Photonic Reservoir Computing: first experiments

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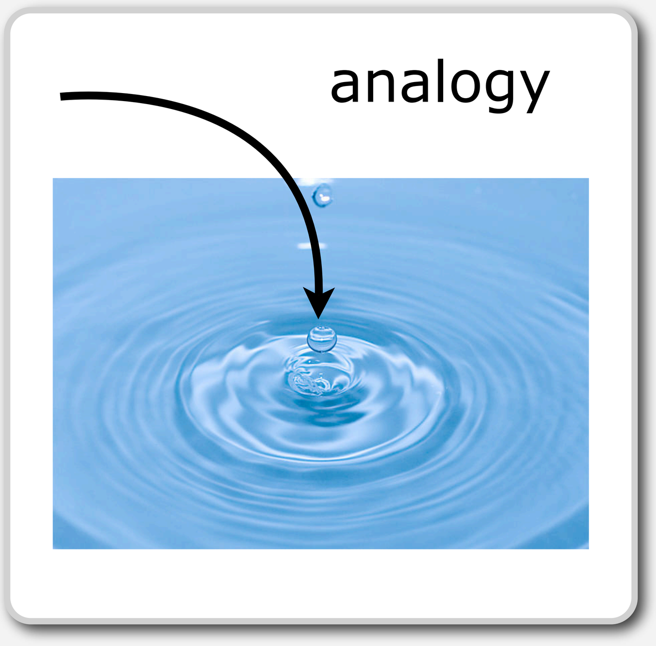
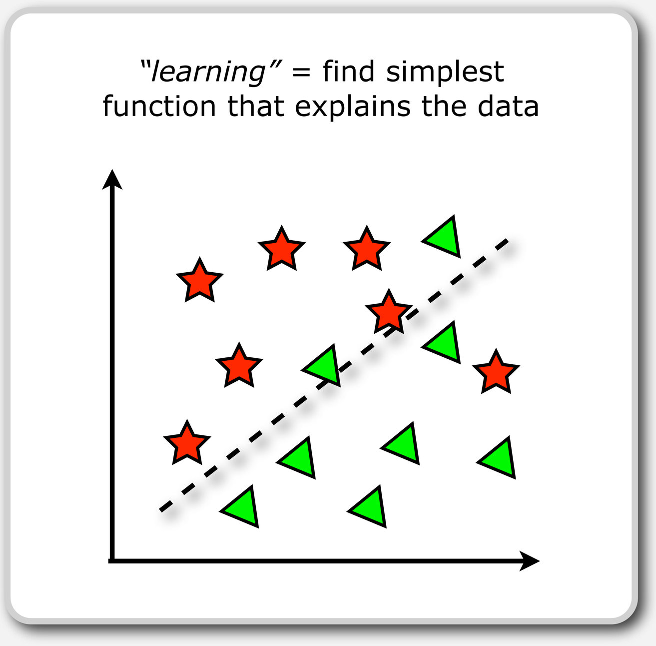
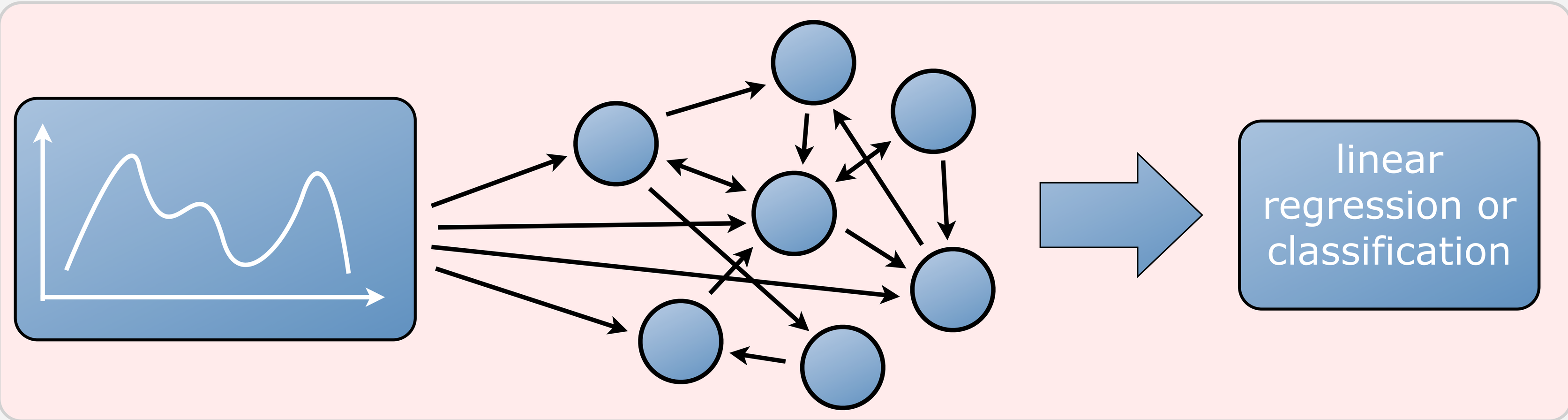
Reservoir Computing

