Contents

Al	About the Author xxi				
Ρŀ	PREAMBLE 1				
1	Fina	ncial N	Machine Learning as a Distinct Subject	3	
	1.1	Motiv	ation, 3		
	1.2	The M	fain Reason Financial Machine Learning Projects Usually Fail,	4	
		1.2.1	The Sisyphus Paradigm, 4		
		1.2.2	The Meta-Strategy Paradigm, 5		
	1.3	Book	Structure, 6		
		1.3.1	Structure by Production Chain, 6		
		1.3.2	Structure by Strategy Component, 9		
		1.3.3	Structure by Common Pitfall, 12		
	1.4	Target	Audience, 12		
	1.5	Requi	sites, 13		
	1.6	FAQs,	, 14		
	1.7	Ackno	owledgments, 18		
	Exer	cises,	19		
	Refe	rences,	20		
	Bibl	iograph	y, 20		
PA	ART 1	DAT	'A ANALYSIS	21	
2	Fina	ncial I	Data Structures	23	
	2.1	Motiv	ation, 23		

X CONTENTS

2.2	Essential Types of Financial Data, 23		
	2.2.1 Fundamental Data, 23		
	2.2.2 Market Data, 24		
	2.2.3 Analytics, 25		
	2.2.4 Alternative Data, 25		
2.3	Bars, 25		
	2.3.1 Standard Bars, 26		
	2.3.2 Information-Driven Bars, 29		
2.4	Dealing with Multi-Product Series, 32		
	2.4.1 The ETF Trick, 33		
	2.4.2 PCA Weights, 35		
	2.4.3 Single Future Roll, 36		
2.5	Sampling Features, 38		
	2.5.1 Sampling for Reduction, 38		
	2.5.2 Event-Based Sampling, 38		
Exer	rcises, 40		
	erences, 41		
Lab	eling	43	
3.1	Motivation, 43		
3.2	The Fixed-Time Horizon Method, 43		
3.3	Computing Dynamic Thresholds, 44		
3.4	The Triple-Barrier Method, 45		
3.5	Learning Side and Size, 48		
3.6	Meta-Labeling, 50		
3.7	How to Use Meta-Labeling, 51		
3.8	The Quantamental Way, 53		
3.9	Dropping Unnecessary Labels, 54		
Exer	rcises, 55		
Bibli	iography, 56		
Sam	ple Weights	59	
4.1	Motivation, 59		
4.2	Overlapping Outcomes, 59		
4.3	Number of Concurrent Labels, 60		
4.4	Average Uniqueness of a Label, 61		
4.5	Bagging Classifiers and Uniqueness, 62		
	4.5.1 Sequential Bootstrap, 63		
	4.5.2 Implementation of Sequential Bootstrap, 64		

		4.5.3 A Numerical Example, 65			
		4.5.4 Monte Carlo Experiments, 66			
	4.6 Return Attribution, 68				
	4.7 Time Decay, 70				
	4.8	Class Weights, 71			
	Exer	cises, 72			
	Refe	erences, 73			
	Bibl	iography, 73			
5	Frac	ctionally Differentiated Features	75		
	5.1	Motivation, 75			
	5.2	The Stationarity vs. Memory Dilemma, 75			
	5.3	Literature Review, 76			
	5.4	The Method, 77			
		5.4.1 Long Memory, 77			
		5.4.2 Iterative Estimation, 78			
		5.4.3 Convergence, 80			
	5.5	Implementation, 80			
		5.5.1 Expanding Window, 80			
		5.5.2 Fixed-Width Window Fracdiff, 82			
	5.6	Stationarity with Maximum Memory Preservation, 84			
	5.7	Conclusion, 88			
		rcises, 88			
		prences, 89			
	Bibl	iography, 89			
PA	RT 2	MODELLING	91		
6	Ense	emble Methods	93		
	6.1	Motivation, 93			
	6.2	The Three Sources of Errors, 93			
	6.3	Bootstrap Aggregation, 94			
		6.3.1 Variance Reduction, 94			
		6.3.2 Improved Accuracy, 96			
	٠.	6.3.3 Observation Redundancy, 97			
	6.4	Random Forest, 98			
	6.5	Boosting, 99			

