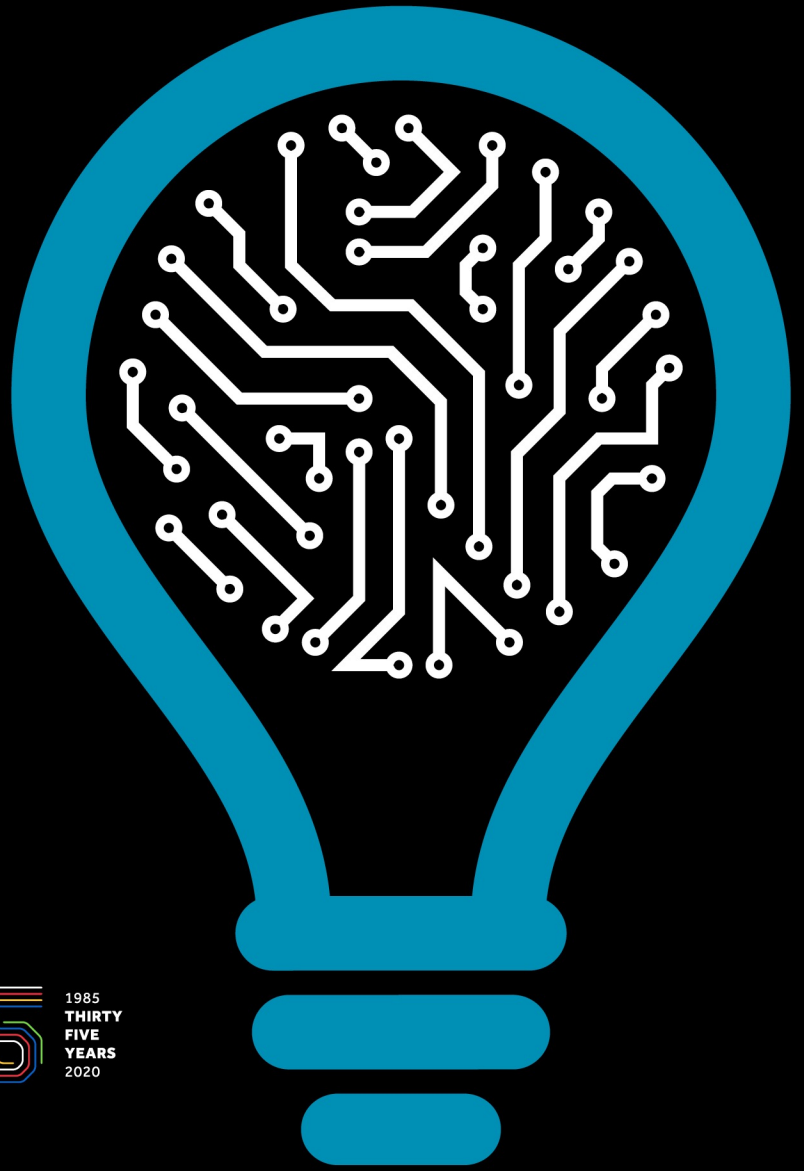
from knowledge generation to science-based innovation