- Take a:
  - Fixed dynamic system, e.g. random recurrent network of simple non-linear nodes
  - Operating in dynamic regime at edge of stability, and excited by an input signal
- Then:
  - Any time-invariant filter can be *learned* using linear mapping of full instantaneous state
  - Possible due to mapping in higher dimensional space
- Also known as Echo State Networks (Jaeger 2001) and Liquid State Machines (Maass 2002)
- On several real-world applications already able to outperform state-of-the-art
- Supports prediction, regression, classification, generation, ... of time-series or sequence data

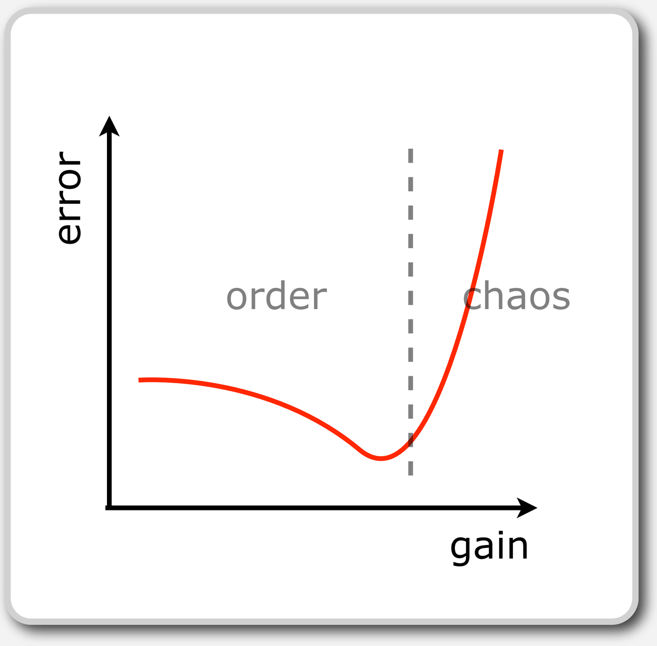


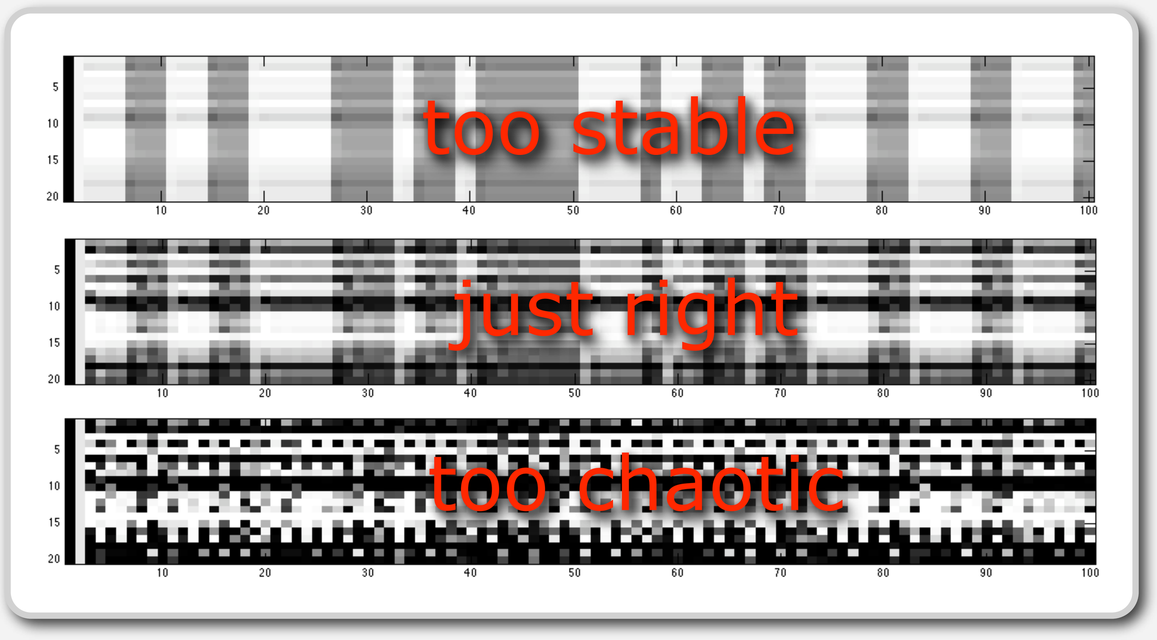




$$\mathbf{x}[t+1] = f\left(W^{res}_{res}\mathbf{x}[t] + W^{res}_{inp}\mathbf{u}[t]\right)$$
$$\hat{\mathbf{y}}[t+1] = W^{out}_{res}\mathbf{x}[t+1] + W^{out}_{inp}\mathbf{u}[t] + W^{out}_{bias}$$

random trained

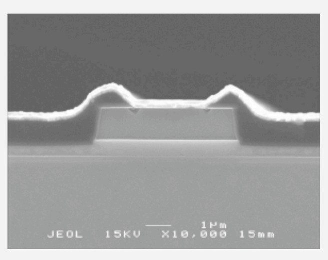




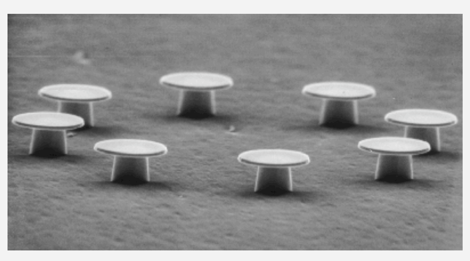
Photonic Reservoir

Idea: build excitable dynamic system using intrinsic properties of photonic components

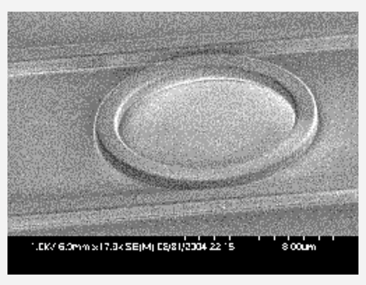
Many possible nodes:



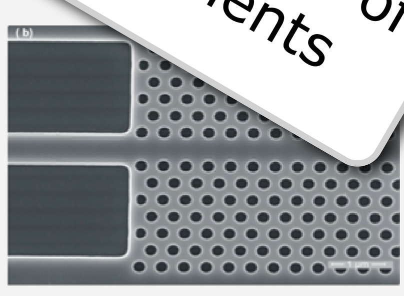
SOA



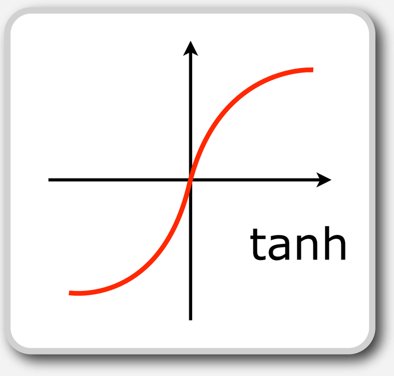
disk lasers

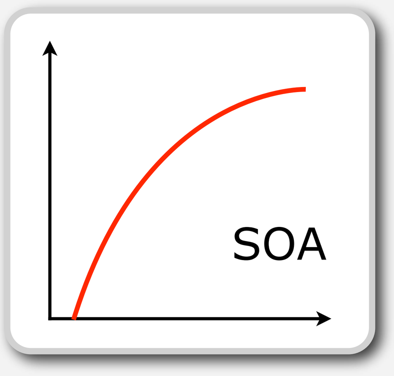


ring resonators



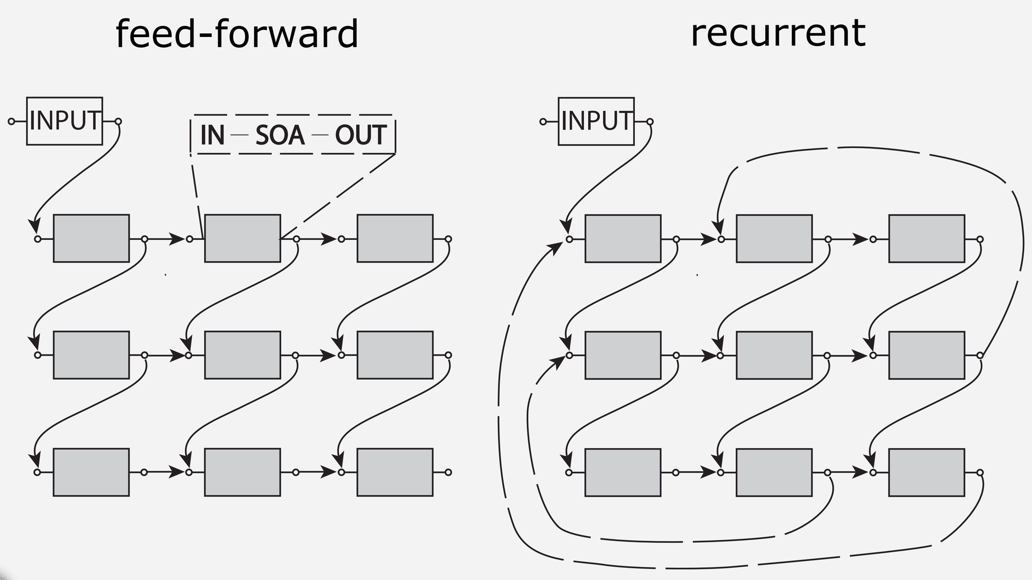
photonic crystal cavity

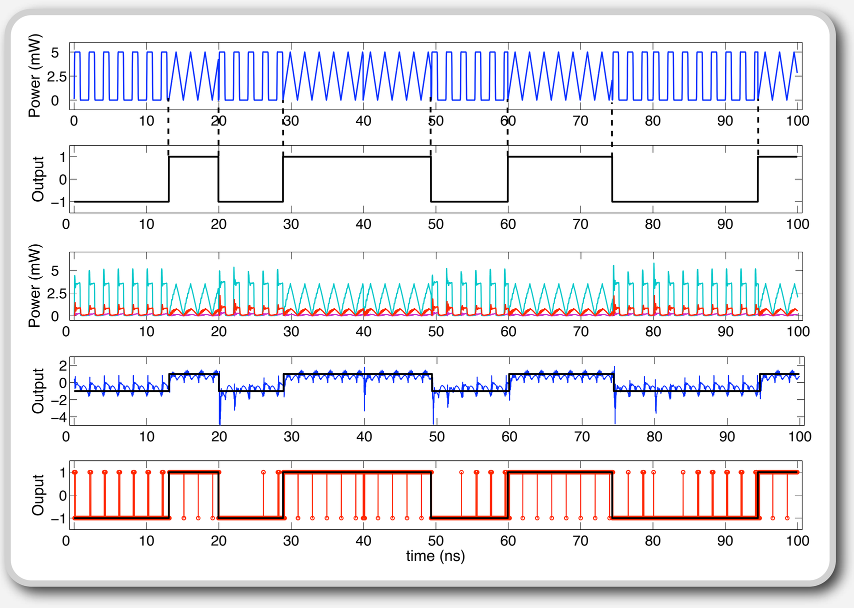




- We opted for an SOA node:
  - Closely resembles non-linearities used in theoretical studies
  - Simple dynamics
  - Gain can easily be controlled electrically

