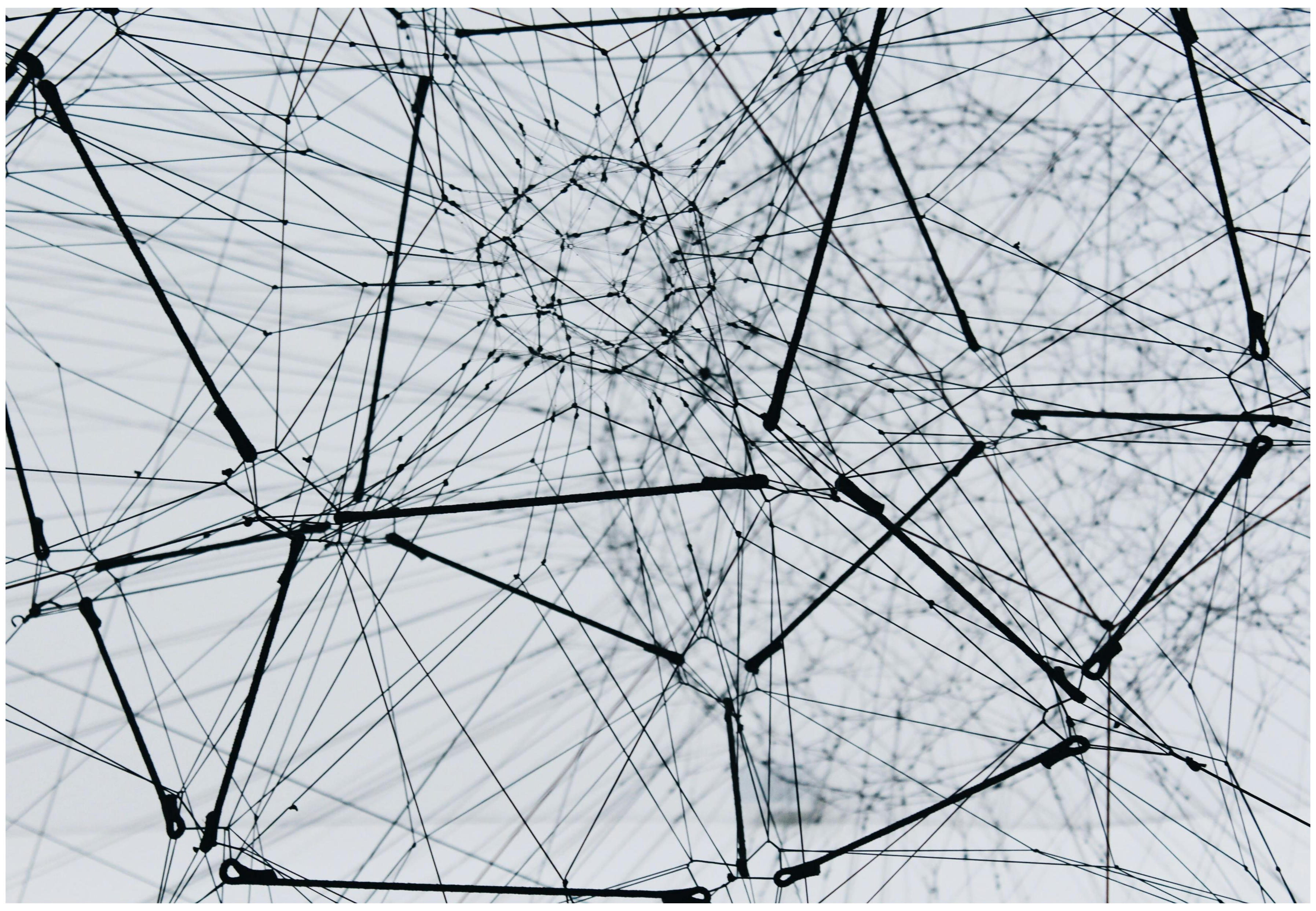
QuTeNet
Quantum Tensor Networks for Quantum Simulations and Artificial Intelligence

