DA VINCI DIALOGUES

SÉMINAIRE DEEP TECH

9-10 AVRIL 2024

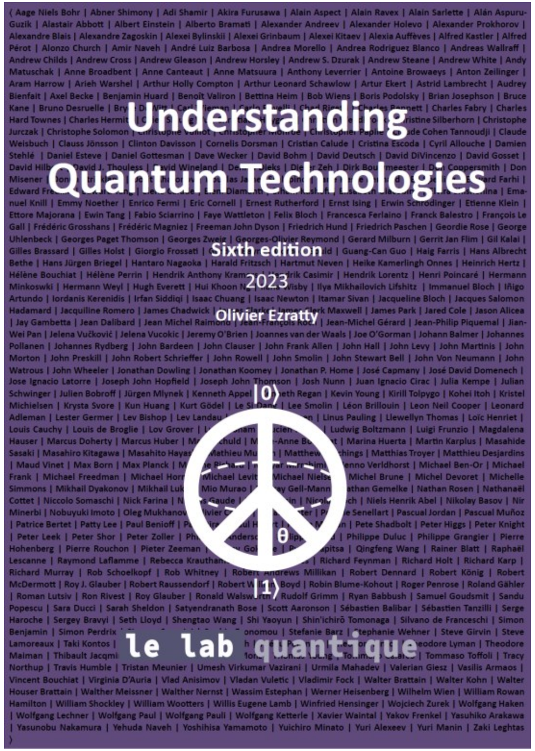
CHÂTEAU LOUISE DE LA VALLIÈRE
REUGNY, INDRE-ET-LOIRE

À LA DÉCOUVERTE DES TECHNOLOGIES QUANTIQUES

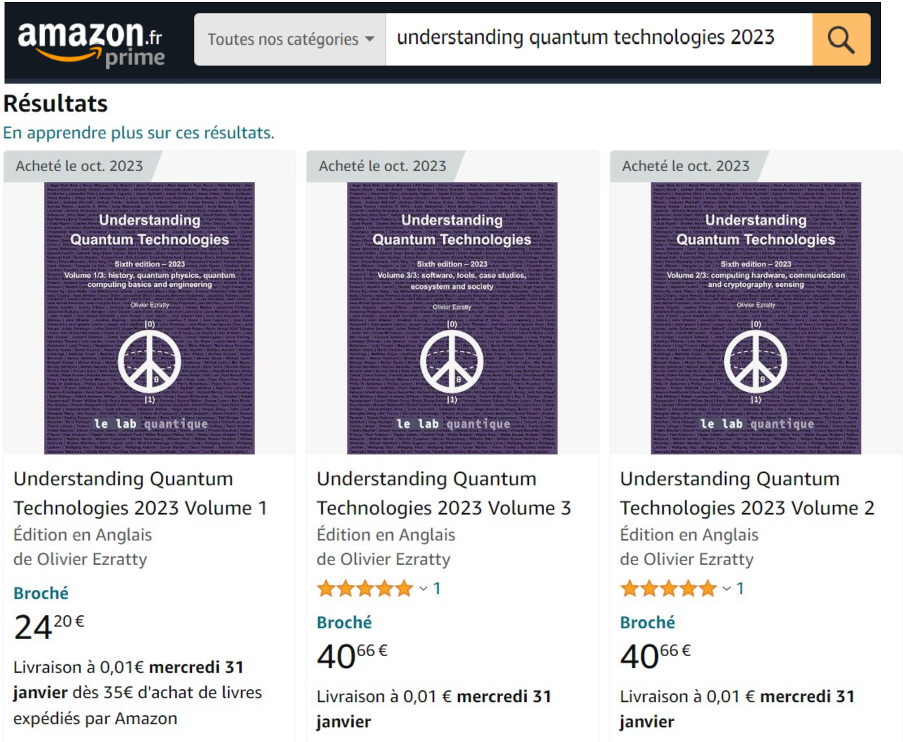
Olivier Ezratty

à la découverte
des technologies quantiques

olivier ezratty
⟨ auteur | … ⟩
Tours, 9 avril 2024
olivier@oezratty.net www.oezratty.net @olivez



2023, 1,366 pages
free PDF download

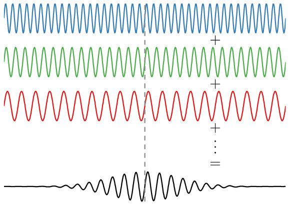


Amazon paperback
edition in 3 volumes

the second quantum revolution

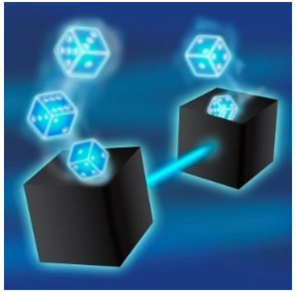
superposition

linked to wave-particle duality and linearity of Schrödinger's equation



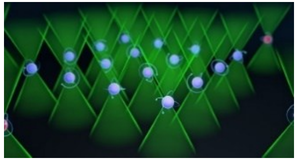
entanglement

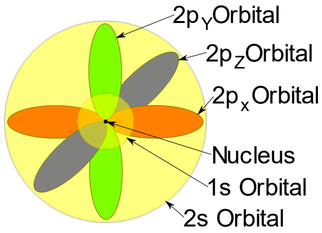
state correlation of distant quantum objects, but random and after measurement

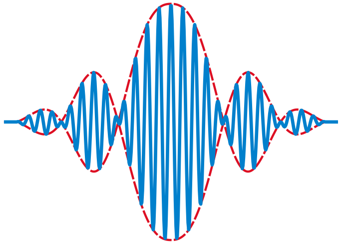


individual control of quantum objects

electrons, photons, atoms







quantum computing

quantum telecommunications

quantum cryptography

quantum sensing

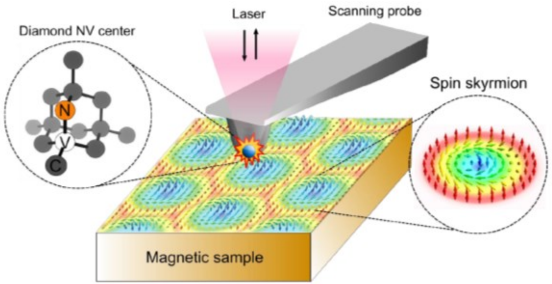
quantum sensors examples

qnami

entanglement TECHNOLOGIES, INC.

μQUANS

exail



ultrasensitive magnetometers
$210\ \mathrm{fT}/\sqrt{\mathrm{Hz}}$

medical imaging
non destructive control

ultrasensitive spectrography

dangerous gas detection

ultrasensitive quantum gravimeters

construction, exploration

quantum sensing vendors

products

atomic clocks
- TELEDYNE e2v Everywhereyoulook™
- Microsemi
- SAFRAN AEROSPACE · DEFENCE · SECURITY
- QUANTX LABS

optical sensing
- OXFORD HIGHQ
- Twinleaf
- Qubic
- QUSPIN
- entanglement TECHNOLOGIES, INC.
- DEVICE
- qurv
- zeropoint motion

NV centers
- THALES
- SBtech
- chipiron
- FieldLine Magnetic sensing and imaging solutions
- qutools
- Southwest Sciences incorporated
- cerca Magnetics Limited
- kwan-tek
- SENSORIX A MEMBER OF QED-C
- NVISION
- ODMR Technologies
- 国仪量子 CIQTEK
- BOSCH
- Qnami
- QDTI Quantum Diamond Technologies
- QUANTUM DIAMONDS SENSOR TECHNOLOGY
- SANDBOXAQ™

SQUIDs
- THALES
- supracon SQUID AND MICROFABRICATION TECHNOLOGIES
- HYPRES

other
- MAG4Health

cold atoms
- exail
- GEM SYSTEMS
- THALES
- ATOMIONICS
- OK Quantum
- NOMAD ATOMICS
- Delta.g
- RYDBERG TECHNOLOGIES
- AQUARK TECHNOLOGIES

enabling
- HYPERLIGHT
- TMD
- Vescent PHOTONICS

NV center diamonds
- elementsix™ DE BEERS GROUP
- LUCIGEM
- LakeDiamond THE BRILLIANT SIDE OF TECHNOLOGY
- DIAMFAB
- HIQUTE DIAMOND
- GREAT LAKES CRYSTAL TECHNOLOGIES
- ORSAY PHYSICS TESCAN ORSAY HOLDING
- ZABRE
- ADÁMAS nano Brilliant Diamond Solutions
- FND BIOTECH
- CYMARIS LABS
- BIKANTA
- Diamond Materials Advanced Diamond Technologies
- Diatope

mini-cryostats
- STAR CRYOELECTRONICS
- THALES

cold atoms (enabling)
- AOSense Sensors for a Quantum World
- TMD
- RYDBERG TECHNOLOGIES

quantum telecommunications

quantum Internet (security) and **distributed quantum computing**

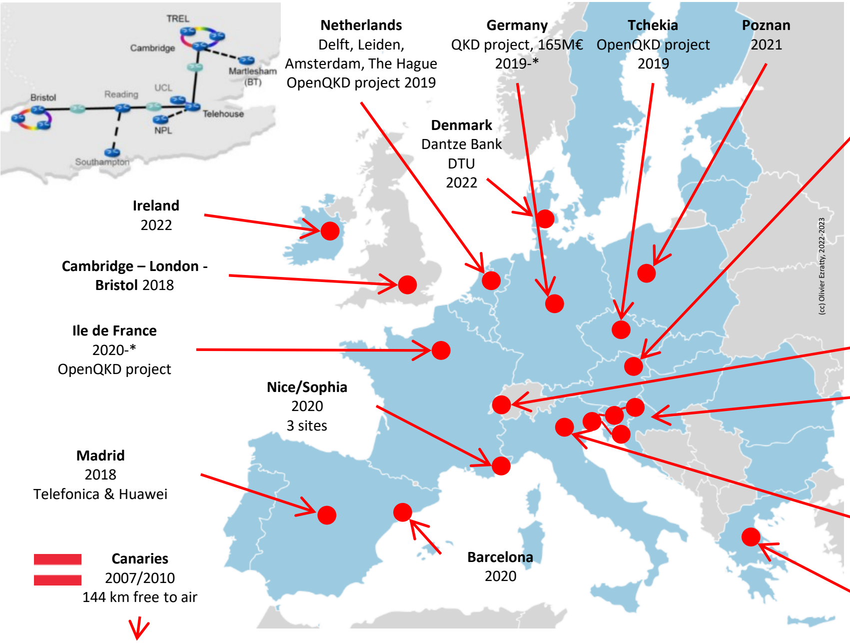
ingredients:

- (entangled) photons sources
- photons detectors
- quantum key distribution
- quantum repeaters
- quantum teleportation
- protocols
- applications

QUANDELA

THALES

VeriQloud



EuroQCI

OPEN QKD

Vienna
2008
SECOQC, 5 nodes, 20/25 km

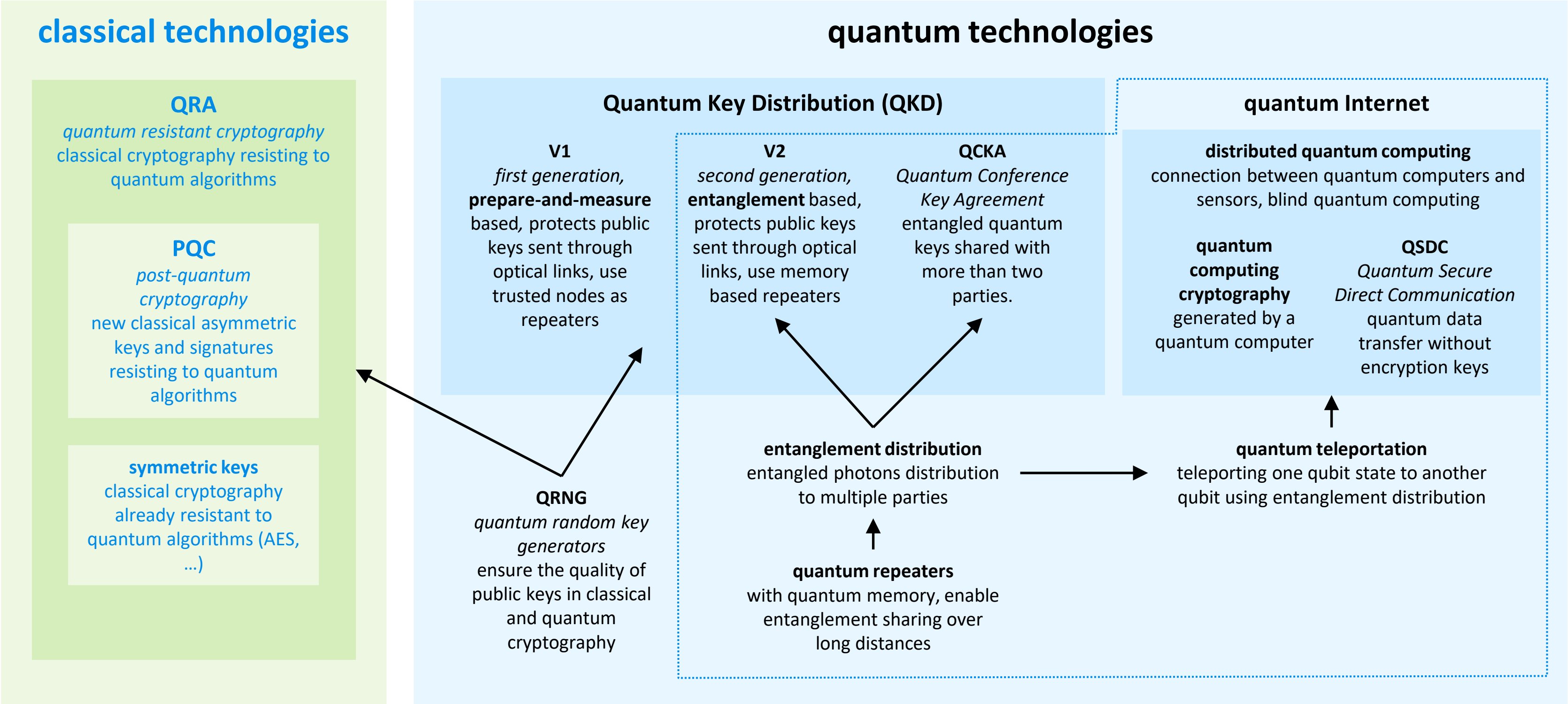
Geneva
1993, 1995, 2007, 2018 (400 km)

Italy-Slovenia-Croatia network

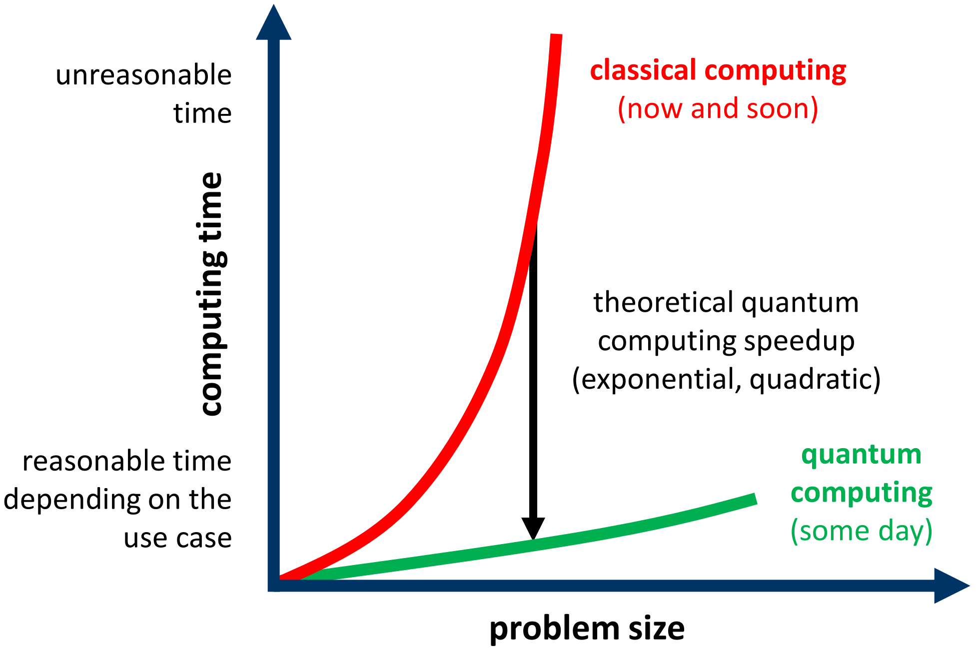
Italian Quantum Backbone (IQB) 1,850 km QKD link connects Turin, Milan, Bologna, …, a 150 km fiber reaches Modane in France, and connects to Grenoble, Lyon and Paris, then Europe + Padua satellite/ground QKD experiment

Athens
2019
OpenQKD project DataCom

quantum telecommunications

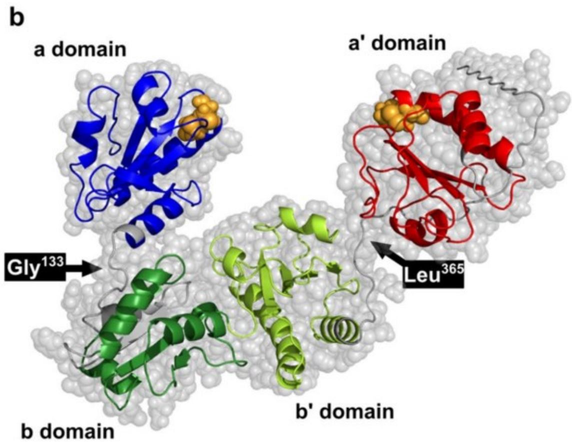


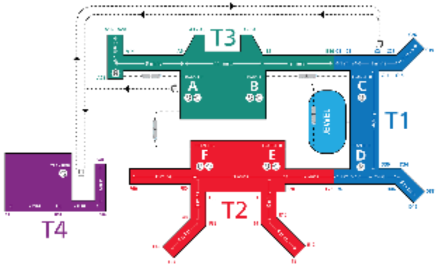
quantum computing *promise*



solving intractable / exponential problems in **reasonable** time

typical exponential problems





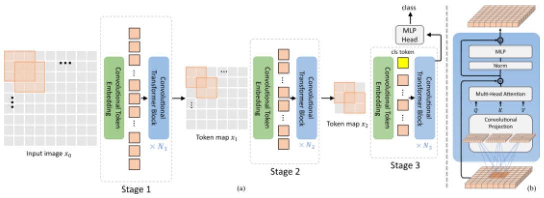
combinatorial optimizations

$$\frac{\partial^2 u_1}{\partial x_1^2}+\frac{\partial^2 u_2}{\partial x_2 \partial x_1}+\frac{\partial^2 u_3}{\partial x_3 \partial x_1}+\frac{\partial^2 u_1}{\partial x_1^2}+\frac{\partial^2 u_1}{\partial x_2^2}+\frac{\partial^2 u_1}{\partial x_3^2}+f_1=0$$
$$\frac{\partial^2 u_1}{\partial x_1 \partial x_2}+\frac{\partial^2 u_2}{\partial x_2^2}+\frac{\partial^2 u_3}{\partial x_3 \partial x_2}+\frac{\partial^2 u_2}{\partial x_1^2}+\frac{\partial^2 u_2}{\partial x_2^2}+\frac{\partial^2 u_2}{\partial x_3^2}+f_2=0$$
$$\frac{\partial^2 u_1}{\partial x_1 \partial x_3}+\frac{\partial^2 u_2}{\partial x_2 \partial x_3}+\frac{\partial^2 u_3}{\partial x_3^2}+\frac{\partial^2 u_3}{\partial x_1^2}+\frac{\partial^2 u_3}{\partial x_2^2}+\frac{\partial^2 u_3}{\partial x_3^2}+f_3=0$$

