This report will be divided into three parts. Firstly, the trading strategy will be illustrated, followed by the pseudo-code. The second part will be the code and the corresponding results. The last part will be the backtesting and some limitation related to the strategy.

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[1] illustration of strategy

> ### [1.1] The trading strategy explanation:

Firstly, the directional change (DC) is confirmed only after the price has changed by the amount of θ (the threshold value) from the peak (highest price in the current upward trend) or trough (lowest price in the current downward trend) to a lower price or a higher price. Before the confirmation point, the price movement is still in an OS (over shoot) event.

Therefore, predicting the endpoint of the OS event is required. To predict the endpoint of the OS event, the scaling law is applied which is if the length of DC event is physical time t, then the length of OS event will be $2t$. Thus, the strategy I applied, two variables were generated: r_d and r_u. The r_d is the ratio of downward OS to the downward DC, and r_u is corresponding to the ratio of the upward OS to upward DC. According to the scaling law, these two variables were assigned a value equal to 2.

Additionally, the trading window was not sufficiently defined by using only r_u and r_d due to the OS event may last longer or short than the average ratio described by these two variables. Hence, two investor-specified parameters used to define the trading window during OS events are created: b_1 and b_2. For instance, the [b_1,b_2] was set as [0.7, 1] and the OS event lasts from [10, 20], then the user-defined trading window will be [10, 17].

> **The expression of trading window is displayed as follow:**

$t_0^U = t_1^{dc} + 1 + (t_1^{dc} - t_0^{dc}) \times r_u \times b_1$

$t_1^U = t_1^{dc} + 1 + (t_1^{dc} - t_0^{dc}) \times r_u \times b_2$

$t_0^D = t_1^{dc} + 1 + (t_1^{dc} - t_0^{dc}) \times r_d \times b_1$

$t_0^D = t_1^{dc} + 1 + (t_1^{dc} - t_0^{dc}) \times r_d \times b_2$

where the start time of trading window is t_0^U and the end time of trading window is t_1^U in an upward trend, t_0^D and t_1^D are corresponding to the start and end times of a trading window in a downward trend. Moverover, $t_1^{dc} + 1$ is the start time of a upward or downword OS event and $(t_1^{dc} - t_0^{dc}) \times r_u(r_d)$ is the duration of OS.

Lastly, considering trading in the tick data, there can exist numerous of time points to trade, though the trading window has been defined.

In this trading strategy, we try to buy at the price close to P_{trough} and sell at the price which is close to P_{peak}. Hence, b_3 was generated which also is a user-defined variable rangeing within [0,1].

Therefore, buy when the $price = P_{trough} + P_{trough} \times (1 - b_3)$ and sell when the $price = P_{peak} \times b_3$

Additionally, another investor-controlled parameter is Q which used to set the trading quantity.

This coursework uses a multi-threshold DC trading strategy derived by Kampouridis and Otero (2017), this strategy combines the information collected at different thresholds to make a decision on a buy or sell then. Due to the thresholds will suggest different trading actions, weights are assigned to each threshold like: $W_1, W_2, \ldots W_{N\theta}$. $N\theta$ is the total number of thresholds.

If the sum of weights of all thresholds recommending a buy action larger than the sum of all weights of thresholds recommending a sell action, the buy action will be made, and vice versa. The investor will stay inactive when the price is not within the range defined by b_3 or the number of thresholds suggesting a buy or sell is smaller than zero.

Consequently, the trading quantity can be computed as well based on the different thresholds.

$Q_{trade} = (1 + \frac{N_{up}}{N_\theta}) \times Q$

where N_{up} denotes for the how many thresholds suggesting sell.

$Q_{trade} = (1 + \frac{N_{down}}{N_\theta}) \times Q$

where N_{down} denotes for the how many thresholds suggesting buy.

> ### [1.2] The Pseudo-code for strategies are displayed as followed:

In [1]:
```
"""
importing packages for display the Screenshot:
"""
from IPython.display import Image
from IPython.core.display import HTML
from IPython.display import display
# the Pseudo-code is compiled with Latex
```

In [2]:
```
Image(filename='/Users/ambladeky/Desktop/alg_1.png',width=500, height=500)
```

Out[2]:

Algorithm 1 Pseudo-code for calculating the return of trading strategy

Require: Initializing variables $b_1, b_2, b_3 and Q_{trade}$
for $t = 0$, t <the length of imported data **do**
initializing the weight of buying and selling:$W_B = 0, W_S = 0$ and the number of thresholds that suggest a buy or sell action:$N_{up} = 0, N_{down} = 0$
$t \leftarrow t + 1$
if $p(t) > P_{peak}$ **then**
$P_{peak} \leftarrow p(t)$
else if $p(t) < P_{through}$ **then**
$P_{through} \leftarrow p(t)$
end if
for $i = 0, i < N_\theta, i++$ **do** ▷ for each threshold
if t is the confirmation point **then**
compute the start and end times for OS event which are t_0^U, t_1^U, t_0^D and t_1^D
(above variables only updated at the confirmation points of DC)
end if
if t is between the confirmation point of a downward DC and the next confirmation point of an upward DC **then**
$W_B \leftarrow W_B + W_i$
if t is between t_0^D and t_1^D **then**
$N_{down} \leftarrow N_{down} + 1$
else
$N_{down} \leftarrow N_{down} - 1$
end if
else if t is between the confirmation point of an upward DC and the next confirmation point of a downward DC **then**
$W_S \leftarrow W_S + W_i$
if t is between t_0^U and t_1^U **then**
$N_{up} \leftarrow N_{up} + 1$
else
$N_{up} \leftarrow N_{up} - 1$
end if
end if
if $W_S > W_B$ **then**
[sell action] ▷ will be illustrated in Algorithm 2
else if $W_S < W_B$ **then**
[buy action] ▷ will be illustrated in Algorithm 2
end if
end for
end for

1

In [3]:
```
Image(filename='/Users/ambladeky/Desktop/alg_2.png',width=500, height=500)
```

Out[3]:

Algorithm 2 Pseudo-code for the buy and sell actions

if $W_S > W_B$ **then**
if $N_{up} > 0$ and $p(t) \geq P_{peak} \times b_3$ **then**
$Q_{trade} \leftarrow (1 + \frac{N_{up}}{N_\theta}) \times Q$
$cash \leftarrow cash + Q_{trade} \times p(t)$
$QH \leftarrow QH - Q_{trade}$ ▷ QH is the quantity currently holding
else
hold
end if
else if $W_S < W_B$ **then**
if $N_{down} > 0$ and $p(t) \leq P_{trough} \times (1 - b_3)$ **then**
$Q_{trade} \leftarrow (1 + \frac{N_{down}}{N_\theta}) \times Q$
if $cash > Q_{trade} \times p(t)$ **then**
$cash \leftarrow cash - Q_{trade} \times p(t)$
$QH \leftarrow QH + Q_{trade}$
else
buy the amount that can afford
$Q^*_{trade} \leftarrow cash \div p(t)$
$cash \leftarrow cash - Q^*_{trade} \times p(t)$
$QH \leftarrow QH + Q^*_{trade}$
end if
else
hold
end if
end if

[2] The code:

This section will have two components. Firstly, the function used to constructed the intrinsic time framework will be testified. Secondly, the whole strategy class will be delivered.

