

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	121
5	Measuring the level of entanglement in the recommendation process	123
5.1	EntDetector package	123
5.2	Test database for recommendation	124
5.3	Identifier entanglement evaluation mechanism	125
5.4	Entanglement level analysis	128
5.5	Conclusion	134
6	Conclusion	135
6.1	Conclusions and observations	135
6.2	Further research	139
6.3	Conclusion	139

A Basic concepts of quantum computing	141
A.1 Vector space	141
A.2 Hilbert space	142
A.3 Tensor product	143
A.4 Dirac notation	144
A.5 Density matrix	146
A.6 Polar decomposition	147
A.7 SVD decomposition	147
A.8 Hamming distance	148
A.9 Conclusion	149
B Calibration Parameters	151
B.1 Calibration parameters of completed experiments of classical-quantum recommender systems	151
B.2 Calibration parameters of completed experiments of the hybrid profiling mechanism	157
B.3 Conclusion	157
C Classification of usefulness of obtained information	159
C.1 Quality assessment of the obtained data	159
C.2 Data cleaning process	160
C.3 Conclusion	161
D Description of IBM's Quantum Computing Cloud	163
D.1 IBM Quantum	163
D.2 IBM Qiskit package	165
D.3 Conclusion	167
Bibliography	169
Index	179
List of figures	181
List of tables	185
Streszczenie	187