Research Notes

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Chapter 1

Data collection

For the daily stock ranking, we use End of Day US Stock Prices dataset published by Quotemedia.

The dataset columns are: `date`, `open`, `high`, `low`, `close`, `volume`, `dividend`, `split`, `adj_open`, `adj_high`, `adj_low`, `adj_close`, and `adj_volume`.

1.1 Downloading metadata–getting list of symbols

The set of all symbols in the Quandl EOD dataset can downloaded at the following endpoint:

```
META_ENDPOINT = 'https://www.quandl.com/api/v3/databases/EOD/metadata?api_key={}'
response = requests.get(META_ENDPOINT.format(settings.QUANDL_API_KEY))
```

From this CSV file, we extract the following columns: `qdl_code`, `qdl_name`, `qdl_ticker`, and `qdl_exchange`. On a few occasions, `qdl_code` can defer from `qdl_ticker`. RegEx is used to parse HTML for `qdl_ticker` and `qdl_exchange`.

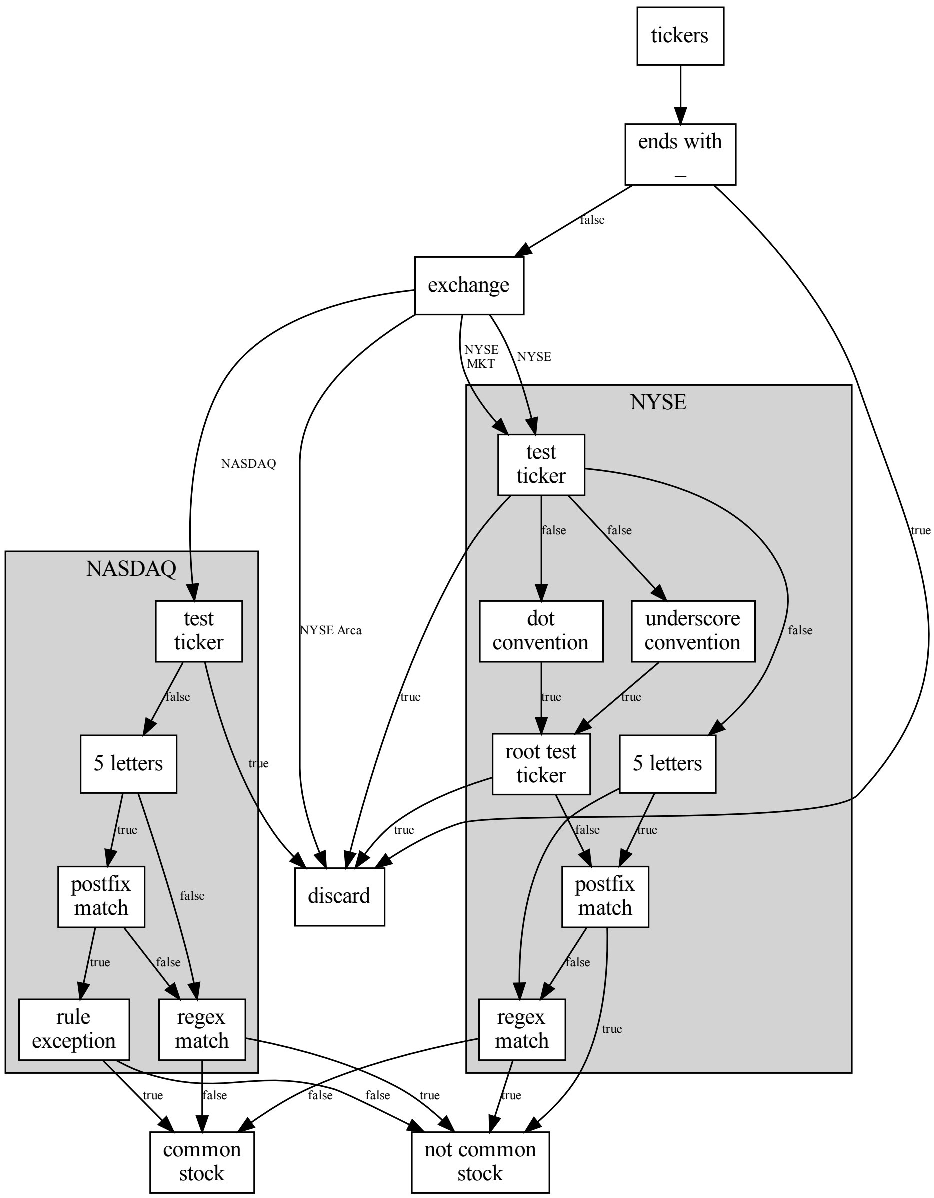
1.2 Filtering list of symbols

1.2.1 Exchanges as denoted in Quandl EOD

1. NASDAQ
2. NYSE
3. NYSE MKT; now known as NYSE American, formerly AMEX; small cap equity market
4. NYSE Arca; formely ArcaEx; mostly ETFs, ETNs, and ETVs

