Homework 4

Instructions

- This homework focuses on understanding and applying CoCoOp for CLIP prompt tuning. It consists of **four questions** designed to assess both theoretical understanding and practical application.
- Please organize your answers and results for the questions below and submit this jupyter notebook as **a .pdf file**.
- **Deadline: 11/26 (Sat) 23:59**

Preparation

- Run the code below before proceeding with the homework.
- If an error occurs, click ‘Run Session Again’ and then restart the runtime from the beginning.

```
!git clone https://github.com/mlvlab/ProMetaR.git
%cd ProMetaR/

!git clone https://github.com/KaiyangZhou/Dassl.pytorch.git
%cd Dassl.pytorch/

# Install dependencies
!pip install -r requirements.txt
!cp -r dassl ../
# Install this library (no need to re-build if the source code is modified)
# !python setup.py develop
%cd ..

!pip install -r requirements.txt

%mkdir outputs
%mkdir data

%cd data
%mkdir eurosat
!wget http://madm.dfki.de/files/sentinel/EuroSAT.zip -O EuroSAT.zip

!unzip -o EuroSAT.zip -d eurosat/
%cd eurosat
!gdown 1Ip7yaCWFi0eaOFUGga0lUdVi_DDQth1o

%cd ../../

import os.path as osp
```

```
from collections import OrderedDict
import math
import torch
import torch.nn as nn
from torch.nn import functional as F
from torch.cuda.amp import GradScaler, autocast
from PIL import Image
import torchvision.transforms as transforms
import torch
from clip import clip
from clip.simple_tokenizer import SimpleTokenizer as _Tokenizer
import time
from tqdm import tqdm
import datetime
import argparse
from dassl.utils import setup_logger, set_random_seed, collect_env_info
from dassl.config import get_cfg_default
from dassl.engine import build_trainer
from dassl.engine import TRAINER_REGISTRY, TrainerX
from dassl.metrics import compute_accuracy
from dassl.utils import load_pretrained_weights, load_checkpoint
from dassl.optim import build_optimizer, build_lr_scheduler

# custom
import datasets.oxford_pets
import datasets.oxford_flowers
import datasets.fgvc_aircraft
import datasets.dtd
import datasets.eurosat
import datasets.stanford_cars
import datasets.food101
import datasets.sun397
import datasets.caltech101
import datasets.ucf101
import datasets.imagenet
import datasets.imagenet_sketch
import datasets.imagenetv2
import datasets.imagenet_a
import datasets.imagenet_r

def print_args(args, cfg):
    print("***************")
    print("** Arguments **")
    print("***************")
    optkeys = list(args.__dict__.keys())
    optkeys.sort()
    for key in optkeys:
        print("{}: {}".format(key, args.__dict__[key]))
    print("************")
    print("** Config **")
    print("************")
    print(cfg)

def reset_cfg(cfg, args):
    if args.root:
```

```
        cfg.DATASET.ROOT = args.root
    if args.output_dir:
        cfg.OUTPUT_DIR = args.output_dir
    if args.seed:
        cfg.SEED = args.seed
    if args.trainer:
        cfg.TRAINER.NAME = args.trainer
    cfg.DATASET.NUM_SHOTS = 16
    cfg.DATASET.SUBSAMPLE_CLASSES = args.subsample_classes
    cfg.DATALOADER.TRAIN_X.BATCH_SIZE = args.train_batch_size
    cfg.OPTIM.MAX_EPOCH = args.epoch

def extend_cfg(cfg):
    """
    Add new config variables.
    """
    from yacs.config import CfgNode as CN
    cfg.TRAINER.COOP = CN()
    cfg.TRAINER.COOP.N_CTX = 16  # number of context vectors
    cfg.TRAINER.COOP.CSC = False  # class-specific context
    cfg.TRAINER.COOP.CTX_INIT = ""  # initialization words
    cfg.TRAINER.COOP.PREC = "fp16"  # fp16, fp32, amp
    cfg.TRAINER.COOP.CLASS_TOKEN_POSITION = "end"  # 'middle' or 'end' or 'front'
    cfg.TRAINER.COCOOP = CN()
    cfg.TRAINER.COCOOP.N_CTX = 4  # number of context vectors
    cfg.TRAINER.COCOOP.CTX_INIT = "a photo of a"  # initialization words
    cfg.TRAINER.COCOOP.PREC = "fp16"  # fp16, fp32, amp
