Deep learning

11.3. Conditional GAN and image translation

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All the models we have seen so far model a density in high dimension and provide means to sample according to it, which is useful for synthesis only.

However, most of the practical applications require the ability to sample a **conditional distribution.** E.g.:

- Next frame prediction.
- "in-painting",
- segmentation,
- style transfer.

This would in particular address some of the shortcomings we saw in lecture 7.3. "Denoising autoencoders".

Notes

The following applications require to *condition* the distribution with a signal:

- Next frame prediction where a frame is sampled given the preceding frames.
- Image "in-painting", where the missing part of an image is sampled given the available one.
- Semantic segmentation, where the label map is sampled given the image.
- Style transfer, where a picture in a certain style (e.g. à la Renoir), is sampled given the same image in another style (e.g. à la Picasso).

For all these these applications, the task goes beyond sampling according to a certain distribution: one must have a way to condition the distribution according to an input signal.

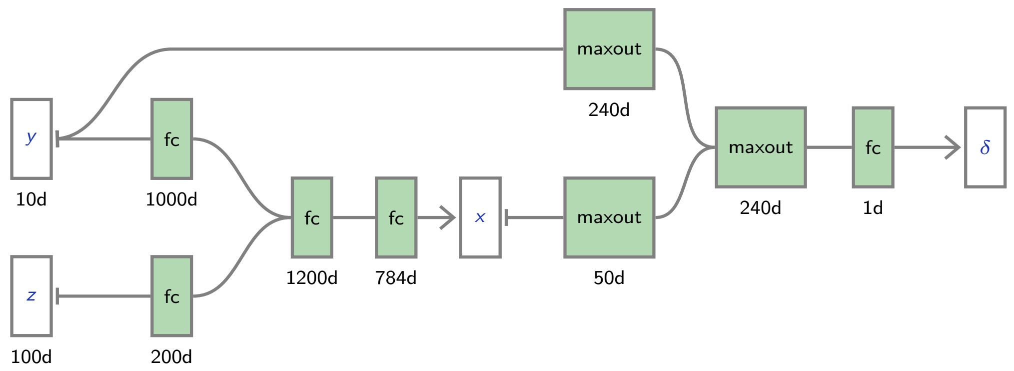
The Conditional GAN proposed by Mirza and Osindero (2014) consists of parameterizing both $\mathbf{G}$ and $\mathbf{D}$ by a conditioning quantity Y.

$$V(\mathbf{D}, \mathbf{G}) = \mathbb{E}_{(X,Y)\sim\mu}\Big[\log \mathbf{D}(X, Y)\Big] + \mathbb{E}_{Z\sim\mathcal{N}(0,I), Y\sim\mu_Y}\Big[\log(1 - \mathbf{D}(\mathbf{G}(Z, Y), Y))\Big],$$

To generate MNIST characters, with

$$Z \sim \mathscr{U}\left([0,1]^{100}\right),$$

and conditioned with the class y, encoded as a one-hot vector of dimension 10, the model is



Notes

In the work of Mirza and Osindero (2014), the generator takes as input

- a random vector z of dimension 100 whose components are uniformly distributed in $[0, 1]$, and
- a conditioning one-hot encoding vector y of the class. This vector is of dimension 10 with zeros everywhere except at the index equal to the class of the sample, where it is 1.

The discriminator takes as input

- the same conditioning vector y as the generator, and
- a sample x which is either a sample generated by the generator, or a real sample from the training dataset.

