COSC 2673/2793 | Machine Learning

Assingment 2

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In [1]:
```
import keras
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import seaborn as sns
import tensorflow as tf

from keras.regularizers import L2, L1
from PIL import Image
from sklearn.metrics import confusion_matrix, ConfusionMatrixDisplay, f1_score, roc_curve
from sklearn.model_selection import train_test_split
from tensorflow.keras.layers import Conv2D, Dense, Dropout, Flatten, MaxPooling2D
from tensorflow.keras.models import Sequential
from tensorflow.keras.preprocessing.image import ImageDataGenerator
```

In [2]:
```
df_main = pd.read_csv('./Image_classification_data/data_labels_mainData.csv')
df_extra = pd.read_csv('./Image_classification_data/data_labels_extraData.csv')
```

Classification

Exploratory Data Analysis

In [3]:
```
df_main.head()
```

Out[3]:

	InstanceID	patientID	ImageName	cellTypeName	cellType	isCancerous
0	22405	1	22405.png	fibroblast	0	0
1	22406	1	22406.png	fibroblast	0	0
2	22407	1	22407.png	fibroblast	0	0
3	22408	1	22408.png	fibroblast	0	0
4	22409	1	22409.png	fibroblast	0	0

In [4]:
```
df_main.describe()
```

Out[4]:

	InstanceID	patientID	cellType	isCancerous
count	9896.000000	9896.000000	9896.000000	9896.000000
mean	10193.880154	29.762025	1.501516	0.412187
std	6652.912660	17.486553	0.954867	0.492253
min	1.000000	1.000000	0.000000	0.000000
25%	4135.750000	14.000000	1.000000	0.000000
50%	9279.500000	26.000000	2.000000	0.000000
75%	16821.250000	47.000000	2.000000	1.000000
max	22444.000000	60.000000	3.000000	1.000000

In [5]:
```
df_extra.head()
```

Out[5]:

	InstanceID	patientID	ImageName	isCancerous
0	12681	61	12681.png	0
1	12682	61	12682.png	0
2	12683	61	12683.png	0
3	12684	61	12684.png	0
4	12685	61	12685.png	0

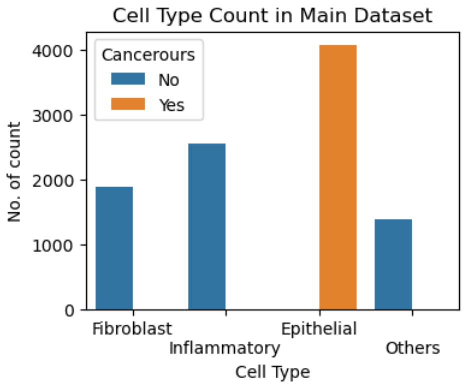
In [6]:
```
df_extra.describe()
```

Out[6]:

	InstanceID	patientID	isCancerous
count	10384.000000	10384.00000	10384.000000
mean	12087.866333	80.38203	0.287943
std	6173.866838	9.40388	0.452826
min	1631.000000	61.00000	0.000000
25%	6655.750000	71.00000	0.000000
50%	12377.500000	81.00000	0.000000
75%	16374.250000	88.00000	1.000000
max	22235.000000	99.00000	1.000000

In [7]:
```
fig = plt.figure(figsize=(4,3))

sns.countplot(x='cellType', data=df_main, hue='isCancerous')

plt.title("Cell Type Count in Main Dataset")
plt.xlabel('Cell Type')
plt.ylabel('No. of count')
plt.legend(title='Cancerours', labels=['No', 'Yes'])
plt.xticks([0, 1, 2, 3])
plt.gca().set_xticklabels(['Fibroblast', '\nInflammatory', 'Epithelial', '\nOthers'])
```

Out[7]:
```
[Text(0, 0, 'Fibroblast'),
 Text(1, 0, '\nInflammatory'),
 Text(2, 0, 'Epithelial'),
 Text(3, 0, '\nOthers')]
```



In [8]:
```
df_main_2 = df_main.copy(True)
df_extra_2 = df_extra.copy(True)

df_main_2['Source'] = 'Main'
df_extra_2['Source'] = 'Extra'

df_all = pd.concat([df_main_2, df_extra_2])
df_all
```

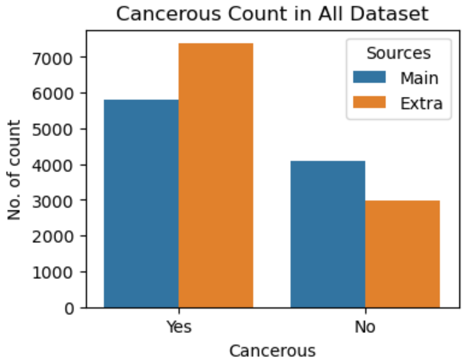
Out[8]:

	InstanceID	patientID	ImageName	cellTypeName	cellType	isCancerous	Source
0	22405	1	22405.png	fibroblast	0.0	0	Main
1	22406	1	22406.png	fibroblast	0.0	0	Main
2	22407	1	22407.png	fibroblast	0.0	0	Main
3	22408	1	22408.png	fibroblast	0.0	0	Main
4	22409	1	22409.png	fibroblast	0.0	0	Main
...	...	...	...	...	...	...	...
10379	20028	99	20028.png	NaN	NaN	0	Extra
10380	20029	99	20029.png	NaN	NaN	0	Extra
10381	20030	99	20030.png	NaN	NaN	0	Extra
10382	20031	99	20031.png	NaN	NaN	0	Extra
10383	20032	99	20032.png	NaN	NaN	0	Extra

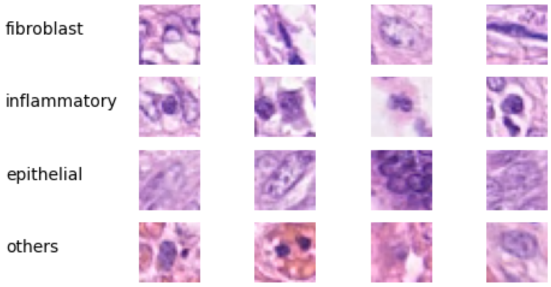
20280 rows × 7 columns

In [9]:
```
fig = plt.figure(figsize=(4,3))

sns.countplot(x='isCancerous', data=df_all, hue='Source')

plt.title("Cancerous Count in All Dataset")
plt.xlabel('Cancerous')
plt.ylabel('No. of count')
plt.legend(title='Sources')
plt.gca().set_xticklabels(['Yes','No'])
```

Out[9]: `[Text(0, 0, 'Yes'), Text(1, 0, 'No')]`



In [10]:
```
cell_types = [0, 1, 2, 3]
NO_OF_IMAGE_SHOW = 4
r_inx = np.random.choice(1000, NO_OF_IMAGE_SHOW)

fig, axs = plt.subplots(len(cell_types), NO_OF_IMAGE_SHOW + 1, figsize=(NO_OF_IMAGE_SHOW + 2, 3))
for i, cell_type in enumerate(cell_types):
    rand_image_name = df_main[df_main['cellType'] == cell_type].reset_index().loc[r_inx, 'ImageName']
    axs[i,0].text(0, 0.5, df_main[df_main['cellType'] == cell_type]['cellTypeName'].iloc[0])
    axs[i,0].axis('off')
    for j, image_path in enumerate(rand_image_name):
        im = np.asarray(Image.open('./Image_classification_data/patch_images/'+image_path))
        axs[i,j+1].imshow(im,cmap='gray')
        axs[i,j+1].axis('off')

plt.show()
```



In [11]:
```
df_main.dtypes
```

Out[11]:
```
InstanceID       int64
patientID        int64
ImageName       object
cellTypeName    object
cellType         int64
isCancerous      int64
dtype: object
```

Data Preprocessing

In [12]:
```
df_main['isCancerous_str'] = df_main['isCancerous'].apply(lambda x: 'No' if x == 0 else 'Yes' )
df_main['ImageName'] = df_main['ImageName'].astype('str')
df_main['cellTypeName'] = df_main['cellTypeName'].astype('str')
df_main['isCancerous_str'] = df_main['isCancerous_str'].astype('str')

df_main.head()
df_main['isCancerous_str'].value_counts()
```

Out[12]:
```
No     5817
Yes    4079
Name: isCancerous_str, dtype: int64
```

In [13]:
```
train_data, test_data = train_test_split(df_main, test_size=0.15, random_state=7)
train_data, val_data = train_test_split(train_data, test_size=0.175, random_state=7)

print(f'Train data : {train_data.shape[0]}, Val Data: {val_data.shape[0]}, Test Data: {test_data.shape[0]}')
df_main.dtypes
train_data['isCancerous_str'].value_counts()
```

```
Train data : 6939, Val Data: 1472, Test Data: 1485
```

Out[13]:
```
No     4104
Yes    2835
Name: isCancerous_str, dtype: int64
```

Cell Type Classification - Multi-class

Baseline Model - Multi-class

In [14]:
```
# [1] Ref:
def plot_learning_curve(train_loss, val_loss, train_metric, val_metric, metric_name='Accuracy'):
    plt.figure(figsize=(10,5))

    plt.subplot(1,2,1)
```

```
    plt.plot(train_loss, 'r--')
    plt.plot(val_loss, 'b--')
    plt.xlabel("epochs")
    plt.ylabel("Loss")
    plt.legend(['train', 'val'], loc='upper left')

    plt.subplot(1,2,2)
    plt.plot(train_metric, 'r--')
    plt.plot(val_metric, 'b--')
    plt.xlabel("epochs")
    plt.ylabel(metric_name)
    plt.legend(['train', 'val'], loc='upper left')

    plt.show()
```

