



# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Multi-relational learning . . . . .	1
1.1.1	Factorization models for Multi-relational data . . . . .	4
1.1.2	Applications of Multi Relational Learning . . . . .	5
1.2	Contribution . . . . .	6
1.3	Submitted and Published Work . . . . .	7
1.4	Chapter Overview . . . . .	9
<b>2</b>	<b>The Multi-Relational Factorization Problem</b>	<b>11</b>
2.1	Problem Formulation . . . . .	12
2.2	State of the Art . . . . .	14
2.2.1	Parametrization of Multi-relational factorization models . . . . .	15
2.2.2	Optimization objectives for multi-relational learning . . . . .	18
2.2.3	Summary of the presented models . . . . .	21
2.3	Evaluating Multi-Relational Learning Models . . . . .	21
2.4	Open Problems in Multi-Relational Factorization . . . . .	23
<b>3</b>	<b>Loss functions for multi-relational learning tasks</b>	<b>26</b>
3.1	Application scenario: Mining RDF Knowledge Bases . . . . .	27
3.1.1	RDF inference and Related Work . . . . .	28
3.2	Predicting RDF Triples . . . . .	30
3.3	Predicting RDF triples by Tensor Factorization . . . . .	31
3.3.1	Factorization Models . . . . .	31
3.3.1.1	Three-way Interaction Model . . . . .	31
3.3.1.2	Pairwise Interaction Model . . . . .	32
3.3.2	The open world assumption and the loss function . . . . .	33
3.3.3	Dealing with the open world assumption through the BPR Framework . . . . .	35
3.3.4	Filtering the Results of Tensor Factorization Models . . . . .	36



3.4	Evaluation . . . . .	39
3.4.1	Datasets . . . . .	39
3.4.2	Methods . . . . .	40
3.4.3	Evaluation Methodology . . . . .	41
3.4.4	Results . . . . .	42
3.4.5	Comparing BPR against RMSE . . . . .	44
3.4.6	Evaluation of Type information through Post Filter . . . . .	45
3.5	Conclusions . . . . .	50
<b>4</b>	<b>Target-Specific Parametrization of Multi-Relational Models</b>	<b>51</b>
4.1	Learning with multiple target relations . . . . .	52
4.2	Multi-Target Factorization . . . . .	53
4.2.1	Optimizing models for Multiple Target Relations . . . . .	54
4.2.2	Coupled Auxiliary and Target Specific Factorization . . . . .	57
4.2.3	Setting up CATSMF . . . . .	60
4.3	Evaluation . . . . .	62
4.3.1	Comparison against the state-of-the-art . . . . .	62
4.3.2	Evaluation Protocol and Metrics . . . . .	64
4.3.3	Experiment I: Benchmark Datasets . . . . .	66
4.3.4	Experiment II: Web Datasets . . . . .	67
4.4	Conclusion . . . . .	74
<b>5</b>	<b>Factorization models for Semi-Supervised Classification</b>	<b>76</b>
5.1	Semi-Supervised Classification . . . . .	77
5.2	Related Work . . . . .	80
5.2.1	Semi-Supervised learning . . . . .	80
5.2.2	Multi-Relational Factorization for Semi-Supervised Classification . . . . .	82
5.3	Semi-supervised classification problem formulation . . . . .	83
5.4	Factorization models for Semi-supervised Classification . . . . .	85
5.4.1	Neighborhood Based Feature Extraction . . . . .	86
5.4.2	Semi-Supervised Learning of PNT-CMF . . . . .	88
5.4.3	Learning Inductive Factorization models for Classification . . . . .	90
5.5	Evaluation . . . . .	91
5.5.1	Datasets . . . . .	92
5.5.2	Setup . . . . .	92
5.5.3	Baselines . . . . .	93
5.5.4	Model Selection . . . . .	94
5.5.5	Results and discussion . . . . .	94



## CONTENTS

---

5.6 Conclusion . . . . .	98
<b>6 Conclusion</b>	<b>100</b>
6.1 Summary . . . . .	100
6.2 Discussion . . . . .	101
6.3 Future Direction . . . . .	102
<b>Index</b>	<b>106</b>
<b>References</b>	<b>114</b>