    cfg.TRAINER.PROMETAR = CN()
    cfg.TRAINER.PROMETAR.N_CTX_VISION = 4  # number of context vectors at the vision bran
    cfg.TRAINER.PROMETAR.N_CTX_TEXT = 4  # number of context vectors at the language bran
    cfg.TRAINER.PROMETAR.CTX_INIT = "a photo of a"  # initialization words
    cfg.TRAINER.PROMETAR.PREC = "fp16"  # fp16, fp32, amp
    cfg.TRAINER.PROMETAR.PROMPT_DEPTH_VISION = 9  # Max 12, minimum 0, for 0 it will be u
    cfg.TRAINER.PROMETAR.PROMPT_DEPTH_TEXT = 9  # Max 12, minimum 0, for 0 it will be usi
    cfg.DATASET.SUBSAMPLE_CLASSES = "all"  # all, base or new
    cfg.TRAINER.PROMETAR.ADAPT_LR = 0.0005
    cfg.TRAINER.PROMETAR.LR_RATIO = 0.0005
    cfg.TRAINER.PROMETAR.FAST_ADAPTATION = False
    cfg.TRAINER.PROMETAR.MIXUP_ALPHA = 0.5
    cfg.TRAINER.PROMETAR.MIXUP_BETA = 0.5
    cfg.TRAINER.PROMETAR.DIM_RATE=8
    cfg.OPTIM_VNET = CN()
    cfg.OPTIM_VNET.NAME = "adam"
    cfg.OPTIM_VNET.LR = 0.0003
    cfg.OPTIM_VNET.WEIGHT_DECAY = 5e-4
    cfg.OPTIM_VNET.MOMENTUM = 0.9
    cfg.OPTIM_VNET.SGD_DAMPNING = 0
    cfg.OPTIM_VNET.SGD_NESTEROV = False
    cfg.OPTIM_VNET.RMSPROP_ALPHA = 0.99
    cfg.OPTIM_VNET.ADAM_BETA1 = 0.9
    cfg.OPTIM_VNET.ADAM_BETA2 = 0.999
    cfg.OPTIM_VNET.STAGED_LR = False
    cfg.OPTIM_VNET.NEW_LAYERS = ()
    cfg.OPTIM_VNET.BASE_LR_MULT = 0.1
    # Learning rate scheduler
```

```
    cfg.OPTIM_VNET.LR_SCHEDULER = "single_step"
    # -1 or 0 means the stepsize is equal to max_epoch
    cfg.OPTIM_VNET.STEPSIZE = (-1, )
    cfg.OPTIM_VNET.GAMMA = 0.1
    cfg.OPTIM_VNET.MAX_EPOCH = 10
    # Set WARMUP_EPOCH larger than 0 to activate warmup training
    cfg.OPTIM_VNET.WARMUP_EPOCH = -1
    # Either linear or constant
    cfg.OPTIM_VNET.WARMUP_TYPE = "linear"
    # Constant learning rate when type=constant
    cfg.OPTIM_VNET.WARMUP_CONS_LR = 1e-5
    # Minimum learning rate when type=linear
    cfg.OPTIM_VNET.WARMUP_MIN_LR = 1e-5
    # Recount epoch for the next scheduler (last_epoch=-1)
    # Otherwise last_epoch=warmup_epoch
    cfg.OPTIM_VNET.WARMUP_RECOUNT = True

def setup_cfg(args):
    cfg = get_cfg_default()
    extend_cfg(cfg)
    # 1. From the dataset config file
    if args.dataset_config_file:
        cfg.merge_from_file(args.dataset_config_file)
    # 2. From the method config file
    if args.config_file:
        cfg.merge_from_file(args.config_file)
    # 3. From input arguments
    reset_cfg(cfg, args)
    cfg.freeze()
    return cfg

_tokenizer = _Tokenizer()

def load_clip_to_cpu(cfg): # Load CLIP
    backbone_name = cfg.MODEL.BACKBONE.NAME
    url = clip._MODELS[backbone_name]
    model_path = clip._download(url)

    try:
        # loading JIT archive
        model = torch.jit.load(model_path, map_location="cpu").eval()
        state_dict = None

    except RuntimeError:
        state_dict = torch.load(model_path, map_location="cpu")

    if cfg.TRAINER.NAME == "":
      design_trainer = "CoOp"
    else:
      design_trainer = cfg.TRAINER.NAME
    design_details = {"trainer": design_trainer,
                      "vision_depth": 0,
                      "language_depth": 0, "vision_ctx": 0,
                      "language_ctx": 0}
    model = clip.build_model(state_dict or model.state_dict(), design_details)
```

```
        return model

    from dassl.config import get_cfg_default
    cfg = get_cfg_default()
    cfg.MODEL.BACKBONE.NAME = "ViT-B/16" # Set the vision encoder backbone of CLIP to ViT.
    clip_model = load_clip_to_cpu(cfg)



    class TextEncoder(nn.Module):
        def __init__(self, clip_model): # 초기화 하는 함수
            super().__init__()
            self.transformer = clip_model.transformer
            self.positional_embedding = clip_model.positional_embedding
            self.ln_final = clip_model.ln_final
