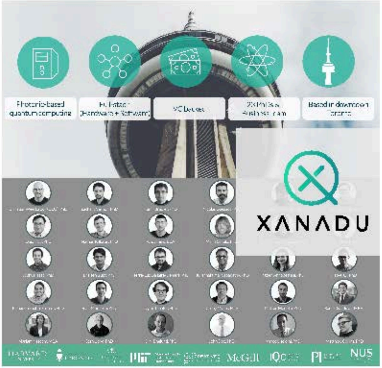
Making quantum algorithms learn from data

Maria Schuld

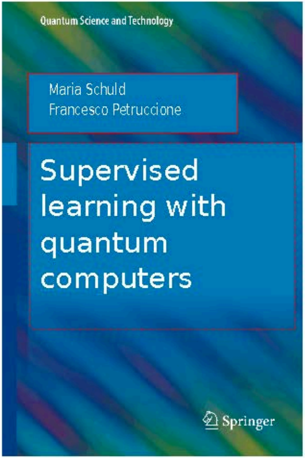
Xanadu and University of KwaZulu-Natal

APS Workshop, October 2018

Between Toronto and Durban.



If you want to know more.



https://www.springer.com/us/book/9783319964232

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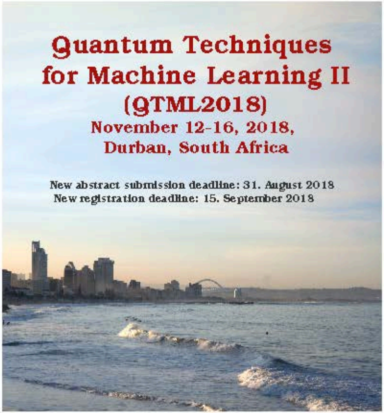
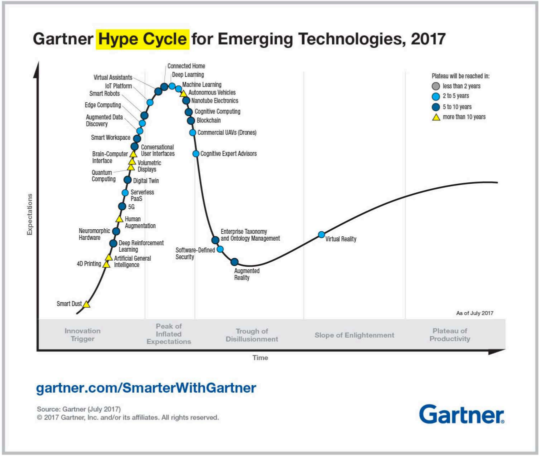


www.quantummachinelearning.org/qtml2018.html

The first generation of quantum devices is here.



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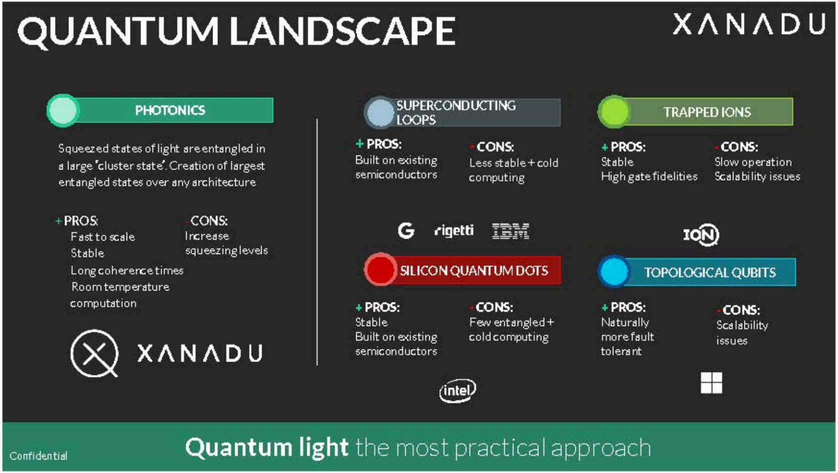

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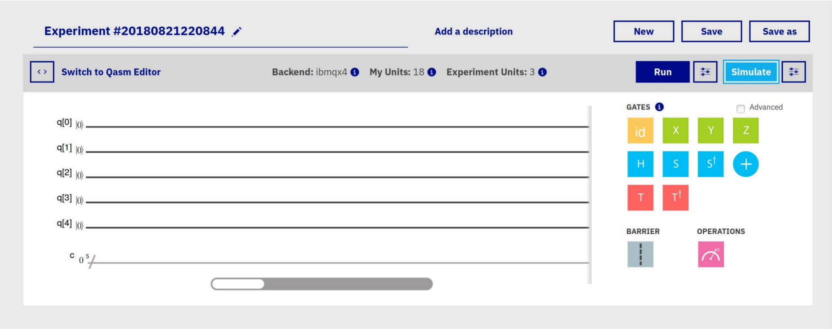

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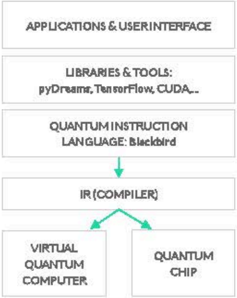
STRAWBERRY FIELDS

