Machine Learning, Optimization and Quantum Computing

Zoltán Zimborás

Application Domain Specific Highly Reliable IT Solutions
Final Workshop
26 May 2022, Budapest

NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE
HUNGARY

PROGRAM FINANCED FROM THE NRDI FUND

The team that helped achieving the results

Where are we at?

1970s
Very sketchy preliminary ideas, nothing concrete

1981
Feynman proposes quantum computers to simulate physics

1984
Bennett & Brassard come up with quantum *cryptography*.

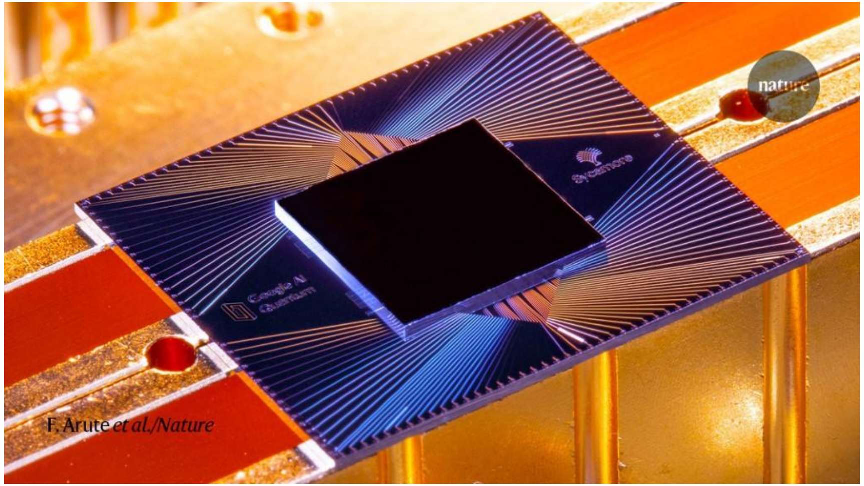
1994-1996
All hell breaks loose. Basically everything at the basic theory level is discovered. Algorithms, entanglement, quantum error correction, etc.

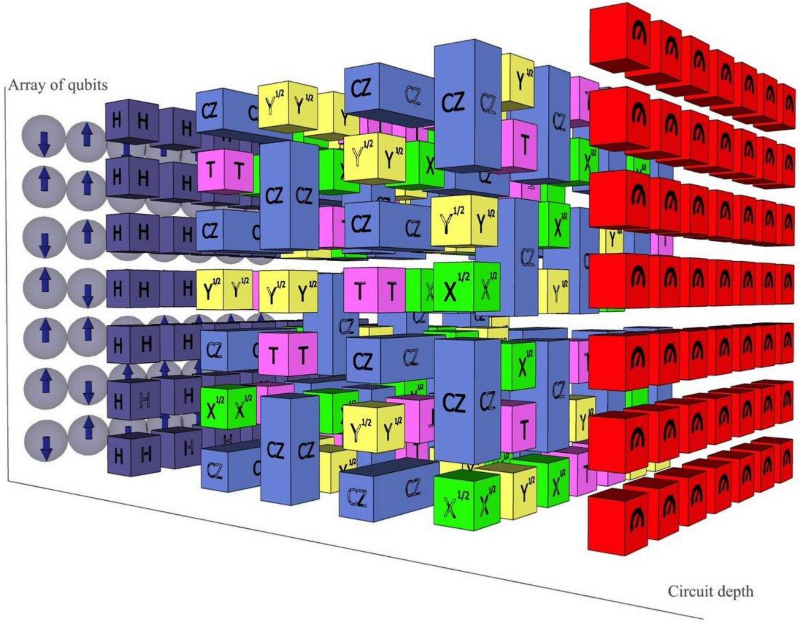
2014
John Martinis (Google) presents first plausible demo of quantum error correction using 9 superconducting qubits.

2016-2020
[First] commercial boom (speculative).

?

