HBO-ICT | Hogeschool van Amsterdam

Introduction Quantum Stack

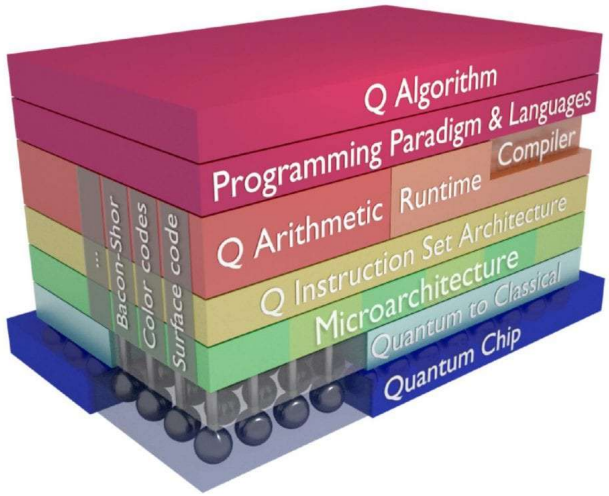
Minor Quantum Computing
Ed Kuijpers, e.a.kuijpers@hva.nl

19-10-2023

Creating Tomorrow

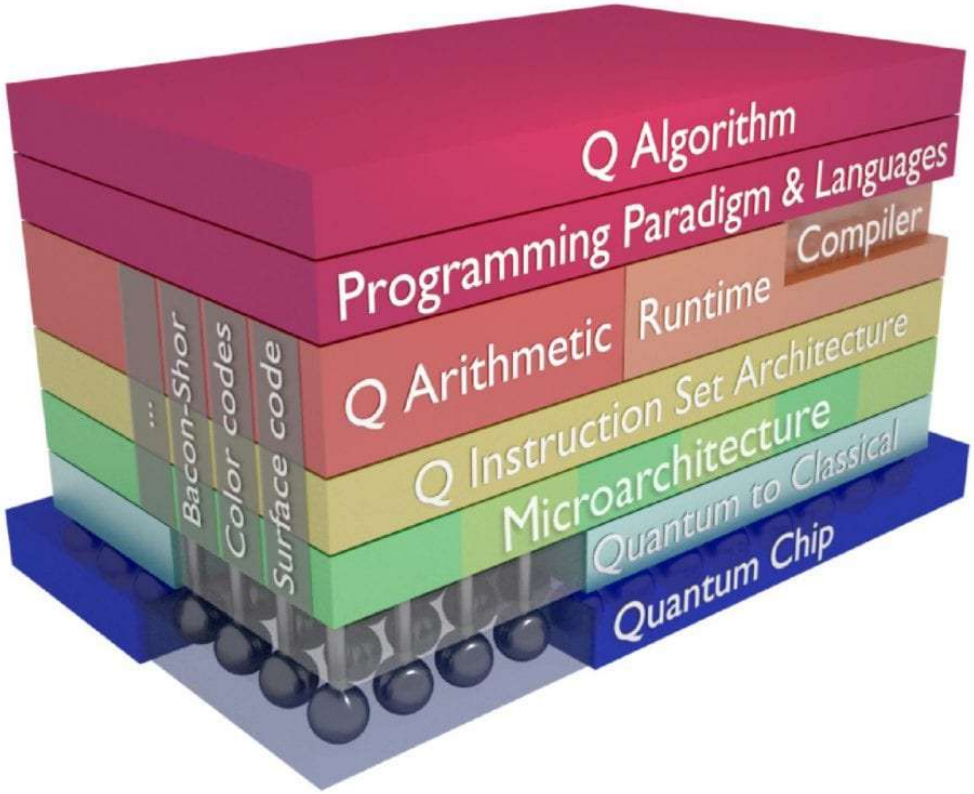
Topics

- Structure lessons
- Writing paper and presentation in phases
- Structure quantum stack
- Discussion topics for paper



Quantum Stack

- Abstraction layers
- Stack models



Structure lessons

- Each lesson presentation wil focus on a layer in Quantum Stack
- Students individually select Quantum stack topic for writing paper
- Students select, motivate and present a topic
- Students present draft paper/progress
- Finalize paper with final presentation

Draft schedule

- Week 1: introduction topics
- Week 2: Quantum computing Languages + student paper proposals
- Week 3: Transpiling and run-time + student paper proposals
- Week 4: Quantum hardware + student proposals
- Week 5: Quantum internet + progress reporting paper students
- Week 6: Quantum Information, sensing and learning + progress reporting paper
- Week 7: (14 June): Quantum programming + progress reporting
- Week 8: TBD
- Week 9 (18 June): Paper presentation
- Week B5: Resit Presentation

Approach

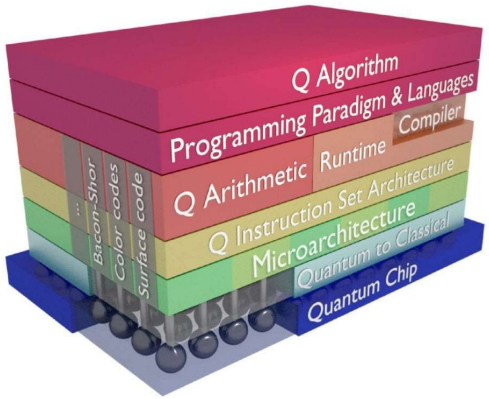
- Assignment-1proposed content paper
  - ✓Title
  - ✓Research questions
  - ✓Motivation
  - ✓Literature reference(s)
- Assignment-2 intermediae results
  - ✓Draft paper material
  - ✓Presentation intermediate results
- Intermediate feedback via paper and presentations
- Assignment-3 upload final paper
- Final presentation
- Grading

Discussion

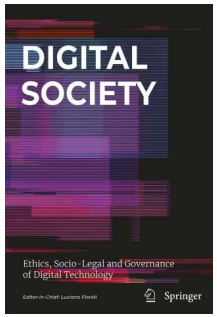
- Previous experience for the Software for Science minor (before Quantum Computing)
- Number of pages (in English): effort in accordance with Credits (3 ECTS) and quality (7 – 12 pages) including some good figures
  - https://studiegids.hva.nl/co/hbo-ict-vt/100000042/100888)
- In assessment: mix of software experiments with documentation appreciated
- Scientific format paper (LaTeX), backup pdf after MSWord conversion
- Diversity in topics to avoid too much overlap, interesting
- Avoid grading work twice, i.e. team project result assessment and paper assessment not overlapping
- Topics lessons will be adapted to research questions as far as possible