In [15]:

```
train_datagen = ImageDataGenerator(rescale=1./255, data_format='channels_last')
val_datagen = ImageDataGenerator(rescale=1./255, data_format='channels_last')

BATCH_SIZE = 32

train_generator = train_datagen.flow_from_dataframe(
        dataframe=train_data,
        directory='./Image_classification_data/patch_images/',
        x_col="ImageName",
        y_col="cellTypeName",
        target_size=(27, 27),
        batch_size=BATCH_SIZE,
        class_mode='categorical',
        seed=7,
        shuffle=True
)

validation_generator = val_datagen.flow_from_dataframe(
        dataframe=val_data,
        directory='./Image_classification_data/patch_images/',
        x_col="ImageName",
        y_col="cellTypeName",
        target_size=(27, 27),
        batch_size=BATCH_SIZE,
        class_mode='categorical',
        shuffle=False
)
```

```
Found 6939 validated image filenames belonging to 4 classes.
Found 1472 validated image filenames belonging to 4 classes.
```

In [16]:

```
cell_type_count = np.bincount(train_generator.classes)
total = np.sum(cell_type_count)
class_weight = {}
print(type(cell_type_count))
print(train_generator.class_indices)
for i, each_type_count in enumerate(cell_type_count):
    class_weight[i] = 1/each_type_count * total/len(cell_type_count)

print(f'Class Weight: {class_weight}')
```

```
<class 'numpy.ndarray'>
{'epithelial': 0, 'fibroblast': 1, 'inflammatory': 2, 'others': 3}
Class Weight: {0: 0.611904761904762, 1: 1.2708791208791208, 2: 0.9751264755480608, 3: 1.8070312499999999}
```

In [17]:

```
early_stopping = tf.keras.callbacks.EarlyStopping(
    monitor='val_categorical_accuracy',
    verbose=1,
    patience=10,
    mode='max',
    restore_best_weights=True)
```

In [18]:

```
LOG_DIR = 'logs'
```

Model Architecture

In [19]:

```
model_1 = Sequential([

    Conv2D(32, (3, 3), padding="same", activation="relu", input_shape=(27, 27, 3)),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(64, (3, 3), padding="same", activation="relu"),
    Conv2D(64, (3, 3), padding="same", activation="relu"),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(128, (3, 3), padding="same", activation="relu"),
    Conv2D(128, (3, 3), padding="same", activation="relu"),
    MaxPooling2D(pool_size=(3,3)),

    Flatten(),
    Dense(512, activation="relu"),
    Dense(512, activation="relu"),

    Dense(4, activation='softmax'),
])

model_1.summary()
```

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d (Conv2D)             (None, 27, 27, 32)        896

 max_pooling2d (MaxPooling2  (None, 9, 9, 32)          0
 D)

 conv2d_1 (Conv2D)           (None, 9, 9, 64)          18496

 conv2d_2 (Conv2D)           (None, 9, 9, 64)          36928

 max_pooling2d_1 (MaxPoolin  (None, 3, 3, 64)          0
 g2D)

 conv2d_3 (Conv2D)           (None, 3, 3, 128)         73856

 conv2d_4 (Conv2D)           (None, 3, 3, 128)         147584

 max_pooling2d_2 (MaxPoolin  (None, 1, 1, 128)         0
 g2D)

 flatten (Flatten)           (None, 128)               0

 dense (Dense)               (None, 512)               66048

 dense_1 (Dense)             (None, 512)               262656

 dense_2 (Dense)             (None, 4)                 2052

=================================================================
Total params: 608516 (2.32 MB)
Trainable params: 608516 (2.32 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

In [20]:

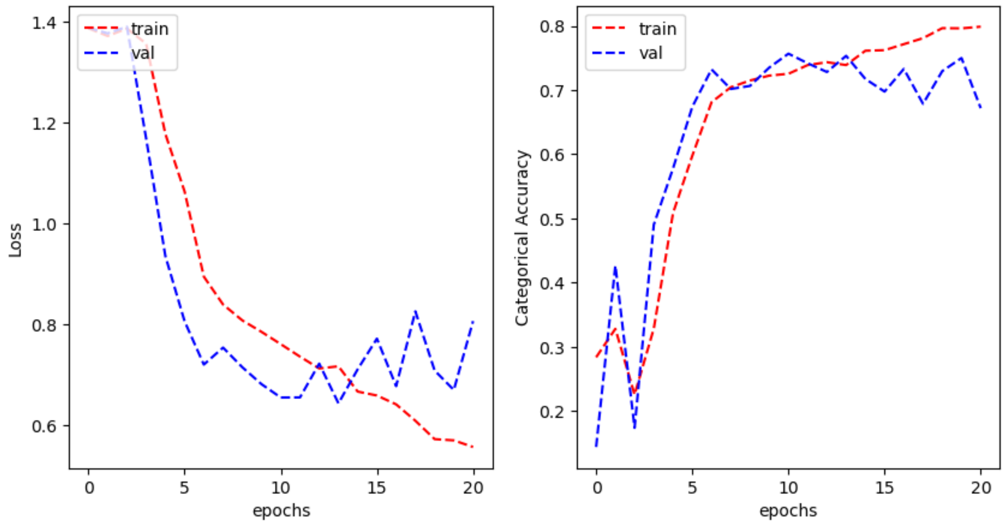
```
model_1.compile("adam", loss=tf.losses.CategoricalCrossentropy(), metrics=['categorical_accuracy'])

tensorboard_callback = tf.keras.callbacks.TensorBoard(log_dir=LOG_DIR)

hist_1 = model_1.fit(
    train_generator,
    epochs=100,
    validation_data=validation_generator,
    callbacks=[tensorboard_callback, early_stopping],
    class_weight=class_weight
)
```

```
Epoch 1/100
2023-05-17 11:24:34.130818: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
214/217 [============================>.] - ETA: 0s - loss: 1.3864 - categorical_accuracy: 0.2863
2023-05-17 11:24:36.244386: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
```

```
217/217 [==============================] - 2s 10ms/step - loss: 1.3861 - categorical_accuracy: 0.2838 - val_loss: 1.3876 - val_catego
rical_accuracy: 0.1440
Epoch 2/100
217/217 [==============================] - 2s 10ms/step - loss: 1.3710 - categorical_accuracy: 0.3281 - val_loss: 1.3761 - val_catego
rical_accuracy: 0.4266
Epoch 3/100
217/217 [==============================] - 2s 10ms/step - loss: 1.3857 - categorical_accuracy: 0.2255 - val_loss: 1.3894 - val_catego
rical_accuracy: 0.1739
Epoch 4/100
217/217 [==============================] - 2s 11ms/step - loss: 1.3557 - categorical_accuracy: 0.3287 - val_loss: 1.1680 - val_catego
rical_accuracy: 0.4905
Epoch 5/100
217/217 [==============================] - 3s 12ms/step - loss: 1.1770 - categorical_accuracy: 0.5086 - val_loss: 0.9354 - val_catego
rical_accuracy: 0.5781
Epoch 6/100
217/217 [==============================] - 3s 13ms/step - loss: 1.0630 - categorical_accuracy: 0.5976 - val_loss: 0.8062 - val_catego
rical_accuracy: 0.6739
Epoch 7/100
217/217 [==============================] - 3s 13ms/step - loss: 0.8947 - categorical_accuracy: 0.6811 - val_loss: 0.7207 - val_catego
rical_accuracy: 0.7323
Epoch 8/100
217/217 [==============================] - 3s 12ms/step - loss: 0.8395 - categorical_accuracy: 0.7044 - val_loss: 0.7542 - val_catego
rical_accuracy: 0.7018
Epoch 9/100
217/217 [==============================] - 3s 12ms/step - loss: 0.8081 - categorical_accuracy: 0.7149 - val_loss: 0.7154 - val_catego
rical_accuracy: 0.7065
Epoch 10/100
217/217 [==============================] - 2s 11ms/step - loss: 0.7854 - categorical_accuracy: 0.7226 - val_loss: 0.6818 - val_catego
rical_accuracy: 0.7351
Epoch 11/100
217/217 [==============================] - 3s 12ms/step - loss: 0.7611 - categorical_accuracy: 0.7255 - val_loss: 0.6555 - val_catego
rical_accuracy: 0.7568
Epoch 12/100
217/217 [==============================] - 3s 13ms/step - loss: 0.7364 - categorical_accuracy: 0.7390 - val_loss: 0.6557 - val_catego
rical_accuracy: 0.7418
Epoch 13/100
217/217 [==============================] - 3s 13ms/step - loss: 0.7130 - categorical_accuracy: 0.7435 - val_loss: 0.7225 - val_catego
rical_accuracy: 0.7283
Epoch 14/100
217/217 [==============================] - 3s 13ms/step - loss: 0.7172 - categorical_accuracy: 0.7390 - val_loss: 0.6440 - val_catego
rical_accuracy: 0.7534
Epoch 15/100
217/217 [==============================] - 3s 14ms/step - loss: 0.6672 - categorical_accuracy: 0.7613 - val_loss: 0.7114 - val_catego
rical_accuracy: 0.7174
Epoch 16/100
217/217 [==============================] - 3s 14ms/step - loss: 0.6594 - categorical_accuracy: 0.7622 - val_loss: 0.7720 - val_catego
rical_accuracy: 0.6977
Epoch 17/100
217/217 [==============================] - 3s 14ms/step - loss: 0.6419 - categorical_accuracy: 0.7716 - val_loss: 0.6780 - val_catego
rical_accuracy: 0.7330
Epoch 18/100
217/217 [==============================] - 3s 15ms/step - loss: 0.6095 - categorical_accuracy: 0.7809 - val_loss: 0.8260 - val_catego
rical_accuracy: 0.6787
Epoch 19/100
217/217 [==============================] - 3s 14ms/step - loss: 0.5731 - categorical_accuracy: 0.7965 - val_loss: 0.7090 - val_catego
rical_accuracy: 0.7296
Epoch 20/100
217/217 [==============================] - 3s 15ms/step - loss: 0.5707 - categorical_accuracy: 0.7962 - val_loss: 0.6704 - val_catego
rical_accuracy: 0.7500
Epoch 21/100
214/217 [============================>.] - ETA: 0s - loss: 0.5574 - categorical_accuracy: 0.7988Restoring model weights from the end
of the best epoch: 11.
217/217 [==============================] - 3s 15ms/step - loss: 0.5575 - categorical_accuracy: 0.7988 - val_loss: 0.8067 - val_catego
rical_accuracy: 0.6719
Epoch 21: early stopping
```

