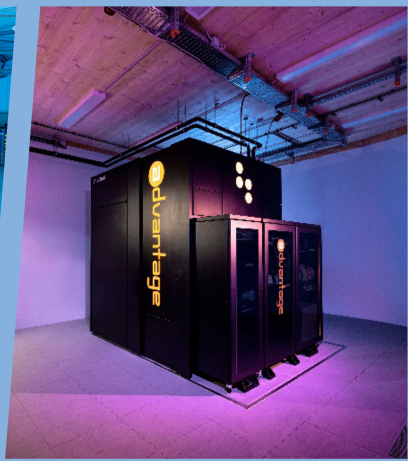
JÜLICH Forschungszentrum | JÜLICH SUPERCOMPUTING CENTRE

# QUANTUM INFORMATION PROCESSING

## SIMULATION ON/OF QUANTUM COMPUTERS

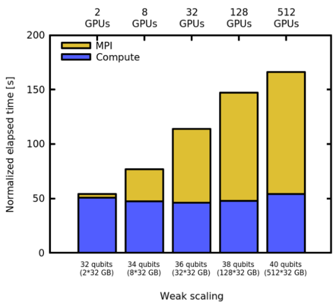



- **High performance computing for simulating quantum computers up to 48 qubits**
- **Simulation of physical models of multi-qubit systems**
- **Exploration of support vector machines on the D-Wave quantum annealer**
- **Solving optimization problems with the approximate quantum optimization algorithm and approximate quantum annealing**

### Ideal quantum computer

Massively parallel quantum spin simulator, JUQCS, to develop and test quantum algorithms and applications on N-qubit quantum computers.

- Beats exponential scaling: wall clock time O(N);
  H. De Raedt, et al., Comp. Phys. Comm. 237, 47-61 (2019)
  D. Willsch, et al., Comp. Phys. Comm. 278, 108411 (2022)
- Used to benchmark Sycamore, Google's 53-qubit quantum processor, which achieved quantum supremacy.
  F. Arute, et al., Nature 574, 505-510 (2019)




*Weak scaling behavior for executing eleven Hadamard gates in a row on each qubit. Elapsed time for executing the quantum circuit only ("Compute"), communication, preparing and postprocessing MPI buffers ("MPI").*

### D-Wave quantum annealer

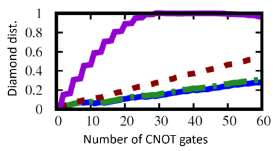
Support Vector Machine (SVM), a supervised machine learning algorithm:

- Classical SVM (CSVM): training corresponds to a convex quadratic optimization problem, having a global minimum;
- Quantum SVM (QSVM) on a D-Wave quantum annealer: quantum annealer produces various close-to-optimal solutions for the training data, which are combined to create an optimized SVM classifier;
- Quantum Multiclass SVM (QMSVM): QSVM for direct multiclass classification. QMSVM can achieve an accuracy that is comparable to standard SVM methods, but it scales much more efficiently with the number of training samples.

*City of Toulouse – Classification maps for the classes "Building" (orange), "Pervious surface" (green) and "Water (blue). Left to right: ground truth, CSVM, QMSVM. | A. Delilbasic, et al., arXiv:2303.11705*

### Superconducting qubits

Simulation of the real-time dynamics of a system of

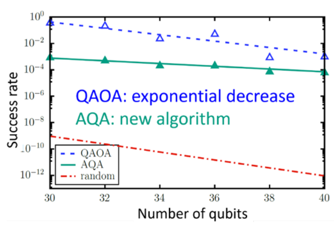



*Sensitivity of the diamond distance to variations of the control pulse amplitude \Delta for a sequence of CNOT gates. \Delta = 0 (blue), \Delta = 10^{-6} (green), \Delta = 10^{-5} (red), \Delta=10^{-4} (violet).*

- two fixed-frequency transmon qubits coupled by LC resonators, shows that gate-error metrics like the diamond distance are poor performance predictors if repetitions of a single quantum gate are considered;
  D. Willsch, et al., Phys. Rev. A 96, 062302 (2017)
- two superconducting flux qubits (rf-SQUIDS) coupled by an rf-SQUID, the building blocks of the D-Wave quantum processors, shows that the system can be well described by two spin-1/2 qubits coupled by an harmonic oscillator;
  M. Willsch, et al., Phys. Rev. A 101, 012327 (2020)
- two, three and four flux-tunable transmon qubits coupled by LC resonators, shows that gate-error metrics like the diamond distance are susceptible to small changes in the system model and/or the model parameters;
  H. Lagemann, et al, arXiv:2211.11011
- flux-tunable transmon qubits, shows that it can be described as a system of time-dependent anharmonic oscillators, assuming that all the relevant time dependencies are taken into account.
  H. Lagemann, et al., Phys. Rev. A106, 022615 (2022)

### Solving optimization problems with QAOA and approximate quantum annealing

Simplified Tail Assignment problems, optimization problems to plan flights between airports so that routes do not overlap, solved with JUQCS using the Quantum Approximate Optimization Algorithm (QAOA) and the Approximate Quantum Annealing (AQA) for different problem sizes.




- QAOA shows higher success rates than AQA;
- The success rate of AQA scales better than the one of QAOA for increasing qubit numbers (problem sizes).
  D. Willsch, et al., Comp. Phys. Comm. 278, 108411 (2022)

*Scaling of the success rate of QAOA and AQA with increasing problem size (number of qubits).*

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