Importing all the modules required for this project

In [1]:
```
import keras
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.decomposition import PCA
# Setting seed for reproducability
np.random.seed(1234)
PYTHONHASHSEED = 0
from sklearn import preprocessing
from sklearn.metrics import confusion_matrix, recall_score, precision_score
from keras.models import Sequential
from keras.layers import Dense, Dropout, LSTM, Activation
%matplotlib inline
import pandas as pd
```

```
Using TensorFlow backend.
```

Reading data

In [2]:
```
#Reading train data
train_df  = pd.read_csv('C:\\Users\\Ashish2448311\
\Anaconda3\\envs\\tensorflow\\lib\\site-packages\\train_FD004.txt', sep=" ", head
train_df.drop(train_df.columns[[26, 27]], axis=1, inplace=True)
train_df.columns = ['id', 'cycle', 'setting1', 'setting2', 'setting3', 's1', 's2'
                     's4', 's5', 's6', 's7', 's8', 's9', 's10', 's11', 's12', 's1
                     's15', 's16', 's17', 's18', 's19', 's20', 's21']
```

Reading labels

In [3]:
```
# reading ground truth data
truth_df = pd.read_csv('C:\\Users\\Ashish2448311\
\Anaconda3\\envs\\tensorflow\\lib\\site-packages\\RUL_FD004.txt', sep=" ", header
truth_df.drop(truth_df.columns[[1]], axis=1, inplace=True)
```

In [4]:
```
train_df = train_df.sort_values(['id','cycle'])
train_df.head()
```

Out[4]:

	id	cycle	setting1	setting2	setting3	s1	s2	s3	s4	s5	...	s12	s1
0	1	1	42.0049	0.8400	100.0	445.00	549.68	1343.43	1112.93	3.91	...	129.78	2387.9
1	1	2	20.0020	0.7002	100.0	491.19	606.07	1477.61	1237.50	9.35	...	312.59	2387.7
2	1	3	42.0038	0.8409	100.0	445.00	548.95	1343.12	1117.05	3.91	...	129.62	2387.9
3	1	4	42.0000	0.8400	100.0	445.00	548.70	1341.24	1118.03	3.91	...	129.80	2388.0
4	1	5	25.0063	0.6207	60.0	462.54	536.10	1255.23	1033.59	7.05	...	164.11	2028.0

5 rows × 26 columns

generation of RUL

In [5]:
```
# Data Labeling - generate column RUL
rul = pd.DataFrame(train_df.groupby('id')['cycle'].max()).reset_index()
rul.columns = ['id', 'max']
train_df = train_df.merge(rul, on=['id'], how='left')
train_df['RUL'] = train_df['max'] - train_df['cycle']
train_df.drop('max', axis=1, inplace=True)
train_df.head()
```

Out[5]:

	id	cycle	setting1	setting2	setting3	s1	s2	s3	s4	s5	...	s13	s
0	1	1	42.0049	0.8400	100.0	445.00	549.68	1343.43	1112.93	3.91	...	2387.99	8074
1	1	2	20.0020	0.7002	100.0	491.19	606.07	1477.61	1237.50	9.35	...	2387.73	8046
2	1	3	42.0038	0.8409	100.0	445.00	548.95	1343.12	1117.05	3.91	...	2387.97	8066
3	1	4	42.0000	0.8400	100.0	445.00	548.70	1341.24	1118.03	3.91	...	2388.02	8076
4	1	5	25.0063	0.6207	60.0	462.54	536.10	1255.23	1033.59	7.05	...	2028.08	7865

5 rows × 27 columns

Adding label in data

In [6]:
```
# generate label columns for training data
w1 = 30

train_df['label1'] = np.where(train_df['RUL'] <= w1, 1, 0 )

train_df.head()
```

Out[6]:

	id	cycle	setting1	setting2	setting3	s1	s2	s3	s4	s5	...	s14	s
0	1	1	42.0049	0.8400	100.0	445.00	549.68	1343.43	1112.93	3.91	...	8074.83	9.3
1	1	2	20.0020	0.7002	100.0	491.19	606.07	1477.61	1237.50	9.35	...	8046.13	9.1
2	1	3	42.0038	0.8409	100.0	445.00	548.95	1343.12	1117.05	3.91	...	8066.62	9.4
3	1	4	42.0000	0.8400	100.0	445.00	548.70	1341.24	1118.03	3.91	...	8076.05	9.3
4	1	5	25.0063	0.6207	60.0	462.54	536.10	1255.23	1033.59	7.05	...	7865.80	10.8

5 rows × 28 columns

MinMax normalization

In [7]:
```
# MinMax normalization
train_df['cycle_norm'] = train_df['cycle']
cols_normalize = train_df.columns.difference(['id','cycle','RUL','label1','label2
min_max_scaler = preprocessing.MinMaxScaler()
norm_train_df = pd.DataFrame(min_max_scaler.fit_transform(train_df[cols_normalize
                             columns=cols_normalize,
                             index=train_df.index)
join_df = train_df[train_df.columns.difference(cols_normalize)].join(norm_train_d
train_df = join_df.reindex(columns = train_df.columns)
train_df.head()
```

Out[7]:

	id	cycle	setting1	setting2	setting3	s1	s2	s3	s4	s5	...	
0	1	1	0.999926	0.997625	1.0	0.000000	0.130347	0.272082	0.212586	0.000000	...	0
1	1	2	0.476147	0.831591	1.0	0.626985	0.647971	0.634407	0.511781	0.507937	...	0
2	1	3	0.999900	0.998694	1.0	0.000000	0.123646	0.271245	0.222481	0.000000	...	0
3	1	4	0.999810	0.997625	1.0	0.000000	0.121351	0.266168	0.224835	0.000000	...	0
4	1	5	0.595275	0.737173	0.0	0.238089	0.005691	0.033916	0.022025	0.293184	...	0

5 rows × 29 columns

In [9]:
```
tr= train_df.drop('label1',axis=1)
y = train_df['label1']
```

In [ ]:
```
```

Over sampling using smote

In [10]:
```
from imblearn.over_sampling import SMOTE
import numpy as np
import pandas as pd
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import train_test_split
from sklearn.metrics import recall_score
from imblearn.over_sampling import SMOTE
from imblearn import under_sampling, over_sampling


sm = SMOTE(random_state=12, ratio = 1.0)
#X_train_sampled, Y_train_sampled = sm.fit_sample(X_train, Y_train)
X_train_sampled, Y_train_sampled = sm.fit_sample(tr, y)
```

```
C:\Users\Ashish2448311\Anaconda3\envs\tensorflow\lib\site-packages\sklearn\util
s\deprecation.py:77: DeprecationWarning: Function _ratio_float is deprecated; U
se a float for 'ratio' is deprecated from version 0.2. The support will be remo
ved in 0.4. Use a dict, str, or a callable instead.
  warnings.warn(msg, category=DeprecationWarning)
```

In [11]:
```
df=pd.DataFrame(X_train_sampled)
df.columns = ['id', 'cycle', 'setting1', 'setting2', 'setting3', 's1', 's2', 's3'
                     's4', 's5', 's6', 's7', 's8', 's9', 's10', 's11', 's12', 's1
                     's15', 's16', 's17', 's18', 's19', 's20', 's21','RUL','cycle
```

