = \mathcal{N}(\mathbf{x}_{t-1}; \mu_t(\mathbf{x}_t, \mathbf{x}_0), \sigma_t^2 \mathbf{I})$$

$$\mu_t(\mathbf{x}_t, \mathbf{x}_0) = \frac{\sqrt{\alpha_t}(1 - \bar{\alpha}_{t-1})}{1 - \bar{\alpha}_t} \mathbf{x}_t + \frac{\sqrt{\bar{\alpha}_{t-1}}(1 - \alpha_t)}{1 - \bar{\alpha}_t} \mathbf{x}_0 \quad \text{and} \quad \sigma_t^2 = \frac{(1 - \bar{\alpha}_{t-1})(1 - \alpha_t)}{1 - \bar{\alpha}_t}$$

How Does DDPM Generate Samples?

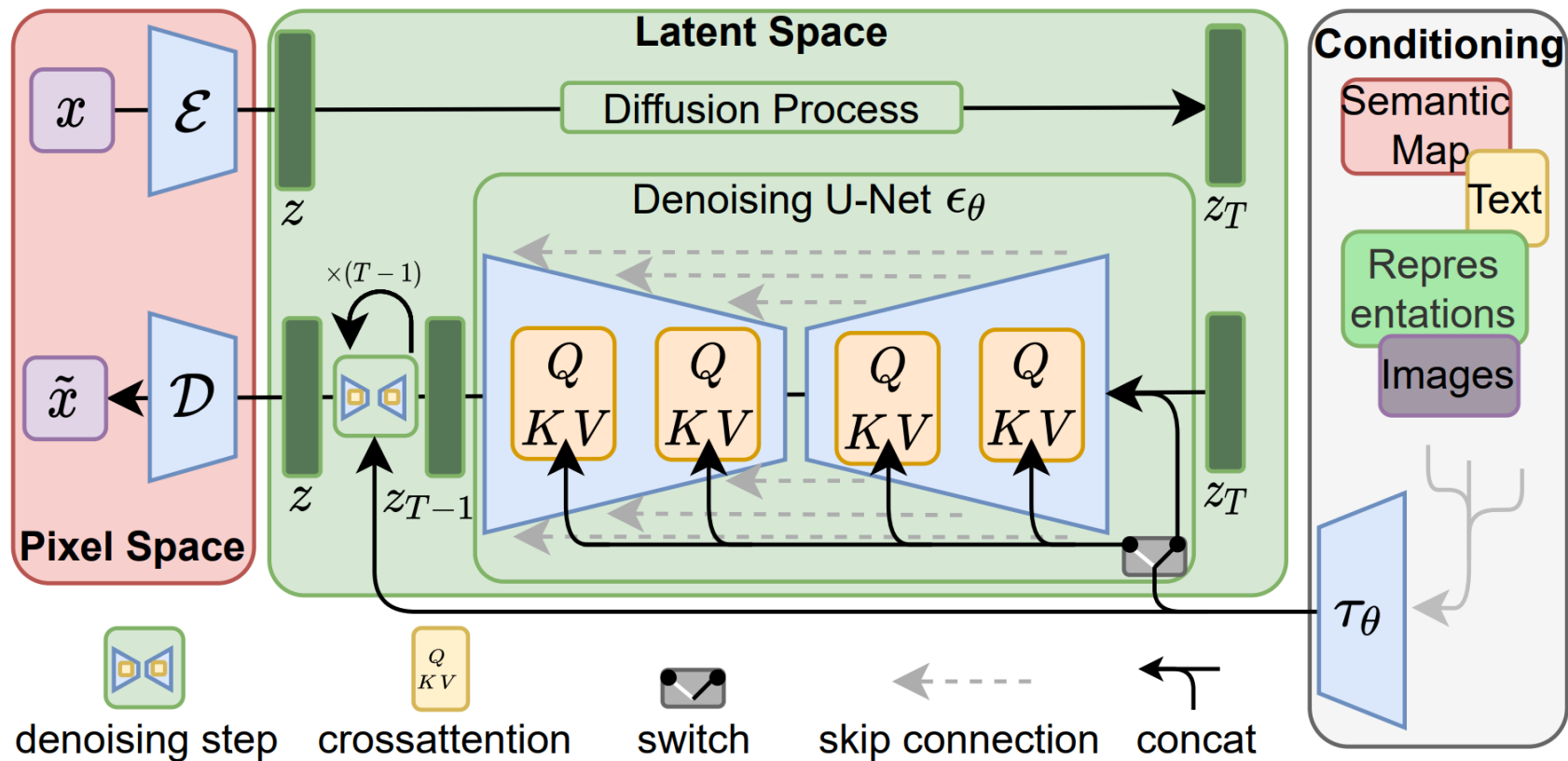


How Does DDPM Generate Samples?

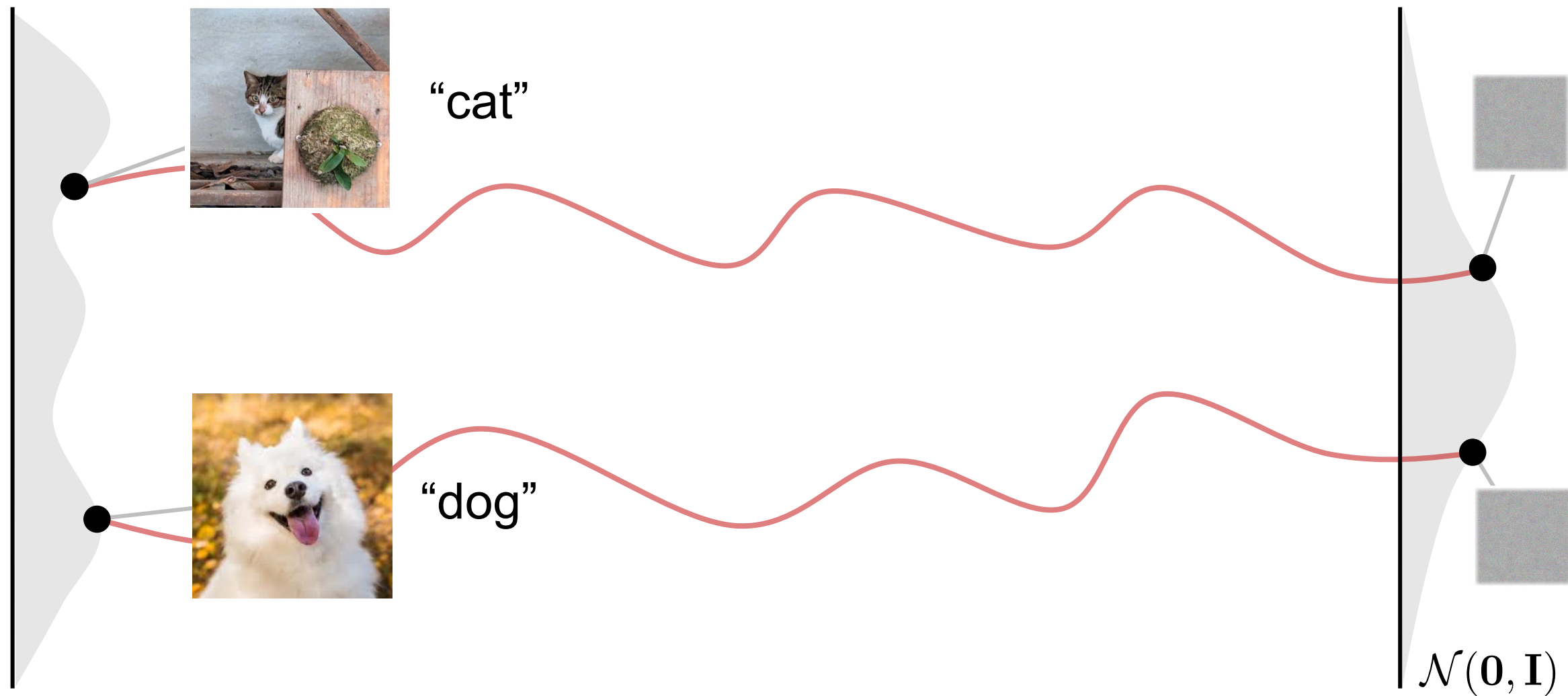


Latent Diffusion Model (LDM) [\[Rombach+ CVPR'22\]](#)

