Interactive Sketch & Fill: Multiclass Sketch-to-Image Translation

Arnab Ghosh\textsuperscript{1} Richard Zhang\textsuperscript{2} Puneet K. Dokania\textsuperscript{1}
Oliver Wang\textsuperscript{2} Alexei A. Efros\textsuperscript{2,3} Philip H. S. Torr\textsuperscript{1} Eli Shechtman\textsuperscript{2}

\textsuperscript{1}University of Oxford \quad \textsuperscript{2}Adobe Research \quad \textsuperscript{3}UC Berkeley

Figure 1: (Top) Given sparse user input (first row), our model estimates the complete shape and provides this as a recommendation to the user (shown in gray), along with the final synthesized object (second row). These estimates are updated as the user adds (green) or removes strokes (red) over time – previous edits are shown in black. (Bottom) This generation is class-conditioned, and our method is able to generate distinct multiple objects for the same outline (e.g. ‘circle’) by conditioning the generator on the object category.

Abstract

We propose an interactive GAN-based sketch-to-image translation method that helps novice users easily create images of simple objects. The user starts with a sparse sketch and a desired object category, and the network then recommends its plausible completion(s) and shows a corresponding synthesized image. This enables a feedback loop, where the user can edit the sketch based on the network’s recommendations, while the network is able to better synthesize the image that the user might have in mind. In order to use a single model for a wide array of object classes, we introduce a gating-based approach for class conditioning, which allows us to generate distinct classes without feature mixing, from a single generator network.

1. Introduction

Conditional GAN-based image translation [25, 43, 61] models have shown remarkable success at taking an abstract user input, such as an edge map or a semantic segmentation map, and translating it to a real image. These methods run at interactive rates, and combining them with a user interface allows the user to quickly create fun (but usually, unrealistic) images. A few limitations prevent them from being used as a true interactive tool that assists the user in generating an image of an object they have in mind. First, the user is required to provide an entire abstract map as input (full edge or label map). This may prove difficult for many, as untrained practitioners generally struggle at freehand drawing of accurate proportions of objects and their parts [6], 3D shapes and perspective [45]. It is much easier with current image translation methods to obtain realistic looking images by editing existing images [8, 40] than creating images from scratch. Second, current GAN-based image translation methods are limited to a single class of images. For example, switching from a cat to a dog requires loading (or storing in memory) a new model per class.

We propose a new GAN-based interactive image generation system for drawing objects that: 1) generates full images given only \textit{sparse} and \textit{partial} user strokes (or...
sketches); 2) serves as a recommender system that suggests or helps the user during their creative process, in order to generate a desired image; and 3) uses a single conditional GAN for multiple image classes with an effective gating mechanism. Such a system allows for creative input to come from the user, while the challenging task of getting exact object proportions correct is left to the model, which constantly predicts a plausible completion of the user’s sketch (Fig. 1).

We use sparse object outlines/sketches/simplified-edges instead of dense edge maps as the user input, as these are closer to the lines that novice users tend to draw [7]. Our model first completes the input, which could be partial outlines or edges, and then generates the image conditioned on the completed shape. There are several advantages to this two-stage approach. For one, we are able to give the artist feedback on the general object shape in our interactive interface (similar to ShadowDraw [31]), allowing them to quickly refine the completed shape until it is satisfactory. Second, we found this to work better than going directly from partial outlines to images, as the additional intermediate supervision on full outlines/sketches breaks the problem into two easier sub-problems – first recover the geometric properties of the object (shape, proportions) and then fill in the appearance (colors, textures).

For the second stage, multi-class conditional generation, we use a gating mechanism conditioned on the input class label. Briefly, gating allows the network to focus on the important parts (activations) of the network specific to the conditioning class. Such an approach allows for a clean separation of classes, enabling us to train a single generator and discriminator across multiple object classes.

To demonstrate the potential of our method as an interactive tool for stroke-based image generation, we collect a new image dataset of ten simple object classes (pineapple, soccer, basketball, etc.) with white background. In order to stress test our gating mechanism, six of the object classes have similar round outlines, so the model is truly conditioned on the class label and cannot figure out the class only from the stroke. Fig. 2 shows a short video of an interactive editing session using our system. Along with these simple objects, we also demonstrate the potential of our method on complicated ones such as faces and shoes.

