
ソースコードから理解する
Stable Diffusion
Prompt: Understand Stable Diffusion from code, cyberpunk theme, best quality, high resolution, concept art

2. 石原 正宗 (Masamune Ishihara)

Computer Engineering Undergrad at University of California, Santa Cruz
AI/MLとGISに興味があります。

好きなもの:

- 紅茶
- テニス
- Rebuild.fm (223: Ear Bleeding Pods (higepon)を聞いてkaggleを始めました。)

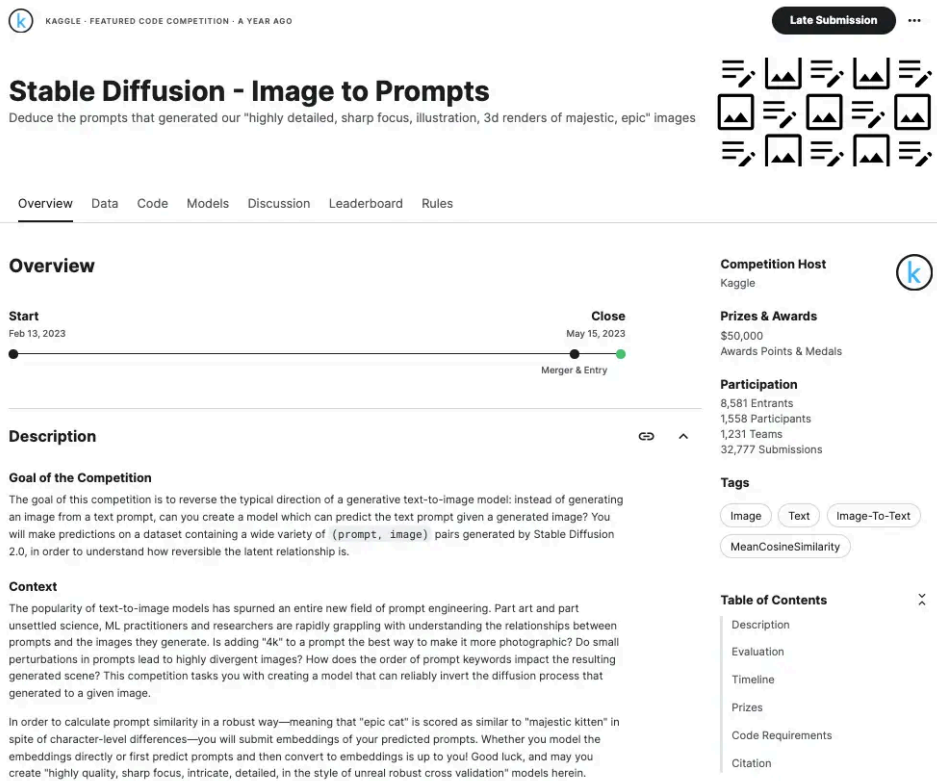
masaishi

@masaishi2001

masamune-ishihara

masaishi

Kagglerにとって画像生成を使う機会は少ない?



KAGGLE · FEATURED CODE COMPETITION · A YEAR AGO

Late Submission

Stable Diffusion - Image to Prompts

Deduce the prompts that generated our "highly detailed, sharp focus, illustration, 3d renders of majestic, epic" images

Overview Data Code Models Discussion Leaderboard Rules

Overview

Start
Feb 13, 2023

Close
May 15, 2023

Merger & Entry

Description

Goal of the Competition

The goal of this competition is to reverse the typical direction of a generative text-to-image model: instead of generating an image from a text prompt, can you create a model which can predict the text prompt given a generated image? You will make predictions on a dataset containing a wide variety of `(prompt, image)` pairs generated by Stable Diffusion 2.0, in order to understand how reversible the latent relationship is.

Context

The popularity of text-to-image models has spurned an entire new field of prompt engineering. Part art and part unsettled science, ML practitioners and researchers are rapidly grappling with understanding the relationships between prompts and the images they generate. Is adding "4k" to a prompt the best way to make it more photographic? Do small perturbations in prompts lead to highly divergent images? How does the order of prompt keywords impact the resulting generated scene? This competition tasks you with creating a model that can reliably invert the diffusion process that generated to a given image.

In order to calculate prompt similarity in a robust way—meaning that "epic cat" is scored as similar to "majestic kitten" in spite of character-level differences—you will submit embeddings of your predicted prompts. Whether you model the embeddings directly or first predict prompts and then convert to embeddings is up to you! Good luck, and may you create "highly quality, sharp focus, intricate, detailed, in the style of unreal robust cross validation" models herein.

Competition Host
Kaggle

Prizes & Awards
$50,000
Awards Points & Medals

Participation
8,581 Entrants
1,558 Participants
1,231 Teams
32,777 Submissions

Tags

Image | Text | Image-To-Text | MeanCosineSimilarity

Table of Contents

- Description
- Evaluation
- Timeline
- Prizes
- Code Requirements
- Citation

https://www.kaggle.com/competitions/stable-diffusion-image-to-prompts/overview

このスライドの目的

画像生成の流れをコードと一緒に紹介したい

このスライドについて

スライドを書くにあたって、自分が理解できていなかったところなどを多く実感しました。間違った説明をしているかもしれないので、不明瞭なところや、間違いを下記のリンクから教えていただけると幸いです。

understand-stable-diffusion-slidev-ja

◉Issues: 間違いを見つけたらご指摘ください。

Discussions: 質問があればこちらからお願いします。

Pull Requests: もし修正があればお送りください。

このスライドについて

画像生成の流れをコードと一緒に紹介というコンセプトのため、基本的に載せている全てのコードは、実際に動かすことができるようになっています。

レポジトリ一覧

- understand-stable-diffusion-slidev-ja: このスライドのレポジトリ
- understand-stable-diffusion-slidev-notebooks: サンプル画像や、gifを生成するためのノートブック
- parediffusers: メインで扱うライブラリ

目次

4. 画像生成の流れ

Prompt: Stable Diffusion, watercolor painting, best quality, high resolution

Stable Diffusionとは?

- StabilityAIによって開発されたLatent Diffusion Model (LDM)をベースとした画像生成モデル
- Text-to-Image, Image-to-Imageなどのタスクに利用可能
- Diffusersを利用することで簡単に動かすことができる。
- https://arxiv.org/abs/2112.10752

Diffusersとは?

- Hugging Face🤗によって開発されたDiffusion Modelsを扱うライブラリ
- 画像生成モデルを簡単に動かすことができる。
- https://github.com/huggingface/diffusers

Diffusersを試す

Open in Colab

Install the Diffusers library:

```
!pip install transformers diffusers accelerate
```

Generate an image from text:

```
import torch
from diffusers import StableDiffusionPipeline

pipe = StableDiffusionPipeline.from_pretrained
  "stabilityai/stable-diffusion-2",
  dtype=torch.float16,
).to(device=torch.device("cuda"))
prompt = "painting depicting the sea, sunrise,

image = pipe(prompt, width=512, height=512).im
display(image)
```

Diffusersは機能が豊富で柔軟性も高いが、
その分コードの理解に時間がかかる。

diffusers/.../pipeline_stable_diffusion.py

```python
# Copyright 2024 The HuggingFace Team. All rights reserved.
#
# Licensed under the Apache License, Version 2.0 (the "License");
# you may not use this file except in compliance with the License.
# You may obtain a copy of the License at
#
#     http://www.apache.org/licenses/LICENSE-2.0
#
# Unless required by applicable law or agreed to in writing, software
# distributed under the License is distributed on an "AS IS" BASIS,
# WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
# See the License for the specific language governing permissions and
# limitations under the License.

import inspect
from typing import Any, Callable, Dict, List, Optional, Union

import torch
from packaging import version
```

parediffusers/.../pipeline.py

```python
import torch
from torchvision.transforms import ToPILImage
from transformers import CLIPTokenizer, CLIPTextModel
from .scheduler import PareDDIMScheduler
from .unet import PareUNet2DConditionModel
from .vae import PareAutoencoderKL


class PareDiffusionPipeline:
    def __init__(
        self,
        tokenizer,
        text_encoder,
        scheduler,
        unet,
        vae,
        device=torch.device("cuda"),
        dtype=torch.float16,
    ):
```

PareDiffusers

Open in Colab

Install the PareDiffusers library:

```
!pip install parediffusers
```

Generate an image from text:

```
import torch
from parediffusers import PareDiffusionPipelin

pipe = PareDiffusionPipeline.from_pretrained(
  "stabilityai/stable-diffusion-2",
  device=torch.device("cuda"),
  dtype=torch.float16,
)
prompt = "painting depicting the sea, sunrise,

image = pipe(prompt, width=512, height=512)
display(image)
```