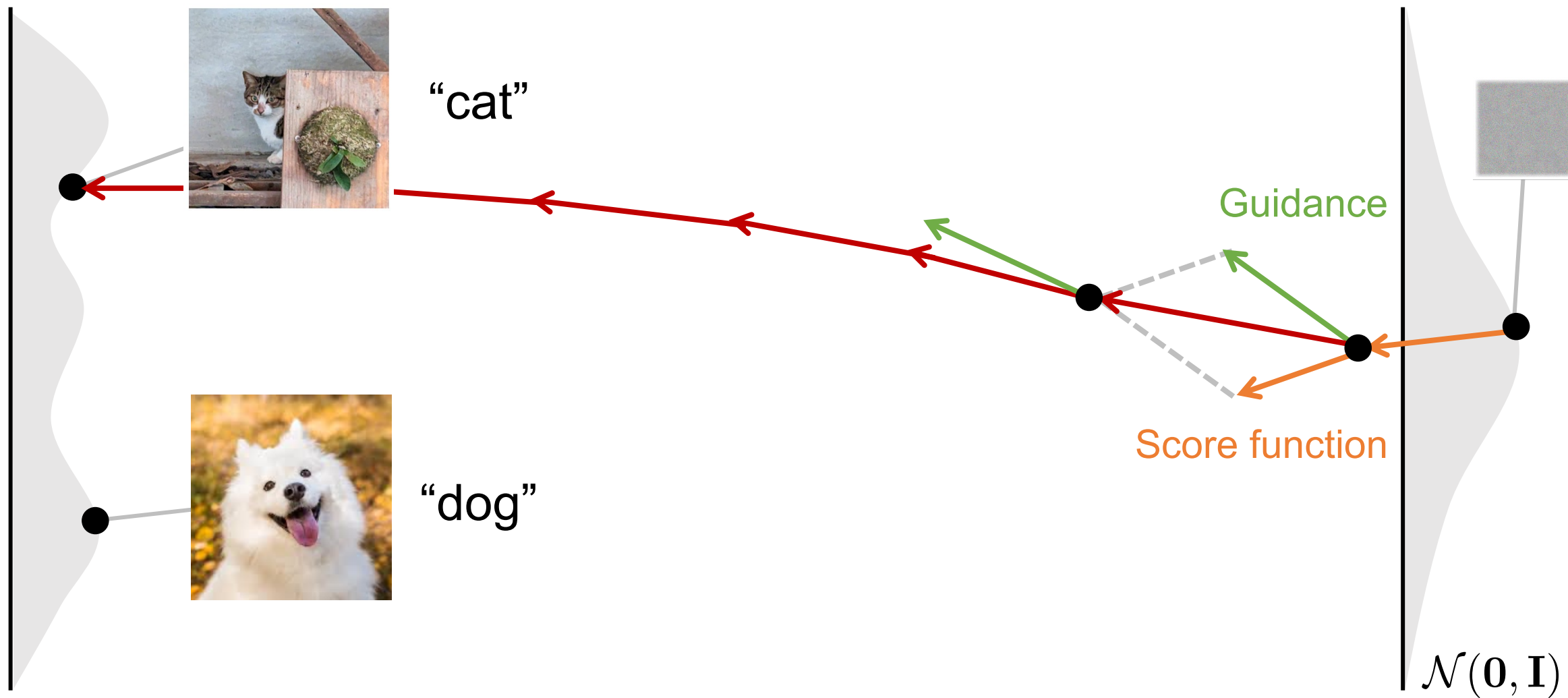
Use the pretrained-VAE to compress the image to latent reducing computation time



Conditional Diffusion Models



Conditional Diffusion Models



Classifier Guidance (CG) [\[Dhariwal+ NeurIPS'21\]](#)

- Bayes' Rule:

$$P\left(\mathbf{x}_t = \text{img} \mid y = \text{"cat"}\right) = \frac{p(\mathbf{x}_t)p(y|\mathbf{x}_t)}{p(y)}$$

- Bayes' Rule for Score Function:

$$\nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t | y) = \underbrace{\nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t)}_{\substack{\text{Unconditional score} \\ \propto \\ -\epsilon_{\theta}(\mathbf{x}_t, t)}} + \nabla_{\mathbf{x}_t} \log \underbrace{p(y | \mathbf{x}_t)}_{\substack{\text{Classifier} \\ \text{(Need to additional training)}}} - \cancel{\nabla_{\mathbf{x}_t} \log p(y)}^0$$

Classifier-Free Guidance (CFG) [\[Ho+ NeurIPS'21\]](#)

From CG, we have

$$\nabla_{\mathbf{x}_t} \log p(\mathbf{y}|\mathbf{x}_t) = \nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t|\mathbf{y}) - \nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t)$$

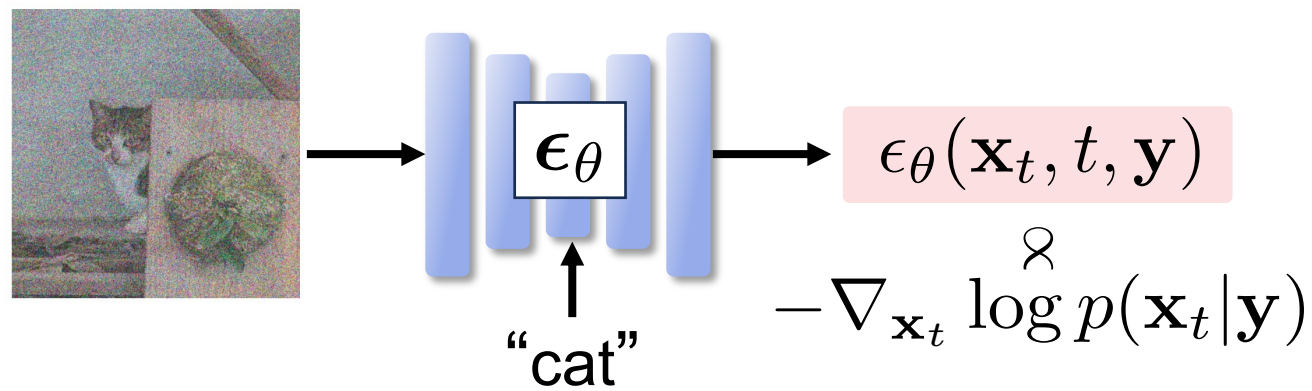
Reweight the coefficient between unconditional score and classifier score

$$\begin{aligned}\nabla_{\mathbf{x}_t} \log \tilde{p}(\mathbf{x}_t|\mathbf{y}) &:= \nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t) + \gamma \nabla_{\mathbf{x}_t} \log p(\mathbf{y}|\mathbf{x}_t) \\ &= \gamma \underbrace{\nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t|\mathbf{y})}_{\text{Conditional score}} + (1 - \gamma) \underbrace{\nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t)}_{\text{Unconditional score}}\end{aligned}$$