Introduction Quantum Stack

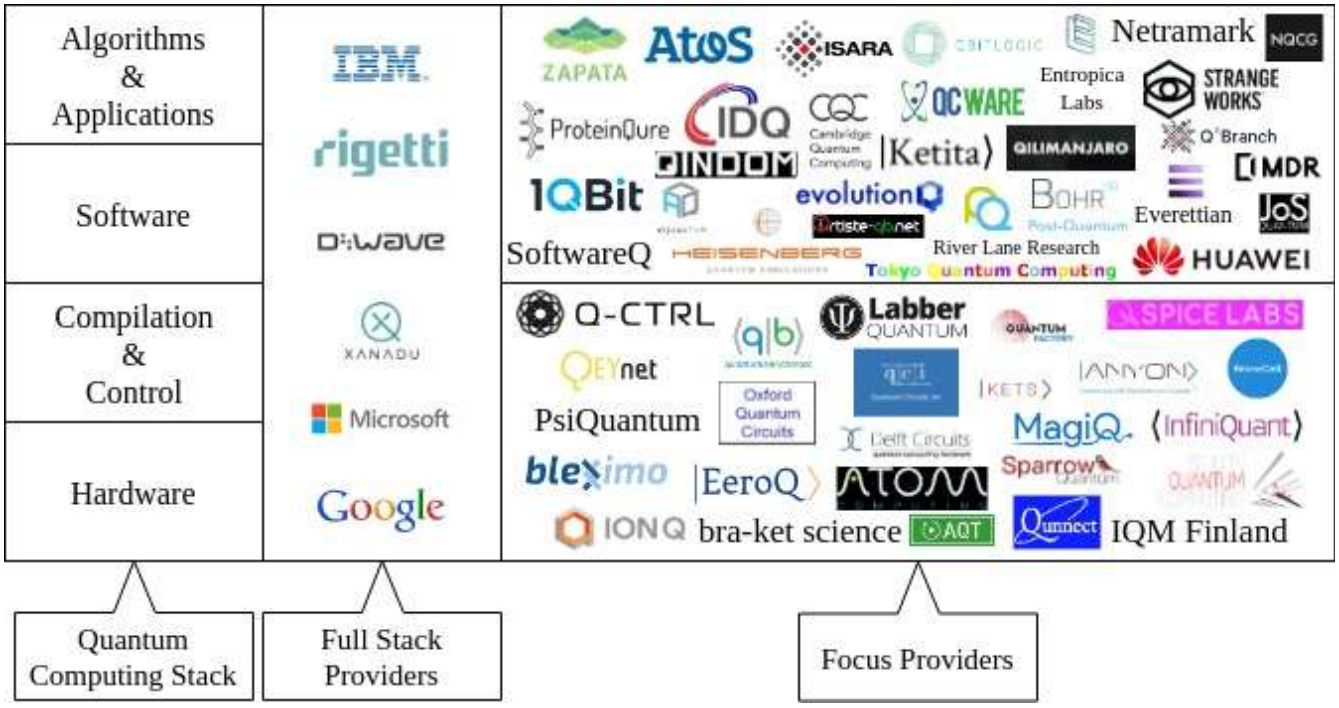
- Focus on technical stack



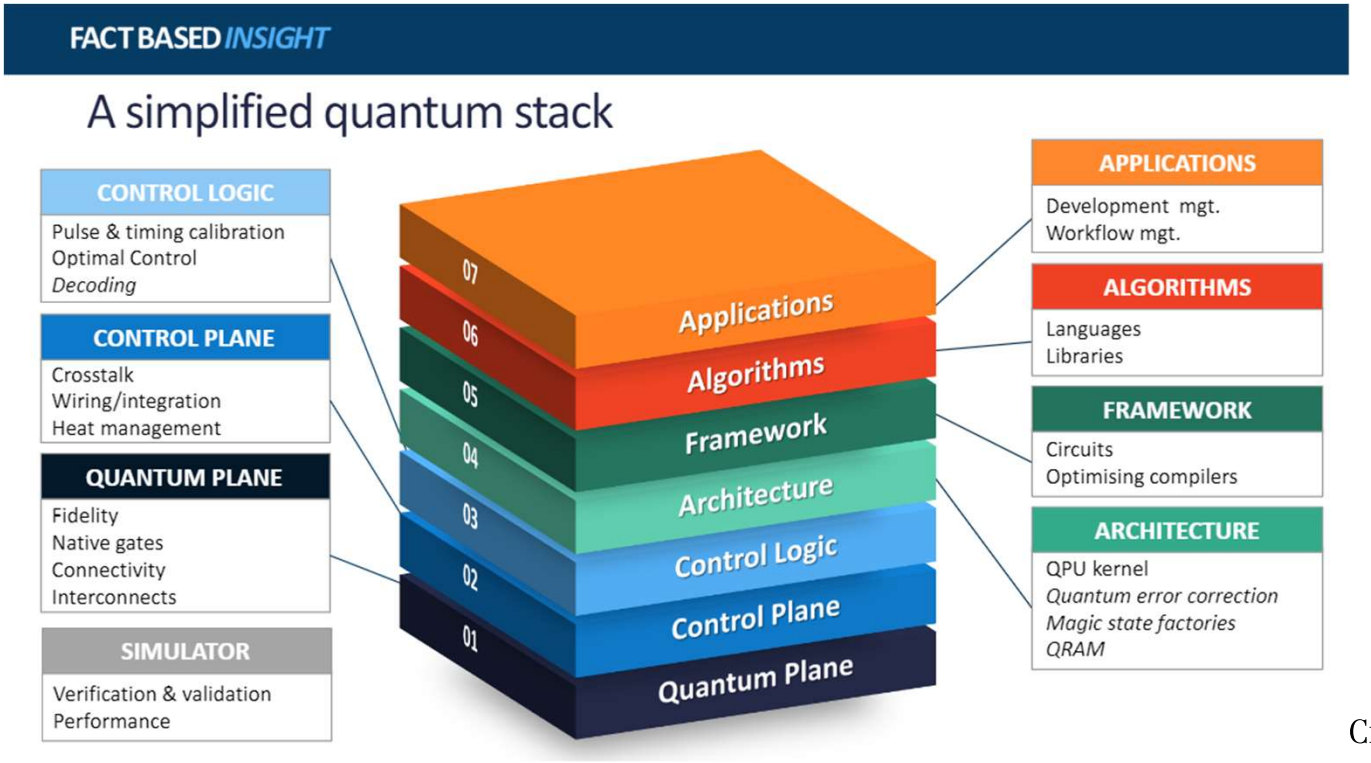
- Alternative definitions “The Quantum Governance Stack: Models of Governance for Quantum Information Technologies, ‘https://link.springer.com/article/10.1007/s44206-022-00019-x



Stack and companies

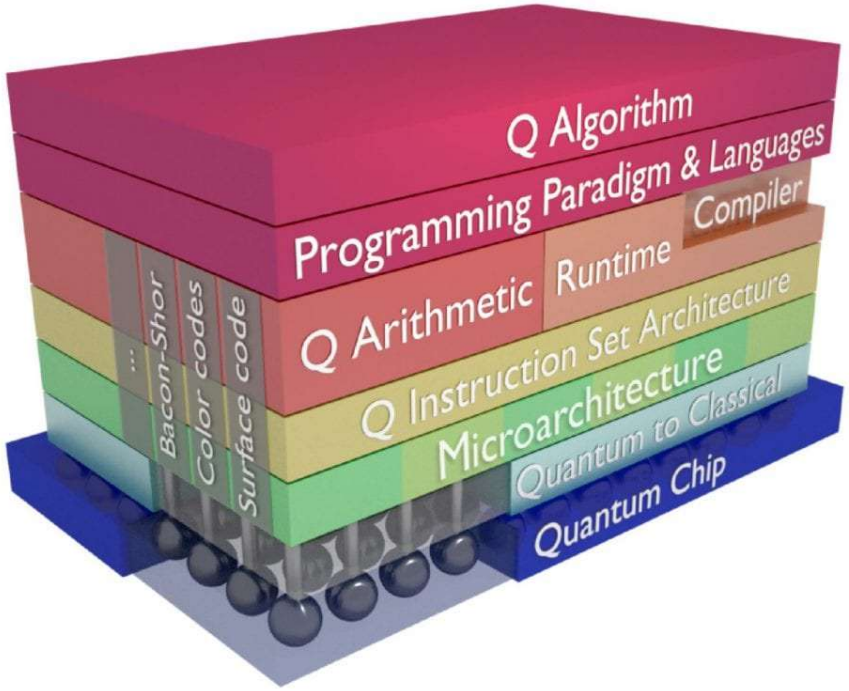


Other stack


FACT BASED INSIGHT
A simplified quantum stack
CONTROL LOGIC
Pulse & timing calibration
Optimal Control
Decoding
CONTROL PLANE
Crosstalk
Wiring/integration
Heat management
QUANTUM PLANE
Fidelity
Native gates
Connectivity
Interconnects
SIMULATOR
Verification & validation
Performance
07
Applications
06
Algorithms
05
Framework
04
Architecture
03
Control Logic
02
Control Plane
01
Quantum Plane
APPLICATIONS
Development mgt.
Workflow mgt.
ALGORITHMS
Languages
Libraries
FRAMEWORK
Circuits
Optimising compilers
ARCHITECTURE
QPU kernel
Quantum error correction
Magic state factories
QRAM

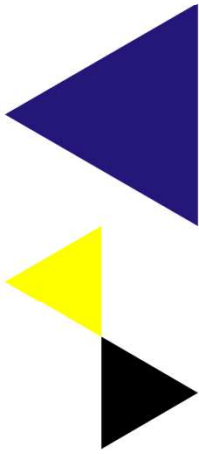
Layer Quantum stack algorithms

- Focus on implications of Q-algorithms on(part of) stack

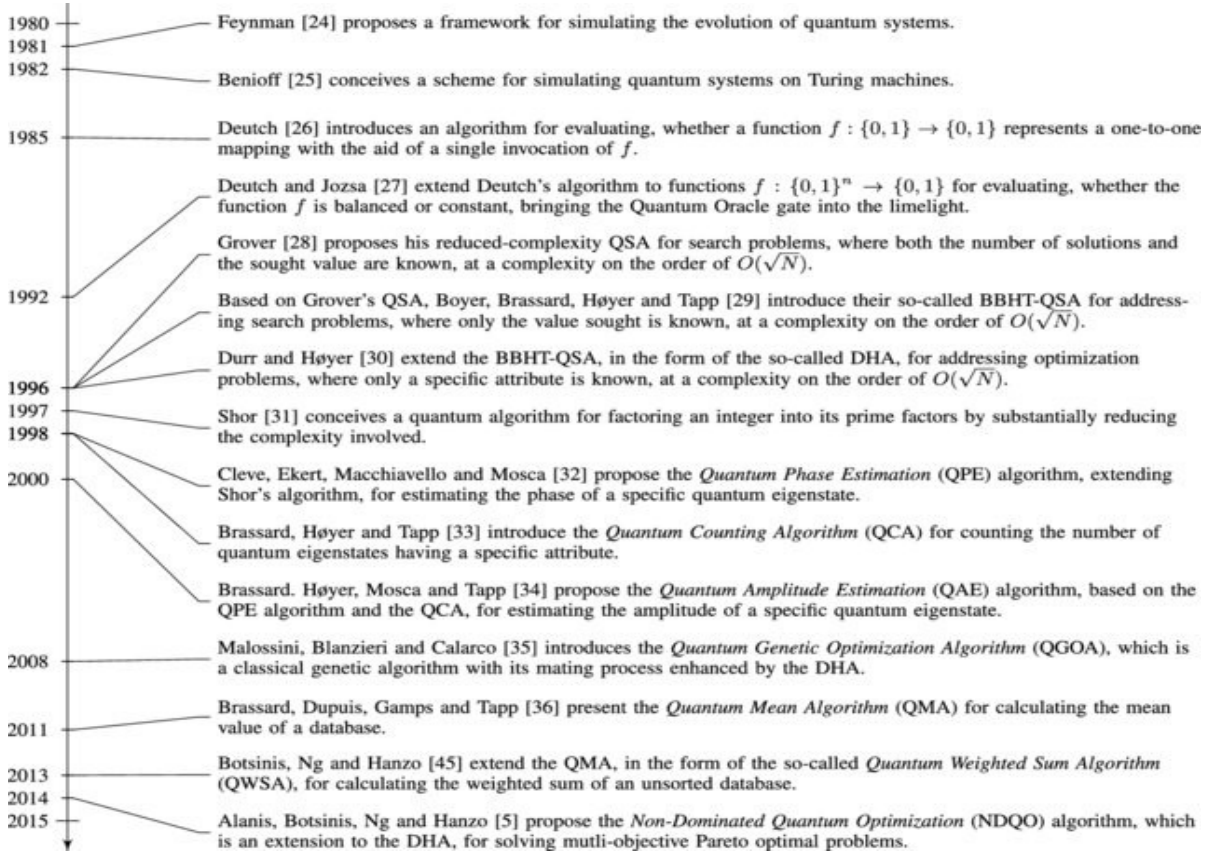


Options Algorithms and stack

- Analyse concept of operating system
- Analyse hardware and software requirements of a specific algorithm for the stack
- Analyse options for parallel processing
- Analyse the combination of a classical stack and quantum stack
- Concepts for integration with supercomputer
- Analyse sustainability



Quantum Computing history



Quantum stack and sustainability

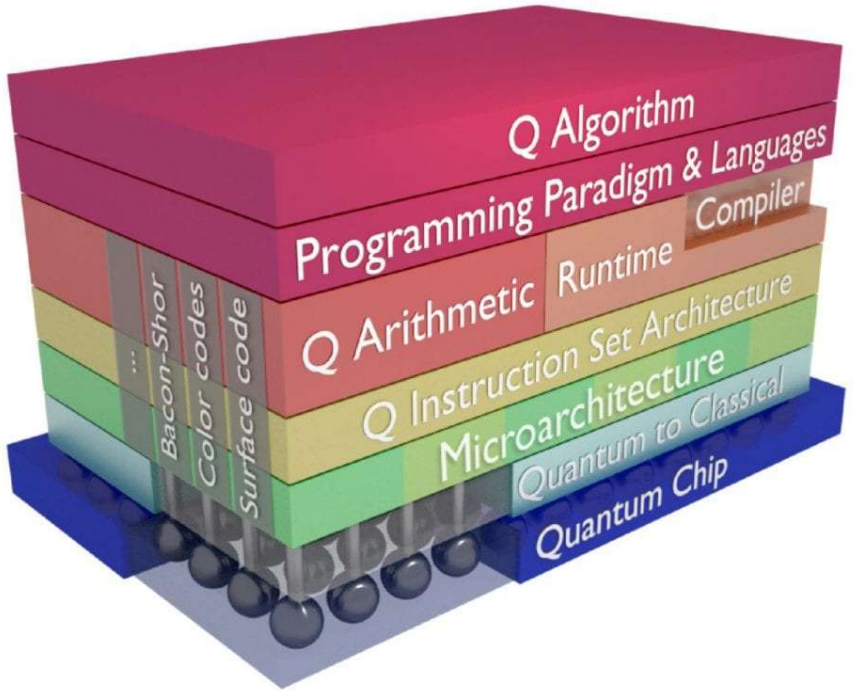
Ivona Brandic: From Sustainable IT to IT for a Sustainable World (youtube.com)