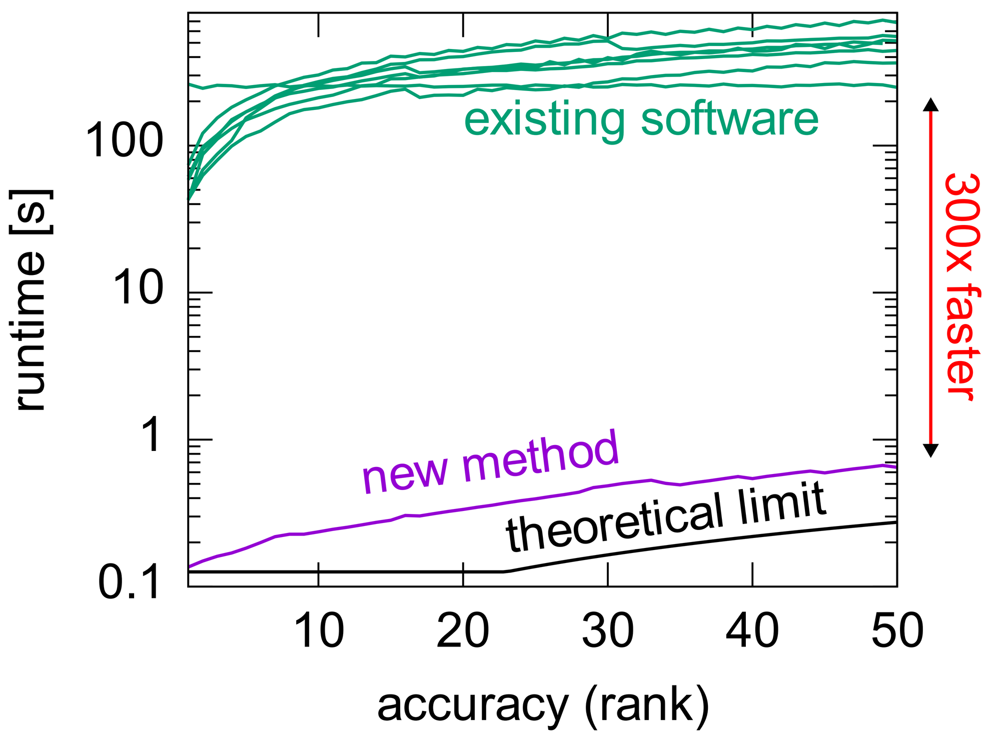
We evaluate the (dis)advantages of quantum tensor networks for applications in quantum simulation and quantum AI, and explore the deployment of quantum tensor networks on real quantum hardware.

- Applications
- Quantum Machine Learning
- Quantum Simulation



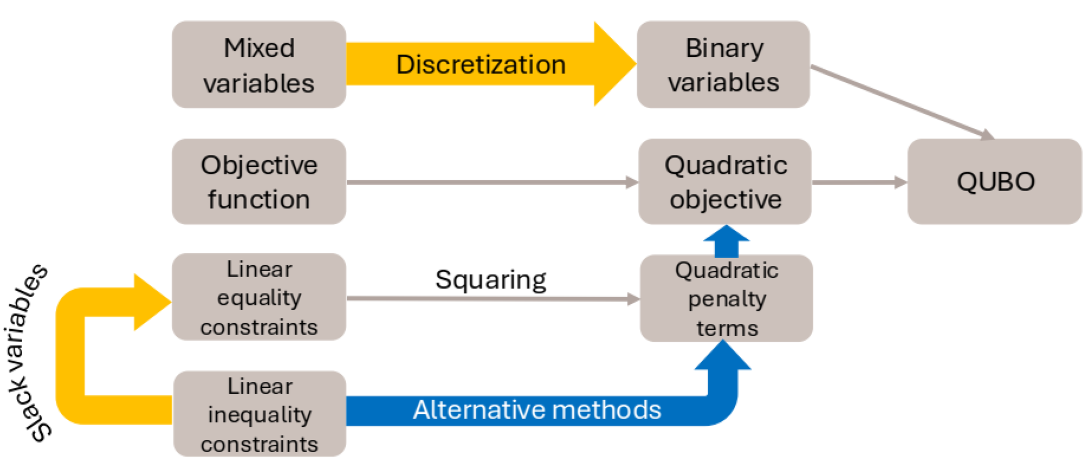
Motivation
Quantum computing promises a paradigm shift for classically extremely computationally intensive problems in the fields of optimisation, simulation of quantum systems, and artificial intelligence. In the QuTeNet project, these fields of application are combined through the use of tensor networks. To this end, we are further developing tensor network methods on classical computers and leveraging them to transfer these problems to quantum computers.

