1. Analysing the outcomes of applying Sequential model to predict investment position signals for chosen stocks

1.1. Testing hyperparameters

In order to experiment with machine learning models and their use for algorithmic trading I have used a Sequential model to define and train a deep neural network which was then utilised in a financial context.
Market data is of sequential nature. The time series provides information about the movement of the market over time. Sequential model is well-suited for this sort of data and that is why the decision to use it in the financial context.
I decided to experiment with this DNN as these models can learn complex relationships and patterns in data. In the context of financial data, DNN are useful in identifying patterns between different financial indicators and how they impact the market movement collectively.
The model was used to generate “go long” and “go short” signals depending on what market movement was predicted. The tables below show the final experiments run on different hyperparameters. One set of experiments was trained on around 1.5 weeks of financial data with an interval of 1 minute, and trained on 2 days worth of data. The other experiment was trained on 2.5 weeks of data and tested on roughly 2 days of data as well.

Experiment from 15-17.02

	A	B	C	D	E	F	G
1	lags >						
2	momentum >						
3	volume >						
4	volatility >						
5	distance >						
6	v TICKER v	[20, 10, 5, 25, 1]	[20, 10, 5, 25, 5]	[20, 10, 5, 25, 10	[20, 10, 5, 25, 15	[20, 10, 5, 25, 20	[20, 10, 5, 25, 25]
7	TSLA(automotive)	1.019959706	1.0559441	1.082542539	1.061262375	1.062077396	1.069598053
8	XOM(energy)	1.037113632	0.9997039745	0.9942682499	0.9987579613	0.9936139715	1.006754493
9	CNX(energy)	0.9868090429	0.9934628589	0.9998595842	1.013880397	1.013023971	0.9991024653
10	UNH(healthcare)	0.9801234608	1.013314781	1.008206863	1.006387162	1.014870378	0.9988465805
11	JNJ(healthcare)	1.002468854	0.9868230703	0.9896185131	0.9877219506	0.9902489335	0.98392775
12	BA(industrial)	1.027071194	0.9570362218	0.9585678289	0.9544132918	0.9496773311	0.9773302033
13	UNP(industrial)	1.004018044	1.047454487	1.04780034	1.047722888	1.045750519	1.043519722
14	JPM(financial)	0.9926722881	1.003574272	1.011439166	0.9966821106	0.9990089887	1.002824976
15	TSP(financial)	1.172661817	1.106945706	1.139386504	1.032912154	1.010247976	1.01265966
16	AAPL(technology)	1.018812871	1.003135701	1.00029253	1.018138591	1.001886098	1.004604747
17	MSFT(technology)	1.040571965	0.9997713881	0.9950348866	1.003726414	1.006668258	0.9984222601
18	NVDA(technology)	1.064942954	1.026411422	1.019490029	1.024340531	1.01734708	1.014621029
19	ALLT(technology)	0.9630682168	1.269399156	1.227935382	1.242732858	1.233744057	1.237322629
20	WMT(retail)	0.997678255	0.9936099766	0.9912840534	0.9836781098	0.9952203725	0.9967985655
21	JMIA(retail)	1.15749998	1.073222338	1.081127232	1.065776273	1.131449871	1.126564069
22	CLF(materials)	1.034056567	1.051814841	1.011113513	1.012827112	1.016099596	1.00314471
23	ABEV(consumer goods)	1.001984172	1.502801892	1.43508305	1.392966014	1.379824062	1.368556257
24	FUBO(entertainment)	1.012711954	1.354959453	1.259248782	1.229155042	1.150295778	1.147568368
25	average	1.028568054	1.079965869	1.069572169	1.059615624	1.056169702	1.055120363
26							

Experiment from 21-24.02

	A	B	C	D	E	F	G
1	lags >						
2	momentum >						
3	volume >						
4	volatility >						
5	distance >						
6	v TICKER v	[10, 1, 15, 10, 1]	[10, 1, 15, 10, 5]	[10, 1, 15, 10, 10]	[10, 1, 15, 10, 15	[10, 1, 15, 10, 20	[10, 1, 15, 10, 25]
7	TSLA(automotive)	1.018899802	0.9900029977	1.007241038	1.021413092	1.002408636	0.9762830382
8	XOM(energy)	1.012988184	1.002874871	1.012946386	1.017514857	1.016488041	1.014301348
9	CNX(energy)	0.9588910439	1.000128552	1.035915739	1.010730079	1.045113552	1.041342308
10	UNH(healthcare)	1.01274961	0.9962052908	0.9969528865	1.007161526	0.9932127052	1.002777276
11	JNJ(healthcare)	0.9882777467	0.9979483736	0.9959604762	0.9934814136	0.984308745	0.9872623877
12	BA(industrial)	1.037294977	0.9768497897	0.9784414379	0.9858739875	0.9739402774	0.9832597647
13	UNP(industrial)	0.9849242192	1.01334889	1.003262038	1.003041099	1.035171247	1.020687647
14	JPM(financial)	0.9784999721	1.013889814	1.012998246	1.015087553	1.012192056	1.015106146
15	TSP(financial)	1.087431674	1.498371195	1.509310653	1.526044252	1.504733171	1.425667993
16	AAPL(technology)	1.013632335	0.9695937966	0.9718906378	1.015497276	0.9889526879	0.9979696344
17	MSFT(technology)	1.008747262	0.9975882348	1.003888726	0.9939513616	0.9816287136	0.9808148172
18	NVDA(technology)	0.8921240443	1.186436684	1.16900585	1.129530865	1.166974622	1.126717264
19	ALLT(technology)	1	1.091435638	1.060841133	1.107844911	1.107844911	1.070698453
20	WMT(retail)	1.005825801	1.017017932	1.017445464	1.017429994	1.022657172	1.0057453
21	JMIA(retail)	1.055722947	1.12466091	1.131454005	1.097900419	1.084339291	1.108082041
22	CLF(materials)	1.004817506	1.018870196	0.9942847573	0.9943157569	0.9996697967	0.9608921064
23	ABEV(consumer goods)	0.996078435	1.511517965	1.491963799	1.488604388	1.469040874	1.460889644
24	FUBO(entertainment)	0.9935345401	1.155481794	1.169803216	1.074027789	1.084056712	1.115859006
25	average	1.002802228	1.086790162	1.086867027	1.083302812	1.081818512	1.071908676
26							

The experiments on hyperparameters for the Sequential model trained on financial data, specifically stock prices, resulted in significantly different optimal values for the hyperparameters. The first experiment showed that the optimal values were 20 for the number of lags, 10 for the number of momentum, 5 for volume, 25 for volatility and 5 for distance, while the second experiment showed that the optimal values were 10 for lags, 1 for momentum, 15 for volume, 10 for volatility and 10 for distance.

It is worth noting that the second experiment was conducted on a 50% larger dataset than the first experiment. The data for the first experiment accounted for 2 weeks worth of data with 1m interval (train + test data sets), whereas the second model was conducted on 3 weeks worth of data. Deep learning models typically require a large amount of data to be trained effectively. This is because these models are highly complex and require a significant amount of input data to learn the patterns and relationships within the data. The difference in the results can be attributed to the larger dataset in the second experiment, providing more diverse and representative samples for the model to learn from.

Despite the difference in optimal hyperparameters, the performance of the model was not significantly affected, as the first experiment resulted in a strategy performance of 1.080, whereas the second experiment's result was 1.087, indicating a minor difference in performance. This change in performance is natural as the tests were performed on different days, and consequently with different market conditions.

In order to confirm the hypothesis another hyperparameter experiment should be run and the results should be compared to the previous results provided above.

Below table illustrates the results of the final hyperparameters test. The model in this case was trained on almost 4 weeks of price data with an interval of 1 minute. The performance was evaluated on roughly 800 data points. The time period of testing is 2-3.02.

lags >						
momentum >						
volume >						
volatility >						
distance >						
v TICKER v	[25, 1, 15, 10, 1]	[25, 1, 15, 10, 5]	[25, 1, 15, 10, 1(	[25, 1, 15, 10, 1[	[25, 1, 15, 10, 2(	[25, 1, 15, 10, 25
TSLA(automotiv	1.027200129	0.9911072646	0.9755272194	1.004055518	0.9856753512	0.99310182
XOM(energy)	1.015391531	1.024699469	1.017963761	1.016758571	1.019212452	1.020536634
CNX(energy)	0.9491421606	1.013327573	1.017480054	1.022778666	1.013772276	0.9968983965
UNH(healthcare	0.9920386209	1.021187003	1.013856671	1.01683617	1.022436514	1.018788831
JNJ(healthcare)	1.010298507	1.017716221	1.013697392	1.014321647	1.011903112	1.006823056
BA(industrial)	1.055133201	1.053028653	1.052262594	1.04413364	1.051943414	1.055723111
UNP(industrial)	0.9945548367	0.996196193	0.9852098657	0.9822955539	0.9918819173	0.9897166894
JPM(financial)	1.009167279	1.030035008	1.025084929	1.03088746	1.022996032	1.023650235
TSP(financial)	0.9137931257	1.509329984	1.513421969	1.491679469	1.484983563	1.486746233
AAPL(technolog	0.9612659329	1.040586432	1.033339471	1.028732688	1.033654237	1.038572398
MSFT(technolog	1.035785256	1.01536038	1.009117542	1.016268448	1.012635174	1.003090686
NVDA(technolog	1.049210506	1.071404594	1.059931717	1.066273446	1.062683979	1.068098602
ALLT(technology	1.256227773	2.548035595	2.337993305	2.316207301	2.250521891	2.147715487
WMT(retail)	0.9947039516	1.007938514	1.015817187	1.016434229	1.01879053	1.011860899
JMIA(retail)	0.9356104202	1.222533283	1.230021837	1.219969456	1.184911732	1.197568293
CLF(materials)	0.9399823777	1.041100261	1.039462763	1.027072411	1.015607396	1.018601776
ABEV(consumer	1.013888923	1.439772426	1.448660882	1.433998266	1.433839252	1.403638017
FUBO(entertainr	1.088757379	1.862825175	1.754246872	1.827758584	1.797152606	1.645939326
average	1.013452884	1.217010224	1.196838668	1.198692307	1.189700079	1.173726138

When we compare the outcome below to the one before (where the model was trained on 3 weeks worth of data) the hyperparameters that generated the best performance compare as follows:

	Sequential model trained on roughly 2,5 weeks of data	Sequential model trained on roughly 3,5 weeks of data
lags	10	25
momentum	1	1
volume	15	15
volatility	10	10
distance	10	5

We can see that both results agree on the same momentum, volume and volatility hyperparameters, and differ on lags and distance. When we look at the performance tables we can see that the performance of the model trained on 2,5 weeks of data and for hyperparameters 10,1,15,10,10 and 10,1,15,10,5 are almost the same with the difference of

0.0001. We can conclude that the difference is minor and the final choice of hyperparameters can as well be 10,1,15,10,5. Making the comparison table look as follows:

	Sequential model trained on roughly 2,5 weeks of data	Sequential model trained on roughly 3,5 weeks of data
lags	10	25
momentum	1	1
volume	15	15
volatility	10	10
distance	5	5

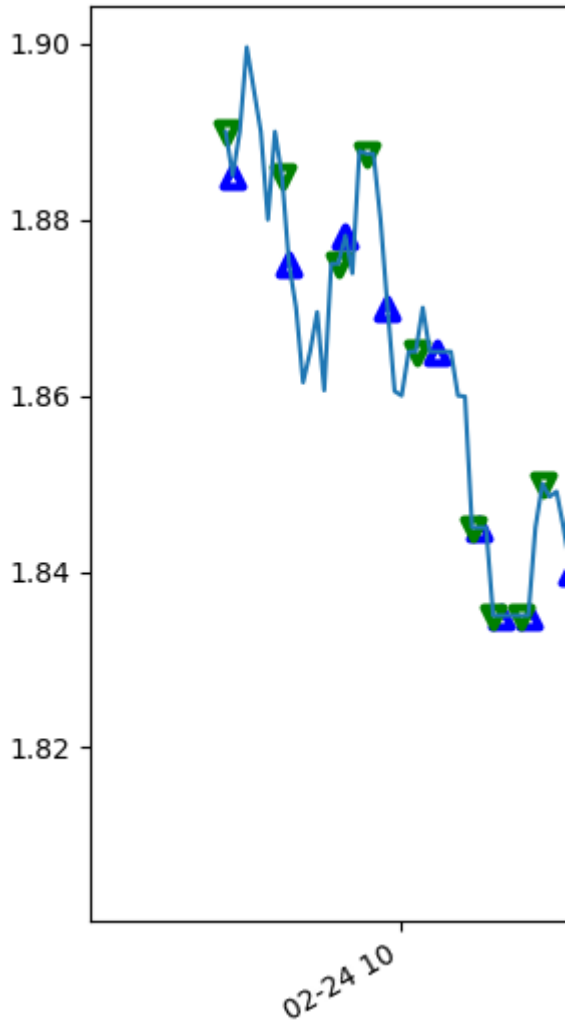
1.2. Model performance on volatile and stable stocks

One of the conclusions that were clearly drawn is that “penny” stocks performed much better than well established, more expensive stocks. They perform exceptionally well. Below you can see the table with stocks, their prices as well as their performance (strategy with Sequential model with hyperparameters specified in the column). You can see that there is a clear distinction between the performance of the expensive and cheap stocks. The performances’ range for more expensive stocks (range $20-$484) is 0.97 to 1.02, with one exception of NVDA with performance 1.17. The “penny stocks” with price range $1.83-$3.52 have performance with range 1.06 to 1.51. It is worth noting these are the results from testing the strategy on roughly 800 minutes of price points - around 2 trading days.

	price(decreasing)	performance(hyperparameters [10, 1, 15, 10, 10])
UNH(healthcare)	484	0.9969528865
MSFT(technology)	249	1.003888726
NVDA(technology)	233	1.16900585
BA(industrial)	198	0.9784414379
TSLA(automotive)	197	1.007241038
UNP(industrial)	194	1.003262038
JNJ(healthcare)	156	0.9959604762
AAPL(technology)	147	0.9718906378
WMT(retail)	142	1.017445464
JPM(financial)	141	1.012998246
XOM(energy)	111	1.012946386
CLF(materials)	20	0.9942847573
CNX(energy)	16	1.035915739
ALLT(technology)	3.52	1.060841133
JMIA(retail)	3.32	1.131454005
ABEV(consumer goods)	2.55	1.491963799
FUBO(entertainment)	2.32	1.169803216
TSP(financial)	1.83	1.509310653

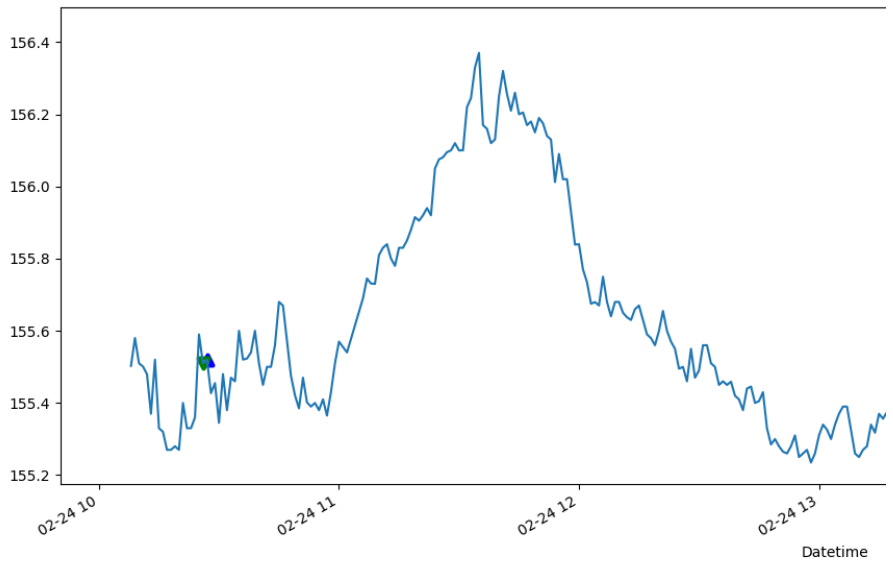
The reason for such a big difference in performances for expensive and cheap stocks might be their volatility. Cheaper stocks tend to be more volatile, meaning they can have larger price swings and offer more opportunities for gains than expensive stocks. On the other hand, expensive stocks tend to be more stable and have less volatility, and therefore smaller changes in prices which result in less opportunities for profit.

For example for TSP which scored 1.51, the price fluctuation on 24th of February from around 9.30 am to 10.30 am looks as shown below:



As can be seen on the graph there are plenty of rises and drops. The first major drop from 1.9 to 1.86 creates a chance for a profit of roughly 2%. These fluctuations continue to appear throughout the day.

On the other hand JNJ - a much more expensive stock which does not yield much profit and does not experience big changes in price is shown below:



The biggest drop in JNJ price on the 24th of February is from $156.4 at around 11.40am to $155.3 at around 1pm and the change accounts for only around 0.7%.

These examples prove the point that daily trading should rather focus on cheaper stocks or simply more volatile ones. These provide opportunities for fund growth as they offer higher potential returns due to their price fluctuations. However, it's important to note that trading in cheaper or more volatile stocks also comes with higher risks, as the prices can change rapidly and unpredictably.