> ### [2.1] Construct the intrinsic time framework:

In [4]:
```
import numpy as np
import pandas as pd


# The code here will allow graphics to switch to dark mode:
import matplotlib.pyplot as plt

import matplotlib as mpl
from matplotlib import cycler
colors = cycler('color',
                ['#669FEE', '#66EE91', '#9988DD',
                 '#EECC55', '#88BB44', '#FFBBBB'])
plt.rc('figure', facecolor='#313233')
plt.rc('axes', facecolor="#313233", edgecolor='none',
       axisbelow=True, grid=True, prop_cycle=colors,
       labelcolor='gray')
plt.rc('grid', color='474A4A', linestyle='solid')
plt.rc('xtick', color='gray')
plt.rc('ytick', direction='out', color='gray')
plt.rc('legend', facecolor="#313233", edgecolor="#313233")
plt.rc("text", color="#C9C9C9")
```

In [5]:
```
"""
Import the tick data, here use the forex-pair of EUR/USD during the period of December in 2021:
"""
df = pd.read_csv("/Users/ambladeky/Desktop/EURUSD_Tick_202112.csv")
df
```

Out[5]:

	datestamp	bid	ask	volume
0	20211201 000000441	1.13318	1.13320	0
1	20211201 000000544	1.13319	1.13322	0
2	20211201 000002108	1.13318	1.13322	0
3	20211201 000002310	1.13320	1.13322	0
4	20211201 000002412	1.13324	1.13325	0
...	...	...	...	...
1048570	20211223 100104547	1.13126	1.13127	0
1048571	20211223 100104598	1.13123	1.13126	0
1048572	20211223 100104700	1.13121	1.13124	0
1048573	20211223 100104801	1.13120	1.13123	0
1048574	20211223 100105206	1.13120	1.13124	0

1048575 rows × 4 columns

In [6]:
```
"""
Transfer the tick time into date object:
"""
from datetime import datetime
new_time=[]
for i in df.datestamp:
    dt=datetime.strptime(i,'%Y%m%d %H%M%S%f')
    new_time.append(dt)
```

In [7]:
```
"""
Setting the tick time as index and drop the original one
"""
df['ticktime']=pd.Series(new_time)
df.drop('datestamp', inplace=True, axis=1)
df.set_index('ticktime',inplace=True)
df
```

Out[7]:

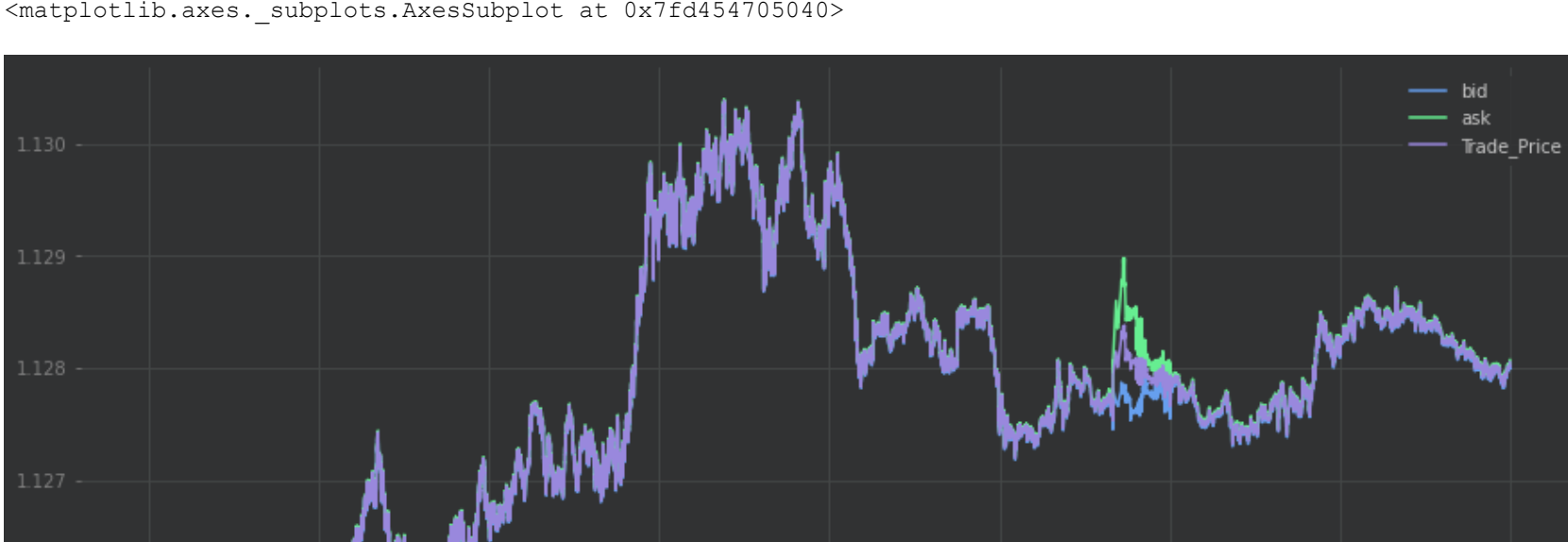
ticktime	bid	ask	volume
2021-12-01 00:00:00.441	1.13318	1.13320	0
2021-12-01 00:00:00.544	1.13319	1.13322	0
2021-12-01 00:00:02.108	1.13318	1.13322	0
2021-12-01 00:00:02.310	1.13320	1.13322	0
2021-12-01 00:00:02.412	1.13324	1.13325	0
...	...	...	...
2021-12-23 10:01:04.547	1.13126	1.13127	0
2021-12-23 10:01:04.598	1.13123	1.13126	0
2021-12-23 10:01:04.700	1.13121	1.13124	0
2021-12-23 10:01:04.801	1.13120	1.13123	0
2021-12-23 10:01:05.206	1.13120	1.13124	0

1048575 rows × 3 columns

In [8]:
```
# Generating the 'Trade_Price' computed as followed:
df['Trade_Price'] = (df['bid']+df['ask'])/2
```

In [9]:
```
# Due to large mount of data, only selected 1 day as an example to draw and check the pattern:
df[["bid", "ask","Trade_Price"]].loc["2021-12-20"].plot(figsize=(15,8))
```

Out[9]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7fd454705040>
```



In [10]:
```
df["current"] = df["Trade_Price"].shift(1)
# only used: 2021-12-20 to check--> due to too large the whole dataset
df_1=df[["bid", "ask","Trade_Price","current"]].loc["2021-12-20"]
df_1
```

Out[10]:

ticktime	bid	ask	Trade_Price	current
2021-12-20 00:00:01.848	1.12492	1.12496	1.124940	1.124935
2021-12-20 00:00:02.052	1.12491	1.12493	1.124920	1.124940
2021-12-20 00:00:03.387	1.12490	1.12493	1.124915	1.124920
2021-12-20 00:00:03.934	1.12492	1.12493	1.124925	1.124915
2021-12-20 00:00:04.795	1.12490	1.12494	1.124920	1.124925
...	...	...	...	...
2021-12-20 23:59:47.446	1.12800	1.12804	1.128020	1.128015
2021-12-20 23:59:47.602	1.12799	1.12803	1.128010	1.128020
2021-12-20 23:59:59.043	1.12801	1.12805	1.128030	1.128010
2021-12-20 23:59:59.144	1.12802	1.12806	1.128040	1.128030
2021-12-20 23:59:59.246	1.12803	1.12807	1.128050	1.128040

59159 rows × 4 columns

In [13]:
```
dc_threshold = np.array([0.0001])
num_of_singledc = 1  # for the testing purpose, for now setting only 1.

event_dict = {}
def trade_dc_pattern(dc_threshold, num_of_singledc, df):
    # Initialization

    for dc in dc_threshold:
        # default to be True:
        event_dict[dc] = [True]  # True -> Upward trend, False -> Downward trend
    b1 = 0  # b1 and b2 defines the trading window
    b2 = 1
    b3 = 1
    # we want buy at the price close to the price trough P_trough
    # and sell at the price close to the peak price P_peak
    ru = rd = 2  # predicts the length of OS
    ph = [df['Trade_Price'][0] for i in
          range(num_of_singledc)]  # the highest price in the current upward trend

    pl = [df['Trade_Price'][0] for i in
          range(num_of_singledc)]  # the lowest price in the current downward trend

    Ppeak = df['Trade_Price'][0]  # the highest recorded price
    Ptrough = df['Trade_Price'][0]  # the lowest recorded price


    tdc_0 = [0 for i in range(num_of_singledc)]  # directional change
    tdc_1 = [0 for i in range(num_of_singledc)]
    tos_0 = [0 for i in range(num_of_singledc)]  # overshoot event
    tos_1 = [0 for i in range(num_of_singledc)]
    tU_0 = [0 for i in range(num_of_singledc)]  # trading window
    tU_1 = [0 for i in range(num_of_singledc)]
    tD_0 = [0 for i in range(num_of_singledc)]
    tD_1 = [0 for i in range(num_of_singledc)]

    for idx in range(1, len(df)):
        Pc = df["Trade_Price"][idx]

