0. Imports

[ ]:
```
# read in data from tiingo
from pandas_datareader import data as pdr
# basic dataframe and array manipulation
import numpy as np
import pandas as pd
from datetime import datetime
# data visualization
import matplotlib.pyplot as plt
%matplotlib inline
plt.style.use("ggplot")
# keras sequential model pipeline
import tensorflow as tf
from tensorflow.keras.layers import Conv1D, MaxPooling1D, MaxPooling2D, Flatten,␣
↪Dense, Dropout
from tensorflow.keras.layers import LSTM, ConvLSTM1D, TimeDistributed
from tensorflow.keras.callbacks import EarlyStopping
from tensorflow.keras.regularizers import L1, L2
from tensorflow.keras.metrics import mean_absolute_error, mean_squared_error
from sklearn.metrics import r2_score
from tensorflow.keras.utils import plot_model
# for GridSearch CV
from keras.wrappers.scikit_learn import KerasRegressor
from sklearn.model_selection import GridSearchCV
# for timing training
import timeit
# plotting results: formating x axis date
import matplotlib.dates as mdates
```

[ ]:
```
# get spy data from tiingo
with open('credentials/tiingo','r') as f:
    TIINGO_API_KEY = f.read().strip()
# get train data, 6 year
start=datetime(2010, 1, 1)  # start day
end=datetime(2016, 12, 31)  # end day
train_data = pdr.DataReader(["AAPL"], 'tiingo', start, end, api_key = TIINGO_API_KEY).
↪loc["AAPL"]
# get test data, 3 year, skipping covid boom period (2020 spring)
start=datetime(2017, 1, 1)  # start day
end=datetime(2019, 12, 31)  # end day
val_data = pdr.DataReader(["AAPL"], 'tiingo', start, end, api_key = TIINGO_API_KEY).
↪loc["AAPL"]
# get test data, 3 year, skipping covid boom period (2020 spring)
start=datetime(2020, 5, 1)  # start day
end=datetime(2023, 5, 1)  # end day
test_data = pdr.DataReader(["AAPL"], 'tiingo', start, end, api_key = TIINGO_API_KEY).
↪loc["AAPL"]
```

1. Data Preprocessing

```
[ ]: window_size = 14
def window_data(df, window_size):
    X = []
    y = []
    for i in range(1 , len(df) - window_size -1 , 1):
        first = df.iloc[i,2]
        temp = []
        temp2 = []
        for j in range(window_size):
            temp.append((df.iloc[i + j, 2] - first) / first)
        temp2.append((df.iloc[i + window_size, 2] - first) / first)
        X.append(np.array(temp).reshape(window_size, 1))
        y.append(np.array(temp2).reshape(1, 1))
    return X, y

X_train, y_train = window_data(train_data, window_size)
X_val, y_val = window_data(val_data, window_size)
X_test, y_test = window_data(test_data, window_size)

X_train = np.array(X_train)
X_val = np.array(X_val)
X_test = np.array(X_test)
y_train = np.array(y_train)
y_val = np.array(y_val)
y_test = np.array(y_test)

X_train = X_train.reshape(X_train.shape[0],1,window_size,1)
X_val = X_val.reshape(X_val.shape[0],1,window_size,1)
X_test = X_test.reshape(X_test.shape[0],1,window_size,1)
```

```
[ ]: print(X_train.shape)
print(X_val.shape)
print(X_test.shape)
```

```
(1746, 1, 14, 1)
(738, 1, 14, 1)
(739, 1, 14, 1)
```