References

- Ivona Brandic: ttps://informatics.tuwien.ac.at/people/ivona-brandic
- Sophia Chen , Are quantum computers really energy efficient?, Nature Computational Science volume 3, pages 457–460 (2023)
- advanced software development kit for the creation and execution of programs for gate-based quantum computers: https://www.quantinuum.com/developers/tket (https://github.com/CQCL/tket)
- QuTube: Home (qutube.nl)
- https://studiegids.hva.nl/co/hbo-ict-vt/100000042/100888

Layer programming languages

- Make a comparison between Quantum computing languages
- Discuss differences functionalities
- Evaluate pros and cons
- Evaluate stack coverage

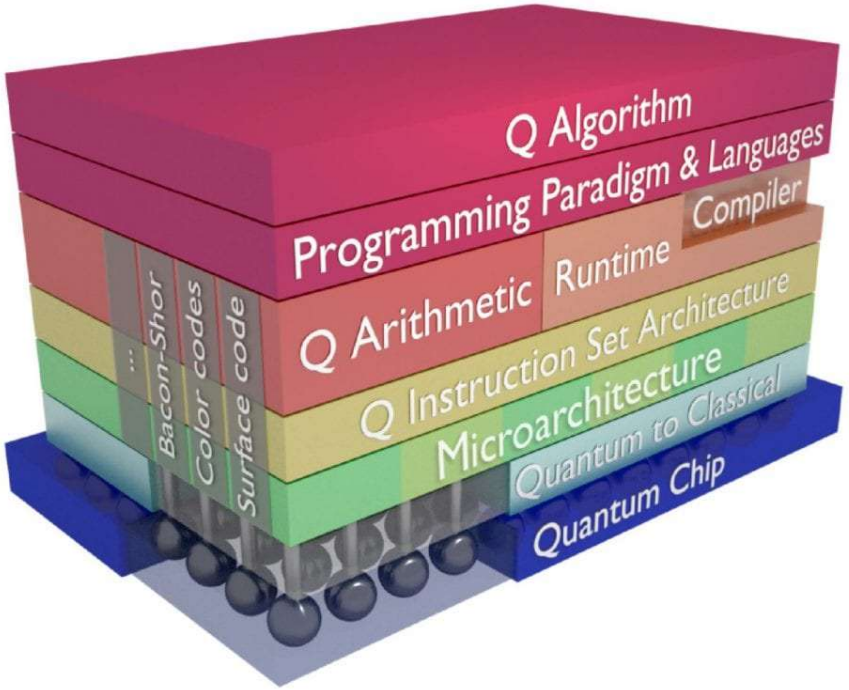


References

- Qiskit documentation: https://www.qiskit.org/
- Cirq documentation: Cirq | Google Quantum AI
- Silq: Silq - What is Silq? (ethz.ch), https://silq.ethz.ch/
- Cambridge computing: https://www.quantinuum.com/developers/tket
- Pennylane cross-platform: https://github.com/PennyLaneAI/pennylane

Layer Programming paradigm

- How to develop new programs?
- How to test programs?
- What standards to use?
- How to document programs?
- Software development environments?



Quality software standards

- Standards under development(IEEE standards association) https://standards.ieee.org/practices/foundational/quantum-standards-activities/

- Software engineering and Machine learning
  - ✓ ML-overzicht: https://se-ml.github.io/
  - ✓ ISO-standaard in ontwikkeling: https://www.iso.org/standard/80655.html
  - ✓ EU: https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai

- Software Engineering Quality open source software: https://fair-software.nl/, https://fair-software.eu/

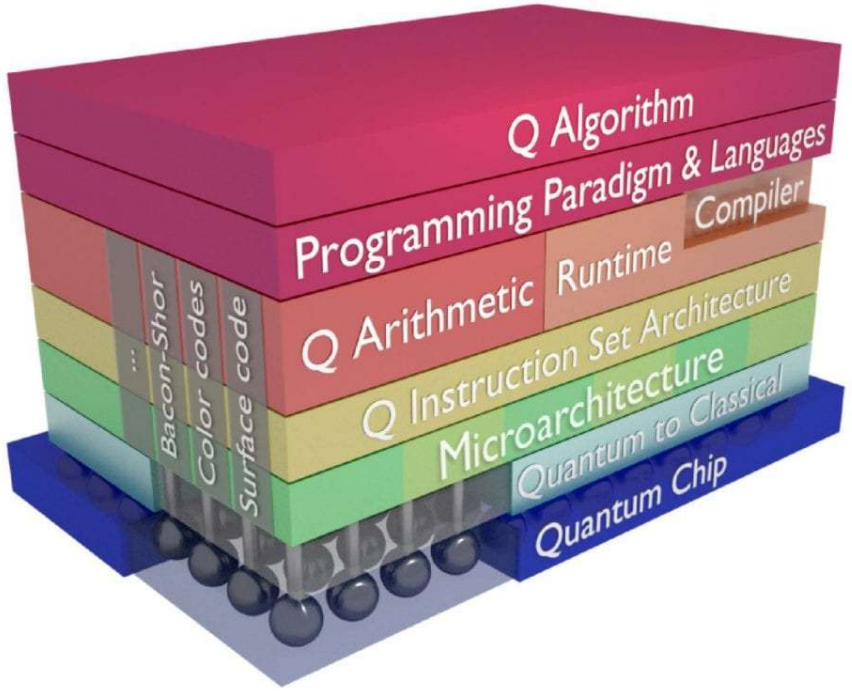
References

- Juan M. Murillo et al., Challenges of Quantum Software Engineering for the Next Decade: The Road Ahead, arXiv:2404.06825

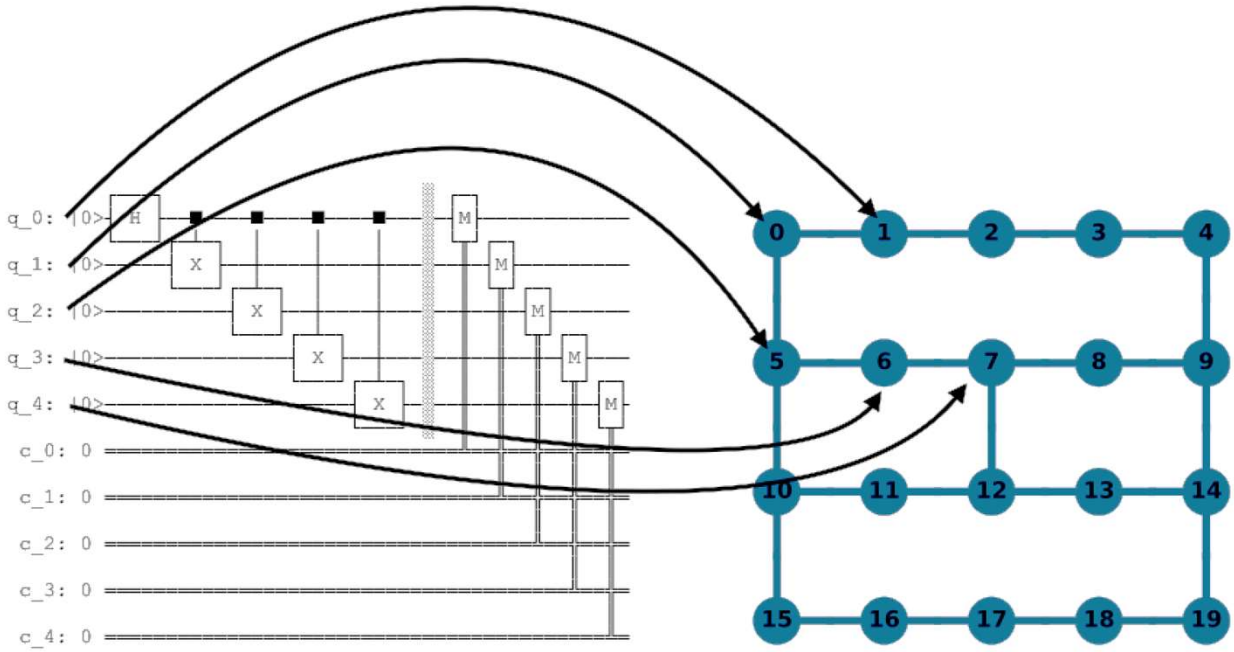
- Jianjun Zhao, Quantum Software Engineering: Landscapes and Horizons, arXiv:2007.07047 [cs.SE], https://arxiv.org/abs/2007.07047