Out of the selection of 17 chosen stocks, one of the worst performing ones are JNJ and BA, they happen to underperform in both experiments and no matter what hyperparameters are chosen. This leads to a conclusion that there are some sort of inherently bad conditions for short interval, intraday trading. In order to investigate more, a graph of stock prices as well as the trades are shown on the figures below:

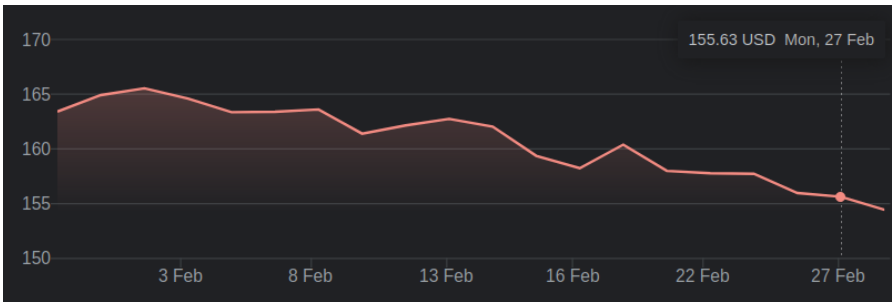
1.3. Worst performing stocks

1.3.1. JNJ

1.3.1.1. Analysis

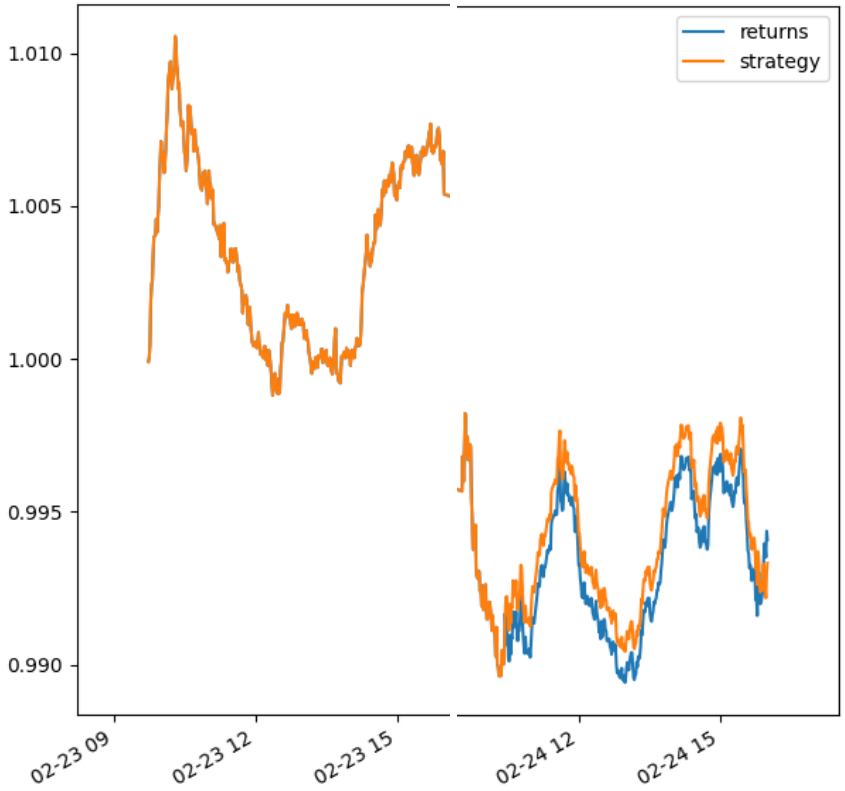
JNJ

The model in the second experiment was trained on data of 1 minute interval from the 3rd of February until the 22nd of February, and the percentage change of price throughout this time accounted for around 4%.



When the model was trained on 3 weeks worth of JNJ data, with parameters [lags=10, momentum=1, volume=15, volatility=10, distance=10] and evaluated of 808 price points the outcome of the strategy was 0.996, which means there was a loss to the initial investment.

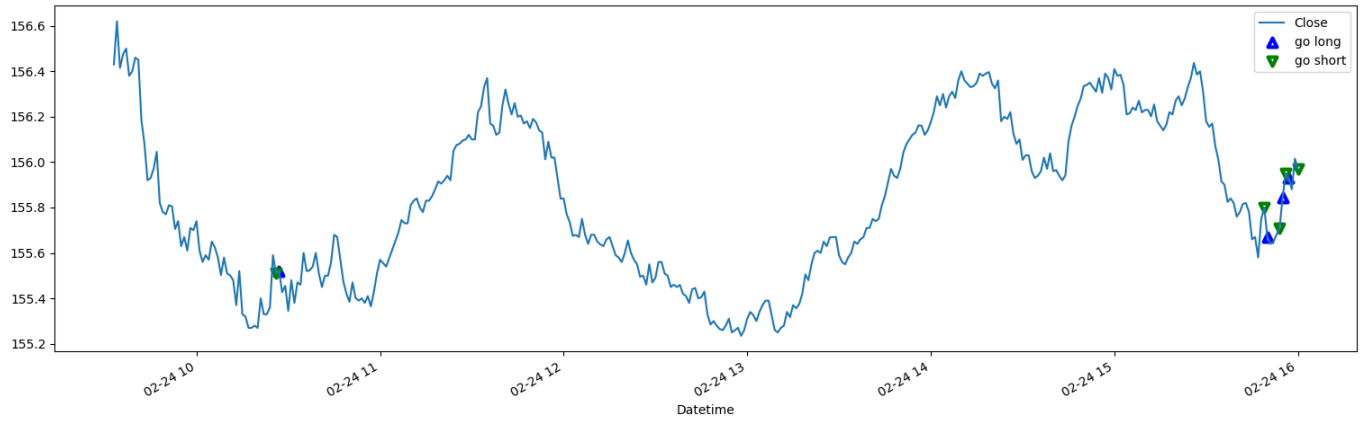
To better visualise the process the cumulative performance of the strategy throughout the two days of testing is provided:



The ideal strategy performance would result in a cumulative return that closely resembles a straight line. This indicates that all possible opportunities for profit were seized, including both upward and downward movements in the market. By taking long or short positions accordingly, the model would have been able to capitalise on both rises and falls in stock prices.

It can be noticed that the strategy for JNJ performs well when there are rises in price but it loses what it's gained when drops in price happen. Additionally, the strategy kept positions after market closing values, which contributed to a lower strategy performance.

Chart showing the the price of JNJ and the trade signals generated by the strategy on the 24th of February:



The confusion matrix for the above model performance looks as follows:
[4 401]
[5 398]

The first row in the matrix describes the classifications of “go short” signals. In this case the “go long” signal was classified correctly 4 times, and misclassified 401 times. In other words there were 401 occurrences where the model predicted “go long” signal when the actual signal was “go short”. The second row in the matrix describes the classifications of “go long” signals. Here, the “go long” signal was classified correctly 398 times, and misclassified 5 times. This means that the model predicted “go short” signal when the actual signal was “go long” on 5 occasions. Overall, the confusion matrix provides a useful summary of the model's classification performance, as it allows for a quick assessment of the number of correct and incorrect classifications for each signal. In this case, the relatively large number of misclassifications of “go short” signals highlights the need for further refinement of the model, or providing more data for training purposes.

Below there is statistics regarding signals/trades

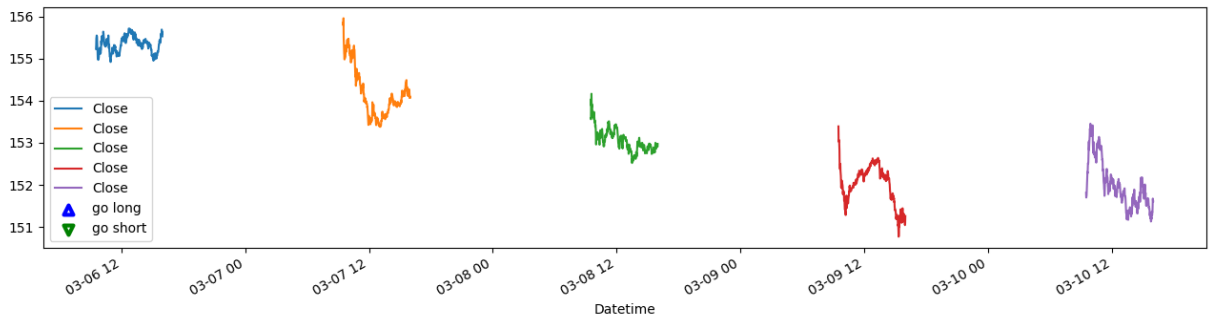
```
Strategy performace:                    0.9959604761751839
Percentage average  profit per trade: -0.0194430739598008
Number of trades:                       14
Number of loss trades:       6 which constitutes to 43% of all trades
Number of profitable trades: 8 which constitutes to 57% of all trades
Average percentage loss per loss trade:         -0.20053217056014827
Average percentage profit per profitable trade: 0.11637374849045982
```

Upon further testing of JNJ stock it is evident that the model is not suitable for predicting market movement for JNJ stock.

1.3.1.2. Hyperparameters adjustment

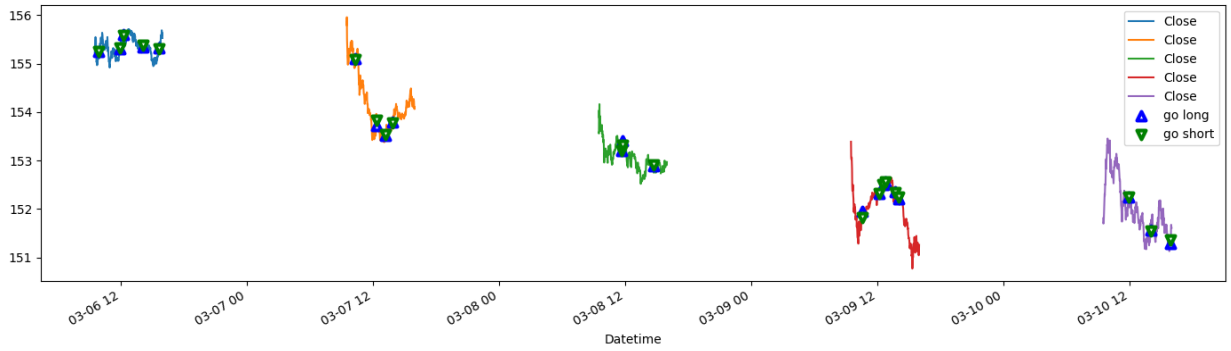
Below there is a chart depicting the price of JNJ and trades made in a period of 6-10 of February. The algorithm used Sequential model with parameters
`lags=25,momentum_rolling=1,volume_rolling=15, volatility_rolling=10, distance_rolling=5`

It is really surprising that the model did not make any trades in the time of the 5 trading days.



For hyperparameters: `lags=10,momentum_rolling=1,volume_rolling=15, volatility_rolling=10, distance_rolling=5`

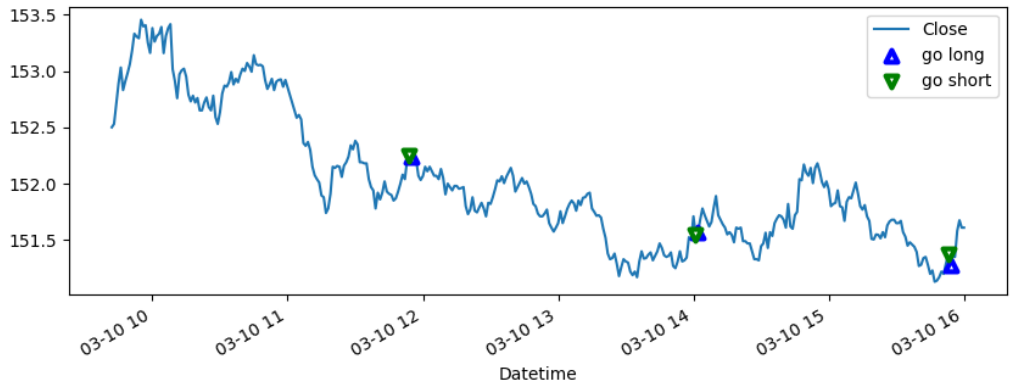
The strategy performance accounts for 0.98 and the chart looks as follows:



In the testing set there were only 42 trades done and the confusion matrix exhibits similar behaviour to the testing from previous week. That is the downwards trends are completely omitted. We can see that “go short” signals were predicted correctly only 6 times.

[6 1023]
[15 879]

Below you can see the behaviour of the strategy on the 10th of March. It is visible that from around 12 until 2pm the downward trend is completely ignored.



In order to investigate further whether the problem is with hyperparameters we have to investigate how the strategy performs with different sets of hyperparameters.

Below you can see the strategy results as well as confusion matrices for the chosen hyperparameters.

lags >									
momentum >									
volume >									
volatility >									
distance >									
v TICKER v	[35, 5, 10, 2, 1]	[35, 5, 10, 5, 1]	[35, 5, 10, 10, 1]	[35, 5, 10, 15, 1]	[35, 5, 10, 20, 1]	[35, 5, 10, 25, 1]	[35, 5, 10, 30, 1]	[35, 5, 10, 35, 1]	[35, 5, 10, 40, 1]
JNJ	0.984352658127 [[0 1029] [0 894]]	1.015896073164 [[1029 0] [894 0]]	0.984352658127 [[0 1029] [0 894]]	1.015896073164 [[1029 0] [894 0]]	1.015896073164 [[1029 0] [894 0]]	1.015896073164 [[1029 0] [894 0]]	0.984352658127 [[0 1029] [0 894]]	0.984352658127 [[0 1029] [0 894]]	0.984352658127149 [[0 1029] [0 894]]

The model does not react to the first 4 hyperparameters at all, it either classifies all the positions as “go long” or “go short”. The only hyperparameter that affects the prediction is the distance parameter (the difference between the price and a moving average of n data points), which is altered in the table below. Unfortunately in all the cases the strategy brings loss anyways.

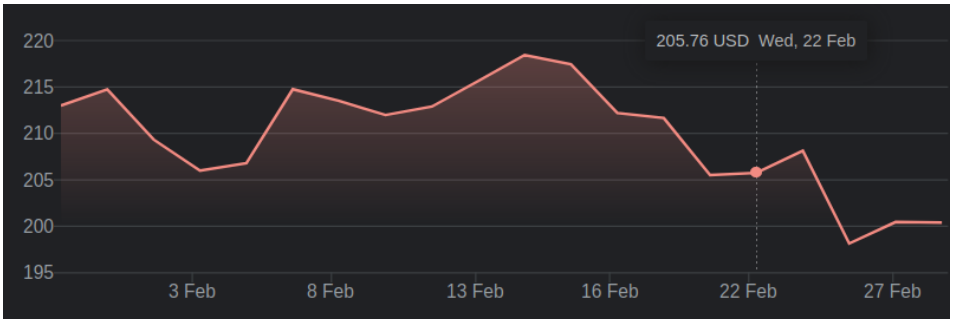
lags >									
momentum >									
volume >									
volatility >									
distance >									
v TICKER v	[35, 5, 10, 30, 1]	[35, 5, 10, 30, 5]	[35, 5, 10, 30, 10]	[35, 5, 10, 30, 15]	[35, 5, 10, 30, 20]	[35, 5, 10, 30, 25]	[35, 5, 10, 30, 30]	[35, 5, 10, 30, 35]	[35, 5, 10, 30, 40]
JNJ	0.984352658127149 [[0 1029] [0 894]]	0.97367075004813 [[101 928] [115 779]]	0.976567400419659 [[125 904] [132 762]]	0.985154458397963 [[95 934] [97 797]]	0.981659648391801 [[108 921] [111 783]]	0.9765300103565 [[111 918] [117 777]]	0.97887388175007 [[103 926] [106 788]]	0.97673827729563 [[100 929] [107 787]]	0.9899388695726477 [[51 978] [56 838]]

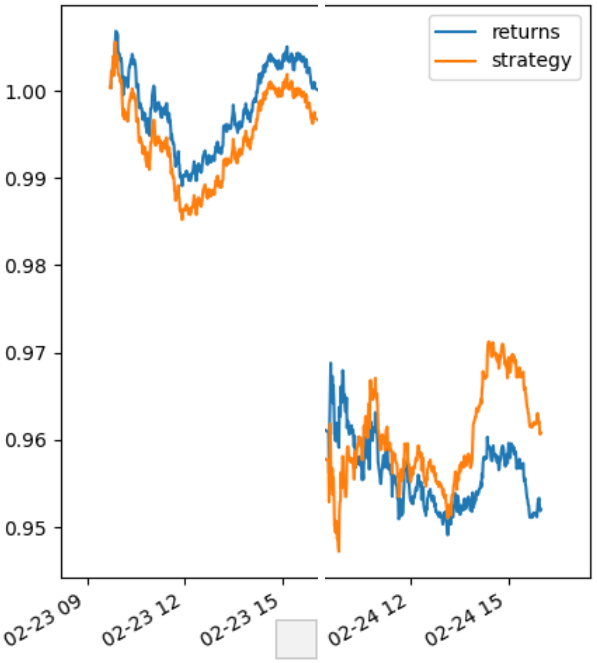
1.3.2. BA

1.3.2.1. Analysis

BA

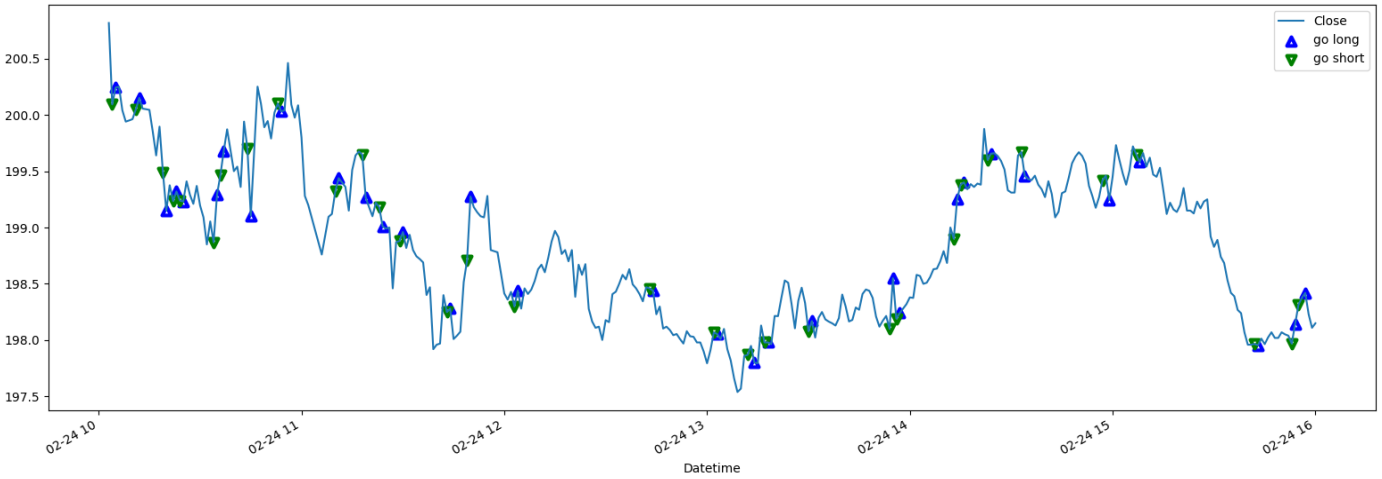
Another worst performing stock is BA. The model in the second experiment was trained on data of 1 minute interval from the 3rd of February until the 22nd of February, and the percentage change of closing price throughout this time accounted for around 0.5%.





