VisionGPT-2 Image Captioning Model

- *almost* built from scratch.
- pretrained weights loading via HF & timm
- dataset preparation from scratch as well.

Imports

```
! pip install timm
```

```
Collecting timm
  Downloading timm-1.0.9-py3-none-any.whl.metadata (42 kB)
     ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 42.4/42.4 kB 3.3 MB/s eta 0:00:00
Requirement already satisfied: torch in /usr/local/lib/python3.10/dist-packages (from timm) (2.4.1+cu121)
Requirement already satisfied: torchvision in /usr/local/lib/python3.10/dist-packages (from timm) (0.19.1+cu121)
Requirement already satisfied: pyyaml in /usr/local/lib/python3.10/dist-packages (from timm) (6.0.2)
Requirement already satisfied: huggingface_hub in /usr/local/lib/python3.10/dist-packages (from timm) (0.24.7)
Requirement already satisfied: safetensors in /usr/local/lib/python3.10/dist-packages (from timm) (0.4.5)
Requirement already satisfied: filelock in /usr/local/lib/python3.10/dist-packages (from huggingface_hub->timm) (3.16.1)
Requirement already satisfied: fsspec>=2023.5.0 in /usr/local/lib/python3.10/dist-packages (from huggingface_hub->timm) (2024.6.1)
Requirement already satisfied: packaging>=20.9 in /usr/local/lib/python3.10/dist-packages (from huggingface_hub->timm) (24.1)
Requirement already satisfied: requests in /usr/local/lib/python3.10/dist-packages (from huggingface_hub->timm) (2.32.3)
Requirement already satisfied: tqdm>=4.42.1 in /usr/local/lib/python3.10/dist-packages (from huggingface_hub->timm) (4.66.5)
Requirement already satisfied: typing-extensions>=3.7.4.3 in /usr/local/lib/python3.10/dist-packages (from huggingface_hub->timm) (4
Requirement already satisfied: sympy in /usr/local/lib/python3.10/dist-packages (from torch->timm) (1.13.3)
Requirement already satisfied: networkx in /usr/local/lib/python3.10/dist-packages (from torch->timm) (3.3)
Requirement already satisfied: jinja2 in /usr/local/lib/python3.10/dist-packages (from torch->timm) (3.1.4)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages (from torchvision->timm) (1.26.4)
Requirement already satisfied: pillow!=8.3.*,>=5.3.0 in /usr/local/lib/python3.10/dist-packages (from torchvision->timm) (10.4.0)
Requirement already satisfied: MarkupSafe>=2.0 in /usr/local/lib/python3.10/dist-packages (from jinja2->torch->timm) (2.1.5)
Requirement already satisfied: charset-normalizer<4,>=2 in /usr/local/lib/python3.10/dist-packages (from requests->huggingface_hub->
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-packages (from requests->huggingface_hub->timm) (3.10
Requirement already satisfied: urllib3<3,>=1.21.1 in /usr/local/lib/python3.10/dist-packages (from requests->huggingface_hub->timm)
Requirement already satisfied: certifi>=2017.4.17 in /usr/local/lib/python3.10/dist-packages (from requests->huggingface_hub->timm)
Requirement already satisfied: mpmath<1.4,>=1.1.0 in /usr/local/lib/python3.10/dist-packages (from sympy->torch->timm) (1.3.0)
Downloading timm-1.0.9-py3-none-any.whl (2.3 MB)
   ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 2.3/2.3 MB 58.0 MB/s eta 0:00:00
Installing collected packages: timm
Successfully installed timm-1.0.9
```

```
import torch
import torch.nn as nn
import torch.nn.functional as F
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from timm import create_model, list_models
from types import SimpleNamespace
from transformers import GPT2LMHeadModel, GPT2TokenizerFast, get_linear_schedule_with_warmup
import albumentations as A
from albumentations.pytorch import ToTensorV2
from PIL import Image
from pathlib import Path
from sklearn.model_selection import train_test_split
from torch.cuda.amp import GradScaler, autocast
from tqdm.auto import tqdm
import gc
import json
```

```
%env TOKENIZERS_PARALLELISM = false
```

```
env: TOKENIZERS_PARALLELISM=false
```

