Step 1: Imports

```
import os
import numpy as np
import matplotlib.pyplot as plt
from tqdm import tqdm

import tensorflow as tf
from tensorflow.keras import layers, models, optimizers, callbacks

from sklearn.metrics import (
    f1_score, precision_score, recall_score,
    confusion_matrix
)
```

Step 2: Global Configuration

```
DATA_ROOT = r"E:\InstruNet-AI\data\post_preprocessing\irmas_mono"

INPUT_SHAPE = (128, 126, 1)
NUM_CLASSES = 11

BATCH_SIZE = 128
EPOCHS = 30
```

Step 3: Load Label Map

```
import json

with open(r"E:\InstruNet-AI\data\splits\label_map.json", "r") as f:
    class_to_id = json.load(f)

id_to_class = {v: k for k, v in class_to_id.items()}
```

Step 4: Data Loader (Multi-Label Ready)

```
def load_split(split):
    X, y = [], []

    split_dir = os.path.join(DATA_ROOT, split)

    for cls in os.listdir(split_dir):
        cls_id = class_to_id[cls]
        cls_dir = os.path.join(split_dir, cls)

        for file in os.listdir(cls_dir):
            if file.endswith(".npy"):
                mel = np.load(os.path.join(cls_dir, file))
                mel = mel[..., np.newaxis]
```

```
                label = np.zeros(NUM_CLASSES)
                label[cls_id] = 1  # multi-label compatible

                X.append(mel)
                y.append(label)

    return np.array(X), np.array(y)
```

Step 5: Load Train / Val / Test

```
X_train, y_train = load_split("train")
X_val, y_val     = load_split("val")
X_test, y_test   = load_split("test")

print(X_train.shape, y_train.shape)
```

```
(4692, 128, 126, 1) (4692, 11)
```

Step 6: CNN Architecture

```
def build_instrunet_cnn():
    inputs = layers.Input(shape=INPUT_SHAPE)

    x = layers.Conv2D(32, (3,3), padding="same", activation="relu")
(inputs)
    x = layers.BatchNormalization()(x)
    x = layers.MaxPooling2D((2,2))(x)

    x = layers.Conv2D(64, (3,3), padding="same", activation="relu")(x)
    x = layers.BatchNormalization()(x)
    x = layers.MaxPooling2D((2,2))(x)

    x = layers.Conv2D(128, (3,3), padding="same", activation="relu")
(x)
    x = layers.BatchNormalization()(x)
    x = layers.MaxPooling2D((2,2))(x)

    x = layers.Conv2D(256, (3,3), padding="same", activation="relu")
(x)
    x = layers.BatchNormalization()(x)

    x = layers.GlobalAveragePooling2D()(x)
    x = layers.Dropout(0.4)(x)

    outputs = layers.Dense(NUM_CLASSES, activation="sigmoid")(x)

    return models.Model(inputs, outputs)
```

Step 7: Compile Model (BCE + SGD)

```
model = build_instrunet_cnn()

optimizer = optimizers.SGD(
    learning_rate=0.01,
    momentum=0.9,
    nesterov=True
)

model.compile(
    optimizer=optimizer,
    loss="binary_crossentropy",
    metrics=[
        tf.keras.metrics.BinaryAccuracy(name="binary_accuracy")
    ]
)

model.summary()
```

```
Model: "functional"

┏━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━┳━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━┳
━━━━━━━━━━━━━━━━━┓
┃ Layer (type)                          ┃ Output Shape                 ┃
Param # ┃
┡━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━╇━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━╇
━━━━━━━━━━━━━━━━━┩
│ input_layer (InputLayer)              │ (None, 128, 126, 1)          │
0 │
├───────────────────────────────────────┼──────────────────────────────┼
─────────────────┤
│ conv2d (Conv2D)                       │ (None, 128, 126, 32)         │
320 │
├───────────────────────────────────────┼──────────────────────────────┼
─────────────────┤
│ batch_normalization                   │ (None, 128, 126, 32)         │
128 │
│ (BatchNormalization)                  │                              │
│
├───────────────────────────────────────┼──────────────────────────────┼
─────────────────┤
│ max_pooling2d (MaxPooling2D)          │ (None, 64, 63, 32)           │
0 │
├───────────────────────────────────────┼──────────────────────────────┼
─────────────────┤
│ conv2d_1 (Conv2D)                     │ (None, 64, 63, 64)           │
18,496 │
├───────────────────────────────────────┼──────────────────────────────┼
─────────────────┤
```

```
| batch_normalization_1                  | (None, 64, 63, 64)          |
256 |
| (BatchNormalization)                   |                             |
|
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| max_pooling2d_1 (MaxPooling2D)         | (None, 32, 31, 64)          |
0 |
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| conv2d_2 (Conv2D)                      | (None, 32, 31, 128)         |
73,856 |
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| batch_normalization_2                  | (None, 32, 31, 128)         |
512 |
| (BatchNormalization)                   |                             |
|
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| max_pooling2d_2 (MaxPooling2D)         | (None, 16, 15, 128)         |
0 |
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| conv2d_3 (Conv2D)                      | (None, 16, 15, 256)         |
295,168 |
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| batch_normalization_3                  | (None, 16, 15, 256)         |
1,024 |
| (BatchNormalization)                   |                             |
|
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| global_average_pooling2d               | (None, 256)                 |
0 |
| (GlobalAveragePooling2D)               |                             |
|
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| dropout (Dropout)                      | (None, 256)                 |
0 |
├────────────────────────────────────────┼─────────────────────────────┼
──────────────────┤
| dense (Dense)                          | (None, 11)                  |
2,827 |
└────────────────────────────────────────┴─────────────────────────────┴
──────────────────┘

 Total params: 392,587 (1.50 MB)
```

```
 Trainable params: 391,627 (1.49 MB)

 Non-trainable params: 960 (3.75 KB)
```