2. Related Work

Interactive Generation Interactive interfaces for free-hand drawing go all the way back to Ivan Sutherland’s Sketchpad [48]. The pre-deep work most related to us, ShadowDraw [31], introduced the concept of generating multiple shadows for novice users to be able to draw sketches. PhotoSketcher [13] introduces a retrieval based method for obtaining real images from sketches. More recently, deep recurrent networks have been used to generate sketches [18, 14]. Sketch-RNN [18] provides a completion of partial strokes, with the advantage of intermediate stroke information via the Quickdraw dataset at training time. SPIRAL [14] learns to generate digits and faces using a reinforcement learning approach. Zhu et al. [60] train a generative model, and an optimization-based interface to generate possible images, given color or edge constraints. The technique is limited to a single class and does not propose a recommendation for the completion of the shape. Sketchy-GAN [3] also aimed at generating multi-class images but lacks interactive capability. In contrast to the above, our method provides interactive prediction of the shape and appearance to the user and supports multiple object classes.

Generative Modeling Parametric modeling of an image distribution is a challenging problem. Classic approaches include autoencoders [21, 54] and Boltzmann machines [47]. More modern approaches include autoregressive models [12, 51], variational autoencoders (VAEs) [28], and generative adversarial networks (GANs). GANs and VAEs both learn mappings from a low-dimensional “latent” code, sampled stochastically, to a high-dimensional image through a feedforward pass of a network. GANs have been successful recently [9, 41, 1], and hybrid models feature both a learned mapping from image to latent space as well as adversarial training [10, 11, 30, 4].

Conditioned Image Generation The methods described above can be conditioned, either by a low-dimensional vector (such as an object class, or noise vector), a high-dimensional image, or both. Isola et al. [25] propose “pix2pix”, establishing the general usefulness of conditional GANs for image-to-image translation tasks. However, they discover that obtaining multimodality by injecting a random noise vector is difficult, a result corroborated in [33, 38, 62]. This is an example of mode collapse [16], a phenomenon especially prevalent in image-to-image GANs, as the generator tends or ignore the low-dimensional latent code in favor of the high-dimensional image. Proposed solutions include layers which better condition the optimization, such as Spectral Normalization [58, 35], modifications to the loss function, such as WGAN [2, 17] or optimization procedure [20], or modeling proposals, such as MAD-GAN [15] and MUNIT [24]. One modeling approach is to add a predictor from the output to the conditioner, to discourage the model from ignoring the conditioner. This has been explored in the classification setting in Auxiliary-Classifier GAN (ACGAN) [36] and regression setting with InfoGAN [4] and ALI/BiGAN (“latent regressor” model) [11, 10], and is one half of BicycleGAN model [62]. We explore a complementary approach of architectural modification via gating.

Gating Mechanisms Residual networks [19], first intro-
We can see two versions of our interface. The left side shows how a user can quickly generate multiple objects using a few strokes, while the right side shows the utility of multimodal completions where the user can quickly explore different possible shape generations while drawing. Please view with Acrobat Reader.

Figure 2: Video of our interface

Figure 3: Our two-stage approach
First, we complete a partial sketch using the shape generator $G_S$. Then we translate the completed sketch into an image using the appearance generator $G_A$. Both generators are trained with their respective discriminators $D_S$ and $D_A$. Example usage is shown in our user interface in Fig. 2.

3. Method

We decouple the problem of interactive image generation into two stages: object shape completion from sparse user sketches, and appearance synthesis from the completed shape. More specifically, as illustrated in Fig. 3 we use the Shape Generator $G_S$ for the automatic shape (outline/sparse-sketch/simplified-edge) generation and the Appearance Generator $G_A$ for generating the final image as well as the adversary discriminators $D_S$ and $D_A$. Example usage is shown in our user interface in Fig. 2.

