Photonic Reservoir Computing

with coupled SOAs

Kristof Vandoorne, Wouter Dierckx, David Verstraete,
Benjamin Schrauwen, Roel Baets, Peter Bienstman
and Jan Van Campenhout

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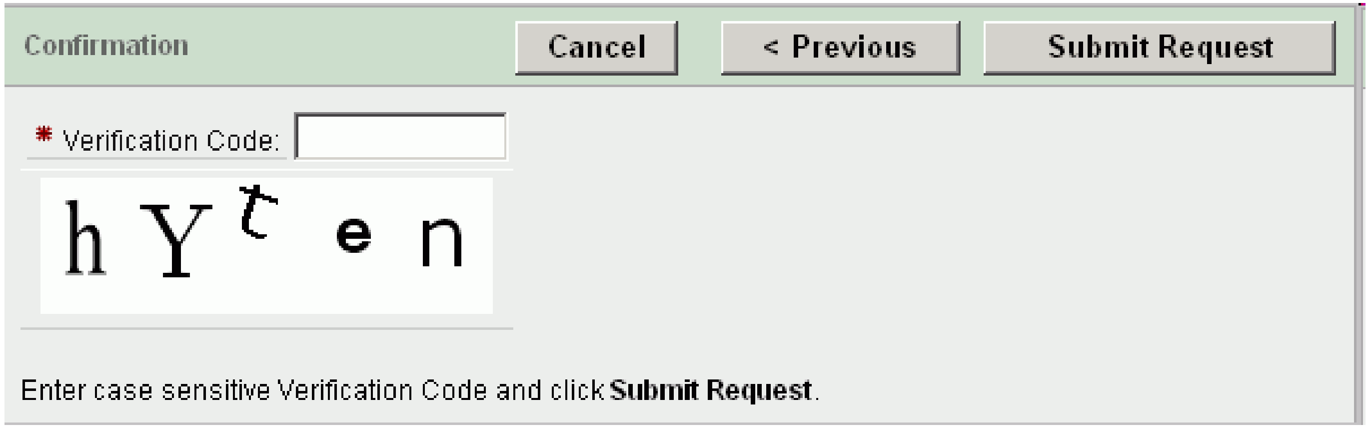
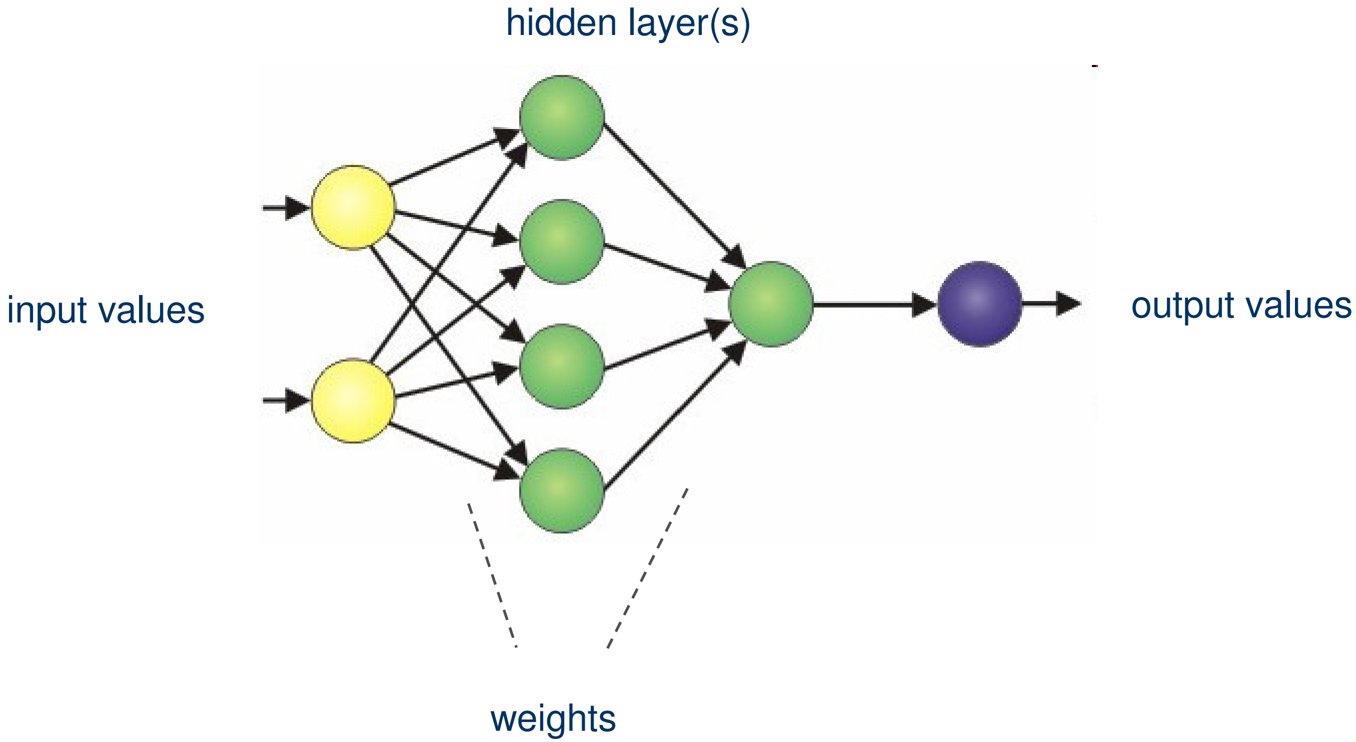
Intelligence is all around us,
but so far limited for computers

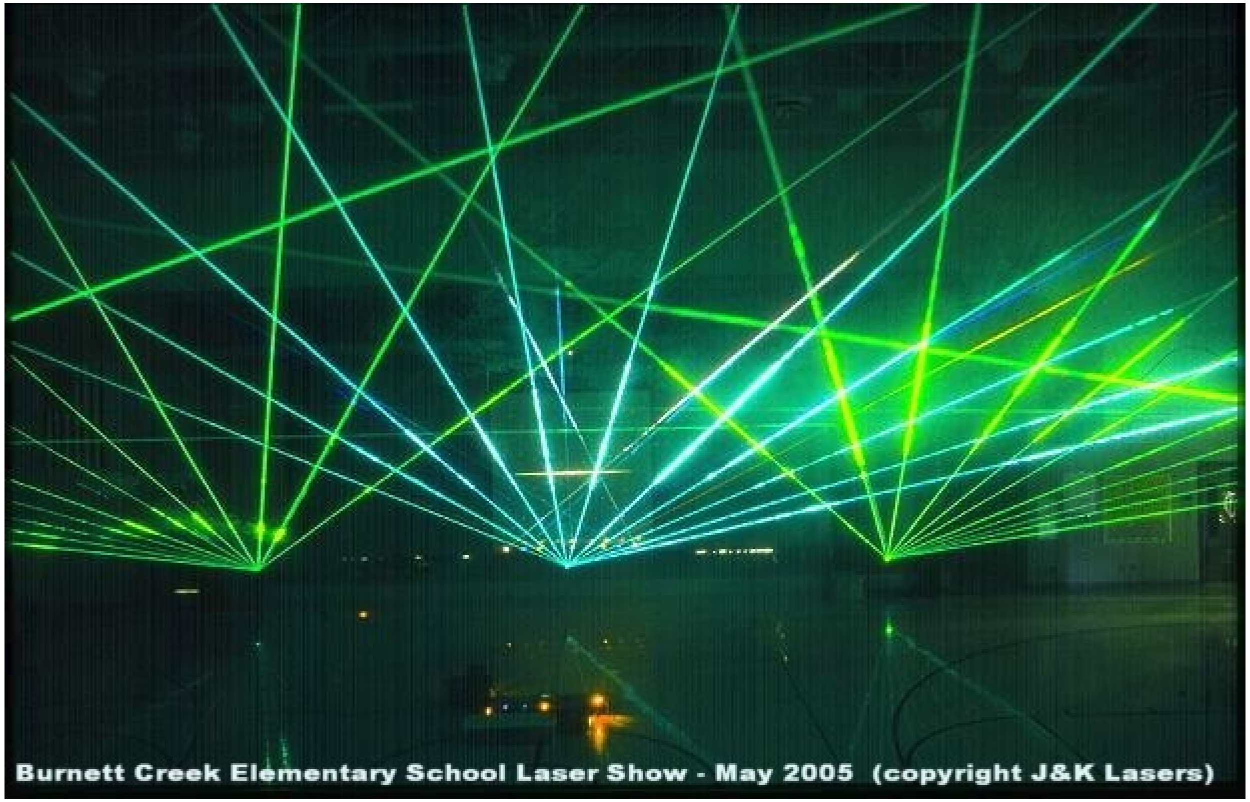


Reservoir Computing is a new approach
coming from the field of artificial neural networks



http://logicalgenetics.com

We use light because it is potentially
faster and more **power efficient**
than the present software implementations