2. Model construction

2.a Baseline model: FC-LSTM

2.a.(i) Hyperparameter Tuning

```
[ ]: def create_fc_lstm(dropout_rate=0.5, recurrent_dropout=0.5, lstm_units = 64):
    model = tf.keras.Sequential()
    model.add(LSTM(lstm_units, recurrent_dropout=recurrent_dropout,␣
 ↪return_sequences=True,
                   input_shape=(window_size, 1)))
    model.add(Dropout(dropout_rate))
```

```
    model.add(LSTM(lstm_units, recurrent_dropout=recurrent_dropout,activation='relu',␣
 ↪return_sequences=True))
    model.add(Dropout(dropout_rate))
    model.add(LSTM(lstm_units, recurrent_dropout=recurrent_dropout,activation='relu',␣
 ↪return_sequences=True))
    model.add(Dropout(dropout_rate))
    model.add(Flatten())
    model.add(Dense(1))
    model.compile(optimizer='adam', loss='mae', metrics=['mse', 'mae'])
    return model
# GridSearch CV
param_grid = {
    'dropout_rate': [0.3, 0.5],
    'recurrent_dropout' :[0.3, 0.5],
    'lstm_units': [32, 64, 128],
}
# create KerasRegressor and GridSearchCV objects
early_stopping = EarlyStopping(monitor='val_loss',patience=5)
tf.keras.backend.clear_session()
model = KerasRegressor(build_fn=create_fc_lstm, epochs=100, batch_size=32,
                       verbose=0, callbacks=[early_stopping])
grid = GridSearchCV(estimator=model, param_grid=param_grid, cv=3, verbose=0)

# perform Grid Search CV
grid_result = grid.fit(X_train.reshape((len(X_train), X_train.shape[2], X_train.
 ↪shape[3])),y_train,
                       validation_data=(X_val.reshape((len(X_val), X_val.shape[2],␣
 ↪X_val.shape[3])),y_val))
fc_lstm_best_params = grid_result.best_params_

# print results
print(f"Best params: {grid_result.best_params_}")
```

```
/anaconda3/lib/python3.7/site-packages/ipykernel_launcher.py:24: DeprecationWarning:
KerasRegressor is deprecated, use Sci-Keras (https://github.com/adriangb/scikeras)
instead. See https://www.adriangb.com/scikeras/stable/migration.html for help migrating.

Best params: {'dropout_rate': 0.3, 'lstm_units': 128, 'recurrent_dropout': 0.3}
```

2.a.(ii) Training the model

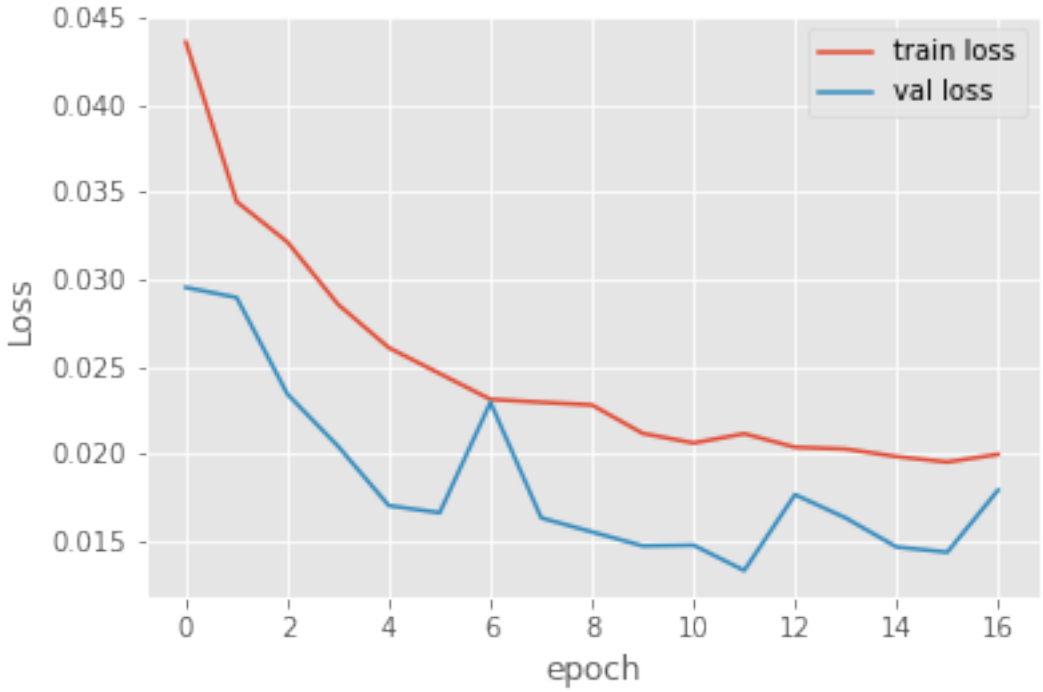
[ ]:
```
tf.keras.backend.clear_session()
fc_lstm = create_fc_lstm(dropout_rate=fc_lstm_best_params['dropout_rate'],
                         recurrent_dropout=fc_lstm_best_params['recurrent_dropout'],
                         lstm_units = fc_lstm_best_params['lstm_units'])
fc_lstm._name = "FC-LSTM"
early_stopping = EarlyStopping(monitor='val_loss',patience=5)
fc_lstm.summary()
```

```
Model: "FC-LSTM"

_________________________________________________________________
 Layer (type)                 Output Shape              Param #
=================================================================
```

```
 lstm (LSTM)                 (None, 14, 128)           66560

 dropout (Dropout)           (None, 14, 128)           0

 lstm_1 (LSTM)               (None, 14, 128)           131584

 dropout_1 (Dropout)         (None, 14, 128)           0

 lstm_2 (LSTM)               (None, 14, 128)           131584

 dropout_2 (Dropout)         (None, 14, 128)           0

 flatten (Flatten)           (None, 1792)              0

 dense (Dense)               (None, 1)                 1793

=================================================================
Total params: 331,521
Trainable params: 331,521
Non-trainable params: 0
_________________________________________________________________
```