Xanadu software stack

XANADU



Our programming environment **Strawberry Fields** is designed to seamlessly integrate with current Python workflows

Confidential

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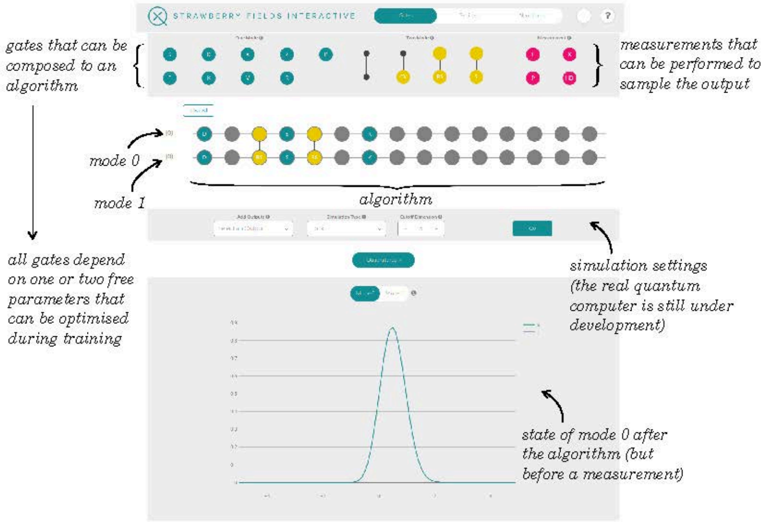

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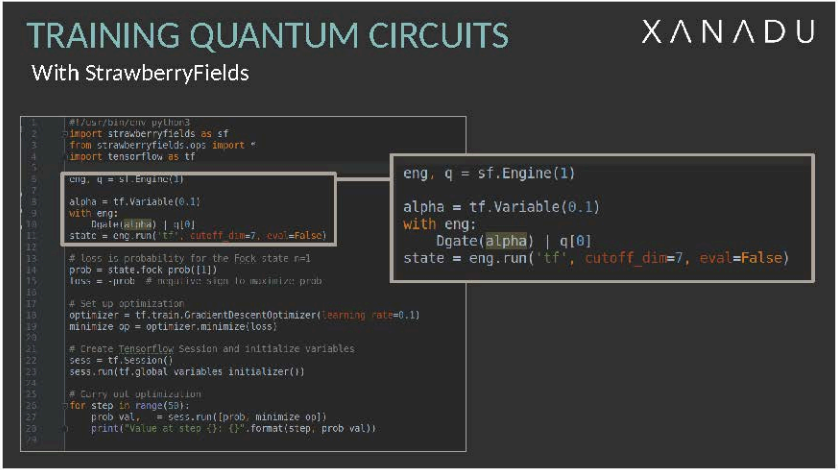

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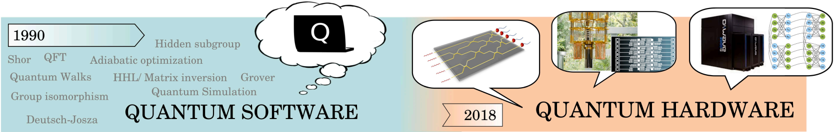
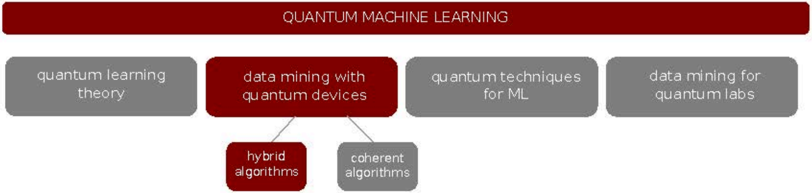


QML may offer the first commercial applications.

QUANTUM MACHINE LEARNING

quantum learning theory	data mining with quantum devices	quantum techniques for ML	data mining for quantum labs

QML may offer the first commercial applications.



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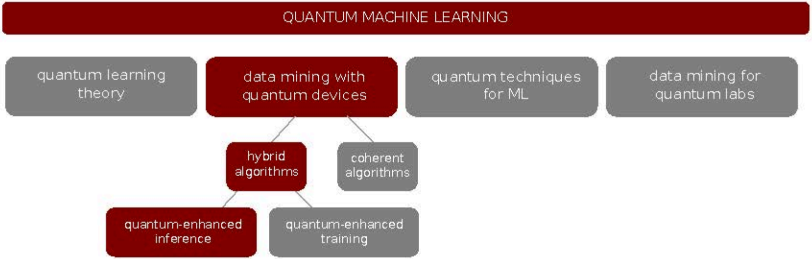
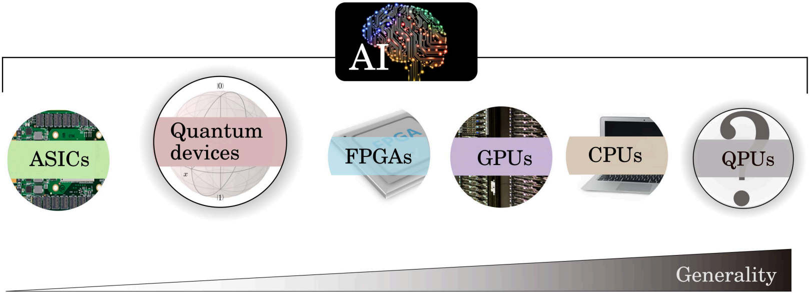


Quantum processing can enter at different levels.