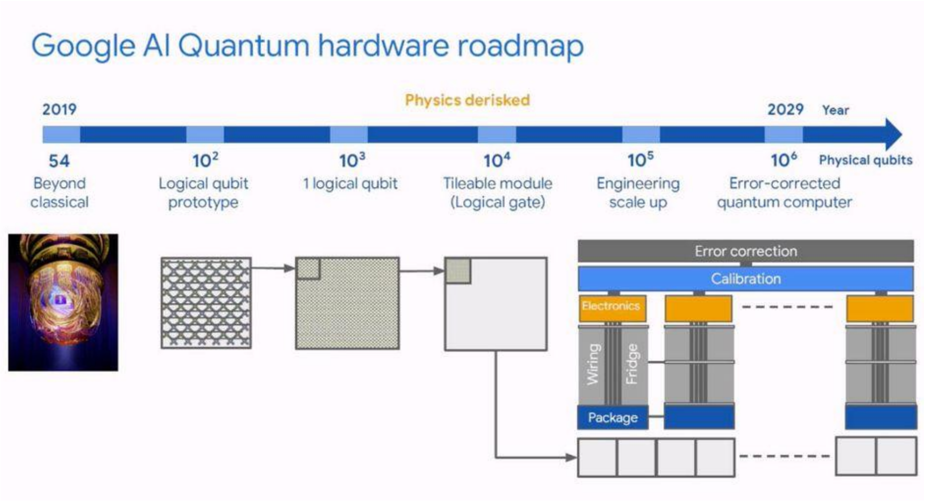
Google's Supremacy Experiment



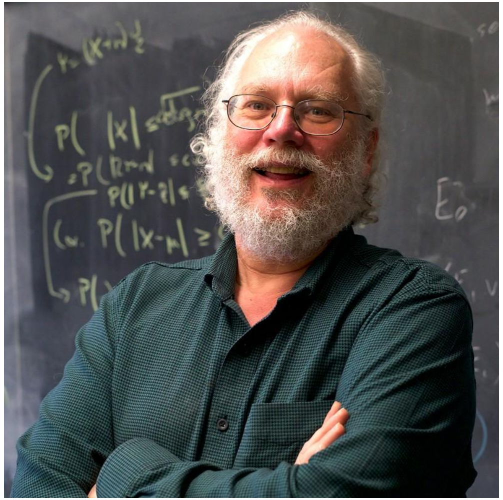


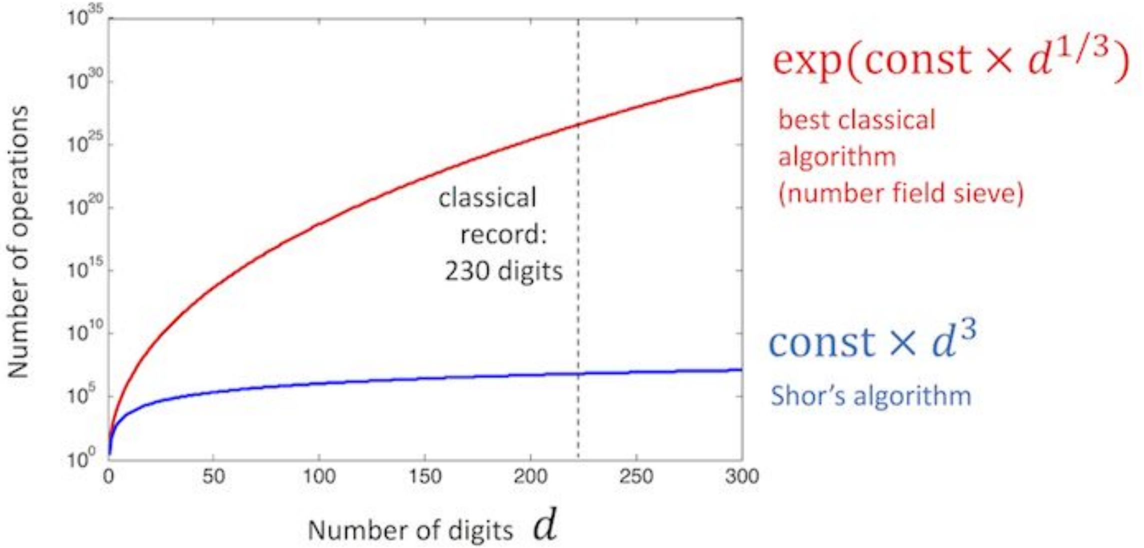
Quantum gates on 53 qubits

The plans of Google and IBM



Shor algorithm for factoring integer numbers





The possibility of running Shor's algorithm

How to factor 2048 bit RSA integers in 8 hours using 20 million noisy qubits

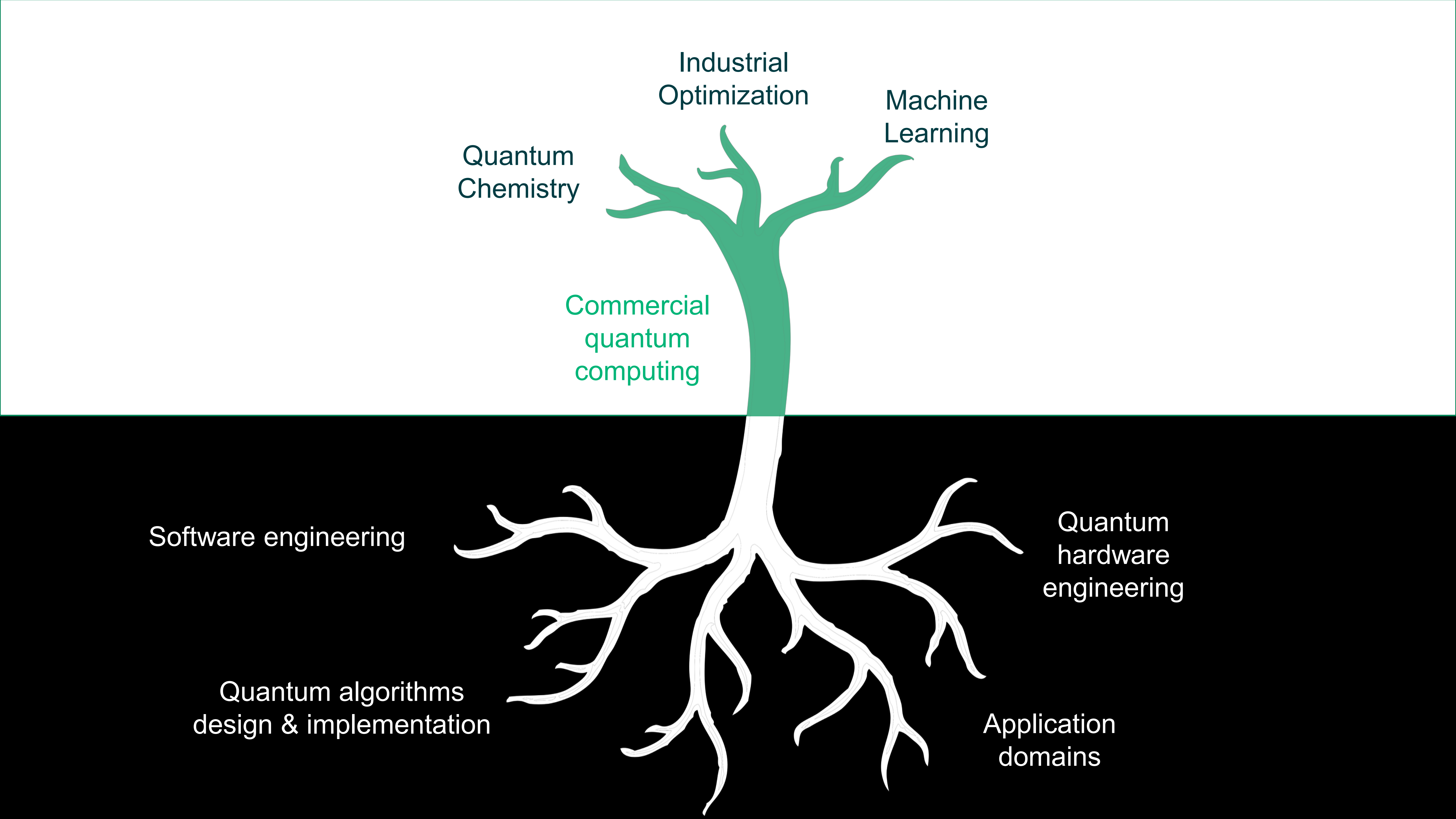
Craig Gidney[1,*] and Martin Ekerå[2]

