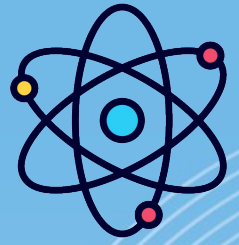

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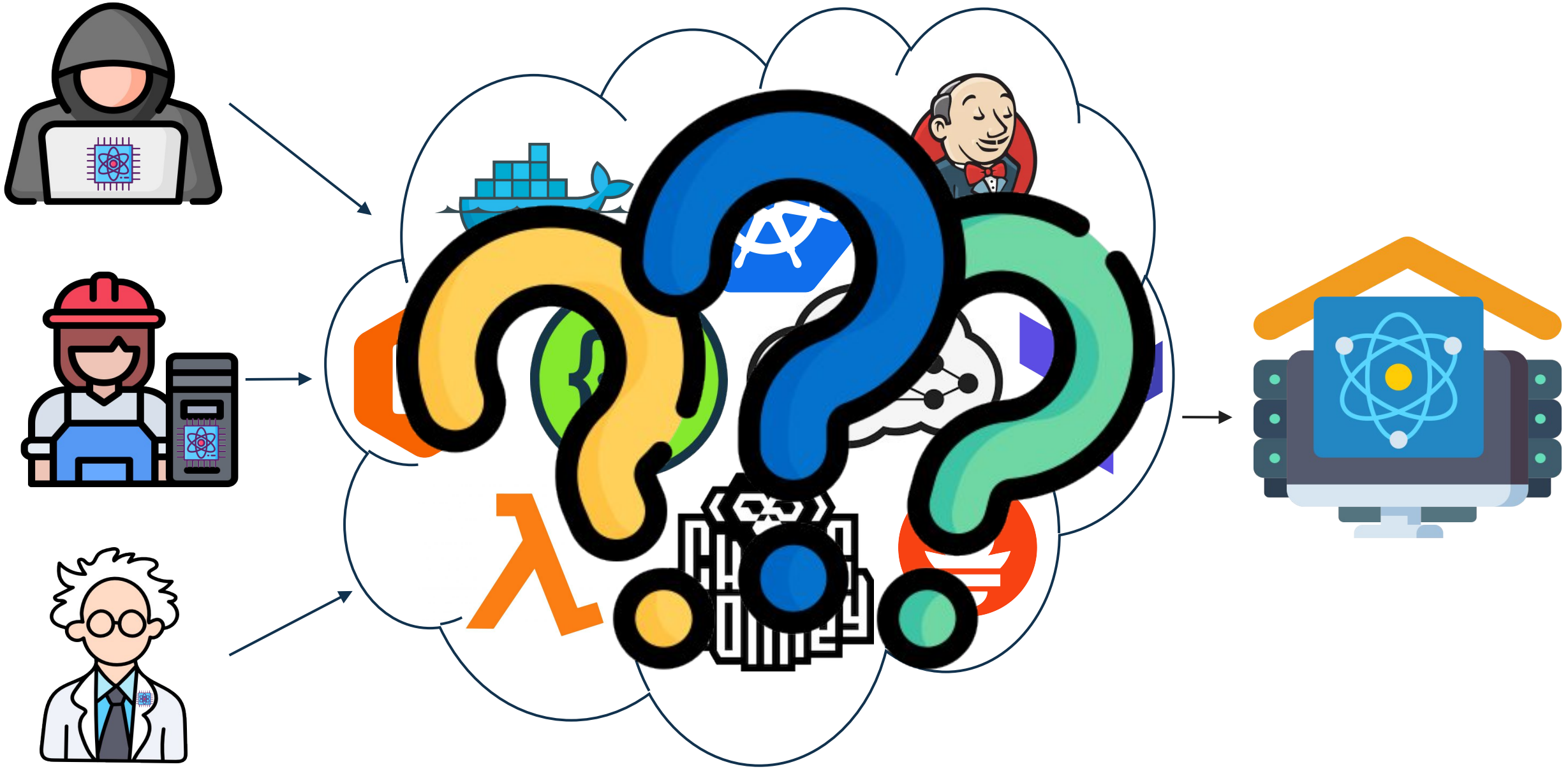