In [12]:
```
unique, counts = np.unique(Y_train_sampled, return_counts=True)
dict(zip(unique, counts))
```

Out[12]:
```
{0: 53530, 1: 53530}
```

In [13]:
```
label=pd.DataFrame(Y_train_sampled)
label.columns=['label1']
df['label1']=label
```

In [ ]:
```
```

window size of 30

In [14]:
```
# pick a  window size of 30 cycles
sequence_length = 30
```

function to reshape features into (samples, time steps, features)

In [15]:
```
# function to reshape features into (samples, time steps, features)
def gen_sequence(id_df, seq_length, seq_cols):
    """ Only sequences that meet the window-length are considered, no padding is
    we need to drop those which are below the window-length. An alternative would
    we can use shorter ones """
    data_array = id_df[seq_cols].values
    num_elements = data_array.shape[0]
    for start, stop in zip(range(0, num_elements-seq_length), range(seq_length, n
        yield data_array[start:stop, :]


# pick the feature columns
sensor_cols = ['s' + str(i) for i in range(1,22)]
sequence_cols = ['setting1', 'setting2', 'setting3', 'cycle_norm']
sequence_cols.extend(sensor_cols)


# generator for the sequences
seq_gen = (list(gen_sequence(df[df['id']==id], sequence_length, sequence_cols))
           for id in train_df['id'].unique())


seq_array = np.concatenate(list(seq_gen)).astype(np.float32)
seq_array.shape


# function to generate labels
def gen_labels(id_df, seq_length, label):
    data_array = id_df[label].values
    num_elements = data_array.shape[0]
    return data_array[seq_length:num_elements, :]

# generate labels
label_gen = [gen_labels(df[df['id']==id], sequence_length, ['label1'])
             for id in df['id'].unique()]
label_array = np.concatenate(label_gen).astype(np.float32)
label_array.shape
```

Out[15]: (90075, 1)

Splitting of data into 20% validation set and 80%training set

In [16]:
```
RANDOM_SEED=40
X_train, X_test, y_train, y_test = train_test_split(
        seq_array, label_array, test_size=0.2, random_state=RANDOM_SEED)#split th
```

building the network

In [17]:
```
# build the network
nb_features = seq_array.shape[2]
nb_out = label_array.shape[1]

model = Sequential()




model.add(LSTM(
         input_shape=(sequence_length, nb_features),
         units=100,
         return_sequences=True))
model.add(Dropout(0.2))

model.add(LSTM(
          units=50,
          return_sequences=False))
model.add(Dropout(0.2))

model.add(Dense(units=nb_out, activation='sigmoid'))
epochs = 10
learning_rate = 0.1
decay_rate = learning_rate / epochs
momentum = 0.8
sgd = SGD(lr=learning_rate, momentum=momentum, decay=decay_rate, nesterov=True)
model.compile(loss='binary_crossentropy', optimizer=sgd, metrics=['accuracy'])
```

In [18]:
```
print(model.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
lstm_1 (LSTM)                (None, 50, 100)           50400
_________________________________________________________________
dropout_1 (Dropout)          (None, 50, 100)           0
_________________________________________________________________
lstm_2 (LSTM)                (None, 50)                30200
_________________________________________________________________
dropout_2 (Dropout)          (None, 50)                0
_________________________________________________________________
dense_1 (Dense)              (None, 1)                 51
=================================================================
Total params: 80,651
Trainable params: 80,651
Non-trainable params: 0
_________________________________________________________________
None
```

Fitting the network

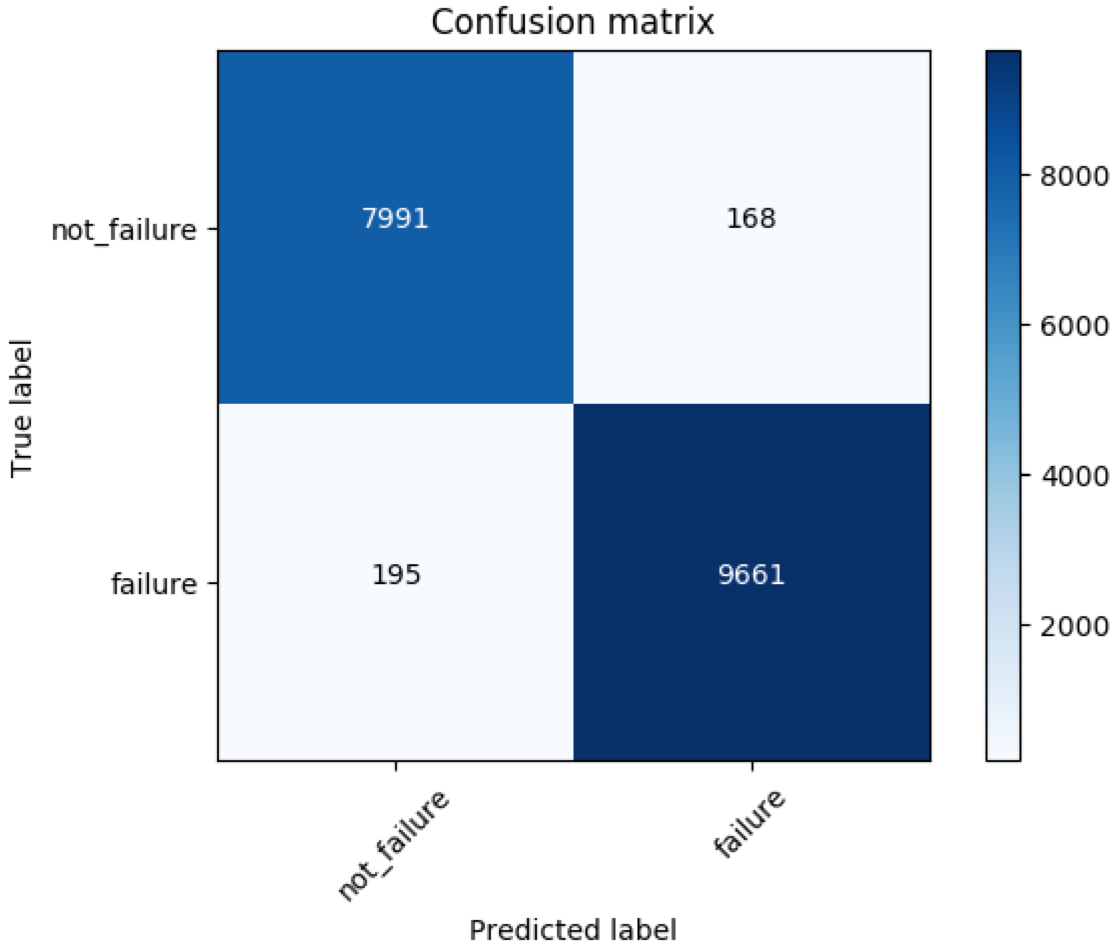
In [22]:
```
%%time
# fit the network

model.fit(X_train,y_train, epochs=10, batch_size=50,validation_data=(X_test,y_tes
        )
```

```
Train on 72060 samples, validate on 18015 samples
Epoch 1/10
72060/72060 [==============================] - 179s - loss: 0.1627 - acc: 0.937
8 - val_loss: 0.1280 - val_acc: 0.9503
Epoch 2/10
72060/72060 [==============================] - 179s - loss: 0.1295 - acc: 0.949
2 - val_loss: 0.1219 - val_acc: 0.9568
Epoch 3/10
72060/72060 [==============================] - 179s - loss: 0.1087 - acc: 0.957
3 - val_loss: 0.0889 - val_acc: 0.9636
Epoch 4/10
72060/72060 [==============================] - 176s - loss: 0.0933 - acc: 0.963
5 - val_loss: 0.1286 - val_acc: 0.9455
Epoch 5/10
72060/72060 [==============================] - 173s - loss: 0.0850 - acc: 0.966
4 - val_loss: 0.1125 - val_acc: 0.9551
Epoch 6/10
72060/72060 [==============================] - 175s - loss: 0.0769 - acc: 0.970
3 - val_loss: 0.0681 - val_acc: 0.9742
Epoch 7/10
72060/72060 [==============================] - 172s - loss: 0.0727 - acc: 0.971
8 - val_loss: 0.0795 - val_acc: 0.9728
Epoch 8/10
72060/72060 [==============================] - 173s - loss: 0.0631 - acc: 0.975
1 - val_loss: 0.0557 - val_acc: 0.9793
Epoch 9/10
72060/72060 [==============================] - 173s - loss: 0.0632 - acc: 0.975
5 - val_loss: 0.0464 - val_acc: 0.9830
Epoch 10/10
72060/72060 [==============================] - 169s - loss: 0.0653 - acc: 0.974
7 - val_loss: 0.0524 - val_acc: 0.9799
Wall time: 29min 13s
```

