

# Follow-Your-Canvas: Higher-Resolution Video Outpainting with Extensive Content Generation

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<https://follow-your-canvas.github.io/>

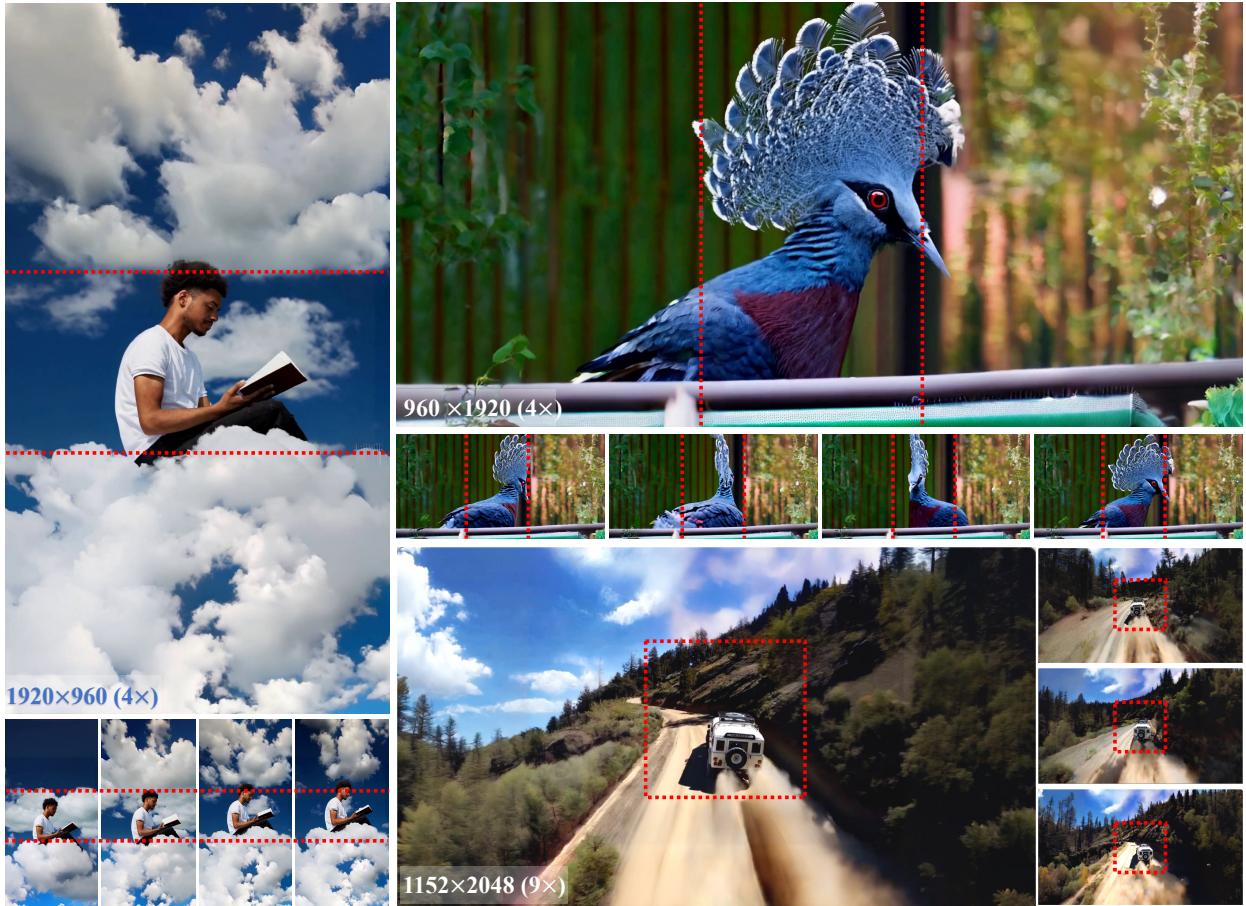


Figure 1. **Results of our Follow-Your-Canvas.** The videos (from OpenAI’s Sora demo cases) within the red dotted boxes are largely outpainted from  $4\times$  to  $9\times$ . Given a video of any size and resolution, Follow-Your-Canvas can generate outpainting results in higher resolution with extensive content, while maintaining consistency of spatial layout, temporal changes, and overall aesthetics.

