

Table of Contents

Preface	xiii
Chapter 1: Machine Learning for Trading – From Idea to Execution	1
The rise of ML in the investment industry	2
From electronic to high-frequency trading	3
Factor investing and smart beta funds	5
Algorithmic pioneers outperform humans	7
ML and alternative data	10
Crowdsourcing trading algorithms	11
Designing and executing an ML-driven strategy	12
Sourcing and managing data	13
From alpha factor research to portfolio management	13
Strategy backtesting	15
ML for trading – strategies and use cases	15
The evolution of algorithmic strategies	15
Use cases of ML for trading	16
Summary	19
Chapter 2: Market and Fundamental Data – Sources and Techniques	21
Market data reflects its environment	22
Market microstructure – the nuts and bolts	23
How to trade – different types of orders	23
Where to trade – from exchanges to dark pools	24
Working with high-frequency data	26
How to work with Nasdaq order book data	26
Communicating trades with the FIX protocol	27
The Nasdaq TotalView-ITCH data feed	27
From ticks to bars – how to regularize market data	35
AlgoSeek minute bars – equity quote and trade data	40
API access to market data	44
Remote data access using pandas	44
yfinance – scraping data from Yahoo! Finance	46

Quantopian	48
Zipline	48
Quandl	50
Other market data providers	50
How to work with fundamental data	51
Financial statement data	51
Other fundamental data sources	56
Efficient data storage with pandas	57
Summary	58
Chapter 3: Alternative Data for Finance – Categories and Use Cases	59
The alternative data revolution	60
Sources of alternative data	62
Individuals	62
Business processes	63
Sensors	63
Criteria for evaluating alternative data	65
Quality of the signal content	65
Quality of the data	67
Technical aspects	68
The market for alternative data	69
Data providers and use cases	70
Working with alternative data	72
Scraping OpenTable data	72
Scraping and parsing earnings call transcripts	77
Summary	80
Chapter 4: Financial Feature Engineering – How to Research	81
Alpha Factors	81
Alpha factors in practice – from data to signals	82
Building on decades of factor research	84
Momentum and sentiment – the trend is your friend	84
Value factors – hunting fundamental bargains	88
Volatility and size anomalies	90
Quality factors for quantitative investing	92
Engineering alpha factors that predict returns	94
How to engineer factors using pandas and NumPy	94
How to use TA-Lib to create technical alpha factors	99
Denoising alpha factors with the Kalman filter	100
How to preprocess your noisy signals using wavelets	104
From signals to trades – Zipline for backtests	106
How to backtest a single-factor strategy	106
Combining factors from diverse data sources	109
Separating signal from noise with Alphalens	111
Creating forward returns and factor quantiles	112
Predictive performance by factor quantiles	113

The information coefficient	115
Factor turnover	117
Alpha factor resources	118
Alternative algorithmic trading libraries	118
Summary	119
Chapter 5: Portfolio Optimization and Performance Evaluation	121
How to measure portfolio performance	122
Capturing risk-return trade-offs in a single number	122
The fundamental law of active management	124
How to manage portfolio risk and return	125
The evolution of modern portfolio management	125
Mean-variance optimization	127
Alternatives to mean-variance optimization	131
Risk parity	134
Risk factor investment	135
Hierarchical risk parity	135
Trading and managing portfolios with Zipline	136
Scheduling signal generation and trade execution	137
Implementing mean-variance portfolio optimization	138
Measuring backtest performance with pyfolio	140
Creating the returns and benchmark inputs	141
Walk-forward testing – out-of-sample returns	142
Summary	146
Chapter 6: The Machine Learning Process	147
How machine learning from data works	148
The challenge – matching the algorithm to the task	149
Supervised learning – teaching by example	149
Unsupervised learning – uncovering useful patterns	150
Reinforcement learning – learning by trial and error	152
The machine learning workflow	153
Basic walkthrough – k-nearest neighbors	154
Framing the problem – from goals to metrics	154
Collecting and preparing the data	160
Exploring, extracting, and engineering features	160
Selecting an ML algorithm	162
Design and tune the model	162
How to select a model using cross-validation	165
How to implement cross-validation in Python	166
Challenges with cross-validation in finance	168
Parameter tuning with scikit-learn and Yellowbrick	170
Summary	172
Chapter 7: Linear Models – From Risk Factors to Return Forecasts	173
From inference to prediction	174

