

# **SERVIR's Applied Deep Learning Handbook**

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# Introduction

Knuth (1984) says some interesting stuff...

Todo: Make some reference to Flores-Anderson et al. (2019)

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# **Part I**

## **Curriculum**

# 1 Data Preparation

```
# 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 ]
```

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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

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

```
!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-aces)

Requirement already satisfied: tensorflow>=2.9.3 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: earthengine-api in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Collecting python-dotenv>=1.0.0 (from servir-aces)

Downloading python\_dotenv-1.0.1-py3-none-any.whl (19 kB)

Requirement already satisfied: matplotlib in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: absl-py>=1.0.0 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: astunparse>=1.6.0 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: flatbuffers>=23.5.26 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: gast!=0.5.0,!0.5.1,!0.5.2,>=0.2.1 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: google-pasta>=0.1.1 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: h5py>=2.9.0 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: libclang>=13.0.0 in /usr/local/lib/python3.10/dist-packages (from servir-aces)

Requirement already satisfied: ml-dtypes~=0.2.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: opt-einsum>=2.3.2 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: packaging in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: protobuf!=4.21.0,!4.21.1,!4.21.2,!4.21.3,!4.21.4,!4.21.5 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: setuptools in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: six>=1.12.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: termcolor>=1.1.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: typing-extensions>=3.6.6 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: wrapt<1.15,>=1.11.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: tensorflow-io-gcs-filesystem>=0.23.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: grpcio<2.0,>=1.24.3 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: tensorboard<2.16,>=2.15 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: tensorflow-estimator<2.16,>=2.15.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: keras<2.16,>=2.15.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-cloud-storage in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-api-python-client>=1.12.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-auth>=1.4.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-auth-http2>=0.0.3 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: http2<1dev,>=0.9.2 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: requests in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: contourpy>=1.0.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: cycycler>=0.10 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: fonttools>=4.22.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: pillow>=6.2.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: pyparsing>=2.3.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: python-dateutil>=2.7 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: wheel<1.0,>=0.23.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-api-core!=2.0.\*,!=2.1.\*,!=2.2.\*,!=2.3.0,<3.0.0dev,>=1.31.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: uritemplate<5,>=3.0.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: cachetools<6.0,>=2.0.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: pyasn1-modules>=0.2.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: rsa<5,>=3.1.4 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-auth-oauthlib<2,>=0.5 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: markdown>=2.6.8 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: werkzeug>=1.0.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: charset-normalizer<4,>=2 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: urllib3<3,>=1.21.1 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: certifi>=2017.4.17 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-cloud-core<3.0dev,>=2.3.0 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

Requirement already satisfied: google-resumable-media>=2.3.2 in /usr/local/lib/python3.10/dist-packages (from tensorflow==2.10.0)