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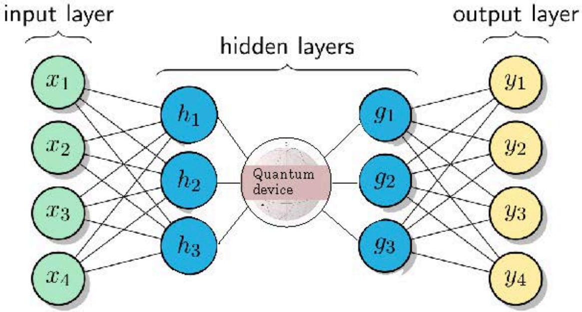

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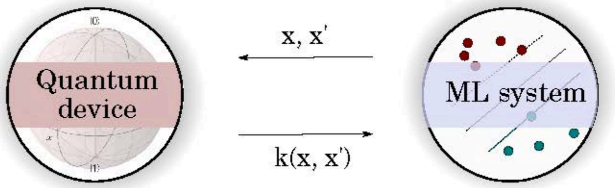

Schuld and Killoran arxiv:1803.07128 (2018), Havlicek, arxiv:1804.11326 (2018)

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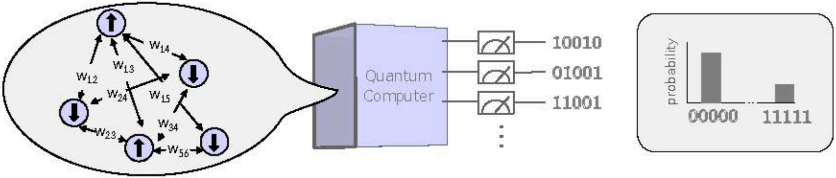
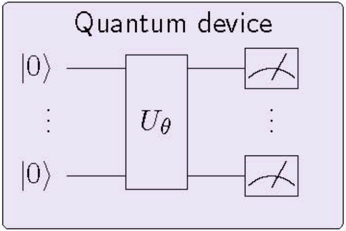


Benedetti et al. Physical Review X 7, 4 (2017), Amin et al. Physical Review X 8, 2 (2018)

VARIATIONAL CIRCUITS

Variational circuits are adaptable quantum algorithms.



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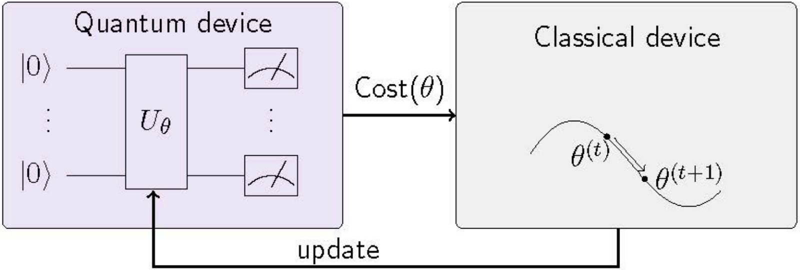

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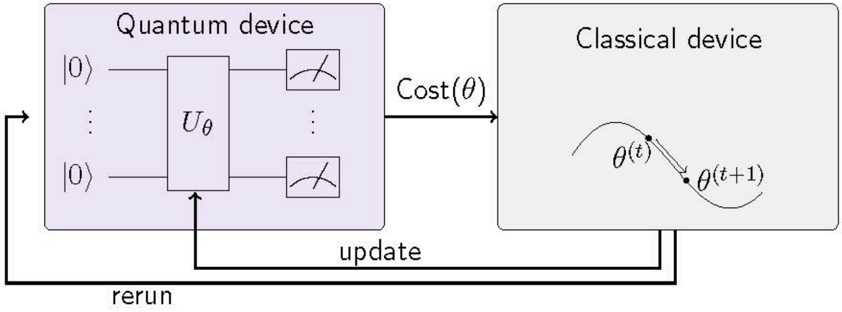
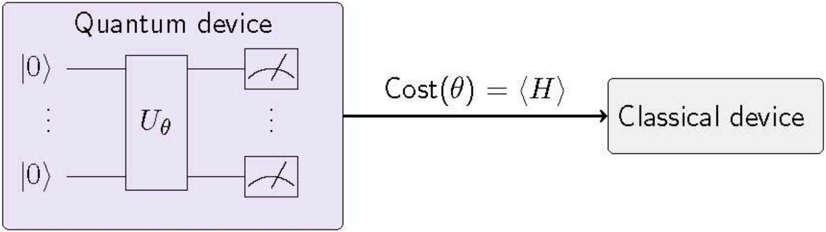


One example are variational quantum eigensolvers.