Once more, it is evident that the signals generated by the model lead to satisfactory results during periods of upward trend. However, regrettably, the declines in price cause the profits acquired during the price surge to be lost.

For the stock BA the performance looks as shown below:



The confusion matrix for 808 minutes evaluation looks as follows:

[26 395]
[23 364]

Overall the model classified the signals correctly 390 times and incorrectly 418 times. The signals to “go long” were mostly classified correctly, the signals to “go short” were mostly misclassified. It can be seen on the chart that big downwards trends were not caught at all. For example from around 3pm until 3.40pm the model kept misclassifying the “go short” signal and did not correct itself even after the small drop that occurred at around 3.30pm.

This misclassification of “go short” signals explains why the strategy performance was very good in the times of price rise and not satisfactory in the times of price drops.

```
Strategy performace:                  0.9784414378717848
Percentage average  profit per trade: -0.0400069453992758
Number of trades:                     89
Number of loss trades:       46 which constitutes to 52% of all trades
Number of profitable trades: 43 which constitutes to 48% of all trades
Average percentage loss per loss trade:         -0.2302645272945962
Average percentage profit per profitable trade: 0.15816943227258798
```

1.4. Best performing stocks

1.4.1. TSP

1.4.1.1. Analysis

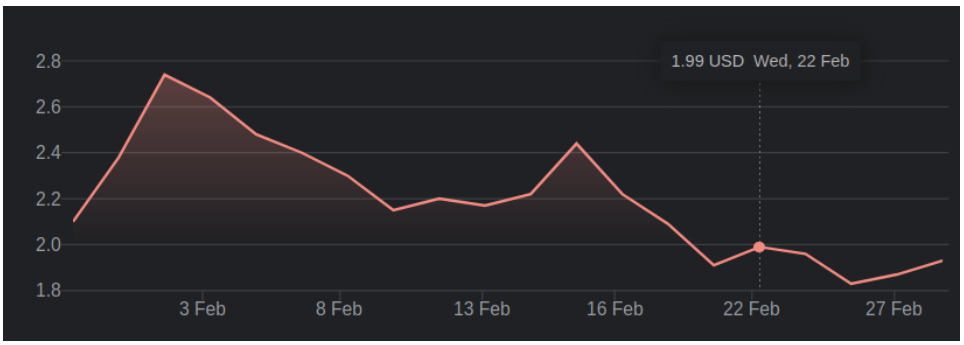
TSP

One of the top performing stocks is TSP, which is categorised as a penny stock. One potential reason for its success is its high level of volatility.

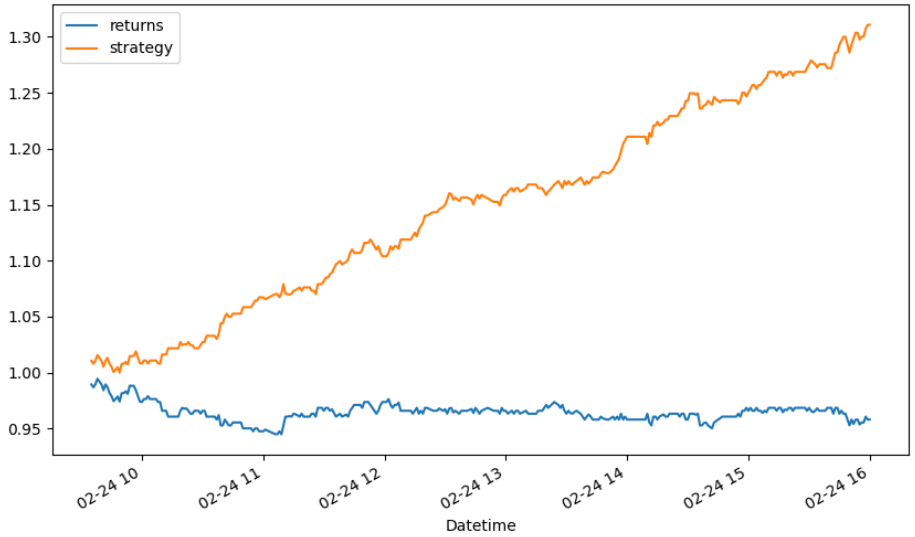
The graph displaying TSP's price movements over one-minute intervals provides a clear illustration of this volatility. As demonstrated, the stock price frequently fluctuates by 1%, 2%, or even 3% within a single day.

The model used to predict the movement was trained on data form the 3rd to 22nd of February and evaluated on data form the 22nd to 24th of February.

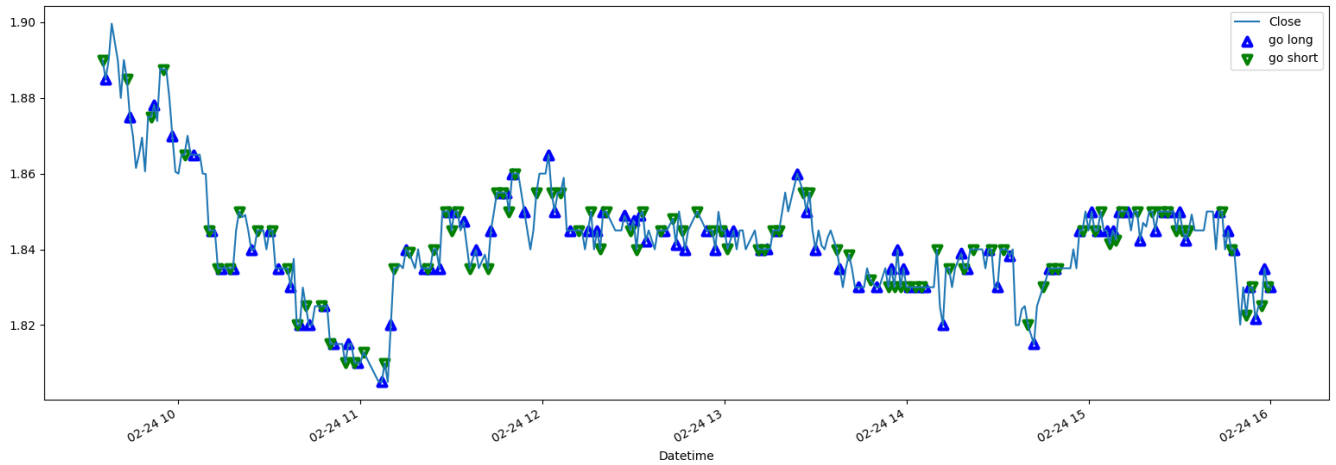
The chart below shows the price fluctuation of the test and train data sets



The cumulative strategy performance on the 24th of February looks as follows:



Upon reviewing the model's performance, it is evident that it took advantage of plenty of opportunities for growth, which indicates that the majority of signals were predicted correctly and the times of entering positions were satisfactory.



The confusion matrix for the model evaluation performance looks as follows:
[282 243]
[92 152]

The correct classification of price movement happened 434 times, whereas misclassification happened 335 times.

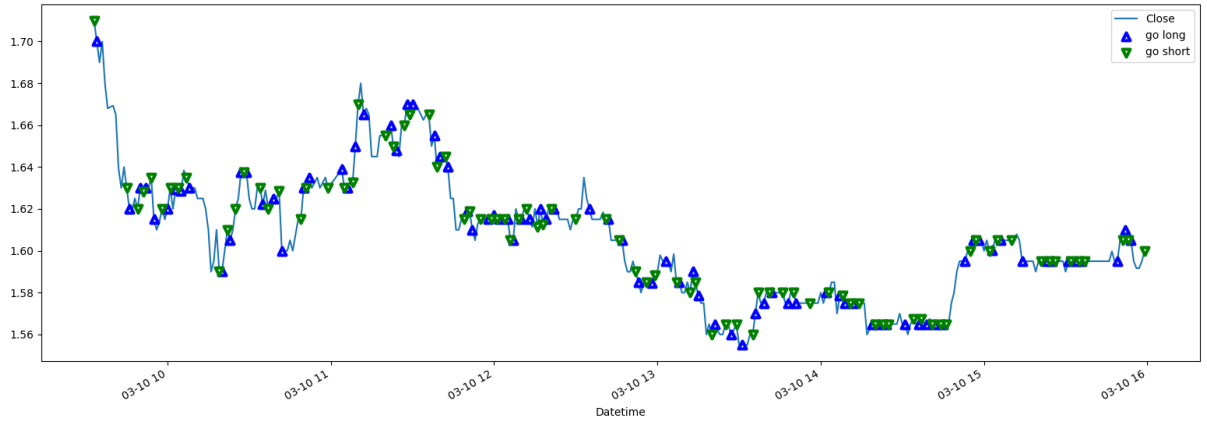
```
Strategy performace:                  1.5093106526570697

Percentage average  profit per trade: 0.01042809778914826

Number of trades:                     388

Number of loss trades:               121 which constitutes to 31% of all trades

Number of profitable trades:         137 which constitutes to 35% of all trades

Number of trades with no gain/loss: 130 which constitutes to 34% of all trades

Average percentage loss per loss trade:          -0.41757882312558303

Average percentage profit per profitable trade: 0.3983440842363874
```

1.4.1.2. Confirming the findings

To confirm the previous findings on the performance of TSP stock, new experiments were conducted on fresh data. The experiment involved using four weeks of training data while the testing data was obtained from the 6th to the 10th of March, 2023. The hyperparameters utilized in the experiment were lags=10, momentum_rolling=1, volume_rolling=15, volatility_rolling=10, and distance_rolling=10.

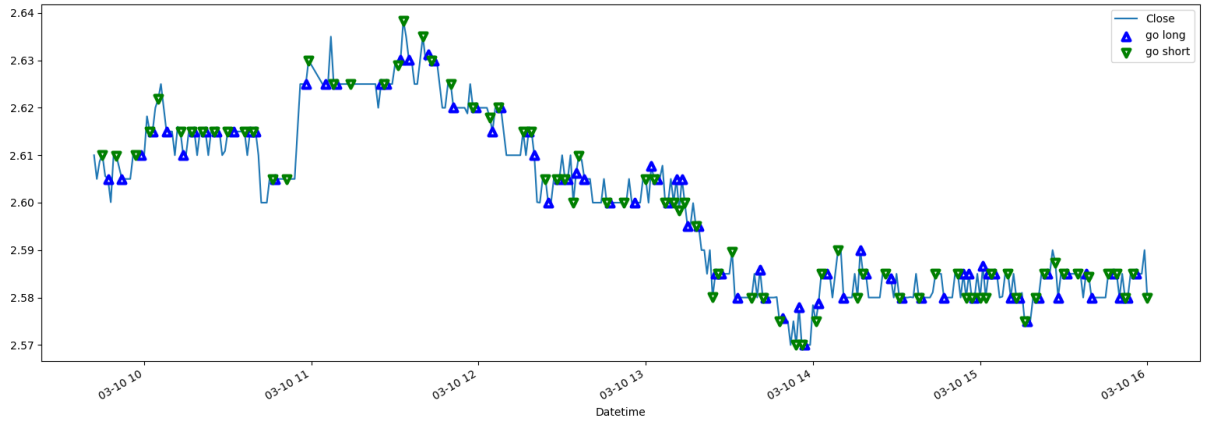
The strategy's performance over the five days recorded a 1.788279 - 78.8% profit. However, the results were lower compared to the previous experiment where testing resulted in approximately 52% profit within 800 minutes. The difference can be attributed to varying market conditions.

On the 10th of March, the model's performance was 1.083176.



To verify that TSP is not an outlier in terms of yielding good results, an investigation was conducted on other stocks that also yield good performance. A closer examination was carried out on the ABEV stock, which is also a penny stock.

The model tested against ABEV recorded a profit of 1.627380 - 62.7% over five days of data. On the 10th of March, the model's performance stood at 1.120645, and the price chart is shown below.



When comparing the charts of ABEV and TSP on March 10th, they appear to be quite similar. Both stocks saw a slight rise in prices from the morning until around 11:40 am, followed by a decline in prices from 11:40 am to 1:30 or 2:00 pm. After 2:00 pm, there was not much movement in either stock. The performance of both stocks was quite similar, with a profit of 12% and 9% respectively. This indicates that the Sequential model performs comparably in cases with similar conditions.

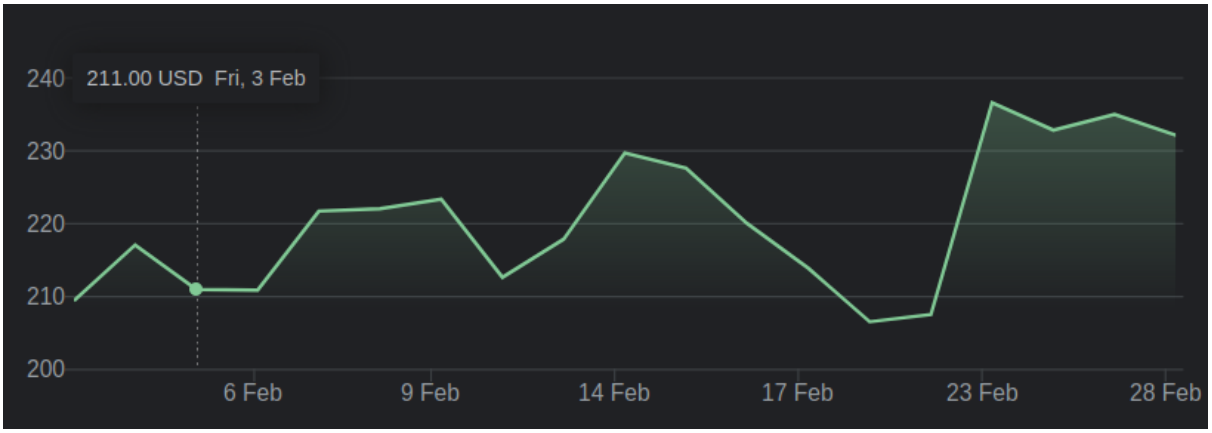
In conclusion, regardless of market conditions, the Sequential model consistently yields profits when tested against highly volatile penny stocks.

1.4.2. NVDA

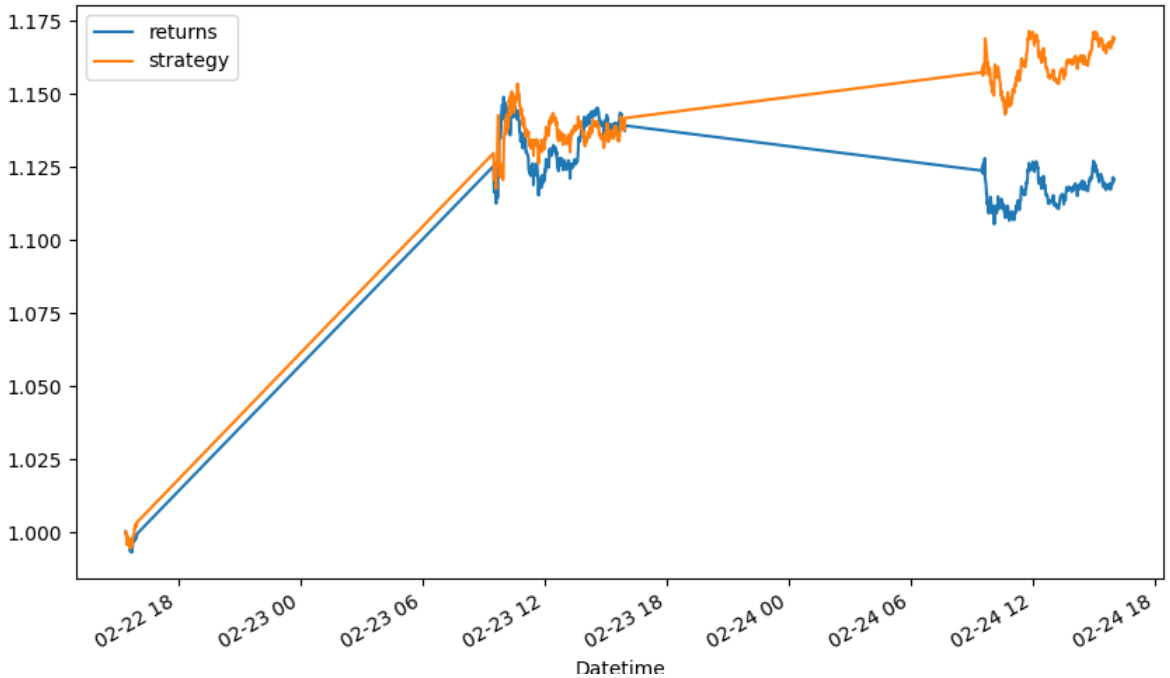
1.4.2.1. Analysis

NVDA

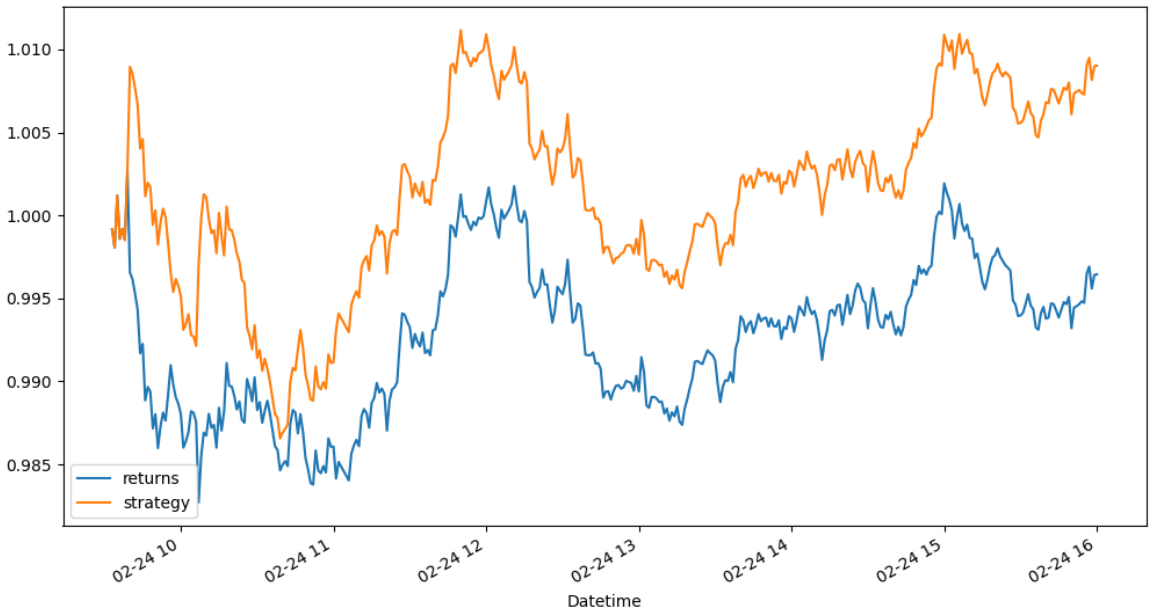
Another stock performing quite well under the Sequential model signals is NVDA. It is the only stock with a price above $20 that performed well under the Sequential model. From the experiment from 22nd-24th of February it scored 1.17, so 17% profit over two days. In order to see what affected its performance a few charts were investigated.