```
Requirement already satisfied: googleapis-common-protos<2.0.dev0,>=1.56.2 in /usr/local/lib/
Requirement already satisfied: requests-oauthlib>=0.7.0 in /usr/local/lib/python3.10/dist-pa
Requirement already satisfied: google-crc32c<2.0dev,>=1.0 in /usr/local/lib/python3.10/dist-p
Requirement already satisfied: pyasn1<0.7.0,>=0.4.6 in /usr/local/lib/python3.10/dist-packag
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://b>

```
Copying gs://dl-book/chapter-1/.DS_Store...
Copying gs://dl-book/chapter-1/dnn_planet_wo_indices/testing/testing.tfrecord.gz...
Copying gs://dl-book/chapter-1/dnn_planet_wo_indices/training/training.tfrecord.gz...
Copying gs://dl-book/chapter-1/dnn_planet_wo_indices/validation/validation.tfrecord.gz...
Copying gs://dl-book/chapter-1/images/image_202100000.tfrecord.gz...
```

```

Copying gs://dl-book/chapter-1/images/image_202100001.tfrecord.gz...
Copying gs://dl-book/chapter-1/images/image_202100002.tfrecord.gz...
Copying gs://dl-book/chapter-1/images/image_202100003.tfrecord.gz...
Copying gs://dl-book/chapter-1/models/dnn_v1/config.env...
Copying gs://dl-book/chapter-1/images/image_202100004.tfrecord.gz...
Copying gs://dl-book/chapter-1/images/image_202100005.tfrecord.gz...
Copying gs://dl-book/chapter-1/images/image_2021mixer.json...
Copying gs://dl-book/chapter-1/models/dnn_v1/aces/keras_metadata.pb...
Copying gs://dl-book/chapter-1/models/dnn_v1/aces/fingerprint.pb...
Copying gs://dl-book/chapter-1/models/dnn_v1/aces/saved_model.pb...
Copying gs://dl-book/chapter-1/models/dnn_v1/aces/variables/variables.data-00000-of-00001...
Copying gs://dl-book/chapter-1/models/dnn_v1/aces/variables/variables.index...
Copying gs://dl-book/chapter-1/models/dnn_v1/config.json...
Copying gs://dl-book/chapter-1/models/dnn_v1/evaluation.txt...
Copying gs://dl-book/chapter-1/models/dnn_v1/logs/train/events.out.tfevents.1713307528.b5c4c...
Copying gs://dl-book/chapter-1/models/dnn_v1/logs/validation/events.out.tfevents.1713307537.1...
Copying gs://dl-book/chapter-1/models/dnn_v1/model.png...
Copying gs://dl-book/chapter-1/models/dnn_v1/model.txt...
Copying gs://dl-book/chapter-1/models/dnn_v1/modelCheckpoint/fingerprint.pb...
Copying gs://dl-book/chapter-1/models/dnn_v1/modelCheckpoint/variables/variables.data-00000-of-00001...
Copying gs://dl-book/chapter-1/models/dnn_v1/modelCheckpoint/keras_metadata.pb...
Copying gs://dl-book/chapter-1/models/unet_v1/aces/fingerprint.pb...
Copying gs://dl-book/chapter-1/models/unet_v1/aces/keras_metadata.pb...
Copying gs://dl-book/chapter-1/models/dnn_v1/model.pkl...
Copying gs://dl-book/chapter-1/models/dnn_v1/modelCheckpoint/variables/variables.index...
Copying gs://dl-book/chapter-1/models/dnn_v1/parameters.txt...
Copying gs://dl-book/chapter-1/models/dnn_v1/prediction/prediction_dnn_v1.TFRecord...
Copying gs://dl-book/chapter-1/models/unet_v1/model.pkl...
Copying gs://dl-book/chapter-1/models/dnn_v1/trained-model/fingerprint.pb...
Copying gs://dl-book/chapter-1/models/dnn_v1/modelCheckpoint/saved_model.pb...
==> 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").

Copying gs://dl-book/chapter-1/models/unet_v1/aces/saved_model.pb...
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Copying gs://dl-book/chapter-1/models/dnn_v1/training.png...
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```

Copying gs://dl-book/chapter-1/models/unet\_v1/logs/train/events.out.tfevents.1713299324.b5c4  
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Copying gs://dl-book/chapter-1/models/unet\_v1/model.txt...  
Copying gs://dl-book/chapter-1/models/unet\_v1/logs/validation/events.out.tfevents.1713299558  
Copying gs://dl-book/chapter-1/models/unet\_v1/aces/variables/variables.index...  
Copying gs://dl-book/chapter-1/models/unet\_v1/modelCheckpoint/fingerprint.pb...  
Copying gs://dl-book/chapter-1/models/unet\_v1/modelCheckpoint/keras\_metadata.pb...  
Copying gs://dl-book/chapter-1/models/unet\_v1/modelCheckpoint/saved\_model.pb...  
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Copying gs://dl-book/chapter-1/models/unet\_v1/trained-model/keras\_metadata.pb...  
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Copying gs://dl-book/chapter-1/models/unet\_v1/trained-model/variables/variables.data-00000-o  
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Copying gs://dl-book/chapter-1/unet\_256x256\_planet\_wo\_indices/testing/testing-00000-of-00038  
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Copying gs://dl-book/chapter-1/unet\_256x256\_planet\_wo\_indices/testing/testing-00006-of-00038  
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Copying gs://dl-book/chapter-1/unet\_256x256\_planet\_wo\_indices/testing/testing-00008-of-00038  
Copying gs://dl-book/chapter-1/unet\_256x256\_planet\_wo\_indices/testing/testing-00009-of-00038  
Copying gs://dl-book/chapter-1/unet\_256x256\_planet\_wo\_indices/testing/testing-00010-of-00038  
Copying gs://dl-book/chapter-1/unet\_256x256\_planet\_wo\_indices/testing/testing-00011-of-00038  
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[illegible]

```
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Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00025-of-
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Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00027-of-
Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00028-of-
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Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00031-of-
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Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00033-of-
Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00034-of-
Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00035-of-
Copying gs://dl-book/chapter-1/unet_256x256_planet_wo_indices/validation/validation-00036-of-
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 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 programmatically.

Note current version does not expose all the model intricacies 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.



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

These datasets have RGBN from Planetscope mosaic. 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 addition, you can use `USE_ELEVATION` and `USE_S1` config to include the topographic and radar information. Since this datasets have topographic and radar features, so we won't be setting 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_during",
# "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 set
# 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 training, 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.

```

BASEDIR    = "/content/" # @param {type:"string"}
OUTPUT_DIR = "/content/drive/MyDrive/Colab Notebooks/DL_Book/Chapter_1/output" # @param {type:"string"}
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]
                   )

```

## 2.3 U-Net Model

### 2.3.1 Load config file variables

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

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

```
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', '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.

```
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.

```
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]]]
```

```

[[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), dtype=float32)
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.]
 [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.]
 [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.]
 [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. 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.]]]
```

...

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

```

```

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

[[0. 0. 1. 0. 0.]
 [0. 1. 0. 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. 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), dtype=float32)
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), dtype=float32)
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][0]']
activation_1 (Activation)	(None, None, None, 32)	0	['activation[0][0]']
separable_conv2d (SeparableConv2D)	(None, None, None, 64)	2400	['activation_1[0][0]']
batch_normalization_1 (Batch Normalization)	(None, None, None, 64)	256	['separable_conv2d[0][0]']
activation_2 (Activation)	(None, None, None, 64)	0	['batch_normalization_1[0][0]']
separable_conv2d_1 (SeparableConv2D)	(None, None, None, 64)	4736	['activation_2[0][0]']
batch_normalization_2 (Batch Normalization)	(None, None, None, 64)	256	['separable_conv2d_1[0][0]']
max_pooling2d (MaxPooling2D)	(None, None, None, 64)	0	['batch_normalization_2[0][0]']
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 (SeparableConv2D)	(None, None, None, 128)	8896	['activation_3[0][0]']
batch_normalization_3 (Batch Normalization)	(None, None, None, 128)	512	['separable_conv2d_2[0][0]']
activation_4 (Activation)	(None, None, None, 128)	0	['batch_normalization_3[0][0]']
separable_conv2d_3 (SeparableConv2D)	(None, None, None, 128)	17664	['activation_4[0][0]']



bleConv2D)			
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][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][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][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]']

batch_normalization_7 (BatchNormalization)	(None, None, None, 256)	1024	['conv2d_transpose[0][0]
activation_8 (Activation)	(None, None, None, 256)	0	['batch_normalization_7[
conv2d_transpose_1 (Conv2DTranspose)	(None, None, None, 256)	590080	['activation_8[0][0]']
batch_normalization_8 (BatchNormalization)	(None, None, None, 256)	1024	['conv2d_transpose_1[0][
up_sampling2d_1 (UpSampling2D)	(None, None, None, 256)	0	['add_2[0][0]']
up_sampling2d (UpSampling2D)	(None, None, None, 256)	0	['batch_normalization_8[
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 (Conv2DTranspose)	(None, None, None, 128)	295040	['activation_9[0][0]']
batch_normalization_9 (BatchNormalization)	(None, None, None, 128)	512	['conv2d_transpose_2[0][
activation_10 (Activation)	(None, None, None, 128)	0	['batch_normalization_9[
conv2d_transpose_3 (Conv2DTranspose)	(None, None, None, 128)	147584	['activation_10[0][0]']
batch_normalization_10 (BatchNormalization)	(None, None, None, 128)	512	['conv2d_transpose_3[0][
up_sampling2d_3 (UpSampling2D)	(None, None, None, 256)	0	['add_3[0][0]']

up_sampling2d_2 (UpSampling2D)	(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 (Batch Normalization)	(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 (Batch Normalization)	(None, None, None, 64)	256	['conv2d_transpose_5[0][0]']
up_sampling2d_5 (UpSampling2D)	(None, None, None, 128)	0	['add_4[0][0]']
up_sampling2d_4 (UpSampling2D)	(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 (Batch Normalization)	(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 Transpose)	(None, None, None, 32)	9248	['activation_14[0][0]']
batch_normalization_14 (Batch Normalization)	(None, None, None, 32)	128	['conv2d_transpose_7[0][0]']
up_sampling2d_7 (UpSampling2D)	(None, None, None, 64)	0	['add_5[0][0]']
up_sampling2d_6 (UpSampling2D)	(None, None, None, 32)	0	['batch_normalization_14']
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/output

\*\*\*\*\*

\*\*\*\*\* training model... \*\*\*\*\*

Epoch 1/30

266/266 [=====] - ETA: 0s - loss: 0.9676 - precision: 0.7271 - recall: 0.7271

Epoch 1: val\_loss improved from inf to 2.63403, saving model to /content/drive/MyDrive/Colab Notebooks/DL\_Book/Chapter\_1/output

266/266 [=====] - 299s 971ms/step - loss: 0.9676 - precision: 0.7271 - recall: 0.7271

Epoch 2/30

266/266 [=====] - ETA: 0s - loss: 0.6959 - precision: 0.8066 - recall: 0.8066

Epoch 2: val\_loss improved from 2.63403 to 1.23879, saving model to /content/drive/MyDrive/Colab Notebooks/DL\_Book/Chapter\_1/output

266/266 [=====] - 263s 958ms/step - loss: 0.6959 - precision: 0.8066 - recall: 0.8066