## Abstract

*This paper explores higher-resolution video outpainting with extensive content generation. We point out common is-*

*sues faced by existing methods when attempting to largely outpaint videos: the generation of low-quality content and limitations imposed by GPU memory. To address these challenges, we propose a diffusion-based method called Follow-Your-Canvas. It builds upon two core designs. First, instead of employing the common practice of “single-shot”*

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*outpainting, we distribute the task across spatial windows and seamlessly merge them. It allows us to outpaint videos of any size and resolution without being constrained by GPU memory. Second, the source video and its relative positional relation are injected into the generation process of each window. It makes the generated spatial layout within each window harmonize with the source video. Coupling with these two designs enables us to generate higher-resolution outpainting videos with rich content while keeping spatial and temporal consistency. Follow-Your-Canvas excels in large-scale video outpainting, e.g., from  $512 \times 512$  to  $1152 \times 2048$  ( $9\times$ ), while producing high-quality and aesthetically pleasing results. It achieves the best quantitative results across various resolution and scale setups. The code is released on <https://github.com/mayuelala/FollowYourCanvas>*

## 1. Introduction

Video outpainting aims to expand spatial contents of a video beyond its original boundaries to fill a designated canvas region. This task has numerous applications, such as enhancing viewing experience by adjusting aspect ratio of videos to match different users’ smartphones [27].

Recently, diffusion models [10] have emerged as the dominant approach for visual generation, demonstrating exceptional visual synthesis ability by producing appealing results [24]. Meanwhile, several diffusion-based video outpainting methods, such as M3DDM [7] and MOTIA [27], have been proposed. They utilize the source video as a condition and generate the canvas region through step-by-step denoising, showing great performance. However, their results are limited in terms of *resolution*, such as  $256 \times 256$  [7] and  $512 \times 1024$  [27], or *content expansion ratio*, for example, from  $256 \times 85$  to  $256 \times 256$  ( $3\times$ ) [7] and from  $512 \times 512$  to  $512 \times 1024$  ( $2\times$ ) [27]. This raises an intriguing question: “*Is it possible to outpaint a video to higher resolution with a higher content expansion ratio?*”

This question drives us to evaluate the capability of existing methods in tackling this difficult task. However, we find that they fall short due to limitations in GPU memory. To further explore their potential, we reduce the resolution of the source video through resizing and then resizing it back after outpainting (see details in Section 4). The results are depicted in Fig 2. We observe that both M3DDM [7] and MOTIA [27] produce low-quality results, e.g., blurry content and temporal inconsistencies. This motivates us to delve deeper into understanding the reasons behind this. We speculate that there are two possible factors contributing to this: (i) the reduced resolution after resizing negatively affects the performance, and (ii) the content expansion ratio is too high to achieve satisfactory results. We conduct experiments with respect to the variations of these factors, see

Fig 3. The results demonstrate that both low resolution and a high content expansion ratio significantly reduce generation quality. In other words, achieving high-quality results requires performing outpainting in the *original/high resolution* with a *low content expansion ratio*.

Based on the analysis above, we propose a diffusion-based method called Follow-Your-Canvas for higher-resolution video outpainting with extensive content generation. We identify that the GPU memory limitations arises from the “single-shot” outpainting practice [7, 27]: directly taking the entire video as the input. In contrast, our Follow-Your-Canvas is designed to distribute the task across spatial windows. It kills two birds with one stone. First, it enables us to outpaint any videos to higher resolution with a high content expansion ratio, without being constrained by GPU memory. Second, it simplifies the challenging task by breaking it down into smaller and easier sub-tasks: outpainting each window in the original/high resolution with a low content expansion ratio. Specifically, during the training phase, we randomly sample an anchor window and a target window from the source video, mimicking the “source video” and “outpainting region” for inference respectively. It helps model learn how to flexibly outpaint with different relative positions and overlaps between the source video and outpainting region. During the inference phase, we outpaint a video by denoising windows that covering the entire video. To accelerate the generation process, we perform window outpainting in parallel on multiple GPUs. After each step of denoising, we seamlessly merge the windows using Gaussian weights [1] to ensure a smooth transition between them. Due to the fact that videos of any resolution can be covered by a certain number of fixed size windows, while each window is limited within the GPU memory range, our Follow-Your-Canvas method could be applied to situations where the canvas size is very large.

