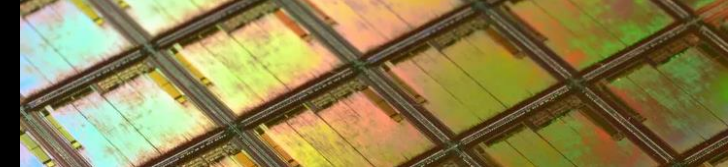


# Sensor Signal Processing for Defence Conference

12<sup>th</sup> and 13<sup>th</sup> September 2023

Royal College of Physicians Conference Centre



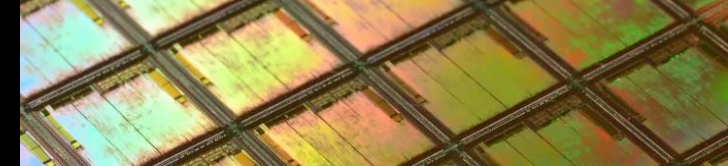


# Low energy (adiabatic) computing

Dr. Alexander Serb

Reader in unconventional AI hardware

Univ. of Edinburgh



# The Centre for Electronics Frontiers (CEF)

Mission statement: “Our ambition is to push the frontiers of electronics through innovating emerging Nanoelectronic Technologies.”

**Safe and efficient  
energy storage**

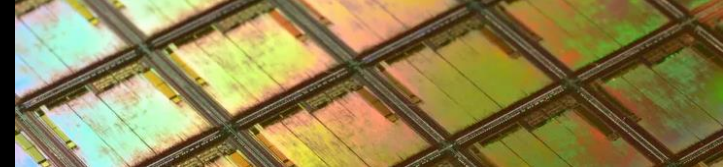
**Advanced nano-bio  
devices**



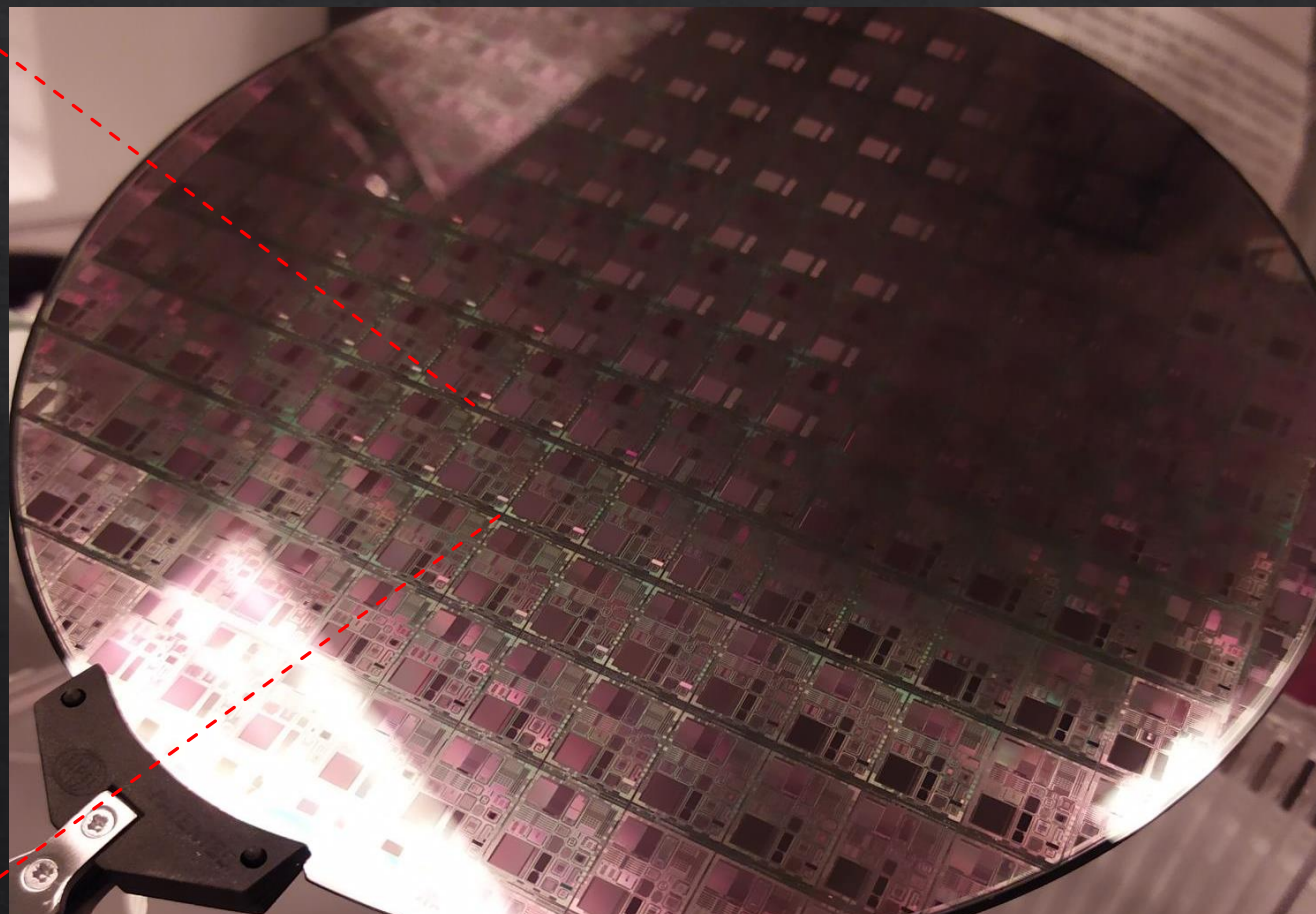
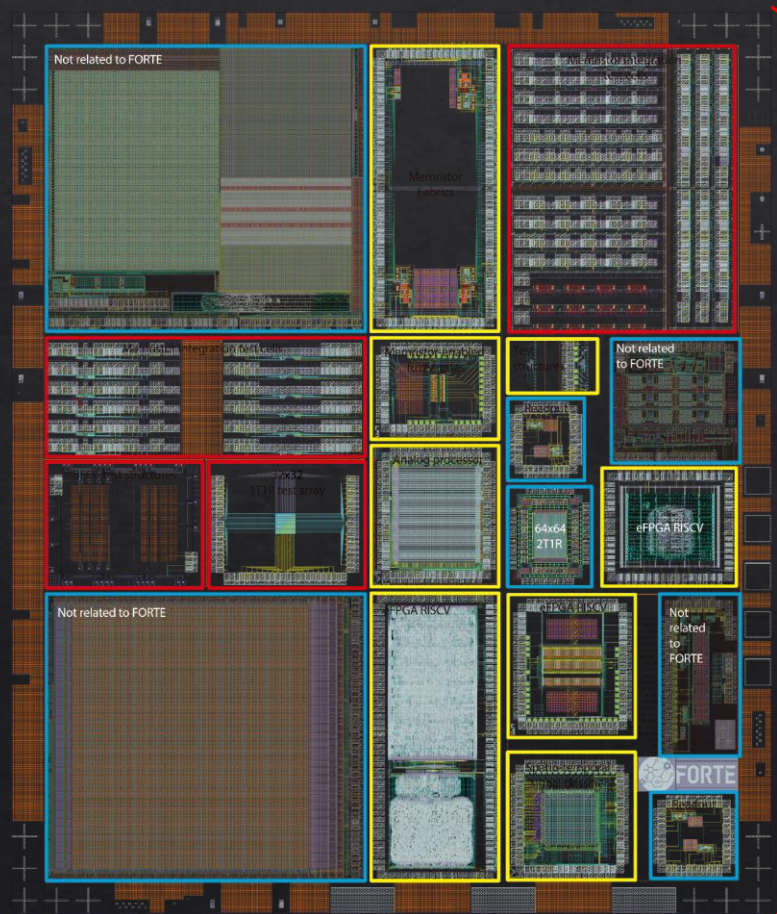
**Novel AI hardware**