Dataset

- the dataset we're using is `COCO 2017`, it has about 500k samples, we will only use 150k samples.
- augmentations: PIL + albumentations. Fun fact: albumentations is a LOT faster than torchvision
- mean and std for ViT models is `[0.5,0.5,0.5]` unlike the standard ImageNet mean and std.

```
sample_tfms = [
    A.HorizontalFlip(),
    A.RandomBrightnessContrast(),
    A.ColorJitter(),
    A.ShiftScaleRotate(shift_limit=0.1, scale_limit=0.3, rotate_limit=45, p=0.5),
    A.HueSaturationValue(p=0.3),
]
train_tfms = A.Compose([
    *sample_tfms,
    A.Resize(224,224),
    A.Normalize(mean=[0.5,0.5,0.5],std=[0.5,0.5,0.5],always_apply=True),
    ToTensorV2()
])
valid_tfms = A.Compose([
    A.Resize(224,224),
    A.Normalize(mean=[0.5,0.5,0.5],std=[0.5,0.5,0.5],always_apply=True),
    ToTensorV2()
])
```

```
tokenizer = GPT2TokenizerFast.from_pretrained('gpt2')
tokenizer.pad_token = tokenizer.eos_token
tokenizer.pad_token
```

```
/usr/local/lib/python3.10/dist-packages/huggingface_hub/utils/_token.py:89: UserWarning:
The secret `HF_TOKEN` does not exist in your Colab secrets.
To authenticate with the Hugging Face Hub, create a token in your settings tab (https://huggingface.co/settings/tokens), set it as s
You will be able to reuse this secret in all of your notebooks.
Please note that authentication is recommended but still optional to access public models or datasets.
  warnings.warn(
tokenizer_config.json: 100%  26.0/26.0 [00:00<00:00, 1.51kB/s]
vocab.json: 100%  1.04M/1.04M [00:00<00:00, 2.41MB/s]
merges.txt: 100%  456k/456k [00:00<00:00, 712kB/s]
tokenizer.json: 100%  1.36M/1.36M [00:00<00:00, 1.57MB/s]
config.json: 100%  665/665 [00:00<00:00, 31.9kB/s]
/usr/local/lib/python3.10/dist-packages/transformers/tokenization_utils_base.py:1601: FutureWarning: `clean_up_tokenization_spaces`
  warnings.warn(
'<|endoftext|>'
```

```
tokenizer.encode_plus('bonjour! WISD caption ')
```

```
{'input_ids': [4189, 73, 454, 0, 370, 1797, 35, 8305, 220], 'attention_mask': [1, 1, 1, 1, 1, 1, 1, 1, 1]}
```

```
class Dataset:
    def __init__(self, df, tfms):
        self.df = df
        self.tfms = tfms
    def __len__(self):
        return len(self.df)
    def __getitem__(self,idx):
        sample = self.df.iloc[idx,:]
        image = sample['image']
        caption = sample['caption']
        image = Image.open(image).convert('RGB')
        image = np.array(image)
        augs = self.tfms(image=image)
        image = augs['image']
        caption = f"{caption}<|endoftext|>"
        input_ids = tokenizer(
            caption,
            truncation=True)['input_ids']
        labels = input_ids.copy()
        labels[:-1] = input_ids[1:]
        return image,input_ids,labels
```

```
import os


from google.colab import files
files.upload()  # Téléchargez 'kaggle.json' ici

!mkdir -p ~/.kaggle
!mv kaggle.json ~/.kaggle/
!chmod 600 ~/.kaggle/kaggle.json

# Installer l'outil Kaggle dans Colab
!pip install -q kaggle
```

```
13
14
```

```
Sélect. fichiers Aucun fichier choisi  Upload widget is only available when the cell has been executed in the current browser session. Please rerun this cell to enable.
Saving kaggle.json to kaggle (1).json
```

```
1 # Remplacer 'dataset' par l'URL ou l'ID du dataset Kaggle que vous voulez télécharger
2 # Par exemple, pour le dataset COCO 2017:
3 !kaggle datasets download -d awsaf49/coco-2017-dataset
4
5 # Extraire les fichiers du zip téléchargé
6 !unzip coco-2017-dataset.zip -d ./coco2017/
```

```
Le flux de sortie a été tronqué et ne contient que les 5000 dernières lignes.
  inflating: ./coco2017/coco2017/val2017/000000000139.jpg
  inflating: ./coco2017/coco2017/val2017/000000000285.jpg
  inflating: ./coco2017/coco2017/val2017/000000000632.jpg
  inflating: ./coco2017/coco2017/val2017/000000000724.jpg
  inflating: ./coco2017/coco2017/val2017/000000000776.jpg
  inflating: ./coco2017/coco2017/val2017/000000000785.jpg
  inflating: ./coco2017/coco2017/val2017/000000000802.jpg
  inflating: ./coco2017/coco2017/val2017/000000000872.jpg
  inflating: ./coco2017/coco2017/val2017/000000000885.jpg
  inflating: ./coco2017/coco2017/val2017/000000001000.jpg
  inflating: ./coco2017/coco2017/val2017/000000001268.jpg
  inflating: ./coco2017/coco2017/val2017/000000001296.jpg
  inflating: ./coco2017/coco2017/val2017/000000001353.jpg
  inflating: ./coco2017/coco2017/val2017/000000001425.jpg
  inflating: ./coco2017/coco2017/val2017/000000001490.jpg
  inflating: ./coco2017/coco2017/val2017/000000001503.jpg
  inflating: ./coco2017/coco2017/val2017/000000001532.jpg
  inflating: ./coco2017/coco2017/val2017/000000001584.jpg
  inflating: ./coco2017/coco2017/val2017/000000001675.jpg
  inflating: ./coco2017/coco2017/val2017/000000001761.jpg
  inflating: ./coco2017/coco2017/val2017/000000001818.jpg
  inflating: ./coco2017/coco2017/val2017/000000001993.jpg
  inflating: ./coco2017/coco2017/val2017/000000002006.jpg
  inflating: ./coco2017/coco2017/val2017/000000002149.jpg
  inflating: ./coco2017/coco2017/val2017/000000002153.jpg
  inflating: ./coco2017/coco2017/val2017/000000002157.jpg
  inflating: ./coco2017/coco2017/val2017/000000002261.jpg
  inflating: ./coco2017/coco2017/val2017/000000002299.jpg
  inflating: ./coco2017/coco2017/val2017/000000002431.jpg
  inflating: ./coco2017/coco2017/val2017/000000002473.jpg
  inflating: ./coco2017/coco2017/val2017/000000002532.jpg
  inflating: ./coco2017/coco2017/val2017/000000002587.jpg
  inflating: ./coco2017/coco2017/val2017/000000002592.jpg
  inflating: ./coco2017/coco2017/val2017/000000002685.jpg
  inflating: ./coco2017/coco2017/val2017/000000002923.jpg
  inflating: ./coco2017/coco2017/val2017/000000003156.jpg
  inflating: ./coco2017/coco2017/val2017/000000003255.jpg
  inflating: ./coco2017/coco2017/val2017/000000003501.jpg
  inflating: ./coco2017/coco2017/val2017/000000003553.jpg
  inflating: ./coco2017/coco2017/val2017/000000003661.jpg
  inflating: ./coco2017/coco2017/val2017/000000003845.jpg
  inflating: ./coco2017/coco2017/val2017/000000003934.jpg
  inflating: ./coco2017/coco2017/val2017/000000004134.jpg
  inflating: ./coco2017/coco2017/val2017/000000004395.jpg
  inflating: ./coco2017/coco2017/val2017/000000004495.jpg
  inflating: ./coco2017/coco2017/val2017/000000004765.jpg
  inflating: ./coco2017/coco2017/val2017/000000004795.jpg
  inflating: ./coco2017/coco2017/val2017/000000005001.jpg
  inflating: ./coco2017/coco2017/val2017/000000005037.jpg
  inflating: ./coco2017/coco2017/val2017/000000005060.jpg
  inflating: ./coco2017/coco2017/val2017/000000005193.jpg
  inflating: ./coco2017/coco2017/val2017/000000005477.jpg
  inflating: ./coco2017/coco2017/val2017/000000005503.jpg
  inflating: ./coco2017/coco2017/val2017/000000005529.jpg
  inflating: ./coco2017/coco2017/val2017/000000005586.jpg
  inflating: ./coco2017/coco2017/val2017/000000005600.jpg
  inflating: ./coco2017/coco2017/val2017/000000005992.jpg
```

```
1
2
3 print(os.listdir('./coco2017/'))
4
```

```
['coco2017']
```

```
1 # COCO 2017
2 base_path = Path('/content/coco2017/coco2017')
3 annot = base_path / 'annotations' / 'captions_train2017.json'
4 with open(annot, 'r') as f:
5     data = json.load(f)
```

```
    data = data['annotations']

samples = []

for sample in data:
    im = '%012d.jpg' % sample['image_id']
    samples.append([im, sample['caption']])

df = pd.DataFrame(samples, columns=['image', 'caption'])
df['image'] = df['image'].apply(
    lambda x: base_path / 'train2017' / x
)
df = df.sample(150_000)
df = df.reset_index(drop=True)
df.head()
```