Layer Q-Arithmetic, Runtime, Compiler

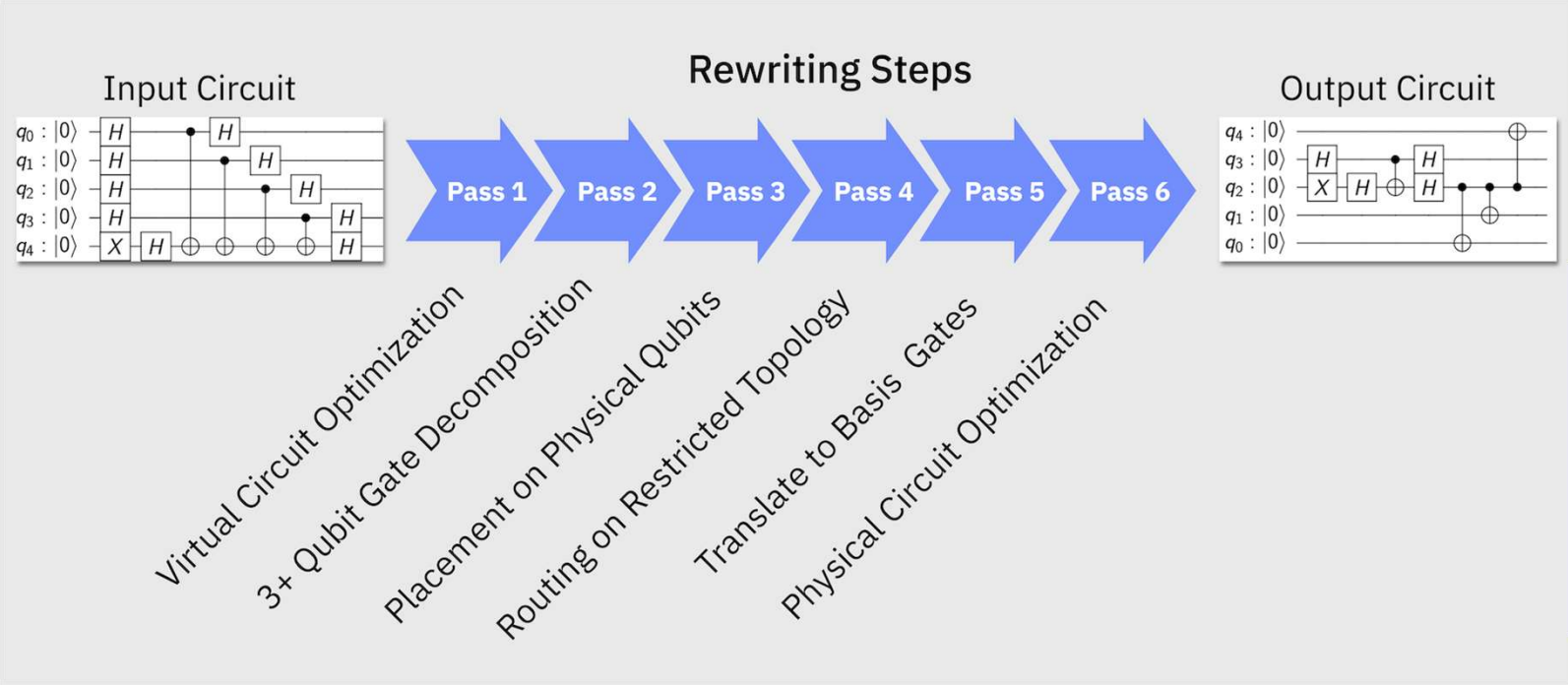
- Program transformations (transpiling)
- How to represent data?
- How to calibrate?
- How to debug Quantum program?
- How to model noise?



Mapping on architecture available

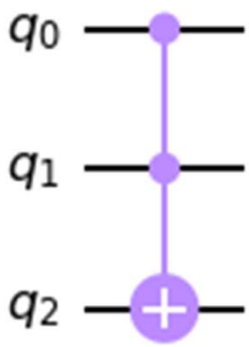


Transpiling performance analyses

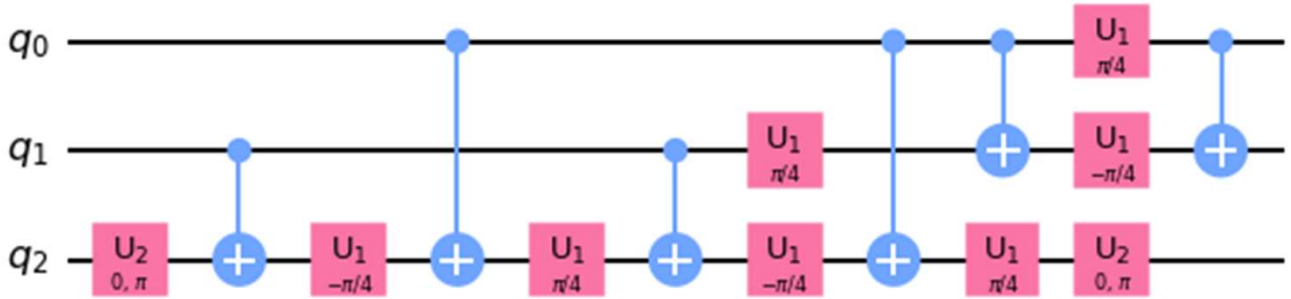


https://docs.quantum.ibm.com/transpile

Transpiling examples



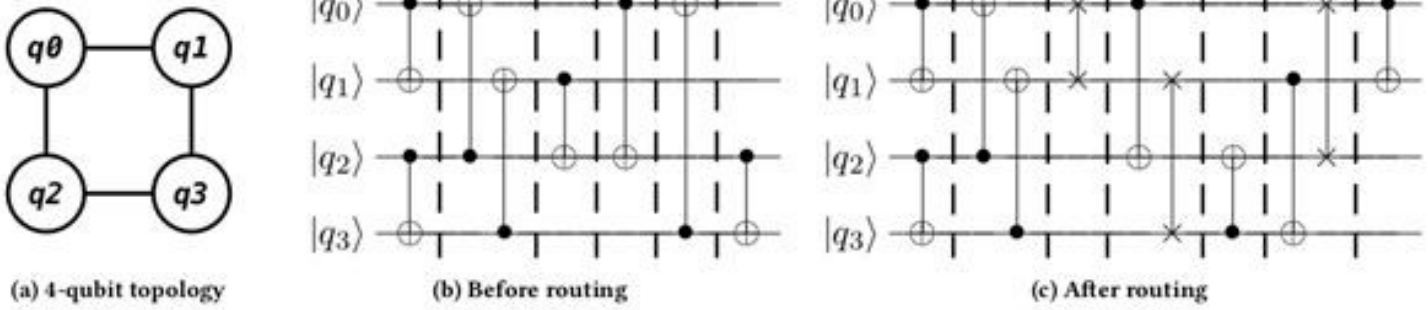
- from qiskit.transpiler.passes import Unroller
- pass_ = Unroller(['u1', 'u2', 'u3', 'cx'])
- pm = PassManager(pass_)
- new_circ = pm.run(circ)
- new circ.draw(output='mpl')



From qiskit tutorial 04_transpiler_passes_and_passmanager

Routing and noise/errors

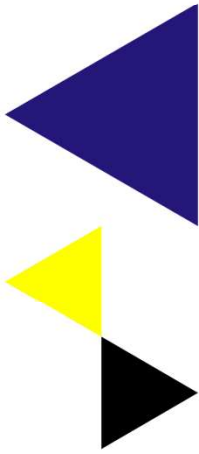
- Limitations routing of qubits and noise/error models (https://docs.quantum.ibm.com/verify/building_noise_models)
-



(a) 4-qubit topology (b) Before routing (c) After routing

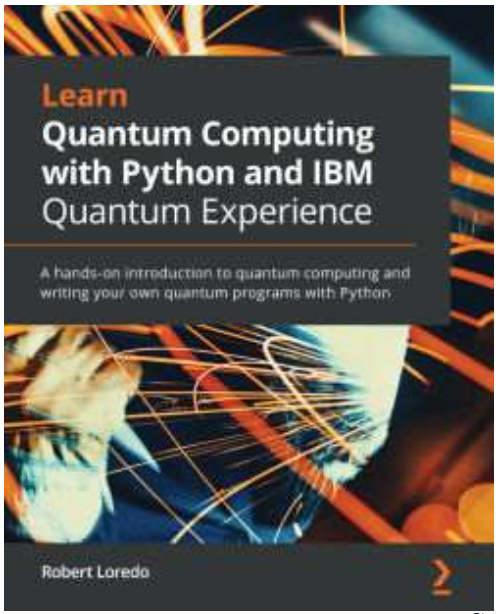
Noise modelling

- Building noise models | IBM Quantum Documentation
- Qiskit part 1: https://www.youtube.com/watch?v=3Ka11boCm1M
- Qiskit part 2: https://youtu.be/gsKOx40gCUU?t=7



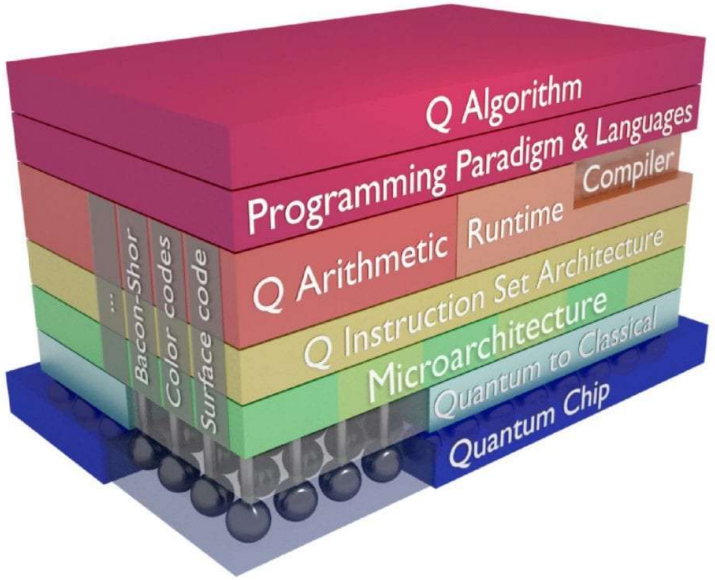
References

Program transformations to take into account available hardware



Layer Quantum instruction set

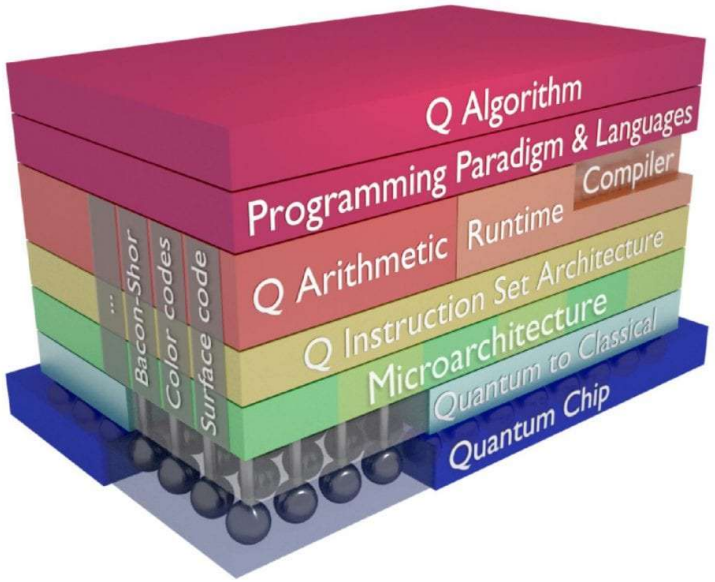
- Use of QASM (Quantum Assembler)?
- Languages used?