The first chart provides an explanation as to why the strategy's performance was relatively high, but unfortunately, it is not due to the Sequential model's exceptional performance. Instead, it is due to the fact that the strategy retained long and short positions beyond the financial market closing hours, and the price of NVDA stock rose significantly during after and pre-market hours, resulting in a favourable outcome for the strategy.



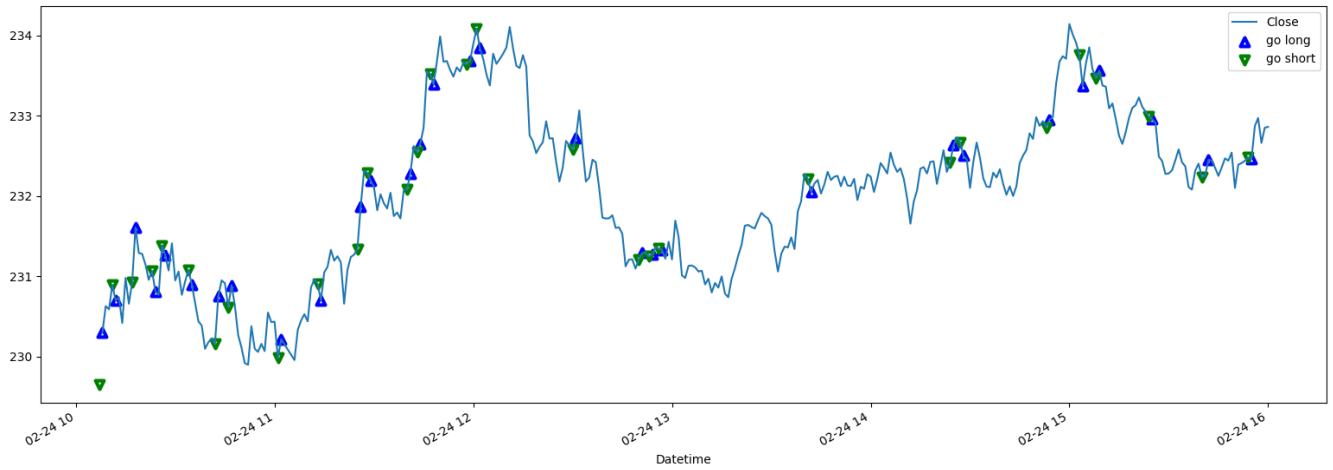
To assess the performance of the strategy with no positions held outside trading hours, we can examine its results on February 24th. However, it appears that the strategy did not perform as well as expected based on the experimental outcome. On that day, the final performance of the strategy was only approximately 1.01, indicating a marginal increase in value.



Analyzing the chart below can provide a deeper understanding of why the strategy's performance was unsatisfactory. It is evident, again, that the model misclassified numerous "go short" signals, resulting in missed opportunities for profitable trades. Specifically, when drops occurred in the market, the model failed to accurately predict the downward trends and did not execute trades that would have yielded profitable outcomes. The reason for such behaviour can be only speculated, it might be that the training data is more skewed towards “go long” signals, the features chosen as variables might not be optimal for this model.

It appears that the model has difficulty operating efficiently during downward movements, but it performs exceptionally well during upward, rapid movements. Specifically, the model's performance between 11 am to 12 pm is impressive, and it is evident that the model quickly adapts to small changes in the market.

During upward movements, there are significantly more trades executed compared to downward movements. For instance, between 11 am to 12 pm, there were 17 trades executed, while from 12 pm to around 1:20 pm, during a downward trend, only 9 trades were executed. This discrepancy suggests that the model is more effective at capturing upward trends and struggles to capitalise on downward trends.



[56 347]
[48 357]

As expected, “go short” signals were heavily misclassified, only 56 of them were classified correctly, and 347 incorrectly.

```
Strategy performace:                  1.1690058495619156
Percentage average  profit per trade: 0.05075434385984849
Number of trades:                     175
Number of loss trades:               83 which constitutes to 47% of all trades
Number of profitable trades:         92 which constitutes to 53% of all trades
Number of trades with no gain/loss: 0 which constitutes to 0% of all trades
Average percentage loss per loss trade:         -0.22405847876716783
Average percentage profit per profitable trade: 0.2986833034037871
```

2. Analysing the outcomes of applying SMA based algorithms to generate investment position signals for chosen stocks

2.1. Testing SMA parameters

After the classical and machine learning strategies were tested on data with daily intervals, a conclusion that SMA based strategies perform much better for long term investing.
Therefore in order to fine-tune the strategies for long term investing a closer look was taken at classical strategies and what is the correlation between final gain and the indicators that were used for a particular strategy.
Below there is a chart that shows the result of testing 6 SMA based strategies (with SMA1=10 days, SMA2=20 days, SMA3=60 days) on 17 stocks.
The time for testing is roughly the past 10 years.

TICKER	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	3 SMA & MACD	average
TSLA(automotive)	571.933614	0.7561796011	95.45528975	44.891894	96.55313812	4.049380369	135.6065826
XOM(energy)	2.14477254	0.7933811056	1.137405123	1.643854498	1.137405123	0.8488961549	1.284285757
CNX(energy)	0.0570377971	0.3311215727	0.07730064763	0.04105009074	0.08018500024	0.29186865	0.1464272931
UNH(healthcare)	0.1524869023	0.4918482382	0.09771453661	0.09283819998	0.09771453661	0.08105042357	0.1689421396
JNJ(healthcare)	1.089535369	0.3215754095	1.015428592	0.8910210632	1.028183087	0.6391933261	0.8308228078
BA(industrial)	4.363575485	1.306742751	4.261720938	3.513805035	4.261720938	2.629087981	3.389442188
UNP(industrial)	0.4183003988	0.660515196	0.3789347927	0.3249881685	0.3792691959	0.2238891157	0.3976494779
JPM(financial)	0.2778905484	1.579714197	0.2383394451	0.2834758345	0.2383394451	0.4641200198	0.5136465816
TSP(financial)	6.384026923	2.196030419	16.89418522	9.472141371	17.06821651	14.16056793	11.02919473
AAPL(technology)	3.614605924	1.118345306	1.741633221	3.557348887	1.738759894	1.141617562	2.152051799
MSFT(technology)	1.296204871	1.158025472	0.4128869357	0.3938694003	0.3978066845	0.1881704814	0.6411606408
NVDA(technology)	2.535760198	2.769212817	1.188600124	1.243082783	1.149454647	0.1327202623	1.503138472
ALLT(technology)	0.3073291562	0.2712789931	0.773122124	0.5355671983	0.773122124	1.192727143	0.6421911232
WMT(retail)	0.9153749036	1.134092223	0.8317321853	0.7224954866	0.8317321853	0.7841127572	0.8699232902
JMIA(retail)	8.611214925	6.906024051	10.90108528	8.182383305	10.90108528	7.557517769	8.843218435
CLF(materials)	2.530578944	4.937359716	0.4438337694	0.816898528	0.4668967157	6.100759407	2.549387847
ABEV(consumer goods)	0.6696061351	0.4592077446	0.4048588612	0.6223945455	0.4048588612	0.7648169754	0.5542905205
FUBO(entertainment)	4.168736822	3.190287819	3.932446909	3.185498164	3.932446909	2.790491438	3.53331801
average	33.97059177	1.687830146	7.788139914	4.467478142	7.857796404	2.446721542	

One of the best strategies are 2SMA, 2SMA&MACD, 2SMA&MACD&Bollinger. The worst performing one is 3SMA.
The most outstanding result is for TSLA and 2SMA strategy, the performance reached a stunning 571, which translated to a profit of 57100% over the past 10 years. TSLA generated considerable profit for other strategies as well, reaching 9600% profit for 2SMA&MACD&Bollinger, following with 1700% for 2SMA&MACD.
The second best stock which generated the most profit is TSP with the result of 1700% under 2SMA&MACD&ollinger and 1689%% for 2SMA&MACD strategy.
The worst stock to trade with is an energy stock CNX. Overall performance accounted for only 0.15, which means there was an average loss of 85% of the initial investment.
The second worst profit, or biggest loss was for a healthcare stock UNH with the average outcome of 0.17, which translates to a loss of 83%. None of the strategies managed to gain any profit when used against UNH.

2.2. 2SMA and 2SMA&MACD and 2SMA&MACD&Bollinger comparison

TICKER	2 SMA	2SMA & MACD & Bollinger	2 SMA & MACD
TSLA(automotive)	571.933614	96.55313812	95.45528975
XOM(energy)	2.14477254	1.137405123	1.137405123
CNX(energy)	0.0570377971	0.08018500024	0.07730064763
UNH(healthcare)	0.1524869023	0.09771453661	0.09771453661
JNJ(healthcare)	1.089535369	1.028183087	1.015428592
BA(industrial)	4.363575485	4.261720938	4.261720938
UNP(industrial)	0.4183003988	0.3792691959	0.3789347927
JPM(financial)	0.2778905484	0.2383394451	0.2383394451
TSP(financial)	6.384026923	17.06821651	16.89418522
AAPL(technology)	3.614605924	1.738759894	1.741633221
MSFT(technology)	1.296204871	0.3978066845	0.4128869357
NVDA(technology)	2.535760198	1.149454647	1.188600124
ALLT(technology)	0.3073291562	0.773122124	0.773122124
WMT(retail)	0.9153749036	0.8317321853	0.8317321853
JMIA(retail)	8.611214925	10.90108528	10.90108528
CLF(materials)	2.530578944	0.4668967157	0.4438337694
ABEV(consumer goods)	0.6696061351	0.4048588612	0.4048588612
FUBO(entertainment)	4.168736822	3.932446909	3.932446909
average	33.97059177	7.857796404	7.788139914

When we compare 3 strategies which are mainly based on 2 SMA crossovers we can see that simple 2SMA outperforms the 2SMA&MACD and 2SMA&MACD&Bollinger in 14 out of 19 cases and its average performance is much higher than the others.
2SMA&MACD and 2SMA&MACD&Bollinger perform on par with each other with minor differences. The average performance for 2SMA&MACD&Bollinger is higher than the 2SMA&MACD's by 0.07.

In order to understand why 2 SMA performs better in most of the cases we can see the statistics regarding the trades for the 2 best performing strategies.

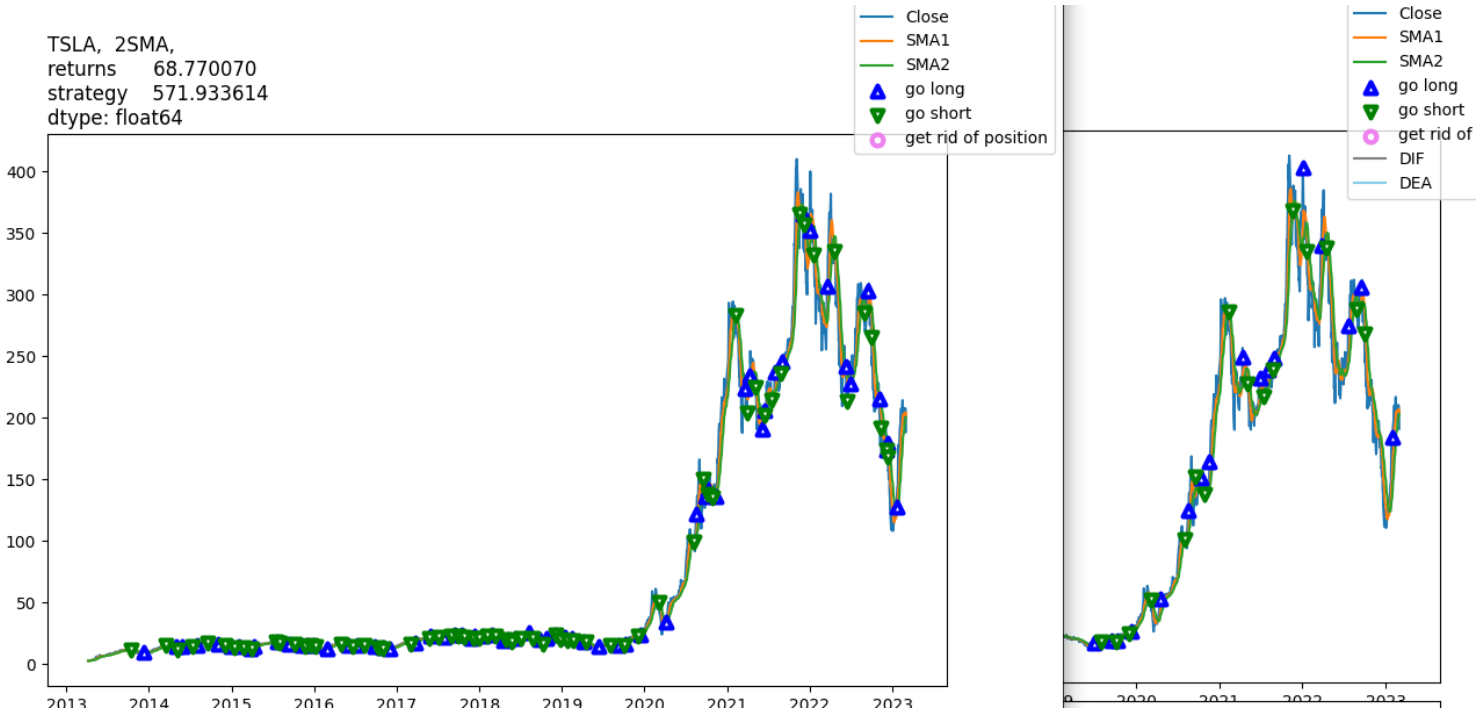
TICKER	2 SMA	2SMA & MACD & Bollinger
TSLA(automotive)	Strategy performace: 571.9336139882802 Percentage average profit per trade: 4.87562009045868 Number of trades: 127 Number of loss trades: 69 which constitutes to 54% of all trades Number of profitable trades: 58 which constitutes to 46% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -7.146239255510739 Average percentage profit per profitable trade: 19.177487243422306	Strategy performace: 96.55313812239983 Percentage average profit per trade: 5.777516663994199 Number of trades: 75 Number of loss trades: 43 which constitutes to 57% of all trades Number of profitable trades: 32 which constitutes to 43% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -6.981477211462153 Average percentage profit per profitable trade: 22.922414684138673
XOM(energy)	Strategy performace: 2.144772540112465 Percentage average profit per trade: 0.5032961061054723 Number of trades: 134 Number of loss trades: 74 which constitutes to 55% of all trades Number of profitable trades: 59 which constitutes to 44% of all trades Number of trades with no gain/loss: 1 which constitutes to 1% of all trades Average percentage loss per loss trade: -3.157238212956308 Average percentage profit per profitable trade: 5.103005186049153	Strategy performace: 1.1374051228487436 Percentage average profit per trade: 0.03580587156625452 Number of trades: 93 Number of loss trades: 58 which constitutes to 62% of all trades Number of profitable trades: 34 which constitutes to 37% of all trades Number of trades with no gain/loss: 1 which constitutes to 1% of all trades Average percentage loss per loss trade: -3.175580021446986 Average percentage profit per profitable trade: 5.51510550881138
CNX(energy)	Strategy performace: 0.057037797097771695 Percentage average profit per trade: -2.10991311315639 Number of trades: 150 Number of loss trades: 99 which constitutes to 66% of all trades Number of profitable trades: 51 which constitutes to 34% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -7.998763892454366 Average percentage profit per profitable trade: 9.321385458422034	Strategy performace: 0.0801850002389788 Percentage average profit per trade: -3.5059010925422935 Number of trades: 101 Number of loss trades: 73 which constitutes to 72% of all trades Number of profitable trades: 27 which constitutes to 27% of all trades Number of trades with no gain/loss: 1 which constitutes to 1% of all trades Average percentage loss per loss trade: -9.86362341655155 Average percentage profit per profitable trade: 13.553648113388574
UNH(healthcare)	Strategy performace: 0.1524869023485894 Percentage average profit per trade: -1.1988609667960772 Number of trades: 143 Number of loss trades: 97 which constitutes to 68% of all trades Number of profitable trades: 46 which constitutes to 32% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -4.077658319578838 Average percentage profit per profitable trade: 4.871646494506697	Strategy performace: 0.09771453661455828 Percentage average profit per trade: -1.9867104534870745 Number of trades: 117 Number of loss trades: 87 which constitutes to 74% of all trades Number of profitable trades: 30 which constitutes to 26% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -4.406620215585788 Average percentage profit per profitable trade: 5.031027856599192
JNJ(healthcare)	Strategy performace: 1.0895353694015903 Percentage average profit per trade: -0.029042670676303905 Number of trades: 132 Number of loss trades: 80 which constitutes to 61% of all trades Number of profitable trades: 52 which constitutes to 39% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -2.3203918416241303 Average percentage profit per profitable trade: 3.49610990001266	Strategy performace: 1.028183086858994 Percentage average profit per trade: -0.08846252325297083 Number of trades: 82 Number of loss trades: 51 which constitutes to 62% of all trades Number of profitable trades: 31 which constitutes to 38% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -2.5653450853431927 Average percentage profit per profitable trade: 3.9864087885728785
BA(industrial)	Strategy performace: 4.363575484712224 Percentage average profit per trade: 1.0586009018501035 Number of trades: 132 Number of loss trades: 82 which constitutes to 62% of all trades Number of profitable trades: 50 which constitutes to 38% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -3.8975609680446603 Average percentage profit per profitable trade: 9.186706368477516	Strategy performace: 4.261720938045797 Percentage average profit per trade: 1.643465856614551 Number of trades: 88 Number of loss trades: 52 which constitutes to 59% of all trades Number of profitable trades: 36 which constitutes to 41% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -4.211527605071887 Average percentage profit per profitable trade: 10.100678634606075

UNP(industrial)	Strategy performace: 0.4183003987709826 Percentage average profit per trade: -0.5429894618435942 Number of trades: 154 Number of loss trades: 103 which constitutes to 67% of all trades Number of profitable trades: 51 which constitutes to 33% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -3.2119611746059995 Average percentage profit per profitable trade: 4.847286742362834	Strategy performace: 0.37926919585498153 Percentage average profit per trade: -0.9841937712996645 Number of trades: 100 Number of loss trades: 68 which constitutes to 68% of all trades Number of profitable trades: 32 which constitutes to 32% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -3.7307544837389157 Average percentage profit per profitable trade: 4.852247742633745
JPM(financial)	Strategy performace: 0.27789054836336946 Percentage average profit per trade: -0.8366747293409945 Number of trades: 157 Number of loss trades: 100 which constitutes to 64% of all trades Number of profitable trades: 56 which constitutes to 36% of all trades Number of trades with no gain/loss: 1 which constitutes to 1% of all trades Average percentage loss per loss trade: -3.8167542948448765 Average percentage profit per profitable trade: 4.469955303177705	Strategy performace: 0.23833944509751864 Percentage average profit per trade: -1.3164656925883507 Number of trades: 111 Number of loss trades: 78 which constitutes to 70% of all trades Number of profitable trades: 33 which constitutes to 30% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -4.207805878835747 Average percentage profit per profitable trade: 5.517611111269134
TSP(financial)	Strategy performace: 6.384026923172899 Percentage average profit per trade: 5.4004584107204625 Number of trades: 21 Number of loss trades: 9 which constitutes to 43% of all trades Number of profitable trades: 12 which constitutes to 57% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -13.523898671276388 Average percentage profit per profitable trade: 19.5937262222181	Strategy performace: 17.068216512856015 Percentage average profit per trade: 15.406763241911825 Number of trades: 8 Number of loss trades: 4 which constitutes to 50% of all trades Number of profitable trades: 4 which constitutes to 50% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -10.10740143355138 Average percentage profit per profitable trade: 40.92092791737504
AAPL(technology)	Strategy performace: 3.6146059240853936 Percentage average profit per trade: 1.3188967335511323 Number of trades: 118 Number of loss trades: 73 which constitutes to 62% of all trades Number of profitable trades: 45 which constitutes to 38% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -4.027054833831756 Average percentage profit per profitable trade: 9.991218165083373	Strategy performace: 1.73875989445541 Percentage average profit per trade: 1.0014215049649327 Number of trades: 87 Number of loss trades: 50 which constitutes to 57% of all trades Number of profitable trades: 37 which constitutes to 43% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -5.321133847487625 Average percentage profit per profitable trade: 9.545415224495418
MSFT(technology)	Strategy performace: 1.2962048709443201 Percentage average profit per trade: 0.15239896127213762 Number of trades: 126 Number of loss trades: 74 which constitutes to 59% of all trades Number of profitable trades: 52 which constitutes to 41% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -3.277938546120056 Average percentage profit per profitable trade: 5.0340331064071835	Strategy performace: 0.3978066844527198 Percentage average profit per trade: -0.9655597435894485 Number of trades: 96 Number of loss trades: 66 which constitutes to 69% of all trades Number of profitable trades: 30 which constitutes to 31% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -3.8557350649552635 Average percentage profit per profitable trade: 5.392825963415345
NVDA(technology)	Strategy performace: 2.5357601983525875 Percentage average profit per trade: 0.856301565409127 Number of trades: 134 Number of loss trades: 79 which constitutes to 59% of all trades Number of profitable trades: 53 which constitutes to 40% of all trades Number of trades with no gain/loss: 2 which constitutes to 1% of all trades Average percentage loss per loss trade: -6.047501222916143 Average percentage profit per profitable trade: 11.17918879953204	Strategy performace: 1.1494546474840837 Percentage average profit per trade: 0.12380405124375539 Number of trades: 109 Number of loss trades: 72 which constitutes to 66% of all trades Number of profitable trades: 37 which constitutes to 34% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -6.296758226879924 Average percentage profit per profitable trade: 12.617871187051996

ALLT(technology)	Strategy performace: 0.3073291562359452 Percentage average profit per trade: -0.8887789222767608 Number of trades: 153 Number of loss trades: 100 which constitutes to 65% of all trades Number of profitable trades: 52 which constitutes to 34% of all trades Number of trades with no gain/loss: 1 which constitutes to 1% of all trades Average percentage loss per loss trade: -5.529692909994277 Average percentage profit per profitable trade: 8.018963767136215	Strategy performace: 0.7731221239581149 Percentage average profit per trade: -1.149514140048163 Number of trades: 97 Number of loss trades: 71 which constitutes to 73% of all trades Number of profitable trades: 25 which constitutes to 26% of all trades Number of trades with no gain/loss: 1 which constitutes to 1% of all trades Average percentage loss per loss trade: -5.5608130832984815 Average percentage profit per profitable trade: 11.33259429318081
WMT(retail)	Strategy performace: 0.9153749035767033 Percentage average profit per trade: -0.056947174059632885 Number of trades: 147 Number of loss trades: 90 which constitutes to 61% of all trades Number of profitable trades: 57 which constitutes to 39% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -2.5112908711254724 Average percentage profit per profitable trade: 3.818332347623272	Strategy performace: 0.831732185260629 Percentage average profit per trade: -0.23322435442471803 Number of trades: 89 Number of loss trades: 57 which constitutes to 64% of all trades Number of profitable trades: 32 which constitutes to 36% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -3.132377674510707 Average percentage profit per profitable trade: 4.9308924969784504
JMIA(retail)	Strategy performace: 8.611214924575492 Percentage average profit per trade: 1.4612181011230065 Number of trades: 43 Number of loss trades: 25 which constitutes to 58% of all trades Number of profitable trades: 18 which constitutes to 42% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -16.465500598974298 Average percentage profit per profitable trade: 26.359438517924822	Strategy performace: 10.901085281515444 Percentage average profit per trade: 2.0122919309140364 Number of trades: 22 Number of loss trades: 10 which constitutes to 45% of all trades Number of profitable trades: 12 which constitutes to 55% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -28.19516976337919 Average percentage profit per profitable trade: 27.18517667615839
CLF(materials)	Strategy performace: 2.5305789443856246 Percentage average profit per trade: 1.1853994514845212 Number of trades: 125 Number of loss trades: 76 which constitutes to 61% of all trades Number of profitable trades: 49 which constitutes to 39% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -10.285120807044128 Average percentage profit per profitable trade: 18.976410464712632	Strategy performace: 0.46689671571498326 Percentage average profit per trade: -0.3322816362991026 Number of trades: 89 Number of loss trades: 54 which constitutes to 61% of all trades Number of profitable trades: 35 which constitutes to 39% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -12.882732846210471 Average percentage profit per profitable trade: 19.031271658992726
ABEV(consumer goo	Strategy performace: 0.6696061350956499 Percentage average profit per trade: -0.43220466427551857 Number of trades: 134 Number of loss trades: 83 which constitutes to 62% of all trades Number of profitable trades: 48 which constitutes to 36% of all trades Number of trades with no gain/loss: 3 which constitutes to 2% of all trades Average percentage loss per loss trade: -5.109935389264441 Average percentage profit per profitable trade: 7.629358589500609	Strategy performace: 0.40485886115948233 Percentage average profit per trade: -1.2972298282045915 Number of trades: 89 Number of loss trades: 56 which constitutes to 63% of all trades Number of profitable trades: 32 which constitutes to 36% of all trades Number of trades with no gain/loss: 1 which constitutes to 1% of all trades Average percentage loss per loss trade: -6.094755591340919 Average percentage profit per profitable trade: 7.057901825152587
FUBO(entertainment)	Strategy performace: 4.1687368216012946 Percentage average profit per trade: 1.4229037284761554 Number of trades: 49 Number of loss trades: 32 which constitutes to 65% of all trades Number of profitable trades: 17 which constitutes to 35% of all trades Number of trades with no gain/loss: 0 which constitutes to 0% of all trades Average percentage loss per loss trade: -13.691433478223571 Average percentage profit per profitable trade: 29.873420823440345	Strategy performace: 3.932446909194653 Percentage average profit per trade: 2.415670607361855 Number of trades: 27 Number of loss trades: 15 which constitutes to 56% of all trades Number of profitable trades: 11 which constitutes to 41% of all trades Number of trades with no gain/loss: 1 which constitutes to 4% of all trades Average percentage loss per loss trade: -17.887746219819704 Average percentage profit per profitable trade: 30.321754517824157

The initial observation is that the number of trades for 2SMA is greater for all stocks examined. Moreover, the number of loss trades overall is higher for 2SMA&MACD&Bollinger, and the average loss per loss trade is also greater compared to 2SMA. However, it is worth noting that the percentage gain per profitable trade for 2SMA&MACD&Bollinger is generally higher than that of 2SMA. Overall, it appears that the trades executed by 2SMA&MACD&Bollinger are less frequent, with their overall gain/loss figures being greater than those of 2SMA. It seems that 2SMA is more responsive to changes in trends and cuts gains/losses more quickly, resulting in a higher number of trades and lower average profits per trade.

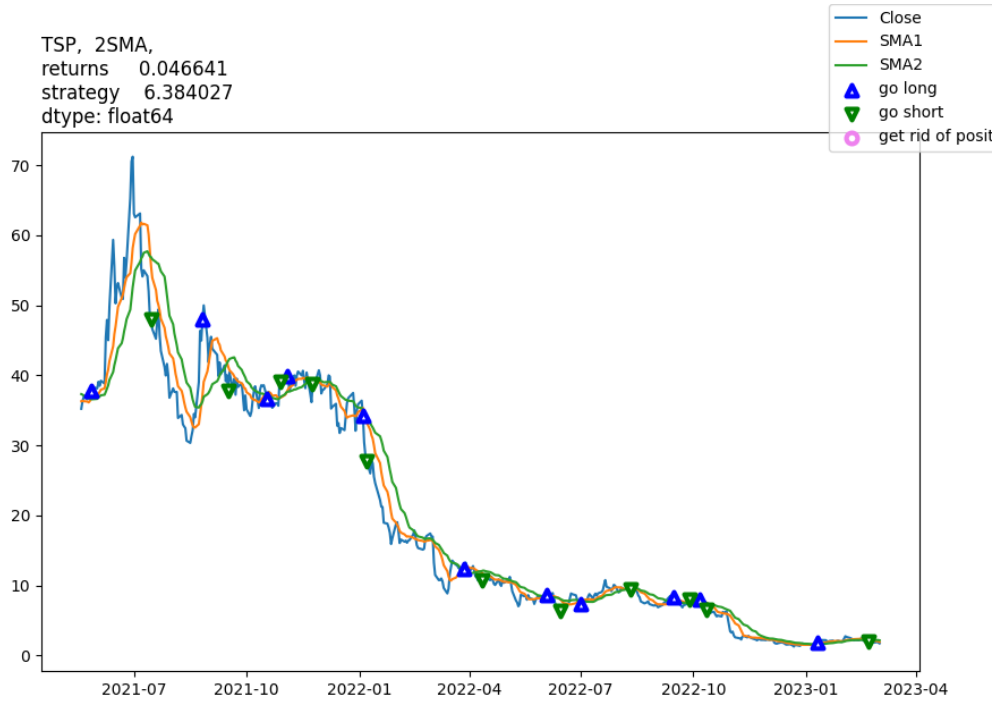
As an illustration of the strategies' performance, the trade charts for TSLA ticker are presented. The graphs below depict the signals generated by the strategies. The front chart displays 2SMA, and the one behind portrays the behavior of 2SMA&MACD&Bollinger.



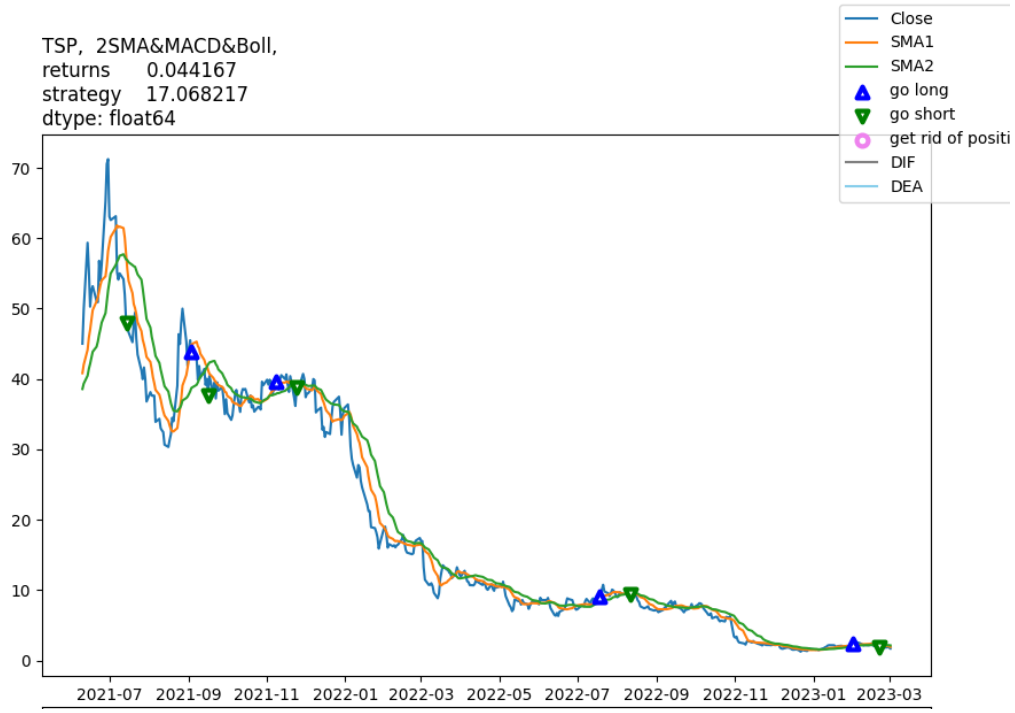
When examining the charts, it is apparent that MACD has a dampening effect on the responsiveness to changes in trends. This is particularly evident when observing the most recent and significant drop in TSLA price. 2SMA's reaction was timed quite closely to the bottom line, while 2SMA&MACD&Bollinger responded much later, resulting in a smaller profit.

Based on the strategies' outcomes and charts, it can be concluded that prioritising more responsive models is preferable to ones that stagnate and produce too few buy/sell signals. This observation emphasises the importance of regularly evaluating and adjusting the parameters of trading strategies to improve their performance in dynamic market conditions.

There is one interesting case with a TSP stock and the amount of trades that were made during the 10 years of backtest.



With 2SMA, the number of trades executed was 21, whereas with 2SMA&MACD&Bollinger, it was only 8. However, the 8 trades yielded a considerably higher profit than the 21 trades made by 2SMA.



This scenario highlights that occasionally, less responsive models can outperform those that react immediately to market movements. Prior to deciding which model to utilise for a specific stock, an in-depth analysis should be conducted with various parameters to determine which parameters are most effective for the given case.

2.3. Bollinger bands experiments

We can see from the previous section that 2SMA&MACD and 2SMA&MACD&Bollinger have very similar outcomes. It seems that the Bollinger bands indicator does not improve the performance and therefore some further experiments must be performed in order to find optimal thresholds for these bands.