[ ]:
```
start_time = timeit.default_timer()
fc_lstm_history = fc_lstm.fit(X_train.reshape((len(X_train), X_train.shape[2], X_train.
↪shape[3])),y_train,
                              validation_data=(X_val.reshape((len(X_val), X_val.
↪shape[2], X_val.shape[3])),y_val),
                                                  epochs=100,batch_size=32, verbose=0,␣
↪callbacks=[early_stopping])
fc_lstm_elapsed = timeit.default_timer() - start_time
plt.plot(fc_lstm_history.history['loss'], label='train loss')
plt.plot(fc_lstm_history.history['val_loss'], label='val loss')
plt.xlabel("epoch")
plt.ylabel("Loss")
plt.legend()
```

[ ]:
```
<matplotlib.legend.Legend at 0x15e0713c8>
```



2.b CNN-LSTM

2.b.(i) Hyperparameter tuning

[ ]:
```
# Use Grid Search to Tune drop out
def create_cnn_lstm(dropout_rate=0.5, recurrent_dropout=0.5, cnn_units=[32, 64, 128],
                    lstm_units = 64, kernel_size=5):
    model = tf.keras.Sequential()
    # CNN layers
    model.add(TimeDistributed(Conv1D(cnn_units[0], kernel_size=kernel_size,
                                     activation='relu', input_shape=(None,␣
↪window_size, 1))))
    model.add(TimeDistributed(Conv1D(cnn_units[1], kernel_size=kernel_size,␣
↪activation='relu')))
    model.add(TimeDistributed(Conv1D(cnn_units[2], kernel_size=kernel_size,␣
↪activation='relu')))
    model.add(TimeDistributed(MaxPooling1D(2)))
    model.add(TimeDistributed(Flatten()))
    # cnn_lstm.add(Dense(5, kernel_regularizer=L2(0.01)))
    # LSTM layers
    model.add(LSTM(lstm_units, recurrent_dropout=recurrent_dropout,␣
↪return_sequences=True))
    model.add(Dropout(dropout_rate))
    model.add(LSTM(lstm_units, recurrent_dropout=recurrent_dropout,␣
↪return_sequences=True))
    model.add(Dropout(dropout_rate))
    model.add(LSTM(lstm_units, recurrent_dropout=recurrent_dropout,␣
↪return_sequences=False))
    model.add(Dropout(dropout_rate))
```

```
    # FC layers, output
    model.add(Dense(1, activation='linear'))
    model.compile(optimizer='adam', loss='mae', metrics=['mse', 'mae'])
    return model
# GridSearch CV
param_grid = {
    'dropout_rate': [0.3, 0.5],
    'recurrent_dropout' :[0.3, 0.5],
    'cnn_units': [[32, 64, 128], [64, 64, 128]],
    'lstm_units': [32, 64, 128],
    'kernel_size': [3, 5]
}
# create KerasRegressor and GridSearchCV objects
early_stopping = EarlyStopping(monitor='val_loss',patience=5)
tf.keras.backend.clear_session()
model = KerasRegressor(build_fn=create_cnn_lstm, epochs=100, batch_size=32,
                       verbose=0, callbacks=[early_stopping])
grid = GridSearchCV(estimator=model, param_grid=param_grid, cv=3, verbose=0)

# perform Grid Search CV
grid_result = grid.fit(X_train, y_train, validation_data=(X_val, y_val))
cnn_lstm_best_params = grid_result.best_params_

# print results
print(f"Best params: {grid_result.best_params_}")
```

```
<ipython-input-12-be7f2ccfb87d>:35: DeprecationWarning: KerasRegressor is deprecated, use
Sci-Keras (https://github.com/adriangb/scikeras) instead. See
https://www.adriangb.com/scikeras/stable/migration.html for help migrating.
  model = KerasRegressor(build_fn=create_cnn_lstm, epochs=100, batch_size=32,

Best params: {'cnn_units': [32, 64, 128], 'dropout_rate': 0.3, 'kernel_size': 3,
'lstm_units': 128, 'recurrent_dropout': 0.5}
```

