InstaFormer: Instance-Aware Image-to-Image Translation with Transformer

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Abstract

We present a novel Transformer-based network architecture for instance-aware image-to-image translation, dubbed InstaFormer, to effectively integrate global- and instance-level information. By considering extracted content features from an image as tokens, our networks discover global consensus of content features by considering context information through a self-attention module in Transformers. By augmenting such tokens with an instance-level feature extracted from the content feature with respect to bounding box information, our framework is capable of learning an interaction between object instances and the global image, thus boosting the instance-awareness. We replace layer normalization (LayerNorm) in standard Transformers with adaptive instance normalization (AdaIN) to enable a multi-modal translation with style codes. In addition, to improve the instance-awareness and translation quality at object regions, we present an instance-level content contrastive loss defined between input and translated image. We conduct experiments to demonstrate the effectiveness of our InstaFormer over the latest methods and provide extensive ablation studies.

1. Introduction

For a decade, image-to-image translation (I2I), aiming at translating an image in one domain (i.e., source) to another domain (i.e., target), has been popularly studied, to the point of being deployed in numerous applications, such as style transfer [14, 21], super-resolution [11, 30], inpainting [24, 44], or colorization [62, 63].

In particular, most recent works have focused on designing better disentangled representation to learn a multi-modal translation from unpaired training data [22, 33, 43]. While they have demonstrated promising results, most of these methods only consider the translation on a whole image, and do not account for the fact that an image often contains many object instances of various sizes, thus showing the limited performance at content-rich scene translation, e.g., driving scene, which is critical for some downstream tasks, such as domain adaptive object detection [3], that require well-translated object instances.

To address the aforementioned issues, some methods [3, 27, 49] seek to explicitly consider an object instance in an image within deep convolutional neural networks (CNNs). This trend was initiated by instance-aware I2I (INIT) [49], which treats the object instance and global image separately. Following this [49], some variants were proposed, e.g., jointly learning translation networks and object detection networks, called detection-based unsupervised I2I (DUNIT) [3], or using an external memory module, called memory-guided unsupervised I2I (MGUIT) [27]. While these methods improve an instance-awareness to some extent, they inherit limitation of CNN-based architectures [3, 27, 49], e.g., local receptive fields or limited encoding of relationships or interactions between pixels or patches within an image which are critical in differentiating an object instance from an whole image and boosting its translation.

To tackle these limitations, for the first time, we present to utilize Transformer [53] architecture within I2I networks that effectively integrates global- and instance-level information present in an image, dubbed InstaFormer. We follow common disentangled representation approaches [22, 33] to extract both content and style vectors. By considering extracted content features from an image as tokens,
our Transformer-based aggregator mixes them to discover global consensus by considering global context information through a self-attention module, thus boosting the instance-awareness during translation. In addition, by augmenting such tokens by an instance-level feature extracted from the global content feature with respect to bounding box information, our framework is able to learn an interaction between not only object instance and global image, but also different instances, followed by a position embedding technique to consider both global- and instance-level patches at once, which helps the networks to better focus on the object instance regions. We also replace layer normalization (LayerNorm) [1] in Transformers with adaptive instance normalization (AdaIN) [21] to facilitate a multi-modal translation with extracted or random style vectors. Since aggregation raw content and style vectors directly with Transformer requires extremely large computation [12,29], we further propose to apply a convolutional patch embedding and deconvolutional module at the beginning and end of our Transformer-based aggregator. In addition, to improve the instance-awareness and quality of translation images at object regions, we present an instance-level content contrastive loss defined between input and translated images.

In experiments, we demonstrate our framework on several benchmarks [8,15,49] that contain content-rich scenes. Experimental results on various benchmarks prove the effectiveness of the proposed model over the latest methods for instance-aware I2I. We also provide an ablation study to validate and analyze components in our model.

2. Related Work

Image-to-Image Translation. While early efforts for I2I are based on supervised learning [26], most recent state-of-the-arts focus on unpaired settings [2,13,37,61,65,67]. CycleGAN [68] attempts this by proposing a cycle-consistency loss which has been one of standard losses for unpaired I2I. Inspired by CycleGAN, numerous methods utilize cycle-consistency [7,20,22,31,33,59], and they can be largely divided into uni-modal models [36,59,61] and multi-modal models [7,22,33] methods. Specifically, MUNIT [22] assumes that an image representation can be disentangled into a domain-specific style and a domain-invariant content representation and uses these disentangled latent features with cycle-consistency to generate the translations. However, the content in translated image can be easily distorted, and cycle mapping requires multiple generators and discriminators. To address these, CUT [43] and F-LSeSim [65] propose novel losses inspired by InfoNCE [42] to directly compute distance between input and translated images in an one-side framework without cycle-consistency. However, they still have shown limited performance to encode an object-awareness at the translated image.

Instance-Aware Image-to-Image Translation. Some methods attempted to address the aforementioned issues [3,27,41,49]. INIT [49] attempted to translate the whole image and object instances independently. DUNIT [3] proposed to further train detection module and adopted instance-consistency loss for object-awareness. MGUIIT [27] utilizes bounding box to read and write class-wise memory module, and has access to class-aware features on memory at test-time. The aforementioned methods inherit limitation of CNN-based architecture, e.g., local receptive fields or limited encoding of relationships or interactions within an image [22,33,68].

Vision Transformers and Image Generation Recently, Vision Transformers (ViT) have shown to attain highly competitive performance for a wide range of vision applications, such as image classification [10,12,52,55], object detection [5,9,69], and semantic segmentation [58,66]. Inspired by ViT [12], some improvements are made to improve the computational complexity [29,38,54,55]. For example, Swin Transformer [38] proposes relative position biases, and restricts self-attention computation within shifted windows. MLP-Mixer [50] suggests to replace self-attention with an MLP, achieving memory efficiency and competitive performance [35,39,51]. In this paper, we introduce ViT-based aggregator to further enhance to learn instance-awareness by aggregating information from local region as well as global image.

On the other hands, there exist several efforts to adapt Vision Transformers to image generation tasks [6,23,28,34,64]. As seminal work, TransGAN [28] first presents a GAN structure using pure Transformer, but has only validated on low-resolution images. [64] has achieved success on generating high-resolution images. [23] leverages Transformers to build the bipartite structure to allow long-range interactions. To our best knowledge, our work is the first attempt to adopt Transformers in instance-aware image translation.

3. Methodology

3.1. Overview

Our approach aims to learn a multi-modal mapping between two domains $\mathcal{X} \subset \mathbb{R}^{H \times W \times 3}$ and $\mathcal{Y} \subset \mathbb{R}^{H \times W \times 3}$ without paired training data, but with a dataset of unpaired instances $X = \{x \in \mathcal{X}\}$ and $Y = \{y \in \mathcal{Y}\}$. Especially, we wish to model such a mapping function to have an ability that jointly accounts for whole image and object instances. Unlike conventional I2I methods [3,16,22,27,33,49] that were formulated in a two-sided framework to exploit a cycle-consistency constraint, which often generates some distortions on the translated images and requires auxiliary networks for inverse mapping [68], we formulate our approach in an one-sided framework [43].

In specific, as illustrated in Fig. 2, our framework,
dubbed InstaFormer, consists of content encoder $E$ and generator $G$, similar to [43,65], and additional encoder $T$ with Transformers [53] to improve the instance-awareness by considering global consensus between whole image and object instances. To translate an image $x$ in domain $X$ to domain $Y$, our framework first extracts a content feature map $c = E(x) \in \mathbb{R}^{h \times w \times l_c}$ from $x$, with height $h$, width $w$, and $l_c$ channels, and randomly draws a style latent code $s \in \mathbb{R}^{1 \times 1 \times l_s}$ from the prior distribution $q(s) \sim \mathcal{N}(0, I)$ to achieve a multi-modal translation. Instead of directly feeding $c$ and $s$ to the generator $G$, as done in the literature [22,33], we aggregate information in the content $c$ to discover global consensus between the global image and object instances in a manner that we first extract an object instance content vector $c_i^{ins}$ for $i$-th object bounding box with parameters $B_i = [x_i, y_i, h_i, w_i]$, where $(x_i, y_i)$ represent a center point, and $h_i$ and $w_i$ represent height and width of the box and $i \in 1, ..., N$ where $N$ is the number of instance, and then mix $\{c, \{c_i^{ins}\}_i, s\}$ through the proposed Transformer module $T$ to extract global embedding $u$ and instance embedding $u_i^{ins}$, which are independently used to generate global-level translated image $\hat{y} = G(u) \in \mathbb{R}^{h' \times w' \times 3}$ and instance-level translated images $\hat{y}_i^{ins} = G(u_i^{ins}) \in \mathbb{R}^{h'_i \times w'_i \times 3}$. In our framework, during training, we have access to the ground-truth object bounding boxes, while we do not access them at test-time.

To train our networks, we first use an adversarial loss defined between a translated image $\hat{y}$ and a real image $y$ from $Y$ with discriminators, and a global content contrastive loss defined between $x$ and $\hat{y}$ to preserve the global content. To improve the disentanglement ability for content and style, following [22], we also use both image reconstruction loss and style reconstruction loss by leveraging an additional style encoder for $Y$. To improve the instance-awareness and the quality of translation images at object instance regions, we newly present an instance-level content contrastive loss between $x$ and $\hat{y}$.

3.2. Content and Style Mixing with Transformers

Most existing I2I methods [3,22,27,33,43,49] attempted to aggregate a content feature map with deep CNNs with residual connections, which are often called residual blocks, often inserted between encoder and generator networks. They are thus limited in the sense that they inherit limitation of CNN-based architecture, e.g., local receptive fields or limited encoding of relationships or interactions between pixels and patches within an image [22,33,49]. In instance-aware I2I task, enlarging the receptive fields and encoding an interaction between objects and global image may be of prime importance. For instance, if an image contains a car object on the road, using the context information of not only global background, e.g., road, but also other instances, e.g., other cars or person, would definitely help to translate the image more focusing on the instance, but existing CNN-based methods [22,33,43] would limitedly handle this.

To overcome this, we present to utilize Transformer architecture [53] to enlarge the receptive fields and encode the interaction between features for instance-aware I2I. To this end, extracted content vector $c \in \mathbb{R}^{h \times w \times l_c}$ from $x$ can be flattened as a sequence $c' = \text{Reshape}(c)$ with the number of tokens $hw$ and channel $l_c$, which can be directly used as input for Transformers. However, this requires extremely
high computational complexity due to the huge number of tokens $hw$, e.g., full HD translation.

**Patch Embedding and Expanding.** To address this issue, inspired by a patch embedding in ViT [12], we first apply sequential convolutional blocks to reduce the spatial resolutions. Instead of applying a single convolution in ViT [12] for extracting non-overlapping patches, we use sequential overlapped convolutional blocks to improve the stability of training while reducing the number of parameters involved [57]. We define this process as follows:

$$p = \text{Conv}(c) \in \mathbb{R}^{(h/k)\times(w/k)\times l'_c},$$

where $k \times k$ is the stride size of convolutions, and $l'_c$ is a projected channel size. After feed-forwarding Transformer blocks such that $z = T(p) \in \mathbb{R}^{(h/k)\times(w/k)\times l'_c}$, downsampled feature map $z$ should be upsampled again with additional deconvolutional blocks, which are symmetric architectures to the convolutions, defined as follows:

$$u = \text{DeConv}(z) \in \mathbb{R}^{h\times w\times l_c}.$$  

In addition, for a multi-modal translation, we leverage a style code vector $s \in \mathbb{R}^{1\times 1\times l_s}$, and thus this should be considered during mixing with Transformers [53]. Conventional methods [21, 22, 33] attempted to mix content and style vectors using either concatenation [33] or AdaIN [21]. In our framework, by slightly changing the normalization module in Transformers, we are capable of simultaneously mixing content and style vectors such that $T(p, s)$.

Any forms of Transformers [12, 38, 50, 55, 60] can be considered as a candidate in our framework, and in experiments, ViT-like [12] architecture is considered for $T$. In the following, we explain the details of Transformer modules.

**Transformer Aggregator.** In order to utilize Transformer to process content patch embeddings $p$, our work is built upon the ViT encoder, which is composed of an multi-head self-attention (MSA) layer and a feed-forward MLP with GELU [53], where normalization layers are applied before both parts. Especially, for I2I, we adopt AdaIN instead of LayerNorm [1] to control the style of the output with the affine parameters from style vector $s$ and to enable multimodal outputs. In specific, content patch embedding $p$ is first reshaped, and position embedding is achieved such that

$$z_0 = \text{Reshape}(p) + E \in \mathbb{R}^{(h/k\cdot w/k)\times l'_c},$$

where $E$ represents a position embedding [53], which will be discussed in the following.

These embedded tokens $z_0$ are further processed by the sequential Transformer encoder blocks as follows:

$$z'_t = \text{MSA}(\text{AdaIN}(z_{t-1}, s')) + z_{t-1},$$
$$z_t = \text{MLP}(\text{AdaIN}(z'_t, s')) + z'_t,$$

where $z'_t$ and $z_t$ denote the output of MSA and MLP modules for $t$-th block respectively and $t \in 1, ..., T$, respectively, $s'$ indicates AdaIN parameters extracted from $s$. After $L$ Transformer modules, followed by reshaping to original resolution, we finally achieve the output of Transformer block $T$ such that $z_T = T(p, s')$. As exemplified in Fig. 3, our learned self-attention well considers the interaction between object instances and global image.

3.3. Instance-Aware Content and Style Mixing

So far we discussed a method for content and style mixing with Transformers [12]. This framework can improve the translation quality especially at instance regions to some extent, but the nature of irregular shape of object instances may hinder the performance boosting of our framework. In particular, global-level aggregation itself is limited to capture details of a tiny object and it is not always guaranteed that an object is located in a single regular patch. To overcome this, we present a novel technique to aggregate instance-level content features and global-level content features simultaneously, which enables the model to pay more attention to the relationships between global scenes and object instances.

In specific, given ground-truth bounding boxes with parameters $B_i$, we extract instance-level content feature maps through through ROI Align [18] module defined as follows:

$$c_{zi} = \text{RoIAlign}(c; B_i) \in \mathbb{R}^{h\times k\times l_c},$$

where $k \times k$ is a fixed spatial resolution. This can be further processed with the convolutional blocks as proposed above such that

$$p_{zi} = \text{Conv}(c_{zi}) \in \mathbb{R}^{1\times 1\times l'_c}.$$  

In our framework, by concatenating $p$ and $p_{zi}$, we build a new input for Transformer $z_0$ such that

$$z_0 = \text{Reshape}(\text{Cat}(p, \{p_{zi}\}_i)) + \hat{E} \in \mathbb{R}^{(h/k\cdot w/k+N)\times l'_c},$$
where \( \text{Cat}(\cdot, \cdot) \) denotes a concatenation operator and \( \hat{E} \) is a corresponding positional embedding. Transformer blocks are then used to process \( z_0 \) similarly to above to achieve \( z_T \), which is decomposed into \( z_{T, r}^{\text{ins}} \).

3.4. Instance-Aware Position Embedding

Since Transformer \([53]\) block itself does not contain positional information, we add positional embedding \( E \) as described above. To this end, our framework basically utilizes existing technique \([12]\), but the main difference is that our proposed strategy enables simultaneously considering regularly-partitioned patches \( p \) and instance patches \( p_i^{\text{ins}} \) in terms of their spatial relationships.

The deep networks are often biased towards learning lower frequency functions \([45]\), so we use high frequency functions to alleviate such bias. We denote \( \gamma(\cdot) \) as a sinusoidal mapping into \( \mathbb{R}^{2K} \) such that \( \gamma(a) = (\sin(2^0 \pi a), \cos(2^0 \pi a), \ldots, \sin(2^{K-1} \pi a), \cos(2^{K-1} \pi a)) \) for a scalar \( a \).

In specific, as a global feature map is divided into regular grids, each regular patch can be represented to have center coordinates \((x_g, y_g)\) with patch width \( w_g \) and height \( h_g \) of regular size for \( g \)-th patch \( p(g) \). After embedding for each information through \( \gamma(\cdot) \) and concatenating along the channel axis, it is further added to the patch embedded tokens.

\[
E = \text{Cat}(\gamma(x_g), \gamma(y_g), \gamma(w_g), \gamma(h_g)) \tag{8}
\]

Unlike regular patches, which have the same size of width and height for each, instance patches contain positional information of corresponding bounding boxes, which contain the centerpoint coordinates \((x_i, y_i)\) and width and height \((w_i, h_i)\). Instance-wise \( E \) is denoted as:

\[
E_i^{\text{ins}} = \text{Cat}(\gamma(x_i), \gamma(y_i), \gamma(w_i), \gamma(h_i)) \tag{9}
\]

Then \( \hat{E} = \text{Cat}(E, E_i^{\text{ins}}) \). Fig. 4 illustrates the difference in how regular patch and instance patch are handled.

3.5. Loss Functions

Adversarial Loss. Adversarial loss aims to minimize the distribution discrepancy between two different features \([17, 40]\). We adopt this to learn the translated image \( \hat{y} \) to be similar to an image \( y \) from \( \mathcal{Y} \) defined such that

\[
L_{\text{GAN}} = \mathbb{E}_{x \sim \mathcal{X}}[\log(1 - D(\hat{y}))] + \mathbb{E}_{y \sim \mathcal{Y}}[\log D(y)], \tag{10}
\]

where \( D(\cdot) \) is the discriminator.

Global Content Loss. To define the content loss between \( x \) and \( \hat{y} \), we exploit infoNCE loss \([42]\), defined as

\[
\ell(v, v^+, v^-) = -\log \left( \frac{\exp(v \cdot v^+ / \tau)}{\exp(v \cdot v^+ / \tau) + \sum_{n=1}^{N} \exp(v \cdot v_n^- / \tau)} \right), \tag{11}
\]

where the temperature parameter, and \( v^+ \) and \( v^- \) represent positive and negative for \( \hat{v} \).

We set pseudo positive samples between input image \( x \) and translated image \( \hat{y} \). For the content feature from translated image \( \hat{c}(s) = \mathcal{E}(\hat{y}) \), we set positive patches \( c(s) \), and negative patches \( c(S \setminus s) \) from \( x \), where \( S \setminus s \) represents indexes except for \( s \), following \([43, 65]\). Global content loss function is then defined as

\[
L_{\text{NCE}}^{\text{global}} = \mathbb{E}_{x \sim \mathcal{X}} \sum_{l} \sum_{s} \ell(\hat{c}_l(s), c_l(s), c_l(S \setminus s)), \tag{12}
\]

where \( c_l \) is feature at \( l \)-th level, \( s \in \{1, 2, ..., S_l\} \) and \( S_l \) is the number of patches in each \( l \)-th layer.

Instance-level Content Loss. To improve the instance-awareness and the quality of translation images at object regions, we newly present an instance-level content contrastive loss. Our instance-level content loss is then defined such that

\[
L_{\text{NCE}}^{\text{ins}} = \mathbb{E}_{x \sim \mathcal{X}} \sum_{l} \sum_{m} \ell(\hat{c}_l^{\text{ins}}(m), c_l^{\text{ins}}(m), c_l^{\text{ins}}(M \setminus m)), \tag{13}
\]

where \( m \in \{1, 2, ..., M_l\} \) and \( M_l \) is the number of patches at each instance. Fig. 5 illustrates how our suggested content losses work, with the procedure to define positive and negative samples.
### Image Reconstruction Loss.
We additionally make use of image reconstruction loss to help disentanglement between content and style. For regularization, we use a reconstruction loss to ensure that our $G$ can reconstruct an image for domain $y$. To be specific, $y$ is fed into $E$ and style encoder $S$ to obtain a content feature map $c^y = E(y)$ and a style code $s^y = S(y)$. We then compare the reconstructed image $G(T(c^y, s^y))$ for domain $y$ with $y$ as follows:

$$L_{recon}^{img} = \mathbb{E}_{y \sim Y} \| G(T(c^y, s^y)) - y \|_1.$$  

(14)

### Style Reconstruction Loss.
In order to better learn disentangled representation, we compute L1 loss between style code from the translated image and randomly generated style code in order to enable mapping generated style features to Gaussian distribution such that

$$L_{recon}^{style} = \mathbb{E}_{x \sim X, y \sim Y} \| S(\hat{y}) - s \|_1.$$  

(15)

### Total Loss.
The total loss function is as follows:

$$\min_{E,G,S,D} \max_{\lambda} L(E,G,D) = L_{GAN} + \lambda_{glob} L_{NCE}^{glob} + \lambda_{ins} L_{NCE}^{ins} + \lambda_{style} L_{recon}^{style} + \lambda_{img} L_{recon}^{img},$$  

(16)

where $\lambda_{glob}, \lambda_{ins}, \lambda_{style},$ and $\lambda_{img}$ are weights that control the importance of each loss.

## 4. Experiments

### 4.1. Implementation Details
We first summarize implementation details in our framework. We conduct experiments using a single 24GB RTX 3090 GPU. Training datasets are resized to the size of 352x352. We employ an Adam optimizer for 200 epochs using a step decay learning rate scheduler. A batch size of 8, an initial learning rate of 2e-4. The number of NCE layers $L$ is 3. For the loss weights, we set as $\lambda_{glob} = 1, \lambda_{ins} = 1, \lambda_{style} = 10,$ and $\lambda_{img} = 5$. As described above, we implement our framework with the most representative vision Transformer-based, i.e., ViT [12], but we will show our framework works with MLP-Mixer [50] in the following. We will make our code publicly available.

### 4.2. Experimental Setup
We conduct experiments on two standard datasets for instance-aware I2I, INIT dataset [49] and KITTI-Cityscapes dataset [8, 15]. INIT dataset [49] provides street scene images including 4 domain categories (sunny, night, rainy, cloudy) with object bounding box annotations for car, person, and traffic sign. We conduct translation experiments for sunny→night, night→sunny, sunny→rainy, sunny→cloudy, and cloudy→sunny. KITTI object detection benchmark [15] and Cityscapes [8] dataset are used to evaluate domain adaptation for object detection on KITTI→Cityscapes. KITTI contains 7,481 images for training and 7,518 images for testing with the bounding box annotations for 60 object classes. Cityscapes dataset consists of 5,000 images with pixel-level annotations for 30 classes.

In this section, we compared our InstaFormer with recent state-of-the-art instance-aware I2I methods: INIT [49], DUNIT [3], MGUIT [27], and several unsupervised image-to-image translation methods: CycleGAN [68], UNIT [36], CUT [43], MUNIT [22], and DRIT [33].

### 4.3. Experimental Results

#### Qualitative Evaluation.
We first conduct qualitative comparisons of our method to CycleGAN [68], UNIT [36], MUNIT [22], DRIT [33], and MGUIT [27] on sunny→night, night→sunny, sunny→rainy, sunny→cloudy, and cloudy→sunny tasks in INIT dataset [49]. As shown in Fig. 6, our model generates higher quality translated results, particularly at object instance regions. Especially, as exemplified in the highlighted regions in Fig. 7, our model is good at capturing local regions within multiple instances thanks to Transformer-based architecture that simultaneously consider object instances and global image, and proposed instance-level contrastive learning. Note that our attention map visualization also proves this, well illustrated in Fig. 3. Note that MGUIT [27] has access on their trained memory module during test-time, which is additional burden.

#### Quantitative Evaluation.
Following the common practice [3, 27, 49], we evaluate our InstaFormer with inception score (IS) [48] and conditional inception score (CIS) [22]. Since the metrics above are related to diversity of translated images, we also evaluate our methods with Fréchet incep-
Figure 6. **Qualitative comparison on INIT dataset [49]:** (top to bottom) sunny→night, night→sunny, and cloudy→sunny results. Among the methods, ours preserves object details well and show realistic results.

Figure 7. **Visual comparison with MGUIT [27]:** (a) input, (b) MGUIT [27], and (c) InstaFormer. We show the results for sunny→rainy (left) and sunny→cloudy (right).

Figure 8. **User study results on INIT dataset [49].** Our method is most preferred for overall quality, semantic consistency and style relevance, compared to CUT [43], MUNIT [22], DRIT [33], and MGUIT [27].
In this paper, we have presented Transformer-based networks, dubbed InstaFormer, for instance-aware image-to-image translation, which enables boosting the translation of object instances as well as global image. By simultaneously considering instance-level features and global-level features with Transformers, we learned an interaction between not only object instance and global image, but also different instances. To improve the instance-awareness during translation, we proposed an instance-level content contrastive loss. Experiments on various datasets with evaluation metrics have shown that our framework outperforms the existing solutions for instance-aware I2I.

5. Conclusion

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