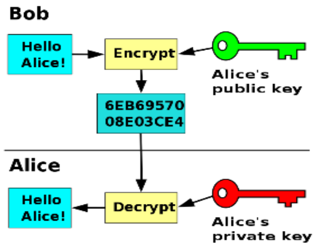
solving partial derivative equations

$$i\hbar\frac{\partial \Psi(x,t)}{\partial t}=-\frac{\hbar^2}{2m}\frac{\partial^2 \Psi(x,t)}{\partial x^2}+V(x)\Psi(x,t)$$

solving Schrodinger's wave equation
to simulate quantum matter



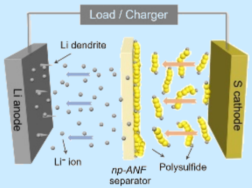
machine learning
and deep learning



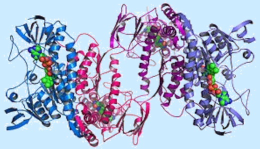
breaking asymmetric
cryptography keys

quantum computing usage categories

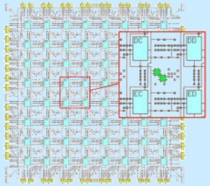
research



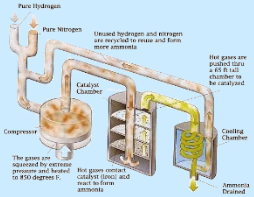
batteries



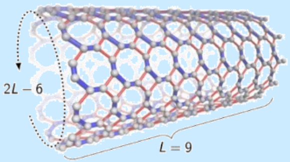
drugs



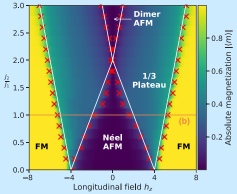
semiconductors



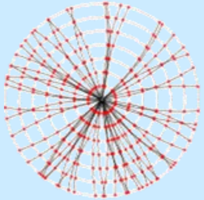
fertilizers production



materials design

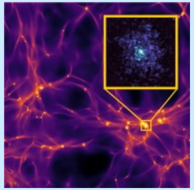


condensed matter physics



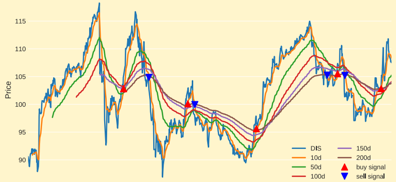
high-energy particle physics

astrophysics



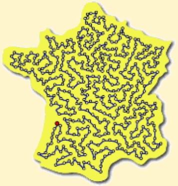
operations

transportation

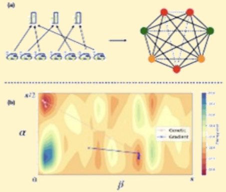


financial services

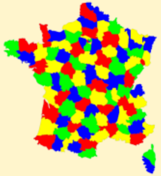
logistics



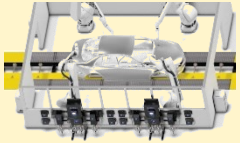
delivery



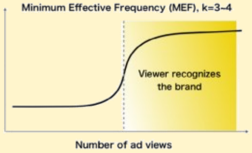
energy utilities



telecoms



manufacturing



marketing

what is a qubit?

mathematically

basic unit of quantum information

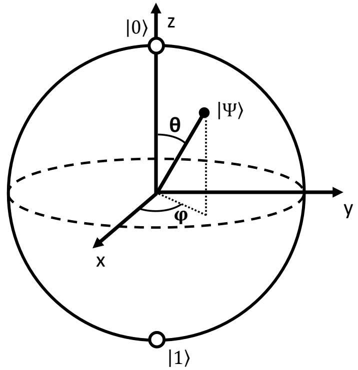
vector in a 2-dimension
complex numbers Hilbert space

complex numbers
amplitudes

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|\alpha|^2 + |\beta|^2 = 1$$

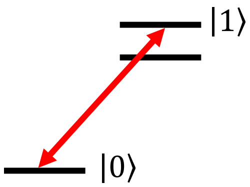
probabilities and Born
normalization constraint



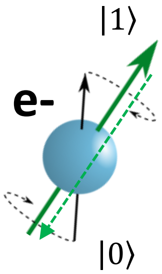
Bloch sphere representation
with amplitude and phase

physically

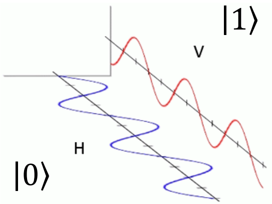
two-level state controllable
quantum object



separable
atom energy
level



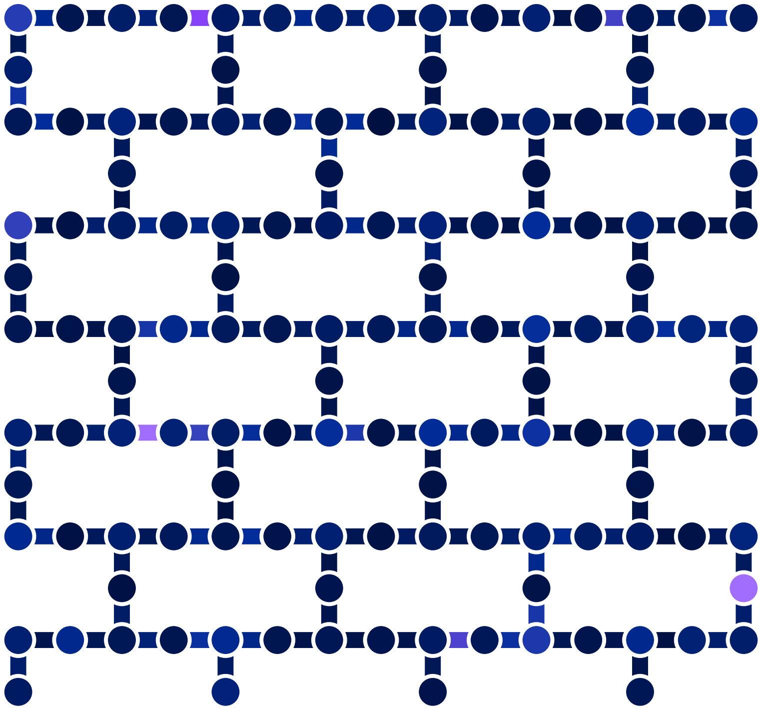
electron or
nucleus spin
orientation



photon mode
(polarization,
number, frequency)

N qubits handle the equivalent of **2^{N+1} real numbers** during computation

it benefits from **quantum parallelism** brought by superposition, engtanglement and interferences

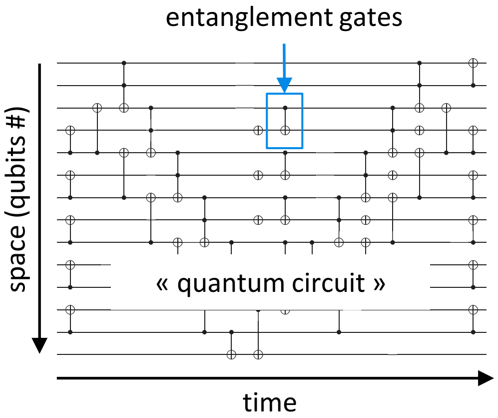


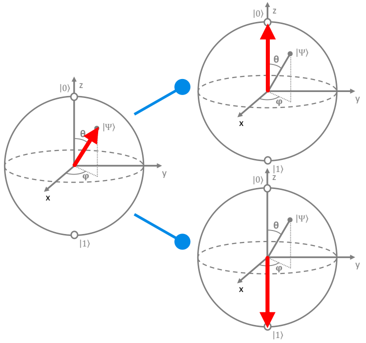
layout of a 133-qubit processor from IBM

from computing to measurement

complex amplitudes | of all combinations of 0 and 1

$$\begin{bmatrix} \alpha_1 \\ \cdots \\ \cdots \\ \cdots \\ \cdots \\ \alpha_{2^N} \end{bmatrix} \quad \begin{matrix} |00 \ldots 00\rangle \\ \vdots \\ |01 \ldots 11\rangle \\ \vdots \\ |11 \ldots 11\rangle \end{matrix}$$





010…011
(N 0s and 1s)

N qubits registers
information in 2^N superposed states

quantum gates
act on qubits and on all the register amplitudes

measurement
ends superposition and entanglement

outputs
N probabilistic classical bits

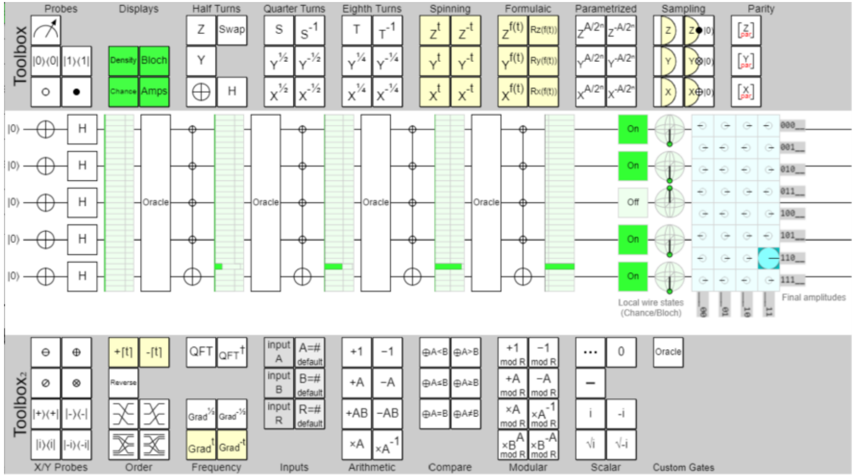
large internal data space
but slow I/Os

speedups brought by algorithms design and entanglement

probabilistic outcomes in most cases

a new programming model

visual quantum circuits design



https://algassert.com/quirk

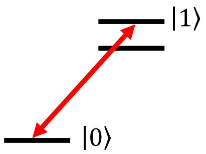
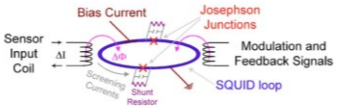
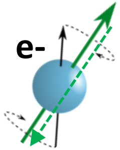
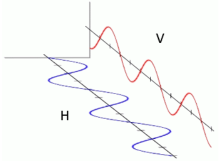
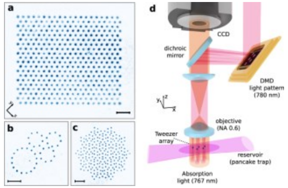
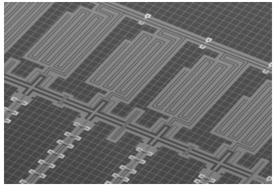
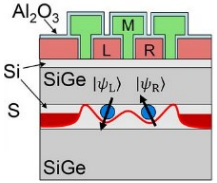
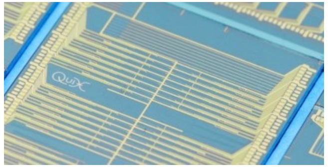
online open source tool to learn, program and emulate up to 16 « perfect » qubits

scripted Python code

```python
# Initialize counting qubits
# in state |+>
for q in range(n_count):
    qc.h(q)

# And auxiliary register in state |1>
qc.x(3+n_count)

# Do controlled-U operations
for q in range(n_count):
    qc.append(c_amod15(a, 2**q),
             [q] + [i+n_count for i in range(4)])

# Do inverse-QFT
qc.append(qft_dagger(n_count), range(n_count))

# Measure circuit
qc.measure(range(n_count), range(n_count))
qc.draw(fold=-1)  # -1 means 'do not fold'
```