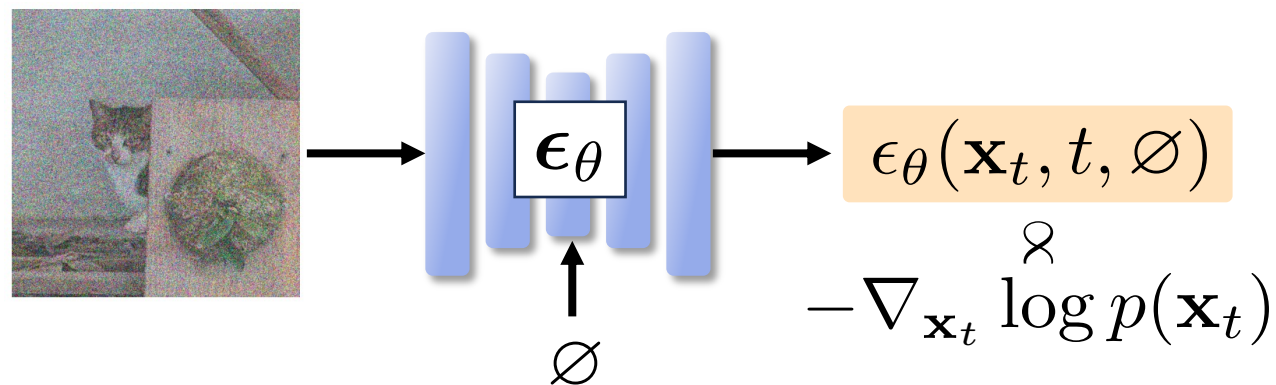
Training CFG

$$\nabla_{\mathbf{x}_t} \log \tilde{p}(\mathbf{x}_t | \mathbf{y}) = \underbrace{\gamma \nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t | \mathbf{y})}_{\text{Conditional score}} + (1 - \gamma) \underbrace{\nabla_{\mathbf{x}_t} \log p(\mathbf{x}_t)}_{\text{Unconditional score}}$$

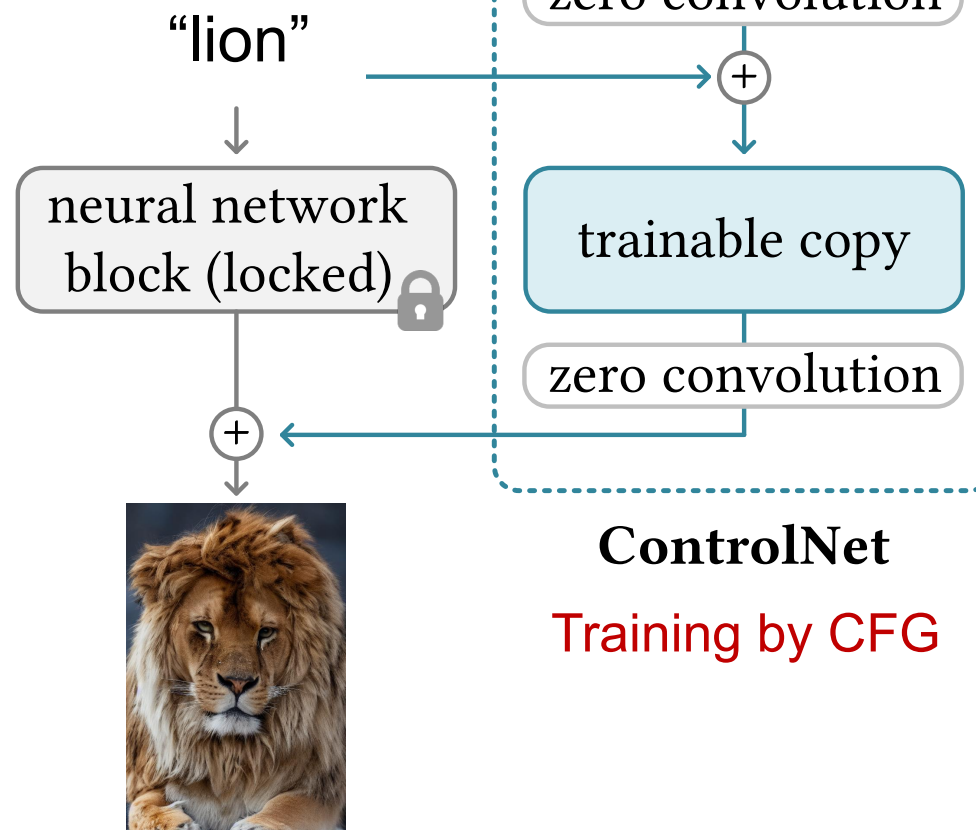
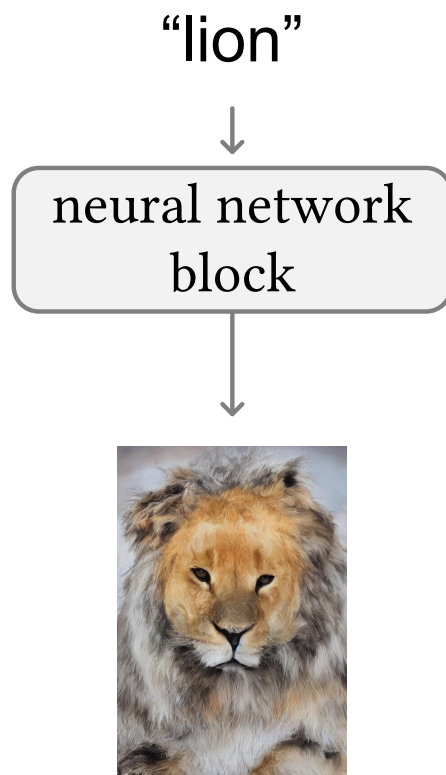
**Predict
Conditional Score**



**Predict
Unconditional Score**



ControlNet [\[Zhang+ ICCV'23\]](#)



Summary

- Diffusion models build a bridge between noise and data, forming a powerful generative modeling framework.
- Conditional methods like CFG and ControlNet significantly improve controllability and application scope.

DiffQRCode: Diffusion-based Aesthetic QR Code Generation with Scanning Robustness Guided Iterative Refinement



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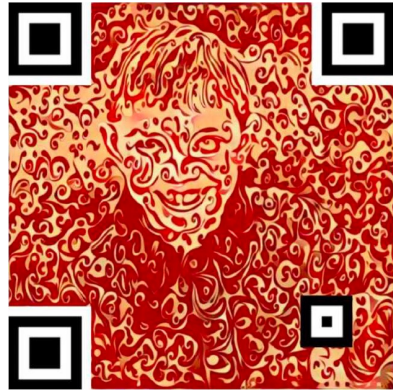
Aesthetic QR Code

Traditional Methods

Qart



ArtCoder



Q-Art Code



Generative-based Method

DiffQRCode (Ours)



Winter wonderland, fresh snowfall, evergreen trees, cozy log cabin, smoke rising from chimney, aurora borealis in night sky.



Cherry blossom festival, pink petals floating in the air, traditional lanterns, peaceful river, people in kimonos, sunny day.

QR Code + Prompt + Diffusion Model → Next-Generation Aesthetic QR Code

Motivation & Challenge

Most Diffusion-based aesthetic QR code generation struggle to balance scannability and aesthetics.