3.1. Shape completion

The shape completion network $G_S$ should provide the user with a visualization of its completed shape(s), based on the user input, and should keep on updating the suggested shape(s) interactively. We take a data-driven approach for this whereby, to train the network, we simulate partial strokes (or inputs) by removing random square patches from the full outline/ full sparse sketch/ full simplified edges. The patches are of three sizes (64×64, 128×128, 192×192) and placed at a random location in the image of size 256×256 (see Fig. 5 for an example). To extend the technique beyond outlines and generate more human-like sketches, we adopt the multistage procedure depicted in Fig. 6. We refer to these generated sketches as “simplified edges”. We automatically generate data in this manner, creating a dataset where for a given full outline/sketch or a simplified edge-map, 75 different inputs are created. The model, shown in Fig. 3, is based on the architecture used for non-image conditional generations in [34]. We modify the architecture such that the conditioning input is provided to the generator and discriminator at multiple scales as shown in Fig. 4. This makes the conditioning input an active part of the generation process and helps in producing multimodal completions.

3.2. Appearance synthesis

An ideal interactive sketch-to-image system should be able to generate multiple different image classes with a single generator. Beside memory and time considerations (avoiding loading/using a separate model per class, reducing overall memory), a single network can share features related to outline recognition and texture generation that are common across classes, which helps training with limited examples per class.

As we later show, class-conditioning by concatenation can fail to properly condition the network about the class information in current image translation networks [25, 62].
To address this, we propose an effective soft gating mechanism, shown in Fig. 7. Conceptually, our network consists of a small external gating network that is conditioned on the object class (encoded as a 1-hot vector). The gating network outputs parameters that are used to modify the features of the main generator network. Given an input feature tensor $X_l$, “vanilla” ResNet [19] maps it to

$$X_{l+1} = X_l + \mathcal{H}(X_l).$$

Changes in resolution are obtained by upsampling before or downsampling after the residual block. Note that we omit $l$ subscript from this point forward to reduce clutter. Our gating network augments this with a predicted scalar $\alpha$ for each layer of the network using a learned network $\mathcal{F}(y)$, where $y$ is the conditioning vector:

$$X + \alpha \mathcal{H}(X), \text{ where } \alpha \in [0, 1].$$

If the conditioning vector $y$ has no use for a particular block, it can predict $\alpha$ close to zero and effectively switch off the layer. During training, blocks within the main network can transform the image in various ways, and $\mathcal{F}$ can modulate such that the most useful blocks are selected. Unlike previous feature map conditioning methods such as AdaIn [50], we apply gating to both the generator and discriminator. This enables the discriminator to select blocks which effectively judge whether generations are real or fake, conditioned on the class input. Some blocks can be shared across regions in the conditioning vector, whereas other blocks can specialize for a given class.

A more powerful method is to apply this weighting channel-wise using a vector $\alpha$:

$$X + \alpha \odot \mathcal{H}(X), \text{ where } \alpha \in [0, 1]^c,$$

where $\odot$ represents channel-wise multiplication. This allows specific channels to be switched “on” or “off”, providing additional degrees of freedom. We found that this channelwise approach for gating provides the strongest results. AdaIn describes the case where an Instance Normalization [50] (IN) operation is applied before scaling and shifting the feature distribution. We constrain each element of $\alpha$ and $\beta$ in $[-1, 1]$. We additionally explored incorporating a bias term after the soft-gating, either block-wise using a scalar $\beta \in [-1, 1]$ per layer, or channel-wise using a vector $\beta \in [-1, 1]^c$ per layer but we found that they did not help much, and so we leave them out of our final model. Refer Fig. 8 for pictorial representation of various gatings.

Finally, we describe our network architecture, which utilizes the gated residual blocks described above. We base our architecture on the proposed residual Encoder-Decoder model from MUNIT [24]. This architecture is comprised of 3 conv layers, 8 residual blocks, and 3 up-conv layers. The residual blocks have 256 channels. First, we deepen the network, based on the principle that deeper networks have more valid disjoint, partially shared paths [53], and add 24 residual blocks. To enable the larger number of residual
blocks, we drastically reduce the width to 32 channels for
every layer. We refer to this network as SkinnyResNet.
Additionally, we found that modifying the downsampling
and upsampling blocks to be residual connections as well
improved results, and also enables us to apply gating to all
blocks. When gating is used, the gate prediction network,
\( H(x) \), is also designed using residual blocks. Additional
architecture details are in the supplementary material.