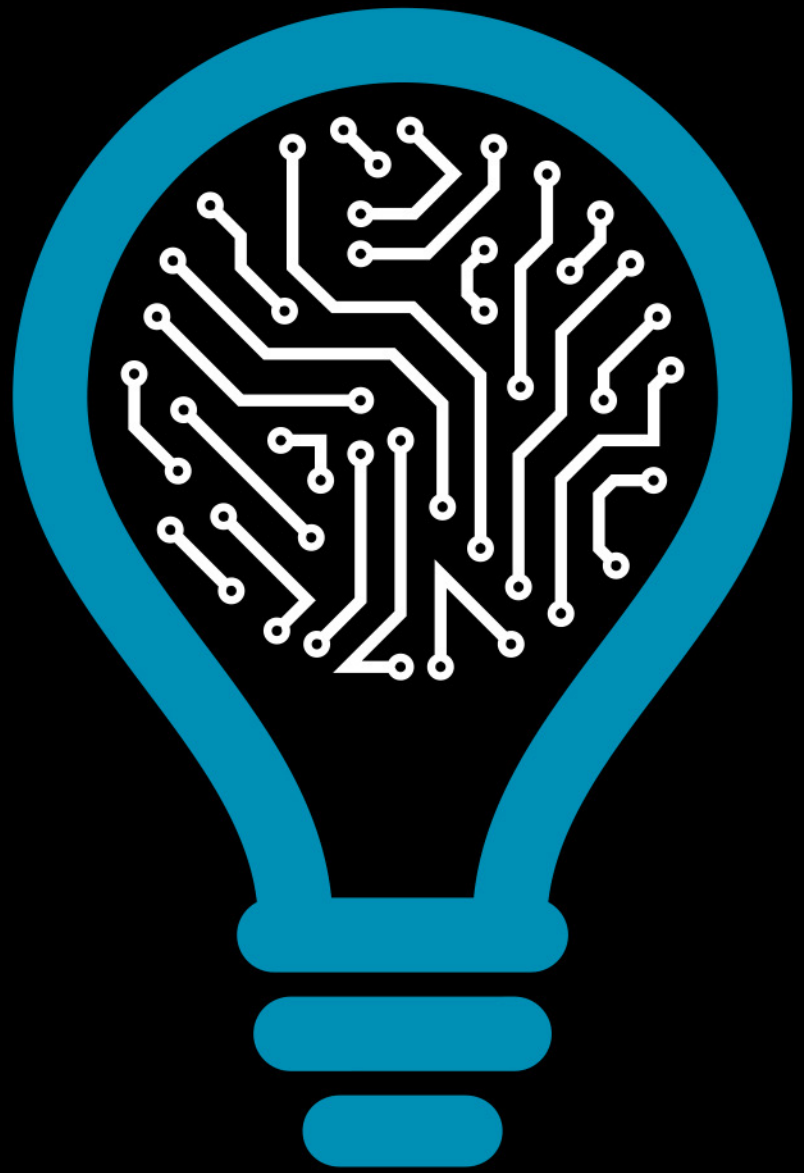


INESCTEC

1985 THIRTY FIVE YEARS 2020

INSTITUTE FOR SYSTEMS AND COMPUTER ENGINEERING, TECHNOLOGY AND SCIENCE

OPEN DAY CTM 2021



Memristors for Neuromorphic Computing

Vítor Grade Tavares / Asal Kiazadeh (i3N — CENIMAT)

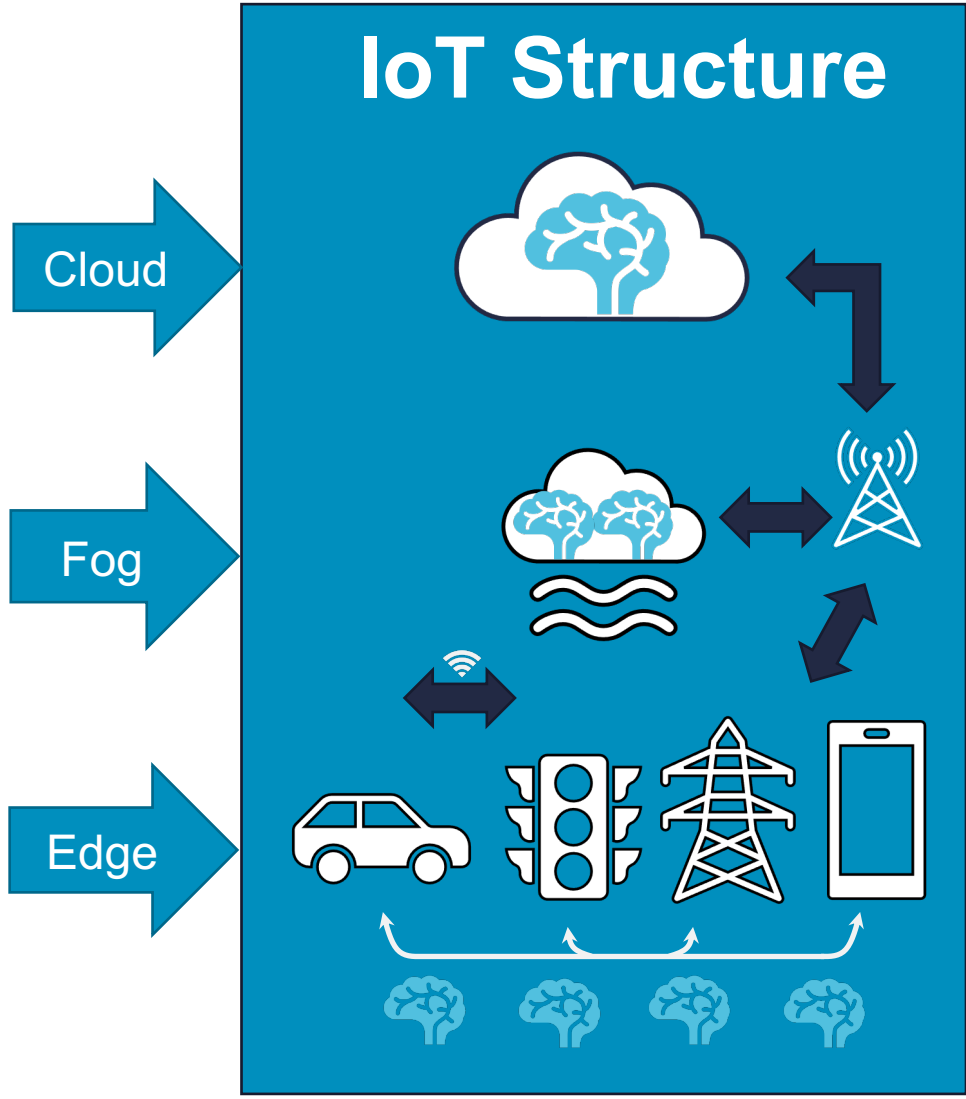
May 4th, 2021

INESCTEC 35 THIRTY FIVE YEARS 1985 2020

CENIMAT | i3N

Current Status

- Edge:
  - Interface with real world
- Computing at the edge improves:
  - Privacy
  - Latency
- Artificial intelligence (AI) on the Edge — Edge AI
  - Inference
  - Machine Learning