            self.text_projection = clip_model.text_projection
            self.dtype = clip_model.dtype

        def forward(self, prompts, tokenized_prompts): # 모델 호출
            x = prompts + self.positional_embedding.type(self.dtype)
            x = x.permute(1, 0, 2)  # NLD -> LND
            x = self.transformer(x)
            x = x.permute(1, 0, 2)  # LND -> NLD
            x = self.ln_final(x).type(self.dtype)

            # x.shape = [batch_size, n_ctx, transformer.width]
            # take features from the eot embedding (eot_token is the highest number in each s
            x = x[torch.arange(x.shape[0]), tokenized_prompts.argmax(dim=-1)] @ self.text_prc

            return x


    @TRAINER_REGISTRY.register(force=True)
    class CoCoOp(TrainerX):
        def check_cfg(self, cfg):
            assert cfg.TRAINER.COCOOP.PREC in ["fp16", "fp32", "amp"]

        def build_model(self):
            cfg = self.cfg
            classnames = self.dm.dataset.classnames
            print(f"Loading CLIP (backbone: {cfg.MODEL.BACKBONE.NAME})")
            clip_model = load_clip_to_cpu(cfg)

            if cfg.TRAINER.COCOOP.PREC == "fp32" or cfg.TRAINER.COCOOP.PREC == "amp":
                # CLIP's default precision is fp16
                clip_model.float()

            print("Building custom CLIP")
            self.model = CoCoOpCustomCLIP(cfg, classnames, clip_model)

            print("Turning off gradients in both the image and the text encoder")
            name_to_update = "prompt_learner"

            for name, param in self.model.named_parameters():
```

```
            if name_to_update not in name:
                param.requires_grad_(False)

        # Double check
        enabled = set()
        for name, param in self.model.named_parameters():
            if param.requires_grad:
                enabled.add(name)
        print(f"Parameters to be updated: {enabled}")

        if cfg.MODEL.INIT_WEIGHTS:
            load_pretrained_weights(self.model.prompt_learner, cfg.MODEL.INIT_WEIGHTS)

        self.model.to(self.device)
        # NOTE: only give prompt_learner to the optimizer
        self.optim = build_optimizer(self.model.prompt_learner, cfg.OPTIM)
        self.sched = build_lr_scheduler(self.optim, cfg.OPTIM)
        self.register_model("prompt_learner", self.model.prompt_learner, self.optim, self

        self.scaler = GradScaler() if cfg.TRAINER.COCOOP.PREC == "amp" else None

        # Note that multi-gpu training could be slow because CLIP's size is
        # big, which slows down the copy operation in DataParallel
        device_count = torch.cuda.device_count()
        if device_count > 1:
            print(f"Multiple GPUs detected (n_gpus={device_count}), use all of them!")
            self.model = nn.DataParallel(self.model)

    def before_train(self):
        directory = self.cfg.OUTPUT_DIR
        if self.cfg.RESUME:
            directory = self.cfg.RESUME
        self.start_epoch = self.resume_model_if_exist(directory)

        # Remember the starting time (for computing the elapsed time)
        self.time_start = time.time()


    def forward_backward(self, batch):
        image, label = self.parse_batch_train(batch)

        model = self.model
        optim = self.optim
        scaler = self.scaler

        prec = self.cfg.TRAINER.COCOOP.PREC
        loss = model(image, label) # Input image 모델 통과
        optim.zero_grad()
        loss.backward() # Backward (역전파)
        optim.step() # 모델 parameter update

        loss_summary = {"loss": loss.item()}

        if (self.batch_idx + 1) == self.num_batches:
            self.update_lr()
```

```
        return loss_summary

    def parse_batch_train(self, batch):
        input = batch["img"]
        label = batch["label"]
        input = input.to(self.device)
        label = label.to(self.device)
