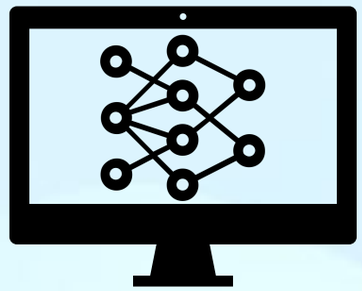
Brain-inspired AI

Neuromorphic computing and beyond

Steve Abreu @ Cover · April 18, 2023

Introduction

Motivation for brain-inspired AI



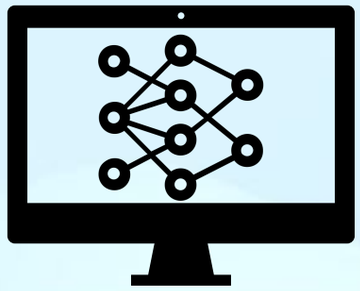
Sample efficiency	200M words[2]	2,000,000M words[1] 10,000x
Online learning	Lifelong learning	Expensive re-training
Representations	Multimodal, Causal, Hierarchical	Limited?
Energy efficiency	20 years of food	Train: 500 years of food[3] 20 questions: 500ml + 🍌

1) GPT-3, **2)** Fermi estimate: 500 tokens/minute, 10 hours per week, 20 years of life, **3)** from BLOOM, based on 2,000kcal/day

BLOOM footprint https://arxiv.org/pdf/2211.02001.pdf, water consumption https://arxiv.org/pdf/2304.03271.pdf, see also here

Introduction

Motivation *against* brain-inspired AI



Constant sugar supply	Electricity
Temperature sensitive & fragile	Robust to environment
Slow (~ 10ms/op)	Fast (~ 1ns)
Forgets things	Non-volatile memory
Emotional	No emotions (*yet?*)

Lesson #1

Deciding *how* to “take inspiration” is difficult

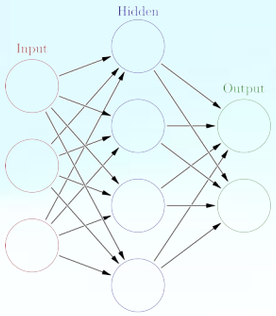
Deep learning

Example of brain-inspired AI

1943

A LOGICAL CALCULUS OF THE IDEAS IMMANENT IN NERVOUS ACTIVITY

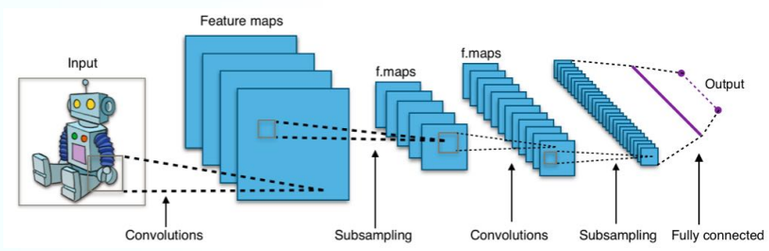
WARREN S. MCCULLOCH AND WALTER PITTS



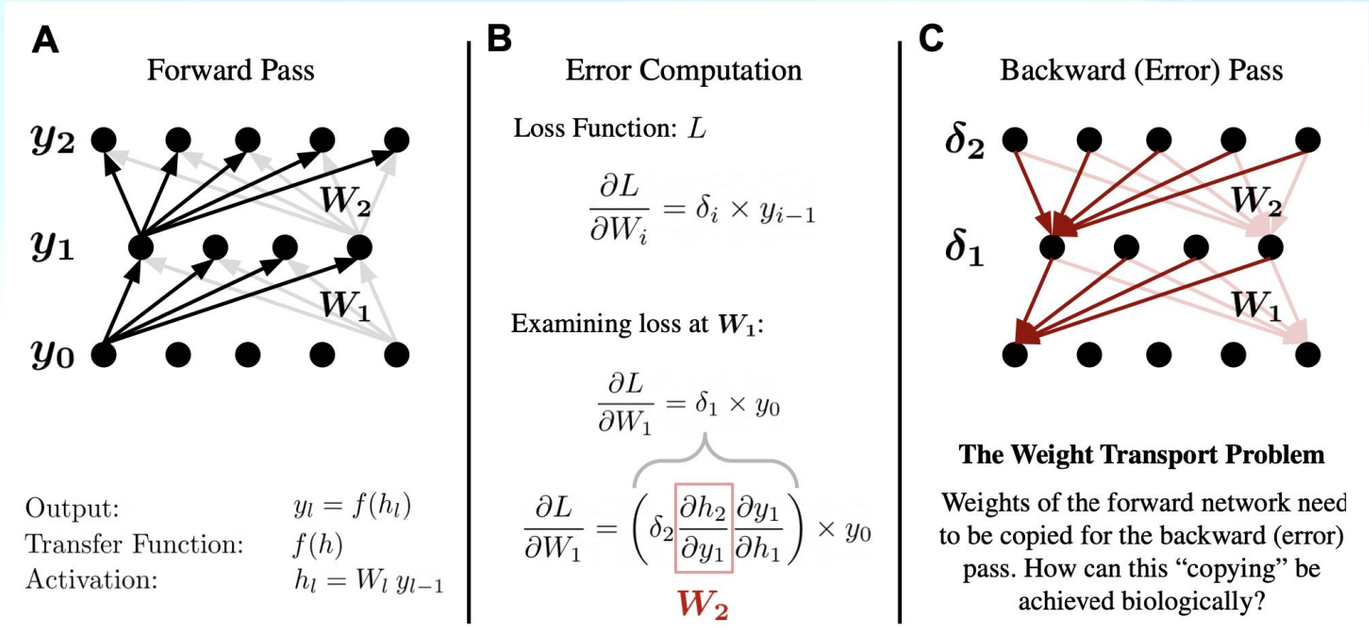
1959

RECEPTIVE FIELDS OF SINGLE NEURONES IN THE CAT'S STRIATE CORTEX

BY D. H. HUBEL* AND T. N. WIESEL*



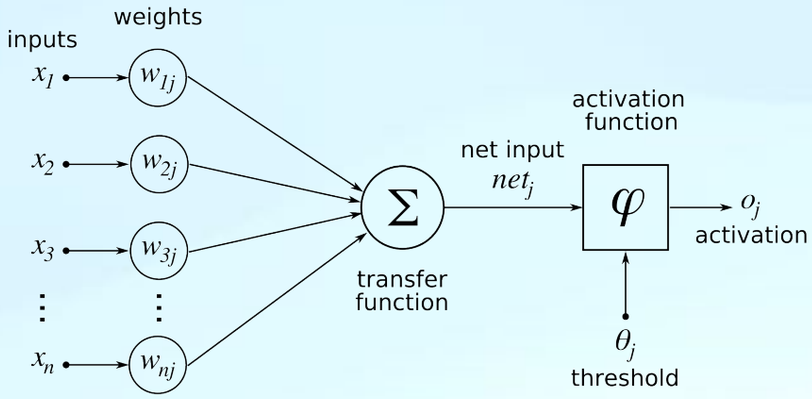
Learning not brain-inspired

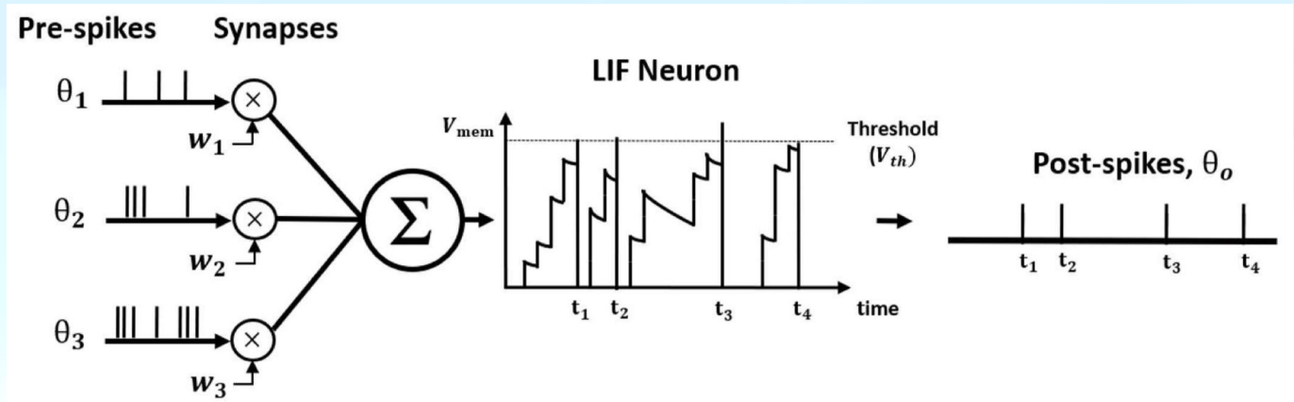


Transformers and LLMs?

Neuromorphic computing

Taking brain-inspired AI to the next level

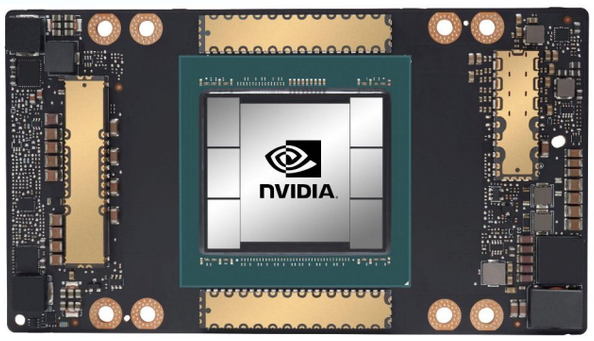


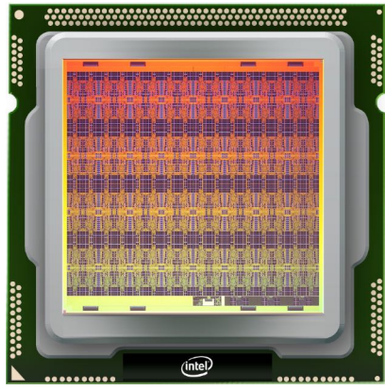


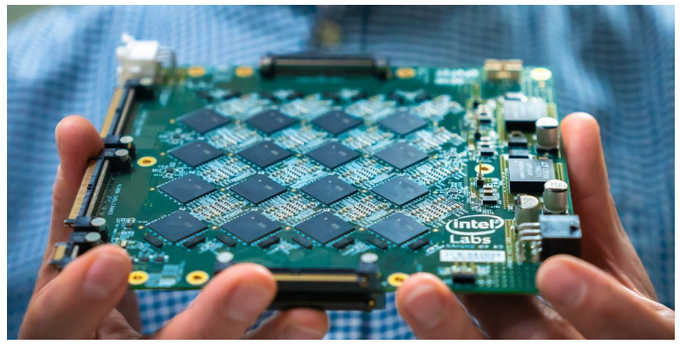
$\vec{x}$ $W\vec{x}$ $f(W\vec{x})$

Artificial neuron

Spiking neuron





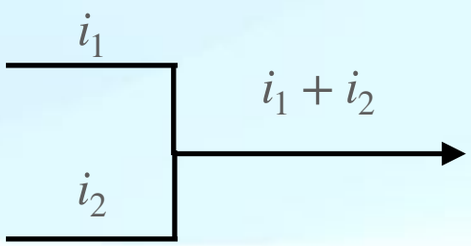


Neuromorphic computing

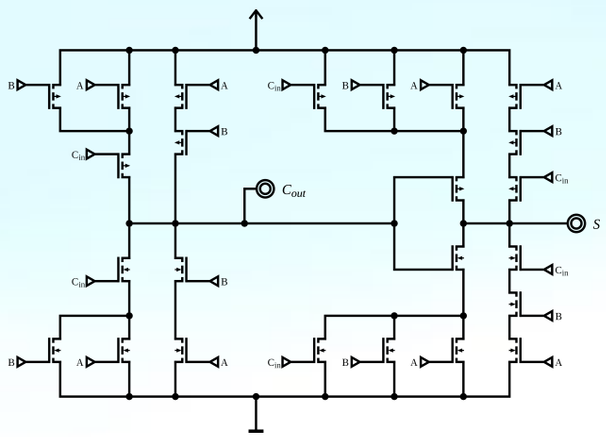
Principle #1: mixed-signal (analog/digital) computation

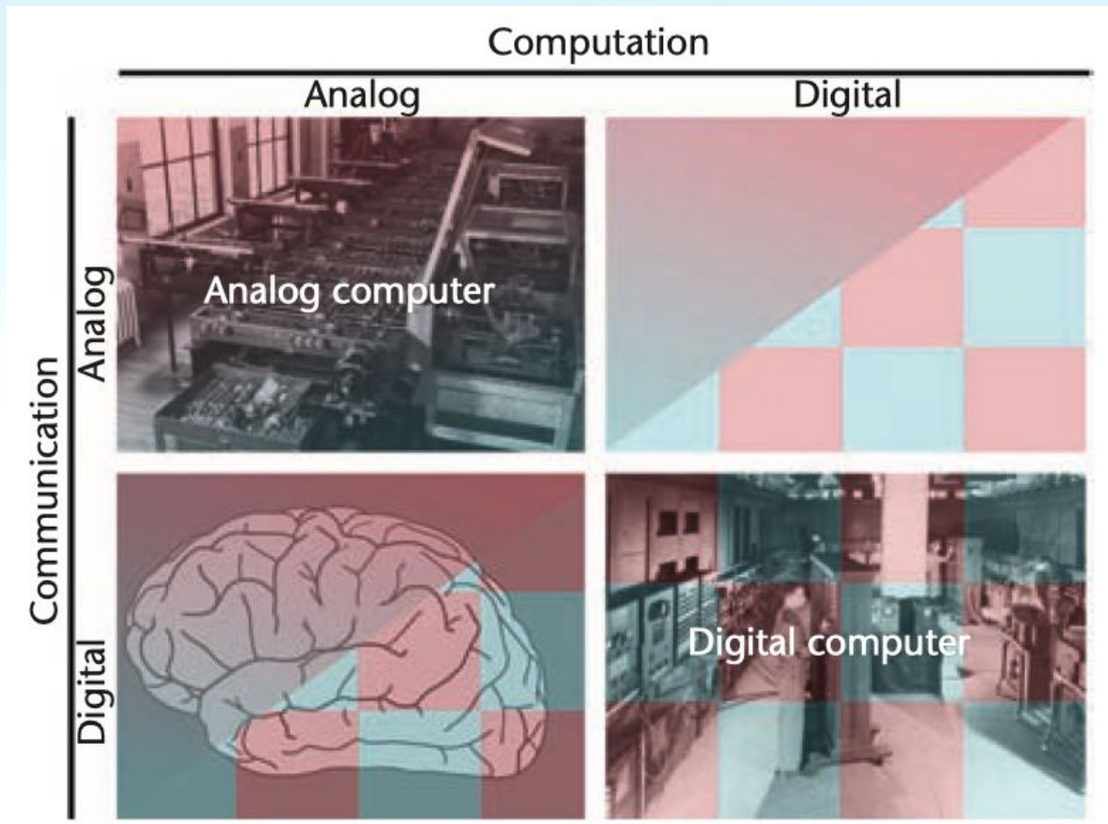
Computation

Analog



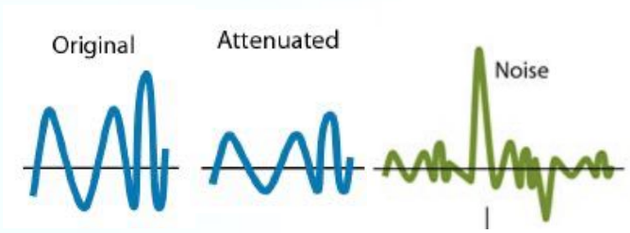
Digital





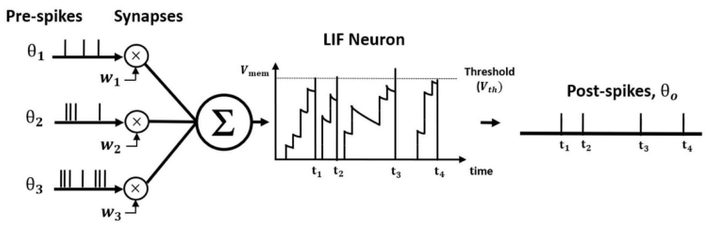
Communication

Analog



Digital

…01110100…

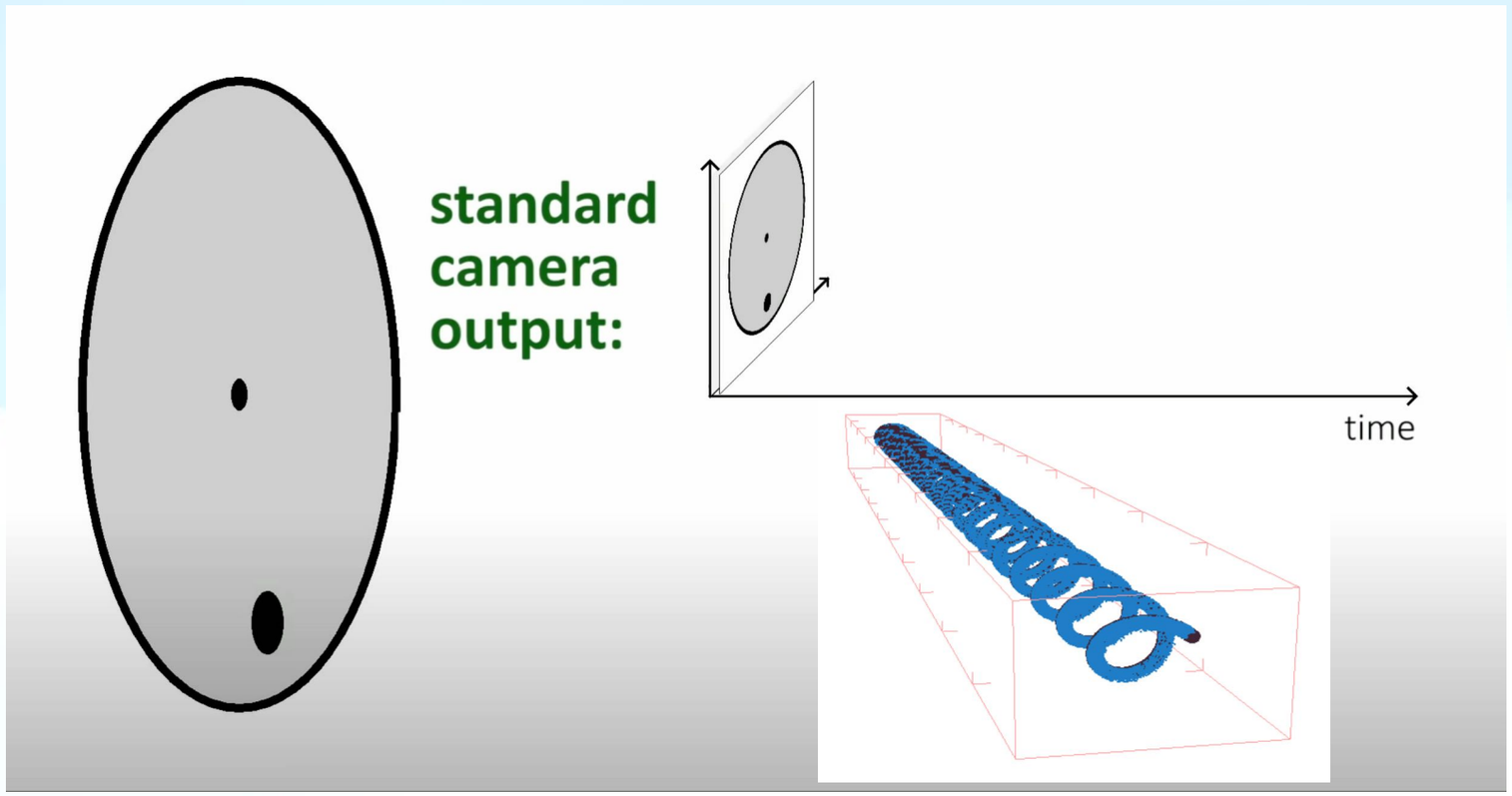


Algorithms and hardware!

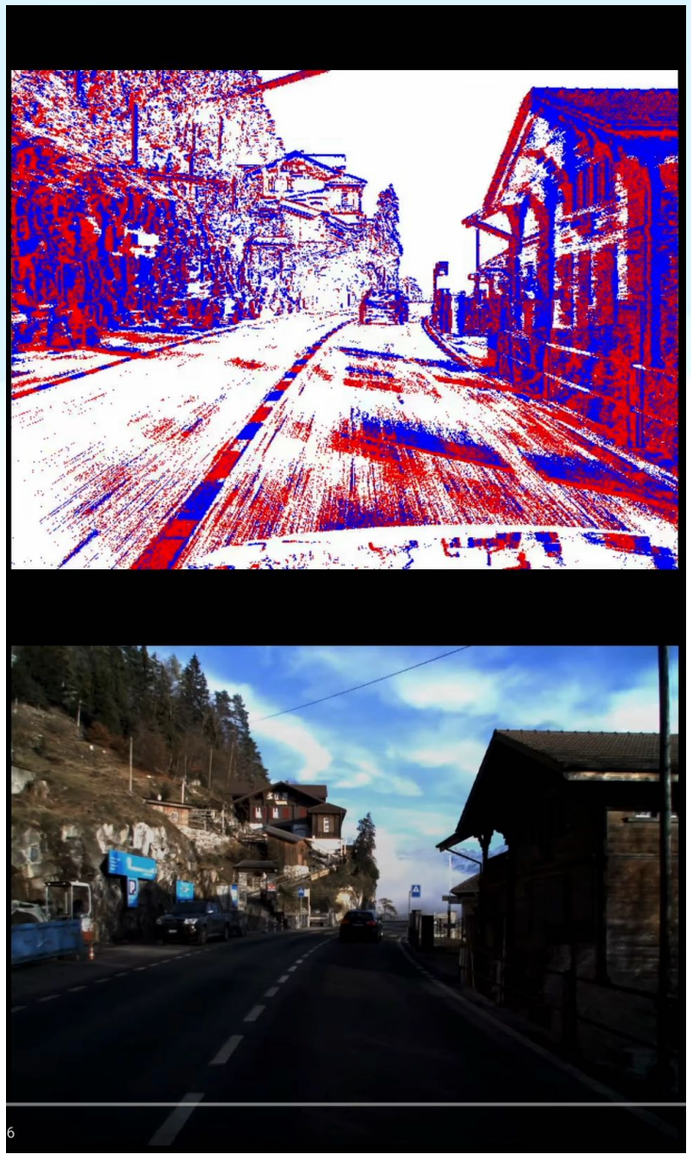
Kwabena Boahen (2017): *A Neuromorph's Prospectus.*

Neuromorphic computing

Principle #2: event-based sensing and processing

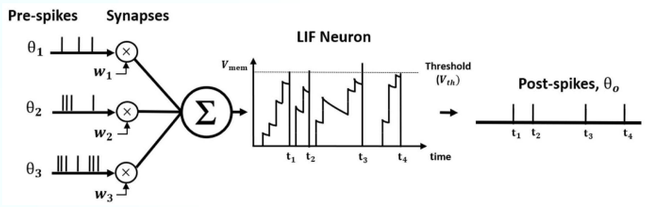


https://youtu.be/W4yW78y4F7A?t=4



Sparse event stream
~ 1 million fps

Difficult to process
on CPUs/GPUs!

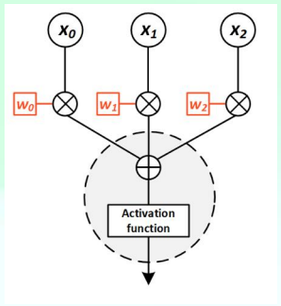


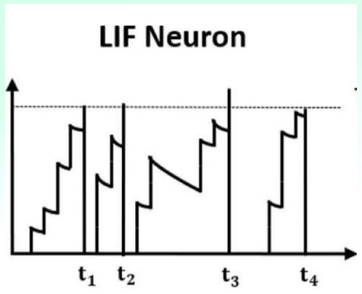
→ **neuromorphic chip!**

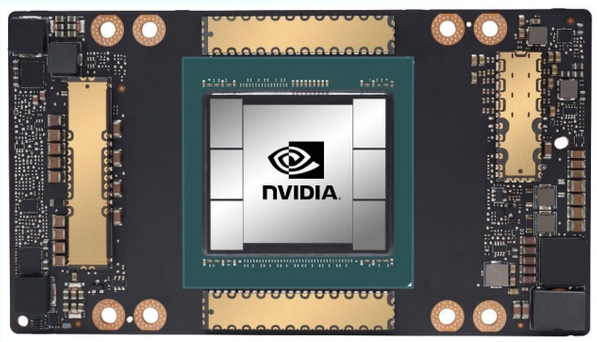
Lesson #2 (a meta-principle)

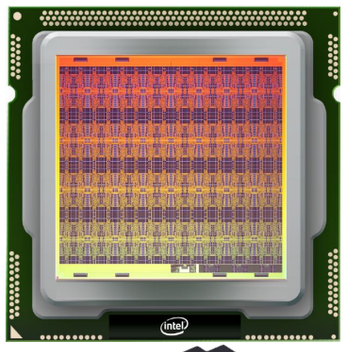
Computation is physical → hardware matters!

- Hardware and algorithms must be ***aligned***









?

Beyond neuromorphic (and GPUs)

A universe of possible computers to be explored

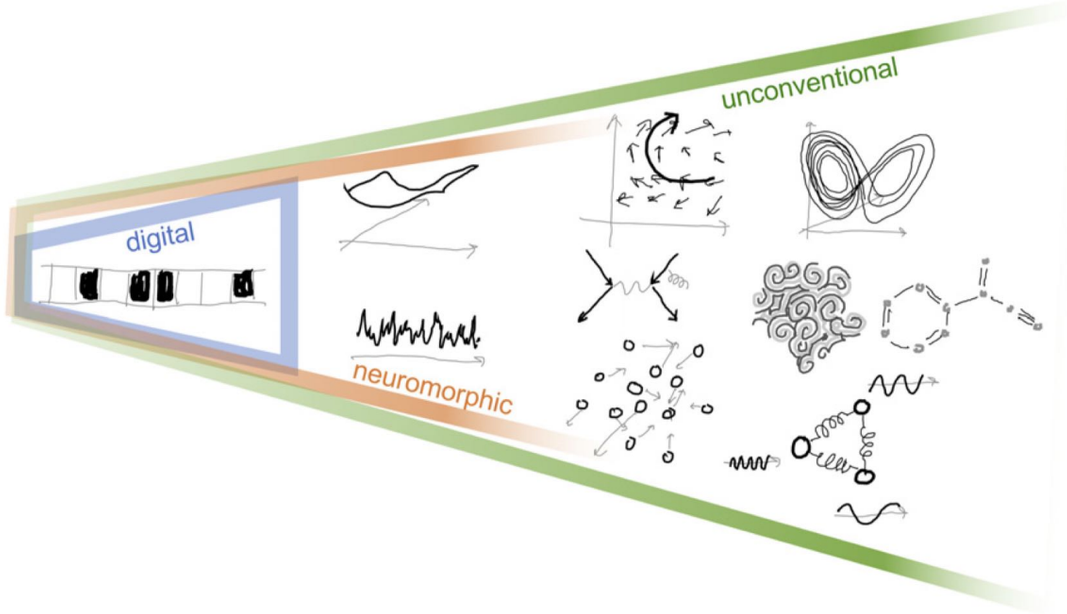
- There is a whole *universe* of alternative computer hardware

"Current AI is what works on GPUs"

The Hardware Lottery

Sara Hooker (Google)

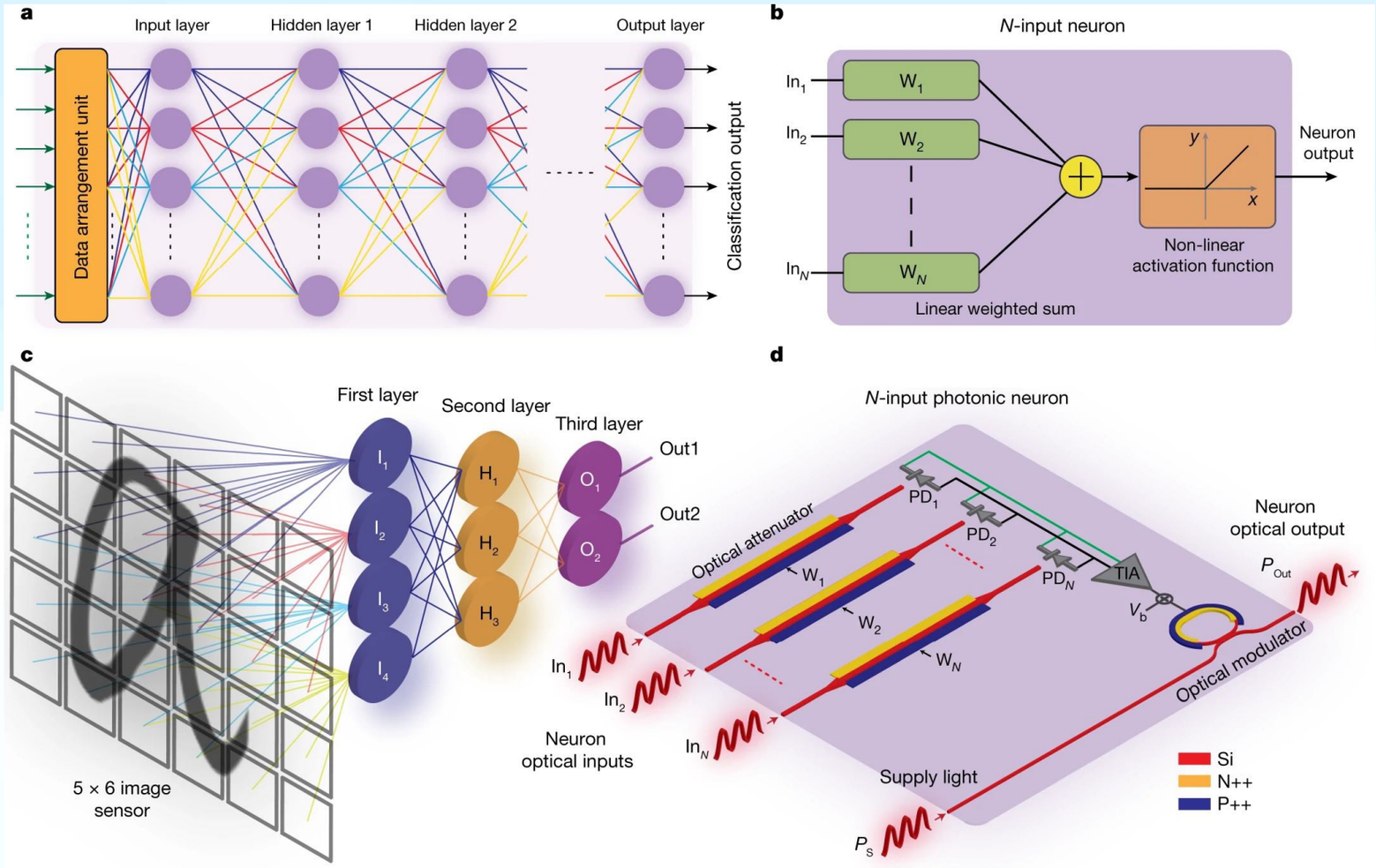
2019



Herbert Jaeger, 2021. *Towards a generalized theory comprising digital, neuromorphic and unconventional computing*

Beyond neuromorphic (and GPUs)

Photonic computing



Ashtiani et al, 2022. *An on-chip photonic deep neural network for image classification*. Nature.

Moving into mainstream AI:

TPU v4: An Optically Reconfigurable...

arXiv:2304.01433, April 2023

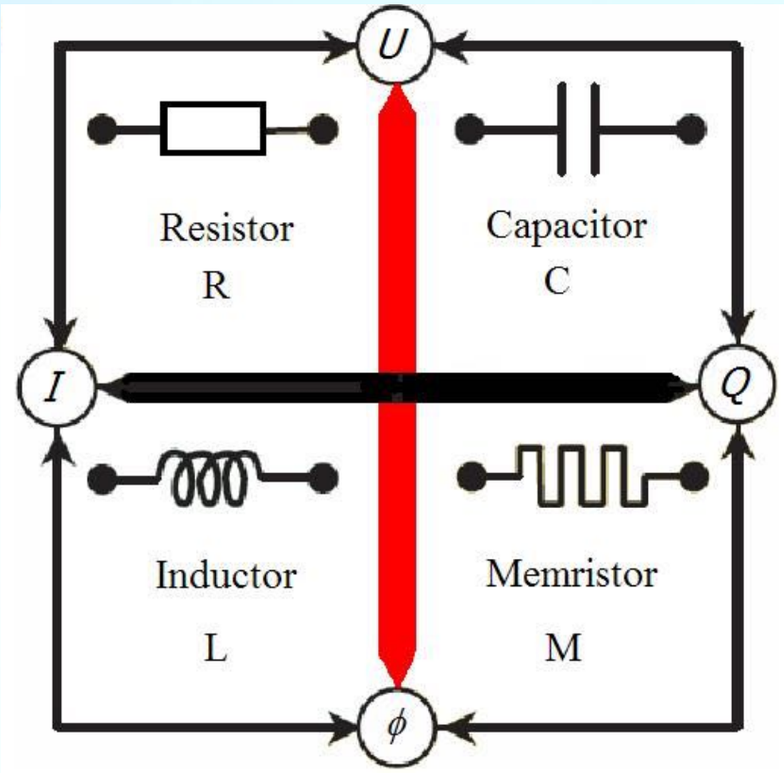
+ much faster

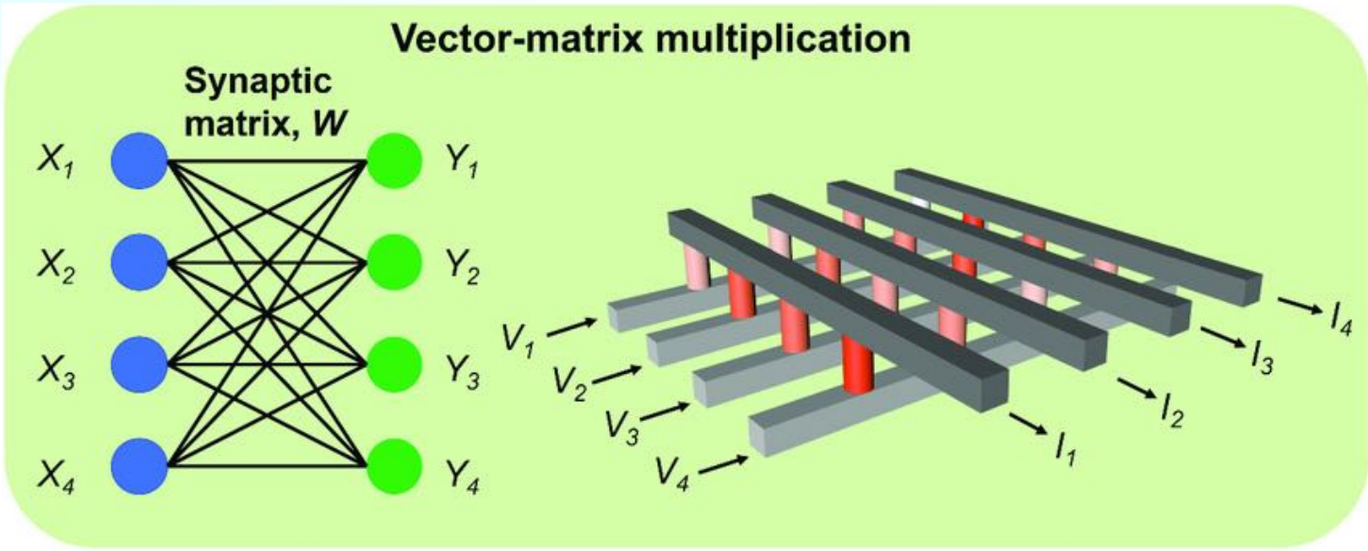
+ less energy

Beyond neuromorphic (and GPUs)

Cognitive materials: memristors & co

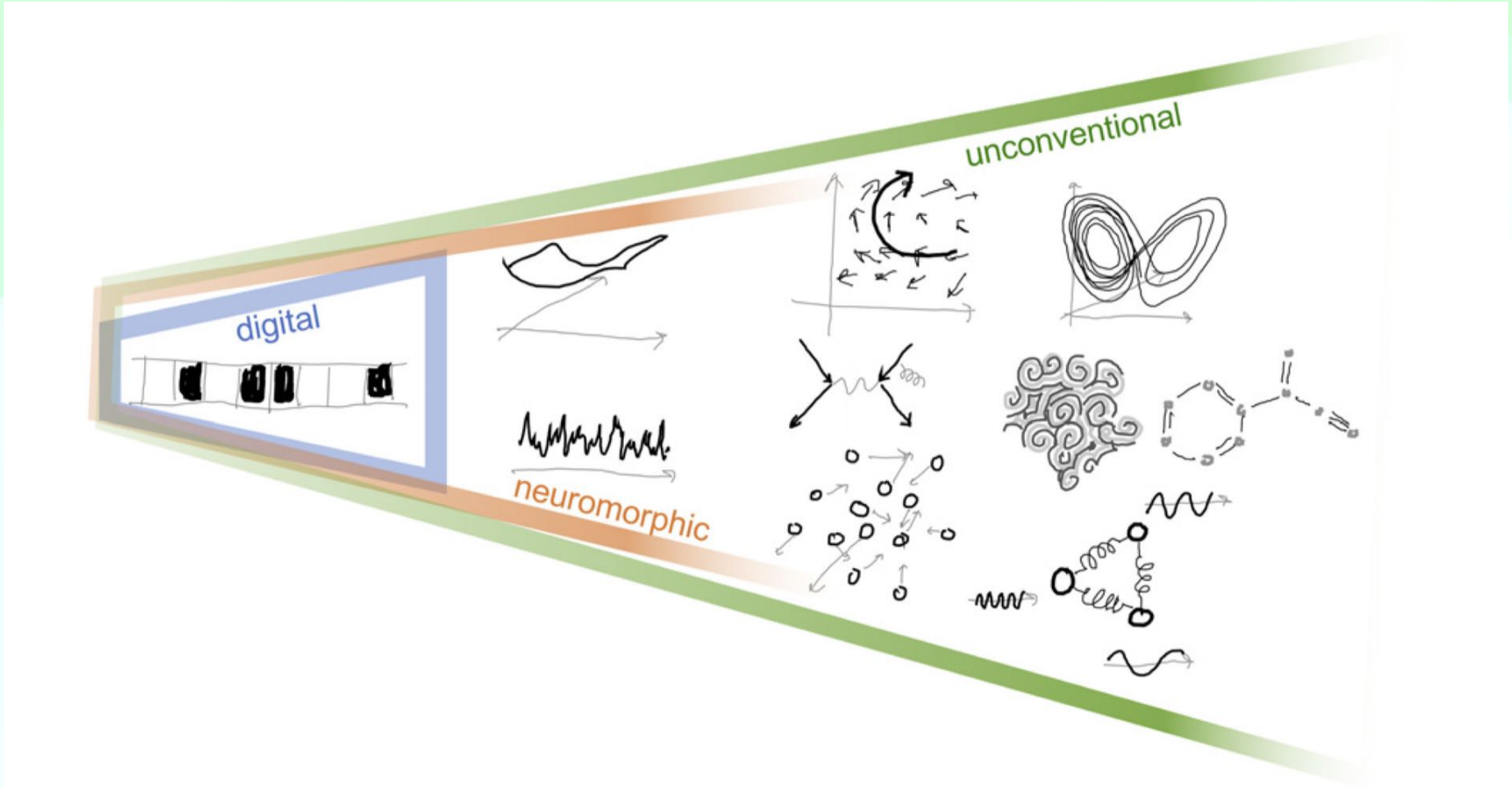
memristors act like synapses





Lesson #3

An explosion of hardware diversity in AI



Herbert Jaeger, 2021. *Towards a generalized theory comprising digital, neuromorphic and unconventional computing*

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thank you

MINDS

ai.rug.nl/minds/

slides on stevenabreu.com

rijksuniversiteit groningen

POST DIGITAL

Image sources

- Slide 4 left: https://en.wikipedia.org/wiki/Artificial_neural_network
- Slide 4 right: https://en.wikipedia.org/wiki/Convolutional_neural_network
- Slide 6 top: https://fr.wikipedia.org/wiki/Ader_Avion_III#/media/Fichier:Ader_Avion_III_001.tif
- Slide 6 left: https://unsplash.com/photos/BRVVZsHuZeg?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText
- Slide 6 right: https://unsplash.com/images/things/airplane?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText
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- Slide 7 right: http://dx.doi.org/10.3389/fnins.2020.00119
- Slide 7 bottom: https://techxplore.com/news/2022-06-neuromorphic-architecture-deep-neural-networks.html
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- Slide 10 right: https://arxiv.org/pdf/2003.03988.pdf
- Slide 10 bottom: https://techxplore.com/news/2022-06-neuromorphic-architecture-deep-neural-networks.html
- Slide 12: TODO
- Brain https://unsplash.com/photos/58Z17InVS4U
- Loihi chip https://qbi.uq.edu.au/brains-chip-neuromorphic-computing
- GPU https://developer.nvidia.com/blog/nvidia-ampere-architecture-in-depth/
- memristive crossbar array https://doi.org/10.1002/aisy.202000149
- memristor https://www.science20.com/alpha_meme/detractors_not_grasping_the_memristor-93011