The Diashow Paradox: Stronger 3D-Aware Representations Emerge from Image Sets, Not Videos

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Abstract

Image-based vision foundation models (VFMs) have demonstrated surprising 3D geometric awareness, despite no explicit 3D supervision or pre-training on multi-view data. While image-based models are widely adopted across a range of downstream tasks, video-based models have yet to share in this success. In this work, we conduct a comparative study of video models against image models on three tasks encapsulating 3D awareness: multi-view consistency, depth and surface normal estimation. To enable a fair and reproducible evaluation of both model families, we develop AnyProbe*, a unified framework for probing network representations. The results of our study reveal a surprising conclusion, which we refer to as* the diashow paradox. *Specifically, video-based pre-training offers no consistent advantage over image-based pre-training on downstream tasks involving 3D understanding. We formulate two hypotheses to explain our observations, which underscore the need for high-quality video datasets and highlight the inherent complexity of video-based pre-training. AnyProbe will be publicly released to streamline evaluation of image- and video-based VFMs in a mutually consistent fashion.*

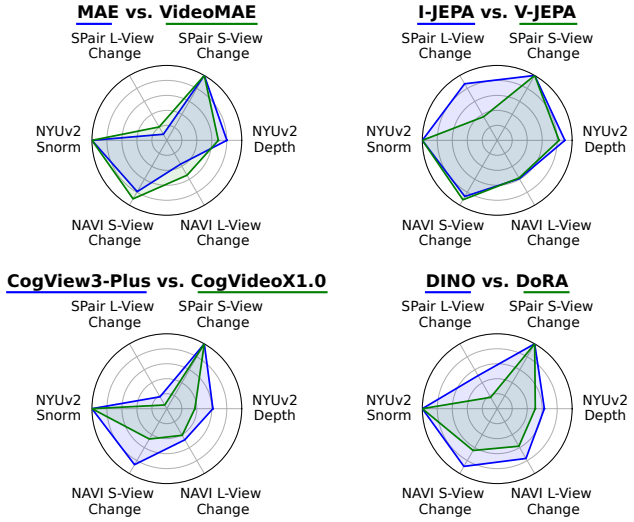

Figure 1. **The diashow paradox.** Streamlining the evaluation protocol, we develop *AnyProbe*, a framework to systematically compare video and image models on depth, surface normals (NYUv2 [26]), and multi-view correspondences [18, 23]. Contrary to a common-sense expectation, we find that video-based vision foundation models (green) do not provide a consistent advantage over image-based models (blue) on 3D awareness tasks.

1. Introduction

Vision foundation models (VFMs), such as DINO [7, 24], have found widespread use in the computer vision community [*e.g.* 31, 32]. Despite using image sets for training, these VFMs encode a surprising degree of 3D spatial reasoning [5]. By contrast, video models, such as V-JEPA [6] and VideoMAE [28], learn from image *sequences*, which can provide multiple views of the same scene. Therefore, it should naturally follow that video models will exhibit enhanced 3D awareness in comparison to the image-based VFMs. Consolidating the scattered empirical evidence in the literature [22, 33], we illuminate an apparent paradox encountered in practice: the representations learned by video models [6, 28] tend to exhibit *a lower level of 3D awareness* than their image-based counterparts.

We implement an evaluation framework, *AnyProbe*, which allows us to benchmark video- and image-based models in a shared unified protocol. Specifically, AnyProbe can train task-specific probes on top of frozen VFMs, including video-based models. In our study, we focus on three key tasks of 3D spatial awareness: monocular depth estimation, surface normal estimation, and multi-view correspondence. Our main contributions are:

- We develop *AnyProbe*, an evaluation framework designed to provide fair and reproducible comparisons of VFMs across diverse downstream tasks with a minimal engineering overhead. We release AnyProbe to the research community under the MIT license.[1]

[1] AnyProbe repository: https://github.com/tum-vision/anyprobe

- Using AnyProbe, we conduct a study to compare video models to image models on 3D awareness tasks. The results, illustrated in Fig. 1, lead to a surprising observation: video models do not provide a consistent advantage over their image-based counterparts on 3D understanding tasks. We dub this phenomenon as *the diashow paradox*, recognizing that state-of-the-art models currently learn from a "slideshow" of the visual world rather than a continuous video stream – in contrast to humans.
- Lastly, we propose two hypotheses to explain the observed results: *(i)* a lack of visual diversity in existing video datasets, and *(ii)* a deceptively high non-triviality of 3D-aware representation learning from videos.