IBM Qiskit, Google Cirq, Eviden Qaptiva

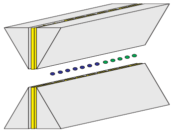
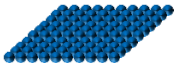
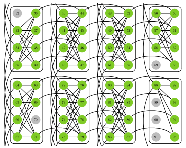
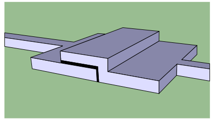
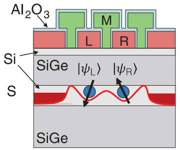
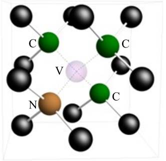
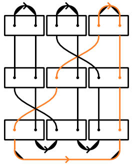
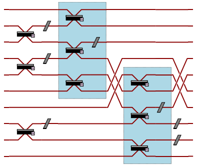
main qubit types

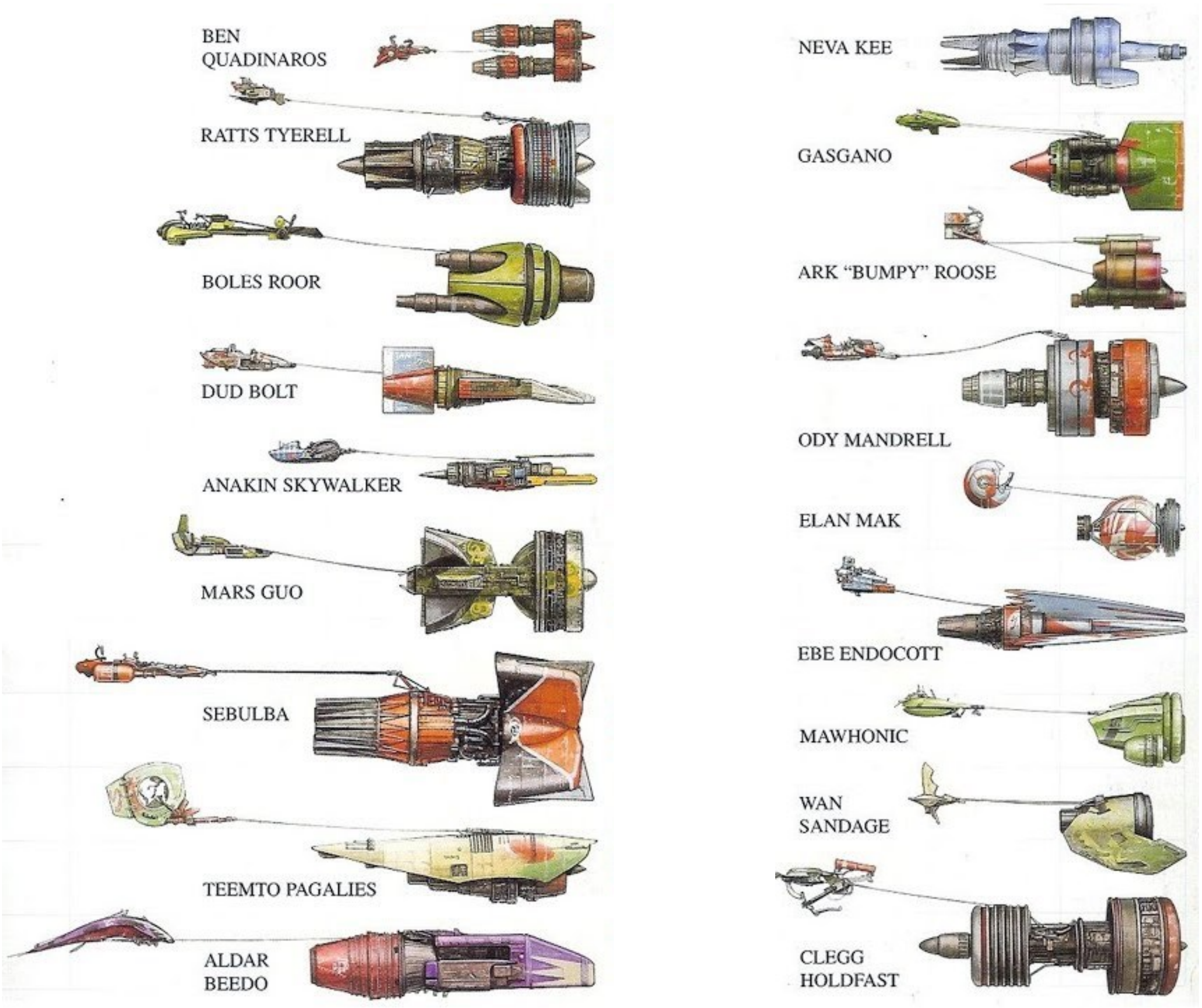
	atoms and ions	superconducting	electron spins	photons
				
quantum states	atom energy level	loop phase or energy	electron spin orientation	photo polarization (or other property)
physical aspect				
interactions	laser pulses and/or microwaves	microwave pulses and/or DC current		interferometers, polarizing beam splitters, ...

quantum & classical computing paradigms

classical computers		**analog** quantum computers		**digital** quantum computers	
quantum inspired classical algorithms running on classical computer, inspired by quantum algorithms.	**quantum emulators** running quantum computers code on classical computers, for training, debugging and testing	quantum **annealing computers**	analog **quantum simulators**	**gate-based** **NISQ** (Noisy Intermediate Scale Quantum) no error correction with a few noisy qubits	**gate-based** **FTQC** (Fault-Tolerant Quantum Computers) error correction and fault tolerance
classical algorithms improvements	quantum algorithms debug and testing	optimization problems and quantum physics simulation		general purpose quantum computing, adds search and integer factoring	
MULTIVERSE COMPUTING, ZAPATA AI	EVIDEN, IBM, FUJITSU, Google, Microsoft, aws, PASQAL, C12, QUANDELA, ALICE & BOB	D-Wave The Quantum Computing Company™	PASQAL, QuEra	IBM, rigetti, PsiQuantum, Google, IQM, ALICE & BOB, Quantinuum, OQC, IONQ, Microsoft, QUANDELA, XANADU	

QPUs vendors per qubit type

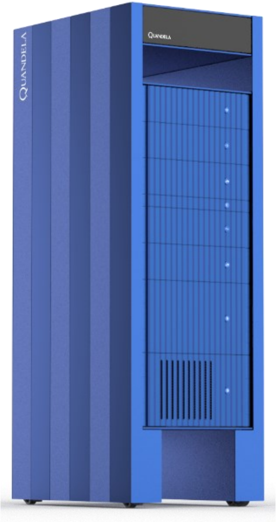
atoms		electron *superconducting loops & controlled spin*					photons
							
trapped ions	**cold atoms**	**annealing**	**super-conducting**	**silicon**	**vacancies**	**topological**	**photons**
Quantinuum, IonQ, AQT, UQ, oxford ionics, eleQtron, Foxconn, Quantum Art, Crystal Quantum Computing, NEQXT, Qudora Technologies	Pasqal, QuEra, Infleqtion, atom computing, planqc, QUANTier, NanoQT Nanofiber Quantum Technologies	D-Wave The Quantum Computing Company, Qilimanjaro Quantum Tech, NEC	IBM, rigetti, amazon, Google, qci, Nord Quantique, OQC, IQM, Alice & Bob, Origin Quantum 本源量子, Anyon, Atlantic Quantum, bleximo, Fujitsu	intel, quobly, Quantum Motion, Silicon Quantum Computing, diraq, EeroQ, equal1.labs, C12, ARQUE, QπAI, ARCHER	Quantum Brilliance, SaxonQ, Turing, photonic, NTT, XEED, Quantum Transistors	Microsoft, Quoherent, Quantum Gravity Research	PsiQuantum, Quandela, Orca Computing, Xanadu, Duality Quantum Photonics, QuiX Quantum, BardeenQ Labs, QBoson, QCi, photonicsQ, Quanfluence, TundraSys


BEN QUADINAROS
RATTS TYERELL
BOLES ROOR
DUD BOLT
ANAKIN SKYWALKER
MARS GUO
SEBULBA
TEEMTO PAGALIES
ALDAR BEEDO
NEVA KEE
GASGANO
ARK “BUMPY” ROOSE
ODY MANDRELL
ELAN MAK
EBE ENDOCOTT
MAWHONIC
WAN SANDAGE
CLEGG HOLDFAST

France QPU startups

atomes		électrons			photons
ions piégés	atomes froids	qubits de chats	silicium	nanotubes de carbone	photons
CRYSTAL QUANTUM COMPUTING	PASQAL	ALICE & BOB	quobly	C12	QUANDELA
2021	2019 140 M€	2020 30 M€	2022 19 M€	2020 10 M€	2017 70 M€
cnrs, Université Paris Cité	cnrs, Institut d'Optique Graduate School	cea, cnrs, Lab PHYS ENS de Lyon, Mines ParisTech, Inria	cea, cnrs, Néel institut	cnrs, LPENS Laboratoire de physique de l'École normale supérieure	cnrs, cea, C2N, université Paris-Saclay