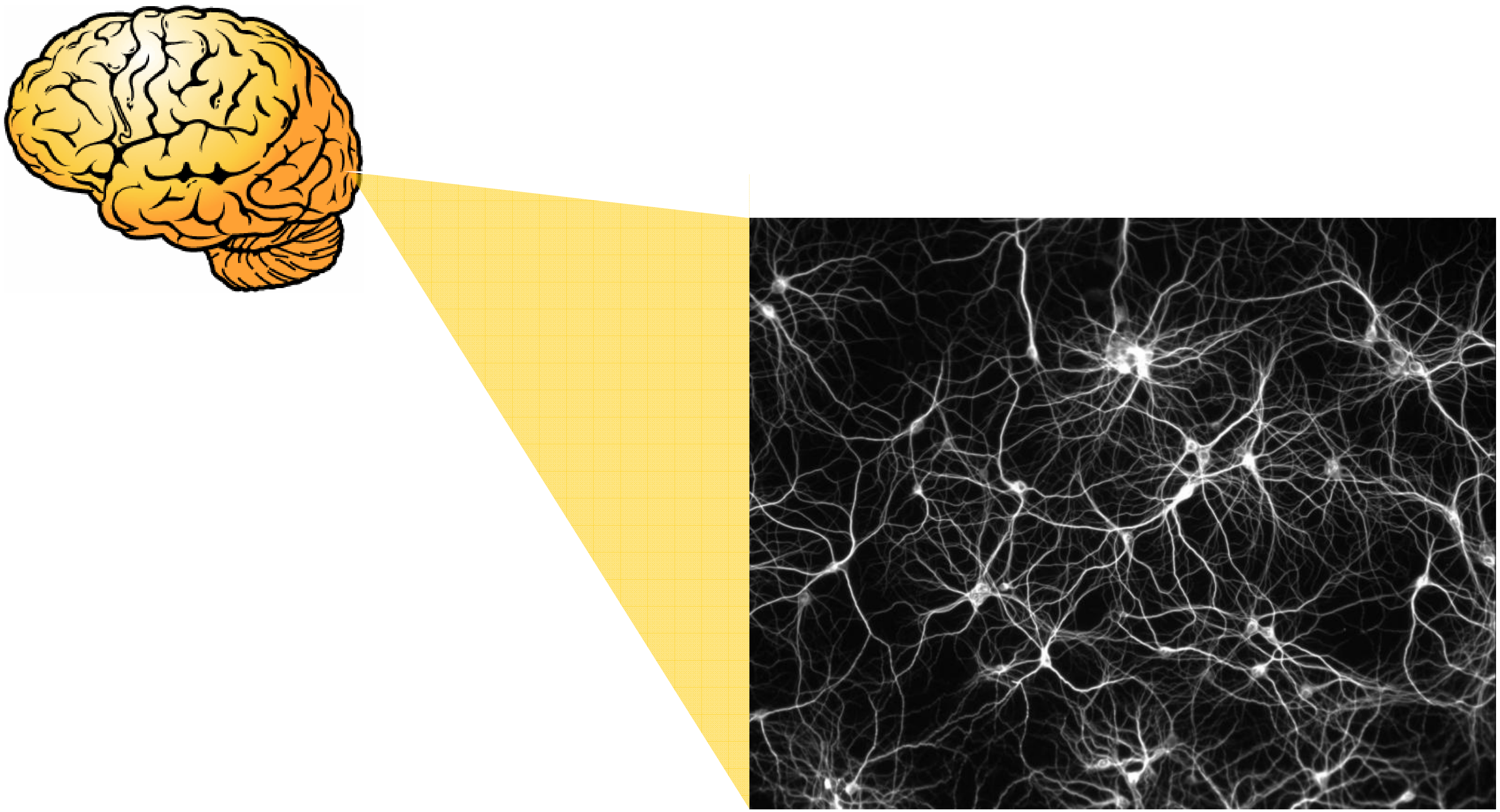


The concept works…

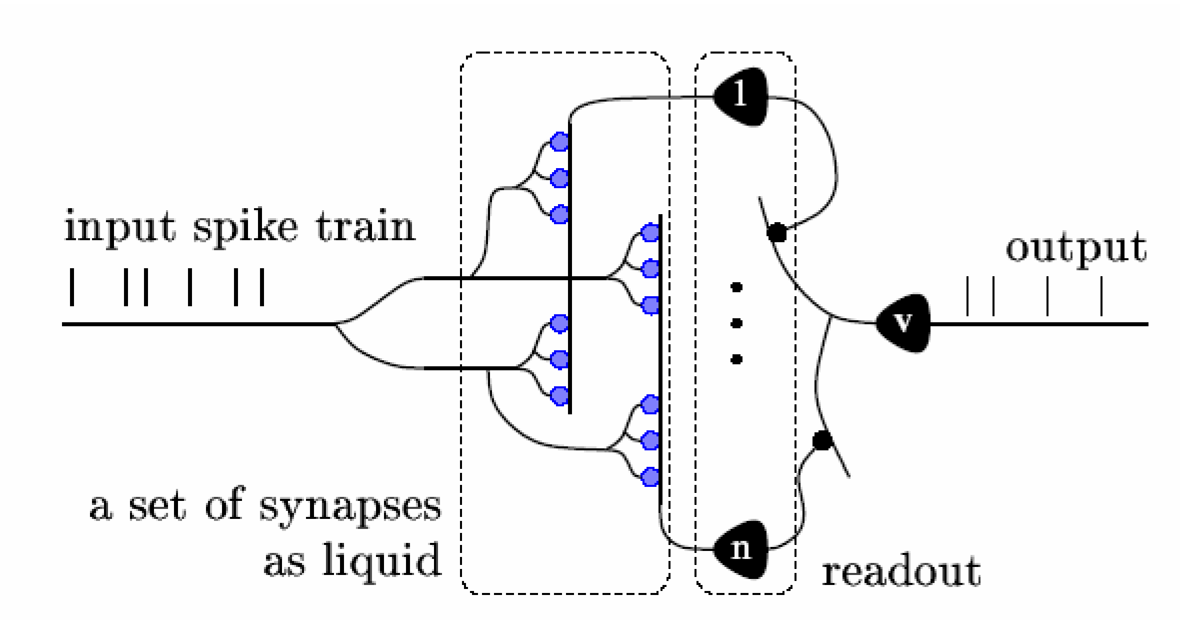
(in simulation)

1. Reservoir Computing
2. How to do it with photonics
3. Simulation results
4. Future

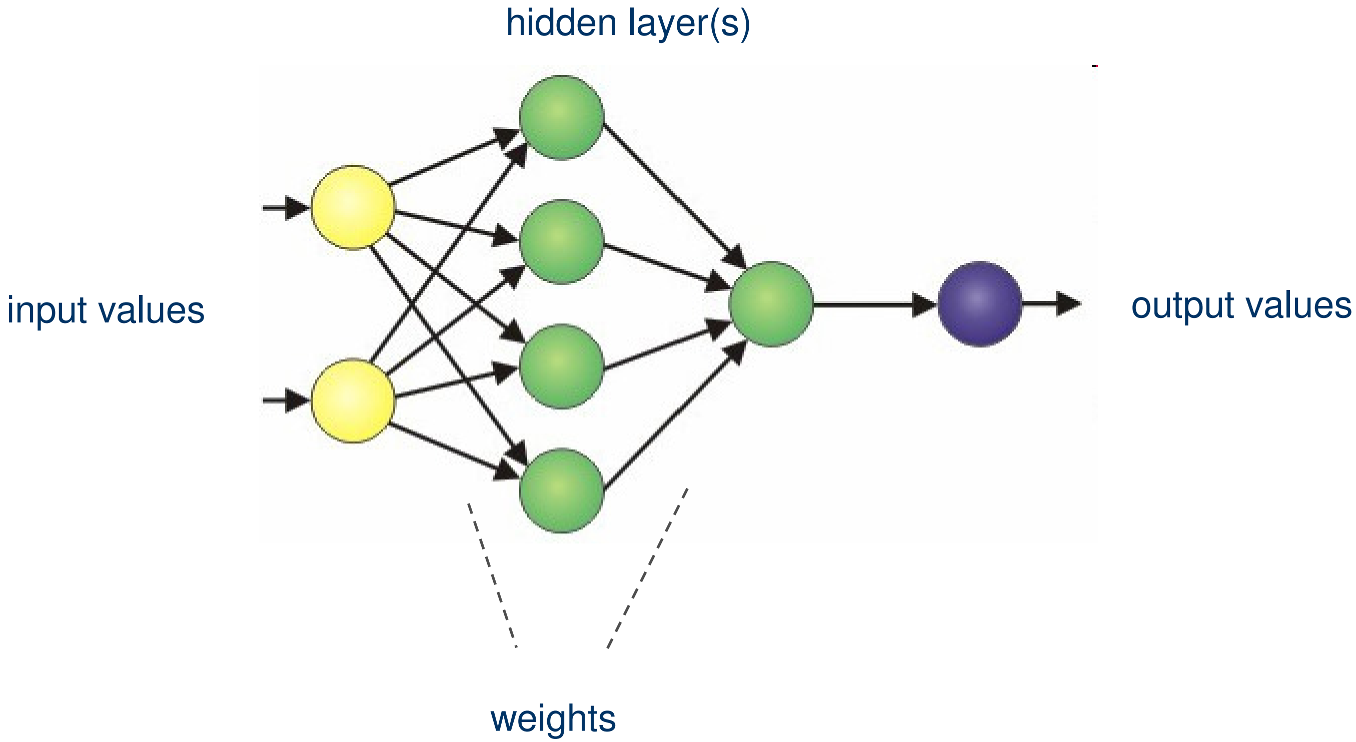
Learn from the best: the brain



And mimic its behaviour

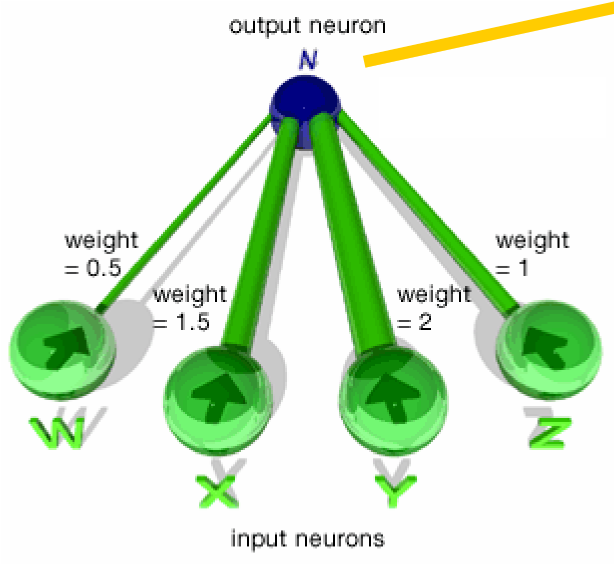


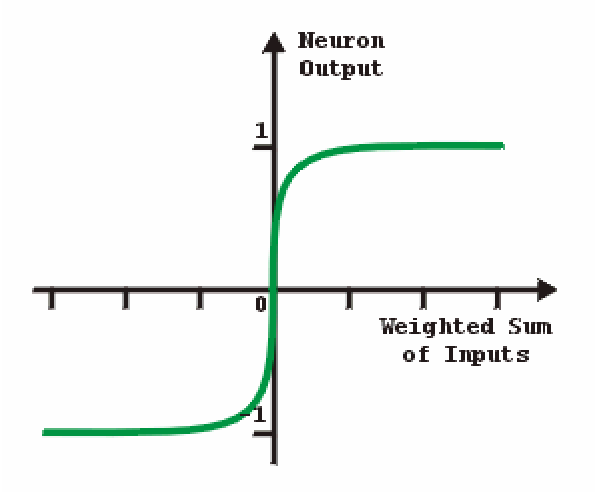
Or simplify it, by removing feedback



Pictures from http://logicalgenetics.com

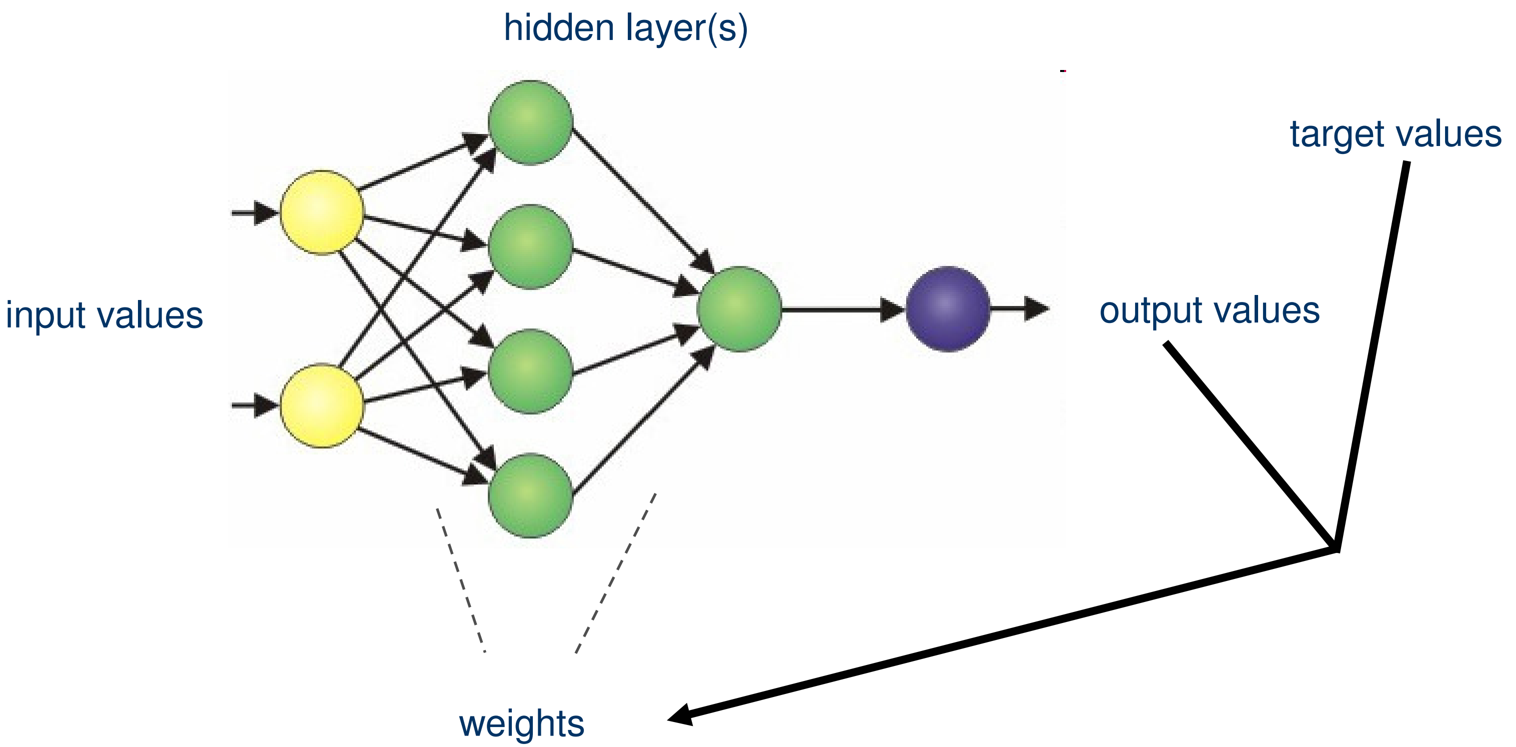
Each node applies a nonlinear function over the weighed sum of its inputs