- QR Code AI Art and QR Diffusion produce better scanning robust QR codes but are visually less appealing.
- QRBTF could generate visually appealing QR codes, however, they lack scanning robustness.

QR Code AI Art



QR Diffusion



QRBTF



DiffQRCode (Ours)



Green: scannable, **Red:** unscannable

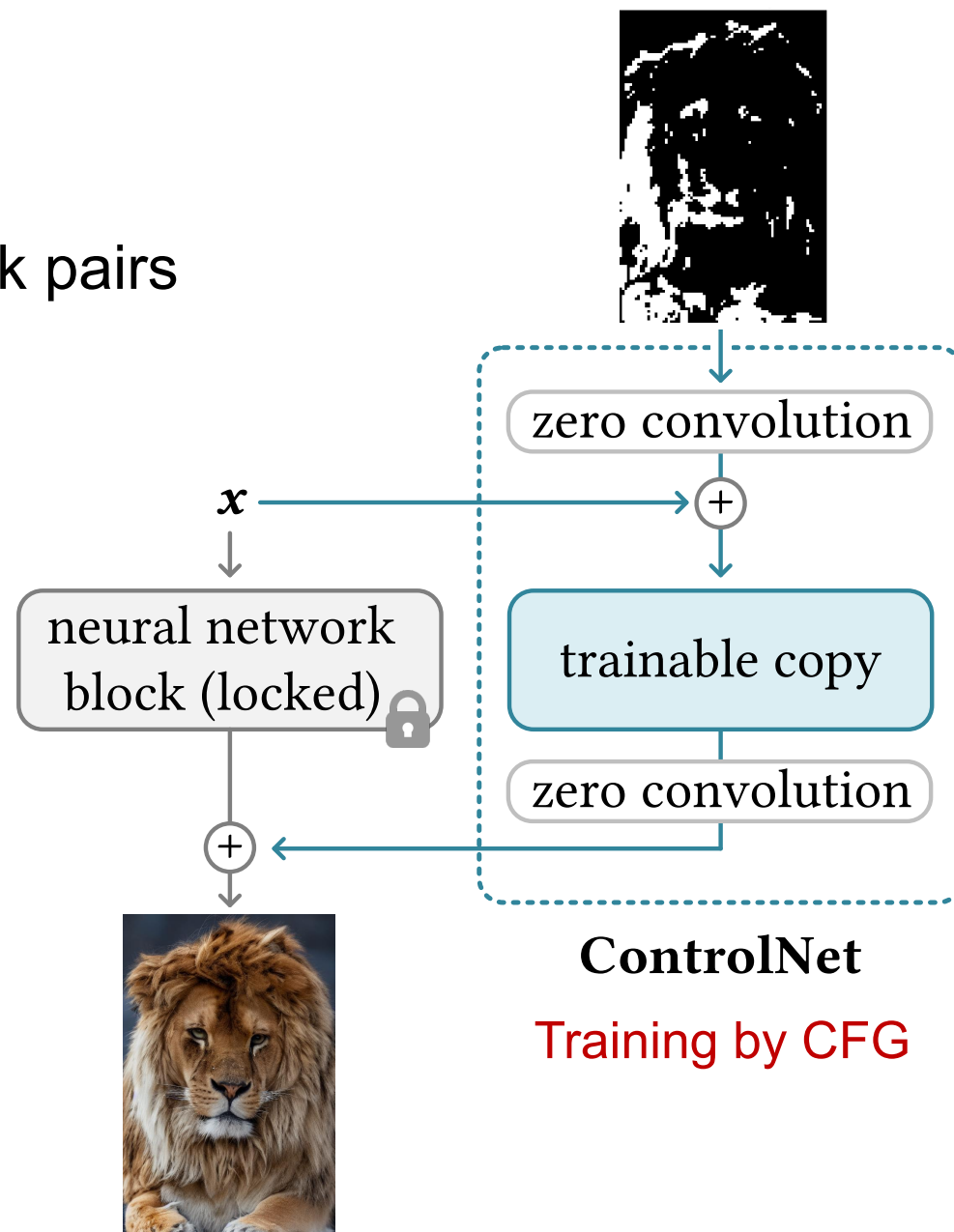
Previous Method

Training ControlNet with image–binary mask pairs

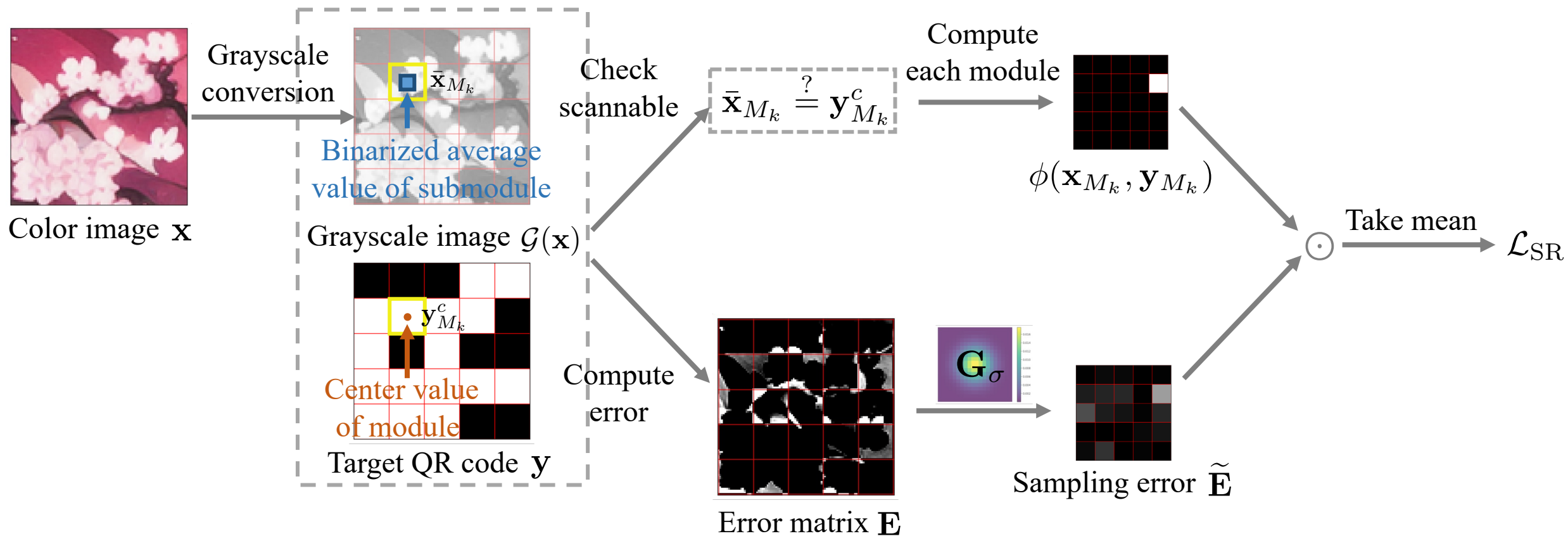
Image



Binarized image

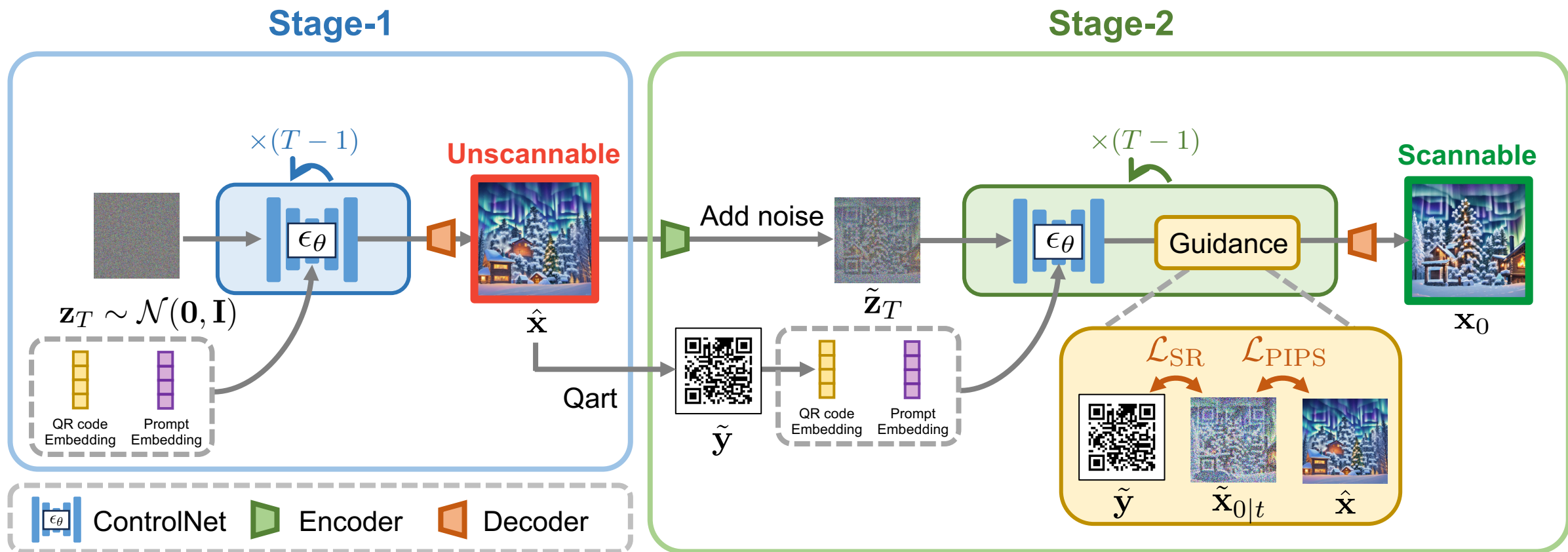


Scanning Robust Perceptual Guidance (SRPG)



CG:
$$\hat{\epsilon}_t = \epsilon_\theta(\tilde{\mathbf{z}}_t, t, \mathbf{e}_p, \mathbf{e}_{\text{code}}) + \sqrt{1 - \bar{\alpha}_t} \nabla_{\tilde{\mathbf{z}}_t} [\lambda_1 \mathcal{L}_{\text{SR}}(\tilde{\mathbf{x}}_{0|t}, \tilde{\mathbf{y}}) + \lambda_2 \mathcal{L}_{\text{LPIPS}}(\tilde{\mathbf{x}}_{0|t}, \hat{\mathbf{x}})]$$

Two-stage Iterative Refinement Pipeline



Qualitative Comparisons

Prompt

Winter wonderland,
fresh snowfall,
evergreen trees,
cozy log cabin,
smoke rising from
chimney, aurora
borealis in night sky.

QR Code AI Art



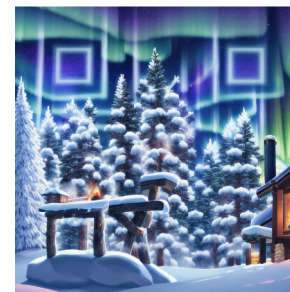
QR Diffusion



QRBTF

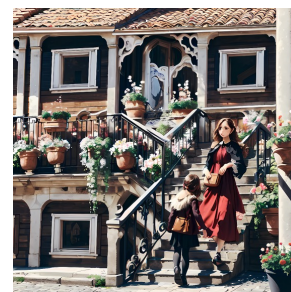
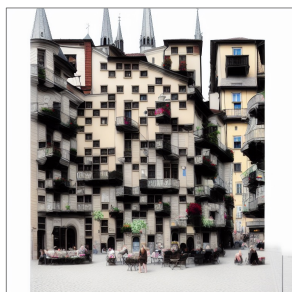


DiffQRCode (Ours)



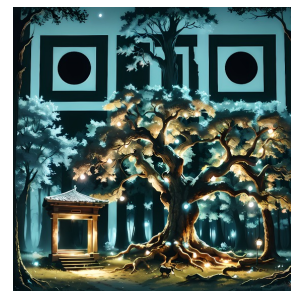
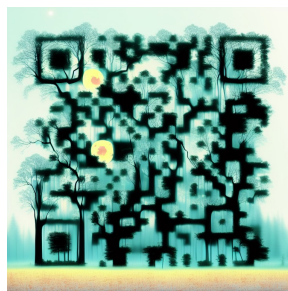
(a) Encoded message: Thanks reviews!

Old European town
square, cobblestone
streets, café terraces,
flowering balconies,
gothic cathedral,
bustling morning.



(b) Encoded message: I think, therefore I am!

Forest clearing at
night, fireflies, full