AI of today and tomorrow

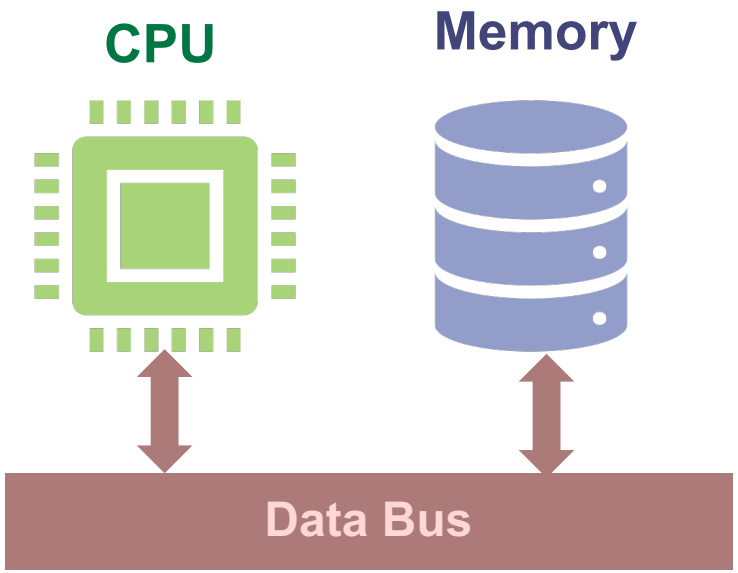
Modern age AI

- AI algorithms
- Big data
- Communication networks
- **Powerful computing hardware (CMOS on the frontline)**

Next generation AI

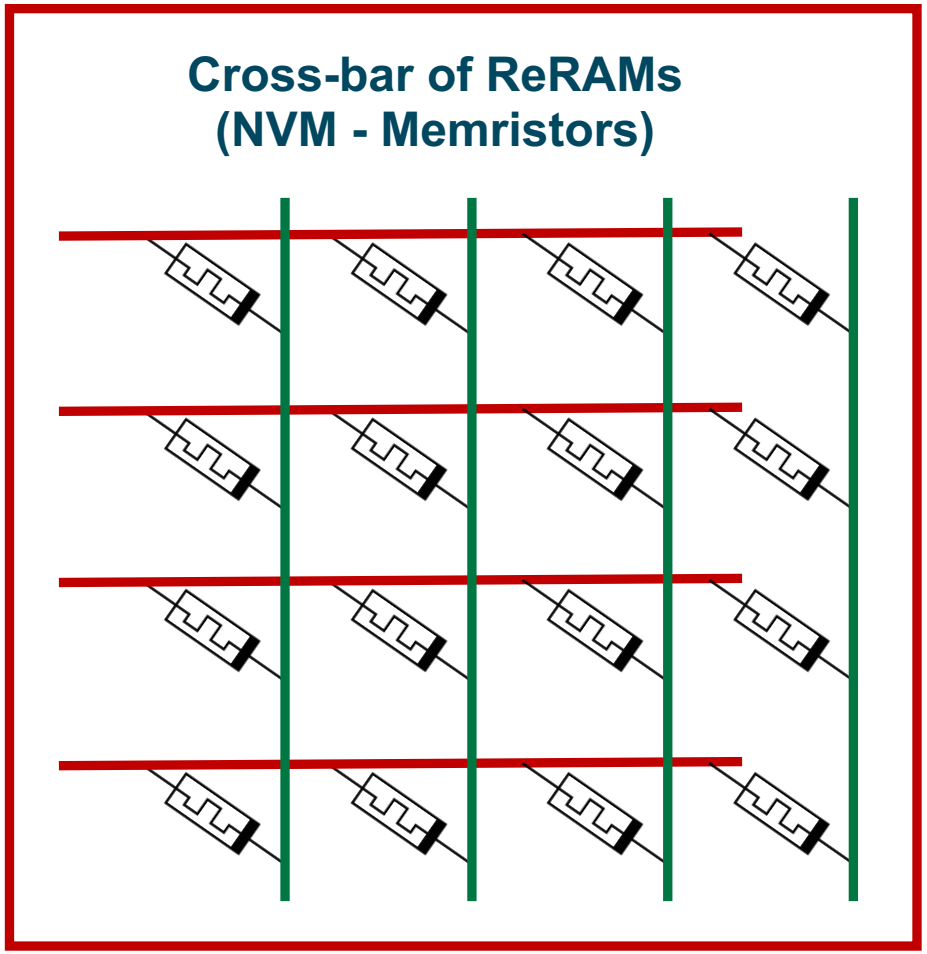
- Self-Learning
- One step learning
- Cognition
- **New hardware paradigms**

