PHOTONICS RESEARCH GROUP

Photonic Neuromorphic Computing Using Silicon Chips

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WHAT IS RESERVOIR COMPUTING?

What is reservoir computing?

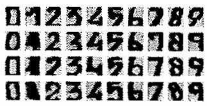
From field of machine learning (2002)

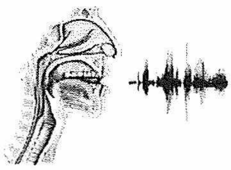
Addressing training issues in recurrent networks

Quite successful:

- Time series prediction
- Speech recognition
- Robot control
- ...

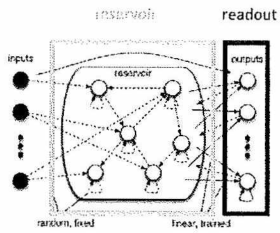
Originally mainly in software



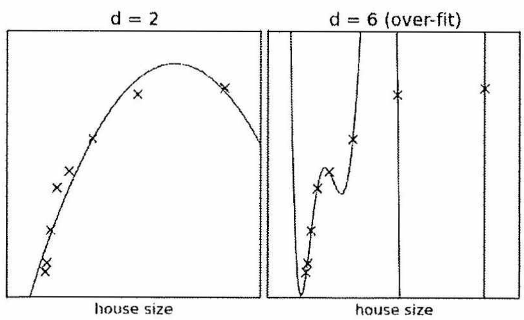


Reservoir computing

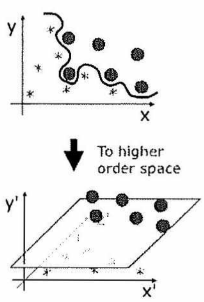
Don't train the neural network, only train the linear readout



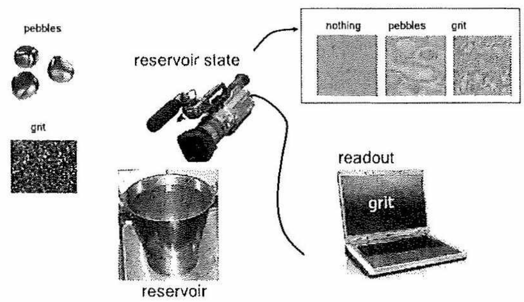
Boundaries with many degrees of freedom are prone to overfitting



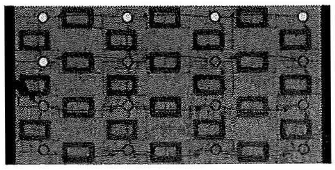
Why does RC work?



A HARDWARE IMPLEMENTATION…



PASSIVE SILICON RESERVOIR



- Silicon photonics: mature technology
- Giant multipath interferometer
- Nodes are simple splitters/combiners
- Non-linearity in readout suffices
- No active power consumption inside chip
- No longer limited by timescale of non-linearity

Vandoorne et al, Nature Comms, 5, 3541, 2014

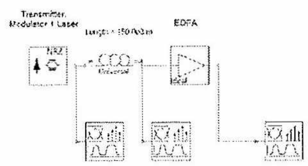
ADVANTAGES

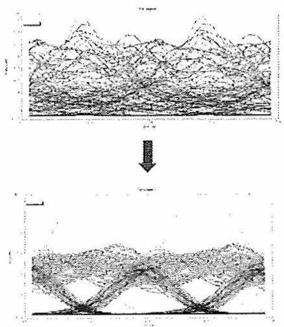
- Scalability:
  - we spent a lot of effort to slow down the signal!
  - easily scalable to higher speeds by shortening the delays
- No active power consumption on chip
- Same generic chip can be used for:
  - digital tasks (Boolean logic, header recognition, …)
  - analog tasks (speech recognition, dispersion compensation)

