StyleInV: A Temporal Style Modulated Inversion Network for Unconditional Video Generation

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Abstract

Unconditional video generation is a challenging task that involves synthesizing high-quality videos that are both coherent and of extended duration. To address this challenge, researchers have used pretrained StyleGAN image generators for high-quality frame synthesis and focused on motion generator design. The motion generator is trained in an autoregressive manner using heavy 3D convolutional discriminators to ensure motion coherence during video generation. In this paper, we introduce a novel motion generator design that uses a learning-based inversion network for GAN. The encoder in our method captures rich and smooth priors from encoding images to latents, and given the latent of an initially generated frame as guidance, our method can generate smooth future latent by modulating the inversion encoder temporally. Our method enjoys the advantage of sparse training and naturally constrains the generation space of our motion generator with the inversion network guided by the initial frame, eliminating the need for heavy discriminators. Moreover, our method supports style transfer with simple fine-tuning when the encoder is paired with a pretrained StyleGAN generator. Extensive experiments conducted on various benchmarks demonstrate the superiority of our method in generating long and high-resolution videos with decent single-frame quality and temporal consistency. Code is available at https://github.com/johannwyh/StyleInV.

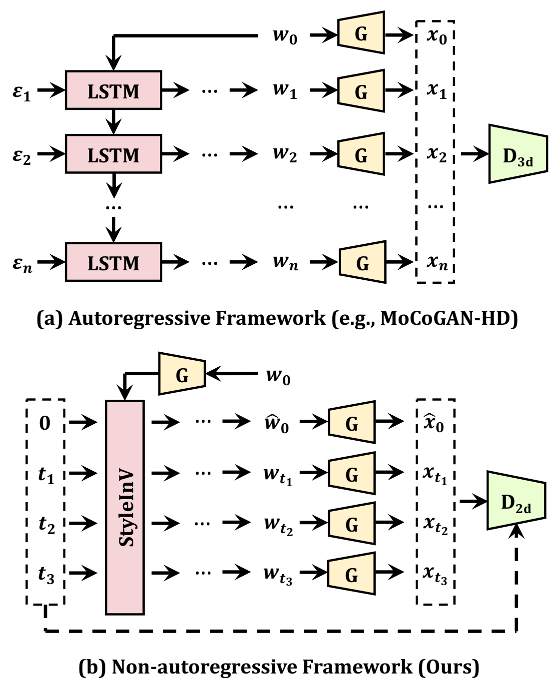


Figure 1: A comparison between autoregressive and non-autoregressive pipeline: (a) Previous autoregressive motion generators require generating the whole clip for a 3D-convolution-based discriminator. (b) Our non-autoregressive motion generator, **StyleInV**, is an inversion network modulated by temporal style (as a random function of t), which enjoys sparse training using a 2D-convolution-based discriminator.

1. Introduction

Unconditional video generation aims at learning a generative model to create novel videos from latent vectors. Despite extensive studies [40, 30, 31, 36, 11, 48] in addressing this problem, it remains challenging to generate high-resolution videos with both favorable quality and motion coherence over a long-term duration. The core difficulties in this task lie in modeling consistent motion and managing the high memory consumption introduced by the addition of the temporal dimension.

To ensure high single-frame resolution and quality, many existing studies, such as MoCoGAN-HD [34], employ a powerful image generator such as StyleGAN [21] as a backbone to serve as a strong generative prior. This approach shifts the focus towards developing a robust motion generator that can capture temporally coherent motion. Most of these methods model motion in an auto-regressive manner, where the next latent is sampled conditioned on the previous one (see Fig. 1). However, this design has two main drawbacks. First, while good performance requires seeing

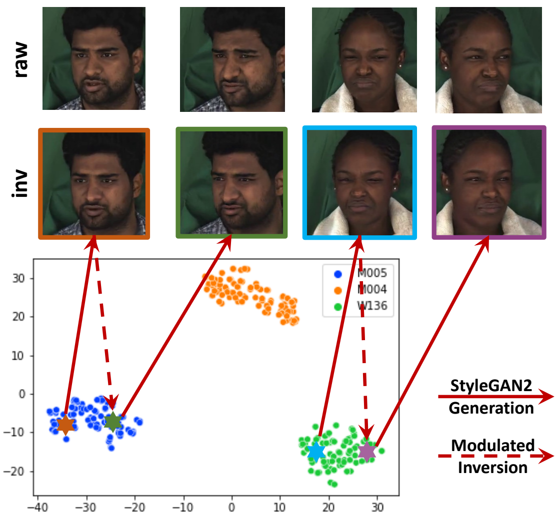


Figure 2: Inverted latent space visualization and modulated inversion process: When the StyleGAN generator is trained with video frame data, $\mathcal{W}$ space is well clustered by human identities and provides promising inversion results. Thus, the modulated inversion process can easily find the target latent corresponding to the same identity (shifted to the next motion) as the source one.

a long sequence of images, the use of heavy 3D discriminators limits its ability to be trained with longer videos. Second, the autoregressive motion generator can lead to motion collapse when extrapolating to generate longer videos.

In this study, we present an effective framework for non-autoregressive motion generation that is capable of generating long and high-resolution videos. Our approach leverages learning-based Generative Adversarial Network (GAN) inversion, which learns the inverse mapping of GANs via an inversion network that consists of an encoder and a decoder[1]. To generate long and coherent videos, we exploit the unique characteristic of the inversion encoder, which captures a rich and smooth manifold between the mapping of images and latent. As illustrated in Fig. 1, to generate a sequence of smooth motion latents, we just need to provide the initial latent code and modulate the inversion encoder with temporal style codes, which are encodings of timestamps with randomness. The motion latents can then be mapped by a StyleGAN decoder to generate a video.

