Table of Contents

Pre	Preface xi		
1.	Overview of Machine Learning Systems	. 1	
	When to Use Machine Learning	3	
	Machine Learning Use Cases	9	
	Understanding Machine Learning Systems	12	
	Machine Learning in Research Versus in Production	12	
	Machine Learning Systems Versus Traditional Software	22	
	Summary	23	
2.	Introduction to Machine Learning Systems Design	25	
	Business and ML Objectives	26	
	Requirements for ML Systems	29	
	Reliability	29	
	Scalability	30	
	Maintainability	31	
	Adaptability	31	
	Iterative Process	32	
	Framing ML Problems	35	
	Types of ML Tasks	36	
	Objective Functions	40	
	Mind Versus Data	43	
	Summary	46	
3.	Data Engineering Fundamentals	49	
	Data Sources	50	
	Data Formats	53	
	JSON	54	

	Row-Major Versus Column-Major Format	54
	Text Versus Binary Format	57
	Data Models	58
	Relational Model	59
	NoSQL	63
	Structured Versus Unstructured Data	66
	Data Storage Engines and Processing	67
	Transactional and Analytical Processing	67
	ETL: Extract, Transform, and Load	70
	Modes of Dataflow	72
	Data Passing Through Databases	72
	Data Passing Through Services	73
	Data Passing Through Real-Time Transport	74
	Batch Processing Versus Stream Processing	78
	Summary	79
4.	Training Data	. 81
	Sampling	82
	Nonprobability Sampling	83
	Simple Random Sampling	84
	Stratified Sampling	84
	Weighted Sampling	85
	Reservoir Sampling	86
	Importance Sampling	87
	Labeling	88
	Hand Labels	88
	Natural Labels	91
	Handling the Lack of Labels	94
	Class Imbalance	102
	Challenges of Class Imbalance	103
	Handling Class Imbalance	105
	Data Augmentation	113
	Simple Label-Preserving Transformations	114
	Perturbation	114
	Data Synthesis	116
	Summary	118
5.	Feature Engineering	119
	Learned Features Versus Engineered Features	119
	Common Feature Engineering Operations	123
	Handling Missing Values	123
	Scaling	126

	Discretization	128
	Encoding Categorical Features	129
	Feature Crossing	132
	Discrete and Continuous Positional Embeddings	133
	Data Leakage	135
	Common Causes for Data Leakage	137
	Detecting Data Leakage	140
	Engineering Good Features	140
	Feature Importance	141
	Feature Generalization	144
	Summary	146
6.	Model Development and Offline Evaluation	147
	Model Development and Training	148
	Evaluating ML Models	148
	Ensembles	154
	Experiment Tracking and Versioning	160
	Distributed Training	165
	AutoML	170
	Model Offline Evaluation	176
	Baselines	177
	Evaluation Methods	179
	Summary	186
7.	Model Deployment and Prediction Service	189
	Machine Learning Deployment Myths	192
	Myth 1: You Only Deploy One or Two ML Models at a Time	192
	Myth 2: If We Don't Do Anything, Model Performance Remains the Same	193
	Myth 3: You Won't Need to Update Your Models as Much	194
	Myth 4: Most ML Engineers Don't Need to Worry About Scale	194
	Batch Prediction Versus Online Prediction	195
	From Batch Prediction to Online Prediction	199
	Unifying Batch Pipeline and Streaming Pipeline	201
	Model Compression	204
	Low-Rank Factorization	204
	Knowledge Distillation	206
	Pruning	206
	Quantization	207
	ML on the Cloud and on the Edge	210
	Compiling and Optimizing Models for Edge Devices	212
	ML in Browsers	220
	Summary	221

8.	Data Distribution Shifts and Monitoring	223
	Causes of ML System Failures	224
	Software System Failures	225
	ML-Specific Failures	226
	Data Distribution Shifts	234
	Types of Data Distribution Shifts	234
	General Data Distribution Shifts	238
	Detecting Data Distribution Shifts	239
	Addressing Data Distribution Shifts	245
	Monitoring and Observability	247
	ML-Specific Metrics	248
	Monitoring Toolbox	253
	Observability	256
	Summary	258
9.	Continual Learning and Test in Production	261
	Continual Learning	262
	Stateless Retraining Versus Stateful Training	263
	Why Continual Learning?	266
	Continual Learning Challenges	268
	Four Stages of Continual Learning	272
	How Often to Update Your Models	277
	Test in Production	279
	Shadow Deployment	280
	A/B Testing	281
	Canary Release	282
	Interleaving Experiments	283
	Bandits	285
	Summary	289
10.	Infrastructure and Tooling for MLOps	291
	Storage and Compute	295
	Public Cloud Versus Private Data Centers	297
	Development Environment	300
	Dev Environment Setup	301
	Standardizing Dev Environments	304
	From Dev to Prod: Containers	306
	Resource Management	308
	Cron, Schedulers, and Orchestrators	309
	Data Science Workflow Management	312
	ML Platform	317
	Model Deployment	318

	Model Store	319
	Feature Store	323
	Build Versus Buy	325
	Summary	327
11.	The Human Side of Machine Learning	329
	User Experience	329
	Ensuring User Experience Consistency	330
	Combatting "Mostly Correct" Predictions	330
	Smooth Failing	332
	Team Structure	332
	Cross-functional Teams Collaboration	333
	End-to-End Data Scientists	333
	Responsible AI	337
	Irresponsible AI: Case Studies	339
	A Framework for Responsible AI	345
	Summary	351
Ер	ilogue	353
Inc	dev	355