	image	caption
0	/content/coco2017/coco2017/train2017/000000497...	A photo of a photo above the urinals in a publ...
1	/content/coco2017/coco2017/train2017/000000558...	There is a blue bird sitting on the person's h...
2	/content/coco2017/coco2017/train2017/000000205...	A photo of a person on a motorcycle on the road.
3	/content/coco2017/coco2017/train2017/000000439...	A man is walking with his horse along a grassy...
4	/content/coco2017/coco2017/train2017/000000471...	a close up of a tennis player swinging a racket

some samples from the dataset

```
sampled_df = df.sample(n=20)
fig, axs = plt.subplots(10, 2, figsize=(20, 30))

for i, row in enumerate(sampled_df.iterrows()):
    ax = axs[i // 2, i % 2]
    image_path = row[1]['image']
    caption = row[1]['caption']
    image = Image.open(image_path)
    ax.imshow(image)
    ax.axis('off')
    ax.set_title(caption)

plt.tight_layout()
plt.show()
```

A person on a snowboard riding over a hill.

A man carrying a surfboard near a beach with people on it.

Several skiers trace a path along a snowy slope.

A couple of guys playing with a frisbee

The banana has many dark spots inside of it.

A red stop sign next to the side of a road.

A giraffel laying in dirt area with a pavilion in the background.

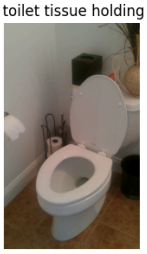
a kid is riding a surfboard is riding on a wave

A box of a variety of pastries on a table

A bench beside a sidewalk in a grassy area.

A bathroom with toilet, bathtub, and towels in it.

A bathroom with a toilet, toilet tissue holding and a garbage can in it.



A balloon of a giraffe next to a parking metter .

Three giraffes all interested in the activity at a zoo building.

A colorful vase filled with a green plant.

A man is throwing a Frisbee in the air.

a laptop sitting on top of a bar with barstools in front of a sofa and coffee table filled with dishes

Memorial bench can be reached by foot or tram

you can also choose to use Flickr30k which has ~160k samples

```
# flickr30k
"""
base_path = Path('/kaggle/input/flickr30k/flickr30k_images')
df = pd.read_csv('/kaggle/input/flickr30k/captions.txt',delimiter=',')
df.rename({'image_name':'image','comment': 'caption'},inplace=True,axis=1)
df['image'] = df['image'].map(lambda x:base_path / x.strip())
df['caption'] = df['caption'].map(lambda x:x.strip().lower())
df.head()
"""
```

```
"\nbase_path = Path('/kaggle/input/flickr30k/flickr30k_images')\ndf =
pd.read_csv('/kaggle/input/flickr30k/captions.txt',delimiter=',')\ndf.rename({'image_name':'image','comment':
'caption'},inplace=True,axis=1)\ndf['image'] = df['image'].map(lambda x:base_path / x.strip())\ndf['caption'] =
df['caption'].map(lambda x:x.strip().lower())\ndf.head()\n"
```

```
train_df, val_df = train_test_split(df,test_size=0.1)
train_df.reset_index(drop=True,inplace=True)
val_df.reset_index(drop=True,inplace=True)
print(len(train_df),len(val_df))
```

```
135000 15000
```

```
train_ds = Dataset(train_df,train_tfms)
val_ds = Dataset(val_df,valid_tfms)
```

Custom collate function

- allows for dynamic padding so the model doesn't have to process `max_len` sequences which would be just filled with pad tokens
- instead, every batch is padded according to the longest sequence in the batch

```
def collate_fn(batch):
    image = [i[0] for i in batch]
    input_ids = [i[1] for i in batch]
    labels = [i[2] for i in batch]
    image = torch.stack(image,dim=0)
    input_ids = tokenizer.pad(
        {'input_ids':input_ids},
        padding='longest',
        return_attention_mask=False,
        return_tensors='pt'
    )['input_ids']
    labels = tokenizer.pad(
        {'input_ids':labels},
        padding='longest',
        return_attention_mask=False,
        return_tensors='pt'
    )['input_ids']
    mask = (input_ids!=tokenizer.pad_token_id).long()
    labels[mask==0]=-100
    return image, input_ids, labels
```

How the data looks:

- every caption is a sequence of tokens, and as it is causal language modeling where the model predicts the next token, the labels are right shifted by 1 position.
- every caption ends with the end of sentence token: eos_token (50256 : <|endoftext|>)
- in GPT models, the pad tokens are same as the eos tokens, hence we also mask the pad tokens in the labels with -100 which are ignored by cross-entropy loss' default behaviour -- check `collate_fn` to see how I masked them.

```
dl = torch.utils.data.DataLoader(train_ds,shuffle=True,batch_size=2,collate_fn=collate_fn)
_,c,l = next(iter(dl))
print(c[0])
print(l[0])
```

```
You're using a GPT2TokenizerFast tokenizer. Please note that with a fast tokenizer, using the `__call__` method is faster than using
tensor([14945,  1180, 45613,   836,  5500,  1978,   287,   257,  3091,    13,
        50256])
tensor([ 1180, 45613,   836,  5500,  1978,   287,   257,  3091,    13, 50256,
         -100])
```

Model

- GPT2 on its own is a decoder-only model. So it understands only textual context. To create a model which also understands image context and applies it to the text, we use cross-attention.
- Cross Attention: It is the second attention layer of the decoder block as per the classic transformer encoder-decoder model
- The query in cross-attention is the output of the previous causal attention layer in the decoder block. The key and value are the outputs of the corresponding encoder block i.e. the image context.
- Since GPT2 doesn't have a cross-attention layer, I coded it as `GPT2CrossAttention` and made it a part of the usual decoder `GPT2Block`.
- The encoder I used was ViT-base with patch_size=16 grabbed from `timm`.
- ViT and GPT2 are extremely compatible with each other. They have the same amount of depth i.e. encoder, decoder blocks respectively. They have the same hidden size of 768 as well. So I didn't have to pool the encoder outputs to match the decoder hidden size. Less parameters yay!
- GPT2 code I wrote was ofc based on what I learnt from NanoGPT

This is somewhat how the architecture looks now.