[1] *Google Inc., Santa Barbara, California 93117, USA*
[2] *KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden*
Swedish NCSA, Swedish Armed Forces, SE-107 85 Stockholm, Sweden

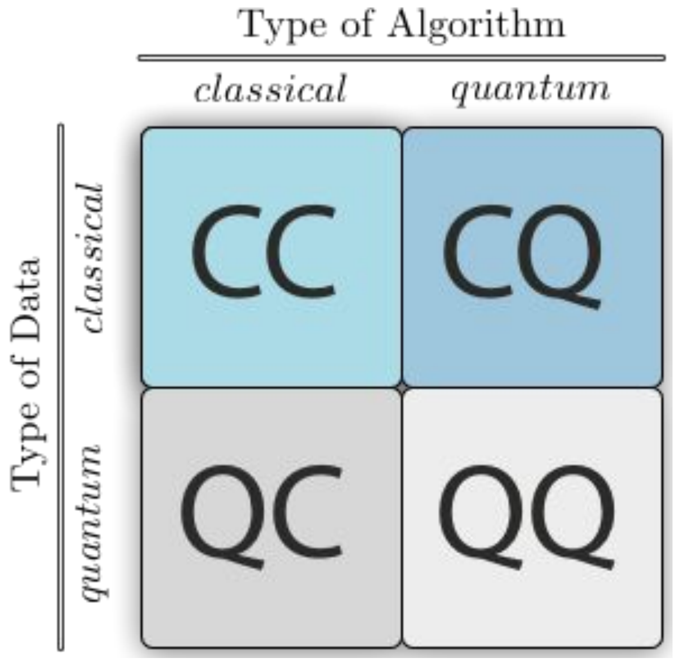
(Dated: December 6, 2019)

	Physical assumptions				Approach		Estimated costs		
Historical cost estimate at $n = 2048$	Physical gate error rate	Cycle time (microseconds)	Reaction time (microseconds)	Physical connectivity	Distillation strategy	Execution strategy	Physical qubits (millions)	Expected runtime (days)	Expected volume (megaqubitdays)
Fowler et al. 2012 [9]	0.1%	1	0.1	planar	1200 T	single threaded	1000	1.1	1100
O'Gorman et al. 2017 [18]	0.1%	10	1	arbitrary	block CCZ	single threaded	230	3.7	850
Gheorghiu et al. 2019 [19]	0.1%	0.2	0.1	planar	1100 T	single threaded	170	1	170
(ours) 2019 (1 factory)	0.1%	1	10	planar	1 CCZ	serial distillation	16	6	90
(ours) 2019 (1 thread)	0.1%	1	10	planar	14 CCZ	single threaded	19	0.36	6.6
(ours) 2019 (parallel)	**0.1%**	**1**	**10**	**planar**	**28 CCZ**	**double threaded**	**20**	**0.31**	**5.9**

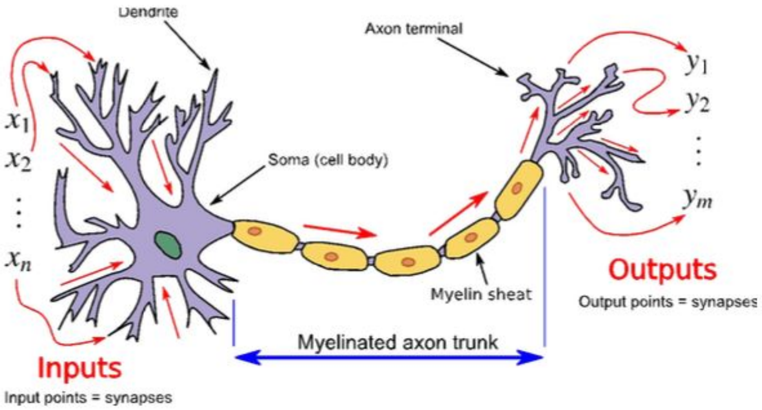
Near-term Quantum Algorithms


Industrial Optimization
Machine Learning
Quantum Chemistry
Commercial quantum computing
Software engineering
Quantum hardware engineering
Quantum algorithms design & implementation
Application domains