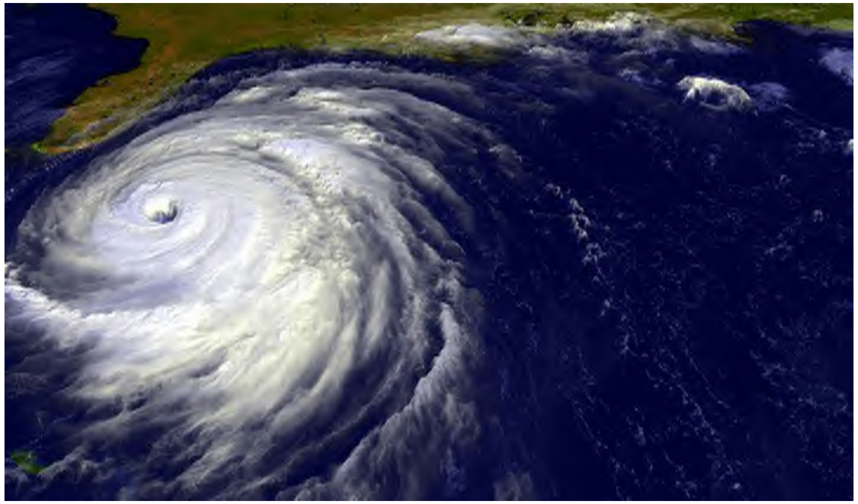


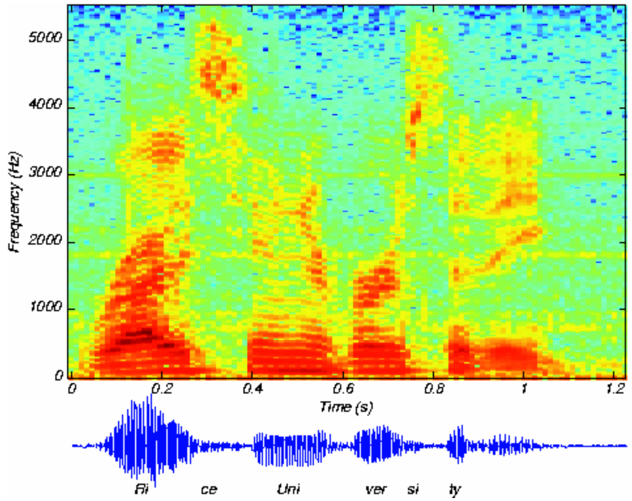
Pictures from http://logicalgenetics.com

The network is trained by tuning the weights of the connections



But many of the real-world problems are temporal, calling for some memory in our system
(e.g. through feedback)





Networks with feedback are hard to train.

Reservoir Computing offers an elegant solution by splitting up the network

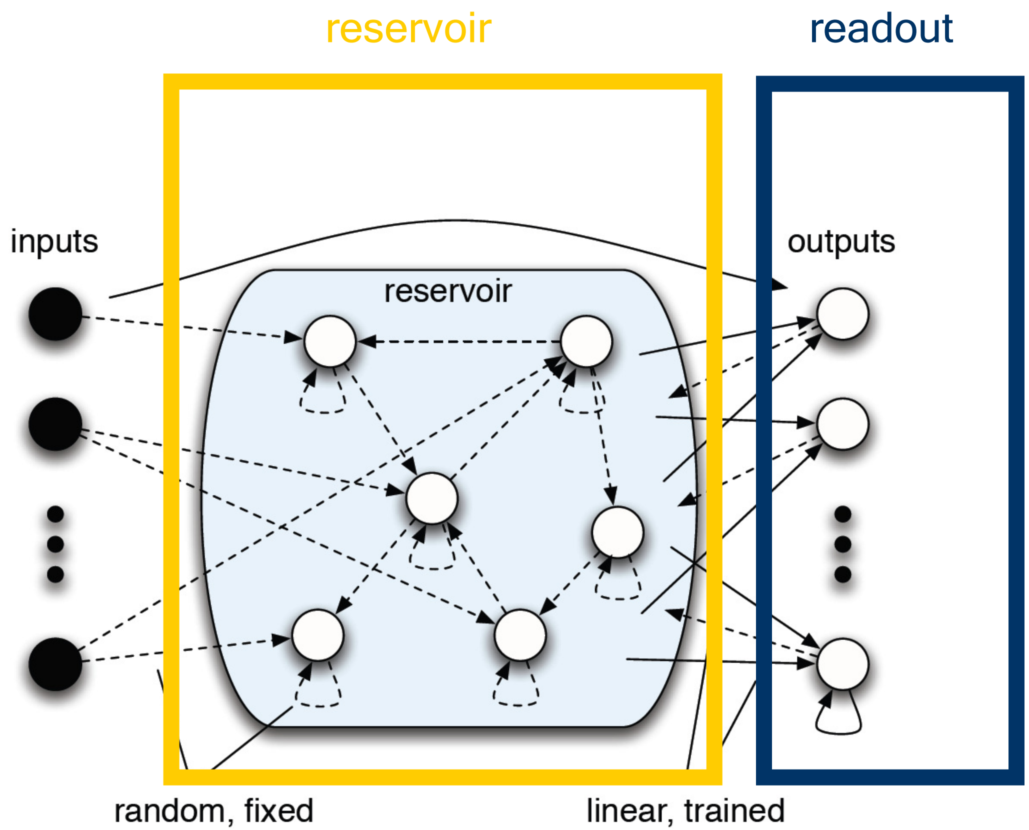


figure taken from B. Schrauwen

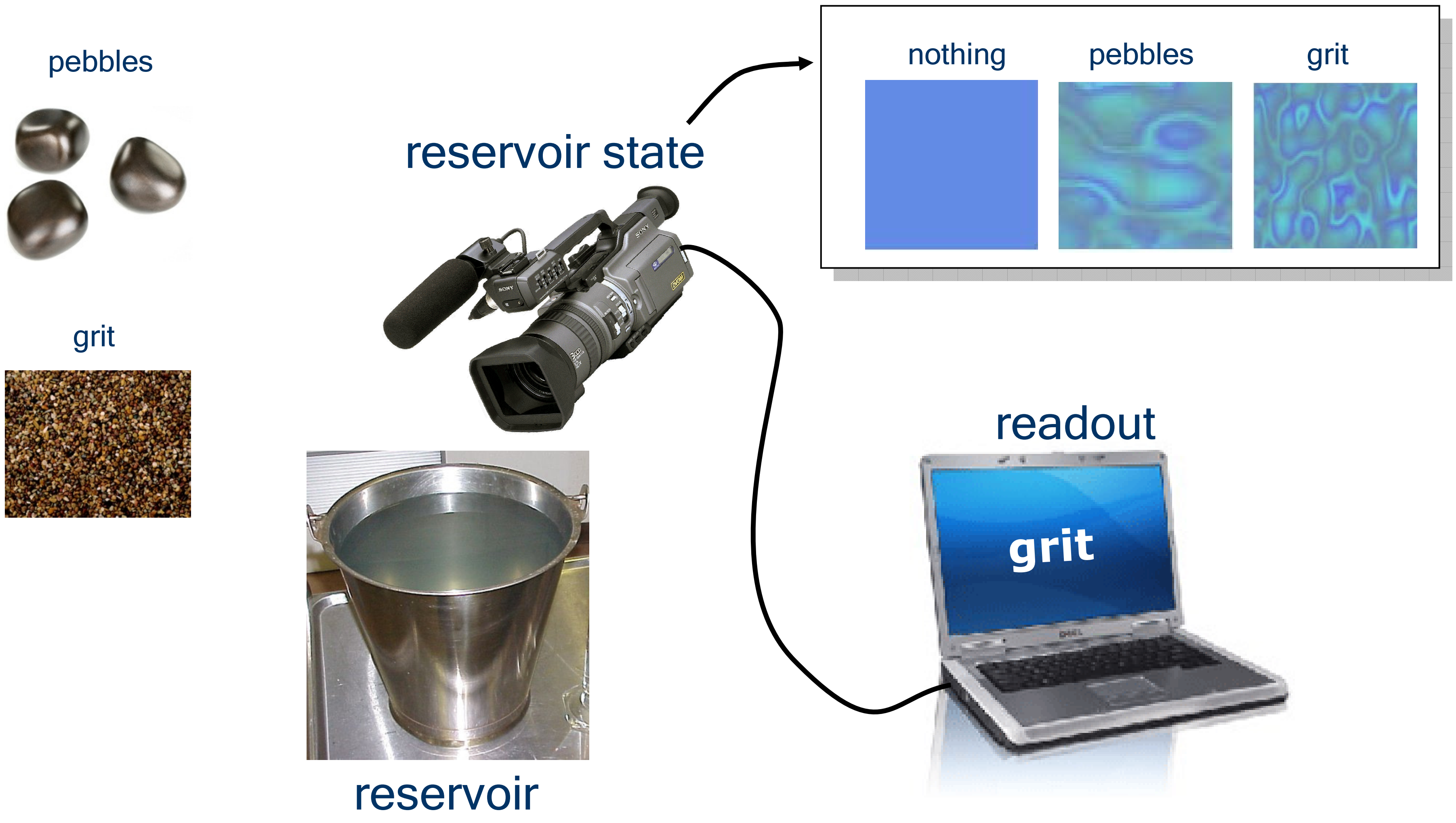
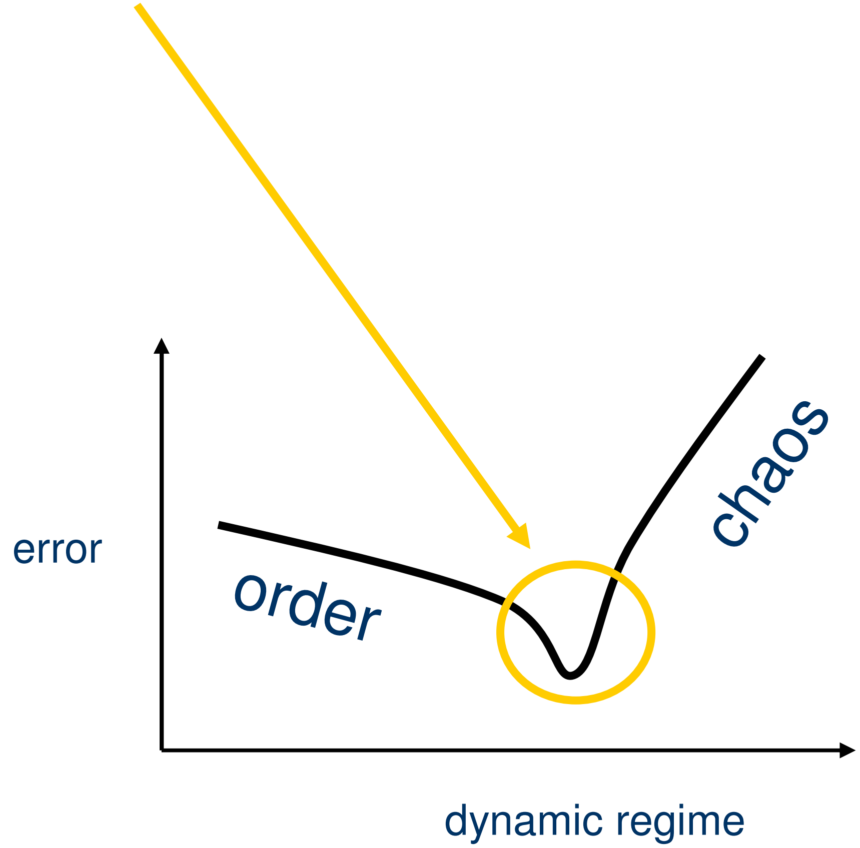


