```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from imblearn.over_sampling import SMOTE
from datetime import datetime, timedelta
FILENAMES = ['participants','blood_pressure','heart_rate','hrv_measurements','surveys','scales_description
URL = 'https://raw.githubusercontent.com/Welltory/hrv-covid19/master/data/'
EXTENSION = '.csv'
dfs = {}
for fn in FILENAMES:
  dfs[fn] = pd.read_csv(URL + fn + EXTENSION)
```

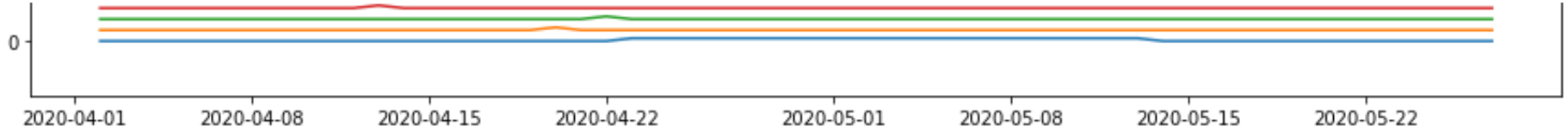
Preprocessing

Covid

```
# Mapping for covid variables
# https://github.com/Welltory/hrv-covid19/blob/master/data/scales_description.csv
vals = {'H': 1, 'M': 1, 'L': 0}
keys = ['S_CORONA', 'S_COVID_OVERALL']
maps = [{1: 'H', 2: 'H', 3: 'M', 4: 'L', 5: 'L'},
        {1: 'L', 2: 'M', 3: 'M', 4: 'H', 5: 'H', 6: 'H'}]

# Initial processing
df = dfs['surveys'].copy()
df['created_at'] = pd.to_datetime(df['created_at'])
df = df.loc[df['scale'].isin(keys)]
for i, key in enumerate(keys):
  df.loc[df['scale'] == key, 'value'] = df.loc[df['scale'] == key, 'value'].map(maps[i])
```

```
df = df.drop(columns=['text', 'scale'])
df = df.replace({'value': vals})

# Pivot to make index the userid and columns each day
df = df.copy().pivot_table(index='user_code', columns='created_at', values='value', aggfunc=np.max).fillna
df = df.reset_index()
df = df.set_index('user_code')
df.columns.name = None
df.index.name = None

# Pad an extra day for envelope
df.insert(0, min(df) - timedelta(1), 0.0)
df.insert(0, max(df) + timedelta(1), 0.0)

# Envelope covid data
def env(y):
  y1 = y.replace(to_replace=0, method='ffill')
  y2 = y.replace(to_replace=0, method='bfill')
  y3 = y1 & y2
  return y3
df = df.astype('int').apply(lambda y: env(y), axis=1)

# # Remove empty rows
# df = df[(df!=0).any(1)].copy()

# # Remove rows where covid symptoms are less than 1 week
# df = df[df.sum(axis=1) > 7].copy();

# Plot
# Each line is a survey response
plt.figure(figsize=(15,12))
for i in range(len(df)):
  x = df.iloc[i,1:].index
  y = df.iloc[i,1:].values + i*4
  plt.plot(x, y)

# Save for later
```

```
50 # Save for later
51 df_covid = df.copy()
52
53 #print(df_covid.head())
```



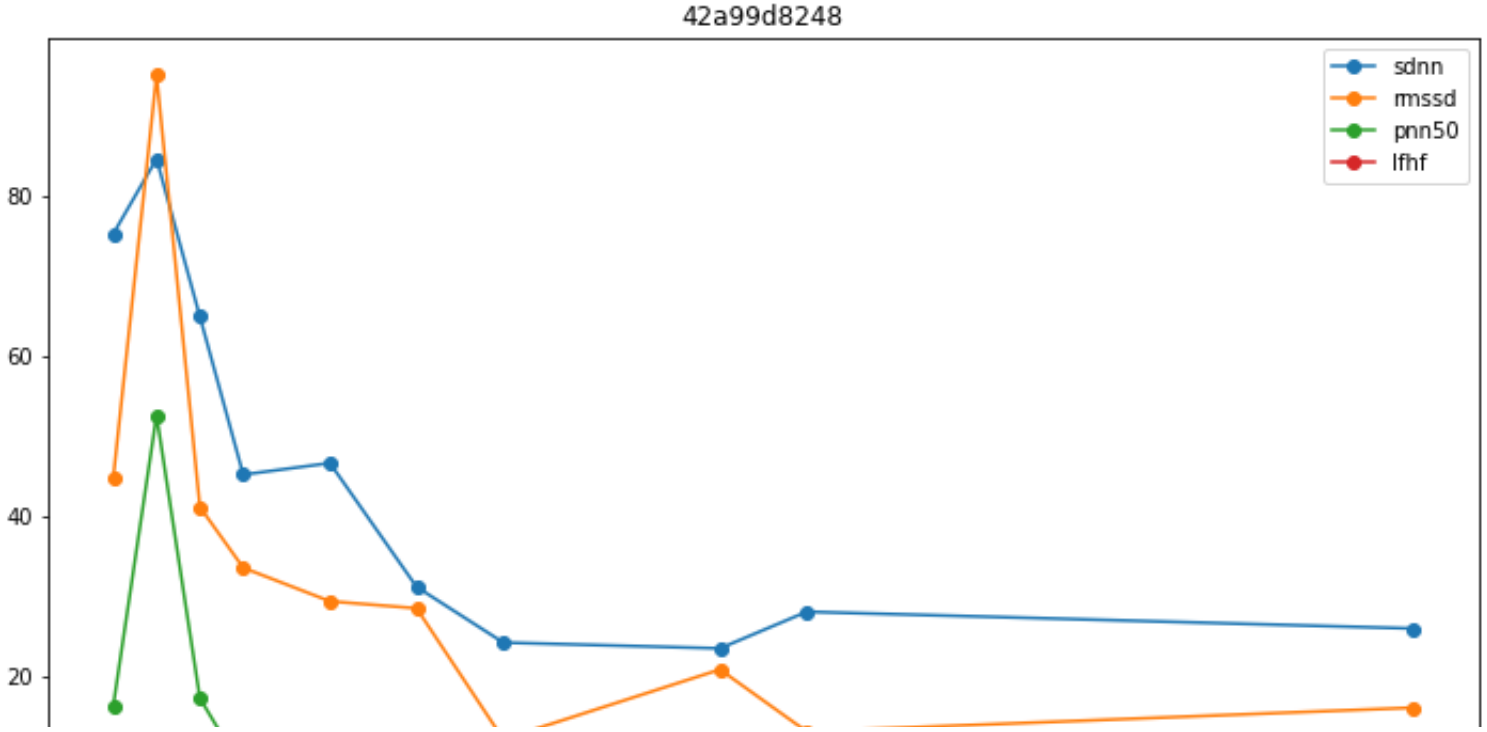
HRV

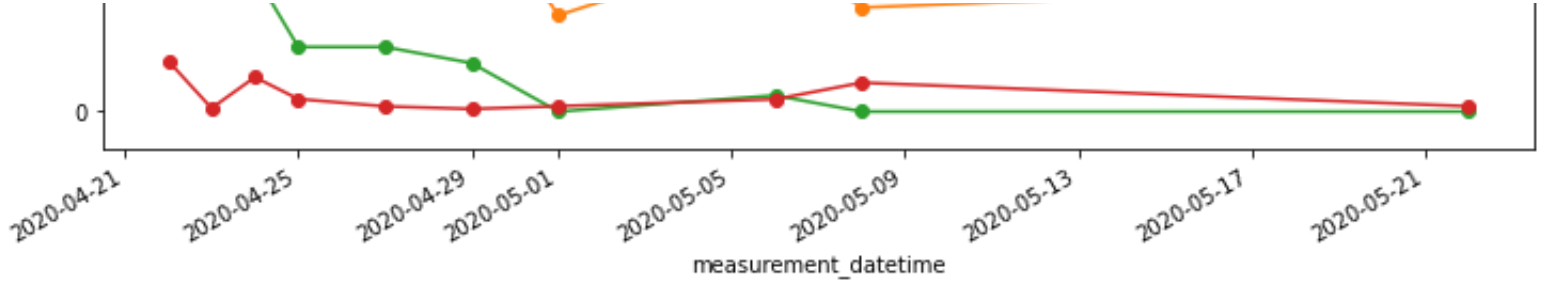
```
# HRV Data (Colman)

df_hrv = dfs['hrv_measurements']

# print the columns to see what data does it have
#print(df_hrv.columns)

# let's look at the datetime column
#print(df_hrv['measurement_datetime'].unique())

# We get a list of dates and use it as the x-axis of the time series (TODO: probably need a better way)
#dlist = pd.to_datetime(df_hrv['measurement_datetime']).dt.date
#dlist = pd.to_datetime(dlist).dt.normalize() # convert from object to datetime[ns]
#dlist = dlist.unique() # turns out only 172 days have measurements

# Note that the measurement is in date + time, but we are predicting the onset date only
# so we have to combine measurement of the same date into one

# get list of column names for new dataframes
#column_names = df_hrv.columns
#column_names = column_names.drop(labels=['user_code', 'measurement_datetime']) # remove unnecessary colum

# prepare to construct a dataframe for each participant (TODO: is there better approach for a 3D dataframe
df_hrv_pp = {}
# get list of participants
plist = df_hrv['user_code'].unique()
```