        # 'Trade_Price' = self.data['Trade_Price'].shift(1)
        Trade_Price = df['current'][idx]  # current trade price

        if df["Trade_Price"][idx] > Ppeak:
            Ppeak = df["Trade_Price"][idx]
        elif df["Trade_Price"][idx] < Ptrough:
            Ptrough = df["Trade_Price"][idx]

        for dc_idx, dc in enumerate(dc_threshold):
            if event_dict[dc][-1]:
                if df['Trade_Price'][idx] <= (ph[dc_idx] * (1 - dc)):
                    event_dict[dc].append(False)  # Confirmation point of downward DC

                    pl[dc_idx] = df['Trade_Price'][idx]
                    tdc_1[dc_idx] = idx
                    tos_0[dc_idx] = idx + 1
                    tD_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[
                        dc_idx]) * rd * b1
                    # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of downward OS
                    tD_1[dc_idx] = tdc_1[dc_idx] + 1 + (
                            tdc_1[dc_idx] - tdc_0[dc_idx]) * rd * b2  # b1 and b2 defines the trading window
                else:
                    event_dict[dc].append(event_dict[dc][-1])  # No DC
                    if ph[dc_idx] < df['Trade_Price'][idx]:
                        ph[dc_idx] = df['Trade_Price'][idx]
                        tdc_0[dc_idx] = idx
                        tos_1[dc_idx] = idx - 1
                    else:
                        try:
                            if event_dict[dc][-3] == False and event_dict[dc][
                                -2] == True:  # [False], [True], [True] -> now is right after the confirmation p
oint,
                        #yet it is not low enough to be directional change, but lower than or same as the confir
mation point
                                tdc_0[dc_idx] = idx - 1
                        except:
                            pass
            else:  # Upward trend
                if df['Trade_Price'][idx] >= (pl[dc_idx] * (1 + dc)):
                    event_dict[dc].append(True)  # Confirmation point of upward DC
                    try:
                        if event_dict[dc][-3] == True and event_dict[dc][
                            -2] == False:  # for the case [True], [False], [True] -> 2 consecutive confirmation
 points
                            tdc_0[dc_idx] = idx - 1
                    except:
                        pass
                    ph[dc_idx] = df['Trade_Price'][idx]
                    tdc_1[dc_idx] = idx
                    tos_0[dc_idx] = idx + 1
                    tU_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[
                        dc_idx]) * ru * b1  # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of upwa
rd OS
                    tU_1[dc_idx] = tdc_1[dc_idx] + 1 + (
                            tdc_1[dc_idx] - tdc_0[dc_idx]) * ru * b2  # b1 and b2 defines the trading window
                else:
                    event_dict[dc].append(event_dict[dc][-1])  # No DC
                    if pl[dc_idx] > df['Trade_Price'][idx]:
                        pl[dc_idx] = df['Trade_Price'][idx]
                        tdc_0[dc_idx] = idx
                        tos_1[dc_idx] = idx - 1
                    else:
                        try:
                            if event_dict[dc][-3] == True and event_dict[dc][
                                -2] == False:
            # [True], [False], [False] -> the current time point is right after the confirmation point,
            # yet it is not high enough to be directional change, but higher than or same as the confirmation po
int
                                tdc_0[dc_idx] = idx - 1
                        except:
                            pass

    e_s=pd.Series(event_dict)
#     print()
    return e_s
```

In [14]:
```
trade_dc_pattern(dc_threshold,num_of_singledc,df_1)
```

Out[14]:
```
0.0001    [True, True, True, True, True, True, True, Tru...
dtype: object
```

In [15]:
```
"""
Get the events from dictionary and merge it with the tick data dataframe:
"""
event=event_dict.get(0.0001)

ev_df=pd.DataFrame(event,index=df_1.index)

ev_df.rename(columns = {0:'event'}, inplace = True)

new_df=pd.merge(df_1,ev_df ,on='ticktime')
new_df
```

Out[15]:

ticktime	bid	ask	Trade_Price	current	event
2021-12-20 00:00:01.848	1.12492	1.12496	1.124940	1.124935	True
2021-12-20 00:00:02.052	1.12491	1.12493	1.124920	1.124940	True
2021-12-20 00:00:03.387	1.12490	1.12493	1.124915	1.124920	True
2021-12-20 00:00:03.934	1.12492	1.12493	1.124925	1.124915	True
2021-12-20 00:00:04.795	1.12490	1.12494	1.124920	1.124925	True
...	...	...	...	...	...
2021-12-20 23:59:47.446	1.12800	1.12804	1.128020	1.128015	True
2021-12-20 23:59:47.602	1.12799	1.12803	1.128010	1.128020	True
2021-12-20 23:59:59.043	1.12801	1.12805	1.128030	1.128010	True
2021-12-20 23:59:59.144	1.12802	1.12806	1.128040	1.128030	True
2021-12-20 23:59:59.246	1.12803	1.12807	1.128050	1.128040	True

59159 rows × 5 columns

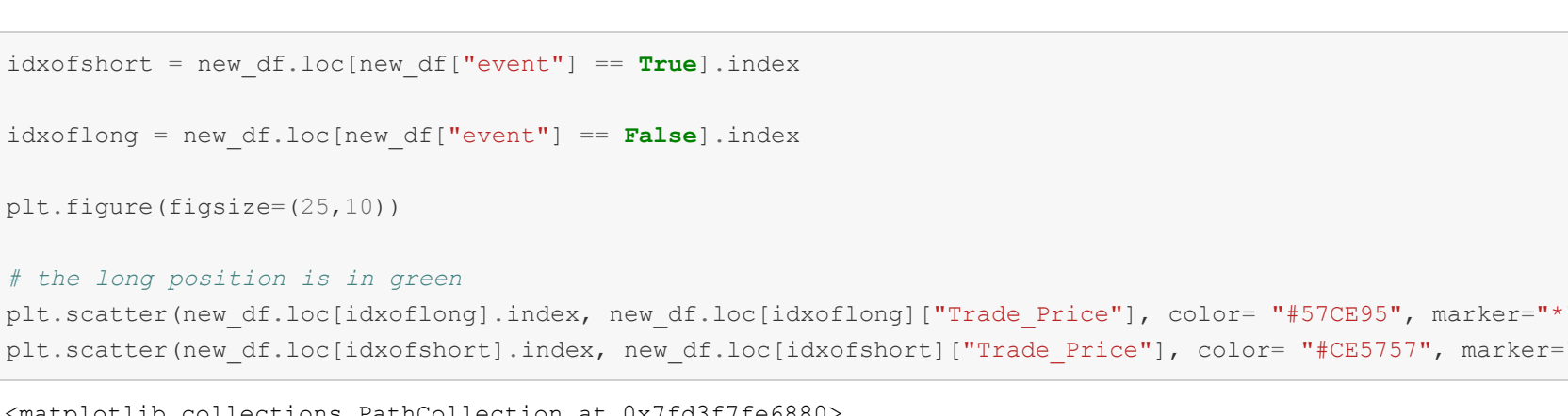
In [38]:
```
idxofshort = new_df.loc[new_df["event"] == True].index

idxoflong = new_df.loc[new_df["event"] == False].index

plt.figure(figsize=(25,10))

# the long position is in green
plt.scatter(new_df.loc[idxoflong].index, new_df.loc[idxoflong]["Trade_Price"], color= "#57CE95", marker="*")
plt.scatter(new_df.loc[idxofshort].index, new_df.loc[idxofshort]["Trade_Price"], color= "#CE5757", marker="o")
```

Out[38]:
```
<matplotlib.collections.PathCollection at 0x7fd3f7fe6880>
```



> ### [2.2] The whole strategy:

The default setting are:

[1] The initial cash hold by investor = 2,000

[2] Default currency unit is USD