The results in the table below are gathered from 10 years of data starting from 23.03.2023 and show how the performance changes when Bollinger bands value is adjusted:

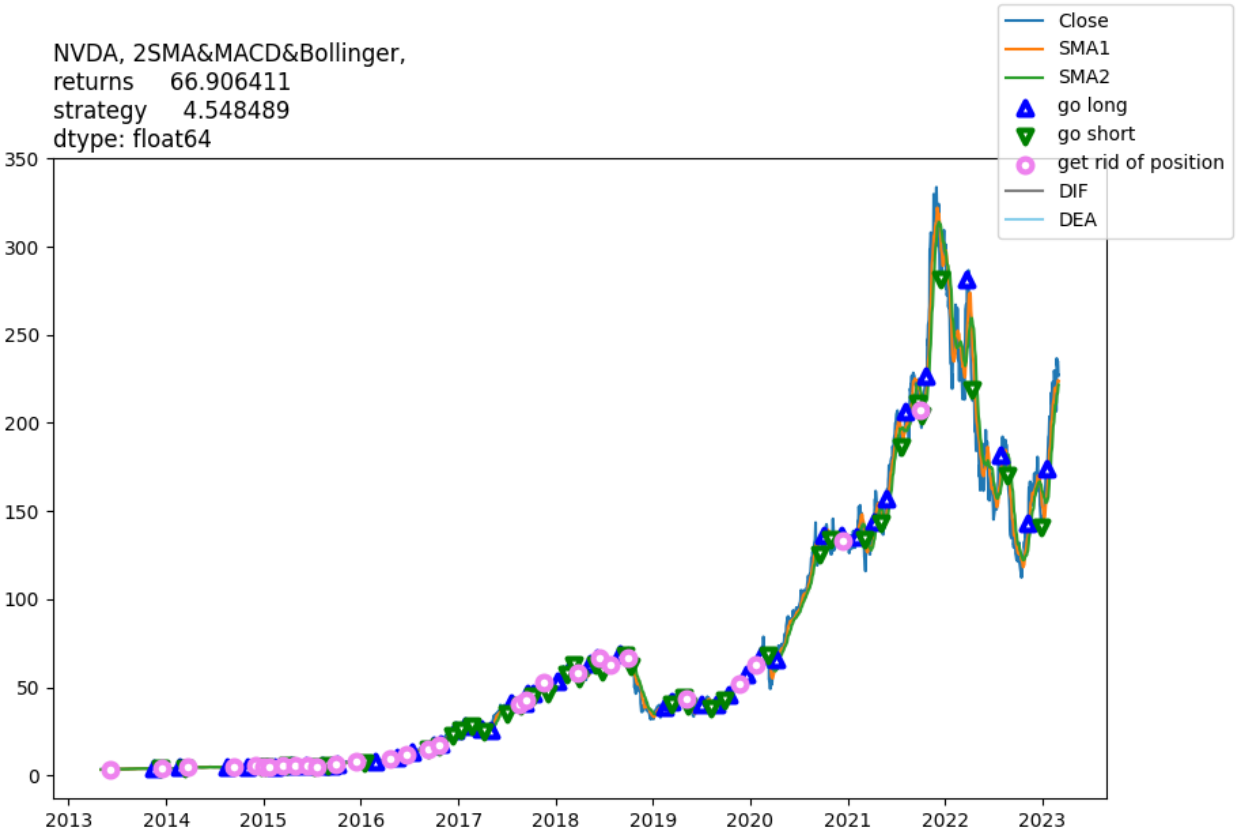
TICKER	MACD	1	2	3	4	5	6	7	8	9	10	stocks for which bollinger bands increased performance when compared to just 2SMA&MACD
TSLA(automotiv	95.45528975	88.62712501	88.62712501	88.62712501	88.62712501	74.45803724	75.67154386	69.65747581	64.41215044	63.47985393	56.95708667	
XOM(energy)	1.137405123	1.137405123	1.153433799	1.020790061	0.9163791181	0.9259979116	1.197337308	1.457573691	1.297351171	1.110153803	1.407480141	
CNX(energy)	0.07730064763	0.07994464119	0.07994464119	0.07994464119	0.07434772588	0.07916117751	0.06825223905	0.07027397557	0.06755419858	0.04132940763	0.05220270036	
UNH(healthcare	0.09771453661	0.09881781535	0.09501365191	0.09061927726	0.0832268967	0.1347109444	0.1864440397	0.305946425	0.4029674808	0.5521074032	0.5593027214	
JNJ(healthcare)	1.015428592	1.013886051	0.9717452759	0.8290758132	1.431154966	0.8682417566	0.7090368291	0.9114539166	0.8467240434	0.8924539998	0.7868270952	
BA(industrial)	4.261720938	4.212101351	4.212101351	3.848183698	4.057315388	2.68125668	2.772777048	2.157774489	2.20840182	2.418582342	3.376100637	
UNP(industrial)	0.3789347927	0.378960483	0.378960483	0.379930707	0.2811101816	0.3724734692	0.5547951806	0.7938759713	0.775601709	0.8835942852	1.028519237	
JPM(financial)	0.2383394451	0.2383394451	0.2383394451	0.2475901094	0.234203231	0.382271567	0.4534627525	0.475272149	0.8767324018	0.934808272	1.171874914	
TSP(financial)	16.89418522	14.72143207	14.72143207	14.72143207	14.72143207	14.72143207	14.72143207	14.72143207	14.72143207	14.72143207	14.72143207	
AAPL(technolog	1.741633221	1.844511074	1.844511074	1.74580193	1.96218264	1.706171817	1.932910127	2.243366482	1.09403912	1.229525499	0.6495208727	
MSFT(technolog	0.4128869357	0.3874376005	0.3961257049	0.3749951085	0.2770818884	0.2674164034	0.2642561846	0.3868228346	0.4943880716	0.4679624192	0.9349473001	
NVDA(technolog	1.188600124	1.131666473	1.131666473	1.131666473	1.147359392	1.196982071	2.074808538	3.499056783	4.548489415	2.581063142	1.720115985	
ALLT(technology	0.773122124	0.773122124	0.773122124	0.8228673668	0.8383982248	1.366467071	1.510011176	1.4137349	1.633567214	1.175268833	0.6122205097	
WMT(retail)	0.8317321853	0.8317321853	0.8081469509	0.7786487966	0.5915310942	0.6123438212	0.8363619002	0.6580447272	0.7285601207	1.01398768	0.8926311421	
JMIA(retail)	10.90108528	10.90108528	10.90108528	10.90108528	10.90108528	10.90108528	10.90108528	10.90108528	10.90108528	10.90108528	10.90108528	
CLF(materials)	0.4438337694	0.5348043478	0.5348043478	0.5348043478	0.5348043478	0.5348043478	0.5348043478	0.5348043478	0.6340396455	0.57491976	0.7208145208	
ABEV(consumer	0.4048588612	0.4048588612	0.4048588612	0.4048588612	0.3770210301	0.5383062763	0.5802553496	0.5837095827	0.9314836561	0.6652500612	0.6476215738	
FUBO(entertainr	3.932446909	3.610701389	3.610701389	3.610701389	3.610701389	3.610701389	3.610701389	3.610701389	3.610701389	3.610701389	3.610701389	

In order to compare the outcomes to the other strategies as well a below table is provided.

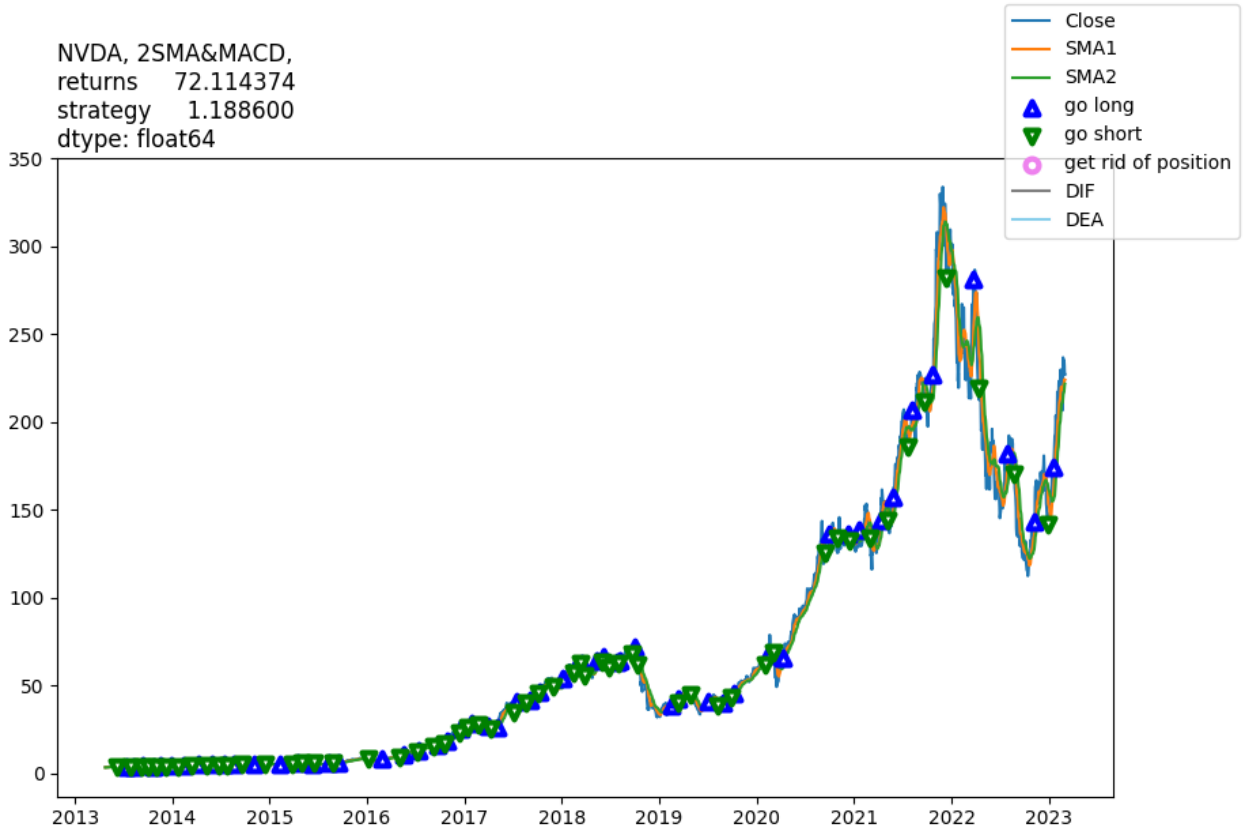
TICKER	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD	2SMA & MACD	3 SMA & MACD	max value
TSLA(automotiv	571.933614	0.7561796011	95.45528975	44.891894	96.55313812	4.049380369	571.933614
XOM(energy)	2.14477254	0.7933811056	1.137405123	1.643854498	1.098492751	0.8488961549	2.14477254
CNX(energy)	0.0570377971	0.3311215727	0.07730064763	0.04105009074	0.08018500024	0.29186865	0.3311215727
UNH(healthcare	0.1524869023	0.4918482382	0.09771453661	0.09283819998	0.0938999767	0.08105042357	0.4918482382
JNJ(healthcare)	1.089535369	0.3215754095	1.015428592	0.8910210632	0.9466200273	0.6391933261	1.089535369
BA(industrial)	4.363575485	1.306742751	4.261720938	3.513805035	4.261720938	2.629087981	4.363575485
UNP(industrial)	0.4183003988	0.660515196	0.3789347927	0.3249881685	0.3792691959	0.2238891157	0.660515196
JPM(financial)	0.2778905484	1.579714197	0.2383394451	0.2834758345	0.2383394451	0.4641200198	1.579714197
TSP(financial)	6.384026923	2.196030419	16.89418522	9.472141371	17.06821651	14.16056793	17.06821651
AAPL(technolog	3.614605924	1.118345306	1.741633221	3.557348887	1.738759894	1.141617562	3.614605924
MSFT(technolog	1.296204871	1.158025472	0.4128869357	0.3938694003	0.4047848997	0.1881704814	1.296204871
NVDA(technolog	2.535760198	2.769212817	1.188600124	1.243082783	1.149454647	0.1327202623	2.769212817
ALLT(technology	0.3073291562	0.2712789931	0.773122124	0.5355671983	0.773122124	1.192727143	1.192727143
WMT(retail)	0.9153749036	1.134092223	0.8317321853	0.7224954866	0.80501305	0.7841127572	1.134092223
JMIA(retail)	8.611214925	6.906024051	10.90108528	8.182383305	10.90108528	7.557517769	10.90108528
CLF(materials)	2.530578944	4.937359716	0.4438337694	0.816898528	0.4668967157	6.100759407	6.100759407
ABEV(consumer	0.6696061351	0.4592077446	0.4048588612	0.6223945455	0.4048588612	0.7648169754	0.7648169754
FUBO(entertainr	4.168736822	3.190287819	3.932446909	3.185498164	3.932446909	2.790491438	4.168736822

Upon comparing the tables, it is evident that some of the stocks have reached new high performances with adjusted Bollinger Bands. For instance, NVDA's latest performance with a

Bollinger Bands indicator at value 8 resulted in a score of 4.55, which is 1.78 higher than its previous best performance (reached with a 3SMA strategy - look at the table above).



Below you can find a 2SMA&MACD strategy behaviour, which at the first glance is similar to 2SMA&MACD&Bollinger, but theyt yield completely different profits with 2SMA&MACD standing at 1.19 and the 2SMA&MACD&Bollinger at 4.55:



Additionally, there are a few other stocks that have achieved their new best performances, such as UNH, JNJ, UNP, ALLT, ABEV.

One of the reasons behind such results when Bollinger Bands are incorporated is that during periods of stagnation, the algorithm refrains from making trades. This helps to avoid losing money during times when the price movements change rapidly, but the changes are not long-lasting. The algorithm cannot keep up with them. By not placing any trades, the strategy prevents any monetary loss resulting from mistimed trades.

2.4. Best performing stocks

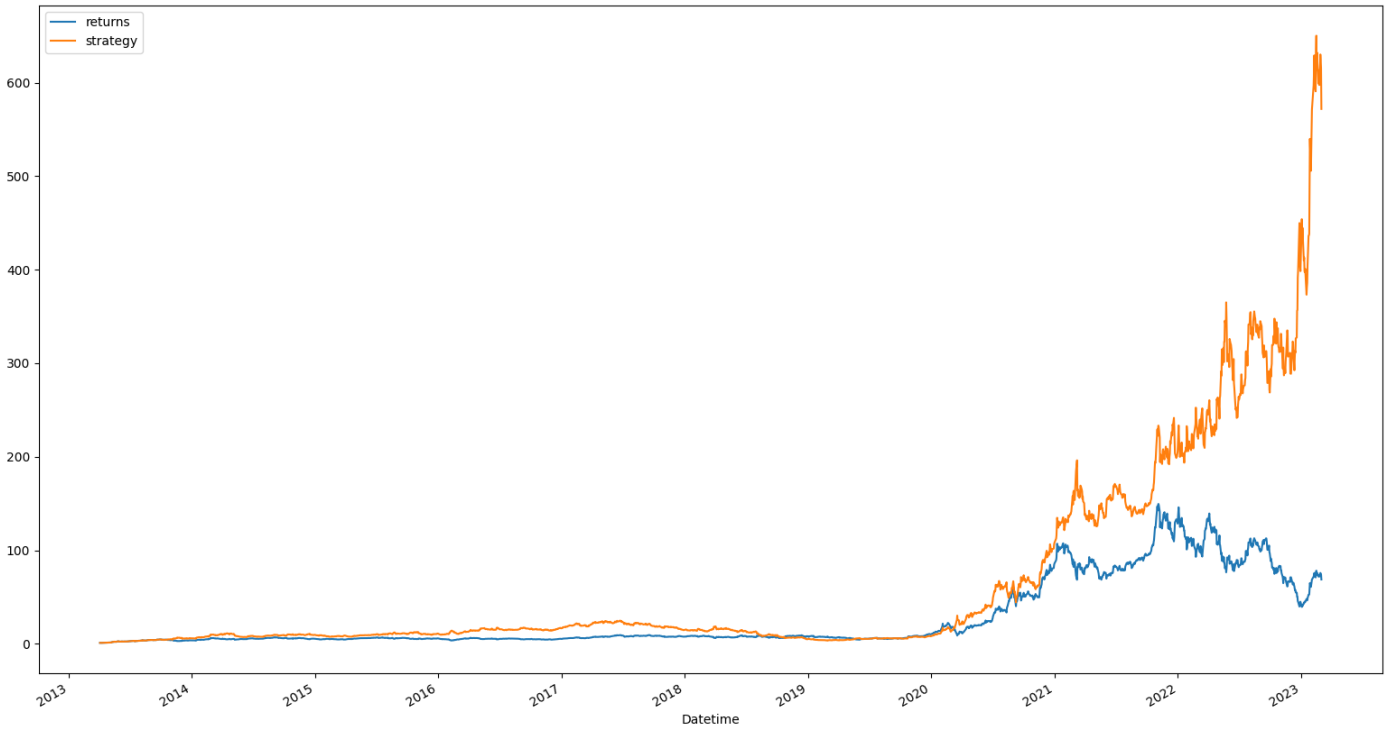
2.3.1. TSLA

2.3.1.1. Analysis

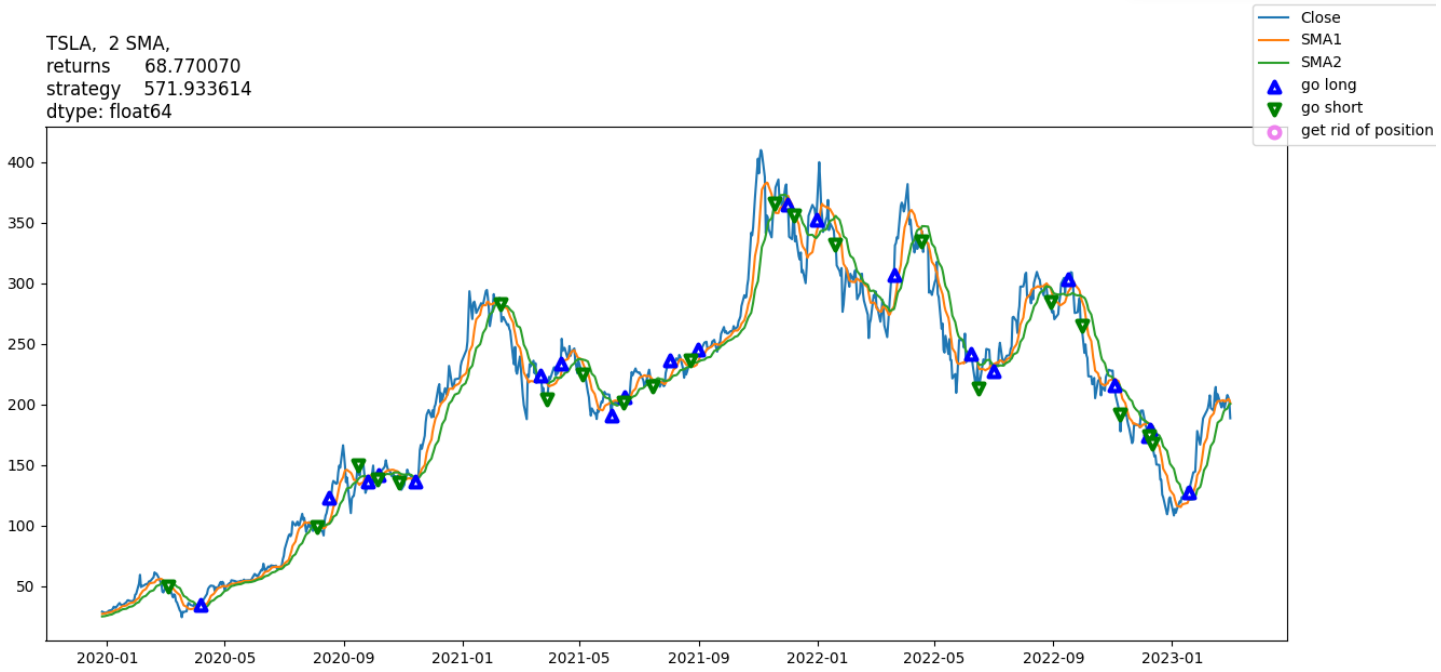
Below are charts displaying the performance of the top two and bottom two performers.