Training and Valuation result

In [21]:
```
plot_learning_curve(
    hist_1.history['loss'],
    hist_1.history['val_loss'],
    hist_1.history['categorical_accuracy'],
    hist_1.history['val_categorical_accuracy'],
    metric_name='Categorical Accuracy'
)
```



In [22]:
```
# model_1.save('baseline')
# model_1 = keras.models.load_model("baseline")
```

Test & Evaluate

In [23]:
```
test_datagen = ImageDataGenerator(rescale=1./255, data_format='channels_last')
TEST_BATCH_SIZE = 1
test_generator = test_datagen.flow_from_dataframe(
        dataframe=test_data,
        directory='./Image_classification_data/patch_images/',
        x_col="ImageName",
        y_col="cellTypeName",
        target_size=(27, 27),
        batch_size=TEST_BATCH_SIZE,
        class_mode='categorical',
        shuffle=False
)
```

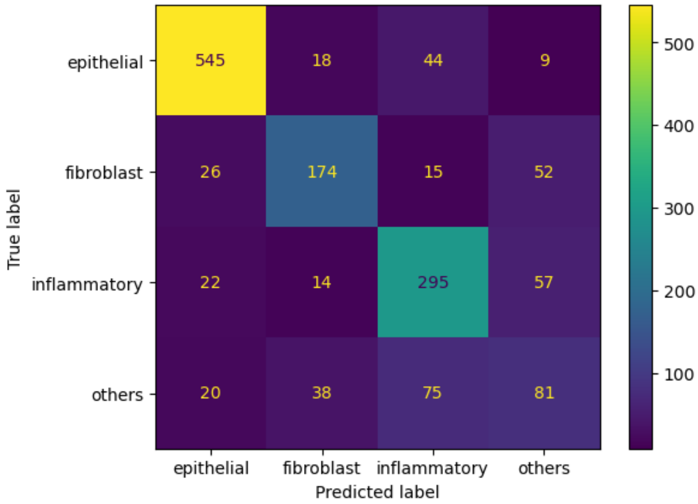
```
Found 1485 validated image filenames belonging to 4 classes.
```

In [24]:
```
def plot_cm(test_gen, predictions, is_binary=False):
    cm = confusion_matrix(test_gen.classes, predictions)
    disp = ConfusionMatrixDisplay(confusion_matrix=cm, display_labels=test_gen.class_indices.keys())
    disp.plot()
    plt.grid(False)
    plt.show()

    if is_binary == True:
        print(f'{"Non Cancerous Cell Detected (True Negatives):":<60}{cm[0][0]}')
        print(f'{"Non Cancerous Cell Incorrectly Detected (False Positives):":<60}{cm[0][1]}')
        print(f'{"Cancerous Cell Missed (False Negatives):":<60}{cm[1][0]}')
        print(f'{"Cancerous Cell Detected (True Positives):":<60}{cm[1][1]}')
    else:
        print(f'{"True Positives Count:":<60}{np.sum([cm[0][0], cm[1][1], cm[2][2], cm[3][3]])}')
    print(f'{"Total Cell Counts:":<60}{np.sum(cm)}')
```

In [25]:
```
def test_and_evaluate(model, test_gen, is_binary=False):
    results = model.evaluate(test_gen)
    test_pred_prob = model.predict(test_gen)
    if is_binary == True:
        test_pred = np.where(test_pred_prob > 0.5, 1, 0)
    else:
        test_pred = np.argmax(test_pred_prob, axis=1)
    for name, value in zip(model.metrics_names, results):
        print(f'{name} : {value}\n')
    plot_cm(test_gen, test_pred, is_binary)
    print(f'{"F1 Score (Weighted):":<60}{f1_score(test_gen.classes, test_pred, average="weighted")}')
    return (results, test_pred_prob)
```

In [26]:
```
test_and_evaluate(model_1, test_generator)
```

```
 145/1485 [=>............................] - ETA: 1s - loss: 0.6580 - categorical_accuracy: 0.7517
2023-05-17 11:25:32.099933: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
1485/1485 [==============================] - 1s 917us/step - loss: 0.6433 - categorical_accuracy: 0.7374
  97/1485 [>.............................] - ETA: 1s
2023-05-17 11:25:33.484999: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
1485/1485 [==============================] - 1s 895us/step
loss : 0.6433002948760986

categorical_accuracy : 0.7373737096786499
```




```
True Positives Count:                                    1095
Total Cell Counts:                                       1485
F1 Score (Weighted):                                     0.7355554070539585
```

Out[26]:
```
([0.6433002948760986, 0.7373737096786499],
 array([[8.3431220e-01, 1.4282605e-01, 6.9907052e-03, 1.5871011e-02],
        [9.8419118e-01, 1.2635541e-02, 4.9407245e-04, 2.6791808e-03],
        [2.7137708e-03, 1.9414803e-02, 6.9636840e-01, 2.8150305e-01],
        ...,
        [1.7250689e-02, 2.4863605e-01, 2.8874025e-01, 4.4537297e-01],
        [1.3185815e-03, 1.3164186e-02, 7.1016139e-01, 2.7535585e-01],
        [5.9357350e-04, 5.5405837e-01, 1.4279572e-02, 4.3106851e-01]],
       dtype=float32))
```

Additional Model

Oversampling

ref: https://www.tensorflow.org/tutorials/structured_data/imbalanced_data#oversampling

In [27]:
```
largest_no = 50000

e_features = train_data[train_data['cellTypeName'] == 'epithelial']['ImageName'].to_numpy()
e_labels = train_data[train_data['cellTypeName'] == 'epithelial']['cellTypeName'].to_numpy()
e_ids = np.arange(len(e_features))
e_choices = np.random.choice(e_ids, largest_no)
e_pick_feature = e_features[e_choices]
e_choices_labels = np.random.choice(e_labels, largest_no)


f_features = train_data[train_data['cellTypeName'] == 'fibroblast']['ImageName'].to_numpy()
f_labels = train_data[train_data['cellTypeName'] == 'fibroblast']['cellTypeName'].to_numpy()
f_ids = np.arange(len(f_features))
f_choices = np.random.choice(f_ids, largest_no)
f_pick_feature = f_features[f_choices]
f_choices_labels = np.random.choice(f_labels, largest_no)

i_features = train_data[train_data['cellTypeName'] == 'inflammatory']['ImageName'].to_numpy()
i_labels = train_data[train_data['cellTypeName'] == 'inflammatory']['cellTypeName'].to_numpy()
i_ids = np.arange(len(i_features))
i_choices = np.random.choice(i_ids, largest_no)
i_pick_feature = i_features[i_choices]
i_choices_labels = np.random.choice(i_labels, largest_no)

o_features = train_data[train_data['cellTypeName'] == 'others']['ImageName'].to_numpy()
o_labels = train_data[train_data['cellTypeName'] == 'others']['cellTypeName'].to_numpy()
o_ids = np.arange(len(o_features))
o_choices = np.random.choice(o_ids, largest_no)
o_pick_feature = o_features[o_choices]
o_choices_labels = np.random.choice(o_labels, largest_no)

resampled_features = np.concatenate([e_pick_feature, f_pick_feature, i_pick_feature, o_pick_feature], axis=0)
resampled_labels = np.concatenate([e_choices_labels, f_choices_labels, i_choices_labels, o_choices_labels], axis=0)

order = np.arange(len(resampled_labels))
np.random.shuffle(order)
resampled_features = resampled_features[order]
resampled_labels = resampled_labels[order]

resampled_features_tr = resampled_features.transpose()
resampled_labels_tr = resampled_labels.transpose()

resampled_train_data = pd.DataFrame({'ImageName': resampled_features_tr, 'cellTypeName': resampled_labels_tr})
resampled_train_data.head()
```

Out[27]:

	ImageName	cellTypeName
0	9110.png	inflammatory
1	1333.png	epithelial
2	13239.png	fibroblast
3	8251.png	epithelial
4	9213.png	epithelial

Data Augmentation

In [28]:

```
train_datagen_aug = ImageDataGenerator(
    rescale=1./255,
    data_format='channels_last',
    zoom_range=0.3,
    channel_shift_range=50,
    rotation_range=359,
    brightness_range=[1.0,1.2],
)

train_generator_aug = train_datagen_aug.flow_from_dataframe(
    dataframe=resampled_train_data,
    directory='./Image_classification_data/patch_images/',
    x_col="ImageName",
    y_col="cellTypeName",
    target_size=(27, 27),
    batch_size=BATCH_SIZE,
    class_mode='categorical'
)

IMAGE_NO = 5
fig, axs = plt.subplots(1, IMAGE_NO, figsize=(IMAGE_NO, 3))
for i in range(IMAGE_NO):
    axs[i].axis('off')
    img, label = train_generator_aug.next()
    axs[i].imshow(img[0])
plt.show()
```

```
Found 200000 validated image filenames belonging to 4 classes.
```

