

# Contents

## Part I Overview of Learning to Rank

<b>1 Introduction</b> . . . . .	3
1.1 Overview . . . . .	3
1.2 Ranking in Information Retrieval . . . . .	7
1.2.1 Conventional Ranking Models . . . . .	7
1.2.2 Query-Level Position-Based Evaluations . . . . .	11
1.3 Learning to Rank . . . . .	15
1.3.1 Machine Learning Framework . . . . .	16
1.3.2 Definition of Learning to Rank . . . . .	17
1.3.3 Learning-to-Rank Framework . . . . .	18
1.4 Book Overview . . . . .	23
1.5 Exercises . . . . .	24
References . . . . .	25

## Part II Major Approaches to Learning to Rank

<b>2 The Pointwise Approach</b> . . . . .	33
2.1 Overview . . . . .	33
2.2 Regression-Based Algorithms . . . . .	33
2.2.1 Subset Ranking with Regression . . . . .	34
2.3 Classification-Based Algorithms . . . . .	35
2.3.1 Binary Classification for Ranking . . . . .	35
2.3.2 Multi-class Classification for Ranking . . . . .	37
2.4 Ordinal Regression-Based Algorithms . . . . .	39
2.4.1 Perceptron-Based Ranking (PRanking) . . . . .	39
2.4.2 Ranking with Large Margin Principles . . . . .	40
2.4.3 Ordinal Regression with Threshold-Based Loss Functions . . . . .	42
2.5 Discussions . . . . .	42
2.5.1 Relationship with Relevance Feedback . . . . .	43
2.5.2 Problems with the Pointwise Approach . . . . .	44

- 2.5.3 Improved Algorithms . . . . . 44
- 2.6 Summary . . . . . 45
- 2.7 Exercises . . . . . 45
- References . . . . . 46
- 3 The Pairwise Approach . . . . . 49**
  - 3.1 Overview . . . . . 49
  - 3.2 Example Algorithms . . . . . 49
    - 3.2.1 Ordering with Preference Function . . . . . 49
    - 3.2.2 SortNet: Neural Network-Based Sorting Algorithm . . . . . 51
    - 3.2.3 RankNet: Learning to Rank with Gradient Descent . . . . . 52
    - 3.2.4 FRank: Ranking with a Fidelity Loss . . . . . 53
    - 3.2.5 RankBoost . . . . . 54
    - 3.2.6 Ranking SVM . . . . . 56
    - 3.2.7 GBRank . . . . . 58
  - 3.3 Improved Algorithms . . . . . 59
    - 3.3.1 Multiple Hyperplane Ranker . . . . . 59
    - 3.3.2 Magnitude-Preserving Ranking . . . . . 60
    - 3.3.3 IR-SVM . . . . . 61
    - 3.3.4 Robust Pairwise Ranking with Sigmoid Functions . . . . . 62
    - 3.3.5 P-norm Push . . . . . 63
    - 3.3.6 Ordered Weighted Average for Ranking . . . . . 64
    - 3.3.7 LambdaRank . . . . . 65
    - 3.3.8 Robust Sparse Ranker . . . . . 66
  - 3.4 Summary . . . . . 67
  - 3.5 Exercises . . . . . 67
  - References . . . . . 68
- 4 The Listwise Approach . . . . . 71**
  - 4.1 Overview . . . . . 71
  - 4.2 Minimization of Measure-Specific Loss . . . . . 72
    - 4.2.1 Measure Approximation . . . . . 72
    - 4.2.2 Bound Optimization . . . . . 77
    - 4.2.3 Non-smooth Optimization . . . . . 78
    - 4.2.4 Discussions . . . . . 80
  - 4.3 Minimization of Non-measure-Specific Loss . . . . . 80
    - 4.3.1 ListNet . . . . . 81
    - 4.3.2 ListMLE . . . . . 82
    - 4.3.3 Ranking Using Cumulative Distribution Networks . . . . . 83
    - 4.3.4 BoltzRank . . . . . 84
  - 4.4 Summary . . . . . 85
  - 4.5 Exercises . . . . . 86
  - References . . . . . 87
- 5 Analysis of the Approaches . . . . . 89**
  - 5.1 Overview . . . . . 89
  - 5.2 The Pointwise Approach . . . . . 89

- 5.3 The Pairwise Approach . . . . . 91
- 5.4 The Listwise Approach . . . . . 94
  - 5.4.1 Non-measure-Specific Loss . . . . . 94
  - 5.4.2 Measure-Specific Loss . . . . . 95
- 5.5 Summary . . . . . 98
- 5.6 Exercises . . . . . 98
- References . . . . . 99