The proposed framework offers several advantages in a single unified framework. **First**, the use of an inversion network naturally constrains the generation space to stay consistent with the desired appearance, which is defined by the initial latent code. As demonstrated in Fig. 2, this leads to a significant benefit. **Second**, thanks to the flexibility of the inversion network in accepting temporal styles of arbitrary timestamps, the framework allows non-autoregressive generation and sparse training [50, 33]. These merits help alleviate the need for heavy discriminators to ensure temporal consistency, as is required in existing approaches. In our implementation, we only need to use a 2D convolutional discriminator instead of a 3D discriminator like MoCoGAN-HD. **Third**, Unlike existing state-of-the-art methods [50, 33, 7] that couples content and motion decoding in one synthesis network, our framework can naturally support content decoder fine-tuning on different image datasets. Specifically, after fine-tuning the decoder (*e.g.*, StyleGAN2) on another image dataset with the mapping layers and low-resolution synthesis layers fixed, given the same sequence of synthesized motion latents, the generated video can possess the new style of the fine-tuning dataset while preserving the motion patterns of the video generated by the parent content decoder.

The main contribution of this work is a novel motion generator that modulates a GAN inversion network. This is the first attempt to build such a generator, and it offers several advantages in a unified framework over existing approaches. These advantages include consistent generation, sparse training, and flexibility in supporting style transfer with simple fine-tuning. We additionally contribute a reformulation to the conventional sparse training, through first-frame-aware acyclic positional encoding (FFA-APE) and first-frame-aware sparse training (FFA-ST), to ensure that our motion generator can faithfully reconstruct the initial frame and that the generated video is smooth and continuous. Extensive experiments on DeeperForensics [17], FaceForensics [29], SkyTimelapse [45] and Tai-Chi-HD [32] datasets show that our model is comparable to or even better than state-of-the-art unconditional video generation methods [34, 50, 33] both qualitatively and quantitatively.

2. Related Work

GAN inversion. The goal of GAN inversion is to find the corresponding vector in the latent space of a pretrained GAN [21, 22] to reconstruct the input image. Existing methods can be classified into three categories [44]: (1) learning-based methods [8, 35, 47, 3, 2, 42, 28], which leverage an encoder network to directly map an image into a latent vector; (2) optimization-based methods [41, 1, 43, 46, 53, 54], which iteratively find the latent vector that best reconstructs the input image using gradient descent; and (3) hybrid models [6, 5, 9, 52], which initialize the iteration process with the result of an encoder network. The design of our motion generator follows the learning-based approach. Therefore, our method is trainable, efficient for single-image inference, and suitable for hierarchical mod-

[1]In many contexts, the decoder is a StyleGAN, and the encoder learns to encode a given image to meaningful latent vectors in the StyleGAN space. There is a variety of image manipulation applications [44, 28, 4] developed based upon such an inversion framework.

ulation. We devise the motion generator on the $\mathcal{W}$ space and use the StyleGAN generated latent as the initial content code to guide the modulated inversion process (see Fig. 2).

Unconditional video generation. Unconditional video generation aims to model the distribution of real videos in a training dataset and generate videos from sampled noise vectors. Many recent studies on this topic are inspired by the success of GANs in image generation. VGAN [40] applies 3D convolutions in both the generator and discriminator, while TGAN [30] optimizes this design by decomposing the generator into an *image generator*, which is shared by the generation of each frame, and a *motion generator*[2]. This framework has been followed by most subsequent studies, such as MoCoGAN [36], which applies a content-motion decomposition. Some approaches [31, 11, 19] have focused on reducing the computational cost of the video discriminator, but the cost is still proportional to the video duration and resolution. Some recent methods have applied more advanced generative frameworks and techniques to unconditional video generation. For example, VideoGPT [48] uses VQ-VAE [27] and GPT [10] to formulate a non-GAN-based video generation approach. Recent studies have also explored unconditional video generation with higher resolution and longer duration. For example, Long-Video-GAN [7] develops a two-phase model that focuses on improving the long-term temporal dynamics of video generation. MoCoGAN-HD [34] and StyleVideoGAN [13] study the generation of latent trajectories in the latent space of a pretrained StyleGAN2 generator.

Our approach is inspired by these studies, but differs in the design of the motion generator. Our motion generator is non-autoregressive, thus alleviating the use of heavy discriminators, and is unique in that it obtains the motion latent via modulating a GAN inversion network. This design allows us to attain better motion consistency and semantics. Concurrent works [50, 33] explored neural representation-based generators and trained them sparsely as an image GAN. In our work, we extend the idea of sparse training to first-frame-aware sparse training, allowing it to be applied to a generation pipeline conditioned on the initial latent.

Diffusion-based video generation. With the emergence of Denoising Diffusion Probabilistic Models (DDPM) [15], the Diffusion model has become a new paradigm for image generation tasks. In the task of unconditional video generation, diffusion-based methods have also achieved significant progress. In [16], Ho *et al.* first propose to use a standard diffusion model to model videos of fixed length and spatial resolution. They introduce 'temporal' as a new channel and process it using a 3D U-Net. VideoFusion [23] introduced the concept of motion-content decomposition, breaking down the noise map into shared noise based on the initial frame, and residual noise that varies over time. MCVD [39] manages to use a 2D U-Net to model video data and employs a masking-based training method to simultaneously achieve video prediction, interpolation, and generation. LGC-VD [49] introduces global context guidance to improve the consistency of autoregressive generation. Despite their success, temporal consistency is still an open problem for diffusion models, and GAN-based models still exhibit a clear advantage in terms of inference speed. Our approach can be combined with existing StyleGAN-based techniques, such as style transfer, which is not achievable with diffusion-based models either.