moon, ancient oak
tree, soft grass,
mystical ambiance.



(c) Encoded message: <https://www.google.com.tw/>

Quantitative Results (I)

- **SSR:** Utilize qr-verify to assess the scanning success rate
- **CLIP-aes.:** Utilize CLIP aesthetic predictor to quantify the aesthetic
- **CLIP-score:** Utilize CLIP to quantify the text-image alignment
- **Avg-rank:** Perform user subjective aesthetic preference study

Method	SSR $\uparrow$	CLIP-aes. $\uparrow$	CLIP-score $\uparrow$	Avg-rank $\downarrow$
QR Code AI Art [13]	90%	5.7003	0.2341	2.71
QR Diffusion [15]	<u>96%</u>	5.5150	0.2780	3.18
QRBTF [18]	56%	7.0156	0.3033	1.86
DiffQRCoder (Ours)	99%	<u>6.8233</u>	<u>0.2992</u>	<u>2.25</u>

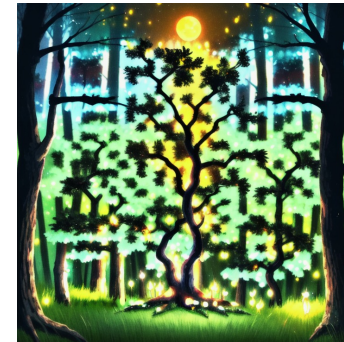
Summary

- We can add control to diffusion models via customized deterministic loss function without relying on pre-trained models or adapting additional modules.
- By breaking down the QR code scanning process and underlying mechanisms, we can design a differentiable loss function that serves as a gradient source for diffusion model guidance.
- Furthermore, leveraging VAE for latent optimization ensures improved visual quality while maintaining scannability.

Project Page



Paper



Code





AAAI-25 / IAAI-25 / EAAI-25
FEBRUARY 25 – MARCH 4, 2025 | PHILADELPHIA, USA



Pixel Is Not A Barrier: An Effective Evasion Attack for Pixel-Domain Diffusion Models



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³ Research Center for Information Technology Innovation, Academia Sinica

Background

Diffusion Models allows users to generate photorealistic image with ease.