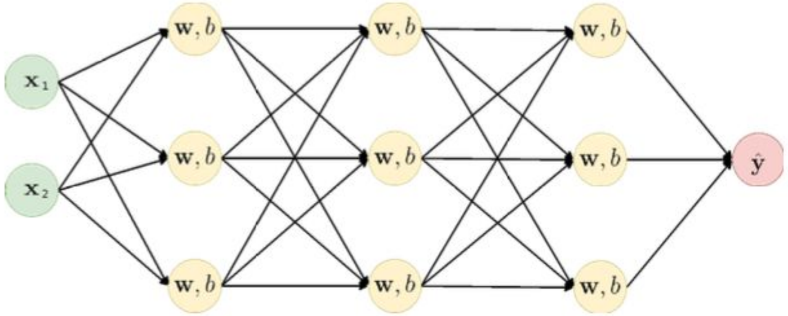
Classification of Machine Learning from a Quantum Computing point of view



Abstraction -> Artificial Neural Networks

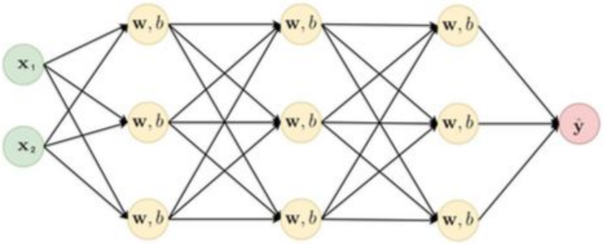


$$y_i = \theta\left(\sum_j J_{ij}x_j - U_0\right)$$

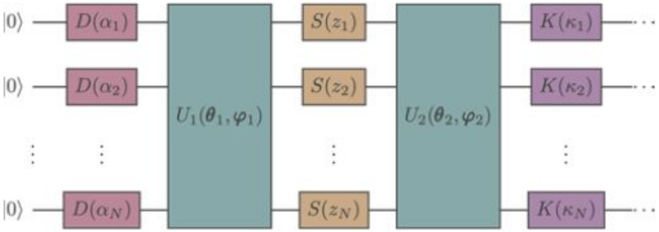


$$\mathbf{y} = g\left(\mathbf{W}^\top \mathbf{x} + \mathbf{b}\right)$$

Further Abstraction -> Quantum Neural Networks

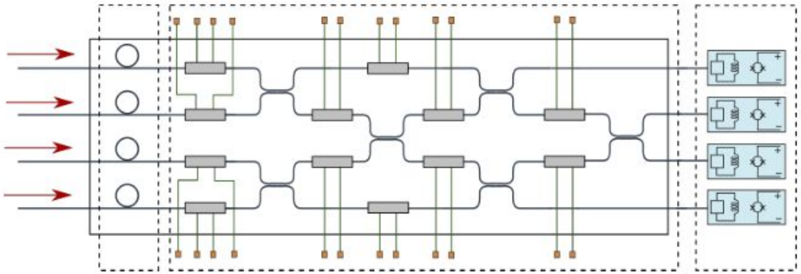


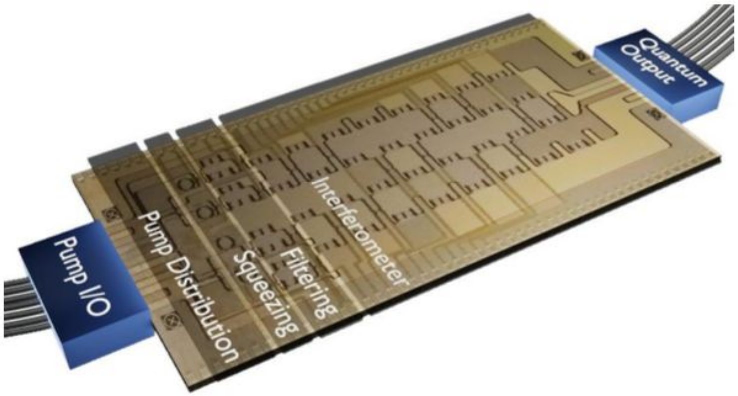
$$\mathcal{L}(\mathbf{x}) = g(\mathbf{W}^\top \mathbf{x} + \mathbf{b})$$



$$\mathcal{L}(\boldsymbol{\xi}) = K(\mathbf{M}\boldsymbol{\xi} + \boldsymbol{\alpha})$$