The results of our study challenge the conventional understanding that using video training data per se implies improved 3D-aware representations in comparison to image-based pre-training. Our findings illuminate two open avenues for future research: curating high-quality video datasets and 3D-aware pre-training strategies on videos.

2. Related Work

Probing VFMs. Recent studies such as Probe3D [5], DepthCues [8], and Lexicon3D [22] compare visual foundation models on core spatial reasoning tasks, including depth estimation, surface normal prediction, multiview consistency, and 3D scene understanding. These works provide a foundation for our AnyProbe framework in assessing the geometric capabilities of VFMs. Specifically, our work considers the impact of video pre-training: we compare video- and image-based models with a similar architecture to isolate the effect of motion in pre-training on videos.

Image- and video-based foundation models. Image-based foundation models leverage large-scale datasets and self-supervised learning techniques to extract visual representations that transfer well across diverse downstream tasks. MAE [15] reconstructs masked image patches; I-JEPA [2] predicts latent codes for missing regions; and the DINO models [7, 24] leverage self-distillation with Vision Transformers for robust feature learning. These methods have naturally been adapted to video input: VideoMAE [28] applies masked auto-encoding to video sequences, V-JEPA and V-JEPA 2 [3, 6] adapt joint-embedding for spatio-temporal data, and DoRA [29], drawing inspiration from DINO, leverages object continuity to learn robust representations from long, unlabeled videos.

3. Methodology

We introduce AnyProbe, a unified foundation probing framework that enables systematic evaluation across diverse datasets, tasks, architectures, and probing protocols. For example, AnyProbe supports lightweight integration of video-based VFMs for monocular image tasks, allowing for a comparative analysis of image- and video-based models on 3D-awareness tasks.

Model	Data	Res.	Arch.
	Video		
VideoMAE [28]	K400, SSV2	224	B/16, L/16
V-JEPA [3, 6]	VM2M, VM22M	224, 384	H/16
DoRA [29]	WTours	224	S/16
CogvideoX [34]	Video-Text Pairs	768×1360	–
	Image		
MAE [15]	IN1K	224	B/16, L/16
I-JEPA [2]	IN1K, IN22K	224, 448	H/16, H/14
DINO [7]	IN1K, WTours	224	S/16
CogView-3Plus [35]	LAION-2B[25]	512	–

Table 1. **VFMs in our study.** Models are categorized by architecture (Arch.), training datasets (Data) and resolution (Res.).

Dataset	Content	Scenes	Frames
ImageNet-1K [10]	Natural object images	1.28M	1.28M
ImageNet-22K [10]	Fine-grained object images	14.2M	14.2M
VM2M [6]	Video datasets	2M	14B
VM22M [3]	Video + image datasets	22M	90B
WTours [29]	Egocentric city walk videos	10	3.5M
Kinetics-400 [19]	Human action clips	240K	71.8 M
SSV2 [13]	Object interaction videos	160K	19.4 M
LAION-2B [25]	Image–text pairs	2.26B	2.26B

Table 2. **Overview of pre-training datasets**. Each dataset is specified by its number of scenes and frames. For video datasets, frame counts are estimated based on the total duration and frame rate.

Model overview. Our study evaluates a diverse set of image- and video-based VFMs summarized in Tab. 1. We contextualize the models with statistics of the underlying training data in Tab. 2. We select official checkpoints and use comparable architectures and training strategies available for both input modalities, images and videos (*e.g.* I-JEPA [2] *vs.* V-JEPA [6]; MAE [15] *vs.* VideoMAE [28]).