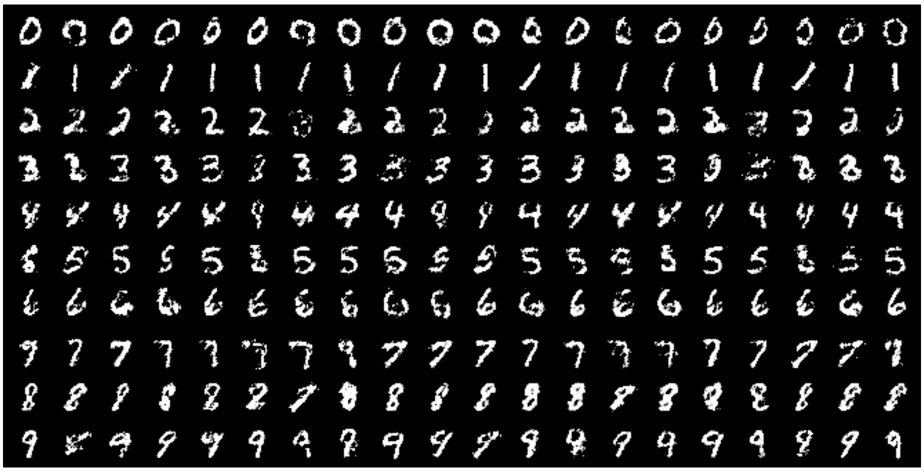


Figure 2: Generated MNIST digits, each row conditioned on one label

(Mirza and Osindero, 2014)

Another option to condition the generator consists of making the parameter of its batchnorm layers class-conditional (Dumoulin et al., 2016).

(Brock et al., 2018)

Notes

When the batchnorm layers are class-specific in each layer, batchnorm for a certain class moves the mean and variance of activation maps to certain values, and for other classes to other values.
The work of Dumoulin et al. (2016) and Brock et al. (2018) scaled-up GANs to large images. This involved a lot of technical tricks, large batches, and a lot computation.

(Brock et al., 2018)

Image-to-Image translations

The main issue to generate realistic signals is that the value X to predict may remain non-deterministic given the conditioning quantity Y.

For a loss function such as MSE, the best fit is $\mathbb{E}(X|Y = y)$ which can be pretty different from the MAP, or from any reasonable sample from $\mu_{X|Y=y}$.

In practice, for images there is often remaining location indeterminacy that results into a blurry prediction.

Sampling according to $\mu_{X|Y=y}$ is the proper way to address the problem.

Notes

For image-to-image translation, the conditioning quantity is no longer a single class but a full image.
We saw in lecture 7.3. "Denoising autoencoders" that the synthesis may produce blurry parts. For instance, due to the uncertainty of the location of a given object or part, the best MSE can do is to average over all the locations of the object, which generate a blurry signal.
The proper way to fix this issue and to produce media with proper statistics, which can be expressed as fooling a discriminator, hence sampled according to the posterior distribution $\mu_{X|Y=y}$ modeled with a conditional generator.

Isola et al. (2016) use a GAN-like setup to address this issue for the "translation" of images with pixel-to-pixel correspondence:

- edges to realistic photos,
- semantic segmentation,
- gray-scales to colors, etc.

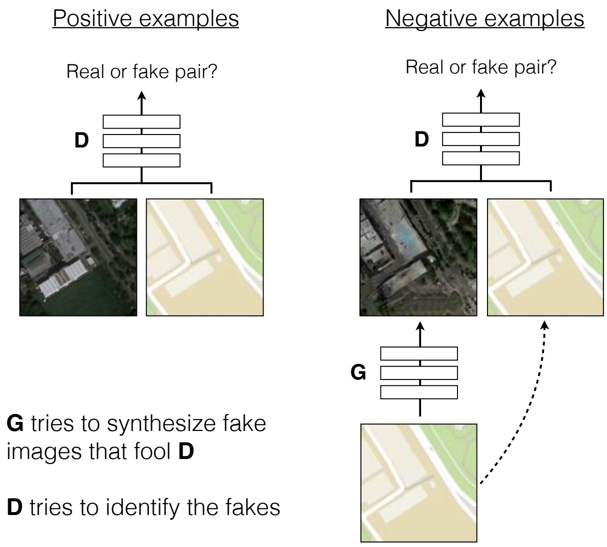


Figure 2: Training a conditional GAN to predict aerial photos from maps. The discriminator, D, learns to classify between real and synthesized pairs. The generator learns to fool the discriminator. Unlike an unconditional GAN, both the generator and discriminator observe an input image.

(Isola et al., 2016)

They define

$$V(\mathbf{D}, \mathbf{G}) = \mathbb{E}_{(X,Y)\sim\mu}\Big[\log \mathbf{D}(Y, X)\Big] + \mathbb{E}_{Z\sim\mu_Z, X\sim\mu_X}\Big[\log(1 - \mathbf{D}(\mathbf{G}(Z, X), X))\Big],$$

$$\mathscr{L}_{L^1}(\mathbf{G}) = \mathbb{E}_{(X,Y)\sim\mu, Z\sim\mathscr{N}(0,I)}\Big[\,\|Y - \mathbf{G}(Z, X)\|_1\Big],$$

and

$$\mathbf{G}^* = \underset{\mathbf{G}}{\operatorname{argmin}} \max_{\mathbf{D}} \; V(\mathbf{D}, \mathbf{G}) + \lambda \mathscr{L}_{L^1}(\mathbf{G}).$$

The term $\mathscr{L}_{L^1}$ pushes toward proper pixel-wise prediction, and V makes the generator prefer realistic images to better fitting pixel-wise.

Note that contrary to Mirza and Osindero's convention, here X is the conditioning quantity and Y the signal to generate.

For **G**, they start with Radford et al. (2015)'s DCGAN architecture and add skip connections from layer i to layer $D - i$ that concatenate channels.

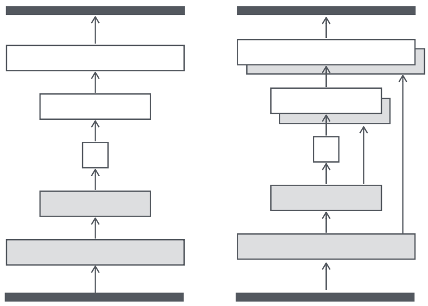


Figure 3: Two choices for the architecture of the generator. The "U-Net" [34] is an encoder-decoder with skip connections between mirrored layers in the encoder and decoder stacks.

(Isola et al., 2016)

Randomness Z is provided through dropout, and not as an additional input.

The discriminator **D** is a regular convnet which scores overlapping patches of size $N \times N$ and averages the scores for the final one.

This controls the network's complexity, while allowing to detect any inconsistency of the generated image (e.g. blurriness).

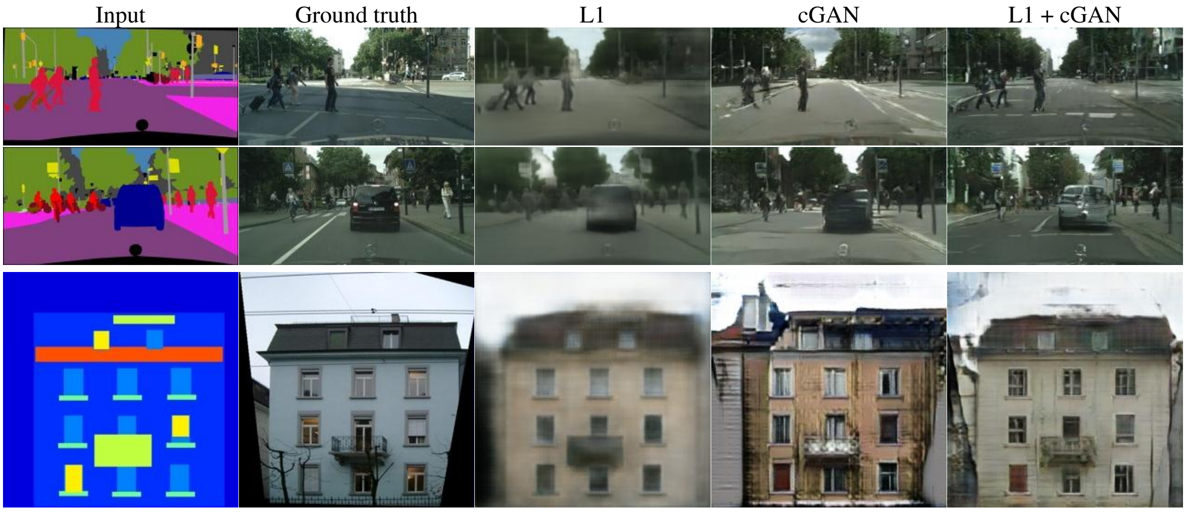


Figure 4: Different losses induce different quality of results. Each column shows results trained under a different loss. Please see `https://phillipi.github.io/pix2pix/` for additional examples.

(Isola et al., 2016)

Figure 6: Patch size variations. Uncertainty in the output manifests itself differently for different loss functions. Uncertain regions become blurry and desaturated under L1. The 1x1 PixelGAN encourages greater color diversity but has no effect on spatial statistics. The 16x16 PatchGAN creates locally sharp results, but also leads to tiling artifacts beyond the scale it can observe. The 70x70 PatchGAN forces outputs that are sharp, even if incorrect, in both the spatial and spectral (coforfulness) dimensions. The full 256x256 ImageGAN produces results that are visually similar to the 70x70 PatchGAN, but somewhat lower quality according to our FCN-score metric (Table 2). Please see `https://phillipi.github.io/pix2pix/` for additional examples.

(Isola et al., 2016)

Figure 8: Example results on Google Maps at 512x512 resolution (model was trained on images at 256x256 resolution, and run convolutionally on the larger images at test time). Contrast adjusted for clarity.

(Isola et al., 2016)

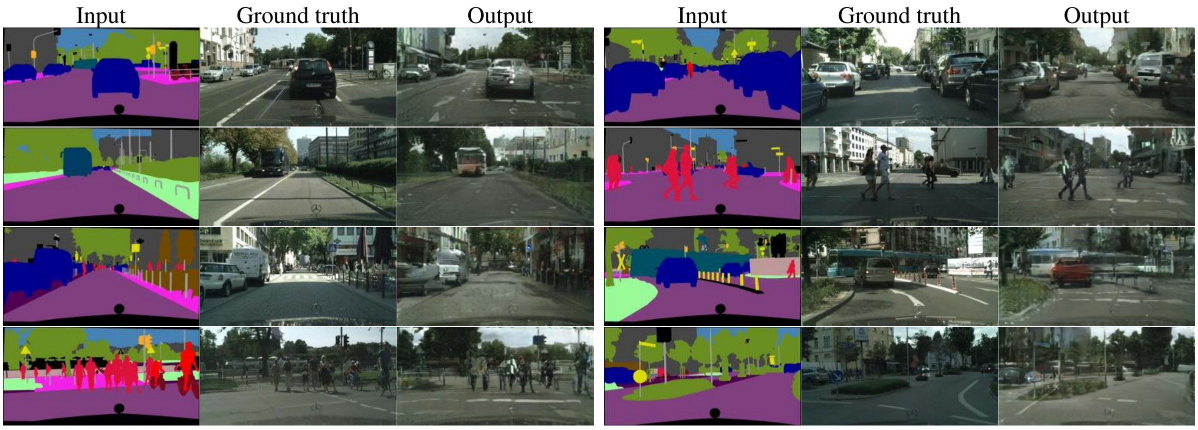


Figure 11: Example results of our method on Cityscapes labels→photo, compared to ground truth.

(Isola et al., 2016)

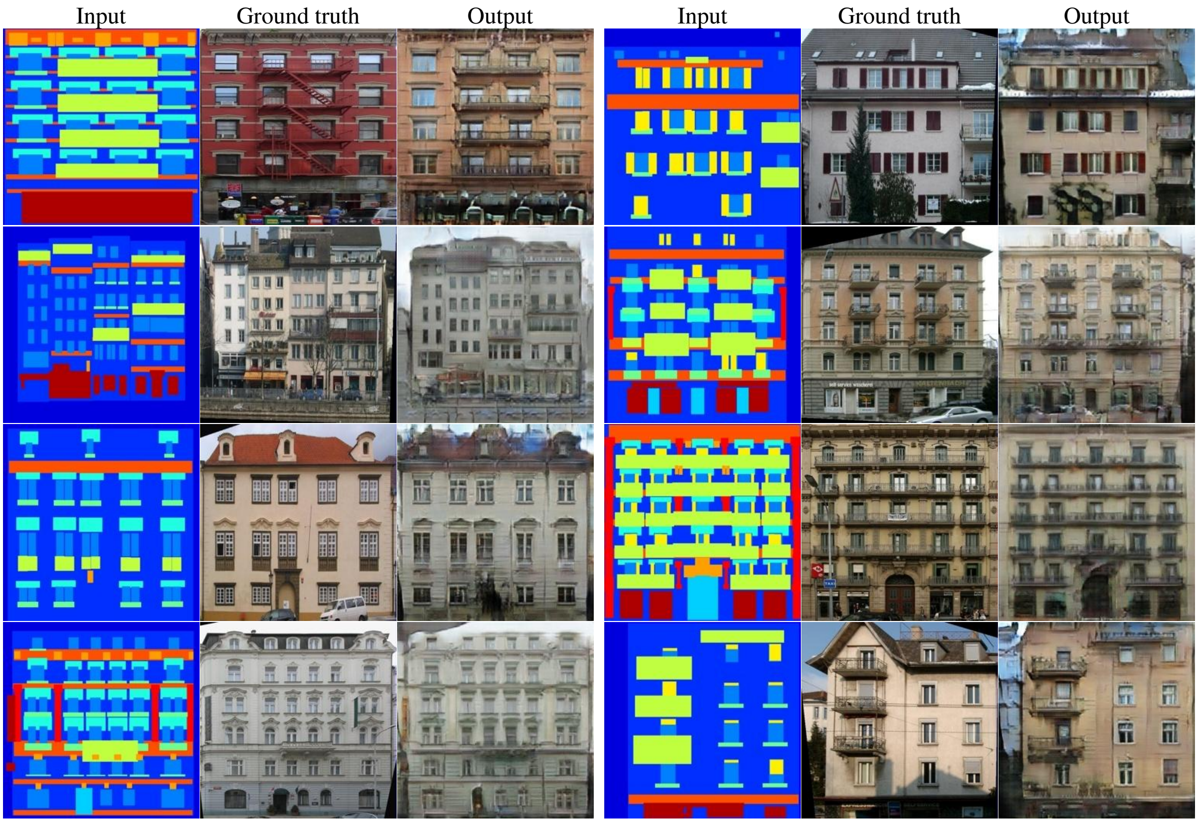


Figure 12: Example results of our method on facades labels→photo, compared to ground truth

(Isola et al., 2016)

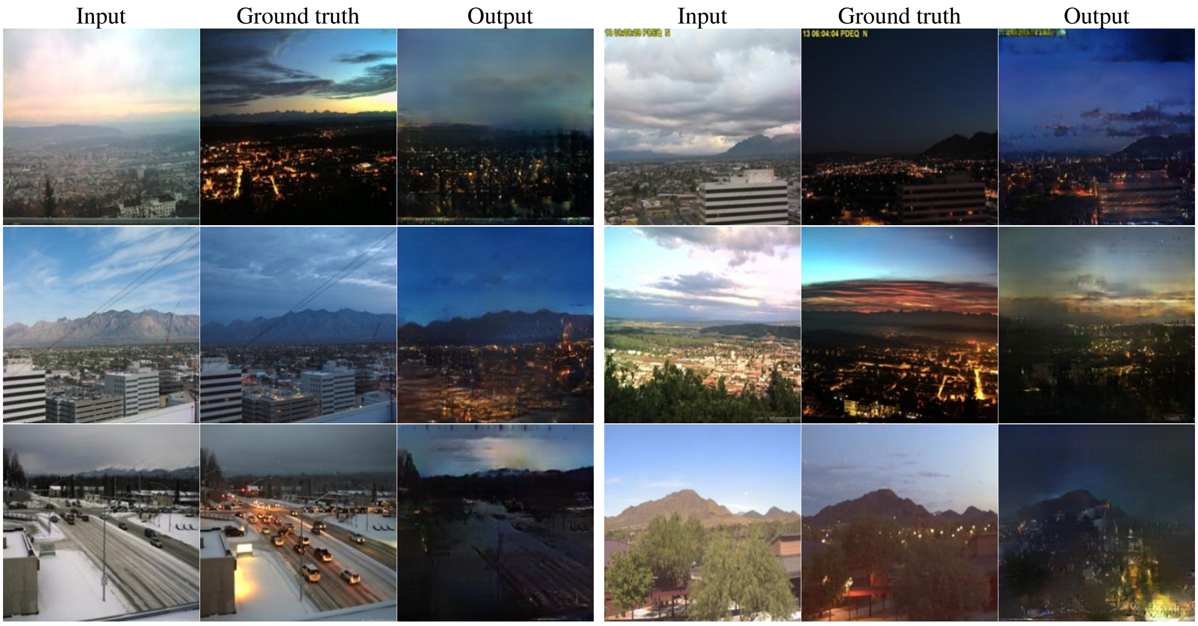


Figure 13: Example results of our method on day→night, compared to ground truth.

(Isola et al., 2016)

Figure 14: Example results of our method on automatically detected edges→handbags, compared to ground truth.

(Isola et al., 2016)

Notes

The task here is to generate a color version of a sketch image.
The training set was generated by taking real images which were used as ground truth, and to apply an edge detector on them to obtain the input.

Figure 16: Example results of the edges→photo models applied to human-drawn sketches from [10]. Note that the models were trained on automatically detected edges, but generalize to human drawings

(Isola et al., 2016)

Notes

Once the generator was trained, it was then applied on sketches done by humans.

The main drawback of this technique is that it requires pairs of samples with pixel-to-pixel correspondence.

In many cases, one has at its disposal examples from two densities and wants to translate a sample from the first ("images of apples") into a sample likely under the second ("images of oranges").

We consider X r.v. on $\mathscr{X}$ a sample from the first data-set, and Y r.v. on $\mathscr{Y}$ a sample for the second data-set. Zhu et al. (2017) propose to train at the same time two mappings

$$\mathbf{G} : \mathscr{X} \to \mathscr{Y}$$
$$\mathbf{F} : \mathscr{Y} \to \mathscr{X}$$

such that

$$\mathbf{G}(X) \sim \mu_Y,$$
$$\mathbf{F} \circ \mathbf{G}(X) \simeq X.$$

Where the matching in density is characterized with a discriminator $\mathbf{D}_Y$ and the reconstruction with the L^1 loss. They also do this both ways symmetrically.

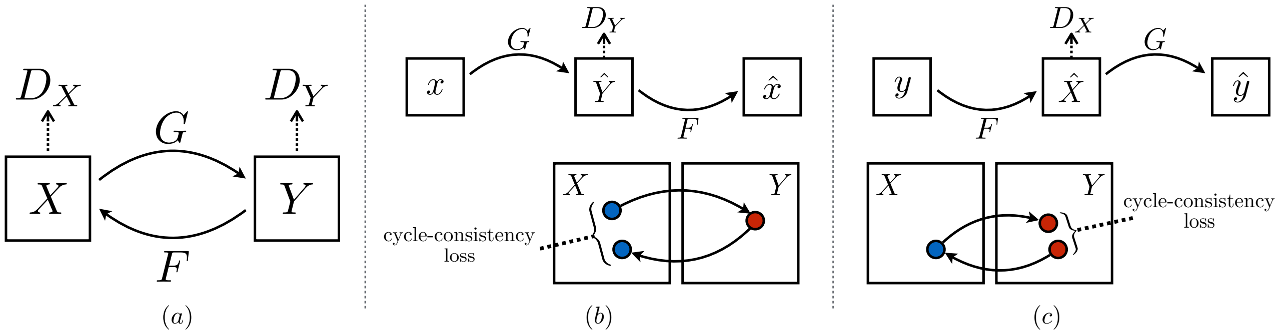
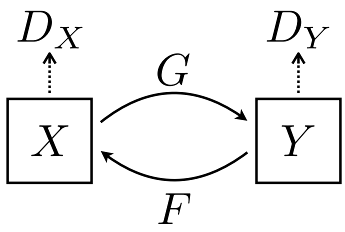


Figure 3: (a) Our model contains two mapping functions $G : X \rightarrow Y$ and $F : Y \rightarrow X$, and associated adversarial discriminators D_Y and D_X. D_Y encourages G to translate X into outputs indistinguishable from domain Y, and vice versa for D_X and F. To further regularize the mappings, we introduce two *cycle consistency losses* that capture the intuition that if we translate from one domain to the other and back again we should arrive at where we started: (b) forward cycle-consistency loss: $x \rightarrow G(x) \rightarrow F(G(x)) \approx x$, and (c) backward cycle-consistency loss: $y \rightarrow F(y) \rightarrow G(F(y)) \approx y$

(Zhu et al., 2017)



The loss optimized alternatively is

$$\begin{aligned} V^*(\mathbf{G}, \mathbf{F}, \mathbf{D}_X, \mathbf{D}_Y) =& V(\mathbf{G}, \mathbf{D}_Y, X, Y) + V(\mathbf{F}, \mathbf{D}_X, Y, X) \\ &+ \lambda \left(\mathbb{E}\Big[\|\mathbf{F}(\mathbf{G}(X)) - X\|_1 \Big] + \mathbb{E}\Big[\|\mathbf{G}(\mathbf{F}(Y)) - Y\|_1 \Big] \right) \end{aligned}$$

where V is a quadratic loss, instead of the usual $\log$ (Mao et al., 2016)

$$V(\mathbf{G}, \mathbf{D}_Y, X, Y) = \mathbb{E}\Big[(\mathbf{D}_Y(Y) - 1)^2 \Big] + \mathbb{E}\Big[\mathbf{D}_Y(\mathbf{G}(X))^2 \Big].$$

The generator is from Johnson et al. (2016), an updated version of Radford et al. (2015)'s DCGAN, with plenty of specific tricks, e.g. using an history of generated images (Shrivastava et al., 2016).

Notes

The loss has four terms:

- $V(\mathbf{G}, \mathbf{D}_Y, X, Y)$ estimates hoe much a signal $X \sim \mu_X$ from $\mathscr{X}$ brought back to $\mathscr{Y}$ by $\mathbf{G}$ looks like a signal from μ_Y,
- $V(\mathbf{F}, \mathbf{D}_X, Y, X)$ estimates how much a signal $Y \sim \mu_Y$ brought back to $\mathscr{X}$ by $\mathbf{F}$ looks like a signal from μ_X,
- $\mathbb{E}\big[\|\mathbf{F}(\mathbf{G}(X)) - X\|_1 \big]$, estimates how well $\mathbf{F} \circ \mathbf{G}$ keeps an $X \sim \mu_X$ unchanged, and
- $\mathbb{E}\big[\|\mathbf{G}(\mathbf{F}(Y)) - Y\|_1 \big]$, estimates how well $\mathbf{G} \circ \mathbf{F}$ keeps an $Y \sim \mu_Y$ unchanged.

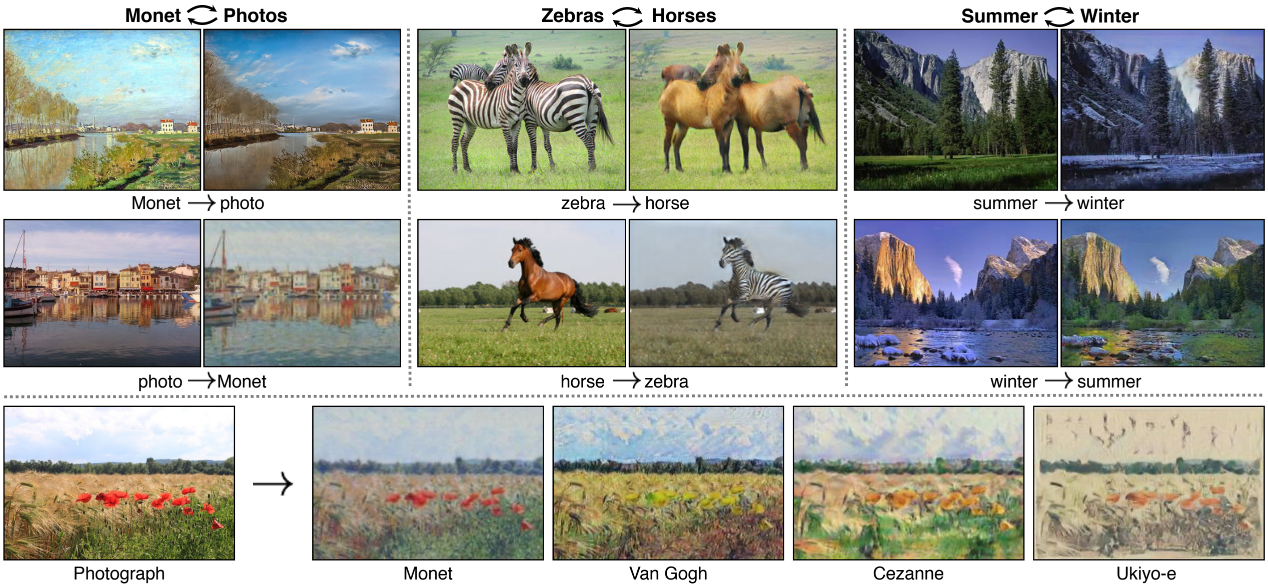


Figure 1: Given any two unordered image collections X and Y, our algorithm learns to automatically "translate" an image from one into the other and vice versa: *(left)* Monet paintings and landscape photos from Flickr; *(center)* zebras and horses from ImageNet; *(right)* summer and winter Yosemite photos from Flickr. Example application *(bottom)*: using a collection of paintings of famous artists, our method learns to render natural photographs into the respective styles.

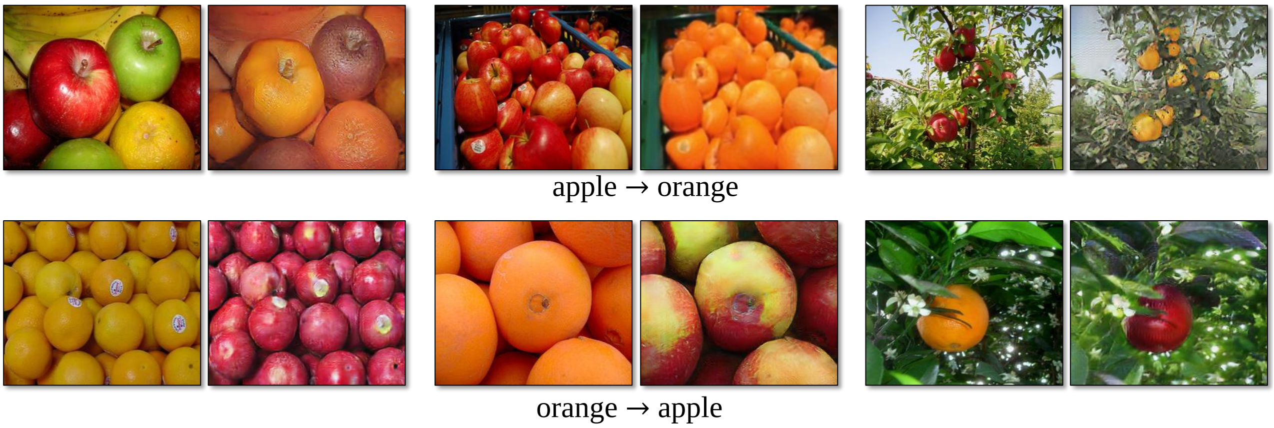
(Zhu et al., 2017)

zebra → horse

winter Yosemite → summer Yosemite

summer Yosemite → winter Yosemite

(Zhu et al., 2017)



(Zhu et al., 2017)

While GANs are often used for their [theoretical] ability to model a distribution, generating consistent samples is enough for image-to-image translation.

In particular, this application does not suffer much from mode collapse, as long as the generated images "look nice".

The key aspect of the GAN here is the "perceptual loss" that the discriminator implements, more than the theoretical convergence to the true distribution.

References

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