Stable Diffusion

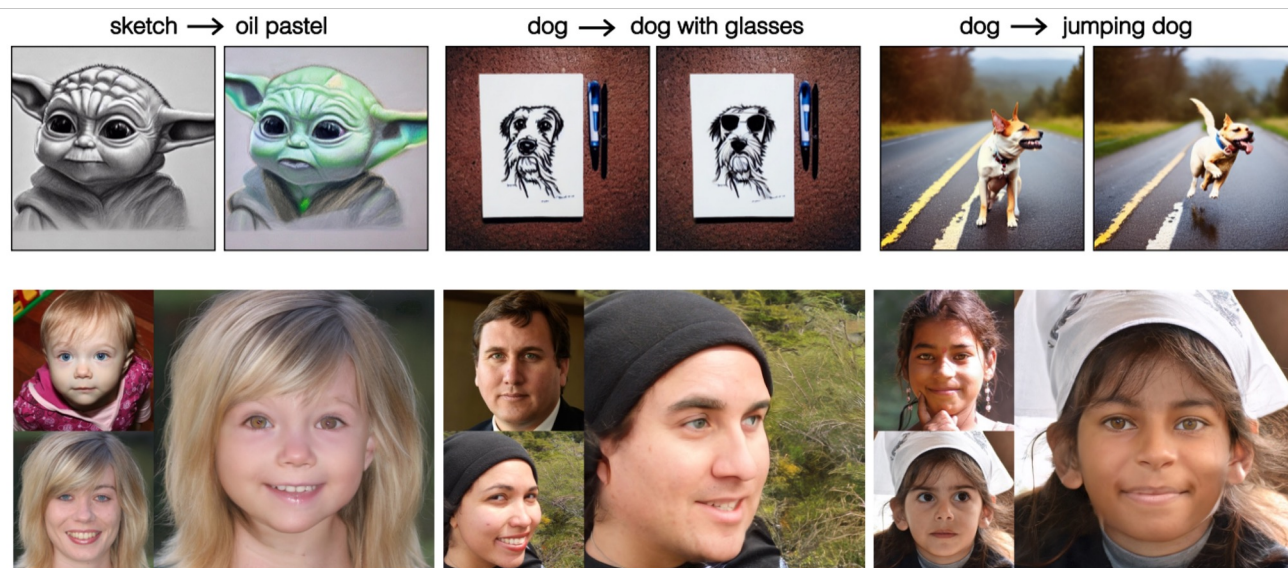
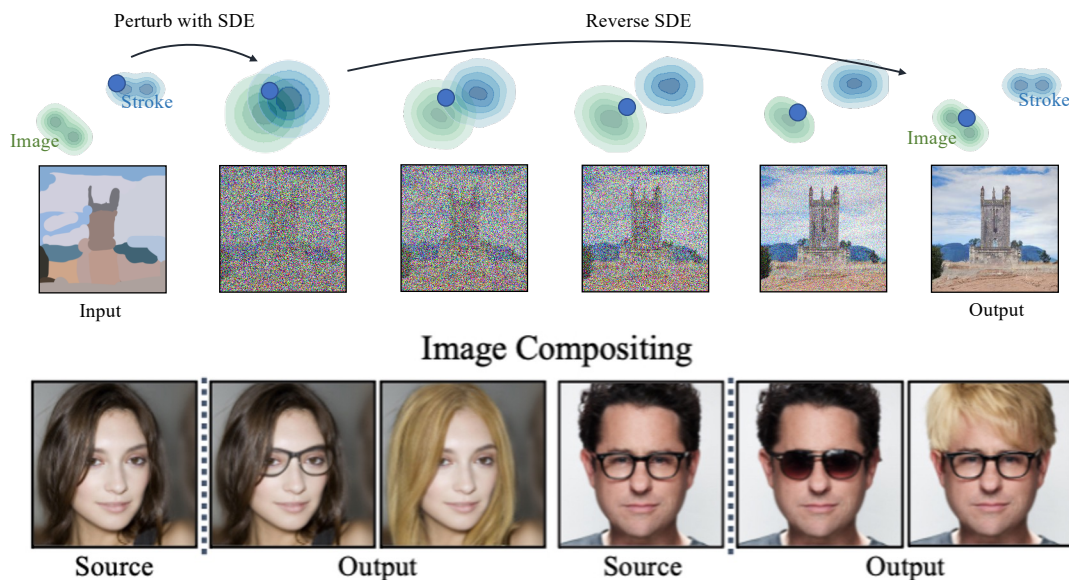


ControlNet



Background

Diffusion Models also allow easily converting image to noisy latent for image translations or editing.

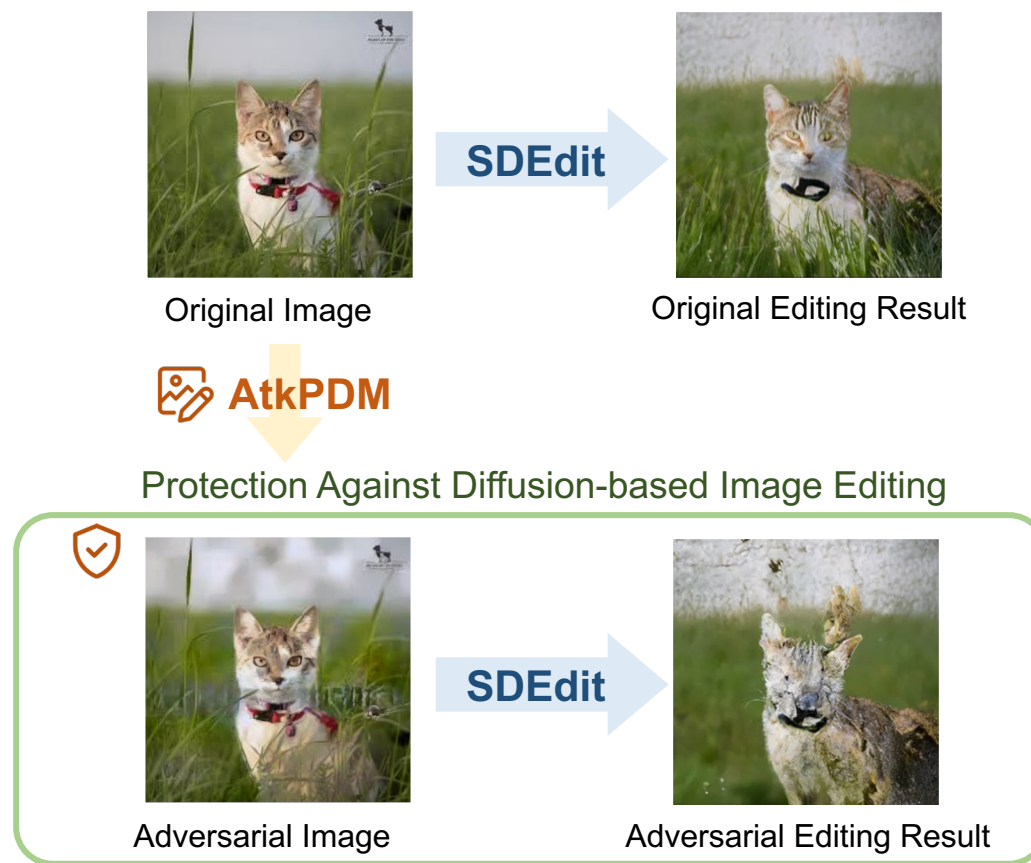


1. Chen-Lin Meng et al. SDEdit: Guided Image Synthesis and Editing with Stochastic Differential Equations. ICLR 2022.
2. Gaurav Parmar et al. Zero-shot image-to-image translation. ACM SIGGRAPH 2023.
3. Wen-Liang Zhao et al. Diffswap: High-fidelity and controllable face swapping via 3d-aware masked diffusion. CVPR 2023