IBM

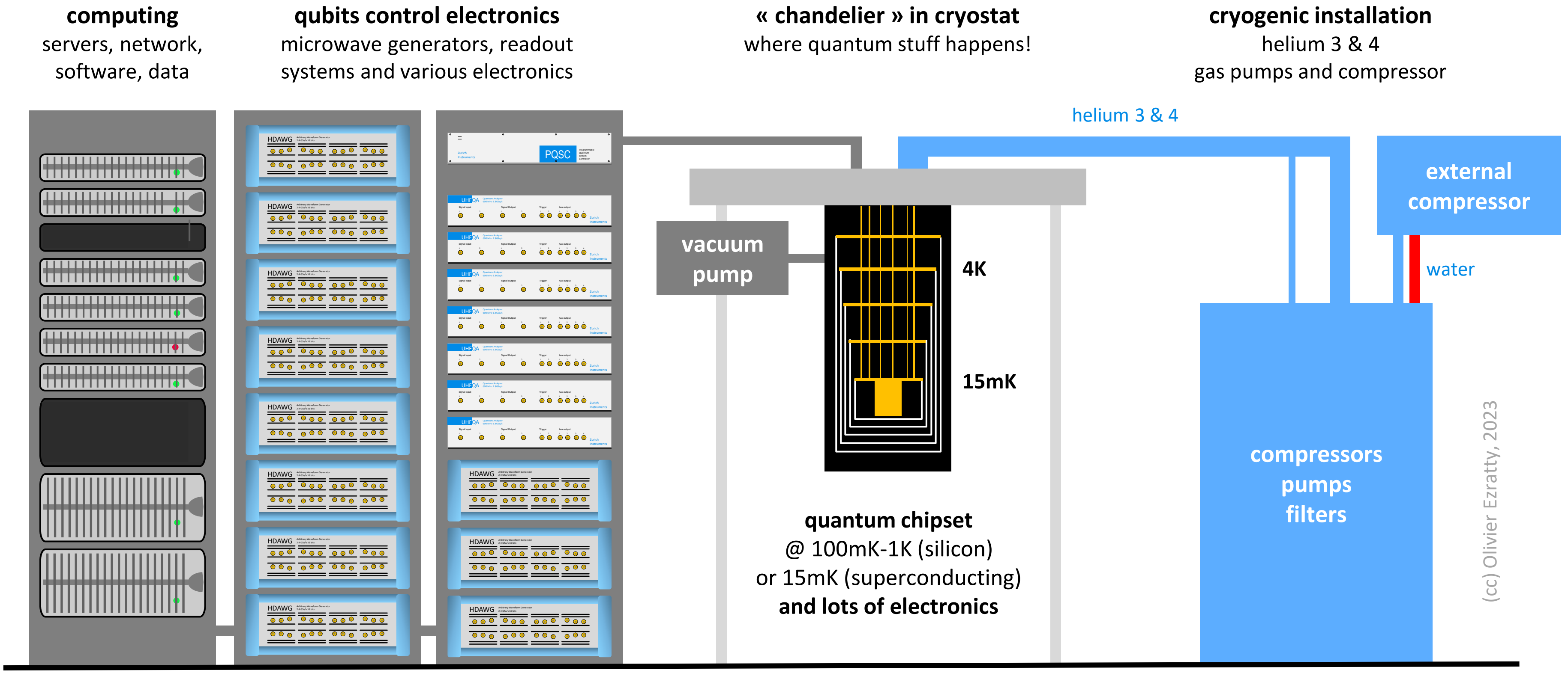


QUANDELA

IONQ

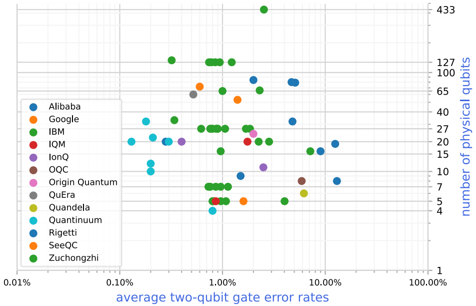
PASQAL

inside a typical quantum computer

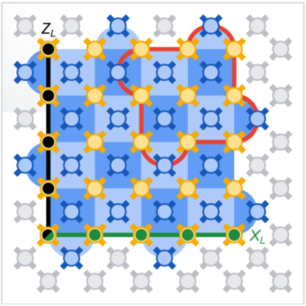


for superconducting or electron spin qubits

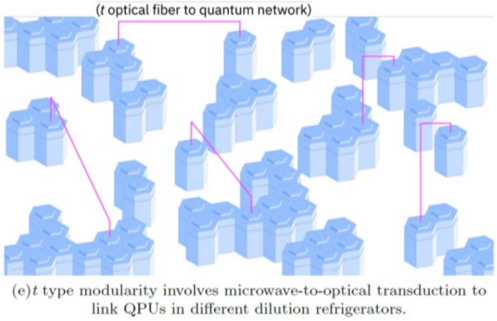
key hardware challenges



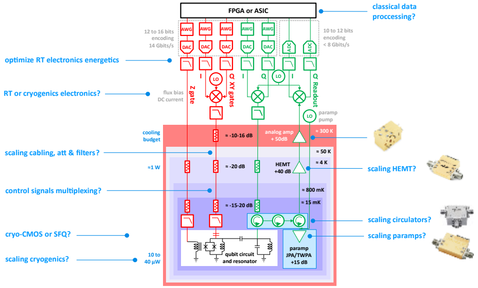
qubits fidelities



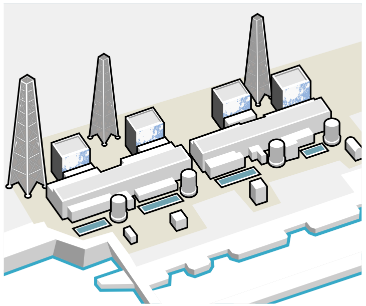
errors mitigation and correction



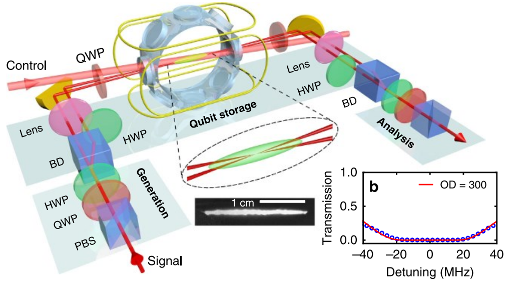
quantum interconnect



enabling technologies scalability

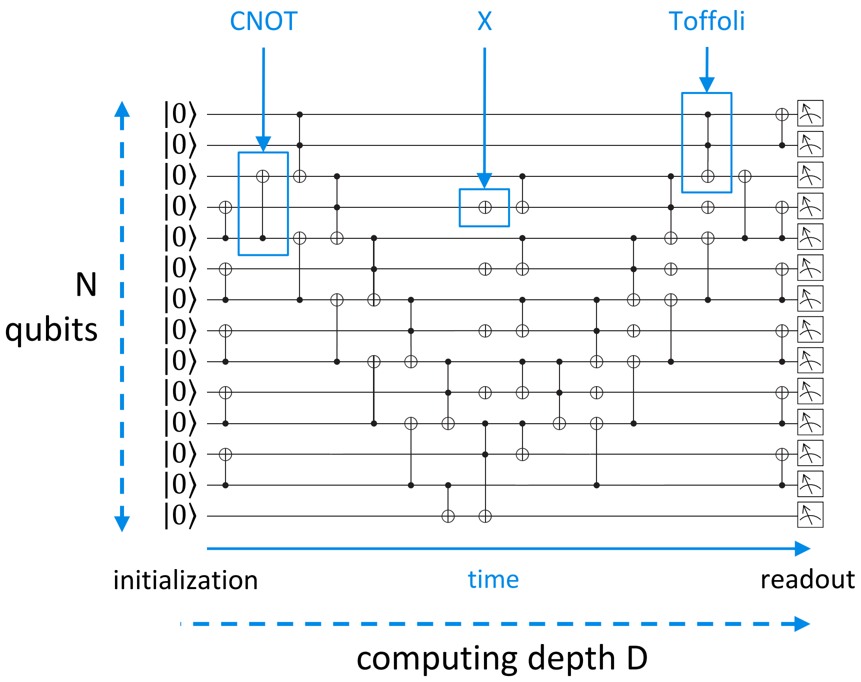


energy consumption



quantum memory

raw algorithm fidelities requirements



desired error rate $< \dfrac{1}{N \times D}$

N qubits	D depth	required error rate (%)	required fidelity (%)	available fidelity (%)
50	100	0.02000%	99.98%	99.30%
133	300	0.00251%	99.9975%	99.6%
433	1000	0.00023%	99.9998%	98%
1121	2000	0.00004%	99.99996%	N/A

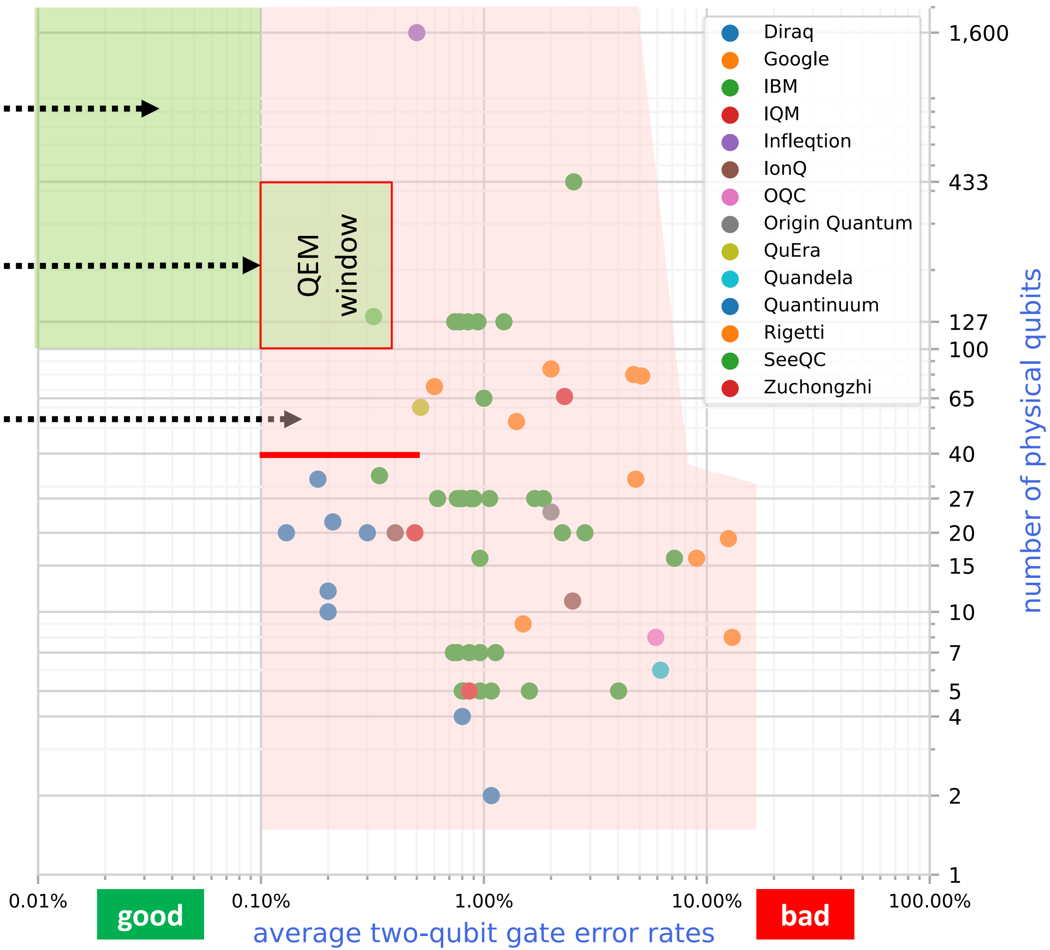
qubit errors quickly kills quantum computing accuracy

useful NISQ* requirements

with quantum error mitigation

state of the art

easy to emulate classically, too noisy to be useful



* NISQ = noisy intermediate scale quantum computers.