2.b.(ii) Training the model

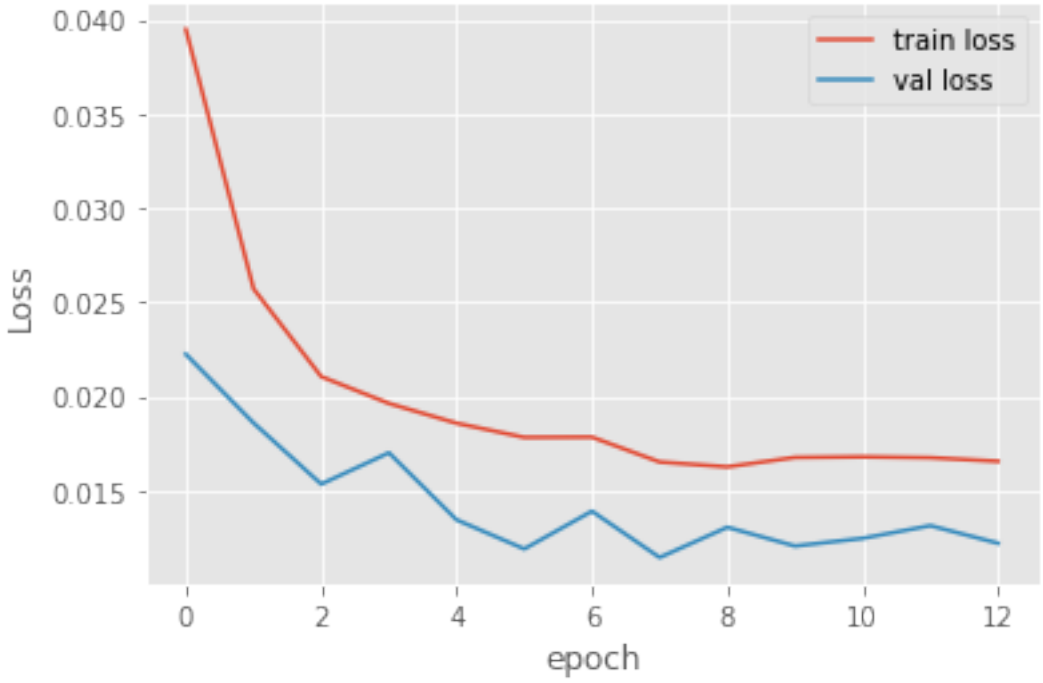
[ ]:
```
tf.keras.backend.clear_session()
cnn_lstm = create_cnn_lstm(dropout_rate=cnn_lstm_best_params['dropout_rate'],
                           recurrent_dropout=cnn_lstm_best_params['recurrent_dropout'],
                           cnn_units=cnn_lstm_best_params['cnn_units'],
                           lstm_units=cnn_lstm_best_params['lstm_units'],
                           kernel_size=cnn_lstm_best_params['kernel_size'])
cnn_lstm._name = "CNN-LSTM"
early_stopping = EarlyStopping(monitor='val_loss',patience=5)
cnn_lstm.build(input_shape=(len(X_train),None, window_size, 1))
cnn_lstm.summary()
```

```
Model: "CNN-LSTM"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 time_distributed (TimeDistr  (1746, None, 12, 32)     128
 ibuted)
```

```
time_distributed_1 (TimeDis  (1746, None, 10, 64)     6208
tributed)

time_distributed_2 (TimeDis  (1746, None, 8, 128)     24704
tributed)

time_distributed_3 (TimeDis  (1746, None, 4, 128)     0
tributed)

time_distributed_4 (TimeDis  (1746, None, 512)        0
tributed)

lstm (LSTM)                  (1746, None, 128)        328192

dropout (Dropout)            (1746, None, 128)        0

lstm_1 (LSTM)                (1746, None, 128)        131584

dropout_1 (Dropout)          (1746, None, 128)        0

lstm_2 (LSTM)                (1746, 128)              131584

dropout_2 (Dropout)          (1746, 128)              0

dense (Dense)                (1746, 1)                129

=================================================================
Total params: 622,529
Trainable params: 622,529
Non-trainable params: 0
_________________________________________________________________
```