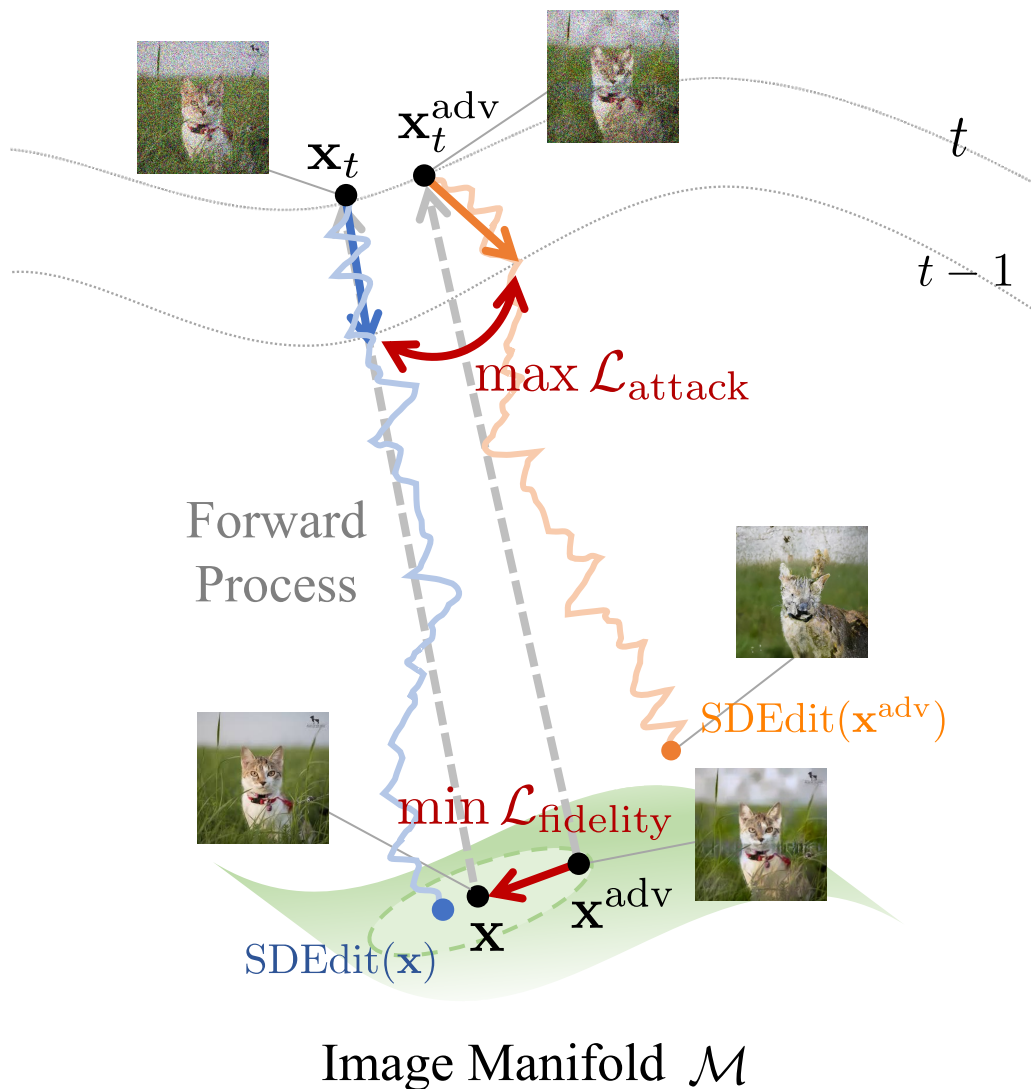
Motivation of Attacking as Protection

How to protect our image against diffusion-based editing?

We can approach this goal as an adversarial attack to the diffusion models.



Problem Formulation and Methodology



Problem

$$\max_{\mathbf{x}^{\text{adv}} \in \mathcal{M}} d(\text{SDEdit}(\mathbf{x}, t), \text{SDEdit}(\mathbf{x}^{\text{adv}}, t))$$

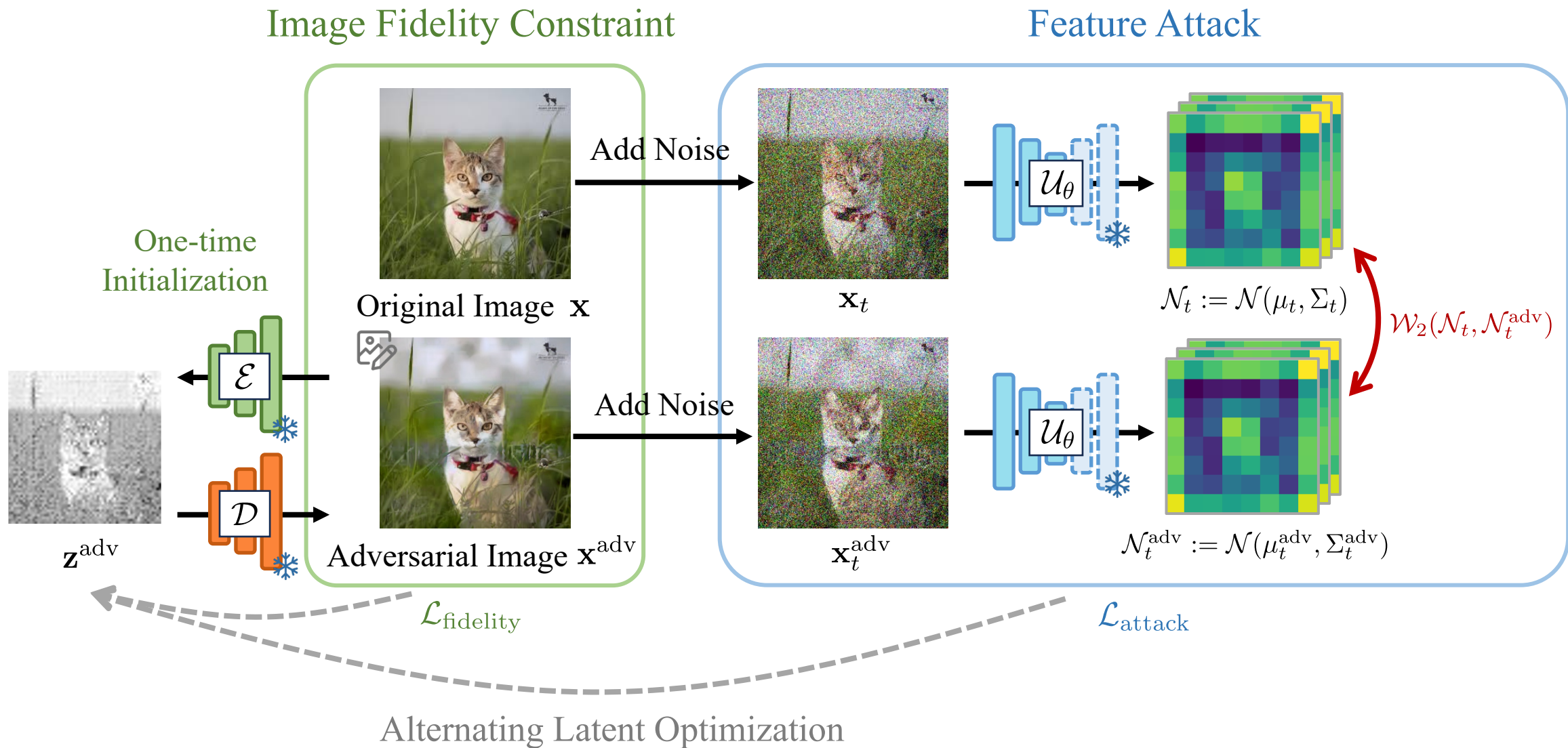
subject to $d'(\mathbf{x}, \mathbf{x}^{\text{adv}}) \leq \delta$