Implementation on classical systems
Classical tensor networks are based on a few runtime-critical linear algebra operations:
- Identify and optimise these operations using performance models
- Allow a fair comparison with quantum tensor networks by efficient classical implementations
- Improve DLR solutions and industry frameworks



Performance gain (300x) for decomposing large data as a tensor network by optimised code on classical hardware.
Adapted from SISC, Vol. **44** Iss. 4 (2022), 10.1137/21M1395545

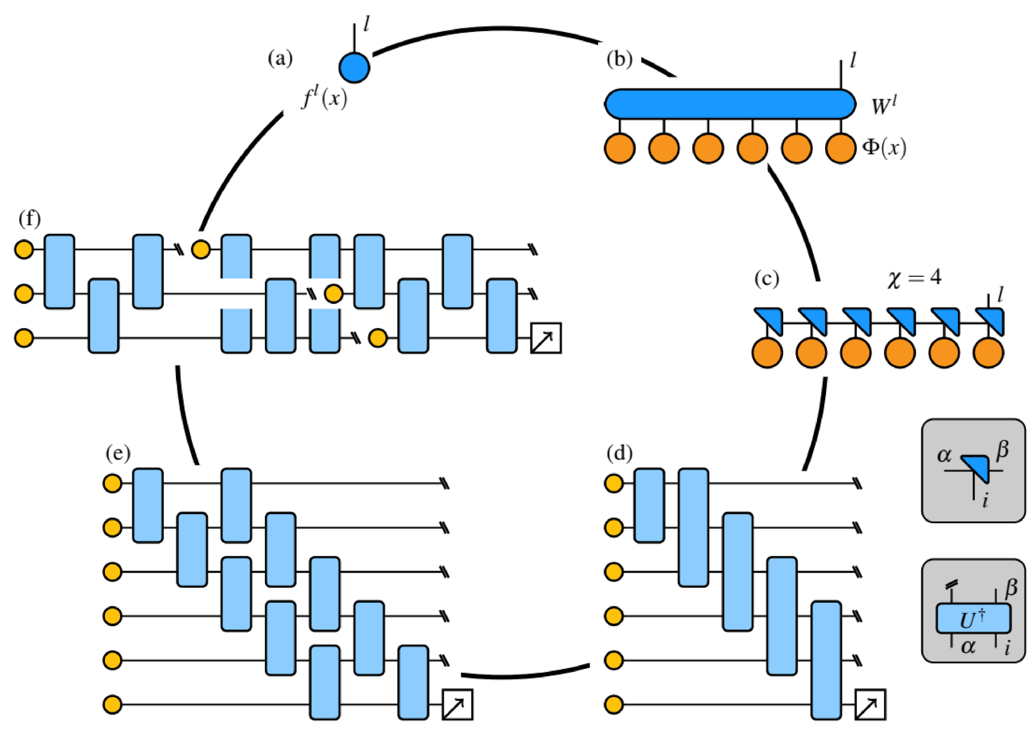
Combinatorial optimisation problems
Tensor networks can be used for solving optimization problems by mapping QUBO to Ising-like problems
- Range of TN algorithms (DMRG, iTEBD, annealing, …) for solving the Ising model
- Need to include constraints – symmetries, local tensors
- Natural mapping to quantum computer, hybrid methods



