

**UNIVERSITY OF THESSALY**  
**SCHOOL OF ENGINEERING**  
**DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING**

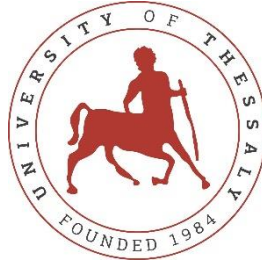
**Algorithmic Trading using Technical Analysis**

Diploma Thesis

Grigorios Fekas

Supervisor: Georgios Stamoulis

February 2022



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**ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΙΑΣ**

**ΠΟΛΥΤΕΧΝΙΚΗ ΣΧΟΛΗ**

**ΤΜΗΜΑ ΗΛΕΚΤΡΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ ΚΑΙ ΜΗΧΑΝΙΚΩΝ ΥΠΟΛΟΓΙΣΤΩΝ**

**Αλγοριθμικές Συναλλαγές με χρήση Τεχνικής Ανάλυσης**

Διπλωματική Εργασία

Γρηγόριος Φέκας

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To Minka

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## ΥΠΕΥΘΥΝΗ ΔΗΛΩΣΗ ΠΕΡΙ ΑΚΑΔΗΜΑΪΚΗΣ ΔΕΟΝΤΟΛΟΓΙΑΣ ΚΑΙ ΠΝΕΥΜΑΤΙΚΩΝ ΔΙΚΑΙΩΜΑΤΩΝ

Με πλήρη επίγνωση των συνεπειών του νόμου περί πνευματικών δικαιωμάτων, δηλώνω ρητά ότι η παρούσα διπλωματική εργασία, καθώς και τα ηλεκτρονικά αρχεία και πηγαίοι κώδικες που αναπτύχθηκαν ή τροποποιήθηκαν στα πλαίσια αυτής της εργασίας, αποτελούν αποκλειστικά προϊόν προσωπικής μου εργασίας, δεν προσβάλλουν οποιασδήποτε μορφής δικαιώματα διανοητικής ιδιοκτησίας, προσωπικότητας και προσωπικών δεδομένων τρίτων, δεν περιέχουν έργα/εισφορές τρίτων για τα οποία απαιτείται άδεια των δημιουργών/δικαιούχων και δεν είναι προϊόν μερικής ή ολικής αντιγραφής, οι πηγές δε που χρησιμοποιήθηκαν περιορίζονται στις βιβλιογραφικές αναφορές και μόνον και πληρούν τους κανόνες της επιστημονικής παράθεσης. Τα σημεία όπου έχω χρησιμοποιήσει ιδέες, κείμενο, αρχεία ή/και πηγές άλλων συγγραφέων αναφέρονται ευδιάκριτα στο κείμενο με την κατάλληλη παραπομπή και η σχετική αναφορά περιλαμβάνεται στο τμήμα των βιβλιογραφικών αναφορών με πλήρη περιγραφή. Δηλώνω επίσης ότι τα αποτελέσματα της εργασίας δεν έχουν χρησιμοποιηθεί για την απόκτηση άλλου πτυχίου. Αναλαμβάνω πλήρως, ατομικά και προσωπικά, όλες τις νομικές και διοικητικές συνέπειες που δύναται να προκύψουν στην περίπτωση κατά την οποία αποδειχθεί, διαχρονικά, ότι η εργασία αυτή ή τμήμα της δεν μου ανήκει διότι είναι προϊόν λογοκλοπής.

Ο Δηλών

Γρηγόριος Φέκας

Diploma Thesis

# **Algorithmic Trading using Technical Analysis**

Grigorios Fekas

## **Abstract**

In this thesis, we are creating a paper trading application, called ALGO PaperTrader. With his application, the user creates a virtual stock portfolio, buys and sells stocks using algorithmic trading strategies, based on Technical Indicators and candlestick patterns. To implement those strategies, ALGO PaperTrader uses real, historical, daily data utilizing Yahoo! Finance API for stocks listed on the S&P 500. The goal of this application is the introduction of the user to algorithmic trading, but also Technical and Fundamental Analysis ideas.

## **Keywords:**

Technical Analysis; Algorithmic Trading; Fundamental Analysis; Technical Indicators; Stock Trading; Backtesting; Candlestick Patterns; Data Visualization;

Διπλωματική Εργασία

## Αλγοριθμικές Συναλλαγές με χρήση Τεχνικής Ανάλυσης

Γρηγόριος Φέκας

### Περίληψη

Σε αυτή τη διπλωματική υλοποιούμε μια εφαρμογή εικονικών συναλλαγών, με όνομα ALGO PaperTrader. Σε αυτή την εφαρμογή ο χρήστης δημιουργεί ένα εικονικό χαρτοφυλάκιο μετοχικών τίτλων, αγοράζει και πουλάει μετοχές με την χρήση αλγοριθμικών στρατηγικών αγοραπωλησιών, βασισμένες στους τεχνικούς δείκτες και τα μοτίβα κηροπήγιων. Για υλοποιήσει αυτές τις στρατηγικές, το ALGO PaperTrader χρησιμοποιεί πραγματικά, ιστορικά, καθημερινά δεδομένα αξιοποιώντας το Yahoo Finance API για καταχωρημένες μετοχές του δείκτη S&P 500. Σκοπός της εφαρμογής είναι η εισαγωγή του χρήστη στις αλγοριθμικές συναλλαγές, αλλά και σε ιδέες Τεχνικής και Θεμελιώδους ανάλυσης.

**Λέξεις-κλειδιά:** Τεχνική Ανάλυση, Αλγοριθμικές Συναλλαγές, Θεμελιώδης Ανάλυση, Τεχνικοί Δείκτες, Μοτίβα Κηροπήγιων, Δοκιμή ιστορικών δεδομένων, Αγοραπωλησίες Μετοχικών Τίτλων; Οπτικοποίηση Δεδομένων

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## Abbreviations

FA	Fundamental Analysis
TA	Technical Analysis
AT	Algorithmic Trading
TI	Technical Indicator
OHLC	Open High Low Close
SMA	Simple Moving Average
EMA	Exponential Moving Average
MACD	Moving Average Convergence Divergence
RSI	Relative Strength Index
BB	Bollinger Bands

# Chapter 1 Introduction

In this thesis, we're creating ALGO PaperTrader [1]. ALGO PaperTrader is a paper trading application, and its goal is to introduce users to stock trading without the financial risks associated with security trading and provide them with a better understanding of the stock markets. In this application, users create a stock portfolio, buy and sell stocks, run Technical Analysis based strategies, and assess their performance. To assess a strategy's performance, the application provides visual aid via the creation of trading charts and trading reports. Within this application, users can also use Fundamental Analysis data to get more information about the stocks they wish to trade and Technical Analysis data, for more detailed analysis of the tools used in the paper trading process. In addition, ALGO PaperTrader uses real, historical, daily data provided by Yahoo! Finance™ for stocks listed on the S&P 500 index. Finally, the application logic is written in Python, the presentation (front-end) is implemented with Streamlit, and the open-sou, algorithmic trading library backtrader is utilized in order to run the strategies.

## 1.1 Structure of ALGO PaperTrader

The application can be broken into two horizontal sections and three vertical sections (or pages). Horizontally is broken into the sidebar and the main page [Figure 1]. The sidebar consists of the 'Select Stock Ticker', a dropdown menu in which the user selects the stock, and 'Choose Analysis Type', a dropdown menu in which the user selects the type of analysis that wishes to perform, and redirects the user to the appropriate page. Those two menus are always present in the sidebars of the pages, but more are added when the application requests user for more inputs. In addition, the sidebar can collapse by clicking X, on the top right of the sidebar, to utilize the full width of the screen. Vertically, ALGO PaperTrader is broken into three pages: Paper Trader (the default page), Fundamental Analysis, and Technical Analysis. We will discuss the use and the content of those pages in the following chapters with the same name.

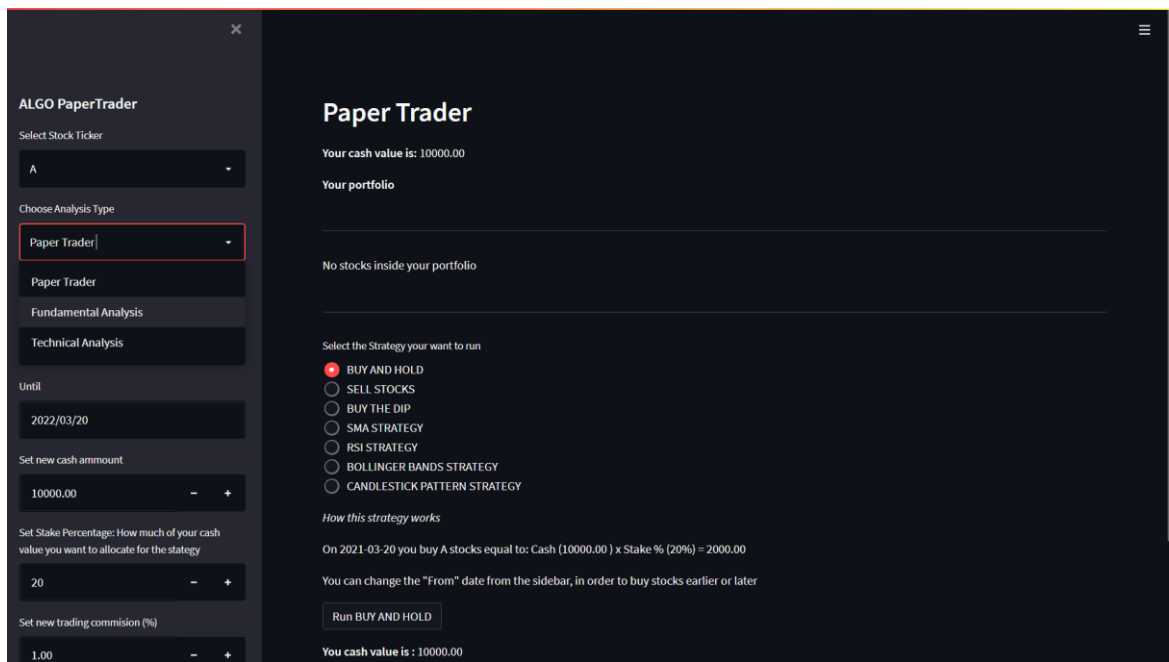


Figure 1. On the left with dark grey background is the ALGO PaperTrader sidebar, and on the right side with black background is the main page. Clicking on the ‘Choose Analysis Type’, the user is prompted with three different page options.