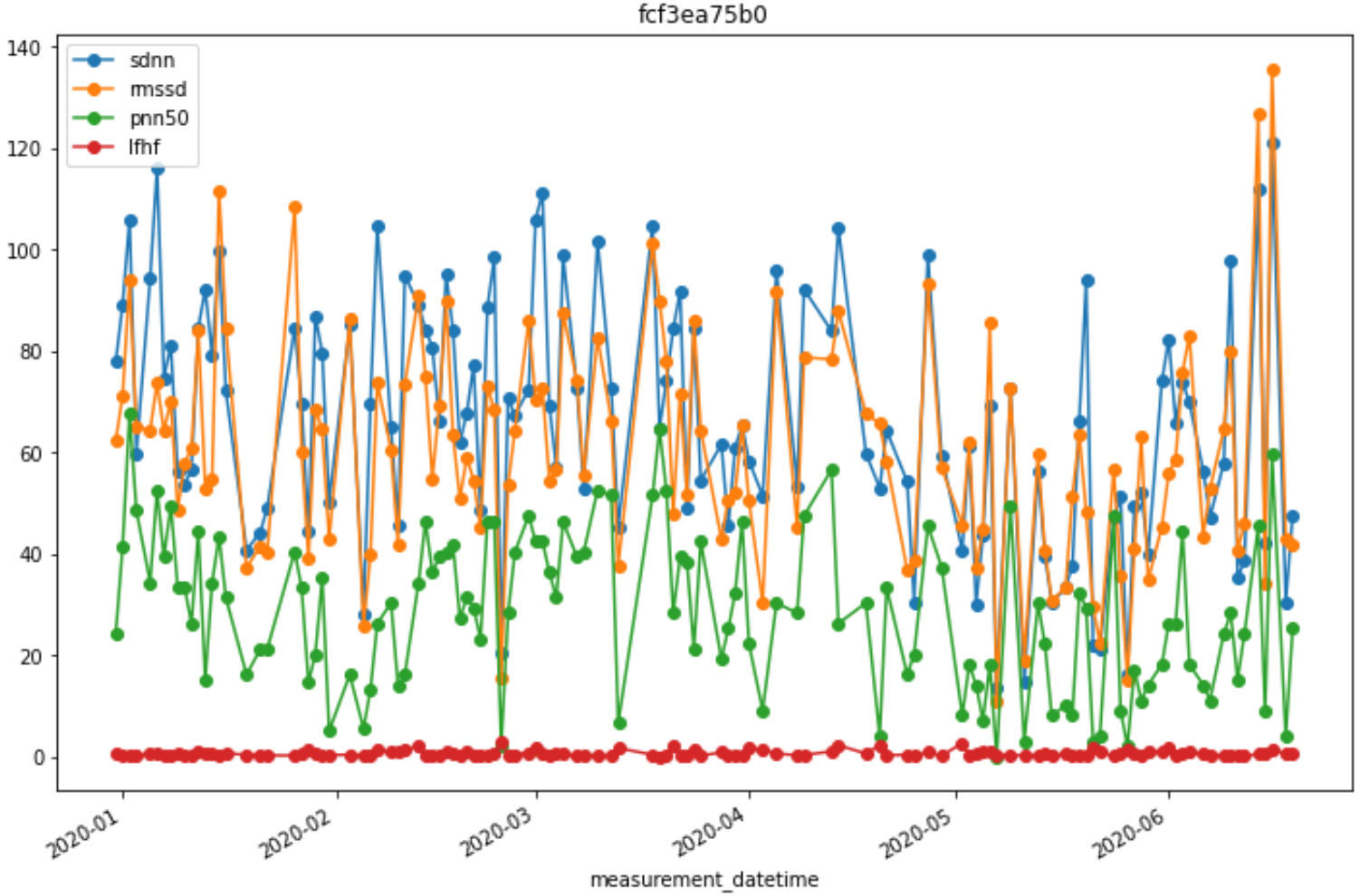
```
27
28 # start with an naive approach: we only get the first entry and drop the remaining ones
29 # (i.e., we take the first measurement of the day to represent the whole day)
30 # iterate participant
31 plist_used = []
32 for p in plist:
33   # filter out measurements and drop NaN
34   tmp = df_hrv.loc[df_hrv['user_code'] == p].copy().dropna()
35
36   # TODO drop data if it does not fulfill requirement (e.g., less than 5 entries)
37   if tmp.shape[0] < 3:
38     continue
39
40   # convert datetime to date only
41   tmp['measurement_datetime'] = pd.to_datetime(tmp['measurement_datetime']).dt.date
42   tmp['measurement_datetime'] = pd.to_datetime(tmp['measurement_datetime']).dt.normalize() # convert from
43   #tmp['measurement_datetime'] =  tmp['measurement_datetime'].dt.strftime('%Y-%m-%d')
44   # drop user_code column
45   tmp = tmp.drop(columns=['user_code', 'rr_code', 'time_of_day', 'how_feel', 'how_mood', 'how_sleep', 'rr_
46
47   # set date time as key
48   tmp.set_index('measurement_datetime', inplace=True)
49
50   # check if datetime is unique
51   if not tmp.index.is_unique:
52     # calculate mean for duplicates
53     tmp = tmp.reset_index().pivot_table(columns=["measurement_datetime"]).T
54
55   # drop duplicates
56   #tmp.drop_duplicates(keep='first')
57
58   # set dataframe
59   df_hrv_pp[p] = tmp
60   plist_used.append(p)
61
62 print("Extracted: " + str(len(df_hrv_pp)) + " participants")
```

```
63
64 # let's randomly plot one participant
65 import random
66 user_code, df_hrv_random = random.choice(list(df_hrv_pp.items()))
67
68 #print(df_hrv_random)
69 df_hrv_random.plot(y=['sdnn','rmssd','pnn50','lfhf'], kind='line', marker='o', figsize=(12, 8), title=user
70
71 # also, fcf3ea75b0 is interesting to look at
72 user_code = 'fcf3ea75b0'
73 df_hrv_pp[user_code].plot(y=['sdnn','rmssd','pnn50','lfhf'], kind='line', marker='o', figsize=(12, 8), tit
```

```
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:41: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.h
Extracted: 60 participants
<matplotlib.axes._subplots.AxesSubplot at 0x7f2a96584f90>
```








```
# # assign 1 if user_code is in df_p, 0 if not
```

```
# old_df_sleep = old_df_sleep.assign(InDFP = old_df_sleep.user_code.isin(df_covid.index).astype(int))
# # only keep user_codes that were in df_p, drop extra column
# old_df_sleep = old_df_sleep[old_df_sleep.InDFP != 0].drop(columns=['InDFP'])

#temp_df_hrv = pd.DataFrame(df_hrv_pp)
sklearn_covid = df_covid.assign(InDF = df_covid.index.isin(df_hrv_pp.keys()).astype(int))
sklearn_covid = sklearn_covid[sklearn_covid.InDF != 0].drop(columns=['InDF'])
#print(sklearn_covid.shape)
covid_codes = sklearn_covid.index.tolist()
covid_dates = sklearn_covid.columns.tolist()

temp_df_hrv = df_hrv_pp.copy()
for key in df_hrv_pp.keys():
    if key not in sklearn_covid.index:
        del temp_df_hrv[key]

col_date = 'measurement_datetime'
dates = []
all_dates = []
for key in temp_df_hrv.keys():
    these_dates = temp_df_hrv[key].index.tolist()
    for date in these_dates:
        if date not in dates and date in covid_dates:
            dates.append(date)
# print(dates)
for i in range(len(dates)):
    dates[i] = dates[i].to_pydatetime()
    dates[i] = dates[i].strftime("%Y-%m-%d")
# print(dates)
# print(len(temp_df_hrv.keys()), len(dates))
# print(temp_df_hrv[covid_codes[0]])
# print(temp_df_hrv[covid_codes[0]].loc[dates[0]]['amo'])

combo_index = []
for code in covid_codes:
    for date in dates:
```

```
        combo_index.append(code + "_" + str(date))

full_hrv_dict = {}
full_covid_dict = {}
hrv_columns = temp_df_hrv[covid_codes[0]].columns.tolist()
for col in hrv_columns:
    full_hrv_dict[col] = []
full_hrv_dict['covid'] = []

errors = 0
for code in covid_codes:
    for date in dates:
        for col in hrv_columns:
            try:
                full_hrv_dict[col].append(temp_df_hrv[code].loc[date][col])
            except:
                full_hrv_dict[col].append(0.0)
        full_hrv_dict['covid'].append(int(sklearn_covid.loc[code][date]))

sklearn_hrv = pd.DataFrame(full_hrv_dict, index=combo_index)
# test_clf = LogisticRegression(random_state=0).fit(df_covid, df_hrv_pp)
```

Sleep

```
# Sleep data (Hunter)
# 1. Bring in sleep data
# 2. Filter by patient ID and dates
# 3. Prepare dataframe for LR or other ML model

#print(df_covid)

old_df_sleep = dfs['sleep']
# drop columns that aren't filled for all users
```

```
old_df_sleep = old_df_sleep.drop(columns=['sleep_awake_duration', 'sleep_rem_duration', 'sleep_light_durat
old_df_sleep = old_df_sleep.drop(columns=['pulse_min', 'pulse_max', 'pulse_average'])
old_df_sleep = old_df_sleep.drop(columns=['sleep_begin', 'sleep_end'])
# assign 1 if user_code is in df_p, 0 if not
old_df_sleep = old_df_sleep.assign(InDFP = old_df_sleep.user_code.isin(df_covid.index).astype(int))
# only keep user_codes that were in df_p, drop extra column
old_df_sleep = old_df_sleep[old_df_sleep.InDFP != 0].drop(columns=['InDFP'])
# print(old_df_sleep)

sleep_columns = list(old_df_sleep.day.unique())
sleep_index = list(old_df_sleep.user_code.unique())
user_dict = {}
for code in sleep_index:
    user_dict[code] = {}

sleep_user_code = old_df_sleep.user_code.tolist()
sleep_day = old_df_sleep.day.tolist()
sleep_duration = old_df_sleep.sleep_duration.tolist()

for i in range(0, len(sleep_user_code)):
    user_dict[sleep_user_code[i]][sleep_day[i]] = sleep_duration[i]

#print(user_dict)

sleep_dict = {}
for date in sleep_columns:
     sleep_dict[date] = []
     for code in sleep_index:
         if date not in user_dict[code].keys():
             sleep_dict[date].append(0)
         else:
             sleep_dict[date].append(user_dict[code][date])

df_sleep = pd.DataFrame(sleep_dict, index = sleep_index)

print(df_sleep)
```

```
             2020-01-21  2020-01-30  2020-01-31  2020-02-02  2020-02-03  \
276ab22485       9543.0         0.0         0.0         0.0         0.0
4985083f4d          0.0     29265.0     24771.0     11410.0     31705.0
6be5033971      29400.0     29700.0     35100.0     30300.0     35700.0
9871ee5e7b          0.0         0.0         0.0         0.0         0.0
a1c2e6b2eb          0.0         0.0         0.0         0.0         0.0
c174f32d88          0.0         0.0         0.0         0.0         0.0
fcf3ea75b0          0.0         0.0         0.0         0.0         0.0

             2020-02-05  2020-02-09  2020-02-12  2020-02-13  2020-02-14  ...  \
276ab22485          0.0         0.0         0.0         0.0         0.0  ...
4985083f4d      24492.0     14522.0      5130.0      5235.0     29883.0  ...
6be5033971      35700.0     33300.0     36600.0     36300.0     33300.0  ...
9871ee5e7b          0.0         0.0         0.0         0.0         0.0  ...
a1c2e6b2eb          0.0         0.0         0.0         0.0         0.0  ...
c174f32d88          0.0         0.0         0.0         0.0         0.0  ...
fcf3ea75b0          0.0         0.0         0.0         0.0         0.0  ...

             2020-04-13  2020-04-14  2020-04-15  2020-04-16  2020-04-17  \
276ab22485          0.0         0.0         0.0         0.0         0.0
4985083f4d          0.0         0.0         0.0         0.0         0.0
6be5033971          0.0         0.0         0.0         0.0         0.0
9871ee5e7b          0.0         0.0         0.0         0.0         0.0
a1c2e6b2eb          0.0         0.0         0.0         0.0         0.0
c174f32d88      35940.0     40050.0     35580.0     42870.0     34980.0
fcf3ea75b0          0.0         0.0         0.0         0.0         0.0

             2020-04-19  2020-04-20  2020-04-21  2020-04-22  2020-04-23
276ab22485          0.0         0.0         0.0         0.0         0.0
4985083f4d          0.0         0.0         0.0         0.0         0.0
6be5033971          0.0         0.0         0.0         0.0         0.0
9871ee5e7b          0.0         0.0         0.0         0.0         0.0
a1c2e6b2eb          0.0         0.0         0.0         0.0         0.0
c174f32d88      47460.0     41610.0     37170.0     39720.0     37710.0
fcf3ea75b0          0.0         0.0         0.0     24841.0     30224.0

[7 rows x 135 columns]
```

Wearables

```
#Wearable Data
#TODO:
# 1 : Load in wearable data
# 2 : Filter by patient ID and dates
# 3 : Prepare dataframe for LR or other ML model

df_wearable = dfs['wearables'].copy()

#drop columns that aren't filled for most users
#adjust if necessary later
df_wearable =  df_wearable.drop(columns=['resting_pulse', 'average_spo2_value','body_temperature_avg', 'st
# assign 1 if user_code is in df_p, 0 if not
df_wearable = df_wearable.assign(InDFP = old_df_sleep.user_code.isin(df_covid.index).astype(int))
df_wearable = df_wearable[df_wearable['user_code'].notna()]

# only keep user_codes that were in df_p, drop extra column
df_wearable = df_wearable[df_wearable.InDFP != 0].drop(columns=['InDFP'])

#remove user codes which are NaN
#Note: Check why this happened
#df_wearable = df_wearable[df_wearable['user_code'].notna()]

df_wearable = df_wearable[df_wearable['user_code'].notna()]
df_wearable['date'] = df_wearable.apply(lambda _: '', axis=1)
df_wearable_cp= df_wearable.copy()
df_wearable_cp = df_wearable_cp.dropna()
# df_wearable_cp2= df_wearable.copy()

df_wearable_pp = {}
plist = df_wearable_cp['user_code'].unique()
for p in plist:
```

```
  # filter out measurements and drop NaN
  tmp = df_wearable_cp.loc[df_wearable_cp['user_code'] == p].copy().dropna()

  # TODO drop data if it does not fulfill requirement (e.g., less than 5 entries)
  if tmp.shape[0] < 3:
    continue

  # convert datetime to date only
  tmp['day'] = pd.to_datetime(tmp['day']).dt.date
  tmp['day'] = pd.to_datetime(tmp['day']).dt.normalize() # convert from object to datetime[ns]
  #tmp['measurement_datetime'] =  tmp['measurement_datetime'].dt.strftime('%Y-%m-%d')
  # drop user_code column
  tmp = tmp.drop(columns=['user_code'])

  # set date time as key
  tmp.set_index('day', inplace=True)

  # check if datetime is unique
  if not tmp.index.is_unique:
    # calculate mean for duplicates
    tmp = tmp.reset_index().pivot_table(columns=["day"]).T

  # drop duplicates
  #tmp.drop_duplicates(keep='first')

  # set dataframe
  df_wearable_pp[p] = tmp
  plist_used.append(p)

temp_df_wearables = df_wearable_pp.copy()

# print(df_wearable_pp)

# wearable_columns = list(df_wearable.day.unique())
# wearable_index = list(df_wearable.user_code.unique())
# user_dict = {}
```

```
# for code in wearable_index:
#     user_dict[code] = {}

# wearable_user_code = df_wearable.user_code.tolist()
# wearable_day = df_wearable.day.tolist()
# wearable_duration = df_wearable.sleep_duration.tolist()
# print(df_wearable_cp.columns)
# print(df_wearable.iloc[0][1])

#Filter Dates
# for i, r in enumerate(df_wearable['day']):
#     str_list = r.split("-")
#     for j in range(0, len(str_list)):
#         if str_list[j][0] == '0':
#             str_list[j] = str_list[j][1:]
#     new_str_list = [str_list[1], str_list[2], str_list[0]]
#     df_wearable.loc[i, 'day'] = '/'.join(new_str_list)

# df_wearable_mapping = df_wearable.assign(StartDate = df_wearable.day.isin(df_p.symptoms_onset).astype(in
# df_wearable_mapping = df_wearable_mapping.dropna()

# print(df_wearable_mapping)
# print(len(list(df_wearable_mapping.user_code.unique())))

df_wearable_cp['combo_index'] = df_wearable_cp['user_code'].str.cat(df_wearable_cp['day'], sep = "_")
# df_wearable_cp = df_wearable_cp.drop(columns=['user_code', 'day'])
# df_wearable_cp = df_wearable_cp.set_index('combo_index')
# print(df_wearable_cp.shape)
```

```
# ['user_code', 'day', 'pulse_average', 'pulse_min', 'pulse_max',
#        'steps_count', 'steps_speed', 'basal_calories_burned',
#        'total_calories_burned', 'date']
print(df_wearable_cp.shape)
wearable_index = df_wearable_cp.index.tolist()
bad_wearable_index_i = []
for i in wearable_index:
    if df_wearable_cp['combo_index'][i] not in combo_index:
        bad_wearable_index_i.append(i)

sklearn_wearable = df_wearable_cp.drop(labels=bad_wearable_index_i, axis=0)
sklearn_wearable = sklearn_wearable.set_index('combo_index')
sklearn_wearable['covid'] = ""

for index in sklearn_wearable.index:
    if sklearn_wearable.loc[index][0] in sklearn_covid.index and sklearn_wearable.loc[index][1] in dates:
        sklearn_wearable.at[index, 'covid'] = int(sklearn_covid.loc[sklearn_wearable.loc[index][0]][sklear
sklearn_wearable_input = sklearn_wearable
sklearn_wearable = sklearn_wearable.drop(columns=['user_code', 'day'])
sklearn_wearable = sklearn_wearable.apply(pd.to_numeric)
sklearn_wearable = sklearn_wearable.drop(columns=['date'])
print(sklearn_wearable.shape)
# print(sklearn_wearable.head())
```

