Basler AG: Neuromorphic Computing

Fishing for Experience – Project 3 || WiSe 22-23

BASLER the power of sight

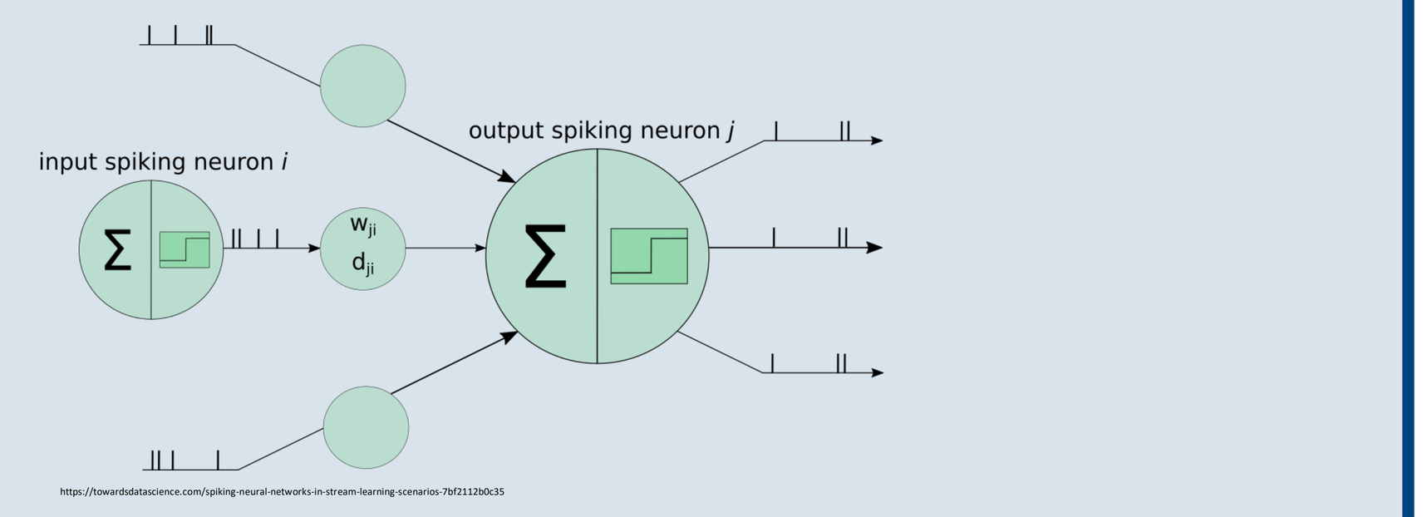
TUHH Technische Universität Hamburg

FISHING FOR EXPERIENCE

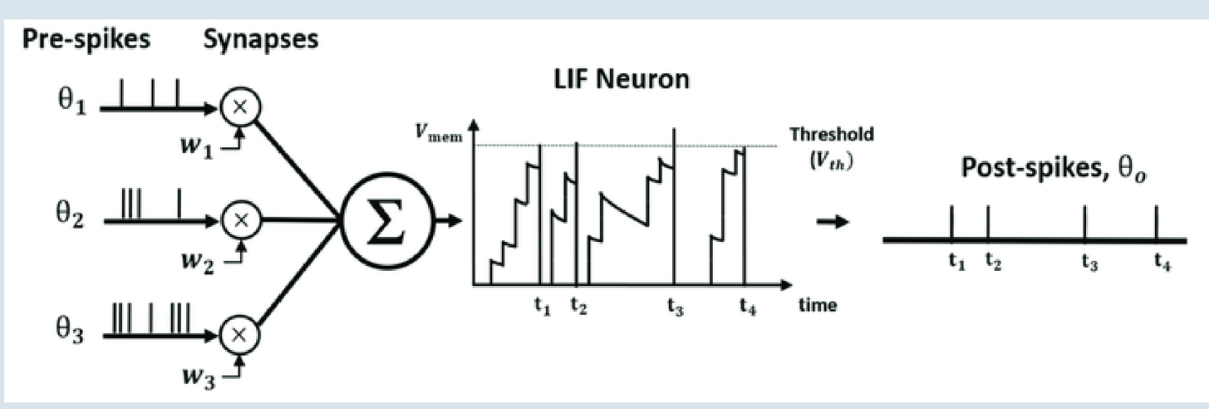
Network Architecture

https://towardsdatascience.com/mcculloch-pitts-model-5fdf65ac5dd1

Spiking neural networks support and are optimized for neuromorphic computing.



https://towardsdatascience.com/spiking-neural-networks-in-stream-learning-scenarios-7bf2112b0c35

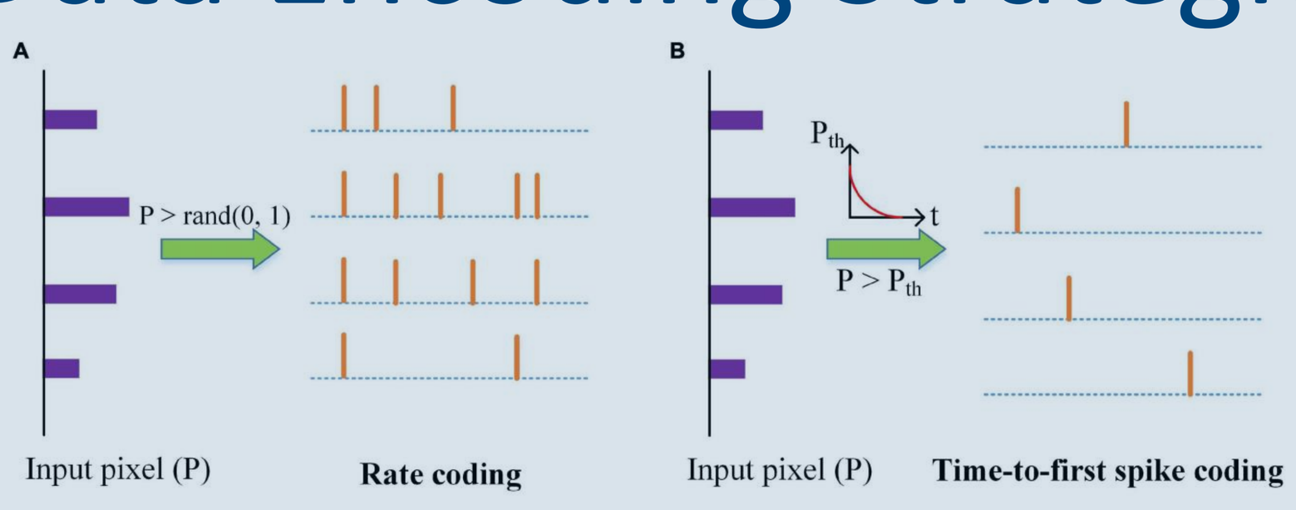


https://www.researchgate.net/figure/The-illustration-of-Leaky-Integrate-and-Fire-LIF-neuron-dynamics-The-pre-spikes-are_fig1_339574089