Model Architecture

In [63]:

```
REG_RATE = 0.0001

model_23 = Sequential([
    Conv2D(32, (3, 3), padding="same", activation="relu", input_shape=(27, 27, 3)),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(64, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    Conv2D(64, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(128, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    Conv2D(128, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    MaxPooling2D(pool_size=(3,3)),

    Flatten(),
    Dense(512, activation="relu", kernel_regularizer=L2(REG_RATE)),
    Dropout(0.1),
    Dense(512, activation="relu", kernel_regularizer=L2(REG_RATE)),
    Dropout(0.1),

    Dense(4, activation='softmax'),
])

model_23.compile("sgd", loss=tf.keras.losses.CategoricalCrossentropy(), metrics=['categorical_accuracy'])

tensorboard_callback_23 = tf.keras.callbacks.TensorBoard(log_dir=LOG_DIR)

model_23.summary()
```

```
Model: "sequential_5"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 conv2d_25 (Conv2D)          (None, 27, 27, 32)        896       
                                                                 
 max_pooling2d_15 (MaxPooli  (None, 9, 9, 32)          0         
 ng2D)                                                           
                                                                 
 conv2d_26 (Conv2D)          (None, 9, 9, 64)          18496     
                                                                 
 conv2d_27 (Conv2D)          (None, 9, 9, 64)          36928     
                                                                 
 max_pooling2d_16 (MaxPooli  (None, 3, 3, 64)          0         
 ng2D)                                                           
                                                                 
 conv2d_28 (Conv2D)          (None, 3, 3, 128)         73856     
                                                                 
 conv2d_29 (Conv2D)          (None, 3, 3, 128)         147584    
                                                                 
 max_pooling2d_17 (MaxPooli  (None, 1, 1, 128)         0         
 ng2D)                                                           
                                                                 
 flatten_5 (Flatten)         (None, 128)               0         
                                                                 
 dense_15 (Dense)            (None, 512)               66048     
                                                                 
 dropout_6 (Dropout)         (None, 512)               0         
                                                                 
 dense_16 (Dense)            (None, 512)               262656    
                                                                 
 dropout_7 (Dropout)         (None, 512)               0         
                                                                 
 dense_17 (Dense)            (None, 4)                 2052      
                                                                 
=================================================================
Total params: 608516 (2.32 MB)
Trainable params: 608516 (2.32 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

In [64]:
```
hist_23 = model_23.fit(
    train_generator_aug,
    epochs=100,
    validation_data=validation_generator,
    callbacks=[tensorboard_callback_23, early_stopping]
)
```

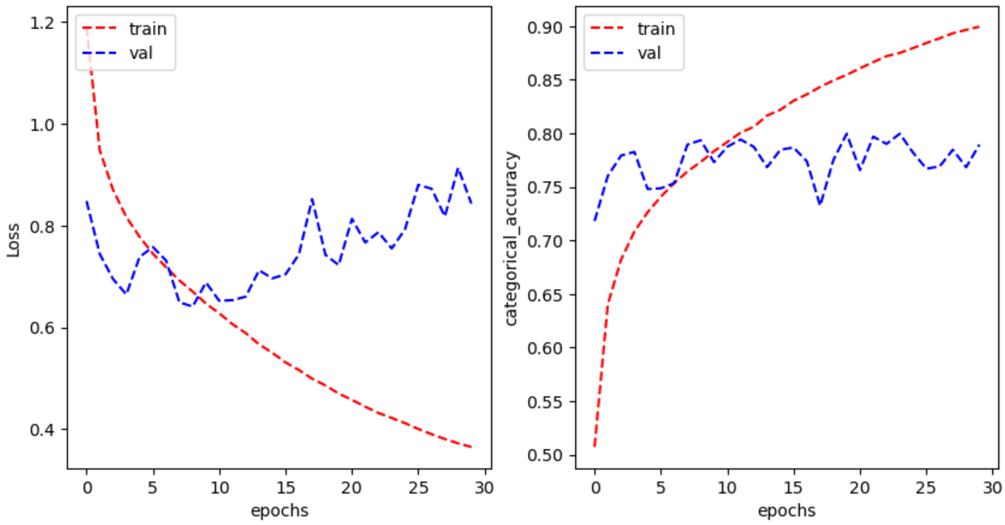
```
Epoch 1/100
2023-05-17 15:04:45.044551: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
	 [[{{node Placeholder/_0}}]]
6250/6250 [==============================] - ETA: 0s - loss: 1.1911 - categorical_accuracy: 0.5072
2023-05-17 15:06:13.503736: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
	 [[{{node Placeholder/_0}}]]
```

```
6250/6250 [==============================] - 89s 14ms/step - loss: 1.1911 - categorical_accuracy: 0.5072 - val_loss: 0.8485 - val_cat
egorical_accuracy: 0.7181
Epoch 2/100
6250/6250 [==============================] - 90s 14ms/step - loss: 0.9479 - categorical_accuracy: 0.6403 - val_loss: 0.7442 - val_cat
egorical_accuracy: 0.7602
Epoch 3/100
6250/6250 [==============================] - 92s 15ms/step - loss: 0.8703 - categorical_accuracy: 0.6821 - val_loss: 0.6951 - val_cat
egorical_accuracy: 0.7792
Epoch 4/100
6250/6250 [==============================] - 93s 15ms/step - loss: 0.8169 - categorical_accuracy: 0.7082 - val_loss: 0.6648 - val_cat
egorical_accuracy: 0.7826
Epoch 5/100
6250/6250 [==============================] - 95s 15ms/step - loss: 0.7782 - categorical_accuracy: 0.7263 - val_loss: 0.7387 - val_cat
egorical_accuracy: 0.7480
Epoch 6/100
6250/6250 [==============================] - 89s 14ms/step - loss: 0.7450 - categorical_accuracy: 0.7408 - val_loss: 0.7580 - val_cat
egorical_accuracy: 0.7486
Epoch 7/100
6250/6250 [==============================] - 92s 15ms/step - loss: 0.7183 - categorical_accuracy: 0.7534 - val_loss: 0.7313 - val_cat
egorical_accuracy: 0.7534
Epoch 8/100
6250/6250 [==============================] - 93s 15ms/step - loss: 0.6923 - categorical_accuracy: 0.7644 - val_loss: 0.6494 - val_cat
egorical_accuracy: 0.7894
Epoch 9/100
6250/6250 [==============================] - 91s 15ms/step - loss: 0.6705 - categorical_accuracy: 0.7732 - val_loss: 0.6411 - val_cat
egorical_accuracy: 0.7935
Epoch 10/100
6250/6250 [==============================] - 93s 15ms/step - loss: 0.6468 - categorical_accuracy: 0.7832 - val_loss: 0.6885 - val_cat
egorical_accuracy: 0.7731
Epoch 11/100
6250/6250 [==============================] - 84s 13ms/step - loss: 0.6278 - categorical_accuracy: 0.7918 - val_loss: 0.6523 - val_cat
egorical_accuracy: 0.7874
Epoch 12/100
6250/6250 [==============================] - 90s 14ms/step - loss: 0.6065 - categorical_accuracy: 0.8006 - val_loss: 0.6537 - val_cat
egorical_accuracy: 0.7942
Epoch 13/100
6250/6250 [==============================] - 92s 15ms/step - loss: 0.5888 - categorical_accuracy: 0.8061 - val_loss: 0.6606 - val_cat
egorical_accuracy: 0.7874
Epoch 14/100
6250/6250 [==============================] - 94s 15ms/step - loss: 0.5669 - categorical_accuracy: 0.8165 - val_loss: 0.7124 - val_cat
egorical_accuracy: 0.7683
Epoch 15/100
6250/6250 [==============================] - 92s 15ms/step - loss: 0.5502 - categorical_accuracy: 0.8219 - val_loss: 0.6964 - val_cat
egorical_accuracy: 0.7846
Epoch 16/100
6250/6250 [==============================] - 94s 15ms/step - loss: 0.5311 - categorical_accuracy: 0.8304 - val_loss: 0.7045 - val_cat
egorical_accuracy: 0.7867
Epoch 17/100
6250/6250 [==============================] - 94s 15ms/step - loss: 0.5164 - categorical_accuracy: 0.8363 - val_loss: 0.7435 - val_cat
egorical_accuracy: 0.7738
Epoch 18/100
6250/6250 [==============================] - 90s 14ms/step - loss: 0.4993 - categorical_accuracy: 0.8433 - val_loss: 0.8523 - val_cat
egorical_accuracy: 0.7323
Epoch 19/100
6250/6250 [==============================] - 92s 15ms/step - loss: 0.4861 - categorical_accuracy: 0.8493 - val_loss: 0.7429 - val_cat
egorical_accuracy: 0.7751
Epoch 20/100
6250/6250 [==============================] - 92s 15ms/step - loss: 0.4701 - categorical_accuracy: 0.8545 - val_loss: 0.7226 - val_cat
egorical_accuracy: 0.7996
Epoch 21/100
6250/6250 [==============================] - 93s 15ms/step - loss: 0.4578 - categorical_accuracy: 0.8607 - val_loss: 0.8135 - val_cat
egorical_accuracy: 0.7656
Epoch 22/100
6250/6250 [==============================] - 94s 15ms/step - loss: 0.4443 - categorical_accuracy: 0.8664 - val_loss: 0.7670 - val_cat
egorical_accuracy: 0.7969
Epoch 23/100
6250/6250 [==============================] - 93s 15ms/step - loss: 0.4319 - categorical_accuracy: 0.8719 - val_loss: 0.7871 - val_cat
egorical_accuracy: 0.7901
Epoch 24/100
6250/6250 [==============================] - 91s 15ms/step - loss: 0.4222 - categorical_accuracy: 0.8750 - val_loss: 0.7552 - val_cat
egorical_accuracy: 0.7996
Epoch 25/100
6250/6250 [==============================] - 91s 15ms/step - loss: 0.4120 - categorical_accuracy: 0.8795 - val_loss: 0.7930 - val_cat
egorical_accuracy: 0.7819
Epoch 26/100
6250/6250 [==============================] - 93s 15ms/step - loss: 0.4005 - categorical_accuracy: 0.8843 - val_loss: 0.8802 - val_cat
egorical_accuracy: 0.7670
Epoch 27/100
6250/6250 [==============================] - 89s 14ms/step - loss: 0.3901 - categorical_accuracy: 0.8886 - val_loss: 0.8726 - val_cat
egorical_accuracy: 0.7690
Epoch 28/100
6250/6250 [==============================] - 91s 15ms/step - loss: 0.3808 - categorical_accuracy: 0.8933 - val_loss: 0.8181 - val_cat
egorical_accuracy: 0.7846
Epoch 29/100
6250/6250 [==============================] - 97s 16ms/step - loss: 0.3722 - categorical_accuracy: 0.8965 - val_loss: 0.9137 - val_cat
egorical_accuracy: 0.7683
Epoch 30/100
6250/6250 [==============================] - ETA: 0s - loss: 0.3651 - categorical_accuracy: 0.8995Restoring model weights from the en
d of the best epoch: 20.
6250/6250 [==============================] - 94s 15ms/step - loss: 0.3651 - categorical_accuracy: 0.8995 - val_loss: 0.8434 - val_cat
egorical_accuracy: 0.7894
Epoch 30: early stopping
```

Training and Valuation result

In [65]:
```
plot_learning_curve(hist_23.history['loss'],
                    hist_23.history['val_loss'],
                    hist_23.history['categorical_accuracy'],
```

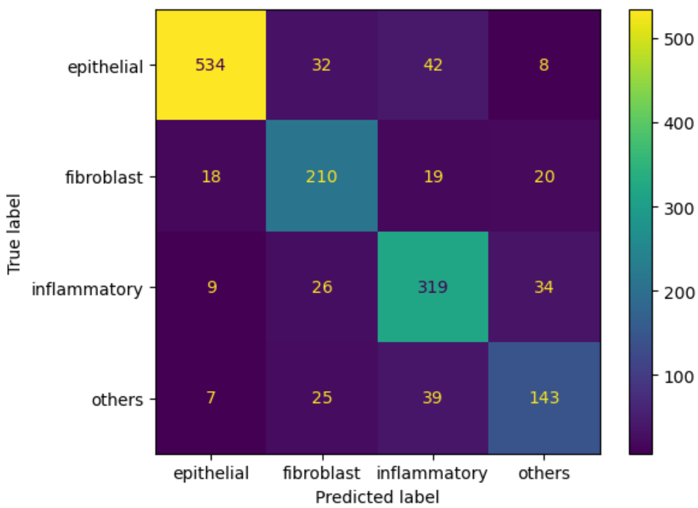
```
            hist_23.history['val_categorical_accuracy'],
            metric_name='categorical_accuracy')
```



Test & Evaluate

In [62]:
```
test_and_evaluate(model_23, test_generator)
```

```
 178/1485 [==>...........................] - ETA: 1s - loss: 0.5621 - categorical_accuracy: 0.8202
2023-05-17 14:46:00.674352: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
1485/1485 [==============================] - 1s 805us/step - loss: 0.6012 - categorical_accuracy: 0.8121
 203/1485 [===>..........................] - ETA: 0s
2023-05-17 14:46:01.897066: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
1485/1485 [==============================] - 1s 719us/step
loss : 0.601179301738739

categorical_accuracy : 0.8121212124824524
```




```
True Positives Count:                         1206
Total Cell Counts:                            1485
F1 Score (Weighted):                          0.8139503167895842
```

Out[62]:
```
([0.601179301738739, 0.8121212124824524],
 array([[5.0105453e-01, 3.8881734e-01, 2.4222458e-02, 8.5905619e-02],
        [9.8651844e-01, 1.1252666e-02, 4.3605280e-04, 1.7928163e-03],
        [8.8025909e-03, 2.3475823e-01, 6.2882078e-01, 1.2761846e-01],
        ...,
        [3.5821971e-02, 4.6506199e-01, 1.9978392e-01, 2.9933211e-01],
        [4.7715672e-04, 1.2048222e-02, 3.2339984e-01, 6.6407478e-01],
        [2.1530944e-04, 4.0741864e-01, 9.9059073e-03, 5.8246017e-01]],
       dtype=float32))
```

Cancerous Classification - Binary

Baseline Model Binary

In [33]:
```
df_all.head()
```

Out[33]:

	InstanceID	patientID	ImageName	cellTypeName	cellType	isCancerous	Source
0	22405	1	22405.png	fibroblast	0.0	0	Main
1	22406	1	22406.png	fibroblast	0.0	0	Main
2	22407	1	22407.png	fibroblast	0.0	0	Main
3	22408	1	22408.png	fibroblast	0.0	0	Main
4	22409	1	22409.png	fibroblast	0.0	0	Main

In [34]:
```
df_all['isCancerous_str'] = df_all['isCancerous'].apply(lambda x: 'No' if x == 0 else 'Yes' )
df_all['ImageName'] = df_all['ImageName'].astype('str')
df_all['isCancerous_str'] = df_all['isCancerous_str'].astype('str')
```

In [35]:
```
train_data_binary, test_data_binary = train_test_split(df_all, test_size=0.15, random_state=7)
train_data_binary, val_data_binary = train_test_split(train_data_binary, test_size=0.175, random_state=7)
```

In [36]:
```
train_data_binary.head()
```

Out[36]:

	InstanceID	patientID	ImageName	cellTypeName	cellType	isCancerous	Source	isCancerous_str
1215	4956	8	4956.png	epithelial	2.0	1	Main	Yes
3434	2369	77	2369.png	NaN	NaN	0	Extra	No
7615	808	48	808.png	epithelial	2.0	1	Main	Yes
8041	3379	51	3379.png	others	3.0	0	Main	No
6080	20548	37	20548.png	fibroblast	0.0	0	Main	No

In [37]:
```
val_data_binary.head()
```

Out[37]:

	InstanceID	patientID	ImageName	cellTypeName	cellType	isCancerous	Source	isCancerous_str
1076	12843	67	12843.png	NaN	NaN	0	Extra	No
4993	2878	80	2878.png	NaN	NaN	1	Extra	Yes
9614	21538	92	21538.png	NaN	NaN	0	Extra	No
5041	16881	29	16881.png	inflammatory	1.0	0	Main	No
2409	3126	14	3126.png	epithelial	2.0	1	Main	Yes

In [38]:
```
train_datagen_binary = ImageDataGenerator(rescale=1./255, data_format='channels_last')
val_datagen_binary = ImageDataGenerator(rescale=1./255, data_format='channels_last')

BATCH_SIZE = 32

train_gen_binary = train_datagen_binary.flow_from_dataframe(
        dataframe=train_data_binary,
        directory='./Image_classification_data/patch_images/',
        x_col="ImageName",
        y_col="isCancerous_str",
        target_size=(27, 27),
        batch_size=BATCH_SIZE,
        class_mode='binary')

val_gen_binary = val_datagen_binary.flow_from_dataframe(
        dataframe=val_data_binary,
        directory='./Image_classification_data/patch_images/',
        x_col="ImageName",
        y_col="isCancerous_str",
        target_size=(27, 27),
        batch_size=BATCH_SIZE,
        class_mode='binary',
        shuffle=False
)
```

```
Found 14221 validated image filenames belonging to 2 classes.
Found 3017 validated image filenames belonging to 2 classes.
```

In [39]:
```
cancerous_count = np.bincount(train_gen_binary.classes)
total = np.sum(cancerous_count)
binary_class_weight = {}
print(type(cancerous_count))
print(train_gen_binary.class_indices)
for i, each_type_count in enumerate(cancerous_count):
    binary_class_weight[i] = 1/each_type_count * total/len(cancerous_count)

print(f'Binary Class Weight: {binary_class_weight}')
```

```
<class 'numpy.ndarray'>
{'No': 0, 'Yes': 1}
Binary Class Weight: {0: 0.7609696061643835, 1: 1.4579659626819768}
```

Model Architecture

In [40]:
```
early_stop_binary = tf.keras.callbacks.EarlyStopping(
    monitor='val_binary_accuracy',
    verbose=1,
    patience=10,
    mode='max',
    restore_best_weights=True)
```

In [41]:
```
REG_RATE_BINARY = 0.0001
```

```
model_binary_1 = Sequential([

    Conv2D(32, (3, 3), padding="same", activation="relu", input_shape=(27, 27, 3)),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(64, (3, 3), padding="same", activation="relu"),
    Conv2D(64, (3, 3), padding="same", activation="relu"),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(128, (3, 3), padding="same", activation="relu"),
    Conv2D(128, (3, 3), padding="same", activation="relu"),
    MaxPooling2D(pool_size=(3,3)),

    Flatten(),
    Dense(512, activation="relu"),
    Dense(512, activation="relu"),

    Dense(1, activation='sigmoid'),
])

model_binary_1.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_10 (Conv2D)          (None, 27, 27, 32)        896

 max_pooling2d_6 (MaxPoolin  (None, 9, 9, 32)          0
 g2D)

 conv2d_11 (Conv2D)          (None, 9, 9, 64)          18496

 conv2d_12 (Conv2D)          (None, 9, 9, 64)          36928

 max_pooling2d_7 (MaxPoolin  (None, 3, 3, 64)          0
 g2D)

 conv2d_13 (Conv2D)          (None, 3, 3, 128)         73856

 conv2d_14 (Conv2D)          (None, 3, 3, 128)         147584

 max_pooling2d_8 (MaxPoolin  (None, 1, 1, 128)         0
 g2D)

 flatten_2 (Flatten)         (None, 128)               0

 dense_6 (Dense)             (None, 512)               66048

 dense_7 (Dense)             (None, 512)               262656

 dense_8 (Dense)             (None, 1)                 513

=================================================================
Total params: 606977 (2.32 MB)
Trainable params: 606977 (2.32 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