[2]In the original paper of TGAN [30], the authors called this module *temporal generator*, which is equivalent to the *motion generator* used in subsequent studies [36, 34, 50] and in our paper.

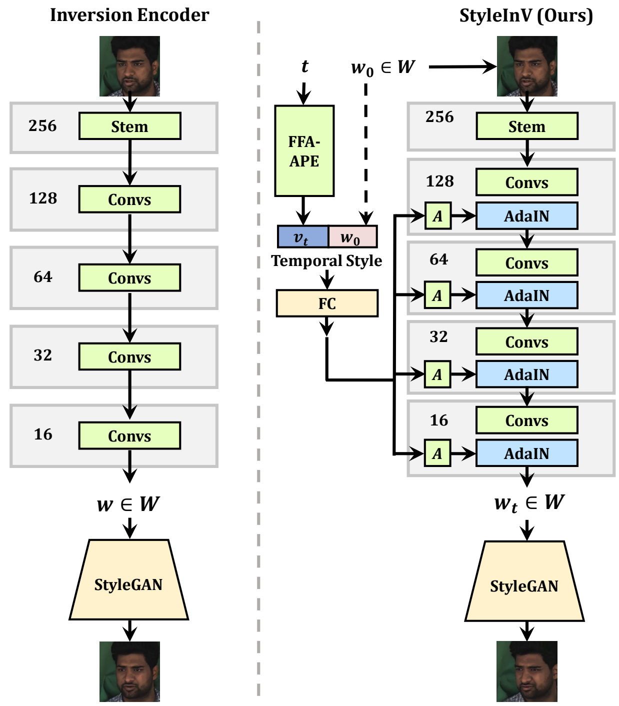


Figure 3: From a typical inversion encoder to StyleInV: We add `AdaIN` layers at the end of each residual block to inject the temporal style, which is a combination of time positional encoding and the first frame latent code. Here "A" stands for a learned affine transform [21].

3. Methodology

3.1. Preliminaries of Inversion Encoder

An inversion encoder maps an input image to a vector in the $\mathcal{W}$ or $\mathcal{W}+$ latent space of a pretrained StyleGAN2 generator. The generated image that corresponds to this vector should faithfully reconstruct the details of the input image. Therefore, when based on $\mathcal{W}$ latent space, given an input image $\mathbf{x}$, the reconstruction process can be defined on top of the inversion network Inv as [28]:

$$\hat{\mathbf{x}} := G(\mathrm{Inv}(\mathbf{x})) := G(E(\mathbf{x}) + \overline{\mathbf{w}}). \quad (1)$$

Here E and G denote the inversion encoder and StyleGAN generator, respectively. $\overline{\mathbf{w}} \in \mathbb{R}^{512}$ denotes the average latent vector of the generator in the $\mathcal{W}$ latent space. In our implementation, the encoder E is a convolutional network backbone that outputs a 512-dimensional vector from the last layer embedding, as shown in Fig. 3(left). We build the encoder on the $\mathcal{W}$ latent space, which eases the design of temporal modulation.

3.2. Temporal Style Modulated Inversion Encoder

The latent space of a StyleGAN trained on a video dataset is typically well-clustered by its content subject. Figure 2 shows an example of human face videos, where we depict the results of inverting video clips of different identities into the $\mathcal{W}$ space and visualizing them with t-SNE [38]. It can be observed that the latent space is grouped by human identities. We also observe the same property in video datasets that follow other distributions. This phenomenon suggests that the inversion network inherits some important temporal priors that we could leverage to maintain motion consistency in generated videos.

Motivated by this observation, we propose **StyleInV**, in which the motion latent is generated by modulating a GAN inversion network with temporal styles. Figure 3(right) illustrates the pipeline of our framework. The temporal style $\boldsymbol{s}_t$ of a timestamp t consists of two parts: the motion code $\boldsymbol{v}_t$ and the latent code of the initial frame $\boldsymbol{w}_0$. Inspired by [33], we use an acyclic positional encoding module to compute a dynamic embedding of the timestamp t. However, unlike [33], we make the embedding of the zero timestamp fixed, so this module becomes first-frame-aware. We provide more details in Section 3.3. The latent code $\boldsymbol{w}_0$ of the initial frame is concatenated with the motion code for content-adaptive affine transform.

The temporal style is injected into the inversion encoder through `AdaIN` layers at the end of each convolution block. With this design, the encoder E of StyleInV becomes a function of the initial latent code w_0 and timestamp t. The modulated inversion process can be defined as:

$$\hat{\mathbf{x}}_t := G(\mathrm{StyleInV}(\boldsymbol{w}_0, t)) := G(E(G(\boldsymbol{w}_0), \boldsymbol{s}_t) + \boldsymbol{w}_0). \quad (2)$$

Notably, the output of E serves as the residual w.r.t. w_0, instead of $\overline{\mathbf{w}}$. This modification provides a more explicit content information guidance for the inversion encoder.

During training, we first train a raw inversion encoder following Eq. (1) on all video frames. Then, we use this network to initialize the weights of all convolution layers in the StyleInV encoder. Other parameters (*e.g.*, FFA-APE and Affine Transforms) are randomly initialized. Finally, the entire StyleInV encoder is trained end-to-end.