The baseline model – multiple linear regression	175
How to formulate the model	175
How to train the model	176
The Gauss–Markov theorem	179
How to conduct statistical inference	180
How to diagnose and remedy problems	181
How to run linear regression in practice	184
OLS with statsmodels	184
Stochastic gradient descent with sklearn	186
How to build a linear factor model	187
From the CAPM to the Fama–French factor models	188
Obtaining the risk factors	189
Fama–Macbeth regression	191
Regularizing linear regression using shrinkage	194
How to hedge against overfitting	194
How ridge regression works	195
How lasso regression works	196
How to predict returns with linear regression	197
Preparing model features and forward returns	197
Linear OLS regression using statsmodels	203
Linear regression using scikit-learn	205
Ridge regression using scikit-learn	208
Lasso regression using sklearn	210
Comparing the quality of the predictive signals	212
Linear classification	212
The logistic regression model	213
How to conduct inference with statsmodels	215
Predicting price movements with logistic regression	217
Summary	219
Chapter 8: The ML4T Workflow –	
From Model to Strategy Backtesting	221
How to backtest an ML-driven strategy	222
Backtesting pitfalls and how to avoid them	223
Getting the data right	224
Getting the simulation right	225
Getting the statistics right	226
How a backtesting engine works	227
Vectorized versus event-driven backtesting	228
Key implementation aspects	230
backtrader – a flexible tool for local backtests	232
Key concepts of backtrader's Cerebro architecture	232
How to use backtrader in practice	235
backtrader summary and next steps	239
Zipline – scalable backtesting by Quantopian	239

Calendars and the Pipeline for robust simulations	240
Ingesting your own bundles with minute data	242
The Pipeline API – backtesting an ML signal	245
How to train a model during the backtest	250
Instead of How to use	254
Summary	254
Chapter 9: Time-Series Models for Volatility Forecasts and Statistical Arbitrage	255
Tools for diagnostics and feature extraction	256
How to decompose time-series patterns	257
Rolling window statistics and moving averages	258
How to measure autocorrelation	259
How to diagnose and achieve stationarity	260
Transforming a time series to achieve stationarity	261
Handling instead of How to handle	261
Time-series transformations in practice	263
Univariate time-series models	265
How to build autoregressive models	266
How to build moving-average models	267
How to build ARIMA models and extensions	268
How to forecast macro fundamentals	270
How to use time-series models to forecast volatility	272
Multivariate time-series models	276
Systems of equations	277
The vector autoregressive (VAR) model	277
Using the VAR model for macro forecasts	278
Cointegration – time series with a shared trend	281
The Engle-Granger two-step method	282
The Johansen likelihood-ratio test	282
Statistical arbitrage with cointegration	283
How to select and trade comoving asset pairs	283
Pairs trading in practice	285
Preparing the strategy backtest	288
Backtesting the strategy using backtrader	292
Extensions – how to do better	294
Summary	294
Chapter 10: Bayesian ML – Dynamic Sharpe Ratios and Pairs Trading	295
How Bayesian machine learning works	296
How to update assumptions from empirical evidence	297
Exact inference – maximum a posteriori estimation	298
Deterministic and stochastic approximate inference	301
Probabilistic programming with PyMC3	305
Bayesian machine learning with Theano	305

The PyMC3 workflow: predicting a recession	305
Bayesian ML for trading	317
Bayesian Sharpe ratio for performance comparison	317
Bayesian rolling regression for pairs trading	320
Stochastic volatility models	323
Summary	326
Chapter 11: Random Forests – A Long-Short Strategy for Japanese Stocks	327
Decision trees – learning rules from data	328
How trees learn and apply decision rules	328
Decision trees in practice	330
Overfitting and regularization	336
Hyperparameter tuning	338
Random forests – making trees more reliable	345
Why ensemble models perform better	345
Bootstrap aggregation	346
How to build a random forest	349
How to train and tune a random forest	350
Feature importance for random forests	352
Out-of-bag testing	352
Pros and cons of random forests	353
Long-short signals for Japanese stocks	353
The data – Japanese equities	354
The ML4T workflow with LightGBM	355
The strategy – backtest with Zipline	362
Summary	364
Chapter 12: Boosting Your Trading Strategy	365
Getting started – adaptive boosting	366
The AdaBoost algorithm	367
Using AdaBoost to predict monthly price moves	368
Gradient boosting – ensembles for most tasks	370
How to train and tune GBM models	372
How to use gradient boosting with sklearn	374
Using XGBoost, LightGBM, and CatBoost	378
How algorithmic innovations boost performance	379
A long-short trading strategy with boosting	383
Generating signals with LightGBM and CatBoost	383
Inside the black box - interpreting GBM results	391
Backtesting a strategy based on a boosting ensemble	399
Lessons learned and next steps	401
Boosting for an intraday strategy	402
Engineering features for high-frequency data	402
Minute-frequency signals with LightGBM	404
Evaluating the trading signal quality	405

Summary	406
Chapter 13: Data-Driven Risk Factors and Asset Allocation with Unsupervised Learning	407
Dimensionality reduction	408
The curse of dimensionality	409
Linear dimensionality reduction	411
Manifold learning – nonlinear dimensionality reduction	418
PCA for trading	421
Data-driven risk factors	421
Eigenportfolios	424
Clustering	426
k-means clustering	427
Hierarchical clustering	429
Density-based clustering	431
Gaussian mixture models	432
Hierarchical clustering for optimal portfolios	433
How hierarchical risk parity works	433
Backtesting HRP using an ML trading strategy	435
Summary	438
Chapter 14: Text Data for Trading – Sentiment Analysis	439
ML with text data – from language to features	440
Key challenges of working with text data	440
The NLP workflow	441
Applications	443
From text to tokens – the NLP pipeline	443
NLP pipeline with spaCy and textacy	444
NLP with TextBlob	448
Counting tokens – the document-term matrix	449
The bag-of-words model	450
Document-term matrix with scikit-learn	451
Key lessons instead of lessons learned	455
NLP for trading	455
The naive Bayes classifier	456
Classifying news articles	457
Sentiment analysis with Twitter and Yelp data	458
Summary	462
Chapter 15: Topic Modeling – Summarizing Financial News	463
Learning latent topics – Goals and approaches	464
Latent semantic indexing	465
How to implement LSI using sklearn	466
Strengths and limitations	468
Probabilistic latent semantic analysis	469
How to implement pLSA using sklearn	470

Strengths and limitations	471
Latent Dirichlet allocation	471
How LDA works	471
How to evaluate LDA topics	473
How to implement LDA using sklearn	475
How to visualize LDA results using pyLDAvis	475
How to implement LDA using Gensim	476
Modeling topics discussed in earnings calls	478
Data preprocessing	478
Model training and evaluation	479
Running experiments	480
Topic modeling for with financial news	481
Summary	482
Chapter 16: Word Embeddings for Earnings Calls and SEC Filings	483
How word embeddings encode semantics	484
How neural language models learn usage in context	485
word2vec – scalable word and phrase embeddings	485
Evaluating embeddings using semantic arithmetic	487
How to use pretrained word vectors	489
GloVe – Global vectors for word representation	489
Custom embeddings for financial news	491
Preprocessing – sentence detection and n-grams	492
The skip-gram architecture in TensorFlow 2	493
Visualizing embeddings using TensorBoard	496
How to train embeddings faster with Gensim	497
word2vec for trading with SEC filings	499
Preprocessing – sentence detection and n-grams	500
Model training	501
Sentiment analysis using doc2vec embeddings	503
Creating doc2vec input from Yelp sentiment data	503
Training a doc2vec model	504
Training a classifier with document vectors	505
Lessons learned and next steps	507
New frontiers – pretrained transformer models	507
Attention is all you need	508
BERT – towards a more universal language model	509
Trading on text data – lessons learned and next steps	511
Summary	511
Chapter 17: Deep Learning for Trading	513
Deep learning – what's new and why it matters	514
Hierarchical features tame high-dimensional data	515
DL as representation learning	516
How DL relates to ML and AI	517
Designing an NN	518

A simple feedforward neural network architecture	519
Key design choices	520
How to regularize deep NNs	522
Training faster – optimizations for deep learning	523
Summary – how to tune key hyperparameters	525
A neural network from scratch in Python	526
The input layer	526
The hidden layer	527
The output layer	528
Forward propagation	529
The cross-entropy cost function	529
How to implement backprop using Python	529
Popular deep learning libraries	534
Leveraging GPU acceleration	534
How to use TensorFlow 2	535
How to use TensorBoard	537
How to use PyTorch 1.4	538
Alternative options	541
Optimizing an NN for a long-short strategy	542
Engineering features to predict daily stock returns	542
Defining an NN architecture framework	542
Cross-validating design options to tune the NN	543
Evaluating the predictive performance	545
Backtesting a strategy based on ensembled signals	547
How to further improve the results	549
Summary	549
Chapter 18: CNNs for Financial Time Series and Satellite Images	551
How CNNs learn to model grid-like data	552
From hand-coding to learning filters from data	553
How the elements of a convolutional layer operate	554
The evolution of CNN architectures: key innovations	558
CNNs for satellite images and object detection	559
LeNet5 – The first CNN with industrial applications	560
AlexNet – reigniting deep learning research	563
Transfer learning – faster training with less data	565
Object detection and segmentation	573
Object detection in practice	573
CNNs for time-series data – predicting returns	577
An autoregressive CNN with 1D convolutions	577
CNN-TA – clustering time series in 2D format	581
Summary	589
Chapter 19: RNNs for Multivariate Time Series and Sentiment Analysis	591
How recurrent neural nets work	592

Unfolding a computational graph with cycles	594
Backpropagation through time	594
Alternative RNN architectures	595
How to design deep RNNs	596
The challenge of learning long-range dependencies	597
Gated recurrent units	599
RNNs for time series with TensorFlow 2	599
Univariate regression – predicting the S&P 500	600
How to get time series data into shape for an RNN	600
Stacked LSTM – predicting price moves and returns	605
Multivariate time-series regression for macro data	611
RNNs for text data	614
LSTM with embeddings for sentiment classification	614
Sentiment analysis with pretrained word vectors	617
Predicting returns from SEC filing embeddings	619
Summary	624
Chapter 20: Autoencoders for Conditional Risk Factors and Asset Pricing	625
Autoencoders for nonlinear feature extraction	626
Generalizing linear dimensionality reduction	626
Convolutional autoencoders for image compression	627
Managing overfitting with regularized autoencoders	628
Fixing corrupted data with denoising autoencoders	628
Seq2seq autoencoders for time series features	629
Generative modeling with variational autoencoders	629
Implementing autoencoders with TensorFlow 2	630
How to prepare the data	630
One-layer feedforward autoencoder	631
Feedforward autoencoder with sparsity constraints	634
Deep feedforward autoencoder	634
Convolutional autoencoders	636
Denoising autoencoders	637
A conditional autoencoder for trading	638
Sourcing stock prices and metadata information	639
Computing predictive asset characteristics	641
Creating the conditional autoencoder architecture	643
Lessons learned and next steps	648
Summary	648
Chapter 21: Generative Adversarial Networks for Synthetic Time-Series Data	649
Creating synthetic data with GANs	650
Comparing generative and discriminative models	651
Adversarial training – a zero-sum game of trickery	651
The rapid evolution of the GAN architecture zoo	652

GAN applications to images and time-series data	653
How to build a GAN using TensorFlow 2	655
Building the generator network	655
Creating the discriminator network	656
Setting up the adversarial training process	657
Evaluating the results	660
TimeGAN for synthetic financial data	660
Learning to generate data across features and time	661
Implementing TimeGAN using TensorFlow 2	663
Evaluating the quality of synthetic time-series data	672
Lessons learned and next steps	678
Summary	678
Chapter 22: Deep Reinforcement Learning – Building a Trading Agent	679
Elements of a reinforcement learning system	680
The policy – translating states into actions	681
Rewards – learning from actions	681
The value function – optimal choice for the long run	682
With or without a model – look before you leap?	682
How to solve reinforcement learning problems	682
Key challenges in solving RL problems	683
Fundamental approaches to solving RL problems	683
Solving dynamic programming problems	684
Finite Markov decision problems	684
Policy iteration	687
Value iteration	688
Generalized policy iteration	688
Dynamic programming in Python	689
Q-learning – finding an optimal policy on the go	694
Exploration versus exploitation – ϵ -greedy policy	695
The Q-learning algorithm	695
How to train a Q-learning agent using Python	695
Deep RL for trading with the OpenAI Gym	696
Value function approximation with neural networks	697
The Deep Q-learning algorithm and extensions	697
Introducing the OpenAI Gym	699
How to implement DDQN using TensorFlow 2	700
Creating a simple trading agent	704
How to design a custom OpenAI trading environment	705
Deep Q-learning on the stock market	709
Lessons learned	711
Summary	711
Chapter 23: Conclusions and Next Steps	713
Key takeaways and lessons learned	714

Data is the single most important ingredient	715
Domain expertise – telling the signal from the noise	716
ML is a toolkit for solving problems with data	717
Beware of backtest overfitting	719
How to gain insights from black-box models	719
ML for trading in practice	720
Data management technologies	720
ML tools	722
Online trading platforms	722
Conclusion	723
Appendix: Alpha Factor Library	725
Common alpha factors implemented in TA-Lib	726
A key building block – moving averages	726
Overlap studies – price and volatility trends	729
Momentum indicators	733
Volume and liquidity indicators	741
Volatility indicators	743
Fundamental risk factors	744
WorldQuant's quest for formulaic alphas	745
Cross-sectional and time-series functions	745
Formulaic alpha expressions	747
Bivariate and multivariate factor evaluation	749
Information coefficient and mutual information	749
Feature importance and SHAP values	750
Comparison – the top 25 features for each metric	750
Financial performance – Alphas	752
References	753
Index	769