logical qubits and FTQC

physical qubit

error rates ≈0.1%

+

error correction code

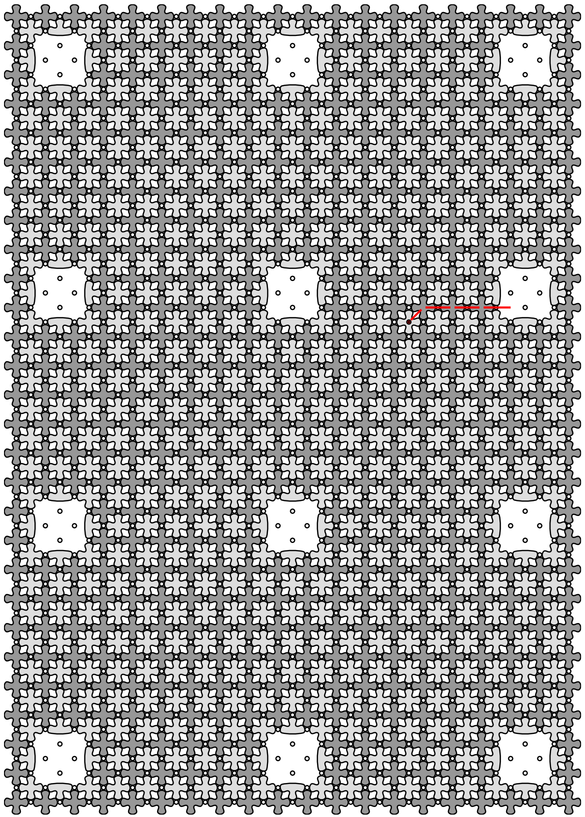
threshold, physical qubits overhead, connectivity requirements, syndrome decoding and scale

logical qubit

error rate $<10^{-8}$ to $<10^{-15}$

fault tolerance

avoid error propagation and amplification
implement a universal gate set
fault-tolerant results readout



tens to thousands qubits

https://arxiv.org/abs/1202.2639

Microsoft-Quantinuum logical qubits

Demonstration of logical qubits and repeated error correction with better-than-physical error rates

M. P. da Silva,[1] C. Ryan-Anderson,[2] J. M. Bello-Rivas,[1] A. Chernoguzov,[2] J. M. Dreiling,[2] C. Foltz,[2] J. P. Gaebler,[2] T. M. Gatterman,[2] D. Hayes,[2] N. Hewitt,[2] J. Johansen,[2] D. Lucchetti,[2] M. Mills,[2] S. A. Moses,[2] B. Neyenhuis,[2] A. Paz,[1] J. Pino,[2] P. Siegfried,[2] J. Strabley,[2] S. J. Wernli,[1] R. P. Stutz,[2] and K. M. Svore[1]

[1] *Microsoft Azure Quantum*
[2] *Quantinuum*

(Dated: April 2, 2024)

The promise of quantum computers hinges on the ability to scale to large system sizes, e.g., to run quantum computations consisting of more than 100 million operations fault-tolerantly. This in turn requires suppressing errors to levels inversely proportional to the size of the computation. As a step towards this ambitious goal, we present experiments on a trapped-ion QCCD processor where, through the use of fault-tolerant encoding and error correction, we are able to suppress logical error rates to levels below the physical error rates. In particular, we entangled logical qubit states encoded in the $[[7,1,3]]$ code with error rates $9.8\times$ to $500\times$ lower than at the physical level, and entangled logical qubit states encoded in a $[[12,2,4]]$ code with error rates $4.7\times$ to $800\times$ lower than at the physical level, depending on the judicious use of post-selection. Moreover, we demonstrate repeated error correction with the $[[12,2,4]]$ code, with logical error rates below physical circuit baselines corresponding to repeated CNOTs, and show evidence that the error rate per error correction cycle, which consists of over 100 physical CNOTs, approaches the error rate of two physical CNOTs. These results signify an important transition from noisy intermediate scale quantum computing to reliable quantum computing, and demonstrate advanced capabilities toward large-scale fault-tolerant quantum computing.

https://arxiv.org/abs/2404.02280

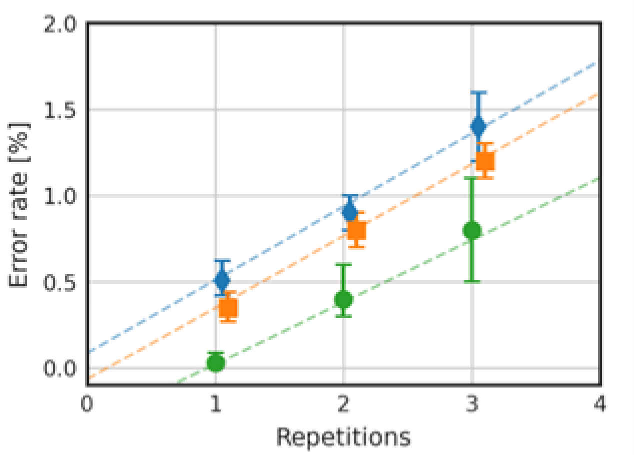


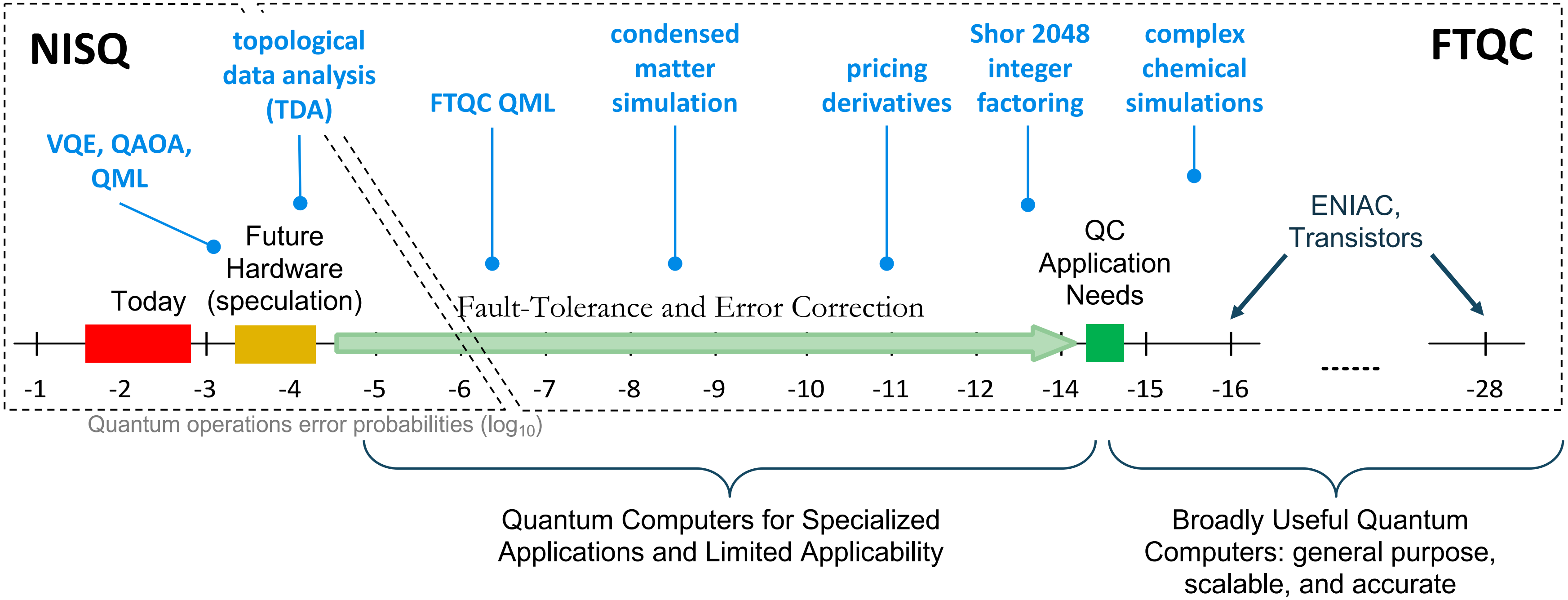
FIG. 7. Observed error rate for circuits with 1 to 3 rounds of error correction with the $[[12,2,4]]$ Carbon code (green circles) and physical baselines (blue diamond for pairs of 1-bit teleportations, and orange squares for pairs of CNOTs). Results are offset along the x-axis for clarity. Linear fits are obtained by maximum-likelihood estimation (see Appendix A for details).