Epoch 3/30

```

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

```

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

```

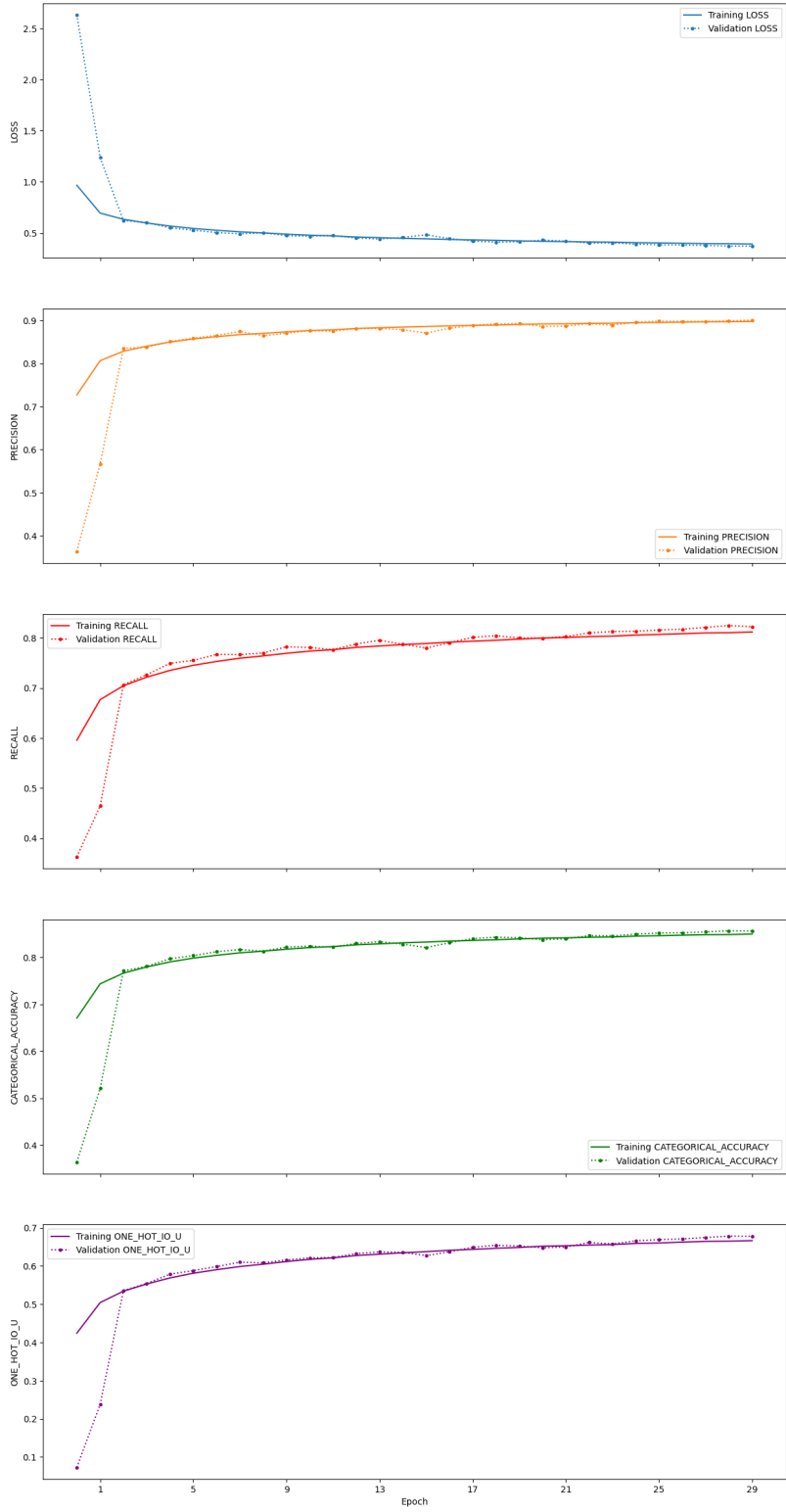
266/266 [=====] - 260s 981ms/step - loss: 0.4117 - precision: 0.893
Epoch 25/30
266/266 [=====] - ETA: 0s - loss: 0.4064 - precision: 0.8948 - reca
Epoch 25: val_loss improved from 0.40218 to 0.39190, saving model to /content/drive/MyDrive/0
266/266 [=====] - 298s 1s/step - loss: 0.4064 - precision: 0.8948 -
Epoch 26/30
266/266 [=====] - ETA: 0s - loss: 0.4038 - precision: 0.8954 - reca
Epoch 26: val_loss improved from 0.39190 to 0.38542, saving model to /content/drive/MyDrive/0
266/266 [=====] - 280s 1s/step - loss: 0.4038 - precision: 0.8954 -
Epoch 27/30
266/266 [=====] - ETA: 0s - loss: 0.4007 - precision: 0.8961 - reca
Epoch 27: val_loss improved from 0.38542 to 0.38379, saving model to /content/drive/MyDrive/0
266/266 [=====] - 283s 1s/step - loss: 0.4007 - precision: 0.8961 -
Epoch 28/30
266/266 [=====] - ETA: 0s - loss: 0.3972 - precision: 0.8969 - reca
Epoch 28: val_loss improved from 0.38379 to 0.37968, saving model to /content/drive/MyDrive/0
266/266 [=====] - 264s 996ms/step - loss: 0.3972 - precision: 0.8969
Epoch 29/30
266/266 [=====] - ETA: 0s - loss: 0.3962 - precision: 0.8970 - reca
Epoch 29: val_loss improved from 0.37968 to 0.37328, saving model to /content/drive/MyDrive/0
266/266 [=====] - 263s 989ms/step - loss: 0.3962 - precision: 0.8970
Epoch 30/30
266/266 [=====] - ETA: 0s - loss: 0.3934 - precision: 0.8977 - reca
Epoch 30: val_loss improved from 0.37328 to 0.37270, saving model to /content/drive/MyDrive/0
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

