SERVIR's Applied Deep Learning Handbook

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Introduction

The SERVIR program which is a partnership of NASA, USAID, and leading technical organizations striving to strengthens the capacity of countries in Asia, Africa, and the Americas to use satellite data and geospatial technology to address critical challenges in weather & climate resilience, agriculture and food security, ecosystem and carbon management, water security, disasters, as well as air quality and health. SERVIR co-develops innovative solutions through a network of regional hubs to improve resilience and sustainable resource management at local, national, and regional scales. Additionally, SERVIR focuses on developing participate in innovative knowledge products such as the SAR Handbook Flores-Anderson et al. (2019) and the GEE book Cardille et al. (2023) designed to support capacity building in applying Remote Sensing and geospatial approaches to address challenges.

The focus of the SERVIR Applied Deep Learning Book is to provide practitioners with a wide variety of applied examples of Remote Sensing Deep Learning approaches. With each chapter focusing on a specific problem set such as object detection of downscaling using Deep Learning. Additionally, throughout the books chapters various examples are provided spanning the aforementioned SERVIR thematic areas. Thereby providing a wide variety of thematic applications to complement reader's domain specific practical knowledge such as agronomy or forestry etc.

We suspect readers are coming to this virtual book with preexisting geospatial expertise. However, limited Deep Learning knowledge and application specifically around environmental and Remote Sensing oriented challenges. We welcome readers to review the initial chapter on data preparation before progressing towards chapters with focused on specific problem sets or thematic use cases.

Each chapter contains both the theoretical background as well as a practical hand-on section facilitated through virtual notebooks. Finally, this book spans a variety of platforms such as TensorFlow and PyTorch to provide readers with a wide set of examples.

Part I

Curriculum

1 Data Preparation

```python
# Print out the Python version used by this environment.
import sys

print(f'{sys.version=}')
```

sys.version='3.11.0 | packaged by conda-forge | (main, Jan 14 2023, 12:26:40) [Clang 14.0.6]

Insert text here

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2 Semantic Segmentation (Crop Mapping)

2.1 Rice mapping in Bhutan with U-Net using high resolution satellite imagery

Run in Colab   View on GitHub

This notebook is also available in this github repo: https://github.com/SERVIR/servir-aces. Navigate to the `notebooks` folder.

2.2 Setup environment

```python
from google.colab import drive
drive.mount("/content/drive")
```

```python
!pip install servir-aces
```

```
Collecting servir-aces
  Downloading servir_aces-0.0.14-py2.py3-none-any.whl (32 kB)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages (from servir-
Requirement already satisfied: tensorflow>=2.9.3 in /usr/local/lib/python3.10/dist-packages
Requirement already satisfied: earthengine-api in /usr/local/lib/python3.10/dist-packages (fi
Collecting python-dotenv>=1.0.0 (from servir-aces)
  Downloading python_dotenv-1.0.1-py3-none-any.whl (19 kB)
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Requirement already satisfied: gast!=0.5.0,!=0.5.1,!=0.5.2,>=0.2.1 in /usr/local/lib/python3
Requirement already satisfied: google-pasta>=0.1.1 in /usr/local/lib/python3.10/dist-packages
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Requirement already satisfied: tensorboard<2.16,>=2.15 in /usr/local/lib/python3.10/dist-pack
Requirement already satisfied: tensorflow-estimator<2.16,>=2.15.0 in /usr/local/lib/python3.
Requirement already satisfied: keras<2.16,>=2.15.0 in /usr/local/lib/python3.10/dist-packages
Requirement already satisfied: google-cloud-storage in /usr/local/lib/python3.10/dist-package
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Requirement already satisfied: google-api-core!=2.0.*,!=2.1.*,!=2.2.*,!=2.3.0,<3.0.0dev,>=1.3
Requirement already satisfied: uritemplate<5,>=3.0.1 in /usr/local/lib/python3.10/dist-packag
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Requirement already satisfied: google-auth-oauthlib<2,>=0.5 in /usr/local/lib/python3.10/dist
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9

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Requirement already satisfied: MarkupSafe>=2.1.1 in /usr/local/lib/python3.10/dist-packages
Requirement already satisfied: oauthlib>=3.0.0 in /usr/local/lib/python3.10/dist-packages (f
Installing collected packages: python-dotenv, servir-aces
Successfully installed python-dotenv-1.0.1 servir-aces-0.0.14
```

```
# !git clone https://github.com/SERVIR/servir-aces
```

```
Cloning into 'servir-aces'...
remote: Enumerating objects: 740, done.
remote: Counting objects: 100% (116/116), done.
remote: Compressing objects: 100% (78/78), done.
remote: Total 740 (delta 46), reused 68 (delta 38), pack-reused 624
Receiving objects: 100% (740/740), 5.07 MiB | 16.12 MiB/s, done.
Resolving deltas: 100% (468/468), done.
```

2.2.1 Download datasets

For this chapter, we have already prepared and exported the training datasets. They can be found at the google cloud storage and we will use `gsutil` to get the dataset in our workspace. The dataset has `training`, `testing`, and `validation` subdirectory. Let's start by downloading these datasets in our workspace.

If you're looking to produce your own datasets, you can follow this notebook which was used to produce these training, testing, and validation datasets provided in this notebook.

```
!mkdir -p content/datasets
```

```
!gsutil -m cp -r gs://dl-book/chapter-1 content/datasets/
```

```
If you experience problems with multiprocessing on MacOS, they might be related to https://bu

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==> NOTE: You are downloading one or more large file(s), which would
run significantly faster if you enabled sliced object downloads. This
feature is enabled by default but requires that compiled crcmod be
installed (see "gsutil help crcmod").

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```

```
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```
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Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00027-of
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Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00037-of
/ [187/192 files][ 16.3 GiB/ 16.3 GiB]  99% Done  43.1 MiB/s ETA 00:00:00
```

2.2.2 Setup config file variables

Now the repo is downloaded. We will create an environment file file to place point to our training data and customize parameters for the model. To do this, we make a copy of the `.env.example` file provided.

Under the hood, all the configuration provided via the environment file are parsed as a config object and can be accessed programatically.

Note current version does not expose all the model intracacies through the environment file but future version may include those depending on the need.

```
!cp servir-aces/.env.example servir-aces/config.env
```

Okay, now we have the `config.env` file, we will use this to provide our environments and parameters.

Note there are several parameters that can be changed. Let's start by changing the `BASEDIR` and `OUTPUT_DIR` as below.

```
BASEDIR = "/content/"
OUTPUT_DIR = "/content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/output"
```

We will start by training a U-Net model using the `dl-book/chapter-1/unet_256x256_planet_wo_indices` dataset inside the `dataset` folder for this exercise. Let's go ahead and change our DATADIR in the `config.env` file as below.

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```
DATADIR = "datasets/unet_256x256_planet_wo_indices"
```

These datasets have RGBN from Planetscope mosiac. Since we are trying to map the rice fields, we use growing season and pre-growing season information. Thus, we have 8 optical bands, namely `red_before`, `green_before`, `blue_before`, `nir_before`, `red_during`, `green_during`, `blue_during`, and `nir_during`. In adidition, you can use `USE_ELEVATION` and `USE_S1` config to include the topographic and radar information. Since this datasets have toppgraphic and radar features, so we won't be settting these config values. Similarly, these datasets are tiled to 256x256 pixels, so let's also change that.

```
# For model training, USE_ELEVATION extends FEATURES with "elevation" & "slope"
# USE_S1 extends FEATURES with "vv_asc_before", "vh_asc_before", "vv_asc_during", "vh_asc_du
# "vv_desc_before", "vh_desc_before", "vv_desc_during", "vh_desc_during"
# In case these are not useful and you have other bands in your training data, you can do se
# USE_ELEVATION and USE_S1 to False and update FEATURES to include needed bands
USE_ELEVATION = False
USE_S1 = False

PATCH_SHAPE = (256, 256)
```

Next, we need to calculate the size of the traiing, testing and validation dataset. For this, we know our size before hand. But `aces` also provides handful of functions that we can use to calculate this. See this notebook to learn more about how to do it. We will also change the `BATCH_SIZE` to 32; if you have larger memory available, you can increase the `BATCH_SIZE`. You can run for longer `EPOCHS` by changing the `EPOCHS` paramter; we will keep it to 5 for now.

```
# Sizes of the training and evaluation datasets.
TRAIN_SIZE = 8531
TEST_SIZE = 1222
VAL_SIZE = 2404
BATCH_SIZE = 32
EPOCHS = 30
```

2.2.3 Update the config file programtically

We can also make a dictionary so we can change these config settings programatically.

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```
BASEDIR   = "/content/" # @param {type:"string"}
OUTPUT_DIR = "/content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/output" # @param {type
DATADIR = "datasets/unet_256x256_planet_wo_indices" # @param {type:"string"}
# PATCH_SHAPE, USE_ELEVATION, USE_S1, TRAIN_SIZE, TEST_SIZE, VAL_SIZE
# BATCH_SIZE, EPOCHS are converted to their appropriate type.
USE_ELEVATION = "False" # @param {type:"string"}
USE_S1 = "False" # @param {type:"string"}
PATCH_SHAPE = "(256, 256)" # @param {type:"string"}
TRAIN_SIZE = "8531" # @param {type:"string"}
TEST_SIZE = "1222" # @param {type:"string"}
VAL_SIZE = "2404" # @param {type:"string"}
BATCH_SIZE = "32" # @param {type:"string"}
EPOCHS = "30" # @param {type:"string"}
MODEL_DIR_NAME = "unet_v1" # @param {type:"string"}
```

```
unet_config_settings = {
    "BASEDIR" : BASEDIR,
    "OUTPUT_DIR": OUTPUT_DIR,
    "DATADIR": DATADIR,
    "USE_ELEVATION": USE_ELEVATION,
    "USE_S1": USE_S1,
    "PATCH_SHAPE": PATCH_SHAPE,
    "TRAIN_SIZE": TRAIN_SIZE,
    "TEST_SIZE": TEST_SIZE,
    "VAL_SIZE": VAL_SIZE,
    "BATCH_SIZE": BATCH_SIZE,
    "EPOCHS": EPOCHS,
    "MODEL_DIR_NAME": MODEL_DIR_NAME,
}
```

```
import dotenv

config_file = "servir-aces/config.env"

for config_key in unet_config_settings:
    dotenv.set_key(dotenv_path=config_file,
                   key_to_set=config_key,
                   value_to_set=unet_config_settings[config_key]
                   )
```

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2.3 U-Net Model

2.3.1 Load config file variables

```python
from aces import Config, DataProcessor, ModelTrainer, EEUtils
```

Let's load our config file through the `Config` class.

```python
unet_config = Config(config_file=config_file)
```

```
BASEDIR: /content
DATADIR: /content/datasets/unet_256x256_planet_wo_indices
using features: ['red_before', 'green_before', 'blue_before', 'nir_before', 'red_during', 'gr
using labels: ['class']
```

Most of the config in the `config.env` is now available via the config instance. Let's check few of them here.

```python
unet_config.TRAINING_DIR, unet_config.OUTPUT_DIR, unet_config.BATCH_SIZE, unet_config.TRAIN_S
```

```
(PosixPath('/content/datasets/unet_256x256_planet_wo_indices/training'),
 PosixPath('/content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/output'),
 32,
 8531)
```

2.3.2 Load `ModelTrainer` class

Next, let's make an instance of the `ModelTrainer` object. The `ModelTrainer` class provides various tools for training, buidling, compiling, and running specified deep learning models.

```python
unet_model_trainer = ModelTrainer(unet_config, seed=42)
```

```
Using seed: 42
```

2.3.3 Train and Save U-Net model

ModelTrainer class provides various functionality. We will use `train_model` function that helps to train the model using the provided configuration settings.

This method performs the following steps: - Configures memory growth for TensorFlow. - Creates TensorFlow datasets for training, testing, and validation. - Builds and compiles the model. - Prepares the output directory for saving models and results. - Starts the training process. - Evaluates and prints validation metrics. - Saves training parameters, plots, and models.

`unet_model_trainer.train_model()`

```
****************************************************************************
***************************** Clear Session... *****************************
****************************************************************************
**************************** Configure memory growth... ********************
 > Found 1 GPUs
****************************************************************************
***************************** creating datasets... *************************
Loading dataset from /content/datasets/unet_256x256_planet_wo_indices/training/*
randomly transforming data
Loading dataset from /content/datasets/unet_256x256_planet_wo_indices/validation/*
Loading dataset from /content/datasets/unet_256x256_planet_wo_indices/testing/*
Printing dataset info:
Training
inputs: float32 (32, 256, 256, 8)
tf.Tensor(
[[[[0.073075 0.063275 0.0411   ... 0.050625 0.0274   0.23925 ]
   [0.084775 0.067375 0.047025 ... 0.057675 0.032075 0.242375]
   [0.083625 0.068575 0.045075 ... 0.059275 0.0332   0.2409  ]
   ...
   [0.0702   0.06825  0.04495  ... 0.055025 0.028325 0.26305 ]
   [0.064475 0.066    0.043575 ... 0.0524   0.027075 0.26705 ]
   [0.0676   0.06355  0.04535  ... 0.05375  0.02875  0.263275]]