So, generalizes to different applications

NON-LINEAR DISPERSION COMPENSATION AT 32 GBPS

SENDING SIGNALS THROUGH AN OPTICAL LINK SUFFERS FROM DISTORTION

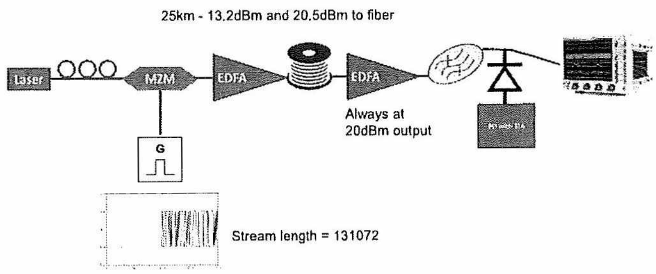




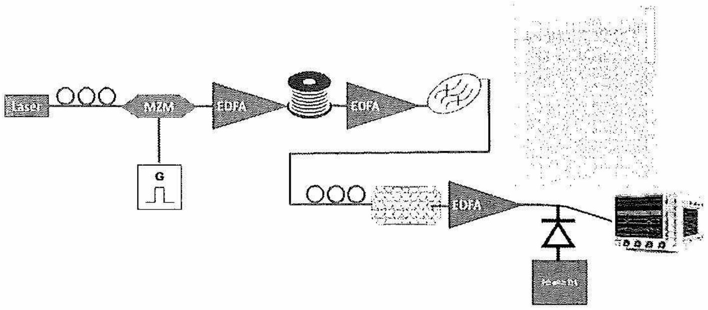
Fixing these problems requires expensive digital processing.

Can we do it in the optical domain at high speeds?

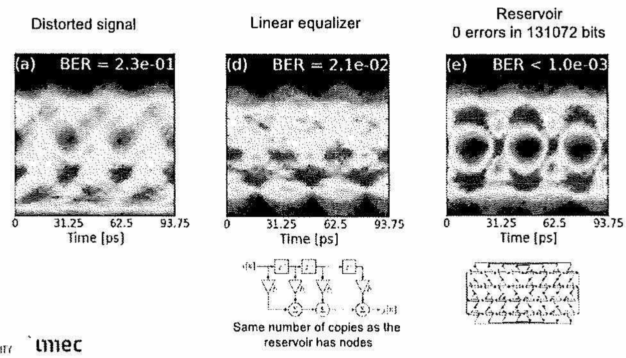
REFERENCE MEASUREMENT WITHOUT RESERVOIR



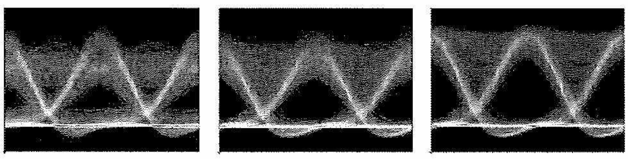
Measurement with reservoir chip



Experiments: RC is better at equalising this NL distorted signal



Simulations: "bad" non-linear detector even better

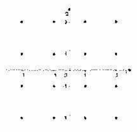


Distorted stream	Compensated stream using RC BER: 3 orders of magnitude better	compensated stream with extra non-linearity from TIA BER: 7 orders of magnitude better

RC EQUALISATION FOR KK RECEIVERS

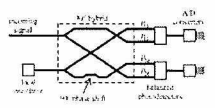
Motivation

Coherent transmission is the optimal choice for medium-long range communications



Spectrally efficient transmission

Coherent detection costs are too high for short links

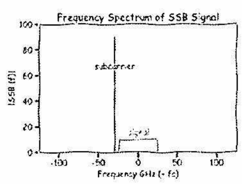


Expensive coherent detection

Kramers-Kronig Rx

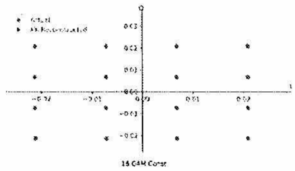
Kramers-Kronig (KK) Receiver is an alternative scheme for coherent receivers which uses direct detection (i.e., amplitude of the signal) to extract the phase information. Certain conditions must be respected for accurate reconstruction:

1. Single sideband signal: the spectrum of the signal must be located to one side of a subcarrier



Kramers-Kronig Rx

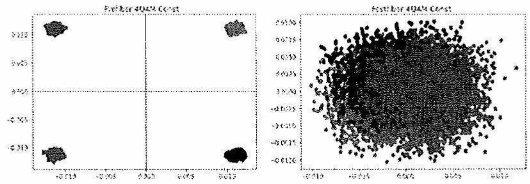
2. Large CSPR: the carrier-to-signal power ratio (CSPR) must be high



Subcarrier can be added...