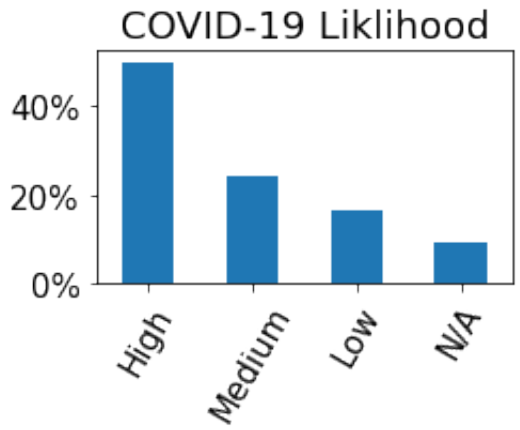
```
(910, 11)
(305, 8)
```

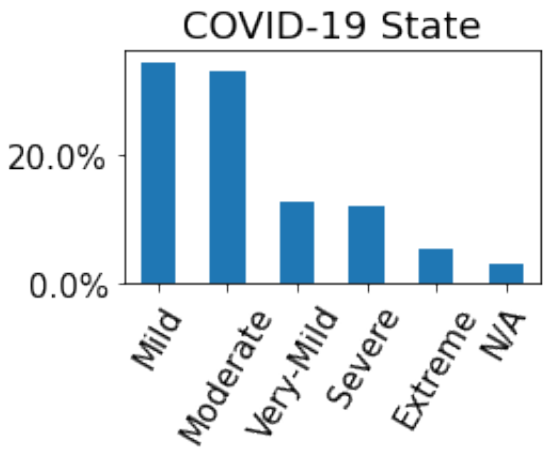
Dataset Analysis

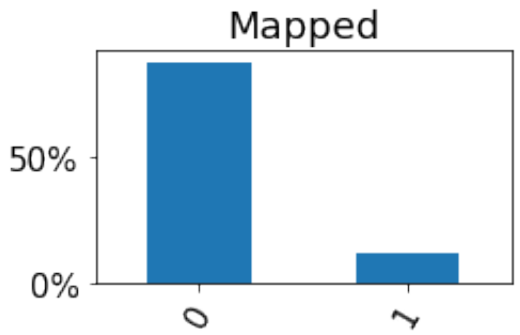
```
import matplotlib.pyplot as plt
import matplotlib.ticker as mtick
plt.rcParams.update({'font.size': 15})

```

```
df = dfs['surveys']
df1 = df[(df['scale'] == 'S_CORONA')]
df2 = df[(df['scale'] == 'S_COVID_OVERALL')]

fig, axs = plt.subplots(1,3)
fig.subplots_adjust(wspace=0.5)
fig.set_figheight(2)
fig.set_figwidth(14)

vc1 = df1['text'].value_counts()
vc1 = 100*vc1/len(df1)
vc1.index = ['High', 'Medium', 'Low', 'N/A']
ax1 = vc1.plot(kind = 'bar', ax=axs[0])
ax1.set_xticklabels(ax1.get_xticklabels(), rotation=60)
ax1.yaxis.set_major_formatter(mtick.PercentFormatter())
ax1.set_title('COVID-19 Liklihood')

vc2 = df2['text'].value_counts()
vc2 = 100*vc2/len(df2)
vc2.index = ['Mild', 'Moderate', 'Very-Mild', 'Severe', 'Extreme', 'N/A']
ax2 = vc2.plot(kind = 'bar', ax=axs[1])
ax2.set_xticklabels(ax2.get_xticklabels(), rotation=60)
ax2.yaxis.set_major_formatter(mtick.PercentFormatter())
ax2.set_title('COVID-19 State')

vc3 = np.sum(df_covid.apply(pd.value_counts), axis=1)
vc3 = 100*vc3/sum(vc3)
ax3 = vc3.plot(kind='bar', ax=axs[2])
# ax3.index = ['Negative', 'Positive']
ax3.set_xticklabels(ax3.get_xticklabels(), rotation=60)
ax3.yaxis.set_major_formatter(mtick.PercentFormatter())
ax3.set_title('Mapped')
```

```
Text(0.5, 1.0, 'Mapped')
```








```
# Participant Stats
print('N_participants =', len(np.unique(dfs['participants']['user_code'])))
print()

# Pre-processing Stats
print('N_hrv =', len(np.unique(dfs['hrv_measurements']['user_code'])))
print('N_sleep =', len(np.unique(dfs['sleep']['user_code'])))
print('N_wearables =', len(np.unique(dfs['wearables']['user_code'])))
print('N_covid =', len(np.unique(dfs['surveys']['user_code'])))
print()

# Processed Stats
print('N_hrv_pp =', len(df_hrv_pp))
print('N_covid_pp =', len(df_covid.index.unique()))
print('N_sleep_pp =', len(df_sleep.index.unique()))
print('N_wearable_pp =', len(df_wearable_cp['user_code'].unique()))
print()

# Time stats
print('T_span =', np.max(df_covid.columns)-np.min(df_covid.columns))
print()

```

```
# Training/testing stats
print('N_covid+hrv =', len(np.intersect1d(df_covid.index,
                                          plist_used)))
print('N_covid+wearables =', len(np.intersect1d(df_covid.index,
                                                df_wearable_cp['user_code'].unique())))
print('N_covid+wearables+hrv =', len(np.intersect1d(np.intersect1d(df_covid.index, plist_used),
                                                    df_wearable_cp['user_code'].unique())))
print()
```

```
N_participants = 185

N_hrv = 185
N_sleep = 10
N_wearables = 79
N_covid = 111

N_hrv_pp = 60
N_covid_pp = 100
N_sleep_pp = 7
N_wearable_pp = 32

T_span = 56 days 00:00:00

N_covid+hrv = 50
N_covid+wearables = 26
N_covid+wearables+hrv = 26
```

Classification

```
1 df
```

	user_code	scale	created_at	value	text
0	01bad5a519	S_CORONA	2020-04-23	2	Symptoms are characteristic of coronavirus
1	01bad5a519	S_COVID_BLUISH	2020-04-23	1	User isn’t experiencing symptom
2	01bad5a519	S_COVID_BLUISH	2020-04-25	1	User isn’t experiencing symptom
3	01bad5a519	S_COVID_BLUISH	2020-04-27	1	User isn’t experiencing symptom
4	01bad5a519	S_COVID_BLUISH	2020-04-29	1	User isn’t experiencing symptom
...	...	...	...	...	...
2254	fe6c1b1349	S_COVID_FATIGUE	2020-05-12	4	Moderate
2255	fe6c1b1349	S_COVID_FEVER	2020-05-12	4	Moderate
2256	fe6c1b1349	S_COVID_OVERALL	2020-05-12	3	Mild
2257	fe6c1b1349	S_COVID_PAIN	2020-05-12	1	User isn’t experiencing symptom
2258	fe6c1b1349	S_COVID_TROUBLE	2020-05-12	1	User isn’t experiencing symptom

2259 rows × 5 columns

HRV

```
1 from sklearn.model_selection import train_test_split
2 from sklearn.linear_model import LogisticRegression
3 from sklearn.svm import SVC, LinearSVC, NuSVC
4 from sklearn.neural_network import MLPClassifier
```

```
X_train, X_test, y_train, y_test = train_test_split(sklearn_hrv.drop(["covid"], axis=1), sklearn_hrv["covi

lr_hrv = LogisticRegression(random_state=42, max_iter=1000).fit(X_train, y_train)
lr_score = lr_hrv.score(X_test, y_test) # Return the mean accuracy on the given test data and labels.
print("Logistic Regression: " + str(lr_score))

mlpc_hrv = MLPClassifier(random_state=42, max_iter=1000).fit(X_train, y_train)
mlpc_score = mlpc_hrv.score(X_test, y_test)
print("MultiLayer Perceptron: " + str(mlpc_score))

# SVMs are SLOW but they eventually complete lol
linsvc_hrv = LinearSVC(random_state=42).fit(X_train, y_train)
linsvc_score = linsvc_hrv.score(X_test, y_test)
print("SVM-LinearSVC: " + str(linsvc_score))

nusvc_hrv = NuSVC(nu=0.2, random_state=42).fit(X_train, y_train)
nusvc_score = nusvc_hrv.score(X_test, y_test)
print("SVM-NuSVC: " + str(nusvc_score))

# svclin_hrv = SVC(kernel="linear", random_state=42).fit(X_train, y_train)
# svclin_score = svclin_hrv.score(X_test, y_test)
# print("SVM-SVC (linear kernel): " + str(svclin_score))

# svcrbf_hrv = SVC(kernel="rbf", random_state=42).fit(X_train, y_train)
# svcrbf_score = svcrbf_hrv.score(X_test, y_test)
# print("SVM-SVC (rbf kernel): " + str(svcrbf_score))
```

```
Logistic Regression: 0.8281853281853282
MultiLayer Perceptron: 0.805019305019305
SVM-LinearSVC: 0.8185328185328186
SVM-NuSVC: 0.8088803088803089
/usr/local/lib/python3.7/dist-packages/sklearn/svm/_base.py:1208: ConvergenceWarning: Liblinear failed t
  ConvergenceWarning,
```

- Wearables

```
X_train, X_test, y_train, y_test = train_test_split(sklearn_wearable.drop(["covid"], axis=1), sklearn_wear

lr_w = LogisticRegression(random_state=42, max_iter=1000).fit(X_train, y_train)
lr_score = lr_w.score(X_test, y_test)
print("Logistic Regression: " + str(lr_score))

mlpc_w = MLPClassifier(random_state=42, max_iter=1000).fit(X_train, y_train)
mlpc_score = mlpc_w.score(X_test, y_test)
print("MultiLayer Perceptron: " + str(mlpc_score))

# SVMs are SLOW but they eventually complete lol
linsvc_w = LinearSVC(random_state=42).fit(X_train, y_train)
linsvc_score = linsvc_w.score(X_test, y_test)
print("SVM-LinearSVC: " + str(linsvc_score))

nusvc_w = NuSVC(random_state=42).fit(X_train, y_train)
nusvc_score = nusvc_w.score(X_test, y_test)
print("SVM-NuSVC: " + str(nusvc_score))

# svclin_w = SVC(kernel="linear", random_state=42).fit(X_train, y_train)
# svclin_score = svclin_w.score(X_test, y_test)
# print("SVM-SVC (linear kernel): " + str(svclin_score))

# svcrbf_w = SVC(kernel="rbf", random_state=42).fit(X_train, y_train)
# svcrbf_score = svcrbf_w.score(X_test, y_test)
# print("SVM-SVC (rbf kernel): " + str(svcrbf_score))
```

```
Logistic Regression: 0.6233766233766234
MultiLayer Perceptron: 0.5714285714285714
SVM-LinearSVC: 0.35064935064935066
SVM-NuSVC: 0.6233766233766234
/usr/local/lib/python3.7/dist-packages/sklearn/svm/_base.py:1208: ConvergenceWarning: Liblinear failed t
  ConvergenceWarning,
```