Instruction set languages

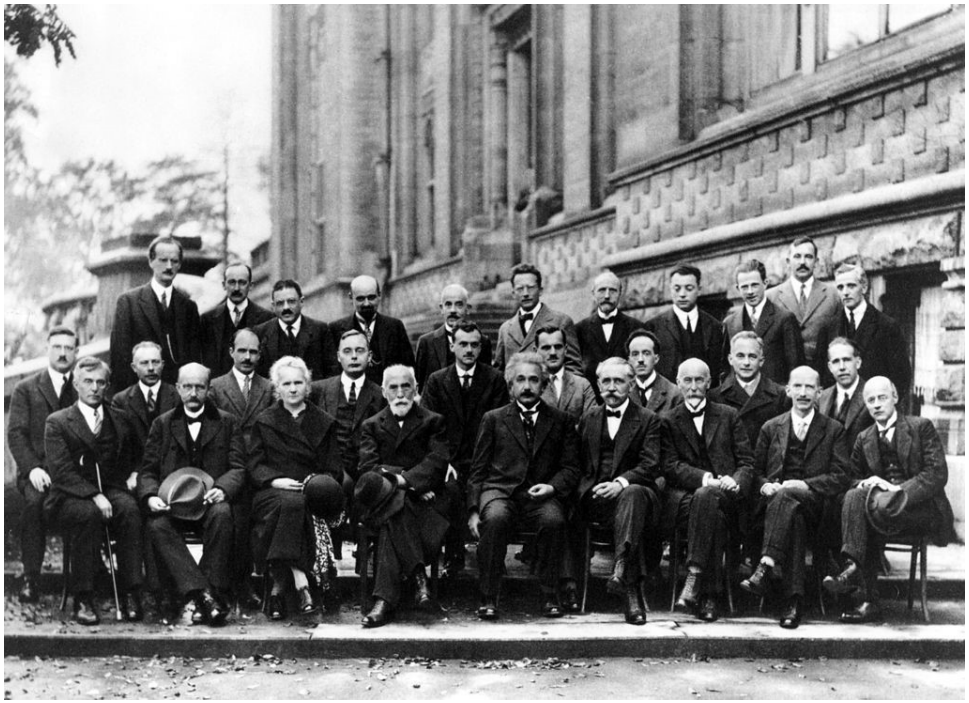
- Quil: Quil (Smith, Curtis, and Zeng 2017)
- QASM: cQASM(Khammassi et al. 2018)
- OpenQASM: OpenQASM(Cross et al. 2017, McKay et al. 2018) \
- Blackbird: Blackbird (Killoran et al. 2019,Bromley et al. 2020)
- QMASM: QMASM(Pakin 2016)

Layer Hardware

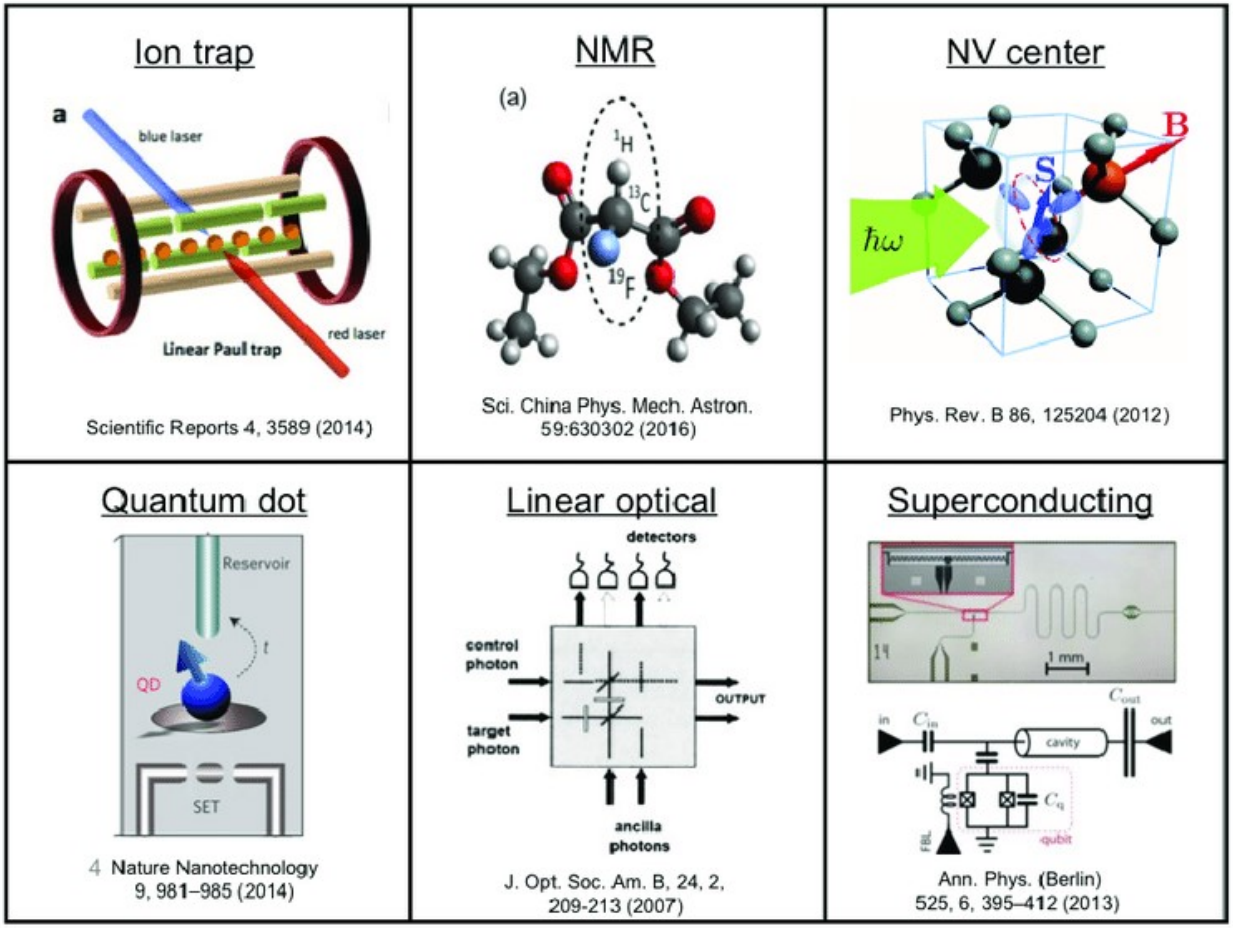


Quantum Mechanics

- Solvay conference 1927

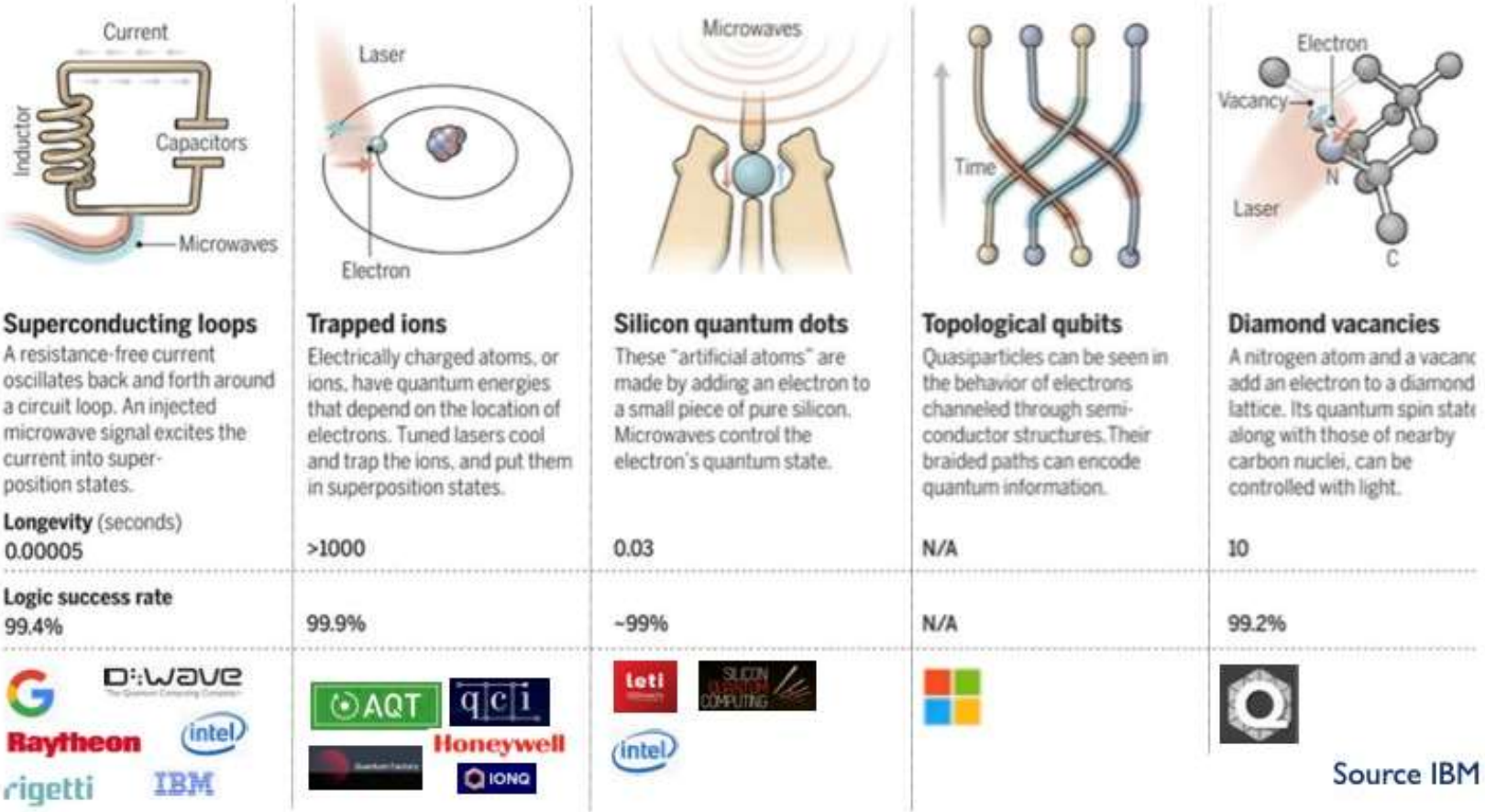


Qubit technologies(1)