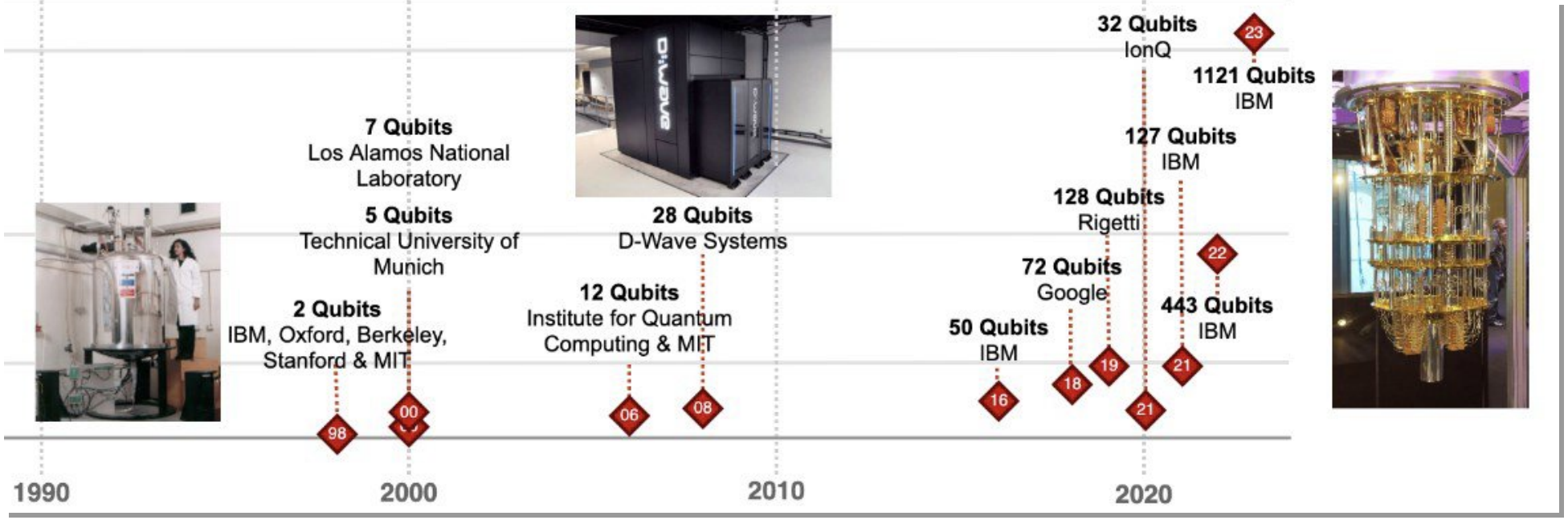
Quantum Cloud: orchestrazione e sicurezza per infrastrutture quantistiche distribuite