RNN Testing

Imports and Helpers

```
%tensorflow_version 2.x
# !pip install tensorflow_addons
```

```
import numpy as np
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers
# from sklearn.metrics import f1_score
import matplotlib.pyplot as plt
```

```
from tensorflow.python.framework.ops import disable_eager_execution
disable_eager_execution()
import warnings
warnings.filterwarnings("ignore")
```

```
# The recall is the ratio tp / (tp + fn) where tp is the number of true positives and fn the number of fal
# The recall is intuitively the ability of the classifier to find all the positive samples.
# The best value is 1 and the worst value is 0.
def recall(y_true, y_pred, threshold):
    # true positive / (true positive / false negative)
    tp = 0
    fn = 0
    for i in range(len(y_true)):
        # if y_true[i] == 1 and y_pred[i][0] >= threshold:
        #     tp += 1
```

```
        # elif y_true[i] == 0 and y_pred[i][0] >= threshold:
        #     fn += 1
        if y_true[i] - threshold <= y_pred[i][0] <= y_true[i] + threshold:
            tp += 1
        elif y_pred[i][0] < y_true[i] - threshold:
            fn += 1
    return tp / (tp + fn)

# The precision is the ratio tp / (tp + fp) where tp is the number of true positives and fp the number of
# The precision is intuitively the ability of the classifier not to label as positive a sample that is neg
# The best value is 1 and the worst value is 0.
def precision(y_true, y_pred, threshold):
    # true positive / (true positive / false positive)
    tp = 0
    fp = 0
    for i in range(len(y_true)):
        # if y_true[i] == 1 and y_pred[i][0] >= threshold:
        #     tp += 1
        # elif y_true[i] == 0 and y_pred[i][0] >= threshold:
        #     fp += 1
        if y_true[i] - threshold <= y_pred[i][0] <= y_true[i] + threshold:
            tp += 1
        elif y_pred[i][0] > y_true[i] + threshold:
            fp += 1
    return tp / (tp + fp)

# The F1 score can be interpreted as a harmonic mean of the precision and recall,
# where an F1 score reaches its best value at 1 and worst score at 0.
def f1_score(y_true, y_pred, threshold):
    precision1 = precision(y_true, y_pred, threshold)
    recall1 = recall(y_true, y_pred, threshold)
    return 2*((precision1*recall1)/(precision1+recall1))
```

```
def roc_curve(y_true, y_pred):
    thresholds = np.arange(0.0, 1.001, 0.001)
    classes = [0, 0.25, 0.5, 0.75, 1.0]

    full_fpr = []
    full_tpr = []
    for cls in classes:
        fpr = []
        tpr = []
        P = sum([1 for y in y_true if y == cls])
        N = len(y_true) - P
        for threshold in thresholds:
            tp=0
            fp=0
            threshold = round(threshold,10)
            for i in range(len(y_true)):
                if cls - threshold <= y_pred[i][0] <= cls + threshold:
                    if y_true[i] == cls:
                        tp += 1
                    else:
                        fp += 1
            fpr.append(fp/N)
            tpr.append(tp/P)
        full_fpr.append(fpr)
        full_tpr.append(tpr)
    return full_fpr, full_tpr
```

HRV Dataset Redo

```
min_length = 4

rnn_hrv_input = []
rnn_hrv_output = []
```

```
5
6 # max_list_length = []
7 # for key in temp_df_hrv.keys():
8 #     this_length = 0
9 #     hrv_dates = list(temp_df_hrv[key].index)
10 #     for date in hrv_dates:
11 #         if date in df_covid.columns:
12 #             this_length += 1
13 #     max_list_length.append(this_length)
14 # max_list_length = sorted(max_list_length)
15 # print(max_list_length)
16
17 for key in temp_df_hrv.keys():
18     covid_hrv_np = []
19     hrv_np = []
20     hrv_dates = list(temp_df_hrv[key].index)
21     for date in hrv_dates:
22         if date in df_covid.columns:
23             covid_hrv_np.append(df_covid.loc[key][date].astype('int'))
24             hrv_np.append(list(temp_df_hrv[key].loc[date].to_numpy().astype('float')))
25     # print(hrv_np)
26     # print(covid_hrv_np)
27
28     #if len(covid_hrv_np) >= min_length:
29     #    if 1 in covid_hrv_np:
30     #        covid_index = covid_hrv_np.index(1)
31     #        if covid_index+1 > min_length:
32     #            rnn_hrv_input.append(hrv_np[covid_index-(min_length-1):covid_index+1])
33     #            # rnn_hrv_output.append(covid_hrv_np[covid_index-(min_length-1):covid_index+1])
34     #        else:
35     #            rnn_hrv_input.append(hrv_np[:min_length])
36     #            # rnn_hrv_output.append(covid_hrv_np[:min_length])
37     #        rnn_hrv_output.append(1)
38     #    else:
39     #        rnn_hrv_input.append(hrv_np[:min_length])
40     #        # rnn_hrv_output.append(covid_hrv_np[:min_length])
```

```
    #        rnn_hrv_output.append(0)

    # sliding window
    if len(covid_hrv_np) >= min_length:
        for w in range(len(covid_hrv_np) - min_length + 1):
            if covid_hrv_np[w:w+min_length][-1] == 0 and covid_hrv_np[w:w+min_length][0] == 1:
                continue
            rnn_hrv_input.append(hrv_np[w:w+min_length])
            rnn_hrv_output.append(sum(covid_hrv_np[w:w+min_length])/min_length)
            # if 1 in covid_hrv_np[w:w+min_length]:
            #     rnn_hrv_output.append(1)
            # else:
            #     rnn_hrv_output.append(0)
```

```
# checking hrv data
print("Number of entries: " + str(len(rnn_hrv_input)))

pos = sum(rnn_hrv_output)

print("Positive: " + str(pos/len(rnn_hrv_output)) + " Negative: " + str(1-pos/len(rnn_hrv_output)))
#total_output = sum( [ len(c) for c in rnn_hrv_output])
print(rnn_hrv_input)
```

```
Number of entries: 215
Positive: 0.513953488372093 Negative: 0.486046511627907
[[[44.0, 69.0, 87.0, 75.0, 0.862, 867.22, 0.875, 0.11, 4.04, 21.894, 31.382, 435.0, 273.0], [69.0, 94.0,
```

HRV RNN

```
# INPUTS
#cut_index = 4
```

```
# cut_index = int(len(rnn_hrv_input) * 0.4) # get more testing samples
cut_index = int(len(rnn_hrv_input) * 0.2) # testing = 20% of our inputs

# shuffle dataset
indices = tf.range(start=0, limit=len(rnn_hrv_input), dtype=tf.int32)
shuffled_indices = tf.random.shuffle(indices, seed=57344, name="hrv_indices")
tf.print(shuffled_indices)

shuffled_rnn_hrv_input = tf.gather(rnn_hrv_input, shuffled_indices)
shuffled_rnn_hrv_output = tf.gather(rnn_hrv_output, shuffled_indices)

tmp_input_hrv_train = tf.convert_to_tensor(shuffled_rnn_hrv_input[cut_index:], dtype=tf.float32)
tmp_input_hrv_val = tf.convert_to_tensor(shuffled_rnn_hrv_input[:cut_index], dtype=tf.float32)

input_hrv_train = layers.Input(shape=tmp_input_hrv_train.shape,
                               tensor=tmp_input_hrv_train)
input_hrv_val = layers.Input(shape=tmp_input_hrv_val.shape,
                             tensor=tmp_input_hrv_val)

output_hrv_train = tf.convert_to_tensor(shuffled_rnn_hrv_output[cut_index:], dtype=tf.float32)
output_hrv_val = tf.convert_to_tensor(shuffled_rnn_hrv_output[:cut_index], dtype=tf.float32)

print(input_hrv_train.shape, output_hrv_train.shape)
print(input_hrv_val.shape, output_hrv_val.shape)
# print(input_hrv_test.shape, output_hrv_test.shape)

tmp_input_hrv_tests = []
input_hrv_tests = []
output_hrv_tests = []
for i in range(0, cut_index):
    tmp_input_hrv_tests.append(tf.convert_to_tensor([shuffled_rnn_hrv_input[i]], dtype=tf.float32))
    input_hrv_tests.append(layers.Input(shape=tmp_input_hrv_tests[i].shape,
                                tensor=tmp_input_hrv_tests[i]))
    output_hrv_tests.append(tf.convert_to_tensor([shuffled_rnn_hrv_output[i]], dtype=tf.float32))
```

```
(172, 4, 13) (172,)
(43, 4, 13) (43,)
```

```
# Adding callbacks (save checkpoint and early stopping)
CHECKPOINT_PATH = '/tmp/checkpoint'

```

```
# MODEL
num_loops = 1

for i in range(num_loops):
    training_callbacks = [
    #tf.keras.callbacks.EarlyStopping(monitor='val_loss', patience=100),
    tf.keras.callbacks.ModelCheckpoint(
        filepath=CHECKPOINT_PATH,
        save_weights_only=True,
        monitor='val_loss',
        mode='min',
        save_best_only=True)
    ]

    model = keras.Sequential()

    # LSTM Layer
    # model.add(layers.LSTM(input_hrv_val.shape[1], input_shape=input_hrv_val.shape[1:]))
    model.add(layers.SimpleRNN(input_hrv_val.shape[1]*16,
                               input_shape=input_hrv_val.shape[1:],
                               recurrent_regularizer=keras.regularizers.L2(0.1),
                               activation='tanh'))
    # Dense Layer
    # kernel_regularizer=keras.regularizers.L2(0.01),
    model.add(layers.Dense(input_hrv_val.shape[1]*8,
                           kernel_regularizer=keras.regularizers.L2(0.05),
                           activation='tanh'))
```

```
    model.add(layers.Dense(input_hrv_val.shape[1]*2,
                           activation='tanh'))
    model.add(layers.Dense(int(input_hrv_val.shape[1]),
                         activation='tanh'))
    # model.add(layers.Dense(input_hrv_val.shape[1]*8, activation='tanh'))
    # if many-to-many, comment out this layer
    # Dense layer size 1 for BCE
    model.add(layers.Dense(1, activation='tanh'))

    # Binary Cross Entropy
    model.compile(loss=tf.keras.losses.MeanAbsoluteError(),
                optimizer=tf.optimizers.SGD(),
                metrics=["accuracy", keras.metrics.AUC()])

    # Fit the model
    history = model.fit(input_hrv_train, output_hrv_train,
                         batch_size=1,
                         steps_per_epoch=input_hrv_train.shape[0],
                         epochs=300,
                         validation_data=(input_hrv_val, output_hrv_val),
                         validation_steps=input_hrv_val.shape[0],#)
                         callbacks = training_callbacks) # colman: added callbacks for early stopping and s
```

```
Train on 172 samples, validate on 43 samples
Epoch 1/300
172/172 [==============================] - 2s 6ms/step - batch: 85.5000 - size: 1.0000 - loss: 6.7804 -
Epoch 2/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 3.9041 -
Epoch 3/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 2.3630 -
Epoch 4/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 1.5163 -
Epoch 5/300
172/172 [==============================] - 1s 7ms/step - batch: 85.5000 - size: 1.0000 - loss: 1.0443 -
Epoch 6/300
172/172 [==============================] - 1s 5ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.7655 -
Epoch 7/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.5983 -
```

```
Epoch 8/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.4977 -
Epoch 9/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.4322 -
Epoch 10/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.3927 -
Epoch 11/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.3609 -
Epoch 12/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.3386 -
Epoch 13/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.3260 -
Epoch 14/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.3130 -
Epoch 15/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.3033 -
Epoch 16/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2987 -
Epoch 17/300
172/172 [==============================] - 1s 5ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2923 -
Epoch 18/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2892 -
Epoch 19/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2873 -
Epoch 20/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2859 -
Epoch 21/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2827 -
Epoch 22/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2798 -
Epoch 23/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2781 -
Epoch 24/300
172/172 [==============================] - 1s 5ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2783 -
Epoch 25/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2754 -
Epoch 26/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2739 -
Epoch 27/300
172/172 [==============================] - 1s 5ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2727 -
Epoch 28/300
```

```
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2725 -
Epoch 29/300
172/172 [==============================] - 1s 4ms/step - batch: 85.5000 - size: 1.0000 - loss: 0.2691 -
```

```python
# Validation set loss & accuracy
results = model.evaluate(input_hrv_val, output_hrv_val, steps=input_hrv_val.shape[0])
print("validation loss, acc, auc: ", results)

# # Predict COVID in a witheld sample from the training set
for i in range(0, cut_index):
    prediction = model.predict(input_hrv_tests[i], output_hrv_tests[i], steps=1)
    print(i, " test actual, prediction: ", rnn_hrv_output[i], prediction[0])
    # print(i, " test prediction: ", prediction)

prediction = model.predict(input_hrv_val, output_hrv_val, steps=1)
# print(rnn_hrv_output[:cut_index], prediction)
print("precision: ", precision(rnn_hrv_output[:cut_index], prediction, 0.125))
print("recall: ", recall(rnn_hrv_output[:cut_index], prediction, 0.125))
print("f1 score: ", f1_score(rnn_hrv_output[:cut_index], prediction, 0.125))

print(model.summary())
```

```
validation loss, acc, auc:  [0.23576700756716173, 0.7349919, 0.8507104]
0  test actual, prediction:  0.75 [0.05415584]
1  test actual, prediction:  1.0 [0.7928586]
2  test actual, prediction:  0.25 [0.00226008]
3  test actual, prediction:  0.0 [0.03835226]
4  test actual, prediction:  0.0 [0.05415584]
5  test actual, prediction:  0.0 [0.00239288]
6  test actual, prediction:  0.0 [0.01662792]
7  test actual, prediction:  1.0 [-0.01478671]
8  test actual, prediction:  1.0 [0.07130896]
9  test actual, prediction:  1.0 [0.69761884]
10  test actual, prediction:  1.0 [0.98390496]
11  test actual, prediction:  1.0 [0.04115556]
12  test actual, prediction:  1.0 [0.2615081]
13  test actual, prediction:  1.0 [0.01662792]
14  test actual, prediction:  1.0 [0.40632954]
```

```
15  test actual, prediction:  1.0 [0.5686112]
16  test actual, prediction:  1.0 [0.00377296]
17  test actual, prediction:  0.0 [0.0055607]
18  test actual, prediction:  0.0 [0.00480684]
19  test actual, prediction:  0.0 [0.0055607]
20  test actual, prediction:  0.0 [0.82839113]
21  test actual, prediction:  0.25 [0.00480684]
22  test actual, prediction:  0.5 [0.7928586]
23  test actual, prediction:  0.0 [0.00226032]
24  test actual, prediction:  0.0 [-0.00539619]
25  test actual, prediction:  0.0 [0.07130896]
26  test actual, prediction:  0.0 [0.8402346]
27  test actual, prediction:  0.0 [0.0383525]
28  test actual, prediction:  0.0 [0.4687522]
29  test actual, prediction:  0.0 [0.00972693]
30  test actual, prediction:  0.0 [0.24261166]
31  test actual, prediction:  0.0 [0.00239288]
32  test actual, prediction:  0.0 [0.96796453]
33  test actual, prediction:  0.0 [0.69177467]
34  test actual, prediction:  1.0 [0.7928586]
35  test actual, prediction:  1.0 [0.7928586]
36  test actual, prediction:  1.0 [0.9078239]
37  test actual, prediction:  1.0 [0.82839113]
38  test actual, prediction:  1.0 [-0.05211063]
39  test actual, prediction:  0.75 [0.9607409]
40  test actual, prediction:  1.0 [0.9992789]
41  test actual, prediction:  1.0 [0.947467]
42  test actual, prediction:  1.0 [0.9987965]
precision:  0.5517241379310345
recall:  0.5333333333333333
f1 score:  0.5423728813559322
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 simple_rnn (SimpleRNN)      (None, 64)                4992

 dense (Dense)               (None, 32)                2080

 dense_1 (Dense)             (None, 8)                 264
```

```
 dense_2 (Dense)             (None, 4)                 36

 dense_3 (Dense)             (None, 1)                 5
```

```
# print result using best model
# Loads the weights
model.load_weights(CHECKPOINT_PATH)

# Validation set loss & accuracy
results = model.evaluate(input_hrv_val, output_hrv_val, steps=input_hrv_val.shape[0])
print("validation loss, acc: ", results)

# # Predict COVID in a witheld sample from the training set
for i in range(0, cut_index):
    prediction = model.predict(input_hrv_tests[i], output_hrv_tests[i], steps=1)
    print(i, " test actual, prediction: ", rnn_hrv_output[i], prediction[0])
    # print(i, " test prediction: ", prediction)

prediction = model.predict(input_hrv_val, output_hrv_val, steps=1)
# print(rnn_hrv_output[:cut_index], prediction)
print("f1 score: ", f1_score(rnn_hrv_output[:cut_index], prediction, 0.125))

```

```
validation loss, acc:  [0.2031002543693365, 0.7625744, 0.8496765]
0  test actual, prediction:  0.75 [-0.02301191]
1  test actual, prediction:  1.0 [0.9930485]
2  test actual, prediction:  0.25 [0.99604124]
3  test actual, prediction:  0.0 [0.20604186]
4  test actual, prediction:  0.0 [-0.01686032]
5  test actual, prediction:  0.0 [-0.04408873]
6  test actual, prediction:  0.0 [0.98865366]
7  test actual, prediction:  1.0 [0.04081639]
8  test actual, prediction:  1.0 [0.20604186]
9  test actual, prediction:  1.0 [-0.13837352]
10  test actual, prediction:  1.0 [0.00765321]
11  test actual, prediction:  1.0 [0.9995754]
12  test actual, prediction:  1.0 [0.99900246]
13  test actual, prediction:  1.0 [-0.13903818]
```

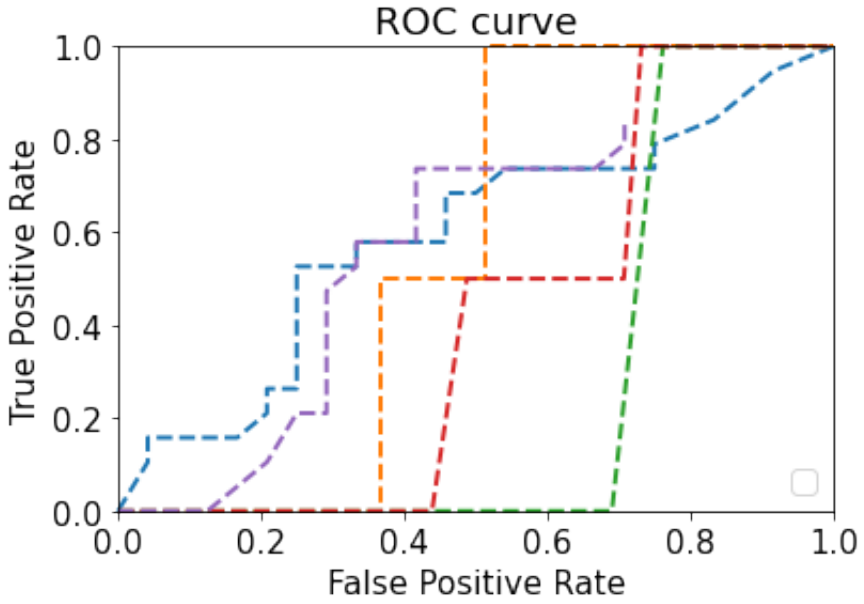
```
14  test actual, prediction:  1.0 [0.99864966]
15  test actual, prediction:  1.0 [-0.04408896]
16  test actual, prediction:  1.0 [0.9974758]
17  test actual, prediction:  0.0 [0.99905545]
18  test actual, prediction:  0.0 [0.02652928]
19  test actual, prediction:  0.0 [0.99940896]
20  test actual, prediction:  0.0 [0.9774733]
21  test actual, prediction:  0.25 [-0.01308831]
22  test actual, prediction:  0.5 [-0.01430998]
23  test actual, prediction:  0.0 [0.00765321]
24  test actual, prediction:  0.0 [0.9989512]
25  test actual, prediction:  0.0 [0.9995189]
26  test actual, prediction:  0.0 [-0.03327321]
27  test actual, prediction:  0.0 [0.9995179]
28  test actual, prediction:  0.0 [0.99859214]
29  test actual, prediction:  0.0 [0.00247275]
30  test actual, prediction:  0.0 [0.99845254]
31  test actual, prediction:  0.0 [0.99940896]
32  test actual, prediction:  0.0 [0.9988275]
33  test actual, prediction:  0.0 [-0.01308831]
34  test actual, prediction:  1.0 [0.12298985]
35  test actual, prediction:  1.0 [0.08198864]
36  test actual, prediction:  1.0 [0.11860078]
37  test actual, prediction:  1.0 [-0.04279965]
38  test actual, prediction:  1.0 [0.9989512]
39  test actual, prediction:  0.75 [0.9923058]
40  test actual, prediction:  1.0 [-0.01686032]
41  test actual, prediction:  1.0 [-0.00028634]
42  test actual, prediction:  1.0 [-0.00036836]
f1 score:  0.676923076923077
```

```
1
```

```
1 full_fpr, full_tpr = roc_curve(rnn_hrv_output[:cut_index], prediction)
```

```
for i in range(len(full_fpr)):
    plt.plot(full_fpr[i], full_tpr[i], linestyle='--', lw = 2, clip_on=False)
# plt.plot([0, 1], [0, 1], color='navy', linestyle='--')
plt.xlim([0.0, 1.0])
plt.ylim([0.0, 1.0])
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title('ROC curve')
plt.legend(loc="lower right")
plt.savefig('AUC_example.png')
plt.show()
```

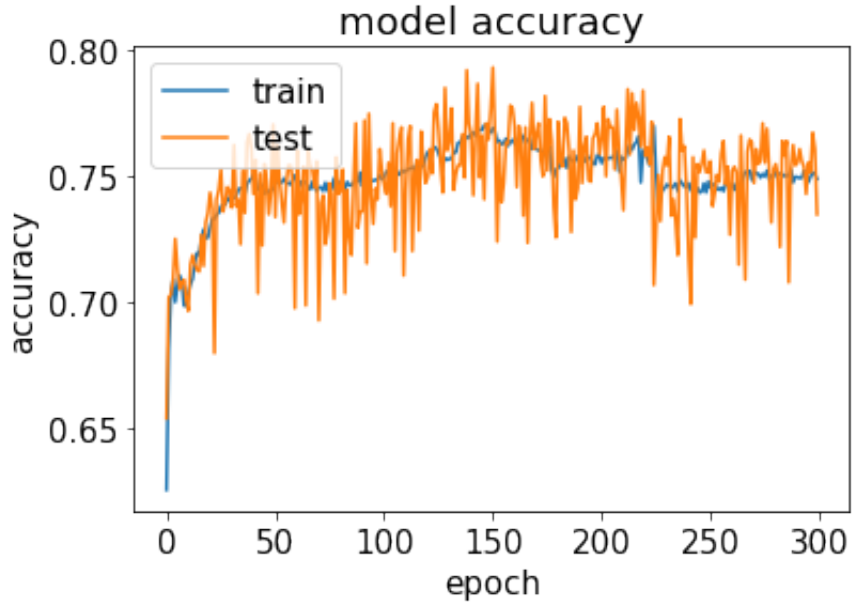
```
No handles with labels found to put in legend.
```



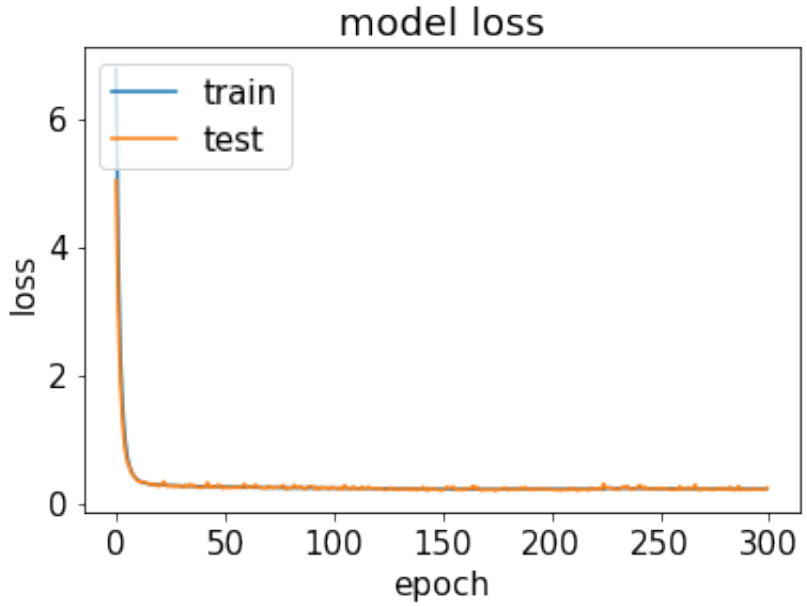

```
print(history.history.keys())
```

```
dict_keys(['loss', 'accuracy', 'auc', 'val_loss', 'val_accuracy', 'val_auc'])
```