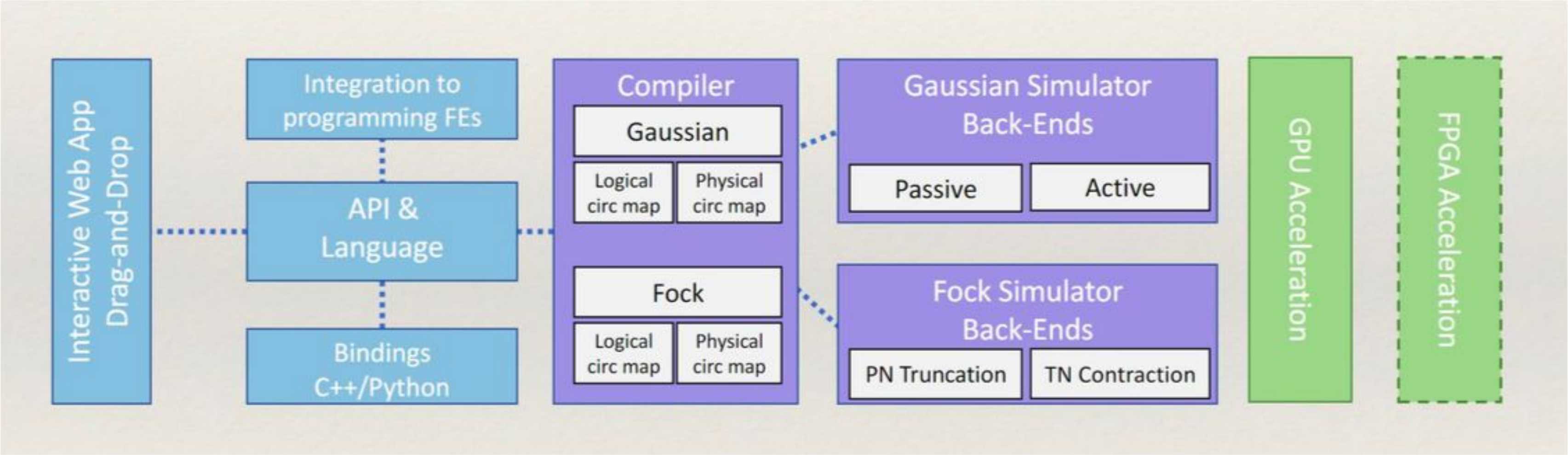
Quantum Neural Networks:
realization with integrated quantum optics



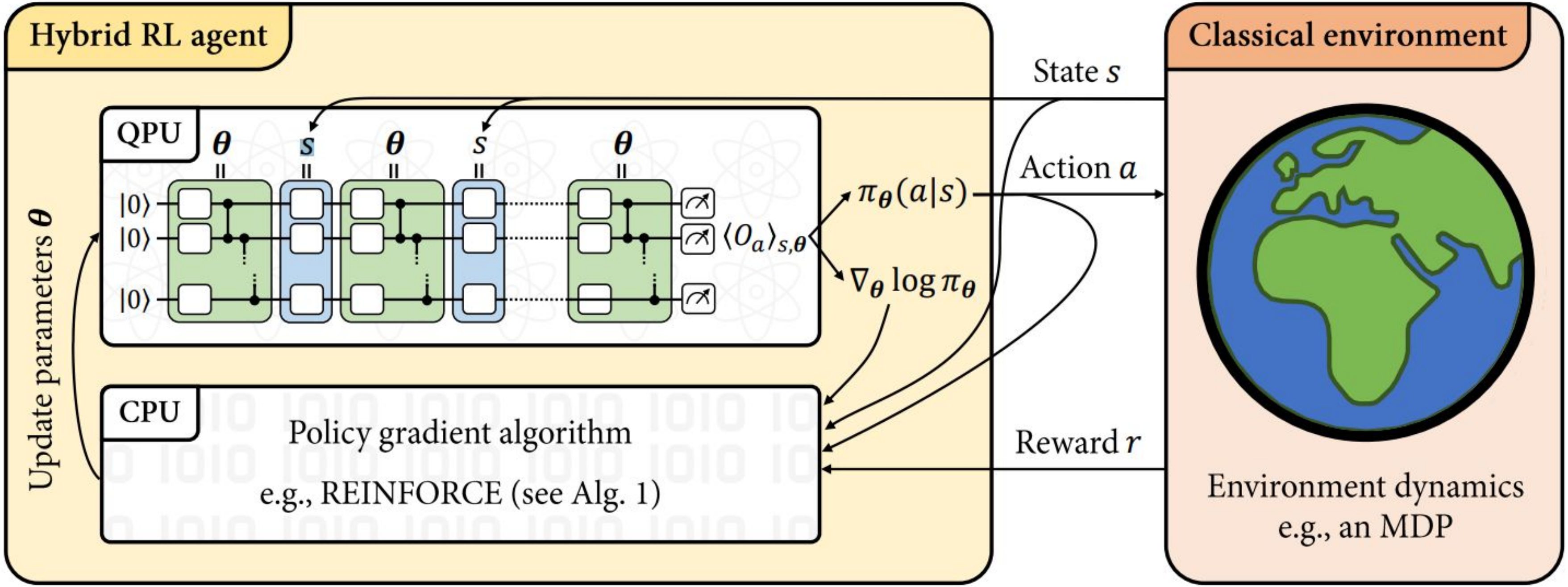


source: https://strawberryfields.ai

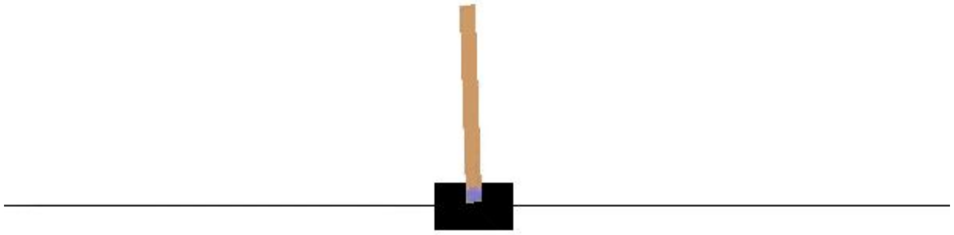
Piquasso photonic quantum computer simulator

