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# Quantum Reservoir Computing

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Reservoir computing:

How a random system can be used for computation

What I will not talk about:

Majorana zero modes for topological quantum computing



### Universal computer



Can run any algorithm without making mistakes

Two stringent requirements:

- Universal
- Error free

## Machine learning



Two simpler requirements:

- Complicated
- Trainable

## What is this black box?



## What if training is too hard?



### **Extreme Learning Machines**

Feed-forward network, run once for each input Reservoir Computing

Recurrent network, time-dependent input

## Why does this work?

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- Non-linear transformations give new points of view of the same data
- Higher dimensional space gives access to many more linear cuts

## Examples of physical reservoirs

## Octopus inspired robotics arm in water tank

Kagaya et al., 2022 IEEE 5th International Conference on Soft Robotics (RoboSoft), 2022



#### **Photonic processor**

Nakajima et al., Commun Phys 4, 20 (2021) 41 mm

*"We could classify hand-written-digits images with an accuracy of 91.7% and ultrafast processing speed of 17.1 ns per image"* 

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## **Quantum Reservoir Computing**



- Classical  $\rightarrow$  Classical
- Classical  $\rightarrow$  Quantum: State preparation
- Quantum  $\rightarrow$  Classical: State characterization
- Quantum  $\rightarrow$  Quantum: State manipulation

## Examples of quantum reservoirs

**Quantum circuit** Yasuda et al., *arXiv:2310.06706* 

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## Reservoir made of quantum dots



Grid of quantum dots, described by

$$H = \underbrace{\sum_{i} \varepsilon_{i} c_{i}^{\dagger} c_{i}}_{\text{Chemical potential}} + \sum_{ij} \underbrace{\left(t_{ij} c_{i}^{\dagger} c_{j} + hc\right)}_{\text{hopping}} + \underbrace{V_{ij} c_{i}^{\dagger} c_{i} c_{j}^{\dagger} c_{j}}_{\text{Coulomb interaction}}$$

Leads, allowing current to flow through the system

Borsoi et al., *Nat. Nanotechnol.* **19**, 21–27 (2024).

Input = voltage Output = current



## Testing the reservoir

Let's make some numerical experiments 6 quantum dots 100 random reservoirs for statistics



We will compare two formalisms for the dynamics



## Measuring non-linearity

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## Summary

Reservoir computing shows how a randomized system can be used for computation  $\Box = C_{ot}^{2}$ 

{x}

Properties you'd like from a reservoir

- Memory
- Non-linearity
- Many outputs



Can quantum reservoirs be useful before we get universal quantum computers? What systems make good reservoirs?