Giuseppe Bisicchia
Università di Pisa





IBM Q

XANADU
Photonic Quantum Computing

D:Wave
The Quantum Computing Company™

Google AI Quantum

rigetti

AQT

aws
Amazon Braket

Microsoft Azure

QCWARE Forge

Quantum Inspire
By QuTech

ibm_cairo	27	64	2.4K	Online	16	Falcon r5.11	premium	OpenQASM 3
ibm_auckland Exploratory	27	64	2.4K	Online	1818	Falcon r5.11	premium	OpenQASM 3
ibm_hanoi	27	64	2.3K	Online - Queue paused	540	Falcon r5.11	premium	OpenQASM 3
ibm_peekskill Exploratory	27	-	-	Online	1	Falcon r8	premium	OpenQASM 3
ibmq_guadalupe	16	32	2.4K	Online - Queue paused	37	Falcon r4P	premium	
ibm_perth	7	32	2.9K	Online	126	Falcon r5.11H	open	OpenQASM 3
ibm_lagos	7	32	2.7K	Online - Reserved	64	Falcon r5.11H	open	OpenQASM 3

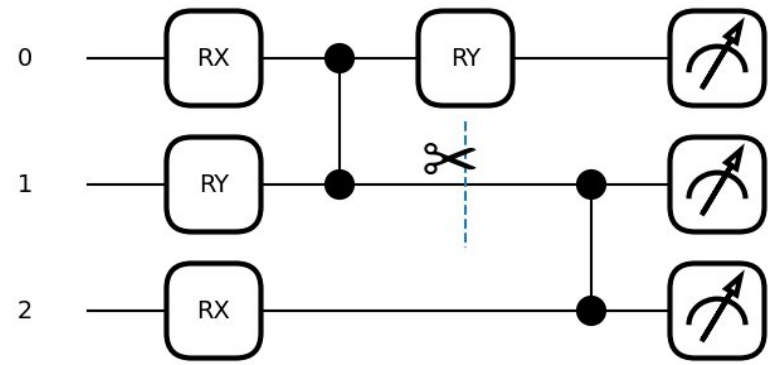
IonQ IonQ	Quantum Computing	Azure Quantum Credits
Microsoft Quantum Computing Microsoft	Quantum Computing	Learn & Develop
Quantinuum Quantinuum	Quantum Computing	Azure Quantum Credits
Rigetti Quantum Rigetti Computing	Quantum Computing	Azure Quantum Credits

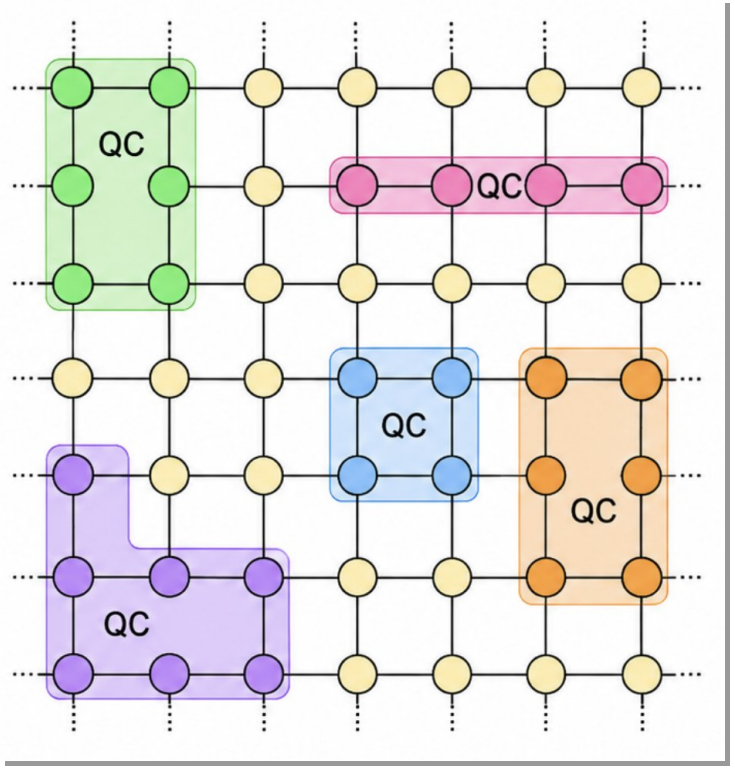
Amazon Web Services	SV1	AVAILABLE NOW
Amazon Web Services	TN1	AVAILABLE NOW
Amazon Web Services	DM1	AVAILABLE NOW
IonQ	Harmony	02:44:47
IonQ	Aria 1	02:44:47
Oxford Quantum Circuits	Lucy	00:44:47
QuEra	Aquila	1 day 06:44:47
Rigetti	Aspen-M-3	05:44:47