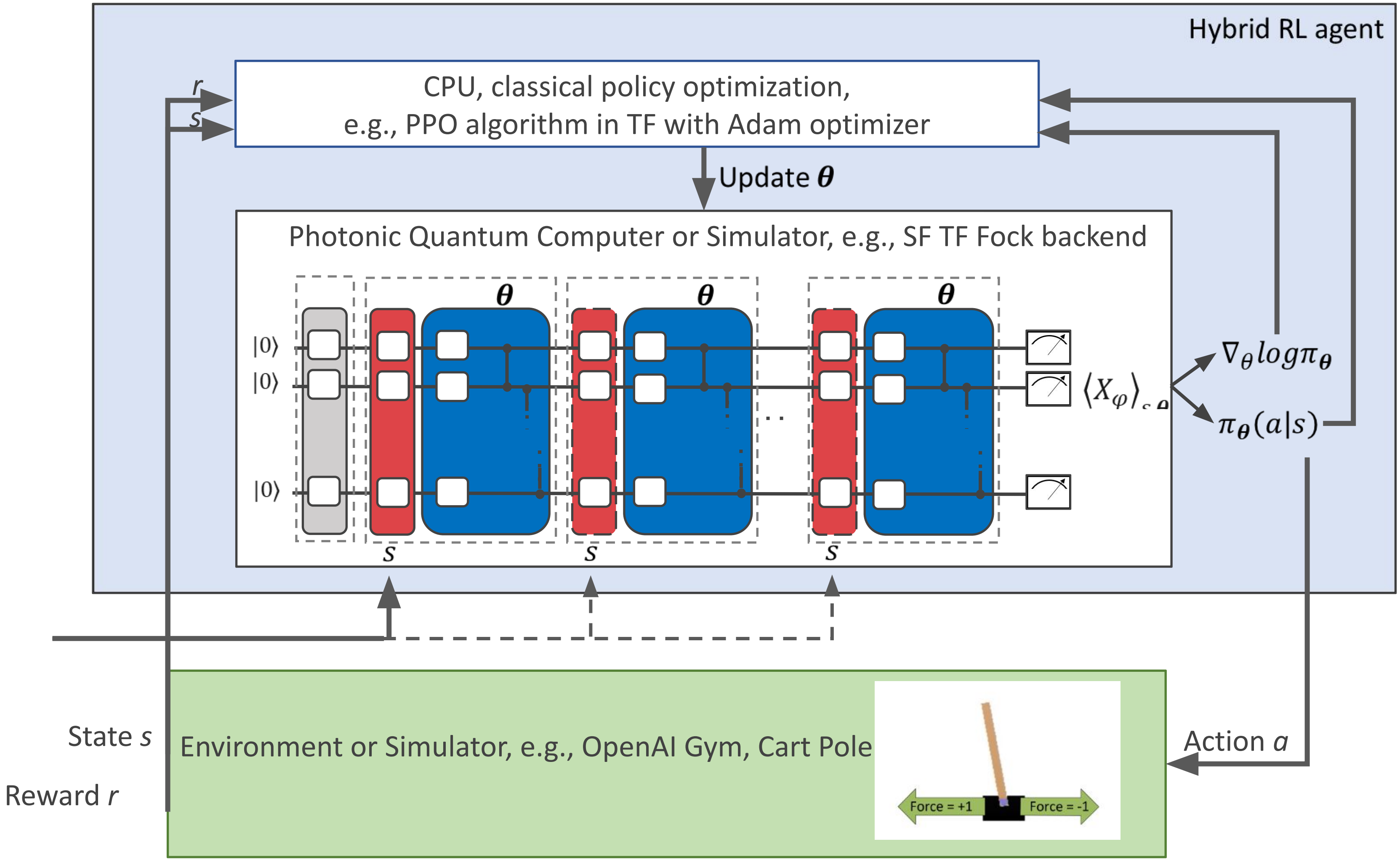


Hybrid Quantum-Classical Reinforcement Learning



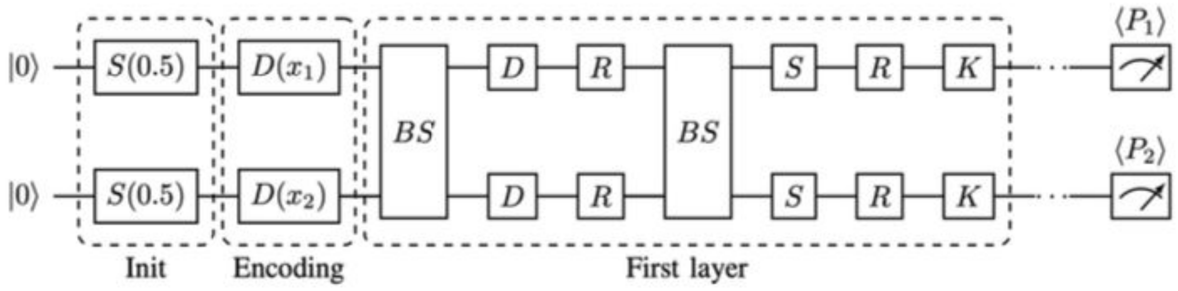
OpenAI Gym problem: cartpole

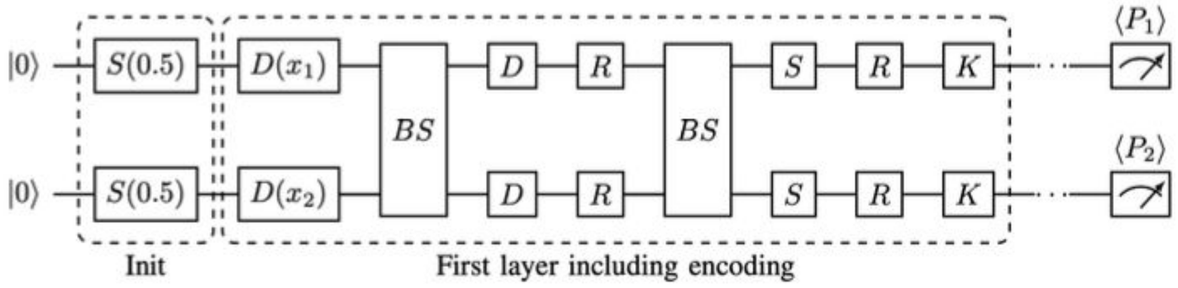




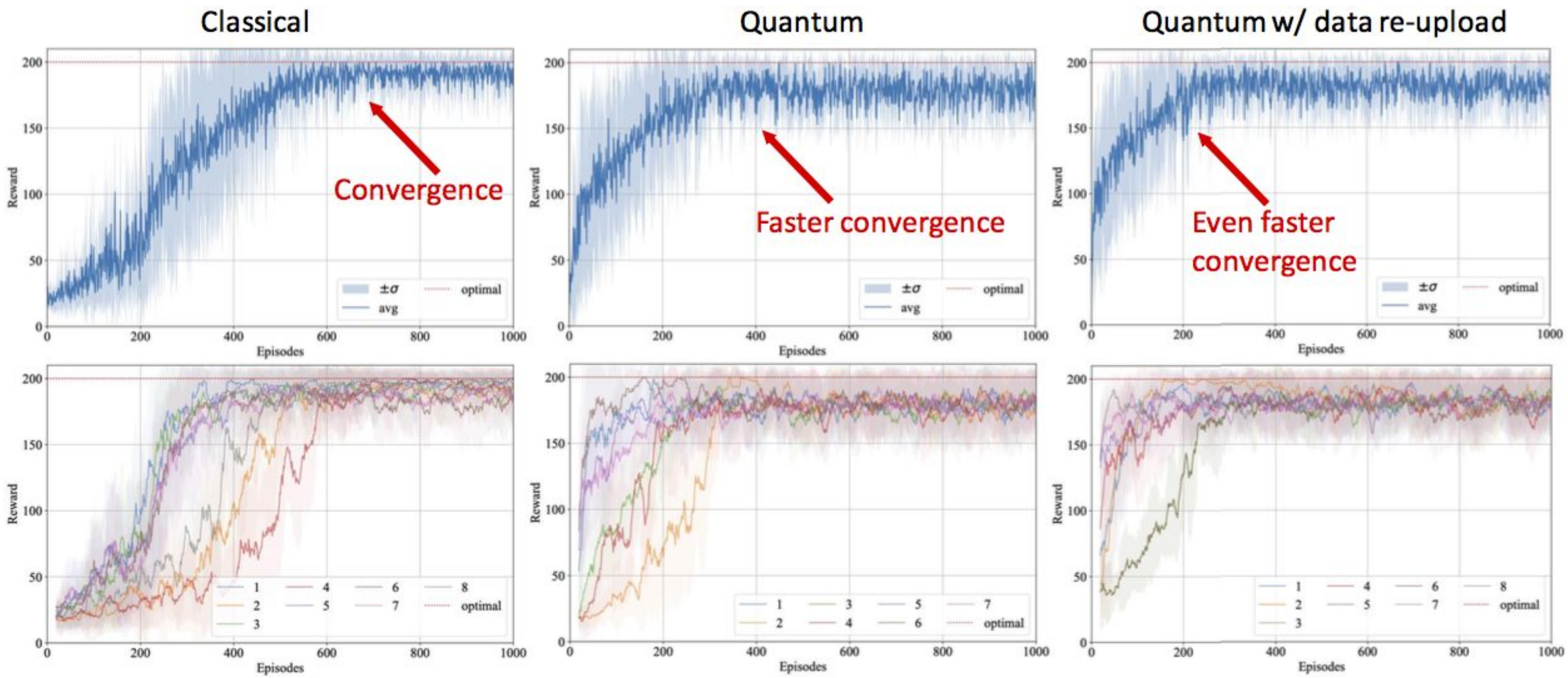
Hybrid RL agent
CPU, classical policy optimization,
e.g., PPO algorithm in TF with Adam optimizer
r
s
Update θ
Photonic Quantum Computer or Simulator, e.g., SF TF Fock backend
θ
θ
θ
|0⟩
|0⟩
|0⟩
s
s
s
⟨X_φ⟩
∇_θ logπ_θ
π_θ(a|s)
State s
Reward r
Environment or Simulator, e.g., OpenAI Gym, Cart Pole
Force = +1
Force = -1
Action a