Causal Attention Block

```
class GPT2Attention(nn.Module):
    def __init__(self,config):
        super().__init__()
        self.embed_dim = config.embed_dim
        self.n_heads = config.num_heads
        assert self.embed_dim % self.n_heads == 0, 'embedding dimension by be divisible by number of heads'
        self.head_size = self.embed_dim // self.n_heads
        self.seq_len = config.seq_len

        self.c_attn = nn.Linear(self.embed_dim, self.head_size * self.n_heads * 3,bias=True)
        self.scale = self.head_size ** -0.5

        self.register_buffer('mask',torch.tril(torch.ones(1,1,self.seq_len,self.seq_len)))

        self.c_proj = nn.Linear(self.embed_dim, self.embed_dim, bias=True)

        self.attn_dropout = nn.Dropout(config.attention_dropout)
        self.resid_dropout = nn.Dropout(config.residual_dropout)


    def forward(self, x):
        b,t,c = x.shape
        # q,k,v shape individually: batch_size x seq_len x embed_dim
        # we know that qk_t = q x k_t, where q=bxtxhead_dim, k_t=bxhead_timxt
        q,k,v = self.c_attn(x).chunk(3,dim=-1)
        q = q.view(b,t,self.n_heads,self.head_size).permute(0,2,1,3) # batch x n_heads x seq_len x head_dim
        k = k.view(b,t,self.n_heads,self.head_size).permute(0,2,1,3)
        v = v.view(b,t,self.n_heads,self.head_size).permute(0,2,1,3)

        qk_t = (q@k.transpose(-2,-1)) * self.scale
        qk_t = qk_t.masked_fill(self.mask[:,:,:t,:t]==0,float('-inf'))
        qk_t = F.softmax(qk_t,dim=-1)
        weights = self.attn_dropout(qk_t)

        attention = weights @ v # batch x n_heads x t x head_size
        attention = attention.permute(0,2,1,3).contiguous().view(b,t,c) # batch x t x embed_dim

        out = self.c_proj(attention)
        out = self.resid_dropout(out)

        return out
```

Cross Attention Block

- Notice how I initialized the parameters with mean=0. and std=0.02. This is an OpenAI trick they used while training GPT2 as well.

```
class GPT2CrossAttention(nn.Module):
    def __init__(self,config):
        super().__init__()
        self.embed_dim = config.embed_dim
        self.n_heads = config.num_heads
        assert self.embed_dim % self.n_heads == 0, 'embedding dimension by be divisible by number of heads'
        self.head_size = self.embed_dim // self.n_heads
        self.seq_len = config.seq_len

        self.q = nn.Linear(self.embed_dim,self.embed_dim)
        self.k = nn.Linear(self.embed_dim,self.embed_dim)
        self.v = nn.Linear(self.embed_dim,self.embed_dim)
        self.scale = self.head_size ** -0.5

        self.c_proj = nn.Linear(self.embed_dim, self.embed_dim, bias=True)

        self.attn_dropout = nn.Dropout(config.attention_dropout)
        self.resid_dropout = nn.Dropout(config.residual_dropout)

        self.apply(self._init_weights)

    def _init_weights(self, module):
        if isinstance(module, nn.Linear):
            torch.nn.init.normal_(module.weight, mean=0.0, std=0.02)
            if module.bias is not None:
                torch.nn.init.zeros_(module.bias)


```

```
    def forward(self, q,k,v):
        b,t,c = q.shape

        q = self.q(q)
        k = self.k(k)
        v = self.v(v)

        q = q.view(b,q.size(1),self.n_heads,self.head_size).permute(0,2,1,3) # batch x n_heads x seq_len x head_dim
        k = k.view(b,k.size(1),self.n_heads,self.head_size).permute(0,2,1,3)
        v = v.view(b,v.size(1),self.n_heads,self.head_size).permute(0,2,1,3)

        qk_t = (q@k.transpose(-2,-1)) * self.scale
        qk_t = F.softmax(qk_t,dim=-1)
        weights = self.attn_dropout(qk_t)

        attention = weights @ v # batch x n_heads x t x head_size
        attention = attention.permute(0,2,1,3).contiguous().view(b,t,c) # batch x t x embed_dim

        out = self.c_proj(attention)
        out = self.resid_dropout(out)

        return out
```

Feed Forward Block

```
class GPT2MLP(nn.Module):
    def __init__(self,config):
        super().__init__()
        self.embed_dim = config.embed_dim
        self.mlp_ratio = config.mlp_ratio
        self.mlp_dropout = config.mlp_dropout

        self.c_fc = nn.Linear(self.embed_dim,self.embed_dim*self.mlp_ratio)
        self.c_proj = nn.Linear(self.embed_dim*self.mlp_ratio,self.embed_dim)
        self.act = nn.GELU()
        self.dropout = nn.Dropout(self.mlp_dropout)

    def forward(self,x):
        x = self.c_fc(x)
        x = self.act(x)
        x = self.c_proj(x)
        x = self.dropout(x)
        return x
```

Decoder Block

- with added cross-attention and pre-normalization

```
class GPT2Block(nn.Module):
    def __init__(self,config):
        super().__init__()
        self.embed_dim = config.embed_dim
        self.ln_1 = nn.LayerNorm(self.embed_dim)
        self.attn = GPT2Attention(config)
        self.ln_2 = nn.LayerNorm(self.embed_dim)
        self.mlp = GPT2MLP(config)
        self.ln_3 = nn.LayerNorm(self.embed_dim)
        self.cross_attn = GPT2CrossAttention(config)

    def forward(self,x,enc_out):
        x = x+self.attn(self.ln_1(x))
        x = x+self.cross_attn(self.ln_2(x),enc_out,enc_out)
        x = x+self.mlp(self.ln_3(x))
        return x
```

The main model

- creating ViT model via timm
- added embedding code and right forward pass for the ViT model as per their code.
- each encoder output is passed to the decoder input and to the next encoder input as well.
- the final decoder outputs are passed through a head block to generate logits as per the vocab size.
- loss is calculated using cross-entropy if labels are present else, logits for the final token in the sequence are returned for generation.