Classical Central Processing

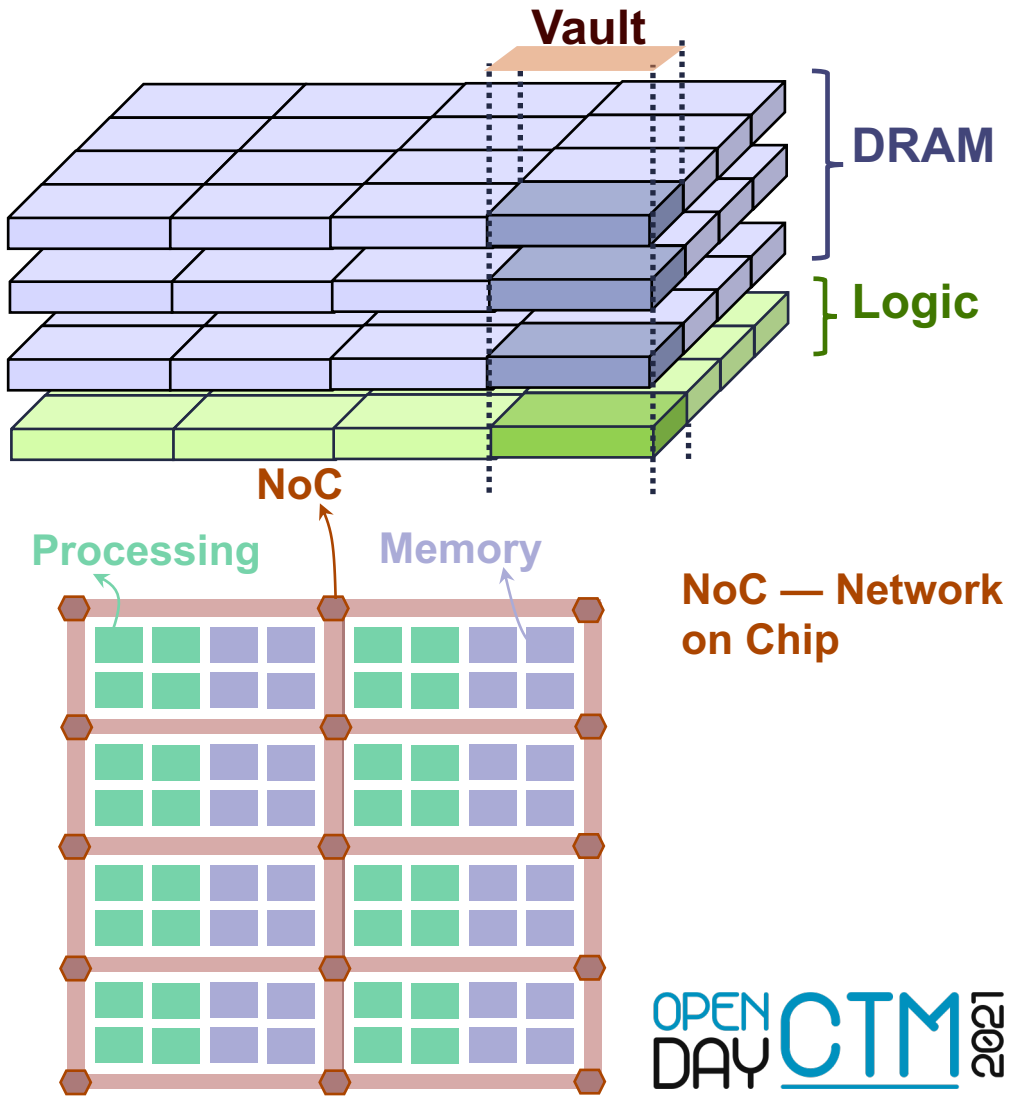


On the way for the next AI generation

In-memory computing



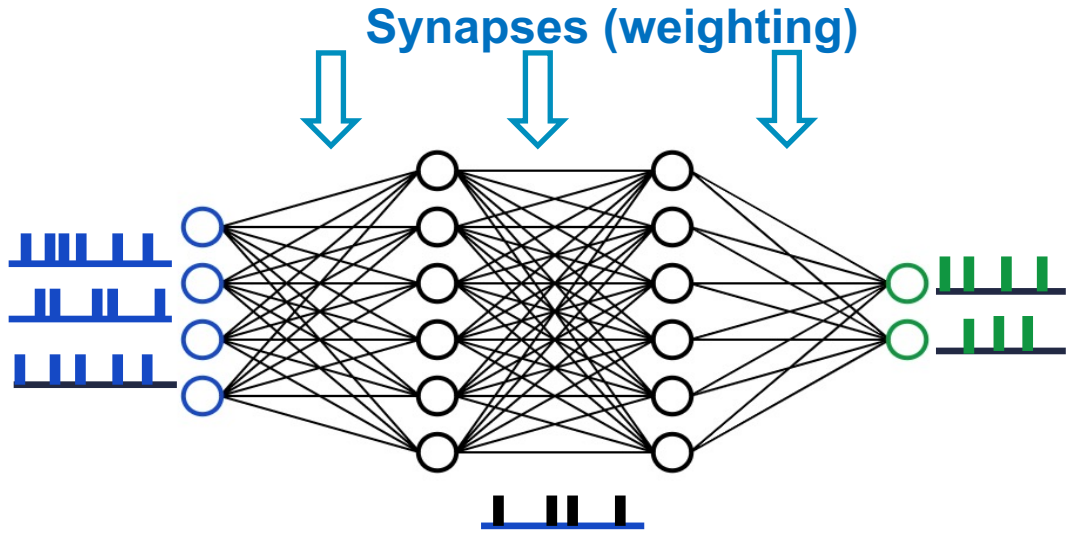
Near Memory Computating



On the way for the next AI generation

Neuromorphic computing

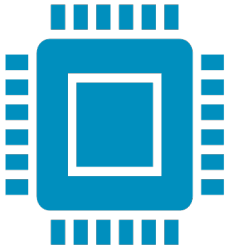
- Brain Inspired
- Event-based processing
- SNNs



Synaptic Learning — Spike Time Dependent Plasticity (STDP)

- Neurons fire pulses
- Weights (synapses) are updated based on time difference between post- and pre-synaptic pulses
- These properties have been demonstrated with memristor like devices

NeurOxide



New computer paradigms to overcome Von Neumann's bottleneck

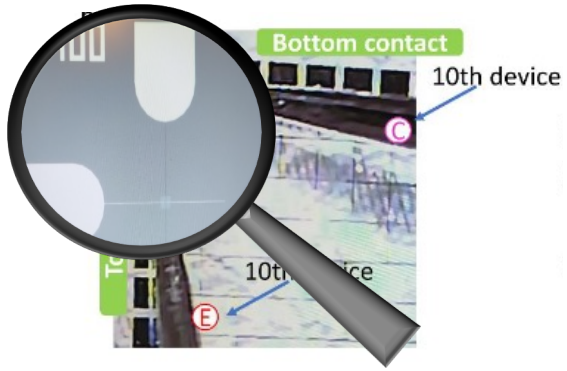
→ **Memristors learn and forget like biological synapses** ←