Adapting video ViT models for image tasks. To fairly compare video to image models, we adapt video models for image tasks. The video models included in our study, V-JEPA [6] and VideoMAE [28], tokenize videos by embedding tubelets of size $T \times H \times W$ with a 3D convolution. To adapt these models for per-image processing, we define a 2D convolution kernel k_{2D}, which derives from its 3D counterpart k_{3D} by summing over the temporal dimension:

$$k_{\text{2D}}(i,j) = \sum_{t=1}^{T} k_{\text{3D}}(t,i,j). \tag{1}$$

This formulation is equivalent to the practice of duplicating the image along the temporal dimension [3], but is more computationally efficient. To adapt the 3D positional embedding, we use only the components of the first frame and discard the rest. As a result, video-based models retain their

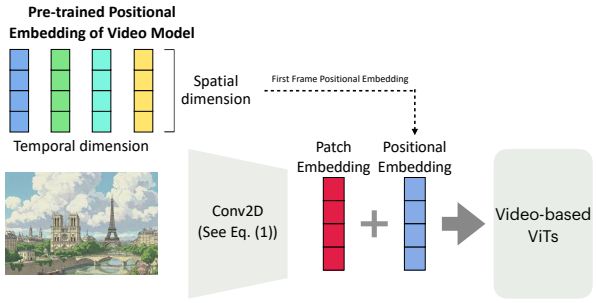

Figure 2. **Adapting video-based ViT models for image tasks**. We tokenize the image using a 2D patch-embedding convolution adapted for the video model (Eq. (1)), as in image ViTs, and use only the spatial positional embeddings of the first frame.

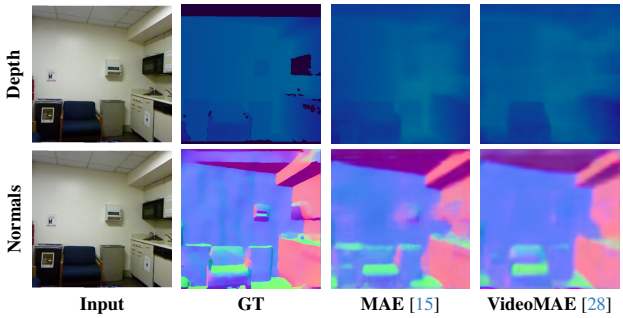

Figure 3. **Qualitative examples.** We visualize depth and surface normal maps derived from running AnyProbe with a DPT [36] head on frozen MAE and VideoMAE on NYUv2 [26]. MAE produces consistently sharper, more accurate geometry.

architecture, but can operate on image tasks without any computational overhead, as visualized in Fig. 2.

Depth and surface normal estimation. We extract pixel-level features and optimize a DPT probe [36]. For depth, we use a scale-invariant sigmoid depth loss [11] and a depth-gradient matching loss [16]; for normal estimation, we use an uncertainty-aware angular loss [4]. To ensure the fairness of our evaluation, we resize input images to the original pre-training resolution. This approach avoids interpolating the positional embedding, which we empirically confirmed to have a negative effect on the downstream accuracy. Instead, we downsample the input to the pre-training resolution. We resize the predicted maps produced by the DPT probe (depth or normals) to the original image size for evaluation. Specifically, we optimize the DPT probe for 10 epochs using AdamW [20] with an initial learning rate of $5e-4$, a cosine decay schedule [21] and batch size of 8.

Multi-view correspondence. We follow the previous metrics and protocols for evaluating multi-view correspondence [5], with adaptations for video models, as shown in Fig. 2. We compute the recall, the fraction of the matches with an error below a threshold. Given two views of the same object or scene, we extract dense feature maps from a frozen backbone and establish feature correspondences based on their cosine similarity. We consider two evaluation scenarios. **SPair-71k** [23] provides class-level keypoints on object instances. We evaluate only the annotated points and perform a single nearest-neighbor lookup in feature space. We calculate 2D pixel-level error in normalized image coordinates and report the aggregate recall at threshold 0.10. We further break down the recall by a relative change in viewpoint levels $d \in \{0, 1, 2\}$ (with $d = 0$ indicating small and $d = 2$ indicating large view change). **NAVI** [18] samples dense points on the object mask. We extract dense features, perform nearest-neighbor matching with Lowe's ratio test [5], and retain the top 1000 correspondences. We then compute the 3D Euclidean error between each match and its ground-truth back-projected point, and report the recall at a fixed 2cm threshold, grouped by relative viewpoint bins $\theta \in \{[0, 30), [30, 60), [60, 90), [90, 120]\}$.