QUBO modelling considerations for TN algorithms: from MILP to QUBO (©BP/Fraunhofer CML/Multiverse)

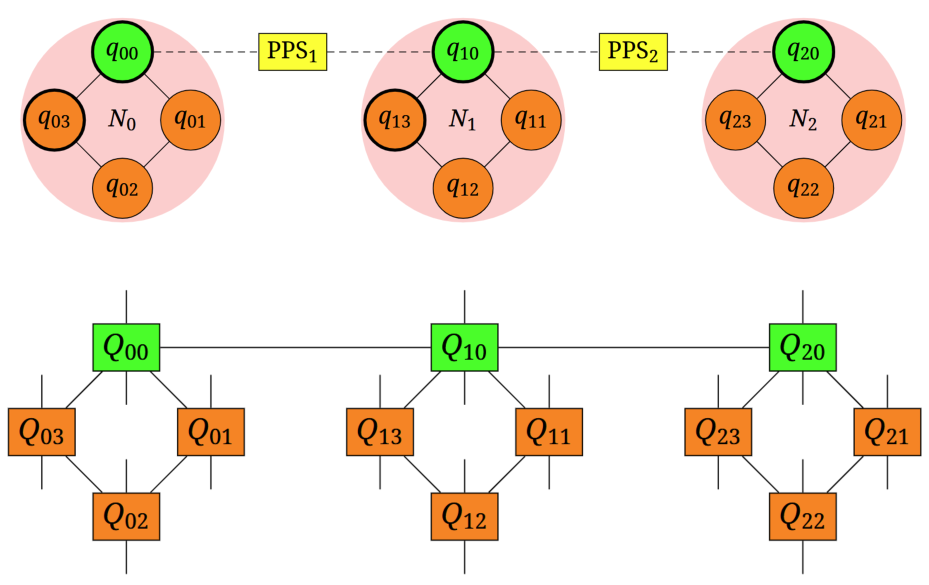
Project goals
- Evaluate the advantages and disadvantages of quantum tensor networks in comparison to classical tensor networks
- Demonstrate an implementation on existing quantum hardware
- Explore possible applications in quantum simulation and quantum AI
- In collaboration with industrial partners, identify fields of application for quantum tensor networks for real-world use cases

Applications with AI methods
Quantum tensor networks are promising candidates for quantum machine learning:
- Direct implementation in variational machine learning algorithms
- Usability of classical tensor network methods in the context of quantum machine learning



Application of tensor networks in quantum machine learning.
Adapted (CC-BY) from Proc. R. Soc. A **479**, 20230218 (2023)

Simulations on quantum computers
Tensor networks are a natural method for simulating quantum systems on quantum and classical hardware:
- Use of tensor networks for applications in quantum technology
- Evaluation and optimisation of simulations through coupling with tensor-network based quantum AI



Abstract quantum network and a possible representation as a tensor network (own illustration)

Tensor network methods
Tensor networks are a method for representing complex (quantum) states:
- Efficient representation of high-dimensional systems by identification of relevant correlations and truncation: no exponential scaling
- Applicability of local arithmetic operations
- Mapping of data in machine learning
- Efficient methods for optimization and control of errors
- Natural mapping to quantum computers

