
Contents

Preface	vii
Reading Guide	xi
1 Introduction	1
1.1 Statistical Learning	1
1.2 Support Vector Machines: An Overview	7
1.3 History of SVMs and Geometrical Interpretation	13
1.4 Alternatives to SVMs	19
2 Loss Functions and Their Risks	21
2.1 Loss Functions: Definition and Examples	21
2.2 Basic Properties of Loss Functions and Their Risks	28
2.3 Margin-Based Losses for Classification Problems	34
2.4 Distance-Based Losses for Regression Problems	38
2.5 Further Reading and Advanced Topics	45
2.6 Summary	46
2.7 Exercises	46
3 Surrogate Loss Functions (*)	49
3.1 Inner Risks and the Calibration Function	51
3.2 Asymptotic Theory of Surrogate Losses	60
3.3 Inequalities between Excess Risks	63
3.4 Surrogates for Unweighted Binary Classification	71
3.5 Surrogates for Weighted Binary Classification	76
3.6 Template Loss Functions	80
3.7 Surrogate Losses for Regression Problems	81
3.8 Surrogate Losses for the Density Level Problem	93
3.9 Self-Calibrated Loss Functions	97
3.10 Further Reading and Advanced Topics	105
3.11 Summary	106
3.12 Exercises	107

4	Kernels and Reproducing Kernel Hilbert Spaces	111
4.1	Basic Properties and Examples of Kernels	112
4.2	The Reproducing Kernel Hilbert Space of a Kernel	119
4.3	Properties of RKHSs	124
4.4	Gaussian Kernels and Their RKHSs	132
4.5	Mercer's Theorem (*)	149
4.6	Large Reproducing Kernel Hilbert Spaces	151
4.7	Further Reading and Advanced Topics	159
4.8	Summary	161
4.9	Exercises	162
5	Infinite-Sample Versions of Support Vector Machines	165
5.1	Existence and Uniqueness of SVM Solutions	166
5.2	A General Representer Theorem	169
5.3	Stability of Infinite-Sample SVMs	173
5.4	Behavior for Small Regularization Parameters	178
5.5	Approximation Error of RKHSs	187
5.6	Further Reading and Advanced Topics	197
5.7	Summary	200
5.8	Exercises	200
6	Basic Statistical Analysis of SVMs	203
6.1	Notions of Statistical Learning	204
6.2	Basic Concentration Inequalities	210
6.3	Statistical Analysis of Empirical Risk Minimization	218
6.4	Basic Oracle Inequalities for SVMs	223
6.5	Data-Dependent Parameter Selection for SVMs	229
6.6	Further Reading and Advanced Topics	234
6.7	Summary	235
6.8	Exercises	236
7	Advanced Statistical Analysis of SVMs (*)	239
7.1	Why Do We Need a Refined Analysis?	240
7.2	A Refined Oracle Inequality for ERM	242
7.3	Some Advanced Machinery	246
7.4	Refined Oracle Inequalities for SVMs	258
7.5	Some Bounds on Average Entropy Numbers	270
7.6	Further Reading and Advanced Topics	279
7.7	Summary	282
7.8	Exercises	283

8	Support Vector Machines for Classification	287
8.1	Basic Oracle Inequalities for Classifying with SVMs	288
8.2	Classifying with SVMs Using Gaussian Kernels	290
8.3	Advanced Concentration Results for SVMs (*)	307
8.4	Sparseness of SVMs Using the Hinge Loss	310
8.5	Classifying with other Margin-Based Losses (*)	314
8.6	Further Reading and Advanced Topics	326
8.7	Summary	329
8.8	Exercises	330
9	Support Vector Machines for Regression	333
9.1	Introduction	333
9.2	Consistency	335
9.3	SVMs for Quantile Regression	340
9.4	Numerical Results for Quantile Regression	344
9.5	Median Regression with the eps-Insensitive Loss (*)	348
9.6	Further Reading and Advanced Topics	352
9.7	Summary	353
9.8	Exercises	353
10	Robustness	355
10.1	Motivation	356
10.2	Approaches to Robust Statistics	362
10.3	Robustness of SVMs for Classification	368
10.4	Robustness of SVMs for Regression (*)	379
10.5	Robust Learning from Bites (*)	391
10.6	Further Reading and Advanced Topics	403
10.7	Summary	408
10.8	Exercises	409
11	Computational Aspects	411
11.1	SVMs, Convex Programs, and Duality	412
11.2	Implementation Techniques	420
11.3	Determination of Hyperparameters	443
11.4	Software Packages	448
11.5	Further Reading and Advanced Topics	450
11.6	Summary	452
11.7	Exercises	453
12	Data Mining	455
12.1	Introduction	456
12.2	CRISP-DM Strategy	457
12.3	Role of SVMs in Data Mining	467
12.4	Software Tools for Data Mining	467
12.5	Further Reading and Advanced Topics	468

12.6	Summary	469
12.7	Exercises	469
Appendix		471
A.1	Basic Equations, Inequalities, and Functions	471
A.2	Topology	475
A.3	Measure and Integration Theory	479
	A.3.1 Some Basic Facts	480
	A.3.2 Measures on Topological Spaces	486
	A.3.3 Aumann’s Measurable Selection Principle	487
A.4	Probability Theory and Statistics	489
	A.4.1 Some Basic Facts	489
	A.4.2 Some Limit Theorems	492
	A.4.3 The Weak* Topology and Its Metrization	494
A.5	Functional Analysis	497
	A.5.1 Essentials on Banach Spaces and Linear Operators	497
	A.5.2 Hilbert Spaces	501
	A.5.3 The Calculus in Normed Spaces	507
	A.5.4 Banach Space Valued Integration	508
	A.5.5 Some Important Banach Spaces	511
	A.5.6 Entropy Numbers	516
A.6	Convex Analysis	519
	A.6.1 Basic Properties of Convex Functions	520
	A.6.2 Subdifferential Calculus for Convex Functions	523
	A.6.3 Some Further Notions of Convexity	526
	A.6.4 The Fenchel-Legendre Bi-conjugate	529
	A.6.5 Convex Programs and Lagrange Multipliers	530
A.7	Complex Analysis	534
A.8	Inequalities Involving Rademacher Sequences	534
A.9	Talagrand’s Inequality	538
References		553
Notation and Symbols		579
Abbreviations		583
Author Index		585
Subject Index		591