どのように画像生成が行われているのか？

PareDiffusers

Open in Colab

Install the PareDiffusers library:

```
!pip install parediffusers
```

Generate an image from text:

```
import torch
from parediffusers import PareDiffusionPipelin

pipe = PareDiffusionPipeline.from_pretrained(
  "stabilityai/stable-diffusion-2",
  device=torch.device("cuda"),
  dtype=torch.float16,
)
prompt = "painting depicting the sea, sunrise,

image = pipe(prompt, width=512, height=512)
display(image)
```

1. `encode_prompt` : PromptをEmbeddingに変換する
2. `get_latent` : ランダムなLatentを作る
3. `denoise` : SchedulerとUNetを使って、デノイズを行う
4. `vae_decode` : VAEで、画像にデコードする

1. `encode_prompt` : PromptをEmbeddingに変換する
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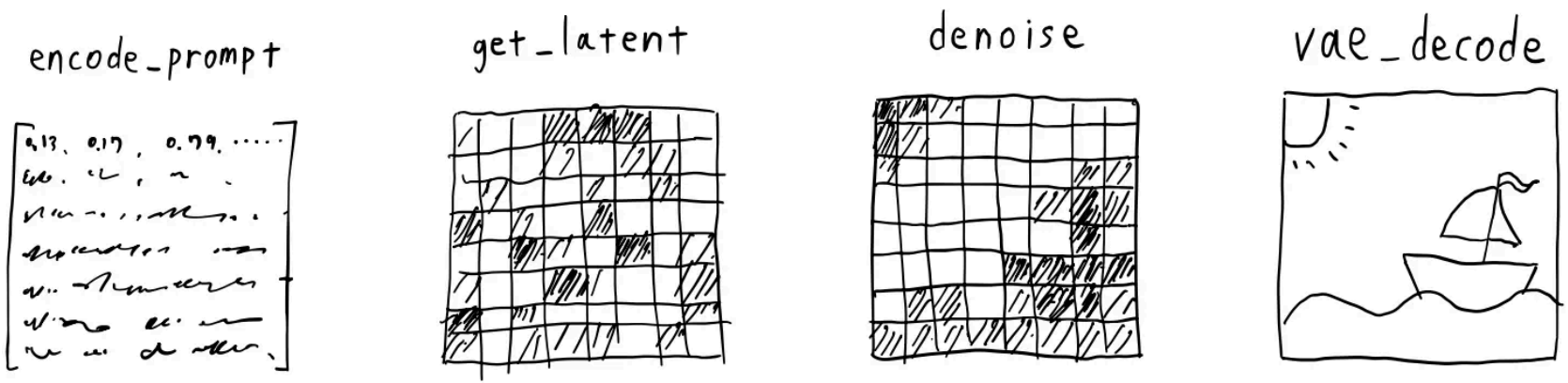


ちょっとだけ理論

Latent Diffusion Model (LDM)とは?

Latent Space (滞在空間)で、DDPMを動かすモデル

Denoising Diffusion Probabilistic Model (DDPM)とは?

画像にノイズを加え、そこから元の画像に復元するモデル

音声などのデータ全般に活用されていますが、このスライドでは画像について説明します。

- Diffusion process(拡散過程)を用い、学習データの前処理を行う。確率過程（マルコフ連鎖)
- Reverse process(逆拡散過程)を用い、ノイズを加えられたデータから元のデータを復元する。

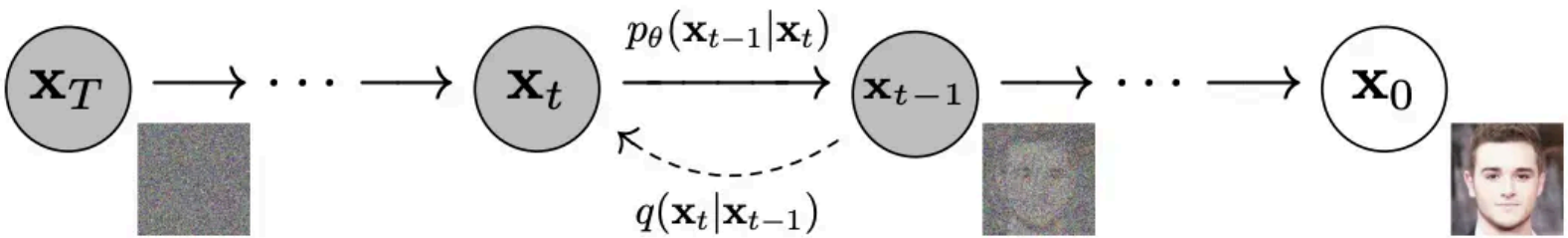


Figure 2: The directed graphical model considered in this work.

Jonathan Ho, Ajay Jain, Pieter Abbeel: “Denoising Diffusion Probabilistic Models”, 2020; arXiv:2006.11239.

Diffusionは前処理でもNNでもないのに、
Diffusion Modelと呼ばれるが面白い

Latent Diffusion Model (LDM)とは?

Latent Space (滞在空間)で、DDPMを動かすモデル

目的関数間違い探し

$$L_{DM} := \mathbb{E}_{x,\epsilon\sim\mathcal{N}(0,1),t}\left[\|\epsilon - \epsilon_\theta(x_t, t)\|_2^2\right].$$

$$L_{LDM} := \mathbb{E}_{\mathcal{E}(x),\epsilon\sim\mathcal{N}(0,1),t}\left[\|\epsilon - \epsilon_\theta(z_t, t)\|_2^2\right].$$

Latent Diffusion Model (LDM)

$$L_{LDM} := \mathbb{E}_{\mathcal{E}(x),\epsilon\sim\mathcal{N}(0,1),t}\left[\|\epsilon - \epsilon_\theta(z_t, t)\|_2^2\right].$$

Latent Diffusion Model (LDM)

$$L_{LDM} := \mathbb{E}_{\mathcal{E}(x),\epsilon\sim\mathcal{N}(0,1),t}\left[\|\epsilon - \epsilon_\theta(z_t, t)\|_2^2\right].$$

Latent Diffusion Model (LDM) with Conditioning

$$L_{LDM} := \mathbb{E}_{\mathcal{E}(x),y,\epsilon\sim\mathcal{N}(0,1),t}\left[\|\epsilon - \epsilon_\theta(z_t, t, \tau_\theta(y))\|_2^2\right],$$

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d}}\right) \cdot V$$

$$Q = W_Q^{(i)} \cdot \varphi_i(z_t),\ K = W_K^{(i)} \cdot \tau_\theta(y),\ V = W_V^{(i)} \cdot \tau_\theta(y).$$

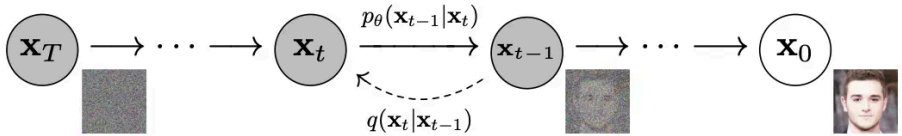
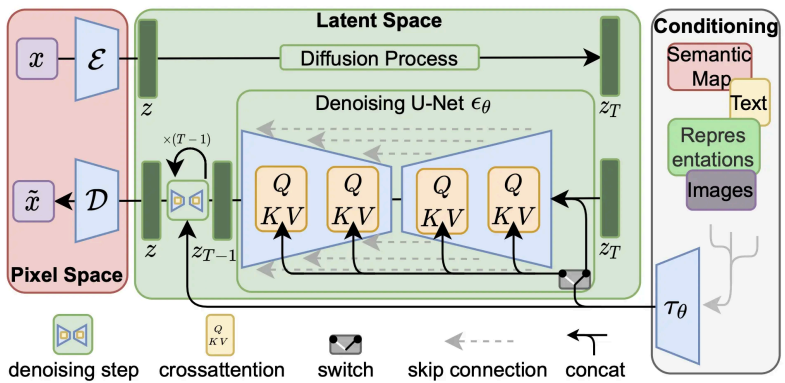


Figure 2: The directed graphical model considered in this work.

Jonathan Ho, Ajay Jain, Pieter Abbeel: “Denoising Diffusion Probabilistic Models”, 2020; arXiv:2006.11239.