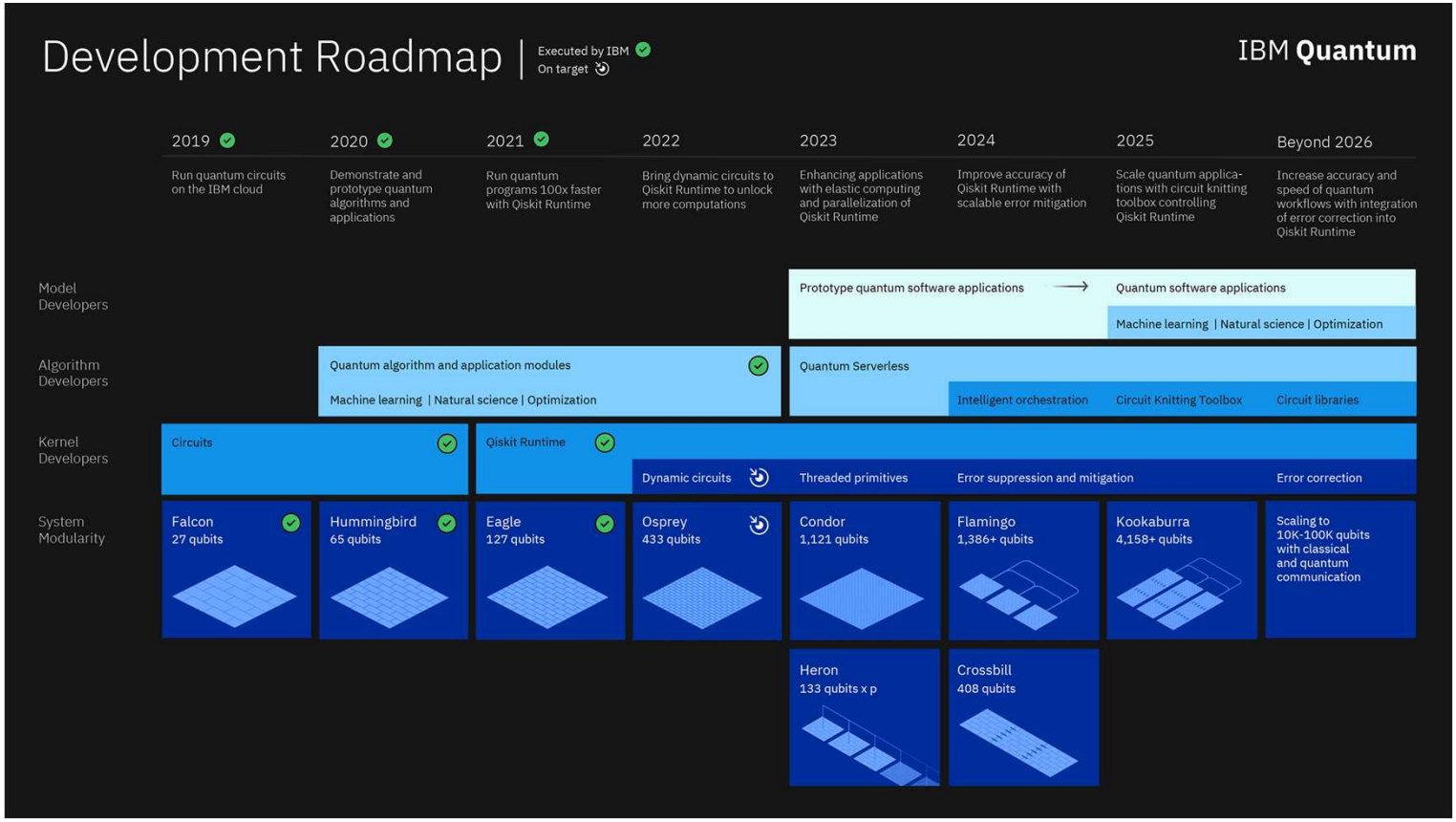
…
many
more

Qubit technologies(2)



IBM roadmap until 2026

- IBM Quantum Computing Blog | IBM Quantum roadmap to build quantum-centric supercomputers



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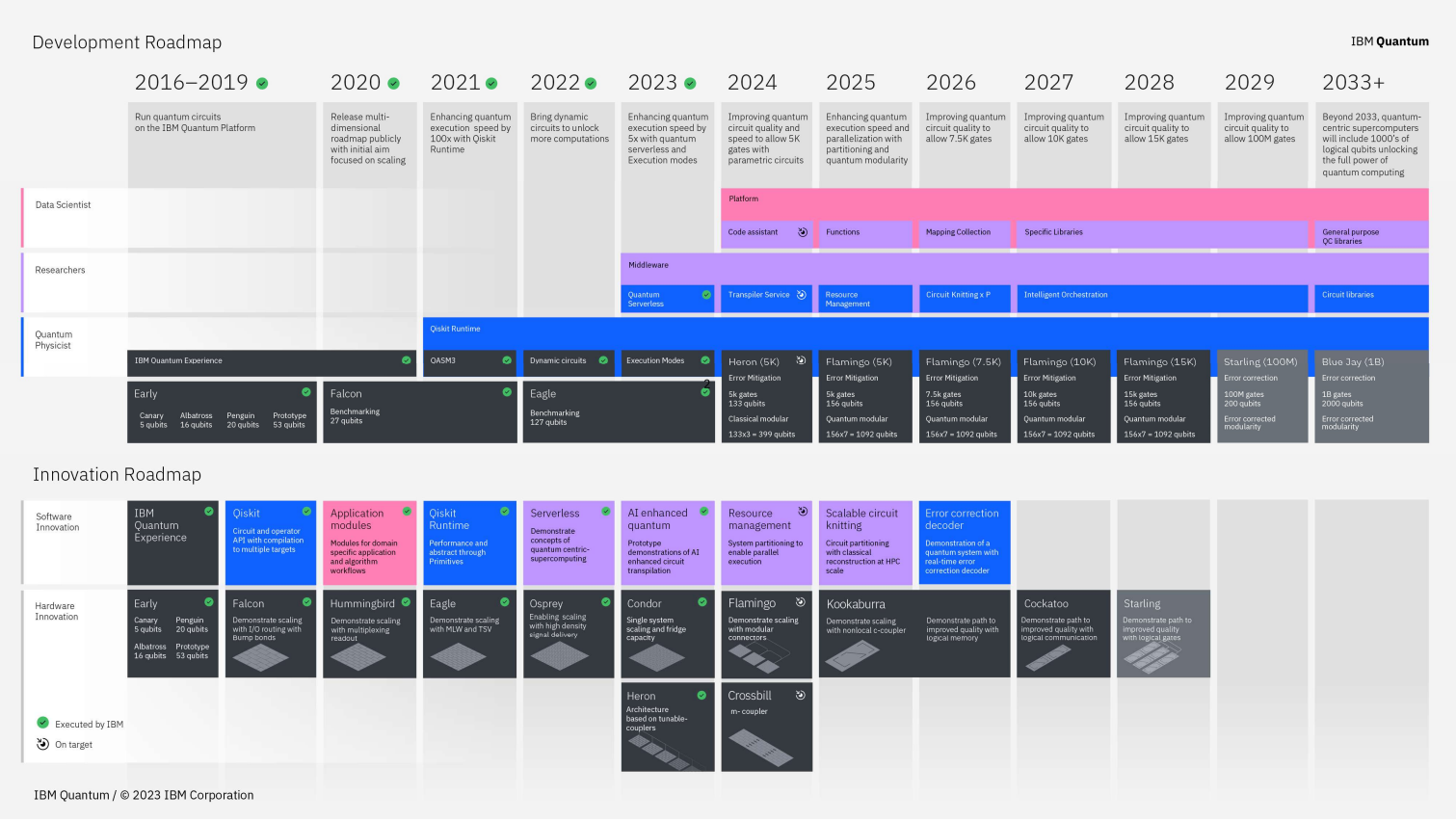
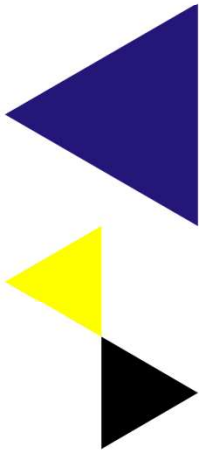
IBM roadmap extended

- IBM Debuts Next-Generation Quantum Processor & IBM Quantum System Two, Extends Roadmap to Advance Era of Quantum Utility - Dec 4, 2023



Machine Learning and impact hardware

- Analyse different hardware platforms and link with hardware
- Use of machine learning for calibration



Machine Learning Classical

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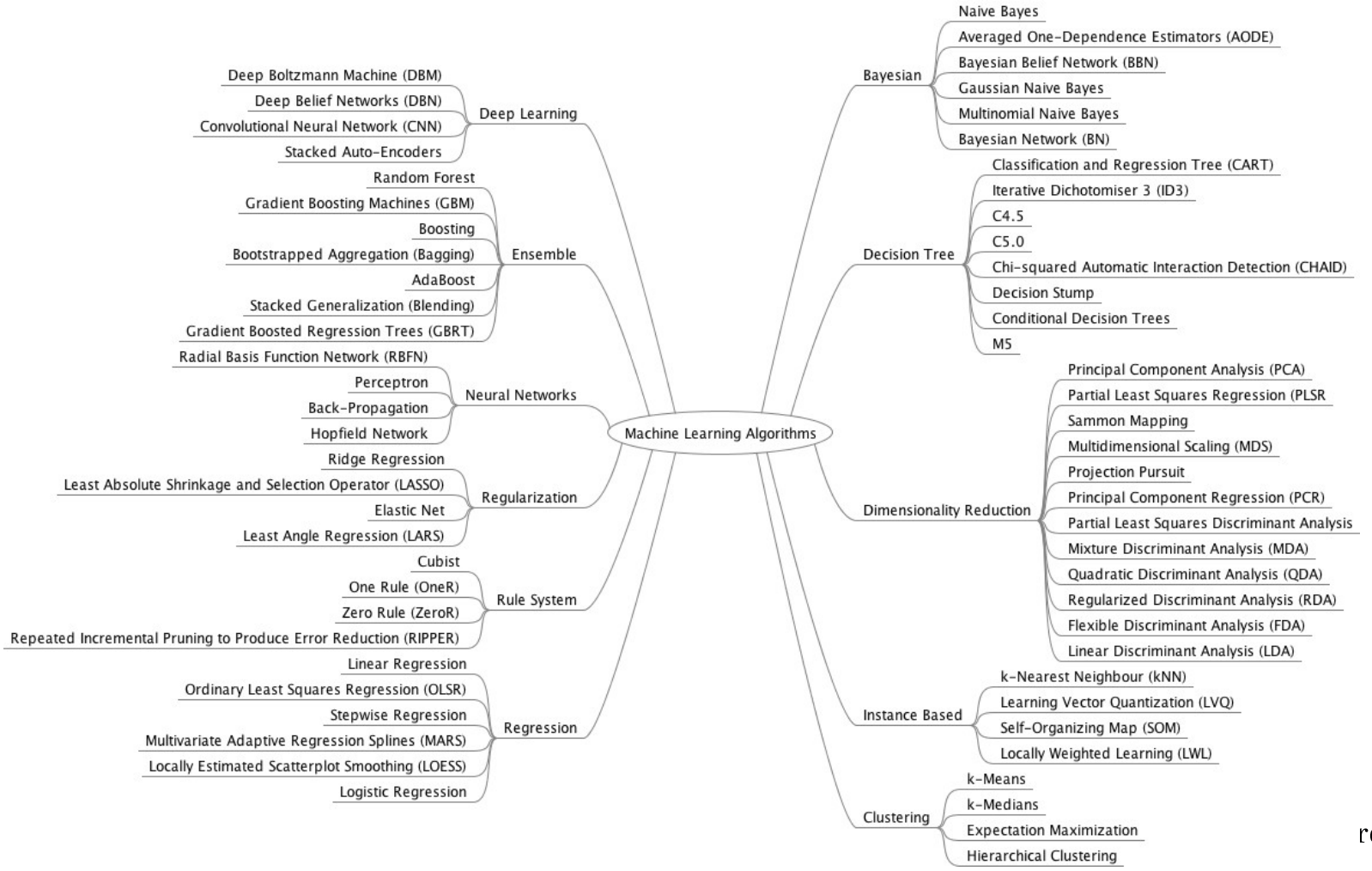
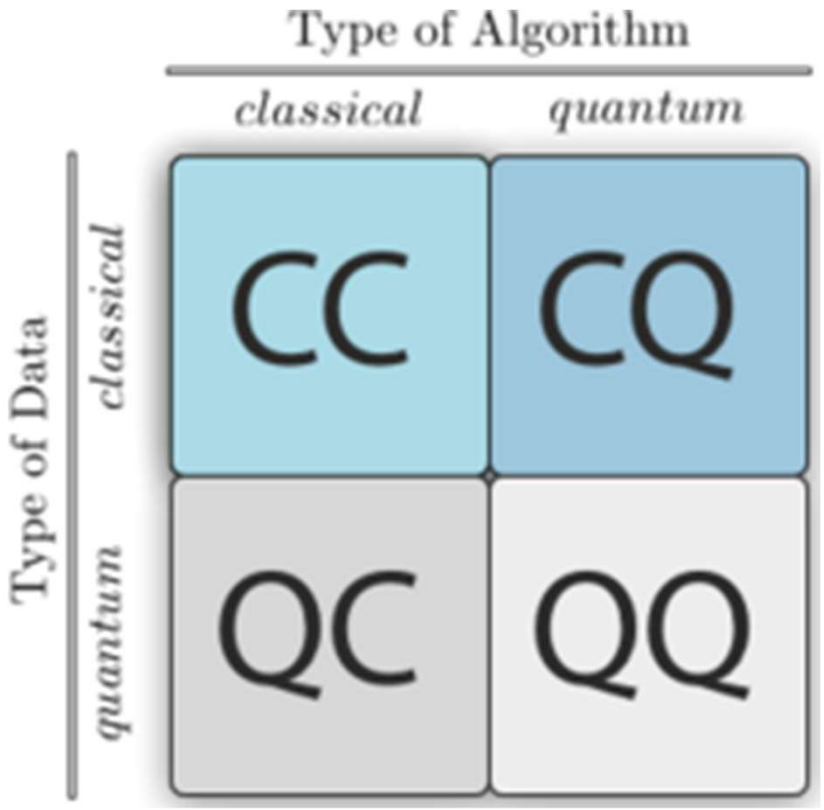