The structure of the Quantum Neural Networks

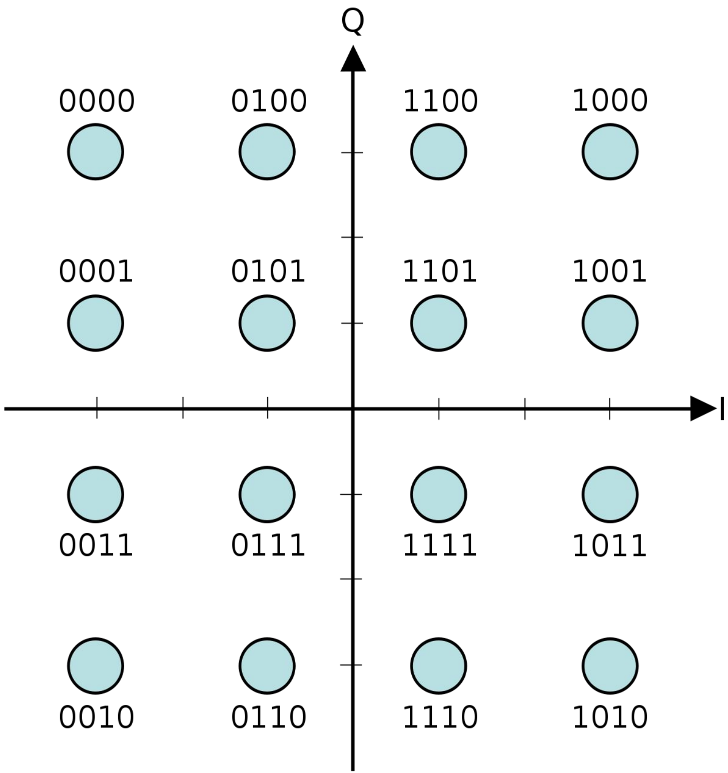




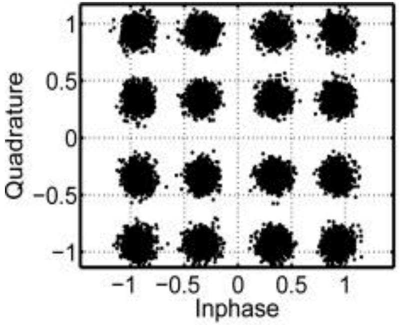
Results


Classical
Quantum
Quantum w/ data re-upload
Convergence
Faster convergence
Even faster convergence
Reward
Episodes
±σ
avg
optimal
1
2
3
4
5
6
7
8

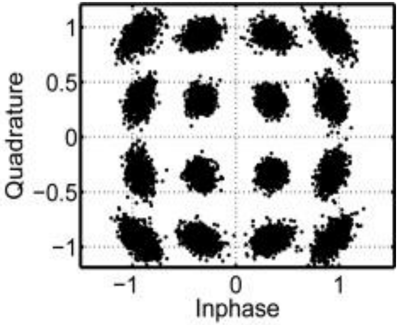
Radio communication: 16 QAM



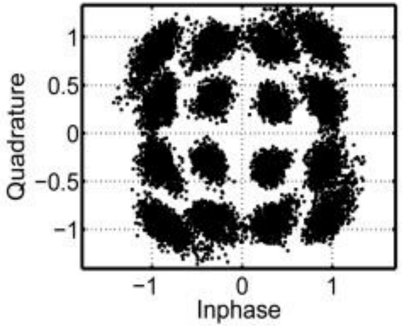
Radio communication: 16 QAM



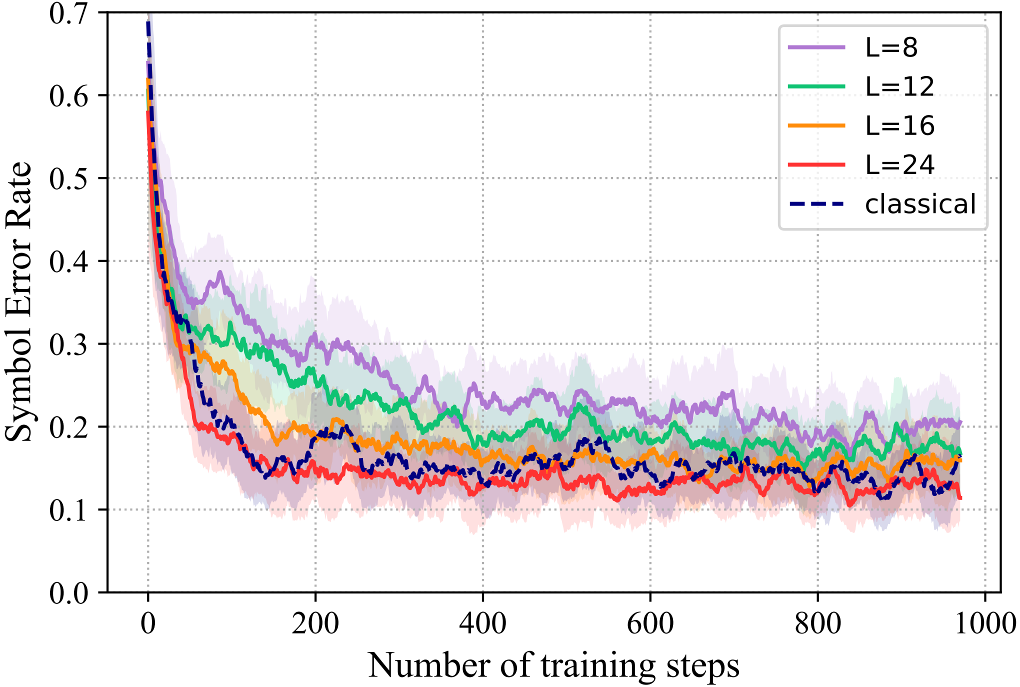
(a)



(b)



(c)



Symbol Error Rate
Number of training steps
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
200
400
600
800
1000
L=8
L=12
L=16
L=24
classical

Thank you!

https://www.inf.elte.hu/

NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE HUNGARY

PROGRAM FINANCED FROM THE NRDI FUND