Figure taken from J. Dambre

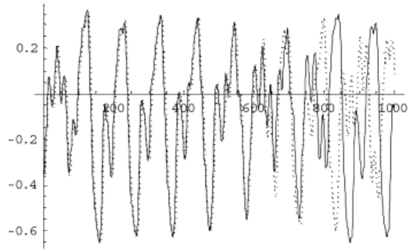
Computational power is the highest
on the **edge of stability**



figures taken from B. Schrauwen

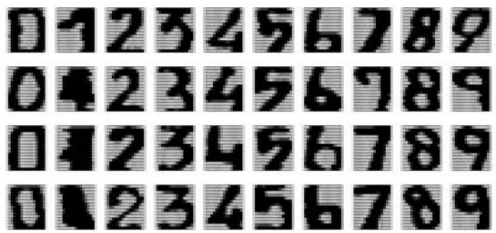
Applications:

- Chaotic time series prediction



- Speech recognition on small vocabulary

- Digits recognition: better than state-of-the-art



- Robot control

figures taken from H. Jaeger

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We should go from slow software
to fast and power efficient hardware

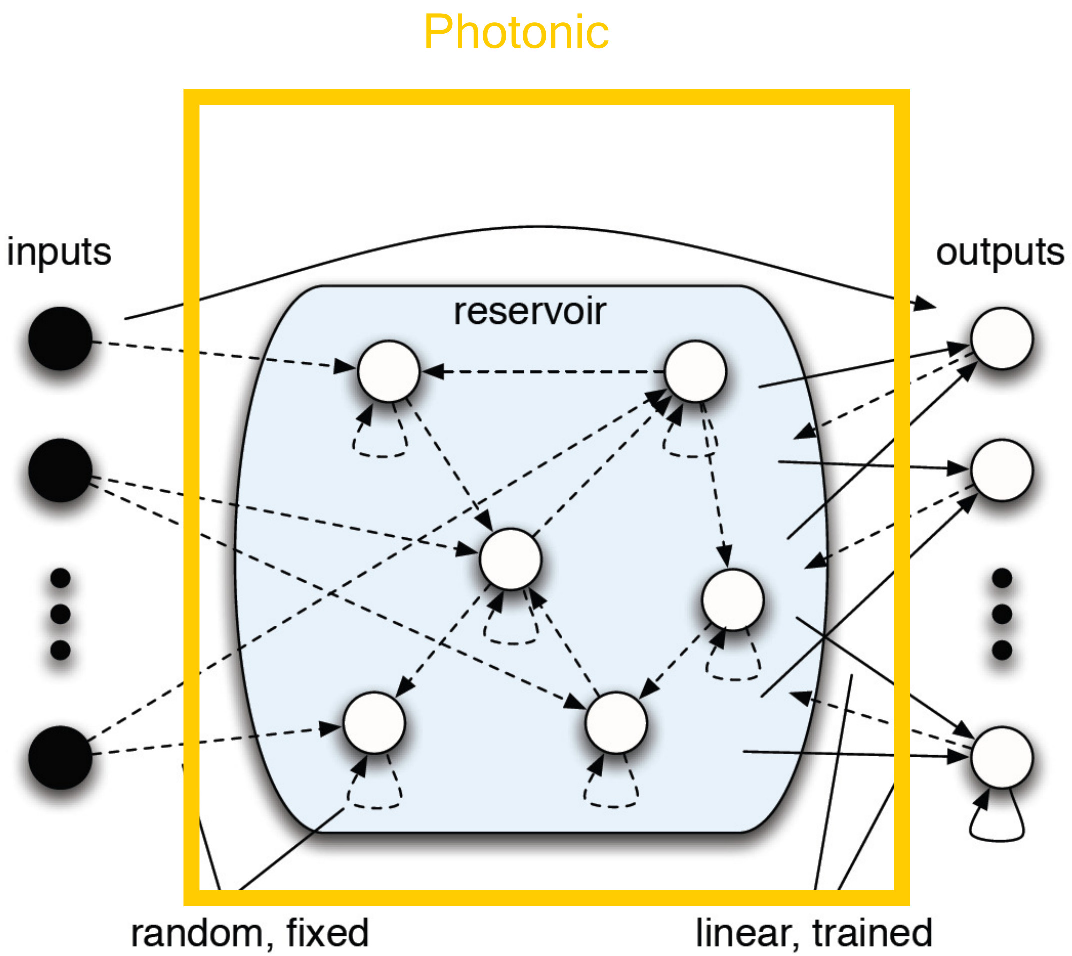
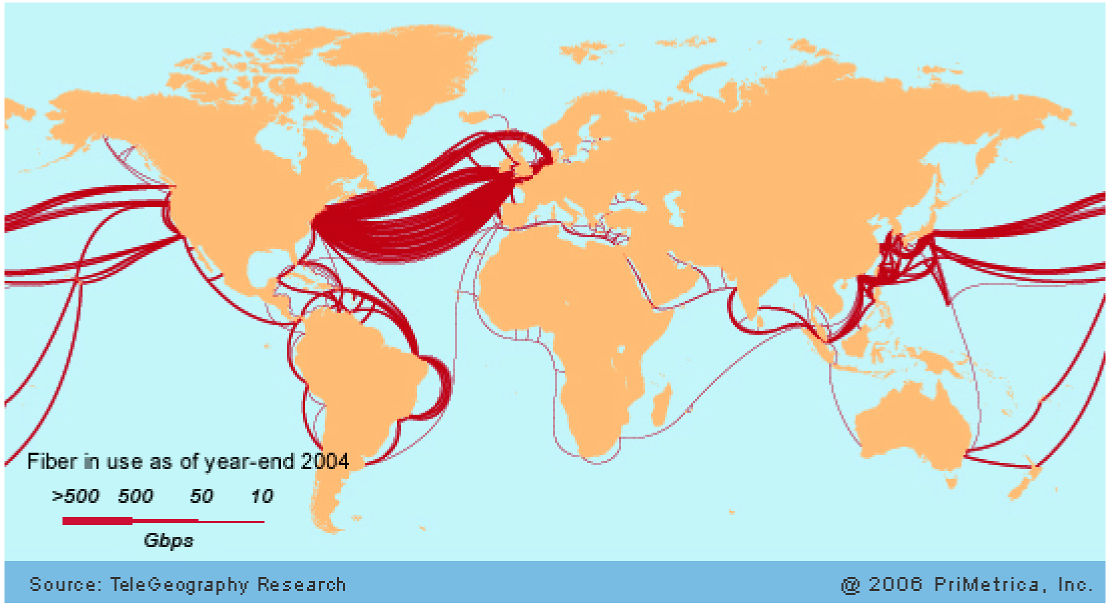
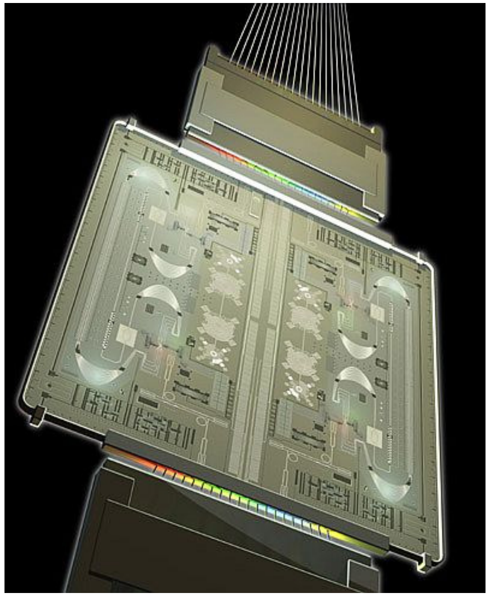


figure taken from B. Schrauwen

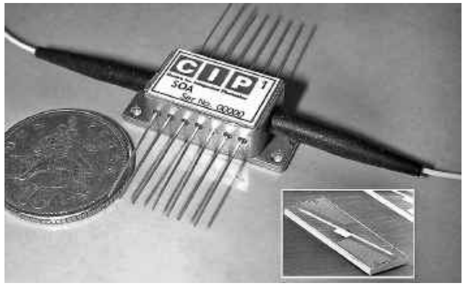
Photonics is replacing electronics for large distances



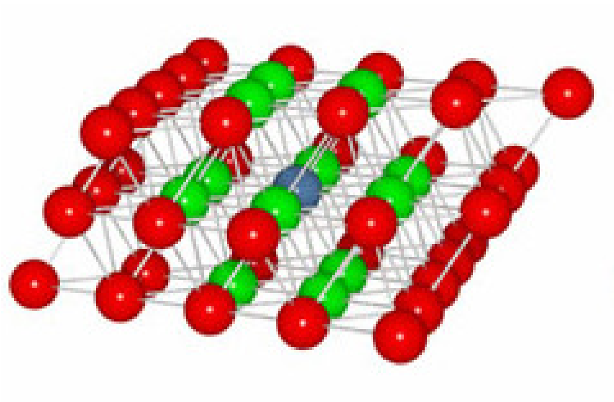
But those distances are getting smaller…

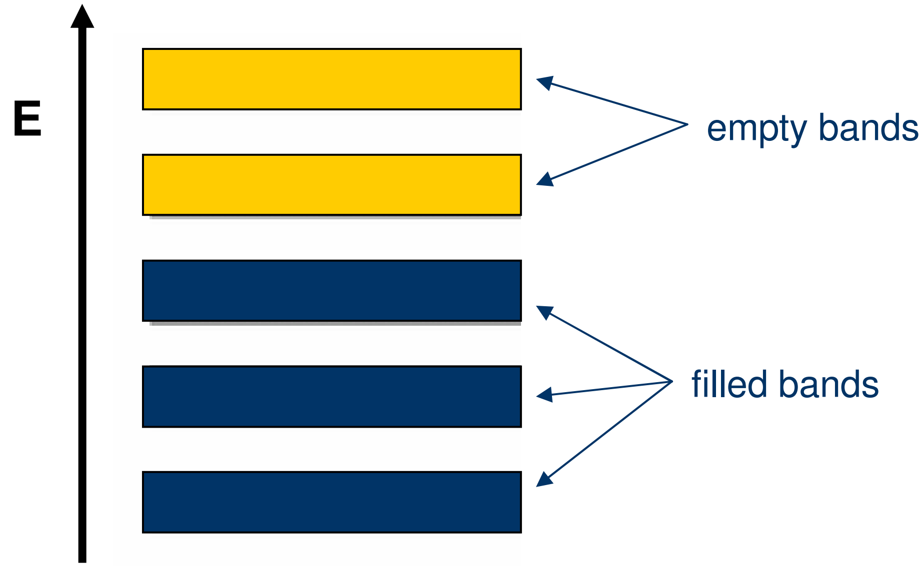


An optical chip with integrated Semiconductor Optical Amplifiers (SOAs) amplifying light