  [[0.071475 0.062225 0.0388   ... 0.0496   0.025375 0.24155 ]
   [0.07815  0.065025 0.044225 ... 0.0545   0.02905  0.24175 ]
   [0.086025 0.069125 0.046175 ... 0.05855  0.0326   0.2355  ]
   ...
   [0.060775 0.0627   0.041875 ... 0.051575 0.029725 0.267475]
   [0.061375 0.06225  0.04225  ... 0.0513   0.02685  0.268375]
   [0.06845  0.064075 0.043925 ... 0.052925 0.028575 0.267975]]
```

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```
[[0.0677    0.0605    0.038625 ... 0.04835  0.024825 0.236075]
 [0.078375 0.0629    0.04215  ... 0.0524   0.02855  0.237375]
 [0.0857    0.065725  0.04635  ... 0.05705  0.030975 0.235375]
 ...
 [0.07     0.062775  0.04485  ... 0.053425 0.0292   0.27015 ]
 [0.0607    0.060675  0.041175 ... 0.053075 0.026275 0.27025 ]
 [0.068     0.0667    0.045375 ... 0.055475 0.029375 0.262725]]

...

[[0.083525 0.06785   0.044125 ... 0.06365  0.0331   0.234825]
 [0.097825 0.07235   0.047925 ... 0.06675  0.03365  0.2363  ]
 [0.1092    0.082125  0.05385  ... 0.072125 0.036225 0.2486  ]
 ...
 [0.08935  0.088725  0.067575 ... 0.079675 0.042425 0.38085 ]
 [0.093725 0.0875    0.06355  ... 0.07565  0.04185  0.344525]
 [0.0937    0.089675  0.066775 ... 0.07465  0.043025 0.330925]]

[[0.0893   0.0732    0.04715  ... 0.065    0.0351   0.233525]
 [0.091325 0.073425  0.047475 ... 0.0653   0.032675 0.238325]
 [0.096775 0.07645   0.051625 ... 0.06875  0.0344   0.252825]
 ...
 [0.0836   0.084875  0.061975 ... 0.07825  0.042875 0.38785 ]
 [0.08865  0.083825  0.060675 ... 0.0765   0.042525 0.3522  ]
 [0.0909   0.084475  0.061975 ... 0.0769   0.043275 0.342625]]

[[0.092075 0.078     0.050925 ... 0.06565  0.03555  0.235275]
 [0.0805    0.0705    0.043325 ... 0.063925 0.03215  0.243875]
 [0.086925 0.074025  0.0495   ... 0.067475 0.03345  0.26095 ]
 ...
 [0.081075 0.078725  0.056425 ... 0.07505  0.0398   0.37805 ]
 [0.0865    0.079375  0.05845  ... 0.076175 0.0439   0.3619  ]
 [0.0886    0.077775  0.057725 ... 0.076175 0.042825 0.3439  ]]]


[[[0.076525 0.0703    0.04595  ... 0.055225 0.028025 0.25075 ]
  [0.072025 0.0658    0.0446   ... 0.05555  0.02795  0.24755 ]
  [0.0669    0.06225   0.038125 ... 0.05245  0.027125 0.241425]
  ...
  [0.054175 0.050575  0.029475 ... 0.04845  0.022375 0.23045 ]
  [0.05465  0.052375  0.031125 ... 0.04935  0.024375 0.2282  ]
  [0.052525 0.052725  0.029275 ... 0.048325 0.02325  0.229475]]
```

```
[[0.0784    0.065975 0.0441   ... 0.0594    0.031425 0.241175]
 [0.075475 0.066225 0.044975 ... 0.05505  0.02915  0.2405  ]
 [0.073375 0.063225 0.044475 ... 0.05435  0.029375 0.243575]
 ...
 [0.047325 0.05035  0.027125 ... 0.04535  0.022275 0.2235  ]
 [0.046475 0.051075 0.026425 ... 0.047025 0.021025 0.2348  ]
 [0.04295  0.050275 0.02575  ... 0.044525 0.01955  0.240875]]

[[0.065825 0.0619   0.04045  ... 0.053225 0.026425 0.236775]
 [0.07745  0.062725 0.040725 ... 0.0573   0.030725 0.2439  ]
 [0.075525 0.063775 0.0434   ... 0.05595  0.030125 0.25005 ]
 ...
 [0.046675 0.048325 0.02605  ... 0.0475   0.0219   0.23165 ]
 [0.046825 0.04955  0.026425 ... 0.0471   0.02055  0.243125]
 [0.04435  0.0498   0.0253   ... 0.04675  0.020775 0.239925]]

...

[[0.028025 0.041275 0.01945  ... 0.039375 0.015675 0.22205 ]
 [0.0245   0.040675 0.018025 ... 0.039575 0.016475 0.2187  ]
 [0.02185  0.03435  0.01665  ... 0.034025 0.015    0.20335 ]
 ...
 [0.1155   0.09395  0.0714   ... 0.058625 0.0275   0.335675]
 [0.117225 0.09435  0.0699   ... 0.05885  0.028175 0.34795 ]
 [0.1168   0.093275 0.06865  ... 0.0585   0.02895  0.353275]]

[[0.032025 0.04075  0.020675 ... 0.04025  0.015525 0.2328  ]
 [0.024525 0.038175 0.018025 ... 0.03785  0.015075 0.21255 ]
 [0.0227   0.03625  0.016425 ... 0.035    0.015075 0.204675]
 ...
 [0.11625  0.093825 0.071275 ... 0.058625 0.02685  0.34765 ]
 [0.115325 0.092175 0.06915  ... 0.05855  0.02745  0.3572  ]
 [0.1143   0.091225 0.067325 ... 0.05835  0.028925 0.357825]]

[[0.033325 0.04015  0.0212   ... 0.037875 0.015575 0.220525]
 [0.027225 0.038525 0.01925  ... 0.03625  0.014825 0.207775]
 [0.02625  0.03785  0.01885  ... 0.035675 0.015175 0.209825]
 ...
 [0.1132   0.09225  0.0699   ... 0.057875 0.027175 0.352875]
 [0.1116   0.090575 0.0685   ... 0.0585   0.027325 0.36045 ]
 [0.110325 0.089725 0.06665  ... 0.059425 0.02975  0.35485 ]]]
```

```
[[[0.076325 0.0714   0.0511   ... 0.05685  0.027375 0.3285   ]
  [0.078825 0.066725 0.044825 ... 0.05665  0.03155  0.3196   ]
  [0.1038   0.0806   0.060575 ... 0.07545  0.048225 0.2805   ]
  ...
  [0.02885  0.040825 0.022125 ... 0.037725 0.016275 0.17815  ]
  [0.0286   0.0422   0.02355  ... 0.039625 0.016675 0.191225]
  [0.02775  0.04375  0.022175 ... 0.043325 0.0181   0.203775]]

 [[0.06785  0.062075 0.04025  ... 0.04975  0.026175 0.31845  ]
  [0.07785  0.06515  0.041575 ... 0.055275 0.033675 0.29555  ]
  [0.099375 0.0823   0.062    ... 0.076125 0.047775 0.27305  ]
  ...
  [0.026425 0.040625 0.021825 ... 0.037175 0.0163   0.180075]
  [0.0283   0.04245  0.02205  ... 0.04045  0.017175 0.192025]
  [0.02925  0.0436   0.022975 ... 0.043725 0.0179   0.20435 ]]

 [[0.064725 0.0621   0.0413   ... 0.05105  0.02655  0.30515  ]
  [0.08075  0.067625 0.0489   ... 0.0599   0.033625 0.28425  ]
  [0.1018   0.078725 0.060025 ... 0.0735   0.043225 0.2772   ]
  ...
  [0.0277   0.0412   0.020975 ... 0.03765  0.01625  0.184425]
  [0.02835  0.043125 0.021675 ... 0.040175 0.017375 0.19335 ]
  [0.030575 0.043325 0.023375 ... 0.04225  0.0173   0.200575]]

 ...

 [[0.06545  0.054525 0.034075 ... 0.05745  0.028325 0.244075]
  [0.06275  0.053075 0.03125  ... 0.055625 0.027675 0.247475]
  [0.060875 0.05235  0.030725 ... 0.053875 0.026575 0.247275]
  ...
  [0.04905  0.0508   0.031375 ... 0.039275 0.018625 0.184025]
  [0.047775 0.04855  0.03135  ... 0.038075 0.017725 0.173025]
  [0.048475 0.052025 0.0336   ... 0.0377   0.018625 0.172875]]

 [[0.061575 0.051675 0.03085  ... 0.052975 0.02525  0.244675]
  [0.056875 0.050975 0.027025 ... 0.051675 0.023125 0.243075]
  [0.051075 0.05215  0.027025 ... 0.052125 0.022625 0.2422   ]
  ...
  [0.051525 0.05075  0.031625 ... 0.039625 0.021775 0.1806   ]
  [0.0485   0.049475 0.031275 ... 0.03685  0.01885  0.181675]
  [0.054275 0.054875 0.036125 ... 0.037525 0.0198   0.171425]]
```

```
[[0.055875 0.051075 0.02745  ... 0.04885  0.02285  0.2407  ]
 [0.056    0.052725 0.0285   ... 0.053175 0.02415  0.24375 ]
 [0.0544   0.05275  0.02815  ... 0.0555   0.0232   0.24885 ]
 ...
 [0.05005  0.051775 0.031    ... 0.03915  0.019525 0.1762  ]
 [0.048825 0.051275 0.0324   ... 0.036175 0.018375 0.18395 ]
 [0.0513   0.051225 0.031875 ... 0.0385   0.020625 0.177575]]


...


[[[0.059125 0.0521   0.0284   ... 0.046025 0.019975 0.234825]
  [0.06905  0.055875 0.0304   ... 0.04825  0.021725 0.237375]
  [0.0699   0.05865  0.031125 ... 0.051375 0.022725 0.23655 ]
  ...
  [0.034575 0.04225  0.0247   ... 0.03785  0.019175 0.157225]
  [0.029975 0.038475 0.023925 ... 0.034475 0.014425 0.175175]
  [0.025325 0.03555  0.02115  ... 0.0325   0.0144   0.157   ]]

 [[0.04895  0.051125 0.02935  ... 0.04475  0.0215   0.2242  ]
  [0.0563   0.05555  0.032025 ... 0.04655  0.0231   0.224225]
  [0.055875 0.0564   0.032875 ... 0.04815  0.023    0.232925]
  ...
  [0.0347   0.0392   0.0209   ... 0.035425 0.015675 0.17295 ]
  [0.031875 0.0362   0.02055  ... 0.029625 0.013925 0.14845 ]
  [0.028125 0.03385  0.020825 ... 0.026825 0.01315  0.13235 ]]

 [[0.0486   0.0514   0.028275 ... 0.046925 0.022425 0.22335 ]
  [0.05655  0.053425 0.028925 ... 0.047275 0.022825 0.219525]
  [0.0573   0.055525 0.0294   ... 0.0482   0.022275 0.2325  ]
  ...
  [0.024925 0.0378   0.019675 ... 0.032725 0.01405  0.18365 ]
  [0.031925 0.033875 0.0206   ... 0.03015  0.014075 0.169075]
  [0.0316   0.032025 0.019625 ... 0.0268   0.012925 0.136325]]


 ...


 [[0.067175 0.0628   0.039875 ... 0.052775 0.0307   0.2282  ]
  [0.080275 0.071475 0.050425 ... 0.0566   0.0342   0.217525]
  [0.07215  0.068375 0.045875 ... 0.056375 0.034375 0.2167  ]
  ...
  [0.03785  0.041425 0.023875 ... 0.043775 0.019575 0.213625]
```

```
 [0.03475  0.0394   0.02255  ... 0.04455  0.02     0.217375]
 [0.032625 0.039025 0.02305  ... 0.043425 0.01985  0.229575]]

[[0.07875  0.068475 0.0437   ... 0.056175 0.0339   0.22795 ]
 [0.08205  0.073825 0.0498   ... 0.057775 0.035225 0.2253  ]
 [0.08115  0.07405  0.0505   ... 0.059475 0.03475  0.2217  ]
 ...
 [0.03895  0.043275 0.026075 ... 0.044775 0.021    0.2286  ]
 [0.03795  0.038525 0.02265  ... 0.04295  0.018625 0.22255 ]
 [0.03365  0.038425 0.02355  ... 0.042    0.0189   0.225125]]

[[0.089    0.076325 0.0531   ... 0.05915  0.0333   0.228925]
 [0.084925 0.075775 0.050825 ... 0.05925  0.0363   0.236375]
 [0.08475  0.077325 0.050925 ... 0.0591   0.03615  0.225875]
 ...
 [0.040075 0.0416   0.025975 ... 0.044    0.020425 0.234125]
 [0.038075 0.036475 0.022375 ... 0.042175 0.01925  0.21895 ]
 [0.0349   0.036575 0.0241   ... 0.041525 0.0202   0.223625]]]


[[[0.039875 0.055875 0.031825 ... 0.046725 0.0206   0.2473  ]
  [0.041225 0.053475 0.031675 ... 0.04425  0.01995  0.2442  ]
  [0.038    0.0509   0.030125 ... 0.04345  0.018975 0.252075]
  ...
  [0.079575 0.068025 0.048175 ... 0.0623   0.0347   0.275575]
  [0.093775 0.08395  0.063975 ... 0.12865  0.096575 0.214425]
  [0.102475 0.09315  0.07065  ... 0.124725 0.11835  0.17915 ]]

 [[0.039875 0.055025 0.034025 ... 0.0453   0.020225 0.25715 ]
  [0.039625 0.053725 0.032925 ... 0.0437   0.01945  0.250625]
  [0.03925  0.051775 0.031525 ... 0.0442   0.018825 0.2608  ]
  ...
  [0.080175 0.073025 0.052975 ... 0.06945  0.0391   0.219825]
  [0.09105  0.0811   0.05875  ... 0.09675  0.067    0.133375]
  [0.08775  0.0791   0.053775 ... 0.097075 0.066325 0.1061  ]]

 [[0.04015  0.05545  0.0358   ... 0.046    0.020325 0.2604  ]
  [0.0386   0.053425 0.035075 ... 0.04415  0.0186   0.259075]
  [0.038875 0.0541   0.035    ... 0.04585  0.0204   0.2731  ]
  ...
  [0.09545  0.086025 0.06205  ... 0.08275  0.050225 0.117975]
  [0.07805  0.07245  0.05015  ... 0.08905  0.06075  0.088825]
  [0.075975 0.07035  0.04505  ... 0.09075  0.064575 0.082325]]
```

```
...

  [[0.041475 0.041475 0.021175 ... 0.03885  0.015775 0.209025]
   [0.039625 0.040275 0.021525 ... 0.0381   0.01435  0.199925]
   [0.034975 0.040175 0.020375 ... 0.0356   0.014575 0.1891  ]
   ...
   [0.0552   0.048575 0.034275 ... 0.037725 0.020475 0.150825]
   [0.046975 0.04565  0.03075  ... 0.0352   0.01815  0.137475]
   [0.049075 0.04705  0.031375 ... 0.03935  0.02075  0.1534  ]]

  [[0.0475   0.04265  0.024375 ... 0.039125 0.0159   0.2042  ]
   [0.048075 0.042075 0.0262   ... 0.039575 0.015975 0.1975  ]
   [0.0455   0.041725 0.02305  ... 0.0391   0.0166   0.203425]
   ...
   [0.054875 0.04825  0.0329   ... 0.036975 0.020325 0.14335 ]
   [0.04635  0.0461   0.0307   ... 0.0349   0.018575 0.1444  ]
   [0.0477   0.045825 0.030225 ... 0.038175 0.0193   0.14945 ]]

  [[0.047625 0.042275 0.025025 ... 0.039375 0.016775 0.2007  ]
   [0.04795  0.043    0.02435  ... 0.039425 0.01655  0.198825]
   [0.057725 0.04625  0.03155  ... 0.0416   0.0185   0.20395 ]
   ...
   [0.0496   0.04615  0.03035  ... 0.036125 0.01925  0.138325]
   [0.0501   0.047175 0.030225 ... 0.0391   0.0216   0.158675]
   [0.04975  0.048025 0.030475 ... 0.038725 0.021075 0.1527  ]]]


[[[0.09655  0.074775 0.050975 ... 0.0516   0.023025 0.261275]
   [0.092725 0.072675 0.0496   ... 0.058225 0.0292   0.208175]
   [0.080925 0.064725 0.04845  ... 0.08235  0.050425 0.170475]
   ...
   [0.047575 0.051725 0.026375 ... 0.044925 0.017175 0.256825]
   [0.055575 0.052925 0.030125 ... 0.048075 0.018    0.27485 ]
   [0.055525 0.0531   0.0318   ... 0.04635  0.01725  0.256675]]

  [[0.095525 0.07545  0.05235  ... 0.053225 0.022625 0.271925]
   [0.0957   0.075225 0.05265  ... 0.057725 0.02675  0.219325]
   [0.0937   0.071825 0.05245  ... 0.0824   0.05045  0.18085 ]
   ...
   [0.042775 0.048825 0.02565  ... 0.043875 0.016375 0.257325]
   [0.050625 0.051    0.028075 ... 0.04785  0.017925 0.282775]
   [0.0558   0.052    0.029675 ... 0.046875 0.017275 0.268275]]
```

```
   [[0.09525   0.076025 0.0528    ... 0.0533   0.021625 0.2891  ]
    [0.09735   0.0765   0.053     ... 0.055425 0.024675 0.244825]
    [0.09475   0.075125 0.05085   ... 0.071575 0.040575 0.1881  ]
    ...
    [0.038275 0.0477   0.0243    ... 0.043325 0.016    0.2494  ]
    [0.04245   0.050225 0.0255    ... 0.046025 0.01685  0.259525]
    [0.0483   0.052175 0.02775   ... 0.04545  0.017225 0.249375]]


   ...


   [[0.033875 0.045775 0.029025 ... 0.0404   0.018975 0.2029  ]
    [0.0357   0.04645  0.028025 ... 0.041925 0.0196   0.20415 ]
    [0.036975 0.046825 0.02825  ... 0.04005  0.018575 0.19235 ]
    ...
    [0.116775 0.0982   0.080175 ... 0.08415  0.06735  0.2857  ]
    [0.104525 0.09055  0.071025 ... 0.0795   0.0627   0.310825]
    [0.0975   0.082025 0.059075 ... 0.06885  0.045825 0.324375]]


   [[0.035775 0.042825 0.02835   ... 0.039125 0.0173   0.20685 ]
    [0.03505   0.0427   0.028275 ... 0.0397   0.017525 0.2041  ]
    [0.03665   0.0459   0.027125 ... 0.041575 0.0189   0.20055 ]
    ...
    [0.10555   0.088325 0.06645   ... 0.081425 0.059475 0.288725]
    [0.10945   0.091575 0.072325 ... 0.084475 0.057925 0.306175]
    [0.096675 0.0814   0.060425 ... 0.069775 0.04325  0.323975]]


   [[0.0381   0.0465   0.027175 ... 0.0385   0.0179   0.199175]
    [0.036325 0.04335   0.027625 ... 0.037975 0.016925 0.1999  ]
    [0.036475 0.047725 0.029125 ... 0.043325 0.019775 0.21835 ]
    ...
    [0.1108   0.1004   0.0796    ... 0.0981   0.084725 0.291575]
    [0.0959   0.0824   0.06165   ... 0.07685  0.0528   0.318575]
    [0.093025 0.07815  0.0585    ... 0.06915  0.0448   0.32745 ]]]], shape=(32, 256, 256, 8),
outputs: float32 (32, 256, 256, 5)
tf.Tensor(
[[[[0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   ...
   [0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]]
```

```
[[0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 ...
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
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[[0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 ...
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]]

...

[[1. 0. 0. 0. 0.]
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 [0. 1. 0. 0. 0.]
 ...
 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]
 [0. 1. 0. 0. 0.]]

[[1. 0. 0. 0. 0.]
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 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]

[[1. 0. 0. 0. 0.]
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 ...
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 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]]
```

```
[[[1. 0. 0. 0. 0.]
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  [1. 0. 0. 0. 0.]
  ...
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]]

 [[1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  ...
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]]

 [[1. 0. 0. 0. 0.]
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  [1. 0. 0. 0. 0.]
  ...
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]]

 ...

 [[1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  ...
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]]

 [[1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  ...
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]]
```

```
 [[1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  ...
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]]]


[[[1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]]

 [[1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]]

 [[1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  ...
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]]

 ...

 [[0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  ...
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]]
```

```
[[0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 ...
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]]

[[0. 0. 1. 0. 0.]
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 [0. 0. 1. 0. 0.]
 ...
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]]]


...


[[[0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]]

 [[0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
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  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]]

 [[0. 0. 1. 0. 0.]
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  ...
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]]]
```

```
...

[[0. 0. 1. 0. 0.]
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 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]

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 [1. 0. 0. 0. 0.]]

[[0. 0. 1. 0. 0.]
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 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]]


[[[0. 0. 1. 0. 0.]
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  [0. 0. 1. 0. 0.]
  ...
  [1. 0. 0. 0. 0.]
  [0. 0. 0. 1. 0.]
  [0. 0. 0. 1. 0.]]

 [[0. 0. 1. 0. 0.]
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  ...
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  [0. 0. 0. 0. 1.]
  [0. 0. 0. 0. 1.]]
```

```
[[0. 0. 1. 0. 0.]
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 ...
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 [0. 0. 0. 0. 1.]
 [0. 0. 0. 0. 1.]]


...

[[0. 0. 1. 0. 0.]
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 ...
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 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]

[[0. 0. 1. 0. 0.]
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 ...
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 [1. 0. 0. 0. 0.]]

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```

```
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 ...
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 [1. 0. 0. 0. 0.]]

[[0. 0. 1. 0. 0.]
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 ...
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 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]


...

[[0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
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 ...
 [0. 0. 0. 1. 0.]
 [0. 1. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]

[[0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 ...
 [0. 0. 0. 1. 0.]
 [0. 1. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]

[[0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 [0. 0. 1. 0. 0.]
 ...
 [0. 0. 0. 1. 0.]
 [1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0.]]]], shape=(32, 256, 256, 5), dtype=float32)
Testing
```

```
inputs: float32 (1, 256, 256, 8)
tf.Tensor(
[[[[0.0853    0.0767    0.052625 ... 0.084725 0.048225 0.266675]
   [0.08645   0.076725 0.05415  ... 0.0815   0.049725 0.256475]
   [0.0881    0.07945  0.05675  ... 0.0833   0.049725 0.267   ]
   ...
   [0.041725 0.046875 0.027925 ... 0.04645  0.019175 0.2598  ]
   [0.03835  0.044725 0.024125 ... 0.04525  0.018175 0.2606  ]
   [0.0354    0.03985  0.021875 ... 0.044    0.017925 0.260925]]

  [[0.08945   0.072675 0.047475 ... 0.084925 0.045675 0.253325]
   [0.096     0.07225  0.048375 ... 0.088875 0.049475 0.25065 ]
   [0.10235   0.0735   0.0509   ... 0.088175 0.050675 0.269075]
   ...
   [0.042225 0.0459   0.026575 ... 0.04655  0.01875  0.265025]
   [0.040375 0.044525 0.02595  ... 0.04585  0.0186   0.26045 ]
   [0.03615   0.041075 0.022125 ... 0.044825 0.017775 0.263675]]

  [[0.087625 0.0762   0.0522   ... 0.084775 0.0459   0.243175]
   [0.09235   0.07215  0.048425 ... 0.0871   0.04725  0.243725]
   [0.104925 0.074375 0.05205  ... 0.0889   0.048275 0.25105 ]
   ...
   [0.04065   0.041975 0.023275 ... 0.043425 0.018075 0.25435 ]
   [0.0382    0.04225  0.02305  ... 0.0432   0.017725 0.254725]
   [0.037025 0.042925 0.022875 ... 0.046575 0.018425 0.259875]]

  ...

  [[0.074575 0.06     0.03945  ... 0.05635  0.03315  0.198025]
   [0.082     0.06205  0.040675 ... 0.058675 0.033075 0.198625]
   [0.080225 0.06355  0.0416   ... 0.059775 0.03395  0.206025]
   ...
   [0.09965   0.082725 0.06805  ... 0.067325 0.05815  0.27725 ]
   [0.0889    0.0679   0.0468   ... 0.0563   0.034875 0.29495 ]
   [0.07205   0.059575 0.04125  ... 0.05235  0.03185  0.3116  ]]

  [[0.0768    0.06205  0.039975 ... 0.058175 0.0334   0.197525]
   [0.0797    0.0638   0.041675 ... 0.060425 0.035925 0.1993  ]
   [0.08345   0.063725 0.04135  ... 0.0606   0.03585  0.2044  ]
   ...
   [0.110425 0.089975 0.071475 ... 0.083225 0.07175  0.261625]
   [0.0995    0.076725 0.053175 ... 0.060975 0.043725 0.29315 ]
   [0.07945   0.06385  0.0462   ... 0.059675 0.038375 0.32095 ]]
```

```
   [[0.074075 0.0615    0.0395    ... 0.0591    0.03185  0.200825]
    [0.0771   0.06265  0.040775 ... 0.059825 0.033975 0.204725]
    [0.0835   0.063125 0.0417    ... 0.059825 0.034325 0.2      ]
    ...
    [0.118575 0.0944   0.070325 ... 0.09795  0.078    0.272   ]
    [0.11975  0.0899   0.063575 ... 0.077975 0.05495  0.306325]
    [0.0861   0.068475 0.049775 ... 0.063225 0.039625 0.3163  ]]]], shape=(1, 256, 256, 8), d
outputs: float32 (1, 256, 256, 5)
tf.Tensor(
[[[[1. 0. 0. 0. 0.]
   [0. 0. 1. 0. 0.]
   [0. 1. 0. 0. 0.]
   ...
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]]

  [[0. 0. 1. 0. 0.]
   [0. 0. 0. 1. 0.]
   [0. 0. 0. 1. 0.]
   ...
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]]

  [[0. 1. 0. 0. 0.]
   [0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   ...
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]]

  ...

  [[1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   ...
   [0. 0. 1. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]]
```

```
  [[1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   ...
   [0. 0. 0. 1. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]]

  [[1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   ...
   [0. 0. 0. 1. 0.]
   [0. 0. 1. 0. 0.]
   [1. 0. 0. 0. 0.]]]], shape=(1, 256, 256, 5), dtype=float32)
Validation
inputs: float32 (1, 256, 256, 8)
tf.Tensor(
[[[[0.053275 0.043025 0.0284   ... 0.042575 0.01925  0.2313  ]
   [0.0535   0.04265  0.0293   ... 0.043975 0.0191   0.246425]
   [0.049125 0.042675 0.027125 ... 0.042275 0.019325 0.228225]
   ...
   [0.0724   0.064525 0.044325 ... 0.0504   0.0264   0.202325]
   [0.07395  0.0651   0.04495  ... 0.05235  0.02625  0.211175]
   [0.075975 0.0647   0.04615  ... 0.0523   0.027625 0.2079  ]]

  [[0.053025 0.042325 0.02895  ... 0.041625 0.018475 0.239625]
   [0.051225 0.0413   0.029    ... 0.042    0.018375 0.238775]
   [0.04785  0.04345  0.02785  ... 0.042625 0.019825 0.21835 ]
   ...
   [0.067    0.059125 0.042375 ... 0.049375 0.023475 0.18365 ]
   [0.0679   0.06215  0.042125 ... 0.050825 0.0246   0.197125]
   [0.066575 0.062775 0.041925 ... 0.049875 0.0247   0.199775]]

  [[0.04975  0.03945  0.0265   ... 0.040925 0.01785  0.243675]
   [0.050625 0.040725 0.027925 ... 0.040825 0.018625 0.236075]
   [0.0546   0.04545  0.029725 ... 0.043575 0.021075 0.20885 ]
   ...
   [0.069075 0.0611   0.0435   ... 0.050075 0.02435  0.186325]
   [0.07345  0.063225 0.0452   ... 0.052325 0.02595  0.19745 ]
   [0.068175 0.06035  0.04155  ... 0.04985  0.023925 0.1912  ]]
```

```
    ...

    [[0.064425 0.062275 0.037175 ... 0.0576   0.027975 0.265325]
     [0.058075 0.059925 0.03495  ... 0.05475  0.02585  0.26375 ]
     [0.040675 0.053675 0.028975 ... 0.0482   0.02065  0.250575]
     ...
     [0.0937   0.09025  0.072    ... 0.0486   0.02375  0.2789  ]
     [0.094125 0.091525 0.072925 ... 0.04795  0.02335  0.273275]
     [0.09135  0.08855  0.067875 ... 0.04985  0.023425 0.282475]]

    [[0.063175 0.05715  0.03525  ... 0.054475 0.0265   0.2553  ]
     [0.0581   0.0556   0.032875 ... 0.0511   0.0242   0.246625]
     [0.0396   0.0509   0.027975 ... 0.0464   0.020075 0.23445 ]
     ...
     [0.09535  0.0905   0.076275 ... 0.048725 0.0235   0.289175]
     [0.093725 0.09015  0.0717   ... 0.048325 0.02345  0.279575]
     [0.09145  0.088125 0.068475 ... 0.0493   0.023075 0.290275]]

    [[0.04605  0.05285  0.0288   ... 0.048925 0.021625 0.2413  ]
     [0.03955  0.051625 0.028325 ... 0.046975 0.020875 0.2319  ]
     [0.0431   0.052225 0.03135  ... 0.042275 0.02     0.221325]
     ...
     [0.099075 0.085075 0.06545  ... 0.051925 0.02575  0.298475]
     [0.100175 0.08775  0.0678   ... 0.05005  0.024175 0.28905 ]
     [0.09685  0.0912   0.07425  ... 0.049975 0.023375 0.290425]]]], shape=(1, 256, 256, 8), d
outputs: float32 (1, 256, 256, 5)
tf.Tensor(
[[[[0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   ...
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]]

  [[0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   [0. 0. 1. 0. 0.]
   ...
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]
   [1. 0. 0. 0. 0.]]
```

```
 [[0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]
  [1. 0. 0. 0. 0.]]

  ...

 [[0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]]

 [[0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]]

 [[0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  [0. 0. 1. 0. 0.]
  ...
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]
  [0. 1. 0. 0. 0.]]]], shape=(1, 256, 256, 5), dtype=float32)
****************************************************************************
*********************** building and compiling model... *******************
DERIVE_FEATURES: False
Model: "unet"
_____
 Layer (type)                Output Shape              Param #   Connected to
================================================================================
 input_1 (InputLayer)        [(None, None, None, 8)]   0         []

 conv2d (Conv2D)             (None, None, None, 32)    2336      ['input_1[0][0]']
```

batch_normalization (Batch Normalization)	(None, None, None, 32)	128	['conv2d[0][0]']
activation (Activation)	(None, None, None, 32)	0	['batch_normalization[0]
activation_1 (Activation)	(None, None, None, 32)	0	['activation[0][0]']
separable_conv2d (Separabl eConv2D)	(None, None, None, 64)	2400	['activation_1[0][0]']
batch_normalization_1 (Bat chNormalization)	(None, None, None, 64)	256	['separable_conv2d[0][0]
activation_2 (Activation)	(None, None, None, 64)	0	['batch_normalization_1[( ]
separable_conv2d_1 (Separa bleConv2D)	(None, None, None, 64)	4736	['activation_2[0][0]']
batch_normalization_2 (Bat chNormalization)	(None, None, None, 64)	256	['separable_conv2d_1[0][(
max_pooling2d (MaxPooling2 D)	(None, None, None, 64)	0	['batch_normalization_2[( ]
conv2d_1 (Conv2D)	(None, None, None, 64)	2112	['activation[0][0]']
add (Add)	(None, None, None, 64)	0	['max_pooling2d[0][0]', 'conv2d_1[0][0]']
activation_3 (Activation)	(None, None, None, 64)	0	['add[0][0]']
separable_conv2d_2 (Separa bleConv2D)	(None, None, None, 128)	8896	['activation_3[0][0]']
batch_normalization_3 (Bat chNormalization)	(None, None, None, 128)	512	['separable_conv2d_2[0][(
activation_4 (Activation)	(None, None, None, 128)	0	['batch_normalization_3[( ]
separable_conv2d_3 (Separa	(None, None, None, 128)	17664	['activation_4[0][0]']

bleConv2D)

Layer	Output Shape	Param #	Connected to
batch_normalization_4 (BatchNormalization)	(None, None, None, 128)	512	['separable_conv2d_3[0][0
max_pooling2d_1 (MaxPooling2D)	(None, None, None, 128)	0	['batch_normalization_4[0]]
conv2d_2 (Conv2D)	(None, None, None, 128)	8320	['add[0][0]']
add_1 (Add)	(None, None, None, 128)	0	['max_pooling2d_1[0][0]' 'conv2d_2[0][0]']
activation_5 (Activation)	(None, None, None, 128)	0	['add_1[0][0]']
separable_conv2d_4 (SeparableConv2D)	(None, None, None, 256)	34176	['activation_5[0][0]']
batch_normalization_5 (BatchNormalization)	(None, None, None, 256)	1024	['separable_conv2d_4[0][0
activation_6 (Activation)	(None, None, None, 256)	0	['batch_normalization_5[0]
separable_conv2d_5 (SeparableConv2D)	(None, None, None, 256)	68096	['activation_6[0][0]']
batch_normalization_6 (BatchNormalization)	(None, None, None, 256)	1024	['separable_conv2d_5[0][0
max_pooling2d_2 (MaxPooling2D)	(None, None, None, 256)	0	['batch_normalization_6[0]
conv2d_3 (Conv2D)	(None, None, None, 256)	33024	['add_1[0][0]']
add_2 (Add)	(None, None, None, 256)	0	['max_pooling2d_2[0][0]' 'conv2d_3[0][0]']
activation_7 (Activation)	(None, None, None, 256)	0	['add_2[0][0]']
conv2d_transpose (Conv2DTranspose)	(None, None, None, 256)	590080	['activation_7[0][0]']

Layer	Output Shape	Param #	Connected to
batch_normalization_7 (Bat chNormalization)	(None, None, None, 256)	1024	['conv2d_transpose[0][0]
activation_8 (Activation)	(None, None, None, 256)	0	['batch_normalization_7[0]
conv2d_transpose_1 (Conv2D Transpose)	(None, None, None, 256)	590080	['activation_8[0][0]']
batch_normalization_8 (Bat chNormalization)	(None, None, None, 256)	1024	['conv2d_transpose_1[0][0
up_sampling2d_1 (UpSamplin g2D)	(None, None, None, 256)	0	['add_2[0][0]']
up_sampling2d (UpSampling2 D)	(None, None, None, 256)	0	['batch_normalization_8[0]
conv2d_4 (Conv2D)	(None, None, None, 256)	65792	['up_sampling2d_1[0][0]'
add_3 (Add)	(None, None, None, 256)	0	['up_sampling2d[0][0]', 'conv2d_4[0][0]']
activation_9 (Activation)	(None, None, None, 256)	0	['add_3[0][0]']
conv2d_transpose_2 (Conv2D Transpose)	(None, None, None, 128)	295040	['activation_9[0][0]']
batch_normalization_9 (Bat chNormalization)	(None, None, None, 128)	512	['conv2d_transpose_2[0][0
activation_10 (Activation)	(None, None, None, 128)	0	['batch_normalization_9[0]
conv2d_transpose_3 (Conv2D Transpose)	(None, None, None, 128)	147584	['activation_10[0][0]']
batch_normalization_10 (Ba tchNormalization)	(None, None, None, 128)	512	['conv2d_transpose_3[0][0
up_sampling2d_3 (UpSamplin g2D)	(None, None, None, 256)	0	['add_3[0][0]']

Layer (type)	Output Shape	Param #	Connected to
up_sampling2d_2 (UpSamplin g2D)	(None, None, None, 128)	0	['batch_normalization_10 ']
conv2d_5 (Conv2D)	(None, None, None, 128)	32896	['up_sampling2d_3[0][0]']
add_4 (Add)	(None, None, None, 128)	0	['up_sampling2d_2[0][0]' 'conv2d_5[0][0]']
activation_11 (Activation)	(None, None, None, 128)	0	['add_4[0][0]']
conv2d_transpose_4 (Conv2D Transpose)	(None, None, None, 64)	73792	['activation_11[0][0]']
batch_normalization_11 (Ba tchNormalization)	(None, None, None, 64)	256	['conv2d_transpose_4[0][0]
activation_12 (Activation)	(None, None, None, 64)	0	['batch_normalization_11 ']
conv2d_transpose_5 (Conv2D Transpose)	(None, None, None, 64)	36928	['activation_12[0][0]']
batch_normalization_12 (Ba tchNormalization)	(None, None, None, 64)	256	['conv2d_transpose_5[0][0]
up_sampling2d_5 (UpSamplin g2D)	(None, None, None, 128)	0	['add_4[0][0]']
up_sampling2d_4 (UpSamplin g2D)	(None, None, None, 64)	0	['batch_normalization_12 ']
conv2d_6 (Conv2D)	(None, None, None, 64)	8256	['up_sampling2d_5[0][0]']
add_5 (Add)	(None, None, None, 64)	0	['up_sampling2d_4[0][0]' 'conv2d_6[0][0]']
activation_13 (Activation)	(None, None, None, 64)	0	['add_5[0][0]']
conv2d_transpose_6 (Conv2D Transpose)	(None, None, None, 32)	18464	['activation_13[0][0]']
batch_normalization_13 (Ba tchNormalization)	(None, None, None, 32)	128	['conv2d_transpose_6[0][0]

```
activation_14 (Activation)    (None, None, None, 32)      0        ['batch_normalization_13
                                                                    ']

conv2d_transpose_7 (Conv2D    (None, None, None, 32)    9248       ['activation_14[0][0]']
Transpose)

batch_normalization_14 (Ba    (None, None, None, 32)     128       ['conv2d_transpose_7[0][0
tchNormalization)

up_sampling2d_7 (UpSamplin    (None, None, None, 64)      0        ['add_5[0][0]']
g2D)

up_sampling2d_6 (UpSamplin    (None, None, None, 32)      0        ['batch_normalization_14
g2D)                                                                ']

conv2d_7 (Conv2D)             (None, None, None, 32)    2080       ['up_sampling2d_7[0][0]'

add_6 (Add)                   (None, None, None, 32)      0        ['up_sampling2d_6[0][0]'
                                                                    'conv2d_7[0][0]']

final_conv (Conv2D)           (None, None, None, 5)     1445       ['add_6[0][0]']

================================================================================
Total params: 2060997 (7.86 MB)
Trainable params: 2057221 (7.85 MB)
Non-trainable params: 3776 (14.75 KB)

--------------------------------------------------------------------------------
None
********************************************************************************
*********************** preparing output directory... ********************
> Saving models and results at /content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/outpu
********************************************************************************
**************************** training model... **************************
Epoch 1/30
266/266 [==============================] - ETA: 0s - loss: 0.9676 - precision: 0.7271 - recal
Epoch 1: val_loss improved from inf to 2.63403, saving model to /content/drive/MyDrive/Colab
266/266 [==============================] - 299s 971ms/step - loss: 0.9676 - precision: 0.7271
Epoch 2/30
266/266 [==============================] - ETA: 0s - loss: 0.6959 - precision: 0.8066 - recal
Epoch 2: val_loss improved from 2.63403 to 1.23879, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 263s 958ms/step - loss: 0.6959 - precision: 0.8066
Epoch 3/30
```

```
266/266 [==============================] - ETA: 0s - loss: 0.6352 - precision: 0.8285 - recal
Epoch 3: val_loss improved from 1.23879 to 0.62282, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 256s 966ms/step - loss: 0.6352 - precision: 0.8285
Epoch 4/30
266/266 [==============================] - ETA: 0s - loss: 0.5988 - precision: 0.8402 - recal
Epoch 4: val_loss improved from 0.62282 to 0.60250, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 252s 949ms/step - loss: 0.5988 - precision: 0.8402
Epoch 5/30
266/266 [==============================] - ETA: 0s - loss: 0.5687 - precision: 0.8498 - recal
Epoch 5: val_loss improved from 0.60250 to 0.55160, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 285s 1s/step - loss: 0.5687 - precision: 0.8498 -
Epoch 6/30
266/266 [==============================] - ETA: 0s - loss: 0.5453 - precision: 0.8571 - recal
Epoch 6: val_loss improved from 0.55160 to 0.52872, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 284s 1s/step - loss: 0.5453 - precision: 0.8571 -
Epoch 7/30
266/266 [==============================] - ETA: 0s - loss: 0.5278 - precision: 0.8624 - recal
Epoch 7: val_loss improved from 0.52872 to 0.50506, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 262s 988ms/step - loss: 0.5278 - precision: 0.8624
Epoch 8/30
266/266 [==============================] - ETA: 0s - loss: 0.5123 - precision: 0.8671 - recal
Epoch 8: val_loss improved from 0.50506 to 0.49242, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 264s 995ms/step - loss: 0.5123 - precision: 0.8671
Epoch 9/30
266/266 [==============================] - ETA: 0s - loss: 0.5018 - precision: 0.8700 - recal
Epoch 9: val_loss did not improve from 0.49242
266/266 [==============================] - 276s 1s/step - loss: 0.5018 - precision: 0.8700 -
Epoch 10/30
266/266 [==============================] - ETA: 0s - loss: 0.4895 - precision: 0.8736 - recal
Epoch 10: val_loss improved from 0.49242 to 0.47591, saving model to /content/drive/MyDrive/C
266/266 [==============================] - 268s 1s/step - loss: 0.4895 - precision: 0.8736 -
Epoch 11/30
266/266 [==============================] - ETA: 0s - loss: 0.4791 - precision: 0.8766 - recal
Epoch 11: val_loss improved from 0.47591 to 0.46856, saving model to /content/drive/MyDrive/C
266/266 [==============================] - 263s 992ms/step - loss: 0.4791 - precision: 0.8766
Epoch 12/30
266/266 [==============================] - ETA: 0s - loss: 0.4726 - precision: 0.8783 - recal
Epoch 12: val_loss did not improve from 0.46856
266/266 [==============================] - 255s 960ms/step - loss: 0.4726 - precision: 0.8783
Epoch 13/30
266/266 [==============================] - ETA: 0s - loss: 0.4617 - precision: 0.8814 - recal
Epoch 13: val_loss improved from 0.46856 to 0.45125, saving model to /content/drive/MyDrive/C
266/266 [==============================] - 266s 1s/step - loss: 0.4617 - precision: 0.8814 -
```

```
Epoch 14/30
266/266 [==============================] - ETA: 0s - loss: 0.4553 - precision: 0.8830 - recal
Epoch 14: val_loss improved from 0.45125 to 0.44229, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 263s 992ms/step - loss: 0.4553 - precision: 0.8830
Epoch 15/30
266/266 [==============================] - ETA: 0s - loss: 0.4488 - precision: 0.8847 - recal
Epoch 15: val_loss did not improve from 0.44229
266/266 [==============================] - 258s 973ms/step - loss: 0.4488 - precision: 0.8847
Epoch 16/30
266/266 [==============================] - ETA: 0s - loss: 0.4440 - precision: 0.8859 - recal
Epoch 16: val_loss did not improve from 0.44229
266/266 [==============================] - 265s 998ms/step - loss: 0.4440 - precision: 0.8859
Epoch 17/30
266/266 [==============================] - ETA: 0s - loss: 0.4378 - precision: 0.8875 - recal
Epoch 17: val_loss did not improve from 0.44229
266/266 [==============================] - 285s 1s/step - loss: 0.4378 - precision: 0.8875 -
Epoch 18/30
266/266 [==============================] - ETA: 0s - loss: 0.4336 - precision: 0.8884 - recal
Epoch 18: val_loss improved from 0.44229 to 0.42199, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 278s 1s/step - loss: 0.4336 - precision: 0.8884 -
Epoch 19/30
266/266 [==============================] - ETA: 0s - loss: 0.4294 - precision: 0.8894 - recal
Epoch 19: val_loss improved from 0.42199 to 0.41151, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 282s 1s/step - loss: 0.4294 - precision: 0.8894 -
Epoch 20/30
266/266 [==============================] - ETA: 0s - loss: 0.4241 - precision: 0.8907 - recal
Epoch 20: val_loss did not improve from 0.41151
266/266 [==============================] - 258s 970ms/step - loss: 0.4241 - precision: 0.8907
Epoch 21/30
266/266 [==============================] - ETA: 0s - loss: 0.4196 - precision: 0.8919 - recal
Epoch 21: val_loss did not improve from 0.41151
266/266 [==============================] - 259s 977ms/step - loss: 0.4196 - precision: 0.8919
Epoch 22/30
266/266 [==============================] - ETA: 0s - loss: 0.4171 - precision: 0.8923 - recal
Epoch 22: val_loss did not improve from 0.41151
266/266 [==============================] - 260s 982ms/step - loss: 0.4171 - precision: 0.8923
Epoch 23/30
266/266 [==============================] - ETA: 0s - loss: 0.4134 - precision: 0.8931 - recal
Epoch 23: val_loss improved from 0.41151 to 0.40218, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 272s 1s/step - loss: 0.4134 - precision: 0.8931 -
Epoch 24/30
266/266 [==============================] - ETA: 0s - loss: 0.4117 - precision: 0.8936 - recal
Epoch 24: val_loss did not improve from 0.40218
```

```
266/266 [==============================] - 260s 981ms/step - loss: 0.4117 - precision: 0.8936
Epoch 25/30
266/266 [==============================] - ETA: 0s - loss: 0.4064 - precision: 0.8948 - recal
Epoch 25: val_loss improved from 0.40218 to 0.39190, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 298s 1s/step - loss: 0.4064 - precision: 0.8948 -
Epoch 26/30
266/266 [==============================] - ETA: 0s - loss: 0.4038 - precision: 0.8954 - recal
Epoch 26: val_loss improved from 0.39190 to 0.38542, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 280s 1s/step - loss: 0.4038 - precision: 0.8954 -
Epoch 27/30
266/266 [==============================] - ETA: 0s - loss: 0.4007 - precision: 0.8961 - recal
Epoch 27: val_loss improved from 0.38542 to 0.38379, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 283s 1s/step - loss: 0.4007 - precision: 0.8961 -
Epoch 28/30
266/266 [==============================] - ETA: 0s - loss: 0.3972 - precision: 0.8969 - recal
Epoch 28: val_loss improved from 0.38379 to 0.37968, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 264s 996ms/step - loss: 0.3972 - precision: 0.8969
Epoch 29/30
266/266 [==============================] - ETA: 0s - loss: 0.3962 - precision: 0.8970 - recal
Epoch 29: val_loss improved from 0.37968 to 0.37328, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 263s 989ms/step - loss: 0.3962 - precision: 0.8970
Epoch 30/30
266/266 [==============================] - ETA: 0s - loss: 0.3934 - precision: 0.8977 - recal
Epoch 30: val_loss improved from 0.37328 to 0.37270, saving model to /content/drive/MyDrive/(
266/266 [==============================] - 265s 998ms/step - loss: 0.3934 - precision: 0.8977
****************************************************************************
**************************** evaluating model... ************************
*************************************************
*************************************************
Validation
1222/1222 [==============================] - 36s 22ms/step - loss: 0.3723 - precision: 0.9009
loss: 0.3722515106201172
precision: 0.9008649587631226
recall: 0.8225432634353638
categorical_accuracy: 0.8566350340843201
one_hot_io_u: 0.6780571341514587


****************************************************************************
**************************** saving parameters... **********************
****************************************************************************
*************** saving model config and history object... *****************
****************************************************************************
```
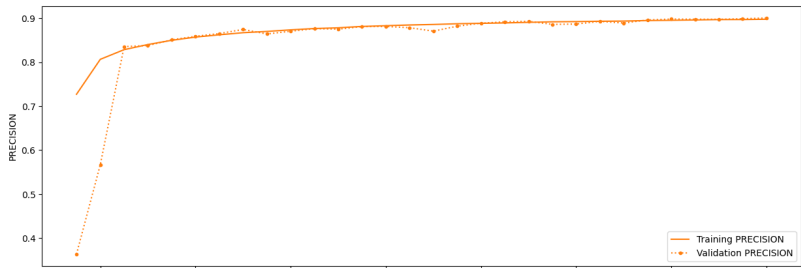
```
****************************** saving plots... ******************************
Saving plots and model visualization at /content/drive/MyDrive/Colab Notebooks/DL_Book/Chapt
**************************************************************************
****************************** saving models... ****************************
**************************************************************************
```
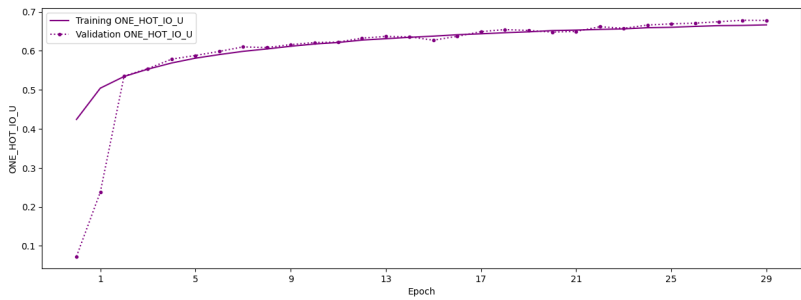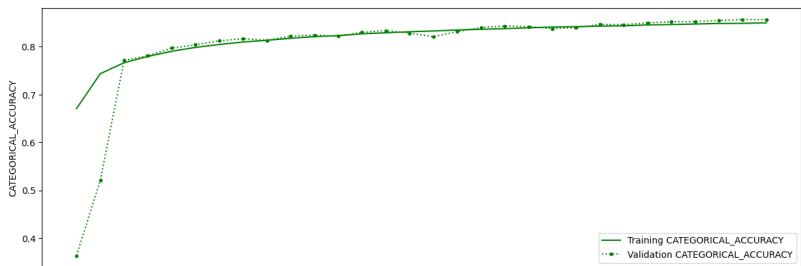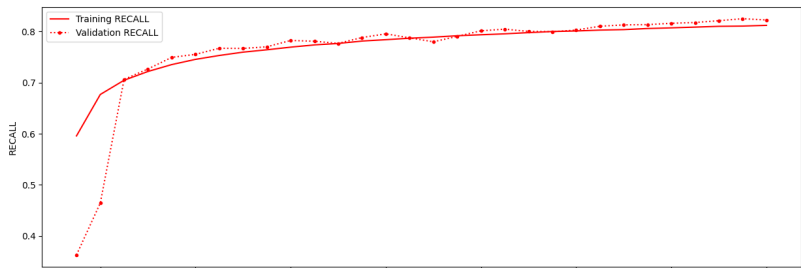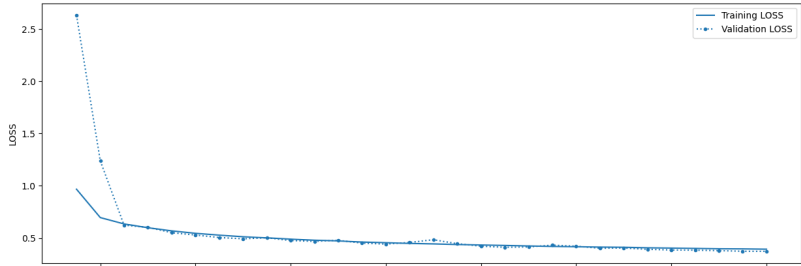
2.3.4 Save the config file

```python
from pathlib import Path
import shutil

config_file = Path(config_file)
drive_config_file = Path(unet_config.MODEL_DIR / f"{str(config_file).split('/')[-1]}")

# Create the target directory if it doesn't exist
drive_config_file.parent.mkdir(parents=True, exist_ok=True)

# Copy the file
shutil.copy(config_file, drive_config_file)

print(f"File copied from {config_file} to {drive_config_file}")
```

```
File copied from servir-aces/config.env to /content/drive/MyDrive/Colab Notebooks/DL_Book/Cha
```

2.3.5 Load the logs files via TensorBoard

Tensorboard provides a unique way to view and interact with the logs while the model is being trained. Learn more here. Here we only show you how you can load them to tensorboard with our training logs.

```python
# Load the TensorBoard notebook extension
%load_ext tensorboard
```

```python
log_dir_unet = f"{str(unet_config.MODEL_DIR)}/logs"
log_dir_unet
```

```
'/content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/output/unet_v1/logs'
```

```python
%tensorboard --logdir "{log_dir_unet}"
```

```
Reusing TensorBoard on port 6007 (pid 5630), started 0:02:00 ago. (Use '!kill 5630' to kill
```

```
<IPython.core.display.Javascript object>
```

2.3.6 Load the Saved U-Net Model

Load the saved model

```
import tensorflow as tf
```

```
unet_model = tf.keras.models.load_model(f"{str(unet_config.MODEL_DIR)}/trained-model")
```

```
print(unet_model.summary())
```

```
Model: "unet"
```

Layer (type)	Output Shape	Param #	Connected to
input_1 (InputLayer)	[(None, None, None, 8)]	0	[]
conv2d (Conv2D)	(None, None, None, 32)	2336	['input_1[0][0]']
batch_normalization (Batch Normalization)	(None, None, None, 32)	128	['conv2d[0][0]']
activation (Activation)	(None, None, None, 32)	0	['batch_normalization[0]
activation_1 (Activation)	(None, None, None, 32)	0	['activation[0][0]']
separable_conv2d (Separabl eConv2D)	(None, None, None, 64)	2400	['activation_1[0][0]']
batch_normalization_1 (Bat chNormalization)	(None, None, None, 64)	256	['separable_conv2d[0][0]
activation_2 (Activation)	(None, None, None, 64)	0	['batch_normalization_1[0]
separable_conv2d_1 (Separa bleConv2D)	(None, None, None, 64)	4736	['activation_2[0][0]']
batch_normalization_2 (Bat chNormalization)	(None, None, None, 64)	256	['separable_conv2d_1[0][0
max_pooling2d (MaxPooling2	(None, None, None, 64)	0	['batch_normalization_2[0

Layer	Output Shape	Param #	Connected to
D)			]
conv2d_1 (Conv2D)	(None, None, None, 64)	2112	['activation[0][0]']
add (Add)	(None, None, None, 64)	0	['max_pooling2d[0][0]', 'conv2d_1[0][0]']
activation_3 (Activation)	(None, None, None, 64)	0	['add[0][0]']
separable_conv2d_2 (Separa bleConv2D)	(None, None, None, 128)	8896	['activation_3[0][0]']
batch_normalization_3 (Bat chNormalization)	(None, None, None, 128)	512	['separable_conv2d_2[0][0
activation_4 (Activation)	(None, None, None, 128)	0	['batch_normalization_3[0]
separable_conv2d_3 (Separa bleConv2D)	(None, None, None, 128)	17664	['activation_4[0][0]']
batch_normalization_4 (Bat chNormalization)	(None, None, None, 128)	512	['separable_conv2d_3[0][0
max_pooling2d_1 (MaxPoolin g2D)	(None, None, None, 128)	0	['batch_normalization_4[0]
conv2d_2 (Conv2D)	(None, None, None, 128)	8320	['add[0][0]']
add_1 (Add)	(None, None, None, 128)	0	['max_pooling2d_1[0][0]' 'conv2d_2[0][0]']
activation_5 (Activation)	(None, None, None, 128)	0	['add_1[0][0]']
separable_conv2d_4 (Separa bleConv2D)	(None, None, None, 256)	34176	['activation_5[0][0]']
batch_normalization_5 (Bat chNormalization)	(None, None, None, 256)	1024	['separable_conv2d_4[0][0
activation_6 (Activation)	(None, None, None, 256)	0	['batch_normalization_5[0]

separable_conv2d_5 (Separa bleConv2D)	(None, None, None, 256)	68096	['activation_6[0][0]']
batch_normalization_6 (Bat chNormalization)	(None, None, None, 256)	1024	['separable_conv2d_5[0][0]
max_pooling2d_2 (MaxPoolin g2D)	(None, None, None, 256)	0	['batch_normalization_6[0]
conv2d_3 (Conv2D)	(None, None, None, 256)	33024	['add_1[0][0]']
add_2 (Add)	(None, None, None, 256)	0	['max_pooling2d_2[0][0]' 'conv2d_3[0][0]']
activation_7 (Activation)	(None, None, None, 256)	0	['add_2[0][0]']
conv2d_transpose (Conv2DTr anspose)	(None, None, None, 256)	590080	['activation_7[0][0]']
batch_normalization_7 (Bat chNormalization)	(None, None, None, 256)	1024	['conv2d_transpose[0][0]
activation_8 (Activation)	(None, None, None, 256)	0	['batch_normalization_7[0]
conv2d_transpose_1 (Conv2D Transpose)	(None, None, None, 256)	590080	['activation_8[0][0]']
batch_normalization_8 (Bat chNormalization)	(None, None, None, 256)	1024	['conv2d_transpose_1[0][0
up_sampling2d_1 (UpSamplin g2D)	(None, None, None, 256)	0	['add_2[0][0]']
up_sampling2d (UpSampling2 D)	(None, None, None, 256)	0	['batch_normalization_8[0]
conv2d_4 (Conv2D)	(None, None, None, 256)	65792	['up_sampling2d_1[0][0]'
add_3 (Add)	(None, None, None, 256)	0	['up_sampling2d[0][0]', 'conv2d_4[0][0]']
activation_9 (Activation)	(None, None, None, 256)	0	['add_3[0][0]']

conv2d_transpose_2 (Conv2D Transpose)	(None, None, None, 128)	295040	['activation_9[0][0]']
batch_normalization_9 (Bat chNormalization)	(None, None, None, 128)	512	['conv2d_transpose_2[0][0
activation_10 (Activation)	(None, None, None, 128)	0	['batch_normalization_9[0]
conv2d_transpose_3 (Conv2D Transpose)	(None, None, None, 128)	147584	['activation_10[0][0]']
batch_normalization_10 (Ba tchNormalization)	(None, None, None, 128)	512	['conv2d_transpose_3[0][0
up_sampling2d_3 (UpSamplin g2D)	(None, None, None, 256)	0	['add_3[0][0]']
up_sampling2d_2 (UpSamplin g2D)	(None, None, None, 128)	0	['batch_normalization_10 ']
conv2d_5 (Conv2D)	(None, None, None, 128)	32896	['up_sampling2d_3[0][0]'
add_4 (Add)	(None, None, None, 128)	0	['up_sampling2d_2[0][0]' 'conv2d_5[0][0]']
activation_11 (Activation)	(None, None, None, 128)	0	['add_4[0][0]']
conv2d_transpose_4 (Conv2D Transpose)	(None, None, None, 64)	73792	['activation_11[0][0]']
batch_normalization_11 (Ba tchNormalization)	(None, None, None, 64)	256	['conv2d_transpose_4[0][0
activation_12 (Activation)	(None, None, None, 64)	0	['batch_normalization_11 ']
conv2d_transpose_5 (Conv2D Transpose)	(None, None, None, 64)	36928	['activation_12[0][0]']
batch_normalization_12 (Ba tchNormalization)	(None, None, None, 64)	256	['conv2d_transpose_5[0][0

```
up_sampling2d_5 (UpSamplin   (None, None, None, 128)    0        ['add_4[0][0]']
g2D)

up_sampling2d_4 (UpSamplin   (None, None, None, 64)     0        ['batch_normalization_12
g2D)                                                             ']

conv2d_6 (Conv2D)            (None, None, None, 64)     8256     ['up_sampling2d_5[0][0]'

add_5 (Add)                  (None, None, None, 64)     0        ['up_sampling2d_4[0][0]'
                                                                  'conv2d_6[0][0]']

activation_13 (Activation)   (None, None, None, 64)     0        ['add_5[0][0]']

conv2d_transpose_6 (Conv2D   (None, None, None, 32)     18464    ['activation_13[0][0]']
Transpose)

batch_normalization_13 (Ba   (None, None, None, 32)     128      ['conv2d_transpose_6[0][(
tchNormalization)

activation_14 (Activation)   (None, None, None, 32)     0        ['batch_normalization_13
                                                                  ']

conv2d_transpose_7 (Conv2D   (None, None, None, 32)     9248     ['activation_14[0][0]']
Transpose)

batch_normalization_14 (Ba   (None, None, None, 32)     128      ['conv2d_transpose_7[0][(
tchNormalization)

up_sampling2d_7 (UpSamplin   (None, None, None, 64)     0        ['add_5[0][0]']
g2D)

up_sampling2d_6 (UpSamplin   (None, None, None, 32)     0        ['batch_normalization_14
g2D)                                                             ']

conv2d_7 (Conv2D)            (None, None, None, 32)     2080     ['up_sampling2d_7[0][0]'

add_6 (Add)                  (None, None, None, 32)     0        ['up_sampling2d_6[0][0]'
                                                                  'conv2d_7[0][0]']

final_conv (Conv2D)          (None, None, None, 5)      1445     ['add_6[0][0]']

============================================================================================
```

```
Total params: 2060997 (7.86 MB)
Trainable params: 2057221 (7.85 MB)
Non-trainable params: 3776 (14.75 KB)

_____
None
```

2.3.7 Inference using Saved U-Net Model

Now we can use the saved model to start the export of the prediction of the image. For prediction, you would need to first prepare your image data. We have already exported the image needed here, which we will use for now. See this notebook to understand how we did it.

In addition, this notebook shows how you can then use the image to predict from the saved Model.

In any case, you now have the prediction in the Earth Engine as image.

2.4 DNN Model

2.4.1 Setup any changes in the config file for DNN Model

There are few config variables that needs to be changed for running a DNN model. First would be the data itself so let's change the `DATADIR`. We also need to change our output directory using `MODEL_DIR_NAME`. This is the sub-directory inside the `OUTPUT_DIR` for this model run. We also need to specify this is the DNN model that we want to run. We have `MODEL_TYPE` parameter for that. Currently, it supports unet, dnn, and cnn (case sensitive) models; default being unet. Make other changes, as appropriate.

```
DATADIR = "datasets/dnn_planet_wo_indices"
MODEL_DIR_NAME = "dnn_v1"
MODEL_TYPE = "dnn"
```

2.4.2 Update the config file programtically

```
DATADIR = "datasets/dnn_planet_wo_indices" # @param {type:"string"}
# PATCH_SHAPE, USE_ELEVATION, USE_S1, TRAIN_SIZE, TEST_SIZE, VAL_SIZE
# BATCH_SIZE, EPOCHS are converted to their appropriate type.
MODEL_DIR_NAME = "dnn_v1" # @param {type:"string"}
```

```
MODEL_TYPE = "dnn" # @param {type:"string"}
BATCH_SIZE = "32" # @param {type:"string"}
EPOCHS = "30" # @param {type:"string"}
```

```
dnn_config_settings = {
    "DATADIR": DATADIR,
    "MODEL_DIR_NAME": MODEL_DIR_NAME,
    "MODEL_TYPE": MODEL_TYPE,
    "BATCH_SIZE": BATCH_SIZE,
    "EPOCHS": EPOCHS,
}
```

```
for config_key in dnn_config_settings:
    dotenv.set_key(dotenv_path=config_file,
                   key_to_set=config_key,
                   value_to_set=dnn_config_settings[config_key]
                   )
```

2.4.3 Load config file variables for DNN Model

```
dnn_config = Config(config_file=config_file, override=True)
```

```
BASEDIR: /content
DATADIR: /content/datasets/dnn_planet_wo_indices
using features: ['red_before', 'green_before', 'blue_before', 'nir_before', 'red_during', 'g
using labels: ['class']
```

Most of the config in the `config.env` is now available via the config instance. Let's check few of them here.

```
dnn_config.TRAINING_DIR, dnn_config.OUTPUT_DIR, dnn_config.BATCH_SIZE, dnn_config.MODEL_TYPE
```

```
(PosixPath('/content/datasets/dnn_planet_wo_indices/training'),
 PosixPath('/content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/output'),
 32,
 'dnn')
```

2.4.4 Load `ModelTrainer` class

Next, let's make an instance of the `ModelTrainer` object. The `ModelTrainer` class provides various tools for training, buidling, compiling, and running specified deep learning models.

```
dnn_model_trainer = ModelTrainer(dnn_config, seed=42)
```

```
Using seed: 42
```

2.4.5 Train and Save DNN model

```
dnn_model_trainer.train_model()
```

```
********************************************************************************
**************************** Clear Session... ******************************
********************************************************************************
**************************** Configure memory growth... ************************
 > Found 1 GPUs
********************************************************************************
**************************** creating datasets... *************************
Loading dataset from /content/datasets/dnn_planet_wo_indices/training/*
Loading dataset from /content/datasets/dnn_planet_wo_indices/validation/*
Loading dataset from /content/datasets/dnn_planet_wo_indices/testing/*
Printing dataset info:
Training
inputs: float32 (32, 1, 8)
tf.Tensor(
[[[0.06445  0.0383   0.09815  0.06755  0.269975 0.207325 0.11135
   0.060025]]

 [[0.075925 0.02705  0.08695  0.054775 0.235575 0.291625 0.1049
   0.0364  ]]

 [[0.043625 0.025    0.064175 0.04265  0.22     0.225    0.062025
   0.03195 ]]

 [[0.07915  0.05365  0.1054   0.093425 0.257325 0.28345  0.1119
   0.079675]]

 [[0.06945  0.025825 0.10755  0.062125 0.245125 0.28365  0.116975
```

```
   0.0485  ]]

[[0.092425 0.07485  0.10285  0.09645  0.238575 0.252075 0.123025
   0.094825]]

[[0.0555   0.02955  0.087325 0.09095  0.230625 0.298175 0.08075
   0.0524  ]]

[[0.0643   0.021275 0.085875 0.0431   0.248075 0.27395  0.098625
   0.0284  ]]

[[0.0747   0.047675 0.094625 0.072125 0.253125 0.267225 0.09725
   0.063825]]

[[0.0626   0.023575 0.083675 0.04705  0.20645  0.2539   0.10465
   0.0317  ]]

[[0.072725 0.030975 0.10185  0.0666   0.26585  0.38635  0.11875
   0.045725]]

[[0.0713   0.0289   0.09355  0.06415  0.236675 0.2564   0.10215
   0.049475]]

[[0.086175 0.077875 0.10745  0.0709   0.263475 0.289175 0.1188
   0.075975]]

[[0.079575 0.027525 0.102325 0.054775 0.253875 0.2761   0.111325
   0.03985 ]]

[[0.08825  0.0803   0.1016   0.0862   0.265025 0.260925 0.115625
   0.092325]]

[[0.08025  0.10325  0.1034   0.13695  0.2283   0.246475 0.109975
   0.124   ]]

[[0.077775 0.029875 0.0953   0.0546   0.235325 0.266    0.122125
   0.0469  ]]

[[0.0778   0.024025 0.103525 0.053975 0.23395  0.263625 0.116025
   0.036825]]

[[0.089475 0.070675 0.10515  0.09125  0.257725 0.254375 0.132675
   0.09745 ]]
```

```
[[0.0785    0.026275 0.105575 0.051025 0.2552   0.2522   0.120125
   0.034825]]

 [[0.07945  0.045775 0.094475 0.0652   0.264175 0.335825 0.1147
   0.059275]]

 [[0.04725  0.031125 0.08165  0.065325 0.23025  0.2299   0.0981
   0.060525]]

 [[0.07475  0.02425  0.10205  0.04945  0.263225 0.178625 0.112775
   0.0373  ]]

 [[0.079875 0.0259   0.105875 0.05245  0.2505   0.269425 0.12245
   0.034975]]

 [[0.0746   0.033975 0.104075 0.0598   0.25375  0.29345  0.117325
   0.04885 ]]

 [[0.067125 0.026625 0.093575 0.05095  0.255925 0.231575 0.10545
   0.0415  ]]

 [[0.076325 0.02685  0.10615  0.05585  0.25805  0.276325 0.116725
   0.0417  ]]

 [[0.061275 0.023975 0.086025 0.041375 0.199425 0.255125 0.111
   0.030825]]

 [[0.059725 0.0203   0.0877   0.0434   0.230125 0.251975 0.105675
   0.027225]]

 [[0.07205  0.02285  0.094025 0.04865  0.2084   0.247225 0.119175
   0.03225 ]]

 [[0.0405   0.023025 0.06625  0.0505   0.218225 0.258275 0.0802
   0.03875 ]]

 [[0.07005  0.023125 0.111925 0.0475   0.2716   0.2495   0.124725
   0.0313  ]]], shape=(32, 1, 8), dtype=float32)
outputs: float32 (32, 1, 5)
tf.Tensor(
[[[0. 1. 0. 0. 0.]]
```

```
[[0. 1. 0. 0. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 1. 0. 0. 0.]]

[[1. 0. 0. 0. 0.]]

[[0. 0. 1. 0. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 0. 0. 1. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 1. 0. 0. 0.]]

[[0. 0. 1. 0. 0.]]

[[0. 1. 0. 0. 0.]]
```

```
 [[0. 1. 0. 0. 0.]]

 [[0. 1. 0. 0. 0.]]

 [[0. 1. 0. 0. 0.]]

 [[0. 1. 0. 0. 0.]]

 [[0. 1. 0. 0. 0.]]

 [[0. 1. 0. 0. 0.]]

 [[0. 0. 0. 0. 1.]]

 [[0. 0. 1. 0. 0.]]

 [[0. 1. 0. 0. 0.]]], shape=(32, 1, 5), dtype=float32)
Testing
inputs: float32 (1, 1, 8)
tf.Tensor(
[[[0.06205  0.0342   0.081075 0.0639   0.24245  0.251675 0.086575
   0.054175]]], shape=(1, 1, 8), dtype=float32)
outputs: float32 (1, 1, 5)
tf.Tensor([[[1. 0. 0. 0. 0.]]], shape=(1, 1, 5), dtype=float32)
Validation
inputs: float32 (1, 1, 8)
tf.Tensor(
[[[0.067225 0.031725 0.092275 0.07245  0.23165  0.2267   0.103025
   0.05155 ]]], shape=(1, 1, 8), dtype=float32)
outputs: float32 (1, 1, 5)
tf.Tensor([[[0. 0. 0. 1. 0.]]], shape=(1, 1, 5), dtype=float32)
****************************************************************************
*********************** building and compiling model... ******************
INITIAL_BIAS: None
Model: "model"

-----------------------------------------------------------------
 Layer (type)              Output Shape             Param #
=================================================================
 input_layer (InputLayer)   [(None, None, 8)]        0


 dense (Dense)              (None, None, 256)        2304
```

61

```
 dropout (Dropout)            (None, None, 256)           0

 dense_1 (Dense)              (None, None, 128)           32896

 dropout_1 (Dropout)          (None, None, 128)           0

 dense_2 (Dense)              (None, None, 64)            8256

 dropout_2 (Dropout)          (None, None, 64)            0

 dense_3 (Dense)              (None, None, 32)            2080

 dropout_3 (Dropout)          (None, None, 32)            0

 dense_4 (Dense)              (None, None, 5)             165

=================================================================
Total params: 45701 (178.52 KB)
Trainable params: 45701 (178.52 KB)
Non-trainable params: 0 (0.00 Byte)

_____
None
*****************************************************************************
*********************** preparing output directory... *********************
> Saving models and results at /content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/outpu
*****************************************************************************
**************************** training model... **************************
Epoch 1/30
264/266 [============================>.] - ETA: 0s - loss: 1.2595 - precision: 0.6700 - recal
Epoch 1: val_loss improved from inf to 1.15955, saving model to /content/drive/MyDrive/Colab
266/266 [==============================] - 31s 99ms/step - loss: 1.2623 - precision: 0.6685 -
Epoch 2/30
265/266 [============================>.] - ETA: 0s - loss: 0.9196 - precision: 0.7593 - recal
Epoch 2: val_loss improved from 1.15955 to 0.87784, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 16s 60ms/step - loss: 0.9206 - precision: 0.7592 -
Epoch 3/30
266/266 [==============================] - ETA: 0s - loss: 0.8111 - precision: 0.7857 - recal
Epoch 3: val_loss did not improve from 0.87784
266/266 [==============================] - 23s 89ms/step - loss: 0.8111 - precision: 0.7857 -
Epoch 4/30
261/266 [============================>.] - ETA: 0s - loss: 0.7535 - precision: 0.8003 - recal
Epoch 4: val_loss improved from 0.87784 to 0.82494, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 16s 61ms/step - loss: 0.7584 - precision: 0.7999 -
```

```
Epoch 5/30
265/266 [============================>.] - ETA: 0s - loss: 0.7328 - precision: 0.8096 - recal
Epoch 5: val_loss improved from 0.82494 to 0.74722, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 18s 66ms/step - loss: 0.7328 - precision: 0.8096 -
Epoch 6/30
264/266 [============================>.] - ETA: 0s - loss: 0.7254 - precision: 0.8092 - recal
Epoch 6: val_loss improved from 0.74722 to 0.69727, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 16s 61ms/step - loss: 0.7268 - precision: 0.8086 -
Epoch 7/30
265/266 [============================>.] - ETA: 0s - loss: 0.7175 - precision: 0.8121 - recal
Epoch 7: val_loss improved from 0.69727 to 0.69563, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 16s 61ms/step - loss: 0.7175 - precision: 0.8121 -
Epoch 8/30
265/266 [============================>.] - ETA: 0s - loss: 0.7065 - precision: 0.8111 - recal
Epoch 8: val_loss improved from 0.69563 to 0.67199, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 24s 92ms/step - loss: 0.7066 - precision: 0.8109 -
Epoch 9/30
266/266 [==============================] - ETA: 0s - loss: 0.6927 - precision: 0.8161 - recal
Epoch 9: val_loss improved from 0.67199 to 0.66129, saving model to /content/drive/MyDrive/Co
266/266 [==============================] - 24s 92ms/step - loss: 0.6927 - precision: 0.8161 -
Epoch 10/30
264/266 [============================>.] - ETA: 0s - loss: 0.6922 - precision: 0.8143 - recal
Epoch 10: val_loss did not improve from 0.66129
266/266 [==============================] - 23s 87ms/step - loss: 0.6936 - precision: 0.8139 -
Epoch 11/30
263/266 [============================>.] - ETA: 0s - loss: 0.6978 - precision: 0.8120 - recal
Epoch 11: val_loss did not improve from 0.66129
266/266 [==============================] - 23s 87ms/step - loss: 0.6984 - precision: 0.8117 -
Epoch 12/30
263/266 [============================>.] - ETA: 0s - loss: 0.6804 - precision: 0.8173 - recal
Epoch 12: val_loss improved from 0.66129 to 0.65464, saving model to /content/drive/MyDrive/C
266/266 [==============================] - 17s 63ms/step - loss: 0.6806 - precision: 0.8177 -
Epoch 13/30
261/266 [============================>.] - ETA: 0s - loss: 0.6858 - precision: 0.8154 - recal
Epoch 13: val_loss did not improve from 0.65464
266/266 [==============================] - 15s 56ms/step - loss: 0.6863 - precision: 0.8152 -
Epoch 14/30
264/266 [============================>.] - ETA: 0s - loss: 0.6880 - precision: 0.8123 - recal
Epoch 14: val_loss did not improve from 0.65464
266/266 [==============================] - 24s 90ms/step - loss: 0.6894 - precision: 0.8119 -
Epoch 15/30
263/266 [============================>.] - ETA: 0s - loss: 0.6748 - precision: 0.8167 - recal
Epoch 15: val_loss improved from 0.65464 to 0.64675, saving model to /content/drive/MyDrive/C
```

```
266/266 [==============================] - 16s 60ms/step - loss: 0.6758 - precision: 0.8164 -
Epoch 16/30
265/266 [=============================>.] - ETA: 0s - loss: 0.6859 - precision: 0.8126 - recal
Epoch 16: val_loss did not improve from 0.64675
266/266 [==============================] - 24s 90ms/step - loss: 0.6850 - precision: 0.8129 -
Epoch 17/30
264/266 [=============================>.] - ETA: 0s - loss: 0.6713 - precision: 0.8203 - recal
Epoch 17: val_loss did not improve from 0.64675
266/266 [==============================] - 14s 54ms/step - loss: 0.6715 - precision: 0.8205 -
Epoch 18/30
261/266 [============================>.] - ETA: 0s - loss: 0.6766 - precision: 0.8158 - recal
Epoch 18: val_loss did not improve from 0.64675
266/266 [==============================] - 24s 91ms/step - loss: 0.6716 - precision: 0.8175 -
Epoch 19/30
266/266 [==============================] - ETA: 0s - loss: 0.6681 - precision: 0.8207 - recal
Epoch 19: val_loss did not improve from 0.64675
266/266 [==============================] - 14s 54ms/step - loss: 0.6681 - precision: 0.8207 -
Epoch 20/30
263/266 [============================>.] - ETA: 0s - loss: 0.6686 - precision: 0.8171 - recal
Epoch 20: val_loss did not improve from 0.64675
266/266 [==============================] - 15s 57ms/step - loss: 0.6676 - precision: 0.8176 -
Epoch 21/30
262/266 [============================>.] - ETA: 0s - loss: 0.6652 - precision: 0.8173 - recal
Epoch 21: val_loss did not improve from 0.64675
266/266 [==============================] - 23s 89ms/step - loss: 0.6622 - precision: 0.8185 -
Epoch 22/30
265/266 [=============================>.] - ETA: 0s - loss: 0.6699 - precision: 0.8170 - recal
Epoch 22: val_loss did not improve from 0.64675
266/266 [==============================] - 17s 63ms/step - loss: 0.6699 - precision: 0.8172 -
Epoch 23/30
262/266 [============================>.] - ETA: 0s - loss: 0.6639 - precision: 0.8248 - recal
Epoch 23: val_loss did not improve from 0.64675
266/266 [==============================] - 23s 87ms/step - loss: 0.6620 - precision: 0.8255 -
Epoch 24/30
262/266 [============================>.] - ETA: 0s - loss: 0.6667 - precision: 0.8214 - recal
Epoch 24: val_loss did not improve from 0.64675
266/266 [==============================] - 24s 90ms/step - loss: 0.6651 - precision: 0.8218 -
Epoch 25/30
266/266 [==============================] - ETA: 0s - loss: 0.6620 - precision: 0.8192 - recal
Epoch 25: val_loss did not improve from 0.64675
266/266 [==============================] - 24s 90ms/step - loss: 0.6620 - precision: 0.8192 -
Epoch 26/30
264/266 [============================>.] - ETA: 0s - loss: 0.6630 - precision: 0.8221 - recal
```

```
Epoch 26: val_loss did not improve from 0.64675
266/266 [==============================] - 14s 55ms/step - loss: 0.6636 - precision: 0.8220 -
Epoch 27/30
266/266 [==============================] - ETA: 0s - loss: 0.6562 - precision: 0.8221 - recal
Epoch 27: val_loss did not improve from 0.64675
266/266 [==============================] - 24s 91ms/step - loss: 0.6562 - precision: 0.8221 -
Epoch 28/30
264/266 [============================>.] - ETA: 0s - loss: 0.6545 - precision: 0.8258 - recal
Epoch 28: val_loss did not improve from 0.64675
266/266 [==============================] - 14s 54ms/step - loss: 0.6543 - precision: 0.8259 -
Epoch 29/30
264/266 [============================>.] - ETA: 0s - loss: 0.6576 - precision: 0.8259 - recal
Epoch 29: val_loss did not improve from 0.64675
266/266 [==============================] - 16s 61ms/step - loss: 0.6561 - precision: 0.8265 -
Epoch 30/30
266/266 [==============================] - ETA: 0s - loss: 0.6533 - precision: 0.8234 - recal
Epoch 30: val_loss did not improve from 0.64675
266/266 [==============================] - 15s 56ms/step - loss: 0.6533 - precision: 0.8234 -
****************************************************************************
*************************** evaluating model... ************************
**********************************************
**********************************************
Validation
1219/1219 [==============================] - 7s 6ms/step - loss: 0.6585 - precision: 0.8038 -
loss: 0.6584734320640564
precision: 0.8037974834442139
recall: 0.7292863130569458
categorical_accuracy: 0.7735849022865295
one_hot_io_u: 0.5688682794570923




****************************************************************************
*************************** saving parameters... ***********************
****************************************************************************
*************** saving model config and history object... ******************
****************************************************************************
*************************** saving plots... ***************************
Saving plots and model visualization at /content/drive/MyDrive/Colab Notebooks/DL_Book/Chapt
****************************************************************************
*************************** saving models... ***************************
****************************************************************************
```
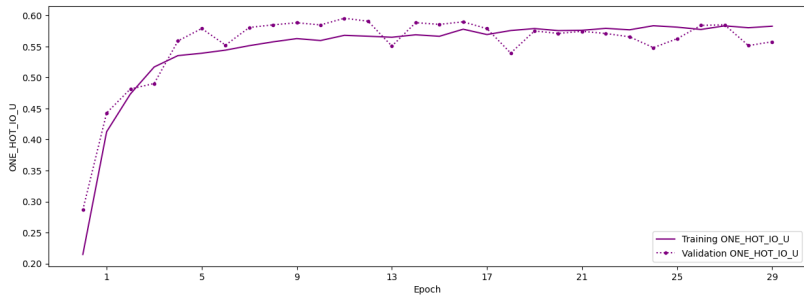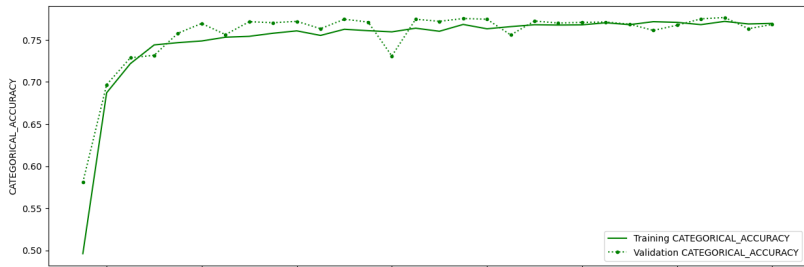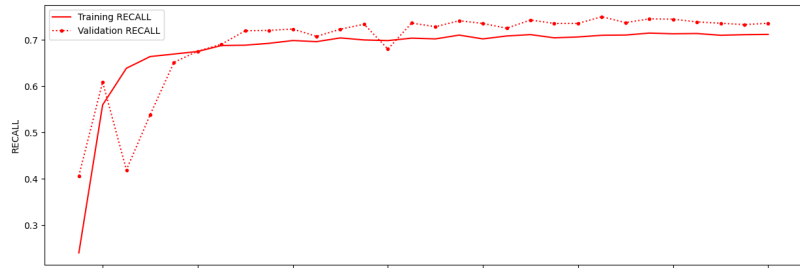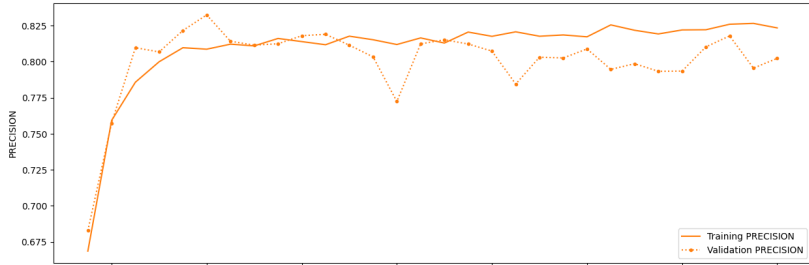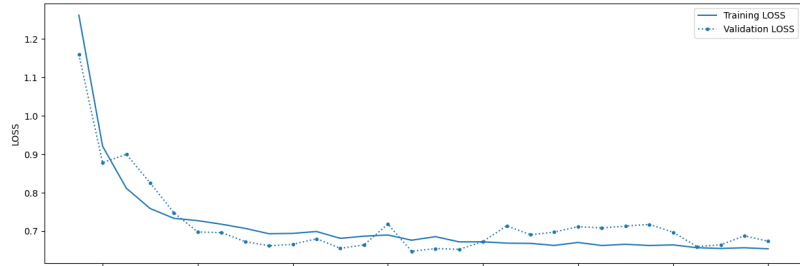
2.4.6 Save the config file

```python
drive_config_file = Path(dnn_config.MODEL_DIR / f"{str(config_file).split('/')[-1]}")

# Create the target directory if it doesn't exist
drive_config_file.parent.mkdir(parents=True, exist_ok=True)

# Copy the file
shutil.copy(config_file, drive_config_file)

print(f"File copied from {config_file} to {drive_config_file}")
```

```
File copied from servir-aces/config.env to /content/drive/MyDrive/Colab Notebooks/DL_Book/Cha
```

2.4.7 Load the logs files via TensorBoard

```python
log_dir_dnn = f"{str(dnn_config.MODEL_DIR)}/logs"
log_dir_dnn
```

```
'/content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/output/dnn_v1/logs'
```

```python
%tensorboard --logdir "{log_dir_dnn}"
```

```
<IPython.core.display.Javascript object>
```

2.4.8 Load the Saved DNN Model

```python
dnn_model = tf.keras.models.load_model(f"{str(dnn_config.MODEL_DIR)}/trained-model")
```

```python
print(dnn_model.summary())
```

```
Model: "model"
 _____
  Layer (type)                Output Shape              Param #
 =================================================================
```

```
input_layer (InputLayer)     [(None, None, 8)]          0

dense (Dense)                (None, None, 256)          2304

dropout (Dropout)            (None, None, 256)          0

dense_1 (Dense)              (None, None, 128)          32896

dropout_1 (Dropout)          (None, None, 128)          0

dense_2 (Dense)              (None, None, 64)           8256

dropout_2 (Dropout)          (None, None, 64)           0

dense_3 (Dense)              (None, None, 32)           2080

dropout_3 (Dropout)          (None, None, 32)           0

dense_4 (Dense)              (None, None, 5)            165

=================================================================
Total params: 45701 (178.52 KB)
Trainable params: 45701 (178.52 KB)
Non-trainable params: 0 (0.00 Byte)

_____
None
```

2.4.9 Inference using Saved DNN Model

Now we can use the saved model to start the export of the prediction of the image. For prediction, you would need to first prepare your image data. We have already exported the image needed here, which we will use for now. See this notebook to understand how we did it.

In addition, this notebook shows how you can then use the image to predict from the saved Model.

In any case, you now have the prediction in the Earth Engine as image.

2.5 Independent Validation

For independent validation, we will use a file that we have prepared. These files were collected using Collect Earth Online by SCO and NASA DEVELOP interns. We will be using GEE here. Before we do that, let's make changes in our config file.

We will make sure our `GCS_PROJECT` is setup correctly.

```
GCS_PROJECT = "servir-ee"
```

2.5.1 Update the config file

```
GCS_PROJECT = "servir-ee" # @param {type:"string"}
```

```
config_settings = {
    "GCS_PROJECT": GCS_PROJECT,
}
```

```
for config_key in config_settings:
    dotenv.set_key(dotenv_path=config_file,
                   key_to_set=config_key,
                   value_to_set=config_settings[config_key]
                   )
```

2.5.2 Load config file variable

```
config = Config(config_file=config_file, override=True)
```

```
BASEDIR: /content
DATADIR: /content/datasets/dnn_planet_wo_indices
using features: ['red_before', 'green_before', 'blue_before', 'nir_before', 'red_during', 'gr
using labels: ['class']
```

2.5.3 Import earthengine and geemap for visualization

```
# Import, authenticate and initialize the Earth Engine library.
import ee
ee.Authenticate()
EEUtils.initialize_session(use_highvolume=True, project=config.GCS_PROJECT)
```

```
import geemap

Map = geemap.Map()
```

2.5.4 Class Information and Masking

```
# CLASS
# 0 - cropland etc.
# 1 - rice
# 2 - forest
# 3 - Built up
# 4 - Others (includes water body)
l1 = ee.FeatureCollection("projects/servir-sco-assets/assets/Bhutan/BT_Admin_1")
paro = l1.filter(ee.Filter.eq("ADM1_EN", "Paro"))


# mask the rice growing zone
# in Paro, rice grows upto 2600 m asl (double check to make sure??)
dem = ee.Image("MERIT/DEM/v1_0_3") # ee.Image('USGS/SRTMGL1_003')
dem = dem.clip(paro)
rice_zone = dem.gte(0).And(dem.lte(2600))
```

```
<IPython.core.display.HTML object>
```

2.5.5 Model: U-Net

2.5.5.1 Load and visualize the prediction output

```
UNET_RGBN = ee.Image("projects/servir-ee/assets/dl-book/chapter-1/prediction/prediction_unet_
UNET_RGBN = UNET_RGBN.updateMask(rice_zone)
Map.centerObject(UNET_RGBN, 11)
Map.addLayer(UNET_RGBN.clip(paro), {"bands": ["prediction"], "min":0, "max":4, "palette": ["
Map
```

```
<IPython.core.display.HTML object>
```

```
Map(center=[27.378354616518475, 89.42005508391453], controls=(WidgetControl(options=['positi
```

2.5.5.2 Calculate classification metrics

Remapping to rice and non-rice output

```
UNET_RGBN_remapped = UNET_RGBN.remap([0, 1, 2, 3, 4], [0, 1, 0, 0, 0], 0, "prediction")
Map.addLayer(UNET_RGBN_remapped, {"min": 0, "max": 1, "palette": ["cfcf00", "267300"]}, "UNE
Map
```

```
<IPython.core.display.HTML object>
```

```
Map(bottom=220961.0, center=[27.378354616518475, 89.42005508391453], controls=(WidgetControl
```

```
sampling_geom = ee.FeatureCollection("projects/servir-ee/assets/dl-book/chapter-1/data/sampl
ceo_final_data = ee.FeatureCollection("projects/servir-ee/assets/dl-book/chapter-1/data/ceoDa
ceo_final_data = ee.FeatureCollection(ceo_final_data.filter(ee.Filter.bounds(sampling_geom).
```

```
<IPython.core.display.HTML object>
```

```
prediction_unet = UNET_RGBN_remapped.sampleRegions(
    collection = ceo_final_data,
    scale = 10,
    geometries = True
)

# print("predictionOutputUnet", prediction_unet.getInfo())
```

```
<IPython.core.display.HTML object>
```

```
error_matrix_unet = prediction_unet.errorMatrix(actual="rice", predicted="remapped")
test_acc_unet = error_matrix_unet.accuracy()
test_kappa_unet = error_matrix_unet.kappa()
test_recall_producer_acc_unet = error_matrix_unet.producersAccuracy().get([1, 0])
test_precision_consumer_acc_unet = error_matrix_unet.consumersAccuracy().get([0, 1])
f1_unet = error_matrix_unet.fscore().get([1])
```

```
<IPython.core.display.HTML object>
```

```
print("error_matrix_unet", error_matrix_unet.getInfo())
print("test_acc_unet", test_acc_unet.getInfo())
print("test_kappa_unet", test_kappa_unet.getInfo())
print("test_recall_producer_acc_unet", test_recall_producer_acc_unet.getInfo())
print("test_precision_consumer_acc_unet", test_precision_consumer_acc_unet.getInfo())
print("f1_unet", f1_unet.getInfo())
```

```
<IPython.core.display.HTML object>
```

```
error_matrix_unet [[1191, 29], [33, 50]]
test_acc_unet 0.9524174980813507
test_kappa_unet 0.5919321924312524
test_recall_producer_acc_unet 0.6024096385542169
test_precision_consumer_acc_unet 0.6329113924050633
f1_unet 0.6172839506172839
```

2.5.5.3 Calculate Probability Distribution

```
prob_output_unet = UNET_RGBN.select(["prediction", "others_etc", "cropland_etc", "urban", "fo
                        .rename(["prediction_class", "others_prob", "cropland_prob", "url
                        .sampleRegions(collection=ceo_final_data, scale=10, geometries=Ti

# print("prob_output_unet", prob_output_unet.getInfo())
```

```
<IPython.core.display.HTML object>
```

```
prob_output_unet = prob_output_unet.getInfo()
```

```
<IPython.core.display.HTML object>
```

2.5.6 Model: DNN

2.5.6.1 Load and visualize the prediction output

```
DNN_RGBN = ee.Image("projects/servir-ee/assets/dl-book/chapter-1/prediction/prediction_dnn_v
DNN_RGBN = DNN_RGBN.updateMask(rice_zone)
Map.centerObject(DNN_RGBN)
Map.addLayer(DNN_RGBN.clip(paro), {"bands": ["prediction"], "min":0, "max":4, "palette": ["FI
Map
```

```
<IPython.core.display.HTML object>
```

```
Map(bottom=220961.0, center=[27.378354616518475, 89.42005508391453], controls=(WidgetControl
```

2.5.6.2 Calculate classification metrics

```
DNN_RGBN_remapped = DNN_RGBN.remap([0, 1, 2, 3, 4], [0, 1, 0, 0, 0], 0, "prediction")
Map.addLayer(DNN_RGBN_remapped, {"min": 0, "max": 1, "palette": ["cfcf00", "267300"]}, "DNN_I
Map
```

```
<IPython.core.display.HTML object>
```

```
Map(bottom=220961.0, center=[27.37845188654284, 89.42005507220328], controls=(WidgetControl(c
```

```
prediction_dnn = DNN_RGBN_remapped.sampleRegions(
    collection = ceo_final_data,
    scale = 10,
    geometries = True
)

# print("predictionOutputDNN", prediction_dnn.getInfo())
```

```
<IPython.core.display.HTML object>
```

```
error_matrix_dnn = prediction_dnn.errorMatrix(actual="rice", predicted="remapped")
test_acc_dnn = error_matrix_dnn.accuracy()
test_kappa_dnn = error_matrix_dnn.kappa()
test_recall_producer_acc_dnn = error_matrix_dnn.producersAccuracy().get([1, 0])
test_precision_consumer_acc_dnn = error_matrix_dnn.consumersAccuracy().get([0, 1])
f1_dnn = error_matrix_dnn.fscore().get([1])
```

```
<IPython.core.display.HTML object>
```

```
print("error_matrix_dnn", error_matrix_dnn.getInfo())
print("test_acc_dnn", test_acc_dnn.getInfo())
print("test_kappa_dnn", test_kappa_dnn.getInfo())
print("test_recall_producer_acc_dnn", test_recall_producer_acc_dnn.getInfo())
print("test_precision_consumer_acc_dnn", test_precision_consumer_acc_dnn.getInfo())
print("f1_dnn", f1_dnn.getInfo())
```

```
<IPython.core.display.HTML object>
```

```
error_matrix_dnn [[1175, 45], [20, 63]]
test_acc_dnn 0.9501151189562548
test_kappa_dnn 0.6332676611314382
test_recall_producer_acc_dnn 0.7590361445783133
test_precision_consumer_acc_dnn 0.5833333333333334
f1_dnn 0.6596858638743456
```

2.5.6.3 Calculate Probability Distribution

```
prob_output_dnn = DNN_RGBN.select(["prediction", "others_etc", "cropland_etc", "urban", "for
                        .rename(["prediction_class", "others_prob", "cropland_prob", "url
                        .sampleRegions(collection=ceo_final_data, scale=10, geometries=Tr

# print("prob_output_dnn", prob_output_dnn.getInfo())
```

```
<IPython.core.display.HTML object>
```

```
prob_output_dnn = prob_output_dnn.getInfo()
```

```
<IPython.core.display.HTML object>
```

2.6 Figures and Plots

2.6.1 Training and Validation Plot

```python
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import pickle

%matplotlib inline
```

<IPython.core.display.HTML object>

```python
with open(unet_config.MODEL_DIR / "model.pkl", "rb") as f:
    unet_model_metrics = pickle.load(f)

with open(dnn_config.MODEL_DIR / "model.pkl", "rb") as f:
    dnn_model_metrics = pickle.load(f)
```

<IPython.core.display.HTML object>

```python
# Create subplots for different metrics in a 3x4 grid
fig, axs = plt.subplots(2, 4, figsize=(4*7, 6*2))

colors = ["#1f77b4", "#ff7f0e", "#2ca02c", "#d62728"]
metrics = ["loss", "precision", "recall", "categorical_accuracy"]
metrics_name = ["Loss", "Precision", "Recall", "Categorical Accuracy"]

epochs = range(1, config.EPOCHS + 1)

title_fontsize = 22
label_fontsize = 22
legend_fontsize = 15
tick_fontsize = 18
lw=1.5

for i in range(2):
    for y in range(len(metrics)):
        if i == 1:
            axs[i][y].plot(epochs, unet_model_metrics[f"val_{metrics[y]}"], color=colors[0],
            axs[i][y].plot(epochs, dnn_model_metrics[f"val_{metrics[y]}"], color=colors[1],
            axs[i][y].set_title(f"Validate {metrics_name[y]}", fontsize=title_fontsize)
            axs[i][y].set_xlabel("epochs", fontsize=label_fontsize)
            axs[i][y].set_ylabel(f"{metrics[y]}", fontsize=label_fontsize)
```

```
        axs[i][y].grid(linestyle="dotted", alpha=0.7)
        axs[i][y].legend(fontsize=legend_fontsize)
        axs[i][y].tick_params(axis="both", which="major", labelsize=tick_fontsize)
    else:
        axs[i][y].plot(epochs, unet_model_metrics[metrics[y]], color=colors[0], lw=lw, ma
        axs[i][y].plot(epochs, dnn_model_metrics[metrics[y]], color=colors[1], lw=lw, ma
        axs[i][y].set_title(f"Train {metrics_name[y]}", fontsize=title_fontsize)
        axs[i][y].set_xlabel("epochs", fontsize=label_fontsize)
        axs[i][y].set_ylabel(f"{metrics[y]}", fontsize=label_fontsize)
        axs[i][y].grid(linestyle="dotted", alpha=0.7)
        axs[i][y].legend(fontsize=legend_fontsize)
        axs[i][y].tick_params(axis="both", which="major", labelsize=tick_fontsize)


# Adjust layout and show the plot
plt.tight_layout()
# plt.savefig("metrics_plot_model_comparison.png", dpi=500, bbox_inches="tight")
plt.show()
```

<IPython.core.display.HTML object>
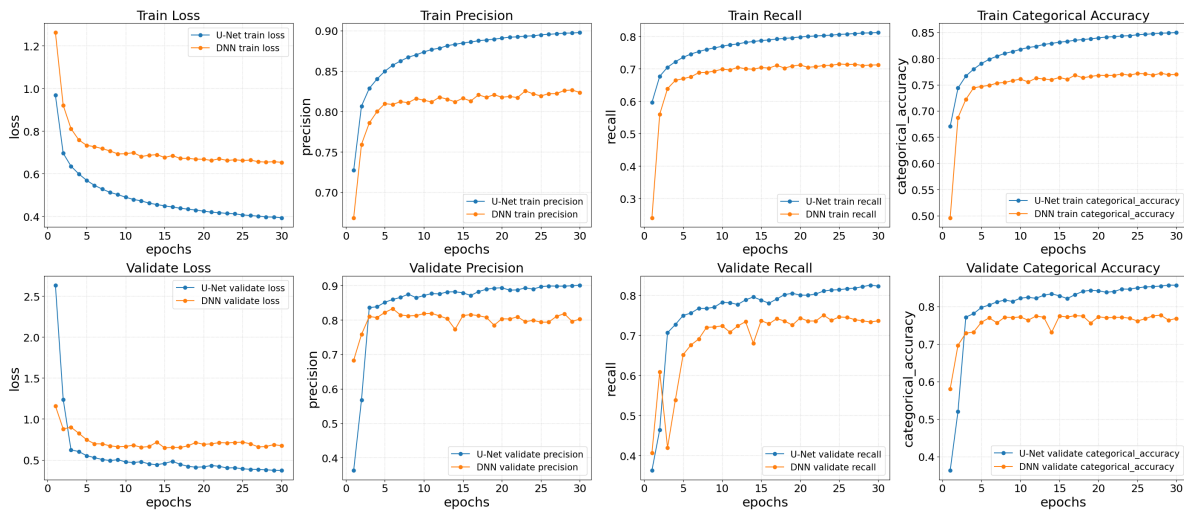

```
# Create subplots for different metrics in a 3x4 grid
fig, axs = plt.subplots(1, 4, figsize=(4*7, 6*1))

colors = ["#1f77b4", "#ff7f0e", "#2ca02c", "#d62728"]
metrics = ["loss", "precision", "recall", "categorical_accuracy"]
```

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```python
metrics_name = ["Loss", "Precision", "Recall", "Categorical Accuracy"]

epochs = range(1, config.EPOCHS + 1)

title_fontsize = 22
label_fontsize = 22
legend_fontsize = 15
tick_fontsize = 18
lw=1.5

for y in range(len(metrics)):
    axs[y].plot(epochs, unet_model_metrics[f"val_{metrics[y]}"], color=colors[0], marker="o"
    axs[y].plot(epochs, dnn_model_metrics[f"val_{metrics[y]}"], color=colors[1], lw=lw, marke

    axs[y].plot(epochs, unet_model_metrics[metrics[y]], color=colors[2], lw=lw, marker="o", 1
    axs[y].plot(epochs, dnn_model_metrics[metrics[y]], color=colors[3], lw=lw, marker="o", la
    axs[y].set_title(f"{metrics_name[y]}", fontsize=title_fontsize)
    axs[y].set_xlabel("epochs", fontsize=label_fontsize)
    axs[y].set_ylabel(f"{metrics[y]}", fontsize=label_fontsize)
    axs[y].grid(linestyle="dotted", alpha=0.7)
    axs[y].legend(fontsize=legend_fontsize)
    axs[y].tick_params(axis="both", which="major", labelsize=tick_fontsize)


# Adjust layout and show the plot
plt.tight_layout()
# plt.savefig("metrics_plot_model_comparison.png", dpi=500, bbox_inches="tight")
plt.show()
```

<IPython.core.display.HTML object>
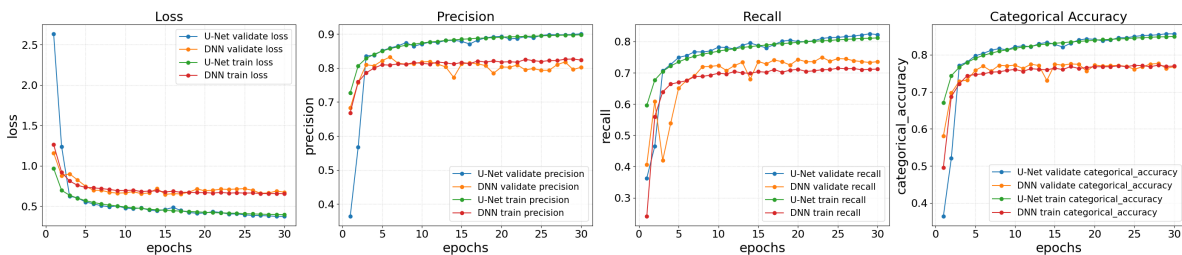
2.6.2 Probability Distribution Plot

```python
all_data = {}

unet_data = []
dnn_data = []

unet_rice_data = []
dnn_rice_data = []

unet_other_data = []
dnn_other_data = []

for i, feature in enumerate(prob_output_unet["features"]):
    unet_rice_prob = round(feature["properties"]["rice_prob"], 5)
    unet_other_prob = round(feature["properties"]["cropland_prob"] + round(feature["propertie
    unet_data.append([unet_rice_prob, unet_other_prob])
    unet_rice_data.append(unet_rice_prob)
    unet_other_data.append(unet_other_prob)

    dnn_feature = prob_output_dnn["features"][i]
    dnn_rice_prob = round(dnn_feature["properties"]["rice_prob"], 5)
    dnn_other_prob = 1. - round(dnn_feature["properties"]["rice_prob"], 5)
    # dnn_other_prob = round(dnn_feature["properties"]["cropland_prob"] + dnn_feature["proper
    dnn_data.append([dnn_rice_prob, dnn_other_prob])
    dnn_rice_data.append(dnn_rice_prob)
    dnn_other_data.append(dnn_other_prob)
```

```
<IPython.core.display.HTML object>
```

```python
fig, (ax1, ax2) = plt.subplots(nrows=1, ncols=2, figsize=(8, 5))

title_fontsize = 22
label_fontsize = 10
tick_fontsize = 10

# rectangular box plot
bplot1 = ax1.boxplot([unet_rice_data, dnn_rice_data],
                     notch=True,
                     vert=True,  # vertical box alignment
                     patch_artist=True,  # fill with color
```

```
                        labels=["U-Net", "DNN"],
                        sym="k+")  # will be used to label x-ticks
ax1.set_title("Rice Probability")

# notch shape box plot
bplot2 = ax2.boxplot([unet_other_data, dnn_other_data],
                        notch=True,  # notch shape
                        vert=True,  # vertical box alignment
                        patch_artist=True,  # fill with color
                        labels=["U-Net", "DNN"],
                        sym="k+")  # will be used to label x-ticks
ax2.set_title("Other Probability")
```

```
<IPython.core.display.HTML object>
```

```
Text(0.5, 1.0, 'Other Probability')
```
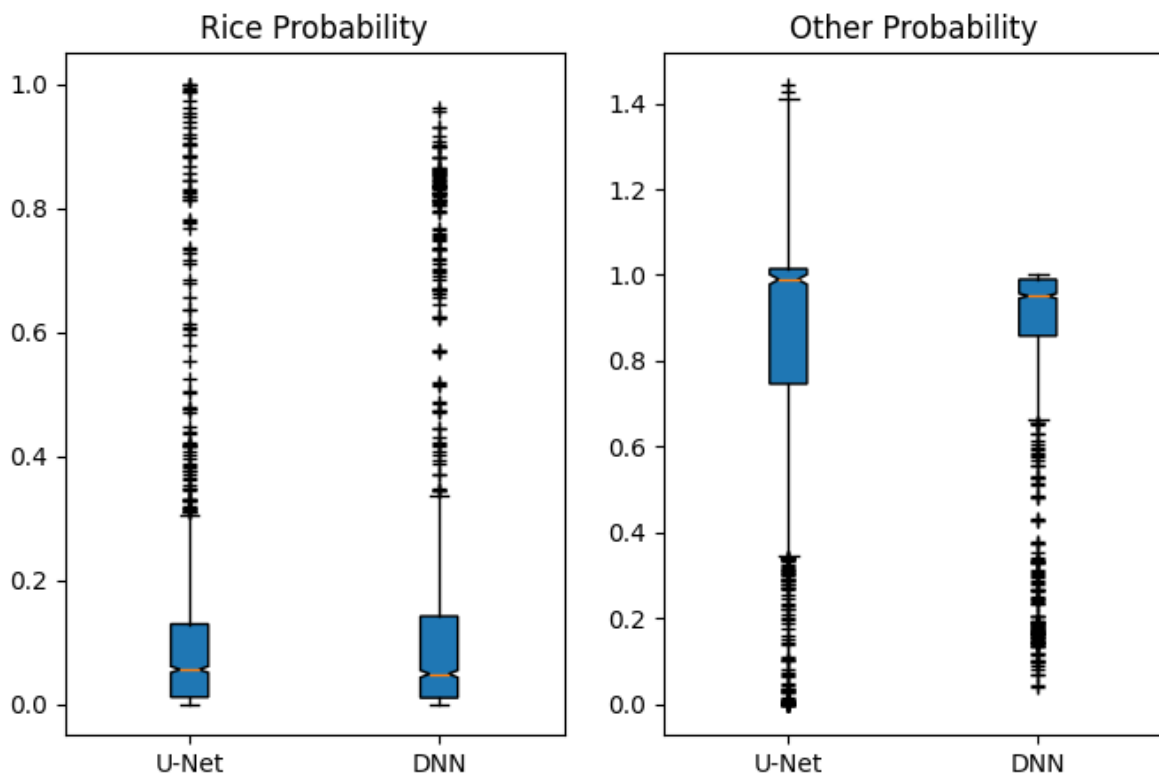
3 Object Detection

```python
# Print out the Python version used by this environment.
import sys

print(f'{sys.version=}')
```

```
sys.version='3.9.0 | packaged by conda-forge | (default, Nov 26 2020, 07:55:15) \n[Clang 11.0
```

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4 Time Series

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Nunc ac dignissim magna. Vestibulum vitae egestas elit. Proin feugiat leo quis ante condimentum, eu ornare mauris feugiat. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris cursus laoreet ex, dignissim bibendum est posuere iaculis. Suspendisse et maximus elit. In fringilla gravida ornare. Aenean id lectus pulvinar, sagittis felis nec, rutrum risus. Nam vel neque eu arcu blandit fringilla et in quam. Aliquam luctus est sit amet vestibulum eleifend. Phasellus elementum sagittis molestie. Proin tempor lorem arcu, at condimentum purus volutpat eu. Fusce et pellentesque ligula. Pellentesque id tellus at erat luctus fringilla. Suspendisse potenti.

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5 Ecological Processes Simulation

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Nunc ac dignissim magna. Vestibulum vitae egestas elit. Proin feugiat leo quis ante condimentum, eu ornare mauris feugiat. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris cursus laoreet ex, dignissim bibendum est posuere iaculis. Suspendisse et maximus elit. In fringilla gravida ornare. Aenean id lectus pulvinar, sagittis felis nec, rutrum risus. Nam vel neque eu arcu blandit fringilla et in quam. Aliquam luctus est sit amet vestibulum eleifend. Phasellus elementum sagittis molestie. Proin tempor lorem arcu, at condimentum purus volutpat eu. Fusce et pellentesque ligula. Pellentesque id tellus at erat luctus fringilla. Suspendisse potenti.

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6 Transfer Learning

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8 Downscaling

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9 Future of Deep Learning and Foundational Models

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10 Ethics and Artificial Intelligence

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Conclusions

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