- Topological structure which can be easily implemented on a 2D substrate:
  - Feed-forward
  - Some recurrent connections
- Input fed into single node
- Realistic splitting and attenuation

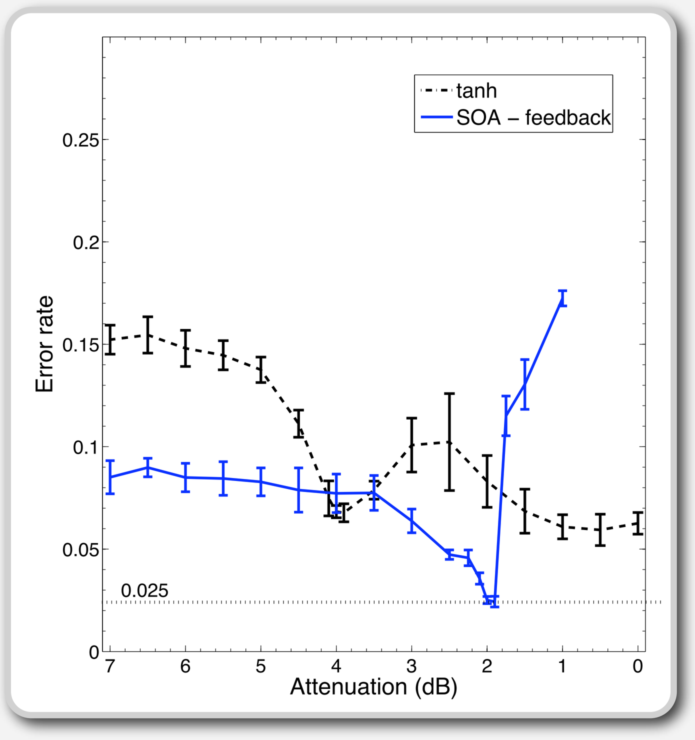


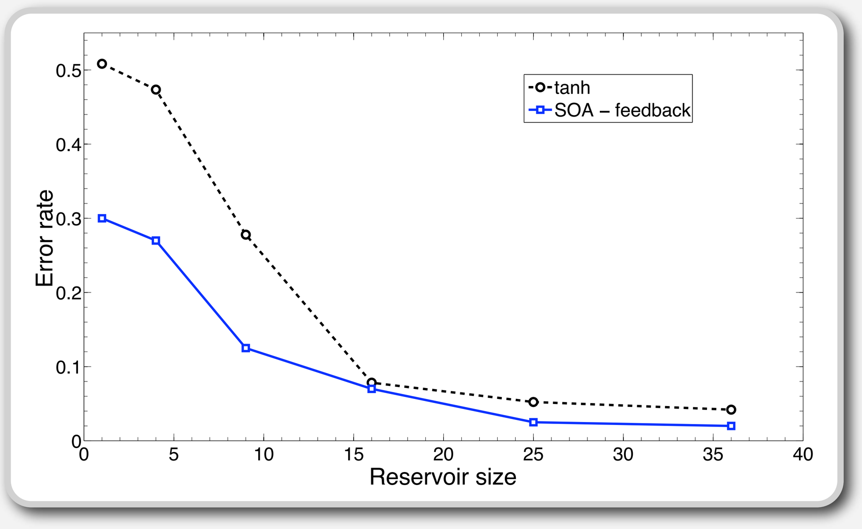


- Applied on simple but representative benchmark: signal classification
- Two waveforms with same base freq.
- Instantaneous state of all nodes is used by memoryless linear function to perform the classification

Results

- Error = ratio of misclassifications
- Recurrent better than feed-forward
- Recurrent network has clear optimum for a given attenuation





- Performance increases with network size
- Small networks can solve the problem
- Outperforms tanh reservoirs

Conclusions

- We can build a practically implementable photonic reservoir
- On a simple application it can outperform "classic" reservoirs
- Recurrency is important
- Intrinsic properties of photonic components are exploited
- Relatively small implementation footprint, very high speed and low power

Future work

- Build prototype system and validate simulation results
- Research other photonic reservoir setups
- Build applications on the photonic reservoir computing technology
- Can result in whole new photonic computing paradigm not based on Turing/Von Neumann architectures