The application consists of 3 main parts [Figure 2]: streamlit, backtrader, and plotting libraries. Streamlit is responsible for the presentation and the application logic. This logic utilizes high-performance libraries, such as NumPy, pandas, and TA-Lib, with an, underline low-level language to process the financial data provided by yfinance (Yahoo! API). In addition, backtrader is responsible for running the strategies. Backtrader is a backtesting engine that iterates over historical price data (and/or other data), passes algorithmic values, and keeps track of the resulting position. Cerebro is the key component of backtrader and interacts with components within its class in order to process inputs, make create and execute a strategy, order and compute all the necessary factors for the strategy. A Cerebro instance manages the overall process from collecting inputs, executing the backtest bar by bar (in this application daily bars), and providing results [2]. Finally, plotting libraries provide data visualization, namely, plotly on the Technical analysis page, and matplotlib with the resulting strategy charts.

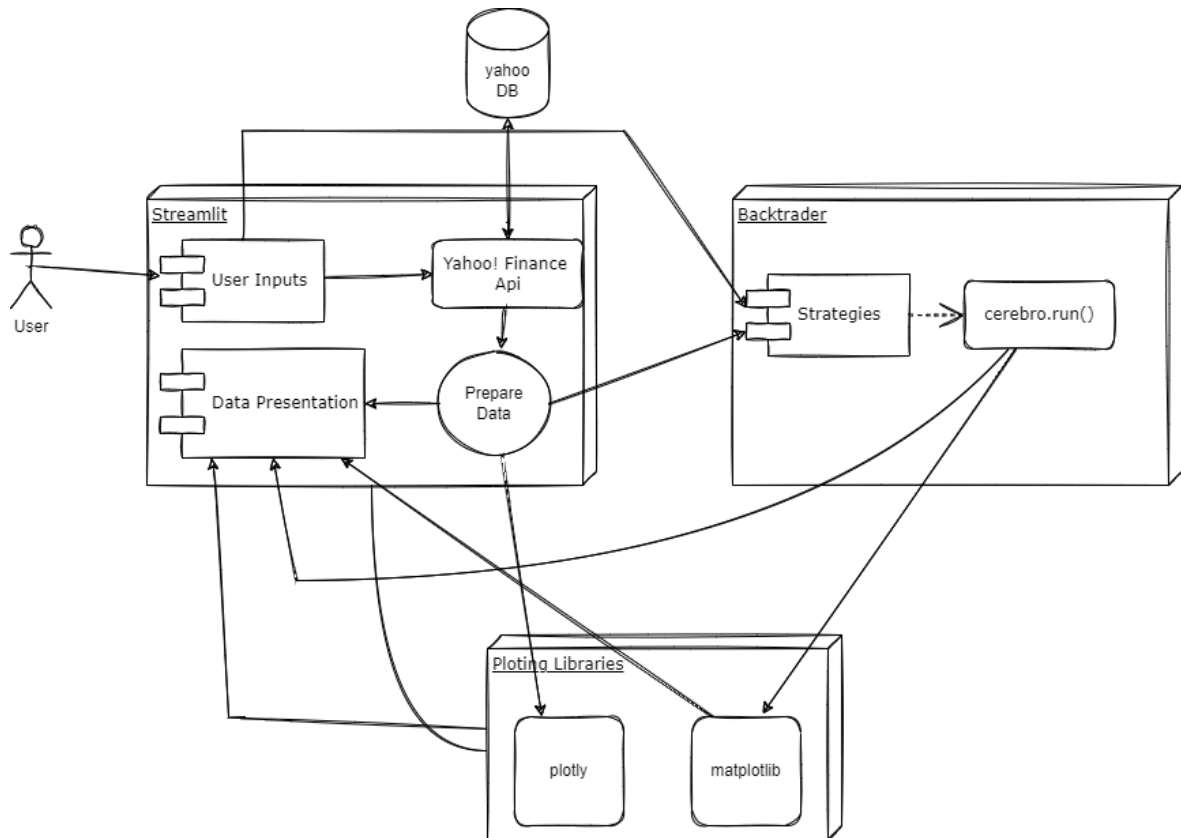


Figure 2. The design scheme of ALGO PaperTrader

This introduction ends with a description of the next chapters. More specifically, in Chapter 2, we review the relevant bibliography, regarding Fundamental Analysis (FA), Technical Analysis (TA), and Algorithmic Trading (AT). In addition in Chapter 3, we present how the paper trading functionality of ALGO PaperTrader works and present the different strategies found in it. Furthermore, in Chapter 4 we review the contents of the Fundamental Analysis sub-section and provide a short description of the data found within it. In Chapter 5 we discuss the content found in the Technical Analysis page of the ALGO PaperTrader and present the theory regarding the Technical Indicators and Charts used in the sub-section. Finally, in Chapter 5 Conclusions, we present limitations but also, possible future improvements of this application.

## Chapter 2 Literature Review

Fundamental Analysis based strategies can be very effective. Those strategies are commonly known as value investing. The observation of a security's sound fundamentals can lead to significant market returns. The research of Greig [3] shows that stock prices do not reflect the true equity values. The researcher re-examines the work of Ou & Penman [4] and concludes that fundamental analysis systematically predicts abnormal returns. In addition, according to Abarbanell & Bushee [5], the use of signals that reflect the rules of fundamental analysis can yield abnormal returns. More specifically they formed a portfolio that yielded an abnormal return of an average of 13.2 percent in a 12-month time period. They noted that a fraction of those returns can be explained from earnings announcements and future earnings projections. Also, firms with low fundamental ratios could be an investment opportunity for traders, through shorting the firm's stock, as Dechow et al. [6] concluded. But weak fundamentals alone are not always the answer for investors who seek alpha via shorting a stock. An example of this is the case of the Gamestop "short-squeeze" that occurred in the January of 2021. Umar et al.[7], concluded that this was the result of a sentiment-driven strategy rather than FA-based strategies or Gamestop's sound fundamentals, which created market inefficiencies.

Fundamental analysis could be viewed as a useful tool in the hands of an investor. Another tool that, according to Bettman et al. [8] complements fundamental analysis is Technical Analysis (TA). They noted that, although both FA and TA perform well on their own, models that combine both, lead to superior explanatory power. Moreover, Petrusheva & Jordanski [9] added that even though, both FA and TA receive criticisms from the academic and scientific community, the combination of both provides optimum results.

Technical Analysis is the method of trading that many investors and retail or institutional traders employ. A survey [10] contacted upon institutional investors (hedge fund managers) showed that TA provides lower risk with better performance. That is true in high-sentiment periods, but in low-sentiment market periods, FA-based strategies tend to outperform TA-based strategies. The researcher [10] noted variations in information processing between market participants and concluded that TA practitioners take advantage of the market's, herd-like psychology. The findings of the survey above are consistent with the research of Smith & Wang [11]. The researchers noted that hedge funds that use TA, exhibit higher performance and risk aversion, and "superior market-timing than nonusers" during high-

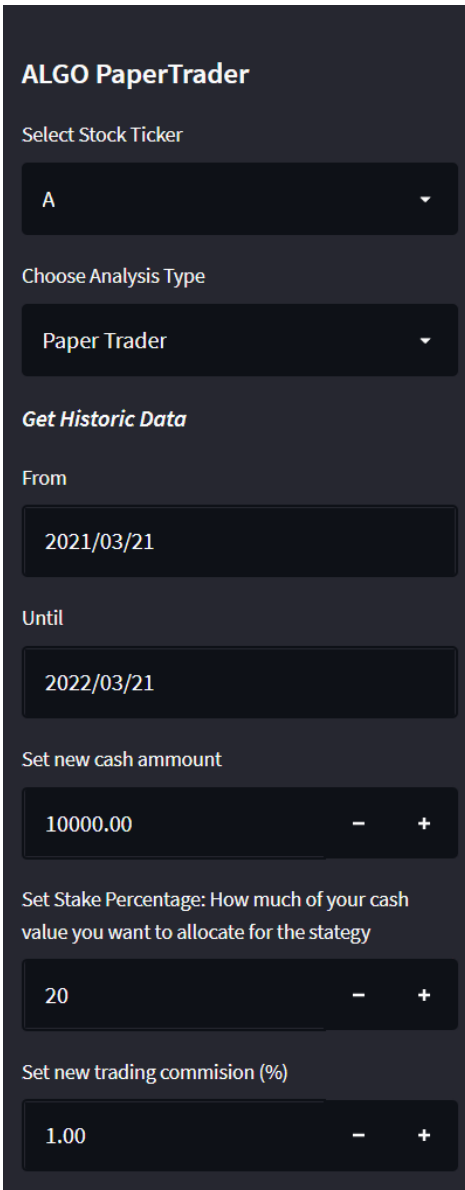
sentiment periods with a large percentage of market mispricing [11]. In addition, the use of TA and Technical Indicators, such as Moving Averages, for asset allocation, provide powerful predictive models [12]. Those predictive models are stronger in a period with underlying market uncertainty [12], which affirms the findings of the research mentioned above [11], [10]. TA models also provide robust predictions in emerging market indexes and their respective exchange-traded funds (ETF). But their predictive ability diminishes significantly after the introduction of their ETFs in the market [13].

Since the 1960s, when computer terminals started routing price data, electronic trading has made major advancements and at the forefront of this worldwide trend are the equity markets. In 1997 the SEC introduced the electronic communications networks (ECNs), automated alternative trading systems that matched buy-sell orders. An argument for the effectiveness of Algorithmic Trading (AT), is the rise of it, alongside electronic trading. More specifically electronic trading grew from 15% in 2000 to 99,9% in 2019 of the market volume, and algorithmic trading grew from 1% in 2000 to 92% in 2019 [14]. The remaining 8% are still transacted electronically. Another argument is the performance of hedge funds that use algorithmic strategies, namely D.E Shaw with \$50 billion Assets Under Management (AUM) in 2019, Citadel with \$32 billion AUM in 2019, and Two Sigma with \$60 billion AUM (started in 2011 with \$8 billion). Those funds, in 2017, entered the list of the all-time top-20, in the returns for investors[2]. The secretive Medallion Fund has estimated annualized returns of the 35% since 1982 and it is closed to outsiders. Most of the information we have regarding AT comes from Wall Street, therefore, there is a strong need for unbiased research academic research.

This thesis and ALGO PaperTrader try to narrow the gap between those hedge funds and the average individual who is interested in, but unfamiliar with algorithmic trading and the stock market in general. If someone bought \$2,000 worth of Apple ('AAPL') stock, back in November of 1993, how much would they be worth today? We all have seen the charts, but an annual, average rate return of 24% and \$2,000 becoming more than \$1 million seems hard to comprehend. Can simple strategies that only track closing prices, thus eliminating the need to track the market during trading hours, actually work? Are Technical Analysis and candlestick patterns effective trading strategies and under what conditions? How do those strategies perform during periods of high volatility? All those questions can be answered with the use of ALGO PaperTrader.

## Chapter 3 Paper Trader

This is the main page of ALGO PaperTrader. On this page, users can buy, sell stocks, and test strategies. In the sidebar [Figure 3], the user finds, in addition to the ‘Select Stock Ticker’ and ‘Choose Analysis Ticker’, the ‘From’ and ‘Until’ date fields, a ‘Set new cash amount number field (default \$10,000), a ‘Set Stake Percentage’, in which the user specifies what percentage of the value wants to allocate for the strategy (default 20%) and finally a ‘Set new trading commission (%)’ in which the user sets a percentage broker’s commission (default 1%).



The image shows a dark-themed sidebar for the ALGO PaperTrader interface. At the top, the title "ALGO PaperTrader" is displayed. Below it, there are several configuration sections:

- Select Stock Ticker:** A dropdown menu with the letter "A" selected.
- Choose Analysis Type:** A dropdown menu with "Paper Trader" selected.
- Get Historic Data:** A section containing two date input fields:
  - From:** A date field containing "2021/03/21".
  - Until:** A date field containing "2022/03/21".
- Set new cash ammount:** A numeric input field with "10000.00" and minus/plus buttons.
- Set Stake Percentage: How much of your cash value you want to allocate for the stategy:** A numeric input field with "20" and minus/plus buttons.
- Set new trading commision (%):** A numeric input field with "1.00" and minus/plus buttons.

Figure 3. The sidebar of ALGO PaperTrader in the strategy backtest page.



On the main page of ‘Paper Trader’, the user’s cash value is displayed, followed by the user’s portfolio. Following the portfolio, the user is prompted with a different strategy. Followed by a description of the strategy.

### 3.1 Buy And Hold

The first strategy is called “BUY AND HOLD”, in which the user buys stocks at the ‘From’ equal to the cash value multiplied by the stake percentage and the stocks are added to the user portfolio. When the user presses the ‘Run BUY AND HOLD’ button the OHLC chart is prompted indicating to the user with a green arrow the moment the trade was made. The top of the chart shows the value of the investment with a blue line and the cash value with a red line. In addition, below the chart, a message informs the user of the stocks added to the portfolio followed by, the Sharpe ratio, a position report, and a trade analysis report. Notably, the trade analysis report becomes more interesting when a strategy performs multiple trades and informs the user about winning and losing trades.

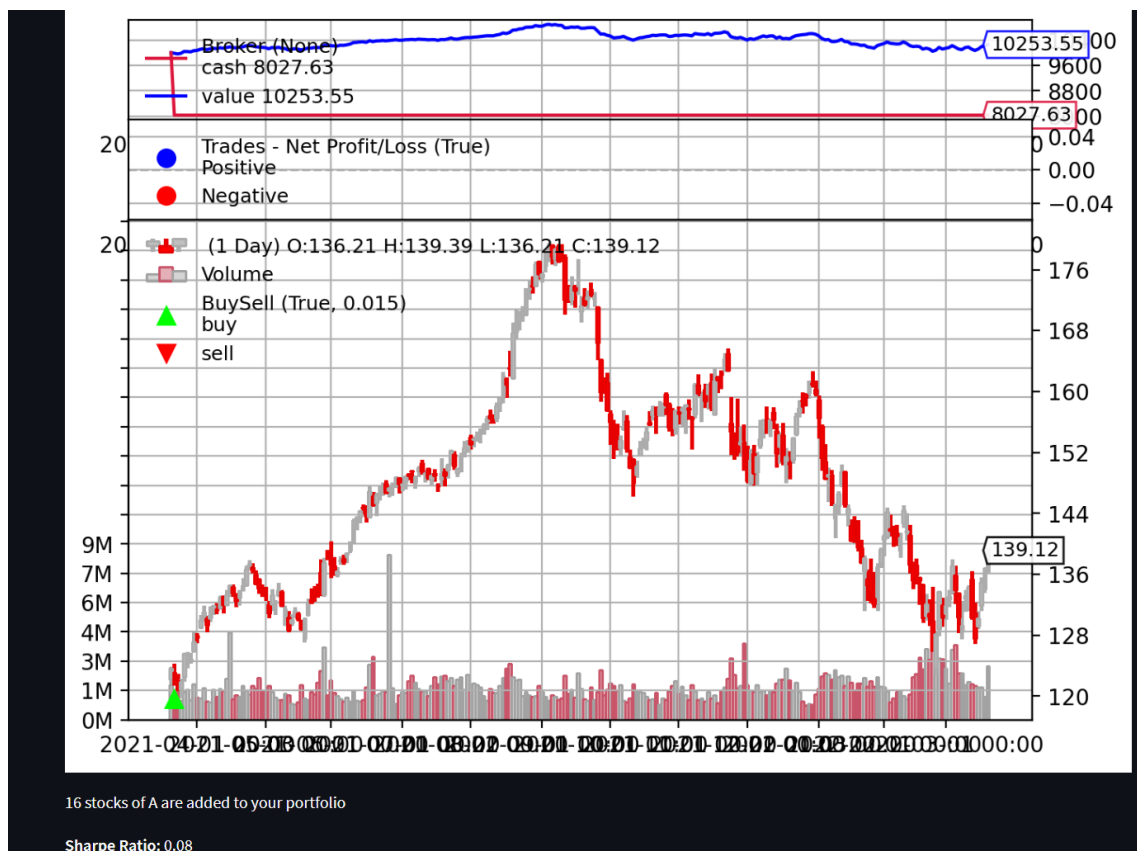


Figure 4. Resulting chart from buy and how strategy of Ticker: ‘A’ on 21/3/2021. Cash value and stake percentage were the default values, \$10,000 and 20%.

Lastly, the user is informed of the new cash value after the trade on the bottom of the page.

```
16 stocks of A are added to your portfolio

Sharpe Ratio: 0.08

Trading Report

Show Position Report

{
  "Size" : 16
  "Price" : 123.1500015258789
  "Price orig" : 0
  "Closed" : 0
  "Opened" : 16
  "Adjbase" : 139.1199951171875
}

Show Trade Analysis

{
  "total" : {
    "total" : 1
    "open" : 1
  }
}

You cash value is : 8027.63
```

Figure 5. Message prompt to use, informing the use for the number of stocks added to the portfolio. Position report notifies the user about the open and the closed positions. Trade report notifies the user about the number of trades.

### 3.2 Sell Stocks

When the 'SELL STOCKS' option is selected, the user is presented with the option to sell stocks from the portfolio. If the user has no stocks inside the portfolio, a message "You have no stocks inside your portfolio" is prompted. The users can choose how many stocks they want to sell, with a maximum the number of each stock inside the portfolio. The Sell 'X' Stock is pressed, 'X' representing the stocker ticker, a message with the trade commission appears and below that the renewed cash value. If all the stock of an individual company are sold, the input number field disappears.

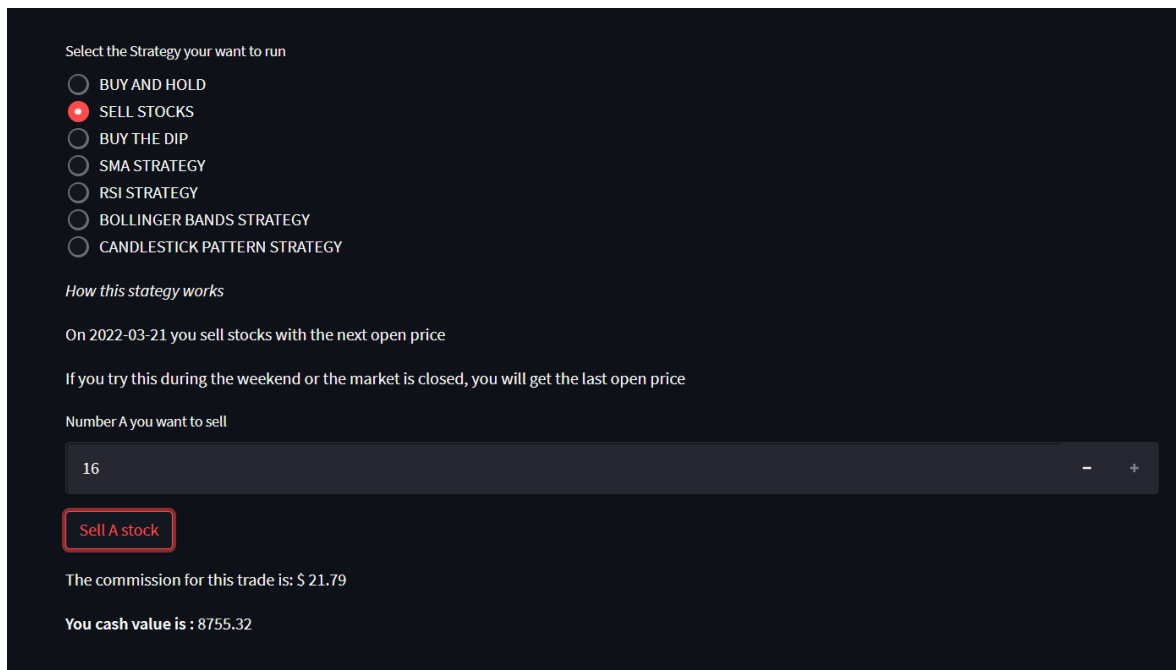


Figure 6. After the user sells 16 A stocks (Agilent Technologies, Inc.), the commission message appears and the cash value is renewed. After the user sells 16 A stocks (Agilent Technologies, Inc.), the commission message appears and the cash value is renewed.

### 3.3 Buy the dip strategy

When 'BUY THE DIP' is selected, a description is prompted, informing the user that a buy signal is triggered when the closing price falls for 4 consecutive days and a sell signal appears when the price rises for 5 days.

---

#### Buy the Dip Strategy

---

Input: OHLCV price data

Output: Buy & Sell signals, Transaction Plot

```

1 For each iteration (next()):
2   | If not in position:
3   |   | If the Closing Price falls for 4 days
4   |   |   | Buy() #enter long position
5   | else:
6   |   | If the Closing Price rises for 5 days
7   |   |   | Close() # close the long position

```

After the “Run Strategy” button is pressed the user is presented with the strategy graph [Figure 7], with green arrows inside the OHLC Chart indicating the buy signals and with red arrows the sell signals. Within the chart, the positive trades are indicated with blue circles and the negative with red. Furthermore, the user is presented with the following: Total Profits and Losses (PnL), Average PnL, Return of investment (ROI) in cash, how many stocks are added in the portfolio, and the Sharpe Ratio. Finally, the user is presented with the position and trade analysis reports. [Figure 8]



Figure 7. Resulting chart, from buy the dip strategy, for user inputs: ticker: 'A', from:22/3/2021 until 22/3/2022.

```

Total PnL: 226.16 Average PnL: 56.54

ROI in Cash: 13.30 %

11 stocks of A are added to your portfolio

Sharpe Ratio: -0.36

Trading Report

Show Position Report

{
  "Size" : 11
  "Price" : 155.49000549316406
  "Price orig" : 0
  "Closed" : 0
  "Opened" : 11
  "Adjbase" : 138.13999938964844
}

Show Trade Analysis

{
  "total" : {
    "total" : 5
    "open" : 1
    "closed" : 4
  }
}

```

Figure 8. The reports prompt after the buy and hold strategy.

### 3.4 SMA Strategy

This is an SMA cross-over strategy. When this strategy is chosen, a description of the strategy appears and the user is presented with the option to modify the two SMA windows [Figure 9]. When the strategy runs, in the init method of the backtrader class we calculate two SMAs, one small window (fast) SMA, and one big window (slow) SMA. Those windows are passed by the user as parameters and their default values are  $SMA_{small\_window}=10$  and  $SMA_{big\_window}=30$ . When  $SMA_{small\_window}$  crosses over the  $SMA_{big\_window}$  a buy signal is generated and when the  $SMA_{big\_window}$  a sell signal is generated. In particular, when  $SMA_{small\_window}$  crosses over the  $SMA_{big\_window}$ , the  $SMA_{crossover}$  is set to 1. When

$SMA_{big\_window}$  crosses over the  $SMA_{small\_window}$ , the  $SMA_{crossover}$  is set to -1. In any other case, the  $SMA_{crossover}$  is equal to zero.

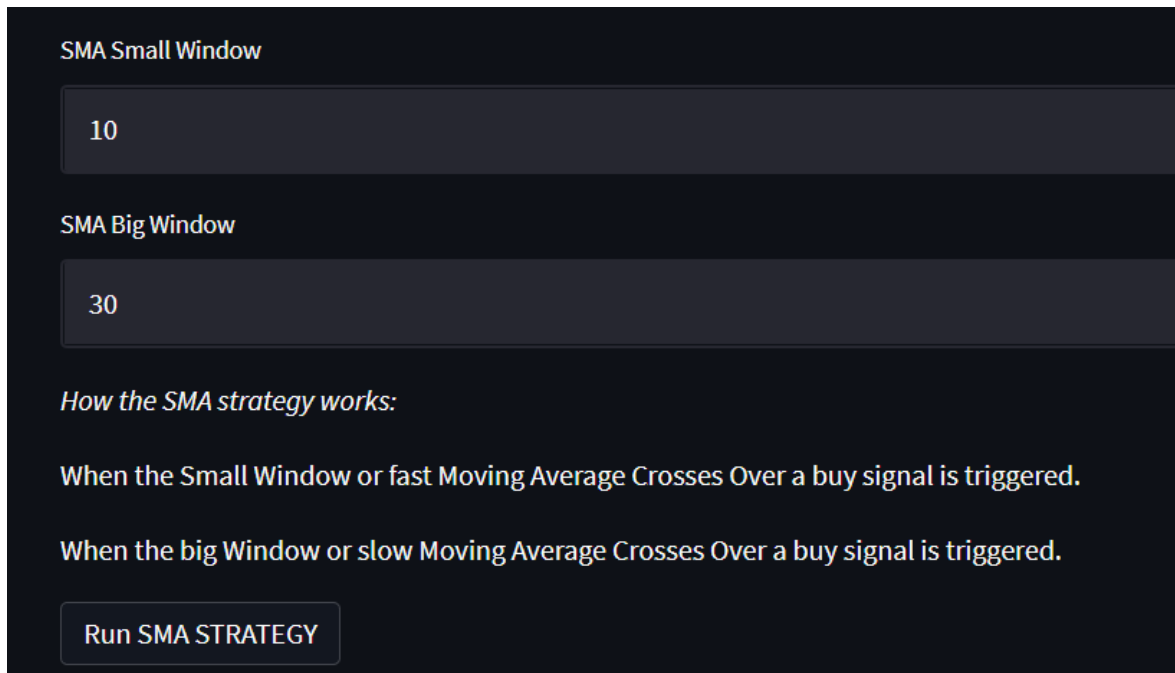


Figure 9. User inputs and SMA strategy description

---

### SMA Crossover Strategy

---

Input: OHLCV price data,  $SMA_{small\_window}=10$ ,  $SMA_{big\_window}=30$

Output: Buy & Sell signals, Transaction Plot

```
1 When instantiating the SMACrossover strategy (init):
2   | Define  $SMA_{small\_window}$ ,  $SMA_{big\_window}$ ,  $SMA_{crossover}$  indicator signal with the backtrader's
   |   built-in methods.
3 For each iteration (next()):
4   | If not in position:
5   |   | If  $SMA_{crossover} > 0$ 
6   |   |   | Buy() #enter long position
7   |   | else:
8   |   |   | If  $SMA_{crossover} < 0$ 
   |   |   |   | Close() # close the long position
```

In the resulting plot [Figure 10], in the top section, the red line represents the cash and the blue line the value of the position (in this strategy the long position). Right below is the number of positive and negative trades, represented with a blue dot for positive trades (meaning the cash value increased) and with a red dot for negative trade (meaning the cash value decreased). Then right below, we show the OHLC and within it, with the  $SMA_{small\_window}$  and  $SMA_{big\_window}$  are the red and blue lines respectively. Also, the green and red arrows correspond to the time, that the strategy enters and closes the long position. Lastly, on the bottom half of the plot, the crossover signal is shown. Following the chart, the application prompts a trading report which includes PnL, ROI in cash, number of stocks added to the portfolio, the Sharpe ratio, finally a position, and a trade report.



Figure 10. Resulting chart, from buy the dip strategy, for user inputs: ticker:'A'; from:22/3/2021 until 22/3/2022.

### 3.5 RSI Strategy

The RSI Strategy takes as parameters from the user the oversold and overbought conditions, which by default are 30 and 70, and the RSI length which by default is equal to 21. In the

instantiation method (init), the RSI Singal is defined with the RSI length as a parameter. For each iteration (next), we check if the RSI is below the oversold condition or above the overbought condition. If those conditions are met, a buy or sell signal is created.

---

## RSI Strategy

---

Input: OHLCV price data, Oversold = 30, Overbought=70, Period =21

Output: Buy & Sell signals, Transaction Plot

```
1 | When instantiating the RSI strategy (init):
2 |   | Define RSI indicator signal with the backtrader's built-in method, using Period as a
   |   | parameter.
3 | For each iteration (next()):
4 |   | If not in position:
5 |     |   | If RSI < Oversold
6 |     |   |   | Buy() #enter long position
7 |     |   | else:
8 |     |   |   | If RSI > Overbought
9 |     |   |   |   | Close() # close the long position
```

The user is asked to set the Overbought and Oversold Conditions and the time of Period of the RSI. When the user selects to run the RSI strategy, the strategy plot [Figure 11] is presented to the user. It is the same as [Figure 10], with the different buy, sell signals, and the bottom signal is the RSI, followed by, the trade report similar to the previous strategies.



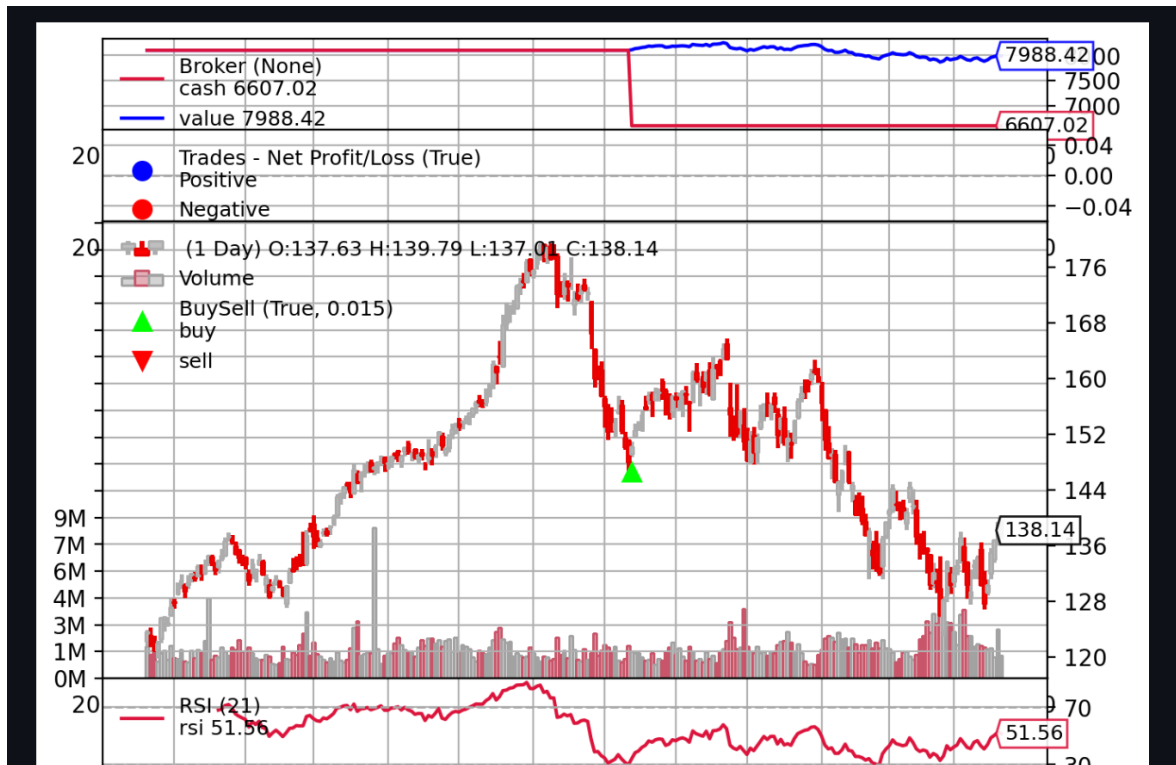


Figure 11. Chart output from the RSI strategy, in which 13 stocks are added to the user's portfolio. User inputs: ticker:A, from:22/3/2021 until 22/3/2022, oversold: 30, overbought:70, and period:21. Chart output from the RSI strategy, in which 13 stocks are added

### 3.6 Bollinger Bands Strategy

The Bollinger Bands Strategy takes no parameters from the user. In the instantiation method, the calculation of the Bollinger bands, using the backtrader's built-in function, produces three signals, the top band, the lower band, and the median band. In this strategy, the median band is not used. In each iteration (next), the algorithm checks if the current close price is lower than the lower Bollinger Band; if the condition is met, then a buy signal is produced. Also in each iteration, it checks if the current close price is higher than the upper Bollinger Band; if the condition is met, the strategy triggers a sell signal.

---

#### Bollinger Bands Strategy

---

Input: OHLCV price data

Output: Buy & Sell signals, Transaction Plot

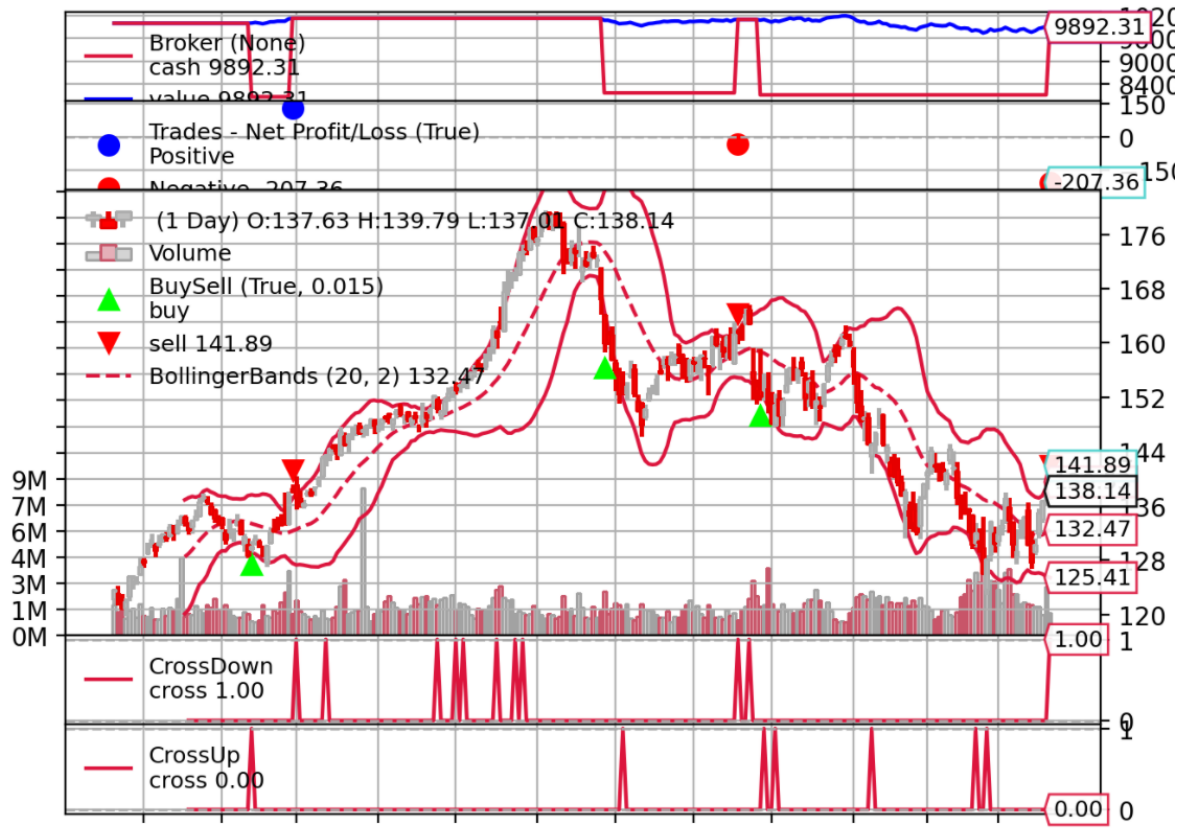
- 1 | When instantiating the Bollinger Bands Strategy strategy (init):
- 2 | | Define  $BBand_{upper}$ ,  $BBand_{lower}$  signal with the backtrader's built-in methods.

```

3 For each iteration (next()):
4   If not in position:
5     If BBandlower > Current Closing Price
6       Buy() #enter long position
7   else:
8     If BBandupper < Current Closing Price
9       Close() # close the long position

```

When the user selects to run the Bollinger Bands Strategy, the strategy plot appears, followed by the trading report.



Bollinger Bands strategy chart. User input ticker: A, from:22/3/2021 to 22/3/2022.

### 3.7 Candlestick Pattern Strategy

This is probably probably the most interesting out of all the strategies. When the user chooses the candlestick pattern strategy, all the possible candlestick patterns within the chosen time period are discovered. Those discoveries are stored in a pandas DataFrame and every column in the DataFrame corresponds to a candlestick pattern. The values of each column are: zero if the pattern is not present in the given DateTime index, +100 if it is a bullish pattern, and -100 if it is a bearish pattern. The user is prompted to choose between 3 sub-strategies: Cumulative Strategy, Choose Specific Candlestick Patterns, and 3 Inside Candlestick strategies [Figure 12]. If the user chooses the Cumulative Strategy, the trading signal is the sum of the discovered patterns, which results in a lot of trades but also introduces a lot of noise. If the user chooses the specific strategy, a prompt appears with all the patterns found and the sum of the chosen patterns is passed as a signal. To aid the user selection, checkboxes that show, bearish, bullish, and neutral patterns are present, that when checked, reveal those patterns. Users can visit the Technical analysis page, zoom in on those patterns, and study their behavior. Lastly, if the user chooses the 3 inside pattern strategy only the 3 inside candlestick patterns is pass a signal.

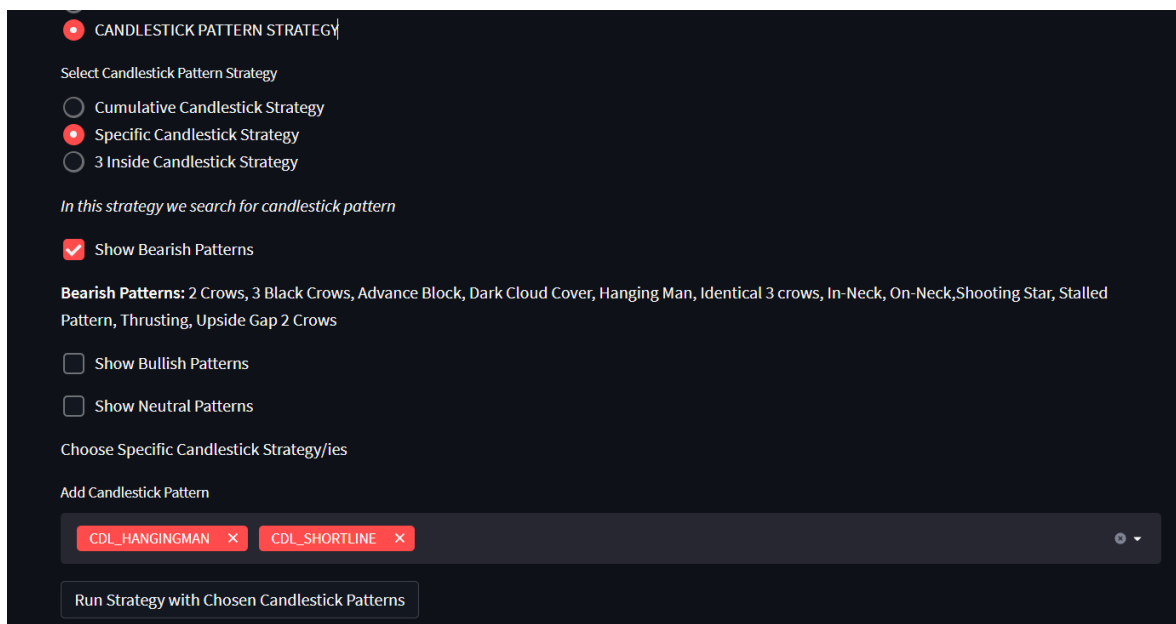


Figure 12. The user chooses the candlestick pattern strategy, specific candlestick strategy and adds the hanging man and shortline patterns, and reviews the bearish patterns to create a strategy.