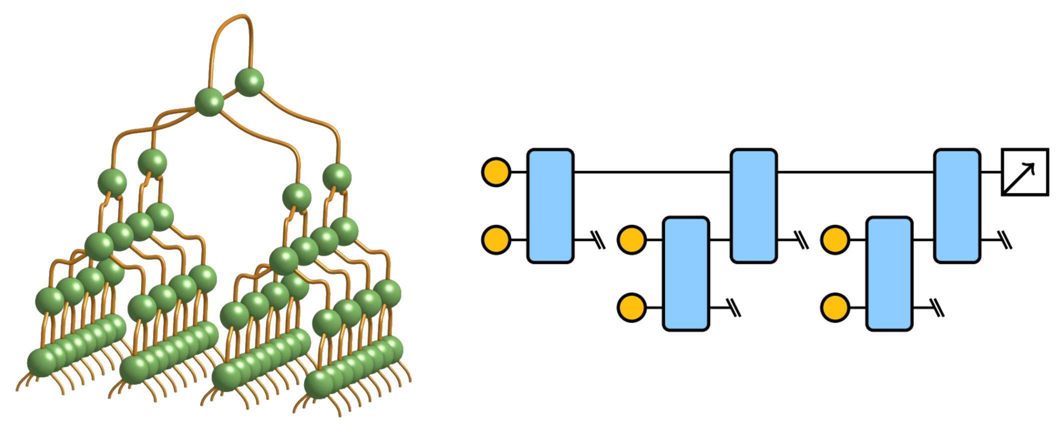
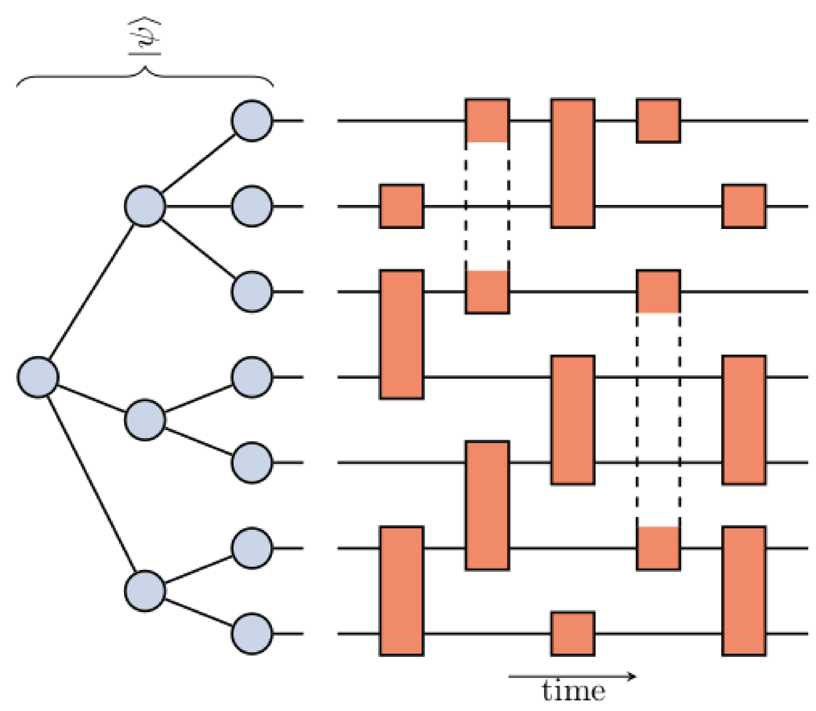


Illustration of a 2D-TTN (left) and a qubit-efficient QTN circuit (right). Adapted (CC-BY) from Phys. Rev. X **10**, 041040 (2020) and Proc. R. Soc. A **479**, 20230218 (2023).



Efficient simulation of quantum circuits with tree tensor networks
Adapted (CC-BY) from Quantum **7**, 964 (2023)

Current research topics
- Classical machine learning with tensor networks
- Data and ML model compression with MPS and TTN
- Mapping general tensor networks to MPS and TTN
- Optimisation of advanced tensor network architectures
- Algorithm optimization for common tensor network operations
- Simulating physical systems (e.g. NV centers in diamond, quantum networks) with tensor networks
- Combinatorial optimization problems with TNs

More information about the project on our website

A project of

DLR Institute for AI Safety and Security
DLR Institute of Quantum Technologies
DLR Institute of Software Technology

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