```
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/Chapter\_1/output/unet\_v1/logs'

### 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.

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

```
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'

```
%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 (SeparableConv2D)	(None, None, None, 64)	2400	['activation_1[0][0]']
batch_normalization_1 (Batch Normalization)	(None, None, None, 64)	256	['separable_conv2d[0][0]
activation_2 (Activation)	(None, None, None, 64)	0	['batch_normalization_1[0]
separable_conv2d_1 (SeparableConv2D)	(None, None, None, 64)	4736	['activation_2[0][0]']
batch_normalization_2 (Batch Normalization)	(None, None, None, 64)	256	['separable_conv2d_1[0][0]
max_pooling2d (MaxPooling2D)	(None, None, None, 64)	0	['batch_normalization_2[0]

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 (SeparableConv2D)	(None, None, None, 128)	8896	['activation_3[0][0]']
batch_normalization_3 (BatchNormalization)	(None, None, None, 128)	512	['separable_conv2d_2[0][0]']
activation_4 (Activation)	(None, None, None, 128)	0	['batch_normalization_3[0][0]']
separable_conv2d_3 (SeparableConv2D)	(None, None, None, 128)	17664	['activation_4[0][0]']
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][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][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][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]']
batch_normalization_7 (BatchNormalization)	(None, None, None, 256)	1024	['conv2d_transpose[0][0]']
activation_8 (Activation)	(None, None, None, 256)	0	['batch_normalization_7[0][0]']
conv2d_transpose_1 (Conv2DTranspose)	(None, None, None, 256)	590080	['activation_8[0][0]']
batch_normalization_8 (BatchNormalization)	(None, None, None, 256)	1024	['conv2d_transpose_1[0][0]']
up_sampling2d_1 (UpSampling2D)	(None, None, None, 256)	0	['add_2[0][0]']
up_sampling2d (UpSampling2D)	(None, None, None, 256)	0	['batch_normalization_8[0][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 (BatchNormalization)	(None, None, None, 128)	512	['conv2d_transpose_2[0][0]']
activation_10 (Activation)	(None, None, None, 128)	0	['batch_normalization_9[0][0]']
conv2d_transpose_3 (Conv2D Transpose)	(None, None, None, 128)	147584	['activation_10[0][0]']
batch_normalization_10 (BatchNormalization)	(None, None, None, 128)	512	['conv2d_transpose_3[0][0]']
up_sampling2d_3 (UpSampling2D)	(None, None, None, 256)	0	['add_3[0][0]']
up_sampling2d_2 (UpSampling2D)	(None, None, None, 128)	0	['batch_normalization_10[0][0]']
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 (BatchNormalization)	(None, None, None, 64)	256	['conv2d_transpose_4[0][0]']
activation_12 (Activation)	(None, None, None, 64)	0	['batch_normalization_11[0][0]']
conv2d_transpose_5 (Conv2D Transpose)	(None, None, None, 64)	36928	['activation_12[0][0]']
batch_normalization_12 (BatchNormalization)	(None, None, None, 64)	256	['conv2d_transpose_5[0][0]']

up_sampling2d_5 (UpSampling2D)	(None, None, None, 128)	0	['add_4[0][0]']
up_sampling2d_4 (UpSampling2D)	(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 (Conv2DTranspose)	(None, None, None, 32)	18464	['activation_13[0][0]']
batch_normalization_13 (BatchNormalization)	(None, None, None, 32)	128	['conv2d_transpose_6[0][0]']
activation_14 (Activation)	(None, None, None, 32)	0	['batch_normalization_13']
conv2d_transpose_7 (Conv2DTranspose)	(None, None, None, 32)	9248	['activation_14[0][0]']
batch_normalization_14 (BatchNormalization)	(None, None, None, 32)	128	['conv2d_transpose_7[0][0]']
up_sampling2d_7 (UpSampling2D)	(None, None, None, 64)	0	['add_5[0][0]']
up_sampling2d_6 (UpSampling2D)	(None, None, None, 32)	0	['batch_normalization_14']
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', 'green_during']
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

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/output

\*\*\*\*\*

\*\*\*\*\* training model... \*\*\*\*\*

Epoch 1/30

264/266 [=====>.] - ETA: 0s - loss: 1.2595 - precision: 0.6700 - recall: 0.6700

Epoch 1: val\_loss improved from inf to 1.15955, saving model to /content/drive/MyDrive/Colab Notebooks/DL\_Book/Chapter\_1/output

266/266 [=====] - 31s 99ms/step - loss: 1.2623 - precision: 0.6685 - recall: 0.6685

Epoch 2/30

265/266 [=====>.] - ETA: 0s - loss: 0.9196 - precision: 0.7593 - recall: 0.7593

Epoch 2: val\_loss improved from 1.15955 to 0.87784, saving model to /content/drive/MyDrive/Colab Notebooks/DL\_Book/Chapter\_1/output

266/266 [=====] - 16s 60ms/step - loss: 0.9206 - precision: 0.7592 - recall: 0.7592