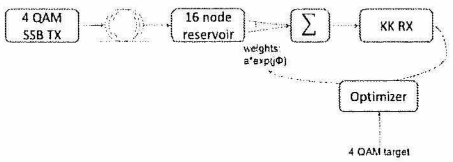
- At the detector (popular, but need for extra local oscillator)
- At the source (leads to extra NL effects in fibre)

High-power carrier leads to NL fibre effects



Compensating Nonlinear Fiber Effects using RC

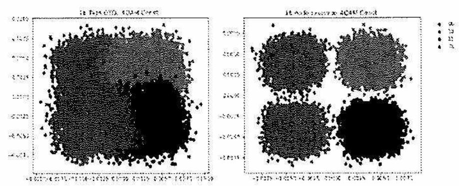
- We backpropagate through entire NL KK receiver during training
- Can use the 4 QAM signal as target signal (as opposed to target signal before the receiver).



RC outperforms linear equalisation

Distorted signal after 40 km fiber equalized using 16-tap optical tapped delay line (left) and 16-node reservoir (right).

Testing on 26,700 symbols, training on 6,000 symbols.



Linear equalization: BER 4e-2 Reservoir equalization: BER 9e-5

EXPLOITING WDM IN RC

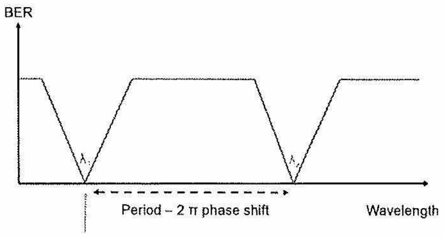
Goal

Can we use a single reservoir with a single set of weights to process the same task in parallel on multiple wavelengths?

→Higher throughput

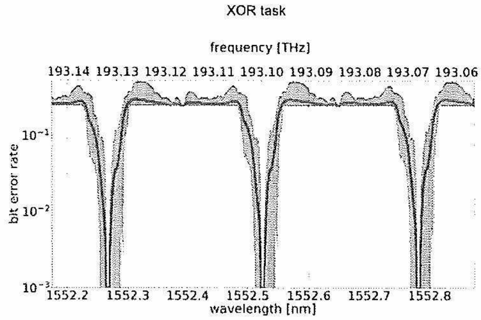
→Save chip area

Strategy 1: Engineered Interconnection Lengths

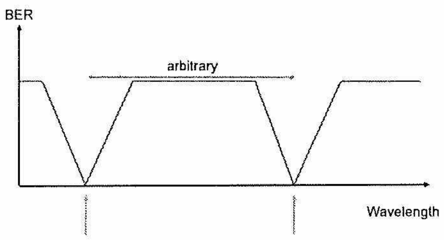


Challenges: roughness, length variations

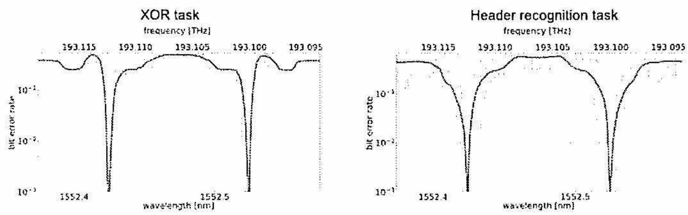
Good performance for high number of wavelength channels with fixed spacing



Strategy 2: Multiple-Wavelength Training

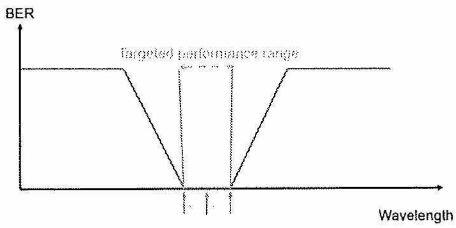


Good performance up to 2 wavelength channels



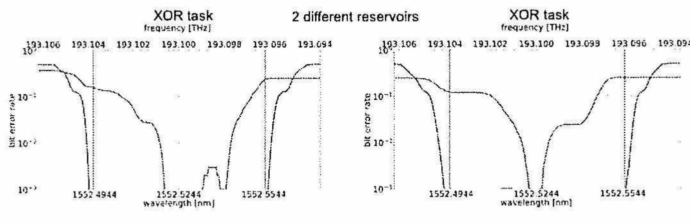
Performance degrades for >2 target wavelengths

Increasing robustness against environmental variations



Challenge: maintaining good performance over entire range
→ appropriate # and spacing of training wavelengths required