Proposed Losses

$$\max_{\mathbf{x}^{\text{adv}} \in \mathcal{M}} \mathbb{E}_{t, \mathbf{x}_t | \mathbf{x}, \mathbf{x}_t^{\text{adv}} | \mathbf{x}} \mathcal{L}_{\text{attack}}(\mathbf{x}_t, \mathbf{x}_t^{\text{adv}})$$

subject to $\mathcal{L}_{\text{fidelity}}(\mathbf{x}, \mathbf{x}^{\text{adv}}) \leq \delta$

Proposed Method



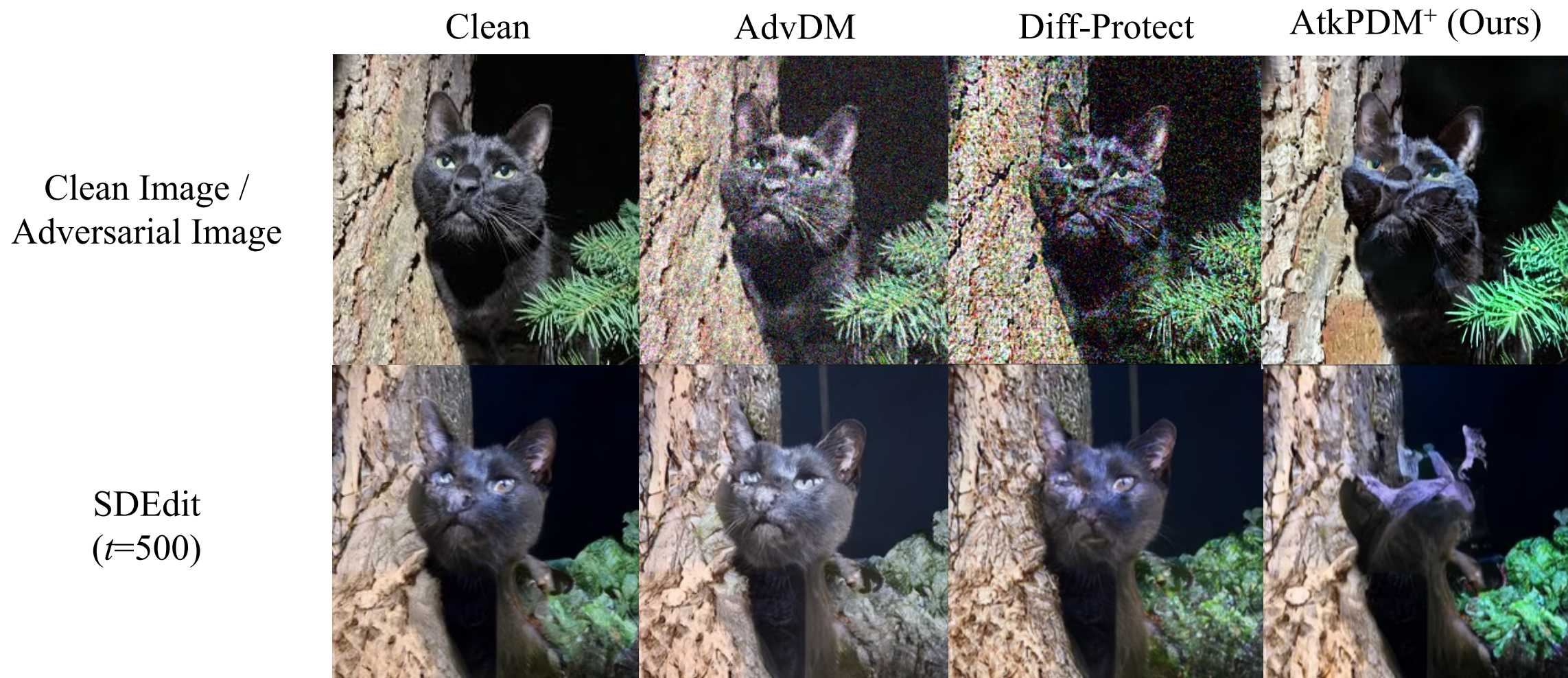
Qualitative Results (I)

Clean Image /
Adversarial Image

SDEdit
($t=500$)



Qualitative Results (II)



Summary

- Although the denoising processes of PDM and LDM seems robust, there still exists vulnerabilities in the feature space inherent in the diffusion models.
- Our study shows the denoising process of the PDMs are robust to pixel-level adversarial perturbation but susceptible to perceptual-level adversarial perturbation.
- We can perform optimization over the latent space of a victim-model-agnostic Variational Autoencoder (VAE) to craft an effective perceptual-level adversarial perturbation against PDM while maintaining the image fidelity.

Project Page



Paper



Code



Takeaway

- Diffusion models learn to generate data by reversing a noise-adding process, forming a powerful generative framework.
- Controllability in diffusion models spans training-free (CG), learning-based (CFG), and semantic-level (ControlNet) approaches.
- DiffQRCode balances aesthetics and scannability by leveraging custom-designed SRPG with CG, generating visually pleasing yet functional QR codes.
- AtkPDM protects images by optimizing feature-space attack loss to break diffusion-based editing.

YouTube Channel: JWAI



JWAI

@jwai1023 · 506位訂閱者 · 76 部影片

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訂閱



Diffusion Models and Flow Matching

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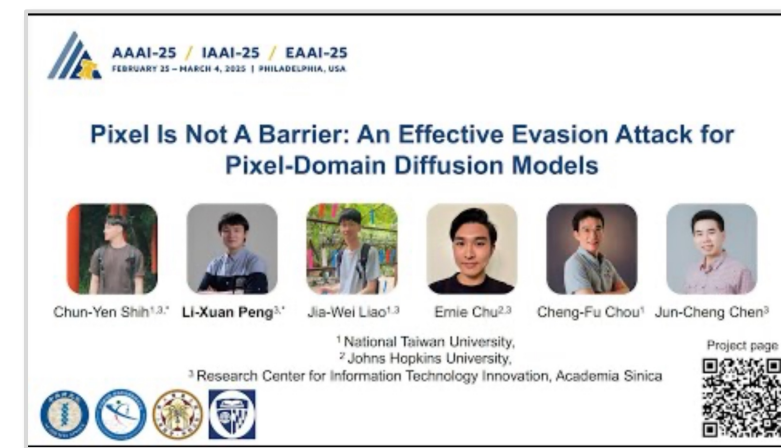
NTU CSIE

Communications and Multimedia Laboratory (CMLab)

[Diffusion Models and Flow Matching](#)



[DiffQRCode](#)



[AtkPDM](#)

Learning Resources for Diffusion Models

- [【漫士科普】人工智慧博士生告訴你 SORA 擴散模型究竟是怎麼產生影片的？](#)
- [Hung-Yi Lee YouTube](#)
- [Jia-Bin Huang YouTube](#)
- [Diffusion and Score-Based Generative Models \(Yang Song\)](#)
- [Evolution of Diffusion Models: From Birth to Enhanced Efficiency and Controllability \(Jesse\)](#)
- [Lil'Log What are Diffusion Models?](#)
- [生成擴散模型漫談 \(蘇劍林\)](#)

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Please take a moment to fill out the feedback form. Your input helps us improve future sessions.



<https://forms.gle/SH5pG8uE7KbzAfHNA>

Thank you



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