```
In [25]: import numpy as np
         import pandas as pd
         import os
         import sys
         import math
         import random

         np.random.seed(20)

         class DC_strategy:

             def __init__(self, num_of_dc, forex_pair, budget, dollar):
                 self.num_of_dc = num_of_dc # number of DC thresholds
                 self.dc_interval = 1
                 self.forex_pair = forex_pair
                 self.budget = budget
                 self.cash = budget # the amount of cash currently holding
                 self.QH = 0 # the amount/quantity currently holding
                 self.dollar = dollar # currency

                 self.generate_threshold() # can randomly generate DC thresholds or use the fixed 2 thresholds
                 self.load_forex_pair()
                 self.trade_dc_pattern()

             def generate_threshold(self):

                 threshold_interval = [i / 100 for i in range(self.num_of_dc + 1)]
                 threshold = []
                 for i in range(1, self.num_of_dc + 1):
                     threshold.append(random.uniform(threshold_interval[i-1], threshold_interval[i]))
                 self.dc_threshold = np.array(threshold)

                 FIXED =True #False#True
                 if FIXED:
                     self.dc_threshold = np.array([0.0001, 0.00013])
                 print(self.dc_threshold)
                 print("threshold value: ",end='')
                 for i in self.dc_threshold:
                     print("{:0.4f}%, ".format(i * 100),end='')
                 print()

                 #---------end of setting threshold-----------------------#


             def load_forex_pair(self):
                 data_path = "/Users/ambladeky/Desktop/" + str(self.forex_pair) + ".csv"
                 self.data = pd.DataFrame(pd.read_csv(data_path))
                 # The trade price: is (bid_price+ask_price)/2
                 self.data['Trade_Price'] = (self.data['bid']+self.data['ask'])/2
                 self.data["current"] = self.data["Trade_Price"].shift(1)
                 self.data = self.data[::self.dc_interval] # Change the observation time interval.
                 self.data.reset_index(drop = True, inplace = True)
                 #debug:
                 print(self.data)

                  #---------end of loading data-----------------------#


             def trade_dc_pattern(self):
                 # Initialization
                 event_dict = {}
                 for dc in self.dc_threshold:
                     event_dict[dc] = [True] # True -> Upward trend, False -> Downward trend
                 b1 = 0.8 # b1 and b2 defines the trading window
                 b2 = 1
                 b3 = 0.9
                 # we want buy at the price close to the price trough P_trough and sell at the price close to the peak pr
         ice P_peak
                 Q = 1 # Q controls the trading quantity
                 ru = rd = 2 # predicts the length of OS
                 Wi = [1 for i in range(self.num_of_dc)] # Weight of each threshold = 1, for simplicity

                 ph = [self.data['Trade_Price'][0] for i in range(self.num_of_dc)] # the highest price in the current upw
         ard trend
                 pl = [self.data['Trade_Price'][0] for i in range(self.num_of_dc)] # the lowest price in the current down
         ward trend
                 Ppeak = self.data['Trade_Price'][0] # the highest recorded price
                 Ptrough = self.data['Trade_Price'][0] # the lowest recorded price
                 tdc_0 = [0 for i in range(self.num_of_dc)] # directional change
                 tdc_1 = [0 for i in range(self.num_of_dc)]
                 tos_0 = [0 for i in range(self.num_of_dc)] # overshoot event
                 tos_1 = [0 for i in range(self.num_of_dc)]
                 tU_0 = [0 for i in range(self.num_of_dc)] # trading window
                 tU_1 = [0 for i in range(self.num_of_dc)]
                 tD_0 = [0 for i in range(self.num_of_dc)]
                 tD_1 = [0 for i in range(self.num_of_dc)]

                 for idx in range(1, len(self.data)):
                     WB = 0 # Weight of Buy
                     WS = 0 # Weight of Sell
                     Nup = 0 # the number of thresholds that recommending a sell action
                     Ndown = 0 # the number of thresholds that recommending a buy action


                     Pc = self.data["current"][idx] # current price
                     Trade_Price = self.data['Trade_Price'][idx] # current trade price

                     if self.data["Trade_Price"][idx] > Ppeak:
                         Ppeak = self.data["Trade_Price"][idx]
                     elif self.data["Trade_Price"][idx] < Ptrough:
                         Ptrough = self.data["Trade_Price"][idx]

                     for dc_idx, dc in enumerate(self.dc_threshold):
                         if event_dict[dc][-1]:
                             if self.data['Trade_Price'][idx] <= (ph[dc_idx] * (1 - dc)):
                                 event_dict[dc].append(False) # Confirmation point of downward DC
                                 try: #error when t = 1
                                     if event_dict[dc][-3] == False and event_dict[dc][-2] == True:
                                         # for the case [False], [True], [False] -> 2 consecutive confirmation points
                                         tdc_0[dc_idx] = idx - 1
                                 except:
                                     pass
                                 pl[dc_idx] = self.data['Trade_Price'][idx]
                                 tdc_1[dc_idx] = idx
                                 tos_0[dc_idx] = idx + 1
                                 tD_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * rd * b1
                                 # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of downward OS
                                 tD_1[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * rd * b2
                                 # b1 and b2 defines the trading window
                             else:
                                 event_dict[dc].append(event_dict[dc][-1]) # No DC
                                 if ph[dc_idx] < self.data['Trade_Price'][idx]:
                                     ph[dc_idx] = self.data['Trade_Price'][idx]
                                     tdc_0[dc_idx] = idx
                                     tos_1[dc_idx] = idx - 1
                                 else:
                                     try:
                                         if event_dict[dc][-3] == False and event_dict[dc][-2] == True:
                                     # [False], [True], [True] -> the current time point is right after the confirmation
          point,
                                     #yet its price is not low enough to be directional change, but lower than or same as
          the confirmation point
                                             tdc_0[dc_idx] = idx - 1
                                     except:
                                         pass
                         else: # False -> Downward trend
                             if self.data['Trade_Price'][idx] >= (pl[dc_idx] * (1 + dc)):
                                 event_dict[dc].append(True)  # Confirmation point of upward DC
                                 try:
                                     if event_dict[dc][-3] == True and event_dict[dc][-2] == False:
                                         # for the case [True], [False], [True] -> 2 consecutive confirmation points
                                         tdc_0[dc_idx] = idx - 1
                                 except:
                                     pass
                                 ph[dc_idx] = self.data['Trade_Price'][idx]
                                 tdc_1[dc_idx] = idx
                                 tos_0[dc_idx] = idx + 1
                                 tU_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * ru * b1
                                 # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of upward OS
                                 tU_1[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * ru * b2
                                 # b1 and b2 defines the trading window
                             else:
                                 event_dict[dc].append(event_dict[dc][-1])  # No DC
                                 if pl[dc_idx] > self.data['Trade_Price'][idx]:
                                     pl[dc_idx] = self.data['Trade_Price'][idx]
                                     tdc_0[dc_idx] = idx
                                     tos_1[dc_idx] = idx - 1
                                 else:
                                     try:
                                         if event_dict[dc][-3] == True and event_dict[dc][-2] == False:
                     # [True], [False], [False] -> the current time point is right after the confirmation point,
                     # yet its price is not high enough to be directional change, but higher than or same as the confirma
         tion point
                                             tdc_0[dc_idx] = idx - 1
                                     except:
                                         pass
                         # trade
                         if event_dict[dc][-1] == False and event_dict[dc][-2] == False:
                             # if event is downward trend and the current time point is not confirmation point
                             WB = WB + Wi[dc_idx]
                             if tD_0[dc_idx] <= idx and idx <= tD_1[dc_idx]:
                             # if the current time point is within the trading window
                                 Ndown += 1
                             else:
                                 Ndown -= 1

                         if event_dict[dc][-1] == True and event_dict[dc][-2] == True:
                             # if event is upward trend and the current time point is not confirmation point
                             WS = WS + Wi[dc_idx]
                             if tU_0[dc_idx] <= idx and idx <= tU_1[dc_idx]:
                                 # if the current time point is within the trading window
                                 Nup += 1
                             else:
                                 Nup -= 1

                     if WS > WB:
                         self.trade_action("sell", b3, Nup, Ppeak, Pc, Trade_Price, Q) # sell
                     elif WS < WB:
                         self.trade_action("buy", b3, Ndown, Ptrough, Pc, Trade_Price, Q) # buy