[ ]:
```
start_time = timeit.default_timer()
cnn_lstm_history = cnn_lstm.fit(X_train, y_train, validation_data=(X_val,y_val),
                    epochs=100,batch_size=32, verbose=0, callbacks=[early_stopping])
cnn_lstm_elapsed = timeit.default_timer() - start_time
plt.plot(cnn_lstm_history.history['loss'], label='train loss')
plt.plot(cnn_lstm_history.history['val_loss'], label='val loss')
plt.xlabel("epoch")
plt.ylabel("Loss")
plt.legend()
```

[ ]:
```
<matplotlib.legend.Legend at 0x159512780>
```



2.c ConVLSTM

2.c.(i) Hyperparameter tuning

[ ]:
```
def create_convlstm(dropout_rate=0.5, recurrent_dropout=0.5, units=[64,64,128],␣
↪kernel_size=5):
    model = tf.keras.Sequential()
    model.add(ConvLSTM1D(filters=units[0], recurrent_dropout=recurrent_dropout,␣
↪kernel_size=kernel_size,
                         padding="same", input_shape=(None, window_size, 1),␣
↪return_sequences=True))
    model.add(Dropout(dropout_rate))
    model.add(ConvLSTM1D(filters=units[1], recurrent_dropout=recurrent_dropout,␣
↪kernel_size=kernel_size,
                         padding="same", return_sequences=True))
    model.add(Dropout(dropout_rate))
    model.add(ConvLSTM1D(filters=units[2], recurrent_dropout=recurrent_dropout,␣
↪kernel_size=kernel_size,
                         padding="same", return_sequences=False))
    model.add(Dropout(dropout_rate))
    model.add(Flatten())
    model.add(Dense(1))
    model.compile(optimizer='adam', loss='mae', metrics=['mse', 'mae'])
    return model
# GridSearch CV
param_grid = {
    'dropout_rate': [0.3, 0.5],
    'recurrent_dropout' :[0.3, 0.5],
    'units': [[128, 64, 32],[32, 64, 128],[64, 64, 64]],
```

```
    'kernel_size': [3, 5]
}
# create KerasRegressor and GridSearchCV objects
early_stopping = EarlyStopping(monitor='val_loss',patience=5)
model = KerasRegressor(build_fn=create_convlstm, epochs=100, batch_size=32,
                       verbose=0, callbacks=[early_stopping])
grid = GridSearchCV(estimator=model, param_grid=param_grid, cv=3, verbose=0)

# perform Grid Search CV
grid_result = grid.fit(X_train, y_train, validation_data=(X_val, y_val))
convlstm_best_params = grid_result.best_params_

# print results
print(f"Best params: {grid_result.best_params_}")
```

```
<ipython-input-15-e965e00549af>:25: DeprecationWarning: KerasRegressor is deprecated, use
Sci-Keras (https://github.com/adriangb/scikeras) instead. See
https://www.adriangb.com/scikeras/stable/migration.html for help migrating.
  model = KerasRegressor(build_fn=create_convlstm, epochs=100, batch_size=32,

Best params: {'dropout_rate': 0.3, 'kernel_size': 5, 'recurrent_dropout': 0.5, 'units':
[128, 64, 32]}
```

2.c.(ii) Training the model

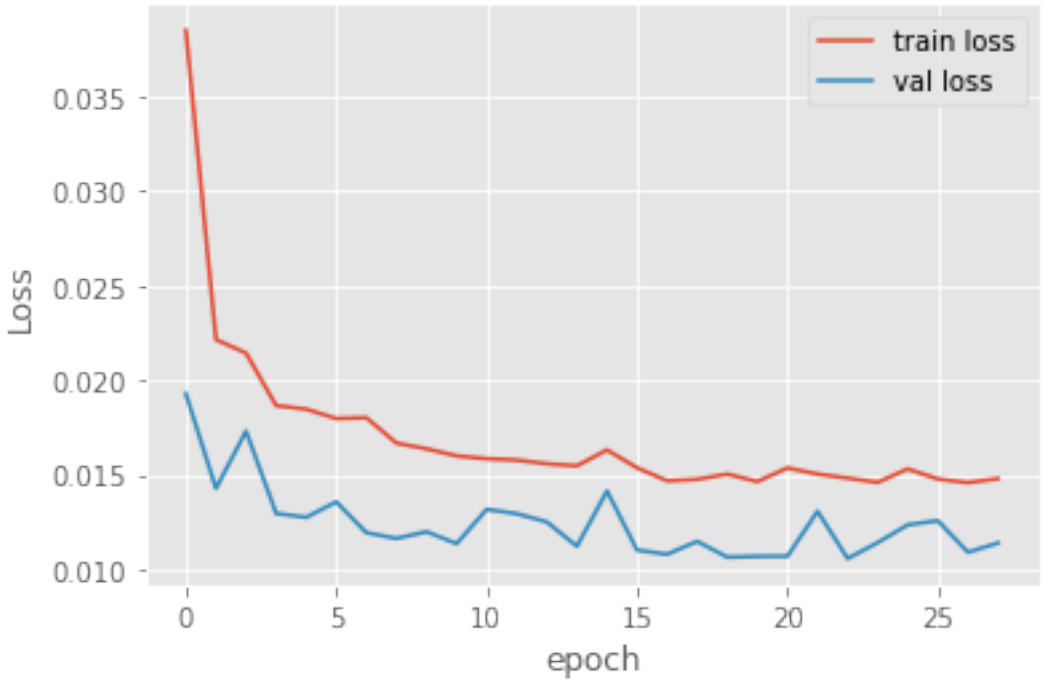
[ ]:
```
tf.keras.backend.clear_session()
convlstm = create_convlstm(dropout_rate=convlstm_best_params['dropout_rate'],
                           recurrent_dropout=convlstm_best_params['recurrent_dropout'],
                           units=convlstm_best_params['units'],
                           kernel_size=convlstm_best_params['kernel_size'])
convlstm._name = "ConVLSTM"
early_stopping = EarlyStopping(monitor='val_loss',patience=5)
convlstm.build(input_shape=(len(X_train),None, 30, 1))
convlstm.summary()
```

```
Model: "ConVLSTM"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv_lstm1d (ConvLSTM1D)    (None, None, 14, 128)     330752

 dropout (Dropout)           (None, None, 14, 128)     0

 conv_lstm1d_1 (ConvLSTM1D)  (None, None, 14, 64)      246016

 dropout_1 (Dropout)         (None, None, 14, 64)      0

 conv_lstm1d_2 (ConvLSTM1D)  (None, 14, 32)            61568

 dropout_2 (Dropout)         (None, 14, 32)            0

 flatten (Flatten)           (None, 448)               0
```

```
 dense (Dense)               (None, 1)                 449

=================================================================
Total params: 638,785
Trainable params: 638,785
Non-trainable params: 0
_________________________________________________________________
```