Despite the advantages offered by the spatial window strategy, we observe conflicts between the layout generated within each window and the overall layout of the source video (see Fig 4). This issue arises due to the fact that the model input for each window is only a portion of the source video. Consequently, while the outpainting results within each window are reasonable, they fail to align with the overall layout, particularly when the overlap is low. To address this challenge, our Follow-Your-Canvas method incorporates the source video and its relative positional relation into the generation process of each window. This ensures that the generated layout harmonizes with the source video. Specifically, we introduce a **Layout Encoder** (LE) module, which takes the source video as input and provides overall layout information to the model through cross-attention. Meanwhile, we incorporate a **Relative Region Embedding** (RRE) into the output of the LE module, which offers information about the relative positional relation. The RRE is



Figure 2. **Results of higher-resolution outpainting with a high content expansion ratio.** The source video (the red dotted box) is outpainted from  $512 \times 512$  to  $1152 \times 2048$  ( $9\times$ ). Existing methods often suffer from blurry content and temporal inconsistencies (yellow boxes). In comparison, our Follow-Your-Canvas method generates well-structured scenes with aesthetically pleasing results.

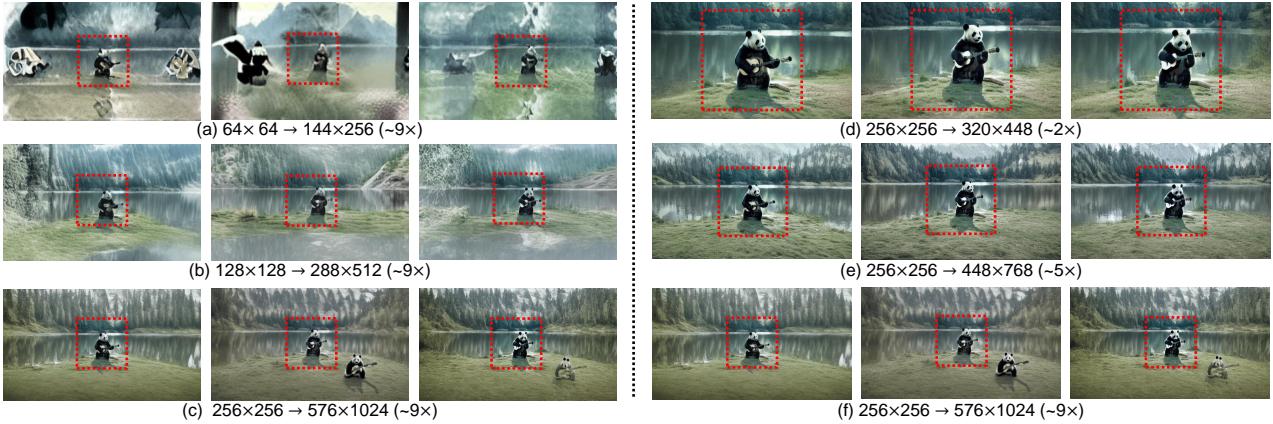


Figure 3. **Results of MOTIA with different resolution (a-c) and content expansion ratio (d-f) setups.** Increasing resolution of the source video improves the generation quality, while reducing content expansion ratio improves spatial-temporal consistency.

calculated based on the offset of the source video to the target window (outpainting region), as well as the size of them. The LE and RRE guide each window to generate outpainting results that conform to the global layout based on its relative position, effectively improving the spatial-temporal consistency.

Coupling with the strategies of spatial window and layout alignment, our Follow-Your-Canvas excels in large-scale video outpainting. For example, it outpaints videos from  $512 \times 512$  to  $1152 \times 2048$  ( $9\times$ ), while delivering high-quality and aesthetically pleasing results (Fig ??). When compared to existing methods, Follow-Your-Canvas produces better results by maintaining spatial-temporal consistency (Fig 2). Follow-Your-Canvas also achieves the best quantitative results across various resolution and scale se-

tups. For example, it improves FVD from 928.6 to 735.3 (+193.3) when outpainting from  $512 \times 512$  to  $2048 \times 1152$  ( $9\times$ ) on the DAVIS 2017 dataset.

Our main contributions are summarized as follow:

- We emphasize the importance of high resolution and a low content expansion ratio for video outpainting.
- Based on the observation, we distribute the task across spatial windows, which not only overcomes GPU memory limitations but also enhances outpainting quality.
- To ensure alignment between the generated layout and the source video, we incorporate the source video and its relative positional relation into the generation process.
- Our Follow-Your-Canvas demonstrates great outpainting capabilities through both qualitative and quantitative results.