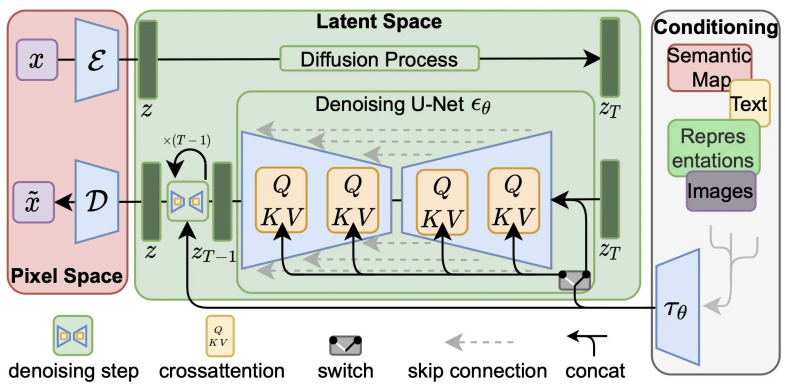
Transformerの次に死ぬほど目にしたStable Diffusionの図



Robin Rombach, Andreas Blattmann, Dominik Lorenz, Patrick Esser, Björn Ommer: “High-Resolution Image Synthesis with Latent Diffusion Models”, 2021; arXiv:2112.10752.

```
131  prompt_embeds = self.encode_prompt(prompt)
132  latents = self.get_latent(width, height).unsqueeze(dim=0)
133  latents = self.denoise(latents, prompt_embeds, num_inference_steps, guidance_scale)
134  image = self.vae_decode(latents)
```

src/parediffusers/pipeline.py delivered with ❤️ by emgithub — view raw



Robin Rombach, Andreas Blattmann, Dominik Lorenz, Patrick Esser, Björn Ommer: “High-Resolution Image Synthesis with Latent Diffusion Models”, 2021; arXiv:2112.10752.

Latent Space(滞在空間)とは?

入力画像の特徴を抽出した空間

4ステップでわかる画像生成の流れ

ステップ1: PromptをEmbeddingに変換する
ステップ2: ランダムなLatentを作る
ステップ3: SchedulerとUNetを使って、デノイズを行う
ステップ4: VAEで、画像にデコードする

これからのスライドの流れ

ステップ1: encode_prompt
ステップ2: get_latent
ステップ3: denoise
ステップ4: vae_decode


ステップ1: encode_prompt
Prompt: Pipeline, cyberpunk theme, best quality, high resolution, concept art

ステップ1: encode_prompt

プロンプトをembeddingに変換する

ステップ1: encode_prompt

プロンプトをモデルが扱いやすい形に変換する

必要なもの

- CLIPTokenizer
- CLIPTextModel

From huggingface/transformers

ステップ1: encode_prompt

encode_prompt内で、別の関数を呼び出している

pipeline.py#L41-L48

```
41  def encode_prompt(self, prompt: str):
42      """
43      Encode the text prompt into embeddings using the t
44      """
45      prompt_embeds = self.get_embes(prompt, self.tokeni
46      negative_prompt_embeds = self.get_embes([''], prom
47      prompt_embeds = torch.cat([negative_prompt_embeds,
48      return prompt_embeds
```

ステップ1: encode_prompt

必要なものはどこで使われているか?

pipeline.py#L41-L57

```
41  def encode_prompt(self, prompt: str):
42      """
43      Encode the text prompt into embeddings using the t
44      """
45      prompt_embeds = self.get_embes(prompt, self.tokeni
46      negative_prompt_embeds = self.get_embes([''], prom
47      prompt_embeds = torch.cat([negative_prompt_embeds,
48      return prompt_embeds
49
50  def get_embes(self, prompt, max_length):
51      """
52      Encode the text prompt into embeddings using the t
53      """
54      text_inputs = self.tokenizer(prompt, padding="max_
55      text_input_ids = text_inputs.input_ids.to(self.dev
56      prompt_embeds = self.text_encoder(text_input_ids)[
57      return prompt_embeds
```

ステップ1: encode_prompt

必要なものはどこで使われているか?

- L54: `CLIPTokenizer`：テキスト(prompt)をトークン化。ベクトルにすることで、AIに扱いやすくさせる。
- L56: `CLIPTextModel`：言語と画像のマルチモーダルモデル。画像生成においては、プロンプトで作りたい画像の表現（embedding）を抽出する。

pipeline.py#L21-L39

```
@classmethod
def from_pretrained(cls, model_name, device=torch.device("
  # Ommit comments
  tokenizer = CLIPTokenizer.from_pretrained(model_name, su
  text_encoder = CLIPTextModel.from_pretrained(model_name,
  scheduler = PareDDIMScheduler.from_config(model_name, su
  unet = PareUNet2DConditionModel.from_pretrained(model_na
  vae = PareAutoencoderKL.from_pretrained(model_name, subf
  return cls(tokenizer, text_encoder, scheduler, unet, vae
```

pipeline.py#L50-L57

```
50    def get_embes(self, prompt, max_length):
51        """
52        Encode the text prompt into embeddings using the t
53        """
54        text_inputs = self.tokenizer(prompt, padding="max_
55        text_input_ids = text_inputs.input_ids.to(self.dev
56        prompt_embeds = self.text_encoder(text_input_ids)[
57        return prompt_embeds
```

ステップ1: encode_prompt

コードを読み全体の流れを理解する

- L54: `CLIPTokenizer`：テキスト(prompt)をトークン化。ベクトルにすることで、AIに扱いやすくさせる。
- L56: `CLIPTextModel`：言語と画像のマルチモーダルモデル。画像生成においては、プロンプトで作りたい画像の表現（embedding）を抽出する。
- L46: シンプルにするために、negative_promptは空の文字列としています。

pipeline.py#L34-L35

```
34      tokenizer = CLIPTokenizer.from_pretrained(model_na
35      text_encoder = CLIPTextModel.from_pretrained(model
```

pipeline.py#L41-L57

```
41    def encode_prompt(self, prompt: str):
42      """
43      Encode the text prompt into embeddings using the t
44      """
45      prompt_embeds = self.get_embes(prompt, self.tokeni
46      negative_prompt_embeds = self.get_embes([''], prom
47      prompt_embeds = torch.cat([negative_prompt_embeds,
48      return prompt_embeds
49
50    def get_embes(self, prompt, max_length):
51      """
52      Encode the text prompt into embeddings using the t
53      """
54      text_inputs = self.tokenizer(prompt, padding="max_
55      text_input_ids = text_inputs.input_ids.to(self.dev
56      prompt_embeds = self.text_encoder(text_input_ids)[
57      return prompt_embeds
```

In [15]:

```
prompt = "painting depicting the sea, sunrise, ship, artstation, 4k, concept art"

text_inputs = pipe.tokenizer(prompt, padding="max_length", max_length=max_length, truncation=True,

print(text_inputs.input_ids.shape, '\n')
print(text_inputs.input_ids)
```

Out [15]:

```
torch.Size([1, 77])

tensor([[49406,  3086, 24970,   518,  2102,   267,  5610,   267,  1158,   267,
          1486,  2631,   267,   275,   330,   267,  6353,   794, 49407,     0,
             0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
             0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
             0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
             0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
             0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
             0,     0,     0,     0,     0,     0,     0]])
```

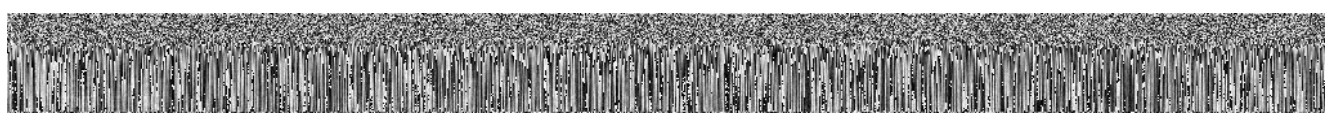
In [18]:

```
text_input_ids = text_inputs.input_ids.to(pipe.device)
prompt_embeds = pipe.text_encoder(text_input_ids)[0].to(dtype=pipe.dtype, device=pipe.device)

print(prompt_embeds.shape, '\n')
print(prompt_embeds, '\n')
display(pipe.tensor_to_image(prompt_embeds))
```

Out [18]:

```
torch.Size([1, 77, 1024])

tensor([[[-0.3135, -0.4475, -0.0083,  ...,  0.2544, -0.0327, -0.2959],
         [ 0.6030, -0.9849, -0.6772,  ...,  1.6953, -0.1359, -0.3333],
         [-0.1290, -0.3606, -0.1376,  ...,  0.5244, -0.8164,  0.8135],
         ...,
         [ 0.4788, -1.6396,  0.7124,  ..., -0.0309, -0.2939,  0.4023],
         [ 0.4790, -1.6875,  0.7222,  ..., -0.2104, -0.3623,  0.5020],
         [ 0.5854, -2.2852,  0.3623,  ..., -0.2250,  0.1294,  0.7236]]],
       device='cuda:0', dtype=torch.float16, grad_fn=<NativeLayerNormBackward0>)
```

Out [18]:



Ch 0.1.2 Play prompt_embeds

Part 0: Setup

In [1]:

```
# Install diffusers and parediffusers
!pip install transformers diffusers accelerate -U
!pip install parediffusers==0.0.0
```

Out [1]:

```
Requirement already satisfied: transformers in /usr/local/lib/python3.10/dist-packages (4.36.2)
Requirement already satisfied: diffusers in /usr/local/lib/python3.10/dist-packages (0.25.0)
Requirement already satisfied: accelerate in /usr/local/lib/python3.10/dist-packages (0.25.0)
Requirement already satisfied: numpy>=1.17 in /usr/local/lib/python3.10/dist-packages (from transfo
Requirement already satisfied: pyyaml>=5.1 in /usr/local/lib/python3.10/dist-packages (from transfo
Requirement already satisfied: packaging>=20.0 in /usr/local/lib/python3.10/dist-packages (from tra
Requirement already satisfied: tqdm>=4.27 in /usr/local/lib/python3.10/dist-packages (from transfor
Requirement already satisfied: tokenizers<0.19,>=0.14 in /usr/local/lib/python3.10/dist-packages (f
Requirement already satisfied: safetensors>=0.3.1 in /usr/local/lib/python3.10/dist-packages (from
Requirement already satisfied: requests in /usr/local/lib/python3.10/dist-packages (from transforme
Requirement already satisfied: huggingface-hub<1.0,>=0.19.3 in /usr/local/lib/python3.10/dist-packa
Requirement already satisfied: filelock in /usr/local/lib/python3.10/dist-packages (from transforme
Requirement already satisfied: regex!=2019.12.17 in /usr/local/lib/python3.10/dist-packages (from t
Requirement already satisfied: Pillow in /usr/local/lib/python3.10/dist-packages (from diffusers) (
Requirement already satisfied: importlib-metadata in /usr/local/lib/python3.10/dist-packages (from
Requirement already satisfied: torch>=1.10.0 in /usr/local/lib/python3.10/dist-packages (from accel
Requirement already satisfied: psutil in /usr/local/lib/python3.10/dist-packages (from accelerate)
Requirement already satisfied: typing-extensions>=3.7.4.3 in /usr/local/lib/python3.10/dist-package
Requirement already satisfied: fsspec>=2023.5.0 in /usr/local/lib/python3.10/dist-packages (from hu
Requirement already satisfied: zipp>=0.5 in /usr/local/lib/python3.10/dist-packages (from importlib
Requirement already satisfied: charset-normalizer<4,>=2 in /usr/local/lib/python3.10/dist-packages
Requirement already satisfied: idna<4,>=2.5 in /usr/lib/python3/dist-packages (from requests->trans
Requirement already satisfied: certifi>=2017.4.17 in /usr/lib/python3/dist-packages (from requests-
Requirement already satisfied: urllib3<1.27,>=1.21.1 in /usr/local/lib/python3.10/dist-packages (fr
WARNING: Running pip as the 'root' user can result in broken permissions and conflicting behaviour
Obtaining file:///
ERROR: file:/// does not appear to be a Python project: neither 'setup.py' nor 'pyproject.toml' fou
```

ステップ2: get_latent

Prompt: Scheduler, flat vector illustration, best quality, high resolution

ステップ2: get_latent

1/8のサイズのランダムなテンソルを生成

必要なもの

torch.randn

ステップ2: get_latent

コードを読み全体の流れを理解する

- L63: 1/8のサイズのランダムなテンソルを生成

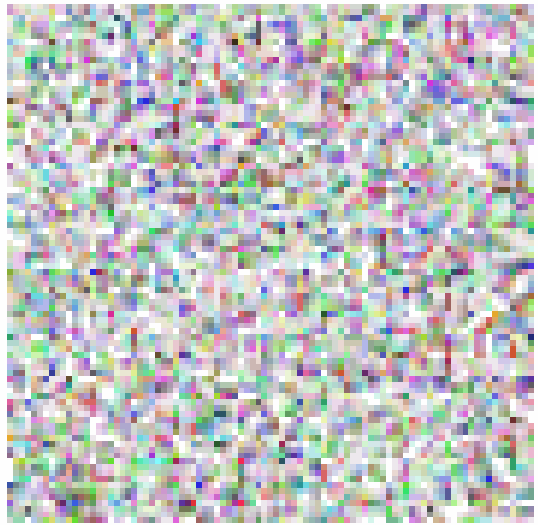
pipeline.py#L59-L65

```
59  def get_latent(self, width: int, height: int):
60    """
61    Generate a random initial latent tensor to start
62    """
63    return torch.randn((4, width // 8, height // 8),
64      device=self.device, dtype=self.dtype
65    )
```

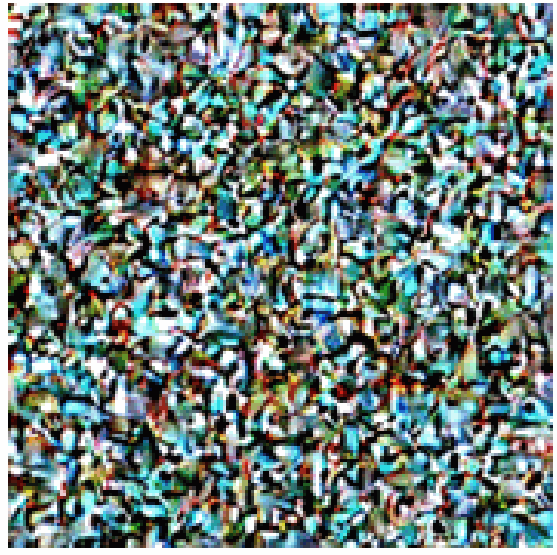

ステップ3: denoise
Prompt: UNet, watercolor painting, detailed, brush strokes, best quality, high resolution

ステップ3: denoise

SchedulerとUNetを使って、デノイズを行う



understand-stable-diffusion-slidev-notebooks/denoise.ipynb



Index: 0

understand-stable-diffusion-slidev-notebooks/denoise.ipynb

必要なもの

scheduler.py

unet.py

ステップ3: denoise

その2つの詳細は置いておき、全体の流れ

ステップ3: denoise

必要なものはどこで使われているか?

- L86: UNet
- L91: Scheduler

pipeline.py#L75-L93

```
75   @torch.no_grad()
76   def denoise(self, latents, prompt_embeds, num_inferenc
77     """
78     Iteratively denoise the latent space using the diff
79     """
80     timesteps, num_inference_steps = self.retrieve_time
81
82     for t in timesteps:
83       latent_model_input = torch.cat([latents] * 2)
84
85       # Predict the noise residual for the current time
86       noise_residual = self.unet(latent_model_input, t,
87       uncond_residual, text_cond_residual = noise_resid
88       guided_noise_residual = uncond_residual + guidanc
89
90       # Update latents by reversing the diffusion proce
91       latents = self.scheduler.step(guided_noise_residu
92
93     return latents
```

ステップ3: denoise

必要なものはどこで使われているか?

- L86: UNet2DConditionModel
- L91: DDIMScheduler

pipeline.py#L21-L39

```
@classmethod
def from_pretrained(cls, model_name, device=torch.device("c
  # Ommit comments
  tokenizer = CLIPTokenizer.from_pretrained(model_name, sub
  text_encoder = CLIPTextModel.from_pretrained(model_name,
  scheduler = PareDDIMScheduler.from_config(model_name, sub
  unet = PareUNet2DConditionModel.from_pretrained(model_nam
  vae = PareAutoencoderKL.from_pretrained(model_name, subfo
  return cls(tokenizer, text_encoder, scheduler, unet, vae,
```

pipeline.py#L82-L93

```
82      for t in timesteps:
83        latent_model_input = torch.cat([latents] * 2)
84
85        # Predict the noise residual for the current time
86        noise_residual = self.unet(latent_model_input, t,
87        uncond_residual, text_cond_residual = noise_resid
88        guided_noise_residual = uncond_residual + guidanc
89
90        # Update latents by reversing the diffusion proce
91        latents = self.scheduler.step(guided_noise_residu
```

ステップ3: denoise

コードを読み全体の流れを理解する

- L80: Schedulerを使いtimestepsの取得
  (Schedulerについては後述)
- L82: timestepsの長さ分ループ
  (timestepsの長さ分 = num_inference_steps)
- L86: UNetでデノイズ
  (UNetについては後述)
- L88: どれだけプロンプトを考慮するかを計算
  (参考: Jonathan Ho, Tim Salimans: “Classifier-Free Diffusion Guidance”, 2022; arXiv:2207.12598.)
- L91: Schedulerによって、デノイズの強さを決定

pipeline.py#L82-L93

```
75    @torch.no_grad()
76    def denoise(self, latents, prompt_embeds, num_inferenc
77      """
78      Iteratively denoise the latent space using the diff
79      """
80      timesteps, num_inference_steps = self.retrieve_time
81
82      for t in timesteps:
83        latent_model_input = torch.cat([latents] * 2)
84
85        # Predict the noise residual for the current time
86        noise_residual = self.unet(latent_model_input, t,
87        uncond_residual, text_cond_residual = noise_resid
88        guided_noise_residual = uncond_residual + guidanc
89
90        # Update latents by reversing the diffusion proce
91        latents = self.scheduler.step(guided_noise_residu
92
93      return latents
```

scheduler.py

デノイズの強さを決定

```python
import json
import numpy as np
import torch
from huggingface_hub import hf_hub_download
from .utils import DotDict


class PareDDIMScheduler:
    def __init__(self, config_dict: dict):
        """Initialize beta and alpha values for the scheduler."""
        self.config = DotDict(**config_dict)
        self.betas = (
            torch.linspace(
                self.config.beta_start**0.5,
                self.config.beta_end**0.5,
                self.config.num_train_timesteps,
                dtype=torch.float32,
            )
            ** 2
        )
        self.alphas = 1.0 - self.betas
        self.alphas_cumprod = torch.cumprod(self.alphas, dim=0)
        self.final_alpha_cumprod = torch.tensor(1.0)

    @classmethod
    def from_config(
        cls,
        model_name: str,
        subfolder: str = "scheduler",
        filename: str = "scheduler_config.json",
    ) -> "PareDDIMScheduler":
        """Create scheduler instance from configuration file."""
        config_file = hf_hub_download(
            model_name, filename=filename, subfolder=subfolder
        )
        with open(config_file, "r", encoding="utf-8") as reader:
            text = reader.read()
        config_dict = json.loads(text)
        return cls(config_dict)

    def set_timesteps(
        self, num_inference_steps: int, device: torch.device = None
    ) -> None:
        """Set the timesteps for the scheduler based on the number of inference steps."""
        self.num_inference_steps = num_inference_steps
        step_ratio = self.config.num_train_timesteps // self.num_inference_steps
        timesteps = (
            (np.arange(0, num_inference_steps) * step_ratio)
            .round()[::-1]
            .copy()
            .astype(np.int64)
        )
        timesteps += self.config.steps_offset
        self.timesteps = torch.from_numpy(timesteps).to(device)

    def step(
        self,
        model_output: torch.FloatTensor,
        timestep: int,
        sample: torch.FloatTensor,
    ) -> list:
        """Perform a single step of denoising in the diffusion process."""
        prev_timestep = (
```

Scheduler

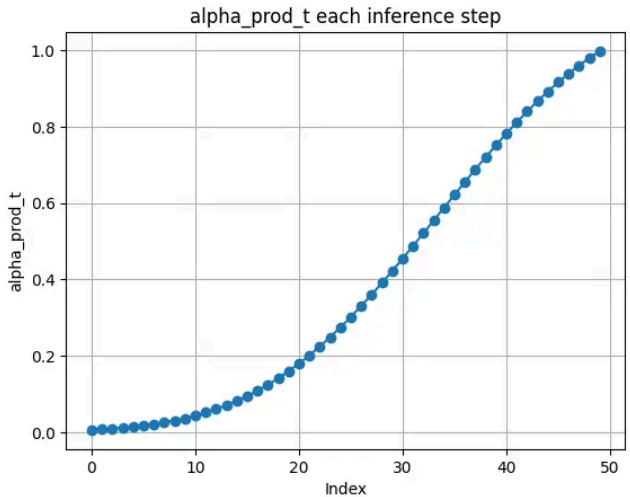
- L49: alpha_prod_t(0~1.0)を取得
  (元のデータがどの程度保持されるかを示します。)
- L50: alpha_prod_t_prev(0~1.0)を取得
- L52: alpha_prod_t + beta_prod_t = 1
- L53: 現在のサンプルとモデル出力から元のサンプルを推定します。
- L54: 追加されたノイズの推定値を計算します。
- L56: 元の画像への復元する方向を計算します。
- L57: 推定された元のサンプルと更新方向を組み合わせて、デノイジングを一歩進めたサンプルを計算します。

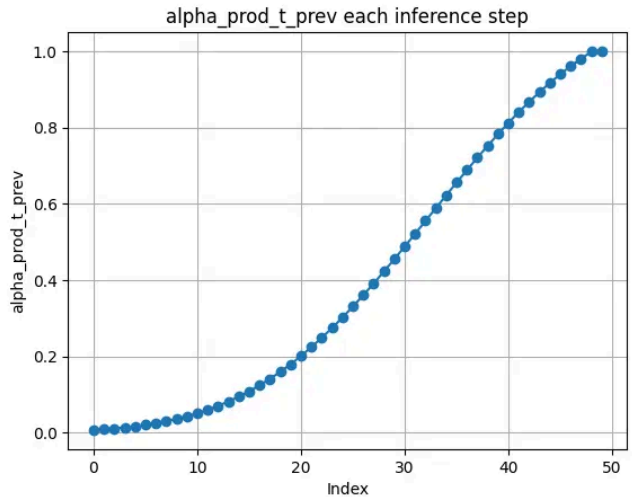
scheduler.py#L40-L59

```
40    def step(
41      self,
42      model_output: torch.FloatTensor,
43      timestep: int,
44      sample: torch.FloatTensor,
45    ) -> list:
46      """Perform a single step of denoising in the diffusion p
47      prev_timestep = timestep - self.config.num_train_timeste
48
49      alpha_prod_t = self.alphas_cumprod[timestep]
50      alpha_prod_t_prev = self.alphas_cumprod[prev_timestep] :
51
52      beta_prod_t = 1 - alpha_prod_t
53      pred_original_sample = (alpha_prod_t**0.5) * sample - (b
54      pred_epsilon = (alpha_prod_t**0.5) * model_output + (bet
55
56      pred_sample_direction = (1 - alpha_prod_t_prev) ** (0.5)
57      prev_sample = alpha_prod_t_prev ** (0.5) * pred_original
58
59      return prev_sample, pred_original_sample
```

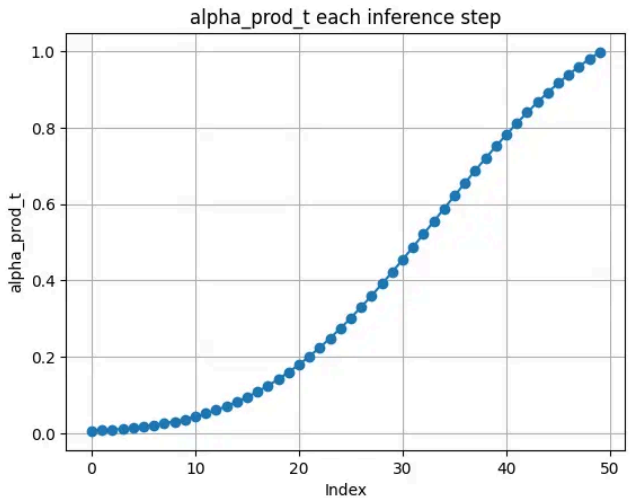
scheduler.py#L40-L59

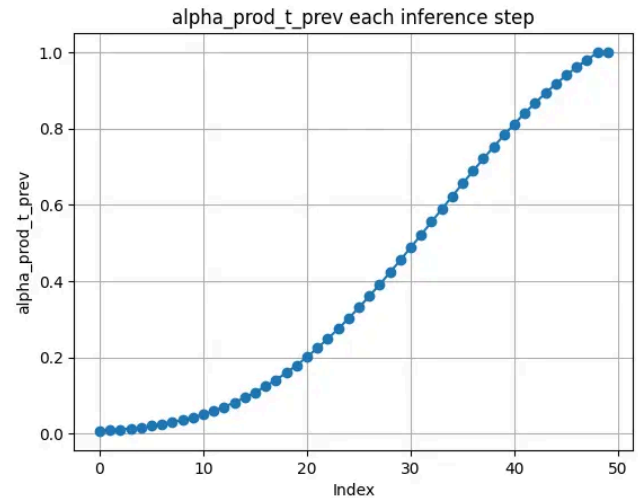
```python
  def step(
    self,
    model_output: torch.FloatTensor,
    timestep: int,
    sample: torch.FloatTensor,
  ) -> list:
    """Perform a single step of denoising in the diffusion process."""
    prev_timestep = timestep - self.config.num_train_timesteps // self.num_inference_steps

    alpha_prod_t = self.alphas_cumprod[timestep]
    alpha_prod_t_prev = self.alphas_cumprod[prev_timestep] if prev_timestep >= 0 else self.final_alpha_cumprod

    beta_prod_t = 1 - alpha_prod_t
    pred_original_sample = (alpha_prod_t**0.5) * sample - (beta_prod_t**0.5) * model_output
    pred_epsilon = (alpha_prod_t**0.5) * model_output + (beta_prod_t**0.5) * sample

    pred_sample_direction = (1 - alpha_prod_t_prev) ** (0.5) * pred_epsilon
    prev_sample = alpha_prod_t_prev ** (0.5) * pred_original_sample + pred_sample_direction

    return prev_sample, pred_original_sample
```



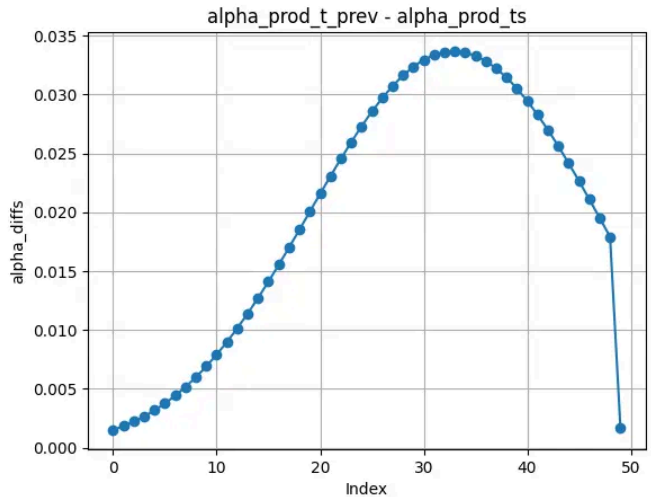


understand-stable-diffusion-slidev-notebooks/scheduler.ipynb





understand-stable-diffusion-slidev-notebooks/scheduler.ipynb



understand-stable-diffusion-slidev-notebooks/scheduler.ipynb

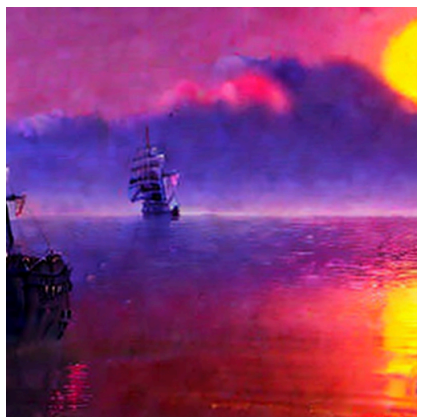
In [5]:

```
latents = init_latents.detach().clone()

# Denoise loop without scheduler
@torch.no_grad()
def custom_denoise(
        pipe, latents, prompt_embeds, num_inference_steps, guidance_scale, ratio
):
        for i in range(num_inference_steps):
                latent_model_input = torch.cat([latents] * 2)

                # Predict the noise residual for the current timestep
                t = torch.tensor((1000/num_inference_steps)*(num_inference_steps-i-1)+1, device=pip
                noise_residual = pipe.unet(latent_model_input, t, encoder_hidden_states=prompt_embe
                uncond_residual, text_cond_residual = noise_residual.chunk(2)
                guided_noise_residual = uncond_residual + guidance_scale * (text_cond_residual - un

                # Update the latents with the predicted noise residual
                latents = latents - (ratio * guided_noise_residual / num_inference_steps)

                #display(pipe.vae_decode(latents))
        return latents

ratio = 1.475
latents = custom_denoise(pipe, latents, prompt_embeds, num_inference_steps, guidance_scale, ratio)
image = pipe.vae_decode(latents)
image
```

Out [5]:

```
/tmp/ipykernel_32/1826561155.py:12: DeprecationWarning: an integer is required (got type float).  I
  t = torch.tensor((1000/num_inference_steps)*(num_inference_steps-i-1)+1, device=pipe.device, dtyp
```

Out [5]:

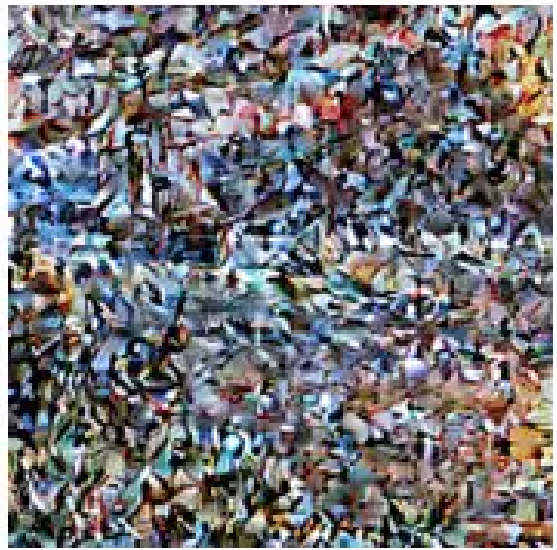


In [4]:

```
latents = init_latents.detach().clone()

@torch.no_grad()
def denoise(
        pipe, latents, prompt_embeds, num_inference_steps=50, guidance_scale=7.5
):
        timesteps, num_inference_steps = pipe.retrieve_timesteps(num_inference_steps)

        for t in timesteps:
                latent_model_input = torch.cat([latents] * 2)

                # Predict the noise residual for the current timestep
                noise_residual = pipe.unet(
                        latent_model_input, t, encoder_hidden_states=prompt_embeds
                )
                uncond_residual, text_cond_residual = noise_residual.chunk(2)
                guided_noise_residual = uncond_residual + guidance_scale * (
                        text_cond_residual - uncond_residual
                )

                # Update latents by reversing the diffusion process for the current timestep
                latents = pipe.scheduler.step(guided_noise_residual, t, latents)[0]

        return latents

latents = denoise(pipe, latents, prompt_embeds, num_inference_steps, guidance_scale)
image = pipe.vae_decode(latents)
image
```

Out [4]:

なぜ`ratio = 1.5`前後がいいかは分からない



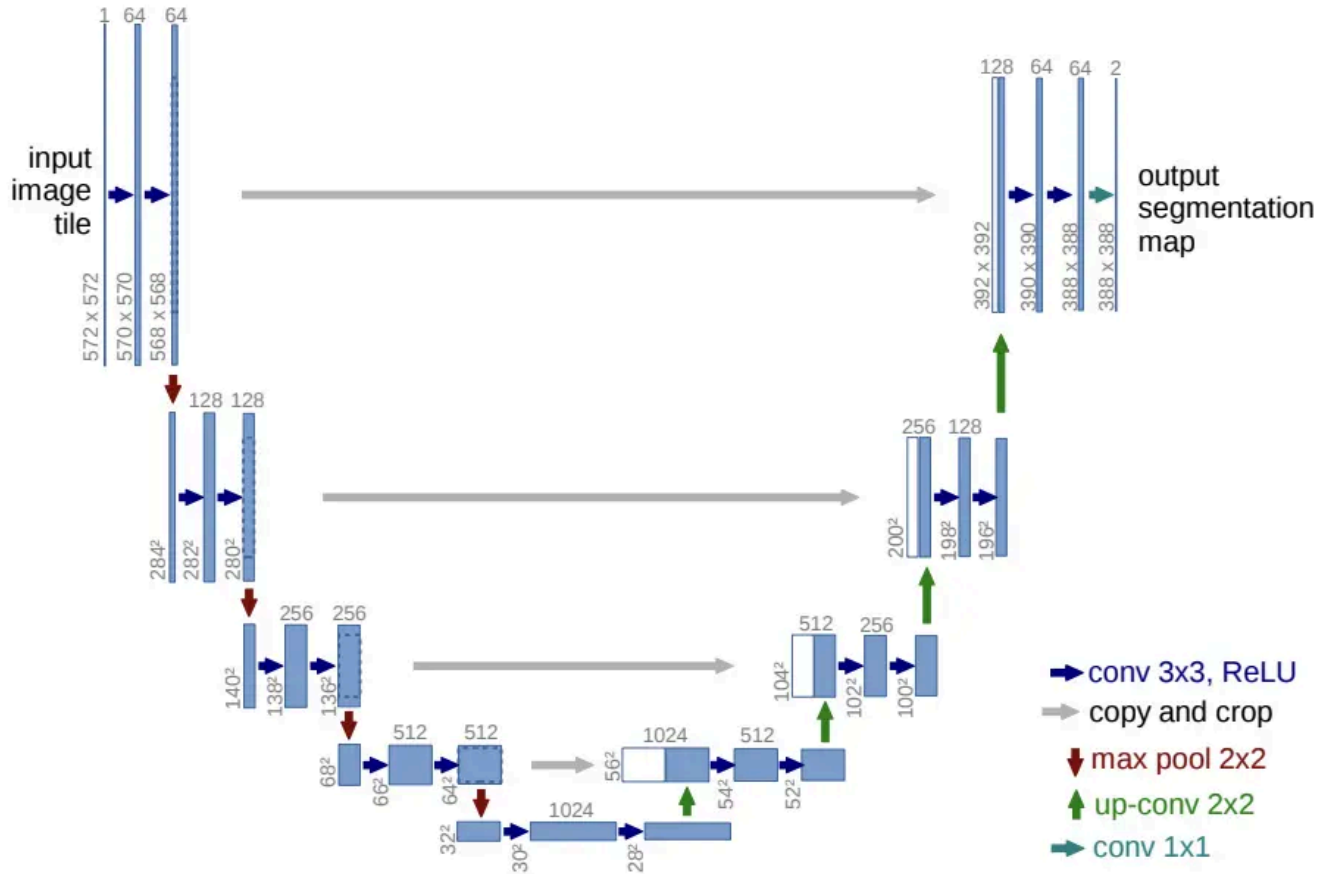
0.5000

understand-stable-diffusion-slidev-notebooks/scheduler_necessity.ipynb

unet.py

デノイジングに使われる

```python
import torch
from torch import nn
from typing import List, Union
import json
from huggingface_hub import hf_hub_download
from .utils import DotDict, get_activation
from .defaults import DEFAULT_UNET_CONFIG
from .models.embeddings import PareTimestepEmbedding, PareTimesteps
from .models.unet_2d_get_blocks import pare_get_down_block, pare_get_up_block
from .models.unet_2d_mid_blocks import PareUNetMidBlock2DCrossAttn


class PareUNet2DConditionModel(nn.Module):
    def __init__(self, **kwargs):
        super().__init__()
        self.config = DotDict(DEFAULT_UNET_CONFIG)
        self.config.update(kwargs)
        self.config.only_cross_attention = [self.config.only_cross_attention] * len(
            self.config.down_block_types
        )
        self.config.num_attention_heads = (
            self.config.num_attention_heads or self.config.attention_head_dim
        )
        self._setup_model_parameters()

        self._build_input_layers()
        self._build_time_embedding()
        self._build_down_blocks()
        self._build_mid_block()
        self._build_up_blocks()
        self._build_output_layers()

    def _setup_model_parameters(self) -> None:
        if isinstance(self.config.num_attention_heads, int):
            self.config.num_attention_heads = (self.config.num_attention_heads,) * len(
                self.config.down_block_types
            )
        if isinstance(self.config.attention_head_dim, int):
            self.config.attention_head_dim = (self.config.attention_head_dim,) * len(
                self.config.down_block_types
            )
        if isinstance(self.config.cross_attention_dim, int):
            self.config.cross_attention_dim = (self.config.cross_attention_dim,) * len(
                self.config.down_block_types
            )
        if isinstance(self.config.layers_per_block, int):
            self.config.layers_per_block = [self.config.layers_per_block] * len(
                self.config.down_block_types
            )
        if isinstance(self.config.transformer_layers_per_block, int):
            self.config.transformer_layers_per_block = [
                self.config.transformer_layers_per_block
            ] * len(self.config.down_block_types)

    def _build_input_layers(self) -> None:
        conv_in_padding = (self.config.conv_in_kernel - 1) // 2
        self.conv_in = nn.Conv2d(
            self.config.in_channels,
            self.config.block_out_channels[0],
            kernel_size=self.config.conv_in_kernel,
            padding=conv_in_padding,
        )

```



Olaf Ronneberger, Philipp Fischer, Thomas Brox: “U-Net: Convolutional Networks for Biomedical Image Segmentation”, 2015; arXiv:1505.04597.

ResnetとTransformerを使いUNetを作成

```python
for i in range(num_layers):
    in_channels = in_channels if i == 0 else out_channels
    resnets.append(
        PareResnetBlock2D(
            in_channels=in_channels,
            out_channels=out_channels,
            temb_channels=temb_channels,
            eps=resnet_eps,
            groups=resnet_groups,
            dropout=dropout,
            non_linearity=resnet_act_fn,
            output_scale_factor=output_scale_factor,
        )
    )
    if not dual_cross_attention:
        attentions.append(
            PareTransformer2DModel(
                num_attention_heads,
                out_channels // num_attention_heads,
                in_channels=out_channels,
                num_layers=transformer_layers_per_block[i],
                cross_attention_dim=cross_attention_dim,
                norm_num_groups=resnet_groups,
                use_linear_projection=use_linear_projection,
                only_cross_attention=only_cross_attention,
                upcast_attention=upcast_attention,
            )
        )
```

src/parediffusers/models/unet_2d_blocks.py delivered with ❤️ by emgithub

view raw


ステップ4: vae_decode
Prompt: VAE, abstract style, highly detailed, colors and shapes

ステップ4: vae_decode

VAEで、画像にデコードする

ステップ4: vae_decode

コードを読み全体の流れを理解する

pipeline.py#L107-L105

```
107   @torch.no_grad()
108   def vae_decode(self, latents):
109     """
110     Decode the latent tensors using the VAE to produce an image.
111     """
112     image = self.vae.decode(latents / self.vae.config.scaling_factor
113     image = self.denormalize(image)
114     image = self.tensor_to_image(image)
115     return image
```

- L112: VAEで画像にデコード

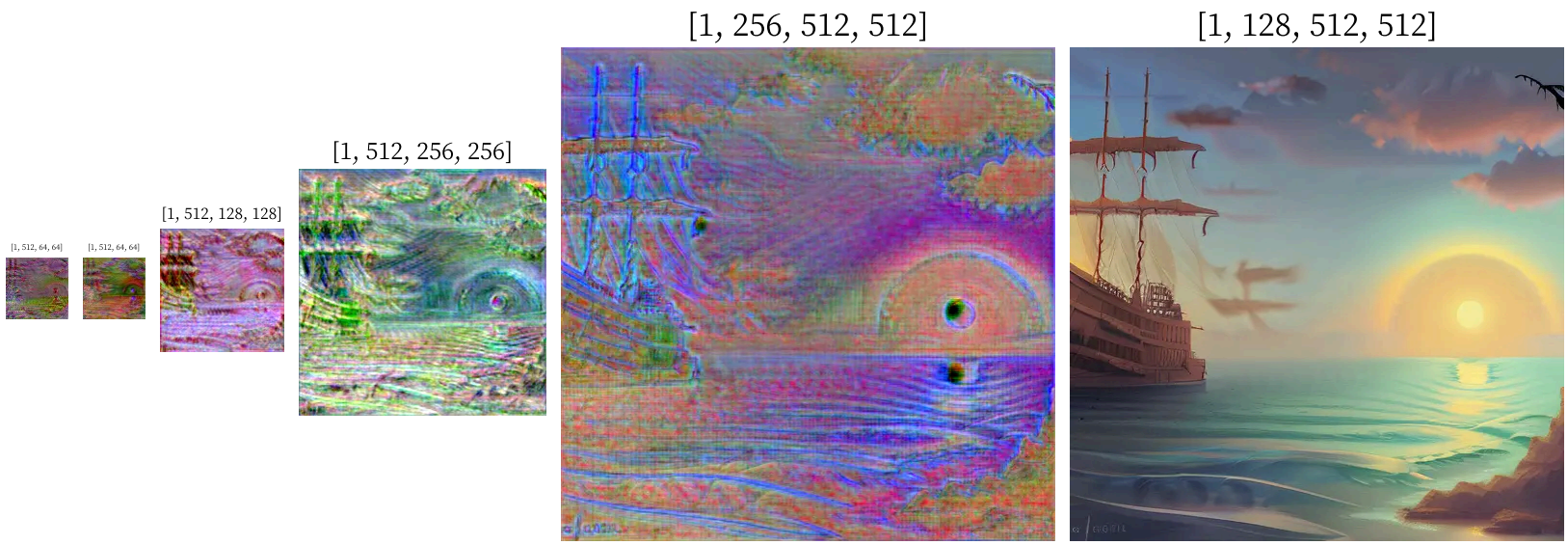
- L113: 正規化して学習しているので、
  逆正規化する必要がある。

- L114: テンソルからPIL.Imageに変換

Variational Autoencoder

変分自己符号化器 (日本語訳かっこいい!)


```python
import json
from typing import List
import torch
import torch.nn as nn
from huggingface_hub import hf_hub_download
from .utils import DotDict
from .defaults import DEFAULT_VAE_CONFIG
from .models.vae_blocks import (
    PareEncoder,
    PareDecoder,
    PareDiagonalGaussianDistribution,
)


class PareAutoencoderKL(nn.Module):
    def __init__(self, **kwargs):
        super().__init__()
        self.config = DotDict(DEFAULT_VAE_CONFIG)
        self.config.update(kwargs)

        # pass init params to Encoder
        self.encoder = PareEncoder(
            in_channels=self.config.in_channels,
            out_channels=self.config.latent_channels,
            down_block_types=self.config.down_block_types,
            block_out_channels=self.config.block_out_channels,
            layers_per_block=self.config.layers_per_block,
        )

        # pass init params to Decoder
        self.decoder = PareDecoder(
            in_channels=self.config.latent_channels,
            out_channels=self.config.out_channels,
            up_block_types=self.config.up_block_types,
            block_out_channels=self.config.block_out_channels,
            layers_per_block=self.config.layers_per_block,
        )

        self.quant_conv = nn.Conv2d(
            2 * self.config.latent_channels, 2 * self.config.latent_channels, 1
        )
        self.post_quant_conv = nn.Conv2d(
            self.config.latent_channels, self.config.latent_channels, 1
        )

        self.use_slicing = False
        self.use_tiling = False

        # only relevant if vae tiling is enabled
        self.tile_sample_min_size = self.config.sample_size
        sample_size = (
            self.config.sample_size[0]
            if isinstance(self.config.sample_size, (list, tuple))
            else self.config.sample_size
        )
        self.tile_latent_min_size = int(
            sample_size / (2 ** (len(self.config.block_out_channels) - 1))
        )
        self.tile_overlap_factor = 0.25

    @classmethod
    def _get_config(
        cls, model_name: str, filename: str = "config.json", subfolder: str = "unet"
```



understand-stable-diffusion-slidev-notebooks/vae.ipynb

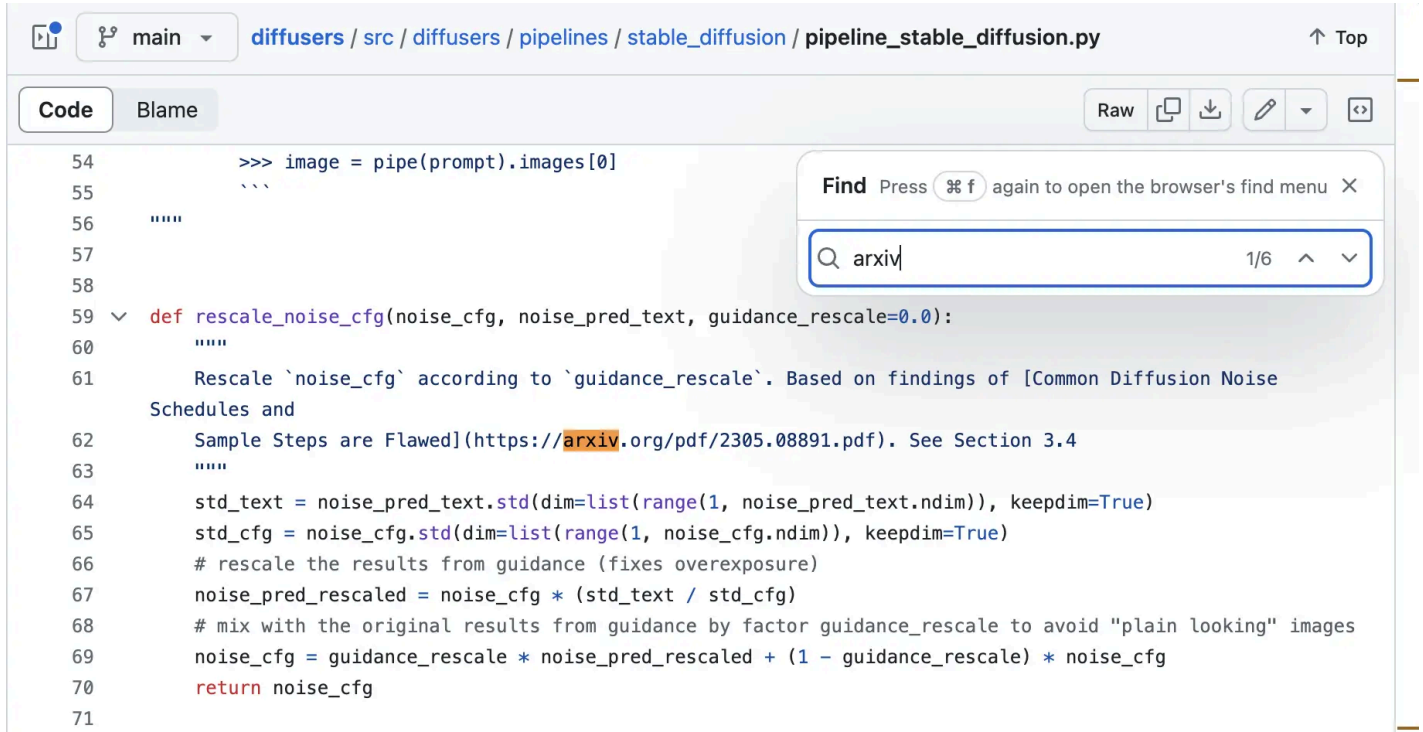
9. まとめ

Prompt: Summary, long-exposure photography, masterpieces

ライブラリのコードを読むの楽しい!

ライブラリの至る所で、論文が引用

diffusers/.../pipeline.py

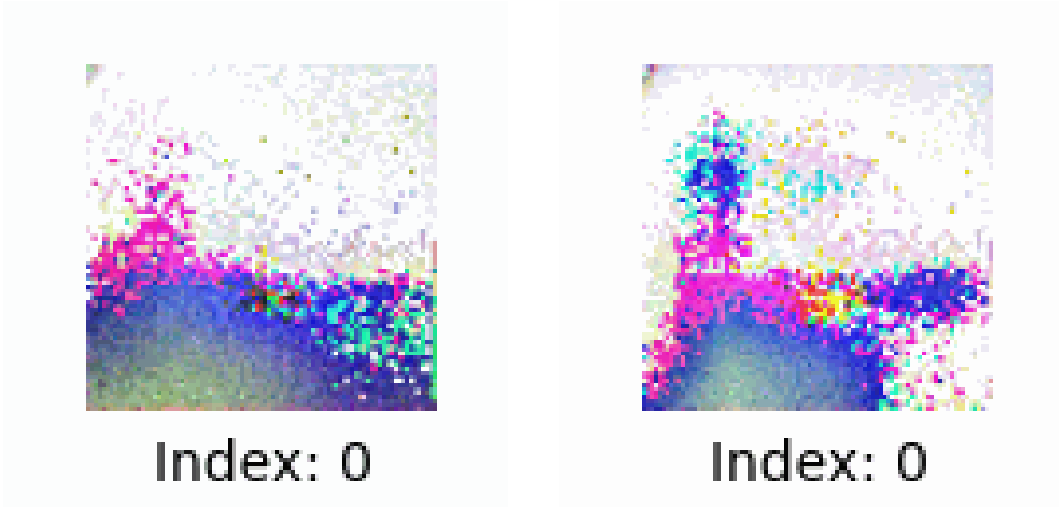


まとめ

1. プロンプトのエンコード
2. ランダムな潜在空間の生成
3. UNetを用いてデノイジング
4. VAEで、画像にデコードする

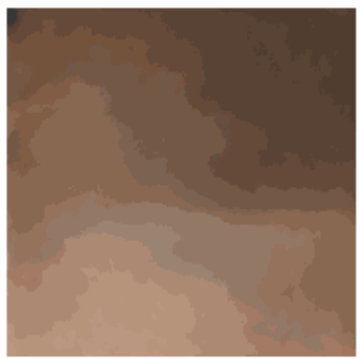
Appendix

Other denoising samples



understand-stable-diffusion-slidev-notebooks/denoise.ipynb

Other decorded denoising samples



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understand-stable-diffusion-slidev-notebooks/denoise.ipynb

UNetは本当にUの形?

```
init            torch.Size([2, 4, 64, 64])
conv_in         torch.Size([2, 320, 64, 64])

down_blocks_0   torch.Size([2, 320, 32, 32])
down_blocks_1   torch.Size([2, 640, 16, 16])
down_blocks_2   torch.Size([2, 1280, 8, 8])
down_blocks_3   torch.Size([2, 1280, 8, 8])

mid_block       torch.Size([2, 1280, 8, 8])

up_blocks0      torch.Size([2, 1280, 16, 16])
up_blocks1      torch.Size([2, 1280, 32, 32])
up_blocks2      torch.Size([2, 640, 64, 64])
up_blocks3      torch.Size([2, 320, 64, 64])

conv_out        torch.Size([2, 4, 64, 64])
```

understand-stable-diffusion-slidev-notebooks/unet.ipynb