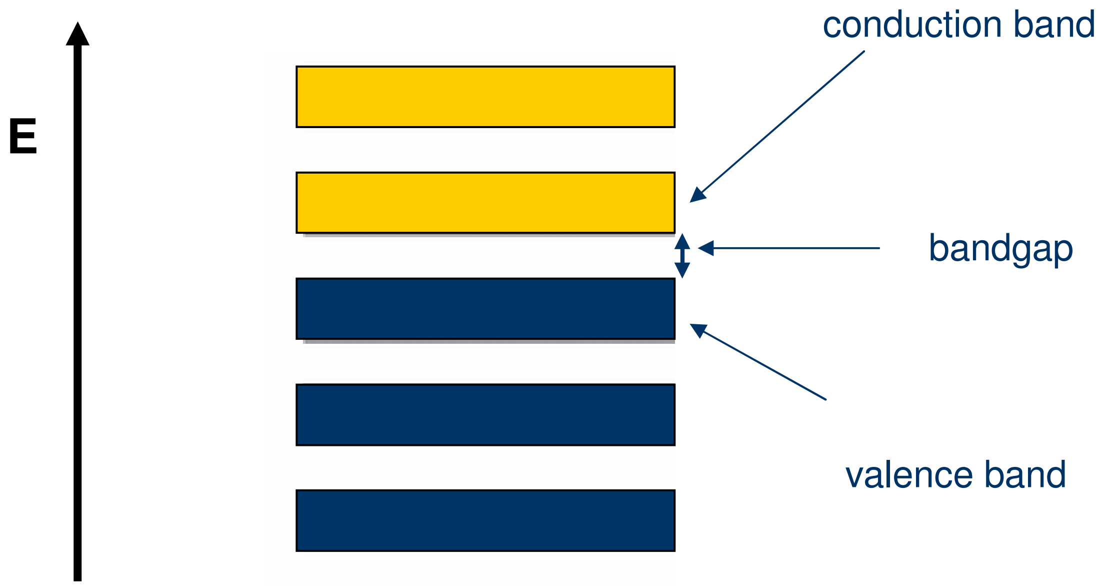


Electrons can only inhabit certain energy bands in solids

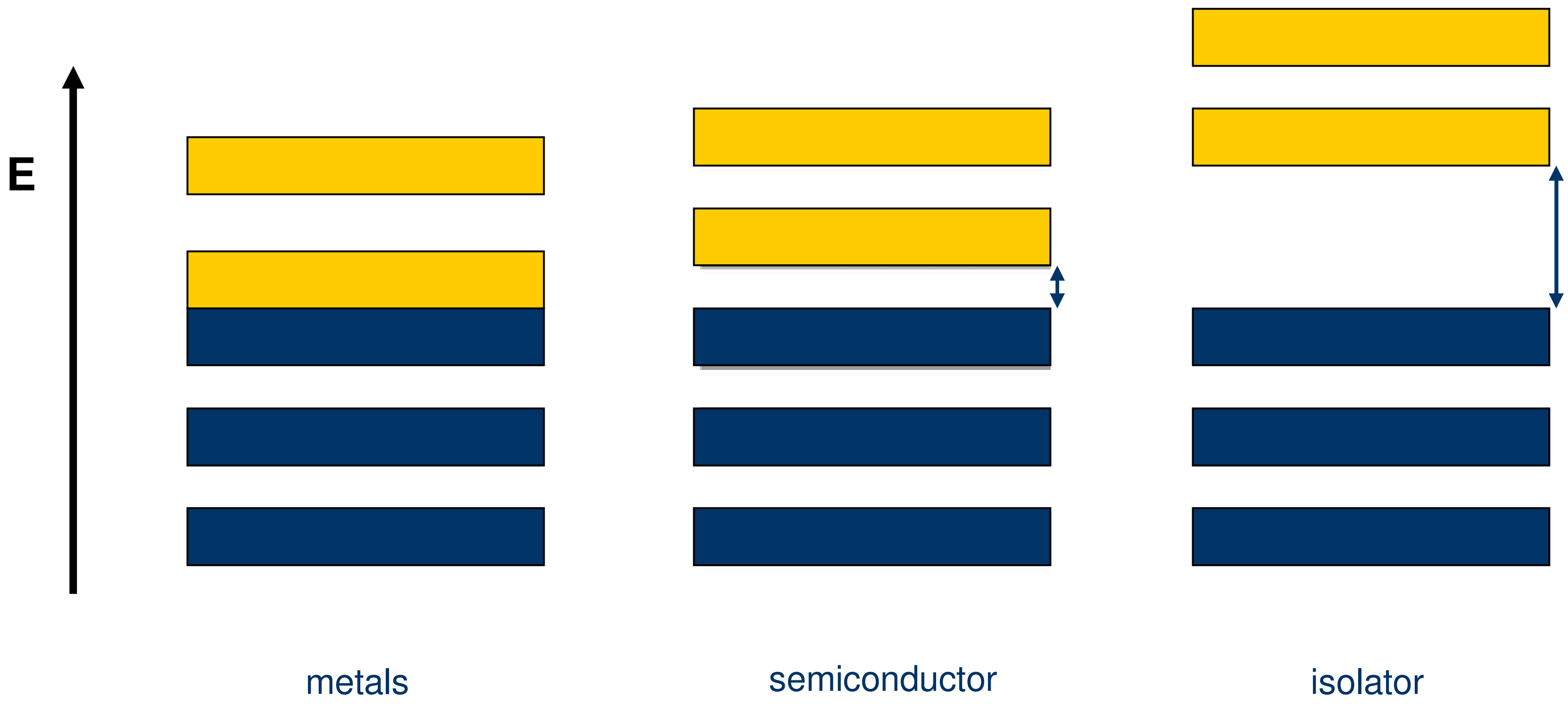




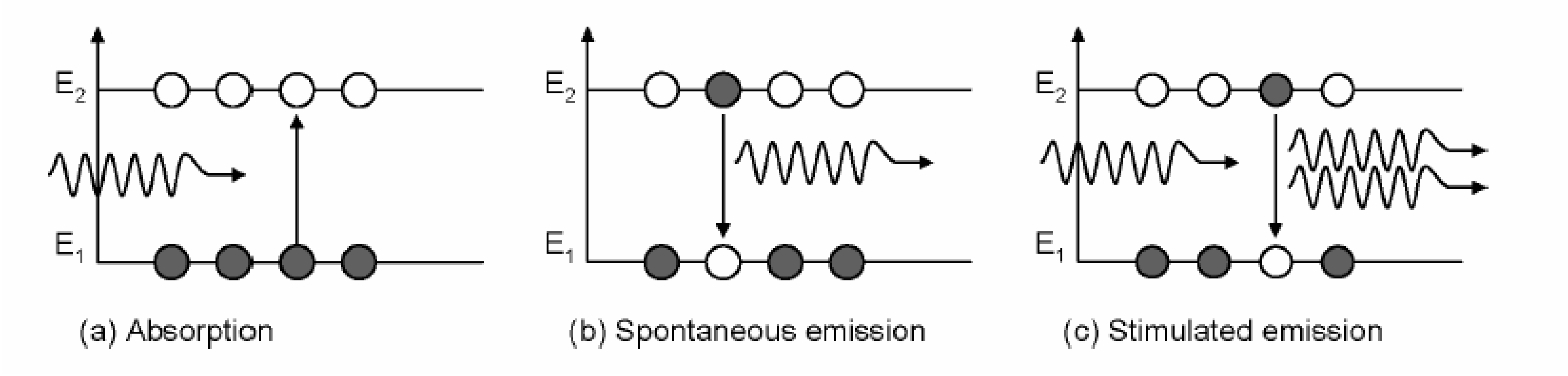
The energy gap between the top band filled with electrons and the first empty band is called the *bandgap*



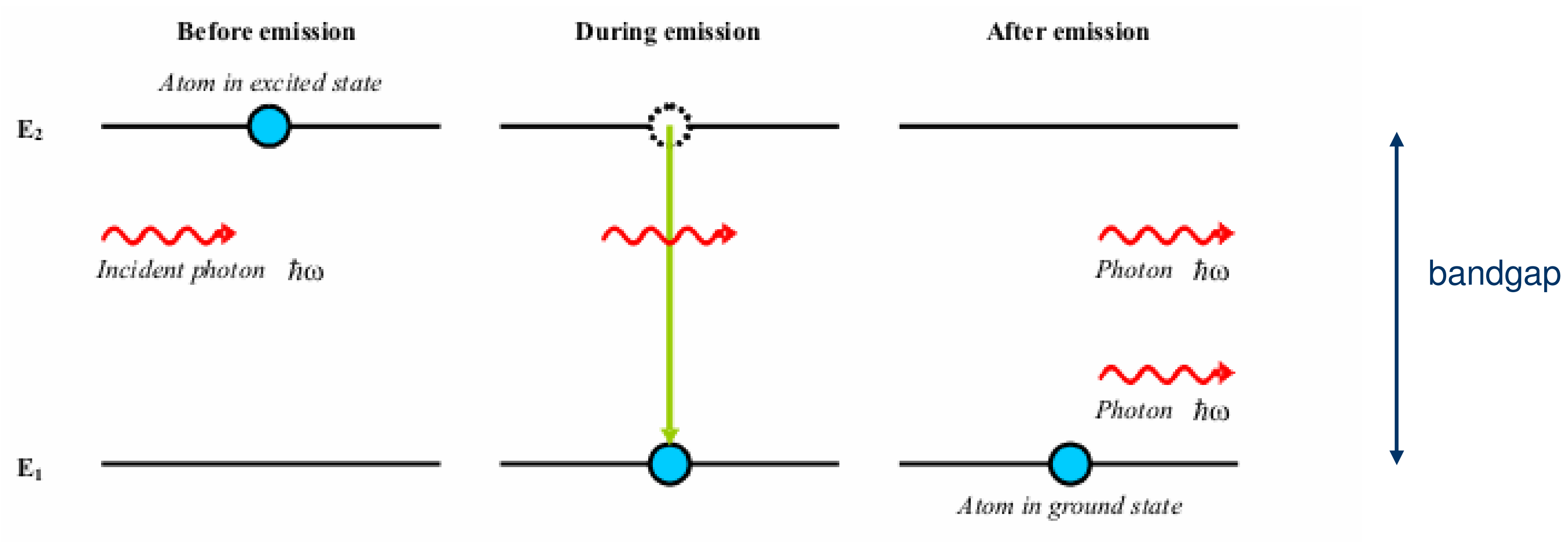
The size of the bandgap differs for
conductors (metals), semiconductors and isolators