Step 8: Callbacks

```
cb_list = [
    callbacks.ModelCheckpoint(
        "best_instrunet.h5",
        monitor="val_loss",
        save_best_only=True,
        verbose=1
    ),
    callbacks.EarlyStopping(
        monitor="val_loss",
        patience=10,
        restore_best_weights=True
    ),
    callbacks.ReduceLROnPlateau(
        monitor="val_loss",
        factor=0.5,
        patience=5,
        min_lr=1e-5,
        verbose=1
    ),
    callbacks.CSVLogger("training_log.csv")
]
```

Step 9: Train Model

```
history = model.fit(
    X_train, y_train,
    validation_data=(X_val, y_val),
    epochs=EPOCHS,
    batch_size=BATCH_SIZE,
    callbacks=cb_list
)
```

```
Epoch 1/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.5784 -
loss: 0.6793
Epoch 1: val_loss improved from None to 0.56062, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.
```

```
37/37 ━━━━━━━━━━━━━━━━━━━━ 139s 4s/step - binary_accuracy: 0.6655 -
loss: 0.6491 - val_binary_accuracy: 0.9091 - val_loss: 0.5606 -
learning_rate: 0.0100
Epoch 2/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.8531 -
loss: 0.5532
Epoch 2: val_loss improved from 0.56062 to 0.45052, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 133s 4s/step - binary_accuracy: 0.8705 -
loss: 0.5269 - val_binary_accuracy: 0.9091 - val_loss: 0.4505 -
learning_rate: 0.0100
Epoch 3/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9035 -
loss: 0.4474
Epoch 3: val_loss improved from 0.45052 to 0.37663, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 141s 4s/step - binary_accuracy: 0.9055 -
loss: 0.4279 - val_binary_accuracy: 0.9091 - val_loss: 0.3766 -
learning_rate: 0.0100
Epoch 4/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9117 -
loss: 0.3688
Epoch 4: val_loss improved from 0.37663 to 0.33780, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 132s 4s/step - binary_accuracy: 0.9118 -
loss: 0.3546 - val_binary_accuracy: 0.9091 - val_loss: 0.3378 -
learning_rate: 0.0100
Epoch 5/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9118 -
loss: 0.3161
```

```
Epoch 5: val_loss improved from 0.33780 to 0.32351, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 131s 4s/step - binary_accuracy: 0.9118 -
loss: 0.3082 - val_binary_accuracy: 0.9091 - val_loss: 0.3235 -
learning_rate: 0.0100
Epoch 6/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9118 -
loss: 0.2861
Epoch 6: val_loss improved from 0.32351 to 0.31821, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 131s 4s/step - binary_accuracy: 0.9121 -
loss: 0.2810 - val_binary_accuracy: 0.9091 - val_loss: 0.3182 -
learning_rate: 0.0100
Epoch 7/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9128 -
loss: 0.2684
Epoch 7: val_loss improved from 0.31821 to 0.31524, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 144s 4s/step - binary_accuracy: 0.9127 -
loss: 0.2650 - val_binary_accuracy: 0.9092 - val_loss: 0.3152 -
learning_rate: 0.0100
Epoch 8/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9119 -
loss: 0.2574
Epoch 8: val_loss improved from 0.31524 to 0.30909, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
```

```
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 140s 4s/step - binary_accuracy: 0.9129 -
loss: 0.2544 - val_binary_accuracy: 0.9093 - val_loss: 0.3091 -
learning_rate: 0.0100
Epoch 9/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9141 -
loss: 0.2484
Epoch 9: val_loss improved from 0.30909 to 0.30420, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 144s 4s/step - binary_accuracy: 0.9141 -
loss: 0.2465 - val_binary_accuracy: 0.9102 - val_loss: 0.3042 -
learning_rate: 0.0100
