



Neuromorphic Photonic Computing with Lasers Antonio Hurtado

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(c)

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Neuromorphic Photonics

- 1) Motivation
 - What and What for?
 - Why Lasers/VCSELs?
- 2) Results
 - Ultrafast Photonic Spiking Neurons
 - Photonic Spike Processing with VCSELs
 - Recurrent Neural Networks with VCSELs
- 3) Summary and Outlook



Neuromorphic Photonics Motivation







Neuromorphic Photonics Motivation







Neuromorphic Photonics Motivation









High speed (>Ghz) ; Low energy (<pJ/spike)

RESEARCH VISION PHOTON-AI:

"To develop transformative lightenabled, laser-based Neuromorphic Photonic Systems for AI that are compact, ultrafast and low energy".



Ultrafast (< 1ns) spiking dynamics at low energy
7 to 9 orders of magnitude faster than neurons!!!

Photonic Spike Processing Systems Coincidence Detection

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System only fires when stimuli arrive within a small temporal window

J. Robertson et al, Sci. Reps., 10, 6098 (2020)



Photonic Spike Processing Systems:

Pattern recognition

C 1001

10.0

15.0

20.0



D 0110



J. Robertson et al, Sci. Reps., 10, 6098 (2020)



Photonic Spike Processing Systems:

Pattern recognition





Target Pattern

4-bit pattern recognition with a single VCSEL-Neuron Ultrafast operation (~100 ps per bit & spike) Telecom Wavelengths (Compatible with optical networks)

J. Robertson et al, Sci. Reps., 10, 6098 (2020)



Photonic Spike Processing Systems: Image Edge-Feature Detection

b







J. Robertson et al, Opt Exp., 37526 (2020)



Photonic Spike Processing Systems: Image Edge-Feature Detection











J. Robertson et al, Opt. Exp., 37526 (2020)

Y. Zhang et al, OSA Phot Res Accepted (2021)



Photonic Spike Processing Systems: Neuronal Circuit Emulation





- Emulation of a neuronal circuit in the retina at ultrafast rates
- A laser neuron network can reproduce the response of Bipolar and Ganglion cells at sub-ns speed.



J. Robertson et al, IEEE JSTQE, INVITED, 26, 7700715 (2020)

Recurrent Neural Networks with VCSELs (Reservoir Computing)



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Time Delay Reservoir

- -Virtual Nodes (Neurons)
- -Connections to neighbouring nodes

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- -Self-connections (memory)
- -Only output weights are trained

Recurrent Neural Networks with VCSELs (Reservoir Computing)





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-Delay time (**τ**): **65.02ns**

-Sampling rate: 5 GSa/s

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Time Delay Reservoir

- -Virtual Nodes (Neurons)
- -Connections to neighbouring nodes
- -Self-connections (memory)

-Only output weights are trained



Oscilloscope

J. Bueno et al, IEEE PTL accepted (2021)

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of PhotonicsRecurrent Neural Networks
with VCSELs (Reservoir Computing)





J. Bueno et al, IEEE PTL accepted (2021)



J. Bueno et al, IEEE PTL accepted (2021)



• Neuromorphic Photonics for AI

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- Artificial Photonic Neurons and Neural Networks with Lasers
- Ultrafast speeds (sub-ns) & Low power
- Towards complex network architectures
- Photonic Spike Processing Systems
- Photonic Reservoir Computing
- Functional tasks (e.g. image processing, pattern recognition)















Acknowledgements







Engineering and Physical Sciences Research Council



TURING AI ACCELERATION FELLOWSHIPS