TSLA

The TSLA stock yielded the highest profit of 57193%. The figure below illustrates the performance of the strategy over time, indicating a clear period of stagnation during the majority of the backtesting period. Prior to 2021, there were slight fluctuations in performance, but from that point on, there was a substantial surge. This behaviour can be readily explained through graphs showcasing the 10-year price movement of TSLA stock, as well as the signals produced by the 2SMA strategy.



Below there is a close up part of the figure above.



The above graph illustrates the moments when the algorithm produced long/short signals. The strategy's performance is exceptional, with the majority of trends being capitalized on with good profitability. The trade timing is also optimal, suggesting that the SMA of 10 and 20 is well-suited for TSLA's price movements. The trade statistics verify this strong performance, as although 54% of trades yielded losses, the profits from each successful trade more than compensated for this.

```
Strategy performace:                  571.9336139882802
Percentage average  profit per trade: 4.87562009045868
Number of trades:                     127
Number of loss trades:               69 which constitutes to 54% of all trades
Number of profitable trades:         58 which constitutes to 46% of all trades
Number of trades with no gain/loss: 0 which constitutes to 0% of all trades
Average percentage loss per loss trade:          -7.146239255510739
Average percentage profit per profitable trade: 19.177487243422306
```

TSLA was the sole stock that yielded enormous profits when compared to the performances of other tickers. One possible reason for this could be the considerable volatility of the stock over the past three years. The price fluctuations were rapid and significant, creating numerous opportunities for the strategy to capitalise on. The circumstances of sharp rises and drops allowed for efficient collaboration between the two SMAs.

2.3.1.2. Confirming the findings

To ensure that the strategy's performance is not overfit, it's a good practice to split the data into a training set and a test set. The training set is used to find the optimal Simple Moving Average (SMA), while the test set is used to evaluate the performance of the chosen SMA.

To test the optimal second SMA, a training set containing six years of daily data is used to find the best SMA (where SMA1=10 and SMA3=60). The results are then applied to the test set (comprises 4 years of data) to evaluate its performance.

The results from the training set(the darker shade of purple shows the SMAs which scored the highest performance):

SMA2=15	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	max
TSLA(automotiv	0.9951114585	0.6998118126	2.332941656	2.487841603	0.6560925314	2.487841603
SMA2=20	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	3.688413442	0.5091067646	7.961209954	6.457540761	0.8161266002	7.961209954
SMA2=30	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	2.495254386	0.6294264241	3.175118706	1.482676192	0.4679532556	3.175118706
SMA2=40	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	2.626481377	0.2713071972	2.626796863	1.021518027	0.358663002	2.626796863
SMA2=50	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	1.675647781	0.1245445504	1.455921478	1.141835841	0.2037714012	1.675647781
SMA2=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	0.8332946053	1	1.096245876	0.7354913043	0.3140880223	1.096245876

We can see that the optimal second SMA (SMA2) for TSLA is 20 (SMA2=20).

The results from the test set(the darker shade of purple shows the SMAs which scored the highest performance):

SMA2=15	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	max
TSLA(automotiv	61.66270081	0.8115879706	10.10373058	8.446351084	2.749250605	61.66270081
SMA2=20	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	146.5566693	0.9604938932	11.03178858	8.248470122	3.208555516	146.5566693
SMA2=30	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	25.27467599	2.446163821	7.13808942	6.292479538	2.392582899	25.27467599
SMA2=40	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	8.065303466	2.015680607	6.065847772	4.068285794	3.429750076	8.065303466
SMA2=50	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	6.370358349	4.779733772	3.525756771	2.541478328	2.185589703	6.370358349
SMA2=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
TSLA(automotiv	2.727313182	1	2.115928418	1.877329258	0.06744503155	2.727313182

Based on the results, it's clear that the second Simple Moving Average (SMA) of 20 produced the best results for TSLA in the test set.

Overall, we can confidently conclude that the results are not overfit. If one had chosen the optimal parameters four years ago and continued trading with the same parameters until the last date point in the test set (February 3rd, 2023), it would still have been the best trading choice as it would yield the highest performance when compared to other SMA2 values.

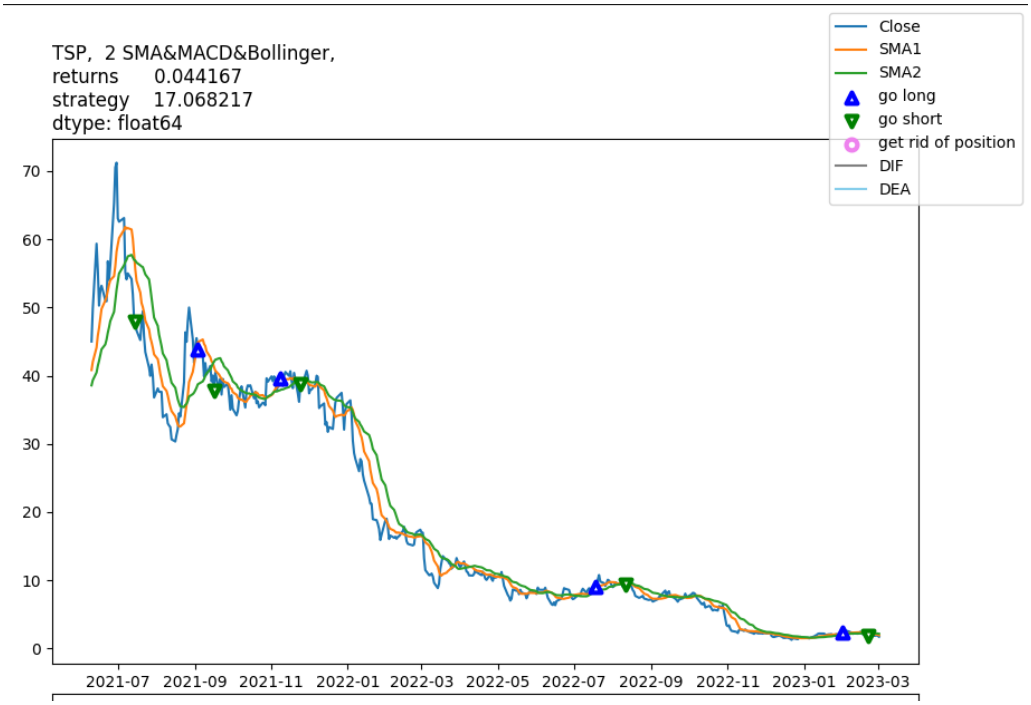
2.3.2. TSP

2.3.2.1. Analysis

TSP

As mentioned before, when 2SMA&MACD&Bollinger was tested against TSP it achieved a great performance, the second best score in all the performances of chosen strategies and stocks. TSP is a fairly new stock, it appeared on the financial market in April 2021. Its performance of around 1700% was built up in only 2 years, and such a score for such a short period of time is exceptional.

Upon closer examination of the price and trades chart, it becomes apparent that the 2SMA&MACD&Bollinger strategy outperforms the 2SMA strategy alone. between November 2021 and July 2022, there were numerous instances of SMAs crossing over each other. Since the 2SMA strategy relies solely on these crossovers to determine position, there were likely many losing trades during this period. However, the addition of MACD to the strategy provided a crucial advantage. MACD is a trend-following momentum indicator that helps to confirm changes in price direction. By using MACD alongside SMAs, there is a greater confidence in position decisions and it helps with avoiding some of the false signals that may have resulted in losses when using only SMAs.



```
Strategy performace:                  17.068216512856015
Percentage average  profit per trade: 15.406763241911825
Number of trades:                     8
Number of loss trades:               4 which constitutes to 50% of all trades
Number of profitable trades:         4 which constitutes to 50% of all trades
Number of trades with no gain/loss: 0 which constitutes to 0% of all trades
Average percentage loss per loss trade:          -10.10740143355138
Average percentage profit per profitable trade: 40.92092791737504
```

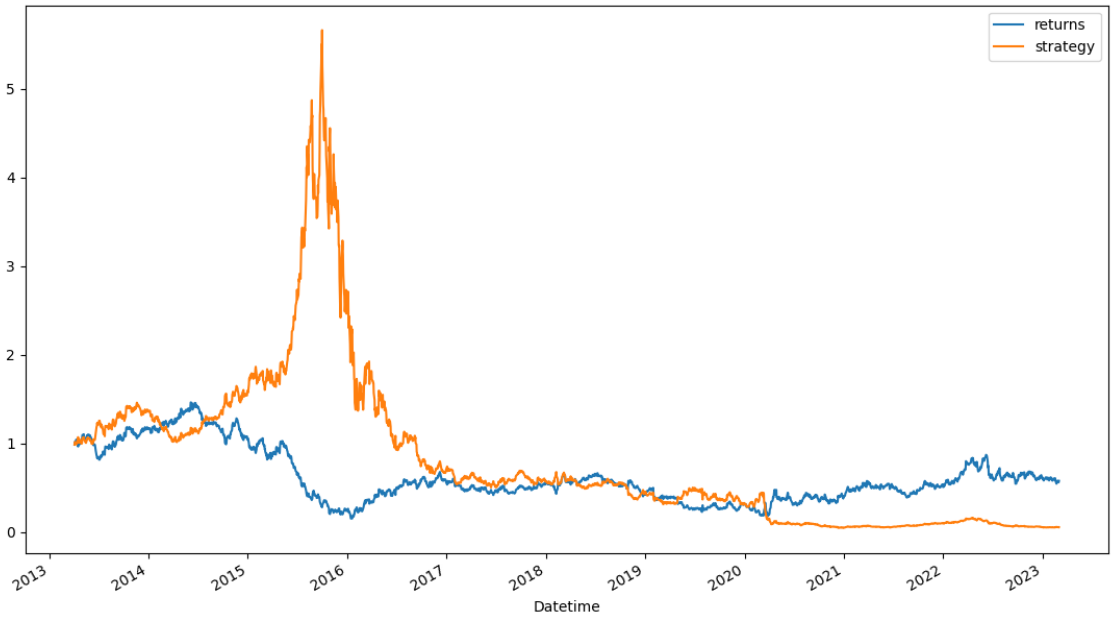
2.5. Worst performing stocks

2.4.1. CNX

2.4.1.1. Analysis

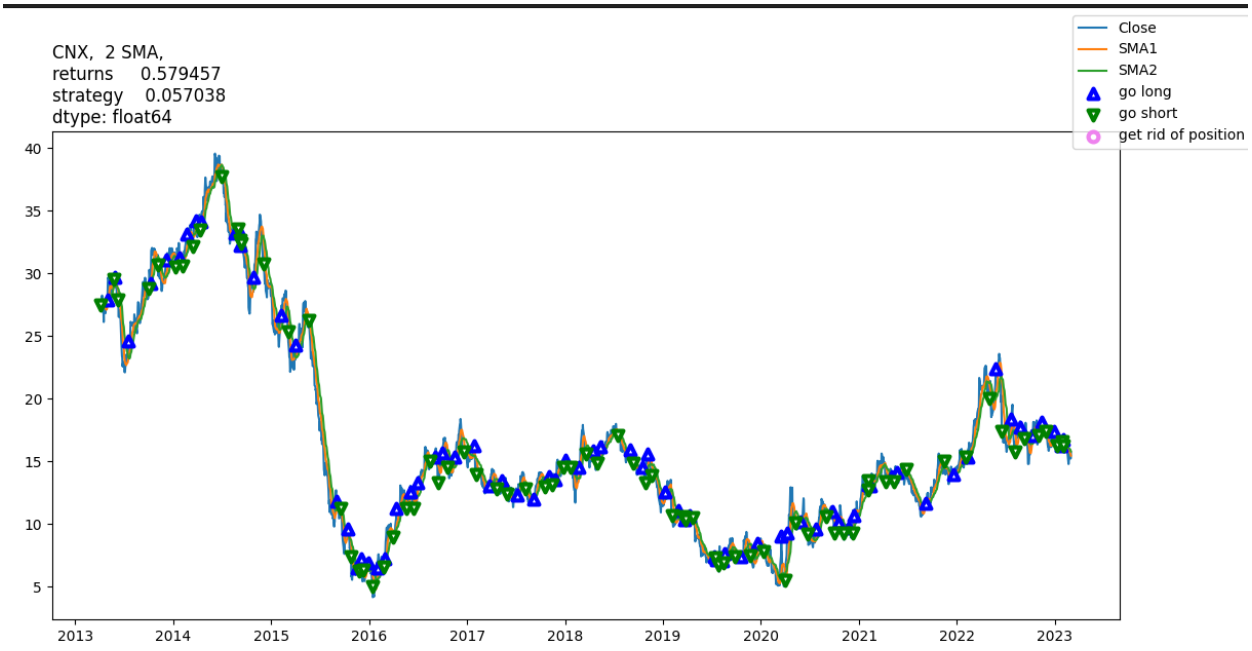
CNX

One of the worst performances was found to be for CNX - an energy stock. The strategy 2SMA scored 0.057 which accounts for 94.3% loss of initial investment.
The cumulative performance over the years looks as follows:



Between the years 2015 to 2016, the performance of the strategy was commendable, reaching a profit of approximately 550%. However, from 2016 onwards, the performance deteriorated drastically, leading to a loss of almost all invested funds. The graph is intriguing as it highlights

that the strategy was in momentum until 2016, after which a shift in price movement seemingly occurred, resulting in a significant drop in performance. To delve deeper into the matter, it would be beneficial to examine a graph illustrating the prices and trades.



The graph above explains the behaviour of the cumulative strategy performance. The peak that was observed in the previous graph can be justified by the significant and sudden drop in CNX price from around mid 2015 to 2016. During this period, the price plummeted from around $25 to $5, and a short position was maintained. From 2016 onwards, there seems to be considerable confusion in the trades. The timing of trades is not optimal, and it is evident that the strategy is excessively responsive to changes in prices.
While there is potential to exploit stock volatility, it is necessary to incorporate different parameters.

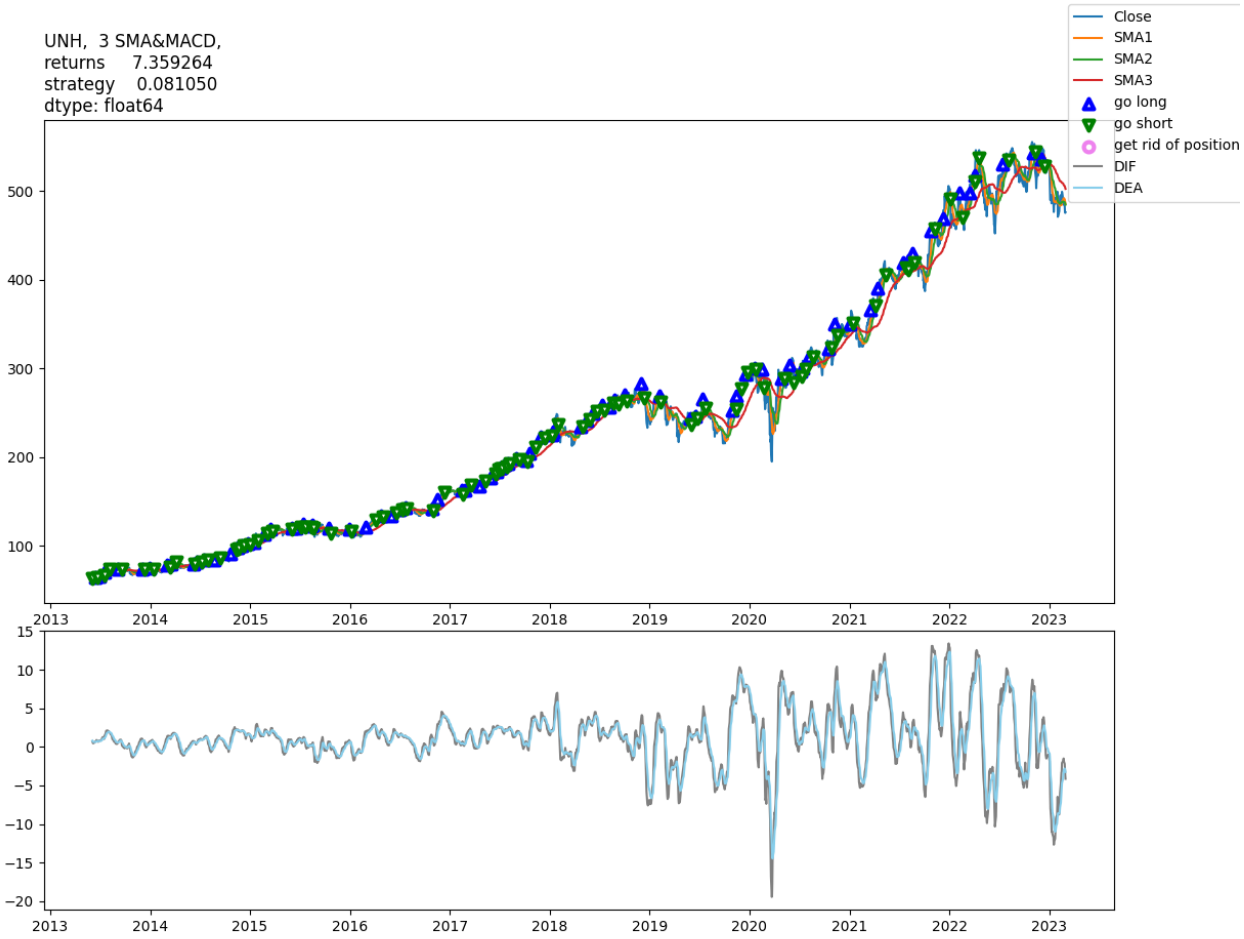
```
Strategy performace:                  0.057037797097771695

Percentage average  profit per trade: -2.10991311315639

Number of trades:                     150

Number of loss trades:                99 which constitutes to 66% of all trades

Number of profitable trades:          51 which constitutes to 34% of all trades

Number of trades with no gain/loss: 0 which constitutes to 0% of all trades

Average percentage loss per loss trade:          -7.998763892454366

Average percentage profit per profitable trade: 9.321385458422034
```