Epoch 10/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9157 -
loss: 0.2413
Epoch 10: val_loss improved from 0.30420 to 0.29444, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 132s 4s/step - binary_accuracy: 0.9156 -
loss: 0.2406 - val_binary_accuracy: 0.9109 - val_loss: 0.2944 -
learning_rate: 0.0100
Epoch 11/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9170 -
loss: 0.2363
Epoch 11: val_loss improved from 0.29444 to 0.28680, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 142s 4s/step - binary_accuracy: 0.9170 -
loss: 0.2362 - val_binary_accuracy: 0.9104 - val_loss: 0.2868 -
learning_rate: 0.0100
```

```
Epoch 12/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9168 -
loss: 0.2328
Epoch 12: val_loss improved from 0.28680 to 0.27939, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 142s 4s/step - binary_accuracy: 0.9173 -
loss: 0.2307 - val_binary_accuracy: 0.9124 - val_loss: 0.2794 -
learning_rate: 0.0100
Epoch 13/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9190 -
loss: 0.2284
Epoch 13: val_loss improved from 0.27939 to 0.25797, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 132s 4s/step - binary_accuracy: 0.9194 -
loss: 0.2268 - val_binary_accuracy: 0.9125 - val_loss: 0.2580 -
learning_rate: 0.0100
Epoch 14/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9211 -
loss: 0.2229
Epoch 14: val_loss improved from 0.25797 to 0.25628, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 142s 4s/step - binary_accuracy: 0.9207 -
loss: 0.2224 - val_binary_accuracy: 0.9145 - val_loss: 0.2563 -
learning_rate: 0.0100
Epoch 15/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9214 -
loss: 0.2201
Epoch 15: val_loss improved from 0.25628 to 0.23779, saving model to
best_instrunet.h5
```

```
WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 142s 4s/step - binary_accuracy: 0.9218 -
loss: 0.2187 - val_binary_accuracy: 0.9159 - val_loss: 0.2378 -
learning_rate: 0.0100
Epoch 16/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9230 -
loss: 0.2147
Epoch 16: val_loss did not improve from 0.23779
37/37 ━━━━━━━━━━━━━━━━━━━━ 147s 4s/step - binary_accuracy: 0.9230 -
loss: 0.2152 - val_binary_accuracy: 0.9164 - val_loss: 0.2410 -
learning_rate: 0.0100
Epoch 17/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9237 -
loss: 0.2133
Epoch 17: val_loss improved from 0.23779 to 0.22714, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 132s 4s/step - binary_accuracy: 0.9240 -
loss: 0.2120 - val_binary_accuracy: 0.9178 - val_loss: 0.2271 -
learning_rate: 0.0100
Epoch 18/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9260 -
loss: 0.2088
Epoch 18: val_loss improved from 0.22714 to 0.22588, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 141s 4s/step - binary_accuracy: 0.9260 -
loss: 0.2086 - val_binary_accuracy: 0.9177 - val_loss: 0.2259 -
learning_rate: 0.0100
Epoch 19/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9262 -
loss: 0.2068
```

```
Epoch 19: val_loss improved from 0.22588 to 0.22514, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 147s 4s/step - binary_accuracy: 0.9263 -
loss: 0.2065 - val_binary_accuracy: 0.9198 - val_loss: 0.2251 -
learning_rate: 0.0100
Epoch 20/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9278 -
loss: 0.2029
Epoch 20: val_loss improved from 0.22514 to 0.22503, saving model to
best_instrunet.h5

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`model.save()` or `keras.saving.save_model(model)`. This file format
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format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 138s 4s/step - binary_accuracy: 0.9274 -
loss: 0.2031 - val_binary_accuracy: 0.9167 - val_loss: 0.2250 -