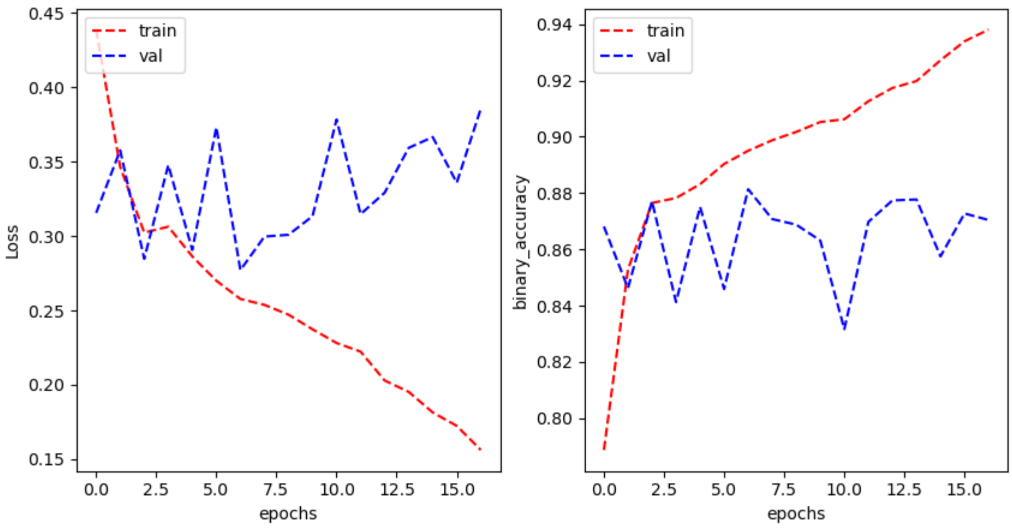
In [42]:
```
model_binary_1.compile("adam", loss=tf.losses.BinaryCrossentropy(), metrics=['binary_accuracy'])

tb_binary_cb= tf.keras.callbacks.TensorBoard(log_dir=LOG_DIR)

hist_binary_1 = model_binary_1.fit(
    train_gen_binary,
    epochs=100,
    validation_data=val_gen_binary,
    callbacks=[tb_binary_cb, early_stop_binary],
    class_weight=binary_class_weight
)
```

```
Epoch 1/100
2023-05-17 11:49:51.592704: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
	 [[{{node Placeholder/_0}}]]
443/445 [============================>.] - ETA: 0s - loss: 0.4391 - binary_accuracy: 0.7884
2023-05-17 11:49:57.779927: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
	 [[{{node Placeholder/_0}}]]
```

```
445/445 [==============================] - 7s 15ms/step - loss: 0.4389 - binary_accuracy: 0.7887 - val_loss: 0.3156 - val_binary_accu
racy: 0.8681
Epoch 2/100
445/445 [==============================] - 7s 15ms/step - loss: 0.3466 - binary_accuracy: 0.8528 - val_loss: 0.3577 - val_binary_accu
racy: 0.8462
Epoch 3/100
445/445 [==============================] - 7s 15ms/step - loss: 0.3023 - binary_accuracy: 0.8765 - val_loss: 0.2847 - val_binary_accu
racy: 0.8770
Epoch 4/100
445/445 [==============================] - 7s 15ms/step - loss: 0.3063 - binary_accuracy: 0.8782 - val_loss: 0.3477 - val_binary_accu
racy: 0.8412
Epoch 5/100
445/445 [==============================] - 7s 16ms/step - loss: 0.2863 - binary_accuracy: 0.8831 - val_loss: 0.2907 - val_binary_accu
racy: 0.8750
Epoch 6/100
445/445 [==============================] - 7s 15ms/step - loss: 0.2700 - binary_accuracy: 0.8903 - val_loss: 0.3732 - val_binary_accu
racy: 0.8459
Epoch 7/100
445/445 [==============================] - 7s 15ms/step - loss: 0.2577 - binary_accuracy: 0.8950 - val_loss: 0.2771 - val_binary_accu
racy: 0.8813
Epoch 8/100
445/445 [==============================] - 6s 14ms/step - loss: 0.2537 - binary_accuracy: 0.8987 - val_loss: 0.2997 - val_binary_accu
racy: 0.8707
Epoch 9/100
445/445 [==============================] - 7s 15ms/step - loss: 0.2471 - binary_accuracy: 0.9017 - val_loss: 0.3009 - val_binary_accu
racy: 0.8687
Epoch 10/100
445/445 [==============================] - 7s 15ms/step - loss: 0.2373 - binary_accuracy: 0.9052 - val_loss: 0.3133 - val_binary_accu
racy: 0.8631
Epoch 11/100
445/445 [==============================] - 7s 15ms/step - loss: 0.2281 - binary_accuracy: 0.9062 - val_loss: 0.3784 - val_binary_accu
racy: 0.8316
Epoch 12/100
445/445 [==============================] - 7s 15ms/step - loss: 0.2223 - binary_accuracy: 0.9126 - val_loss: 0.3148 - val_binary_accu
racy: 0.8697
Epoch 13/100
445/445 [==============================] - 7s 15ms/step - loss: 0.2028 - binary_accuracy: 0.9173 - val_loss: 0.3292 - val_binary_accu
racy: 0.8774
Epoch 14/100
445/445 [==============================] - 7s 15ms/step - loss: 0.1952 - binary_accuracy: 0.9198 - val_loss: 0.3593 - val_binary_accu
racy: 0.8777
Epoch 15/100
445/445 [==============================] - 7s 15ms/step - loss: 0.1814 - binary_accuracy: 0.9272 - val_loss: 0.3666 - val_binary_accu
racy: 0.8575
Epoch 16/100
445/445 [==============================] - 7s 15ms/step - loss: 0.1723 - binary_accuracy: 0.9339 - val_loss: 0.3359 - val_binary_accu
racy: 0.8727
Epoch 17/100
444/445 [============================>.] - ETA: 0s - loss: 0.1564 - binary_accuracy: 0.9379Restoring model weights from the end of th
e best epoch: 7.
445/445 [==============================] - 6s 14ms/step - loss: 0.1561 - binary_accuracy: 0.9380 - val_loss: 0.3857 - val_binary_accu
racy: 0.8704
Epoch 17: early stopping
```

Training and Valuation result

In [43]:
```
plot_learning_curve(
    hist_binary_1.history['loss'],
    hist_binary_1.history['val_loss'],
    hist_binary_1.history['binary_accuracy'],
    hist_binary_1.history['val_binary_accuracy'],
    metric_name='binary_accuracy'
)
```



Test & Evaluate

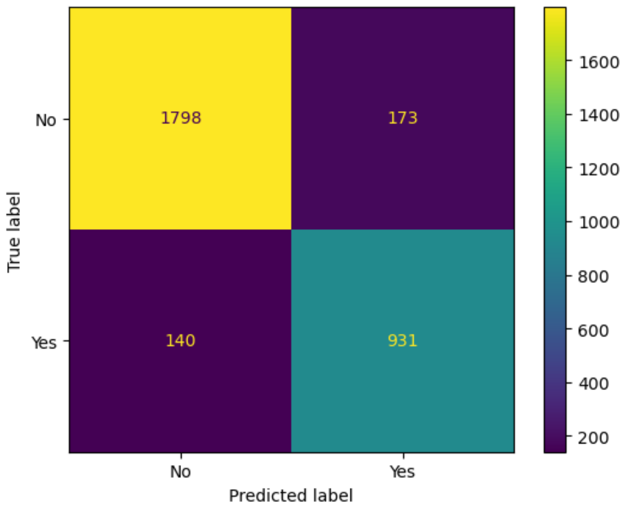
In [44]:
```
test_binary_datagen = ImageDataGenerator(rescale=1./255, data_format='channels_last')
TEST_BATCH_SIZE = 1
test_binary_gen = test_binary_datagen.flow_from_dataframe(
        dataframe=test_data_binary,
        directory='./Image_classification_data/patch_images/',
```

```
        x_col="ImageName",
        y_col="isCancerous_str",
        target_size=(27, 27),
        batch_size=TEST_BATCH_SIZE,
        class_mode='binary',
        shuffle=False
)
```

```
Found 3042 validated image filenames belonging to 2 classes.
```

In [45]:
```
eva, test_pred_binary_base = test_and_evaluate(model_binary_1, test_binary_gen, True)
```

```
 145/3042 [>.............................] - ETA: 3s - loss: 0.3376 - binary_accuracy: 0.8621
2023-05-17 11:51:45.084312: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
	 [[{{node Placeholder/_0}}]]
3042/3042 [==============================] - 3s 916us/step - loss: 0.2686 - binary_accuracy: 0.8971
 182/3042 [>.............................] - ETA: 2s
2023-05-17 11:51:47.892865: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
	 [[{{node Placeholder/_0}}]]
3042/3042 [==============================] - 2s 784us/step
loss : 0.2685542404651642

binary_accuracy : 0.8971071839332581
```




```
Non Cancerous Cell Detected (True Negatives):               1798
Non Cancerous Cell Incorrectly Detected (False Positives):  173
Cancerous Cell Missed (False Negatives):                    140
Cancerous Cell Detected (True Positives):                   931
Total Cell Counts:                                          3042
F1 Score (Weighted):                                        0.897453419089635
```

Oversampling Model - Binary

In [46]:
```
train_data_binary[train_data_binary['isCancerous']==0]['isCancerous_str'].value_counts()
```

Out[46]:
```
No    9344
Name: isCancerous_str, dtype: int64
```

In [47]:
```
largest_no = 50000

t_features = train_data_binary[train_data_binary['isCancerous']==1]['ImageName'].to_numpy()
t_labels = train_data_binary[train_data_binary['isCancerous']==1]['isCancerous_str'].to_numpy()
t_ids = np.arange(len(t_features))
t_choices = np.random.choice(t_ids, largest_no)
t_pick_feature = t_features[t_choices]
t_choices_labels = np.random.choice(t_labels, largest_no)


f_features = train_data_binary[train_data_binary['isCancerous']==0]['ImageName'].to_numpy()
f_labels = train_data_binary[train_data_binary['isCancerous']==0]['isCancerous_str'].to_numpy()
f_ids = np.arange(len(f_features))
f_choices = np.random.choice(f_ids, largest_no)
f_pick_feature = f_features[f_choices]
f_choices_labels = np.random.choice(f_labels, largest_no)


resampled_features = np.concatenate([t_pick_feature, f_pick_feature], axis=0)
resampled_labels = np.concatenate([t_choices_labels, f_choices_labels], axis=0)

order = np.arange(len(resampled_labels))
np.random.shuffle(order)
resampled_features = resampled_features[order]
resampled_labels = resampled_labels[order]

resampled_features_tr = resampled_features.transpose()
resampled_labels_tr = resampled_labels.transpose()

resampled_train_data_binary = pd.DataFrame({'ImageName': resampled_features_tr, 'isCancerous': resampled_labels_tr})
resampled_train_data_binary.head()
```