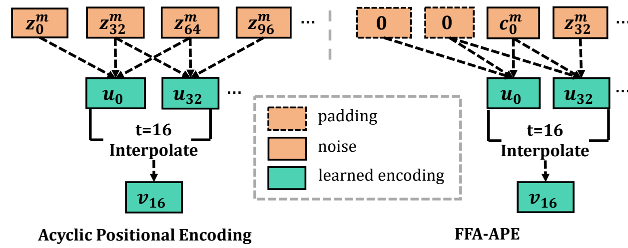


Figure 4: FFA-APE: A simplified case to compute v_{16} for demonstrating the original acyclic positional encoding and our FFA-APE when $\delta^z = 32$ and `conv1d` kernel size is 3. In FFA-APE, the encoding of zero timestamp (u_0) only depends on constant paddings and a constant noise vector, thus is fixed for any sampled noise vector sequence.

3.3. FFA-APE

The original implementation of acyclic positional encoding (APE) [33] samples a series of noise vectors $\boldsymbol{z}^{\mathrm{m}}_{t_0}, \cdots, \boldsymbol{z}^{\mathrm{m}}_{t_n} \sim \mathcal{N}(\mathbf{0}, \boldsymbol{I})$ where $t_i = i \cdot \delta^z$. We call these temporal points *anchor points*. Here δ^z is a set constant distance between adjacent anchor points. Then, the noise vectors are mapped to tokens $\boldsymbol{u}_{t_0}, \cdots, \boldsymbol{u}_{t_n}$ by a padding-less `conv1d`-based motion mapping network. The computation of the acyclic positional encoding $\boldsymbol{v}_t$ of arbitrary timestamp t is achieved by a scalable and learnable interpolation between the tokens of two adjacent *anchor points* that cover t. The computation pipeline is shown in Fig. 4.

In our non-autoregressive generation pipeline, the modulated inversion encoder needs to faithfully reconstruct the initial frame when the input timestamp is zero, making it necessary to fix the computation of the APE for the zero timestamp $\boldsymbol{v}_0$. The original APE computation for $\boldsymbol{v}_0$ is dynamic and depends on randomly sampled noise vectors, which can lead to dynamic output that is not desired. To address this, we devise a first-frame-aware acyclic positional encoding (FFA-APE) method that fixes $\boldsymbol{v}_0$ while maintaining the smoothness of APE (see Fig. 4). We achieve this by replacing the noise vector for the first anchor point with a learnable constant vector $\boldsymbol{c}^{\mathrm{m}}_0$, and using left-sided `conv1d` layers with constant padding instead of the padding-less `conv1d` layers. This way, the value of $\boldsymbol{v}_0$ only depends on the constant vector $\boldsymbol{c}^{\mathrm{m}}_0$ and the left-padded vectors, which are also constant. As a result, $\boldsymbol{v}_0$ is naturally fixed without affecting the continuity of positional encoding.

3.4. FFA-ST

In this section, we introduce the first-frame-aware sparse training specially designed for our framework. Recent non-autoregressive video generation approaches [50, 33] use a discriminator design that only considers k frames $\boldsymbol{x}_{t_1}, \cdots, \boldsymbol{x}_{t_k}$ for each video, distinguishing the realness of the input conditioned on the time difference of input frames $\delta_i = t_{i+1} - t_i$. This training scheme is called sparse training. StyleGAN-V [33] has analyzed the choice of k and found that $k = 3$ is ideal for most datasets. The discriminator is defined as $D(\boldsymbol{x}_{t_{1,2,3}}, \delta_{1,2})$.

We follow this training scheme to make full use of our non-autoregressive framework. Nonetheless, using only three randomly sampled timestamps to train the generator and discriminator can result in sharp transitions at the beginning of the generated video, where the generated $\boldsymbol{x}_0$ and $\boldsymbol{x}_1$ usually diverge too much, and sometimes even switch to another identity and never return. This happens because although we define the generation process of a video as a modulated inversion process of the start frame, the discriminator is unaware of it. The discriminator only focuses on the smoothness of generated latent trajectories, failing to ensure the motion generator produces frames that share the identity with the start frame.

To solve this problem, we introduce the initial frame into the discriminator to enhance content consistency and motion smoothness. The adversarial loss for the first-frame-aware discriminator (FFA-D) can be written as:

$$\begin{aligned} \boldsymbol{y}_{t_{0,1,2,3}} &= G(\mathrm{StyleInV}(w_0, t_{0,1,2,3})), \\ \mathcal{L}_{adv} &= \mathbb{E}_{\boldsymbol{x}\sim p_v}\left[\log D(\boldsymbol{x}_{t_{0,1,2,3}}, \delta_{0,1,2})\right] \\ &\quad + \mathbb{E}_{w_0\sim p_{\mathcal{W}}}\left[\log(1 - D(\boldsymbol{y}_{t_{0,1,2,3}}, \delta_{0,1,2})\right], \end{aligned} \tag{3}$$

where we specify $t_0 = 0$. Here, p_v and $p_{\mathcal{W}}$ denote the real data distribution and $\mathcal{W}$ latent space distribution, respectively. To explicitly enforce initial frame reconstruction, we use a L_2 loss for the generated $\boldsymbol{y}_{t_0}$:

$$\mathcal{L}_{L_2} = ||G(w_0) - G(\mathrm{StyleInV}(w_0, 0))||_2. \tag{4}$$

Finally, we apply latent regularization [28, 25] to the encoder's output, so as to enhance content consistency:

$$\mathcal{L}_{reg} = \sum_{i=0}^{3} ||E(G(w_0), t_i)||_2. \tag{5}$$

The overall loss function for training our motion generator and the discriminator is defined as:

$$\min_E \max_D \mathcal{L}_{adv} + \min_E(\lambda_{L_2}\mathcal{L}_{L_2} + \lambda_{reg}\mathcal{L}_{reg}). \tag{6}$$

Here λ_{L_2} and λ_{reg} are the loss hyperparameters. We also apply discriminator adaptive augmentation [20, 33] and $r1$ regularization [21, 33] to further improve the training stability and generation quality.