We keep symbols from NASDAQ, NYSE, and NYSE MKT. NYSE Arca are discarded at moment, as it contains mainly EFTs and similiar securities.

Figure 1.1: Diagram of ticker filtering



1.2.2 NASDAQ symbol convention

On NASDAQ a ticker might have a 5 letter name. The 5th letter conveys special meaning.

1. A - class A shares
2. B - class B shares
3. C - NextShares ETMF (type of ETF)
4. D - new issue
5. E - denotes delinquiency in SEC filings
6. F - foreign issue
7. G - first convertible bond
8. H - second convertible bond
9. I - third convertible bond
10. J - voting; temporarily denotes shareholder vote situation
11. K - non-voting
12. L - miscellaneous situation; seems to be bonds and preferred stock
13. M - foruth preferred issue
14. N - third preferred issue
15. O - second preferred issue
16. P - first preferred issue
17. Q - indicates bankruptcy
18. R - rights
19. S - shares of beneficial interest
20. T - securities with warrants or rights
21. U - units
22. V - when issued or when distributed; sahres that are set to split or similiar corporate action
23. W - warrants
24. X - mutual fund quoation service
25. Y - american depository receipt
26. Z - miscellaneous situations

The following NASDAQ postfixes are treated as non-common stocks: `C, D, E, G, H, I, J, L, M, N, O, P, Q, R, S, T, U, W, V, W, X`, and `Z`.

Note: Special treatment is given to `GOOGL`, it ends in the 5-letter postfix `L`, but breaks from the standard naming convention.

1.2.3 NYSE symbol convention

Similar to section 1.2.2, the following postfixes are treated as non-common securities: `F, Q, I, Z, L, N, O, C, CL, P, WS, WD, U, V, W, R`, and `V`.

NYSE and NYSE MKT features dot, underscore, and 5-letter naming convention. In the case of dot or underscore convention, the ticker is split into tokens delimited by `.` or `_`. We examine the root for known test tickers, and the last token for postfixes.

1.2.4 Test tickers

Some tickers are for internal exchange testing purposes, and must be filtered out.

NYSE test tickers: `ATEST`, `CTEST`, `MEST`, `NTEST`, `ZTST`, and `CBX`.

NASDAQ test tickers: `ZAZZT`, `ZBZZT`, `ZJZZT`, `ZVZZT`, `ZXYZ_A`, and `ZVZZCNX`.
With dot or underscore convention, both the whole ticker and the root token is examined.

1.3 Indices as additional features

1.3.1 S&P500 market index

The S&P500 market index, denoted `$SPX` is scraped from Yahoo Finance. We use the following endpoint:

```
endpoint = 'https://query1.finance.yahoo.com/v7/finance/download/%5EGSPC'
endpoint += '?period1={}&period2={}&interval=1d&events=history'
```

The API provides the following columns: `open, high, low, close, volume`, and `adj_close`. We can calculate an adjustment ratio κ_a = `adj_close`/`close`. This allows us to also calculate `adj_open, adj_high, adj_low`, and `adj_volume`.

1.3.2 VIX market volatillity index

The VIX market volatillity index, denoted `$VIX` is scraped from Yahoo Finance. We use the following endpoint:

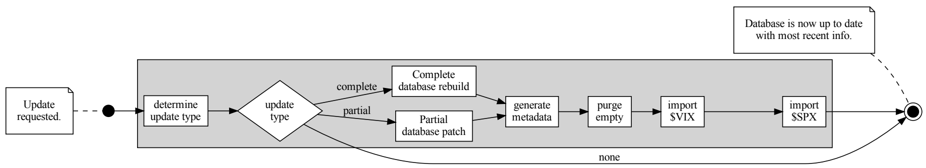
```
endpoint = 'https://query1.finance.yahoo.com/v7/finance/download/%5EVIX'
endpoint += '?period1={}&period2={}&interval=1d&events=history'
```

We only use the `adj_close` column.

1.4 IB symbol lookup

Interactive Brokers' TWS API allows one to query symbols in order to map ticker names to TWS contracts. This is both a way to determine if a symbol is currently tradable, and enables one to capture high frequency tick level market data.

Figure 1.2: Incremental update mechanism



1.5 Incremental database updates

Quandl's Python API has bulk download functionality which can used to build a local database. The bulk download can either be the whole EOD database, or a partial patch file to update dataset when it is a maximum of 1 day behind.

1.5.1 Determining update type

Past updates are tracked in a JSON file. A complete database rebuild is triggered under the following conditions:

1. `qdl.sqlite3` database file not found.
2. JSON update history file not found.
3. JSON update history file currupted or invalid keys.
4. No past updates.
5. Version bump detected.
6. Database is more than 1 day out of date.

We can determine by how many days the database is out of date by using `pandas_market_calendars` to count the number of trading days between the latest date in the sqlite3 database, and the latest date in the patch file, downloaded via the Quandl API.

```
# Get NYSE and NASDAQ trading days in current date range.
nyse = mcal.get_calendar('NYSE').schedule(start_date=last_date,
                                          end_date=newest_date)
nasdaq = mcal.get_calendar('NASDAQ').schedule(start_date=last_date,
                                              end_date=newest_date)

# Check assumption that NYSE and NASDAQ have same calendars.
pd.testing.assert_frame_equal(nyse, nasdaq)

missing_days = len(nyse.index) - 1
```

Figure 1.3: Determining update type

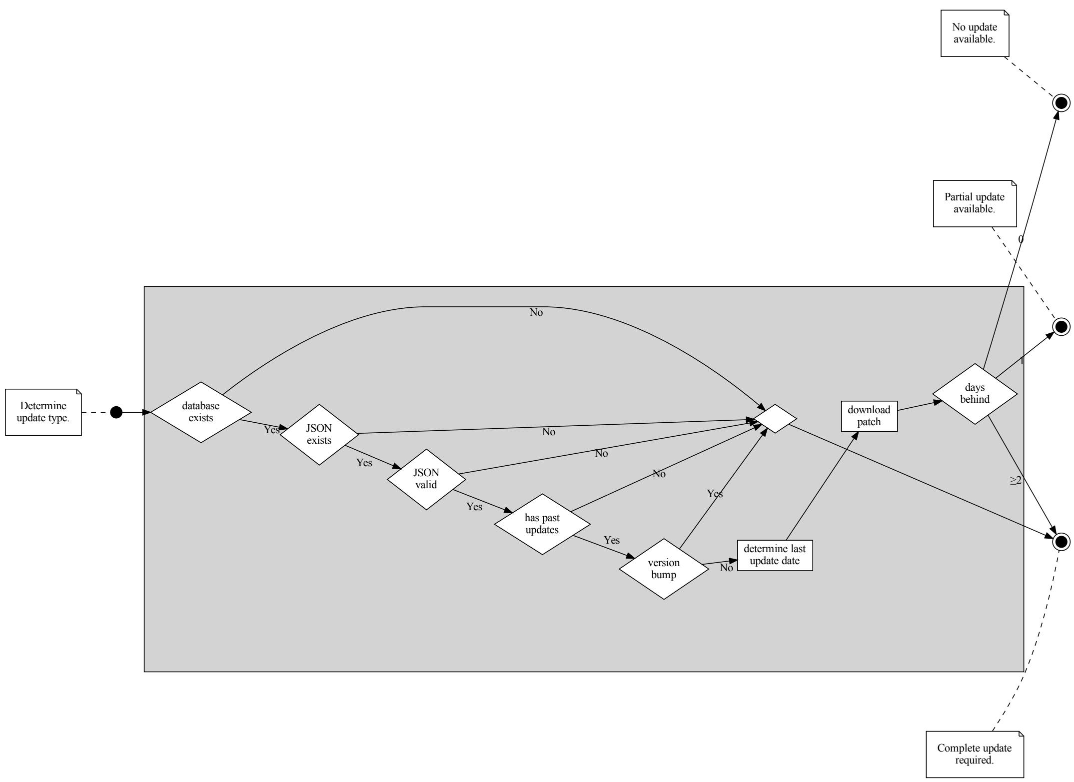
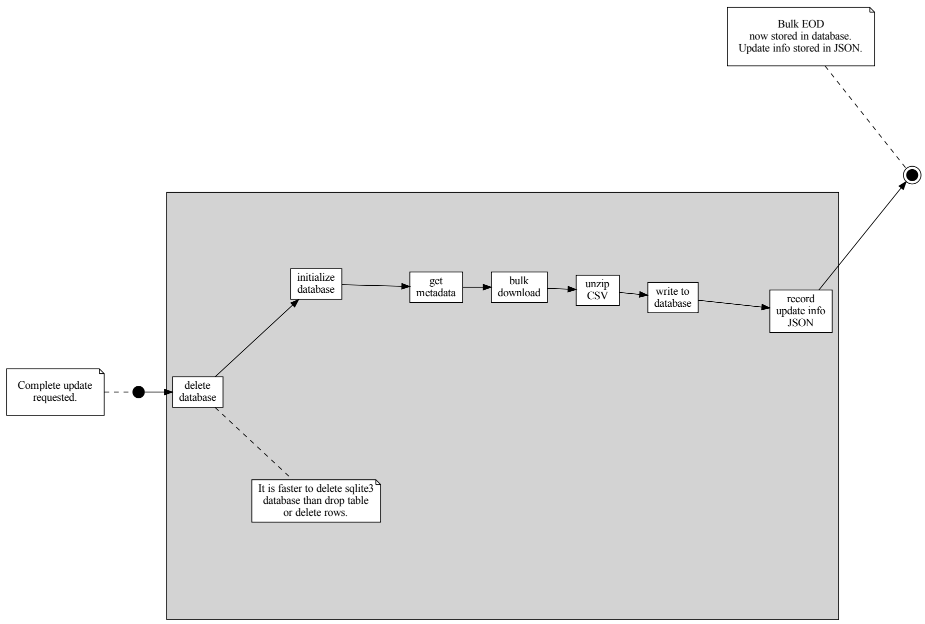


Figure 1.4: Complete database rebuild



1.5.2 Complete database rebuild

When we are forced to do a complete database rebuild, the entire EOD dataset must be downloaded via the Quandl API. The following API call is used:

```
quandl.bulkdownload('EOD',
                    api_key=settings.QUANDL_API_KEY,
                    download_type='complete')
```

The result is zip file in the current working directory (approximately 1Gb). The file is unzipped and its records are placed into the `qdl.sqlite3` database.

1.5.3 Partial database patch

When the database has been kept up to date, and all other conditions for partial update are met, we can significantly speed up the database update, by only downloading a small patch file. The following Quandl API call is used:

```
quandl.bulkdownload('EOD',
                    api_key=settings.QUANDL_API_KEY,
                    download_type='partial')
```

The patch may include both new rows for new trading days, but also corrections and row updates (for things such as adjustments, due to corporate action). New rows are simply appended. Retroactive updates are applied by deleting matching old rows, and inserting new values.

Chapter 2

Realtime strategy

2.1 Feature engineering

2.1.1 Technical indicators

EMA

A simple exponential moving average can be used to smooth the timeseries. Given some length l and smoothing parameter α, we can calculate EMA as follows:

$$\mathrm{EMA}_t = \left(x_t * \frac{\alpha}{1+l}\right) + \mathrm{EMA}_{t-1} * \left(1 - \frac{\alpha}{1+l}\right) \tag{2.1}$$

Since we require EMA_{t-1} at time step t, for $t = 0$ we can simply use $\mathrm{EMA}_0 = x_0$, i.e., we initialize the moving average with the starting value of $\boldsymbol{x}$.

MACD

Moving Average Convergence Divergence is a trend-following momentum indicator. It is calculated as the difference between two moving avareges. Typically values are $l_1 = 12, l_2 = 26$, and $\alpha = 0.5$, for daily prices. It is simply calculated with

$$\mathrm{MACD}_t = \mathrm{EMA}_t^{(1)} - \mathrm{EMA}_t^{(2)} \tag{2.2}$$

It is common to smoothe the MACD signal by applying an EMA on its output. Buy/sell signals can be generated by zero-crossings.

Bollinger Bands

2.1.2 Probability distribution fitting

2.1.3 Heavy-tailed process

The log returns of financial time series typically follow a heavy-tailed distribution. The probability of extreme price swings fall off slowly.

The Lambert W transform can be used to model heavier-tailed process as in done in Quant GAN.

2.2 Naive strategy

Chapter 3

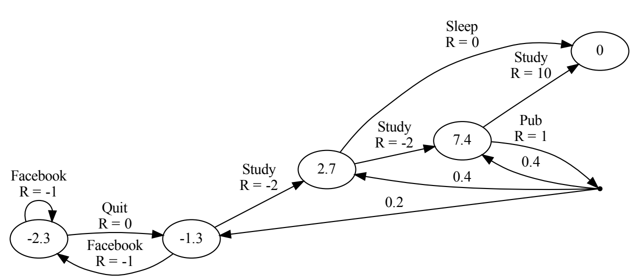
Reinforcement learning

3.1 Markov Decision Process

A Markov decision process is defined as (S, A, P_a, R_a) with

- S is the state space.
- A is the action space; A_s is the set of actions available in state s.
- $P_a(s, s') = Pr(s_{t+1} = s' | s_t = s, a_t = a)$ is the probability that action a in state s will lead to transition $s \to s'$ for timestep $t \to t+1$.
- $R_a(s, s')$ is the immediate reward received from the transition $s \to s'$ as result of action a.

Figure 3.1: MDP example from David Silver's RL lectures



3.2 REINFORCE

The policy gradient equation is

Chapter 4

Actor Critic

$$\nabla_\theta J(\theta) = \mathbb{E}_\tau \left[\sum_{t=0}^{T-1} \nabla_\theta \log \pi_\theta \left(a_t | s_t \right) G_t \right] \tag{4.1}$$

$$\nabla_\theta J(\theta) = \mathbb{E}_\tau \left[\sum_{t=0}^{T-1} \nabla_\theta \log \pi_\theta \left(a_t | s_t \right) \left(G_t - b(s_t) \right) \right] \tag{4.2}$$

$$\nabla_\theta(\theta) = \mathbb{E}_{s_0, a_0, \ldots, s_t, a_t} \left[\sum_{t=0}^{T-1} \nabla_\theta \log \pi_\theta(a_t | s_t) \right] \mathbb{E}_{r_{t+1}, s_{t+1}, \ldots, r_T, s_T} \left[G_t \right] \tag{4.3}$$

Second term is the Q value.

$$Q(s_t, a_t) = \mathbb{E}_{r_{t+1}, s_{t+1}, \ldots, r_T, s_T} \left[G_t \right] \tag{4.4}$$

The update equation is then:
Actor Critic algorithms can be summarized as:

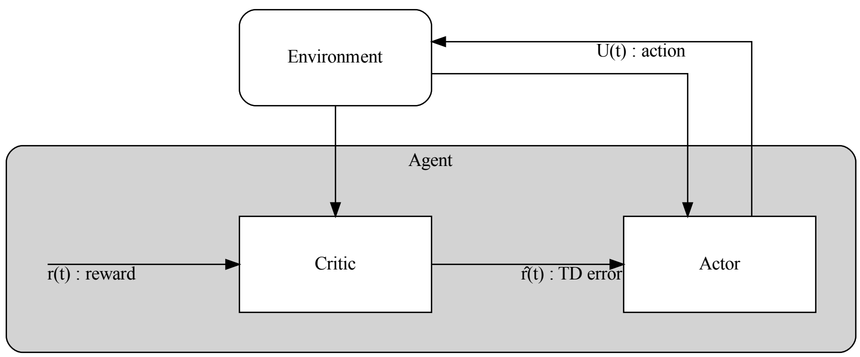
1. The *critic* estimates the value function; either action value $Q(s_t, a_t)$ or state value $V(s_t)$.
2. The *actor* update policy distribution $\pi_\theta(a_t | s_t)$ in the direction suggested by *critic*.

The evaluation of the TD error is

$$\delta_t = r_{t+1} + \gamma V(s_{t+1}) + V(s_t) \tag{4.5}$$

$$\pi_t(s, a) = Pr \left\{ a_t = 0 | s_t = s \right\} = \frac{e^{p(s,a)}}{\sum_b e^{p(s,b)}} \tag{4.6}$$

Figure 4.1: Actor Critic Algorithm



Chapter 5

Discrete Soft Actor Critic

Chapter 6

Planned future work