Epoch 3/30

266/266 [=====] - ETA: 0s - loss: 0.8111 - precision: 0.7857 - recall: 0.7857

Epoch 3: val\_loss did not improve from 0.87784

266/266 [=====] - 23s 89ms/step - loss: 0.8111 - precision: 0.7857 - recall: 0.7857

Epoch 4/30

261/266 [=====>.] - ETA: 0s - loss: 0.7535 - precision: 0.8003 - recall: 0.8003

Epoch 4: val\_loss improved from 0.87784 to 0.82494, saving model to /content/drive/MyDrive/Colab Notebooks/DL\_Book/Chapter\_1/output

266/266 [=====] - 16s 61ms/step - loss: 0.7584 - precision: 0.7999 - recall: 0.7999

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



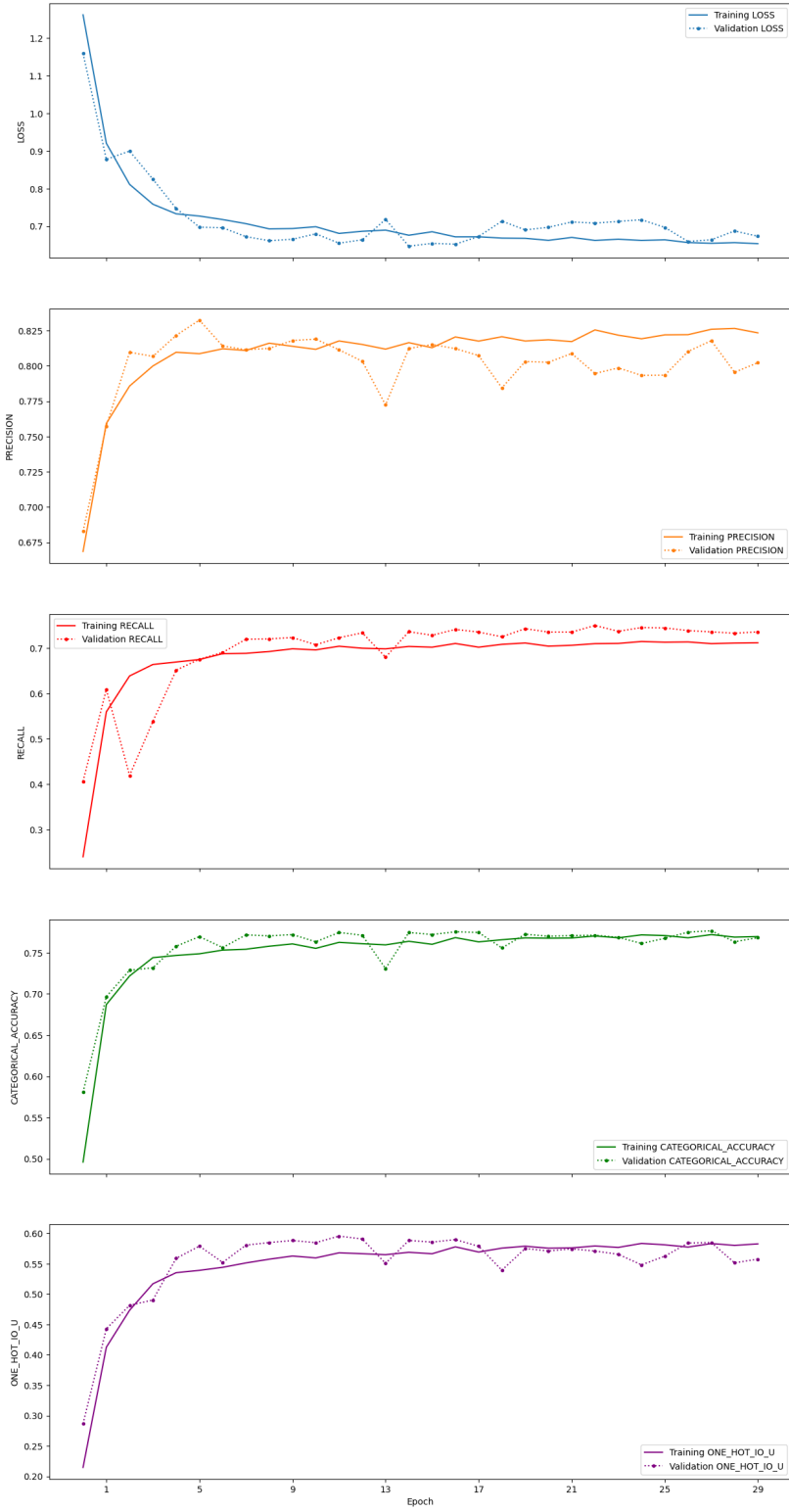
266/266 [=====] - 16s 60ms/step - loss: 0.6758 - precision: 0.8164 - recall: 0.8164  
Epoch 16/30  
265/266 [=====>.] - ETA: 0s - loss: 0.6859 - precision: 0.8126 - recall: 0.8126  
Epoch 16: val\_loss did not improve from 0.64675  
266/266 [=====] - 24s 90ms/step - loss: 0.6850 - precision: 0.8129 -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

```

Epoch 26: val_loss did not improve from 0.64675
266/266 [=====] - 14s 55ms/step - loss: 0.6636 - precision: 0.8220 - recall: 0.7292
Epoch 27/30
266/266 [=====] - ETA: 0s - loss: 0.6562 - precision: 0.8221 - recall: 0.7292
Epoch 27: val_loss did not improve from 0.64675
266/266 [=====] - 24s 91ms/step - loss: 0.6562 - precision: 0.8221 - recall: 0.7292
Epoch 28/30
264/266 [=====>.] - ETA: 0s - loss: 0.6545 - precision: 0.8258 - recall: 0.7292
Epoch 28: val_loss did not improve from 0.64675
266/266 [=====] - 14s 54ms/step - loss: 0.6543 - precision: 0.8259 - recall: 0.7292
Epoch 29/30
264/266 [=====>.] - ETA: 0s - loss: 0.6576 - precision: 0.8259 - recall: 0.7292
Epoch 29: val_loss did not improve from 0.64675
266/266 [=====] - 16s 61ms/step - loss: 0.6561 - precision: 0.8265 - recall: 0.7292
Epoch 30/30
266/266 [=====] - ETA: 0s - loss: 0.6533 - precision: 0.8234 - recall: 0.7292
Epoch 30: val_loss did not improve from 0.64675
266/266 [=====] - 15s 56ms/step - loss: 0.6533 - precision: 0.8234 - recall: 0.7292
*****
***** evaluating model... *****
*****
*****
Validation
1219/1219 [=====] - 7s 6ms/step - loss: 0.6585 - precision: 0.8038 - recall: 0.7292
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/Chapter 10
*****
***** saving models... *****
*****