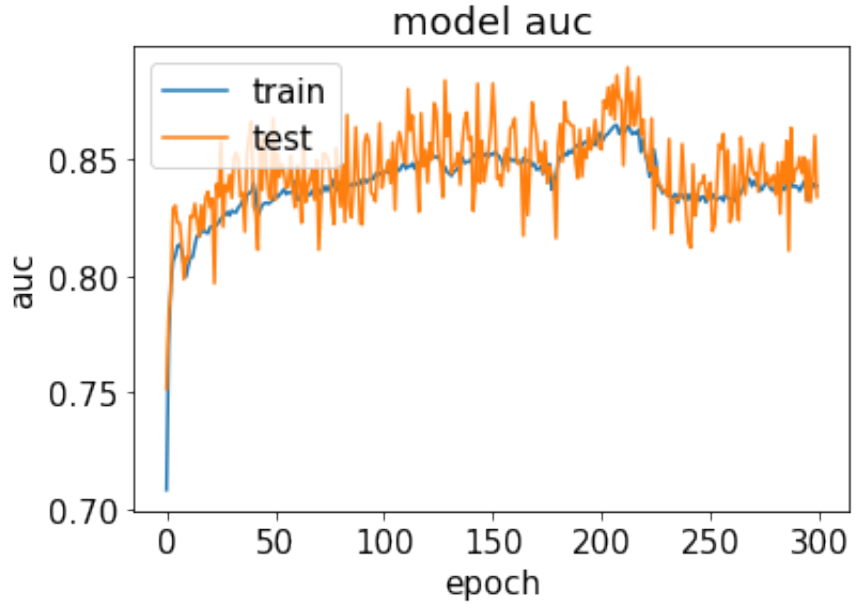
```
plt.plot(history.history['accuracy'])
plt.plot(history.history['val_accuracy'])
plt.title('model accuracy')
plt.ylabel('accuracy')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```



```
plt.plot(history.history['loss'])
plt.plot(history.history['val_loss'])
plt.title('model loss')
plt.ylabel('loss')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```



```
plt.plot(history.history[list(history.history.keys())[2]])
plt.plot(history.history[list(history.history.keys())[5]])
plt.title('model auc')
plt.ylabel('auc')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```



Wearables Dataset Redo

```
min_length = 4

rnn_wearables_input = []
rnn_wearables_output = []

# max_list_length = []
```

```
# for key in temp_df_hrv.keys():
#     this_length = 0
#     hrv_dates = list(temp_df_hrv[key].index)
#     for date in hrv_dates:
#         if date in df_covid.columns:
#             this_length += 1
#     max_list_length.append(this_length)
# max_list_length = sorted(max_list_length)
# print(max_list_length)

for key in temp_df_wearables.keys():
    covid_wearables_np = []
    wearables_np = []
    wearables_dates = list(temp_df_wearables[key].index)
    for date in wearables_dates:
        if date in df_covid.columns and key in df_covid.index:
            covid_wearables_np.append(df_covid.loc[key][date].astype('int'))
            # print(list(temp_df_wearables[key].loc[date].to_numpy()[:-1]))
            wearables_np.append(list(temp_df_wearables[key].loc[date].to_numpy()[:-1].astype('float')))
    # print(hrv_np)
    # print(covid_hrv_np)

    #if len(covid_hrv_np) >= min_length:
    #    if 1 in covid_hrv_np:
    #        covid_index = covid_hrv_np.index(1)
    #        if covid_index+1 > min_length:
    #            rnn_hrv_input.append(hrv_np[covid_index-(min_length-1):covid_index+1])
    #            # rnn_hrv_output.append(covid_hrv_np[covid_index-(min_length-1):covid_index+1])
    #        else:
    #            rnn_hrv_input.append(hrv_np[:min_length])
    #            # rnn_hrv_output.append(covid_hrv_np[:min_length])
    #        rnn_hrv_output.append(1)
    #    else:
    #        rnn_hrv_input.append(hrv_np[:min_length])
    #        # rnn_hrv_output.append(covid_hrv_np[:min_length])
    #        rnn_hrv_output.append(0)
```

```
43
44      # sliding window
45      if len(covid_wearables_np) >= min_length:
46          for w in range(len(covid_wearables_np) - min_length + 1):
47              if covid_wearables_np[w:w+min_length][-1] == 0 and covid_wearables_np[w:w+min_length][0] == 1:
48                  continue
49              rnn_wearables_input.append(wearables_np[w:w+min_length])
50              rnn_wearables_output.append(sum(covid_wearables_np[w:w+min_length])/min_length)
51              # if 1 in covid_hrv_np[w:w+min_length]:
52              #     rnn_hrv_output.append(1)
53              # else:
54              #     rnn_hrv_output.append(0)
```

```
1 # checking wearables data
2 print("Number of entries: " + str(len(rnn_wearables_input)))
3
4 pos = sum(rnn_wearables_output)
5
6 print("Positive: " + str(pos/len(rnn_wearables_output)) + " Negative: " + str(1-pos/len(rnn_wearables_outp
7 #total_output = sum( [ len(c) for c in rnn_hrv_output])
8 # print(rnn_wearables_input)
```

```
Number of entries: 251
Positive: 0.3605577689243028 Negative: 0.6394422310756972
```

Wearables RNN

```
1 # INPUTS
2 #cut_index = 4
3 # cut_index = int(len(rnn_hrv_input) * 0.4) # get more testing samples
4 cut_index_w = int(len(rnn_wearables_input) * 0.2) # testing = 20% of our inputs
5
6 # shuffle dataset
```

```
indices = tf.range(start=0, limit=len(rnn_wearables_input), dtype=tf.int32)
shuffled_indices = tf.random.shuffle(indices, seed=57344, name="wearables_indices")
tf.print(shuffled_indices)

shuffled_rnn_wearables_input = tf.gather(rnn_wearables_input, shuffled_indices)
shuffled_rnn_wearables_output = tf.gather(rnn_wearables_output, shuffled_indices)

tmp_input_wearables_train = tf.convert_to_tensor(shuffled_rnn_wearables_input[cut_index_w:], dtype=tf.floa
tmp_input_wearables_val = tf.convert_to_tensor(shuffled_rnn_wearables_input[:cut_index_w], dtype=tf.float3

input_wearables_train = layers.Input(shape=tmp_input_wearables_train.shape,
                                     tensor=tmp_input_wearables_train)
input_wearables_val = layers.Input(shape=tmp_input_wearables_val.shape,
                                   tensor=tmp_input_wearables_val)

output_wearables_train = tf.convert_to_tensor(shuffled_rnn_wearables_output[cut_index_w:], dtype=tf.float3
output_wearables_val = tf.convert_to_tensor(shuffled_rnn_wearables_output[:cut_index_w], dtype=tf.float32)

print(input_wearables_train.shape, output_wearables_train.shape)
print(input_wearables_val.shape, output_wearables_val.shape)
# print(input_wearables_test.shape, output_wearables_test.shape)

tmp_input_wearables_tests = []
input_wearables_tests = []
output_wearables_tests = []
for i in range(0, cut_index_w):
    tmp_input_wearables_tests.append(tf.convert_to_tensor([shuffled_rnn_wearables_input[i]], dtype=tf.floa
    input_wearables_tests.append(layers.Input(shape=tmp_input_wearables_tests[i].shape,
                                      tensor=tmp_input_wearables_tests[i]))
    output_wearables_tests.append(tf.convert_to_tensor([shuffled_rnn_wearables_output[i]], dtype=tf.float3
```

```
(201, 4, 7) (201,)
(50, 4, 7) (50,)
```

```
# Adding callbacks (save checkpoint and early stopping)
CHECKPOINT_PATH_W = '/tmp/checkpoint'
```

```
# MODEL
num_loops = 1

for i in range(num_loops):
    training_callbacks_w = [
    #tf.keras.callbacks.EarlyStopping(monitor='val_loss', patience=100),
    tf.keras.callbacks.ModelCheckpoint(
        filepath=CHECKPOINT_PATH_W,
        save_weights_only=True,
        monitor='val_loss',
        mode='min',
        save_best_only=True)
    ]

    model_w = keras.Sequential()

    # LSTM Layer
    # model_w.add(layers.LSTM(input_hrv_val.shape[1], input_shape=input_hrv_val.shape[1:]))
    model_w.add(layers.SimpleRNN(input_wearables_val.shape[1]*16,
                            input_shape=input_wearables_val.shape[1:],
                            recurrent_regularizer=keras.regularizers.L2(0.1),
                            activation='tanh'))
    # Dense Layer
    # kernel_regularizer=keras.regularizers.L2(0.01),
    model_w.add(layers.Dense(input_wearables_val.shape[1]*8,
                         kernel_regularizer=keras.regularizers.L2(0.05),
                         activation='tanh'))
    model_w.add(layers.Dense(input_wearables_val.shape[1]*2,
                            activation='tanh'))
    model_w.add(layers.Dense(input_wearables_val.shape[1],
                         activation='tanh'))
```

```
    # model_w.add(layers.Dense(input_hrv_val.shape[1]*8, activation='tanh'))
    # if many-to-many, comment out this layer
    # Dense layer size 1 for BCE
    model_w.add(layers.Dense(1, activation='tanh'))

    # Binary Cross Entropy
    model_w.compile(loss=tf.keras.losses.MeanAbsoluteError(),
                optimizer=tf.optimizers.SGD(),
                metrics=["accuracy", keras.metrics.AUC()])

    # Fit the model_w
    history_w = model_w.fit(input_wearables_train, output_wearables_train,
                        batch_size=1,
                        steps_per_epoch=input_wearables_train.shape[0],
                        epochs=300,
                        validation_data=(input_wearables_val, output_wearables_val),
                        validation_steps=input_wearables_val.shape[0],
                        callbacks = training_callbacks_w)

    # Validation set loss & accuracy
    results = model_w.evaluate(input_wearables_val, output_wearables_val, steps=input_wearables_val.shape[
    print("validation loss, acc: ", results)

    # # Predict COVID in a witheld sample from the training set
    for i in range(0, cut_index_w):
        prediction = model_w.predict(input_wearables_tests[i], output_wearables_tests[i], steps=1)
        print(i, " test actual, prediction: ", rnn_wearables_output[i], prediction[0])
        # print(i, " test prediction: ", prediction)

    prediction = model_w.predict(input_wearables_val, output_wearables_val, steps=1)
    # print(rnn_hrv_output[:cut_index_w], prediction)
    print("f1 score: ", f1_score(rnn_wearables_output[:cut_index_w], prediction, 0.125))

    print(model_w.summary())
```

```
Train on 201 samples, validate on 50 samples
Epoch 1/300
```

```
Epoch 1/300
201/201 [==============================] - 2s 7ms/step - batch: 100.0000 - size: 1.0000 - loss: 6.5147 -
Epoch 2/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 3.4849 -
Epoch 3/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 2.0035 -
Epoch 4/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 1.2582 -
Epoch 5/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.8645 -
Epoch 6/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.6502 -
Epoch 7/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.5267 -
Epoch 8/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.4593 -
Epoch 9/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.4139 -
Epoch 10/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3851 -
Epoch 11/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3675 -
Epoch 12/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3553 -
Epoch 13/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3452 -
Epoch 14/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3408 -
Epoch 15/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3370 -
Epoch 16/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3335 -
Epoch 17/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3311 -
Epoch 18/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3327 -
Epoch 19/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3325 -
Epoch 20/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3295 -
Epoch 21/300
```

```
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3311 -
Epoch 22/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3306 -
Epoch 23/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3294 -
Epoch 24/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3297 -
Epoch 25/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3295 -
Epoch 26/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3277 -
Epoch 27/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3264 -
Epoch 28/300
201/201 [==============================] - 1s 5ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3238 -
Epoch 29/300
201/201 [==============================] - 1s 4ms/step - batch: 100.0000 - size: 1.0000 - loss: 0.3227 -
Epoch 30/300
```

```
# print result using best model
# Loads the weights
model_w.load_weights(CHECKPOINT_PATH_W)

# Validation set loss & accuracy
results = model_w.evaluate(input_wearables_val, output_wearables_val, steps=input_wearables_val.shape[0])
print("validation loss, acc, auc: ", results)

# # Predict COVID in a witheld sample from the training set
for i in range(0, cut_index_w):
    prediction = model_w.predict(input_wearables_tests[i], output_wearables_tests[i], steps=1)
    print(i, " test actual, prediction: ", rnn_wearables_output[i], prediction[0])
    # print(i, " test prediction: ", prediction)

prediction = model_w.predict(input_wearables_val, output_wearables_val, steps=1)
# print(rnn_hrv_output[:cut_index], prediction)
print("precision: ", precision(rnn_wearables_output[:cut_index_w], prediction, 0.125))
print("recall: ", recall(rnn_wearables_output[:cut_index_w], prediction, 0.125))
print("f1 score: ", f1_score(rnn_wearables_output[:cut_index_w], prediction, 0.125))

```