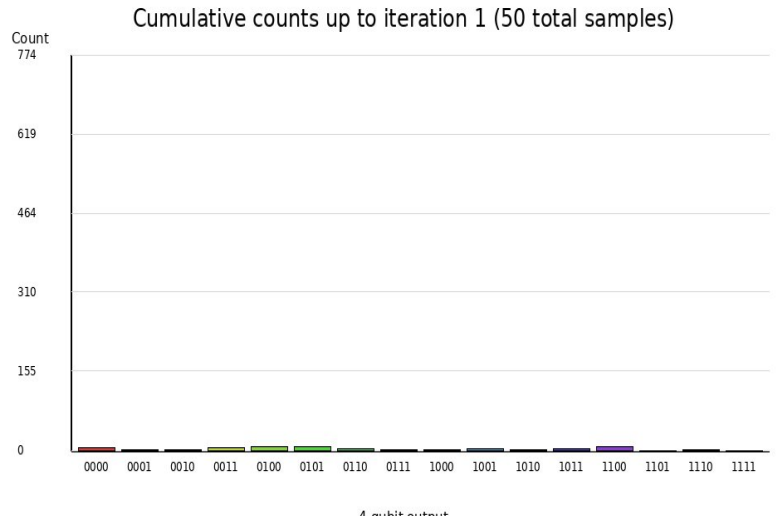
Classification	Description	Examples	Qubit lifetime (1)	Gate fidelity (2)	Gate operation time (3)	Connectivity	Scalability	Pros	Cons
Superconducting	Two level system of a superconducting circuit which forms a qubit (a transmon, first developed at Yale)	IBM, Google, Rigetti, Alibaba, Intel, Quantum Circuits	c.50-100µs	c.99.4%	c.10-50ns	Neighbours	Highly scalable (see OQC coaxmon tech)	- Fast gate times - Builds on existing semiconductor industry	- Typically low longevity - Must be kept very cold to work
Ion trap	Single charged ions trapped in magnetic fields. Energy level of its spin comprises the qubits	IonQ; Alpine Quantum Technologies; Honeywell	>1,000s	c.99.9%	c.3-50µs	All-to-all	TBC	- High gate fidelity - Very stable	- Slow operations
Photonics	Qubits made from single particles of light (photons) operating on silicon chips pathways	PsiQuantum, Xanadu	c. 150µs	c. 98.0%	c.1ns	Unknown	Highly scalable (see Psi Quantum)	- Highly scalable - Utilises existing SC industry infrastructure - No temperature requirements	- Nascent technology - Connectivity to be demonstrated
Neutral atoms	Qubits made from individual atoms (rather than ions which have a charge)	Atom Computing, PASQAL, QuEra	Similar to ion trap	c.95%	TBC	TBC	TBC	- Long qubit coherence times	- Must be kept cold - Nascent
Silicon	Artificial atoms made by adding an electron to a small piece of pure silicon and microwaves control the electrons state	Intel, Silicon Quantum Computing	c. 1-10s	c. 99%	c.1-10ns	Neighbours	Expect high scalability	- Stable - Utilises existing semiconductor industry infrastructure	- Must be kept cold - Nascent
Topological qubits	Qubits made from non-Abelian forms of matter	Microsoft (WIP)	Very high	Very high	Unknown	Unknown	Unknown	- Estimated long lifetime and high fidelities	- Existence to be confirmed

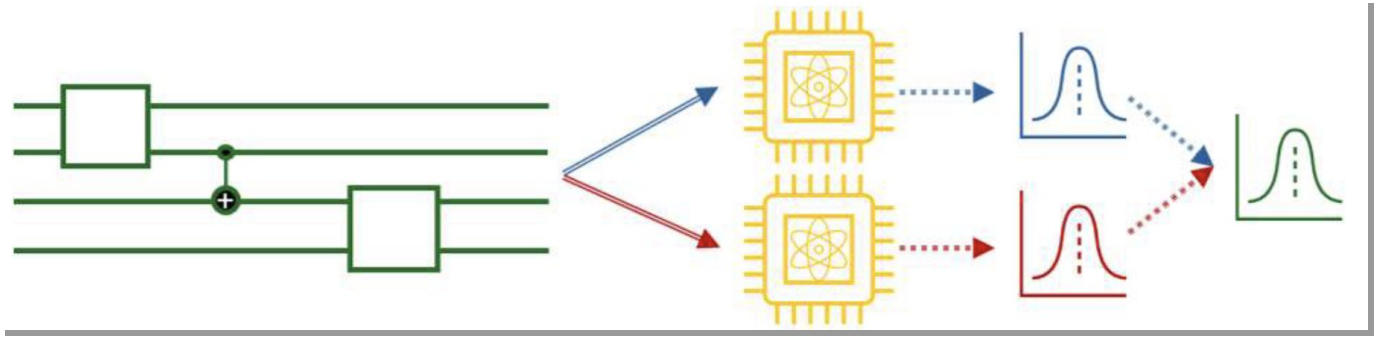
Notes: (1) Record coherence time for a single qubit position state; (2) Highest reported fidelity for two qubit gate operations; (3) Speed of gate operations
Sources: Literature review, TQD expert interviews. Special reference to BCG reports, Science Mag and NAE report on quantum computing.
s = seconds
µs = microsecond (10^ -6 seconds)
ns = nanosecond (10^ -9 seconds)