learning_rate: 0.0100
Epoch 21/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9279 -
loss: 0.2009
Epoch 21: val_loss improved from 0.22503 to 0.22232, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 132s 4s/step - binary_accuracy: 0.9280 -
loss: 0.2007 - val_binary_accuracy: 0.9224 - val_loss: 0.2223 -
learning_rate: 0.0100
Epoch 22/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9290 -
loss: 0.1991
Epoch 22: val_loss improved from 0.22232 to 0.21217, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
```

```
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 132s 4s/step - binary_accuracy: 0.9289 -
loss: 0.1984 - val_binary_accuracy: 0.9227 - val_loss: 0.2122 -
learning_rate: 0.0100
Epoch 23/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9303 -
loss: 0.1962
Epoch 23: val_loss improved from 0.21217 to 0.21165, saving model to
best_instrunet.h5

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`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 142s 4s/step - binary_accuracy: 0.9299 -
loss: 0.1963 - val_binary_accuracy: 0.9264 - val_loss: 0.2116 -
learning_rate: 0.0100
Epoch 24/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9299 -
loss: 0.1939
Epoch 24: val_loss improved from 0.21165 to 0.20735, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 145s 4s/step - binary_accuracy: 0.9304 -
loss: 0.1929 - val_binary_accuracy: 0.9245 - val_loss: 0.2073 -
learning_rate: 0.0100
Epoch 25/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9309 -
loss: 0.1923
Epoch 25: val_loss did not improve from 0.20735
37/37 ━━━━━━━━━━━━━━━━━━━━ 138s 4s/step - binary_accuracy: 0.9314 -
loss: 0.1911 - val_binary_accuracy: 0.9205 - val_loss: 0.2162 -
learning_rate: 0.0100
Epoch 26/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 14s/step - binary_accuracy: 0.9315 -
loss: 0.1886
Epoch 26: val_loss improved from 0.20735 to 0.20055, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
```
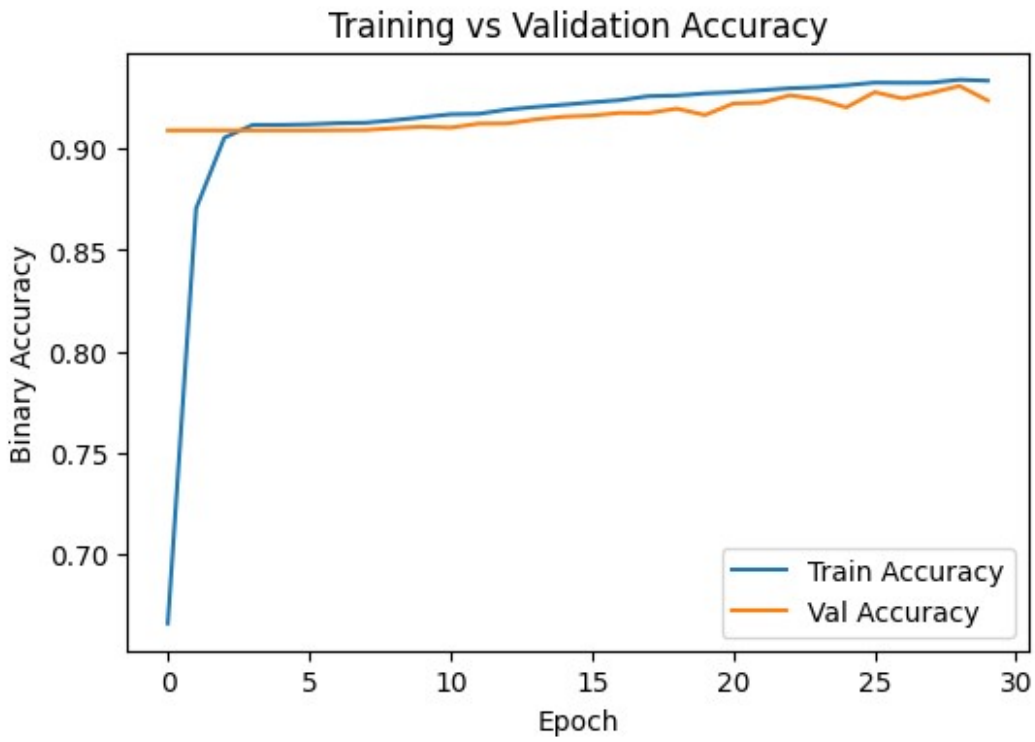

```
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 515s 14s/step - binary_accuracy: 0.9327 -
loss: 0.1886 - val_binary_accuracy: 0.9280 - val_loss: 0.2005 -
learning_rate: 0.0100
Epoch 27/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9319 -
loss: 0.1872
Epoch 27: val_loss did not improve from 0.20055
37/37 ━━━━━━━━━━━━━━━━━━━━ 116s 3s/step - binary_accuracy: 0.9326 -
loss: 0.1870 - val_binary_accuracy: 0.9248 - val_loss: 0.2125 -
learning_rate: 0.0100
Epoch 28/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9333 -
loss: 0.1850
Epoch 28: val_loss improved from 0.20055 to 0.19708, saving model to
best_instrunet.h5

WARNING:absl:You are saving your model as an HDF5 file via
`model.save()` or `keras.saving.save_model(model)`. This file format
is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')` or
`keras.saving.save_model(model, 'my_model.keras')`.

37/37 ━━━━━━━━━━━━━━━━━━━━ 131s 4s/step - binary_accuracy: 0.9327 -
loss: 0.1850 - val_binary_accuracy: 0.9276 - val_loss: 0.1971 -
learning_rate: 0.0100
Epoch 29/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9343 -
loss: 0.1831
Epoch 29: val_loss did not improve from 0.19708
37/37 ━━━━━━━━━━━━━━━━━━━━ 143s 4s/step - binary_accuracy: 0.9341 -
loss: 0.1827 - val_binary_accuracy: 0.9311 - val_loss: 0.1994 -
learning_rate: 0.0100
Epoch 30/30
37/37 ━━━━━━━━━━━━━━━━━━━━ 0s 3s/step - binary_accuracy: 0.9340 -
loss: 0.1823
Epoch 30: val_loss did not improve from 0.19708
37/37 ━━━━━━━━━━━━━━━━━━━━ 140s 3s/step - binary_accuracy: 0.9336 -
loss: 0.1819 - val_binary_accuracy: 0.9238 - val_loss: 0.2149 -
learning_rate: 0.0100
```