2.4.2. UNH

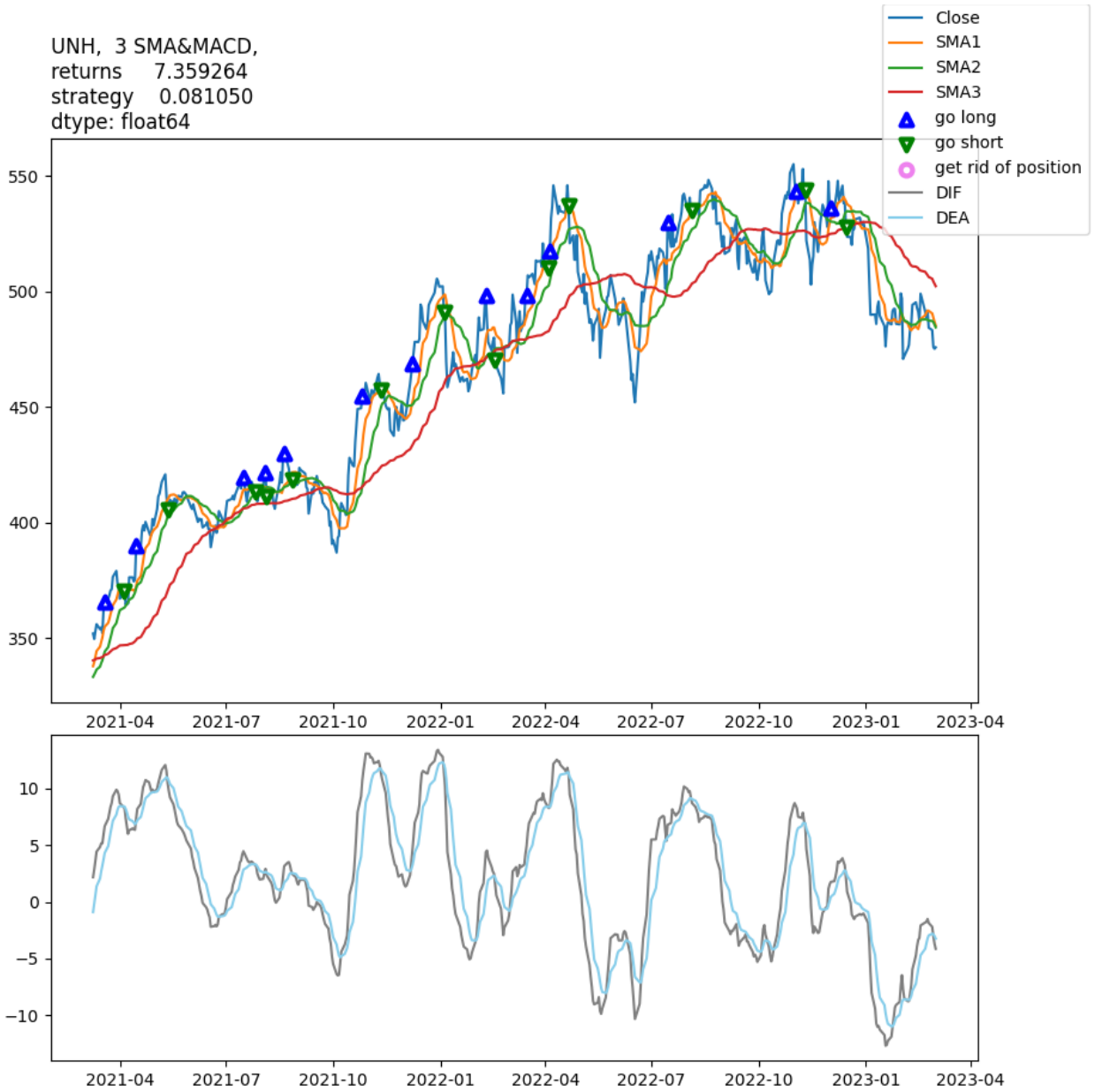
2.4.2.1. Analysis

UNH

The second-worst performing case was for UNH with a strategy 3SMA&MACD and a performance of 0.08, indicating a loss of 92%. Upon examining the price chart for the past 10 years, it is evident that there was an overall upward trend, with the price rising from around $50 to $500. This type of trend would be ideal for SMA-based strategies as the upward trend is clearly defined. However, looking at the chart below, it is apparent that plenty of trades were made, indicating that the algorithm was excessively responsive to price changes.

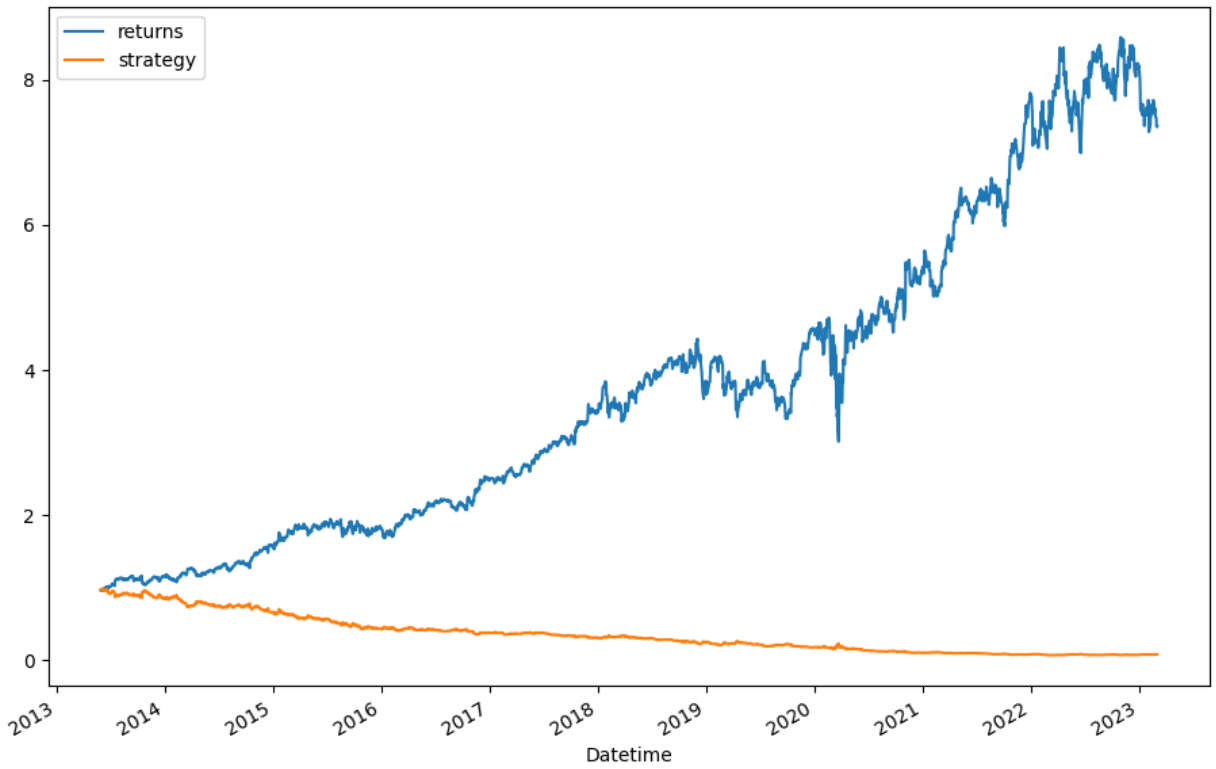


A close up chart of the figure above is shown below.



It is noticeable that most of the trades bring loss, and the trade statistics confirm this observation. It turns out 71% of the trades brought loss.

The cumulative performance:



Upon further examination, it was revealed that the strategy had a higher frequency of loss trades (71%) as compared to profitable ones (28%). Furthermore, the average loss per trade was found to be approximately 50% greater than the average profit per profitable trade. These metrics contributed to an average percentage loss of 1.5% per trade.

```
Strategy performace:                  0.08105042357056762
Percentage average  profit per trade: -1.5216065489885038
Number of trades:                     172
Number of loss trades:                122 which constitutes to 71% of all trades
Number of profitable trades:          49 which constitutes to 28% of all trades
Number of trades with no gain/loss: 1 which constitutes to 1% of all trades
Average percentage loss per loss trade:          -2.9171933456699057
Average percentage profit per profitable trade: 1.9220665662388952
```

2.5.2.2. Improving the performance

To improve the performance for UNH, an experiment was conducted to find the optimal second and third Simple Moving Averages (SMA2, SMA3). The experiment involved using a training set containing six years of daily data to determine the best SMAs (with SMA1=10). The results obtained were then applied to a test set consisting of four years of data to evaluate the performance.

The results for the training set are as follows (the darker shade of purple shows the SMAs which scored the highest performance):

SMA2=15,SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD	2SMA & MACD & Bollinger	max
UNH(healthcare)	0.3919908115	0.8629867238	0.2176120202	0.7656396329	0.1641490409	0.8629867238
SMA2=20,SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.3837504365	1.095889744	0.3556137335	0.7781741423	0.231327389	1.095889744
SMA2=30,SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.7040408694	1.105993592	0.5357164257	0.7240813951	0.1987303298	1.105993592
SMA2=40,SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.7264930367	1.365469183	0.599084137	0.7348100132	0.205543634	1.365469183
SMA2=50,SMA3=70	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.7227977484	2.449510054	0.661268142	0.7314819853	0.242401623	2.449510054
SMA2=60,SMA3=100	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.6993534828	2.29138447	0.6846975201	0.7501435883	0.2065329032	2.29138447

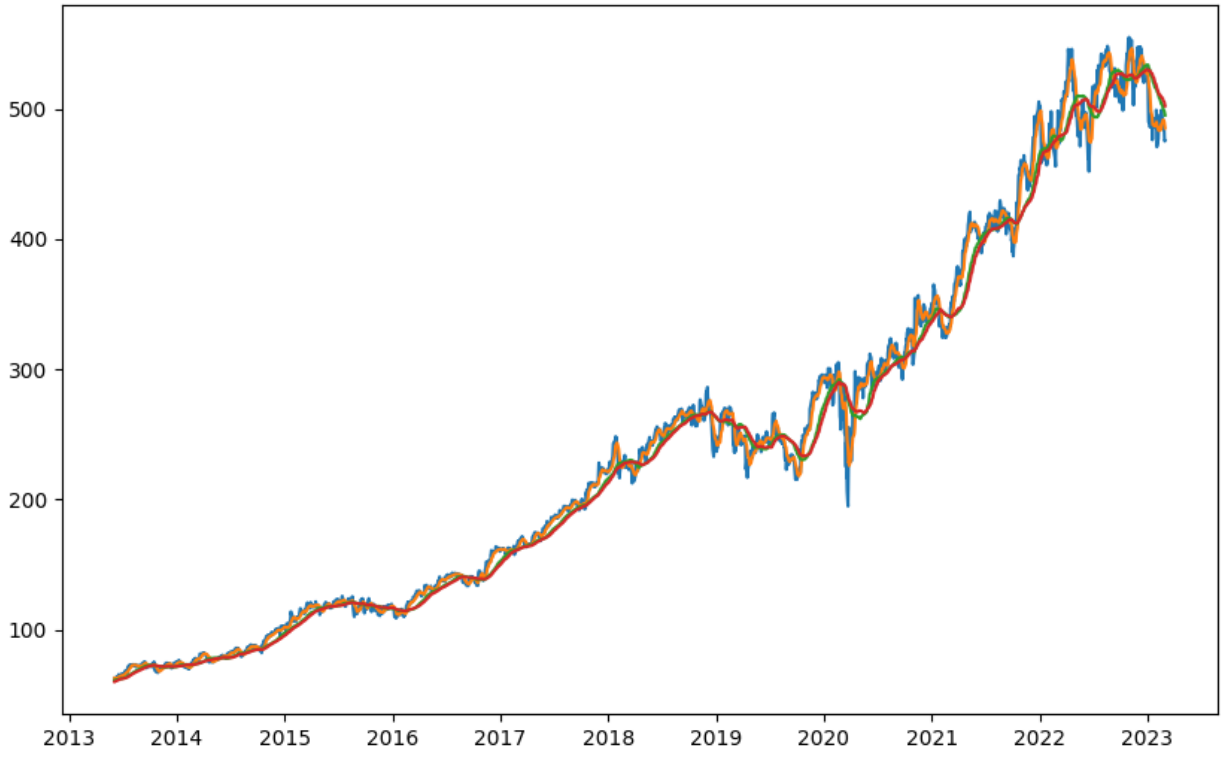
As shown in the table, the new results obtained from the training set are significantly better than those presented in the previous section. The best outcome achieved in the current experiment was 2.45 with SMA2=50 and SMA3=70. However, to ensure that these results are not overfit, we need to evaluate the performance on the test set.

The results for the test set(the darker shade of purple shows the SMAs which scored the highest performance):

SMA2=15, SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	max
UNH(healthcare)	0.4299089258	0.5583210915	0.2536188967	0.6544631939	0.3466533576	0.6544631939
SMA2=20, SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.4232782354	0.4777538599	0.2408976549	0.7438919231	0.3465990509	0.7438919231
SMA2=30, SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.5317334641	0.4032844162	0.4232860485	0.7734098558	0.3094258298	0.7734098558
SMA2=40, SMA3=60	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.5041957955	0.6728460079	0.4673681997	0.7578118335	0.3802292805	0.7578118335
SMA2=50, SMA3=70	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.6152946134	0.3713913072	0.6240583338	0.7678445662	0.4459109988	0.7678445662
SMA2=60, SMA3=100	2 SMA	3 SMA	2 SMA & MACD	2SMA & MACD & ROC	2SMA & MACD & Bollinger	0
UNH(healthcare)	0.6772269713	0.9080282713	0.6719538346	0.8343349197	0.6231282899	0.9080282713

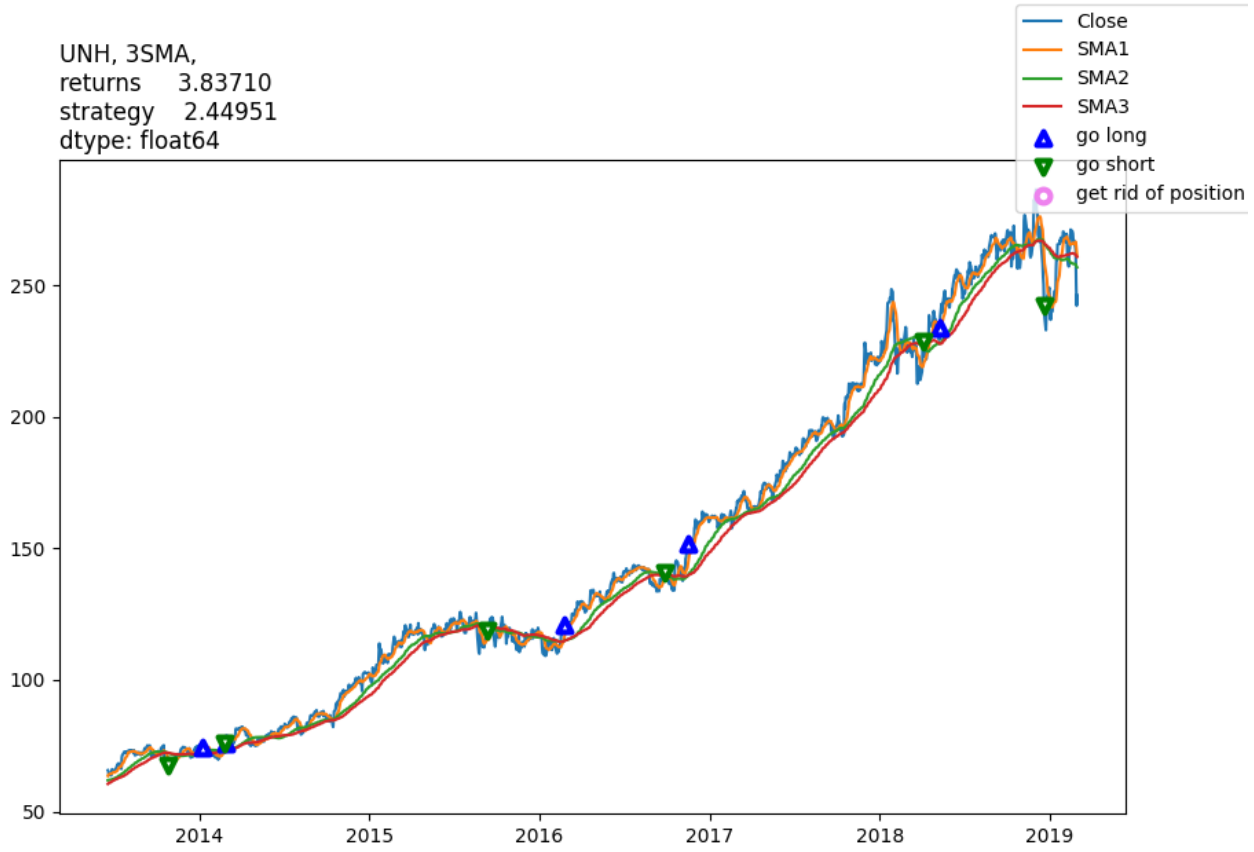
Unfortunately, the results obtained from the training and test sets are not consistent. The optimal SMAs found in the test set were SMA2=60 and SMA3=100 with the highest score of 0.91.

It is unfortunate that all of these strategies resulted in financial losses during the past four years. In order to understand why there was such a big difference in the outcomes a closer look at the price chart is taken:



We can see that until 2019 the upwards trend was quite smooth, and from 2019 onwards it is more volatile. We can deduce that the chosen parameter of SMA2=50 was overfitted to the training data and disappointed when applied to the testing data set, which had different price movement tendencies when compared to the training set.

In order to see the strategy behaviour (with SMA2=50 and SMA3=70) when applied on a training set a chart is created:



And for the test set with the same parameters: