Quantum classical hybrid computing models in modular HPC systems with potential applications in Earth Observation

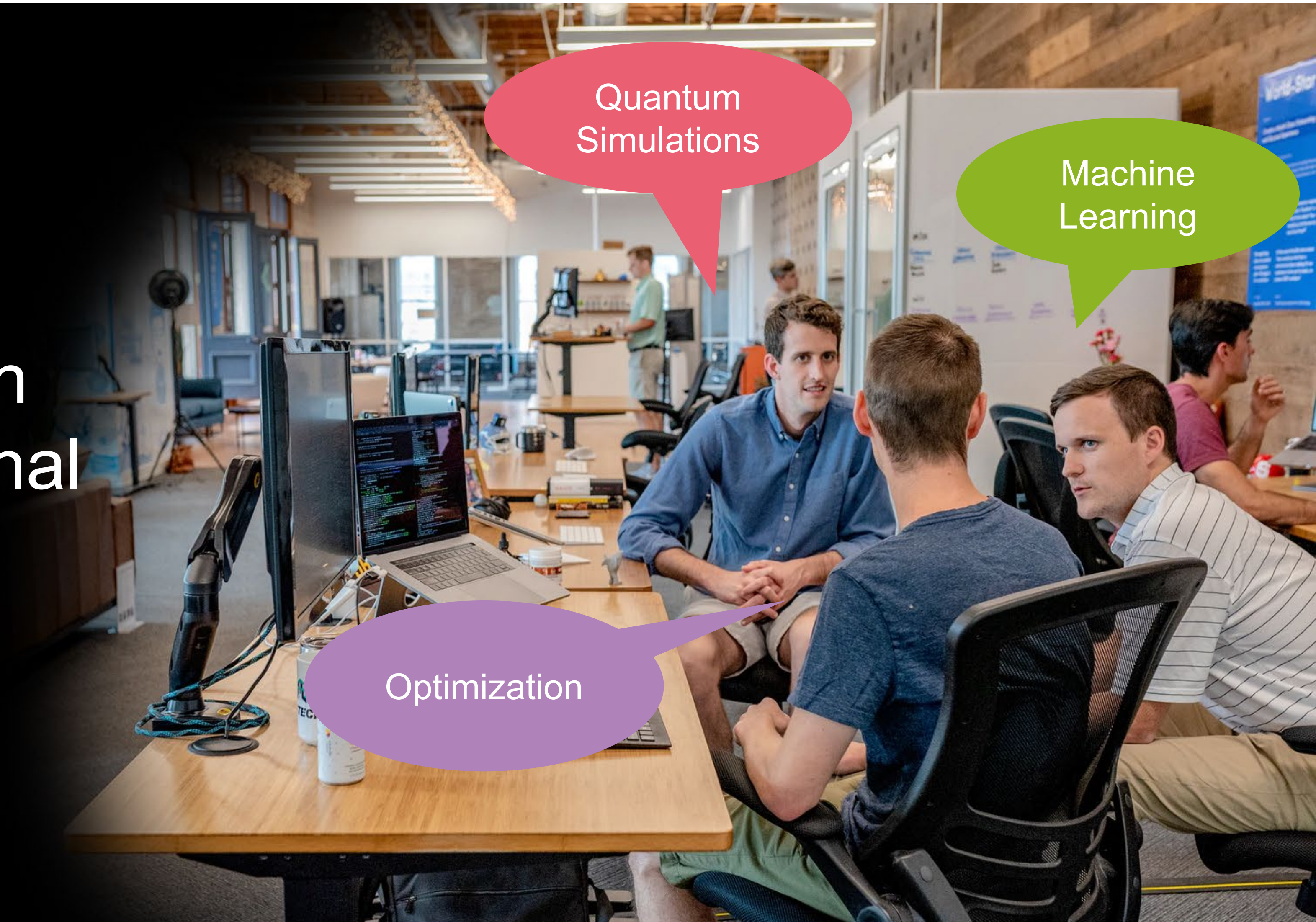
ELLIS-ESA Workshop 2021 | May 27, 2021 | KRISTEL MICHIELSEN

JÜLICH Forschungszentrum | JUNIQ QUANTUM USER FACILITY

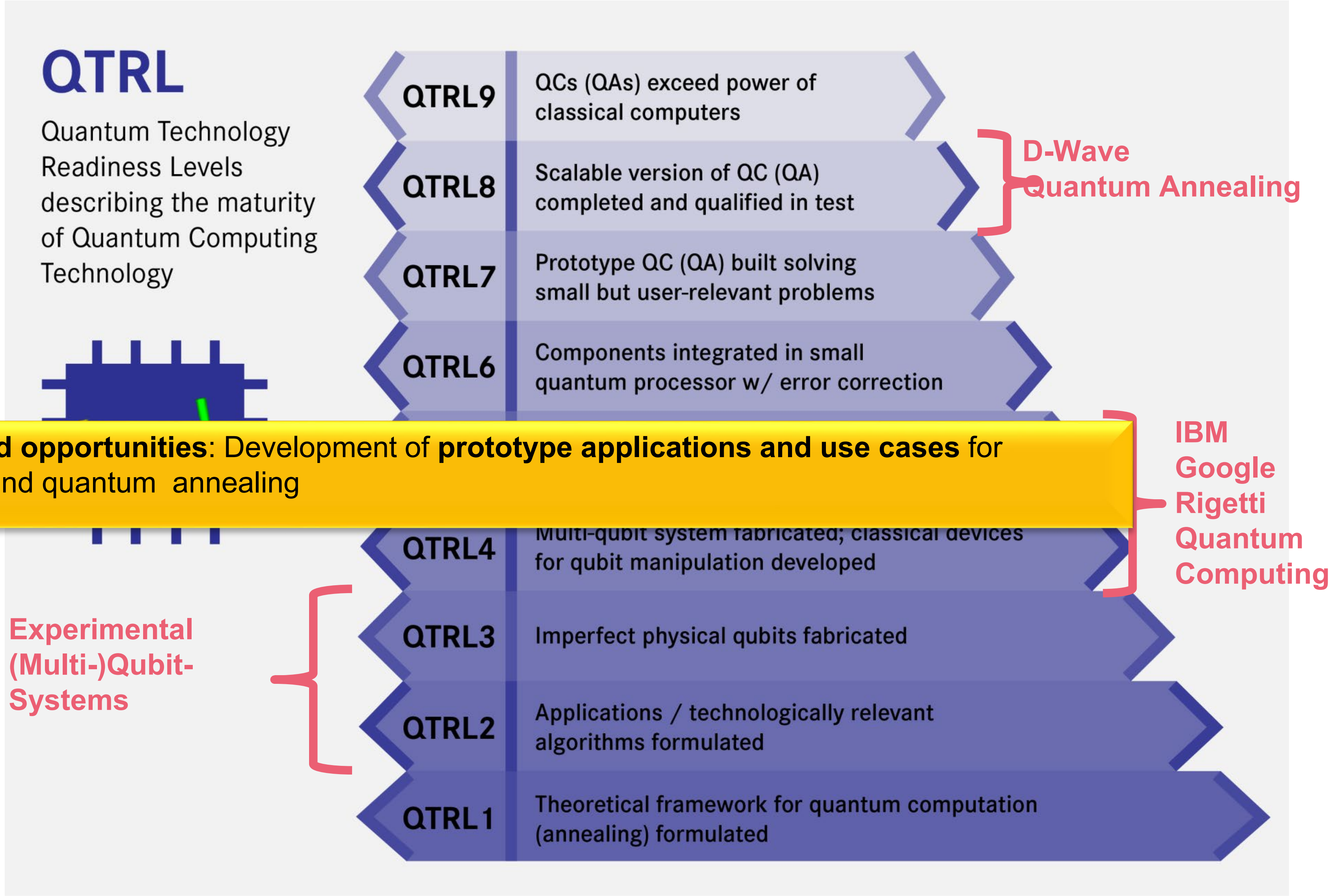
Quantum computing:

new, disruptive compute technology

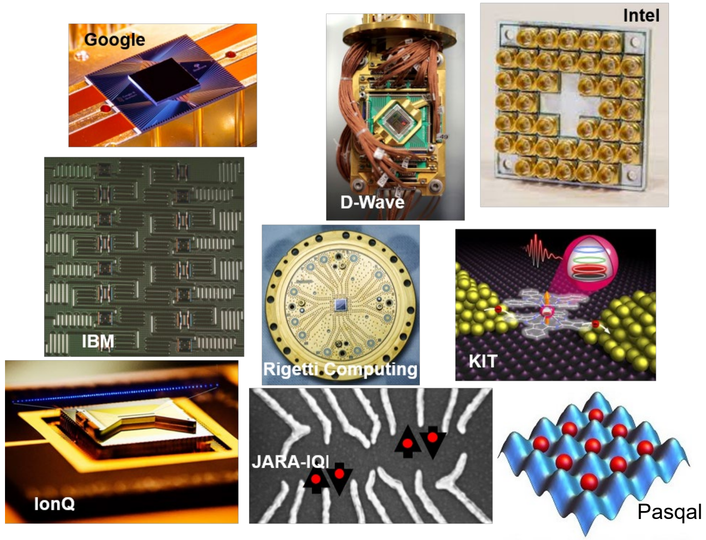
Science & Industry:
Diverse user group with various hard computational challenges to unravel complex systems



Quantum Technology Readiness Levels



Huge challenges and opportunities: Development of **prototype applications and use cases** for quantum computing and quantum annealing



(http://www.fz-juelich.de/ias/jsc/EN/Research/ModellingSimulation/QIP/QTRL/_node.html)

High performance & Quantum Computers

linked, to solve problems optimally

Quantum Computers & Annealers

Understanding – Design – Benchmarking

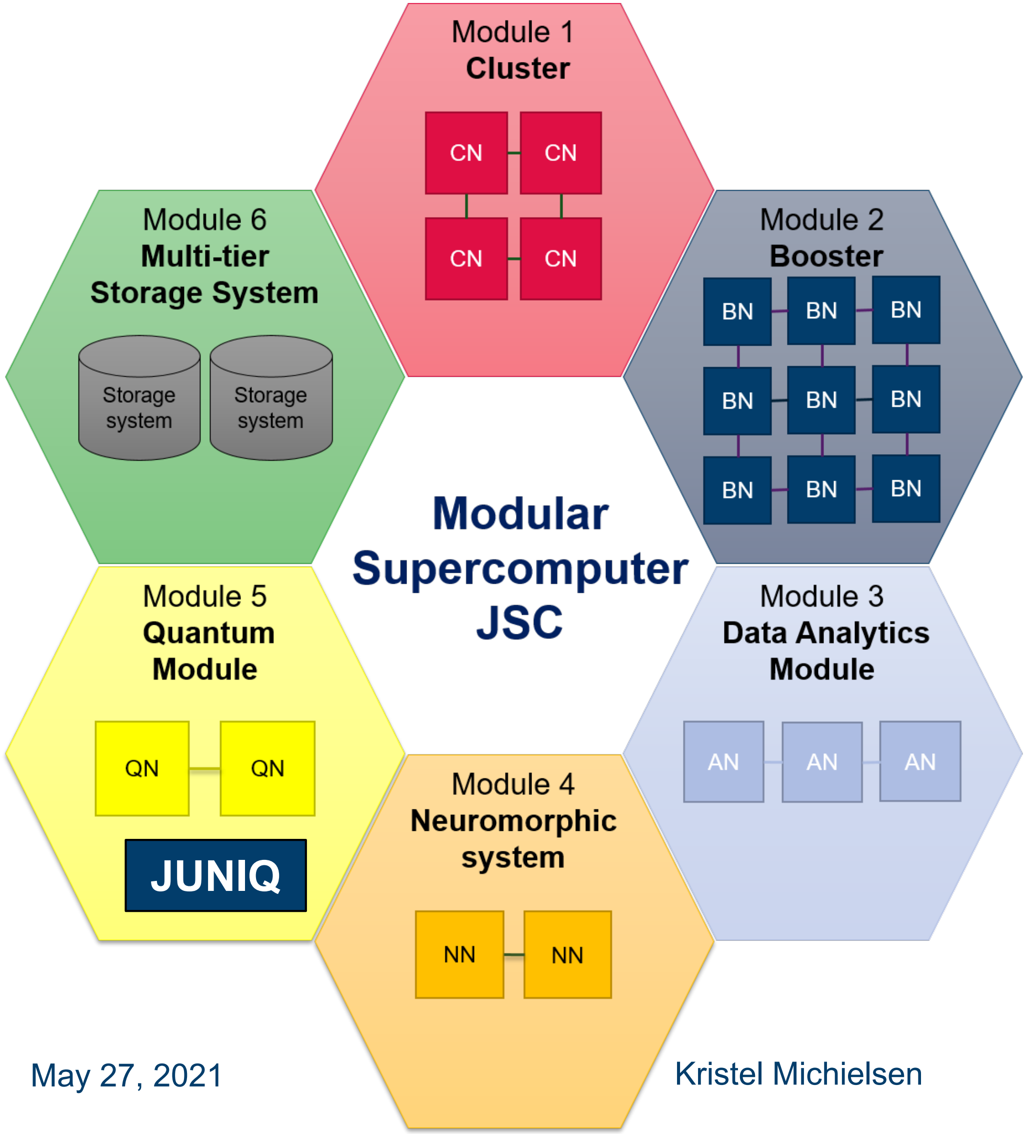
High Performance Computers

HPC simulations of quantum computing / annealing devices

(Hybrid) simulations for applications

JUNIQ - Jülich UNified Infrastructure for Quantum computing

Building a European quantum computer user facility at the Jülich Supercomputing Centre



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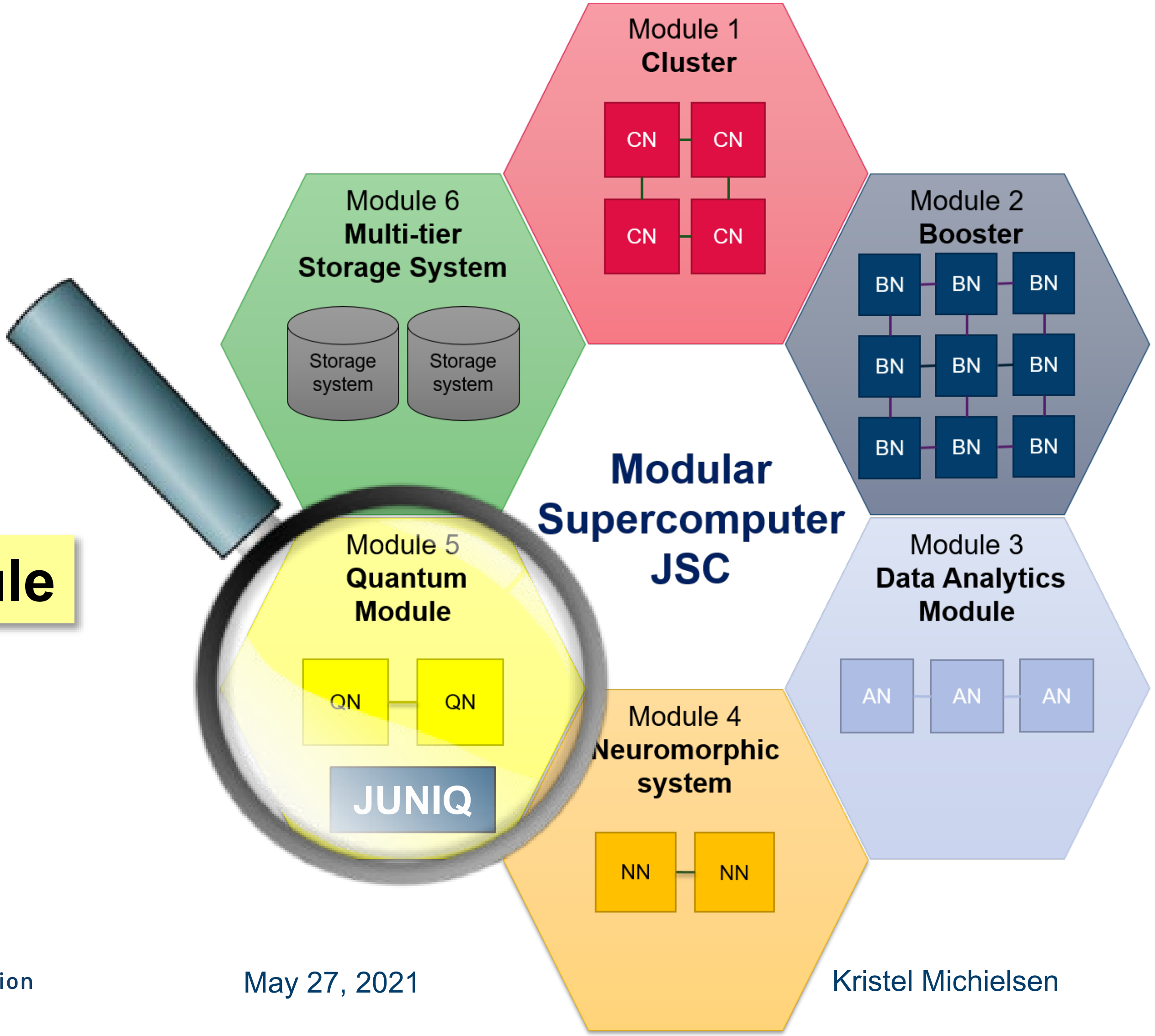
Quantum Module

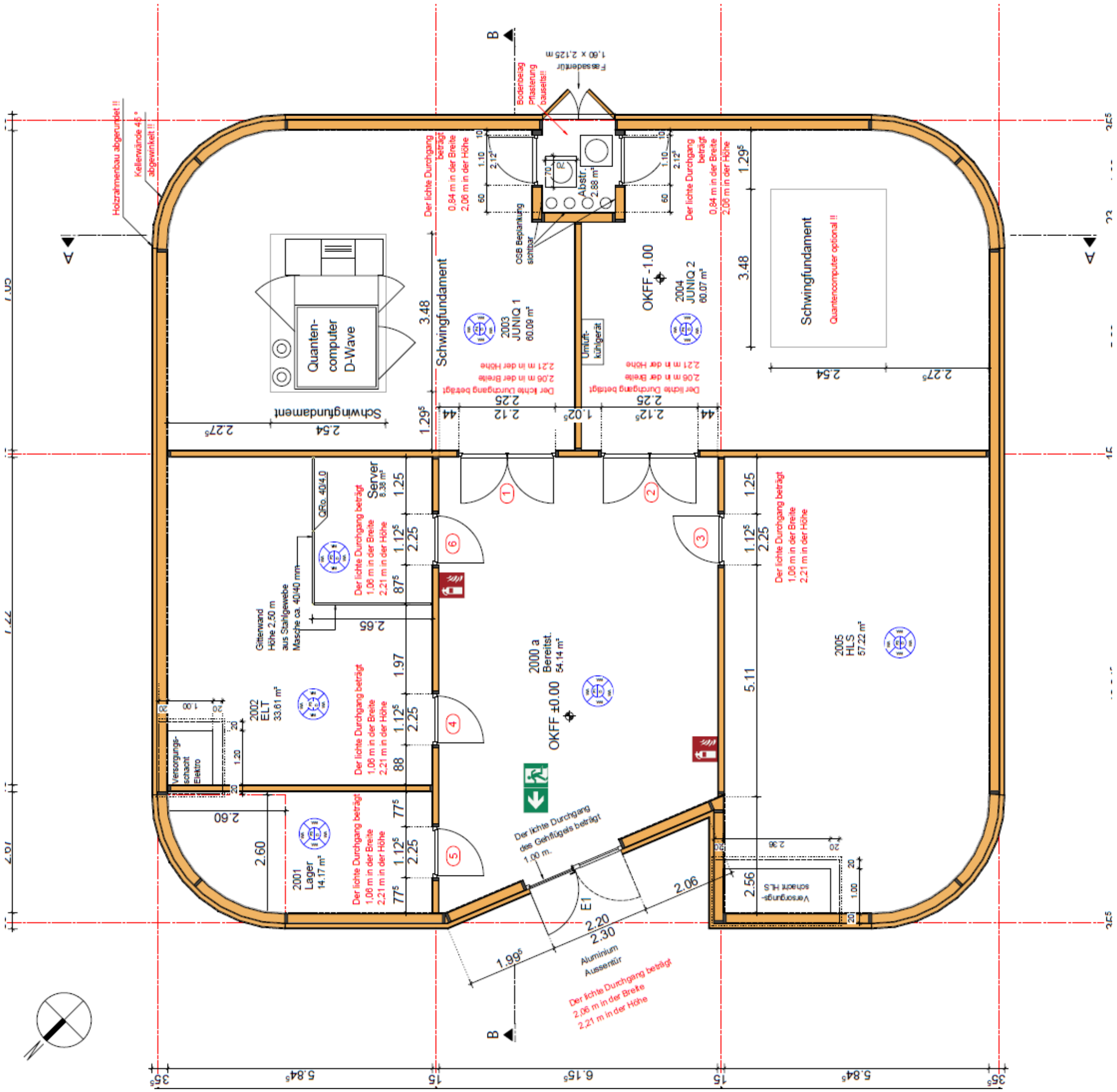


Perspective:
Quantum-Classical
Hybrid Computing Models

JUNIQ - Jülich UNified Infrastructure for Quantum computing

1. QC user facility for science and industry
2. Installation, operation and provision of QCs
3. Unified portal for access to QC simulators and to QC devices at different levels of technological maturity (QC-PaaS)
4. Development of algorithms and prototype applications
5. Services, training and user support
6. Modular quantum-HPC hybrid computing

JUNIQ Building



PROTOTYPE APPLICATIONS

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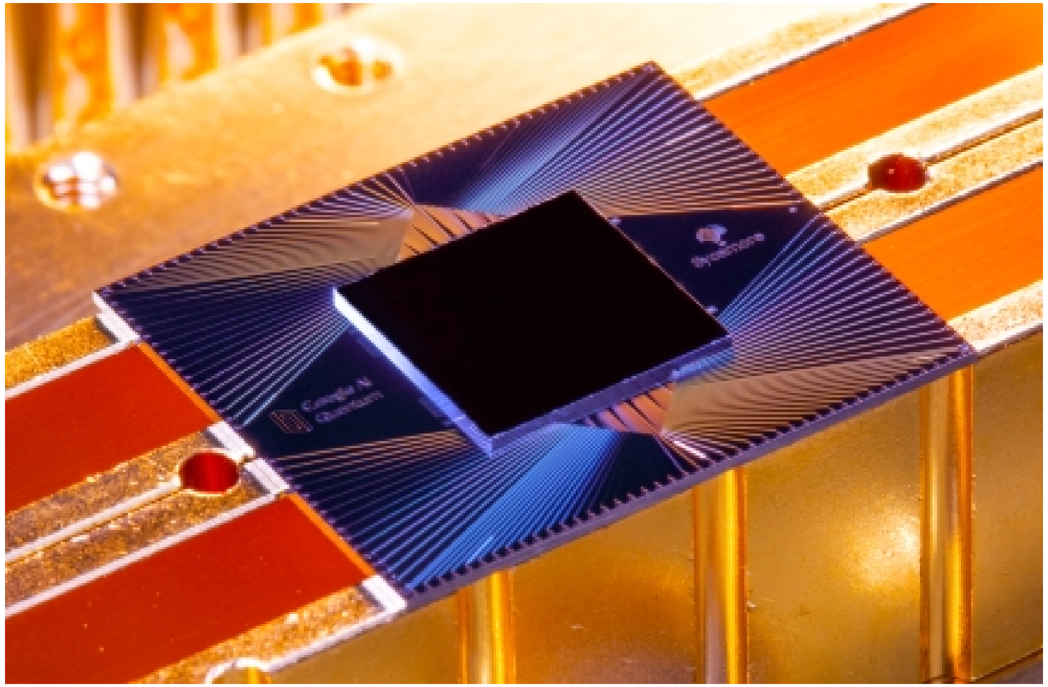
BENCHMARKING – QUANTUM SUPREMACY

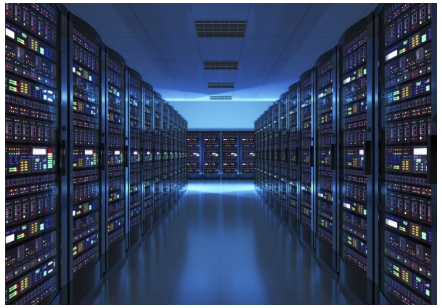
Google Sycamore quantum processor

F. Arute et al., *Quantum supremacy using a programmable superconducting processor*, Nature 574, 505-510 (2019)

BENCHMARKING SYCAMORE

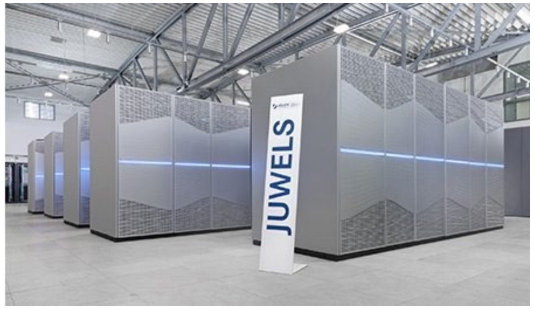


WITH SUPERCOMPUTERS



Google clusters

SUMMIT
Oak Ridge National Laboratory



JUWELS
Jülich Supercomputing Centre

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OPTIMIZATION

M. Willsch, et al., *Benchmarking the Quantum Approximate Optimization Algorithm,* Quant. Inf. Proc. 19, 197 (2020)

Quantum Approximate Optimization Algorithm (QAOA) & quantum annealing

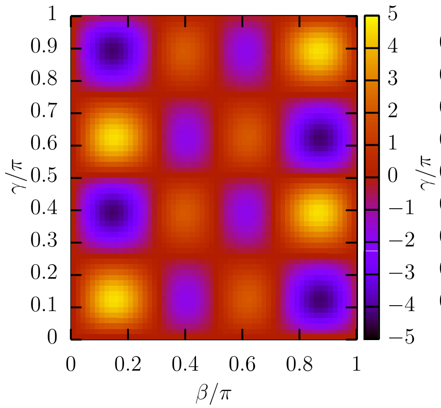
QAOA

- Variational quantum algorithm (**hybrid** algorithm)
- Relies on iteratively applying a series of parametrized unitary transformations to a quantum register, measuring its resulting state and evaluating the **energy expectation value**
  - Number of iterations $p \geq 1$
- A **classical optimization algorithm** is used to optimize the parameters β and γ of the unitary transformations
- For $p \to \infty$ and β and γ taken according to a quantum annealing scheme the solution is found

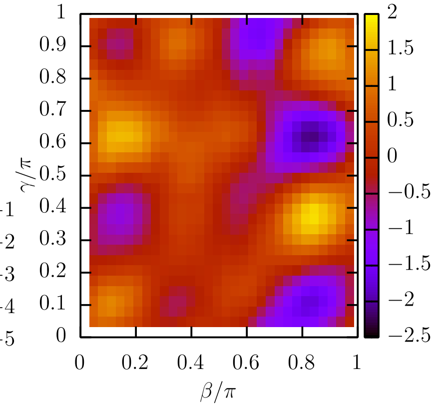
Gate-based quantum computer

Quantum annealer

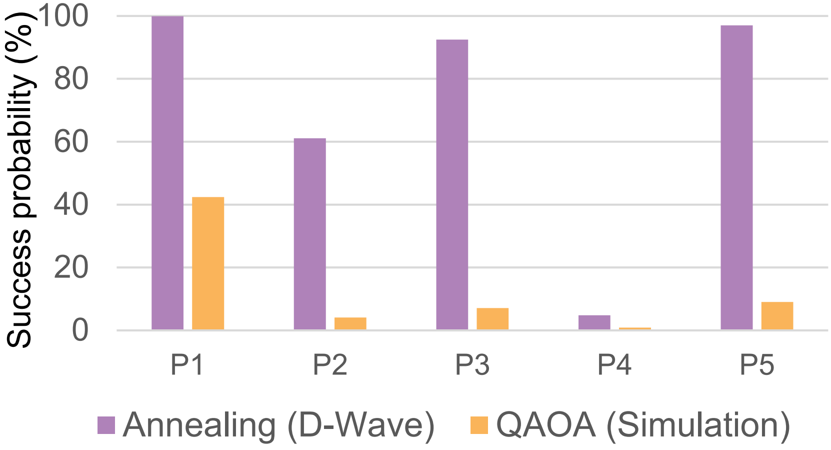
QAOA



Simulation



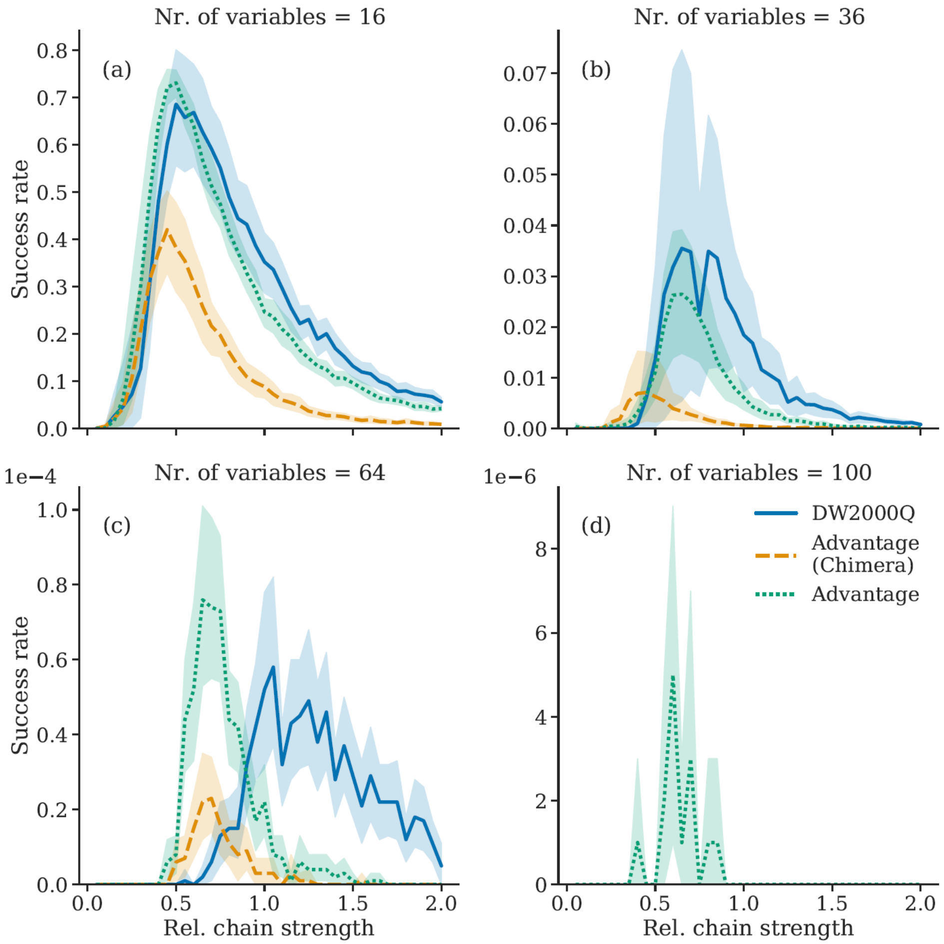
IBM-Q16 Melbourne (2019)



Companion planting

Quadratic Assignment Problem with constraints

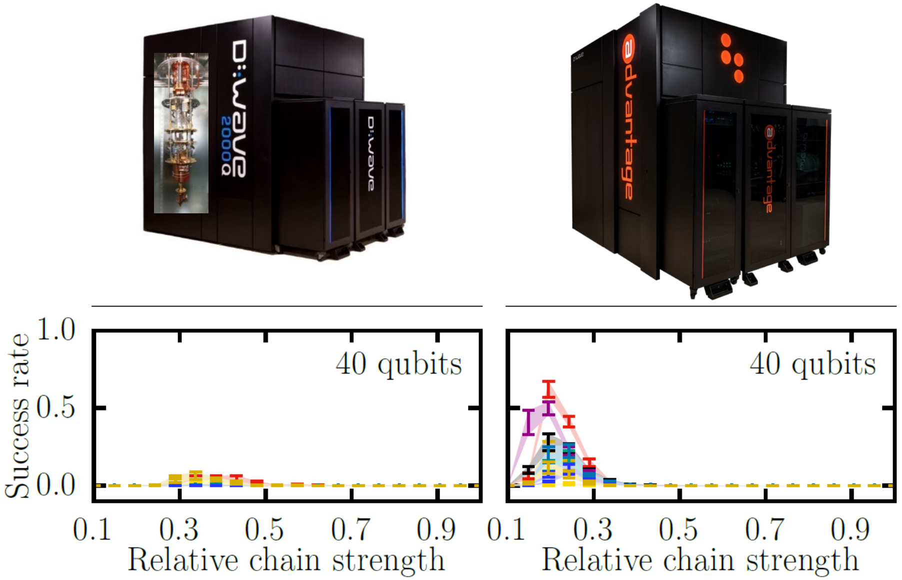
C.D. Gonzalez Calaza et al., *Garden optimization problems for benchmarking quantum annealers*, arXiv:2101.10827

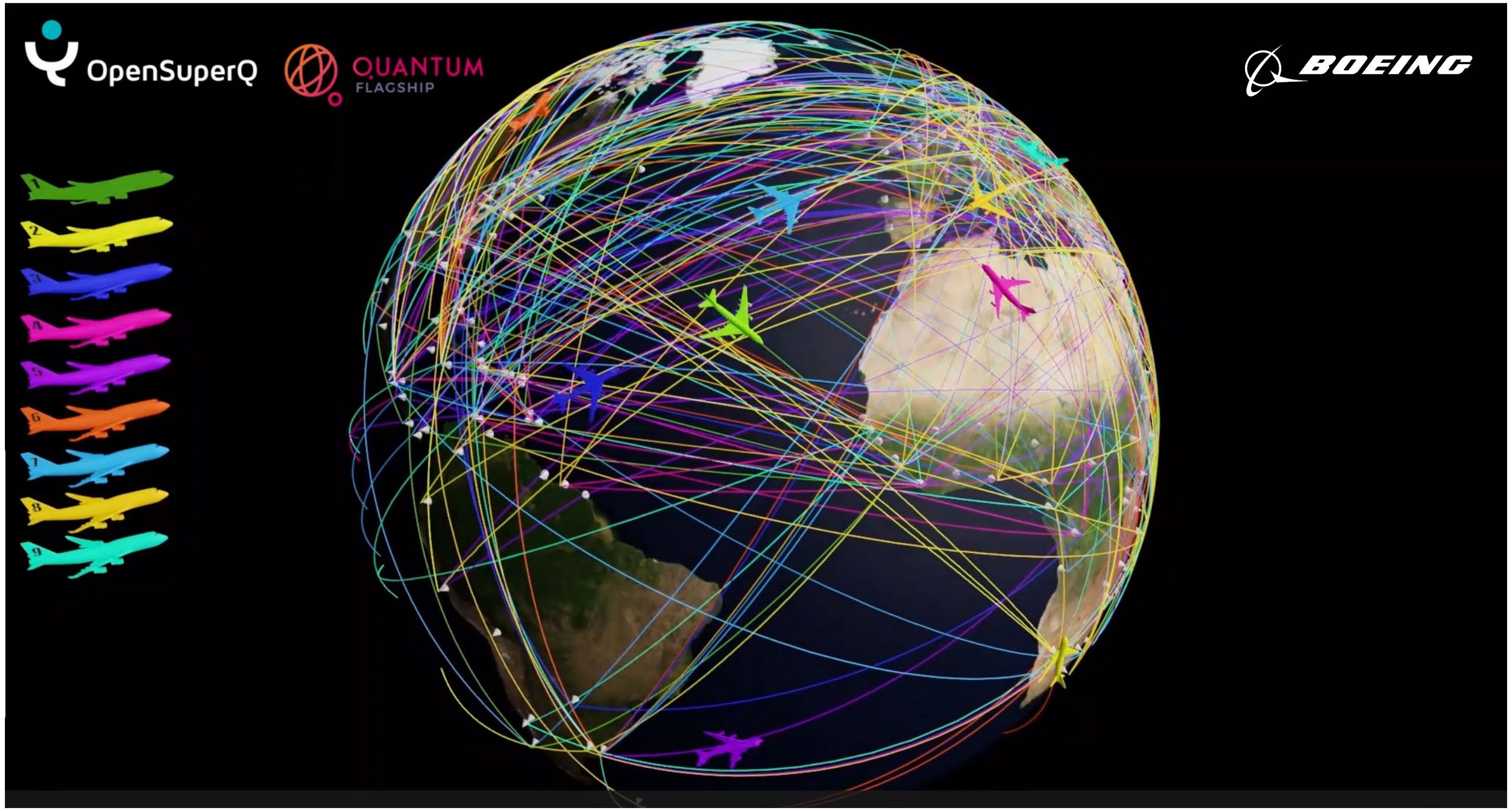


Simplified tail assignment problem

Exact cover problem

D. Willsch et al., *Benchmarking Advantage and D-Wave 2000Q quantum annealers with exact cover problems* (in preparation)



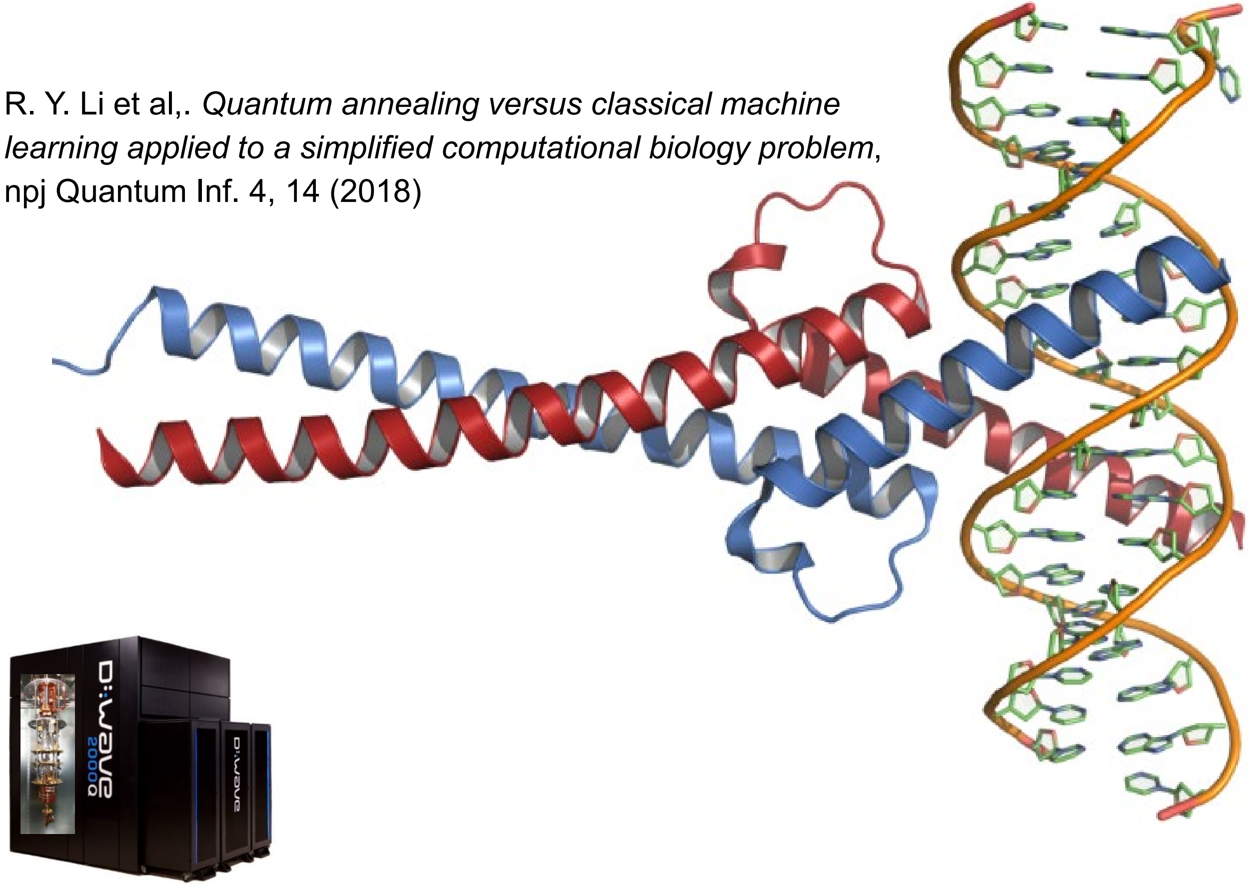


Protein-DNA binding

Classification (machine learning)

D. Willsch et al., *Support vector machines on the D-Wave quantum annealer,* Comp. Phys. Comm. 248, 107006 (2020)

R. Y. Li et al,. *Quantum annealing versus classical machine learning applied to a simplified computational biology problem*, npj Quantum Inf. 4, 14 (2018)

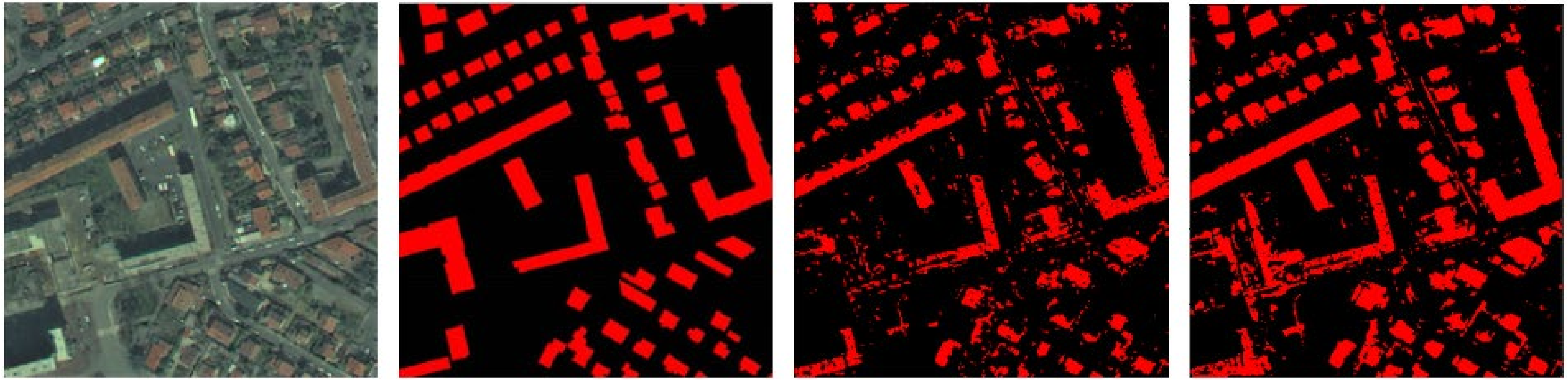


1. qSVM on a D-Wave quantum annealer (hybrid workflow) can produce significantly stronger classifiers than cSVM for the same little training data and parameters
2. qSVM performs better or comparative to cSVM for all datasets

Quantum machine learning for EO

Classification of Remote Sensing Multispectral Images with Quantum SVM

False color | Ground truth | Classical SVM | Quantum SVM

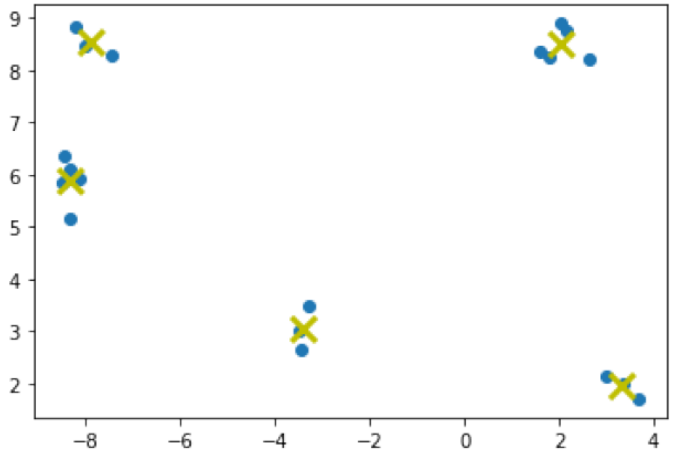


A. Delilbasic, G. Cavallaro, M. Willsch, F. Melgani, M. Riedel and K. Michielsen,
Quantum Support Vector Machine Algorithms for Remote Sensing Data Classification,
in IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 2021 (accepted)

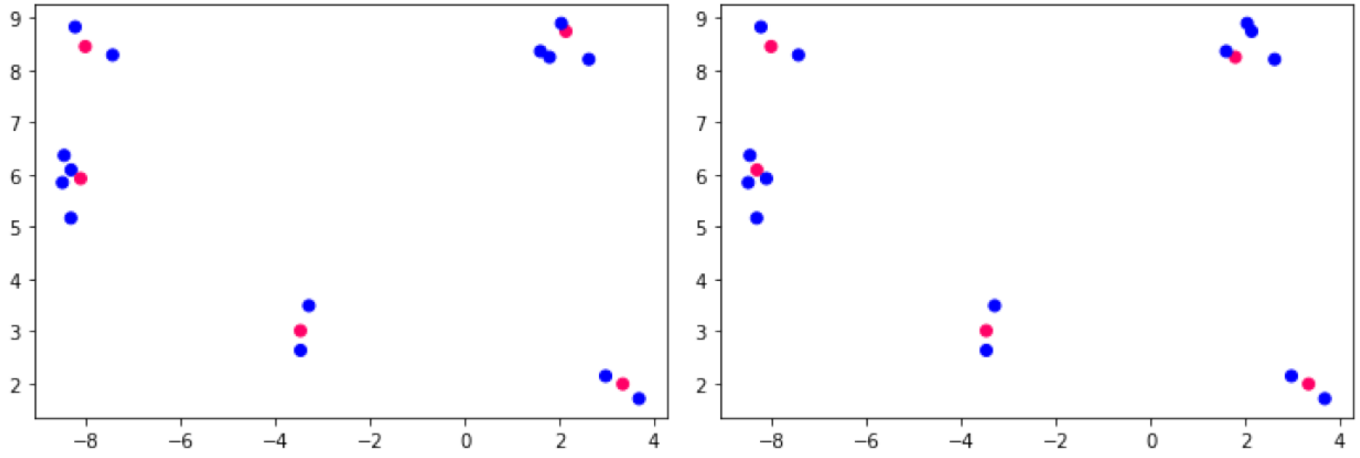
G. Cavallaro, D. Willsch, M. Willsch, K. Michielsen, and M. Riedel,
Approaching Remote Sensing Image Classification with Ensembles of Support Vector Machines on the D-Wave Quantum Annealer,
in Proc. of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 1973-1976, 2020,
https://doi.org/10.1109/IGARSS39084.2020.9323544

Quantum machine learning for EO

Compress Convolutional Neural Networks with Quantum Clustering



Classical K-means



K-medoids with D-Wave Advantage system

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Hybrid usage of High performance & Quantum Computers

Quantum Computers & Annealers

High Performance Computers

Succesful development of quantum computing applications