```



### 2.4.6 Save the config file

```
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/Chapter\_1/output/dnn\_v1/logs'

### 2.4.7 Load the logs files via TensorBoard

```
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'

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

<IPython.core.display.Javascript object>

### 2.4.8 Load the Saved DNN Model

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

```
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', 'g
```

```
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": ["1", "2", "3", "4"]}, "Prediction")
Map
```

<IPython.core.display.HTML object>

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

### 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"]}, "UNET_RGBN_remapped")
Map
```

<IPython.core.display.HTML object>

```
Map(bottom=220961.0, center=[27.378354616518475, 89.42005508391453], controls=(WidgetControl(options=['positioning'])
```

```
sampling_geom = ee.FeatureCollection("projects/servir-ee/assets/dl-book/chapter-1/data/sampling_geom")
ceo_final_data = ee.FeatureCollection("projects/servir-ee/assets/dl-book/chapter-1/data/ceo_final_data")
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", "f
                                .rename(["prediction_class", "others_prob", "cropland_prob", "ur
                                .sampleRegions(collection=ceo_final_data, scale=10, geometries=T

# 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": ["F
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(

```
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", "forest_etc"]
                                   .rename(["prediction_class", "others_prob", "cropland_prob", "urban_prob", "forest_prob"])
                                   .sampleRegions(collection=ceo_final_data, scale=10, geometries=True))

# 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

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

```
%matplotlib inline
```

<IPython.core.display.HTML object>

```
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>

```
# 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)
```

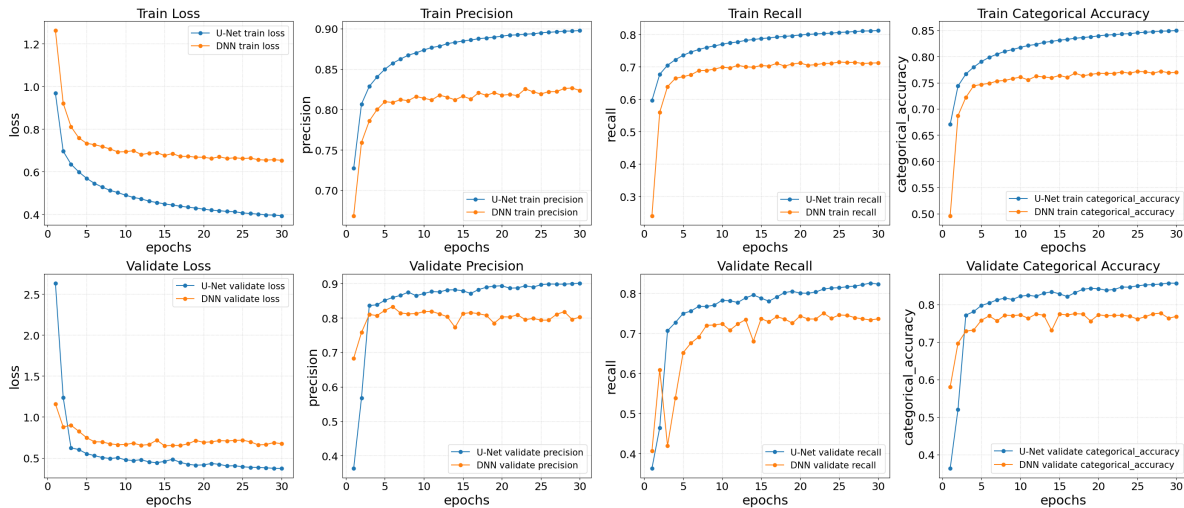
```

        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"]