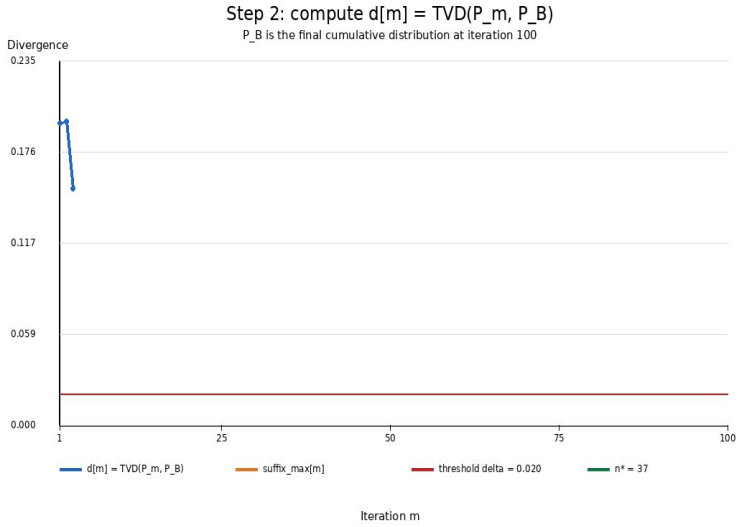
www.thequantumdaily.com

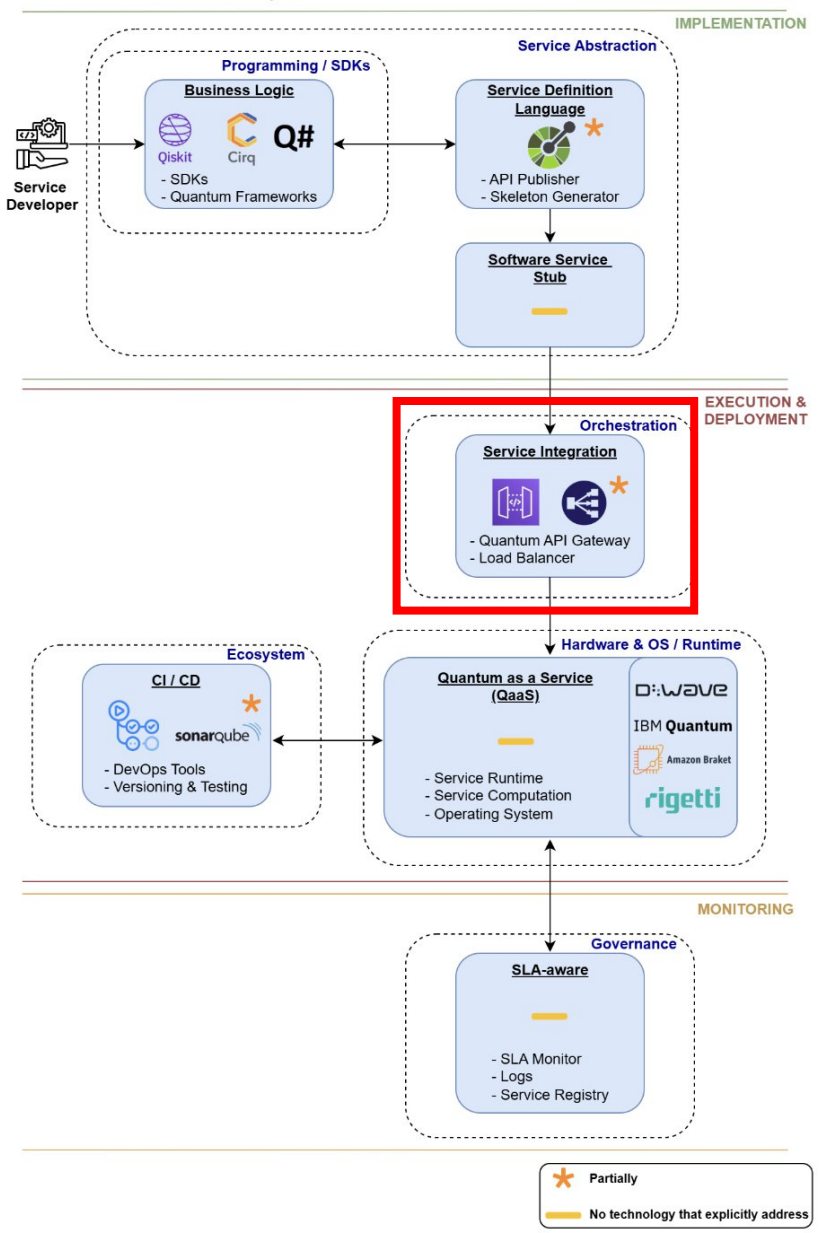

0
1
2
RX
RY
RY
RX


QC
QC
QC
QC
QC


Cumulative counts up to iteration 1 (50 total samples)
Count
774
619
464
310
155
0
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111

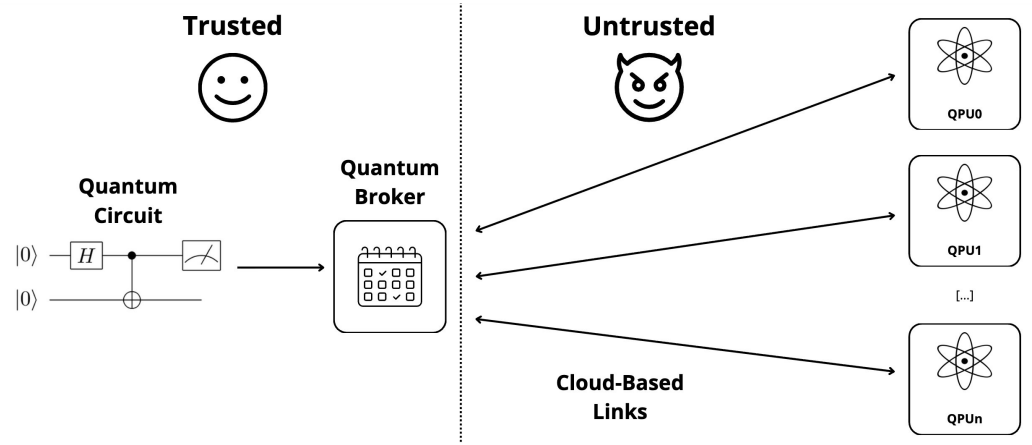



Step 2: compute d[m] = TVD(P_m, P_B)
P_B is the final cumulative distribution at iteration 100
Divergence
0.235
0.176
0.117
0.059
0.000
1
25
50
75
100
d[m] = TVD(P_m, P_B)
suffix_max[m]
threshold delta = 0.020
n* = 37
Iteration m



Listing 4.4: Quantum QoS Specification Language Grammar (EBNF)

```
statement      ::= constraint | objective

constraint     ::= expression comparator expression

objective      ::= expression

expression     ::= term { operator term }

term           ::= aggregate
                 | indexed_variable
                 | variable
                 | number
                 | "(" expression ")"

aggregate      ::= ( "sum" | "max" | "min" ) "(" expression ")"

indexed_variable ::= variable "[" index "]"

variable       ::= "shots"
                 | "used"
                 | "cost"
                 | "execution_time"
                 | "waiting_time"
                 | "fidelity"
                 | "total_shots"
                 | weight_name

index          ::= integer
                 | backend_name

operator       ::= "+" | "-" | "*" | "/" | "**"

comparator     ::= "<" | ">" | "<=" | ">=" | "==" | "!="
```



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