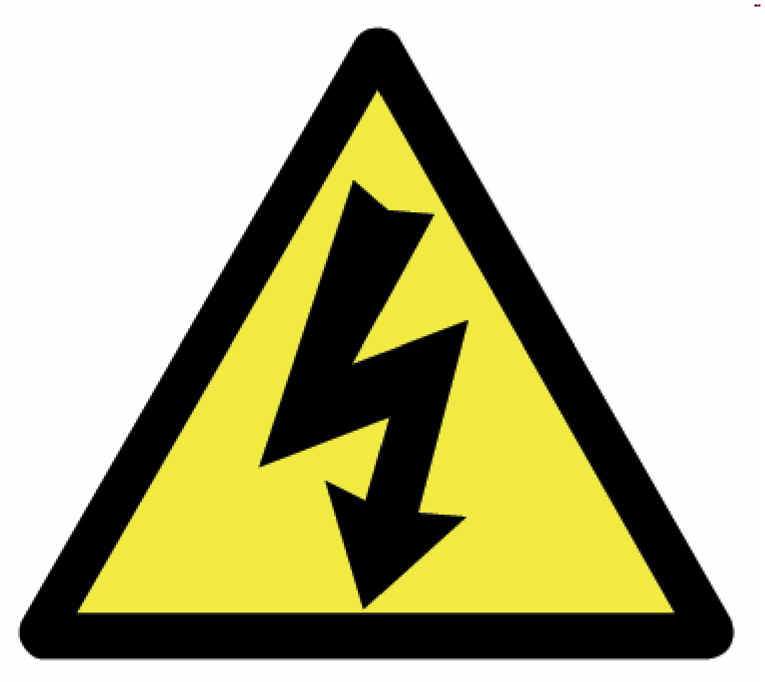
The small bandgap for semiconductors is the origin of three different interactions between electrons and photons

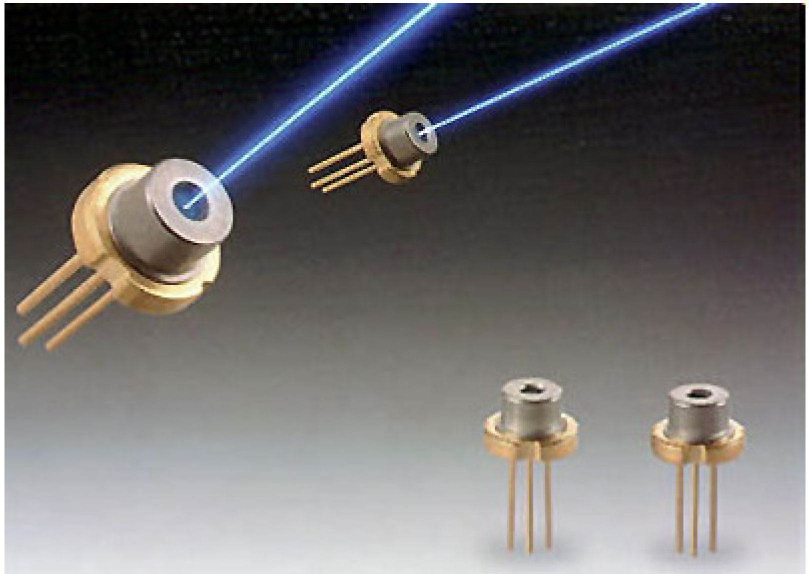


Efficient stimulated emission requires more excited states than ground states (population inversion)

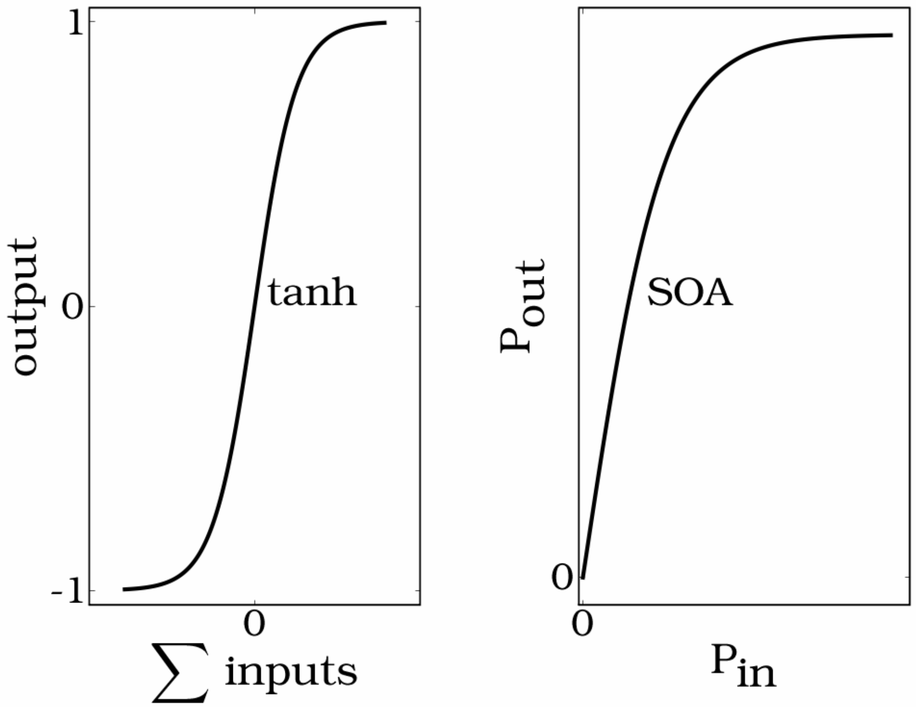


Therefor they need to be pumped (current, light,…).
They are not particularly energy efficient or fast,
but they are broadband





SOAs are a bridge between the reservoir and the photonic world



The gain in the SOA model is dependent on the **input power** and its own history

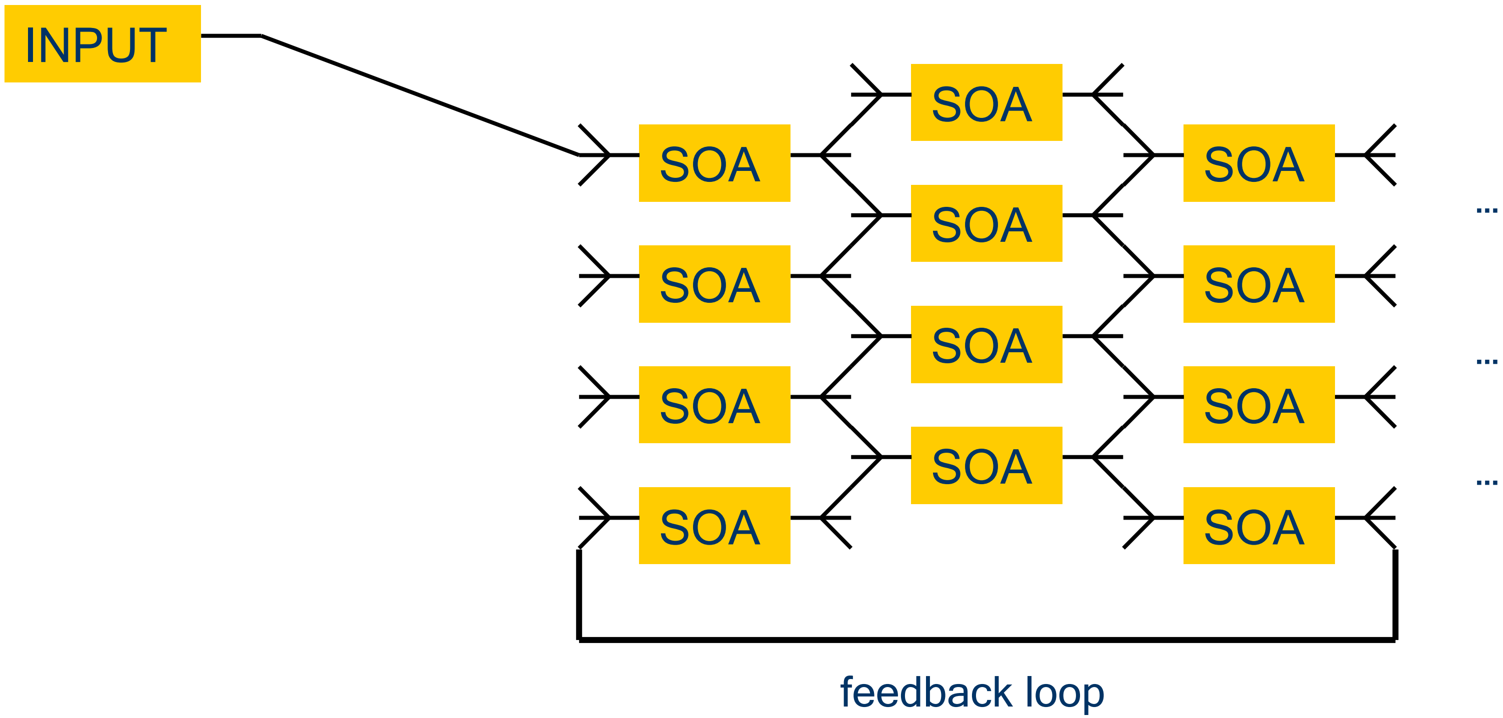
$$P_{out}(\tau) = P_{in}\exp[h(\tau)]$$

$$\phi_{out}(\tau) = \phi_{in} - \frac{1}{2}\alpha h(\tau)$$

$$h(\tau) = \int_0^L g(z,\tau)dz$$

$$\frac{dh}{d\tau} = \frac{g_0 L - h}{\tau_c} - \frac{P_{in}(\tau)}{P_{sat}\tau_c}[\exp(h) - 1]$$