- `pretrained_layers_trainable` : freezes/unfreezes ViT and GPT2 pretrained layers
- `unfreeze_gpt_layers` : unfreezes GPT2 layers only
- `from_pretrained` : loads GPT2 weights via huggingface gpt2
- `generate` : generates caption, sampling via `torch.multinomial` or deterministic via `argmax` with `temperature` control.

```
class VisionGPT2Model(nn.Module):
    def __init__(self,config):
        super().__init__()

        self.config = config

        vit = create_model('vit_base_patch16_224',pretrained=True,num_classes=0)
        self.patch_embed = vit.patch_embed
        num_patches = self.patch_embed.num_patches

        self.cls_token = vit.cls_token
        embed_len = num_patches + vit.num_prefix_tokens
        self.pos_embed = vit.pos_embed
        self.pos_drop = nn.Dropout(p=0.)

        self.blocks = nn.ModuleList([vit.blocks[i] for i in range(config.depth)])

        self.transformer = nn.ModuleDict(dict(
            wte = nn.Embedding(config.vocab_size,config.embed_dim),
            wpe = nn.Embedding(config.seq_len,config.embed_dim),
            drop = nn.Dropout(config.emb_dropout),
            h = nn.ModuleList([GPT2Block(config) for _ in range(config.depth)]),
            ln_f = nn.LayerNorm(config.embed_dim)
        ))
        self.lm_head = nn.Linear(config.embed_dim,config.vocab_size,bias=False)
        self.transformer.wte.weight = self.lm_head.weight

    def _pos_embed(self,x):
        pos_embed = self.pos_embed
        x = torch.cat((self.cls_token.expand(x.shape[0], -1, -1), x), dim=1)
        x = x + pos_embed
        return self.pos_drop(x)

    def pretrained_layers_trainable(self,trainable=False):
        layers = [
            self.cls_token, self.patch_embed, self.pos_embed, self.blocks,
            self.transformer.wte, self.transformer.wpe,
            self.transformer.ln_f, self.lm_head
        ]
        gpt_layers = [[
            self.transformer.h[i].ln_1,self.transformer.h[i].ln_2,
            self.transformer.h[i].attn,self.transformer.h[i].mlp
        ] for i in range(self.config.depth)]
        for l in gpt_layers:
            layers.extend(l)

        for layer in layers:
            if not isinstance(layer,nn.Parameter):
                for p in layer.parameters():
                    p.requires_grad = trainable
            else:
                layer.requires_grad = trainable

        total_frozen_params = sum([p.numel() for p in self.parameters() if not p.requires_grad])
        print(f'{total_frozen_params=}')

    def unfreeze_gpt_layers(self,):
        gpt_layers = [[
            self.transformer.h[i].ln_1,self.transformer.h[i].ln_2,
            self.transformer.h[i].attn,self.transformer.h[i].mlp
        ] for i in range(self.config.depth)]
        flatten = []
        for l in gpt_layers:
            flatten.extend(l)

        for layer in flatten:
            if not isinstance(layer,nn.Parameter):
                for p in layer.parameters():
                    p.requires_grad = True
            else:
                layer.requires_grad = True

    @classmethod
    def from_pretrained(self,config):
        model = VisionGPT2Model(config)
```

```
        sd = model.state_dict()
        keys = sd.keys()
        ignore_matches = ['blocks.','cross_attn.','ln_3','cls_token','pos_embed','patch_embed.','.attn.mask']
        vit_keys = [key for key in keys if any(match in key for match in ignore_matches)]
        gpt_keys = [key for key in keys if key not in vit_keys]

        gpt2_small = GPT2LMHeadModel.from_pretrained('gpt2')
        sd_hf = gpt2_small.state_dict()
        hf_keys = sd_hf.keys()
        hf_keys = [k for k in hf_keys if not k.endswith('.attn.masked_bias')]
        hf_keys = [k for k in hf_keys if not k.endswith('.attn.bias')]
        transposed = ['attn.c_attn.weight', 'attn.c_proj.weight', 'mlp.c_fc.weight', 'mlp.c_proj.weight']

        for k in hf_keys:
            if any(match in k for match in ignore_matches):
                continue
            if any(k.endswith(w) for w in transposed):
                assert sd_hf[k].shape[::-1] == sd[k].shape
                with torch.no_grad():
                    sd[k].copy_(sd_hf[k].t())
            else:
                assert sd_hf[k].shape == sd[k].shape
                with torch.no_grad():
                    sd[k].copy_(sd_hf[k])

        model.load_state_dict(sd)

        return model

    def forward(self,image,input_ids,labels=None):

        image = self.patch_embed(image)
        image = self._pos_embed(image)

        token_embeddings = self.transformer.wte(input_ids) # batch x seq_len
        pos_embs = torch.arange(0,input_ids.size(1)).to(input_ids.device)
        positional_embeddings = self.transformer.wpe(pos_embs)
        input_ids = self.transformer.drop(token_embeddings+positional_embeddings)

        for i in range(self.config.depth):
            image = self.blocks[i](image)
            input_ids = self.transformer.h[i](input_ids, image)

        input_ids = self.transformer.ln_f(input_ids)

        if labels is not None:
            lm_logits = self.lm_head(input_ids)
            loss = F.cross_entropy(lm_logits.view(-1, lm_logits.shape[-1]), labels.view(-1))
            return loss

        lm_logits = self.lm_head(input_ids[:,[-1],:])
        return lm_logits

    def generate(self,image,sequence,max_tokens=50,temperature=1.0,deterministic=False):
        for _ in range(max_tokens):
            out = self(image,sequence)
            out = out[:,-1,:] / temperature
            probs = F.softmax(out,dim=-1)
            if deterministic:
                next_token = torch.argmax(probs,dim=-1,keepdim=True)
            else:
                next_token = torch.multinomial(probs,num_samples=1)
            sequence = torch.cat([sequence,next_token],dim=1)
            if next_token.item() == tokenizer.eos_token_id:
                break

        return sequence.cpu().flatten()
```

Training

- the pretrained layers are initially frozen as I need to train the cross attention layers first
- in the following epochs, GPT2 is unfreezed and trained, in the final few epochs, the ViT is unfreezed as well.
- optimizer: Adam
- scheduler: OneCycleLR
- mixed-precision fp16 training with autocast and grad-scaler in torch
- metrics: cross-entropy loss and perplexity = e^loss, both lower the better
- best model is saved based on validation perplexity and the same is loaded while generating captions.

Generation

- GPT2 generally requires context before generating anything, since for image captioning we can't really provide an initial context except the image itself, the initial context we provide to GPT is just `[50256]` i.e `<|endoftext|>` which is also the beginning of sentence token in GPT. For other models such as OPT it is `</s>`. This one token acts as the initial context.

```
class Trainer:
    def __init__(self,model_config,train_config, dls):

        self.train_config = train_config
        self.model_config = model_config
        self.device = self.train_config.device

        self.model = VisionGPT2Model.from_pretrained(model_config).to(self.device)
        self.model.pretrained_layers_trainable(trainable=False)

        print(f'trainable parameters: {sum([p.numel() for p in self.model.parameters() if p.requires_grad])}')

        self.tokenizer = GPT2TokenizerFast.from_pretrained('gpt2')
        self.tokenizer.pad_token = self.tokenizer.eos_token

        self.scaler = GradScaler()

        self.train_dl, self.val_dl = dls

        total_steps = len(self.train_dl)

        self.optim = torch.optim.Adam(self.model.parameters(), lr=self.train_config.lr / 25.)
        self.sched = torch.optim.lr_scheduler.OneCycleLR(
            self.optim,
            max_lr=self.train_config.lr,
            epochs=self.train_config.epochs,
            steps_per_epoch=total_steps
        )

#         self.sched = get_linear_schedule_with_warmup(self.optim,num_warmup_steps=0,num_training_steps=total_steps)

        self.metrics = pd.DataFrame()
        self.metrics[['train_loss','train_perplexity','val_loss','val_perplexity']] = None

        self.gen_tfms = A.Compose([
            A.Resize(224,224),
            A.Normalize(mean=[0.5,0.5,0.5],std=[0.5,0.5,0.5],always_apply=True),
            ToTensorV2()
        ])


    def save_model(self,):
        self.train_config.model_path.mkdir(exist_ok=True)
        sd = self.model.state_dict()
        torch.save(sd,self.train_config.model_path/'captioner.pt')


    def load_best_model(self,):
        sd = torch.load(self.train_config.model_path/'captioner.pt')
        self.model.load_state_dict(sd)


    def train_one_epoch(self,epoch):

        prog = tqdm(self.train_dl,total=len(self.train_dl))

        running_loss = 0.

        for image, input_ids, labels in prog:

            with autocast():
                image = image.to(self.device)
                input_ids = input_ids.to(self.device)
                labels = labels.to(self.device)

                loss = self.model(image,input_ids,labels)

                self.scaler.scale(loss).backward()
                self.scaler.step(self.optim)
                self.scaler.update()
                self.sched.step()
                self.optim.zero_grad(set_to_none=True)

                running_loss += loss.item()
```

```
                prog.set_description(f'train loss: {loss.item():.3f}')

            del image, input_ids, labels, loss

        train_loss = running_loss / len(self.train_dl)
        train_pxp = np.exp(train_loss)

        self.metrics.loc[epoch,['train_loss','train_perplexity']] = (train_loss,train_pxp)


    @torch.no_grad()
    def valid_one_epoch(self,epoch):

        prog = tqdm(self.val_dl,total=len(self.val_dl))

        running_loss = 0.

        for image, input_ids, labels in prog:

            with autocast():
                image = image.to(self.device)
                input_ids = input_ids.to(self.device)
                labels = labels.to(self.device)

                loss = self.model(image,input_ids,labels)
                running_loss += loss.item()

                prog.set_description(f'valid loss: {loss.item():.3f}')

            del image, input_ids, labels, loss

        val_loss = running_loss / len(self.val_dl)
        val_pxp = np.exp(val_loss)

        self.metrics.loc[epoch,['val_loss','val_perplexity']] = (val_loss,val_pxp)

        return val_pxp


    def clean(self):
        gc.collect()
        torch.cuda.empty_cache()


    def fit(self,):

        best_pxp = 1e9
        best_epoch = -1
        prog = tqdm(range(self.train_config.epochs))

        for epoch in prog:

            if epoch == self.train_config.freeze_epochs_gpt:
                self.model.unfreeze_gpt_layers()
                print('unfreezing GPT2 entirely...')

            if epoch == self.train_config.freeze_epochs_all:
                self.model.pretrained_layers_trainable(trainable=True)

            self.model.train()
            prog.set_description('training')
            self.train_one_epoch(epoch)
            self.clean()

            self.model.eval()
            prog.set_description('validating')
            pxp = self.valid_one_epoch(epoch)
            self.clean()

            print(self.metrics.tail(1))

            if pxp < best_pxp:
                best_pxp = pxp
                best_epoch = epoch
                print('saving best model...')
                self.save_model()

        return {
            'best_perplexity': best_pxp,
            'best_epoch': best_epoch
        }
```

```
    @torch.no_grad()
    def generate_caption(self,image,max_tokens=50,temperature=1.0,deterministic=False):

        self.model.eval()

        image = Image.open(image).convert('RGB')
        image = np.array(image)
        image = self.gen_tfms(image=image)['image']
        image = image.unsqueeze(0).to(self.device)
        sequence = torch.ones(1,1).to(device=self.device).long() * self.tokenizer.bos_token_id

        caption = self.model.generate(
            image,
            sequence,
            max_tokens=max_tokens,
            temperature=temperature,
            deterministic=deterministic
        )
        caption = self.tokenizer.decode(caption.numpy(),skip_special_tokens=True)

        return caption
```

```
model_config = SimpleNamespace(
    vocab_size = 50_257,
    embed_dim = 768,
    num_heads = 12,
    seq_len = 1024,
    depth = 12,
    attention_dropout = 0.1,
    residual_dropout = 0.1,
    mlp_ratio = 4,
    mlp_dropout = 0.1,
    emb_dropout = 0.1,
)
train_config = SimpleNamespace(
    epochs = 2,
    freeze_epochs_gpt = 1,
    freeze_epochs_all = 2,
    lr = 1e-4,
    device = 'cuda',
    model_path = Path('captioner'),
    batch_size = 32
)
```

```
train_dl = torch.utils.data.DataLoader(train_ds,batch_size=train_config.batch_size,shuffle=True,pin_memory=True,num_workers=2,persis
val_dl = torch.utils.data.DataLoader(val_ds,batch_size=train_config.batch_size,shuffle=False,pin_memory=True,num_workers=2,persisten
```

```
trainer = Trainer(model_config,train_config,(train_dl,val_dl))
```

```
total_frozen_params=210236928
trainable parameters: 28366848
/usr/local/lib/python3.10/dist-packages/transformers/tokenization_utils_base.py:1601: FutureWarning: `clean_up_tokenization_spaces`
  warnings.warn(
<ipython-input-28-4e526974c5c0>:16: FutureWarning: `torch.cuda.amp.GradScaler(args...)` is deprecated. Please use `torch.amp.GradSca
  self.scaler = GradScaler()
```

```
trainer.fit()
```