Step 10: Accuracy Curve

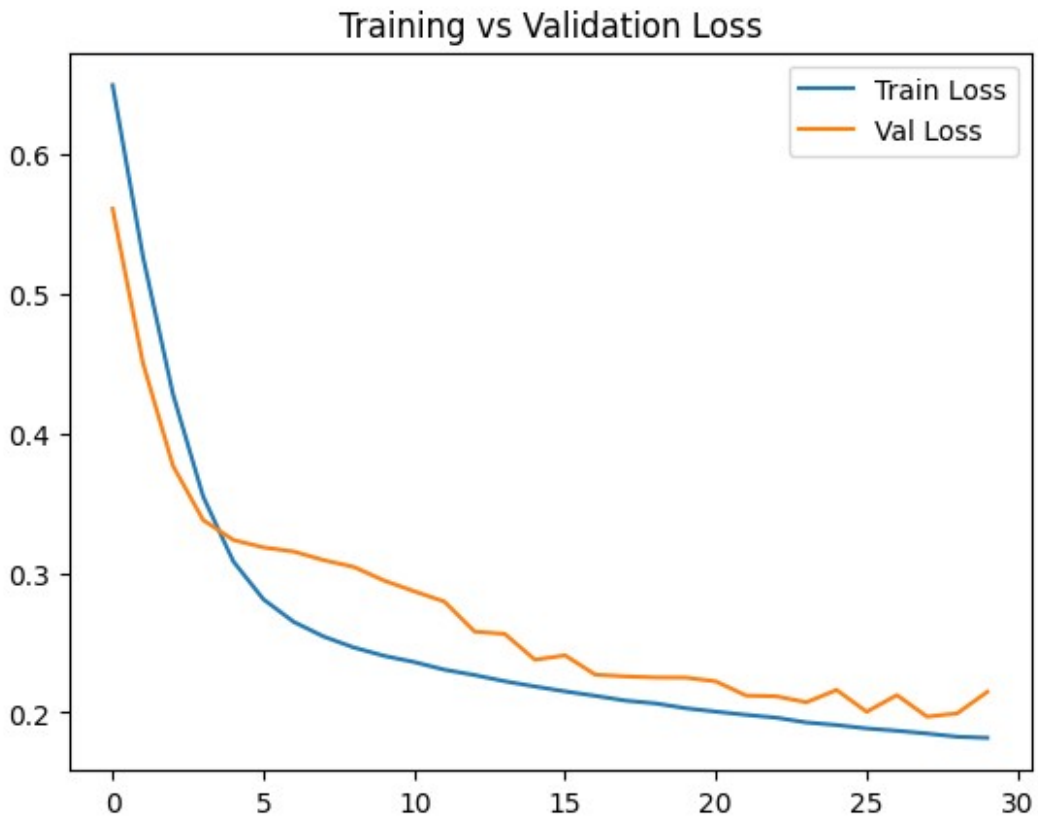
```
plt.figure(figsize=(6,4))
plt.plot(history.history["binary_accuracy"], label="Train Accuracy")
plt.plot(history.history["val_binary_accuracy"], label="Val Accuracy")
plt.legend()
```

```
plt.title("Training vs Validation Accuracy")
plt.xlabel("Epoch")
plt.ylabel("Binary Accuracy")
plt.show()
```