https://scottaaronson.blog/?p=7916#comment-1973425

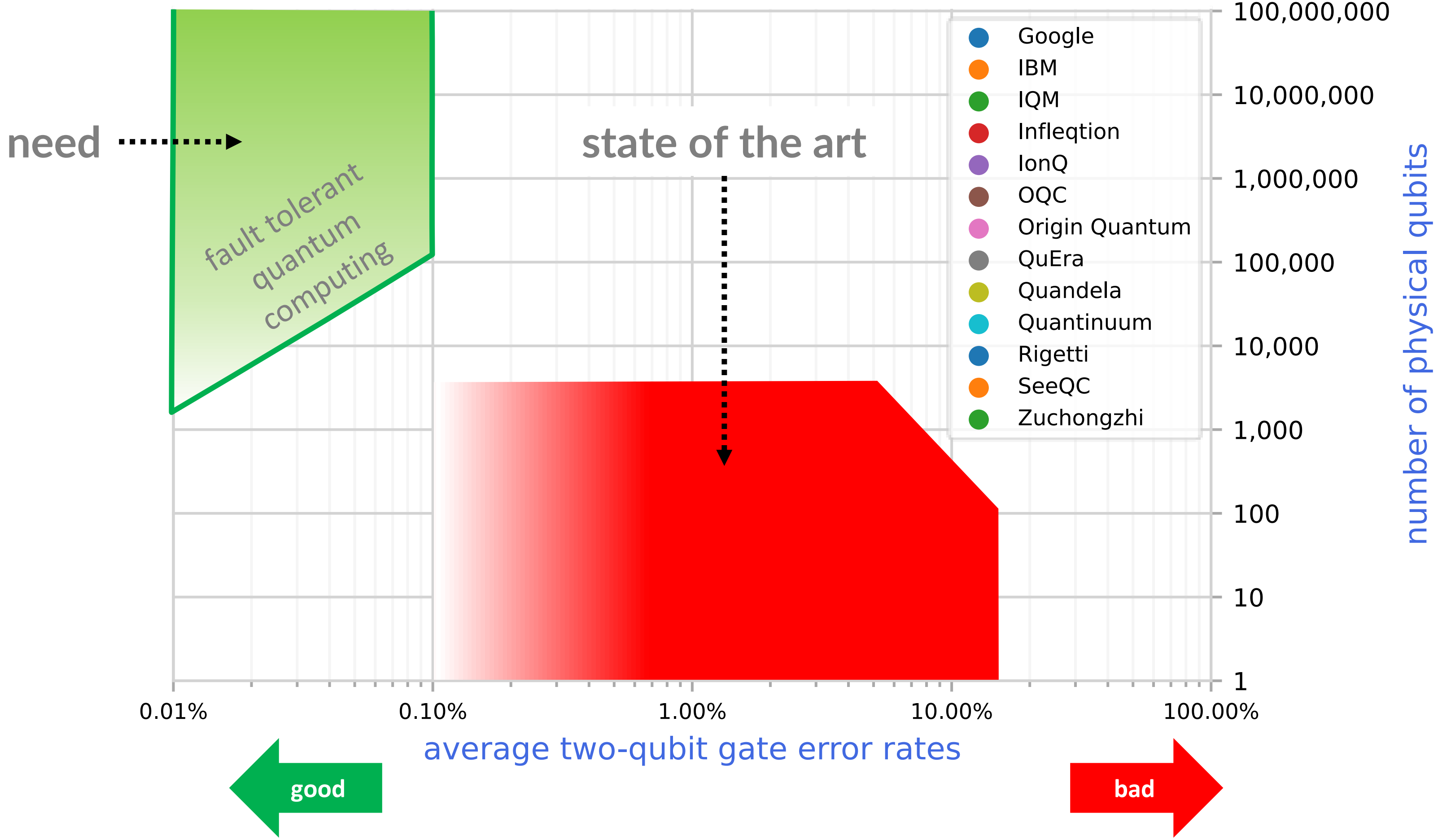
claim: logical qubit with x800 improvement vs physical qubit

reality: x800 improvement only for the first gate cycle!

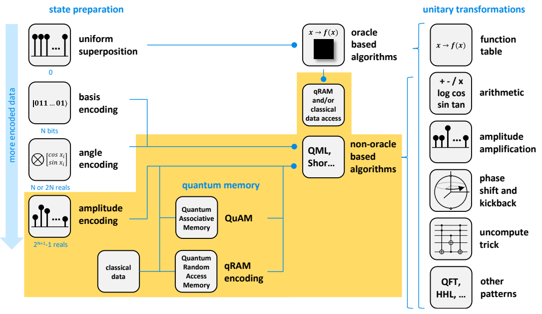
logical qubits requirements



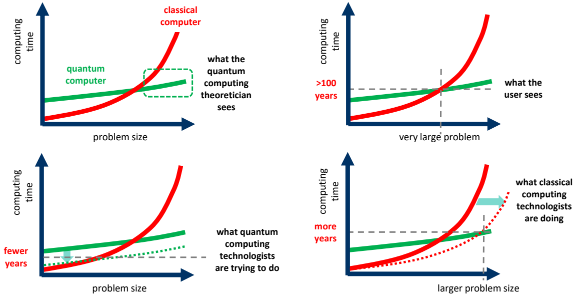
source: How about quantum computing? by Bert de Jong, DoE Berkeley Labs, June 2019 (47 slides) + Olivier Ezratty additions, 2021-2024.


need
fault tolerant quantum computing
state of the art
Google
IBM
IQM
Infleqtion
IonQ
OQC
Origin Quantum
QuEra
Quandela
Quantinuum
Rigetti
SeeQC
Zuchongzhi
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
number of physical qubits
0.01%
0.10%
1.00%
10.00%
100.00%
average two-qubit gate error rates
good
bad

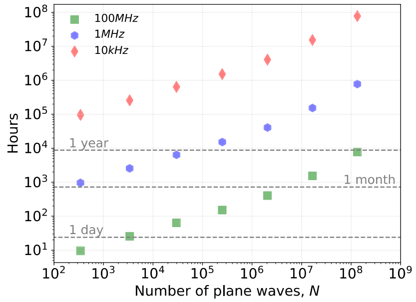
key software challenges



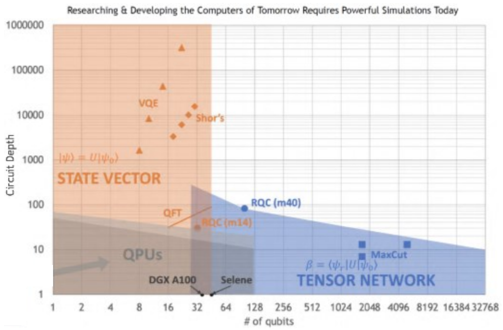
data loading



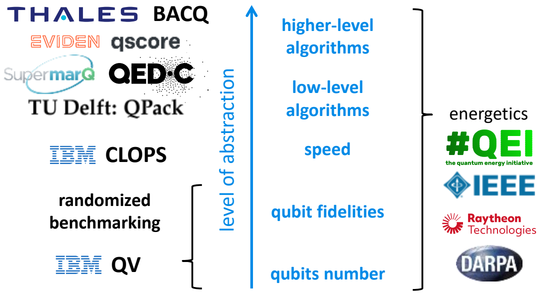
actual speedups



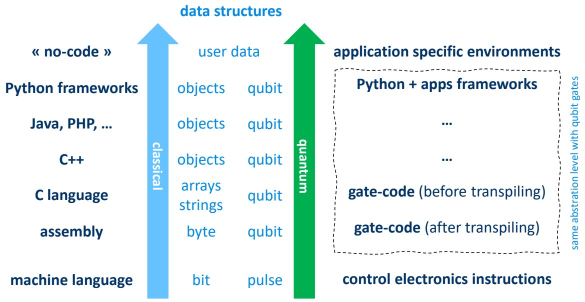
actual computing time



tensor networks competition

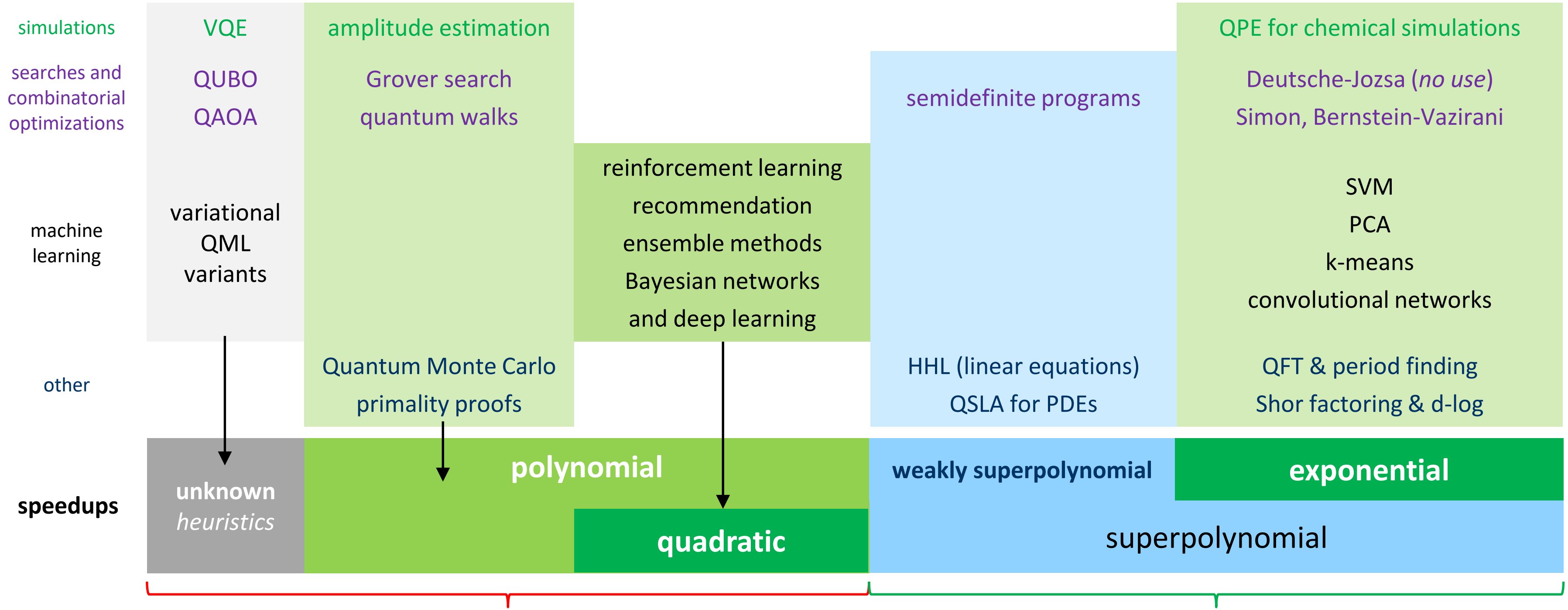


benchmarking



coding abstraction level

potential quantum speedups



limited advantage

QPU fixed costs make it difficult to exceed classical computing capabilities in reasonable times and problem sizes

requires FTQC QPUs

and many logical and physical qubits with higher fidelities than today, and preferably monolithic QPUs

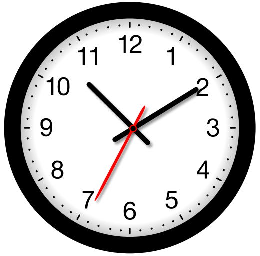
quantum advantages taxonomy

complex amplitudes — of all combinations of 0 and 1

$$\begin{bmatrix} \alpha_1 \\ \dots \\ \dots \\ \dots \\ \dots \\ \alpha_{2^N} \end{bmatrix} \quad \begin{matrix} |00 \dots 00\rangle \\ \\ |01 \dots 11\rangle \\ \\ |11 \dots 11\rangle \end{matrix}$$

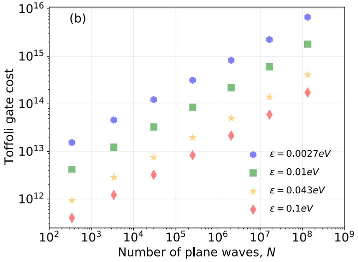
space

the qubit register data space - scaling in 2^N complex numbers with N qubits - exceeds the memory capacity of classical computers.