Find circuit U_θ that prepares lowest energy eigenstate with respect to Hamiltonian H.



Peruzzo et al (2014) Nature Communications

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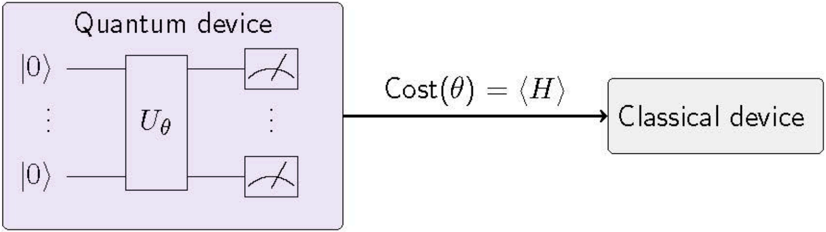
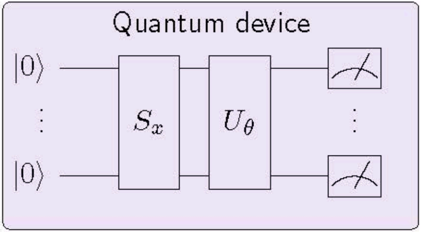


$$\langle H \rangle = \sum_{i,\alpha} h^i_\alpha \langle \sigma^i_\alpha \rangle + \sum_{\substack{i,j \\ \alpha,\beta}} h^{ij}_{\alpha,\beta} \langle \sigma^i_\alpha \sigma^j_\beta \rangle + \cdots$$

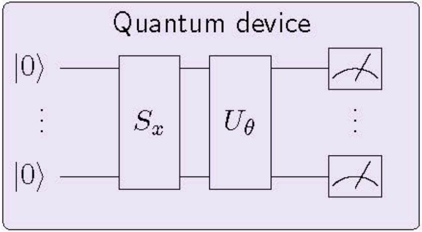
Peruzzo et al (2014) Nature Communications

LEARNING WITH VARIATIONAL CIRCUITS

We can turn the variational circuit into a classifier.

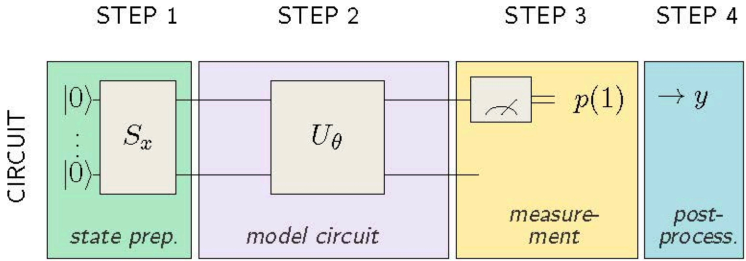


We can turn the variational circuit into a classifier.



$$x \to f(x, \theta) = y$$

We can turn the variational circuit into a classifier.



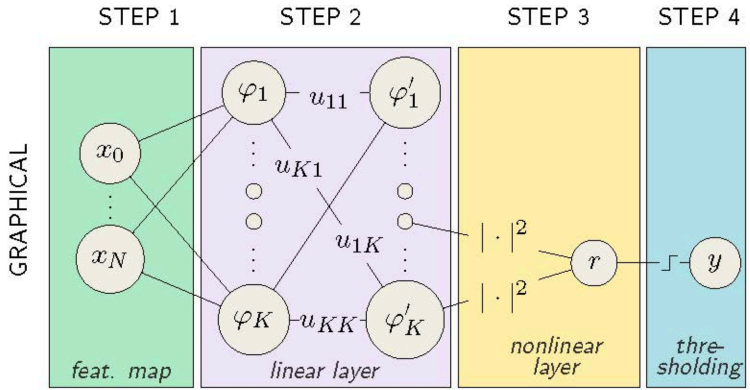
Schuld et al (2018) arxiv1804.00633

We can turn the variational circuit into a classifier.

	STEP 1	STEP 2	STEP 3	STEP 4
FORMAL	$x \rightarrow \varphi(x)$ *nonlin. map*	$\rightarrow \varphi' = U_\theta \varphi(x)$ *unitary transform.*	$\rightarrow \sum_{\{k\}} \lvert\varphi'_k\rvert^2$	$\rightarrow y$

Schuld et al (2018) arxiv1804.00633

We can turn the variational circuit into a classifier.



Schuld et al (2018) arxiv1804.00633

For training we have to compute a gradient.

Usually in supervised learning, one takes the least squares cost,

$$\text{Cost}(\theta) \propto \sum_{m=1}^{M} (t^m - f(x^m, \theta))^2,$$

and does gradient descent.

For training we have to compute a gradient.

Usually in supervised learning, one takes the least squares cost,

$$\mathsf{Cost}(\theta) \propto \sum_{m=1}^{M} (t^m - f(x^m, \theta))^2,$$

and does gradient descent. For this one computes the gradient of the cost with regards to a parameter $w \in \theta$,

$$\partial_w \mathsf{Cost}(\theta) \propto -\sum_{m=1}^{M} \frac{1}{2}(t^m - f(x^m, \theta))\partial_w f(x^m, \theta)$$

We can compute gradients of quantum circuits.