[ ]:
```
start_time = timeit.default_timer()
convlstm_history = convlstm.fit(X_train, y_train,␣
 ↪validation_data=(X_val,y_val),epochs=100,
                                batch_size=32, verbose=0, callbacks=[early_stopping])
convlstm_elapsed = timeit.default_timer() - start_time
plt.plot(convlstm_history.history['loss'], label='train loss')
plt.plot(convlstm_history.history['val_loss'], label='val loss')
plt.xlabel("epoch")
plt.ylabel("Loss")
plt.legend()
```

[ ]:
```
<matplotlib.legend.Legend at 0x161f34ac8>
```



3. Testing Phase

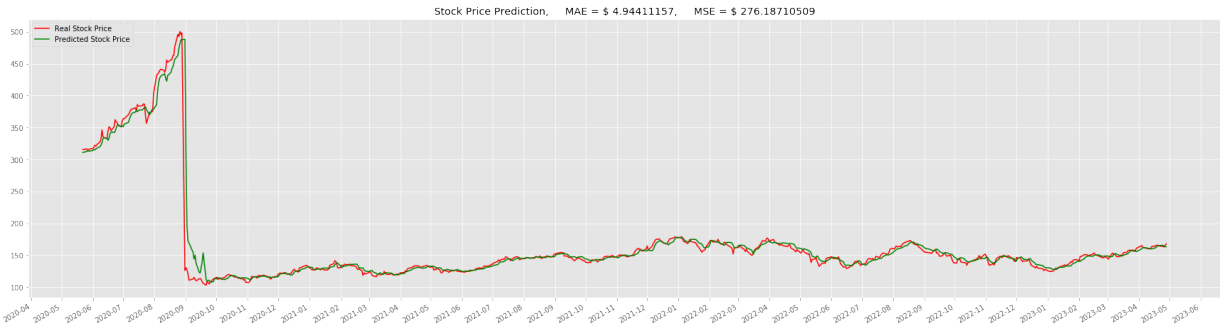
[ ]:
```
def plot_stock_prediction(window,model,X_test):
    test_result = model.evaluate(X_test, y_test)
    predicted = model.predict(X_test)
    true_Y = test_data['low'].iloc[(window+1):-1]
    true_Y_prev = test_data['low'].iloc[1:-1-window]
    df_test_time = true_Y.index.date
```

```
    pred_Y = (np.array(predicted[:,0])*true_Y_prev)+true_Y_prev
    print("R2 score of ",model._name,": ",r2_score(y_test.reshape(-1,1), predicted))
    # plot test data
    %matplotlib inline
    fig, ax = plt.subplots(figsize=(30, 8))
    monthly_locator = mdates.MonthLocator()
    half_year_locator = mdates.MonthLocator(interval=1)
    year_month_formatter = mdates.DateFormatter("%Y-%m")
    ax.xaxis.set_major_locator(half_year_locator)
    ax.xaxis.set_minor_locator(monthly_locator)
    ax.xaxis.set_major_formatter(year_month_formatter)
    ax.plot(np.array(df_test_time), true_Y,color = 'red', label = 'Real Stock Price')
    ax.plot(np.array(df_test_time), pred_Y,color = 'green', label = 'Predicted Stock␣
↪Price')
    ax.title.set_text(f'Stock Price Prediction, \
    MAE = \$ {round(float(mean_absolute_error(pred_Y,true_Y)),8)}, \
    MSE = \$ {round(float(mean_squared_error(true_Y,pred_Y)),8)}')
    ax.legend(loc='upper left')
    fig.autofmt_xdate()
```