```
21 print(model_w.summary())
```

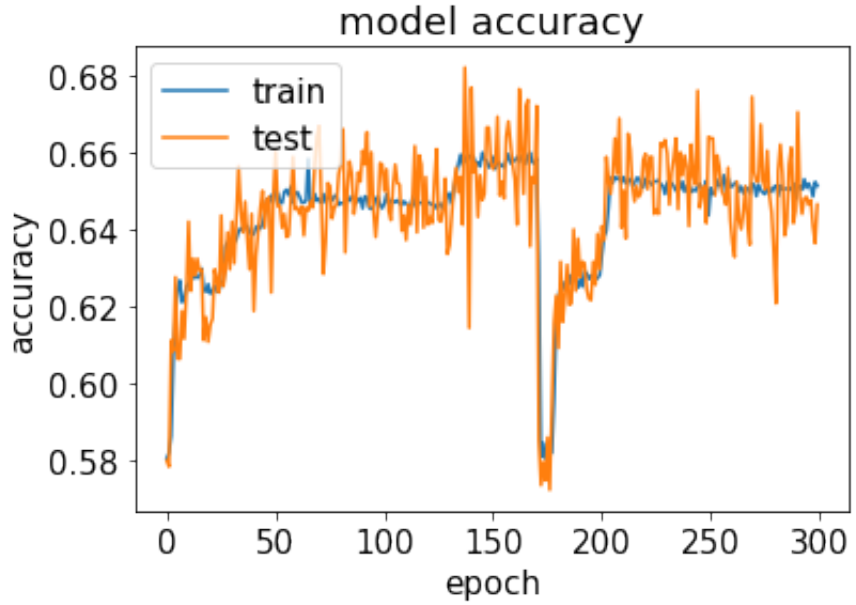
```
validation loss, acc, auc:  [0.3009482154250145, 0.6504, 0.6505481]
0  test actual, prediction:  0.0 [0.00553048]
1  test actual, prediction:  0.0 [-0.00595241]
2  test actual, prediction:  0.0 [0.00120956]
3  test actual, prediction:  0.0 [-0.00019109]
4  test actual, prediction:  0.0 [0.05764998]
5  test actual, prediction:  0.0 [0.00808996]
6  test actual, prediction:  0.0 [0.00671984]
7  test actual, prediction:  0.0 [0.00155586]
8  test actual, prediction:  0.0 [0.00034344]
9  test actual, prediction:  0.0 [0.00120956]
10  test actual, prediction:  0.0 [0.30144763]
11  test actual, prediction:  0.0 [0.00808996]
12  test actual, prediction:  0.0 [0.89052844]
13  test actual, prediction:  0.25 [-0.00312464]
14  test actual, prediction:  0.5 [0.05764998]
15  test actual, prediction:  0.75 [-0.00019109]
16  test actual, prediction:  1.0 [0.00541783]
17  test actual, prediction:  1.0 [-0.00239604]
18  test actual, prediction:  1.0 [0.00553048]
19  test actual, prediction:  0.0 [0.9830175]
20  test actual, prediction:  0.0 [0.00808996]
21  test actual, prediction:  0.0 [-0.00409339]
22  test actual, prediction:  0.0 [0.04807673]
23  test actual, prediction:  0.0 [0.0167819]
24  test actual, prediction:  0.0 [0.00155586]
25  test actual, prediction:  0.0 [0.00553048]
26  test actual, prediction:  0.0 [-0.00312464]
27  test actual, prediction:  0.0 [0.04807661]
28  test actual, prediction:  0.0 [0.00808996]
29  test actual, prediction:  0.0 [0.00671984]
30  test actual, prediction:  0.0 [0.9134626]
31  test actual, prediction:  0.25 [-0.00016332]
32  test actual, prediction:  0.5 [0.01536701]
33  test actual, prediction:  0.75 [-0.00312464]
34  test actual, prediction:  0.0 [0.00808996]
35  test actual, prediction:  0.0 [0.7861338]
36  test actual, prediction:  0.0 [0.00671984]
37  test actual, prediction:  0.0 [0.0167819]
```

```
37  test actual, prediction:  0.0 [0.0167819]
38  test actual, prediction:  1.0 [0.81261003]
39  test actual, prediction:  1.0 [0.00808996]
40  test actual, prediction:  1.0 [0.00671984]
41  test actual, prediction:  1.0 [0.0167819]
42  test actual, prediction:  1.0 [0.0167819]
43  test actual, prediction:  0.25 [0.00319355]
44  test actual, prediction:  0.5 [0.81261003]
45  test actual, prediction:  0.75 [0.0167819]
46  test actual, prediction:  1.0 [0.05764998]
47  test actual, prediction:  1.0 [-0.00595241]
48  test actual, prediction:  1.0 [-0.00019109]
49  test actual, prediction:  1.0 [0.98963594]
precision:  0.8387096774193549
recall:  0.5777777777777777
f1 score:  0.6842105263157895
Model: "sequential_1"
_________________________________________________________________
 Layer (type)                 Output Shape              Param #
=================================================================
 simple_rnn_1 (SimpleRNN)    (None, 64)                4608
```

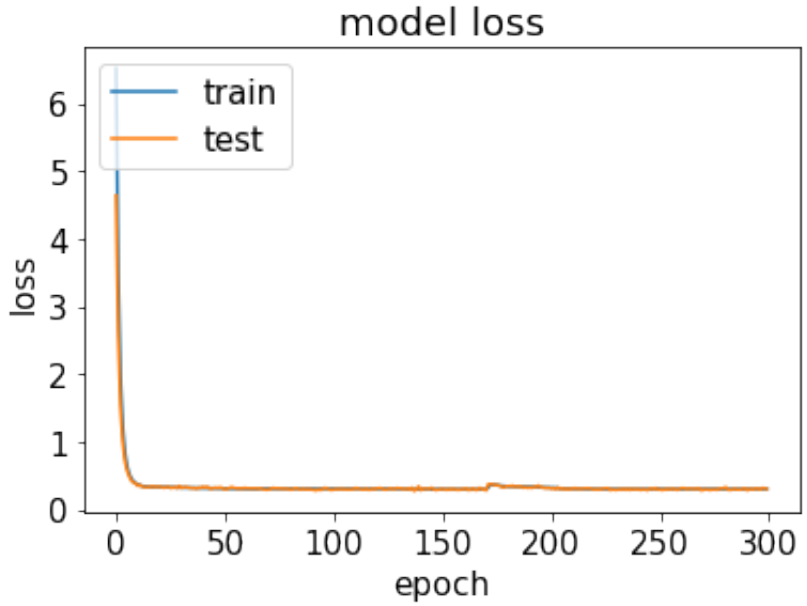
```
1 print(history_w.history.keys())
```

```
dict_keys(['loss', 'accuracy', 'auc_1', 'val_loss', 'val_accuracy', 'val_auc_1'])
```

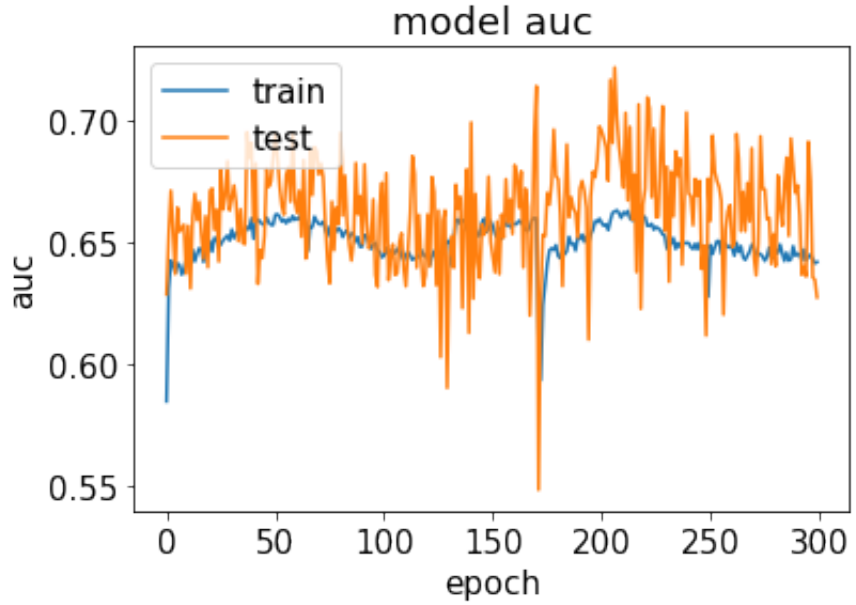
```
plt.plot(history_w.history['accuracy'])
plt.plot(history_w.history['val_accuracy'])
plt.title('model accuracy')
plt.ylabel('accuracy')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```



```
plt.plot(history_w.history['loss'])
plt.plot(history_w.history['val_loss'])
plt.title('model loss')
plt.ylabel('loss')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```



```
plt.plot(history_w.history[list(history_w.history.keys())[2]])
plt.plot(history_w.history[list(history_w.history.keys())[5]])
plt.title('model auc')
plt.ylabel('auc')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```




```
# print(input_hrv_train.head())
# print(output_hrv_train.head())
# print(input_wearables_train.head())
# print(output_wearables_train.head())
```

Combo Dataset Redo

```
min_length = 4
```

```
 2
 3 rnn_combo_input = []
 4 rnn_combo_output = []
 5
 6 # max_list_length = []
 7 # for key in temp_df_hrv.keys():
 8 #     this_length = 0
 9 #     hrv_dates = list(temp_df_hrv[key].index)
10 #     for date in hrv_dates:
11 #         if date in df_covid.columns:
12 #             this_length += 1
13 #     max_list_length.append(this_length)
14 # max_list_length = sorted(max_list_length)
15 # print(max_list_length)
16
17 for key in temp_df_wearables.keys():
18     covid_combo_np = []
19     combo_np = []
20     combo_dates_1 = list(temp_df_wearables[key].index)
21     if key not in temp_df_hrv.keys():
22         continue
23     combo_dates_2 = list(temp_df_hrv[key].index)
24     for date in combo_dates_1:
25         if date in df_covid.columns and key in df_covid.index and date in combo_dates_2:
26             covid_combo_np.append(df_covid.loc[key][date].astype('int'))
27             # print(list(temp_df_wearables[key].loc[date].to_numpy()[:-1]))
28             combo_np.append(list(temp_df_wearables[key].loc[date].to_numpy()[:-1].astype('float')) +
29                             list(temp_df_hrv[key].loc[date].to_numpy().astype('float')))
30     # print(hrv_np)
31     # print(covid_hrv_np)
32
33     #if len(covid_hrv_np) >= min_length:
34     #    if 1 in covid_hrv_np:
35     #        covid_index = covid_hrv_np.index(1)
36     #        if covid_index+1 > min_length:
37     #            rnn_hrv_input.append(hrv_np[covid_index-(min_length-1):covid_index+1])
```

```
    #            # rnn_hrv_output.append(covid_hrv_np[covid_index-(min_length-1):covid_index+1])
    #        else:
    #            rnn_hrv_input.append(hrv_np[:min_length])
    #            # rnn_hrv_output.append(covid_hrv_np[:min_length])
    #        rnn_hrv_output.append(1)
    #    else:
    #        rnn_hrv_input.append(hrv_np[:min_length])
    #        # rnn_hrv_output.append(covid_hrv_np[:min_length])
    #        rnn_hrv_output.append(0)

    # sliding window
    if len(covid_combo_np) >= min_length:
        for w in range(len(covid_combo_np) - min_length + 1):
            if covid_combo_np[w:w+min_length][-1] == 0 and covid_combo_np[w:w+min_length][0] == 1:
                continue
            rnn_combo_input.append(combo_np[w:w+min_length])
            rnn_combo_output.append(sum(covid_combo_np[w:w+min_length])/min_length)
            # if 1 in covid_hrv_np[w:w+min_length]:
            #     rnn_hrv_output.append(1)
            # else:
            #     rnn_hrv_output.append(0)
```

```
# checking wearables data
print("Number of entries: " + str(len(rnn_combo_input)))

pos = sum(rnn_combo_output)

print("Positive: " + str(pos/len(rnn_combo_output)) + " Negative: " + str(1-pos/len(rnn_combo_output)))
#total_output = sum( [ len(c) for c in rnn_hrv_output])
# print(rnn_wearables_input)
```

```
Number of entries: 64
Positive: 0.625 Negative: 0.375
```

Combo RNN

```
# INPUTS
#cut_index = 4
# cut_index = int(len(rnn_hrv_input) * 0.4) # get more testing samples
cut_index_c = int(len(rnn_combo_input) * 0.1) # testing = 10% of our inputs

# print(rnn_combo_input[cut_index_w:])
# shuffle dataset
indices = tf.range(start=0, limit=len(rnn_combo_input), dtype=tf.int32)
shuffled_indices = tf.random.shuffle(indices, seed=57344, name="combo_indices")
tf.print(shuffled_indices)

shuffled_rnn_combo_input = tf.gather(rnn_combo_input, shuffled_indices)
shuffled_rnn_combo_output = tf.gather(rnn_combo_output, shuffled_indices)

tmp_input_combo_train = tf.convert_to_tensor(shuffled_rnn_combo_input[cut_index_c:], dtype=tf.float32)
tmp_input_combo_val = tf.convert_to_tensor(shuffled_rnn_combo_input[:cut_index_c], dtype=tf.float32)

input_combo_train = layers.Input(shape=tmp_input_combo_train.shape,
                                 tensor=tmp_input_combo_train)
input_combo_val = layers.Input(shape=tmp_input_combo_val.shape,
                               tensor=tmp_input_combo_val)

output_combo_train = tf.convert_to_tensor(shuffled_rnn_combo_output[cut_index_c:], dtype=tf.float32)
output_combo_val = tf.convert_to_tensor(shuffled_rnn_combo_output[:cut_index_c], dtype=tf.float32)

print(input_combo_train.shape, output_combo_train.shape)
print(input_combo_val.shape, output_combo_val.shape)
# print(input_combo_test.shape, output_combo_test.shape)

tmp_input_combo_tests = []
input_combo_tests = []
```

```
output_combo_tests = []
for i in range(0, cut_index_c):
    tmp_input_combo_tests.append(tf.convert_to_tensor([shuffled_rnn_combo_input[i]], dtype=tf.float32))
    input_combo_tests.append(layers.Input(shape=tmp_input_combo_tests[i].shape,
                                tensor=tmp_input_combo_tests[i]))
    output_combo_tests.append(tf.convert_to_tensor([shuffled_rnn_combo_output[i]], dtype=tf.float32))
```

```
(58, 4, 20) (58,)
(6, 4, 20) (6,)
```

```
# MODEL
num_loops = 1

for i in range(num_loops):
    training_callbacks_c = [
    #tf.keras.callbacks.EarlyStopping(monitor='val_loss', patience=100),
    tf.keras.callbacks.ModelCheckpoint(
        filepath=CHECKPOINT_PATH_W,
        save_weights_only=True,
        monitor='val_loss',
        mode='min',
        save_best_only=True)
    ]

    model_c = keras.Sequential()

    # LSTM Layer
    # model_c.add(layers.LSTM(input_hrv_val.shape[1], input_shape=input_hrv_val.shape[1:]))
    model_c.add(layers.SimpleRNN(input_combo_val.shape[1]*16,
                            input_shape=input_combo_val.shape[1:],
                            recurrent_regularizer=keras.regularizers.L2(0.1),
                            activation='tanh'))
    # Dense Layer
    # kernel_regularizer=keras.regularizers.L2(0.01),
    model_c.add(layers.Dense(input_combo_val.shape[1]*8,
                          kernel_regularizer=keras.regularizers.L2(0.05),
```

```
                        activation='tanh'))
    model_c.add(layers.Dense(input_combo_val.shape[1]*2,
                           activation='tanh'))
    model_c.add(layers.Dense(input_combo_val.shape[1],
                        activation='tanh'))
    # model_c.add(layers.Dense(input_hrv_val.shape[1], activation='tanh'))
    # if many-to-many, comment out this layer
    # Dense layer size 1 for BCE
    model_c.add(layers.Dense(1, activation='tanh'))

    # Binary Cross Entropy
    model_c.compile(loss=tf.keras.losses.MeanAbsoluteError(),
                optimizer=tf.optimizers.SGD(),
                metrics=["accuracy", keras.metrics.AUC()])

    # Fit the model_c
    history_c = model_c.fit(input_combo_train, output_combo_train,
                        batch_size=1,
                        steps_per_epoch=input_combo_train.shape[0],
                        epochs=300,
                        validation_data=(input_combo_val, output_combo_val),
                        validation_steps=input_combo_val.shape[0],
                        callbacks = training_callbacks_c)

# Validation set loss & accuracy
results = model_c.evaluate(input_combo_val, output_combo_val, steps=input_combo_val.shape[0])
print("validation loss, acc: ", results)

# # Predict COVID in a witheld sample from the training set
for i in range(0, cut_index_c):
    prediction = model_c.predict(input_combo_tests[i], output_combo_tests[i], steps=1)
    print(i, " test actual, prediction: ", rnn_combo_output[i], prediction[0])
    # print(i, " test prediction: ", prediction)

prediction = model_c.predict(input_combo_val, output_combo_val, steps=1)
# print(rnn_hrv_output[:cut_index_c], prediction)
```

```
print("f1 score: ", f1_score(rnn_combo_output[:cut_index_c], prediction, 0.125))

print(model_c.summary())
```

```
Train on 58 samples, validate on 6 samples
Epoch 1/300
58/58 [==============================] - 1s 16ms/step - batch: 28.5000 - size: 1.0000 - loss: 8.1410 - a
Epoch 2/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 6.6729 - ac
Epoch 3/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 5.5268 - ac
Epoch 4/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 4.6038 - ac
Epoch 5/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 3.8538 - ac
Epoch 6/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 3.2453 - ac
Epoch 7/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 2.7497 - ac
Epoch 8/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 2.3339 - ac
Epoch 9/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 1.9922 - ac
Epoch 10/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 1.7153 - ac
Epoch 11/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 1.4846 - ac
Epoch 12/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 1.2920 - ac
Epoch 13/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 1.1346 - ac
Epoch 14/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 1.0026 - ac
Epoch 15/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.8938 - ac
Epoch 16/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.7967 - ac
Epoch 17/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.7198 - ac
Epoch 18/300
```

```
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.6539 - ac
Epoch 19/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.6013 - ac
Epoch 20/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.5607 - ac
Epoch 21/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.5267 - ac
Epoch 22/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.4911 - ac
Epoch 23/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.4575 - ac
Epoch 24/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.4316 - ac
Epoch 25/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.4129 - ac
Epoch 26/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.3916 - ac
Epoch 27/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.3729 - ac
Epoch 28/300
58/58 [==============================] - 0s 3ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.3602 - ac
Epoch 29/300
58/58 [==============================] - 0s 4ms/step - batch: 28.5000 - size: 1.0000 - loss: 0.3455 - ac
Epoch 30/300
```

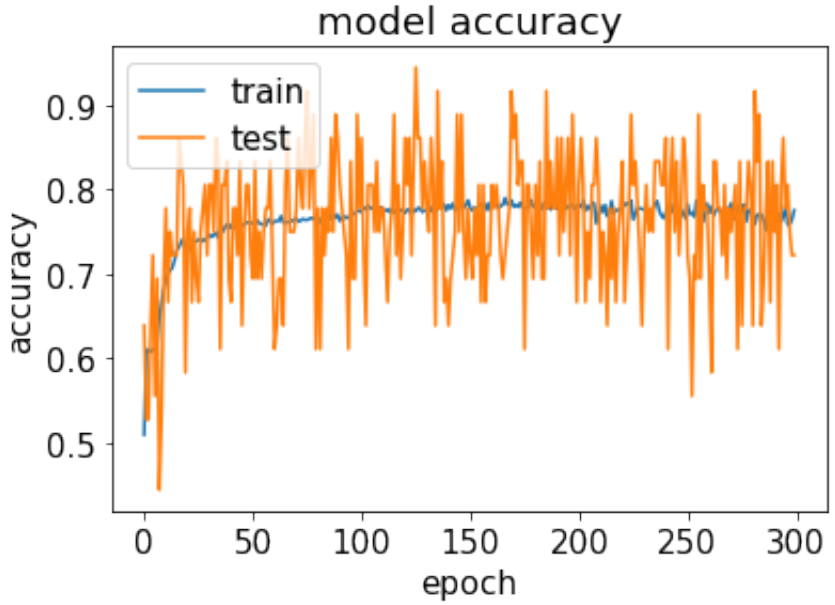
```
# print result using best model
# Loads the weights
model_c.load_weights(CHECKPOINT_PATH)

# Validation set loss & accuracy
results = model_c.evaluate(input_combo_val, output_combo_val, steps=input_combo_val.shape[0])
print("validation loss, acc, auc: ", results)

# # Predict COVID in a witheld sample from the training set
for i in range(0, cut_index_c):
    prediction = model_c.predict(input_combo_tests[i], output_combo_tests[i], steps=1)
    print(i, " test actual, prediction: ", rnn_combo_output[i], prediction[0])
    # print(i, " test prediction: ", prediction)

prediction = model_c.predict(input_combo_val, output_combo_val, steps=1)
# print(rnn_hrv_output[:cut_index], prediction)
print("precision: ", precision(rnn_combo_output[:cut_index_c], prediction, 0.125))
print("recall: ", recall(rnn_combo_output[:cut_index_c], prediction, 0.125))
print("f1 score: ", f1_score(rnn_combo_output[:cut_index_c], prediction, 0.125))
```

```
validation loss, acc, auc:  [0.15715149541695914, 0.8888889, 0.8489584]
0  test actual, prediction:  0.25 [0.95433086]
1  test actual, prediction:  0.5 [0.95433086]
2  test actual, prediction:  1.0 [0.6598532]
3  test actual, prediction:  1.0 [-0.03755715]
4  test actual, prediction:  0.75 [0.95870686]
5  test actual, prediction:  1.0 [0.9971713]
precision:  0.4
recall:  0.6666666666666666
f1 score:  0.5
```

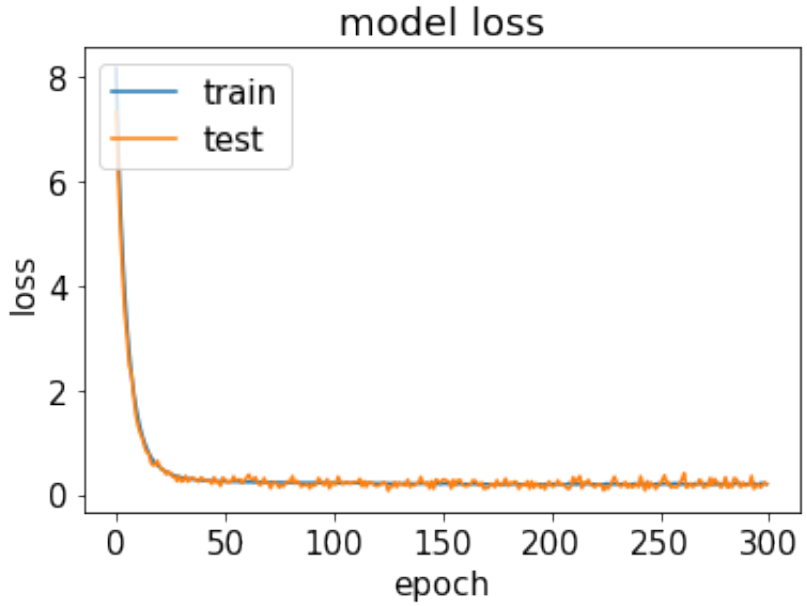
```
print(history_c.history.keys())
```

```
dict_keys(['loss', 'accuracy', 'auc_2', 'val_loss', 'val_accuracy', 'val_auc_2'])
```

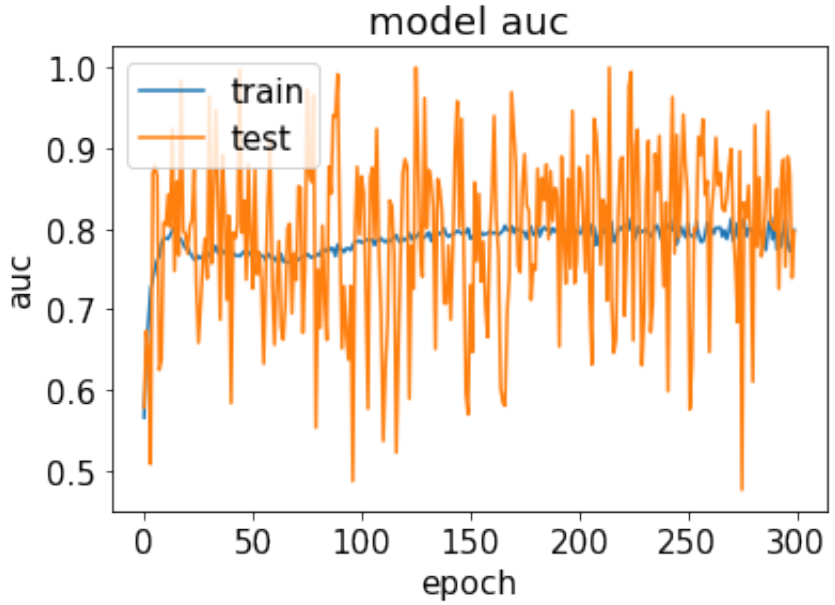
```
plt.plot(history_c.history['accuracy'])
plt.plot(history_c.history['val_accuracy'])
plt.title('model accuracy')
plt.ylabel('accuracy')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```



```
plt.plot(history_c.history['loss'])
plt.plot(history_c.history['val_loss'])
plt.title('model loss')
plt.ylabel('loss')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```



```
plt.plot(history_c.history[list(history_c.history.keys())[2]])
plt.plot(history_c.history[list(history_c.history.keys())[5]])
plt.title('model auc')
plt.ylabel('auc')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper left')
plt.show()
```




```
1
```