Because chips are planar,
we try to avoid too many crossings



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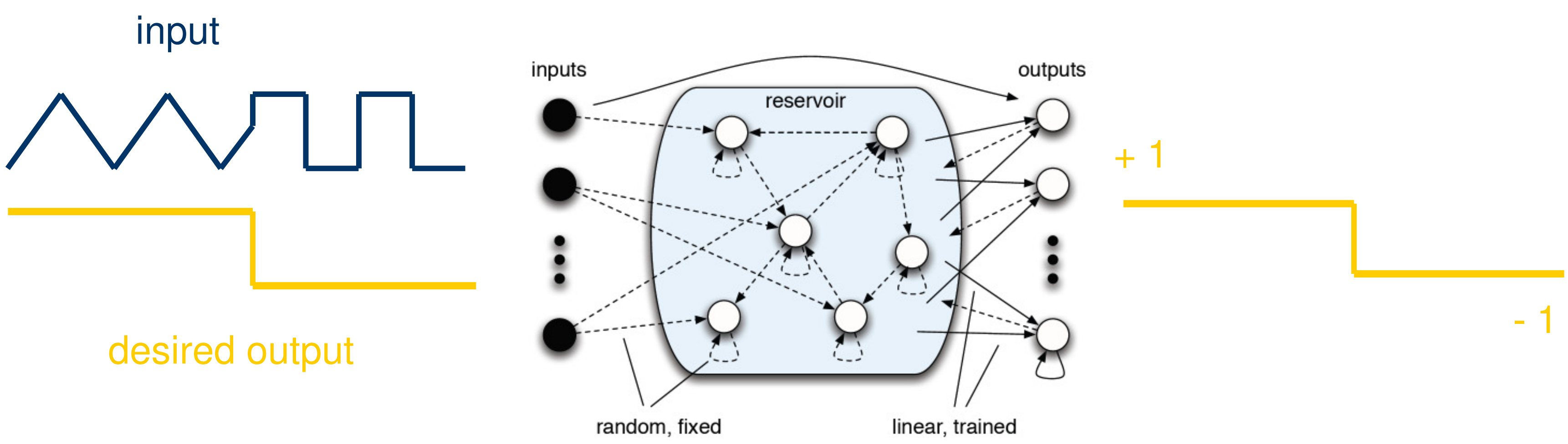
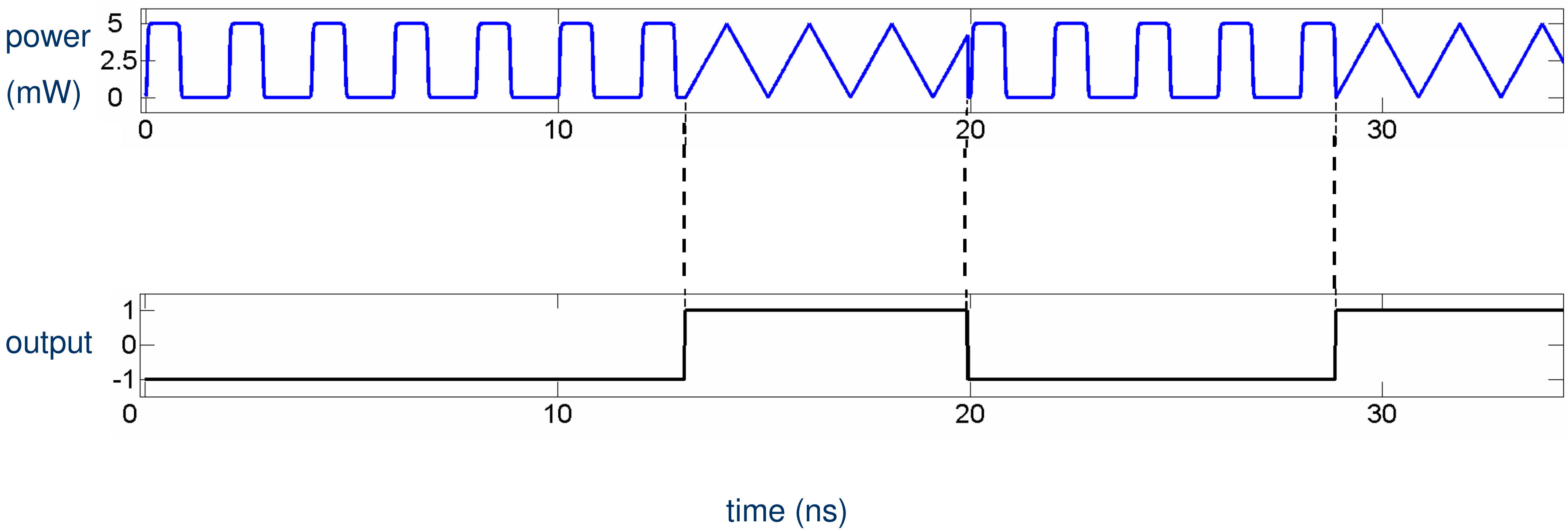
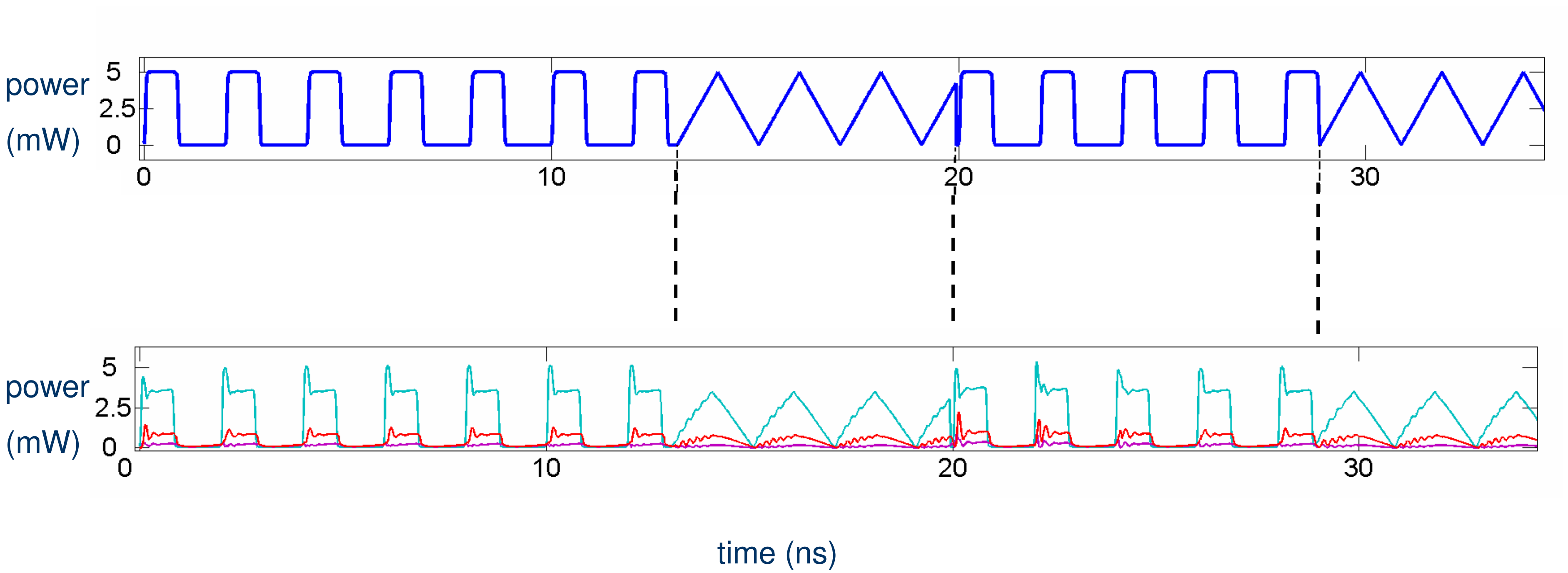
Train the network to distinguish between
a triangular and a rectangular function



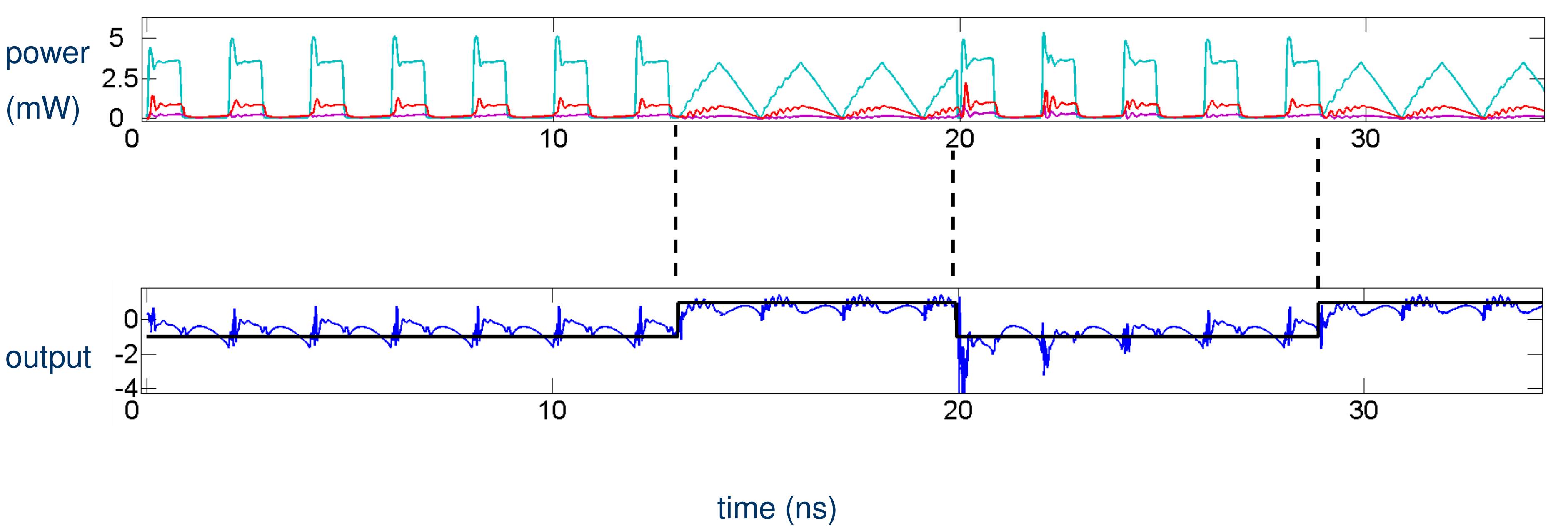
First the input signals and their desired output are defined



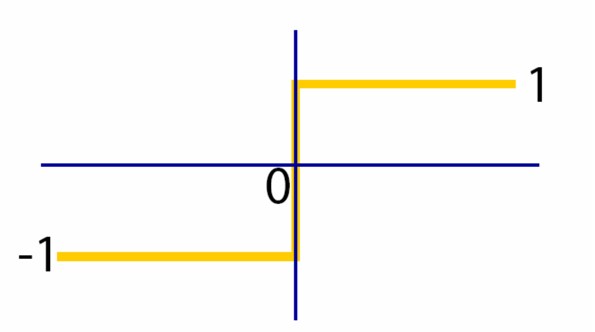
The input is fed into the reservoir

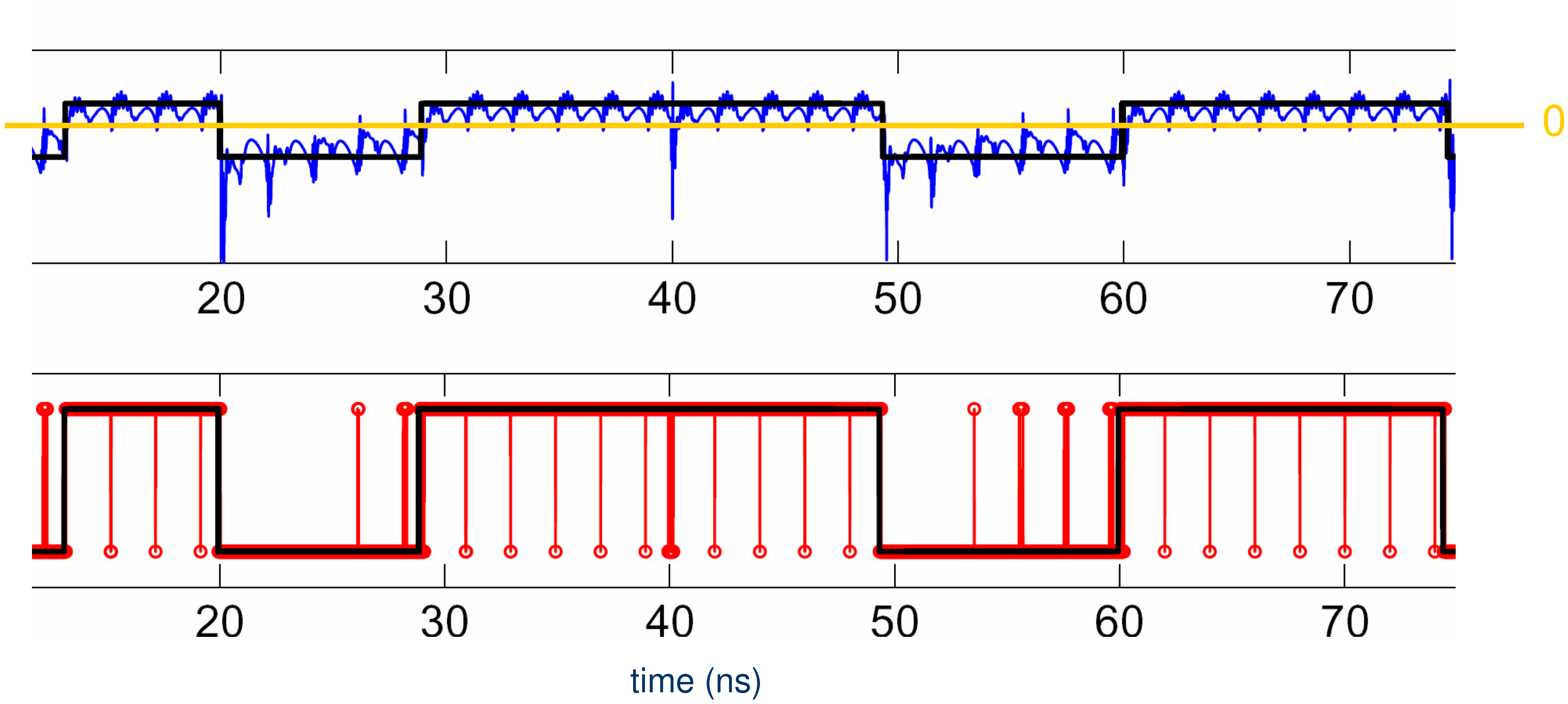


Train the readout function to follow transitions, by using a linear combination of reservoir states