If precision is not an issue: **Numerical optimization**.

$$\partial_w f(x,\theta) \approx \frac{f(x,\theta) + f(x,\theta+\Delta_w)}{\Delta_w}$$

Guerreschi et al (2018), Farhi and Neven (2018), Schuld et al (2018), Mitarai et al (2018)

We can compute gradients of quantum circuits.

If precision is not an issue: **Numerical optimization**.

If we are simulating the quantum device: **Automatic differentiation**.

$$f(x, \theta) = f(e(\dots b(a(w)))) \rightarrow \partial_w f(x, \theta) = \frac{df}{de} \dots \frac{db}{da} \frac{da}{dw}$$

Guerreschi et al (2018), Farhi and Neven (2018), Schuld et al (2018), Mitarai et al (2018)

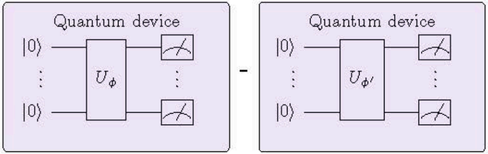
We can compute gradients of quantum circuits.

If precision is not an issue: **Numerical optimization**.

If we are simulating the quantum device: **Automatic differentiation**.

Else: **Quantum automatic differentiation**.

$$\partial_w f(x, \theta) =$$



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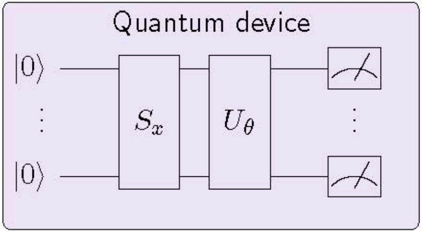
PHOTONIC QUANTUM NEURAL NETWORK

A photonic quantum neural network



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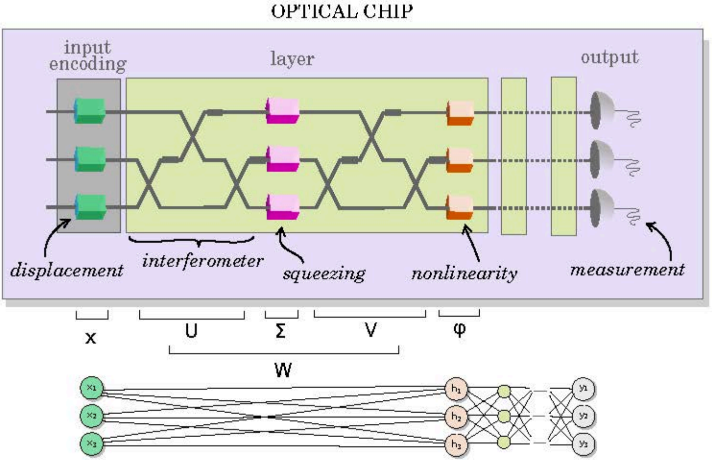
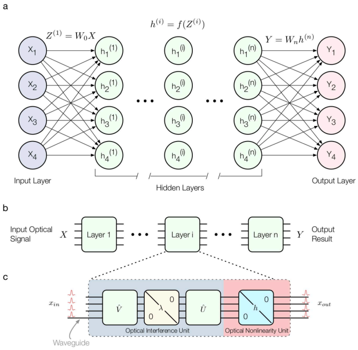
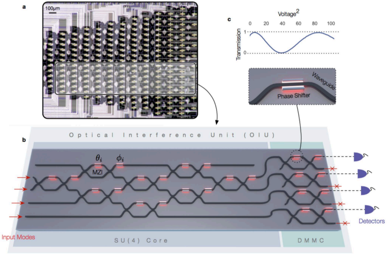


Killoran et al. arxiv1806.06871

Photonic neural networks have been investigated before.





Shen et al *Deep learning with coherent nanophotonic circuits* Nature Photonics 11 (2017)

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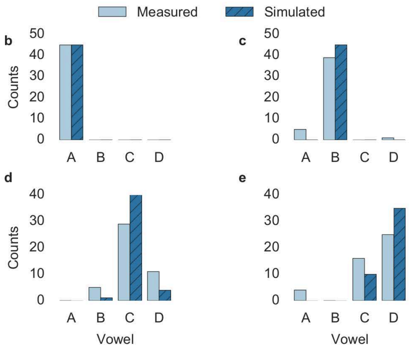

Shen et al *Deep learning with coherent nanophotonic circuits* Nature Photonics 11 (2017)

However, we are processing quantum information.