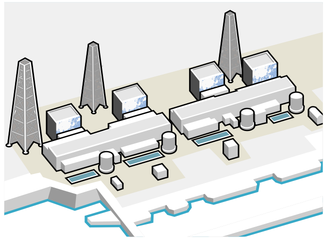
speed

a quantum algorithm, including its classical part, runs faster than an equivalent best-in-class classical algorithms running on either the largest supercomputers or a given HPC configuration.



quality

the quality of the results of a quantum algorithm is better for some respect than the best-in-class classical algorithms. e.g: an error rate of a machine learning classification, a chemical simulation accuracy, or a better combinatorial problem solution.



energetic

a fully-burdened quantum computer and algorithm configuration consumes less energy than the best-in-class classical equivalent.

Krisztian Benyo (Pasqal)
today's talk

€ $ £

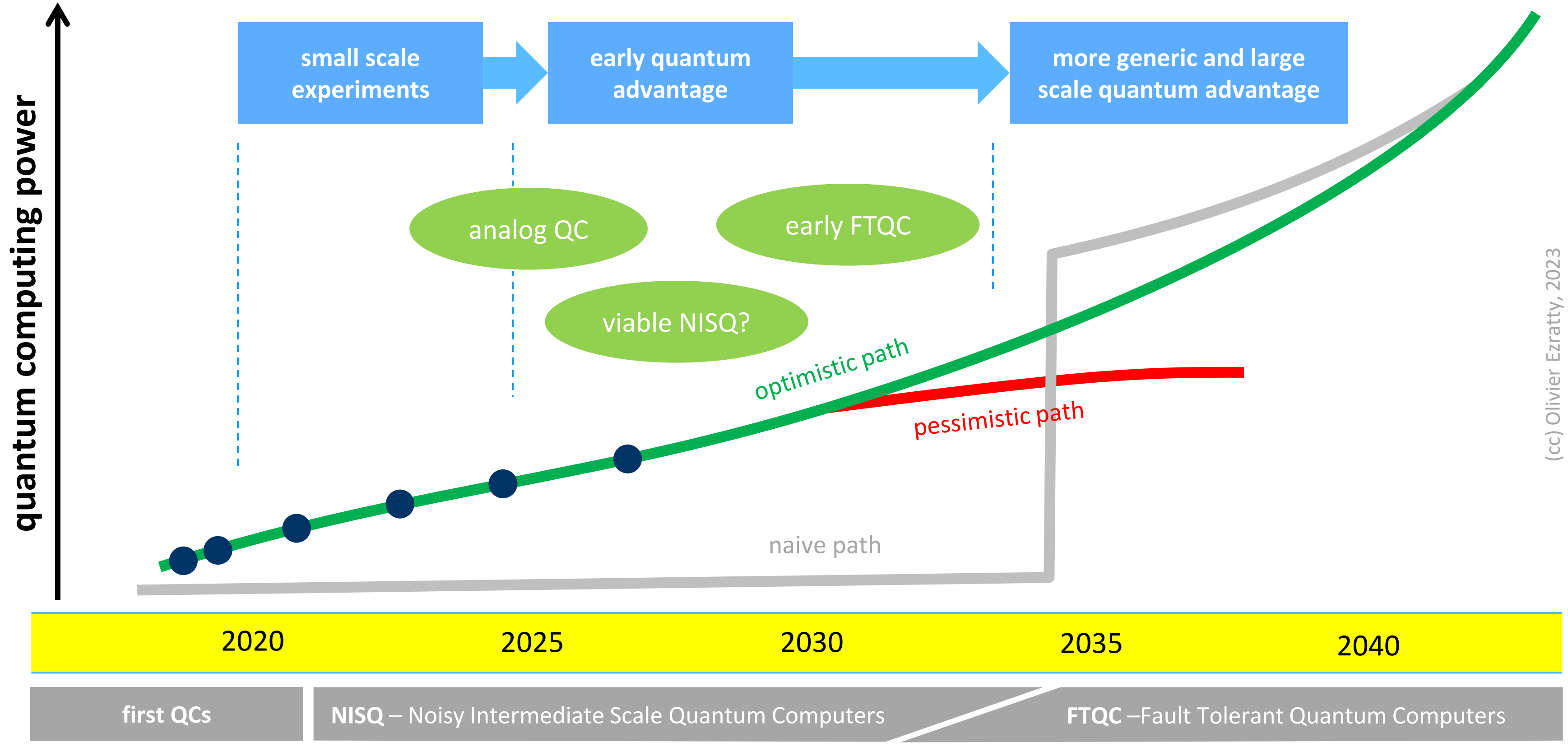
TCO

ROI

cost

the total cost of the quantum solution is lower than the total cost of a best-in-class classical solution.

a long journey



quantum computing cloud offerings

	hybrid computing centers	OVHcloud	IBM	aws	Microsoft	Google
emulation	40 qubits EVIDEN	EVIDEN C12 QUANDELA		34-50 qubits	30 qubits	40 qubits
quantum computing	hybrid quantum TGCC Très Grand Centre de calcul du CEA JÜLICH Forschungszentrum JÜLICH SUPERCOMPUTING CENTRE LUMI in 2023	PASQAL 100 qubits (simulation) QUANDELA …	IBM 5 to 133 qubits	D-Wave 5000 qubits (annealing) IONQ 32 qubits rigetti 80 qubits OQC 8 qubits QuEra Computing Inc. XANADU	PASQAL 100 qubits (simulation) IONQ 32 qubits rigetti 80 qubits QUANTINUUM 12-32 qubits	IONQ 11 qubits

and also

D-Wave
QCWARE
XANADU
Quantum Inspire - By QuTech

Europe early evaluation examples

EDF
BNP PARIBAS
AIRBUS
BOSCH
MBDA MISSILE SYSTEMS
Mercedes-Benz
TOTAL
BASF We create chemistry
CA
NAVAL GROUP
BMW
VW
BANQUE DE FRANCE
THALES
CMA CGM
OVHcloud
Raiffeisen Bank International Member of RBI Group
sopra steria
T Systems
CaixaBank
FERROVIE DELLO STATO ITALIANE
DLR
IONOS
Capgemini

what is being practically done

classical computers		analog quantum computers		digital quantum computers	
quantum inspired	quantum emulators	quantum **annealing computers**	analog **quantum simulators**	**gate-based**	
				NISQ (Noisy Intermediate Scale Quantum)	**FTQC** (Fault-Tolerant Quantum Computing)
• financial services solutions improvements. • machine learning improvements.	• code learning. • code debugging. • designing new algorithms. • simulating qubit physics. • simulating error correction codes.	• solving optimization problems at mid-sized scale, in transportation (Volkswagen, Denso), retail (Ocado, Pattison), job shop scheduling and financial services (Mastercard, CACIB). • physics simulations (statistical physics, spin glass, ferromagnetism, topological matter, …). • potential energetic advantage.		• low-level physics simulations (“IBM quantum utility” with 127 qubits and kicked Ising model). • creating and testing algorithms at small scale (QML, optimizations, chemical simulations).	• large algorithms and resource estimations. • creating and testing error correction codes (Google, Quantinuum, QuEra, PsiQuantum, …).
ALPHARAIL NatWest	Qubit PHARMACEUTICALS	CaixaBank Raiffeisen Bank International Member of RBI Group	CRÉDIT AGRICOLE CORPORATE & INVESTMENT BANK	EDF AIRBUS MBDA MISSILE SYSTEMS TOTAL	HYUNDAI J.P.Morgan Goldman Sachs

why study quantum computing now?

1. **understand** the quantum computing technology and buzz.
2. **become ready** when quantum computing delivers.
3. attract **high-level talent** in your organization.
4. challenge and revisit **legacy classical solutions.**
5. envision **lower energy consumption** in HPC applications.

industry vendors ecosystem

computing
- PASQAL
- ALICE & BOB
- C12
- quobly
- QUANDELA
- CRYSTAL QUANTUM COMPUTING
- EVIDEN an atos business

software
- Qubit PHARMACEUTICALS
- EVIDEN an atos business
- QuantFi
- mol|ket
- QPerfect
- QbitSoft Quantum as a Service
- VeriQloud
- ColibrITD
- AQEMIA

cybersecurity
- CRYPTONEXT SECURITY
- CRYPTO EXPERTS
- ravel
- SECURE-IC THE SECURITY SCIENCE COMPANY
- CYFERALL
- QuRISK ADVISORY

photonics
- cailabs SHAPING THE LIGHT
- Lytid
- exail
- SPARK LASERS
- LUMIBIRD
- AUREA TECHNOLOGY
- teem PHOTONICS
- SCINTIL PHOTONICS
- GLOphotonics
- QUANDELA

sensing
- THALES
- exail
- kwan-tek
- Syrlinks
- orolia
- chipiron
- MAG 4He alth

cryogeny
- Air Liquide
- CryoConcept
- INNOVATIVE SOLUTIONS ABSOLUT SYSTEM

electronics
- SILENT WAVES
- Viqthor
- Welinq
- Radiall
- ATEM
- SILENTSYS ultralow noise systems

manufacturing
- PLASSYS
- RIBER
- SERMA TECHNOLOGIES

materials
- orano
- DIAMFAB
- HIQUTE DIAMOND


Hope to see you again next year!
QuantAlps


ALICE & BOB


quobly


PASQAL

discussion