Out[47]:

	ImageName	isCancerous
0	19604.png	No
1	8328.png	Yes
2	1356.png	Yes
3	8968.png	Yes
4	11047.png	No

Model Architecture

In [48]:

```
train_datagen_aug_binary = ImageDataGenerator(
    rescale=1./255,
    data_format='channels_last',
    zoom_range=0.3,
    channel_shift_range=50,
    rotation_range=359,
    brightness_range=[1.0,1.2],
)

train_generator_aug_binary = train_datagen_aug_binary.flow_from_dataframe(
    dataframe=resampled_train_data_binary,
    directory='./Image_classification_data/patch_images/',
    x_col="ImageName",
    y_col="isCancerous",
    target_size=(27, 27),
    batch_size=BATCH_SIZE,
    class_mode='binary'
)

IMAGE_NO = 5
fig, axs = plt.subplots(1, IMAGE_NO, figsize=(IMAGE_NO, 3))
for i in range(IMAGE_NO):
    axs[i].axis('off')
    img, label = train_generator_aug.next()
    axs[i].imshow(img[0])
plt.show()
```

```
Found 100000 validated image filenames belonging to 2 classes.
```

In [49]:

```
REG_RATE = 0.001

model_binary_2 = Sequential([
    Conv2D(32, (3, 3), padding="same", activation="relu", input_shape=(27, 27, 3)),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(64, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    Conv2D(64, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    MaxPooling2D(pool_size=(3,3)),

    Conv2D(128, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    Conv2D(128, (3, 3), padding="same", activation="relu", kernel_regularizer=L2(REG_RATE)),
    MaxPooling2D(pool_size=(3,3)),

    Flatten(),
    Dense(512, activation="relu", kernel_regularizer=L2(REG_RATE)),
    Dropout(0.2),
    Dense(512, activation="relu", kernel_regularizer=L2(REG_RATE)),
    Dropout(0.2),

    Dense(1, activation='sigmoid'),
])

model_binary_2.compile("sgd", loss=tf.keras.losses.BinaryCrossentropy(), metrics=['binary_accuracy'])

tb_callback_binary_2 = tf.keras.callbacks.TensorBoard(log_dir=LOG_DIR)

model_binary_2.summary()
```

```
Model: "sequential_3"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 conv2d_15 (Conv2D)          (None, 27, 27, 32)        896       
                                                                 
 max_pooling2d_9 (MaxPoolin  (None, 9, 9, 32)          0         
 g2D)                                                            
                                                                 
 conv2d_16 (Conv2D)          (None, 9, 9, 64)          18496     
                                                                 
 conv2d_17 (Conv2D)          (None, 9, 9, 64)          36928     
                                                                 
 max_pooling2d_10 (MaxPooli  (None, 3, 3, 64)          0         
 ng2D)                                                           
                                                                 
 conv2d_18 (Conv2D)          (None, 3, 3, 128)         73856     
                                                                 
 conv2d_19 (Conv2D)          (None, 3, 3, 128)         147584    
                                                                 
 max_pooling2d_11 (MaxPooli  (None, 1, 1, 128)         0         
 ng2D)                                                           
                                                                 
 flatten_3 (Flatten)         (None, 128)               0         
                                                                 
 dense_9 (Dense)             (None, 512)               66048     
                                                                 
 dropout_2 (Dropout)         (None, 512)               0         
                                                                 
 dense_10 (Dense)            (None, 512)               262656    
                                                                 
 dropout_3 (Dropout)         (None, 512)               0         
                                                                 
 dense_11 (Dense)            (None, 1)                 513       
                                                                 
=================================================================
Total params: 606977 (2.32 MB)
Trainable params: 606977 (2.32 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

In [50]:
```
hist_binary_2 = model_binary_2.fit(
    train_generator_aug_binary,
    epochs=100,
    validation_data=val_gen_binary,
    callbacks=[tb_callback_binary_2, early_stop_binary]
)
```

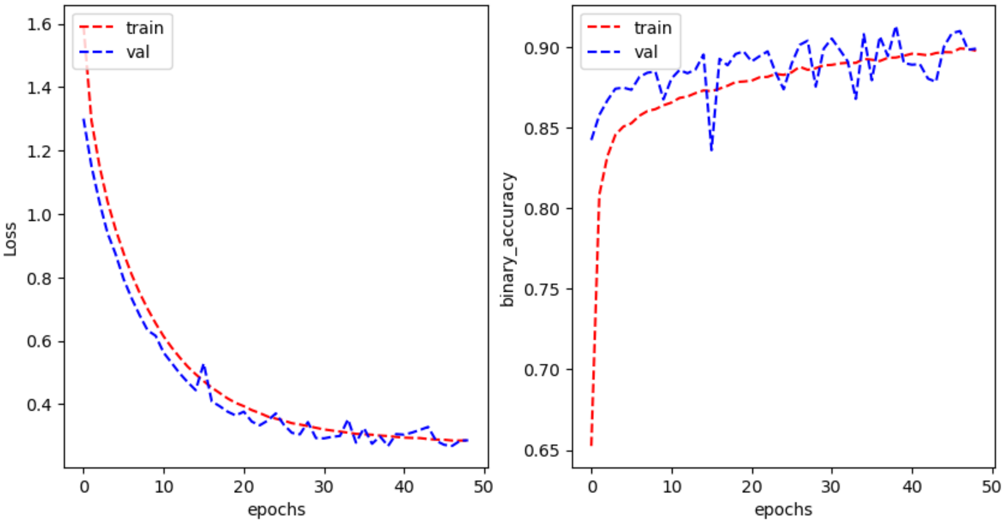
```
Epoch 1/100
2023-05-17 11:51:51.574647: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
3124/3125 [============================>.] - ETA: 0s - loss: 1.5938 - binary_accuracy: 0.6524
2023-05-17 11:52:34.290817: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
```