        return input, label

    def load_model(self, directory, epoch=None):
        if not directory:
            print("Note that load_model() is skipped as no pretrained model is given")
            return

        names = self.get_model_names()

        # By default, the best model is loaded
        model_file = "model-best.pth.tar"

        if epoch is not None:
            model_file = "model.pth.tar-" + str(epoch)

        for name in names:
            model_path = osp.join(directory, name, model_file)

            if not osp.exists(model_path):
                raise FileNotFoundError('Model not found at "{}"'.format(model_path))

            checkpoint = load_checkpoint(model_path)
            state_dict = checkpoint["state_dict"]
            epoch = checkpoint["epoch"]

            # Ignore fixed token vectors
            if "token_prefix" in state_dict:
                del state_dict["token_prefix"]

            if "token_suffix" in state_dict:
                del state_dict["token_suffix"]

            print("Loading weights to {} " 'from "{}" (epoch = {})'.format(name, model_pa
            # set strict=False
            self._models[name].load_state_dict(state_dict, strict=False)

    def after_train(self):
      print("Finish training")

      do_test = not self.cfg.TEST.NO_TEST
      if do_test:
          if self.cfg.TEST.FINAL_MODEL == "best_val":
              print("Deploy the model with the best val performance")
              self.load_model(self.output_dir)
          else:
              print("Deploy the last-epoch model")
          acc = self.test()
```

```
        # Show elapsed time
        elapsed = round(time.time() - self.time_start)
        elapsed = str(datetime.timedelta(seconds=elapsed))
        print(f"Elapsed: {elapsed}")

        # Close writer
        self.close_writer()
        return acc

    def train(self):
        """Generic training loops."""
        self.before_train()
        for self.epoch in range(self.start_epoch, self.max_epoch):
            self.before_epoch()
            self.run_epoch()
            self.after_epoch()
        acc = self.after_train()
        return acc

parser = argparse.ArgumentParser()
parser.add_argument("--root", type=str, default="data/", help="path to dataset")
parser.add_argument("--output-dir", type=str, default="outputs/cocoop3", help="output dir
parser.add_argument(
    "--seed", type=int, default=1, help="only positive value enables a fixed seed"
)
parser.add_argument(
    "--config-file", type=str, default="configs/trainers/ProMetaR/vit_b16_c2_ep10_batch4_
)
parser.add_argument(
    "--dataset-config-file",
    type=str,
    default="configs/datasets/eurosat.yaml",
    help="path to config file for dataset setup",
)
parser.add_argument("--trainer", type=str, default="CoOp", help="name of trainer")
parser.add_argument("--eval-only", action="store_true", help="evaluation only")
parser.add_argument(
    "--model-dir",
    type=str,
    default="",
    help="load model from this directory for eval-only mode",
)
parser.add_argument("--train-batch-size", type=int, default=4)
parser.add_argument("--epoch", type=int, default=10)
parser.add_argument("--subsample-classes", type=str, default="base")
parser.add_argument(
    "--load-epoch", type=int, default=0, help="load model weights at this epoch for evalu
)
args = parser.parse_args([])

def main(args):
    cfg = setup_cfg(args)
    if cfg.SEED >= 0:
        set_random_seed(cfg.SEED)
```

```
    if torch.cuda.is_available() and cfg.USE_CUDA:
        torch.backends.cudnn.benchmark = True

    trainer = build_trainer(cfg)
    if args.eval_only:
        trainer.load_model(args.model_dir, epoch=args.load_epoch)
        acc = trainer.test()
        return acc

    acc = trainer.train()
    return acc
```