	CV	Qubit
Basic element	Qumodes	Qubits
Information unit	1 nat ($\log_2 e$ bits)	1 bit
Relevant operators	Quadrature operators $\hat{x}, \hat{p}$ Mode operators $\hat{a}, \hat{a}^\dagger$	Pauli operators $\hat{\sigma}_x, \hat{\sigma}_y, \hat{\sigma}_z$
Common states	Coherent states $\|\alpha\rangle$ Squeezed states $\|z\rangle$ Number states $\|n\rangle$	Pauli eigenstates $\|0/1\rangle$, $\|\pm\rangle$, $\|\pm i\rangle$
Common gates	Rotation, Displacement, Squeezing, Beamsplitter, Cubic Phase	Phase Shift, Hadamard, CNOT, T Gate
Common measurements	Homodyne $\hat{x}_\phi$, Heterodyne $Q(\alpha)$, Photon-counting $\|n\rangle\langle n\|$	Pauli-basis measurements $\|0/1\rangle\langle 0/1\|, \|\pm\rangle\langle\pm\|, \|\pm i\rangle\langle\pm i\|$

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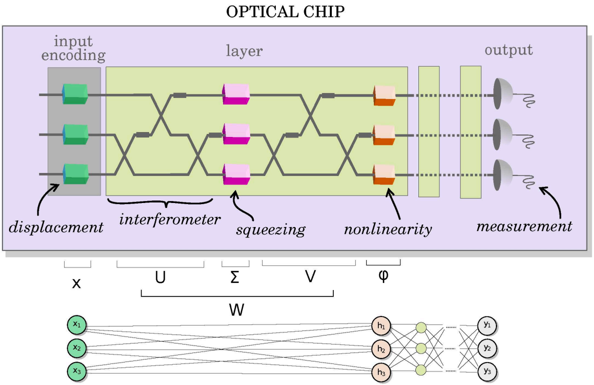

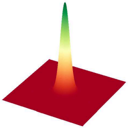

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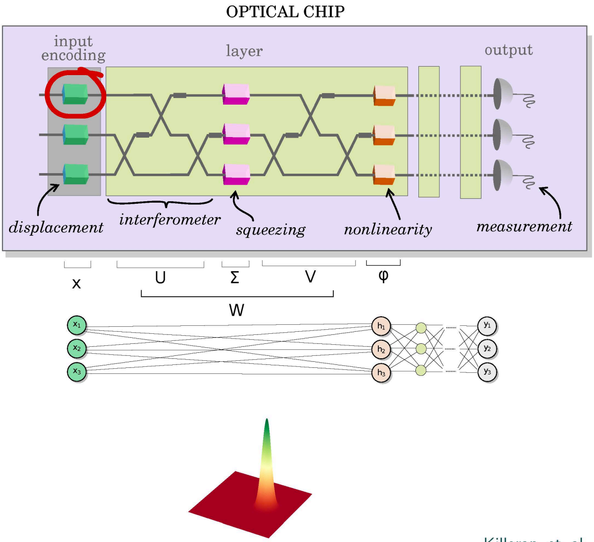

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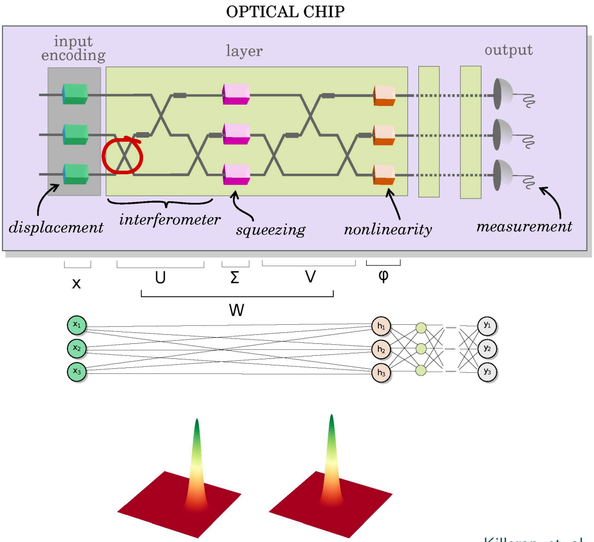

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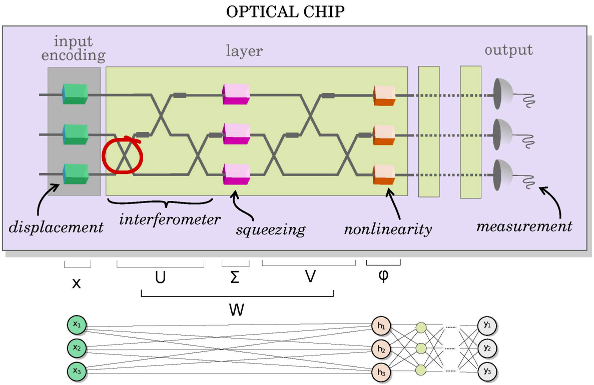