3.5. Finetuning-based Style Transfer

Our 'inversion encoder+decoder' framework can naturally take a pretrained StyleGAN model as the generator. And such a configuration allows the generator to be finetuned for different styles, and yet still able to use the motion generator for generating new video with styles. The capability is not possible with existing non-autoregressive video generation methods [50, 33] because they cannot be finetuned under an image GAN training scheme.

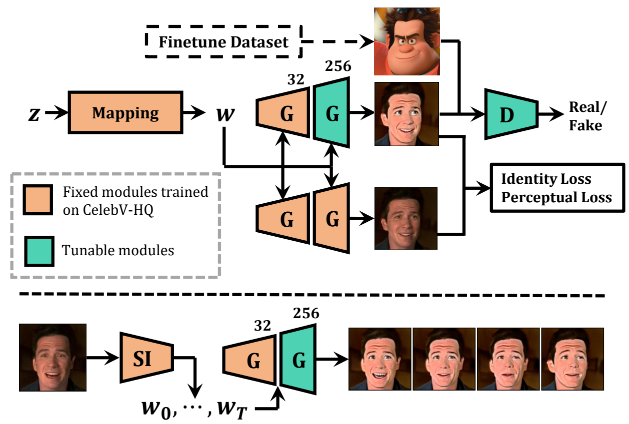


Figure 5: Finetuning-based style transfer: our framework allows easy fine-tuning of decoder (a pretrained StyleGAN generator) to a new domain by freezing mapping and low-resolution ($\leqslant 32^2$) layers. Standard identity loss and perceptual loss are applied to improve identity preservation and reduce artifacts. The style-transferred videos can then be generated by incorporating the StyleInV motion generator.

To achieve style transfer, as illustrated in Fig. 5, we fine-tune the pre-trained StyleGAN model using an image dataset, such as MegaCartoon [26], while keeping the mapping network and low-resolution ($\leqslant 32^2$, coarse and middle layers in [21]) synthesis blocks fixed. This configuration maintains the distribution of the $\mathcal{W}$ space during fine-tuning. To improve identity preservation and reduce artifacts, we apply both a perceptual loss [18] and an identity loss [12] between the images generated by the original and fine-tuned StyleGAN. We show some visual results in Fig. 8. The style-transferred video maintains the same motion pattern as the video generated by the parent model, while adopting a new style from the fine-tuning image dataset. It is noteworthy that the finetuning process is independent of the video generation training. It means that the finetuning-based style transfer is "plug-and-play" as the fine-tuned image generator can be used on any StyleInV models. There is no additional computational cost in the inference either.

4. Experiments

Datasets. We use four video datasets in our main experiments: DeeperForensics 256^2 [17], FaceForensics 256^2 [29], SkyTimelapse 256^2 [45] and TaiChi 256^2 [32]. The cropping strategy for DeeperForensics [17] and FaceForensics [29] is different. For DeeperForensics, we use a stabilized FFHQ [21] cropping strategy [24], while we follow the strategy firstly adopted by TGAN-V2 [31] for FaceForensics. Please refer to the *supplementary material* for a detailed discussion. We will release our processed dataset.

Baselines. We explore four state-of-the-art methods for comparison: MoCoGAN-HD [34], DIGAN [50], StyleGAN-V [33] and Long-Video-GAN [7]. Among these methods, MoCoGAN-HD and DIGAN require an explicit setting of the training clip length. We follow the default setting of their paper to set the clip length as 16 for both methods. This setting is identical to StyleGAN-V [33].

In addition, on DeeperForensics, we explore an optimized setting on DIGAN and MoCoGAN-HD for a more fair comparison. For DIGAN, we directly increase the clip length to 128 frames. For MoCoGAN-HD, we apply the first-frame-aware sparse training to train its motion generator, so as to avoid using a heavy 3D discriminator, allowing it to be trained with 128-frame clips as other methods.

Evaluation. We use Fréchet Inception Distance (FID) [14] and Fréchet Video Distance (FVD) [37] to evaluate all models quantitatively. In practice, we follow the metric calculation framework provided by StyleGAN-V [33] to first generate a fake video dataset with 2,048 synthesized clips, each of 128 frames. For FID, we sample 50k frames from real and fake video datasets to compute the result. For FVD, we compute FVD_{16} and FVD_{128} with the first 16 frames and all 128 frames of each clip, respectively. We use FID results to show the single-frame image quality of each method.

To ensure a fair comparison, we re-benchmark the quantitative results of every method on every dataset. We retrain all the baselines using the official paper setting, except for MoCoGAN-HD on SkyTimelapse, where an officially released checkpoint is available. For more implementation details, please refer to the supplementary material.

4.1. Main Results

Quantitative results. Table 1 summarizes the quantitative results of our method compared to other baselines. Our method achieves competitive quantitative results on all the benchmarks. Notably, although MoCoGAN-HD and DIGAN are trained with clips of 16 frames, we still outperform them in terms of FVD_{16} metrics on all four datasets.

Qualitative results. Fig. 6 shows the qualitative comparison between our method and the baselines on all four datasets. MoCoGAN-HD and DIGAN both suffer from motion collapse, resulting in a degraded generation quality over time. StyleGAN-V shows an impressive visual performance on FaceForensics and SkyTimelapse, but it sometimes fails to maintain the identity and accessories on DeeperForensics and lacks diversity and magnitude of motion over a long time span on TaiChi (the subject gradually fixes at one state). Long-Video-GAN is exceptionally good at SkyTimelapse, but it cannot achieve similar performance on

Table 1: FID, FVD_{16} and FVD_{128} results of video generation methods on (a) DeeperForensics 256^2, (b) FaceForensics 256^2, (c) TaiChi 256^2, and (d) SkyTimelapse 256^2. **Bolds** indicate best and underlines indicate the second best.