Q1. Understanding and implementing CoCoOp

- We have learned how to define CoOp in Lab Session 4.
- The main difference between CoOp and CoCoOp is **meta network** to extract image tokens that is added to the text prompt.
- Based on the CoOp code given in Lab Session 4, fill-in-the-blank exercise (4 blanks!!) to test your understanding of critical parts of the CoCoOp.

```
import torch.nn as nn

class CoCoOpPromptLearner(nn.Module):
    def __init__(self, cfg, classnames, clip_model):
        super().__init__()
        n_cls = len(classnames)
        n_ctx = cfg.TRAINER.COCOOP.N_CTX
        ctx_init = cfg.TRAINER.COCOOP.CTX_INIT
        dtype = clip_model.dtype
        ctx_dim = clip_model.ln_final.weight.shape[0]
        vis_dim = clip_model.visual.output_dim
        clip_imsize = clip_model.visual.input_resolution
        cfg_imsize = cfg.INPUT.SIZE[0]
        assert cfg_imsize == clip_imsize, f"cfg_imsize ({cfg_imsize}) must equal to clip_

        if ctx_init:
            # use given words to initialize context vectors
            ctx_init = ctx_init.replace("_", " ")
            n_ctx = len(ctx_init.split(" "))
            prompt = clip.tokenize(ctx_init)
            with torch.no_grad():
                embedding = clip_model.token_embedding(prompt).type(dtype)
            ctx_vectors = embedding[0, 1: 1 + n_ctx, :]
            prompt_prefix = ctx_init
        else:
            # random initialization
            ctx_vectors = torch.empty(n_ctx, ctx_dim, dtype=dtype)
            nn.init.normal_(ctx_vectors, std=0.02)
            prompt_prefix = " ".join(["X"] * n_ctx)
```

```
        print(f'Initial context: "{prompt_prefix}"')
        print(f"Number of context words (tokens): {n_ctx}")

        self.ctx = nn.Parameter(ctx_vectors)  # Wrap the initialized prompts above as par

        ### Tokenize ###
        classnames = [name.replace("_", " ") for name in classnames]  # 예) "Forest"
        name_lens = [len(_tokenizer.encode(name)) for name in classnames]
        prompts = [prompt_prefix + " " + name + "." for name in classnames] # 예) "A phot

        tokenized_prompts = torch.cat([clip.tokenize(p) for p in prompts]) # 예) [49406,



        ######################################
        ####### Q1. Fill in the blank #######
        ########## Define Meta Net ##########
        self.meta_net = nn.Sequential(OrderedDict([
            ("linear1", nn.Linear(vis_dim, vis_dim // 16)),
            ("relu", nn.ReLU(inplace=True)),
            ("linear2", nn.Linear(vis_dim // 16, ctx_dim))
        ]))
        ######################################
        ## Hint: meta network is composed to linear layer, relu activation, and linear la



        if cfg.TRAINER.COCOOP.PREC == "fp16":
            self.meta_net.half()

        with torch.no_grad():
            embedding = clip_model.token_embedding(tokenized_prompts).type(dtype)

        # These token vectors will be saved when in save_model(),
        # but they should be ignored in load_model() as we want to use
        # those computed using the current class names
        self.register_buffer("token_prefix", embedding[:, :1, :])  # SOS
        self.register_buffer("token_suffix", embedding[:, 1 + n_ctx:, :])  # CLS, EOS
        self.n_cls = n_cls
        self.n_ctx = n_ctx
        self.tokenized_prompts = tokenized_prompts  # torch.Tensor
        self.name_lens = name_lens

    def construct_prompts(self, ctx, prefix, suffix, label=None):
        # dim0 is either batch_size (during training) or n_cls (during testing)
        # ctx: context tokens, with shape of (dim0, n_ctx, ctx_dim)
        # prefix: the sos token, with shape of (n_cls, 1, ctx_dim)
        # suffix: remaining tokens, with shape of (n_cls, *, ctx_dim)

        if label is not None:
            prefix = prefix[label]
            suffix = suffix[label]

        prompts = torch.cat(
```

```
            [
                prefix,  # (dim0, 1, dim)
                ctx,  # (dim0, n_ctx, dim)
                suffix,  # (dim0, *, dim)
            ],
            dim=1,
        )

        return prompts

    def forward(self, im_features):
        prefix = self.token_prefix
        suffix = self.token_suffix
        ctx = self.ctx  # (n_ctx, ctx_dim)



        ############################################
        ########## Q2,3. Fill in the blank #########
        bias = self.meta_net(im_features)  # (batch, ctx_dim)
        bias = bias.unsqueeze(1)  # (batch, 1, ctx_dim)
        ctx = ctx.unsqueeze(0)  # (1, n_ctx, ctx_dim)
        ctx_shifted = ctx + bias  # (batch, n_ctx, ctx_dim)
        ############################################
        ############################################



        # Use instance-conditioned context tokens for all classes
        prompts = []
        for ctx_shifted_i in ctx_shifted:
            ctx_i = ctx_shifted_i.unsqueeze(0).expand(self.n_cls, -1, -1)
            pts_i = self.construct_prompts(ctx_i, prefix, suffix)  # (n_cls, n_tkn, ctx_d
            prompts.append(pts_i)
        prompts = torch.stack(prompts)

        return prompts


class CoCoOpCustomCLIP(nn.Module):
    def __init__(self, cfg, classnames, clip_model):
        super().__init__()
        self.prompt_learner = CoCoOpPromptLearner(cfg, classnames, clip_model)
        self.tokenized_prompts = self.prompt_learner.tokenized_prompts
        self.image_encoder = clip_model.visual
        self.text_encoder = TextEncoder(clip_model)
        self.logit_scale = clip_model.logit_scale
        self.dtype = clip_model.dtype

    def forward(self, image, label=None):
        tokenized_prompts = self.tokenized_prompts
        logit_scale = self.logit_scale.exp()

        image_features = self.image_encoder(image.type(self.dtype))
        image_features = image_features / image_features.norm(dim=-1, keepdim=True)
```

```
        #############################################
        ########## Q4. Fill in the blank #########
        prompts = self.prompt_learner(image_features)
        #############################################
        #############################################


        logits = []
        for pts_i, imf_i in zip(prompts, image_features):
            text_features = self.text_encoder(pts_i, tokenized_prompts)
            text_features = text_features / text_features.norm(dim=-1, keepdim=True)
            l_i = logit_scale * imf_i @ text_features.t()
            logits.append(l_i)
        logits = torch.stack(logits)

        if self.prompt_learner.training:
            return F.cross_entropy(logits, label)

        return logits
```

Q2. Trainining CoCoOp

In this task, you will train CoCoOp on the EuroSAT dataset. If your implementation of CoCoOp in Question 1 is correct, the following code should execute without errors. Please submit the execution file so we can evaluate whether your code runs without any issues.

```
# Train on the Base Classes Train split and evaluate accuracy on the Base Classes Test sp
args.trainer = "CoCoOp"
args.train_batch_size = 4
args.epoch = 100
args.output_dir = "outputs/cocoop"

args.subsample_classes = "base"
args.eval_only = False
cocoop_base_acc = main(args)


# Accuracy on the New Classes.
args.model_dir = "outputs/cocoop"
args.output_dir = "outputs/cocoop/new_classes"
args.subsample_classes = "new"
args.load_epoch = 100
args.eval_only = True
coop_novel_acc = main(args)
```

Q3. Analyzing the results of CoCoOp

Compare the results of CoCoOp with those of CoOp that we trained in Lab Session 4. Discuss possible reasons for the performance differences observed between CoCoOp and CoOp.

1. CoOp displays better accuracy than CoCoOp where CoOp manages to obtain 51.4% of accuracy while CoCoOp manages to obtain a measly 43.3% which couldnt obtain more than half of the total dataset.
2. This disparity in accuracy appears because of the low number of training and validation sets compared to the thousands of test datasets which can make it overfit the dataset itself and not learn any distinct features. In reality, if the training set is large enough CoCoOp will perform better than CoOp in general because of its meta network that adapts prompts based on visual features.