The user chooses candlestick pattern strategy, specific candlestick strategy and adds the hanging man and shortline patterns and reviews the bearish patterns to create a strategy.

---

## Candlestick Pattern Strategy

---

Input: OHLCV price data, Candlestick Pattern Signal

Output: Buy & Sell signals, Transaction Plot

```
1 | When instantiating the Candlestick Pattern Strategy strategy (init):
2 | | Set the Candlestick Signal pass as input as the Strategy Signal (CDL_SIGNAL)
3 | For each iteration (next()):
4 | | If not in position:
5 | | | If CDL_SIGNAL > 0
6 | | | | Buy() #enter long position
7 | | | else:
8 | | | | If CDL_SIGNAL < 0
9 | | | | | Close() # close the long position
```

When the user runs the strategy a similar chart appears followed by the trade report.

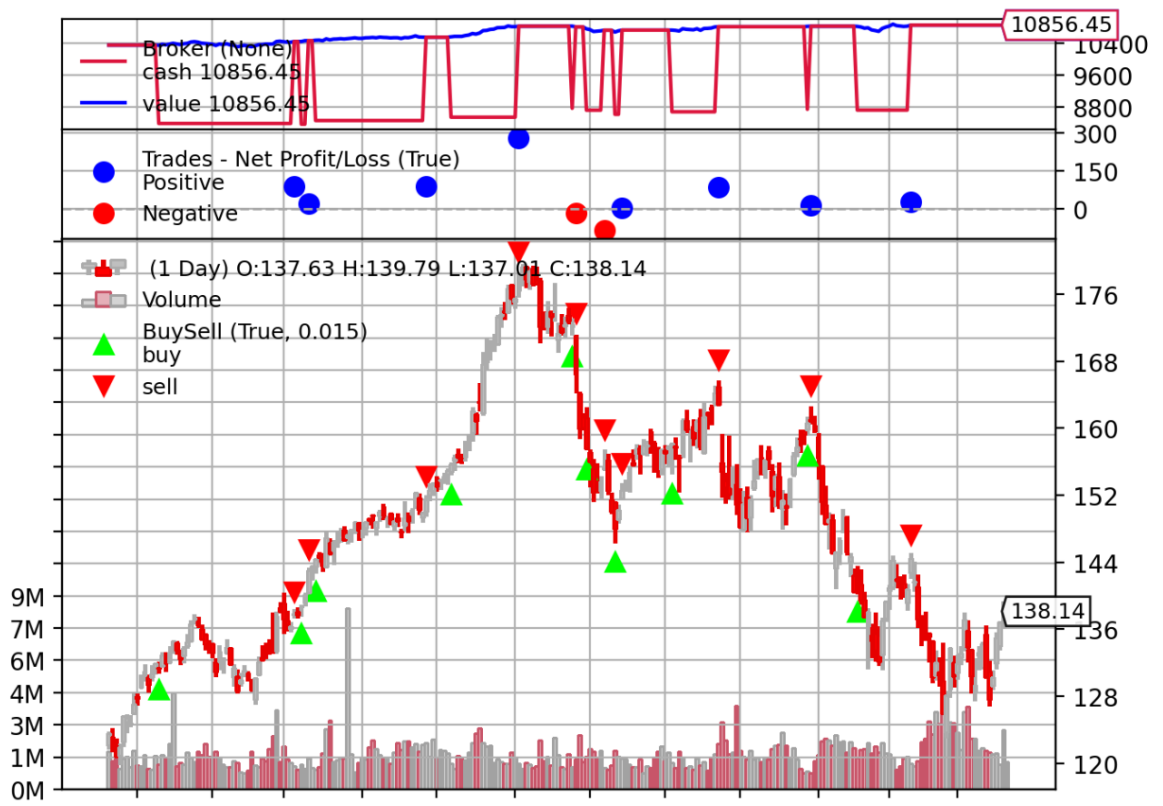


Figure 13. Candlestick pattern strategy – specific strategy using the hanging man and shortline. User input ticker: A, from 22/3/2021 to 2022/3/2022

## Chapter 4 Fundamental Analysis

### 4.1 Definition of Fundamental Analysis

Fundamental Analysis (FA) is the methodology of examining financial and accounting factors with the purpose of measuring a security's intrinsic value. FA is usually broken into two categories: qualitative, fundamentals that can not be quantified such as technology disruption and management style, and quantitative, fundamentals that can be quantified such as earnings, assets, debt, and ratios, etc. In this thesis, we only use quantitative metrics.

### 4.2 Fundamental Analysis in ALGO PaperTrader

To provide the users with a stronger understanding of the stocks traded within the paper trader page, ALGO PaperTrader provides a plethora of metrics, such as summaries, valuation, financial and accounting information. Users may ask, why a certain uptrend occur or the volume of the stock skyrocketed. It might be a positive earnings report or a stock split accordingly. Within this page, the user might find the answer, but at the very least, will have improved comprehension of the stock traded and the business aspect of it.

### 4.3 Business Summary

Business summary is a concise description of the company's business goals, its place in the market, and the offered products or services. The summary might contain historical facts and milestones of the company.

**Business Summary:** Tesla, Inc. designs, develops, manufactures, leases, and sells electric vehicles, and energy generation and storage systems in the United States, China, and internationally. The company operates in two segments, Automotive, and Energy Generation and Storage. The Automotive segment offers electric vehicles, as well as sells automotive regulatory credits. It provides sedans and sport utility vehicles through direct and used vehicle sales, a network of Tesla Superchargers, and in-app upgrades; and purchase financing and leasing services. This segment is also involved in the provision of non-warranty after-sales vehicle services, sale of used vehicles, retail merchandise, and vehicle insurance, as well as sale of products to third party customers; services for electric vehicles through its company-owned service locations, and Tesla mobile service technicians; and vehicle limited warranties and extended service plans. The Energy Generation and Storage segment engages in the design, manufacture, installation, sale, and leasing of solar energy generation and energy storage products, and related services to residential, commercial, and industrial customers and utilities through its website, stores, and galleries, as well as through a network of channel partners. This segment also offers service and repairs to its energy product customers, including under warranty; and various financing options to its solar customers. The company was formerly known as Tesla Motors, Inc. and changed its name to Tesla, Inc. in February 2017. Tesla, Inc. was incorporated in 2003 and is headquartered in Austin, Texas.

Figure 14. Business Summary of Tesla, Inc., ticker: 'TSLA'

## 4.4 Summary Section

This section presents important FA metrics to the user. The summary section [Figure 15] is useful because it provides a quick estimation of FA metrics of the stock. A short description of these metrics is provided below.

### Summary

**Previous Close:** 838.3

**Open:** 840.197

**Bid:** 820.52 x 1800

**Ask:** 821.26 x 2200

**Day's Range:** 814.4 - 843.55

**52 Week Range:** 546.98 - 1243.49

**Volume:** 4875531

**Avg. Volume:** 26515321

**Market Cap:** 844274204672

**Beta(5Y Monthly):** 2.04872

**EPS (TTM)::** 4.901

**1y Target Est:** 959.3

Figure 15. The summary section of Tesla, Inc., ticker: 'TSLA'

#### 4.4.1 Previous Close

The stock's closing price on the last trading day.

#### 4.4.2 Open

The stock's opening price today if it's a business day or the opening price of the last trading day during weekends.

#### 4.4.3 Bid

The product of the bid price and the bid size. A bid is an offer by a corporation or an individual to purchase an asset, in our example company stocks.

#### 4.4.4 Ask

The product of the ask price and the ask size. Ask is an offer of a seller who is willing to sell a security.

#### 4.4.5 Day's Range

The minimum and the maximum stock price during the current trading day or the last trading day if the markets are closed.

#### 4.4.6 52 Week Range

The minimum and the maximum stock price within the last trading year.

#### 4.4.7 Volume

The number of shares traded during the last trading day.

#### 4.4.8 Avg. Volume

The 3-month average volume

#### 4.4.9 Market Cap.

Market capitalization is the product of the number of outstanding shares and the current market price of one share.

#### 4.4.10 Beta (5Y Monthly)

Beta is a measure of a stock's volatility in relation to the overall market. Markets, by definition, have a beta of 1.0. If a stock moves less than the market, the stock's beta is less than 1.0. If the stock moves more than the market, the stock's beta is more than 1.0. Stocks with high beta are considered riskier but provide higher return potential. Stocks with low beta are less risky but also can provide lower returns.

#### 4.4.11 EPS (TTM)

Short for Earnings Per Share (Trailing Twelve Months). EPS is the ratio of a company's profit by the outstanding shares of its common stock. Companies with higher EPS are considered more profitable. Using financial data, in this case, EPS, TTM describes the past twelve consecutive months of the company's performance.

#### 4.4.12 Forward Dividend & Yield

Dividend is the distribution of a portion of the company's earnings to a class of shareholders. Yield is the ratio of dividend by the stock price, and it is expressed as a percentage.

#### 4.4.13 Ex-Dividend Date

The date of the last dividend payment.

#### 4.4.14 1y Target Est

A one-year forward price estimate was provided by yahoo! Finance™.

### 4.5 Valuation Metrics

With the use of valuation metrics [Figure 16] investors try to estimate the true value of a company's stock price

#### Valuation Metrics

	0	1
0	Market Cap (intraday)	837.01B
1	Enterprise Value	828.17B
2	Trailing P/E	165.28
3	Forward P/E	81.97
4	PEG Ratio (5 yr expected)	2.39
5	Price/Sales (ttm)	16.99
6	Price/Book (mrq)	27.73
7	Enterprise Value/Revenue	15.39
8	Enterprise Value/EBITDA	86.04

Figure 16. Valuation metrics of Tesla, Inc., ticker = 'TSLA'

#### 4.5.1 Trailing P/E

Is the ratio of the current stock price of a company divided by the earnings per share of the last 12 months. Trailing P/E limited to past earnings, thus may not be an accurate reflection of future earnings.

#### 4.5.2 Forward P/E

Is the ratio of the current stock price of a company divided by the estimated future earnings per share (next 12 months). Forecasting future earnings may introduce incorrect or biased results.

#### 4.5.3 PEG Ratio (5 yr expected)

Is the P/E ratio divided by the growth rate of its earnings per share for a time period ( 5 years)? If two stocks have similar P/E but has a lower PEG, the latter is considered undervalued.



#### 4.5.4 Price/Sales

It's the company's market capitalization divided by the company's total sales over the past 12 months.

#### 4.5.5 Price/Book

It is calculated by dividing the stock's current price by its book value per share. P/B ratios under 1 are considered a solid investment.

#### 4.5.6 Enterprise Value/Revenue

It is calculated by dividing the company's enterprise value by its revenue.

#### 4.5.7 Enterprise Value/EBITDA

The enterprise value to the earnings before interest, taxes, depreciation, and amortization.

### 4.6 Statistics Section:

In the Statistics Section [Figure 17], some of the terms in this section have been also described in the Summary Section, but time periods may differ.

## Statistics

	Attribute	Value
0	Beta (5Y Monthly)	2.05
1	52-Week Change 3	20.84%
2	S&P500 52-Week Change 3	8.02%
3	52 Week High 3	1243.49
4	52 Week Low 3	546.98
5	50-Day Moving Average 3	937.27
6	200-Day Moving Average 3	844.51
7	Avg Vol (3 month) 3	26.52M
8	Avg Vol (10 day) 3	24.12M
9	Shares Outstanding 5	1.03B

Figure 17. Statistics sections of Tesla, Inc., ticker: 'TSLA'

#### 4.6.1 Float

The number of shares available for investors to trade. Float is delivered by subtracting the number of a company's restricted shares from its outstanding shares.

#### 4.6.2 Held by Insiders

Percentage of shares held by senior officers, executives, and the firm's board of directors.

#### 4.6.3 % Held by Institutions

Percentage of shares held by institutions such as mutual funds, pension funds, private foundations, etc.

#### 4.6.4 Shares Short

Short selling is a trading strategy that speculates a fall of a stock's price at the end of the month. This field represents the number of shares shorted.

#### 4.6.5 Short Ratio

The number of shorted shares is divided by the average daily volume.

#### 4.6.6 Short % of Float

The percentage of a company's stock that has been shorted by institutional traders

#### 4.6.7 Payout Ratio

Expressed as a percentage of the company's total earnings, the payout ratio shows the proportion of a company's earnings paid to the shareholders.

#### 4.6.8 Last Split Factor

Stock splits occur when a company wants to increase stock liquidity in the market. Expressed as a ratio  $n:1$ , that means the investor will hold  $n$  stocks every stock held before the split.

#### 4.6.9 Profit margin

The ratio of a company's profit (sales minus all expenses) divided by its revenue

#### 4.6.10 Operating Margin

It is calculated by dividing a company's operating income by its net sales.

#### 4.6.11 Return on Assets

Expressed as a percentage by using a company's net income and its average assets. ROA indicates a company's profitability in relation to its total assets.

#### 4.6.12 Return on Equity

Calculated by dividing net income by shareholders' equity.

#### 4.6.13 Revenue

The amount of money generated from normal business operations, calculated as the average sales price times the number of units sold

#### 4.6.14 Gross Profit

The profit a business makes after subtracting all the costs that are related to manufacturing and selling its products or services.

#### 4.6.15 EBITDA

Earnings Before Interest, Taxes, Depreciation, and Amortization

#### 4.6.16 Net Income Available to Common

The capital is left after subtracting expenses, taxes, and dividends to preferred shares from earnings for the year.

#### 4.6.17 Diluted EPS

Calculates a company's earnings per share if all convertible securities were converted.

#### 4.6.18 Levered Free Cash Flow

The amount of money (cash) a company has left remaining after paying all of its financial obligations

### **4.7 Financials Section**

In the financials section [Figure 18] the company's financials and accounting data, for the last four years, are presented to the user.

## Financials

	2021-12-31 00:00:00	2020-12-31 00:00:00	2019-12-31 00:00:00	2018-12-31 00:00:00
Research Development	2,593,000,000.0000	1,491,000,000.0000	1,343,000,000.0000	1,460,000,000.0000
Income Before Tax	6,343,000,000.0000	1,154,000,000.0000	-665,000,000.0000	-1,005,000,000.0000
Minority Interest	1,394,000,000.0000	1,454,000,000.0000	1,492,000,000.0000	1,390,000,000.0000
Net Income	5,519,000,000.0000	721,000,000.0000	-862,000,000.0000	-976,000,000.0000
Selling General Administrative	4,517,000,000.0000	3,188,000,000.0000	2,646,000,000.0000	2,835,000,000.0000
Gross Profit	13,606,000,000.0000	6,630,000,000.0000	4,069,000,000.0000	4,042,000,000.0000
Ebit	6,523,000,000.0000	1,951,000,000.0000	80,000,000.0000	-253,000,000.0000
Operating Income	6,523,000,000.0000	1,951,000,000.0000	80,000,000.0000	-253,000,000.0000
Other Operating Expenses	-27,000,000.0000	-27,000,000.0000	-27,000,000.0000	-27,000,000.0000
Interest Expense	-358,000,000.0000	-784,000,000.0000	-725,000,000.0000	-653,000,000.0000

Figure 18. Financials Section of Tesla, Inc., ticker: 'TSLA'

### 4.7.1 Research Development

Dollar amount spend in research and development

### 4.7.2 Minority Interestest

Also known as Non-Controlling Interest (NCI), represents an ownership that consists of less than 50% of an enterprise.

### 4.7.3 Selling General Administrative

Selling, General & Administrative expenses (SG&A). Include all everyday operating expenses of running a business that is not included in the production of goods or delivery of services

### 4.7.4 Net Income

Dollar amount made after deducting cost, allowances, and taxes.

### 4.7.5 Gross Profit

Gross profit is the profit a company makes after the deduction of costs associated with making and selling its products, or the costs associated with providing its services.

### 4.7.6 Ebit

Earnings Before Interest and Taxes.

### 4.7.7 Operating Income

The amount of profit realized from a business's operations, after deducting operating expenses such as wages, depreciation, and cost of goods sold.

#### 4.7.8 Interest Expense

The payable interest cost incurred by a firm from borrowed funds such as loans, bonds, lines of credit, or convertible debt.

#### 4.7.9 Cost Of Revenue

The total cost of manufacturing and delivering a product or service to consumers

#### 4.7.10 Net Income from Continuing Ops

Net income category that accounts for a company's regular business activities.

#### 4.7.11 Net Income Applicable to Common Shares

Dollar amount left after subtracting expenses, taxes, and dividends to preferred shares from earnings for the year

## **Chapter 5 Technical Analysis**

### **5.1 Definition of Technical Analysis**

Technical Analysis (TA) is a trading methodology employed to evaluate investments and identify trading opportunities by analyzing statistical trends gathered from past trading activity, primarily price movement and volume. With the use of TA tools such as Technical Indicators and Charts, investors try to forecast the direction of a security, currency, or commodity.

### **5.2 Definition of Technical Indicators**

Technical indicators (TI) are pattern-based or heuristic mathematical calculations produced from past price, volume, and/or (in the case of futures contracts) open interest data, that aims to forecast the market's direction. TIs are the devices that aid investors and traders to perform TA-based models and strategies.

### **5.3 Technical Analysis in ALGO PaperTrader**

This page provides more flexibility to the user, regarding charts and technical indicators. It also allows the user to have full control of the OHLC charts because there are zoom and span capabilities built in the produced charts, unlike the OHLC from the paper trading page that produces static images. This feature becomes extremely useful in the combination with the candlestick pattern strategy; the user can locate, study the pattern and use it as a feature reference. The following section are describing the charts and technical indicators found on the TA page.



Figure 19. The user zooms in the OHLC to observe the candlestick patterns.

The plot is divided into four subplots, with the OHLC chart being the largest and always on, and depending on the user input the rest are added dynamically. User are also provided with the capability to change the parameters of the TIs and notice their behavior.



Figure 20. . All the available indicators. User inputs ticker: 'AAPL', from 22/3/2021 to 22/2/2022

## 5.4 Close Price Chart

As the name suggests, is a chart that displays the date/time (depending on the interval) on the X-axis and the closing price on the Y-axis. It is a useful tool for estimating quickly the general price movements, and the underlying volatility of a security.



Figure 21. Closing price chart. Closing price chart of Tesla, Inc. from 1/1/2021 to 31/12/2021

### 5.5 Open High Low Close Chart (OHLC Chart)

An OHLC chart [Figure 22] is a type of bar chart that indicates the open, high, low, and closing prices for time intervals. OHLC charts are used to determine the decreasing or increasing momentum and are useful in assessing volatility. Also, many Technical Analysts look for specific patterns in OHLC Charts, commonly known as candlestick patterns [Figure 23], to aid in their decision-making process or to affirm a hypothesis of market direction. In Chapter 4 we implement a trading algorithm based on discovered candlestick patterns.



Figure 22. OHCL chart (top) and volume chart (bottom) of Tesla, Inc. from 1/1/2021 to 31/12/2021



## 5.6 Candlestick Patterns

OHLC charts contain data for multiple time frames into single price bars. Candlesticks have colorful names and contain patterns that can predict the direction of a price. They separated into three categories bullish (signal buy), bearish (signal sell), and neutral (can signal both buy and sell). In the candlestick patterns strategy, the application detects the existence of the following patterns.

**Bearish Patterns:** 2 Crows, 3 Black Crows, Advance Block, Dark Cloud Cover, Hanging Man, Identical 3 crows, In-Neck, On-Neck, Shooting Star, Stalled Pattern, Thrusting and Upside Gap 2 Crows.

**Bullish Patterns:** 3 Stars In South, 3 White Soldiers, Abandoned Baby, Conceal Babies Wall, Hammer, Homing Pigeon, Inverted Hammer, Matching Low, Morning Doji Star, Morning-star, Piercing, Rising Three Methods, Separating Lines, Takuri, Unique 3 River

**Neutral Patterns:** 3 Inside, 3 Line Strike, 3 Outside, Belthold, Breakaway, Closing Marubozu, Counterattack, Doji, Dojistar, Dragon-fly Doji, Harami, Harami Cross, High-wave, Hikkake, Modified Hikkake, Kicking, Kicking by Length, Ladder Bottom, Long Legged Loji, Long-line, Marubozu, Mat Hold, Rick Shaw, Spinning Top, Stick Sandwich, Tasuki Gap, Tristar, upside and downside Gap 3 methods

Readers can refer to the work of Nison S. [15] for more information regarding candlestick patterns.

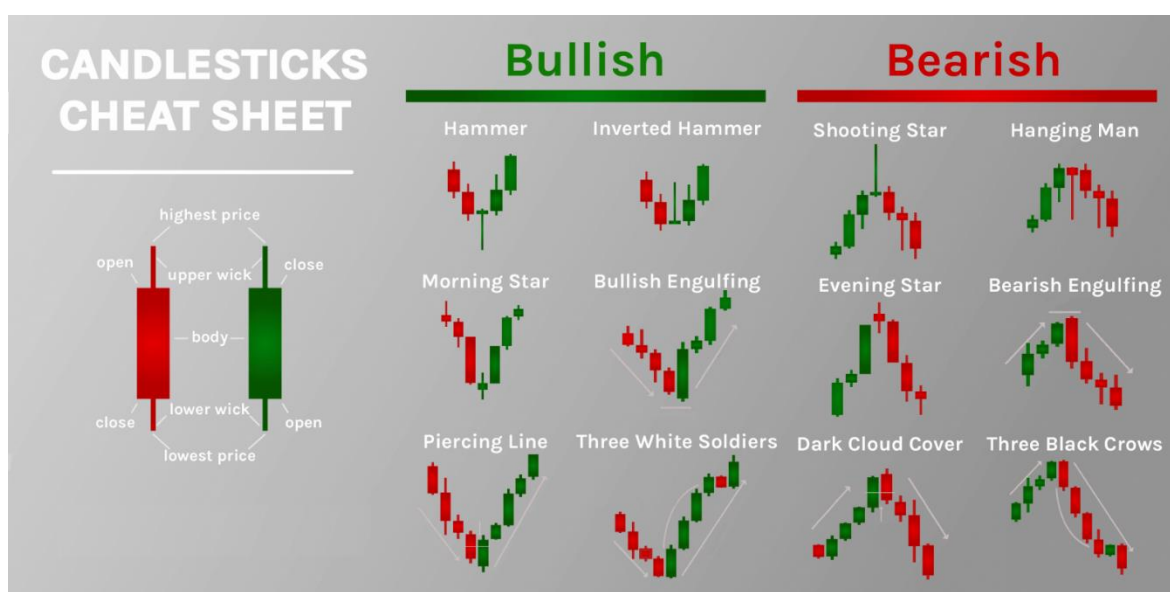


Figure 23. Example of candlestick patterns, source: <https://cryptoitunes.com/>

## 5.7 Volume Bar Chart

A bar chart that indicates the total number of a security traded in each time interval [Figure 22]. Volume determines how “active” a security is, and subsequently, it is a level of liquidation. Furthermore, it is a measure of the significance of a price movement, the higher volume the more significant the price movement, and vice versa.

## 5.8 Simple Moving Average (SMA)

SMA [Figure 24] is one of the most popular TA tools that creates constantly updated average price data. It “smooths out” the data making the drastic price changes less severe. It is calculated by dividing the sum of the  $n$  closing prices, where  $n$  is the number of time intervals, by  $n$ . SMA of  $n = 10$  days is the sum of the closing prices of the last 10 days, divided by 10. This calculation represents the consensus of investor expectations over the last 10 days [[16]]

### 5.8.1 Simple Moving Average Formula

$$SMA_n = \frac{\sum_{i=1}^n P_i}{n}$$

Where  $P_i$  : the  $i$ -th closing price and,

$n$  : the number of time intervals (in most of the cases days)



Figure 24. SMA12 (yellow line) for Tesla, Inc. from 1/1/2021 to 31/12/2021

## 5.9 Exponential Moving Average (EMA)

EMA [Figure 25] is a type of moving average that places a greater weight and significance on the most recent price data points. It is also known as an exponentially weighted moving average (EWMA).

### 5.9.1 Exponential Moving Average Formula

$$EMA_{today} = EMA_{yesterday} + a(P_i - EMA_{yesterday})$$

$$EMA_{today} = a[p_1 + (1 - a)p_2 + (1 - a)^2p_3 + (1 - a)^3p_4 + \dots]$$

$$EMA_{today} = \frac{p_1 + (1 - a)p_2 + (1 - a)^2p_3 + (1 - a)^3p_4 + \dots}{1 + (1 - a) + (1 - a)^2 + (1 - a)^3 + \dots}$$

Where  $P_i$  : the i-th closing price and,

a: the degree of weighting decrease



Figure 25. EMA14 (blue line) for Tesla, Inc. from 1/1/2021 to 31/12/2021

## 5.10 Moving Average Convergence Divergence (MACD)

MACD [Figure 26] is a trend-following momentum indicator that measures the relationship between two moving averages. It is plotted as an oscillator and shows the strength of the prevailing trend and signals of the change in trend. It is commonly plotted as a histogram showing strength and weakness in price. MACD is the difference between a longer-term EMA, most commonly equal to a 26-time period, and a shorter-term EMA, commonly equal to a 12-time period. MACD is plotted with a short-term EMA, typically a 9-time period. Crossovers between the lines indicate bullish or bearish signals. A sell signal is triggered the

signal line crosses over the MACD line and a buy signal when the MACD line crosses over the signal line [[16]].

### 5.10.1 Moving Average Convergence Divergence Formula

$$MACD_{(26,12,9)} = EMA_{26} - EMA_{12}$$

$$MACD_{Signal} = EMA_9$$



Figure 26. MACD(26,12,9) (bottom) plotted as a line and as a histogram, for Tesla, Inc from 1/1/2021 to 31/12/2021

## 5.11 Relative Strength Index (RSI)

RSI [Figure 27] is a momentum auscultator that measures the magnitude of recent price changes to evaluate overbought or oversold conditions in the price of a stock or other asset. The RSI is most typically used on a 14-day timeframe, measured on a scale from 0 to 100, with high (tops) and low levels (bottoms) marked at 70 and 30, respectively.

### 5.11.1 RSI Calculation

$$RS = \frac{EMA(U, n)}{EMA(D, n)}$$

RS: Relative Strength

EMA(U,n): The EMA of n time intervals with an upward trend ( $Close_{now} > Close_{previous}$ )

EMA(D,n): The EMA of n time intervals with a downward trend ( $Close_{now} < Close_{previous}$ )

$$RSI = 100 - \frac{100}{1 + RS}$$



Figure 27. RSI of length 14 for Tesla, Inc from 1/1/2021 to 31/12/2021. Tops or overbought condition is set to 70 and bottoms or oversold condition is set to 30.

## 5.12 Bollinger Bands®

Bollinger Bands (BB) [Figure 28] are a set of trendlines plotted (typically) two standard deviations away from an SMA of (usually) 20 days. BB are used to determine when an asset is oversold or overbought.

### 5.12.1 Bollinger Bands Calculation:

$$BOLU = MA(TP, n) + m * \sigma[TP, n]$$

$$BOLD = MA(TP, n) - m * \sigma[TP, n]$$

where:

BOLU: Upper Bollinger Band

BOLD: Lower Bollinger Band

MA: Moving average

$$TP(\text{typical price}) = \frac{P_{High} + P_{Low} + P_{Close}}{3}$$

n: Number of days in the smoothing period (typically 20)

m: Number of standard deviations (typically 2)

$\sigma[TP,n]$ : Standard Deviation over the last n periods of TP



Figure 28. Bollinger Bands of Tesla, Inc from 1/1/2021 to 21/12/2021 with the default settings (Middle Band is set to a 20 day EMA, Upper and Lower are set to two standard deviations for the middle band).

## **Chapter 6 Conclusions**

In this thesis, we successfully created an application to serve as an introduction to stock trading and finance in general. We introduced the user to ideas of FA and TA, with the purpose of comprehension of the stock market. In addition, the created strategies, mainly the candlestick strategies, even though they are simple, they can be profitable, especially the combination of them and a topic of future academic studies.

### **6.1 Limitations and future improvements**

There is a lack of reliable, fast, real-time, and free market data available to perform real-time intraday trading and this is the reason for the daily interval, trade compromise was made. On the application side, a feature implementation that includes a database with all historic market data would improve the performance as it would enable the user, to test strategies and receive the relevant FA and TA information offline. In addition, an improvement would be the inclusion of portfolio allocation and/or diversification strategies as well as cost-minimizing algorithmic strategies. Finally, a given price of equity is depended on many factors, not only its historic price data and volume. In order to discover those dependencies, a logical approach is to incorporate FA metrics and data within algorithmic trading strategies. Lastly, a reasonable direction is the discovery of relevant, but external data (outside of the market) and building models using Machine Learning. Those models can be backtested, to examine their predictive capabilities.

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