Structure-Aware Manipulation of Images and Videos

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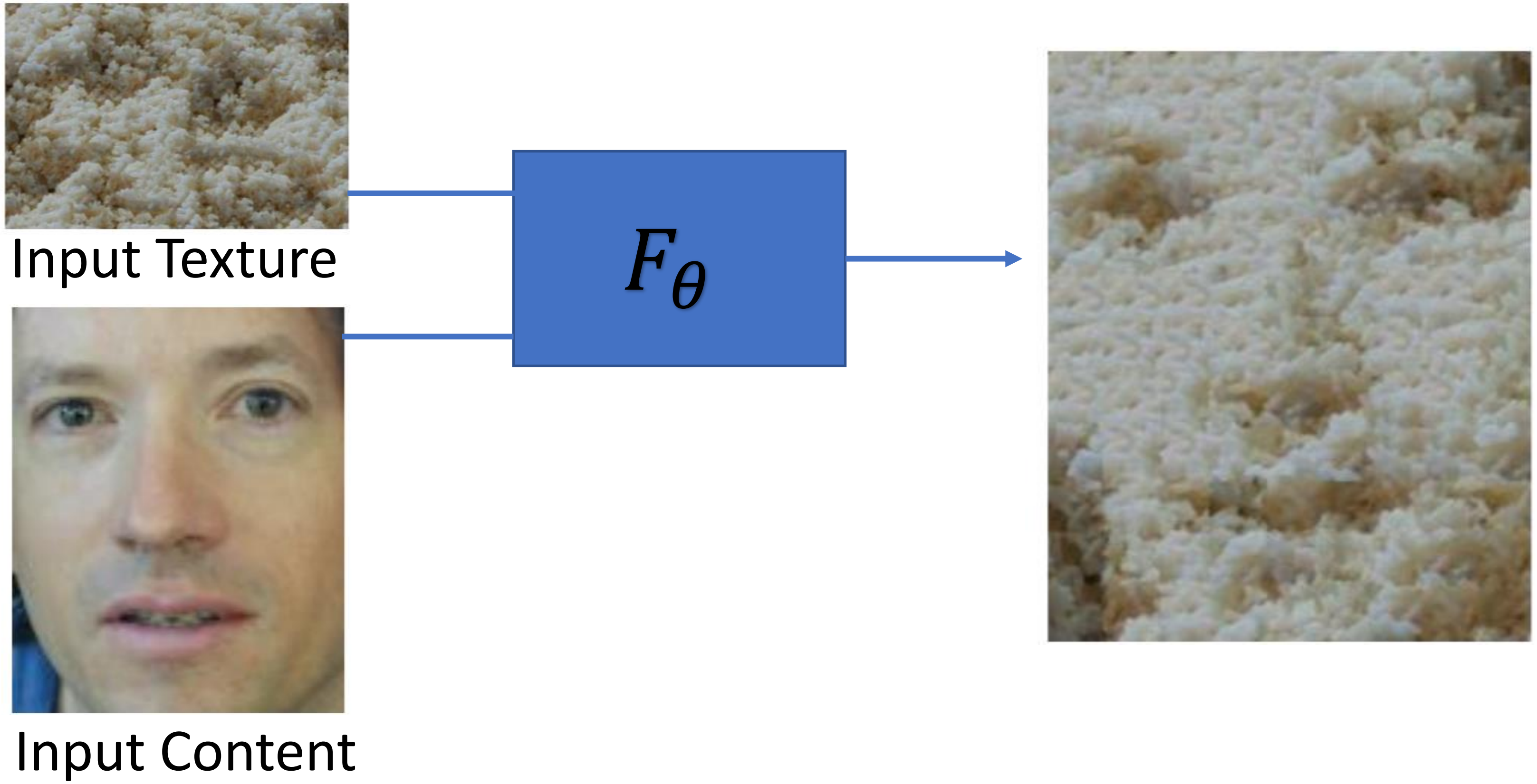
What is a natural image?

Intelligent machines must **understand** perceived content

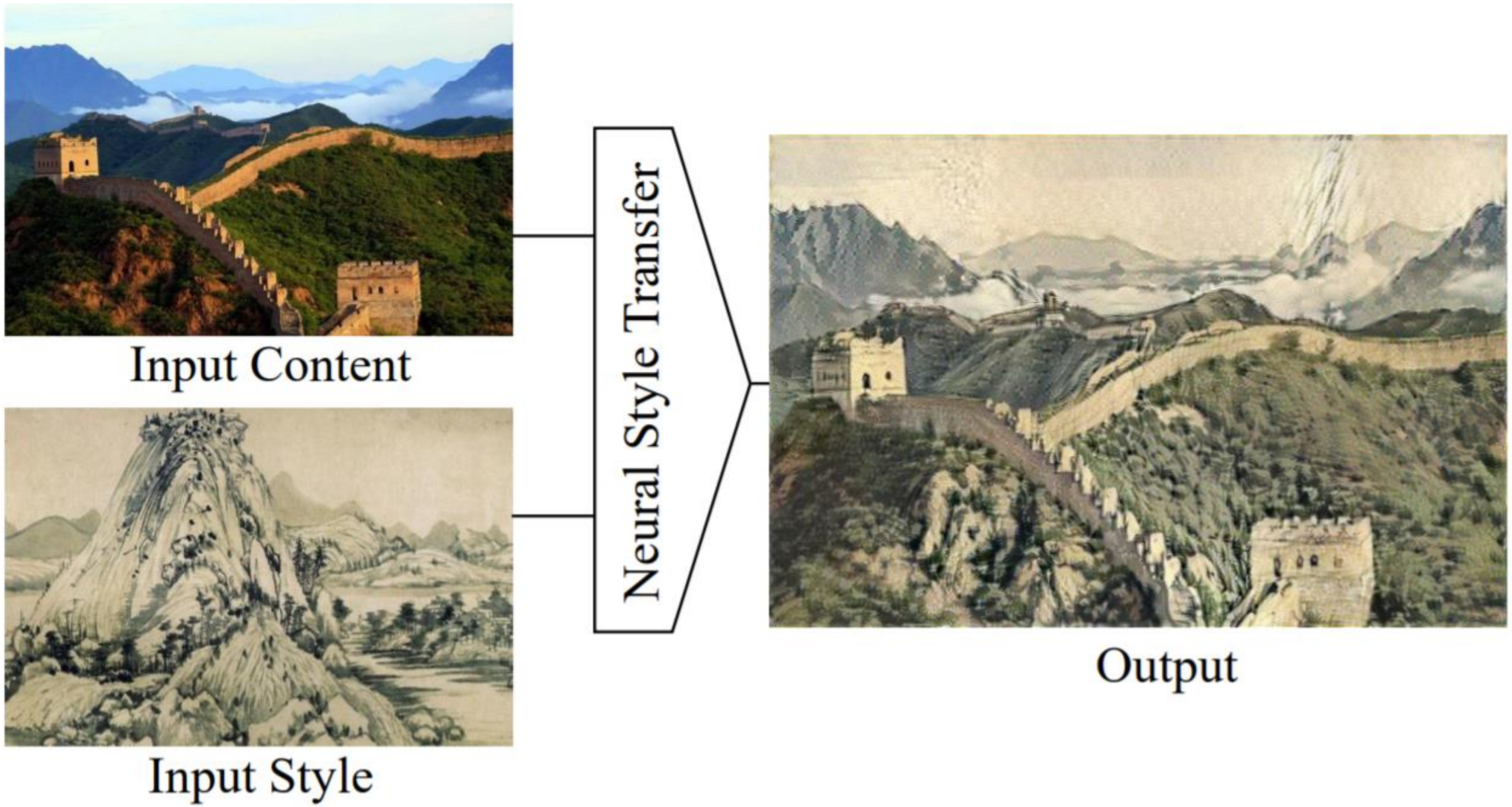
Understanding by creating/manipulating: "What I cannot create, I do not understand" (Richard Feynman)

Manipulating Texture



A.A.Efros, W.T.Freeman. “Image Quilting for Texture Synthesis and Transfer”. SIGGRAPH01

Manipulating Style

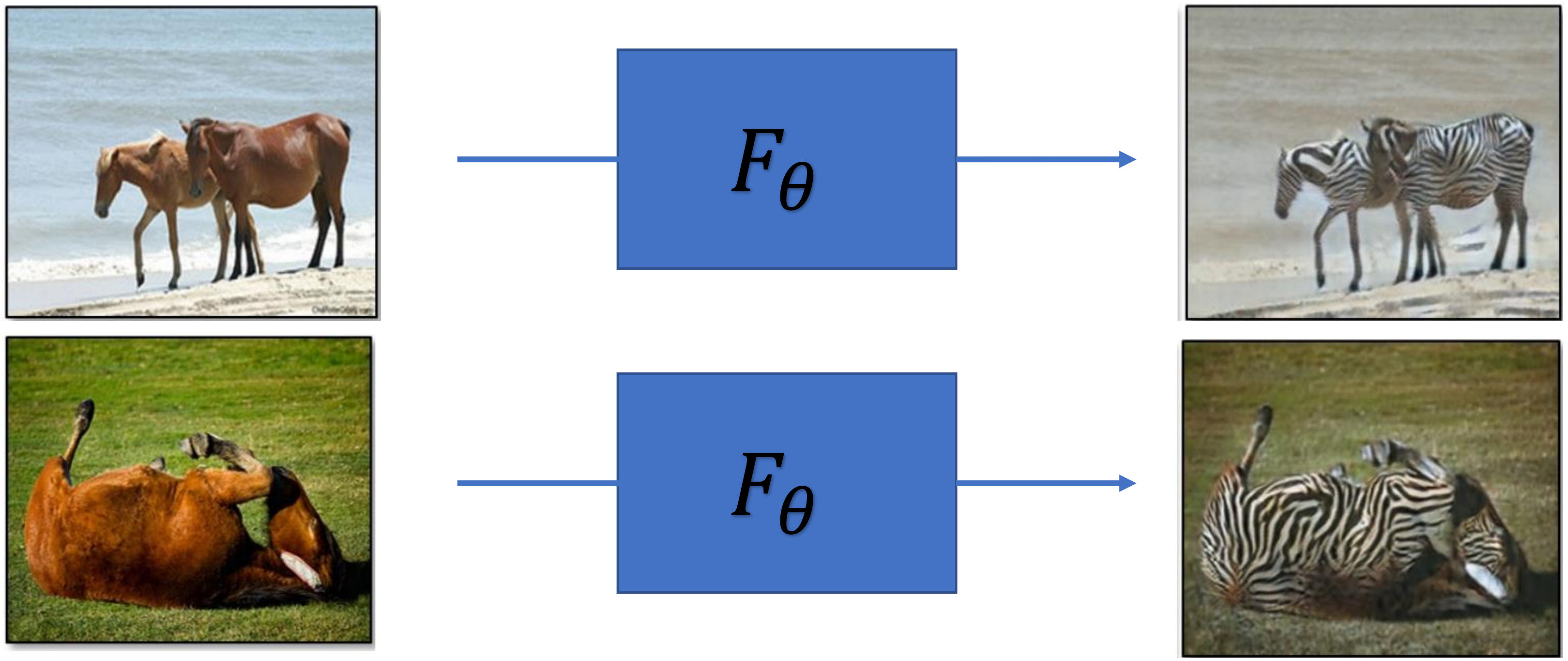


L. A. Gatys, A. S. Ecker, and M. Bethge. “A neural algorithm of artistic style”. 2015.

Image to Image Translation

1. $\mathrm{F}_\theta(\mathrm{x})$ preserves the **structure** of objects of x
2. $\mathrm{F}_\theta(\mathrm{x})$ belongs to Y's distribution (changes **style**)

$x \in X$ $F_\theta(x) \in Y$

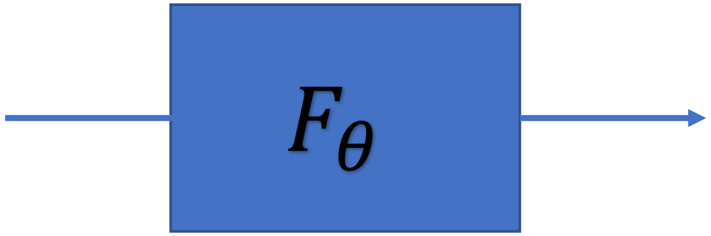


CycleGAN, Zhu et al., ICCV 2017
DistanceGAN, Benaim at al., NeurIPS 2017
MUNIT, Huang et al., ECCV 2018
Many more…

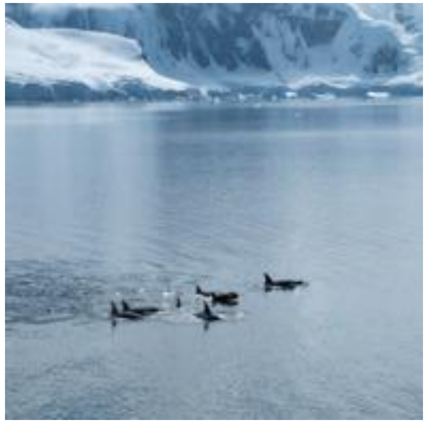
Manipulating Structure

Target

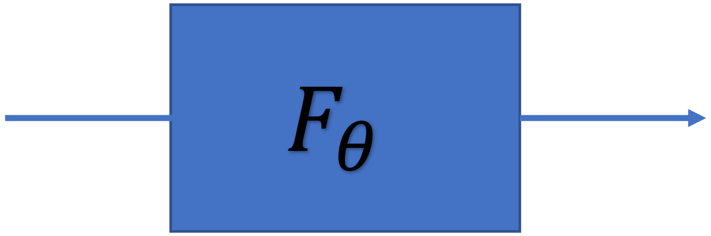
Source Structure

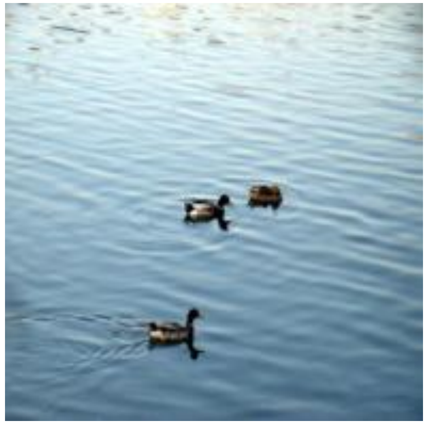


Manipulating Structure



Target





Source Structure

Applications

Architecture

Video games

Movies

Advertising

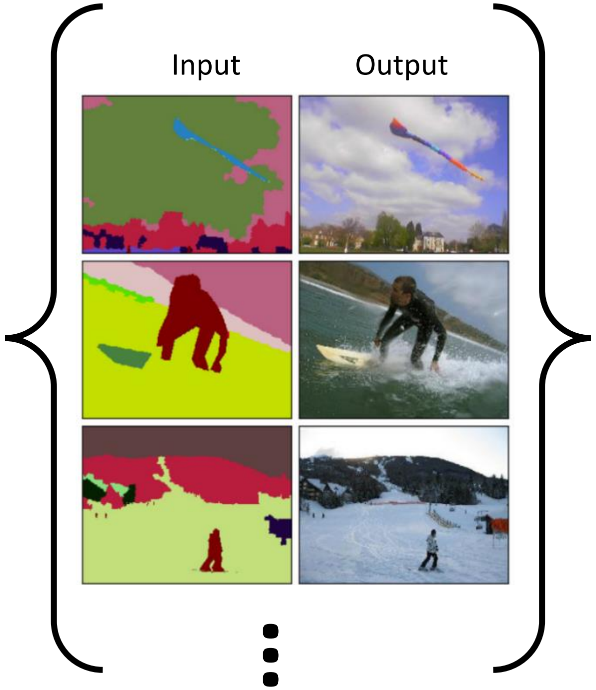
AR/VR

Autonomous Driving Simulations

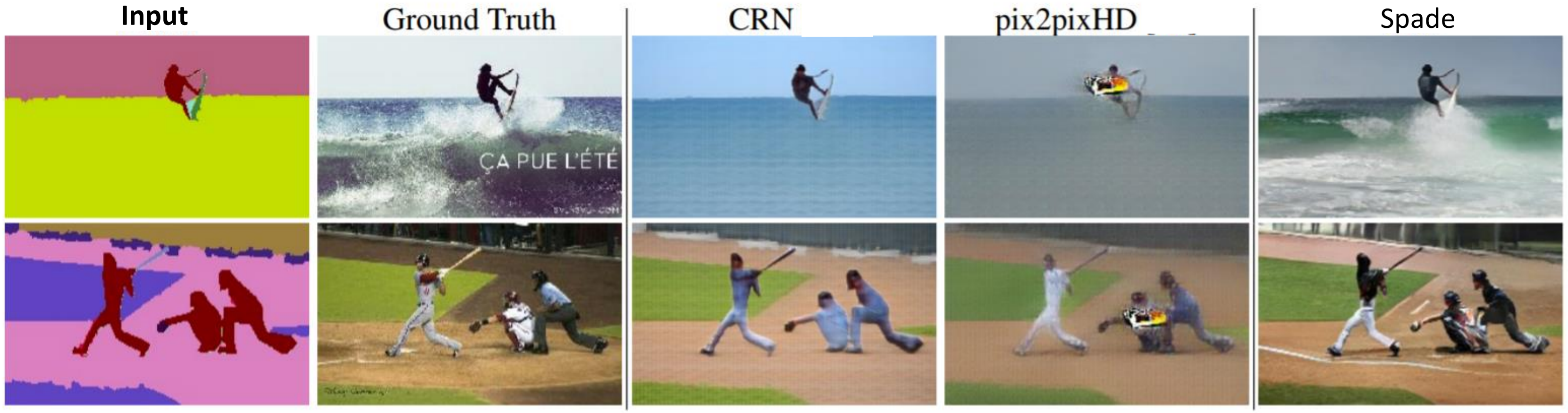
Multi-Image Approaches

Supervised (Paired) Setting

Train



Test



Unsupervised (Unpaired) Setting

A

Faces <u>without</u> glasses

B

Faces with glasses

Control Structure of Generated Faces (Transfer Glasses)

Domain Intersection and Domain Difference

S. Benaim, M. Khaitov, T. Galanti, L. Wolf. ICCV 2019.

Given two visual domains, disentangle the **separate (domain specific)** information and **common (domain invariant)** information.

See also: Emerging Disentanglement in Auto-Encoder BasedUnsupervised Image Content Transfer. ICLR 2019.
O. Press, T. Galanti, **S. Benaim**, L. Wolf

Unsupervised Content Transfer

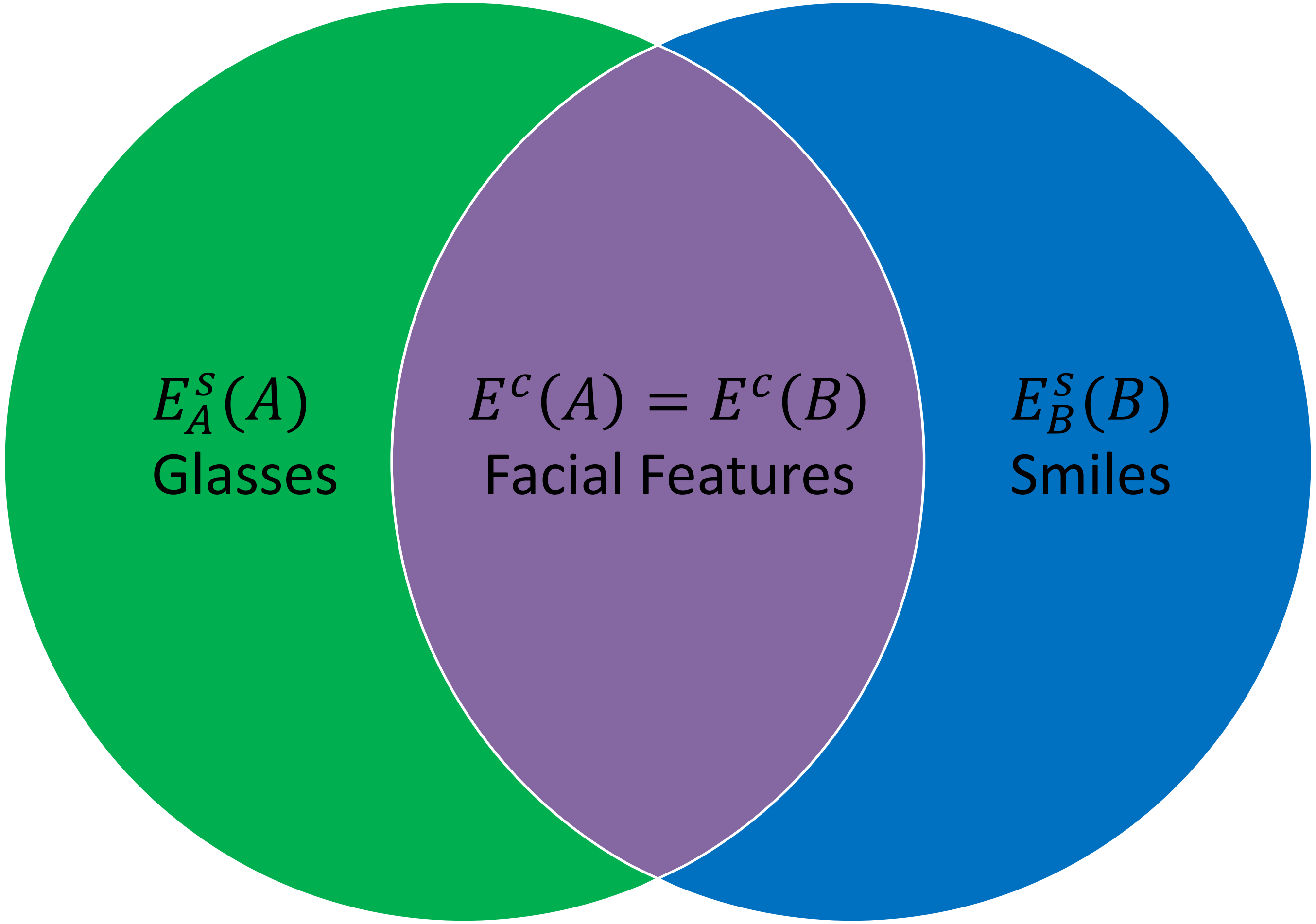
A

Non-smiling faces with glasses

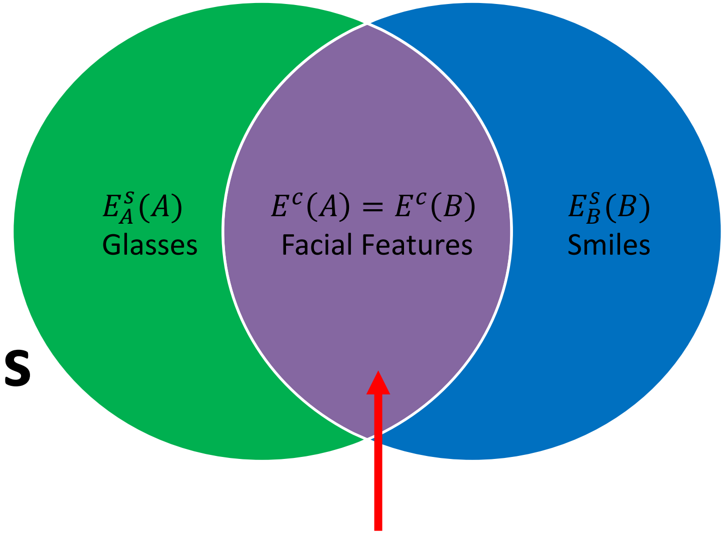
B

Smiling faces without glasses

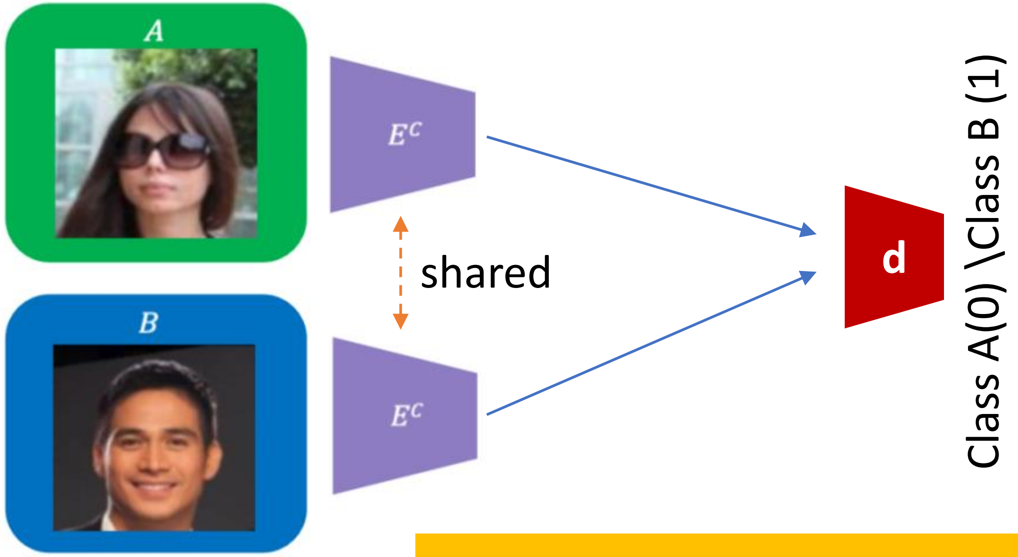
1. "Common" latent space, $E^c(A) = E^c(B)$. The space of **common facial features.**
2. "Separate" latent space for domain A, $E_A^s(A)$. The **space of glasses.**
3. "Separate" latent space for domain B, $E_B^s(B)$. The **space of smiles.**



The "common" Loss



Ensures E_c encodes information common to both domains



Discriminator d attempts to separate distributions (classify to correct label):

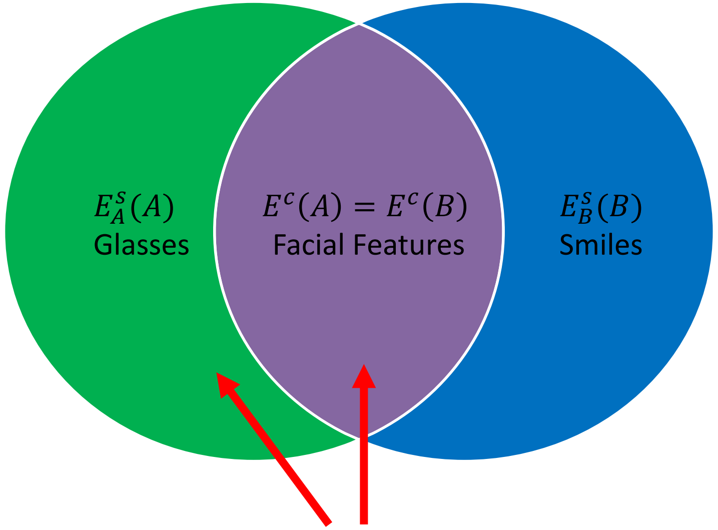
$$\frac{1}{m_1}\sum_{i=1}^{m_1} l(d(E^c(a_i)),0) + \frac{1}{m_2}\sum_{j=1}^{m_2} l(d(E^c(b_j)),1)$$

Encoder E_c attempts to match distributions of $E_c(A)$ and $E_c(B)$:

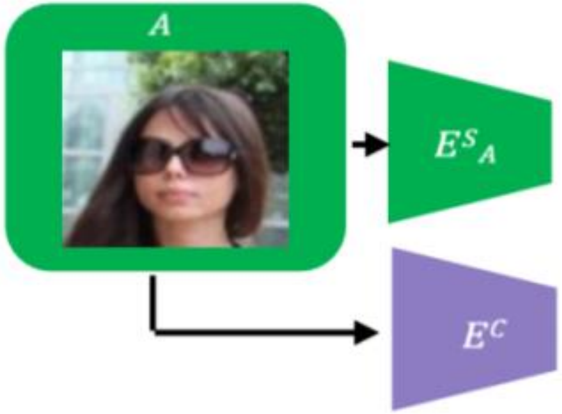
$$\frac{1}{m_1}\sum_{i=1}^{m_1} l(d(E^c(a_i)),1) + \frac{1}{m_2}\sum_{j=1}^{m_2} l(d(E^c(b_j)),1)$$

d can encode zero information

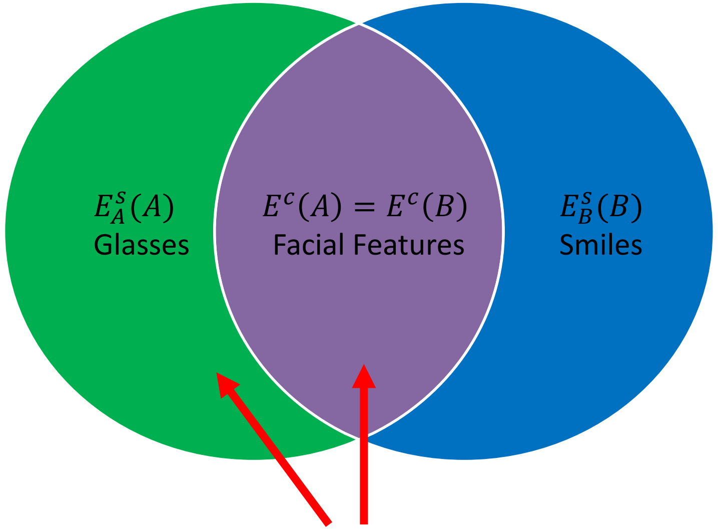
Reconstruction Losses



Ensures the "common" and "separate" encodings contain all the information in A



Reconstruction Losses



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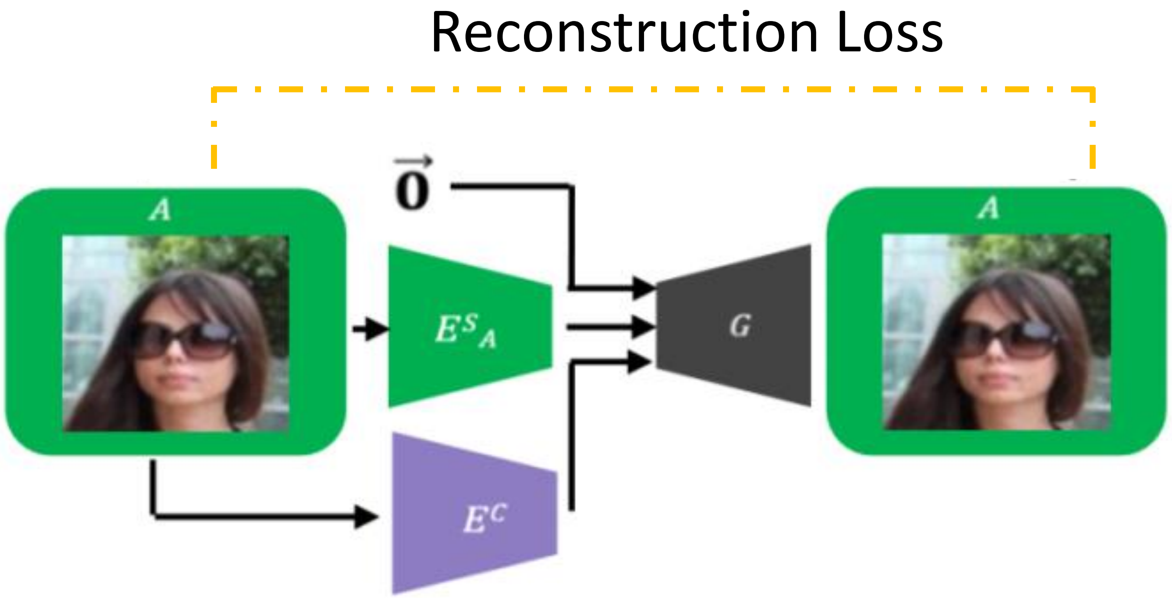
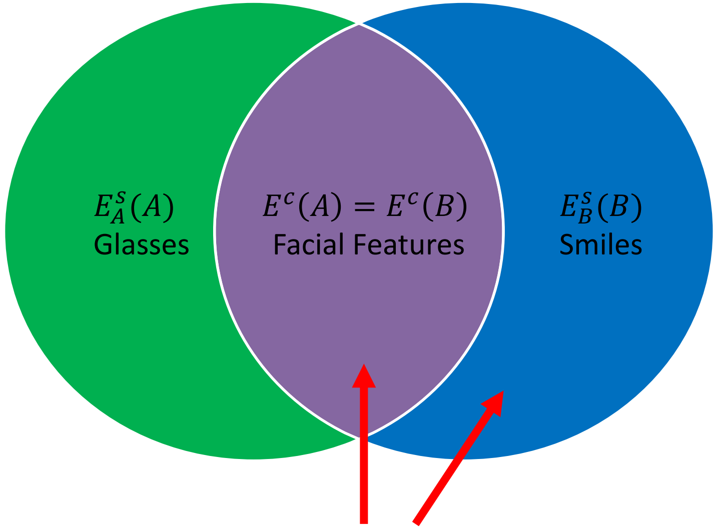
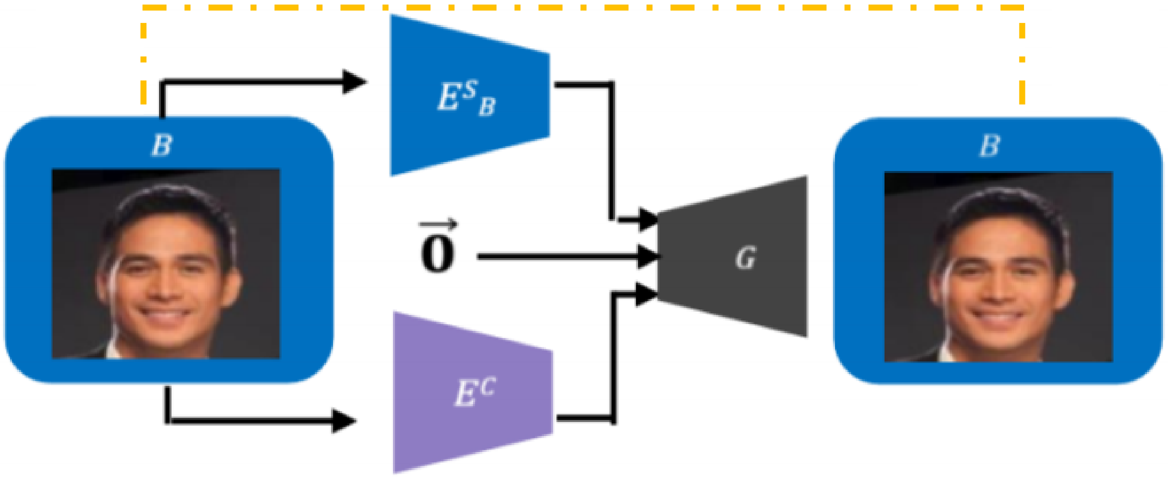


Reconstruction Losses

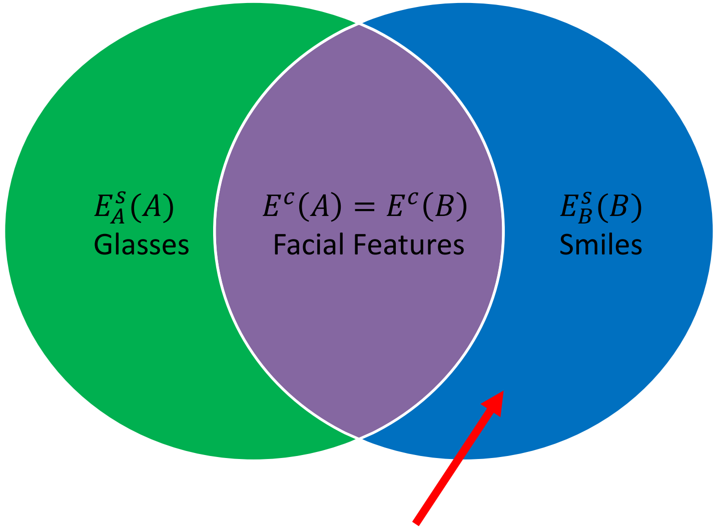


Ensures the "common" and "separate" encodings contain all the information in A



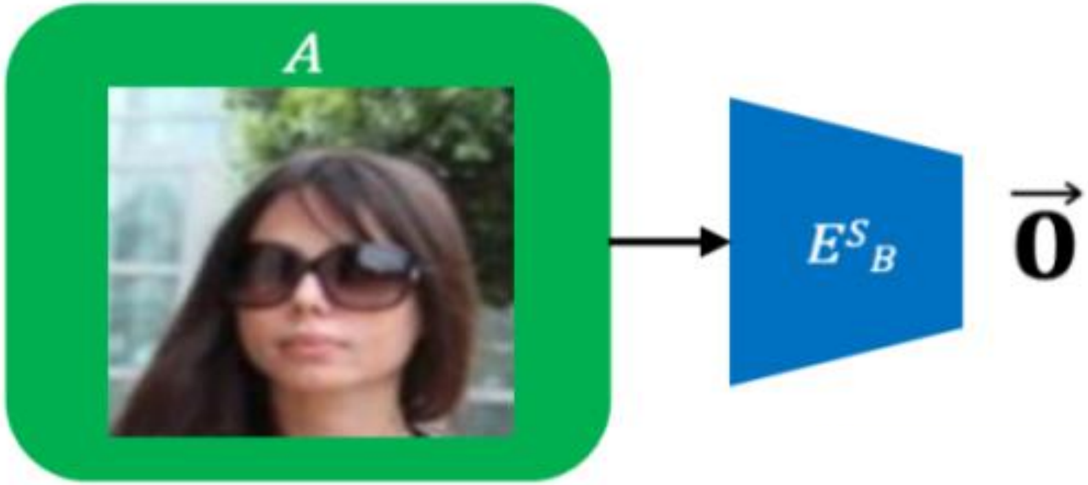
E_A^S (E_B^S)can encode all the information of A (B)

"Zero" Loss

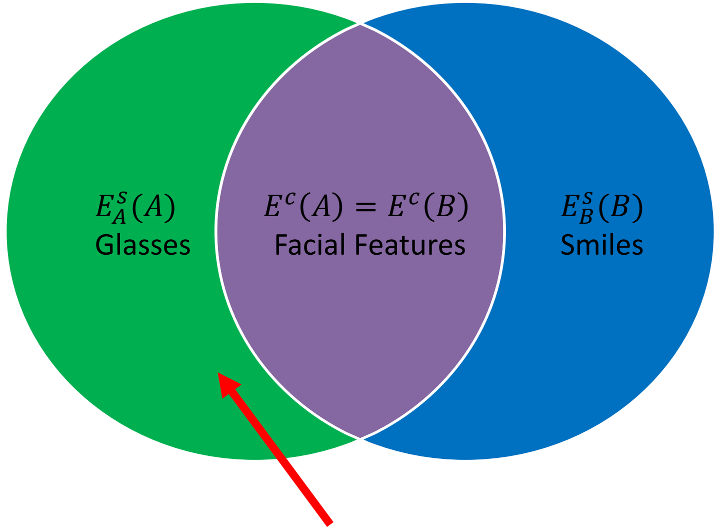


Ensures the separate encoder of B does not encode information about A

$$\mathcal{L}_{zero}^{B} := \frac{1}{m_1} \sum_{i=1}^{m_1} \| E_B^s(a_i) \|_1$$

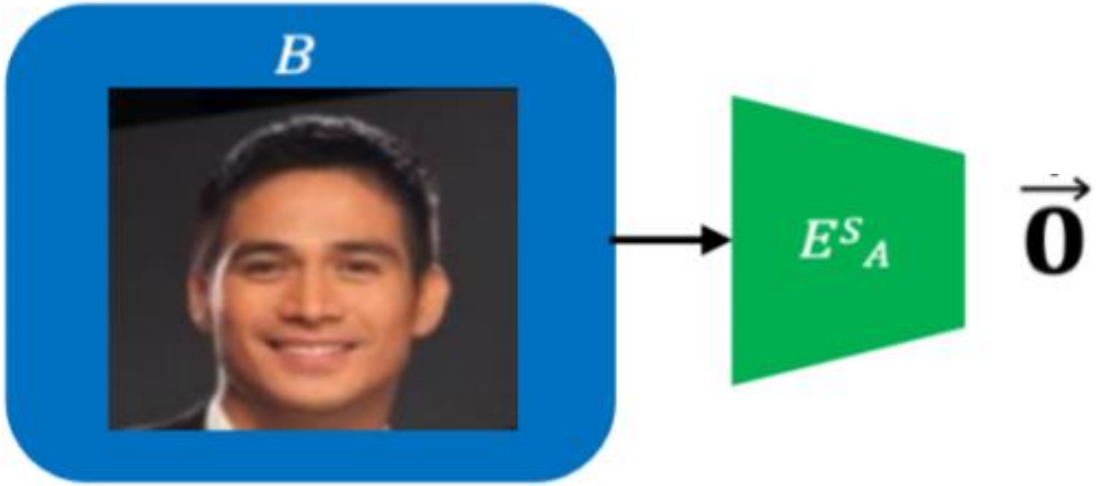


"Zero" Loss



Ensures the separate encoder of B does not encode information about A

$$\mathcal{L}_{zero}^{A} := \frac{1}{m_2} \sum_{j=1}^{m_2} \|E_A^s(b_j)\|_1$$



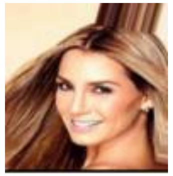
$$G\left(\mathrm{E}_c(c), E_A^S(a), E_B^S(b)\right) \longrightarrow$$

c's face
a's glasses
b's smile

<u>c's face</u> **<u>a's glasses</u>** **<u>b's smile</u>**

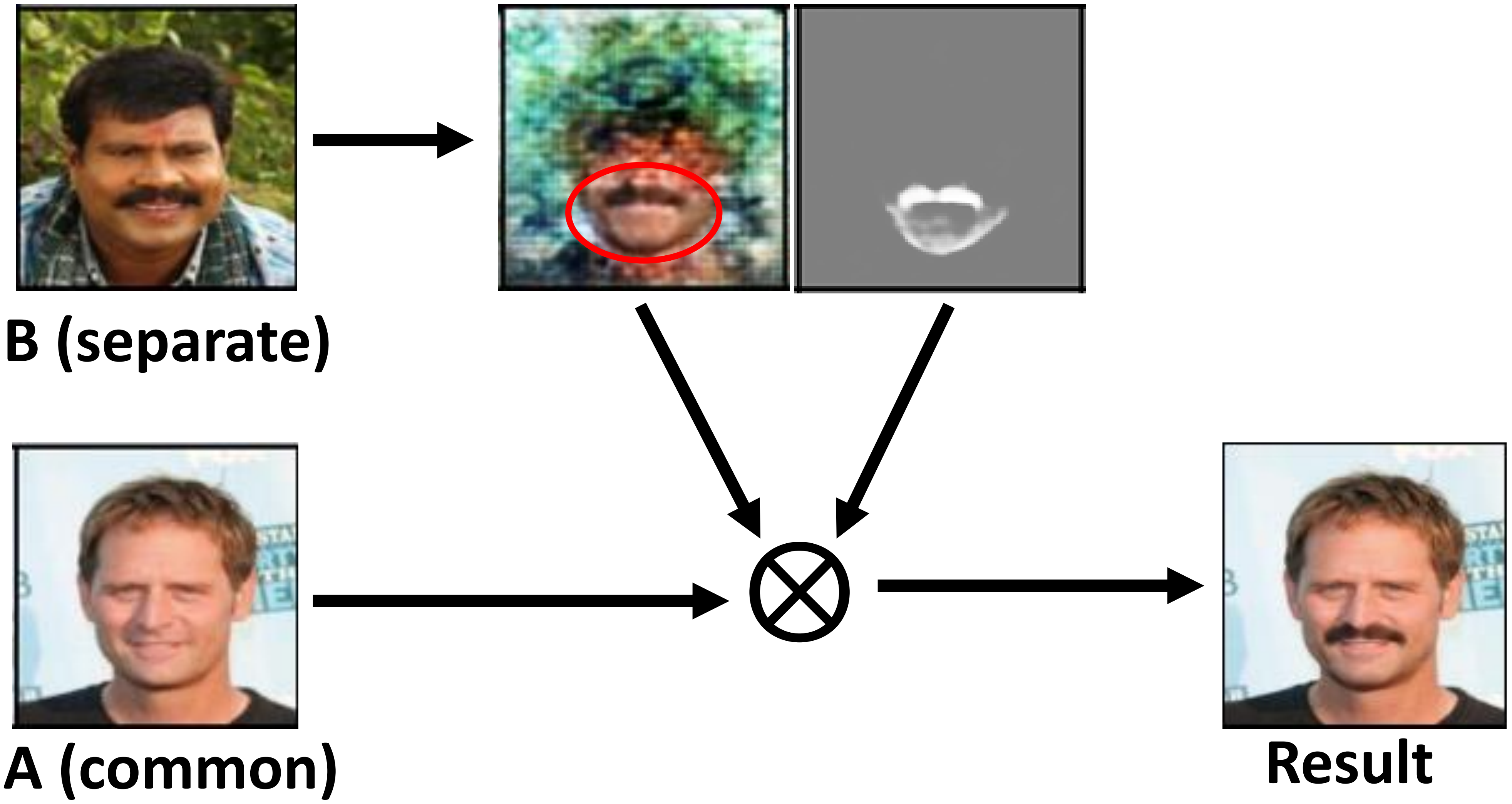
$G(\mathrm{E}_c($  $), E_A^S($  $), 0\ ) \longrightarrow$ 

$G(\mathrm{E}_c($  $), E_A^S($  $), 0\ ) \longrightarrow$ 

$G(\mathrm{E}_c($  $), E_A^S($  $), 0\ ) \longrightarrow$ 

Masked Based Unsupervised Content Transfer

R. Mokady, **S. Benaim**, L. Wolf, A. Bermano. ICLR 2020.



Common
Source
Glasses
Separate

Two Attributes

Attribute removal

Input **Result**

Facial Hair Removal

Input **Result**

Smile Removal

Out of Domain Manipulation

Weakly-Supervised Segmentation

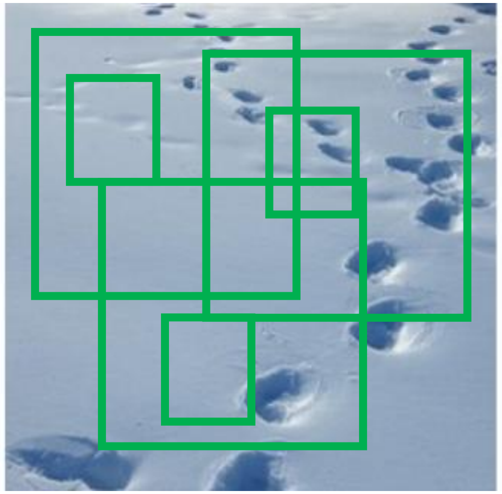
Table 5: Mean and SD IoU for the two hair segmentation benchmarks.

Method	Women's hair	Men's hair
Ours	0.77± 0.15	0.77 ± 0.13
Press et al.	0.67± 0.13	0.58 ± 0.11
Ahn & Kwak.	0.54± 0.10	0.52 ± 0.10
CAM	0.43± 0.09	0.56 ± 0.07

Patch-Based Approaches

Multi-Image Distribution

Multi-Scale Patch Distribution

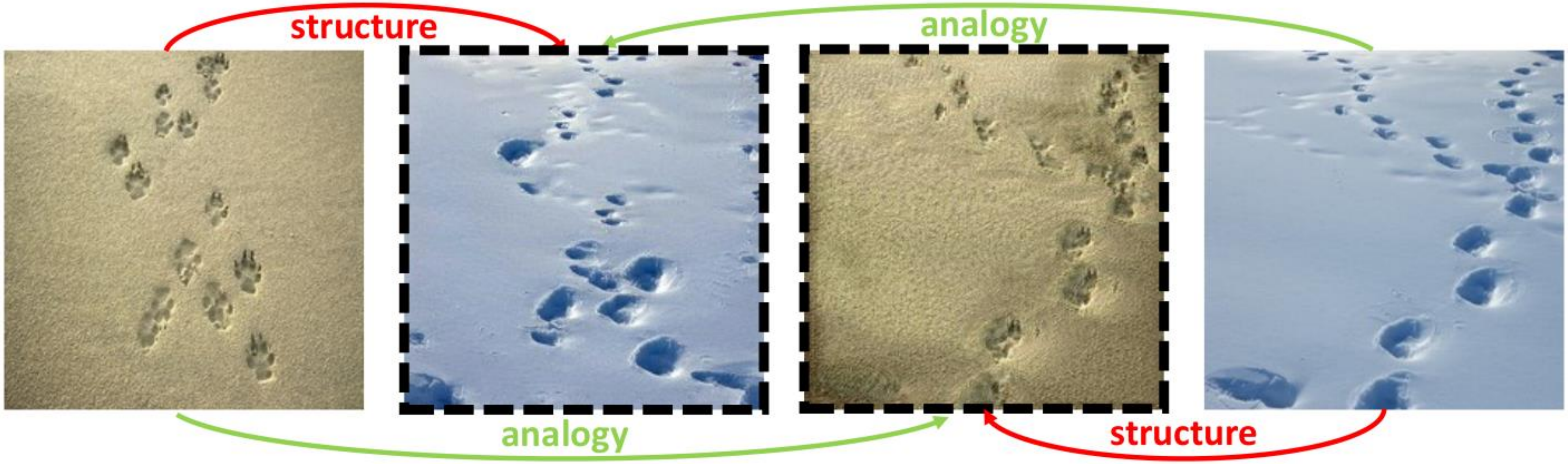


Karras et al., A Style-Based Generator Architecture for Generative Adversarial Networks. CVPR 2019

Structural-analogy from a **Single Image Pair**

S. Benaim*, R. Mokady*, A. Bermano, D Cohen-Or, L. Wolf. CGF 2020. (*Equal contribution)

Generate an image which is **aligned to the source** image but depicts **structure from a target image**



Structural Analogy

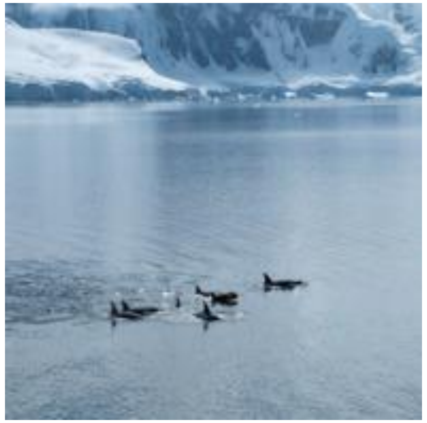
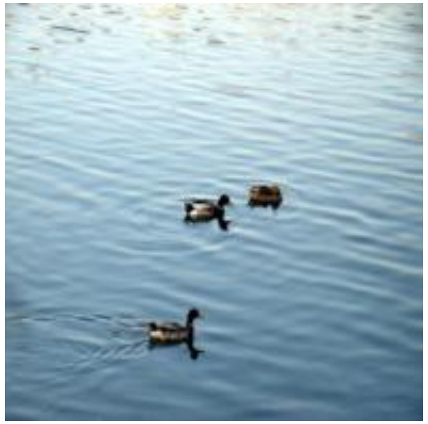
Target

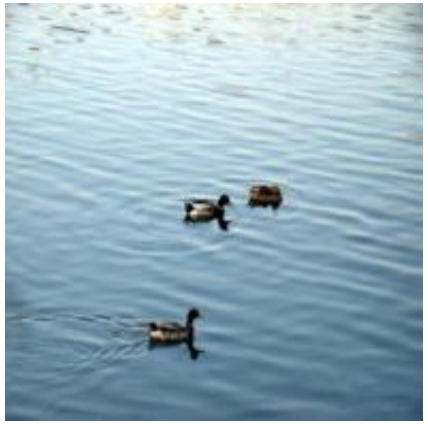
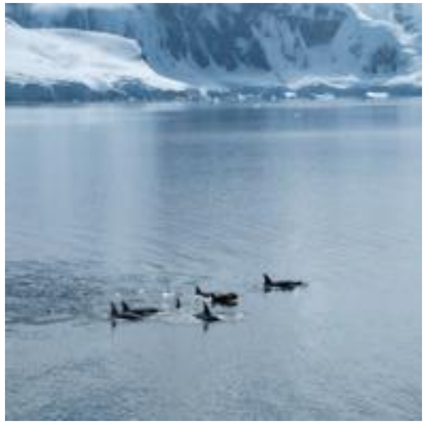
Source

Output

Structural Analogy

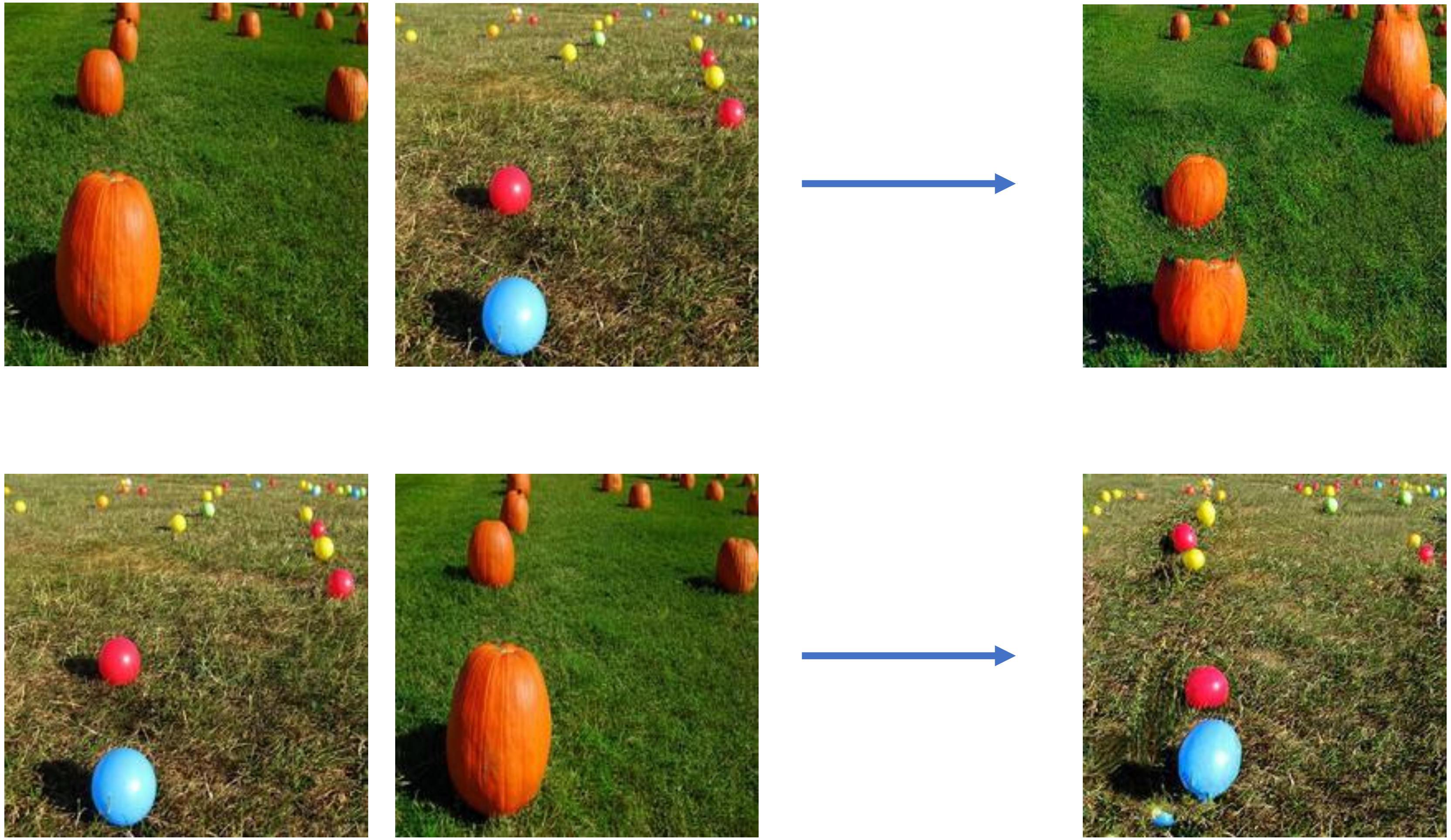
Target Source Output


Structural Analogy

Target Source Output



Style Transfer

Style

Content

Result

Deep Image Analogy

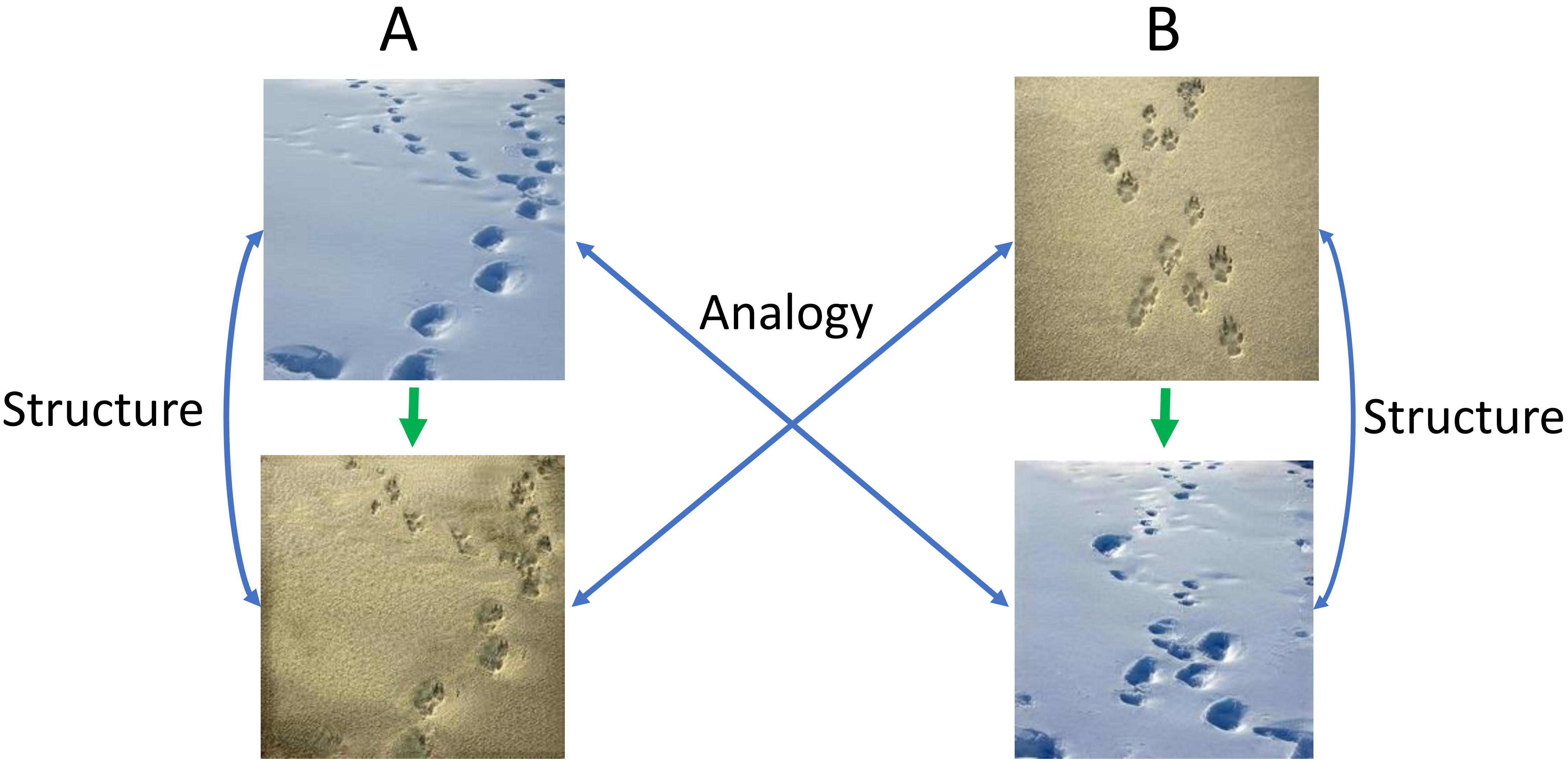
Style

Content

Result

Cannot Change Object Shape

Structural Analogy



Motivation

A

B

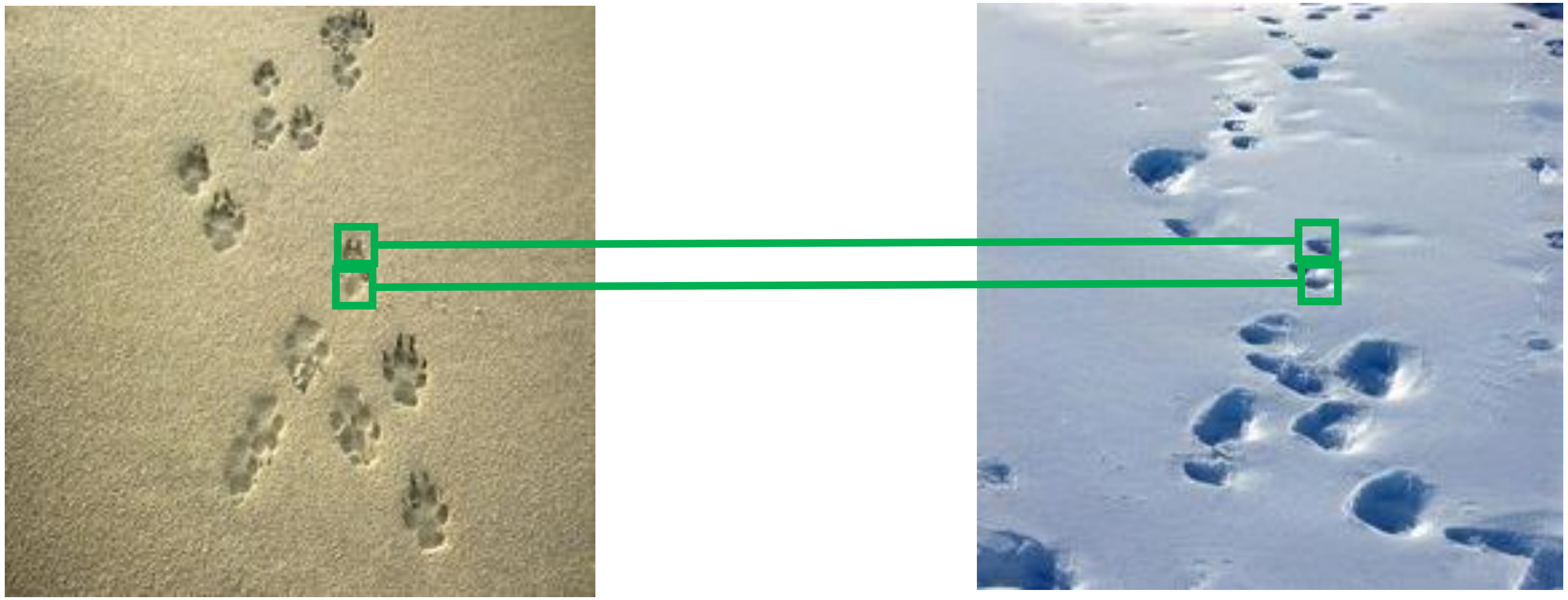
Motivation

A B

Motivation

A

B



Proposed Hierarchical Approach

Coarsest scale:
Large Patches

$\bar{a}^{0}$(Unconditional)
$\overline{ab}^{0}$(Conditional)

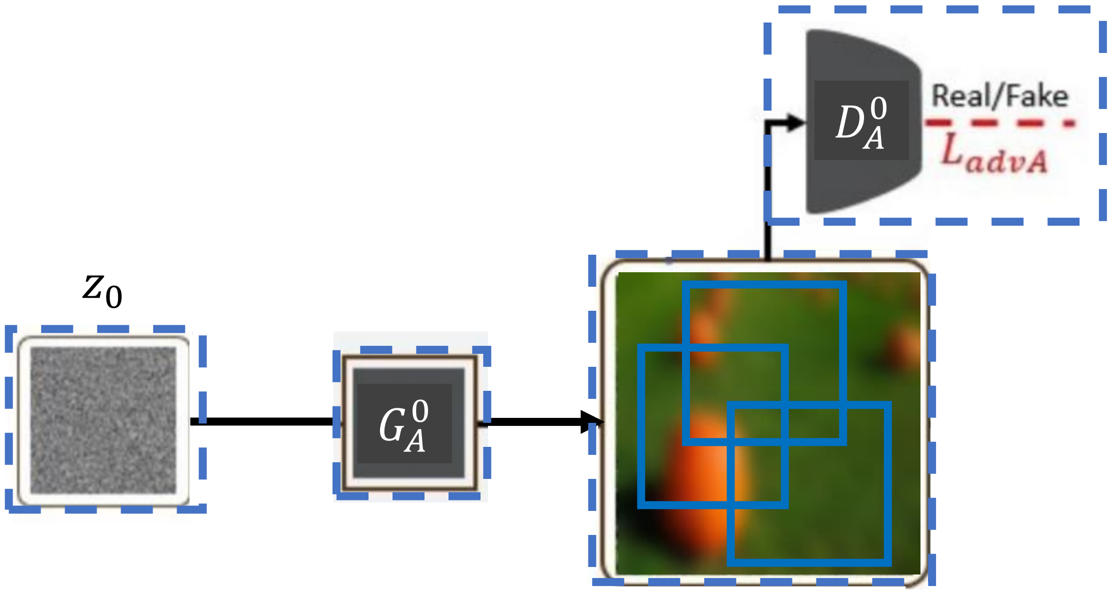
LEVEL $= 0$

Finest scale:
Small Patches

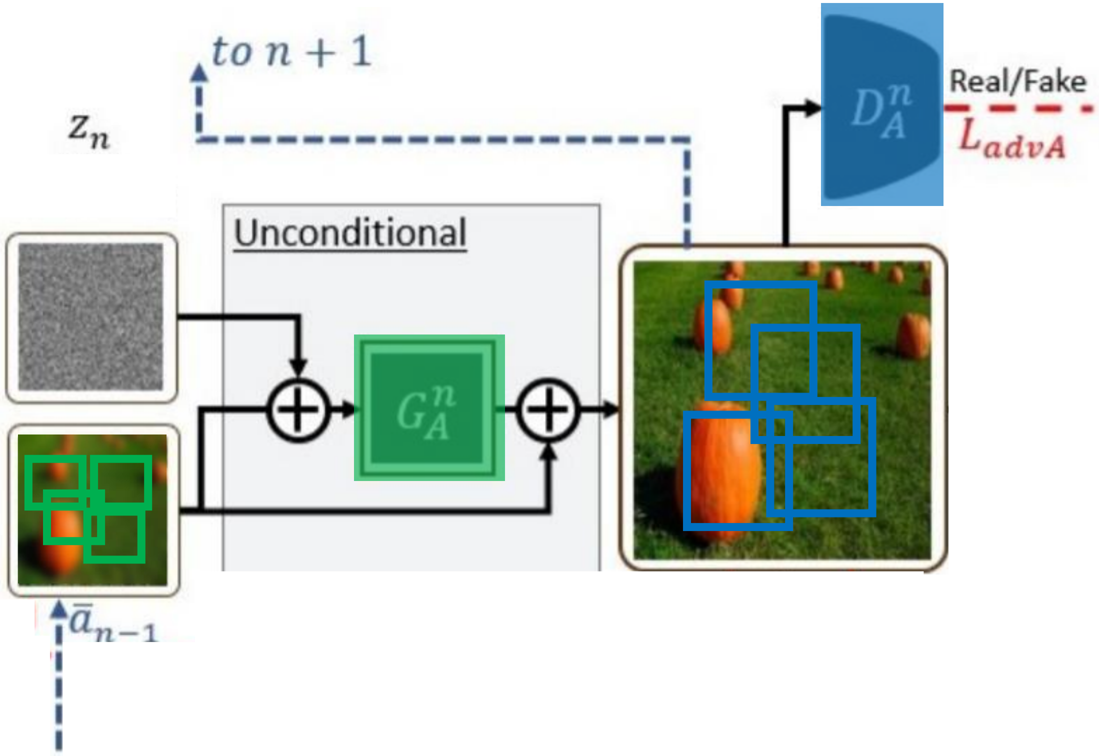
$\bar{a}^{N}$(Unconditional)
$\overline{ab}^{N}$(Conditional)

LEVEL $= N$

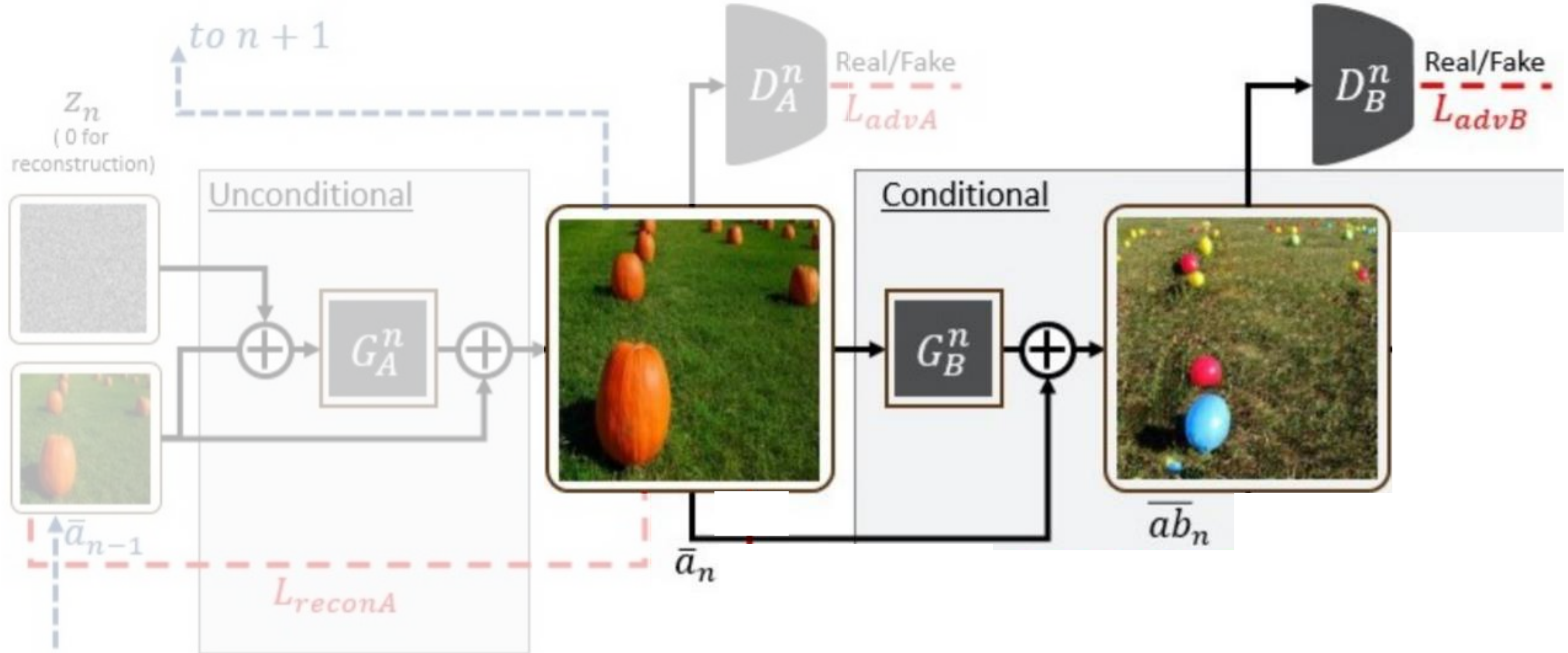
Unconditional Generation (Level 0)



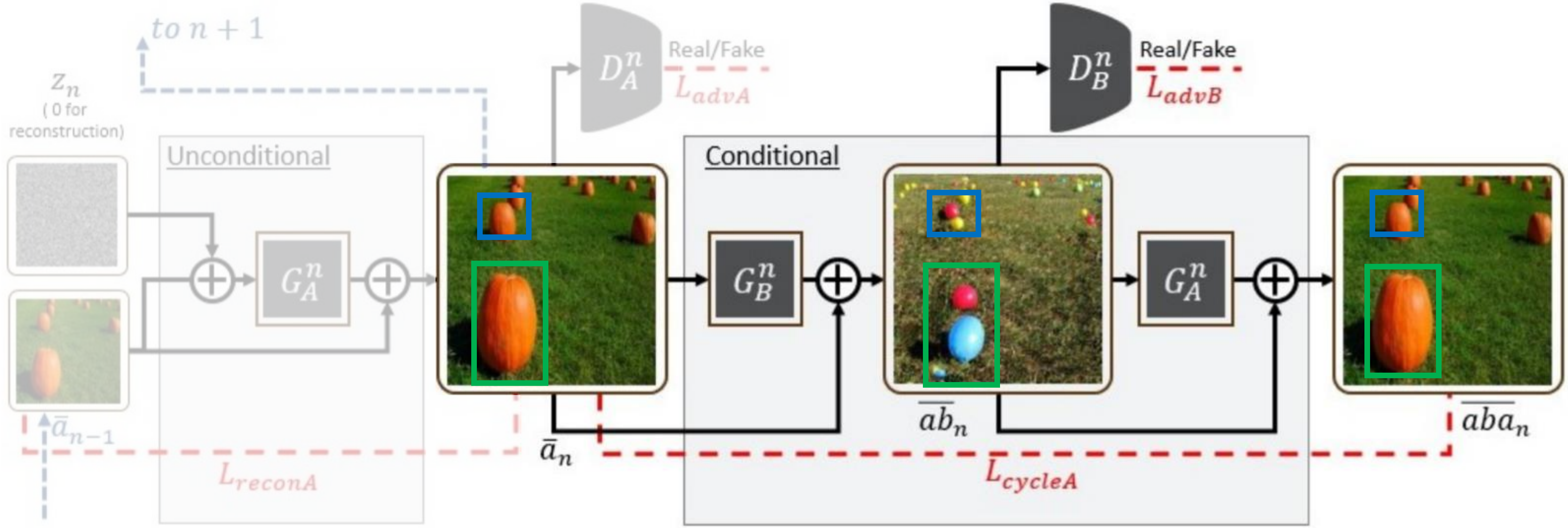
Unconditional Generation (Level n)



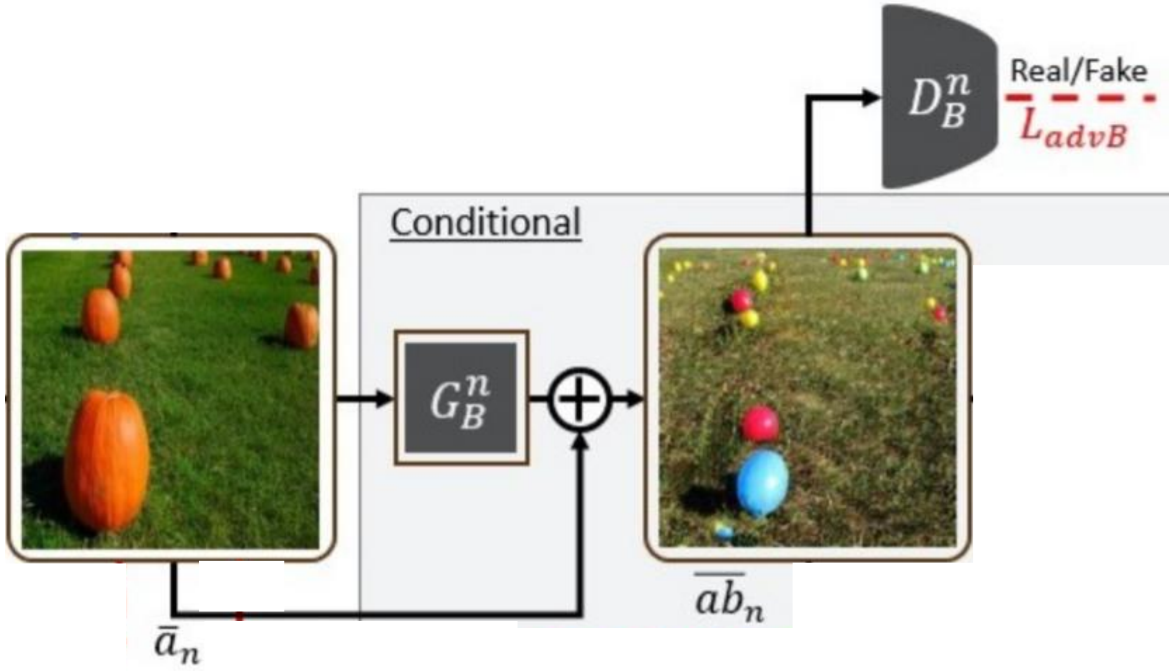
Conditional Generation (Level n)

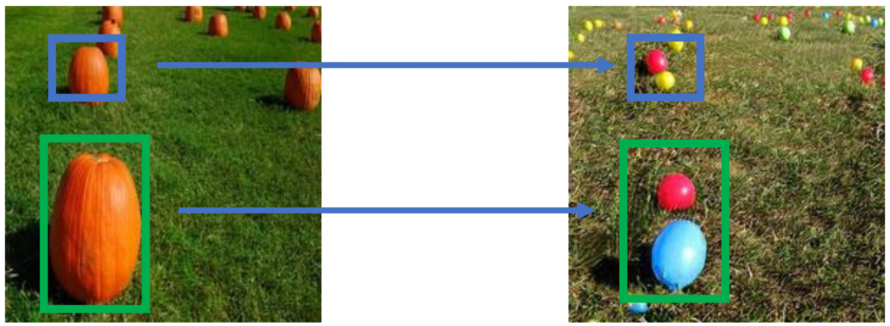


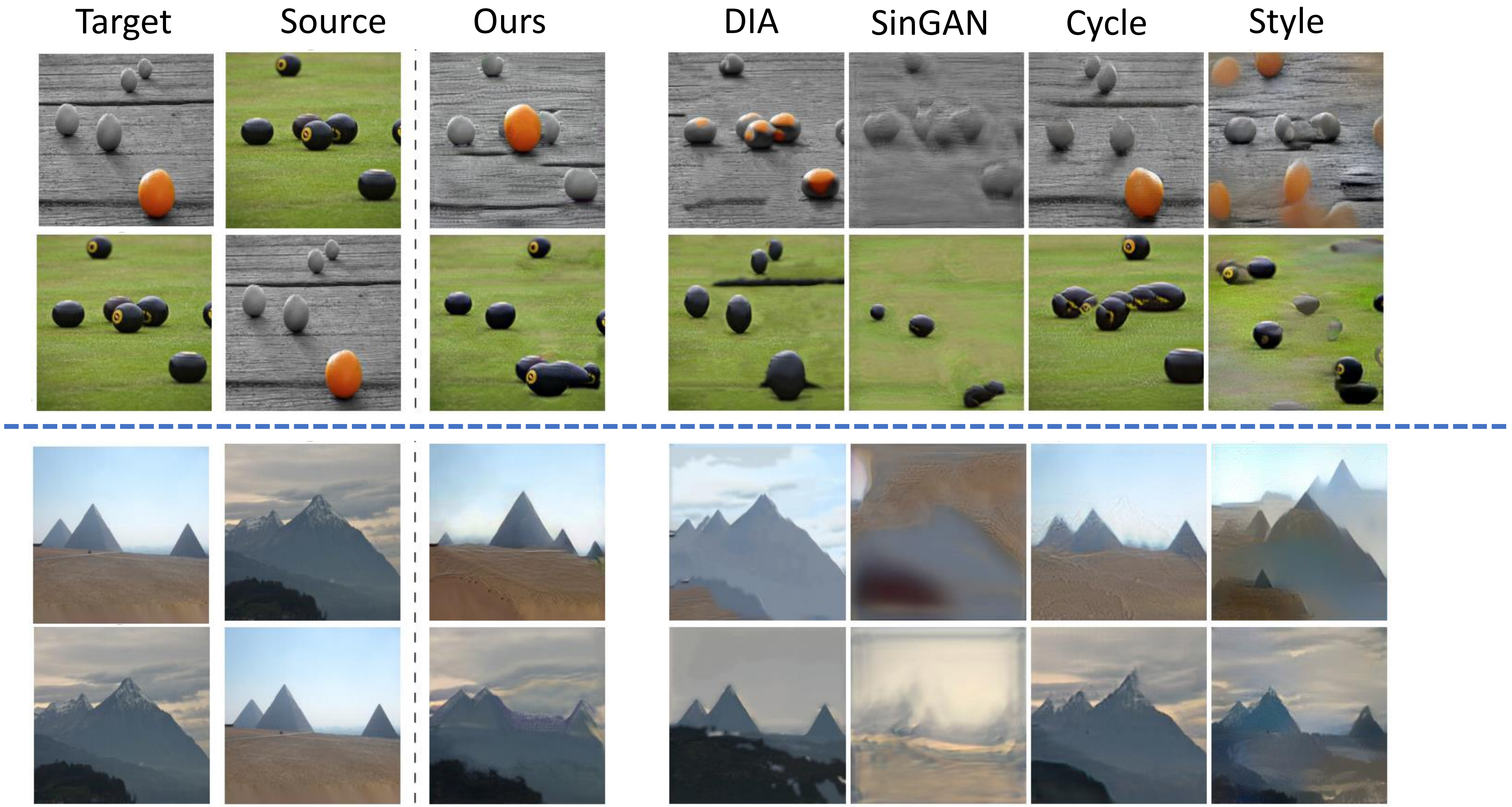
Conditional Generation (Level n)



Coarse and Mid Scales: Residual Training





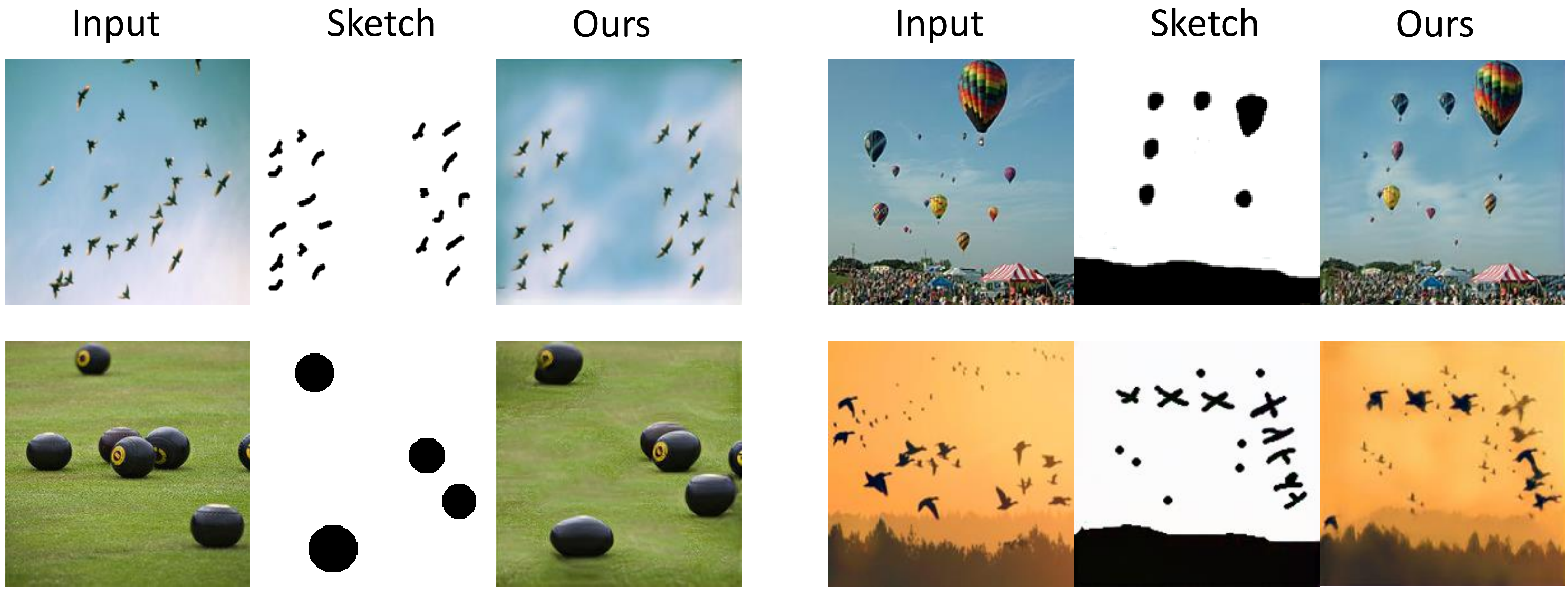

Target
Source
Ours
DIA
SinGAN
Cycle
Style

Multiple Class Types

Input

Output

Paint to Image



Video Generation

Structure Manipulation for **Videos**

Hierarchical Patch VAE-GAN: Generating Diverse Videos from a **Single Sample**

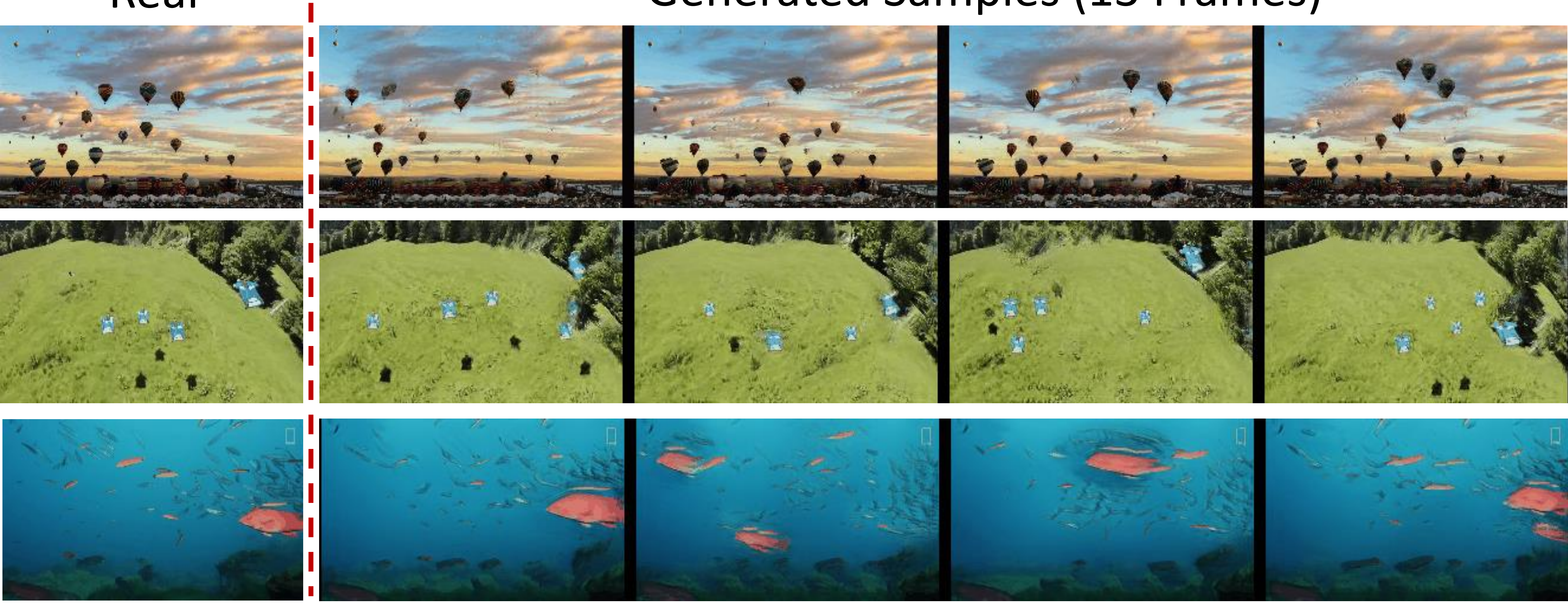
S. Gur*, **S. Benaim***, L. Wolf. NeurIPS 2020 (*Equal contribution)

Real

Hierarchical Patch VAE-GAN:
Generating Diverse Videos from a Single Sample

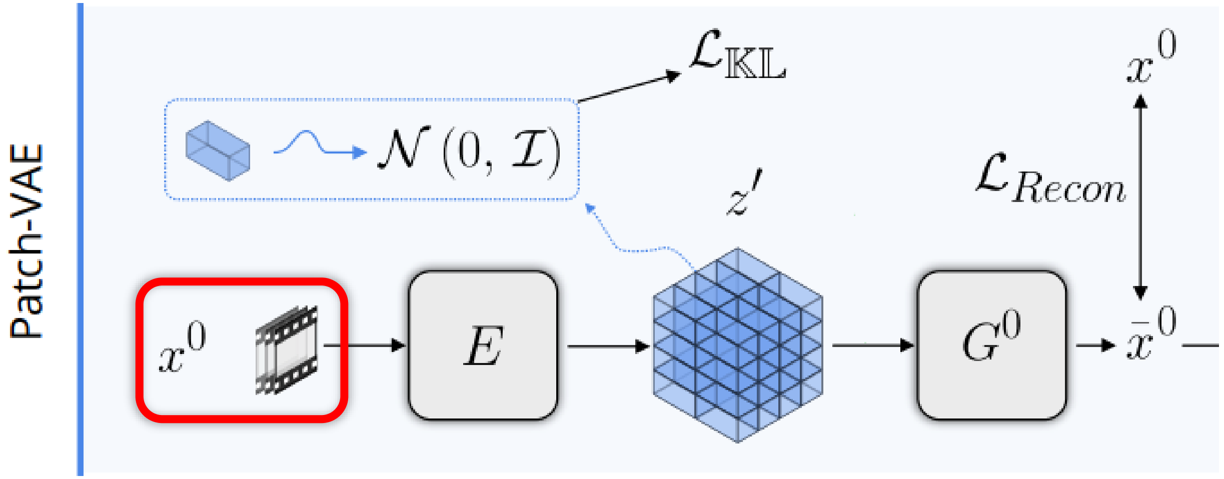
S. Gur*, **S. Benaim***, L. Wolf. NeurIPS 2020 (*Equal contribution)

Real | Generated Samples (13 Frames)



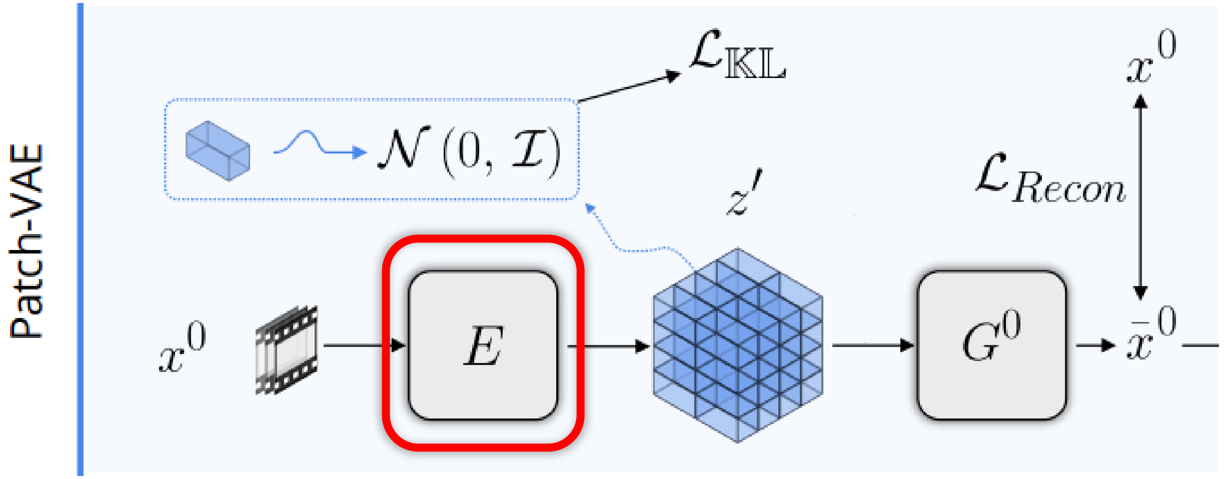
Proposed Approach: Patch VAE

Input video - x^0



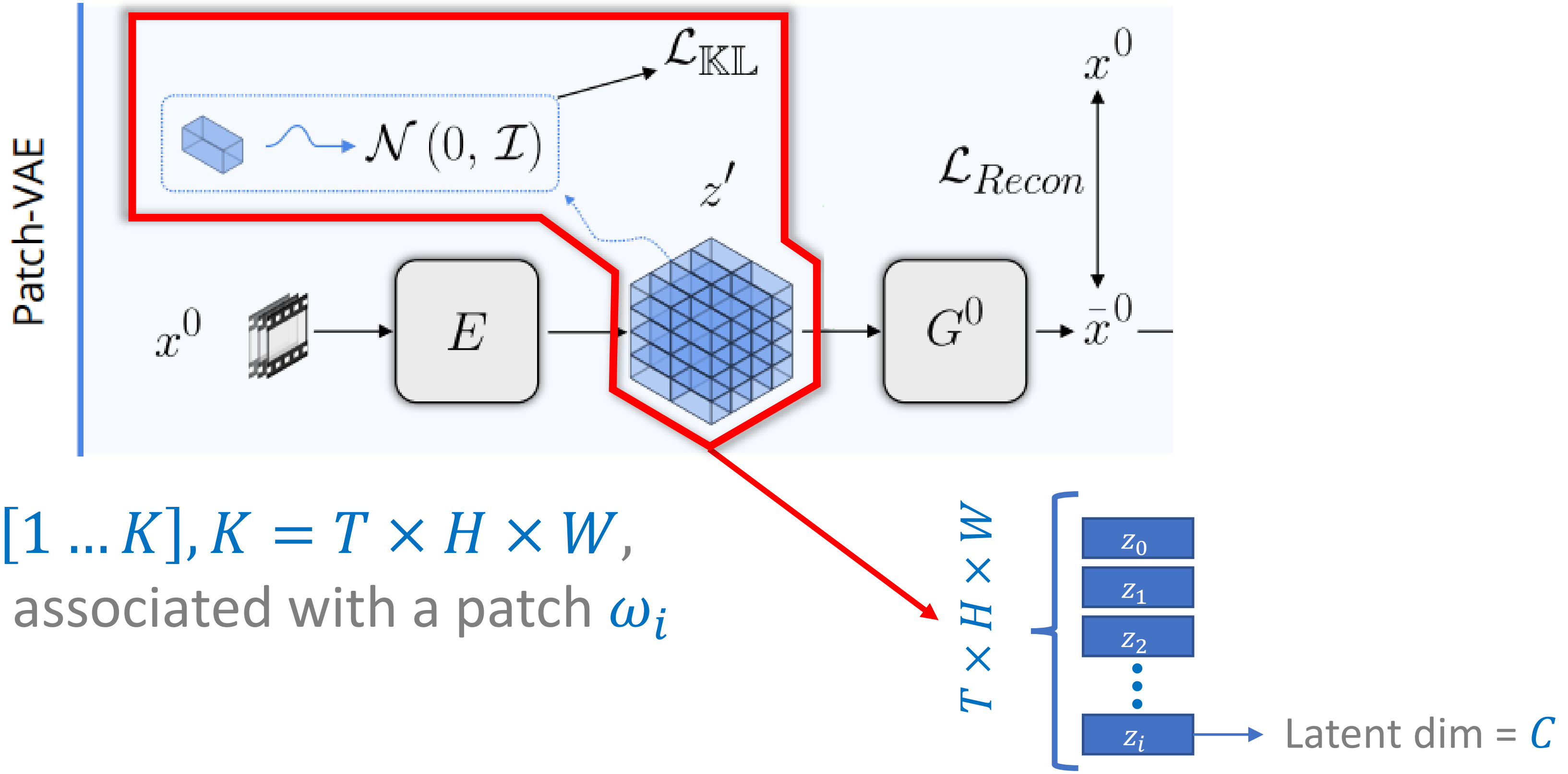
Proposed Approach: Patch VAE

Encoder – $\mathrm{E}(x^0)$



Proposed Approach: Patch VAE

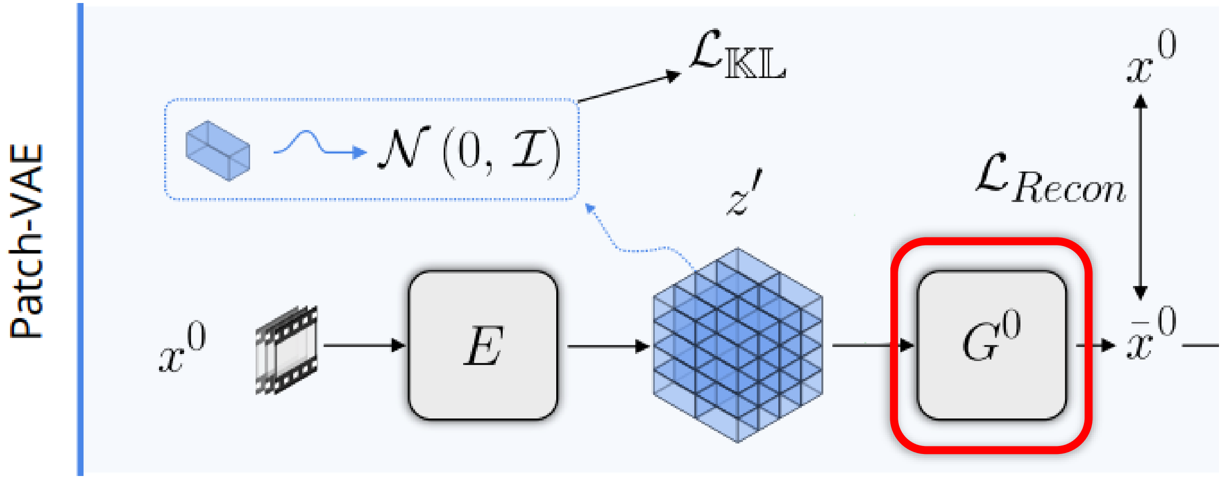
KL Loss – z'



Each feature z_i , $i = [1 \ldots K], K = T \times H \times W$,
in the latent space is associated with a patch ω_i

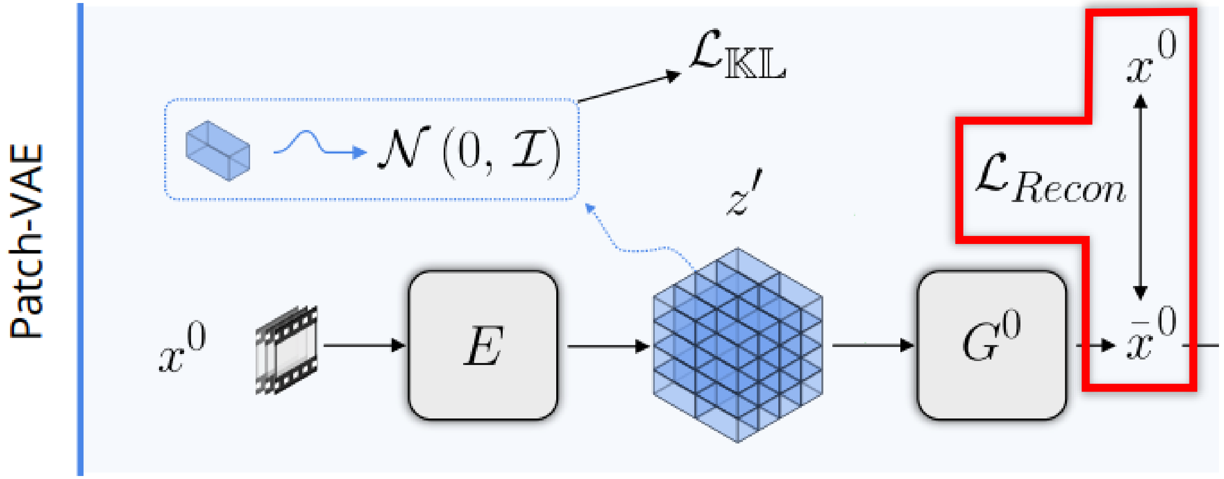
Proposed Approach: Patch VAE

Decoder - $\bar{x}^0$



Proposed Approach: Patch VAE

Reconstruction loss



Proposed Approach: Hierarchical Patch VAE

Coarsest scale:
Low resolution
and frame rate

x^0 (Real)
$\bar{x}^0$(Generated)

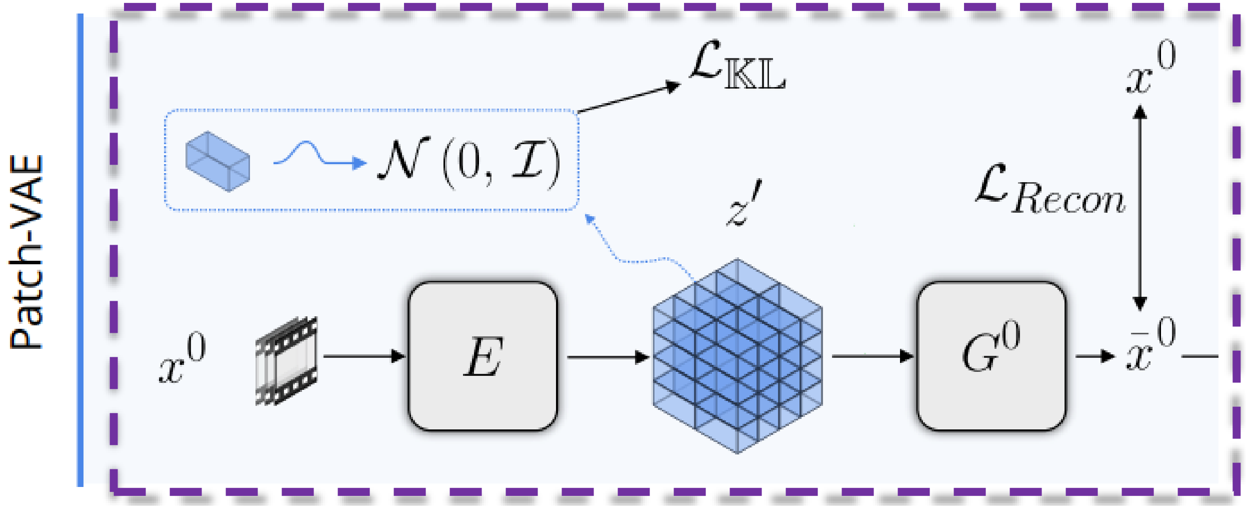
LEVEL $= 0$

Finest scale:
High resolution
and frame rate

x^N (Real)
$\bar{x}^N$(Generated)

LEVEL $= N$

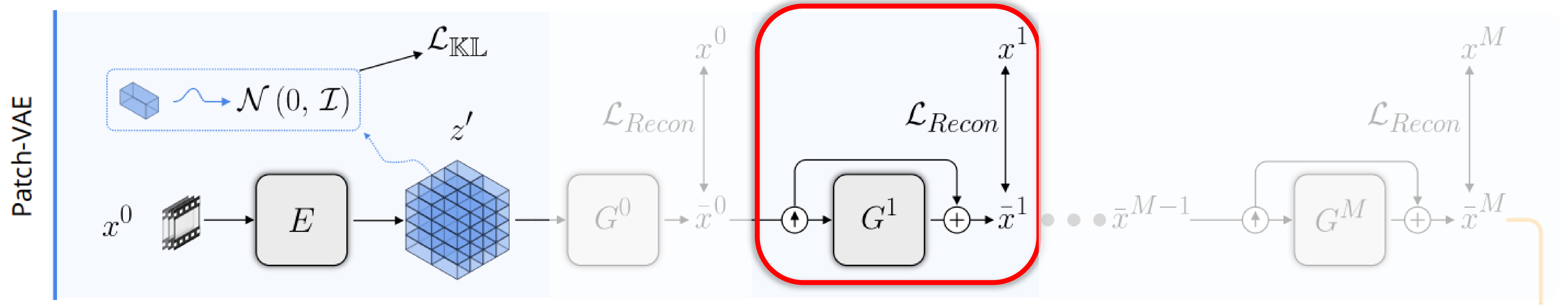
Proposed Approach: Hierarchical Patch VAE



LEVEL = 0

Proposed Approach: Hierarchical Patch VAE

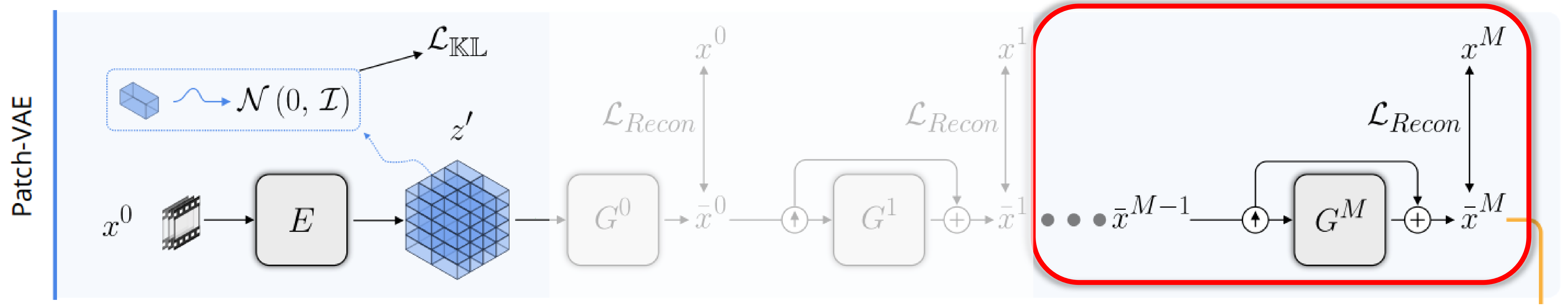
Up-sampling block - $\bar{x}^1$



LEVEL = 1

Proposed Approach: Hierarchical Patch VAE

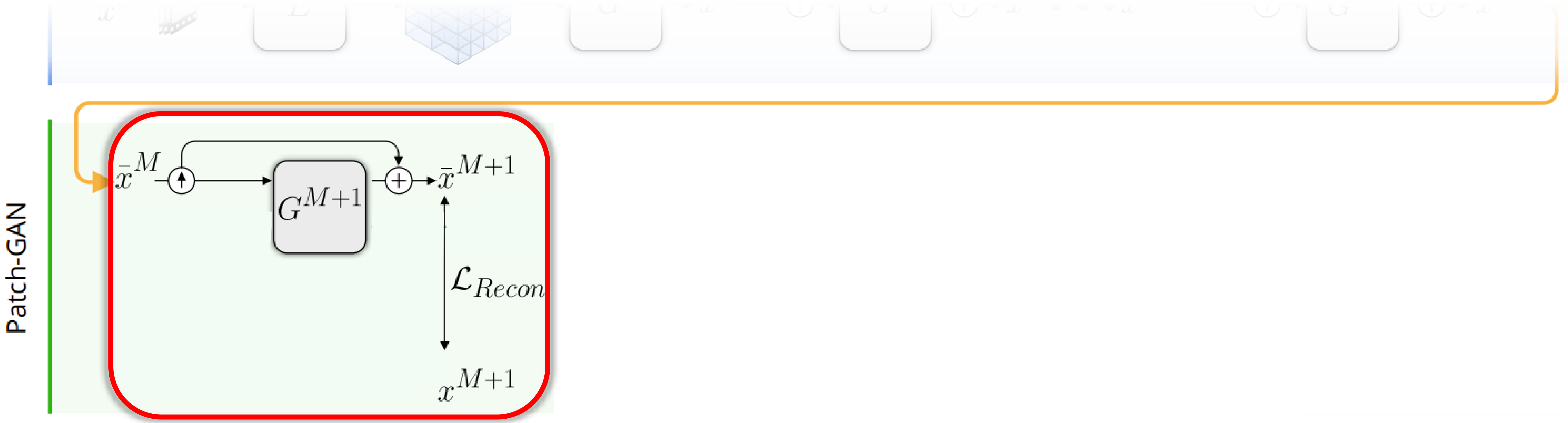
Hierarchical up-sampling up to $\bar{x}^M$



LEVEL $\leq M$

Proposed Approach: Hierarchical Patch VAE GAN

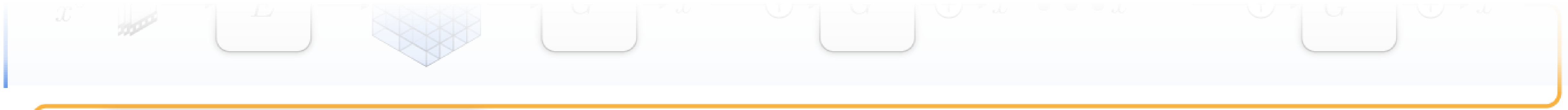
Up-sampling block $\bar{x}^{M+1}$

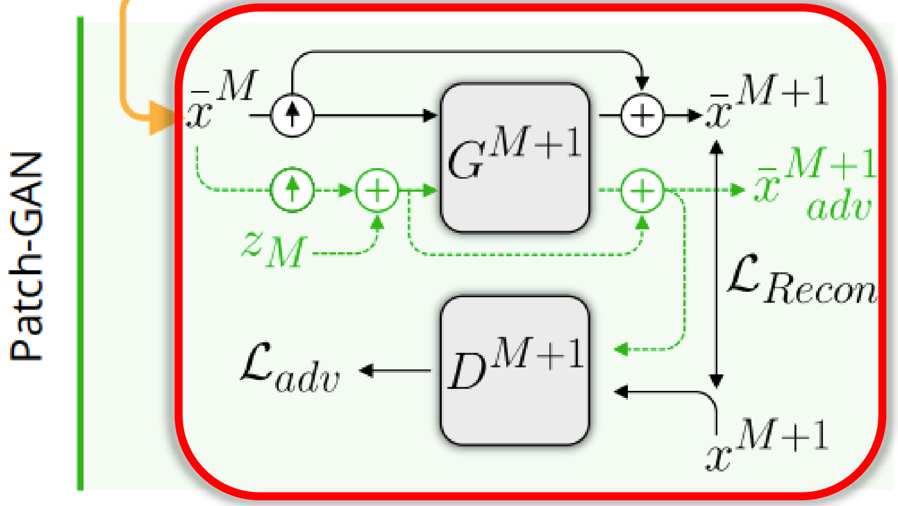


LEVEL $= M+1$

Proposed Approach: Hierarchical Patch VAE GAN

Adversarial training



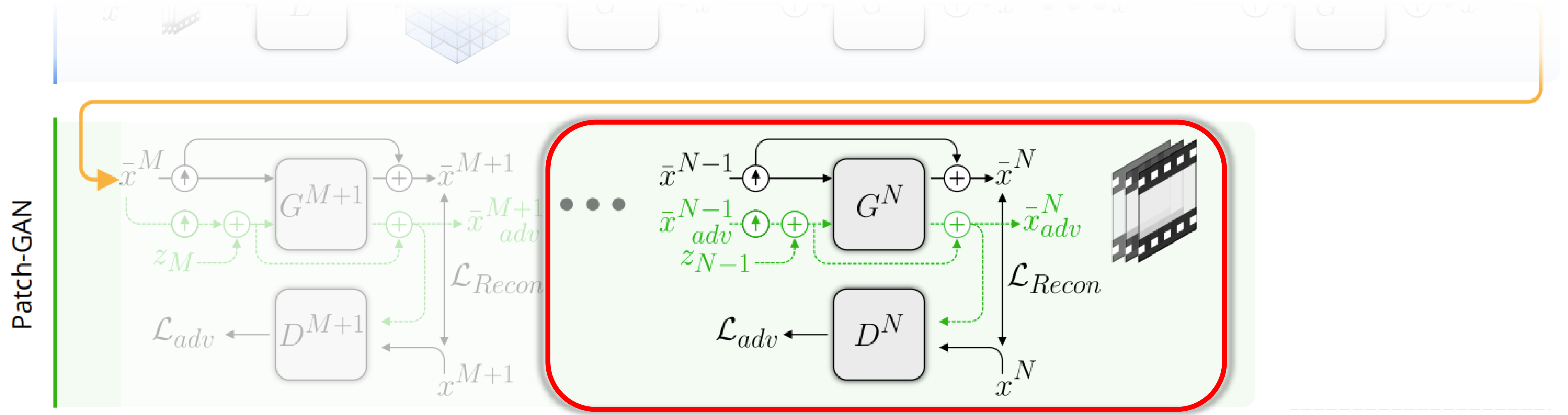


Added noise z_M

LEVEL $= M + 1$

Proposed Approach: Hierarchical Patch VAE GAN

Hierarchical up-sampling up to final resolution $\bar{x}^N$



$M + 1 <$ LEVEL $\leq N$

Effect of Number of patch-VAE levels

Training Video

9 Levels Total

1 p-VAE – 8 p-GAN

8 p-VAE – 1 p-GAN

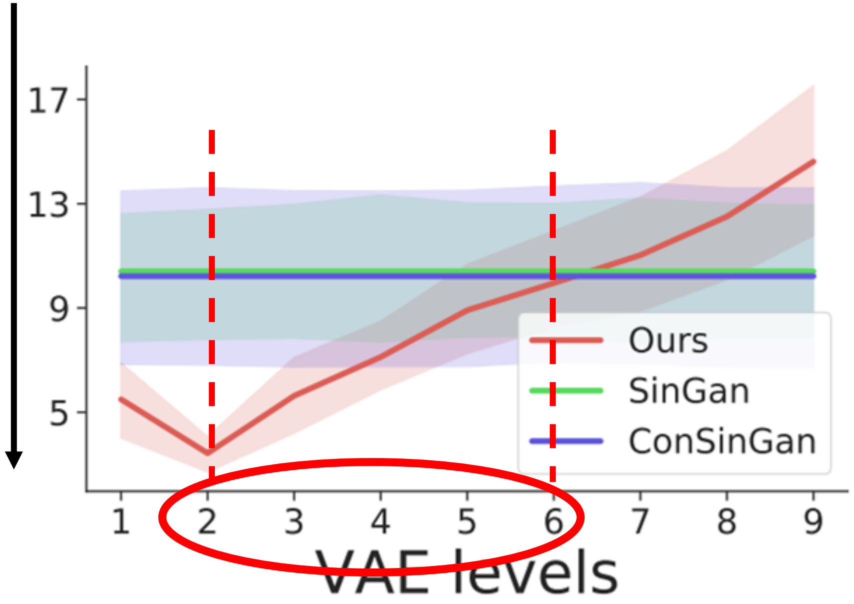
3 p-VAE – 6 p-GAN

Effect of Number of patch-VAE levels

Total of 9 layers

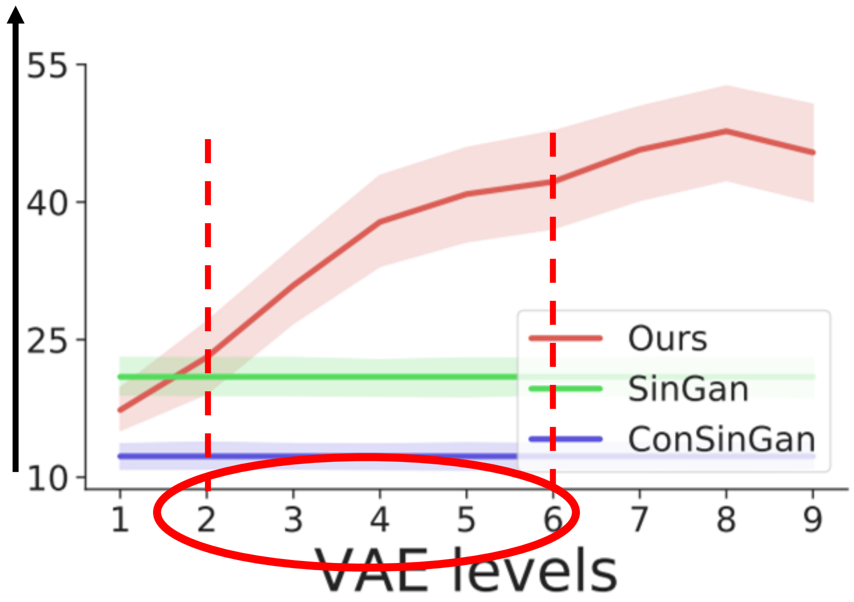
Quality

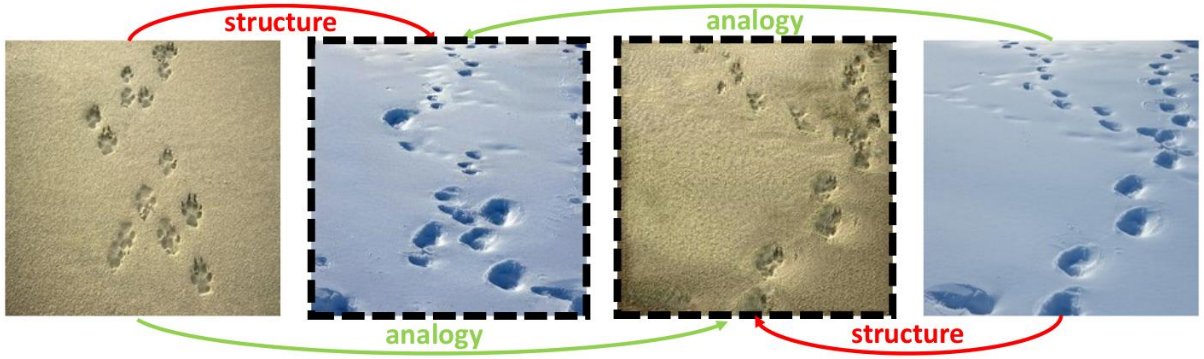
(**Lower** is Better)



Diversity

(**Higher** is Better)





Part II: Manipulating Structure by Understanding Structure

SpeedNet: **Learning the Speediness in Videos**

S. Benaim, A. Ephrat, O. Lang, I. Mosseri, W. T. Freeman, M. Rubinstein, M. Irani, T. Dekel.
CVPR 2020.

Slower

Normal speed

Faster

https://speednet-cvpr20.github.io/

Automatically predict "speediness"

Uniform Speed Up (2x)

Adaptive speed up (2x)

Other Applications:

- Self-supervised action recognition
- Video retrieval

Training SpeedNet

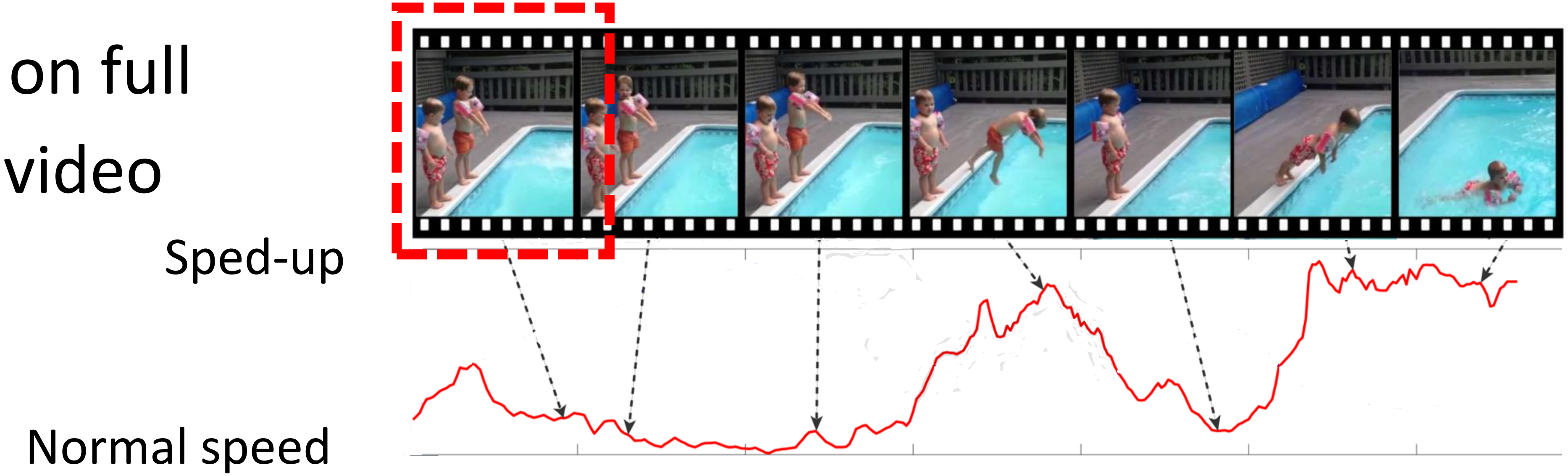
Self-supervised training

Input video

Sped Up

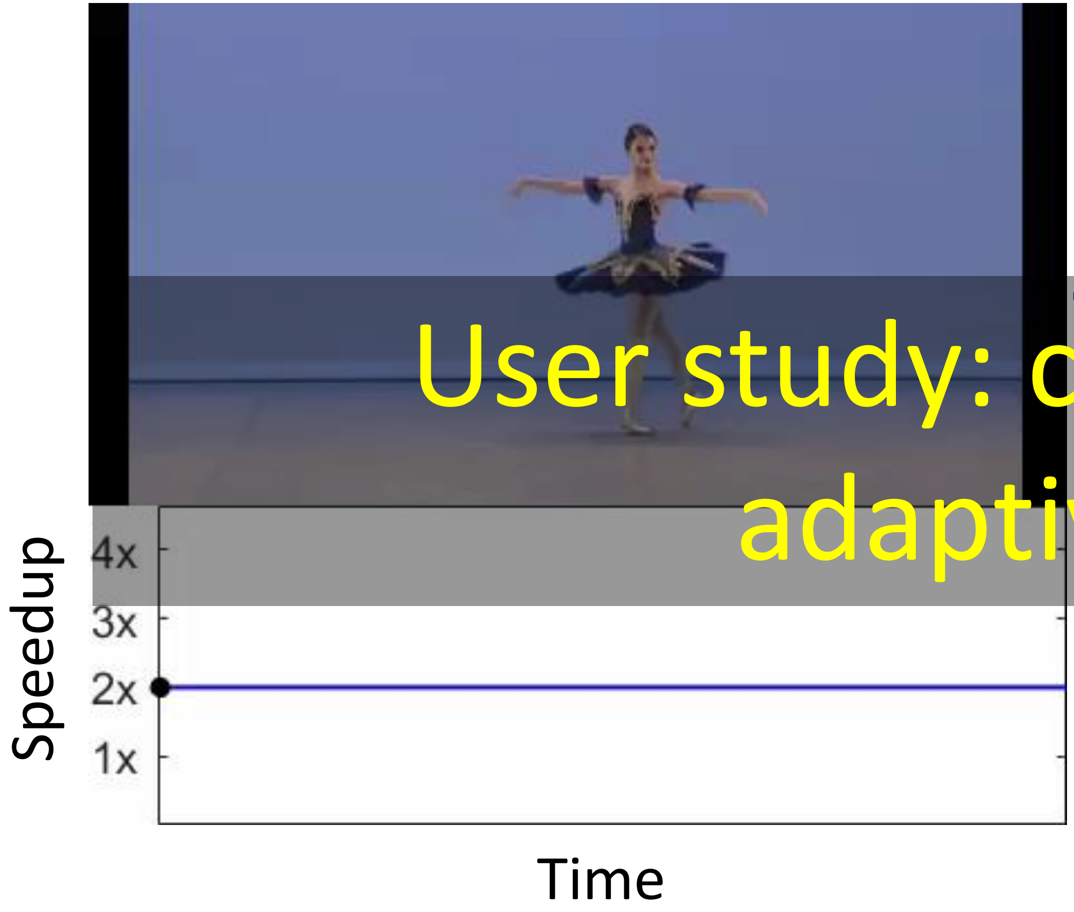
Adaptive video speedup

Inference on full **sped-up** video



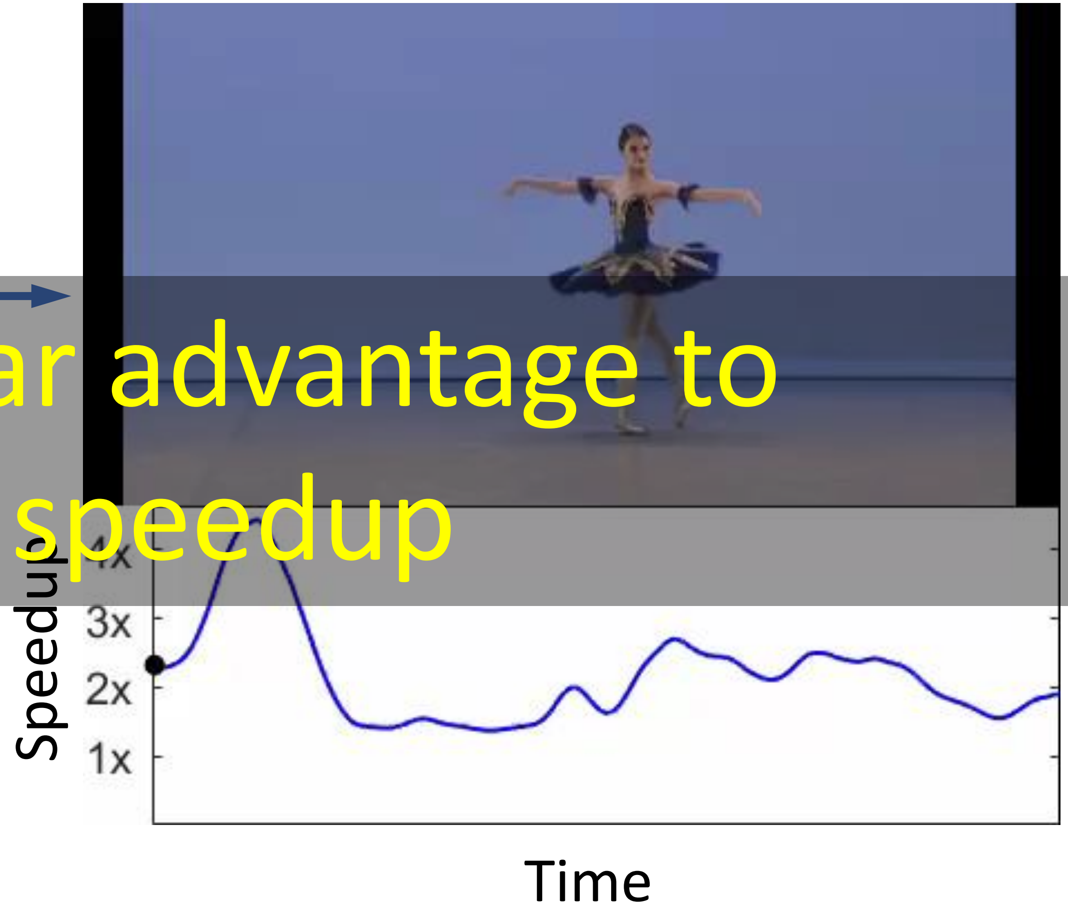
Adaptive video speedup

Total time = $\frac{1}{2}$ input time



Uniform Speedup

Total time = $\frac{1}{2}$ input time

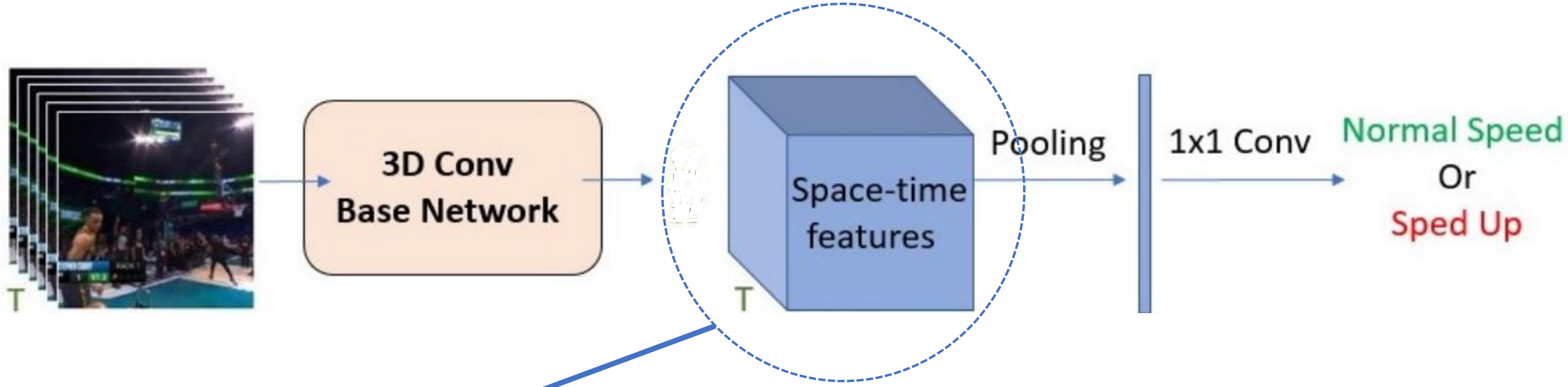


Adaptive Speedup (ours)

User study: clear advantage to adaptive speedup

Other self supervised tasks

Train SpeedNet

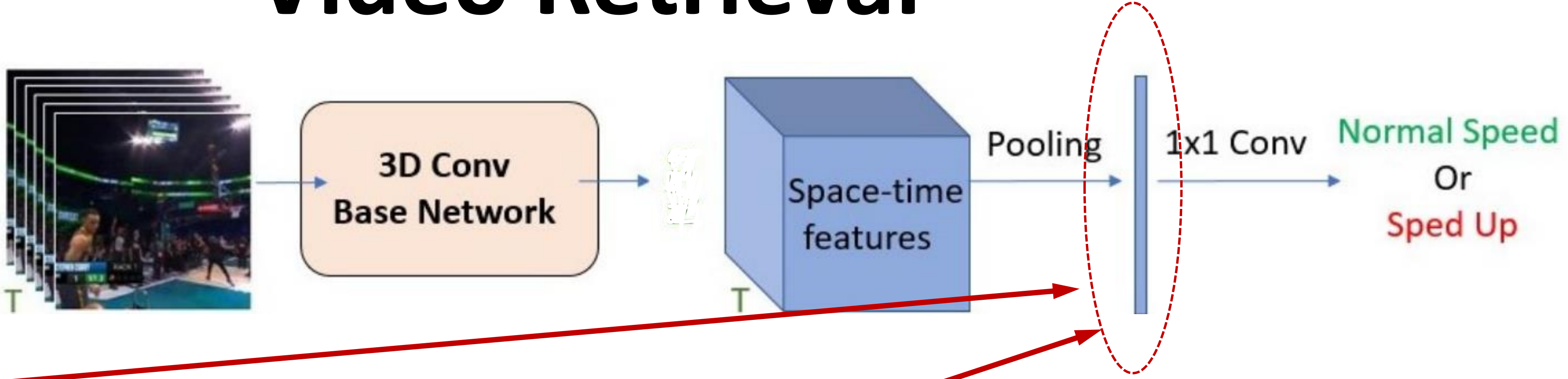


Self Supervised Action Recognition

Initialization		Supervised accuracy	
Method	**Architecture**	**UCF101**	**HMDB51**
Random init	S3D-G	73.8	46.4
ImageNet inflated	S3D-G	86.6	57.7
Kinetics supervised	S3D-G	96.8	74.5
CubicPuzzle [19]	3D-ResNet18	65.8	33.7
Order [40]	R(2+1)D	72.4	30.9
DPC [13]	3D-ResNet34	75.7	35.7
AoT [38]	T-CAM	79.4	-
SpeedNet (Ours)	S3D-G	**81.1**	**48.8**
Random init	I3D	47.9	29.6
SpeedNet (Ours)	I3D	66.7	43.7

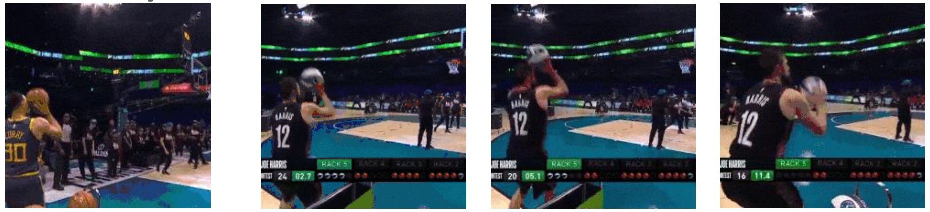
Other self supervised tasks: Video Retrieval

Train SpeedNet



Query

Retrieved top-3 results (Within)



Query

Retrieved top-3 results (Across)

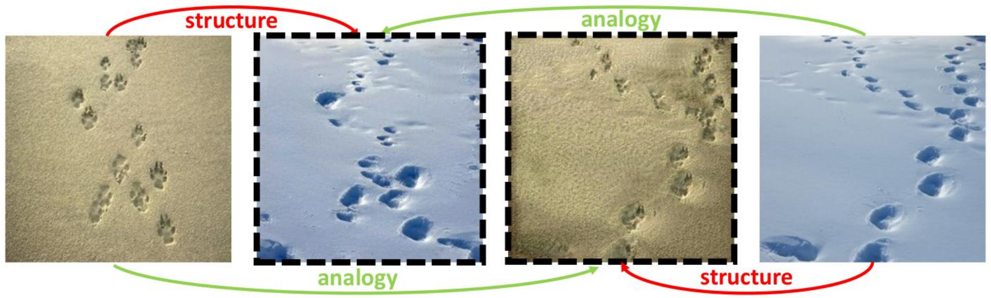
“Memory Eleven”: An artistic video by Bill Newsinger:
https://www.youtube.com/watch?v=djylS0Wi_Io

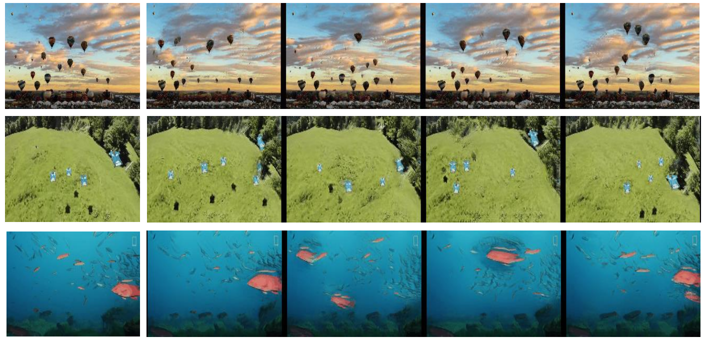
Spatio-Temporal Visualizations

blue/green = normal speed

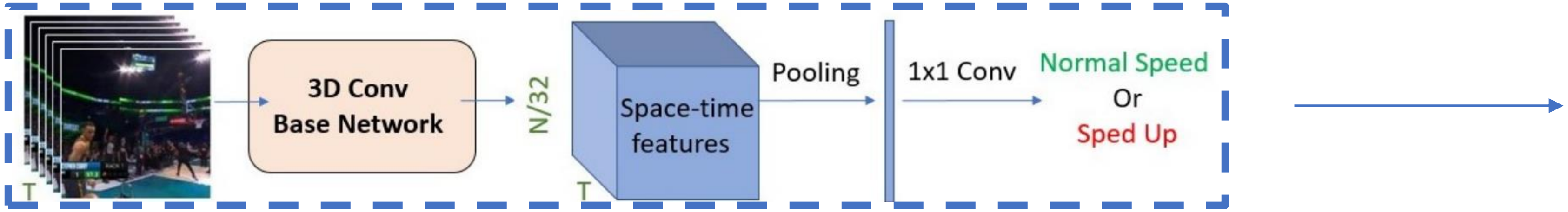
yellow/orange = slowed down

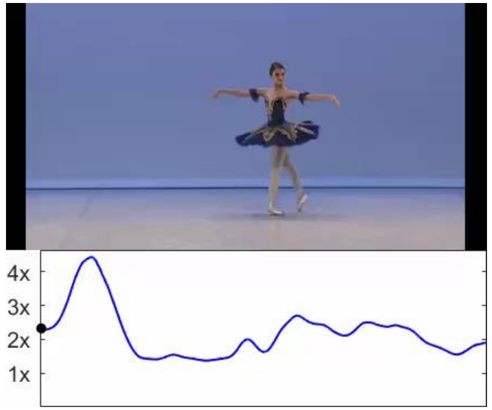
Part I: Manipulating **Structure**





Part II: Manipulating **by Understanding Structure**





Part III: **Structure Preserving** Manipulation

Permuted AdaIN: Reducing the Bias Towards Global Statistics in Image Classification

O. Nuriel, **S. Benaim**, L. Wolf. CVPR 2021.

Style

Content

Result

Huang et al., Arbitrary Style Transfer in Real-time with Adaptive Instance Normalization. ICCV2017

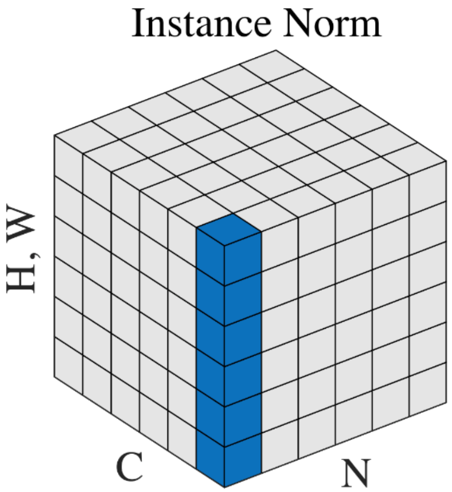
Structure Preserving Transformation

- $a \in \mathbb{R}^{C\times H\times W}$ and $b \in \mathbb{R}^{C\times H\times W}$ be the activations of some encoder E applied on images I_a and I_b respectively.

$a = E($  $)$

$b = E($  $)$

Instance Normalization



$b = E($  $)$

$$IN(b)_{chw} = \left(\frac{a_{chw} - \mu_c(b)}{\sigma_c(b)}\right)$$

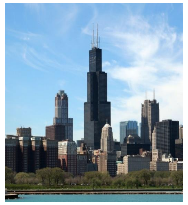
Adaptive Instance Normalization

$a = E($  $)$

$b = E($  $)$

$$AdaIN(a,b)_{chw} = \sigma_c(a)\left(\frac{a_{chw} - \mu_c(b)}{\sigma_c(b)}\right) + \mu_c(a)$$

Adaptive Instance Normalization



$$AdaIN(a,b)_{chw} = \overbrace{\sigma_c(a)}^{\text{Global Statistics}} \underbrace{\left(\frac{a_{chw} - \mu_c(b)}{\sigma_c(b)}\right)}_{\text{Structure}} + \overbrace{\mu_c(a)}^{\text{Global Statistics}}$$

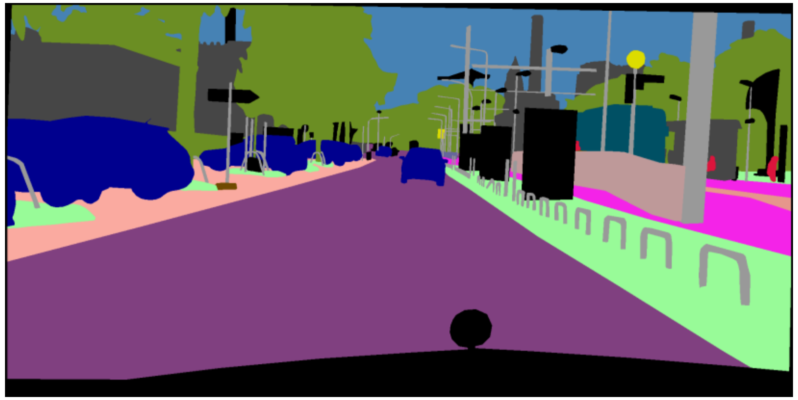
- AdaIN **swaps the global statistics** of a to those of b
- μ and σ represent the **global statistics** of an image (such as brightness, contrast, lighting, global color changes and global texture)
- **Structure** represents information relating to shape of objects

Domain Adaptation

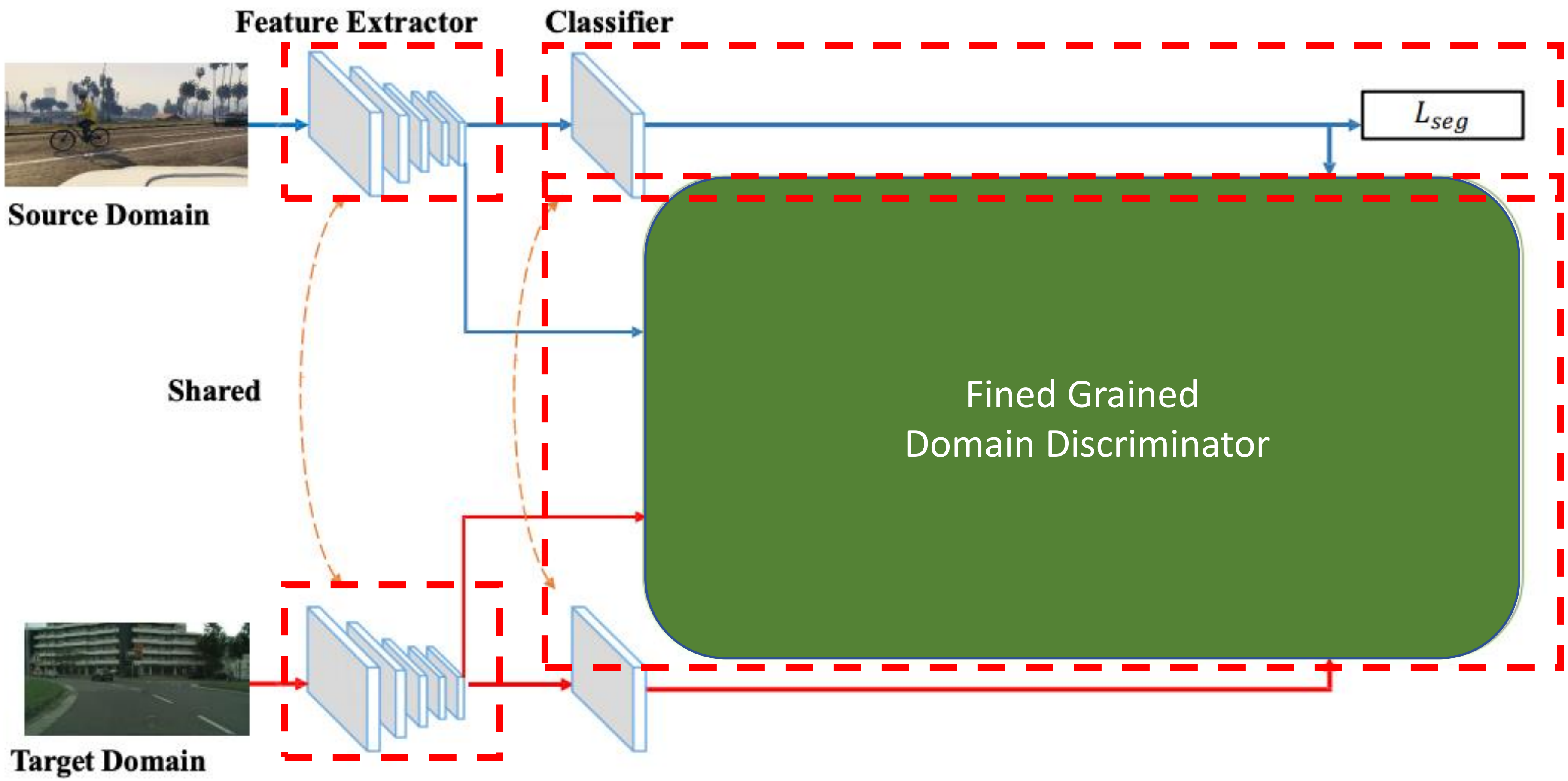
Supervised training on source domain and unsupervised on target domain

Source: GTAV

Target: Cityscapes



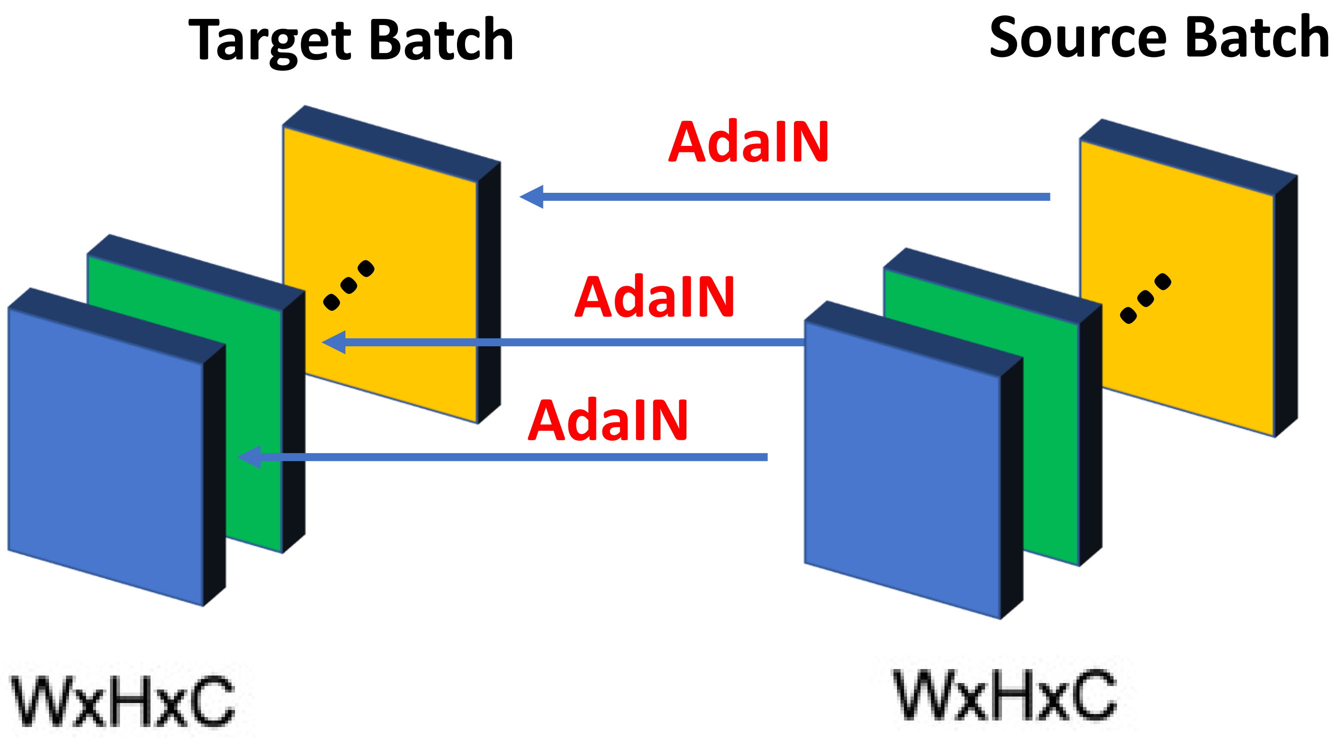
Domain Adaptation



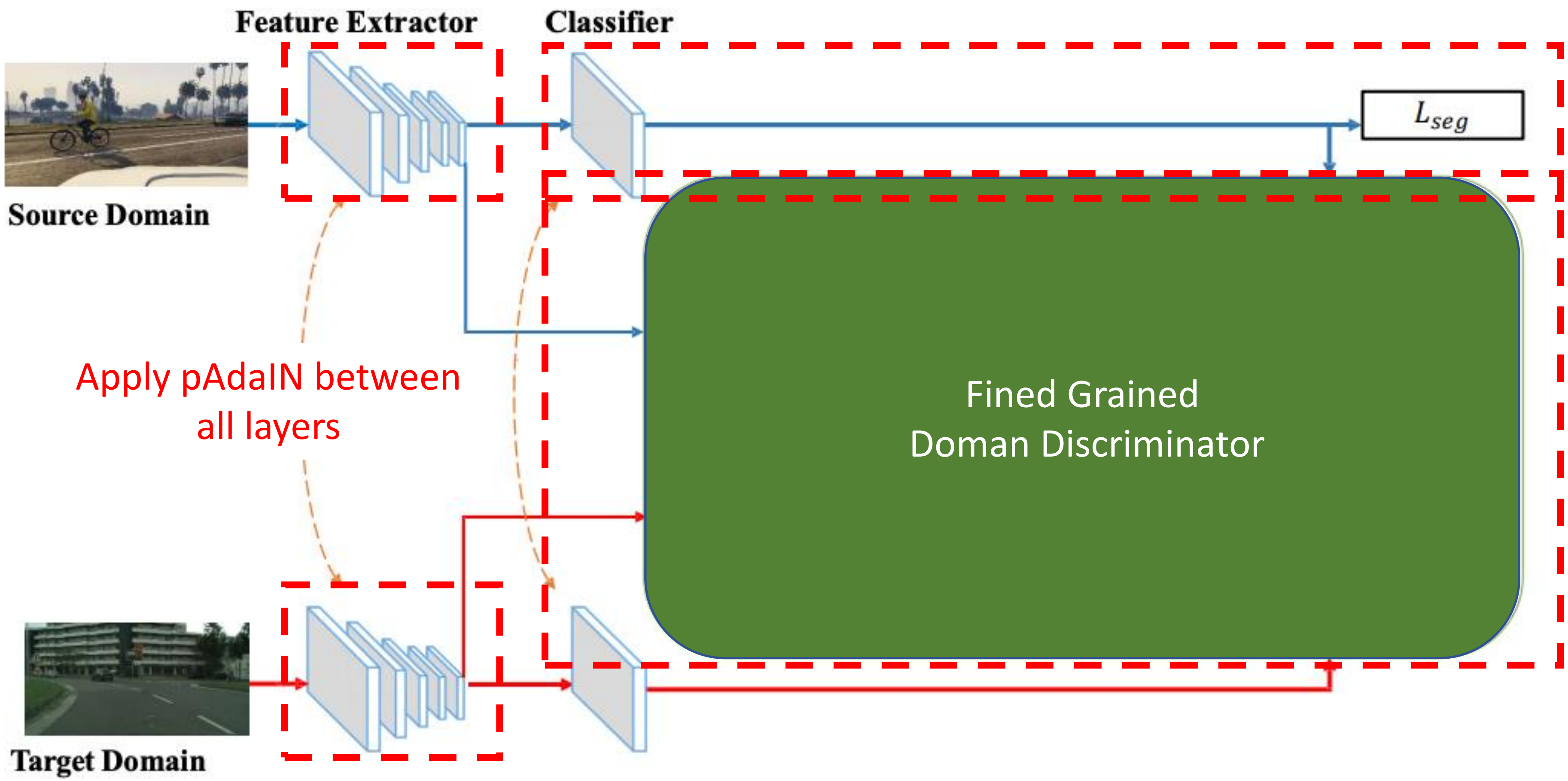
Classes Matter: A Fine-grained Adversarial Approach to Cross-domain Semantic Segmentation. Wang et al., ECCV 2020.

Domain Adaptation

- **Swap global statistics of target features with those of source features** by applying AdaIN with probability p.
- Apply at every layer of the feature extractor.



Domain Adaptation



Classes Matter: A Fine-grained Adversarial Approach to Cross-domain Semantic Segmentation. Wang et al., ECCV 2020.

Domain Adaptation

GTAV to Cityscapes

AdaptSegNet [35]	86.5	36.0	79.9	23.4	23.3	23.9	35.2	14.8	83.4	33.3	75.6	58.5	27.6	73.7	32.5	35.4	3.9	30.1	28.1	42.4
SIBAN [28]	88.5	35.4	79.5	26.3	24.3	28.5	32.5	18.3	81.2	40.0	76.5	58.1	25.8	82.6	30.3	34.4	3.4	21.6	21.5	42.6
CLAN [29]	87.0	27.1	79.6	27.3	23.3	28.3	**35.5**	24.2	83.6	27.4	74.2	58.6	28.0	76.2	33.1	36.7	6.7	31.9	31.4	43.2
AdaptPatch [36]	92.3	51.9	82.1	29.2	25.1	24.5	33.8	**33.0**	82.4	32.8	82.2	58.6	27.2	84.3	33.4	46.3	2.2	29.5	32.3	46.5
ADVENT [38]	89.4	33.1	81.0	26.6	26.8	27.2	33.5	24.7	83.9	36.7	78.8	58.7	30.5	84.8	38.5	44.5	1.7	31.6	32.4	45.5
FADA [40]	92.5	47.5	85.1	37.6	**32.8**	**33.4**	33.8	18.4	85.3	37.7	83.5	63.2	**39.7**	87.5	32.9	47.8	1.6	34.9	**39.5**	49.2
FADA [40] + pAdaIN	**93.3**	**55.7**	**85.6**	**38.3**	29.6	31.2	34.2	17.8	**86.2**	**41.0**	**88.8**	**65.1**	37.1	**87.6**	**45.9**	**55.1**	15.1	**39.4**	31.1	**51.5**

Domain Adaptation

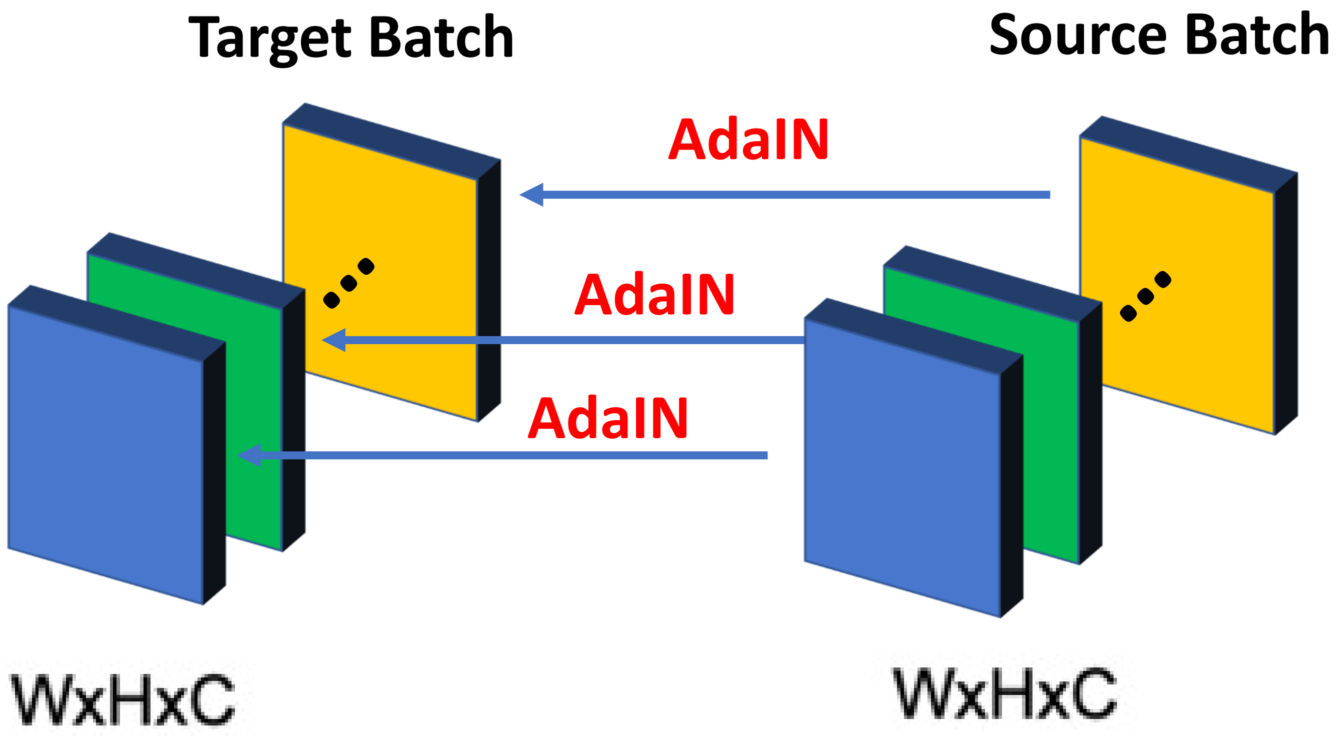


Image Classification

Swap global statistics between every two elements in the batch

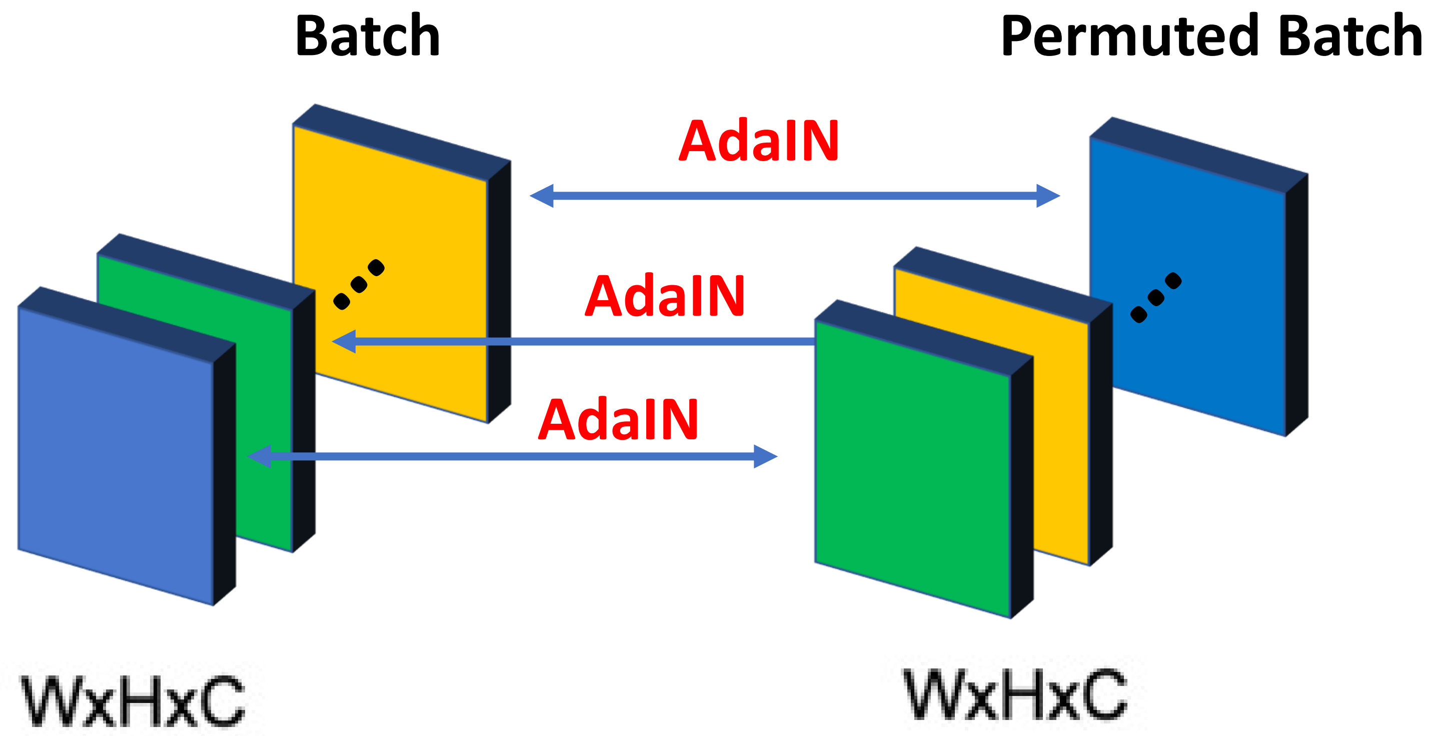


Image Classification

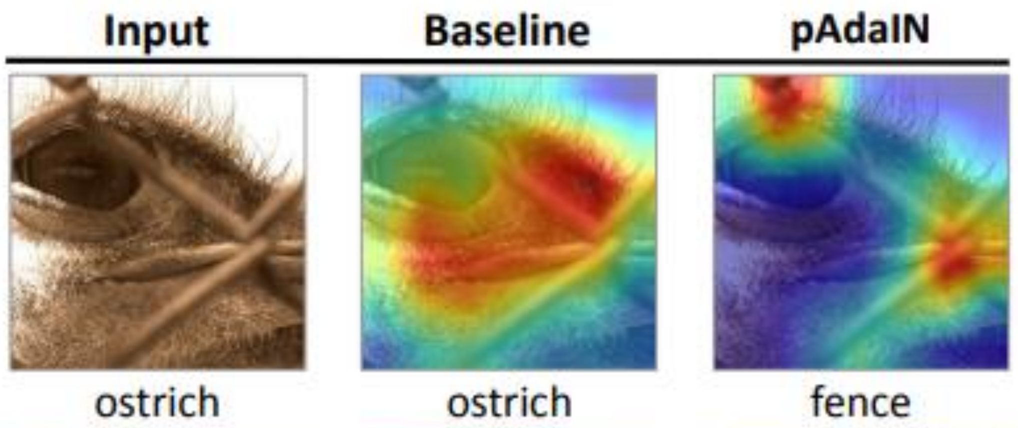
ImageNet

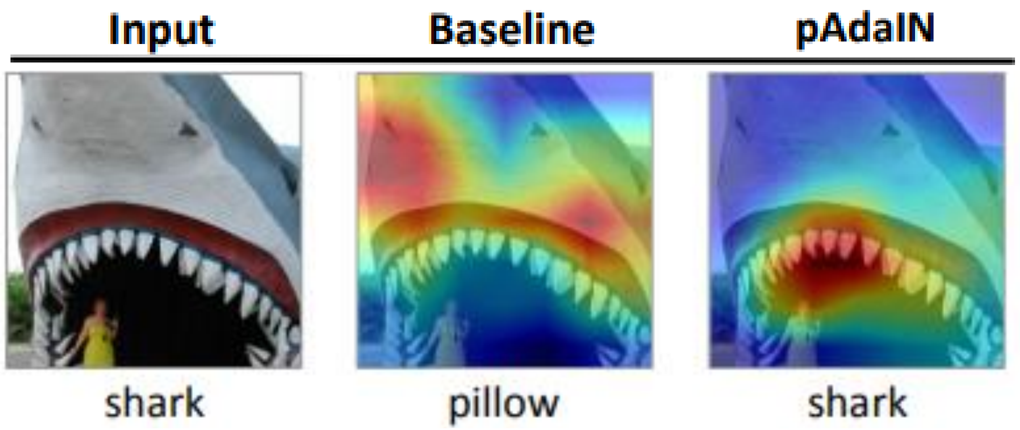
Method	Architecture	Top-1 Accuracy	Top-5 Accuracy
Baseline	ResNet50	77.1	93.63
pAdaIN	ResNet50	**77.7**	**93.93**
Baseline	ResNet101	78.13	93.71
pAdaIN	ResNet101	**78.8**	**94.35**
Baseline	ResNet152	78.31	94.06
pAdaIN	ResNet152	**79.13**	**94.64**

Cifar100

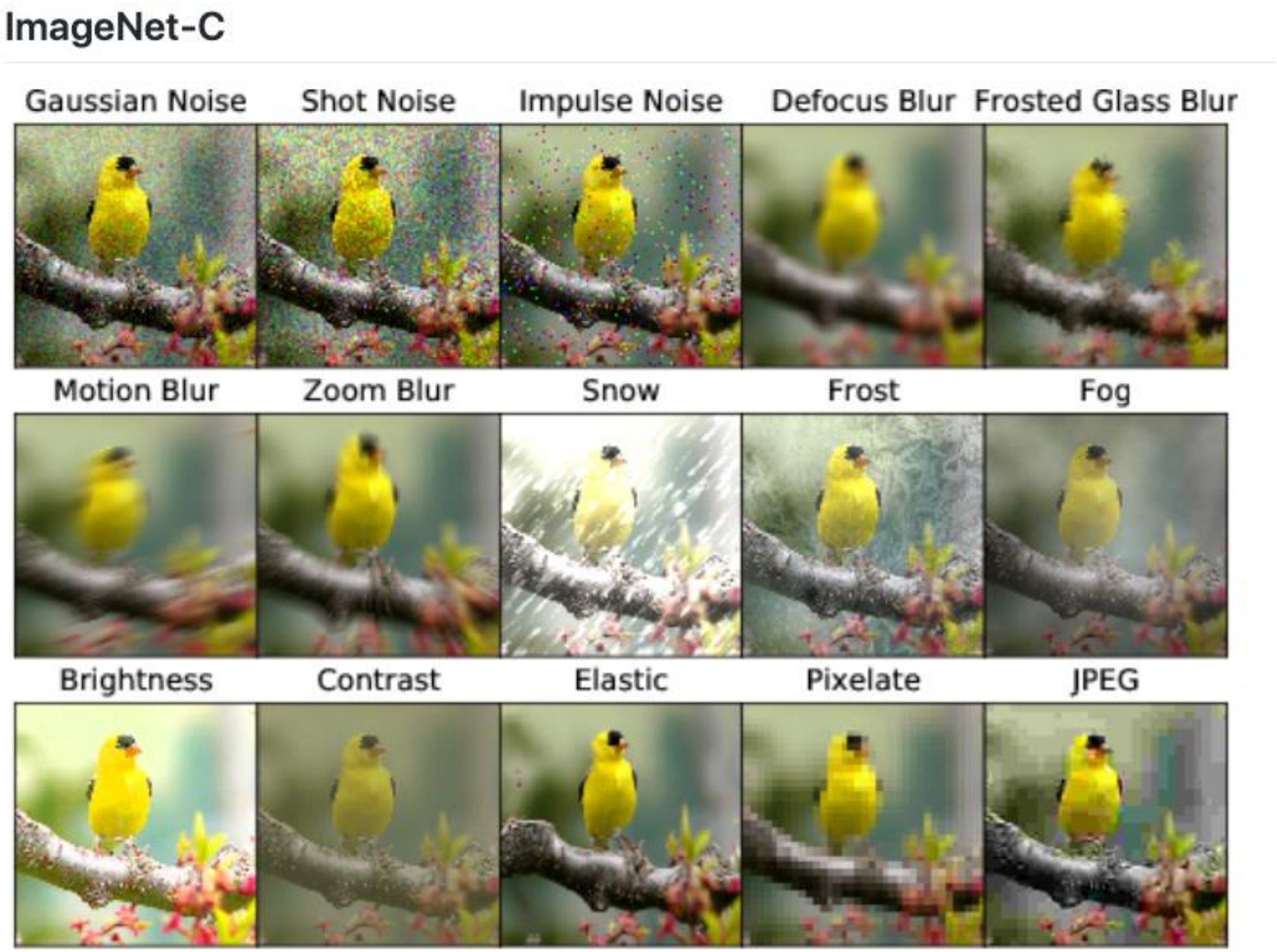
Method	Architecture	CIFAR 100
Baseline	PyramidNet	83.49
pAdaIN	PyramidNet	**84.17**
Baseline	ResNet18	76.13
pAdaIN	ResNet18	**77.82**
Baseline	ResNet50	78.22
pAdaIN	ResNet50	**79.03**

Image Classification





Robustness Towards Corruption



Robustness Towards Corruption

CIFAR100-C

	Baseline	Cutout [8]	Mixup [43]	CutMix [43]	Auto-Augment [7]	Adversarial Training [30]	Augmix [18]	pAdaIN+ Augmix
DenseNet-BC	59.3	59.6	55.4	59.2	53.9	55.2	38.9	**37.5**
ResNext-29	53.4	54.6	51.4	54.1	51.3	54.4	34.4	**31.6**

Category Wise Breakdown

Dataset	Network	Architecture	E	mCE	Noise			Blur				Weather				Digital			
					Gauss.	Shot	Impulse	Defocus	Glass	Motion	Zoom	Snow	Frost	Fog	Bright	Contrast	Elastic	Pixel	JPEG
INet-C	Baseline	ResNet50	22.9	76.7	80	82	83	75	89	78	80	78	75	66	57	71	85	77	77
INet-C	pAdaIN	ResNet50	**22.3**	**72.8**	**78**	**79**	**81**	**70**	**87**	**74**	**76**	**74**	**71**	**64**	**55**	**65**	**82**	**66**	**71**
C100-C	Augmix [18]	DenseNet-BC	24.2	38.9	60	51	41	27	55	31	29	36	39	35	28	37	33	39	41
C100-C	Augmix+pAdaIN	DenseNet-BC	**22.2**	**37.5**	**58**	**49**	**40**	**26**	**54**	**30**	**28**	**35**	**38**	**33**	**25**	**36**	**32**	**37**	**40**
C100-C	Augmix [18]	ResNext-29	21.0	34.4	**56**	**48**	32	23	**49**	27	25	32	35	32	24	32	30	34	37
C100-C	Augmix+pAdaIN	ResNext-29	**17.3**	**31.6**	58	**48**	**24**	**20**	54	**23**	**21**	**28**	**30**	**25**	**19**	**27**	**27**	**33**	**36**

Manipulating Structure

- Multi-sample approaches
- Structural analogies
- Novel videos of similar structure

Manipulating by Understanding Structure

- Speed up videos “gracefully” using “speed” as supervision

Structure Preserving Manipulation

- Image classification and domain adaptation

Structure is Key to **Image Understanding**

Demonstrate using **Structure Aware Manipulation**

Next?

- 3D-aware structure manipulation
- Manipulating multiple objects in videos
- Functional relationships: A person riding a bike vs a person beside a bike

Thank You! Questions?