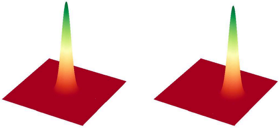

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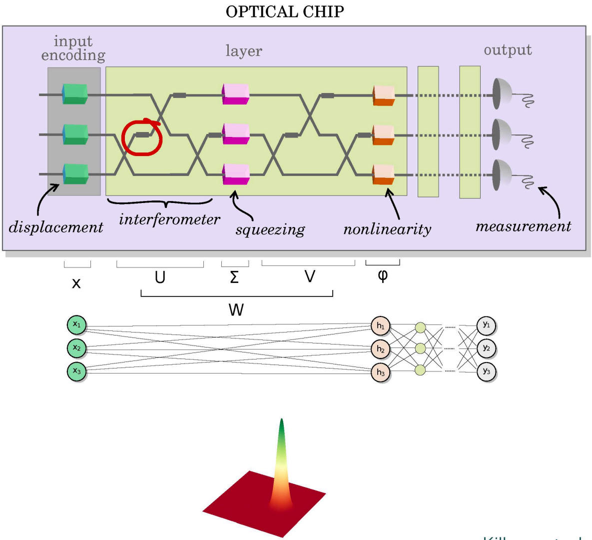

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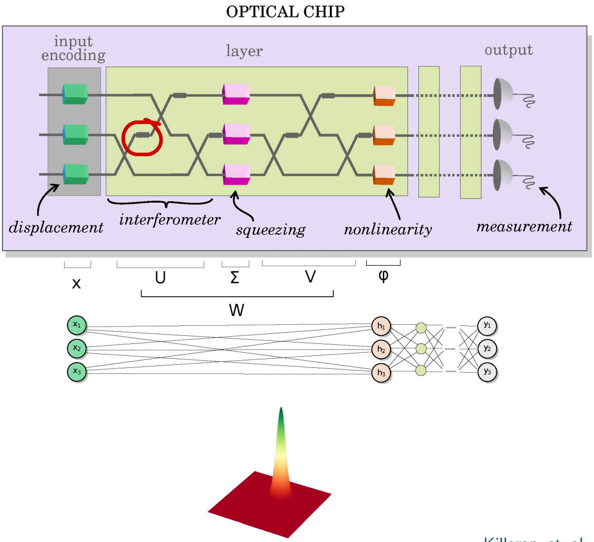

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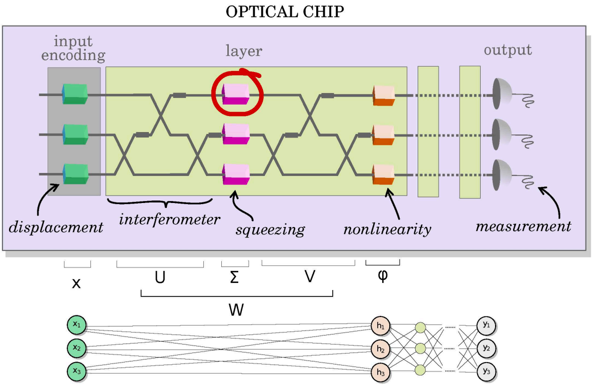

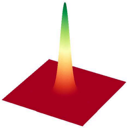

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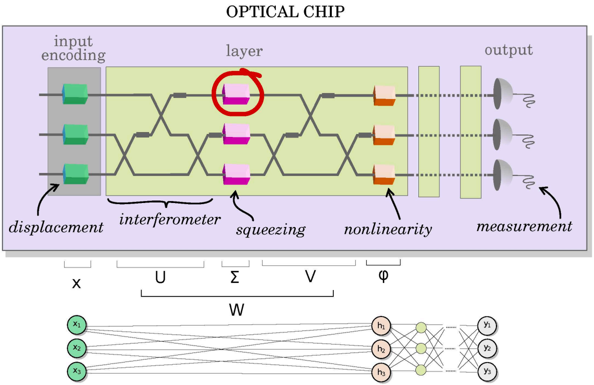

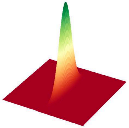

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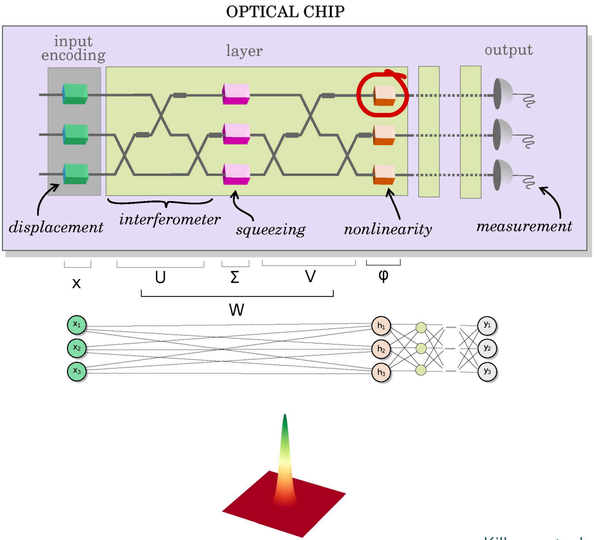