(a) DeeperForensics 256^2

Method	FID (↓)	FVD_{16} (↓)	FVD_{128} (↓)
MoCoGAN-HD	135.30	101.07	610.30
DIGAN	191.99	46.69	1060.27
StyleGAN-V	59.59	**39.33**	<u>68.81</u>
Long-Video-GAN	<u>56.54</u>	74.77	169.45
StyleInV (ours)	**54.05**	<u>41.58</u>	**53.93**

(b) FaceForensics 256^2

Method	FID (↓)	FVD_{16} (↓)	FVD_{128} (↓)
MoCoGAN-HD	24.45	112.67	486.69
DIGAN	151.53	146.62	1993.20
StyleGAN-V	**8.64**	<u>52.92</u>	<u>108.86</u>
Long-Video-GAN	40.40	233.26	567.78
StyleInV (ours)	<u>12.06</u>	**47.88**	**103.63**

(c) TaiChi 256^2

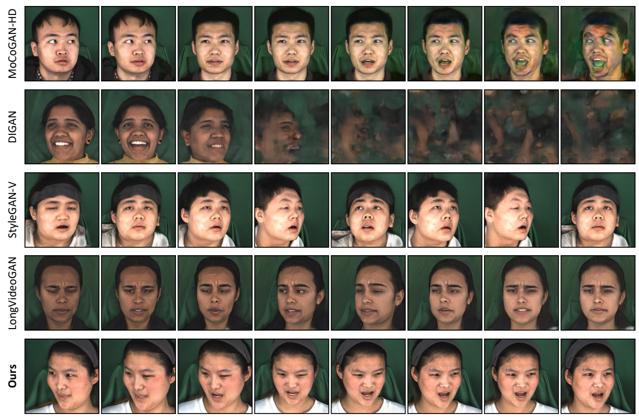
Method	FID (↓)	FVD_{16} (↓)	FVD_{128} (↓)
MoCoGAN-HD	73.61	315.03	622.95
DIGAN	67.24	196.77	954.93
StyleGAN-V	**35.68**	254.74	<u>477.78</u>
Long-Video-GAN	43.90	<u>248.55</u>	502.65
StyleInV (ours)	<u>41.55</u>	**185.72**	**328.90**

(d) SkyTimelapse 256^2

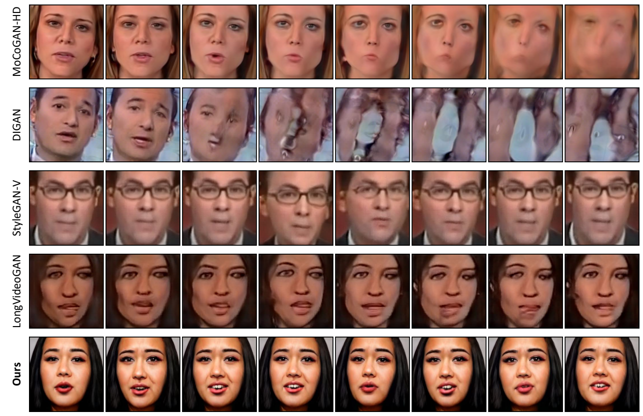
Method	FID (↓)	FVD_{16} (↓)	FVD_{128} (↓)
MoCoGAN-HD	251.81	696.58	4116.03
DIGAN	32.83	148.08	269.43
StyleGAN-V	<u>16.95</u>	<u>81.32</u>	197.83
Long-Video-GAN	25.41	116.50	**152.70**
StyleInV (ours)	**14.32**	**77.04**	<u>194.25</u>

Table 2: FID, FVD_{16} and FVD_{128} results of extended experiments on DeeperForensics 256^2. We apply sparse training to MoCoGAN-HD [34] (#1) and change the preset clip length of DIGAN [50] to 128 (#2). **Bolds** indicate best. (-) indicates a smaller (better) quantitative result, while (+) indicates a larger (worse) one, compared with Table 1a.

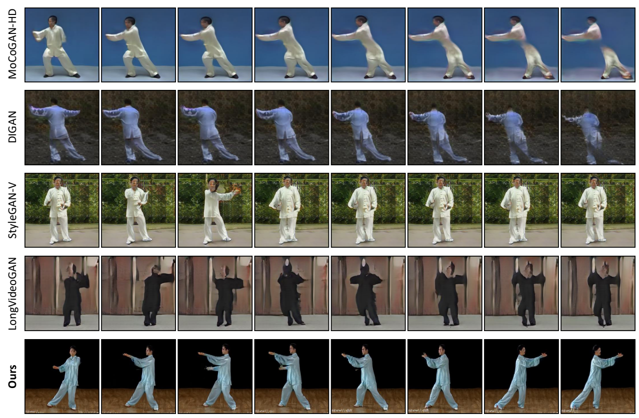
#	Method	FID (↓)	FVD_{16} (↓)	FVD_{128} (↓)
1	[34] + Sparse Training	55.84 (-)	54.58 (-)	129.13 (-)
2	[50] + Clip 128	74.80 (-)	87.42 (+)	95.80 (-)
3	StyleInV (ours)	**54.05**	**41.58**	**53.93**