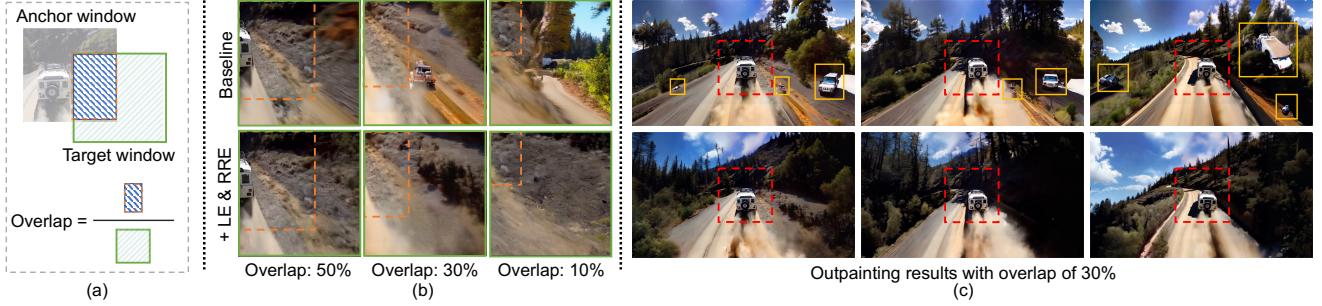


Figure 4. **Ablation of layout encoder (LE) & relative region embedding (RRE).** Under different overlap (a), results within target windows (b) and the final results (c) are presented. The orange dashed line represents the model input for target windows. While the results appear reasonable within windows, they fail to align with the overall layout (see yellow boxes). By incorporating RRE and LE, the model unifies layout of windows with that of the anchor window, improving spatial-temporal consistency.

## 2. Related Work

**Diffusion models** [10, 25] are a class of generative models that progressively convert noise into structured data through a learned denoising process. It has garnered significant attention in visual generation [20, 23, 32]. By applying diffusion models in the latent space, LDM [24] has demonstrated the ability to generate high-quality images by utilizing limited computational resources. Meanwhile, many works [2, 8, 11] generate impressive videos by inserting temporal layers into the model structure. This has promoted the rapid development of video generation in editing [3, 16, 21], controllable generation [17–19, 29], outpainting [7, 27], etc.

**Video outpainting** seeks to extend the spatial contents of a video beyond its initial boundaries, allowing it to fill a specific canvas region. Although image outpainting [5, 31, 34] has been extensively studied, video outpainting [6] still needs to be fully researched. Recently, some diffusion-based approaches have been introduced. M3DDM [7] presents global frame-guided training with a coarse-to-fine inference pipeline to tackle the artifact accumulation issue. Meanwhile, MOTIA [27] proposes a test sample-specific fine-tuning strategy to learn the patterns of each sample. Despite their great results, they are limited in terms of resolution such as  $256 \times 256$  and  $512 \times 1024$ , or content expansion ratio such as  $2\times$  and  $3\times$ . As these two factors are the core of outpainting, this paper makes the first attempt to study video outpainting with high resolution, *e.g.*,  $1152 \times 2048$ , and a high content expansion ratio, *e.g.*,  $9\times$ .

## 3. Method

We present Follow-Your-Canvas, a diffusion-based method, which enables higher-resolution video outpainting with extensive content generation. Our approach is built upon two key designs. First, we employ spatial windows to divide the outpainting task into smaller and easier sub-tasks. Second, we introduce a layout encoder module as well as a relative

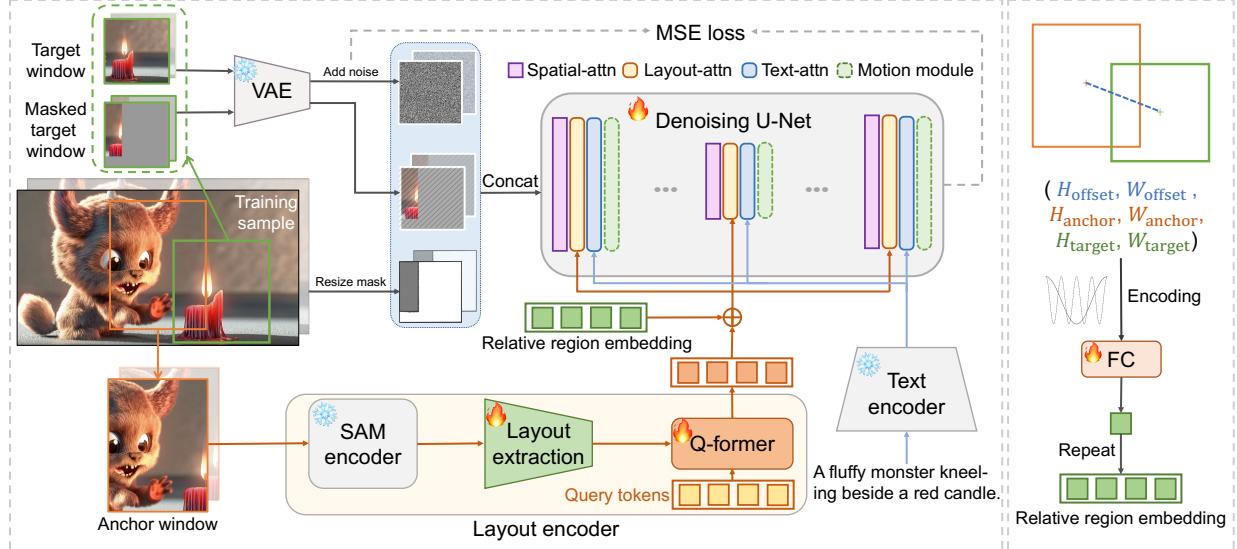
region embedding to align the generated spatial layout.

### 3.1. Outpainting by Spatial Windows

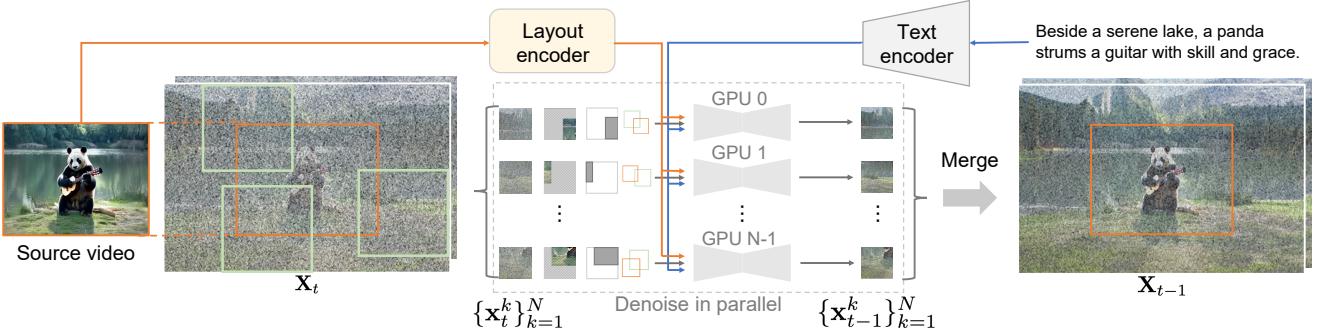
To address the GPU memory limitations, we distribute the outpainting task across spatial windows. It allows us to outpaint any videos to higher resolution with a high content expansion ratio without being constrained by GPU memory. Moreover, it simplifies the task by breaking it down into smaller and easier sub-tasks: outpainting each window in its original/high resolution with a low content expansion ratio.

**Training phase.** Fig 5 illustrates the training phase of Follow-Your-Canvas. Given each training video sample, we randomly crop an anchor window and a target window. They serve as the “source video” and the “region to perform outpainting” respectively, mimicking the source video and the outpainting windows during inference, respectively. The conventional training practice of the latent diffusion model adds noise to the latent representation of the data (the target window) to build the model input and makes the model predict the noise. Here, we concatenate it with conditions: the latent representation of a masked target window and the binary mask. They offer information of the original video and its position. Since the channel of the mask and the latent representations output by the VAE encoder are 1 and 4 respectively, the final model input has 9 channels. We modify the first convolution layer of the denoising UNet to adjust to the channel changes, similar to previous works [7, 27]. However, instead of employing a fixed region for outpainting [7, 27], we use a random sample of the anchor window and the target window. It helps the model learn to flexibly outpaint with different relative positions and overlaps between the source video and the outpainting region, enabling the sliding window-based inference phase described next. Note that the size of the anchor window, the target window, and their overlap are all variables. See details in experiments.