Aims to achieve a fully integrated system with memristors and supporting electronics with the same materials
— amorphous oxide semiconductors (AOS) —

- Same processing steps for transistors and resistive switching devices
- Less interface issues
- Low-temperature fabrication process
- Low cost

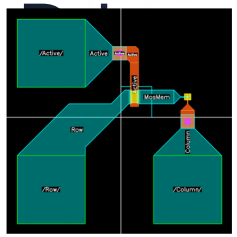
NeurOxide

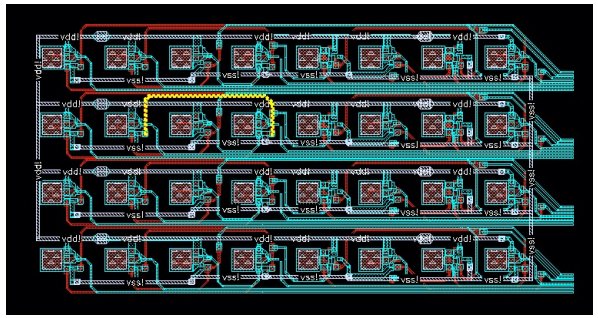
Memristor → Transistor (TFT) + Memristor → Neuromorphic Architecture (full integration)

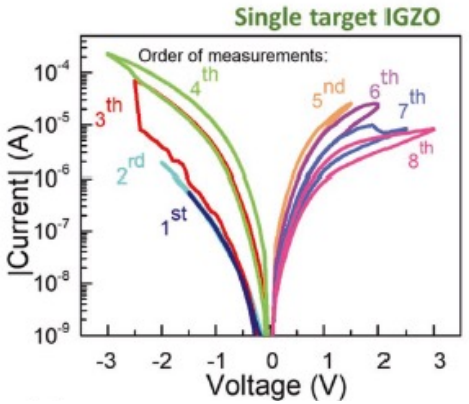


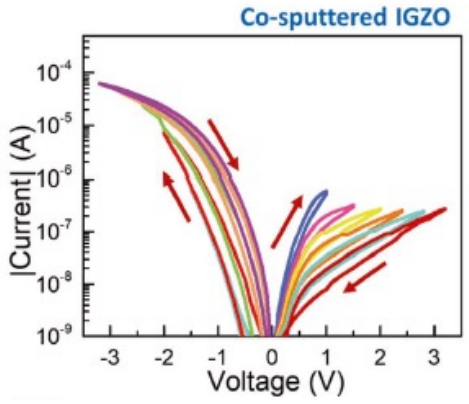
Modeling

Physical Data

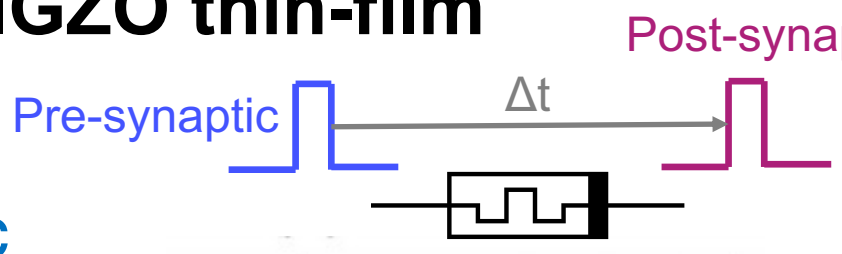






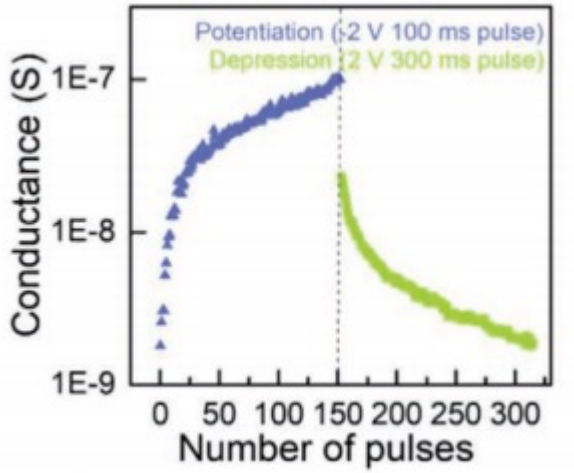


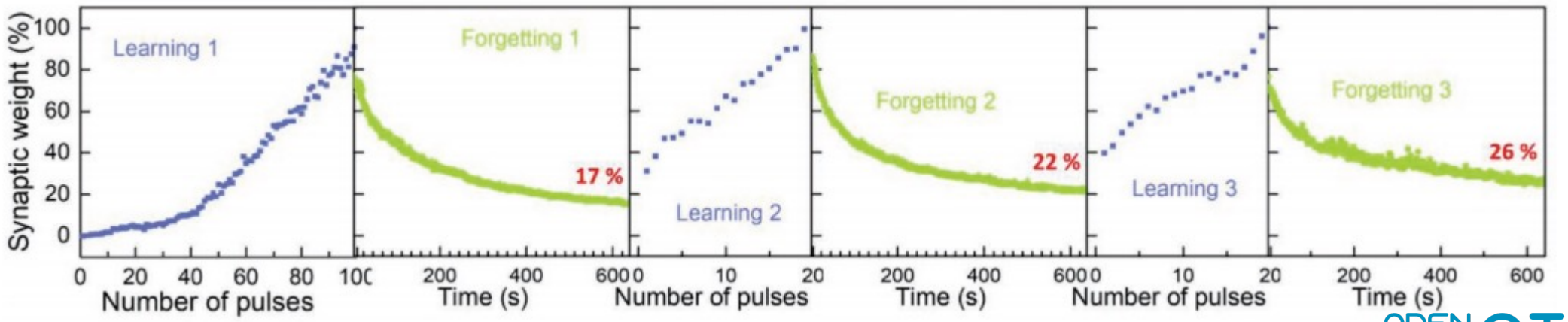
NeurOxide — synaptic learning — IGZO thin-film memristors