4. Experiments

We first compare our 2 step approach for interactive im-
age generation on existing datasets such as the UTZappos
Shoes dataset [57] and CelebA-HQ [26]. State-of-the-art
techniques such as pix2pixHD [55] are used to generate the
final image from the autocompleted sketches. We finally
evaluate our approach on a multi-class dataset that we col-
clected to test our proposed gating mechanism.

4.1. Single Class Generation

Datasets We use the edges2shoes[25], CelebA-HQ[26]
datasets to test our method on single class generation. We

simplify the edges to attempt to more closely resemble how
humans would draw strokes by first using the preprocessing
code of [32] further reducing the strokes with a sketch
simplification network [46].

Architecture We use the architecture described in Sec-
section 3.1 for shape completion. In this case, each dataset
only contains a single class, so we can use an off-the-shelf
network, such as pix2pixHD [56] for rendering.

Results As seen in Fig. 9, our 2 step technique allows
us to complete the simplified edge maps from the partial
strokes and also generate realistic images from the auto-
completed simplified edges. Table 1 also demonstrates,
across two datasets (faces and shoes), that using a 2 step
procedure produces stronger results than mapping directly
from the partial sketch to the completed image.
Figure 9: Example Sketch & Fill Progression. The first row represents the progressive addition of new strokes on the canvas, the second row shows the autocompleted sketch, and the third row is the final generated image. As the sparse strokes are changed by the user, the completed shape and generated image evolve as well. Note that changing a stroke locally produces coherent changes in other parts of the image.

<table>
<thead>
<tr>
<th>Method</th>
<th>SkinnyResNet</th>
<th>EncDec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class. Acc [%]</td>
<td>AMT Fool. Rate [%]</td>
</tr>
<tr>
<td>Ground truth</td>
<td>100.0</td>
<td>50.0</td>
</tr>
<tr>
<td>1 gen/class</td>
<td>97.0</td>
<td>17.7±1.46</td>
</tr>
<tr>
<td>Concat (In)</td>
<td>62.6</td>
<td>15.0±1.41</td>
</tr>
<tr>
<td>Concat (All)</td>
<td>64.5</td>
<td>15.3±1.41</td>
</tr>
<tr>
<td>Cat(In)+Aux-Class</td>
<td>65.6</td>
<td>14.5±1.5</td>
</tr>
<tr>
<td>Cat(All)+Aux-Class</td>
<td>67.0</td>
<td>19.7±1.42</td>
</tr>
<tr>
<td>BlockGate(+bias)</td>
<td>89.6</td>
<td>19.6±1.34</td>
</tr>
<tr>
<td>BlockGate</td>
<td>99.6</td>
<td>17.3±1.61</td>
</tr>
<tr>
<td>AdaIn</td>
<td>94.5</td>
<td>14.9±1.47</td>
</tr>
<tr>
<td>ChanGate(+bias)</td>
<td>94.1</td>
<td>14.8±1.43</td>
</tr>
<tr>
<td>ChanGate</td>
<td>97.0</td>
<td>23.4±1.99</td>
</tr>
</tbody>
</table>

Table 3: Accuracy vs Realism on Multiclass Outline→Image task. We measure generation accuracy with a pretrained network. We measure realism using the real vs. fake judges from AMT. Higher is better for both. Our SkinnyResNet architecture outperforms the Encoder-Decoder network, inspired by MUNIT [24]. We perform a thorough ablation on our architecture and find that channel-wise gating achieves high accuracy and higher realism.

