Machine Learning for Quantum Computing and Quantum-Enhanced Machine Learning

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Content

Machine learning (ML) and quantum computing (QC) are two of the hottest topics in research today, attracting the attention of scientific institutions, companies, and policymakers worldwide, due to the life-changing potential and importance. Promising the solvability of problems which are currently computationally unsolvable, both fields will have enormous impact on our lives. The relationship between the two fields is double-sided. ML can enhance research in QC, and quantum technologies can revolutionize the field of ML. ML techniques, such as reinforcement learning and deep learning, due to their ability to process large amounts of computed or experimental data and solve high-dimensional problems are currently heavily applied to the study of quantum systems. Another emergent area of research is the study of quantumenhanced ML, a field focused on developing quantum algorithms to perform ML tasks. Quantum ML further enhances the capabilities of ML algorithms to work with immense amounts of data and will lead to exponential increases in speed and power compared to the classical algorithms by using the principles of quantum mechanics. The participants will study contemporary and prominent research on the application of classical machine learning approaches for diverse areas of quantum computing and will learn the implementation of certain aspects of quantum computing and on different quantum machine learning algorithms. Topics of the seminar are classical supervised, unsupervised, and reinforcement learning approaches, commonly used in physics in general and in QC in particular, including deep learning architectures and deep reinforcement learning algorithms. We will investigate prominent examples of how these techniques are used in quantum state and process tomography, quantum state engineering, and quantum error correction. The seminar will further cover topics of quantum machine learning including quantum versions of classical ML algorithms for classification, quantum optimization algorithms, quantum population-based methods, quantum neural networks, quantum deep learning, quantum reinforcement learning. Additional research topics include the near-term intermediate scale quantum devices (NISQ) and hybrid quantum-classical algorithms that are suitable for running on current hardware such as QAOA and VQE. The seminar will include a few introductory talks/lectures and then continue with presentations by the participants. The topics will be from recent research. The scope of the seminar includes the assessment of relevant literature including research

articles and the preparation of the presentation. Both will be done under the supervision of the course instructors.

Recommended Literature

- Quantum Computation and Quantum Information (Cambridge Series on Information and the Natural Sciences)

  by Michael A. Nielsen (Autor), Isaac L. Chuang (Autor)

  Chapters 4, 8, and 10

- Machine Learning

  by Tom Mitchel

  1. Introduction
  2. Concept Learning and the General-to-Specific Ordering 2.1-2.5
  3. Decision Tree Learning 3.1-3.7
  4. Artificial Neural Networks 4.1.-4.6
  5. Evaluating Hypotheses 5.1., 5.2, 5.3.1-5.3.4
  7. Computational Learning Theory 7.1-7.3
  13. Reinforcement Learning 13.1-13.4, 13.7

- Deep Learning (Adaptive Computation and Machine Learning series)

  by Ian Goodfellow, Yoshua Bengio, Aaron Courville

  Chapters 6, 7, and 8

- Quantum Machine Learning: What Quantum Computing Means to Data Mining

  by Peter Wittek

  Chapters 5, 6, (and 7)

- A high-bias, low-variance introduction to Machine Learning for physicists

  Pankaj Mehta, Marin Bukov, Ching-Hao Wang, Alexandre G.R. Day, Clint Richardson, Charles K. Fisher, David J. Schwab,

  https://arxiv.org/abs/1803.08823

- Machine learning & artificial intelligence in the quantum domain

  Vedran Dunjko, Hans J. Briegel

  https://arxiv.org/abs/1709.02779

For optional further reading

- An introduction to quantum machine learning

  M. Schuld, I. Sinayskiy, F. Petruccione,

  https://arxiv.org/abs/1409.3097

- Supervised Learning with Quantum Computers (Quantum Science and Technology)

  by Maria Schuld, Francesco Petruccione

- Machine Learning for Physicists, lecture notes

  Florian Marquardt