xii CONTENTS

	Refe	Bagging vs. Boosting in Finance, 100 Bagging for Scalability, 101 rcises, 101 erences, 102 iography, 102	
7	Cro	ss-Validation in Finance	103
	7.1	Motivation, 103	
	7.2	The Goal of Cross-Validation, 103	
	7.3	Why K-Fold CV Fails in Finance, 104	
	7.4	A Solution: Purged K-Fold CV, 105	
		7.4.1 Purging the Training Set, 105	
		7.4.2 Embargo, 107	
		7.4.3 The Purged K-Fold Class, 108	
	7.5	Bugs in Sklearn's Cross-Validation, 109	
	Exe	rcises, 110	
	Bibl	iography, 111	
8	Feat	ture Importance	113
	8.1	Motivation, 113	
	8.2	The Importance of Feature Importance, 113	
	8.3	Feature Importance with Substitution Effects, 114	
		8.3.1 Mean Decrease Impurity, 114	
		8.3.2 Mean Decrease Accuracy, 116	
	8.4	Feature Importance without Substitution Effects, 117	
		8.4.1 Single Feature Importance, 117	
		8.4.2 Orthogonal Features, 118	
	8.5	Parallelized vs. Stacked Feature Importance, 121	
	8.6	Experiments with Synthetic Data, 122	
	Exe	rcises, 127	
	Refe	erences, 127	
9	Нур	er-Parameter Tuning with Cross-Validation	129
	9.1	Motivation, 129	
	9.2	Grid Search Cross-Validation, 129	
	9.3	Randomized Search Cross-Validation, 131	
		9.3.1 Log-Uniform Distribution, 132	

CON	CONTENTS xiii					
	Exercis	ses, 135				
	References, 136					
	Bibliography, 137					
PAI	RT 3	BACKTESTING	139			
10	Bet S	lizing	141			
	10.1	Motivation, 141				
	10.2	Strategy-Independent Bet Sizing Approaches, 141				
	10.3	Bet Sizing from Predicted Probabilities, 142				
	10.4	Averaging Active Bets, 144				
	10.5	Size Discretization, 144				
	10.6	Dynamic Bet Sizes and Limit Prices, 145				
	Exerc	rises, 148				
		rences, 149				
	Biblio	ography, 149				
11	The I	Dangers of Backtesting	151			
	11.1	Motivation, 151				
		Mission Impossible: The Flawless Backtest, 151				
		Even If Your Backtest Is Flawless, It Is Probably Wrong, 152				
	11.4	,				
	11.5	A Few General Recommendations, 153				
	11.6	Strategy Selection, 155				
		tises, 158				
		rences, 158				
	BIDIIC	ography, 159				
12	Back	testing through Cross-Validation	161			
	12.1	Motivation, 161				
	12.2	The Walk-Forward Method, 161				
		12.2.1 Pitfalls of the Walk-Forward Method, 162				
	12.3	The Cross-Validation Method, 162				
	12.4	The Combinatorial Purged Cross-Validation Method, 163				
		12.4.1 Combinatorial Splits, 164				
		12.4.2 The Combinatorial Purged Cross-Validation Backtesting Algorithm, 165				