Out[22]: `<keras.callbacks.History at 0x1afd394fa20>`

Function for confusion matrix

In [98]:
```
import itertools
def plot_confusion_matrix(cm, classes,
                          normalize=False,
                          title='Confusion matrix',
                          cmap=plt.cm.Blues):
    """
    This function prints and plots the confusion matrix.
    Normalization can be applied by setting `normalize=True`.
    """


    plt.imshow(cm, interpolation='nearest', cmap=cmap)
    plt.title(title)
    plt.colorbar()
    tick_marks = np.arange(len(classes))
    plt.xticks(tick_marks, classes, rotation=45)
    plt.yticks(tick_marks, classes)

    fmt = '.2f' if normalize else 'd'
    thresh = cm.max() / 2.
    for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
        plt.text(j, i, format(cm[i, j], fmt),
                 horizontalalignment="center",
                 color="white" if cm[i, j] > thresh else "black")

    plt.tight_layout()
    plt.ylabel('True label')
    plt.xlabel('Predicted label')

class_names = ['not_failure','failure']
np.set_printoptions(precision=2)

# Plot non-normalized confusion matrix
plt.figure()
plot_confusion_matrix(cm, classes=class_names,
                      title='Confusion matrix')


plt.show()
# compute precision and recall
precision = precision_score(y_true, y_pred)
recall = recall_score(y_true, y_pred)
print( 'precision = ', precision, '\n', 'recall = ', recall)
```



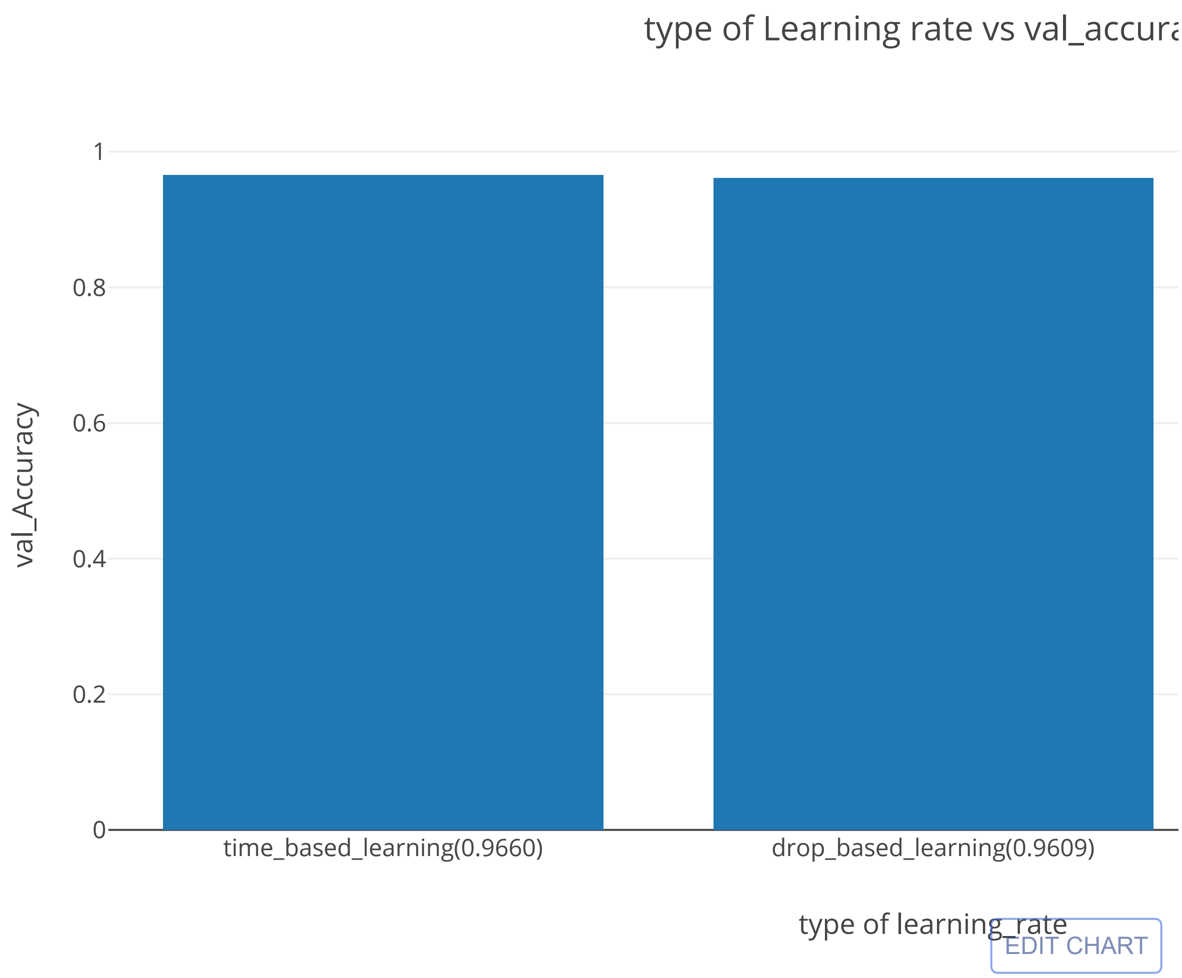

```
precision =  0.982907722047
 recall =  0.980215097403
```

In [ ]:

type of learning rate vs val accuracy

In [86]:
```
import plotly.plotly as py
import plotly.graph_objs as go

data = [go.Bar(
            x=['time_based_learning(0.9660)', 'drop_based_learning(0.9609)', 'con
            y=[0.9660, 0.9609, 0.951]
    )]
layout = dict(title = 'type of Learning rate vs val_accuracy',
              xaxis = dict(title = 'type of learning_rate'),
              yaxis = dict(title = 'val_Accuracy'),
              )

fig = dict(data=data, layout=layout)
py.iplot(fig, filename='basic-bar')
```

