

Contents

Acknowledgements	ix
Notation and abbreviations	xi
1 Introduction	13
1.1 Main thesis of this contribution	17
1.2 Book structure	18
1.3 Bibliography review	20
1.4 Recommendation systems overview	23
1.5 Conclusion	28
2 Quantum computational methods	29
2.1 Classical and probabilistic model of bit	29
2.2 The representation of quantum classical information	30
2.2.1 The Quantum Register	32
2.3 Entanglement of quantum states	32
2.3.1 Schmidt decomposition	33
2.4 Unitary operations	33
2.4.1 Unitary operation	33
2.5 Invertibility of Quantum Gates	35
2.6 Circumferential model	35
2.6.1 One-qubit quantum gates	35
2.6.2 Multi-qubit quantum gates	39
2.7 Quantum register measurement operations	43
2.7.1 General measurement operation	43
2.7.2 The von Neumann measurement operation	44
2.8 Quantum k-nearest neighbors algorithm	45
2.9 The Grover algorithm	47
2.10 Conclusion	51
3 Hybrid classical-quantum recommendation systems	53
3.1 Introduction	53
3.2 Architecture	57
3.3 Data source	57
3.3.1 Mechanisms of data acquisition	58
3.4 States of feature vectors and user preferences	58
3.5 Encoding of identifiers	59
3.6 Construction of the quantum register	59

3.7	Quantum register database structure	62
3.8	Recommendation process	65
3.8.1	A quantum recommendation algorithm circuit	65
3.8.2	Correctness analysis	70
3.8.3	Scheme of a quantum recommendation algorithm	73
3.8.4	Searching for k-nearest neighbors	74
3.8.5	Application of Grover’s algorithm to amplify probability . .	78
3.8.6	Properties resulting from the use of quantum technology . .	78
3.9	Implementation of the circuit on the IBM Quantum computer . .	79
3.9.1	Description of the experiment	79
3.9.2	Numerical simulation	80
3.9.3	Execution of the experiment	81
3.9.4	Comparison of implementation results between simulation and real environment	82
3.10	Conclusion	88
4	Hybrid profiling mechanism in the recommendation system . .	89
4.1	Decision Trees	89
4.2	Hybrid classical-quantum profiling trees	92
4.2.1	Determining the system user profile	94
4.2.2	Quantum Amplitude Amplification Mechanism	95
4.2.3	Hybrid profiling mechanism	99
4.2.4	The process of profiling users of the hybrid classical-quantum recommendation system	101
4.2.5	Realization of the experiment	102
4.2.6	Implementation on quantum computers	109
4.2.7	Comparison of implementation results between simulation and real environment	109
4.3	Forests of hybrid classical-quantum profiling trees	112
4.3.1	Architecture and structuring	116
4.4	Conclusion	120
5	Measuring the level of entanglement in the recommendation pro-	
cess		121
5.1	EntDetector package	121
5.2	Test database for recommendation	122
5.3	Identifier entanglement evaluation mechanism	123
5.4	Entanglement level analysis	126
5.5	Conclusion	132
6	Conclusion	133
6.1	Conclusions and observations	133
6.2	Further research	137
6.3	Conclusion	138

A Basic concepts of quantum computing 139

 A.1 Vector space 139

 A.2 Hilbert space 140

 A.3 Tensor product 141

 A.4 Dirac notation 142

 A.5 Density matrix 144

 A.6 Polar decomposition 145

 A.7 SVD decomposition 145

 A.8 Hamming distance 146

 A.9 Conclusion 147

B Calibration Parameters 149

 B.1 Calibration parameters of completed experiments of classical-quantum recommender systems 149

 B.2 Calibration parameters of completed experiments of the hybrid profiling mechanism 151

 B.3 Conclusion 154

C Classification of usefulness of obtained information 155

 C.1 Quality assessment of the obtained data 155

 C.2 Data cleaning process 156

 C.3 Conclusion 156

D Description of IBM’s Quantum Computing Cloud 157

 D.1 IBM Quantum 157

 D.2 IBM Qiskit package 160

 D.3 Conclusion 160

Bibliography 161

Index 171

List of figures 173

List of tables 177

Streszczenie 179