12.4.3 A Few Examples, 165

xiv CONTENTS

12.5 How Combinatorial Purged Cross-Validation Addresses Backtest Overfitting, 166						
	Exerc	rises, 167				
	Refer	ences, 168				
13	Back	testing on Synthetic Data	169			
	13.1	Motivation, 169				
	13.2	Trading Rules, 169				
	13.3	The Problem, 170				
	13.4	Our Framework, 172				
	13.5	Numerical Determination of Optimal Trading Rules, 173				
		13.5.1 The Algorithm, 173				
		13.5.2 Implementation, 174				
	13.6	Experimental Results, 176				
		13.6.1 Cases with Zero Long-Run Equilibrium, 177				
		13.6.2 Cases with Positive Long-Run Equilibrium, 180				
		13.6.3 Cases with Negative Long-Run Equilibrium, 182				
	13.7	Conclusion, 192				
	Exerc	ises, 192				
	Refer	ences, 193				
14	Back	test Statistics	195			
	14.1	Motivation, 195				
	14.2	Types of Backtest Statistics, 195				
	14.3	General Characteristics, 196				
	14.4	Performance, 198				
		14.4.1 Time-Weighted Rate of Return, 198				
	14.5	Runs, 199				
		14.5.1 Returns Concentration, 199				
		14.5.2 Drawdown and Time under Water, 201				
		14.5.3 Runs Statistics for Performance Evaluation, 201				
	14.6	Implementation Shortfall, 202				
	14.7	Efficiency, 203				
		14.7.1 The Sharpe Ratio, 203				
		14.7.2 The Probabilistic Sharpe Ratio, 203				
		14.7.3 The Deflated Sharpe Ratio, 204				
		14.7.4 Efficiency Statistics, 205				
	14.8	Classification Scores, 206				
	14.9	Attribution, 207				

CONTENTS XV

		es, 208 ces, 209 raphy, 209	
15	5 Understanding Strategy Risk		
	15.1 15.2 15.3 15.4	Motivation, 211 Symmetric Payouts, 211 Asymmetric Payouts, 213 The Probability of Strategy Failure, 216 15.4.1 Algorithm, 217 15.4.2 Implementation, 217	
		ces, 220	
16			221
	16.1 Motivation, 221 16.2 The Problem with Convex Portfolio Optimization, 221 16.3 Markowitz's Curse, 222 16.4 From Geometric to Hierarchical Relationships, 223 16.4.1 Tree Clustering, 224 16.4.2 Quasi-Diagonalization, 229 16.4.3 Recursive Bisection, 229 16.5 A Numerical Example, 231 16.6 Out-of-Sample Monte Carlo Simulations, 234 16.7 Further Research, 236 16.8 Conclusion, 238 Appendices, 239 16.A.1 Correlation-based Metric, 239 16.A.2 Inverse Variance Allocation, 239 16.A.3 Reproducing the Numerical Example, 240 16.A.4 Reproducing the Monte Carlo Experiment, 242 Exercises, 244		
PAI	RT 4 US	SEFUL FINANCIAL FEATURES	247
17	Structu	ral Breaks	249
	17.1 17.2	Motivation, 249 Types of Structural Break Tests, 249	

xvi CONTENTS

	17.3	CUSUN	M Tests, 250		
		17.3.1	Brown-Durbin-Evans CUSUM Test on Recursive		
			Residuals, 250		
		17.3.2	Chu-Stinchcombe-White CUSUM Test on Levels, 251		
	17.4	Explosi	veness Tests, 251		
		17.4.1	Chow-Type Dickey-Fuller Test, 251		
		17.4.2	Supremum Augmented Dickey-Fuller, 252		
		17.4.3	Sub- and Super-Martingale Tests, 259		
	Exerc	ises, 26	1		
	Refer	ences, 2	61		
18	Entro	py Feat	ures	263	
	18.1	Motivat	tion, 263		
	18.2	Shanno	n's Entropy, 263		
	18.3	The Plu	g-in (or Maximum Likelihood) Estimator, 264		
	18.4	Lempel	-Ziv Estimators, 265		
	18.5	Encodi	ng Schemes, 269		
		18.5.1	Binary Encoding, 270		
		18.5.2	Quantile Encoding, 270		
		18.5.3	Sigma Encoding, 270		
	18.6	Entropy	of a Gaussian Process, 271		
	18.7	Entropy	and the Generalized Mean, 271		
	18.8	A Few	Financial Applications of Entropy, 275		
		18.8.1	Market Efficiency, 275		
		18.8.2	Maximum Entropy Generation, 275		
		18.8.3	Portfolio Concentration, 275		
		18.8.4	Market Microstructure, 276		
	Exercises, 277				
	References, 278				
	Biblio	ography,	279		
10	3.41		LP 4	201	
19			ral Features	281	
	19.1		tion, 281		
	19.2		of the Literature, 281		
	19.3		eneration: Price Sequences, 282		
		19.3.1	The Tick Rule, 282		
		19.3.2	The Roll Model, 282		

xvii CONTENTS

		19.3.3	High-Low Volatility Estimator, 283	
		19.3.4	Corwin and Schultz, 284	
19.4 Second Generation: Strategic Trade Models, 286				
		19.4.1	Kyle's Lambda, 286	
		19.4.2	Amihud's Lambda, 288	
		19.4.3	Hasbrouck's Lambda, 289	
19.5 Third Generation: Sequential Trade Models, 290		Generation: Sequential Trade Models, 290		
		19.5.1	Probability of Information-based Trading, 290	
		19.5.2	Volume-Synchronized Probability of Informed Trading, 292	
	19.6	Additio	onal Features from Microstructural Datasets, 293	
		19.6.1	Distibution of Order Sizes, 293	
		19.6.2	Cancellation Rates, Limit Orders, Market Orders, 293	
		19.6.3	Time-Weighted Average Price Execution Algorithms, 294	,
		19.6.4	Options Markets, 295	
		19.6.5	Serial Correlation of Signed Order Flow, 295	
	19.7	What Is	s Microstructural Information?, 295	
	Exerc	ises, 29	5	
References, 298				
PAI	RT 5	HIGH-I	PERFORMANCE COMPUTING RECIPES	301
20	Multi	iprocessi	ing and Vectorization	303
	20.1	Motiva	tion, 303	
	20.2	Vectori	zation Example, 303	
	20.3	Single-	Thread vs. Multithreading vs. Multiprocessing, 304	
	20.4	Atoms	and Molecules, 306	
		20.4.1	Linear Partitions, 306	
		20.4.2	Two-Nested Loops Partitions, 307	
	20.5	Multipa	rocessing Engines, 309	
		20.5.1	Preparing the Jobs, 309	
		20.5.2	Asynchronous Calls, 311	
		20.5.3	Unwrapping the Callback, 312	
		20.5.4	Pickle/Unpickle Objects, 313	
		20.5.5	Output Reduction, 313	
	20.6	Multipa	rocessing Example, 315	
	Exerc	ises, 31	5	

xviii CONTENTS

		ence, 31 ography,			
21	Brute	e Force a	and Quantum Computers	319	
	21.1	Motiva	tion, 319		
	21.2	Combin	natorial Optimization, 319		
	21.3	The Ob	jective Function, 320		
	21.4	The Pro	oblem, 321		
	21.5	An Inte	ger Optimization Approach, 321		
			Pigeonhole Partitions, 321		
		21.5.2	Feasible Static Solutions, 323		
		21.5.3	Evaluating Trajectories, 323		
	21.6	A Num	erical Example, 325		
		21.6.1	Random Matrices, 325		
		21.6.2	Static Solution, 326		
		21.6.3	Dynamic Solution, 327		
	Exerc	ises, 32	7		
	Refer	ences, 3	28		
22	High-Performance Computational Intelligence and Forecasting Technologies Kesheng Wu and Horst D. Simon				
	Kesne	eng wu a	na Horst D. Simon		
	22.1	Motiva	tion, 329		
		U	tory Response to the Flash Crash of 2010, 329		
		_	ound, 330		
			ardware, 331		
	22.5		oftware, 335		
			Message Passing Interface, 335		
			Hierarchical Data Format 5, 336		
			In Situ Processing, 336		
			Convergence, 337		
	22.6		ses, 337		
			Supernova Hunting, 337		
			Blobs in Fusion Plasma, 338		
			Intraday Peak Electricity Usage, 340		
		22.6.4	The Flash Crash of 2010, 341		
		22.6.5	Volume-synchronized Probability of Informed Trading Calibration. 346		

CONTENTS	xix

	22.6.6	Revealing High Frequency Events with Non-uniform
		Fast Fourier Transform, 347
22.7	Summary and Call for Participation, 349	
22.8	Acknowledgments, 350	
References, 350		

Index 353