**Part III Advanced Topics in Learning to Rank**

- 6 Relational Ranking . . . . . 103**
  - 6.1 General Relational Ranking Framework . . . . . 104
    - 6.1.1 Relational Ranking SVM . . . . . 104
    - 6.1.2 Continuous Conditional Random Fields . . . . . 106
  - 6.2 Learning Diverse Ranking . . . . . 107
  - 6.3 Discussions . . . . . 110
  - References . . . . . 111
- 7 Query-Dependent Ranking . . . . . 113**
  - 7.1 Query-Dependent Loss Function . . . . . 113
  - 7.2 Query-Dependent Ranking Function . . . . . 115
    - 7.2.1 Query Classification-Based Approach . . . . . 115
    - 7.2.2 K Nearest Neighbor-Based Approach . . . . . 116
    - 7.2.3 Query Clustering-Based Approach . . . . . 118
    - 7.2.4 Two-Layer Learning Approach . . . . . 119
  - 7.3 Discussions . . . . . 120
  - References . . . . . 121
- 8 Semi-supervised Ranking . . . . . 123**
  - 8.1 Inductive Approach . . . . . 123
  - 8.2 Transductive Approach . . . . . 124
  - 8.3 Discussions . . . . . 125
  - References . . . . . 125
- 9 Transfer Ranking . . . . . 127**
  - 9.1 Feature-Level Transfer Ranking . . . . . 128
  - 9.2 Instance-Level Transfer Ranking . . . . . 128
  - 9.3 Discussions . . . . . 130
  - References . . . . . 130

**Part IV Benchmark Datasets for Learning to Rank**

- 10 The LETOR Datasets . . . . . 133**
  - 10.1 Overview . . . . . 133
  - 10.2 Document Corpora . . . . . 133
    - 10.2.1 The “Gov” Corpus and Six Query Sets . . . . . 134
    - 10.2.2 The OHSUMED Corpus . . . . . 134
    - 10.2.3 The “Gov2” Corpus and Two Query Sets . . . . . 135

10.3	Document Sampling . . . . .	135
10.4	Feature Extraction . . . . .	136
10.5	Meta Information . . . . .	136
10.6	Learning Tasks . . . . .	138
10.7	Discussions . . . . .	142
	References . . . . .	142
<b>11</b>	<b>Experimental Results on LETOR . . . . .</b>	<b>145</b>
11.1	Experimental Settings . . . . .	145
11.2	Experimental Results on LETOR 3.0 . . . . .	146
11.3	Experimental Results on LETOR 4.0 . . . . .	149
11.4	Discussions . . . . .	150
11.5	Exercises . . . . .	151
	References . . . . .	151
<b>12</b>	<b>Other Datasets . . . . .</b>	<b>153</b>
12.1	Yahoo! Learning-to-Rank Challenge Datasets . . . . .	153
12.2	Microsoft Learning-to-Rank Datasets . . . . .	154
12.3	Discussions . . . . .	155
	References . . . . .	155
<b>Part V Practical Issues in Learning to Rank</b>		
<b>13</b>	<b>Data Preprocessing for Learning to Rank . . . . .</b>	<b>159</b>
13.1	Overview . . . . .	159
13.2	Ground Truth Mining from Logs . . . . .	160
	13.2.1 User Click Models . . . . .	160
	13.2.2 Click Data Enhancement . . . . .	166
13.3	Training Data Selection . . . . .	168
	13.3.1 Document and Query Selection for Labeling . . . . .	169
	13.3.2 Document and Query Selection for Training . . . . .	171
	13.3.3 Feature Selection for Training . . . . .	175
13.4	Summary . . . . .	176
13.5	Exercises . . . . .	176
	References . . . . .	177
<b>14</b>	<b>Applications of Learning to Rank . . . . .</b>	<b>181</b>
14.1	Overview . . . . .	181
14.2	Question Answering . . . . .	181
	14.2.1 Definitional QA . . . . .	182
	14.2.2 Quantity Consensus QA . . . . .	183
	14.2.3 Non-factoid QA . . . . .	184
	14.2.4 Why QA . . . . .	185
14.3	Multimedia Retrieval . . . . .	186
14.4	Text Summarization . . . . .	187
14.5	Online Advertising . . . . .	188
14.6	Summary . . . . .	189

14.7 Exercises . . . . . 190  
 References . . . . . 190

**Part VI Theories in Learning to Rank**

**15 Statistical Learning Theory for Ranking . . . . . 195**  
 15.1 Overview . . . . . 195  
 15.2 Statistical Learning Theory . . . . . 195  
 15.3 Learning Theory for Ranking . . . . . 197  
     15.3.1 Statistical Ranking Framework . . . . . 197  
     15.3.2 Generalization Analysis for Ranking . . . . . 198  
     15.3.3 Statistical Consistency for Ranking . . . . . 198  
 15.4 Exercises . . . . . 199  
     References . . . . . 199