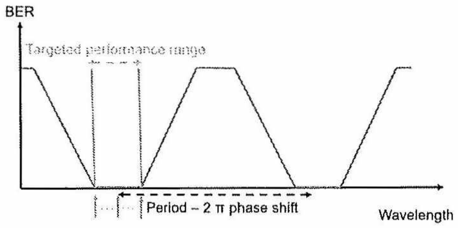
Operating range increases by factor >2



Green: single wavelength training
Blue: multiple wavelength training
Orange: targetted performance range

Average: 24.5 pm -> 63.1 pm / 3 GHz -> 7.6 GHz

Combining length engineering with robustness against environmental variations



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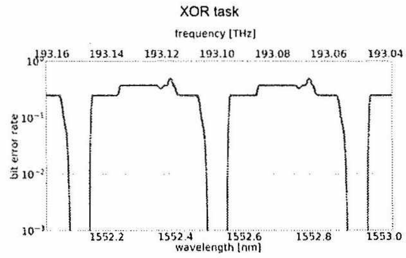
Good performance along broad wavelength range for high number of wavelength channels at fixed spacing



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OTHER TELECOM TASKS

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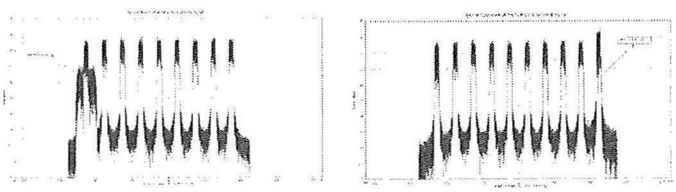
Jamming detection

Successful identification in real time of in-band and out-of-band jamming



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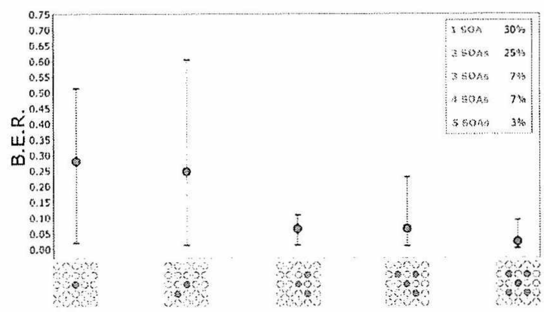
Modulation format identification: BPSK vs QPSK



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BIOLOGICAL CELL SORTING

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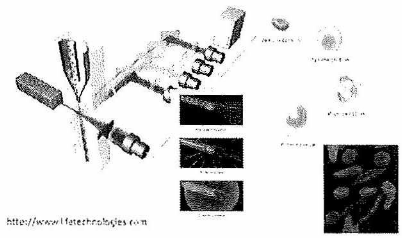
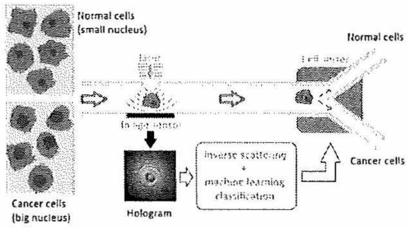
FLOW CYTOMETRY

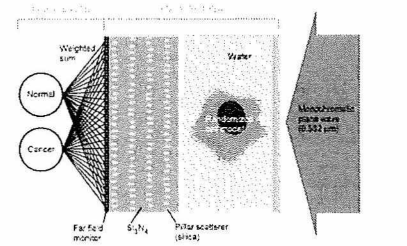


DIGITAL HOLOGRAPHY



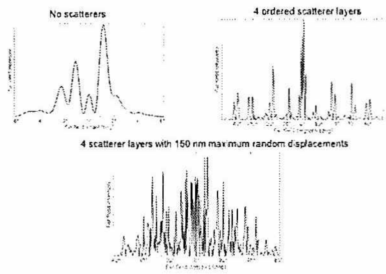
Goal: 1000 microfluidic channels in parallel ⟹ ~ 1000 classifications each ms

A SPATIAL ANALOG OF RESERVOIR COMPUTING

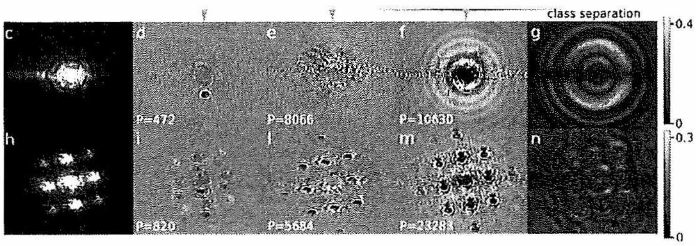


Phase-to-intensity transfer function is sinusoidal ⟹ Power-independent nonlinearity available for computation