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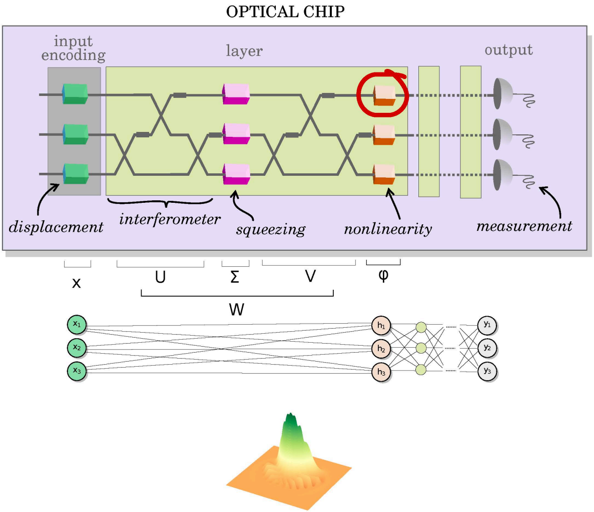

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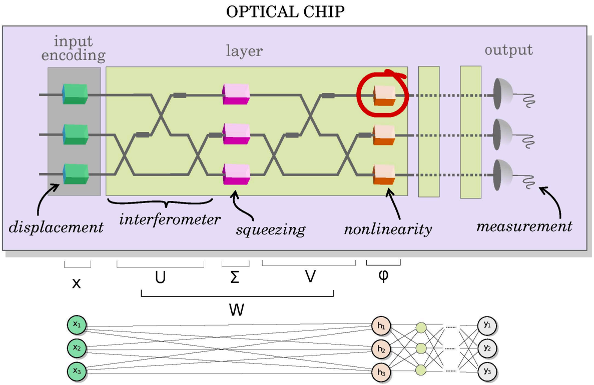

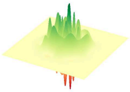

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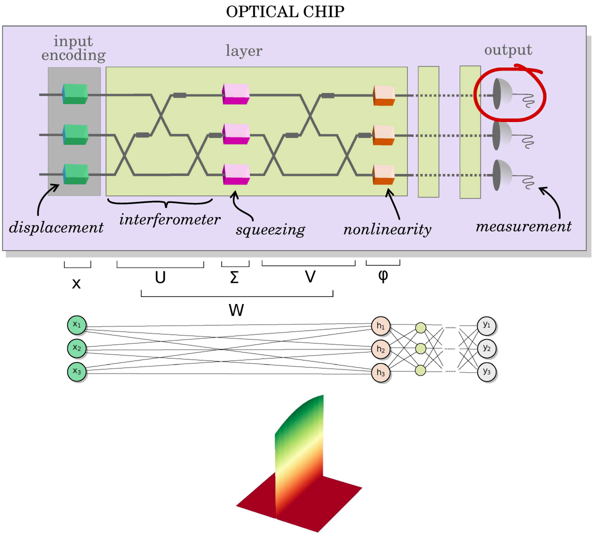

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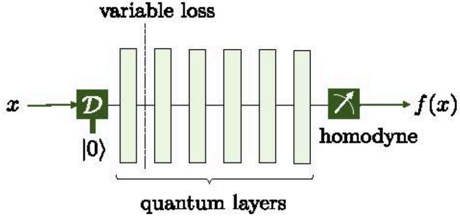
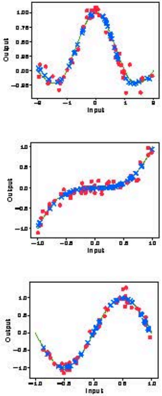
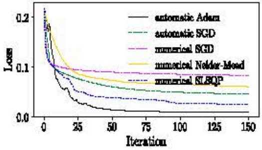
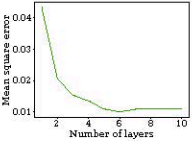
Some results.









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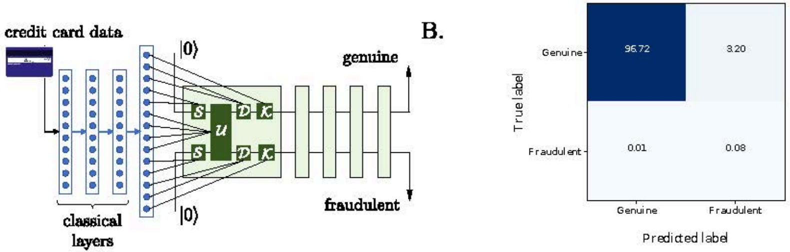

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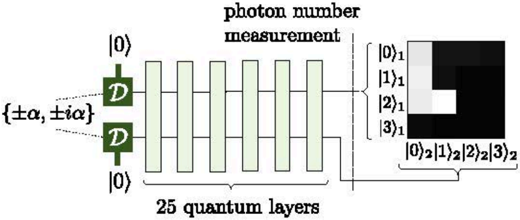

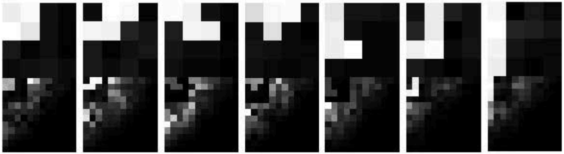

Open questions...

- What quantum advantages are to expect?
- What are good circuit architectures?
- What are good training strategies?
- Are quantum models easily trainable?

… and challenges.

- How can we benchmark these models?
- How can we simulate them?
- How can we get the machine learning community interested?
- How can we convince editors that our limited simulations are worth publishing?