Resistive switching emulates synaptic learning (weighting)

- Potentiation decreases resistance / increases conductance (Δt>0 ⟼ Positive pulse)
- Depression increases resistance / decreases conductance (Δt<0 ⟼ Negative pulse)





PhD. Student: Maria Pereira

NeurOxide — Memristor Modelling — Black Box

Dynamical system with memory

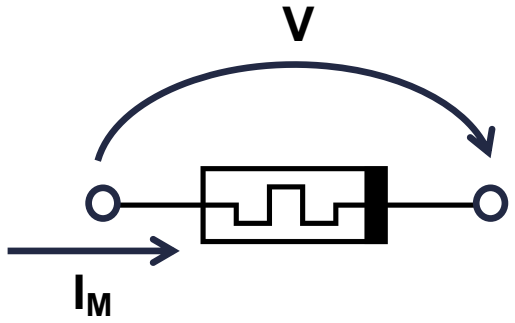
$$I_M(t) = G_M(w, V) \times V(t)$$

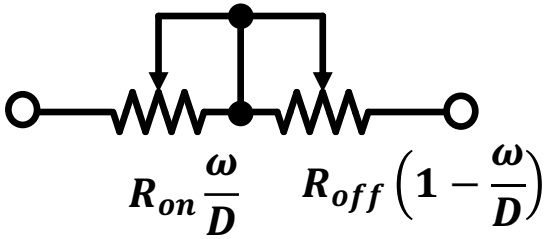
$$\frac{\partial w}{\partial t} = f(w, V) \times g(w, V)$$

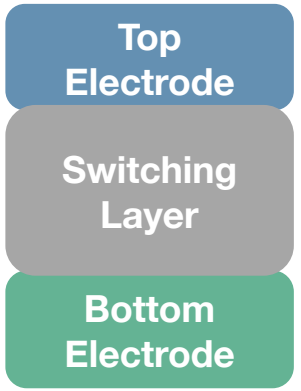
$G_M(w, V)$ **Conductance**

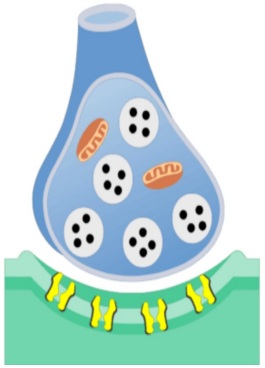
$g(w, V)$ **Window Function**

$f(w, V)$ **Threshold Function**



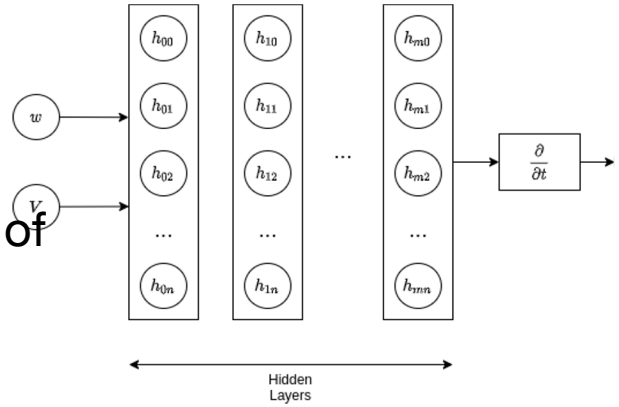


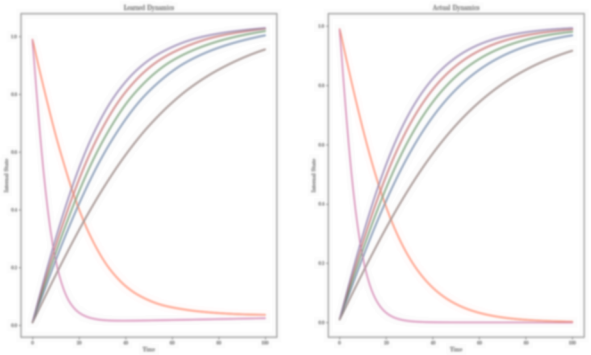




Multistep Neural Networks (MSNN)

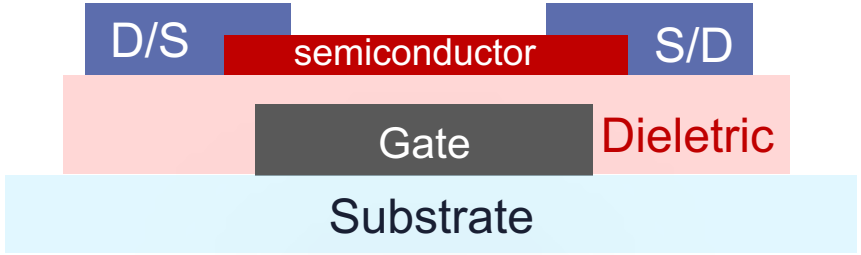
— ANN that captures the underlined ODE of the system by learning from the numerical multistep integration algorithms —