                 Wealth = self.cash + self.QH * Pc
                 Return = 100 * (Wealth - self.budget) / self.budget # calculate return
                 print(Return)
                 print("Wealth = {:0.4f} ".format(Wealth) + self.dollar + ", Return = {:0.4f}".format(Return) + "%")
                 #debug:
         #         print(event_dict)



             def trade_action(self, action, b3, N, P, Pc, Trade_Price, Q): # performs the buy and sell actions
                 N0 = self.num_of_dc #N0 is the total number of thresholds
                 if action == "sell":
                     Nup = N
                     if Nup > 0 and Pc >= P * b3: # sell
                         Qtrade = math.floor((1 + Nup / N0) * Q)
                         if self.QH > Qtrade:
                             self.cash = self.cash + Qtrade * Trade_Price
                             self.QH = self.QH - Qtrade
                         else:
                             self.cash = self.cash + self.QH * Trade_Price
                             self.QH = 0
                     else:
                         pass #will hold

                 elif action == "buy":
                     Ndown = N
                     if Ndown > 0 and Pc <= P + (P * (1 - b3)): # buy
                         Qtrade = math.floor((1 + Ndown / N0) * Q)
                         if self.cash > Qtrade * Trade_Price:
                             self.cash = self.cash - Qtrade * Trade_Price
                             self.QH = self.QH + Qtrade
                         else:
                             Qtrade_m = self.cash // Trade_Price
                             self.cash = self.cash - Qtrade_m * Trade_Price
                             self.QH = self.QH + Qtrade_m
                     else:
                         pass # will hold

         output = DC_strategy(2, "EURUSD_Tick_202112", 2000, "USD")
```

```
[0.0001  0.00013]
threshold value: 0.0100%, 0.0130%,
                  datestamp      bid      ask  volume  Trade_Price   current
0        20211201 000000441  1.13318  1.13320       0     1.133190       NaN
1        20211201 000000544  1.13319  1.13322       0     1.133205  1.133190
2        20211201 000002108  1.13318  1.13322       0     1.133200  1.133205
3        20211201 000002310  1.13320  1.13322       0     1.133210  1.133200
4        20211201 000002412  1.13324  1.13325       0     1.133245  1.133210
...                     ...      ...      ...     ...          ...       ...
1048570  20211223 100104547  1.13126  1.13127       0     1.131265  1.131285
1048571  20211223 100104598  1.13123  1.13126       0     1.131245  1.131265
1048572  20211223 100104700  1.13121  1.13124       0     1.131225  1.131245
1048573  20211223 100104801  1.13120  1.13123       0     1.131215  1.131225
1048574  20211223 100105206  1.13120  1.13124       0     1.131220  1.131215

[1048575 rows x 6 columns]
-0.08827349999958187
Wealth = 1998.2345 USD, Return = -0.0883%
```

[3] Backtest

The dataset used for backtesting is the same forex-pair but during the period of Junuary and February in 2022.

> ***Backtesting during the period of February in 2022***

```
In [45]: np.random.seed(20)

         class DC_strategy:

             def __init__(self, num_of_dc, forex_pair, budget, dollar):
                 self.num_of_dc = num_of_dc # number of DC thresholds
                 self.dc_interval = 1
                 self.forex_pair = forex_pair
                 self.budget = budget
                 self.cash = budget # the amount of cash we are currently holding
                 self.QH = 0 # the amount/quantity currently holding
                 self.dollar = dollar # currency

                 self.generate_threshold() # can randomly generate DC thresholds or use the fixed 2 thresholds
                 self.load_forex_pair()
                 self.trade_dc_pattern()

             def generate_threshold(self):

                 threshold_interval = [i / 100 for i in range(self.num_of_dc + 1)]
                 threshold = []
                 for i in range(1, self.num_of_dc + 1):
                     threshold.append(random.uniform(threshold_interval[i-1], threshold_interval[i]))
                 self.dc_threshold = np.array(threshold)

                 FIXED =True #False#True
                 if FIXED:
                     self.dc_threshold = np.array([0.0001, 0.00013])
                 print(self.dc_threshold)
                 print("threshold value: ",end='')
                 for i in self.dc_threshold:
                     print("{:0.4f}%, ".format(i * 100),end='')
                 print()

                 #---------end of setting threshold-----------------------#


             def load_forex_pair(self):
                 data_path = "/Users/ambladeky/Desktop/" + str(self.forex_pair) + ".csv"
                 self.data = pd.DataFrame(pd.read_csv(data_path))
                 # The trade price: is (bid_price+ask_price)/2
                 self.data['Trade_Price'] = (self.data['bid']+self.data['ask'])/2
                 self.data["current"] = self.data["Trade_Price"].shift(1)
                 self.data = self.data[::self.dc_interval] # Change the observation time interval.
                 self.data.reset_index(drop = True, inplace = True)
                 #debug:
                 print(self.data)

                  #---------end of loading data-----------------------#


             def trade_dc_pattern(self):
                 # Initialization
                 event_dict = {}
                 for dc in self.dc_threshold:
                     event_dict[dc] = [True] # True -> Upward trend, False -> Downward trend
                 b1 = 0.8 # b1 and b2 defines the trading window
                 b2 = 1
                 b3 = 0.9
                 # we want buy at the price close to the price trough P_trough and sell at the price close to the peak pr
         ice P_peak
                 Q = 1 # Q controls the trading quantity
                 ru = rd = 2 # predicts the length of OS
                 Wi = [1 for i in range(self.num_of_dc)] # Weight of each threshold = 1, for simplicity

                 ph = [self.data['Trade_Price'][0] for i in range(self.num_of_dc)] # the highest price in the current upw
         ard trend
                 pl = [self.data['Trade_Price'][0] for i in range(self.num_of_dc)] # the lowest price in the current down
         ward trend
                 Ppeak = self.data['Trade_Price'][0] # the highest recorded price
                 Ptrough = self.data['Trade_Price'][0] # the lowest recorded price
                 tdc_0 = [0 for i in range(self.num_of_dc)] # directional change
                 tdc_1 = [0 for i in range(self.num_of_dc)]
                 tos_0 = [0 for i in range(self.num_of_dc)] # overshoot event
                 tos_1 = [0 for i in range(self.num_of_dc)]
                 tU_0 = [0 for i in range(self.num_of_dc)] # trading window
                 tU_1 = [0 for i in range(self.num_of_dc)]
                 tD_0 = [0 for i in range(self.num_of_dc)]
                 tD_1 = [0 for i in range(self.num_of_dc)]

                 for idx in range(1, len(self.data)):
                     WB = 0 # Weight of Buy
                     WS = 0 # Weight of Sell
                     Nup = 0 # the number of thresholds that recommending a sell action
                     Ndown = 0 # the number of thresholds that recommending a buy action


                     Pc = self.data["current"][idx] # current price
                     Trade_Price = self.data['Trade_Price'][idx] # current trade price

                     if self.data["Trade_Price"][idx] > Ppeak:
                         Ppeak = self.data["Trade_Price"][idx]
                     elif self.data["Trade_Price"][idx] < Ptrough:
                         Ptrough = self.data["Trade_Price"][idx]

                     for dc_idx, dc in enumerate(self.dc_threshold):
                         if event_dict[dc][-1]:
                             if self.data['Trade_Price'][idx] <= (ph[dc_idx] * (1 - dc)):
                                 event_dict[dc].append(False) # Confirmation point of downward DC
                                 try: #error when t = 1
                                     if event_dict[dc][-3] == False and event_dict[dc][-2] == True:
                                         # for the case [False], [True], [False] -> 2 consecutive confirmation points
                                         tdc_0[dc_idx] = idx - 1
                                 except:
                                     pass
                                 pl[dc_idx] = self.data['Trade_Price'][idx]
                                 tdc_1[dc_idx] = idx
                                 tos_0[dc_idx] = idx + 1
                                 tD_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * rd * b1
                                 # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of downward OS
                                 tD_1[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * rd * b2
                                 # b1 and b2 defines the trading window
                             else:
                                 event_dict[dc].append(event_dict[dc][-1]) # No DC
                                 if ph[dc_idx] < self.data['Trade_Price'][idx]:
                                     ph[dc_idx] = self.data['Trade_Price'][idx]
                                     tdc_0[dc_idx] = idx
                                     tos_1[dc_idx] = idx - 1
                                 else:
                                     try:
                                         if event_dict[dc][-3] == False and event_dict[dc][-2] == True:
                             # [False], [True], [True] -> the current time point is right after the confirmation point,
                             #yet its price is not low enough to be directional change, but lower than or same as the con
         firmation point
                                             tdc_0[dc_idx] = idx - 1
                                     except:
                                         pass
                         else: # False -> Downward trend
                             if self.data['Trade_Price'][idx] >= (pl[dc_idx] * (1 + dc)):
                                 event_dict[dc].append(True)  # Confirmation point of upward DC
                                 try:
                                     if event_dict[dc][-3] == True and event_dict[dc][-2] == False: # for the case [Tru
         e], [False], [True] -> 2 consecutive confirmation points
                                         tdc_0[dc_idx] = idx - 1
                                 except:
                                     pass
                                 ph[dc_idx] = self.data['Trade_Price'][idx]
                                 tdc_1[dc_idx] = idx
                                 tos_0[dc_idx] = idx + 1
                                 tU_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * ru * b1
                                 # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of upward OS
                                 tU_1[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * ru * b2
                                 # b1 and b2 defines the trading window
                             else:
                                 event_dict[dc].append(event_dict[dc][-1])  # No DC
                                 if pl[dc_idx] > self.data['Trade_Price'][idx]:
                                     pl[dc_idx] = self.data['Trade_Price'][idx]
                                     tdc_0[dc_idx] = idx
                                     tos_1[dc_idx] = idx - 1
                                 else:
                                     try:
                                         if event_dict[dc][-3] == True and event_dict[dc][-2] == False:
                             # [True], [False], [False] -> the current time point is right after the confirmation point,
                             # yet its price is not high enough to be directional change, but higher than or same as the
          confirmation point
                                             tdc_0[dc_idx] = idx - 1
                                     except:
                                         pass
                         # trade
                         if event_dict[dc][-1] == False and event_dict[dc][-2] == False:
                             # if event is downward trend and the current time point is not confirmation point
                             WB = WB + Wi[dc_idx]
                             if tD_0[dc_idx] <= idx and idx <= tD_1[dc_idx]:
                             # if the current time point is within the trading window
                                 Ndown += 1
                             else:
                                 Ndown -= 1

                         if event_dict[dc][-1] == True and event_dict[dc][-2] == True:
                             # if event is upward trend and the current time point is not confirmation point
                             WS = WS + Wi[dc_idx]
                             if tU_0[dc_idx] <= idx and idx <= tU_1[dc_idx]:
                                 # if the current time point is within the trading window
                                 Nup += 1
                             else:
                                 Nup -= 1

                     if WS > WB:
                         self.trade_action("sell", b3, Nup, Ppeak, Pc, Trade_Price, Q) # sell
                     elif WS < WB:
                         self.trade_action("buy", b3, Ndown, Ptrough, Pc, Trade_Price, Q) # buy

                 Wealth = self.cash + self.QH * Pc
                 Return = 100 * (Wealth - self.budget) / self.budget # calculate return
                 print(Return)
                 print("Wealth = {:0.4f} ".format(Wealth) + self.dollar + ", Return = {:0.4f}".format(Return) + "%")
                 #debug:
         #         print(event_dict)



             def trade_action(self, action, b3, N, P, Pc, Trade_Price, Q): # performs the buy and sell actions
                 N0 = self.num_of_dc #N0 is the total number of thresholds
                 if action == "sell":
                     Nup = N
                     if Nup > 0 and Pc >= P * b3: # sell
                         Qtrade = math.floor((1 + Nup / N0) * Q)
                         if self.QH > Qtrade:
                             self.cash = self.cash + Qtrade * Trade_Price
                             self.QH = self.QH - Qtrade
                         else:
                             self.cash = self.cash + self.QH * Trade_Price
                             self.QH = 0
                     else:
                         pass #will hold

                 elif action == "buy":
                     Ndown = N
                     if Ndown > 0 and Pc <= P + (P * (1 - b3)): # buy
                         Qtrade = math.floor((1 + Ndown / N0) * Q)
                         if self.cash > Qtrade * Trade_Price:
                             self.cash = self.cash - Qtrade * Trade_Price
                             self.QH = self.QH + Qtrade
                         else:
                             Qtrade_m = self.cash // Trade_Price
                             self.cash = self.cash - Qtrade_m * Trade_Price
                             self.QH = self.QH + Qtrade_m
                     else:
                         pass # will hold

         output = DC_strategy(2, "EURUSD_T_202202", 2000, "USD")
```

```
[0.0001  0.00013]
threshold value: 0.0100%, 0.0130%,
                  datestamp      bid      ask  volume  Trade_Price   current
0        20220201 000006460  1.12430  1.12433       0     1.124315       NaN
1        20220201 000007663  1.12430  1.12434       0     1.124320  1.124315
2        20220201 000008739  1.12430  1.12433       0     1.124315  1.124320
3        20220201 000018681  1.12426  1.12429       0     1.124275  1.124315
4        20220201 000018732  1.12428  1.12432       0     1.124300  1.124275
...                     ...      ...      ...     ...          ...       ...
1048570  20220218 080441679  1.13566  1.13568       0     1.135670  1.135665
1048571  20220218 080441781  1.13566  1.13569       0     1.135675  1.135670
1048572  20220218 080444295  1.13568  1.13570       0     1.135690  1.135675
1048573  20220218 080444397  1.13570  1.13573       0     1.135715  1.135690
1048574  20220218 080445252  1.13567  1.13570       0     1.135685  1.135715

[1048575 rows x 6 columns]
0.07917200000033517
Wealth = 2001.5834 USD, Return = 0.0792%
```

> ***Backtesting during the period of Junuary in 2022:***

```
In [29]: np.random.seed(20)

         class DC_strategy:

             def __init__(self, num_of_dc, forex_pair, budget, dollar):
                 self.num_of_dc = num_of_dc # number of DC thresholds
                 self.dc_interval = 1
                 self.forex_pair = forex_pair
                 self.budget = budget
                 self.cash = budget # the amount of cash we are currently holding
                 self.QH = 0 # the amount/quantity currently holding
                 self.dollar = dollar # currency

                 self.generate_threshold() # can randomly generate DC thresholds or use the fixed 2 thresholds
                 self.load_forex_pair()
                 self.trade_dc_pattern()

             def generate_threshold(self):

                 threshold_interval = [i / 100 for i in range(self.num_of_dc + 1)]
                 threshold = []
                 for i in range(1, self.num_of_dc + 1):
                     threshold.append(random.uniform(threshold_interval[i-1], threshold_interval[i]))
                 self.dc_threshold = np.array(threshold)

                 FIXED =True #False#True
                 if FIXED:
                     self.dc_threshold = np.array([0.0001, 0.00013])
                 print(self.dc_threshold)
                 print("threshold value: ",end='')
                 for i in self.dc_threshold:
                     print("{:0.4f}%, ".format(i * 100),end='')
                 print()

                 #---------end of setting threshold-----------------------#


             def load_forex_pair(self):
                 data_path = "/Users/ambladeky/Desktop/" + str(self.forex_pair) + ".csv"
                 self.data = pd.DataFrame(pd.read_csv(data_path))
                 # The trade price: is (bid_price+ask_price)/2
                 self.data['Trade_Price'] = (self.data['bid']+self.data['ask'])/2
                 self.data["current"] = self.data["Trade_Price"].shift(1)
                 self.data = self.data[::self.dc_interval] # Change the observation time interval.
                 self.data.reset_index(drop = True, inplace = True)
                 #debug:
                 print(self.data)

                  #---------end of loading data-----------------------#


             def trade_dc_pattern(self):
                 # Initialization
                 event_dict = {}
                 for dc in self.dc_threshold:
                     event_dict[dc] = [True] # True -> Upward trend, False -> Downward trend
                 b1 = 0.8 # b1 and b2 defines the trading window
                 b2 = 1
                 b3 = 0.9
                 # we want buy at the price close to the price trough P_trough and sell at the price close to the peak pr
         ice P_peak
                 Q = 1 # Q controls the trading quantity
                 ru = rd = 2 # predicts the length of OS
                 Wi = [1 for i in range(self.num_of_dc)] # Weight of each threshold = 1, for simplicity

                 ph = [self.data['Trade_Price'][0] for i in range(self.num_of_dc)] # the highest price in the current upw
         ard trend
                 pl = [self.data['Trade_Price'][0] for i in range(self.num_of_dc)] # the lowest price in the current down
         ward trend
                 Ppeak = self.data['Trade_Price'][0] # the highest recorded price
                 Ptrough = self.data['Trade_Price'][0] # the lowest recorded price
                 tdc_0 = [0 for i in range(self.num_of_dc)] # directional change
                 tdc_1 = [0 for i in range(self.num_of_dc)]
                 tos_0 = [0 for i in range(self.num_of_dc)] # overshoot event
                 tos_1 = [0 for i in range(self.num_of_dc)]
                 tU_0 = [0 for i in range(self.num_of_dc)] # trading window
                 tU_1 = [0 for i in range(self.num_of_dc)]
                 tD_0 = [0 for i in range(self.num_of_dc)]
                 tD_1 = [0 for i in range(self.num_of_dc)]

                 for idx in range(1, len(self.data)):
                     WB = 0 # Weight of Buy
                     WS = 0 # Weight of Sell
                     Nup = 0 # the number of thresholds that recommending a sell action
                     Ndown = 0 # the number of thresholds that recommending a buy action


                     Pc = self.data["current"][idx] # current price
                     Trade_Price = self.data['Trade_Price'][idx] # current trade price

                     if self.data["Trade_Price"][idx] > Ppeak:
                         Ppeak = self.data["Trade_Price"][idx]
                     elif self.data["Trade_Price"][idx] < Ptrough:
                         Ptrough = self.data["Trade_Price"][idx]

                     for dc_idx, dc in enumerate(self.dc_threshold):
                         if event_dict[dc][-1]:
                             if self.data['Trade_Price'][idx] <= (ph[dc_idx] * (1 - dc)):
                                 event_dict[dc].append(False) # Confirmation point of downward DC
                                 try: #error when t = 1
                                     if event_dict[dc][-3] == False and event_dict[dc][-2] == True:
                                         # for the case [False], [True], [False] -> 2 consecutive confirmation points
                                         tdc_0[dc_idx] = idx - 1
                                 except:
                                     pass
                                 pl[dc_idx] = self.data['Trade_Price'][idx]
                                 tdc_1[dc_idx] = idx
                                 tos_0[dc_idx] = idx + 1
                                 tD_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * rd * b1
                                 # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of downward OS
                                 tD_1[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * rd * b2
                                 # b1 and b2 defines the trading window
                             else:
                                 event_dict[dc].append(event_dict[dc][-1]) # No DC
                                 if ph[dc_idx] < self.data['Trade_Price'][idx]:
                                     ph[dc_idx] = self.data['Trade_Price'][idx]
                                     tdc_0[dc_idx] = idx
                                     tos_1[dc_idx] = idx - 1
                                 else:
                                     try:
                                         if event_dict[dc][-3] == False and event_dict[dc][-2] == True:
                             # [False], [True], [True] -> the current time point is right after the confirmation point,
                             #yet its price is not low enough to be directional change, but lower than or same as the con
         firmation point
                                             tdc_0[dc_idx] = idx - 1
                                     except:
                                         pass
                         else: # False -> Downward trend
                             if self.data['Trade_Price'][idx] >= (pl[dc_idx] * (1 + dc)):
                                 event_dict[dc].append(True)  # Confirmation point of upward DC
                                 try:
                                     if event_dict[dc][-3] == True and event_dict[dc][-2] == False:
                                         # for the case [True], [False], [True] -> 2 consecutive confirmation points
                                         tdc_0[dc_idx] = idx - 1
                                 except:
                                     pass
                                 ph[dc_idx] = self.data['Trade_Price'][idx]
                                 tdc_1[dc_idx] = idx
                                 tos_0[dc_idx] = idx + 1
                                 tU_0[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * ru * b1
                                 # "(tdc_1[dc_idx] - tdc_0[dc_idx]) * rd" predicts the length of upward OS
                                 tU_1[dc_idx] = tdc_1[dc_idx] + 1 + (tdc_1[dc_idx] - tdc_0[dc_idx]) * ru * b2
                                 # b1 and b2 defines the trading window
                             else:
                                 event_dict[dc].append(event_dict[dc][-1])  # No DC
                                 if pl[dc_idx] > self.data['Trade_Price'][idx]:
                                     pl[dc_idx] = self.data['Trade_Price'][idx]
                                     tdc_0[dc_idx] = idx
                                     tos_1[dc_idx] = idx - 1
                                 else:
                                     try:
                                         if event_dict[dc][-3] == True and event_dict[dc][-2] == False:
                     # [True], [False], [False] -> the current time point is right after the confirmation point,
                 # yet its price is not high enough to be directional change, but higher than or same as the confirmation
          point
                                             tdc_0[dc_idx] = idx - 1
                                     except:
                                         pass
                         # trade
                         if event_dict[dc][-1] == False and event_dict[dc][-2] == False:
                             # if event is downward trend and the current time point is not confirmation point
                             WB = WB + Wi[dc_idx]
                             if tD_0[dc_idx] <= idx and idx <= tD_1[dc_idx]:
                             # if the current time point is within the trading window
                                 Ndown += 1
                             else:
                                 Ndown -= 1

                         if event_dict[dc][-1] == True and event_dict[dc][-2] == True:
                             # if event is upward trend and the current time point is not confirmation point
                             WS = WS + Wi[dc_idx]
                             if tU_0[dc_idx] <= idx and idx <= tU_1[dc_idx]:
                                 # if the current time point is within the trading window
                                 Nup += 1
                             else:
                                 Nup -= 1

                     if WS > WB:
                         self.trade_action("sell", b3, Nup, Ppeak, Pc, Trade_Price, Q) # sell
                     elif WS < WB:
                         self.trade_action("buy", b3, Ndown, Ptrough, Pc, Trade_Price, Q) # buy

                 Wealth = self.cash + self.QH * Pc
                 Return = 100 * (Wealth - self.budget) / self.budget # calculate return
                 print(Return)
                 print("Wealth = {:0.4f} ".format(Wealth) + self.dollar + ", Return = {:0.4f}".format(Return) + "%")
                 #debug:
         #         print(event_dict)



             def trade_action(self, action, b3, N, P, Pc, Trade_Price, Q): # performs the buy and sell actions
                 N0 = self.num_of_dc #N0 is the total number of thresholds
                 if action == "sell":
                     Nup = N
                     if Nup > 0 and Pc >= P * b3: # sell
                         Qtrade = math.floor((1 + Nup / N0) * Q)
                         if self.QH > Qtrade:
                             self.cash = self.cash + Qtrade * Trade_Price
                             self.QH = self.QH - Qtrade
                         else:
                             self.cash = self.cash + self.QH * Trade_Price
                             self.QH = 0
                     else:
                         pass #will hold

                 elif action == "buy":
                     Ndown = N
                     if Ndown > 0 and Pc <= P + (P * (1 - b3)): # buy
                         Qtrade = math.floor((1 + Ndown / N0) * Q)
                         if self.cash > Qtrade * Trade_Price:
                             self.cash = self.cash - Qtrade * Trade_Price
                             self.QH = self.QH + Qtrade
                         else:
                             Qtrade_m = self.cash // Trade_Price
                             self.cash = self.cash - Qtrade_m * Trade_Price
                             self.QH = self.QH + Qtrade_m
                     else:
                         pass # will hold

         output = DC_strategy(2, "EURUSD_T_202201", 2000, "USD")
```

```
[0.0001  0.00013]
threshold value: 0.0100%, 0.0130%,
                  datestamp      bid      ask  volume  Trade_Price   current
0        20220102 170354650  1.13690  1.13776       0     1.137330       NaN
1        20220102 170428267  1.13689  1.13776       0     1.137325  1.137330
2        20220102 170507458  1.13692  1.13776       0     1.137340  1.137325
3        20220102 170651613  1.13668  1.13690       0     1.136790  1.137340
4        20220102 170651715  1.13671  1.13690       0     1.136805  1.136790
...                     ...      ...      ...     ...          ...       ...
1048570  20220125 045715605  1.12855  1.12859       0     1.128570  1.128565
1048571  20220125 045715809  1.12855  1.12858       0     1.128565  1.128570
1048572  20220125 045716052  1.12855  1.12859       0     1.128570  1.128565
1048573  20220125 045716205  1.12858  1.12860       0     1.128590  1.128570
1048574  20220125 045716557  1.12859  1.12862       0     1.128605  1.128590

