

# Towards 20 GHz realtime neural network processors via semiconductor lasers

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#### NN architecture and energy consumption



Reuther, et al., Arxiv: 2009:00993.

MIT Technology Review

Artificial Intelligence / Machine Learning

≡Q

#### Training a single AI model can emit as much carbon as five cars in their lifetimes

Deep learning has a terrible carbon footprint.

by <b>Karen Hao</b>	Jun 6, 2019





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## **Experimental setup / scheme**





Reservoir	VCSEL Reservoir
Nodes / Neurons	Modes $\approx 30$
Connections	Carrier diffusion / Cavity diffraction

Porte, et al., J. Phys. Photonics https://doi.org/10.1088/2515-7647/abf6bd.



#### **Experimental setup / scheme**





# Injection locking / Information injection



Scan  $\lambda$  :highest susceptibility to optical injection

Locking: scan the injection ring width to fully lock the VCSEL.

Porte, et al., J. Phys. Photonics https://doi.org/10.1088/2515-7647/abf6bd.



#### **Optical modes: neurons embedding in near field**





#### Laser injection locking: linking neurons to input information



#### sciences & TECHNOLOGIES

#### Learning strategy





 $n_{\text{mirrors}} = \text{ceil}(\alpha * \text{MSE})$ 

Porte, et al., J. Phys. Photonics https://doi.org/10.1088/2515-7647/abf6bd.



## Header recognition task

• Training sequence of size N (batch size): 50% of the classification target, 50% of the other digits:



- After each epoch flip mirrors on DMDb:
  - If the MSE decreases keep the change
  - If it increases: revert the change then flip other mirrors
- Keep going until the error is bellow a threshold.

Porte, et al., J. Phys. Photonics https://doi.org/10.1088/2515-7647/abf6bd.

LA VCSEL

DMDb



#### **Results**

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#### **Error and injection locking parameters**







#### Weight initialization matters (for classification)











# **Finally: classification error rates**



## NN breakthrough: long term effort

#### **Parallel networks**



Moughames, et al., Optica 7, 640 (2020).

#### Hardware-motivated learning



Bueno, et al., Optica 5, 756 (2015).

#### **Photonic neurons**





Liu et al., Laser and Photonics Reviews 9, 172 (2015). Heuser, et al., J. Appl. Phys 3, 116103 (2018).

#### Noise



Semenova, et al., Chaos 29, 103128 (2015).



#### Summary

- Full implementation of all network connections: truly realtime
- Learning realized on physical substrate
- Very efficient learning and system: 1W power consumption
- Next: push the bandwidth





#### Emerging Topics in Artificial Intelligence (ETAI) 2021 (OP110)

Conference Chairs: Giovanni Volpe, Göteborgs Univ. (Sweden); Joana B. Pereira, Karolinska Institute (Sweden); Daniel Brunner, Institut Franche-Comte Electronique Mecanique Thermique et Optique (France); Aydogan Ozcan, Univ. of California, Los Angeles (USA)