SCATTERERS INCREASE HOLOGRAM COMPLEXITY



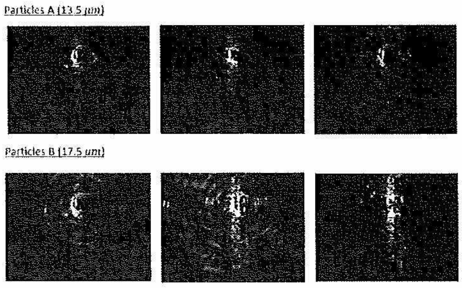
EXPERIMENTS ON BEADS WITH DIFFERENT SIZES



MUCH FASTER THAN OTHER WORKS IN LITERATURE

Classification task	Classifier	Image resolution	Imaging method	Image FoV	Classification performance	Accelerator	execution time / particle	Meas. bias control
Beads with diameters of 7, 10 and 15µm	CNN	21 × 21	Microscope	Centered and cropped	93.3% mAP	GPU	< 1 ms	Unreported
3 white blood cell (WBC) types	Rand. forest on extracted features	31 × 31	Lens-free - raw hologram	Unreported	96.8% accuracy	GPU	0.2 ms	Unreported
1 WBC type and an epithelial cancer cell	Deep CNN	Unreported	Time-stretch microscope	25µm along channel	95.74% accuracy	GPU	3.6 ms	Unreported
Beads with diameters of 15.2 and 18.6µm (our work)	Linear (log. regression)	32 × 26	Lens-free - raw hologram	~ 300µm along channel	> 90% accuracy	None	0.013 ms	Yes

NEXT STEPS: EXPERIMENTS WITH AN EVENT CAMERA



No need for background subtraction!

CONCLUSIONS

Reservoir computing
is interesting new paradigm
for all-optical information processing

invited.

Qmusic - Q sounds better with | athena ugent - Search | Athena | photonics research group - Sear | Publications | Workshop Schedule

Not secure | plasmoniac.eu/workshops/schedule.html

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Schedule

Join us online this December to take part along with prestigious academia and industrial speakers in discussing the latest trends in photonic Neuromorphic processing!

Day 1 | Day 2

Tuesday, 7th December 2021 (CET)

9:10 - 9:20 AM **Get connected**

Session 4: Reservoir Computing

Chairman: Prof. P. Bienstman

9:20 - 10:00 AM	"Silicon photonics for brain-inspired neuromorphic information processing" **Download presentation → pdf: video:**	Prof. P. Bienstman
10:00 - 10:40 AM	"Time Multiplexed Photonic Reservoir Computing" **Download presentation → pdf: video:**	Prof. Lorenzo Pavessi
10:40 - 11:20 AM	"NEBULA (Neuro-augmented 112Gbaud CMOS plasmonic transceiver platform for	Prof. K. Vyrsokinos

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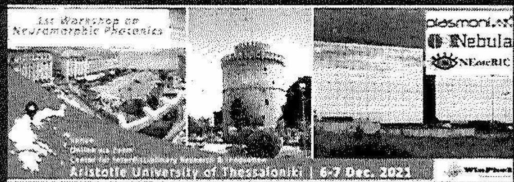
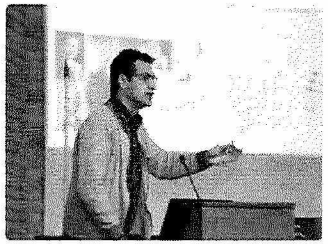


December 6-7th — Online

1st Workshop on Neuromoprhic Photonics

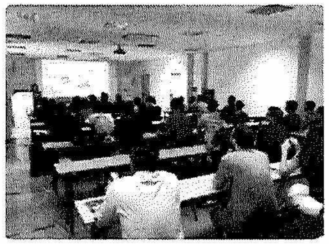
Join us online on December 6-7 to take part along with prestigious academia and industrial speakers in discussing the latest trends in photonic Neuromorphic processing.

ACADEMIA & INDUSTRY EXPERTS



Speakers

SCHEDULE



Two Inspiring Days

ORGANIZATION

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NEoteRIC

Online Participation