Out[86]:

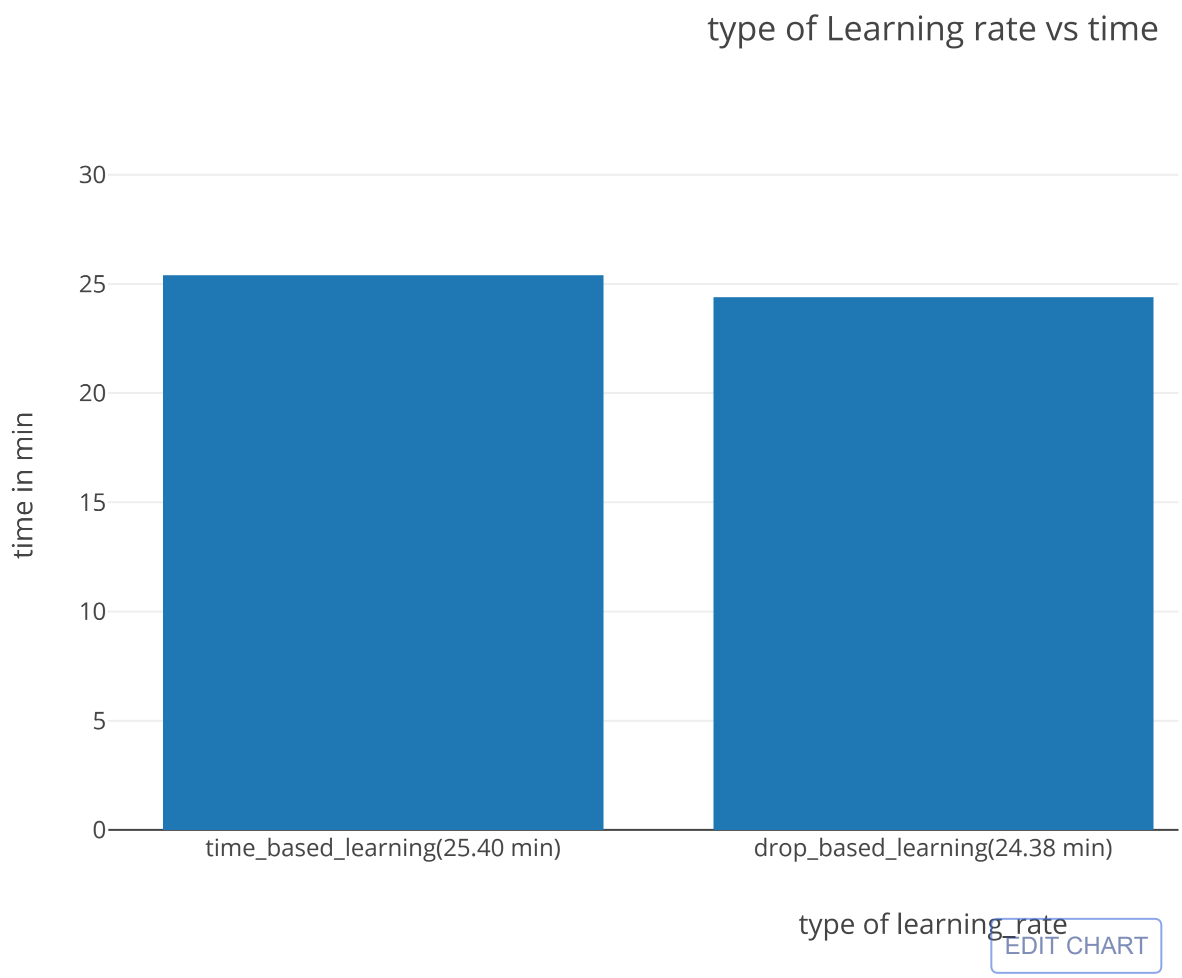


In [ ]:

type of learning rate vs time

In [89]:
```
import plotly.plotly as py
import plotly.graph_objs as go

data = [go.Bar(
            x=['time_based_learning(25.40 min)', 'drop_based_learning(24.38 min)'
            y=[25.40, 24.38, 30]
    )]
layout = dict(title = 'type of Learning rate vs time',
              xaxis = dict(title = 'type of learning_rate'),
              yaxis = dict(title = 'time in min'),
              )

fig = dict(data=data, layout=layout)
py.iplot(fig, filename='basic-bar')
```

Out[89]:



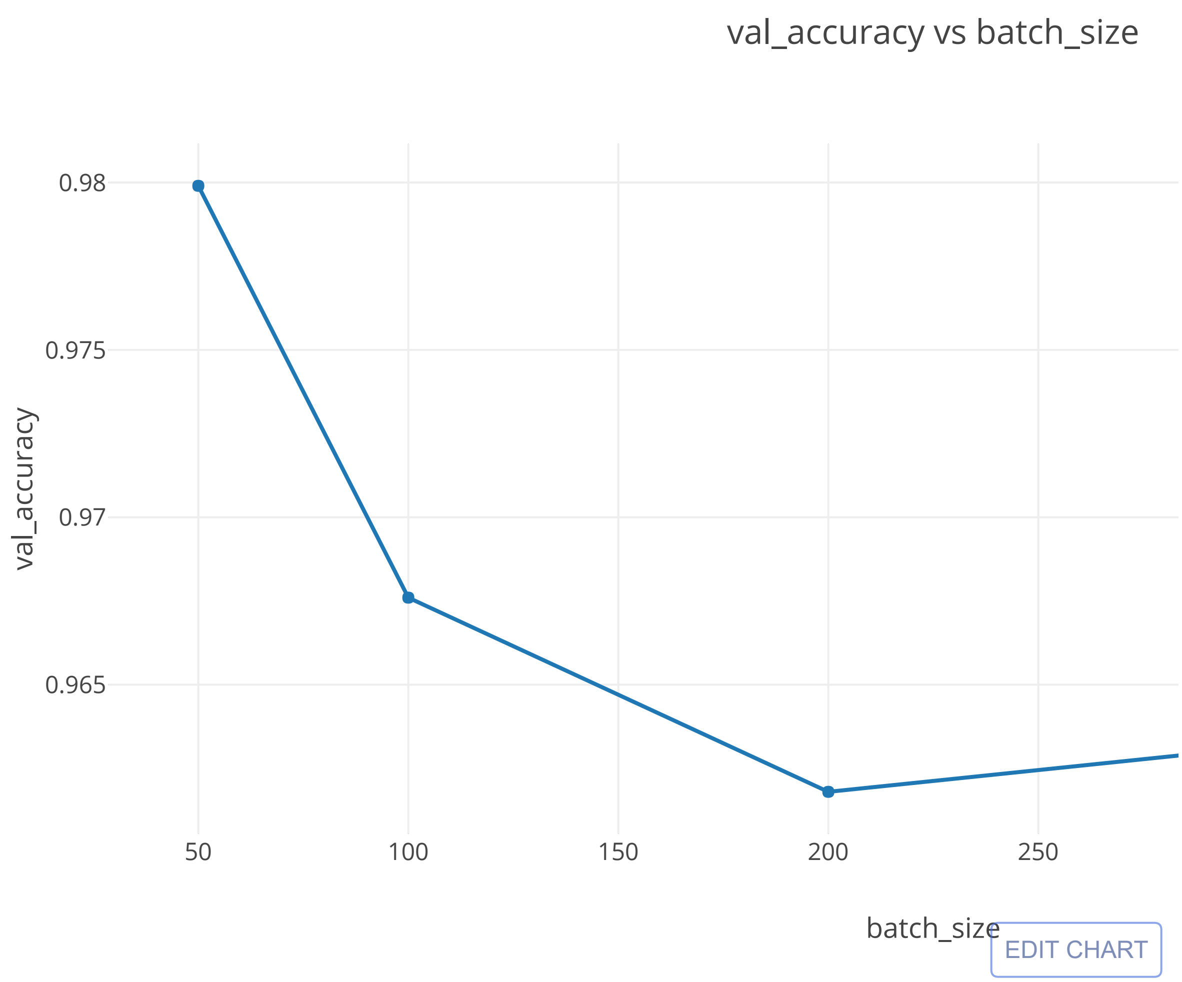
In [ ]:

val accuracy v batch size

In [82]:

```
import plotly.plotly as py
import plotly.graph_objs as go

trace1 = go.Scatter(
    x=[50,100,200,400],
    y=[0.9799,0.9676,0.9618,0.9644],
    name='accurcy'
)

data = [trace1]
layout = go.Layout(
    title='val_accuracy vs batch_size',
    xaxis = dict(title = 'batch_size'),
    yaxis=dict(
        title='val_accuracy'
    )

)
fig = go.Figure(data=data, layout=layout)
py.iplot(fig, filename='multiple-axes-double')
```

Out[82]:



In [ ]:

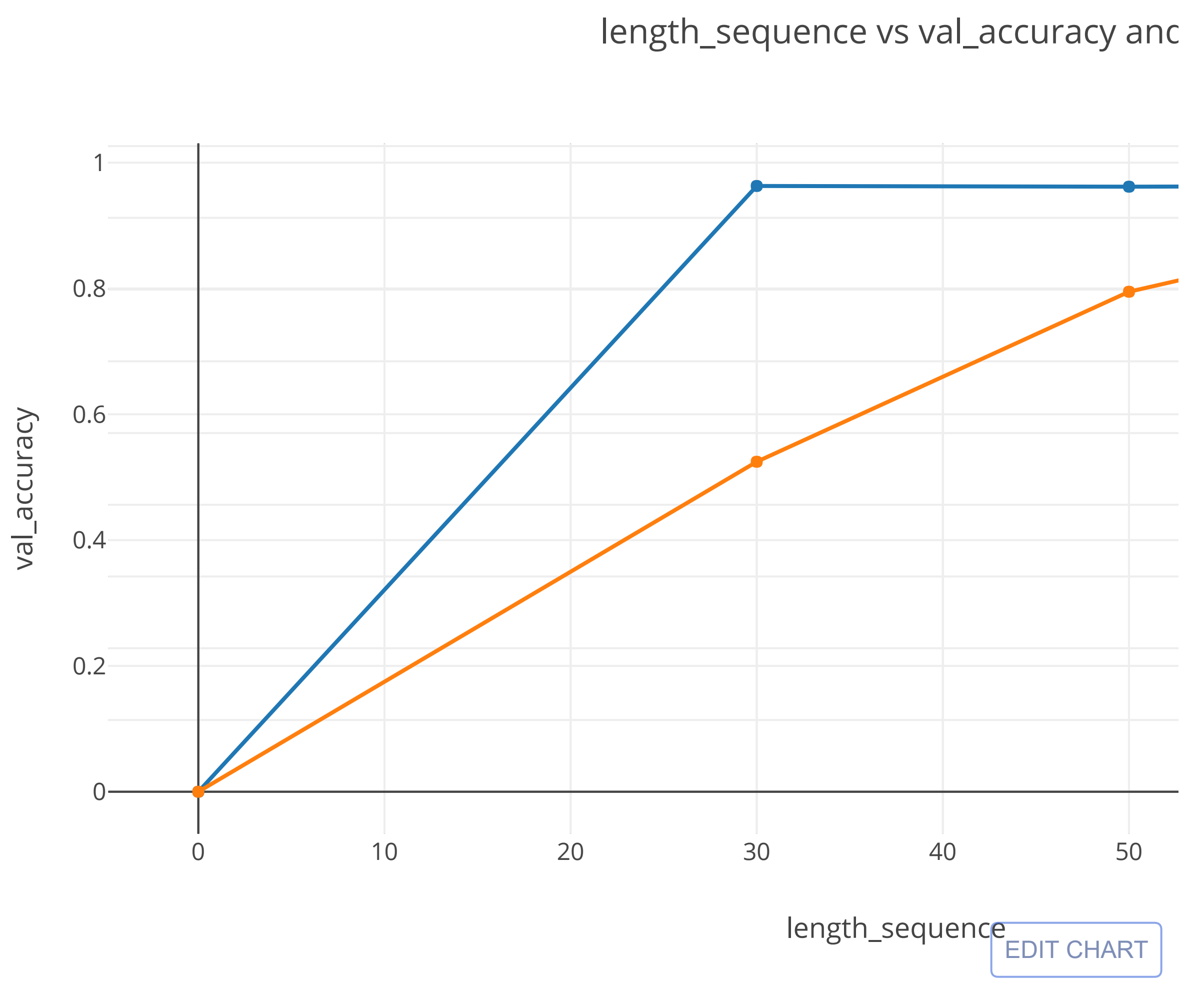
```

```

Length sequence vs val accuracy and time

In [90]:

```
import plotly.plotly as py
import plotly.graph_objs as go

trace1 = go.Scatter(
    x=[0,30,50,75],
    y=[0,0.9629,0.9618,0.9638],
    name='accurcy'
)
trace2 = go.Scatter(
    x=[0,30,50,75],
    y=[0,23,34.85,42.26],
    name='time',
    yaxis='y2'
)
data = [trace1, trace2]
layout = go.Layout(
    title='length_sequence vs val_accuracy and time',
    xaxis = dict(title = 'length_sequence'),
    yaxis=dict(
        title='val_accuracy'
    ),
    yaxis2=dict(
        title='time in minutes',
        titlefont=dict(
            color='rgb(148, 103, 189)'
        ),
        tickfont=dict(
            color='rgb(148, 103, 189)'
        ),
        overlaying='y',
        side='right'
    )
)
fig = go.Figure(data=data, layout=layout)
py.iplot(fig, filename='multiple-axes-double')
```

Out[90]:

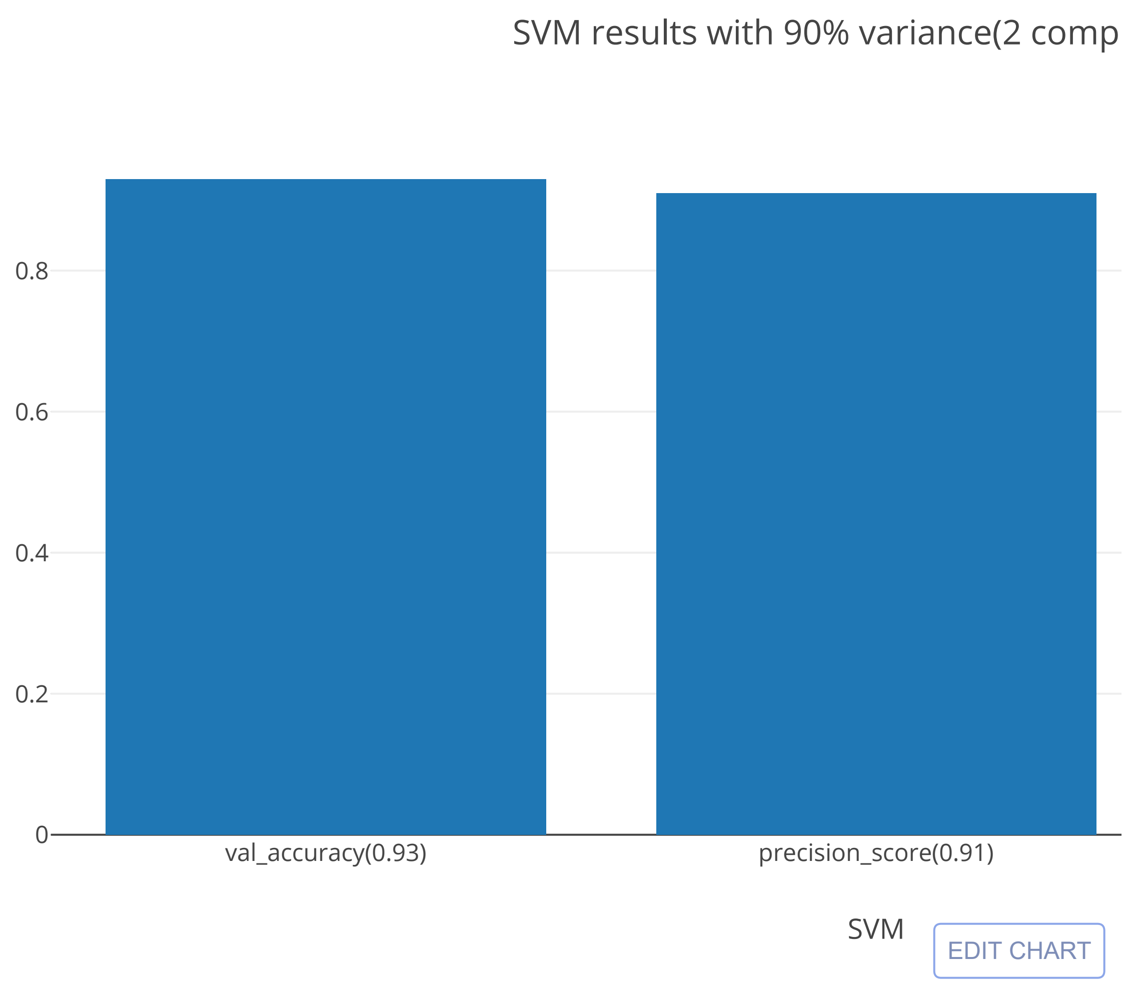


In [ ]:

SVM Results

In [99]:
```
import plotly.plotly as py
import plotly.graph_objs as go

data = [go.Bar(
            x=['val_accuracy(0.93)', 'precision_score(0.91)', 'recall(0.52)'],
            y=[0.93, 0.91, 0.52]
    )]
layout = dict(title = 'SVM results with 90% variance(2 components)',
              xaxis = dict(title = 'SVM')
              )

fig = dict(data=data, layout=layout)
py.iplot(fig, filename='basic-bar')
```

Out[99]:

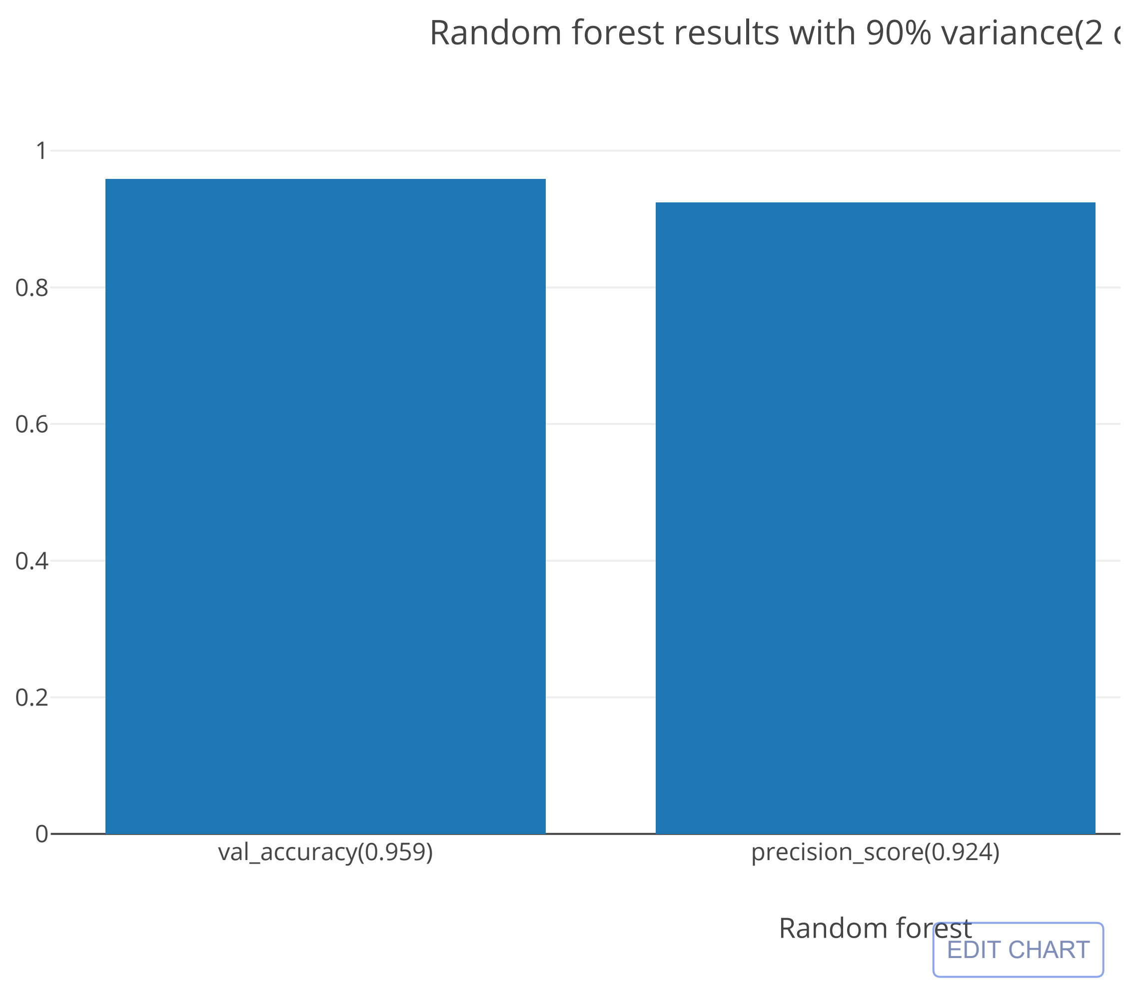


In [ ]:

Random forest

In [101]:
```
import plotly.plotly as py
import plotly.graph_objs as go

data = [go.Bar(
            x=['val_accuracy(0.959)', 'precision_score(0.924)', 'recall(0.748)'],
            y=[0.959, 0.924, 0.748]
    )]
layout = dict(title = 'Random forest results with 90% variance(2 components)',
              xaxis = dict(title = 'Random forest')
              )

fig = dict(data=data, layout=layout)
py.iplot(fig, filename='basic-bar')
```

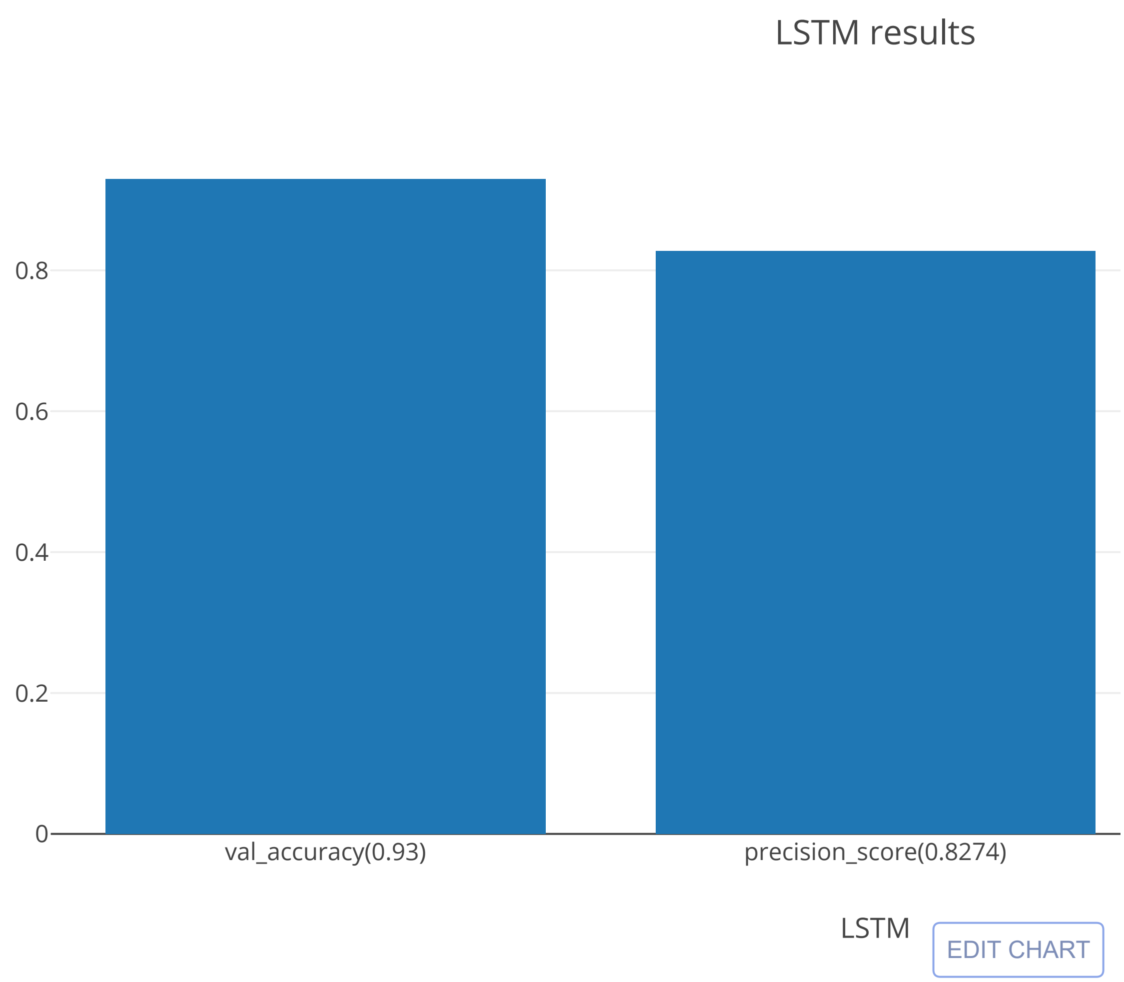
Out[101]:



LSTM results

In [105]:
```
import plotly.plotly as py
import plotly.graph_objs as go

data = [go.Bar(
            x=['val_accuracy(0.93)', 'precision_score(0.8274)', 'recall( 0.825)']
            y=[0.93, 0.8274, 0.825]
    )]
layout = dict(title = 'LSTM results ',
              xaxis = dict(title = 'LSTM')
              )

fig = dict(data=data, layout=layout)
py.iplot(fig, filename='basic-bar')
```

Out[105]:



In [ ]:

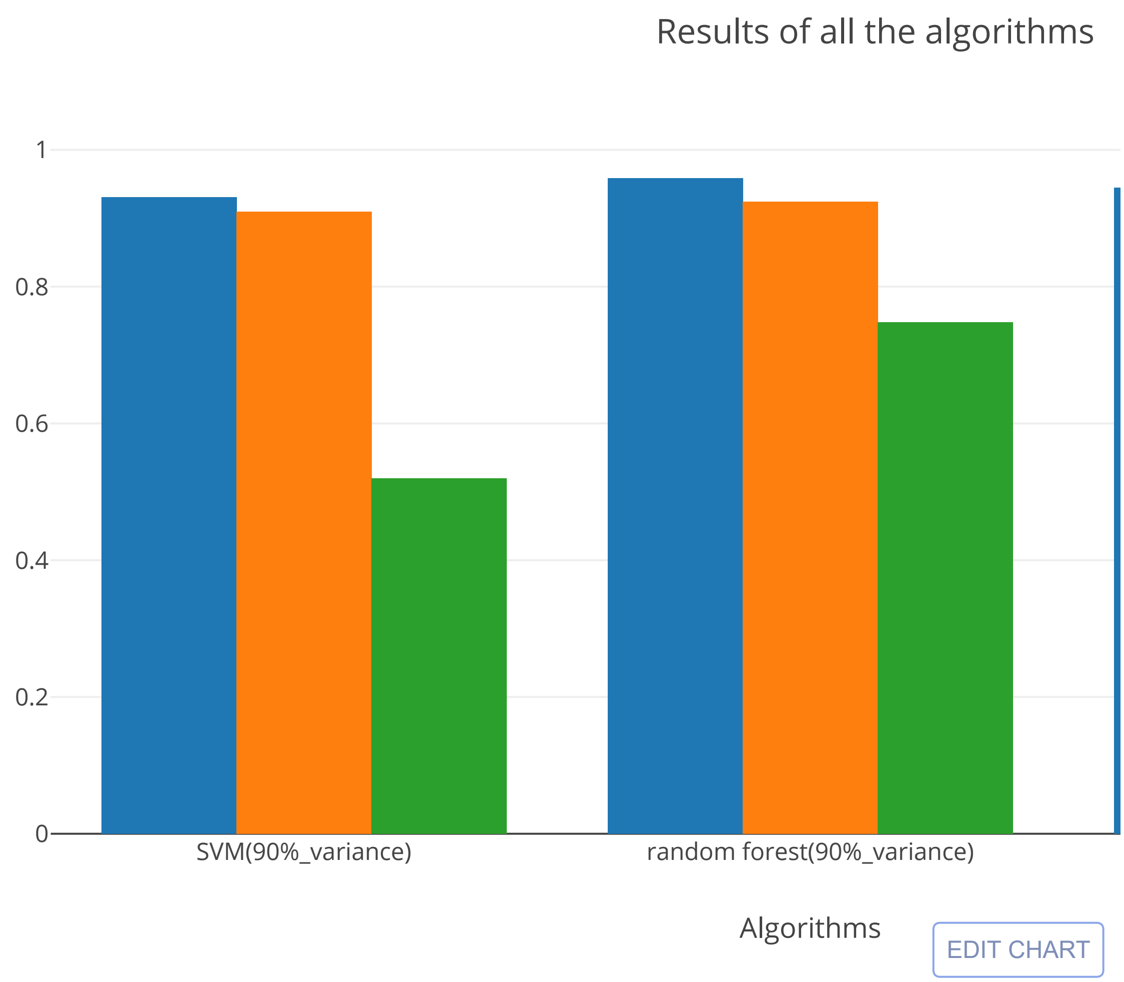
In [ ]:

In [ ]:

results of all the algorithm

In [65]:
```
import plotly.plotly as py
import plotly.graph_objs as go

trace1 = go.Bar(
    x=['SVM(90%_variance)', 'random forest(90%_variance)', 'LSTM'],
    y=[0.931, 0.959, 0.9799],
    name='val_accuracy'
)
trace2 = go.Bar(
    x=['SVM(90%_variance)', 'random forest(90%_variance)', 'LSTM'],
    y=[0.91,0.924,0.82],
    name='precision'
)
trace3 = go.Bar(
    x=['SVM(90%_variance)', 'random forest(90%_variance)', 'LSTM'],
    y=[0.52, 0.748,0.825 ],
    name='recall'
)


data = [trace1, trace2,trace3 ]

layout = go.Layout(
    barmode='group',
    title='Results of all the algorithms',
    xaxis = dict(title = 'Algorithms')

)
fig = go.Figure(data=data, layout=layout)
py.iplot(fig, filename='multiple-axes-double')
```

Out[65]:



In [ ]:

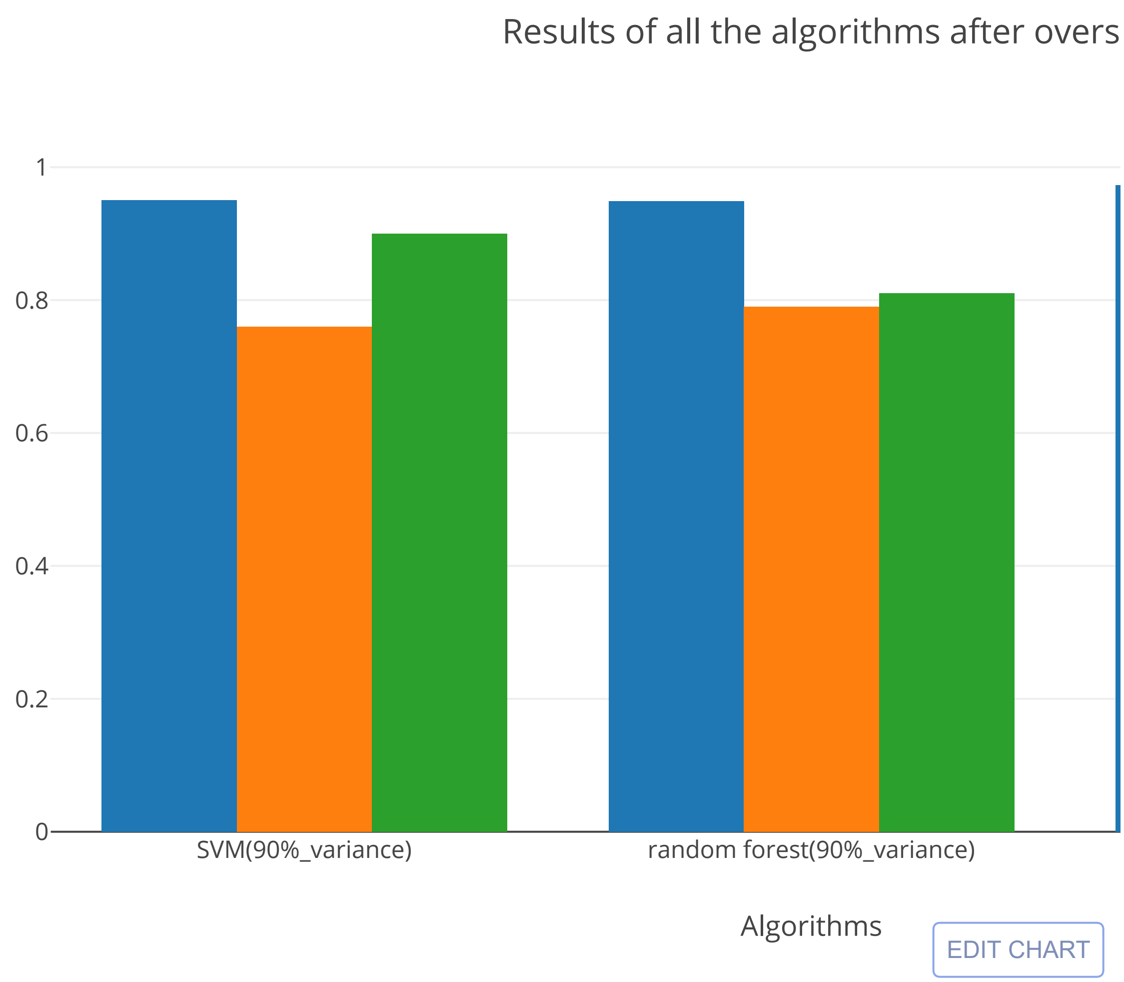
In [ ]:

Results of all algorithm after sampling

In [102]:

```
import plotly.plotly as py
import plotly.graph_objs as go

trace1 = go.Bar(
    x=['SVM(90%_variance)', 'random forest(90%_variance)', 'LSTM'],
    y=[0.95, 0.949, 0.9732],
    name='val_accuracy'
)
trace2 = go.Bar(
    x=['SVM(90%_variance)', 'random forest(90%_variance)', 'LSTM'],
    y=[0.76,0.79,0.984],
    name='precision'
)
trace3 = go.Bar(
    x=['SVM(90%_variance)', 'random forest(90%_variance)', 'LSTM'],
    y=[0.90, 0.81,0.974 ],
    name='recall'
)


data = [trace1, trace2,trace3 ]

layout = go.Layout(
    barmode='group',
    title='Results of all the algorithms after oversampling',
    xaxis = dict(title = 'Algorithms')

)
fig = go.Figure(data=data, layout=layout)
py.iplot(fig, filename='multiple-axes-double')
```

Out[102]:



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