3.a FC-LSTM

[ ]:
```
plot_stock_prediction(window_size,fc_lstm,X_test.reshape((len(X_test), X_test.
↪shape[2], X_test.shape[3])))
```

```
24/24 [==============================] - 1s 40ms/step - loss: 0.0241 - mse: 0.0020 - mae:
0.0241
24/24 [==============================] - 1s 34ms/step
R2 score of  FC-LSTM :  0.8740441414805302
```



[ ]:
```
print("Model training time:",fc_lstm_elapsed)
```

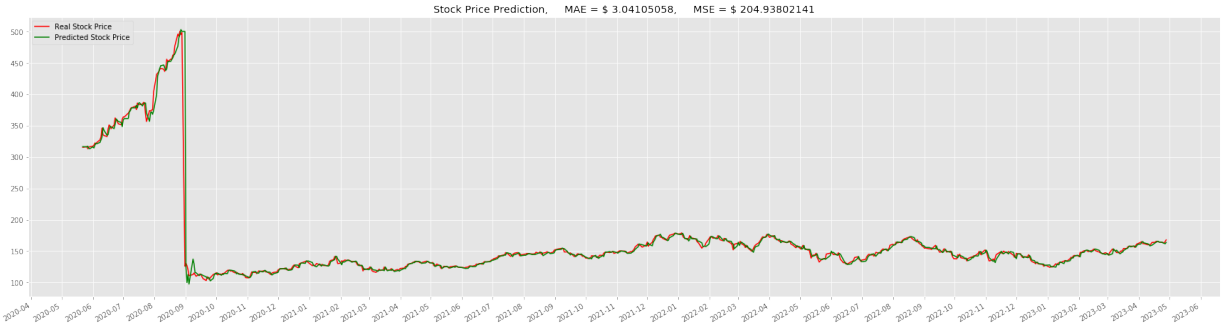
```
Model training time: 94.75706969799921
```

3.b CNN-LSTM

[ ]:
```
plot_stock_prediction(window_size,cnn_lstm,X_test)
```

```
24/24 [==============================] - 0s 11ms/step - loss: 0.0160 - mse: 0.0014 - mae:
0.0160
```

```
24/24 [==============================] - 0s 10ms/step
R2 score of  CNN-LSTM :  0.9139324437237274
```



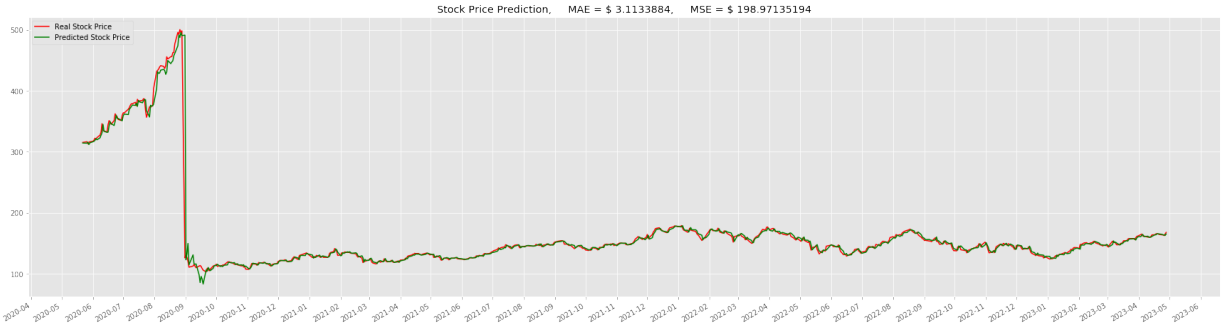
[ ]:
```
print("Model training time:",cnn_lstm_elapsed)
```

```
Model training time: 35.57562987100005
```

3.c ConVLSTM

[ ]:
```
plot_stock_prediction(window_size,convlstm,X_test)
```

```
24/24 [==============================] - 1s 31ms/step - loss: 0.0157 - mse: 0.0013 - mae:
0.0157
24/24 [==============================] - 1s 31ms/step
R2 score of  ConVLSTM :  0.9177376534570053
```



[ ]:
```
print("Model training time:",convlstm_elapsed)
```

```
Model training time: 161.20439217799958
```