4.2. Multi-Class Generation

Datasets To explore the efficacy of our full pipeline, we introduce a new outline dataset consisting of 200 images (150 train, 50 test) for each of 10 classes – basketball, chicken, cookie, cupcake, moon, orange, soccer, strawberry, watermelon, and pineapple. All the images have a white background and were collected using search keywords on popular search engines. In each image, we obtain rough outlines for the image. We find the largest blob in the image after thresholding it into a black and white image. We fill the interior holes of the largest blob and obtain a smooth outline using the SavitzkyGolay filter [44].

Architecture For the shape completion, we use the architecture in Section 3.1. For class-conditioned image generation, test the gated architectures in Section 3.2.

Results In order to test the fidelity of the automatically completed shapes, we evaluate the accuracy of a trained classifier on being able to correctly label a particular generation. We first test in Table 2 that our 2 stage technique is better than 1 step generation. We evaluate the results on the multi-class outline to image generations on two axes: adherence to conditioning and realism. We first test the conditioning adherence – whether the network generates an image of the correct class. Off-the-shelf networks have been previously used to evaluate colorizations [59], street scenes [25, 56], and ImageNet generations [42]. We take a similar approach and fine-tune a pretrained InceptionV3 network [49] for our 10 classes. The generations are then tested with this network for classification accuracy. Results are presented in Table 3.

To judge the generation quality, we also perform a “Visual Turing test” using Amazon Mechanical Turk (AMT). Turkers are shown a real image, followed by a generated image, or vice versa, and asked to identify the fake. An algorithm which generates a realistic image will “fool” Turkers into choosing the incorrect image. We use the implementation from [59]. Results are presented in Table 3, and qualitative examples are shown in Fig. 10.

Gating Architectures We compare our proposed model to the residual Encoder-Decoder model [24]. In addition, we compare our proposed gating strategy and SkinnyResNet architecture to the following methods for conditional image generation:
**Figure 10:** Conditioning injection comparison. We show results across methods on the outline→image task using the **SkinnyResNet** architecture. Naive Concatenation **Concat** often confuses classes, such as oranges and basketballs, while gating mechanisms such as the **ChannelGate** method succeed. The gating method also improves results for the **EncoderDecoder** architecture.
of concatenation. For the object class information, for either network and for either type of classes, naive concatenation is unable to successfully inject conditioning.

However, when a single network is trained to generate all of the 10 classes. The per-class baseline trivially adheres to the geometry of each class. However, an interesting test scenario is whether the technique generalizes to unseen shape and class combinations. In Fig. 1, we show that an input circle not only produces circular objects, such as a basketball, watermelon, and cookie, but also noncircular objects such as strawberry, pineapple, and cupcake. Note that both the pineapple crown and bottom are generated, even without any structural indication of these parts in the outline.

**Is gating effective across architectures?** As seen in Table 3, using channelwise gating instead of naive concatenation improves performance both accuracy and realism across architectures. For example, for the EncoderDecoder architecture, gating enables successful generation of the pineapple. Both quantitatively and qualitatively, results are better for our proposed SkinnyResNet architecture.

**Do the generations generalize to unusual outlines?** The training images consist of the outlines corresponding to the geometry of each class. However, an interesting test scenario is whether the technique generalizes to unseen shape and class combinations. In Fig. 1, we show that an input circle not only produces circular objects, such as a basketball, watermelon, and cookie, but also noncircular objects such as strawberry, pineapple, and cupcake. Note that both the pineapple crown and bottom are generated, even without any structural indication of these parts in the outline.

### 5. Discussion

We present a two-stage approach for interactive object generation, centered around the idea of a shape completion intermediary. This step both makes training more stable and also allows us to give coarse geometric feedback to the user, which they can choose to integrate as they desire.

**Acknowledgements**

AG, PKD, and PHST are supported by the ERC grant ERC-2012-AdG, EPSRC grant Seebibble EP/M013774/1, EPSRC/MURI grant EP/N019474/1 and would also like to acknowledge the Royal Academy of Engineering and FiveAI. Part of the work was done while AG was an intern at Adobe.
References


[50] D Ulyanov, A Vedaldi, and VS Lempitsky. Instance normalization: the missing ingredient for fast stylization. corr abs/1607.0 (2016). 4