**Inference phase.** Fig 6 illustrates the inference phase



**Figure 5. The training phase of Follow-Your-Canvas.** An anchor window and a target window are randomly sampled, mimicking the “source video” and “region to perform outpaint” for inference respectively. The anchor window is injected into the model through a layout encoder, as well as a relative region embedding calculated by the positional relation between the anchor window and the target window, helping the model align the generated layout of the target window with the anchor window.



**Figure 6. The inference phase of Follow-Your-Canvas.** The given source video is covered by  $N$  spatial windows. During each denoising step  $t$ , outpainting is performed within each window in parallel on separate GPUs to accelerate inference. The windows are then merged through Gaussian weights to get the outcome at step  $t - 1$ . Note that these windows may cover layer upon layer, allowing Follow-Your-Canvas to outpaint any videos to a higher resolution without being limited by the GPU memory constraints.

of Follow-Your-Canvas. Given a source video to be out-painted, our Follow-Your-Canvas first determines the number (denoted as  $N$ ) of spatial windows and their positions, which should cover the source video and fill the target region to be outpainted (find more details in experiments). During each denoising step  $t$ , Follow-Your-Canvas performs outpainting within each window  $k$  on noisy data  $\mathbf{x}_t^k$ , where  $k \in \{1, \dots, N\}$ . Here, the source video and the window correspond to the anchor window and the target window of the training phase respectively. The denoised outputs in the  $N$  windows, i.e.,  $\{\mathbf{x}_{t-1}^k\}_{k=1}^N$ , are then merged via Gaussian weights [1] to get a smooth outcome  $\mathbf{x}_{t-1}$ . The process is repeated until the final outpainting result  $\mathbf{x}_0$  is obtained. Importantly, the inference process of each window

is independent of the others, allowing us to perform out-painting within each window in parallel on separate GPUs, thereby accelerating the inference. We analyze its efficiency in experiments.

**Layout Alignment** Despite the advantages offered by the spatial window strategy, we observe conflicts between the layout generated within each window and the overall layout of the source video, as shown in Fig 4. The outpainting results within each window of the “baseline”, which only applies the spatial window strategy, are reasonable. However, they do not align with the global layout because each window is provided with a view of only a part of the source video. To enable spatial and temporal consistency, we introduce a layout encoder and relative region embedding. They

deliver the layout information of the source video and its relative position relation to each window respectively, effectively helping the model generate more stable and consistent outpainting videos (see the results of “+LE & RRE” method in Fig 4).

**Layout Encoder (LE).** Similar to the text encoder that injects the text prompts into the model, we introduce LE to incorporate layout information from the source video, see Fig 5. Specifically, LE consists of a SAM encoder [14], a layout extraction module, and a Q-former [15]. Instead of employing the CLIP visual encoder [22] like many previous works [29, 30], we find SAM encoder (ViT-B/16 structure) is more effective to extract visual features by providing finer visual details (see comparisons in experiments). Then, the layout features are extracted by the layout extraction module, including a pseudo-3D convolution layer, two temporal attention layers, and a temporal pooling layer. Inspired by 15, we employ a Q-former (Querying Transformer) to extract and refine visual representations of the layout information by learnable query tokens. We train the layout extraction module and the Q-former while fixing the SAM encoder. The relative region embedding is added to the output of the LE to provide a positional relation between the anchor window and the target window, introduced next.

**Relative Region Embedding (RRE).** RRE provides the positional relation between the anchor window and the target window (see Fig 5). We denote the height, width, and center point coordinates of the anchor window as  $H_{\text{anchor}}$ ,  $W_{\text{anchor}}$ , and  $(X_{\text{anchor}}, Y_{\text{anchor}})$  respectively. The target window is defined in the same way. RRE employs sinusoidal position encoding [34] to embed the size and relative position relation between the anchor and target windows, i.e.,  $\{H_{\text{anchor}}, W_{\text{anchor}}, H_{\text{target}}, W_{\text{target}}, H_{\text{offset}}, W_{\text{offset}}\}$ , where  $H_{\text{offset}} = Y_{\text{target}} - Y_{\text{anchor}}$ ,  $W_{\text{offset}} = X_{\text{target}} - X_{\text{anchor}}$ . The embeddings are then fed to a fully-connected (FC) layer. The output of the FC layer is repeated to match the output of the LE. We incorporate the LE and RRE using a cross-attention layer inserted in each spatial-attention block of the model. Due to the limitation of paper length, we leave more details about the design of the model structure in the appendix.

## 4. Experiments

### 4.1. Setup

**Dataset.** M3DDM [7] use a private dataset with  $\sim 5\text{M}$  video samples. Here, we employ a random subset ( $\sim 1\text{M}$  video samples) of the public Panda-70M dataset [4] for training, improving reproducibility of our work.

**Implementation details.** Our implementation and model initialization is based on the popular video generation framework of AnimateDiff-V2 [8]. Due to the limitation of paper length, we leave more specific details about the training recipe, the design of the anchor and target windows, and

the inference pipeline in the appendix.

**Evaluation metrics.** We first employ metrics of PSNR, SSIM [28], LPIPS [33], and FVD [26] by following 27. To evaluate high-resolution video generation, we further utilize aesthetic quality (AQ) and imaging quality (IQ) [13], assessing the layout/color harmony and visual distortion (e.g., noise and blur) respectively.

**Baselines.** We compare our Follow-Your-Canvas with the following baseline methods. (1) 6 use the approach of flow estimation and background prediction. (2) M3DDM [7] employs global-frame features to achieve global and long-range information transfer. 3) MOTIA [27] trains a LoRA [12] to learn patterns of test samples. We reproduce these baseline methods using their official codes for high-resolution video outpainting and directly cite their results in low-resolution.

### 4.2. Comparisons to Baseline Methods

#### 4.2.1 Quantitative results.

We compare methods in both high and low-resolution settings. (1) *High-resolution with large content expansion ratios.* Table 1 shows the results. Our Follow-Your-Canvas consistently achieves the best performance for all metrics and outpainting settings. Meanwhile, as the resolution and content expansion ratio increase, the performance improvement of many metrics becomes more significant. For example, Follow-Your-Canvas improves FVD from 473.7 to 440.0 (+33.7) in 720P ( $\sim 3.5\times$ ), improves from 575.9 to 486.1 (+89.8) in 1.5K, and improves from 928.6 to 735.3 (+193.3) in 2K. Our Follow-Your-Canvas effectively improves performance in the challenging task of high-resolution outpainting with high content expansion ratios. (2) *Conventional settings in low-resolution.* Following 7 and 27, we also compare results in low-resolution, which outpaint videos to  $256 \times 256$  in the horizontal direction using mask ratio of 0.25 ( $\sim 1.3\times$ ) and 0.66 ( $\sim 3\times$ ) and calculate the average performance. Table 2 shows the results. Our Follow-Your-Canvas still achieves excellent performance under this conventional setting. Note that MOTIA [27] fine-tunes the model for each test sample which may not be efficient, while our Follow-Your-Canvas method performs zero-shot inference after model training.

#### 4.2.2 Qualitative results.

In Fig. 7, we showcase the qualitative results. It is evident that M3DDM fails to generate meaningful content in the majority of outpainting regions. On the other hand, MOTIA faces difficulties in maintaining spatial and temporal consistencies, which can be attributed to the challenging task of handling high resolution and content expansion ratios. In contrast, our Follow-Your-Canvas successfully generates well-structured visual content. It is because the de-

Table 1. **Quantitative comparisons for higher resolution video outpainting with high content expansion ratios.** The resolution of the source video is  $512 \times 512$ . MOTIA is noted by gray because it is based on test sample-specific fine-tuning.

Resolution	Method	FVD $\downarrow$	LPIPS $\downarrow$	AQ $\uparrow$	IQ $\uparrow$	PSNR $\uparrow$	SSIM $\uparrow$
$1280 \times 720$ (720P, $\sim 3.5\times$ )	MOTIA [27]	473.7	0.418	0.494	0.634	15.38	0.582
	Dehan [6]	736.0	0.604	0.435	0.542	13.95	0.605
	M3DDM [7]	631.3	0.524	0.446	0.556	15.28	0.605
	<b>Follow-Your-Canvas (Ours)</b>	<b>440.0</b>	<b>0.390</b>	<b>0.509</b>	<b>0.658</b>	<b>15.38</b>	<b>0.606</b>
$1440 \times 810$ (1.5K, $\sim 4.5\times$ )	MOTIA [27]	575.9	0.457	0.484	0.648	14.52	0.539
	Dehan [6]	857.2	0.650	0.415	0.543	13.38	0.553
	M3DDM [7]	767.4	0.579	0.447	0.519	14.43	0.542
	<b>Follow-Your-Canvas (Ours)</b>	<b>486.1</b>	<b>0.440</b>	<b>0.505</b>	<b>0.650</b>	<b>14.90</b>	<b>0.559</b>
$2048 \times 1152$ (2K, $9\times$ )	MOTIA [27]	928.6	0.587	0.419	0.629	12.45	0.524
	Dehan [6]	1302.1	0.707	0.394	0.607	11.40	0.501
	M3DDM [7]	1181.4	0.691	0.411	0.473	12.43	0.530
	<b>Follow-Your-Canvas (Ours)</b>	<b>735.3</b>	<b>0.573</b>	<b>0.472</b>	<b>0.657</b>	<b>12.72</b>	<b>0.535</b>