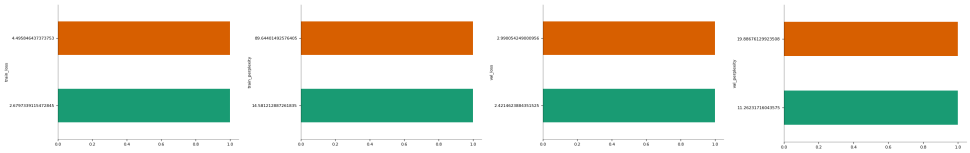
```
validating: 100%                                                    2/2 [1:58:57<00:00, 3584.01s/it]
train loss: 3.357: 100%                                             4219/4219 [55:47<00:00,  1.39it/s]
<ipython-input-28-4e526974c5c0>:61: FutureWarning: `torch.cuda.amp.autocast(args...)` is deprecated. Please use `torch.amp.autocast
  with autocast():
valid loss: 2.593: 100%                                             469/469 [02:08<00:00,  5.01it/s]
<ipython-input-28-4e526974c5c0>:95: FutureWarning: `torch.cuda.amp.autocast(args...)` is deprecated. Please use `torch.amp.autocast
  with autocast():
  train_loss train_perplexity  val_loss val_perplexity
0   4.495846        89.644015  2.990054      19.886761
saving best model...
unfreezing GPT2 entirely...
train loss: 2.847: 100%                                             4219/4219 [58:39<00:00,  2.05it/s]
<ipython-input-28-4e526974c5c0>:61: FutureWarning: `torch.cuda.amp.autocast(args...)` is deprecated. Please use `torch.amp.autocast
  with autocast():
valid loss: 2.199: 100%                                             469/469 [02:04<00:00,  3.35it/s]
<ipython-input-28-4e526974c5c0>:95: FutureWarning: `torch.cuda.amp.autocast(args...)` is deprecated. Please use `torch.amp.autocast
  with autocast():
  train_loss train_perplexity  val_loss val_perplexity
1   2.679734        14.581213  2.421462      11.262317
saving best model...
```

Results

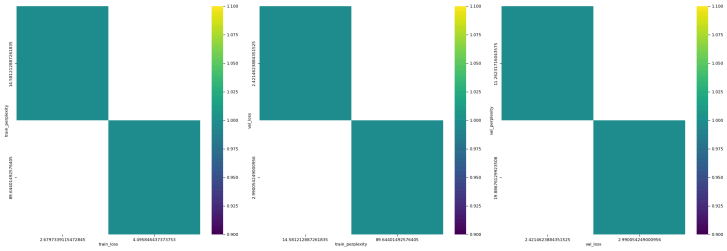
```
1 trainer.metrics
```

	train_loss	train_perplexity	val_loss	val_perplexity
0	4.495846	89.644015	2.990054	19.886761
1	2.679734	14.581213	2.421462	11.262317

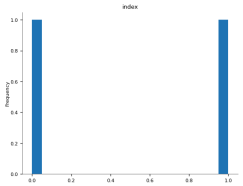
Categorical distributions



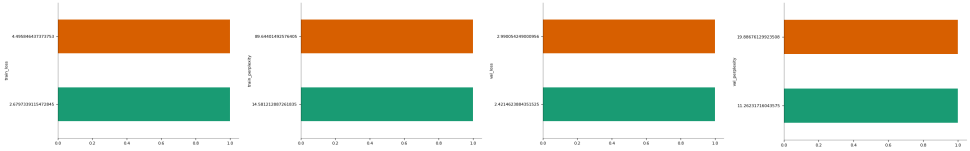
2-d categorical distributions



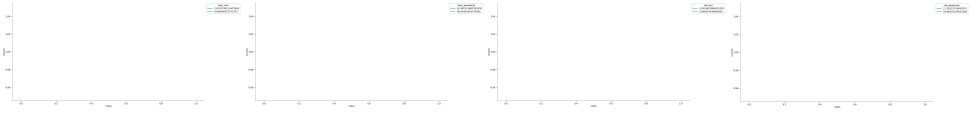
Distributions



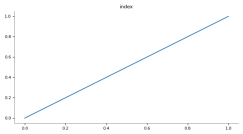
Categorical distributions



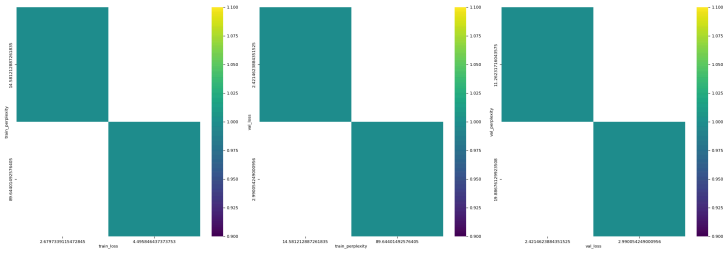
Time series



Values



2-d categorical distributions



Faceted distributions

```
<string>:5: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in v0.14.0. Assign the `x` variable to `hue` and set `le
```

```
<string>:5: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in v0.14.0. Assign the `x` variable to `hue` and set `le
```

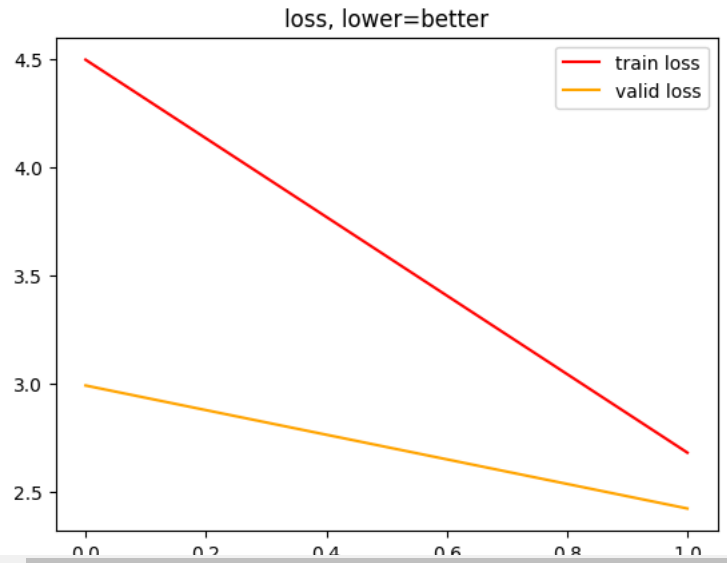
```
<string>:5: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in v0.14.0. Assign the `x` variable to `hue` and set `le
```