**16 Statistical Ranking Framework . . . . . 201**  
 16.1 Document Ranking Framework . . . . . 202  
     16.1.1 The Pointwise Approach . . . . . 202  
     16.1.2 The Pairwise Approach . . . . . 202  
     16.1.3 The Listwise Approach . . . . . 204  
 16.2 Subset Ranking Framework . . . . . 204  
     16.2.1 The Pointwise Approach . . . . . 205  
     16.2.2 The Pairwise Approach . . . . . 205  
     16.2.3 The Listwise Approach . . . . . 206  
 16.3 Two-Layer Ranking Framework . . . . . 206  
     16.3.1 The Pointwise Approach . . . . . 206  
     16.3.2 The Pairwise Approach . . . . . 207  
     16.3.3 The Listwise Approach . . . . . 208  
 16.4 Summary . . . . . 208  
 16.5 Exercises . . . . . 208  
     References . . . . . 209

**17 Generalization Analysis for Ranking . . . . . 211**  
 17.1 Overview . . . . . 211  
 17.2 Uniform Generalization Bounds for Ranking . . . . . 212  
     17.2.1 For Document Ranking . . . . . 212  
     17.2.2 For Subset Ranking . . . . . 214  
     17.2.3 For Two-Layer Ranking . . . . . 216  
 17.3 Algorithm-Dependent Generalization Bound . . . . . 217  
     17.3.1 For Document Ranking . . . . . 218  
     17.3.2 For Subset Ranking . . . . . 219  
     17.3.3 For Two-Layer Ranking . . . . . 220  
 17.4 Summary . . . . . 220  
 17.5 Exercises . . . . . 221  
     References . . . . . 221

<b>18</b>	<b>Statistical Consistency for Ranking</b>	223
18.1	Overview	223
18.2	Consistency Analysis for Document Ranking	224
18.2.1	Regarding Pairwise 0–1 Loss	224
18.3	Consistency Analysis for Subset Ranking	224
18.3.1	Regarding DCG-Based Ranking Error	225
18.3.2	Regarding Permutation-Level 0–1 Loss	225
18.3.3	Regarding Top- $k$ True Loss	226
18.3.4	Regarding Weighted Kendall’s $\tau$	227
18.4	Consistency Analysis for Two-Layer Ranking	229
18.5	Summary	229
18.6	Exercises	230
	References	230

## Part VII Summary and Outlook

<b>19</b>	<b>Summary</b>	235
	References	238
<b>20</b>	<b>Future Work</b>	241
20.1	Sample Selection Bias	241
20.2	Direct Learning from Logs	242
20.3	Feature Engineering	243
20.4	Advanced Ranking Models	243
20.5	Large-Scale Learning to Rank	244
20.6	Online Complexity Versus Accuracy	245
20.7	Robust Learning to Rank	245
20.8	Online Learning to Rank	246
20.9	Beyond Ranking	247
	References	247

## Part VIII Appendix

<b>21</b>	<b>Mathematical Background</b>	251
21.1	Probability Theory	251
21.1.1	Probability Space and Random Variables	251
21.1.2	Probability Distributions	252
21.1.3	Expectations and Variances	254
21.2	Linear Algebra and Matrix Computation	255
21.2.1	Notations	255
21.2.2	Basic Matrix Operations and Properties	256
21.2.3	Eigenvalues and Eigenvectors	261
21.3	Convex Optimization	262
21.3.1	Convex Set and Convex Function	262
21.3.2	Conditions for Convexity	263
21.3.3	Convex Optimization Problem	263
21.3.4	Lagrangian Duality	264

- 21.3.5 KKT Conditions . . . . . 265
- References . . . . . 266
- 22 Machine Learning . . . . . 267**
- 22.1 Regression . . . . . 267
  - 22.1.1 Linear Regression . . . . . 267
  - 22.1.2 Probabilistic Explanation . . . . . 268
- 22.2 Classification . . . . . 269
  - 22.2.1 Neural Networks . . . . . 270
  - 22.2.2 Support Vector Machines . . . . . 271
  - 22.2.3 Boosting . . . . . 273
  - 22.2.4 K Nearest Neighbor (KNN) . . . . . 274
- 22.3 Statistical Learning Theory . . . . . 274
  - 22.3.1 Formalization . . . . . 275
  - 22.3.2 Bounds for  $|R(g) - \hat{R}(g)|$  . . . . . 277
  - References . . . . . 282
- Index . . . . . 283**



<http://www.springer.com/978-3-642-14266-6>

Learning to Rank for Information Retrieval

Liu, T.-Y.

2011, XVII, 285 p., Hardcover

ISBN: 978-3-642-14266-6