4. Experiments

We use NYUv2 [26] for our experiments with depth and surface normal estimation. For multi-view correspondence, we use SPair-71k [23] and NAVI [18]. We rely on AnyProbe to obtain the results, summarized in Tab. 3. Notably, DINOv2 [24], provided for reference, surpasses all video models in both single-image estimation and multi-view consistency. Comparing video and image models with the same architecture, we make the following observations:

I. VideoMAE [28] exhibits higher multi-view consistency than MAE [15], but inferior accuracy of depth and surface normals. Within the autoencoder family, MAE consistently outperforms VideoMAE [28] across all architectures in depth and surface normal estimation, achieving lower RMSE scores on ViT-L16 (0.277 *vs.* 0.323 RMSE for depth; 24.79 *vs.* 26.53 RMSE for normals). The results with ViT-B16 align with these trends. While VideoMAE shows improved multi-view consistency over MAE, this advantage is rather marginal: DINO [7] outperforms both MAE variants substantially on both SPair-71k and NAVI.

II. V-JEPA [6] and its sequel V-JEPA 2 [3] yield inferior accuracy than their image-based counterpart, I-JEPA [2], across all benchmarks. Specifically, I-JEPA models (H16/H14) significantly outperform V-JEPA-H16 and V-JEPA 2 in view consistency on SPairs-71k, achieving the average recall of 44.81/35.74 *vs.* 25.13/28.4, respectively.

III. An image model, DINO [7], pre-trained on videos is only marginally worse than a video model, DoRA [29]. However, a DINO model pre-trained on IN1K consistently outperforms DoRA pre-trained on the World Tours dataset in terms of depth (0.353 *vs.* 0.437 RSME), surface normals (28.49 *vs.* 31.60 RSME), and multi-view consistency (*e.g.* 25.66 *vs.* 11.36 recall on SPairs-71k).

Arch	Model	Dataset	Res.	SPair-71k ↑				NAVI ↑				NYUv2 ↓	
				$d=0$	$d=1$	$d=2$	all	θ^{0}_{30}	θ^{30}_{60}	θ^{60}_{90}	θ^{90}_{120}	Depth RMSE	Snorm RMSE
B14	DINOv2	LVD-142M	518x518	62.55	51.40	48.79	56.26	94.27	69.04	39.65	25.85	0.222	24.79
B16	DINO	IN1K	224x224	28.83	24.40	24.90	26.10	86.33	55.79	30.65	22.69	0.334	28.01
	MAE	IN1K	224x224	9.60	6.24	4.91	7.92	76.91	40.15	19.68	11.96	**0.317**	**25.95**
	VideoMAE	K400	224x224	8.98	**6.45**	**5.47**	7.73	88.32	**48.32**	**20.38**	**11.58**	0.384	28.37
	VideoMAE	SSV2	224x224	**13.03**	6.21	4.21	**10.03**	**89.14**	46.69	19.56	11.10	0.413	29.17
L16	MAE	IN1K	224x224	8.22	6.00	4.57	7.17	74.58	37.92	14.55	11.39	**0.277**	**24.79**
	VideoMAE	K400	224x224	**20.11**	**12.68**	**10.07**	**16.51**	**85.02**	**49.72**	**21.32**	**12.12**	0.323	26.53
H16	I-JEPA	IN1K	448x448	**51.35**	**38.47**	**42.52**	**44.81**	81.58	**52.57**	**27.42**	**17.72**	**0.246**	**23.43**
	V-JEPA	VM2M	224x224	29.00	17.47	17.75	23.34	**86.39**	52.56	23.03	13.79	0.269	26.09
	V-JEPA	VM2M	384x384	30.92	18.74	19.60	25.13	77.19	45.41	21.23	15.03	0.270	24.88
	V-JEPA 2	VM22M	224x224	32.48	25.78	24.46	28.40	76.01	48.11	23.12	13.15	0.259	25.05
H14	I-JEPA	IN22K	224x224	**43.18**	**31.28**	32.12	**37.45**	**83.07**	**49.84**	23.89	**14.88**	**0.294**	**25.64**
	I-JEPA	IN1K	224x224	40.48	30.79	**32.75**	35.74	82.51	49.73	**24.99**	14.83	0.329	27.69
S16	DINO	IN1K	224x224	**27.97**	**24.32**	**24.88**	**25.66**	**83.85**	**53.77**	**30.42**	**22.46**	**0.353**	**28.49**
	DINO	WTours	224x224	8.98	9.05	6.63	8.41	54.76	32.75	21.51	14.81	0.477	33.70
	DoRA	WTours	224x224	12.45	10.28	8.55	11.36	60.74	36.71	22.93	16.37	0.437	31.60
3B	CogView-3Plus	LAION-2B	512x512	**20.02**	**12.04**	**8.95**	**15.91**	**81.34**	**45.66**	**19.02**	10.31	**0.361**	**29.32**
2B	CogVideoX1.0	Video-Text Pairs	768x1360	3.17	2.93	2.77	3.05	44.08	28.27	16.26	**11.54**	0.594	34.47

Table 3. **Image *vs.* video comparison on 3D awareness.** We evaluate all models with AnyProbe, which extracts features for multi-view correspondence and train a DPT probe for depth and surface normal estimation. For multi-view consistency, we use SPair-71k (200 keypoints) and NAVI (1000 keypoints) and report recall (*cf*. Sec. 3). We use NYUv2 for depth and surface normal estimation and report RMSE. Across most architectures, image-based models (highlighted in blue) consistently outperform their video counterparts on 3D tasks. The image-based DINOv2 achieves the best overall results.

IV. An image-based diffusion model, CogView-3Plus [35], substantially outperforms its video-based counterpart, CogVideoX [34]. Consolidating previous observations, we test text-to-image diffusion models, CogView-3Plus and CogVideoX. The video-based CogVideoX shows diminished 3D awareness compared to image pre-training across all metrics, despite sharing similarities in the architecture and the pre-training scheme.

5. Discussion and Conclusion

Our findings highlight an apparent paradox, referred to as *the diashow paradox*. Contrary to the prevailing belief, learning from image sets, not videos, appears to yield more 3D-aware representations. Our study supports this postulation with empirical evidence: VFMs trained on static images consistently match or exceed their video-based counterparts in geometric 3D-awareness tasks (*cf*. Tab. 3). We discuss two hypotheses to explain our observations:

Existing video datasets lack visual diversity. Deep models benefit from data diversity and size. The temporal continuity inherent to videos renders image sequences highly redundant. More technically, the gradients in video pre-training exhibit high correlation [14]. Recall from Tab. 3 that DINO trained on Walking Tours (a few, but long videos) performs significantly worse than its IN1K variant across all metrics. Furthermore, existing video datasets are known to contain low-resolution sequences and compression artifacts. While a "golden bullet" dataset exists for image pre-training (ImageNet) [17], we may have yet to curate such a dataset for the video modality. However, the same curation effort would apply to image sets as well. Amassing diverse image sets may still prove more cost-efficient than curating videos in the long term.

Learning 3D-aware representations from videos is deceptively non-trivial. The photographic bias leveraged by self-supervised methods on image datasets [7, 15] might be less prominent in videos, where strong frame-to-frame correlations and camera motion introduce additional challenges [9, 12, 14, 30]. Consequently, learning multi-view consistency and geometric priors from videos becomes a highly non-trivial task (*e.g*. V-JEPA 2 lacks I-JEPA's multi-view robustness despite larger-scale pre-training).

Perhaps as a consequence of the task complexity, a typical evaluation protocol of video models is rarely a 3D-aware task, favoring instead other spatio-temporal benchmarks, such as action recognition and anticipation [*e.g*. 3]. We hope that AnyProbe will encourage more comprehensive evaluation of future video models, including 3D awareness tasks, by simplifying the engineering effort of probing experiments and streamlining cross-modal comparison.

Conclusion. Systematically comparing video to image models, our study exposes *the diashow paradox*: image sets yield surprisingly more 3D-aware representations than videos. By highlighting the paradox, we hope to incentivize the community in future explorations of video curation, and 3D-aware training and evaluation of video-based models.

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