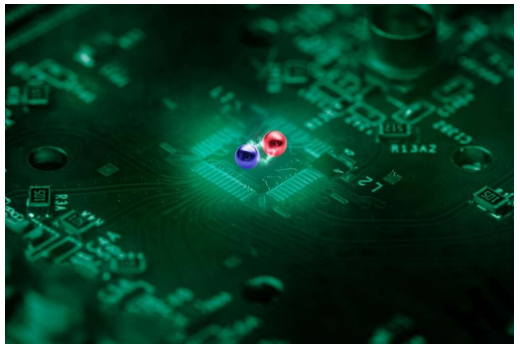
reating Tomorrow

Type of machine learning algorithms

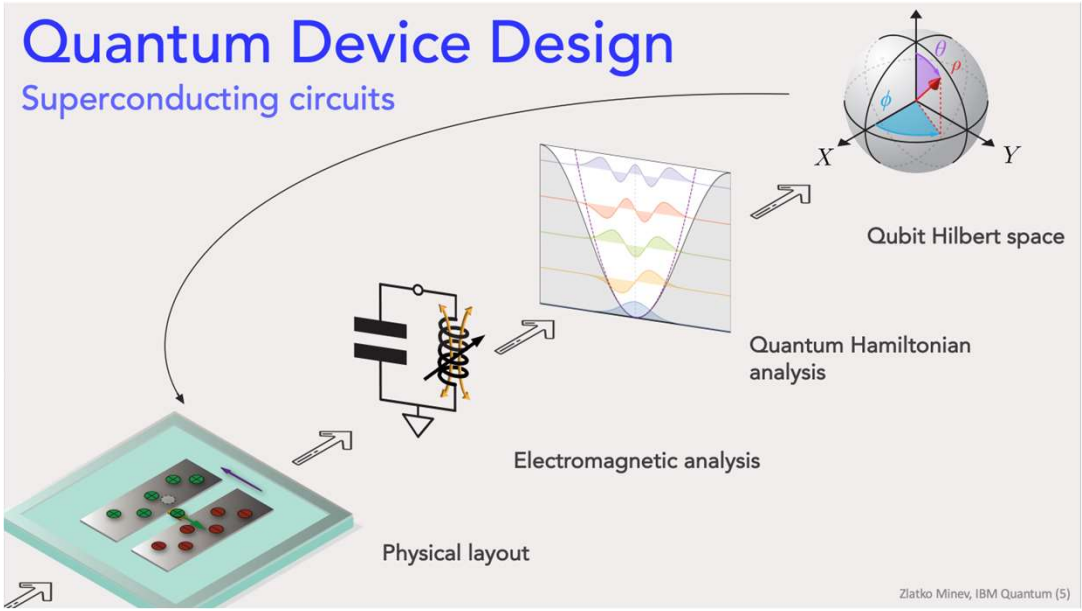


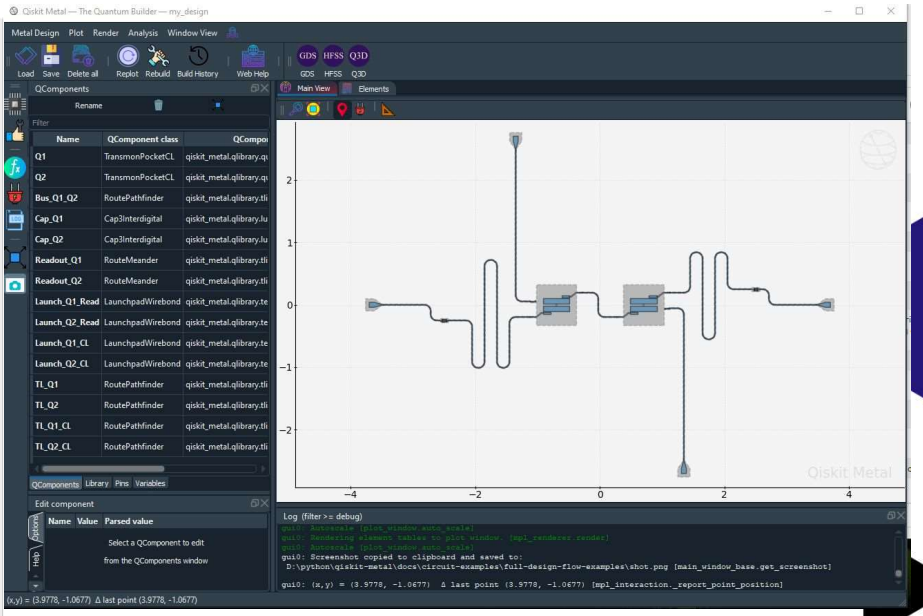
Progress in technology

- Quantum dot arrays in Silicon: https://qutech.nl/2022/01/19/semiconductor-spin-qubits/
- Atomics arrays: https://pasqal.io/
  - ➢ Aiming for 1000 in 2023
- ➢ Further progress discussed in hardware lesson



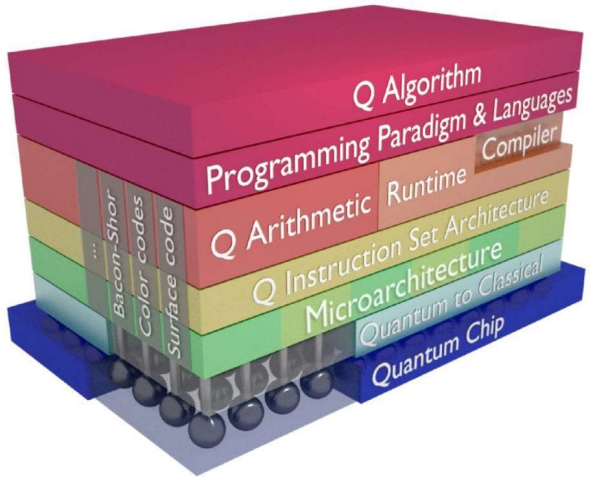
Qiskit Metal



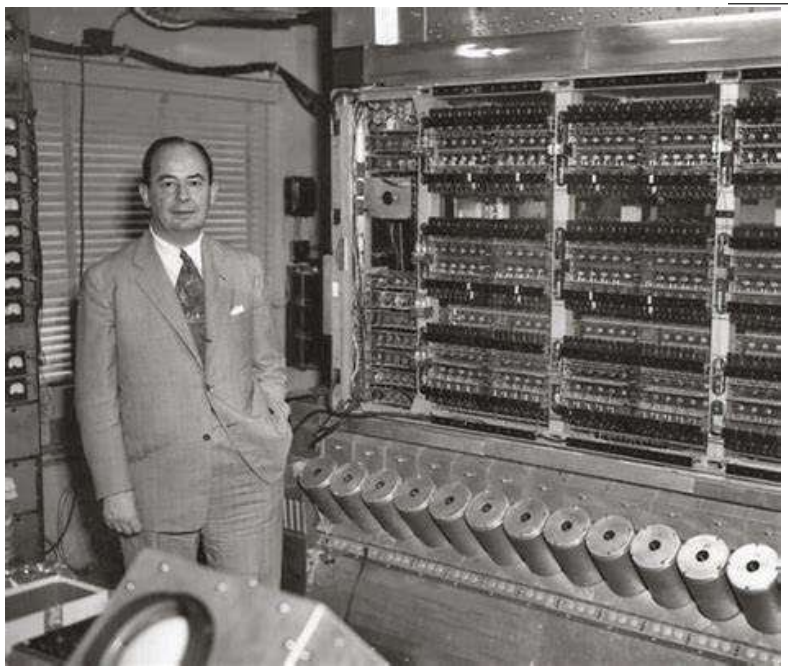


Quantum Information

- Definitions of Information at algorithm level
- Definitions at physical layer
- Interaction with measurement (sensing)
- How to model noise
- Error correction (see Capita Selecta)
- Microsoft and Quantinuum say they've ushered in the next era of quantum computing | TechCrunch