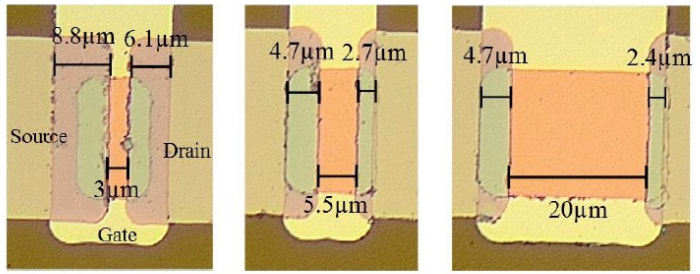


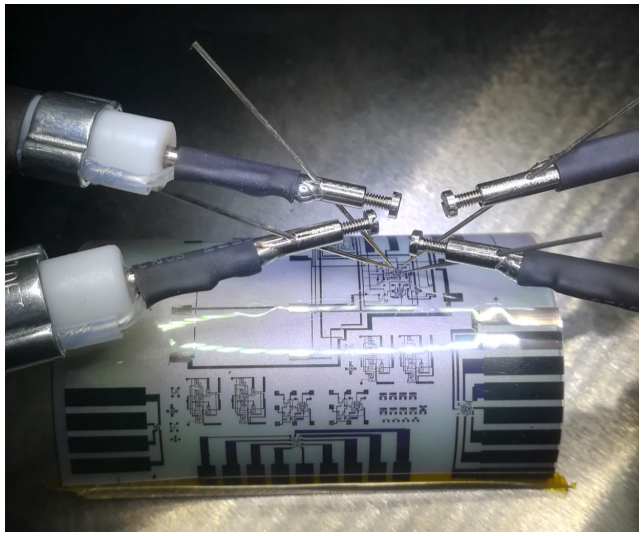


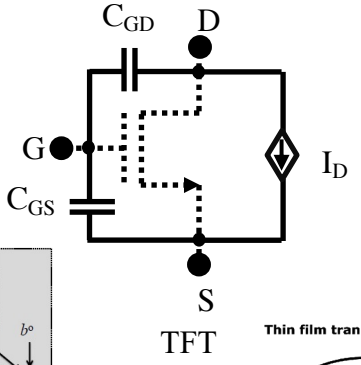
PhD. Student: Guilherme Carvalho

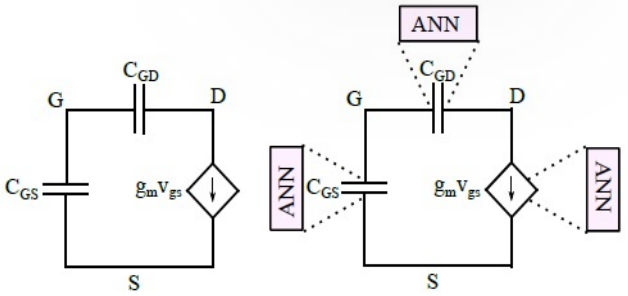
NeurOxide — TFT



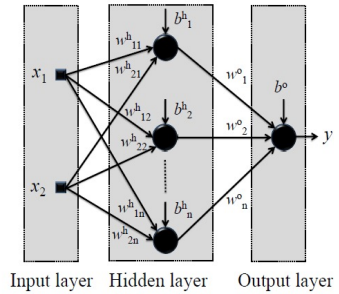




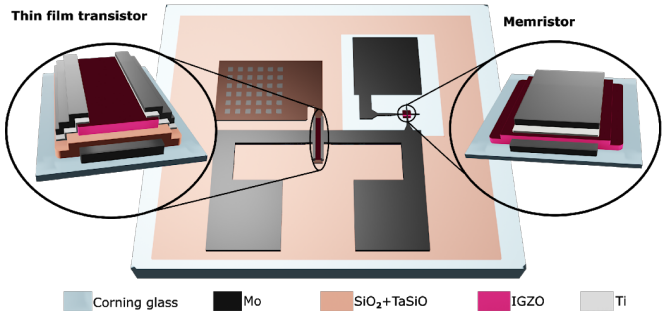


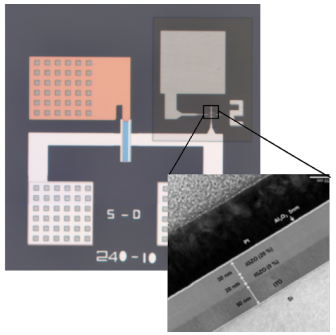


Equivalent circuit with the neural models

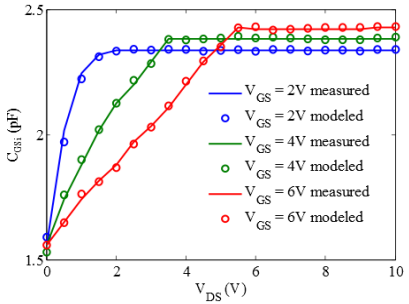


ANN topology

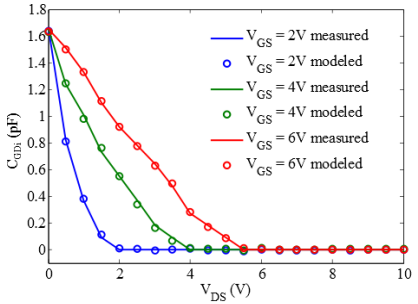




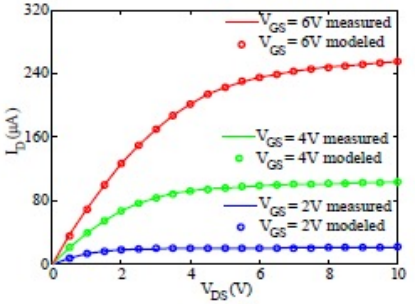
TFT equivalent circuit



C_{GSi} modeled



C_{GDi} modeled

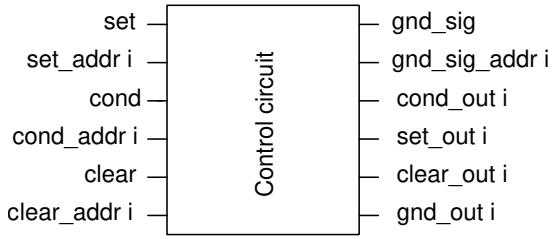


I_D modeled

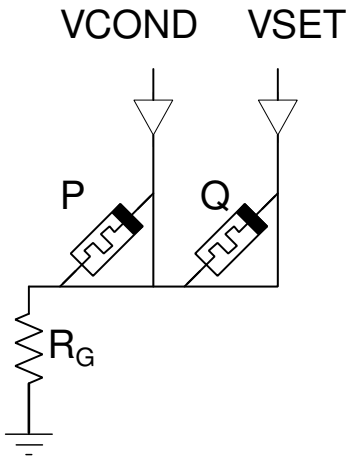
