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Supervised learning with quantum computers. (English) Zbl 1411.81008

The book provides a thorough introduction into the recently established field of quantum machine learning, which concerns itself with machine learning algorithms that are to be run on quantum computers. To this end it discusses how classical supervised learning algorithms can be ported to quantum computers such that their strengths are properly utilized. The book is intended as an extended introduction to this new research field and provides all required foundations both for the area of machine learning as well as quantum computing including the relevant knowledge and insights from quantum physics. In this manner, the book is relevant for computer science as well as physics graduates that each find the missing parts covered in the book. The advanced material covered in the later chapters includes proper data encoding as well as algorithms for training as well as inference, thus completing the pipeline of standard supervised machine learning approaches.

The book starts with a detailed introduction that positions the field in the established areas and provides a gentle introductory example for a trivial learning task. This example motivates the different perspective as well as the benefits and the surprises involved with quantum computing. Chapter 2 provides a rather comprehensive high-level review of current supervised machine learning approaches including the discussion of the basic terminology used. Predictive models are introduced and it is demonstrated how they can be evaluated. This naturally leads to the notion of cost functions and standard training procedures based on loss. Finally, several common machine learning models are presented in this abstract setting with a strong focus on neural network and support vector machine approaches.

Chapter 3 introduces quantum information theory and the foundations of quantum physics required to understand and appreciate quantum computation. This includes the basic storage unit as well as standard principles and common quantum processes. Multiple examples are used to illustrate the notions to the uninitiated and provide at least a working intuition. Based on these foundations the specific advantages that quantum computing offers are presented and discussed in detail. The potentially better complexity of learning also sparks a short discussion of the complexity measures used and the relations between the required sample sizes to achieve exact and probably approximately correct learning.

The following chapters now offer advanced discussions of individual parts of standard machine learning pipelines. Chapter 5 starts with a discussion of various methods of encoding the classical discrete input data. There are best practices for these encodings in traditional machine learning, but these still have to be developed in the quantum setting. In particular, the actual choice of the encoding has a deeper impact and actually also influences the learning approach to be used. Chapters 6 and 7 discuss in turn inference and training for quantum learning. In these chapters the corresponding notions to distances, kernels, inner products, stochastic gradient descent, etc. are derived and discussed in the quantum setting. In this manner a standard toolbox is developed that allows the creation of quantum learning pipelines. Chapter 8 discusses additional models that are genuine quantum models in the sense that they are not directly based on classical approaches, but rather were developed directly for the quantum setup. Finally, the last chapter gives a short outlook and hazards some guesses how the field might develop in the future.

Overall, the book is very well written and contains sufficiently many examples and illustrations. The authors make a concerted effort to make the material accessible to both computer science graduates as well as scientists with a quantum physics background. Some mathematical maturity is required since the overview, although detailed in the sense that all required information is provided, does not allow an in-depth discussion of each individual equation. The intended audience are thus machine learning scientists that want to explore the quantum approach to their discipline or quantum information scientists that want to enter the field of machine learning.

Reviewer: Andreas Maletti (Leipzig)
MSC:
81-02 Research exposition (monographs, survey articles) pertaining to quantum theory
81P68 Quantum computation
68Q05 Models of computation (Turing machines, etc.) (MSC2010)
68Q12 Quantum algorithms and complexity in the theory of computing
68Q32 Computational learning theory
68T05 Learning and adaptive systems in artificial intelligence
82C32 Neural nets applied to problems in time-dependent statistical mechanics

Keywords:
quantum computer; quantum learning; machine learning; neural networks; support vector machines; quantum data

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