Starting points



ENTROPY

Boltzmann $S_B = k_B \log w_e$ Gibbs $S_G(p) = -k_B \sum_i p_i \log p_i$

Boltzmann constant $1.38065 \cdot 10^{-23} \frac{J}{K}$

Total number of configurations of the system

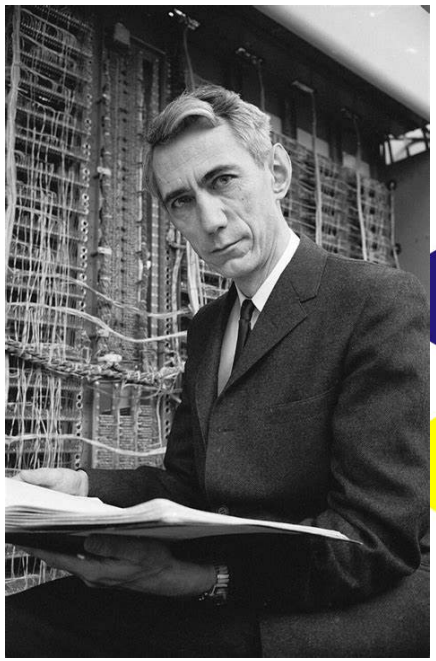
Rényi $H_\alpha(p) = \frac{1}{1-\alpha} \log \sum_i p_i^\alpha$ $\alpha \to 1$ Shannon $H(p) = -\sum_i p_i \log p_i$

$\alpha \geq 0$
$\alpha \neq 1$

Probability of each element of the alphabet

Rényi $S_\alpha(\rho) = \frac{1}{1-\alpha} \log \mathrm{Tr}(\rho^\alpha)$ $\alpha \to 1$ von Neumann $S(\rho) = -\mathrm{Tr}(\rho \log \rho)$

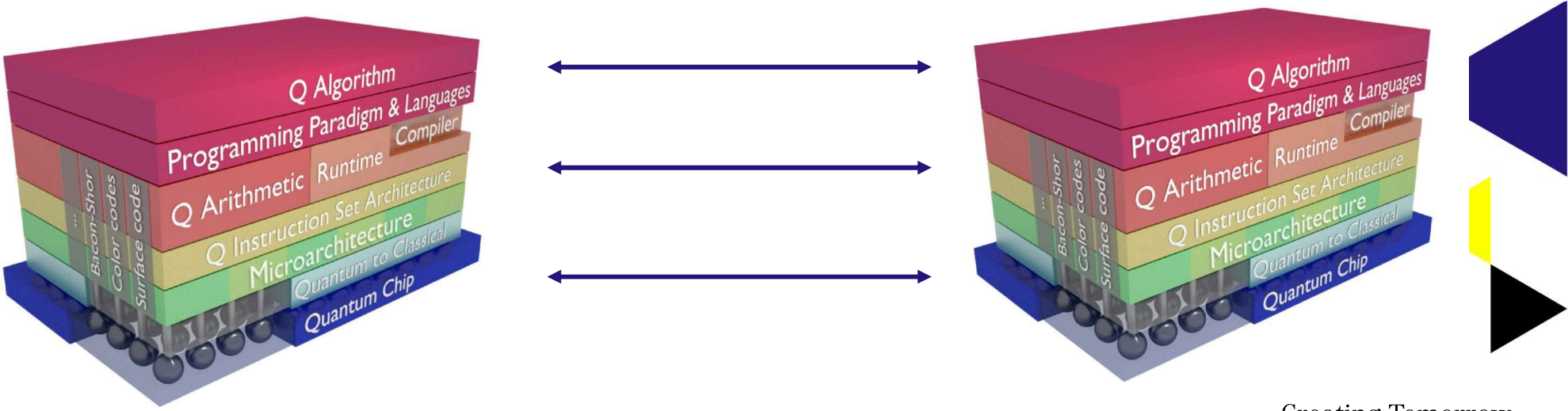
Density matrix



Integration of sensing

- https://nikal.eventsair.com/6th-quantum-technology-conference/ (see program)

Interfacing quantum computers



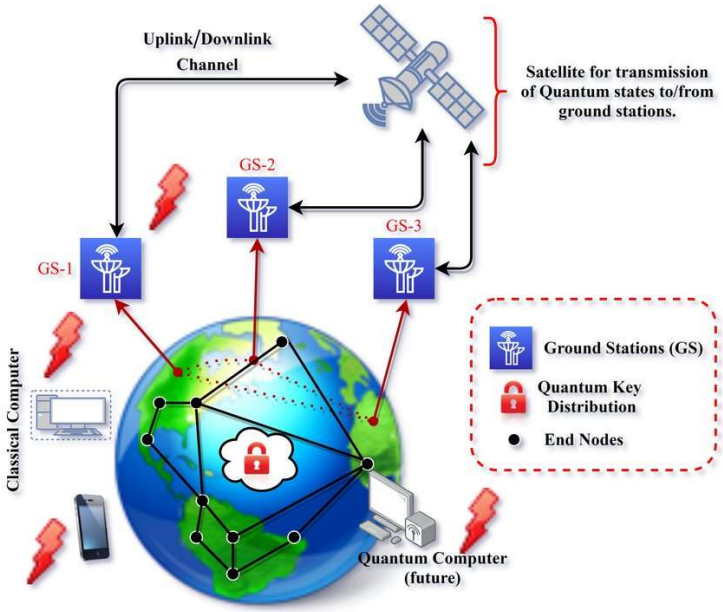
Quantum Network stack

- Similar to ISO model

Application	
Transport	Qubit transmission
Network	Long distance entanglement
Link	Robust entanglement generation
Physical	Attempt entanglement generation

Quantum Internet

- Satellites
- Via Optical netwerks
- Applications
- Space activities and quantum
- https://iqtevent.com/thehague/

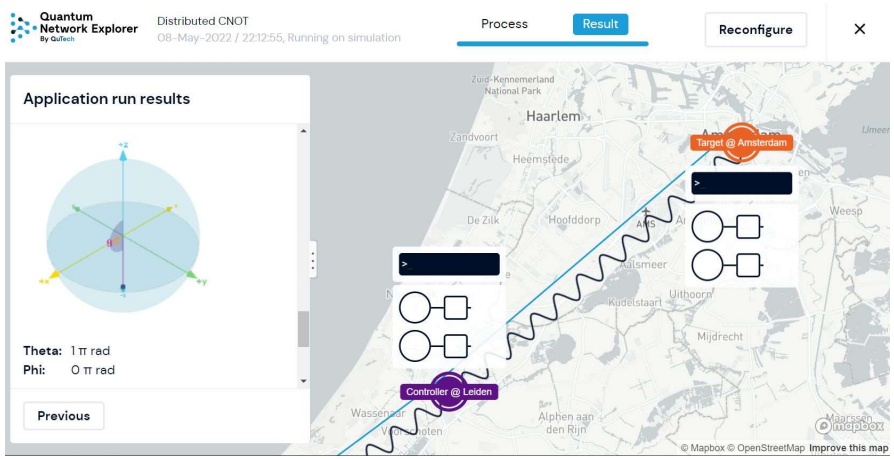


https://www.researchgate.net/figure/Vision-of-future-quantum-internet-working-in-synergy-with-classical-internet_fig2_354349149

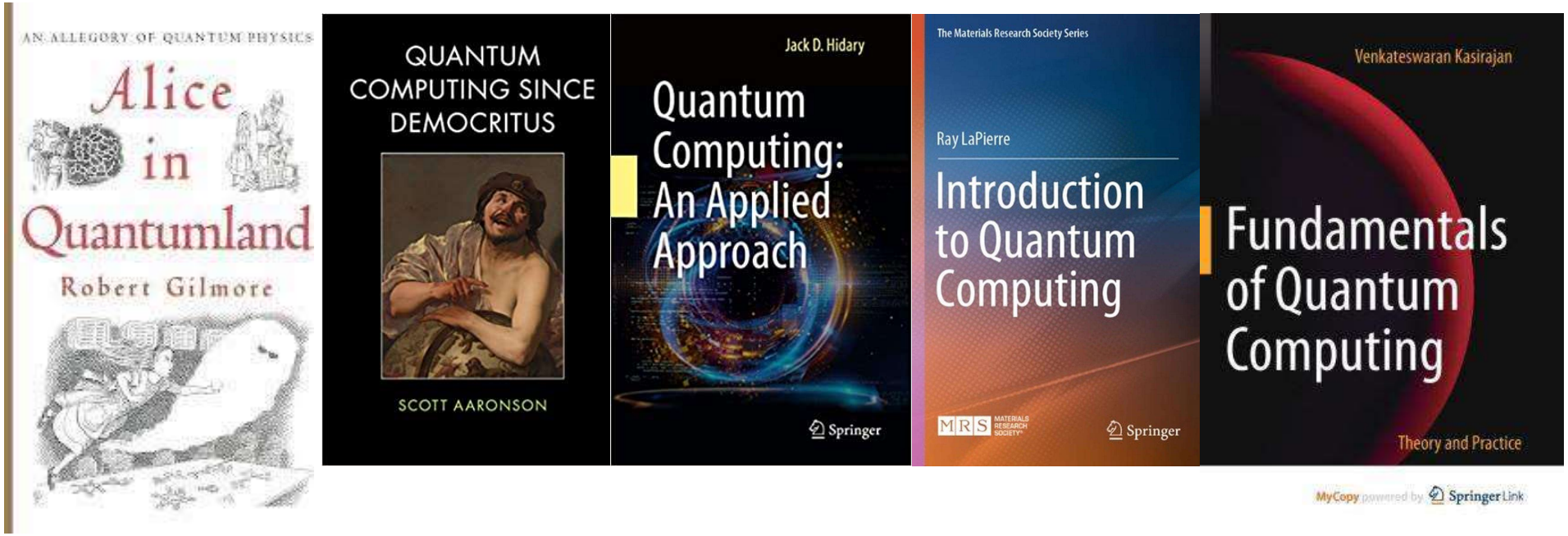
Network simulators

NetQasm, Netsquid, Quantum Network Explorer

- ✓ https://www.quantum-network.com/applications/
- ✓ https://github.com/QuTech-Delft/netqasm



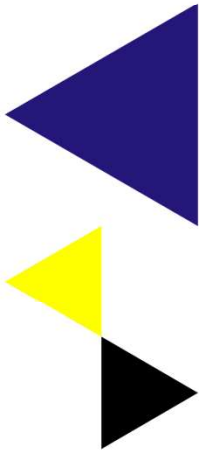
Background books(1)



Background books(2)

More references

- Ask teacher
- Use HvA library
- https://arxiv.org



Discussion of paper topics

- Who has idea for topic?
- What information you need?
- References ?
- Short introduction?