PhD. Students: Maria Pereira & Guilherme Carvalho

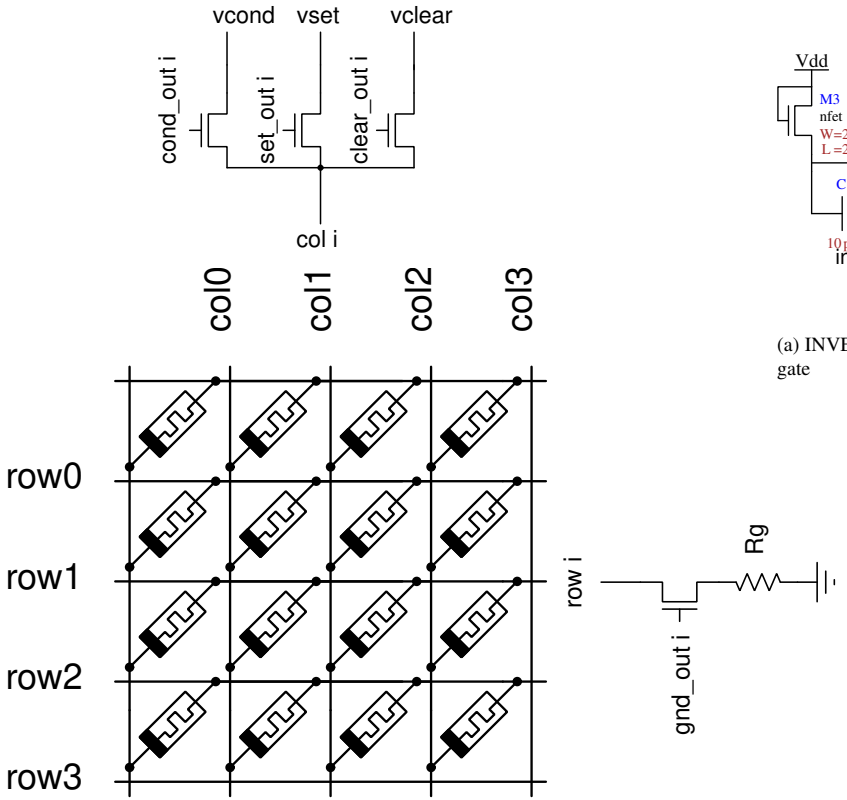
NeurOxide — in-memory computation logic

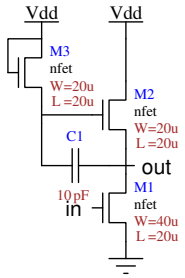
Imply or Material Implication Logic



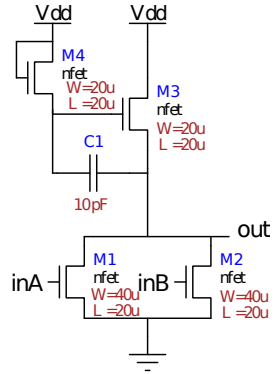
P	Q	P→Q
0	0	1
0	1	1
1	0	0
0	1	1



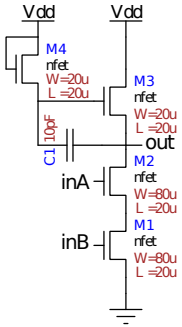




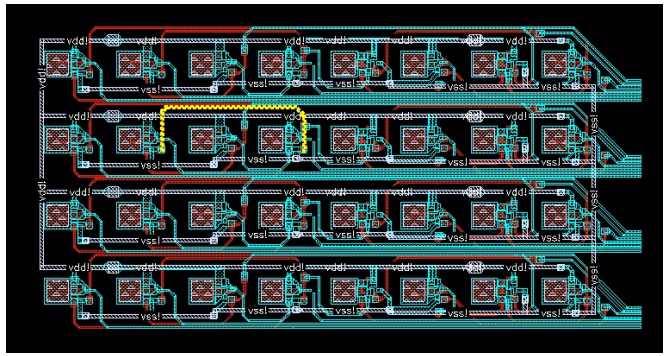
(a) INVERTER logic gate



(b) NOR logic gate



(c) NAND logic gate



MSc. Student: Luís Outeiro

Conclusion

Next Generation AI

- Self-Learning
- One step learning
- Cognition

New possible Hardware Paradigms

- In-memory computating
- Event based computation (SNNs)

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