```

```

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", lw=lw)
    axs[y].plot(epochs, dnn_model_metrics[f"val_{metrics[y]}"], color=colors[1], lw=lw, marker="o", lw=lw)

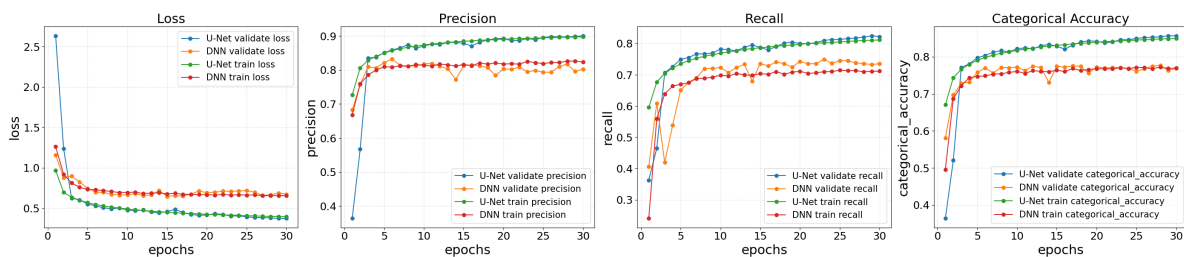
    axs[y].plot(epochs, unet_model_metrics[metrics[y]], color=colors[2], lw=lw, marker="o", lw=lw)
    axs[y].plot(epochs, dnn_model_metrics[metrics[y]], color=colors[3], lw=lw, marker="o", lw=lw)

    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

```
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["properties"], 5))
    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["properties"], 5)
    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>

```
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
```

```

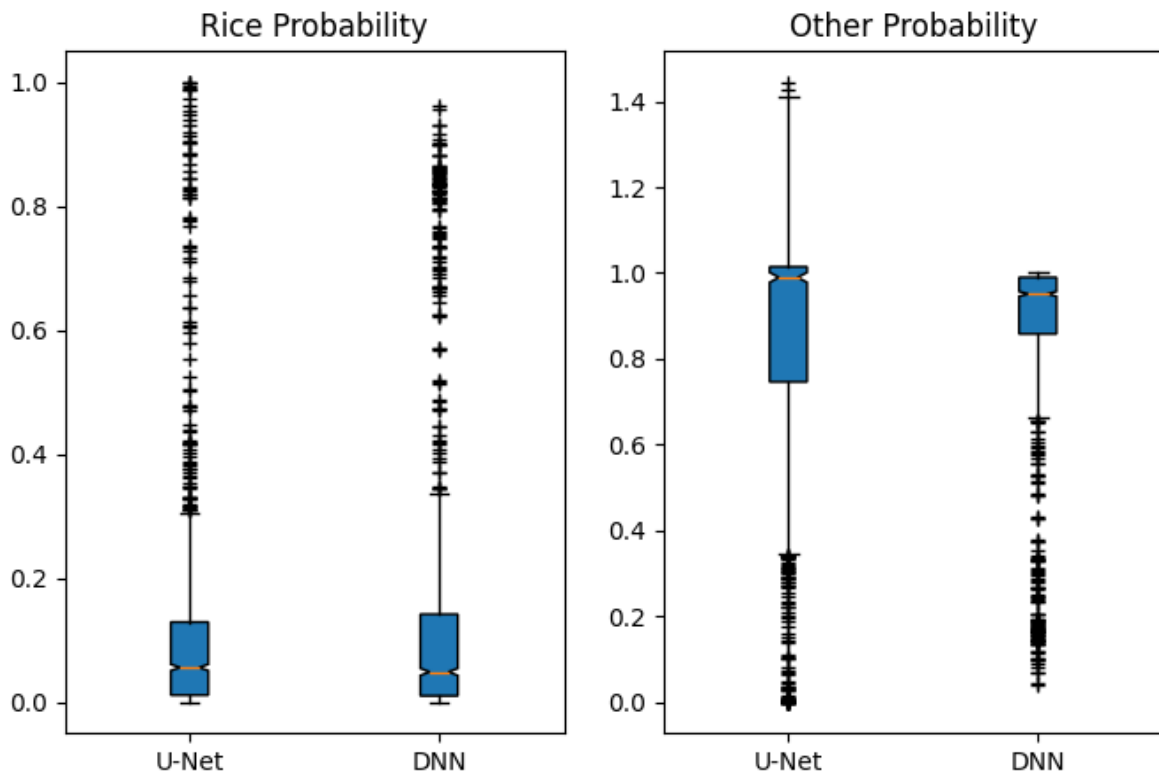
        labels=["U-Net", "DNN"],
        sym="k+") # will be used to label x-ticks
ax1.set_title("Rice Probability")

# 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

```
# 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 11.0.0]
```

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## 4 Time Series

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## 5 Ecological Processes Simulation

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## 6 Transfer Learning

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## 7 Fusion

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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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