[1048575 rows x 6 columns]
0.04909025000021074
Wealth = 2000.9818 USD, Return = 0.0491%
```

> **[3.1] The discussion of the empirical results**

Firstly, the return of fixed multi-threshold strategy can not compared to the return of randomly generated single threshold strategy for the monthly tick data in February.

In [44]:
```
x = Image(filename='/Users/ambladeky/Desktop/02_random.png',width=400, height=400)
y = Image(filename='/Users/ambladeky/Desktop/02_fixed.png',width=400, height=400)
display(x, y)
```

```
[0.00017327]
threshold value: 0.0173%,
                    datestamp      bid      ask  volume  Trade_Price   current
0        20220201 000006460  1.12430  1.12433       0     1.124315       NaN
1        20220201 000007663  1.12430  1.12434       0     1.124320  1.124315
2        20220201 000008739  1.12430  1.12433       0     1.124315  1.124320
3        20220201 000018681  1.12426  1.12429       0     1.124275  1.124315
4        20220201 000018732  1.12428  1.12432       0     1.124300  1.124275
...                     ...      ...      ...     ...          ...       ...
1048570  20220218 080441679  1.13566  1.13568       0     1.135670  1.135665
1048571  20220218 080441781  1.13566  1.13569       0     1.135675  1.135670
1048572  20220218 080444295  1.13568  1.13570       0     1.135690  1.135675
1048573  20220218 080444397  1.13570  1.13573       0     1.135715  1.135690
1048574  20220218 080445252  1.13567  1.13570       0     1.135685  1.135715

[1048575 rows x 6 columns]
0.27778700000098977
Wealth = 2005.5557 USD, Return = 0.2778%
```

```
204 output = DC_strategy(2, "EURUSD_T_202202", 2000, "USD")
```

```
[0.0001  0.00013]
threshold value: 0.0100%, 0.0130%,
                    datestamp      bid      ask  volume  Trade_Price   current
0        20220201 000006460  1.12430  1.12433       0     1.124315       NaN
1        20220201 000007663  1.12430  1.12434       0     1.124320  1.124315
2        20220201 000008739  1.12430  1.12433       0     1.124315  1.124320
3        20220201 000018681  1.12426  1.12429       0     1.124275  1.124315
4        20220201 000018732  1.12428  1.12432       0     1.124300  1.124275
...                     ...      ...      ...     ...          ...       ...
1048570  20220218 080441679  1.13566  1.13568       0     1.135670  1.135665
1048571  20220218 080441781  1.13566  1.13569       0     1.135675  1.135670
1048572  20220218 080444295  1.13568  1.13570       0     1.135690  1.135675
1048573  20220218 080444397  1.13570  1.13573       0     1.135715  1.135690
1048574  20220218 080445252  1.13567  1.13570       0     1.135685  1.135715

[1048575 rows x 6 columns]
0.07917200000033517
Wealth = 2001.5834 USD, Return = 0.0792%
```

Secondly, the return of the fixed multi-thresholds strategy is much less compared to the randomly generated single threshold strategy for the monthly tick data in January, where the fixed multi-thresholds strategy only yields 0.0491%.

In [39]:
```
x = Image(filename='/Users/ambladeky/Desktop/backtest_random_01.png',width=400, height=400)
y = Image(filename='/Users/ambladeky/Desktop/01_fixed.png',width=400, height=400)
display(x, y)
```

```
204 output = DC_strategy(1, "EURUSD_T_202201", 2000, "USD")
```

```
[0.00801634]
threshold value: 0.8016%,
                    datestamp      bid      ask  volume  Trade_Price   current
0        20220102 170354650  1.13690  1.13776       0     1.137330       NaN
1        20220102 170428267  1.13689  1.13776       0     1.137325  1.137330
2        20220102 170507458  1.13692  1.13776       0     1.137340  1.137325
3        20220102 170651613  1.13668  1.13690       0     1.136790  1.137340
4        20220102 170651715  1.13671  1.13690       0     1.136805  1.136790
...                     ...      ...      ...     ...          ...       ...
1048570  20220125 045715605  1.12855  1.12859       0     1.128570  1.128565
1048571  20220125 045715809  1.12855  1.12858       0     1.128565  1.128570
1048572  20220125 045716052  1.12855  1.12859       0     1.128570  1.128565
1048573  20220125 045716205  1.12858  1.12860       0     1.128590  1.128570
1048574  20220125 045716557  1.12859  1.12862       0     1.128605  1.128590

[1048575 rows x 6 columns]
0.5574332500004289
Wealth = 2011.1487 USD, Return = 0.5574%
```

```
204 output = DC_strategy(2, "EURUSD_T_202201", 2000, "USD")
```

```
[0.0001  0.00013]
threshold value: 0.0100%, 0.0130%,
                    datestamp      bid      ask  volume  Trade_Price   current
0        20220102 170354650  1.13690  1.13776       0     1.137330       NaN
1        20220102 170428267  1.13689  1.13776       0     1.137325  1.137330
2        20220102 170507458  1.13692  1.13776       0     1.137340  1.137325
3        20220102 170651613  1.13668  1.13690       0     1.136790  1.137340
4        20220102 170651715  1.13671  1.13690       0     1.136805  1.136790
...                     ...      ...      ...     ...          ...       ...
1048570  20220125 045715605  1.12855  1.12859       0     1.128570  1.128565
1048571  20220125 045715809  1.12855  1.12858       0     1.128565  1.128570
1048572  20220125 045716052  1.12855  1.12859       0     1.128570  1.128565
1048573  20220125 045716205  1.12858  1.12860       0     1.128590  1.128570
1048574  20220125 045716557  1.12859  1.12862       0     1.128605  1.128590

[1048575 rows x 6 columns]
0.04909025000021074
Wealth = 2000.9818 USD, Return = 0.0491%
```

In the backtesting, the multi-thresholds strategy can not beat the single threshold strategy in both cases. The following part will display several reasons and improvements:

> **[3.2] Limitation and improvement of strategy:**

Firstly, a multi-threshold trading strategy has been applied and simply assigned equal weight to each threshold. However, this is not an effective trading strategy because some thresholds may be more critical and should be assigned higher weights.

Secondly, the four parameters: Q, b_1, b_2, b_3 are assigned fixed values: Q = 1, $b_1 = 0.8, b_2 = 1, b_3 = 0.9$. This setup is based on the observation form Kampouridis and Otero (2017). But it is not the optimal setup because these parameters are not optimized. Perhaps the Genetic algorithms can be implemented to optimize the parameters later as Tsang and Chen (2018) did.

Next, I have used the first two same threshold values θ [0.01%, 0.013%] (Kampouridis and Otero, 2017) for the data in this coursework. But the return generated is not good. It may show that threshold values θ suitable for one dataset may not be proper for other datasets. Moreover, maybe applied the whole threshold values θ [0.01%, 0.013%, 0.015%, 0.018% and 0.02%] will yield better result.

Lastly, the length of the OS event in this report is approximated using the scaling law. Perhaps, using the average length of tick time measured depending on the dataset will result in different returns.

Reference lists:

Kampouridis, M., & Otero, F. E. (2017). Evolving trading strategies using directional changes. Expert Systems with Applications, 73, 145-160.

Tsang, E., & Chen, J. (2018). Regime change detection using directional change indicators in the foreign exchange market to chart Brexit. IEEE Transactions on Emerging Topics in Computational Intelligence, 2(3), 185-193.

In [ ]: