

---

# Contents

Preface	vii
<b>1 The Learning Problem</b>	<b>1</b>
1.1 Problem Setup . . . . .	1
1.1.1 Components of Learning . . . . .	3
1.1.2 A Simple Learning Model . . . . .	5
1.1.3 Learning versus Design . . . . .	9
1.2 Types of Learning . . . . .	11
1.2.1 Supervised Learning . . . . .	11
1.2.2 Reinforcement Learning . . . . .	12
1.2.3 Unsupervised Learning . . . . .	13
1.2.4 Other Views of Learning . . . . .	14
1.3 Is Learning Feasible? . . . . .	15
1.3.1 Outside the Data Set . . . . .	16
1.3.2 Probability to the Rescue . . . . .	18
1.3.3 Feasibility of Learning . . . . .	24
1.4 Error and Noise . . . . .	27
1.4.1 Error Measures . . . . .	28
1.4.2 Noisy Targets . . . . .	30
1.5 Problems . . . . .	33
<b>2 Training versus Testing</b>	<b>39</b>
2.1 Theory of Generalization . . . . .	39
2.1.1 Effective Number of Hypotheses . . . . .	41
2.1.2 Bounding the Growth Function . . . . .	46
2.1.3 The VC Dimension . . . . .	50
2.1.4 The VC Generalization Bound . . . . .	53
2.2 Interpreting the Generalization Bound . . . . .	55
2.2.1 Sample Complexity . . . . .	57
2.2.2 Penalty for Model Complexity . . . . .	58
2.2.3 The Test Set . . . . .	59
2.2.4 Other Target Types . . . . .	61
2.3 Approximation-Generalization Tradeoff . . . . .	62

2.3.1	Bias and Variance . . . . .	62
2.3.2	The Learning Curve . . . . .	66
2.4	Problems . . . . .	69
<b>3</b>	<b>The Linear Model</b>	<b>77</b>
3.1	Linear Classification . . . . .	77
3.1.1	Non-Separable Data . . . . .	79
3.2	Linear Regression . . . . .	82
3.2.1	The Algorithm . . . . .	84
3.2.2	Generalization Issues . . . . .	87
3.3	Logistic Regression . . . . .	88
3.3.1	Predicting a Probability . . . . .	89
3.3.2	Gradient Descent . . . . .	93
3.4	Nonlinear Transformation . . . . .	99
3.4.1	The $\mathcal{Z}$ Space . . . . .	99
3.4.2	Computation and Generalization . . . . .	104
3.5	Problems . . . . .	109
<b>4</b>	<b>Overfitting</b>	<b>119</b>
4.1	When Does Overfitting Occur? . . . . .	119
4.1.1	A Case Study: Overfitting with Polynomials . . . . .	120
4.1.2	Catalysts for Overfitting . . . . .	123
4.2	Regularization . . . . .	126
4.2.1	A Soft Order Constraint . . . . .	128
4.2.2	Weight Decay and Augmented Error . . . . .	132
4.2.3	Choosing a Regularizer: Pill or Poison? . . . . .	134
4.3	Validation . . . . .	137
4.3.1	The Validation Set . . . . .	138
4.3.2	Model Selection . . . . .	141
4.3.3	Cross Validation . . . . .	145
4.3.4	Theory Versus Practice . . . . .	151
4.4	Problems . . . . .	154
<b>5</b>	<b>Three Learning Principles</b>	<b>167</b>
5.1	Occam's Razor . . . . .	167
5.2	Sampling Bias . . . . .	171
5.3	Data Snooping . . . . .	173
5.4	Problems . . . . .	178
<b>Epilogue</b>		<b>181</b>
<b>Further Reading</b>		<b>183</b>

<b>Appendix Proof of the VC Bound</b>	<b>187</b>
A.1 Relating Generalization Error to In-Sample Deviations . . . . .	188
A.2 Bounding Worst Case Deviation Using the Growth Function . .	190
A.3 Bounding the Deviation between In-Sample Errors . . . . .	191
<b>Notation</b>	<b>193</b>
<b>Index</b>	<b>197</b>