

# DALL-E: Text to Image Generation

[paper \(https://arxiv.org/pdf/2102.12092.pdf\)](https://arxiv.org/pdf/2102.12092.pdf)

[OpenAI DALL-E 2 announcement \(https://openai.com/dall-e-2/\)](https://openai.com/dall-e-2/)

DALL-E is a generative model for creating Images, conditioned on Text input.

That is:

- Given some Text that describes the output
- DALL-E will create an image based on the Text input

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DALL-E: Text to Image

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Text input: "An illustration of a baby daikon radish in a tutu walking a dog"

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Image output:

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Before we began our journey into Generative ML, imagining how to achieve such a result would have been puzzling.

But, in concept, it follows a familiar path

- A Generative Language Model (e.g., GPT) is able to solve a "predict the next token" task
  - Giving a sequence of tokens
  - Generate a token likely to follow
- "Text to Text" as a universal API
  - turn *your* task into a type of translation of
    - an input sequence of Source tokens
    - to to an output sequence of tokens

The key prerequisite to DALL-E (in addition to a Language Model)

- representation of a (flattened) Image as a sequence of (discrete) tokens

We have *already* encountered such a representation

- A Discrete Variational Autoencoder (dVAE) such as the VQ-VAE represents an Image
- as a higher dimensional Tensor (e.g, 2D grid)
- of discrete values
  - indexes into a finite "codebook" of latent vectors
  - the codebook implements an embedding of Image "elements" into a finite set of vector encodings

Hopefully: the idea underlying DALL-E has come into focus

- We train a Language Model on a sequences of generalized tokens
  - First part of sequence are Text tokens
  - Separated by an "end of Text" token
  - Second part of sequence are Image tokens
- The Language Model learns
  - not only what "words" follow the prefix of a sequence of word tokens
  - but what Image tokens follow the "end of Text"

Voila !

Text to Image is just another use of the "Text to Text" API

- akin to translating from one language to another

## Details

A dVAE is trained

- Encoder reduces a 3D (RGB) image to smaller ( $32 \times 32$ ) spatial grid of latent vectors
- the dVAE learns a codebook
  - of 8192 elements (the Image Vocabulary size)
- Using the dVAE Encoder, an image is translated into a ( $32 \times 32$ ) spatial grid



A Text Encoder is used

- BPE encoding of tokens
- Text Vocabulary size is 16,384

The Language Model is trained

- Examples are (Text, Image) pairs
  - Obtained from images with captions
- Given training example  $(\text{text}^{(i)}, \text{image}^{(i)})$
- Text  $\text{text}^{(i)}$  is converted to a sequence using the Text Encoder
  - maximum text sequence length limited to 256 Text tokens
- Image  $\text{image}^{(i)}$  is converted to a  $(32 \times 32)$  spatial grid
  - which is flattened to a sequence of  $1024 = 32 * 32$  Image tokens

The training example is thus a sequence of

- 256 Text tokens
- 1024 Image tokens

The Language Model learns to Autoregressively model the training sequences

- Using Decoder style Transformer

Here is what a training example that mixes text and an image looks like:

### Training example: Representing mixed Text + Image as a sequence



*Figure 10.* Illustration of the embedding scheme for a hypothetical version of our transformer with a maximum text length of 6 tokens. Each box denotes a vector of size  $d_{\text{model}} = 3968$ . In this illustration, the caption has a length of 4 tokens, so 2 padding tokens are used (as described in Section 2.2). Each image vocabulary embedding is summed with a row and column embedding.

Notice the positional embeddings

- position in text
- row/column position for image

A Language Model is not deterministic: running the same input multiple times can generate different outputs

- LLM creates a probability distribution over token vocabulary
  - we *sample* a token from this distribution as the LLM "next token" output

DALL-E uses CLIP to rank the outputs

- CLIP finds the images that are the least distance from the Text

# Interesting results and observations

[OpenAI announcement of DALL-E 2 \(https://openai.com/dall-e-2/\)](https://openai.com/dall-e-2/)

DALL-E seems to have learned to generalize

- the "baby daikon radish wearing a tutu walking a dog"
  - even though radishes don't wear clothing, DALL-E positions the tutu around the "waist" of the radish
  - the radish is in a ballerina (dancer who wears a tutu) pose
  - the dog is on a leash (as are dogs being walked)
  - even though a radish does not have arms, DALL-E creates an arm to hold the leash
- Different styles of Image are created according to the text "illustration", "sketch", "photo", "painting in the style of Picasso"

### Image editing via Text

- Given the text sequence "the exact same cat on the top as a sketch at the bottom"
- Followed by Image tokens (half the length of the total Image sequence length) encoding a cat
- Will generate the remaining available Image tokens of the cat in the style of a sketch

Doesn't always understand

- "tree bark" (the "skin" of a tree) is **not** an animal barking at a tree



## Social concerns

The DALL-E 2 preview included a [model card \(https://github.com/openai/dalle-2-preview/blob/main/system-card\\_04062022.md#bias-and-representation\)](https://github.com/openai/dalle-2-preview/blob/main/system-card_04062022.md#bias-and-representation) describing possible Risks and Limitations.

Among them are

- [Inappropriate training examples \(https://github.com/openai/dalle-2-preview/blob/main/system-card\\_04062022.md#model-training-data\)](https://github.com/openai/dalle-2-preview/blob/main/system-card_04062022.md#model-training-data).
- "Signing" to indicate DALL-E generated image ([https://github.com/openai/dalle-2-preview/blob/main/system-card\\_04062022.md#signature-and-image-provenance](https://github.com/openai/dalle-2-preview/blob/main/system-card_04062022.md#signature-and-image-provenance)).
- [Biases present in training data \(https://github.com/openai/dalle-2-preview/blob/main/system-card\\_04062022.md#bias-and-representation\)](https://github.com/openai/dalle-2-preview/blob/main/system-card_04062022.md#bias-and-representation).

# Playing with DALL-E

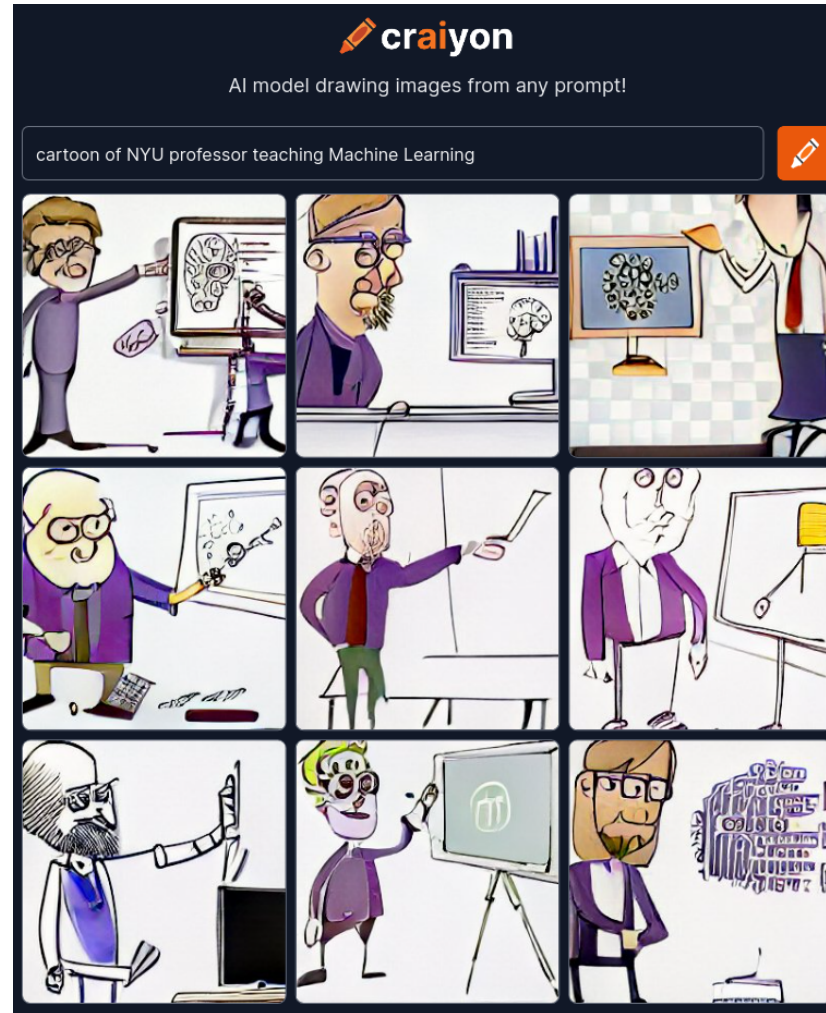
There is a [waiting list \(https://labs.openai.com/waitlist\)](https://labs.openai.com/waitlist) to get access to the official version of DALL-E.

However there are some Open Source replicas (trained on much less data)

- [Craiyon \(https://craiyon.com\)](https://craiyon.com)
  - Advertisement supported :-)
- [Huggingface.co \(https://huggingface.co/spaces/dalle-mini/dalle-mini\)](https://huggingface.co/spaces/dalle-mini/dalle-mini)
  - Moving to Craiyon

Text input: "Cartoon of NYU professor teaching Machine Learning"

Image output:



- It gets the NYU colors right !
  - Princeton professors wear orange



```
In [1]: print("Done")
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Done