The network is composed of multiple Leaky Integrate-and-Fire Neuron

- Each neuron is composed of a membrane that can stock a voltage potential
- Once the membrane reaches a certain potential threshold, it will fire a spike
- The membrane has a constant decay time to 0

Data Encoding Strategies



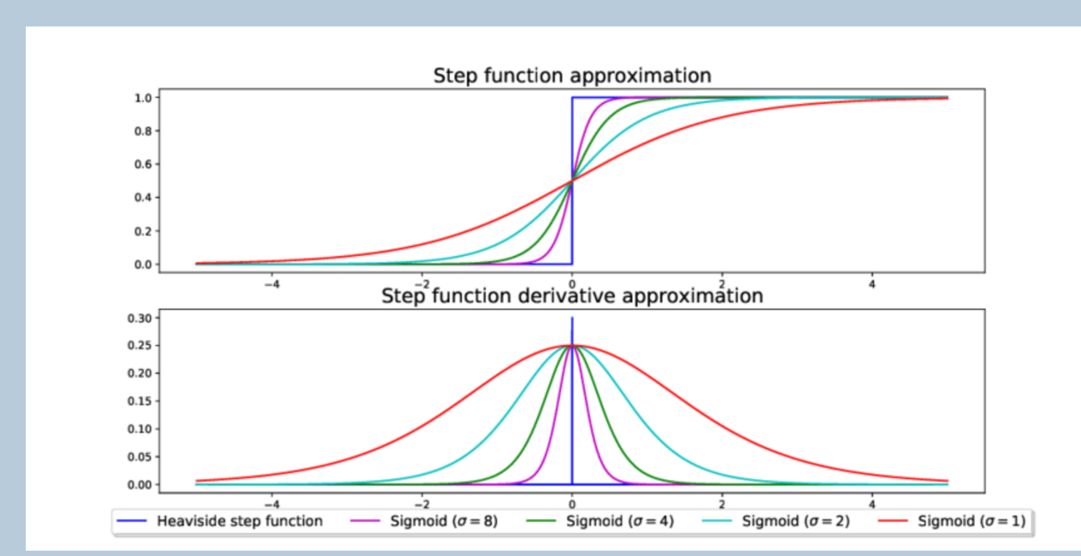
https://www.frontiersin.org/articles/10.3389/fnins.2021.638474/full

Because of the nature of spiking neural networks, raw data must be converted to spikes. There are two encoding schemes:

1. Spike frequency (rate codes):
   - Information is stored in spike count or firing rate throughout the firing window
2. Spike time (temporal codes):
   - Information is stored in the timing of a single spike throughout the firing window.

Training

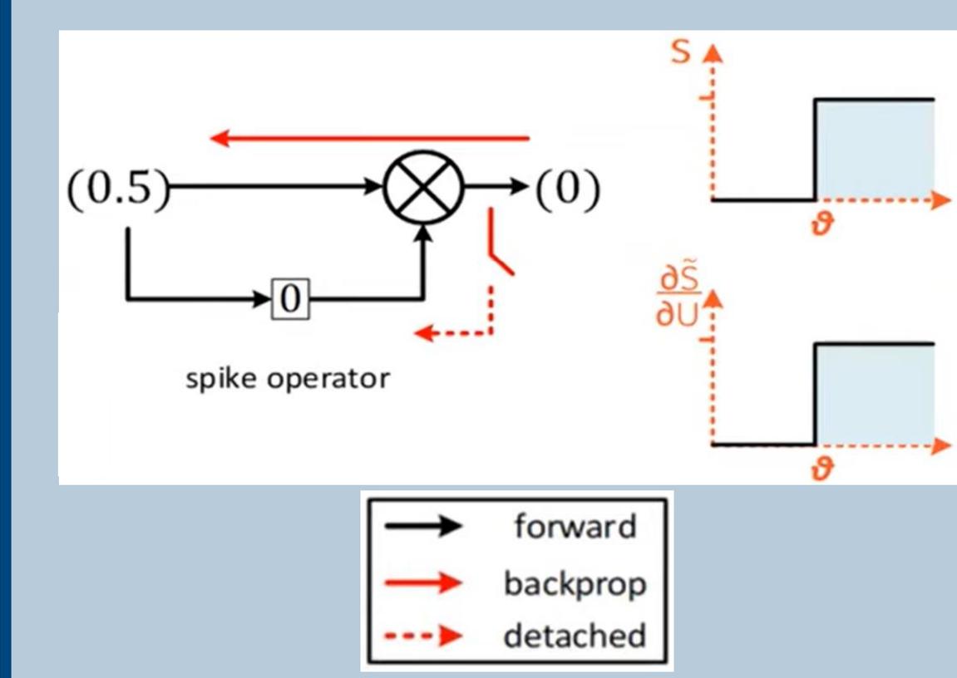
Back Propagation Through Time Surrogate Gradients



https://www.frontiersin.org/articles/10.3389/fnins.2021.638474/full

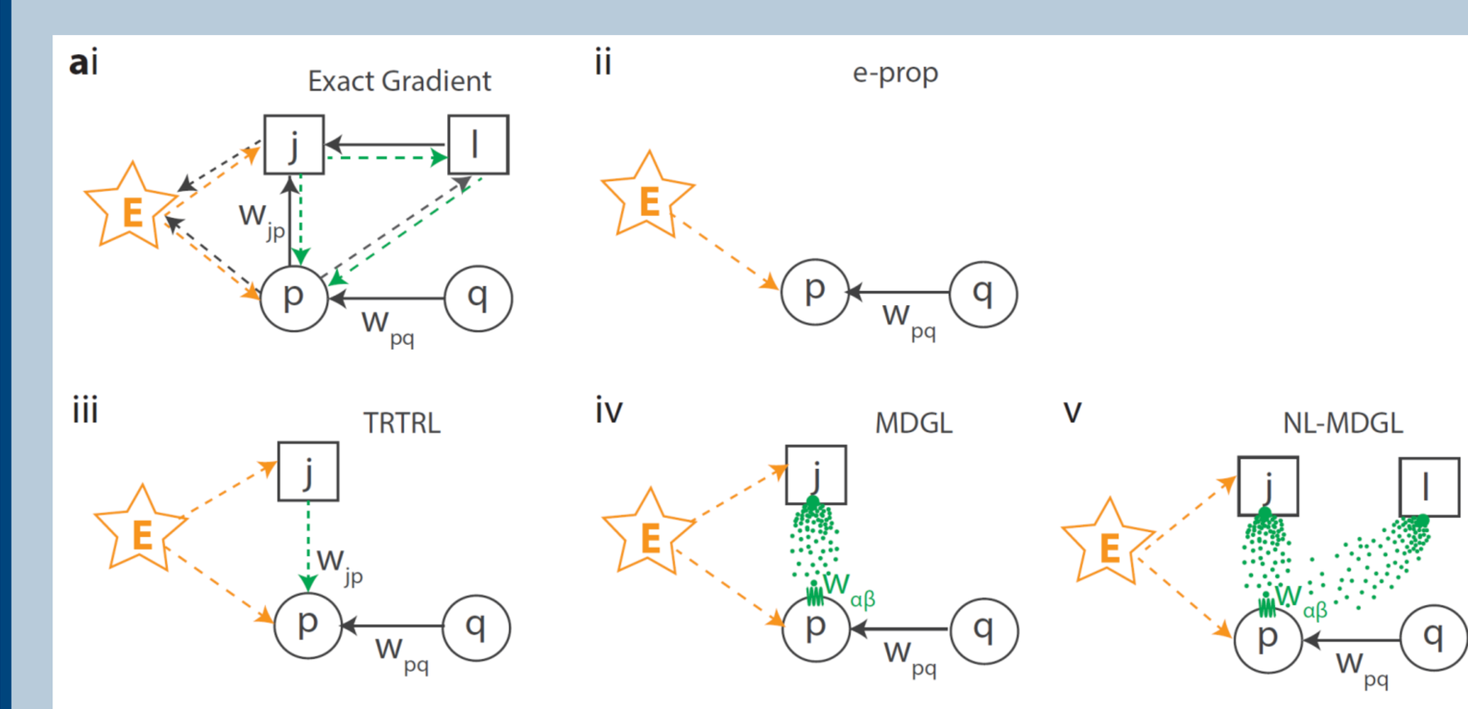
- Approximate the gradient through other activation functions during the backward pass
- Smooth out the Heaviside function to a sigmoid of a double exponential

Spike Operator



- A neuron is separated into two operating modes: one where it spikes and one where it doesn't
- The derivative is equal to the occurrence of a spike, so the gradient will be calculated at the same time as the forward pass
- The gradient of non-spiking neurons will be replaced with a small random value which provides an unbiased estimator that can overcome the dead neuron problem

Online Learning



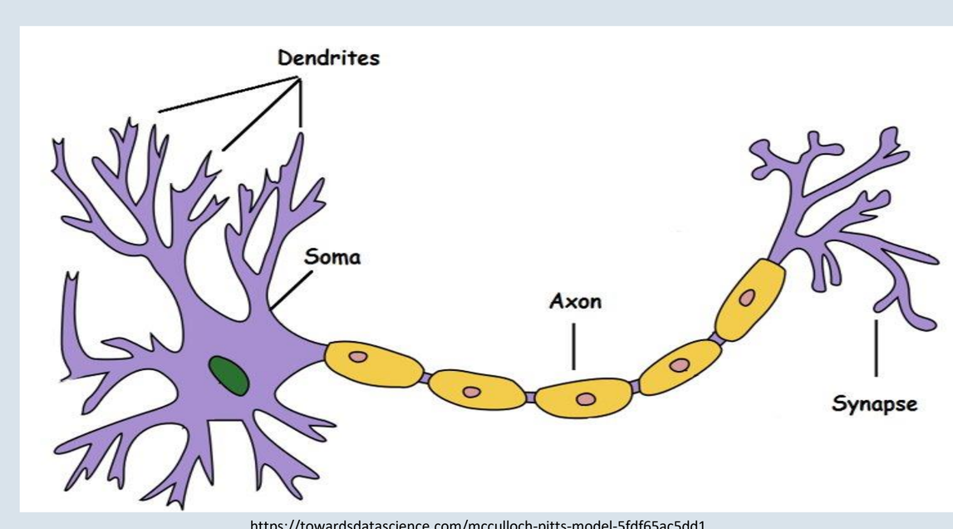
https://www.biorxiv.org/content/10.1101/2020.11.22.393504v1

Real-time Recurrent Learning (RTRL): Calculates the same gradients as BPTT, but with a different method of computation (influence matrix) to make it temporally local.

e-prop: The weights are then updated by multiplying the eligibility trace (approx. of its derivative * the incoming spike train) and the learning signal (similar to the loss function).

Multi-digraph learning (MDGL): Uses the Hebbian eligibility trace, which is a unified framework that integrates the eligibility trace as well as local and top-down modulatory signals into a new multi-factor learning rule.

Neuromorphic Computing



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Inspiration from Biology

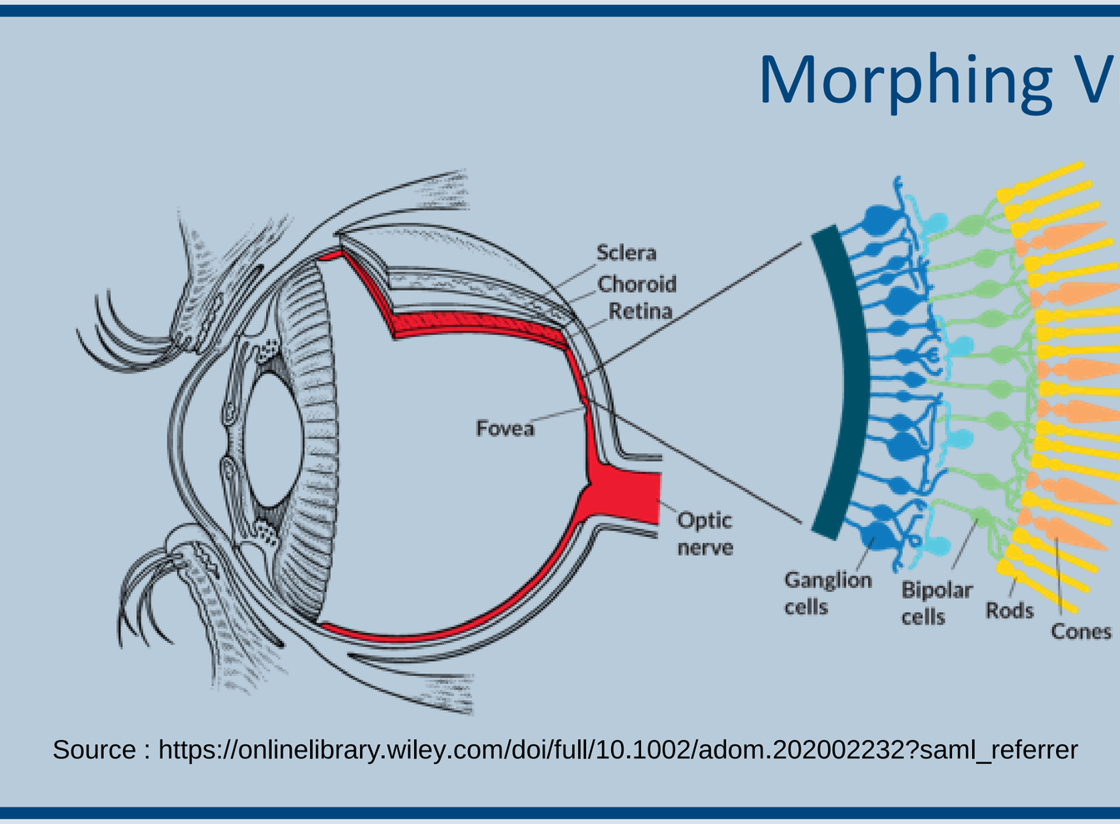
Events in Nervous System

Excitatory postsynaptic current (EPSC) :The binding of neurotransmitters induces the opening of cationic channels, which is depolarizing the cell. These induced electrical events are called excitatory postsynaptic currents.

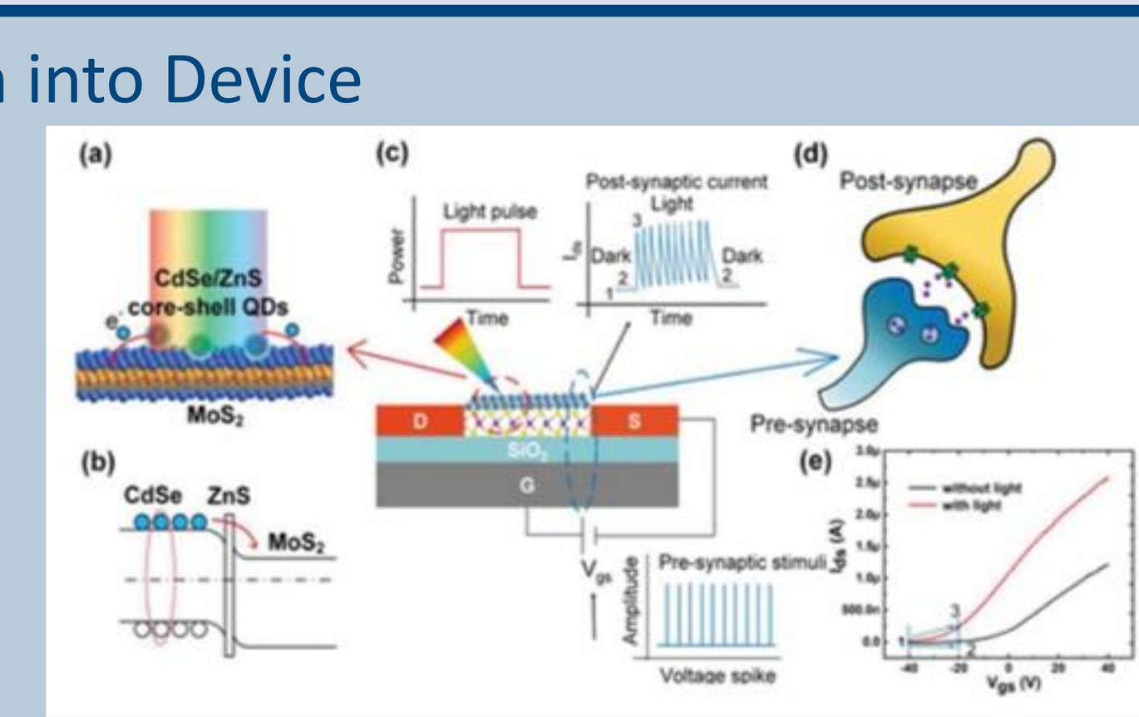
Inhibitory postsynaptic current (IPSC) : An inhibitory postsynaptic potential (IPSP) is a kind of synaptic potential that makes a postsynaptic neuron less likely to generate an action potential.

Potentiation & Depression : Long-term potentiation and long-term depression are enduring changes in synaptic strength, induced by specific patterns of synaptic activity.

Morphing Vision into Device

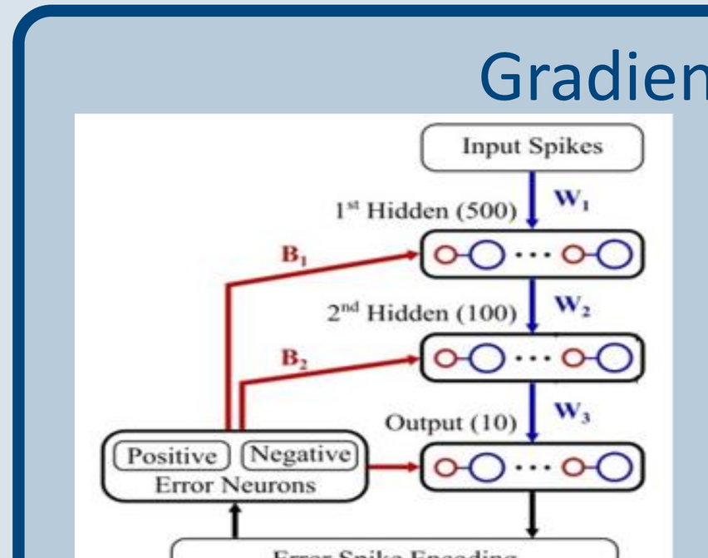


Source : https://onlinelibrary.wiley.com/doi/full/10.1002/adom.202002232?saml_referrer



Source: https://onlinelibrary.wiley.com/doi/full/10.1002/adom.202002232?saml_referrer

Gradient Based Learning for Spiking Neural Networks

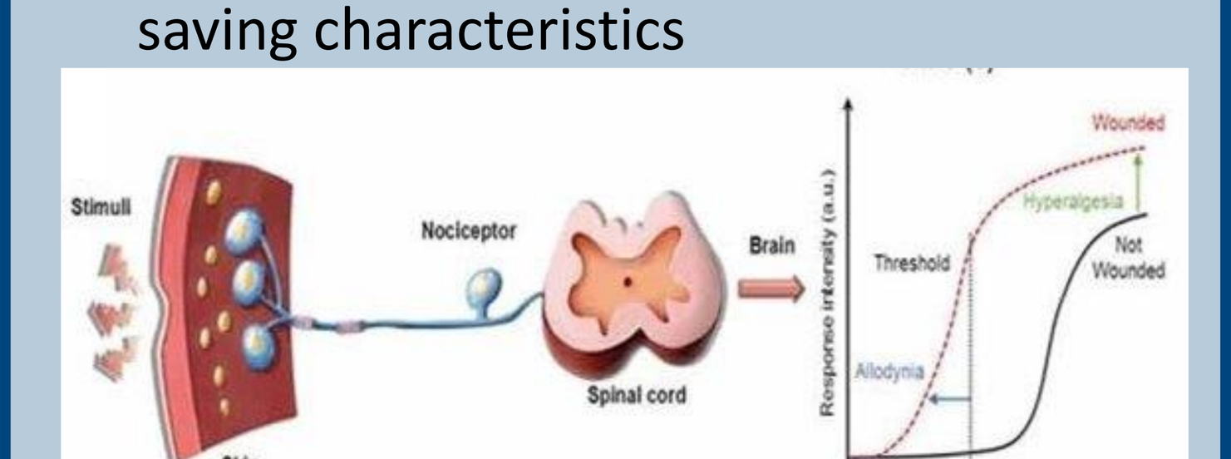


Source : https://arxiv.org/pdf/2110.14092.pdf

- Inspired by Neocortical pyramidal neurons: multi-compartment neurons
- Receive the feedforward and feedback information in separate compartments
- In the periodic "sleep" phase, feedback weights are updated to match the feedforward weights

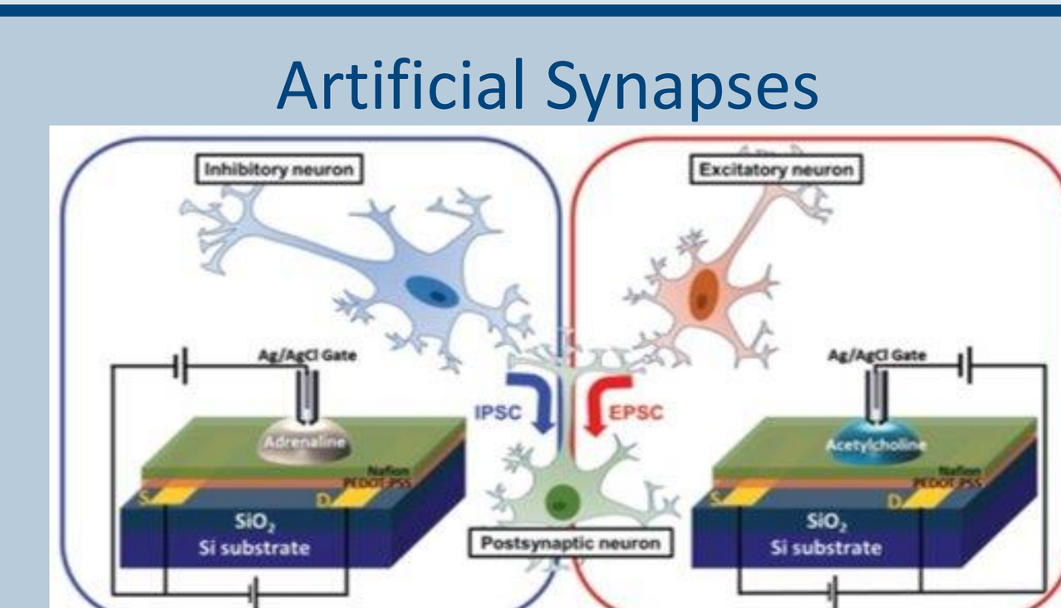
Artificial tactile perception system

- Artificial tactile sensing system by coupling resistive-type tactile sensor with neuromorphic device
- Tactile sensor is based on the triboelectric effect simple structure, which has high efficiency and energy-saving characteristics



Source: https://www.tandfonline.com/doi/full/10.1080/14686996.2022.2152290

Artificial Synapses



Source: https://onlinelibrary.wiley.com/doi/full/10.1002/adfm.202200497?saml_referrer

- Neuro transmitters control the signal transmission in the nervous system
- EPSC, IPSC behaviours are emulated by the modulating conductance of electrolytes
- Acetylcholine exhibited EPSC functions
- Adrenaline based device exhibit IPSC characteristics

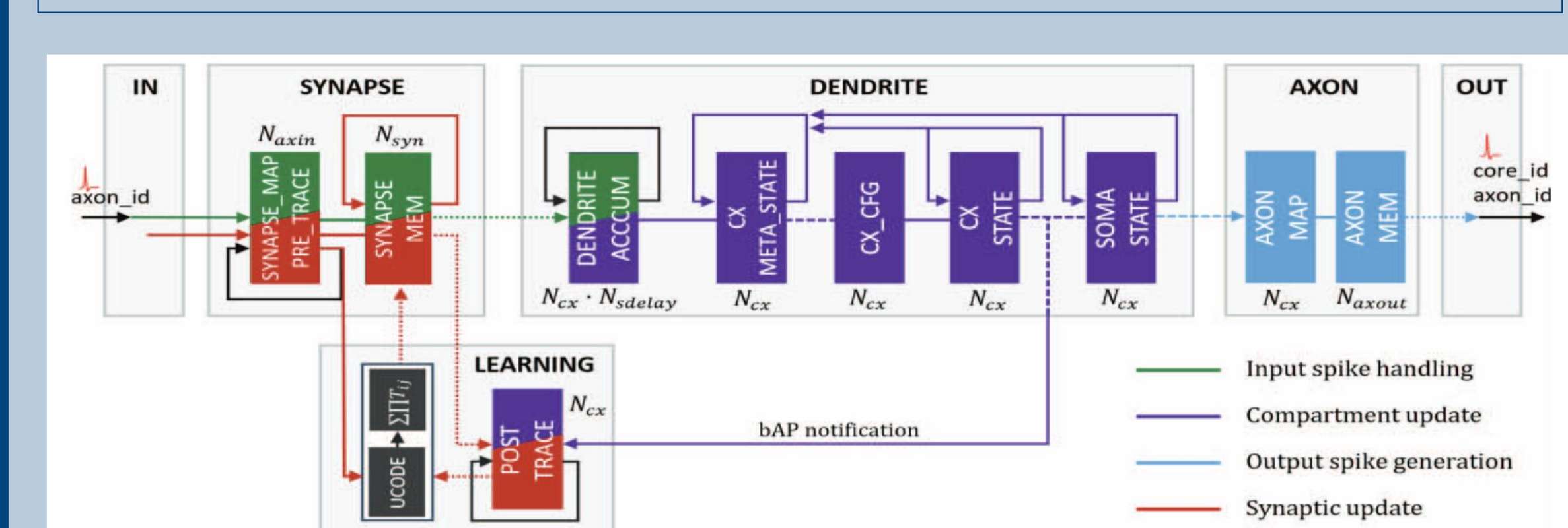
Hardware

Microarchitecture of Neuromorphic chip

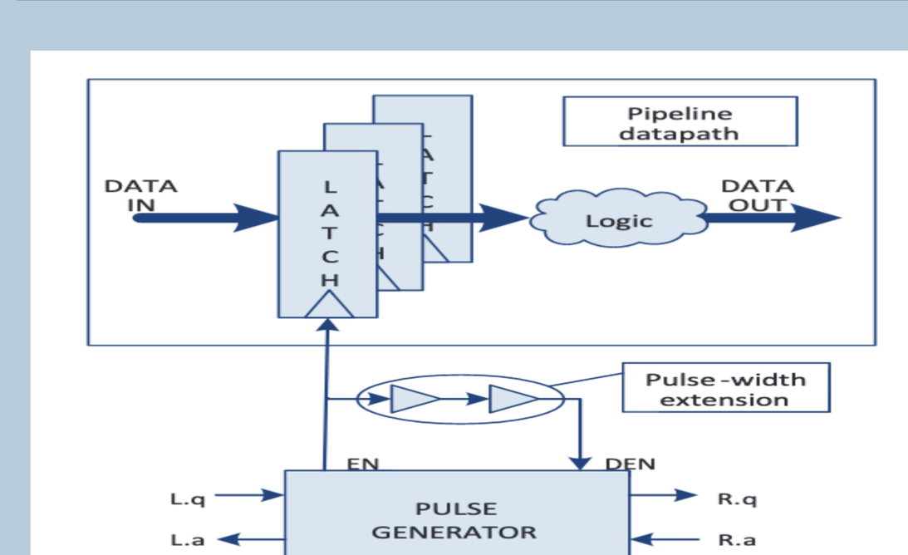
Highly integrated digital neuromorphic chips:-

1. TrueNorth – more energy efficient than previous analog hardware.
2. Loihi – Focused on Research to compare architecture with Von Neumann.
3. BrainChip – Commerical chip for applications in cyber security, edge classification. It provides ultra-low power consumption.

- Any neuron may direct a single spike to any number of destination cores out of 128.
- It supports precision between one and nine bits, signed or unsigned.



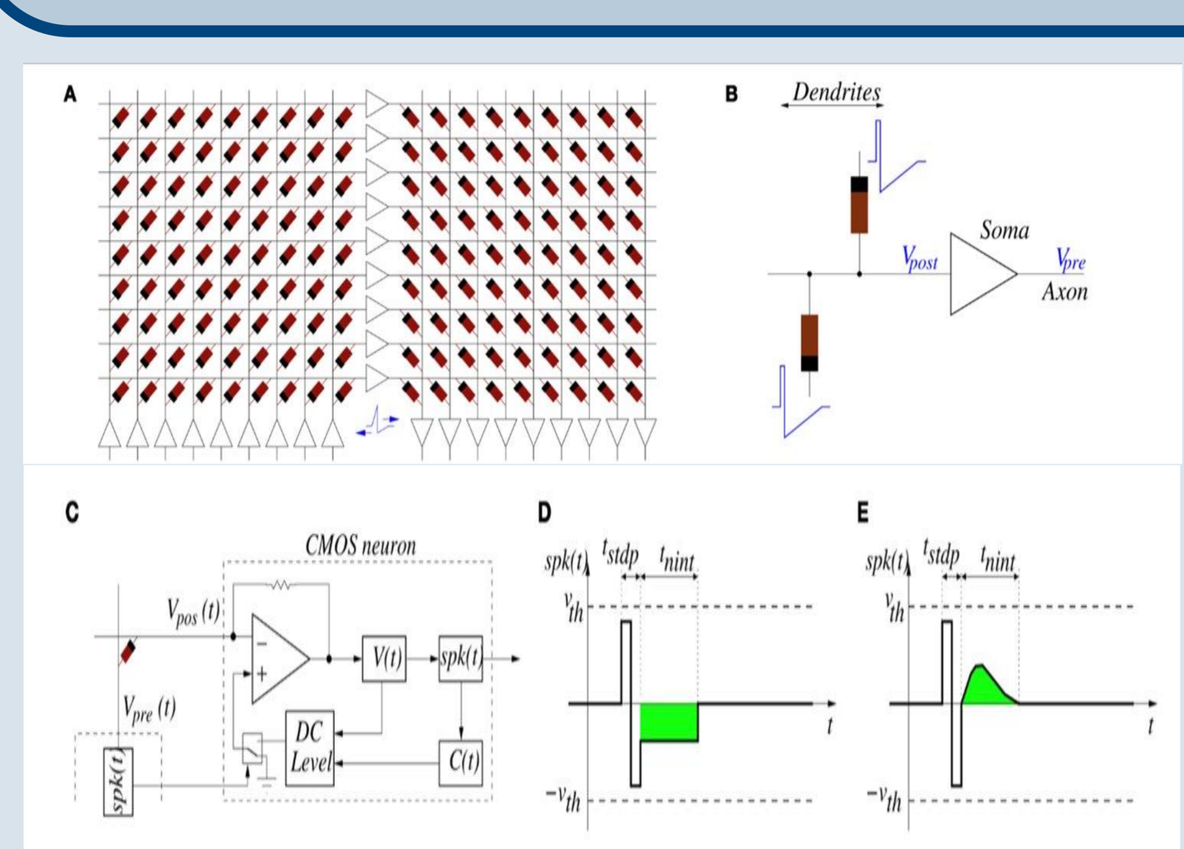
https://www.researchgate.net/publication/322548911_Loihi_A_Neuromorphic_Manycore_Processor_with_On-Chip_Learning



The SYNAPSE unit processes all incoming spikes and reads out the associated synaptic weights from the memory.
The DENDRITE unit updates the state variables of all neurons in the core.
The AXON unit generates spike messages for each firing neuron.
The LEARNING unit updates synaptic weights.

Loihi 2 is better, why?

- 3-D Scaling.
- Generalised Spikes – 32 bit.
- 8x more neurons - Smaller die size.
- Generation of Spikes – 10x faster.

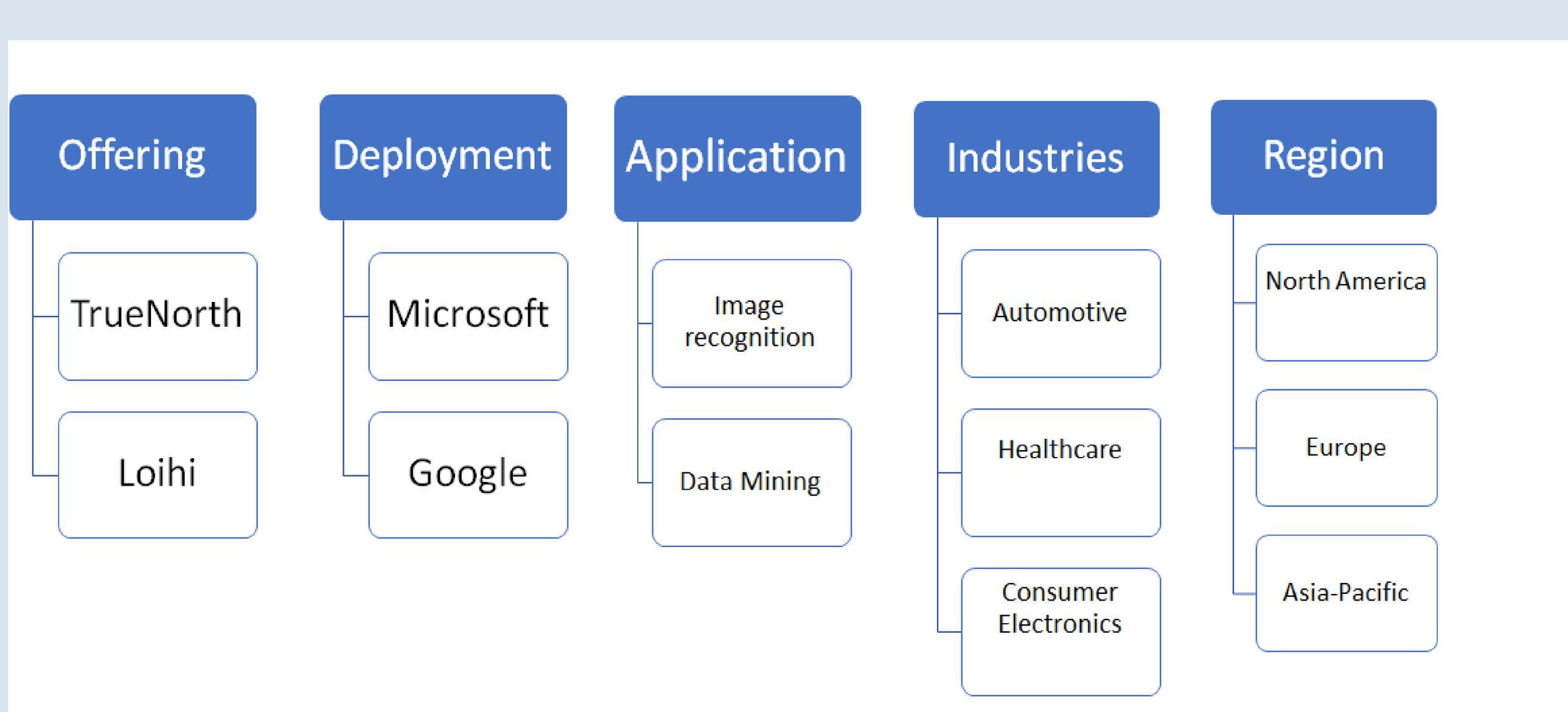


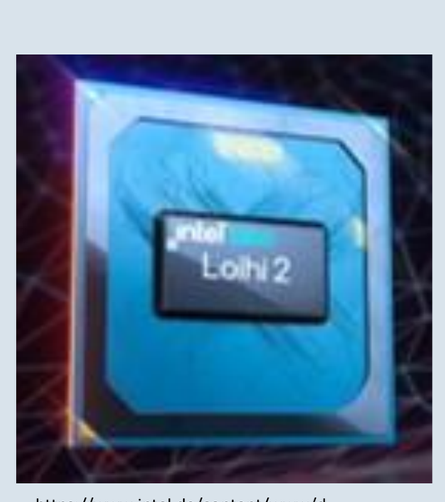
https://www.researchgate.net/publication/235669807_STDP_and_STDP_Variations_with_Memristors_for_Spiking_Neuromorphic_Learning_Systems

CMOS - Memristors

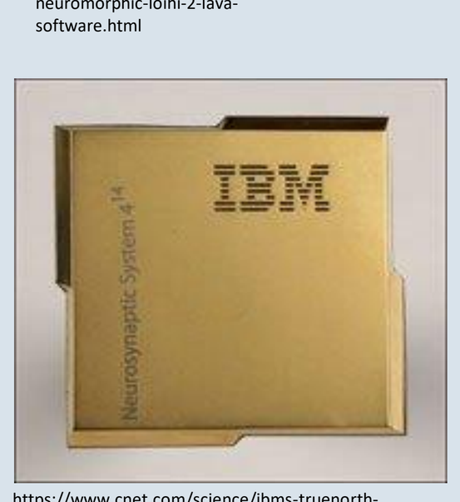
- Parts around one post-synaptic neuron :-
  When a neuron is sending a spike, it sets a voltage spike at both nodes otherwise a constant DC voltage.
- CMOS neuron together with single memristor synapse connected between pre- and post-synaptic neurons.
- Spike waveform with negative square neural activation shape, and waveform with positive biological neural activation.

Neuromorphic Computing Market



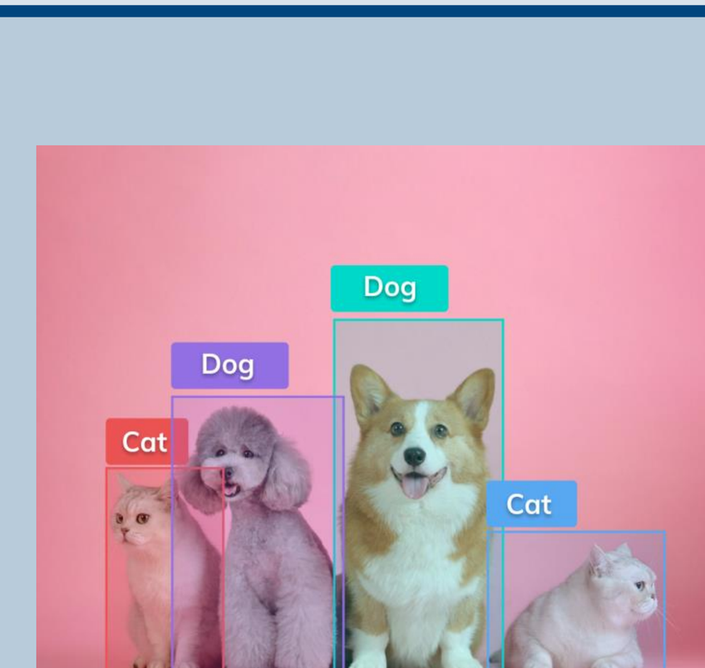


https://www.intel.de/content/www/de/de/newsroom/news/intel-unveils-neuromorphic-loihi-2-lava-software.html



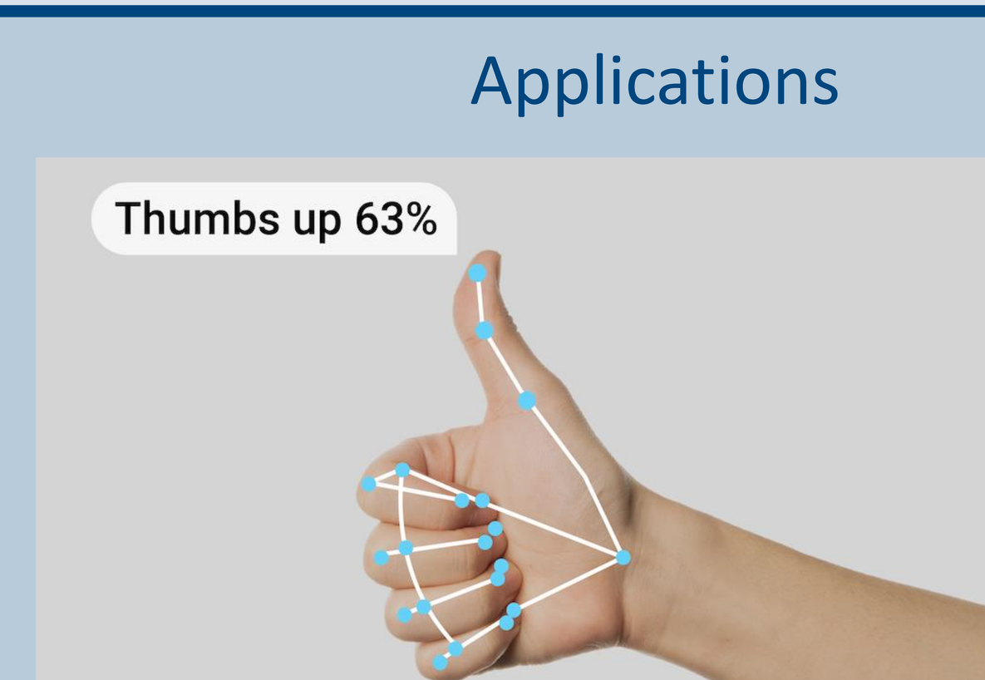
https://www.cnet.com/science/ibms-truenorth-processor-mimics-the-human-brain/

Applications



https://www.v7labs.com/blog/object-detection-guide

Object Detection



https://developers.google.com/mediapipe/solutions/vision/gesture_recognizer

Gesture Recognition

https://www.cio.de/a/wann-augmented-reality-wirklich-sinn-macht,3577297

Augmented Reality