Figure 7. **Qualitative results.** The source video (the red dotted box) is outpainted from  $512 \times 512$  to  $2048 \times 1152$  (left) or  $1440 \times 810$  (right). Baseline methods suffer from blurry content, and spatial and temporal inconsistencies (yellow boxes).

Table 2. **Quantitative comparisons for low resolution video outpainting.** The source video with different aspect ratios is outpainted to  $256 \times 256$ . MOTIA is noted by gray because it is based on test sample-specific fine-tuning.

method	PSNR $\uparrow$	SSIM $\uparrow$	LPIPS $\downarrow$	FVD $\downarrow$
MOTIA [27]	20.36	0.758	0.159	286.3
Dehan [9]	17.96	0.627	0.233	363.1
SDM [9]	20.02	0.708	0.216	334.6
M3DDM [7]	20.26	0.708	0.203	300.0
<b>Follow-Your-Canvas (Ours)</b>	<b>20.80</b>	<b>0.726</b>	<b>0.160</b>	<b>242.8</b>

sign of spatial windows that outpaint within each window in its original/high resolution with a low content expansion ratio. Moreover, the layout alignment plays a crucial role in guiding the overall layout of the outpainting results.

### 4.3. Ablation Study

We conduct the ablation study by outpainting the source video from  $512 \times 512$  to  $1440 \times 810$ , as shown in Table 3. We find relative region embedding (RRE), layout encoder (LE), and layout extraction module are all important to achieve the best results. Compared to the popular CLIP encoder, we observe that the SAM encoder helps the model to further improve outpainting results. Visual results are shown in Fig 8.

## 5. Conclusion

Largely expanding an image/video is the core of the outpainting task. In this study, we take the first step towards exploring higher-resolution video outpainting with high content expansion ratios. We achieve this by introducing the spatial window strategy combined with the design of lay-



Figure 8. **Visual results of ablation study.** Layout encoder (LE) and relative region embedding (RRE) effectively guide the generation by providing information of the source video and its positional relation to the outpainting window respectively.

Table 3. **Ablation study.**

Method	PSNR↑	SSIM↑	LPIPS↓	FVD ↓
w/o LE & RRE	13.44	0.527	0.464	774.1
w/o LE	14.02	0.542	0.450	512.2
w/o RRE	13.63	0.532	0.458	670.3
w/o layout extraction	13.77	0.535	0.456	550.2
w/ CLIP image encoder	14.56	0.553	0.441	506.8
<b>Follow-Your-Canvas (ours)</b>	<b>14.90</b>	<b>0.559</b>	<b>0.440</b>	<b>486.1</b>

Table 4. **Run time (minutes).** Parallel inference for outpainting a video of  $512 \times 512$  resolution with 64 frames.

Resolution	1 GPU	2 GPUs	4 GPUs	8 GPUs
$1280 \times 720$	25.2	14.8	7.8	4.3
$1440 \times 810$	58.3	33.5	18.2	11.5
$2048 \times 1152$	85.8	51.9	28.9	16.2

out alignment. Our Follow-Your-Canvas method allows for large-scale video outpainting, e.g., from  $512 \times 512$  to  $1152 \times 2048$  ( $9\times$ ). We hope our work can pave the way for further progress in this promising direction and push this frontier.

**Limitations.** Although Follow-Your-Canvas has achieved great outpainting performance, it may have a longer inference time due to the spatial window strategy, as shown in Table 4. To reduce time consumption, we suggest users utilize multiple GPUs in parallel. Besides, we encourage further research to investigate techniques for improving inference speed.

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