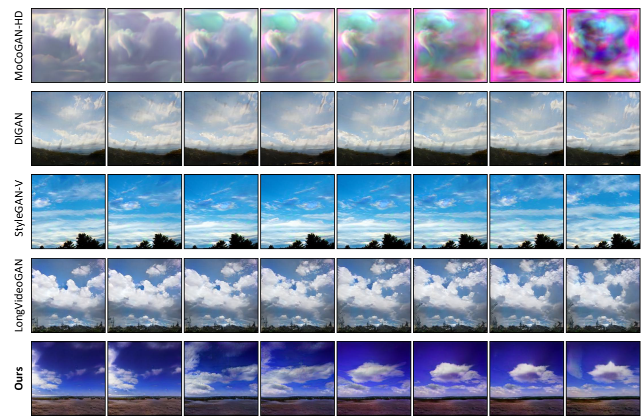
(a) DeeperForensics 256^2



(b) FaceForensics 256^2



(c) TaiChi 256^2



(d) SkyTimelapse 256^2

Figure 6: *Uncurated* samples from the existing methods on DeeperForensics 256^2, FaceForensics 256^2, TaiChi 256^2 and SkyTimelapse 256^2, respectively. We sample a 128-frame video and display every 16 frames, starting from $t = 0$.

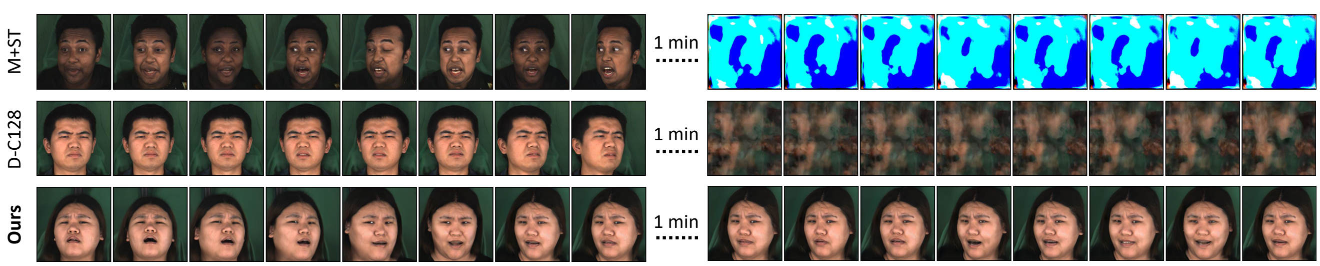


Figure 7: Qualitative comparison of extended experiments. "M+ST" and "D-C128" correspond to Table 2 (#1) and (#2), respectively. Each row shows the first and last 128 frames of a 2056-frame (68.5s) video, displayed every 16 frames.

other datasets. It fails to maintain the identity on DeeperForensics, and its single-frame content on TaiChi lacks details and is inferior to other methods. The generated videos by Long-Video-GAN collapse on FaceForensics.

In contrast to existing methods, our method demonstrates stable results on all four datasets, particularly with superior identity preservation on human-face video and long-term generation quality on TaiChi. Although our method outperforms existing methods in terms of content quality, continuity, and quantitative results, the motion semantics of our generated videos on SkyTimelapse are inferior to those on other datasets. This could be one of the limitations of our work and an area for future improvement.

Extended experiments. We present more in-depth comparisons in Table 2 and Fig. 7 by introducing training im-

Figure 8: Finetuning-based style transfer result. The 1st row is generated by the parent model trained on CelebV-HQ [51]. The 2nd, 3rd, and 4th row uses the StyleGAN generator fintuned on Cartoon, Arcane, and MetFace, respectively.

provements to baselines. Increasing the clip length generally improves the results of MoCoGAN-HD and DIGAN, but they are still inferior to our method. Notably, training with longer clips harms the short-term FVD_{16} result of DIGAN, which indicates its tradeoff between duration length and local temporal quality. Qualitatively, for both methods, the generated content is evidently improved within 128 frames, although the sparsely trained MoCoGAN-HD exhibits issues with identity switching. Motion collapse is still observed when MoCoGAN-HD and DIGAN generates long videos. In contrast, our method can stably generate extremely long videos without motion collapse. Our method outperforms the sparsely trained MoCoGAN-HD, demonstrating the superiority of our motion generator design.

4.2. Properties

As discussed in Section 3.5, our method has the unique advantage over state-of-the-art methods, such as StyleGAN-V and Long-Video-GAN, on its high compatibility with StyleGAN-based downstream techniques.

Finetuning-based style transfer. We train the parent model (motion generator and StyleGAN) on CelebV-HQ [51], as its rich identity makes it more suitable for transfer learning. To perform style transfer, we fine-tune the StyleGAN on the Cartoon [26], MetFace [20], and Arcane datasets following the procedure outlined in Section 3.5. In Fig. 8, we show examples where the same StyleInV-generated latent sequence is decoded by different but aligned StyleGAN generators. Our method achieves satisfactory results in terms of smooth video style transfer with well-aligned face structure, identity, and expression, demonstrating its desirable properties and potential for various applications. More results can be found in the supplementary video.

Initial-frame conditioned generation. Our network supports generating a series of content given a real-world image as the initial frame. We first inverse the image into the StyleGAN2 latent space with a pSp [28] encoder, which is trained to initialize the weights of StyleInV. We treat it as the 512-dimensional initial frame latent w_0, then use it to generate a video with our StyleInV. The generated latent sequence can be also applied to a finetuned image generator to synthesize a style-transferred animation video. Through this pipeline, the real image is reconstructed twice, the first time is during the inversion process, while the second time is when synthesizing $G(\text{StyleInV}(w_0, 0))$.