Step 11: Training Loss and Validation Loss Curves

```
plt.plot(history.history["loss"], label="Train Loss")
plt.plot(history.history["val_loss"], label="Val Loss")
plt.legend()
plt.title("Training vs Validation Loss")
plt.show()
```



Step 11: Model Evaluation with Thresholded Metrics

(a) Generate probabilities

```
y_prob = model.predict(X_test)
```

```
32/32 ━━━━━━━━━━━━━━━━━━━━ 6s 188ms/step
```

(b) Apply thresholding

```
THRESHOLD = 0.3
y_pred = (y_prob >= THRESHOLD).astype(int)

print(f"Using decision threshold = {THRESHOLD}")
```

```
Using decision threshold = 0.3
```

(c) Global F1 scores

```
micro_f1 = f1_score(y_test, y_pred, average="micro")
macro_f1 = f1_score(y_test, y_pred, average="macro")

print("\n=== Global Metrics ===")
print("Micro F1-score :", round(micro_f1, 4))
print("Macro F1-score :", round(macro_f1, 4))
```

```
=== Global Metrics ===
Micro F1-score : 0.5454
Macro F1-score : 0.5168
```

(d) Per-class Recall (CRITICAL)

```python
recalls = recall_score(y_test, y_pred, average=None)

print("\n=== Per-class Recall ===")
for i, r in enumerate(recalls):
    print(f"{id_to_class[i]} : {round(r, 3)}")
```

```
=== Per-class Recall ===
cel : 0.362
cla : 0.579
flu : 0.324
gac : 0.663
gel : 0.482
org : 0.728
pia : 0.75
sax : 0.234
tru : 0.36
vio : 0.23
voi : 0.581
```

(e) Per-class Precision

```python
precisions = precision_score(
    y_test,
    y_pred,
    average=None,
    zero_division=0
)

print("\n=== Per-class Precision ===")
for i, p in enumerate(precisions):
    print(f"{id_to_class[i]} : {round(p, 3)}")
```

```
=== Per-class Precision ===
cel : 0.7
cla : 0.44
flu : 0.367
gac : 0.663
gel : 0.561
org : 0.636
pia : 0.704
sax : 0.478
```

```
tru : 0.674
vio : 0.4
voi : 0.883
```

(f) Per-class Confusion Matrices

```
print("\n=== Per-class Confusion Matrices ===")
for i in range(NUM_CLASSES):
    print(f"\nConfusion Matrix for {id_to_class[i]}")
    print(confusion_matrix(y_test[:, i], y_pred[:, i]))
```

```
=== Per-class Confusion Matrices ===

Confusion Matrix for cel
[[939   9]
 [ 37  21]]

Confusion Matrix for cla
[[874  56]
 [ 32  44]]

Confusion Matrix for flu
[[900  38]
 [ 46  22]]

Confusion Matrix for gac
[[879  32]
 [ 32  63]]

Confusion Matrix for gel
[[849  43]
 [ 59  55]]

Confusion Matrix for org
[[860  43]
 [ 28  75]]

Confusion Matrix for pia
[[864  34]
 [ 27  81]]

Confusion Matrix for sax
[[888  24]
 [ 72  22]]

Confusion Matrix for tru
[[905  15]
 [ 55  31]]

Confusion Matrix for vio
```

```
[[889  30]
 [ 67  20]]

Confusion Matrix for voi
[[880   9]
 [ 49  68]]
```