```
3125/3125 [==============================] - 43s 14ms/step - loss: 1.5937 - binary_accuracy: 0.6525 - val_loss: 1.3005 - val_binary_a
ccuracy: 0.8422
Epoch 2/100
3125/3125 [==============================] - 45s 15ms/step - loss: 1.2937 - binary_accuracy: 0.8083 - val_loss: 1.1504 - val_binary_a
ccuracy: 0.8578
Epoch 3/100
3125/3125 [==============================] - 46s 15ms/step - loss: 1.1509 - binary_accuracy: 0.8320 - val_loss: 1.0362 - val_binary_a
ccuracy: 0.8668
Epoch 4/100
3125/3125 [==============================] - 47s 15ms/step - loss: 1.0390 - binary_accuracy: 0.8454 - val_loss: 0.9395 - val_binary_a
ccuracy: 0.8740
Epoch 5/100
3125/3125 [==============================] - 48s 15ms/step - loss: 0.9520 - binary_accuracy: 0.8506 - val_loss: 0.8737 - val_binary_a
ccuracy: 0.8747
Epoch 6/100
3125/3125 [==============================] - 47s 15ms/step - loss: 0.8766 - binary_accuracy: 0.8526 - val_loss: 0.7949 - val_binary_a
ccuracy: 0.8734
Epoch 7/100
3125/3125 [==============================] - 45s 14ms/step - loss: 0.8095 - binary_accuracy: 0.8573 - val_loss: 0.7343 - val_binary_a
ccuracy: 0.8813
Epoch 8/100
3125/3125 [==============================] - 44s 14ms/step - loss: 0.7513 - binary_accuracy: 0.8602 - val_loss: 0.6807 - val_binary_a
ccuracy: 0.8840
Epoch 9/100
3125/3125 [==============================] - 45s 14ms/step - loss: 0.7005 - binary_accuracy: 0.8614 - val_loss: 0.6328 - val_binary_a
ccuracy: 0.8847
Epoch 10/100
3125/3125 [==============================] - 45s 15ms/step - loss: 0.6551 - binary_accuracy: 0.8638 - val_loss: 0.6157 - val_binary_a
ccuracy: 0.8674
Epoch 11/100
3125/3125 [==============================] - 48s 15ms/step - loss: 0.6138 - binary_accuracy: 0.8655 - val_loss: 0.5625 - val_binary_a
ccuracy: 0.8803
Epoch 12/100
3125/3125 [==============================] - 47s 15ms/step - loss: 0.5788 - binary_accuracy: 0.8683 - val_loss: 0.5300 - val_binary_a
ccuracy: 0.8856
Epoch 13/100
3125/3125 [==============================] - 45s 14ms/step - loss: 0.5474 - binary_accuracy: 0.8692 - val_loss: 0.4972 - val_binary_a
ccuracy: 0.8837
Epoch 14/100
3125/3125 [==============================] - 44s 14ms/step - loss: 0.5184 - binary_accuracy: 0.8713 - val_loss: 0.4693 - val_binary_a
ccuracy: 0.8860
Epoch 15/100
3125/3125 [==============================] - 45s 15ms/step - loss: 0.4944 - binary_accuracy: 0.8730 - val_loss: 0.4441 - val_binary_a
ccuracy: 0.8953
Epoch 16/100
3125/3125 [==============================] - 46s 15ms/step - loss: 0.4725 - binary_accuracy: 0.8725 - val_loss: 0.5287 - val_binary_a
ccuracy: 0.8359
Epoch 17/100
3125/3125 [==============================] - 48s 15ms/step - loss: 0.4522 - binary_accuracy: 0.8741 - val_loss: 0.4090 - val_binary_a
ccuracy: 0.8926
Epoch 18/100
3125/3125 [==============================] - 45s 14ms/step - loss: 0.4350 - binary_accuracy: 0.8759 - val_loss: 0.3935 - val_binary_a
ccuracy: 0.8886
Epoch 19/100
3125/3125 [==============================] - 45s 15ms/step - loss: 0.4178 - binary_accuracy: 0.8782 - val_loss: 0.3761 - val_binary_a
ccuracy: 0.8956
Epoch 20/100
3125/3125 [==============================] - 49s 16ms/step - loss: 0.4040 - binary_accuracy: 0.8785 - val_loss: 0.3643 - val_binary_a
ccuracy: 0.8972
Epoch 21/100
3125/3125 [==============================] - 45s 14ms/step - loss: 0.3937 - binary_accuracy: 0.8790 - val_loss: 0.3764 - val_binary_a
ccuracy: 0.8910
Epoch 22/100
3125/3125 [==============================] - 47s 15ms/step - loss: 0.3812 - binary_accuracy: 0.8812 - val_loss: 0.3450 - val_binary_a
ccuracy: 0.8943
Epoch 23/100
3125/3125 [==============================] - 46s 15ms/step - loss: 0.3719 - binary_accuracy: 0.8814 - val_loss: 0.3334 - val_binary_a
ccuracy: 0.8972
Epoch 24/100
3125/3125 [==============================] - 44s 14ms/step - loss: 0.3608 - binary_accuracy: 0.8832 - val_loss: 0.3484 - val_binary_a
ccuracy: 0.8840
Epoch 25/100
3125/3125 [==============================] - 47s 15ms/step - loss: 0.3543 - binary_accuracy: 0.8826 - val_loss: 0.3710 - val_binary_a
ccuracy: 0.8737
Epoch 26/100
3125/3125 [==============================] - 46s 15ms/step - loss: 0.3481 - binary_accuracy: 0.8842 - val_loss: 0.3351 - val_binary_a
ccuracy: 0.8896
Epoch 27/100
3125/3125 [==============================] - 50s 16ms/step - loss: 0.3400 - binary_accuracy: 0.8877 - val_loss: 0.3096 - val_binary_a
ccuracy: 0.9012
Epoch 28/100
3125/3125 [==============================] - 52s 17ms/step - loss: 0.3357 - binary_accuracy: 0.8858 - val_loss: 0.3048 - val_binary_a
ccuracy: 0.9039
Epoch 29/100
3125/3125 [==============================] - 187s 60ms/step - loss: 0.3310 - binary_accuracy: 0.8868 - val_loss: 0.3434 - val_binary_
accuracy: 0.8754
Epoch 30/100
3125/3125 [==============================] - 1621s 519ms/step - loss: 0.3255 - binary_accuracy: 0.8886 - val_loss: 0.2931 - val_binar
y_accuracy: 0.8989
Epoch 31/100
3125/3125 [==============================] - 174s 56ms/step - loss: 0.3203 - binary_accuracy: 0.8888 - val_loss: 0.2921 - val_binary_
accuracy: 0.9052
Epoch 32/100
3125/3125 [==============================] - 51s 16ms/step - loss: 0.3169 - binary_accuracy: 0.8898 - val_loss: 0.2968 - val_binary_a
ccuracy: 0.8982
Epoch 33/100
3125/3125 [==============================] - 49s 16ms/step - loss: 0.3135 - binary_accuracy: 0.8902 - val_loss: 0.2997 - val_binary_a
ccuracy: 0.8910
Epoch 34/100
3125/3125 [==============================] - 52s 17ms/step - loss: 0.3101 - binary_accuracy: 0.8901 - val_loss: 0.3523 - val_binary_a
```

```
ccuracy: 0.8677
Epoch 35/100
3125/3125 [==============================] - 50s 16ms/step - loss: 0.3064 - binary_accuracy: 0.8926 - val_loss: 0.2786 - val_binary_a
ccuracy: 0.9079
Epoch 36/100
3125/3125 [==============================] - 50s 16ms/step - loss: 0.3051 - binary_accuracy: 0.8920 - val_loss: 0.3247 - val_binary_a
ccuracy: 0.8794
Epoch 37/100
3125/3125 [==============================] - 50s 16ms/step - loss: 0.3036 - binary_accuracy: 0.8912 - val_loss: 0.2750 - val_binary_a
ccuracy: 0.9065
Epoch 38/100
3125/3125 [==============================] - 48s 15ms/step - loss: 0.3010 - binary_accuracy: 0.8932 - val_loss: 0.2983 - val_binary_a
ccuracy: 0.8943
Epoch 39/100
3125/3125 [==============================] - 49s 16ms/step - loss: 0.2995 - binary_accuracy: 0.8934 - val_loss: 0.2681 - val_binary_a
ccuracy: 0.9132
Epoch 40/100
3125/3125 [==============================] - 50s 16ms/step - loss: 0.2968 - binary_accuracy: 0.8945 - val_loss: 0.3056 - val_binary_a
ccuracy: 0.8900
Epoch 41/100
3125/3125 [==============================] - 50s 16ms/step - loss: 0.2944 - binary_accuracy: 0.8958 - val_loss: 0.3038 - val_binary_a
ccuracy: 0.8890
Epoch 42/100
3125/3125 [==============================] - 52s 17ms/step - loss: 0.2935 - binary_accuracy: 0.8954 - val_loss: 0.3105 - val_binary_a
ccuracy: 0.8893
Epoch 43/100
3125/3125 [==============================] - 52s 17ms/step - loss: 0.2930 - binary_accuracy: 0.8948 - val_loss: 0.3189 - val_binary_a
ccuracy: 0.8803
Epoch 44/100
3125/3125 [==============================] - 52s 17ms/step - loss: 0.2899 - binary_accuracy: 0.8962 - val_loss: 0.3283 - val_binary_a
ccuracy: 0.8784
Epoch 45/100
3125/3125 [==============================] - 50s 16ms/step - loss: 0.2883 - binary_accuracy: 0.8967 - val_loss: 0.2844 - val_binary_a
ccuracy: 0.9002
Epoch 46/100
3125/3125 [==============================] - 52s 17ms/step - loss: 0.2879 - binary_accuracy: 0.8967 - val_loss: 0.2718 - val_binary_a
ccuracy: 0.9085
Epoch 47/100
3125/3125 [==============================] - 52s 17ms/step - loss: 0.2853 - binary_accuracy: 0.8990 - val_loss: 0.2684 - val_binary_a
ccuracy: 0.9098
Epoch 48/100
3125/3125 [==============================] - 53s 17ms/step - loss: 0.2853 - binary_accuracy: 0.8987 - val_loss: 0.2847 - val_binary_a
ccuracy: 0.8982
Epoch 49/100
3124/3125 [============================>.] - ETA: 0s - loss: 0.2855 - binary_accuracy: 0.8976Restoring model weights from the end of
the best epoch: 39.
3125/3125 [==============================] - 51s 16ms/step - loss: 0.2855 - binary_accuracy: 0.8976 - val_loss: 0.2861 - val_binary_a
ccuracy: 0.8989
Epoch 49: early stopping
```

Training and Valuation result

In [51]:
```
plot_learning_curve(
    hist_binary_2.history['loss'],
    hist_binary_2.history['val_loss'],
    hist_binary_2.history['binary_accuracy'],
    hist_binary_2.history['val_binary_accuracy'],
    metric_name='binary_accuracy'
)
```

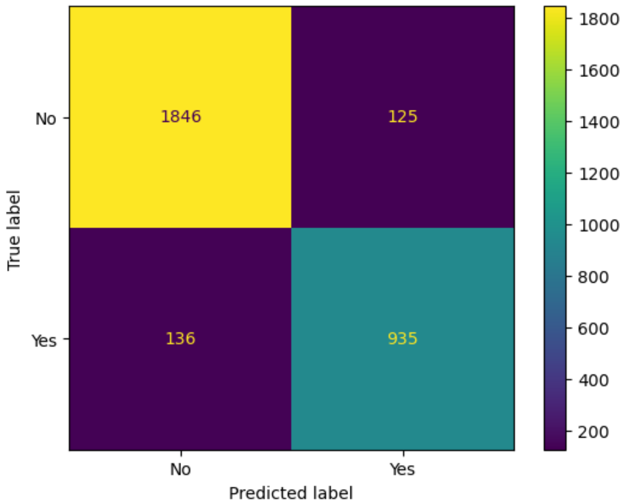


Test & Evaluate

In [52]:
```
eva, test_pred_binary_oversample = test_and_evaluate(model_binary_2, test_binary_gen, True)
```

```
 149/3042 [>.............................] - ETA: 2s - loss: 0.3449 - binary_accuracy: 0.8859
2023-05-17 13:01:42.401361: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting
(this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Pl
aceholder/_0' with dtype int32
         [[{{node Placeholder/_0}}]]
3042/3042 [==============================] - 3s 940us/step - loss: 0.2722 - binary_accuracy: 0.9142
 115/3042 [>.............................] - ETA: 2s
```

```
2023-05-17 13:01:45.289148: I tensorflow/core/common_runtime/executor.cc:1210] [/device:CPU:0] (DEBUG INFO) Executor start aborting (this does not indicate an error and you can ignore this message): INVALID_ARGUMENT: You must feed a value for placeholder tensor 'Placeholder/_0' with dtype int32
	 [[{{node Placeholder/_0}}]]
3042/3042 [==============================] - 3s 863us/step
loss : 0.27222928404808044

binary_accuracy : 0.9142012000083923
```




```
Non Cancerous Cell Detected (True Negatives):            1846
Non Cancerous Cell Incorrectly Detected (False Positives):  125
Cancerous Cell Missed (False Negatives):                  136
Cancerous Cell Detected (True Positives):                 935
Total Cell Counts:                                        3042
F1 Score (Weighted):                                      0.9140991171967641
```