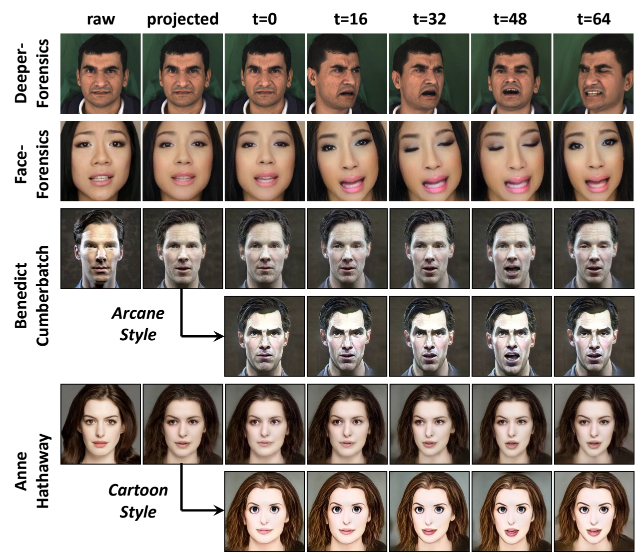


Figure 9: Initial-frame conditioned generation and style transferred results.

When the real images are sampled from the training dataset (see Fig. 9 first two rows), $G(\text{StyleInV}(w_0, 0))$ can faithfully reconstruct the raw image and generate high-quality videos. We then test the generation quality for real images sampled out of the training set (see Fig. 9 last two rows, where we select Benedict Cumberbatch and Anne Hathaway). We use the StyleGAN2 generator and StyleInV

Table 3: Ablation result on the DeeperForensics dataset.

#	Method	FID (↓)	FVD_{16} (↓)	FVD_{128} (↓)
1	w/o inversion encoder	54.35	59.49	152.82
2	w/o FFA-APE	55.26	88.98	144.52
3	w/o Eq.(4) & Eq.(3)	52.55	67.43	58.88
4	w/o Eq.(3)	53.95	86.32	59.76
5	Ours	54.05	41.58	53.93

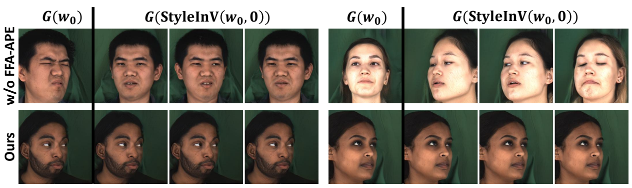


Figure 10: Ablating FFA-APE. Generate the first frame with a fixed w_0 but different temporal noise sequences.

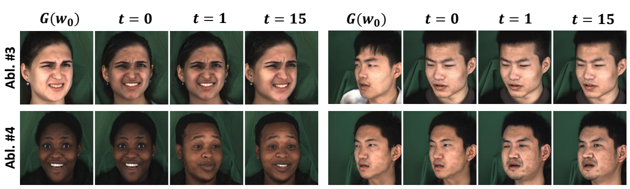


Figure 11: Ablating FFA-ST. The L_2 loss ensures the initial frame reconstruction. But without the initial frame included in the discriminator, we still cannot preserve the identity.

model trained on CelebV-HQ [51] dataset as it is richer in its identities. The results show that our StyleInV network can still generate meaningful videos while reconstructing the initial frame decently, and the style transfer results are smooth and well-aligned. Please refer to the supplementary material for more results.

Other properties. Our method also supports other intriguing properties such as long video generation, temporal interpolation, etc. Please refer to the supplementary material for more results.

4.3. Ablation Studies

Motion generator design. We explore two alternative motion generator designs. The first is the autoregressive MoCoGAN-HD design, which has been discussed in Section 4.1. For the second design, we remove all `Convs`, `AdaIN` and affine transform layers in Fig. 3 and let the mapped temporal style be the output of inversion encoder, *i.e.*, the residual w.r.t. initial frame latent w_0. It largely harms identity preservation. Both FVD_{16} and FVD_{128} degrade significantly as is shown in Table 3(#1).

FFA-APE. We evaluate the importance of our first-frame-aware acyclic positional encoding (FFA-APE) module by replacing it with the original design proposed by [33]. As shown in Fig. 10, the dynamic embedding of the zero timestamp prevents the network from faithfully reconstructing the initial frame. In contrast, our full method can stably realize reconstruction. In addition, the L2 loss in Eq. (4) fails to converge for the ablation method, and its gradient further harms the learning of the positional encoding module, leading to a much worse quantitative result shown in Table 3 (#2).

FFA-ST. We conduct two ablation experiments for the FFA-ST modules. In the first experiment, we remove the initial frame from the discriminator and remove the reconstruction loss (Eq.(4)) (Table 3(#3)). In the second experiment, we only remove the initial frame from the discriminator while keeping the reconstruction loss (Table 3(#4)). As shown in Fig. 11, without the reconstruction loss, our model cannot reconstruct the initial frame accurately. With the L_2 loss, the initial frame is reconstructed, but there is a sudden transition between the first two frames, and sometimes, the identity also changes, leading to a worse FVD_{16} result. These experiments demonstrate the importance of our first-frame-aware discriminator (FFA-D).

5. Conclusion

We have presented a novel approach for unconditional video generation by employing a pretrained StyleGAN image generator. The proposed StyleInV motion generator generates latents in the StyleGAN2 latent space by modulating a learning-based inversion network, and thus capable of inheriting its informative priors of the initial latent. Our network features non-autoregressive training and uniquely supports fine-tuning based style transfer. Extensive experiments demonstrate the superiority of our method in generating long and high-resolution videos, outperforming state-of-the-art baselines. The limitations and broader impact of our work are discussed in the supplementary material.

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