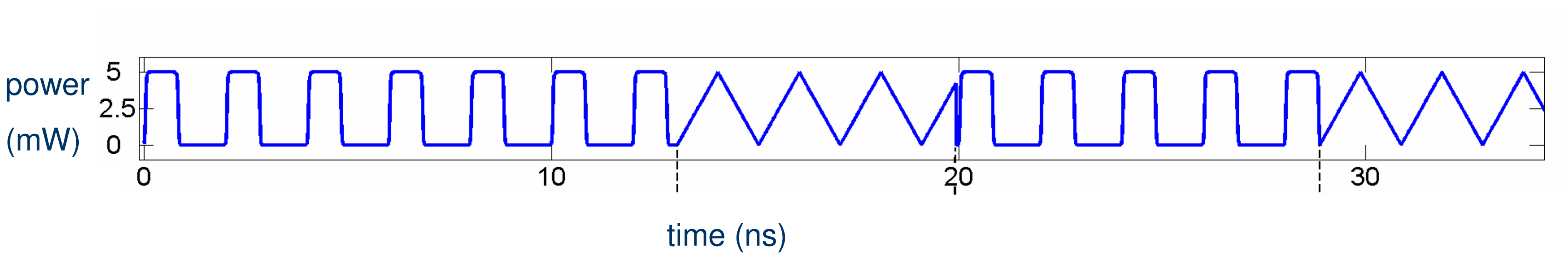


We use a sign function
to establish the final output

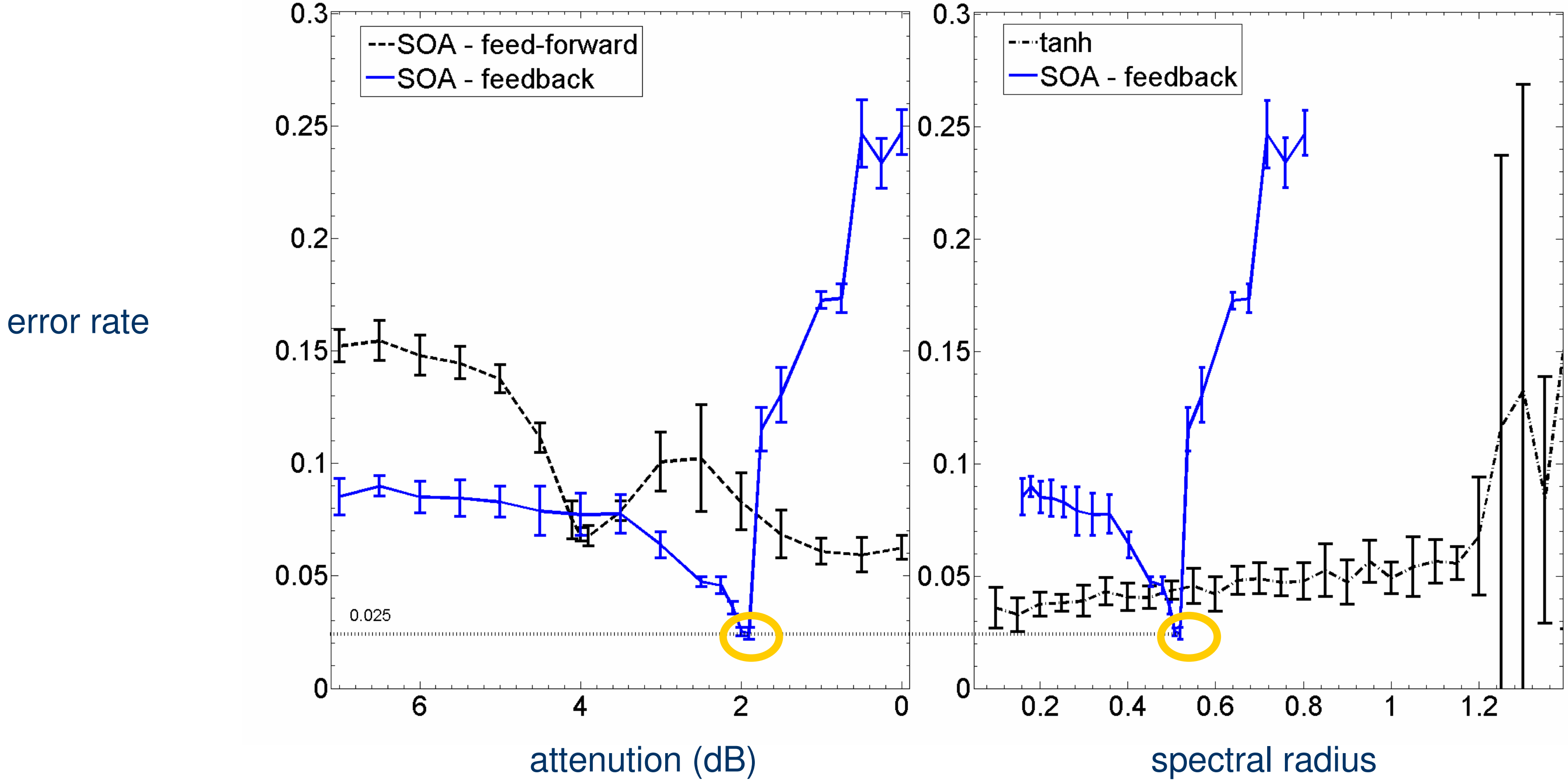




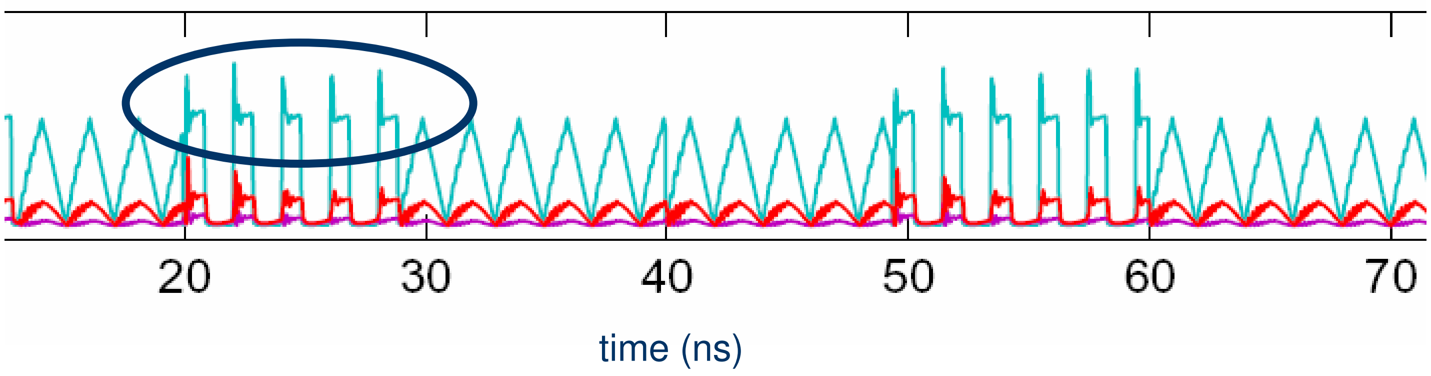
Different input signals are created with transitions on different instants. Some are used to train the network; the rest to test it



The optimum result is a correct classification 97% of the time

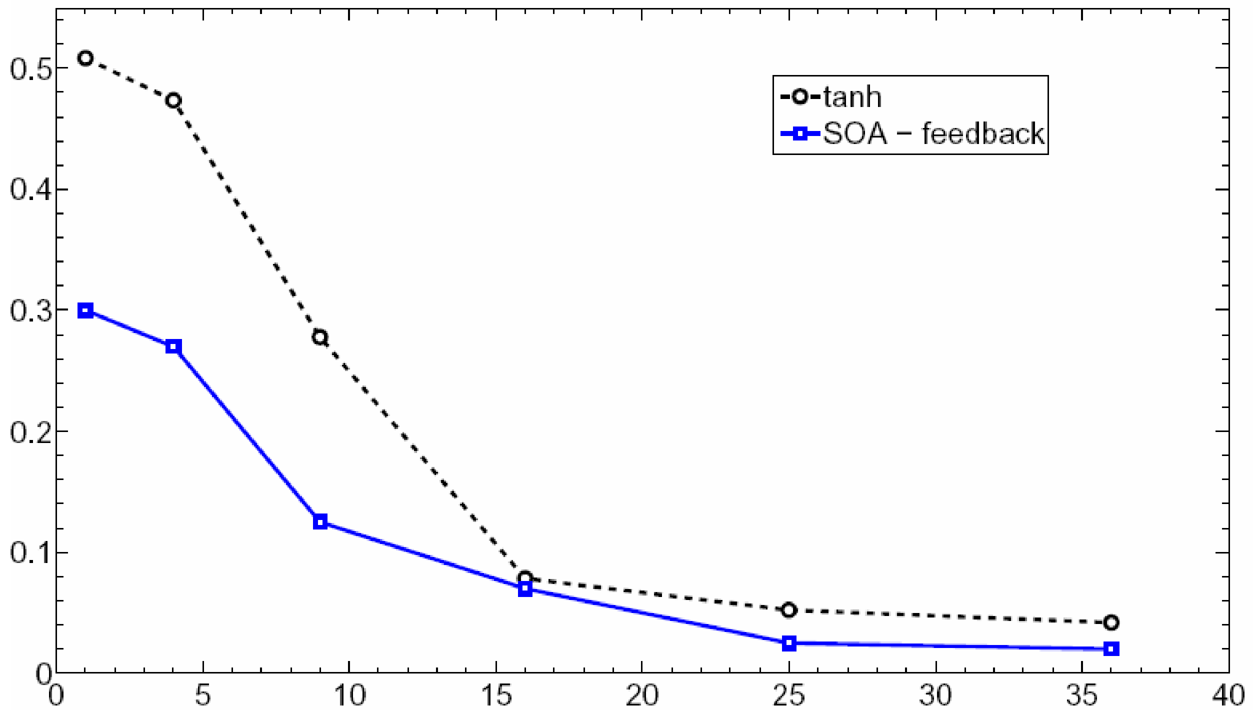


The reason could be the dynamic behavior of the SOA with **transients** for fast-rising slopes



The results saturate for larger reservoirs

error rate



reservoir nodes

1. Reservoir Computing

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Perhaps this won’t do any more in the future

A price I am willing to pay

kristof.vandoorne@UGent.be