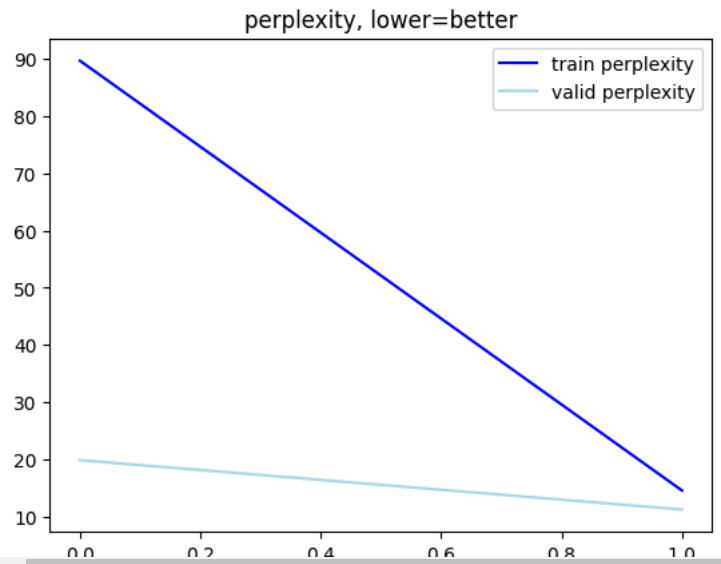
```
<string>:5: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in v0.14.0. Assign the `x` variable to `hue` and set `le
```

```
plt.plot(trainer.metrics['train_loss'],color='red',label='train loss')
plt.plot(trainer.metrics['val_loss'],color='orange',label='valid loss')
plt.title('loss, lower=better')
plt.legend()
plt.show()
```




```
plt.plot(trainer.metrics['train_perplexity'],color='blue',label='train perplexity')
plt.plot(trainer.metrics['val_perplexity'],color='lightblue',label='valid perplexity')
plt.title('perplexity, lower=better')
plt.legend()
plt.show()
```



Predictions

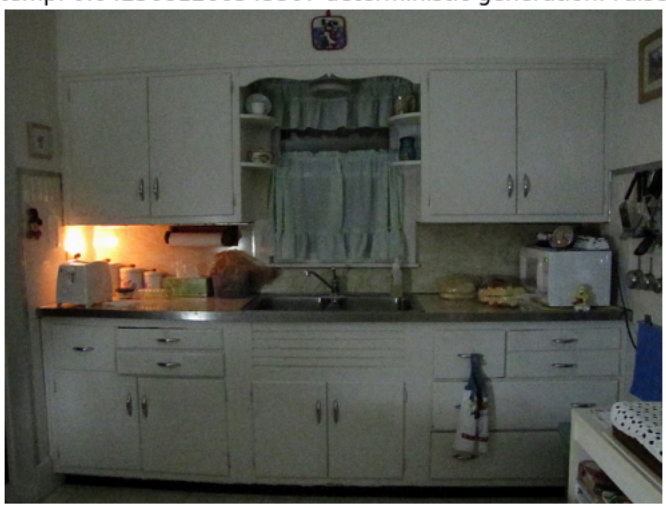
```
trainer.load_best_model()
```

```
<ipython-input-28-4e526974c5c0>:49: FutureWarning: You are using `torch.load` with `weights_only=False` (the current default value),
  sd = torch.load(self.train_config.model_path/'captioner.pt')
```

```
for i in range(50):
    det = False
    test = val_df.sample(n=1).values[0]
    test_img, test_caption = test[0],test[1]
    plt.imshow(Image.open(test_img).convert('RGB'))
    t = np.random.uniform(0.5,1.5)
    if i > 40:
```

```
        det = True
    gen_caption = trainer.generate_caption(test_img,temperature=t,deterministic=det)
    plt.title(f"actual: {test_caption}\nmodel: {gen_caption}\ntemp: {t} deterministic generation: {det}")
    plt.axis('off')
    plt.show()
```

actual: A large very dimly lit kitchen with white cabinets.
model: kitchen with a stove and oven in the kitchen.
temp: 0.6425681266345307 deterministic generation: False



actual: A pile of banana sitting next to a stack of books.
model: = some apples, bananas, bananas, and fruit.
temp: 0.8758196029979488 deterministic generation: False

actual: A woman sitting a table on a laptop.
model: one of the benchescharging their burgers.
temp: 1.363645290152989 deterministic generation: False

actual: The people are outside in the sun with umbrealla over them
model: and women walking in a field of people.
temp: 0.6228119971393166 deterministic generation: False

actual: Rail yard with many tank and rail cars in large city.
model: live trains waiting in the railroad yard a road and a black station.
temp: 1.007670069937599 deterministic generation: False

actual: this plate has two pieces of bread on it
model: wrap every sandwich on a blue plate featuring handwritten teddy bears.
temp: 1.316646845769678 deterministic generation: False

actual: A vintage turquoise and beige truck is shown.
model: top of a blue truck with the name on it
temp: 0.6975312843490961 deterministic generation: False

actual: A woman in a bikini stands next to a surfboard.
model: is a woman holding an unidentified surfboard in the ocean

temp: 1.0293469299888411 deterministic generation: False

actual: A giraffe standing at attention in a zoo pin.
model: giraffes are standing at a zoo.
temp: 0.5238897311195714 deterministic generation: False

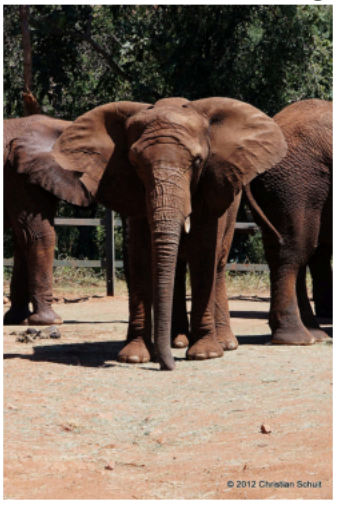
actual: A person stands by a wire fence as a cow looks around.
model: USE A BEHARISTIC ON A WHITE BOW WITH UPPIC ON THE SIDE
temp: 1.0044229990840443 deterministic generation: False

actual: A person in a yellow shirt swinging a tennis racket on a tennis court.
model: tennis player in action on court with racket.
temp: 0.564683112325976 deterministic generation: False

actual: A woman holds a plate of food while she has phone to her ear.
model: closeup for picture showing two adequate tools a hand adapter someones higher changes cases
temp: 1.4406396096151037 deterministic generation: False

actual: A white and orange cat in front of a flock of birds.
model: irds standing in the shade near a large tree.
temp: 0.7854483608022964 deterministic generation: False

actual: an elephant standing and looking into the camera
model: dead tiring area with ape, stone tree impable meenary.
temp: 1.4698097606799791 deterministic generation: False



actual: A table with a couch and joysticks on the table
model: sitting in a couch beside a TV with a dog.
temp: 0.8938652374742175 deterministic generation: False