*“CEF brings together diverse expertise ranging from materials science and electronic devices to circuits and systems for transforming modern society through technology.”*

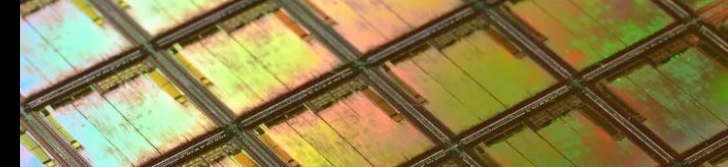




# At CEF we design and build microchips







# Hardware power is a fundamental issue

Editorial | [Published: 17 April 2018](#)

## Does AI have a hardware problem?

[Nature Electronics](#) 1, 205 (2018) | [Cite this article](#)

8049 Accesses | 12 Citations | 46 Altmetric | [Metrics](#)

As deep neural networks continue to improve and grow, it is becoming increasingly clear that the hardware required in order to meet the increasing computational demands of AI is a significant challenge.

<https://www.nature.com/articles/s41928-018-0068-2>

**ComputerWeekly.com**

## Rising energy costs erode competitive edge of colocation datacentres

As a result, more than half of the UK participants in the survey said that energy costs are now between 10-to-30% of their total operating costs, while a further 25% said they are paying “well over” that amount.

<https://www.computerweekly.com/news/252523862/Rising-energy-costs-erode-competitive-edge-of-colocation-datacentre-operators>

## Global trends in digital and energy indicators, 2015-2021

	2015	2021	Change
Internet users	3 billion	4.9 billion	+60%
Internet traffic	0.6 ZB	3.4 ZB	+440%
Data centre workloads	180 million	650 million	+260%
Data centre energy use (excluding crypto)	200 TWh	220-320 TWh	+10-60%
Crypto mining energy use	4 TWh	100-140 TWh	+2 300-3 300%
Data transmission network energy use	220 TWh	260-340 TWh	+20-60%

<https://www.iea.org/reports/data-centres-and-data-transmission-networks>

**Forbes**

FORBES > INNOVATION > CONSUMER TECH

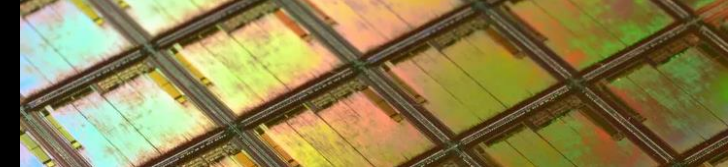
## Generative AI Turns Millions Every Day into Computer Scientists

### Will AI Make Us a Million Times Smarter?

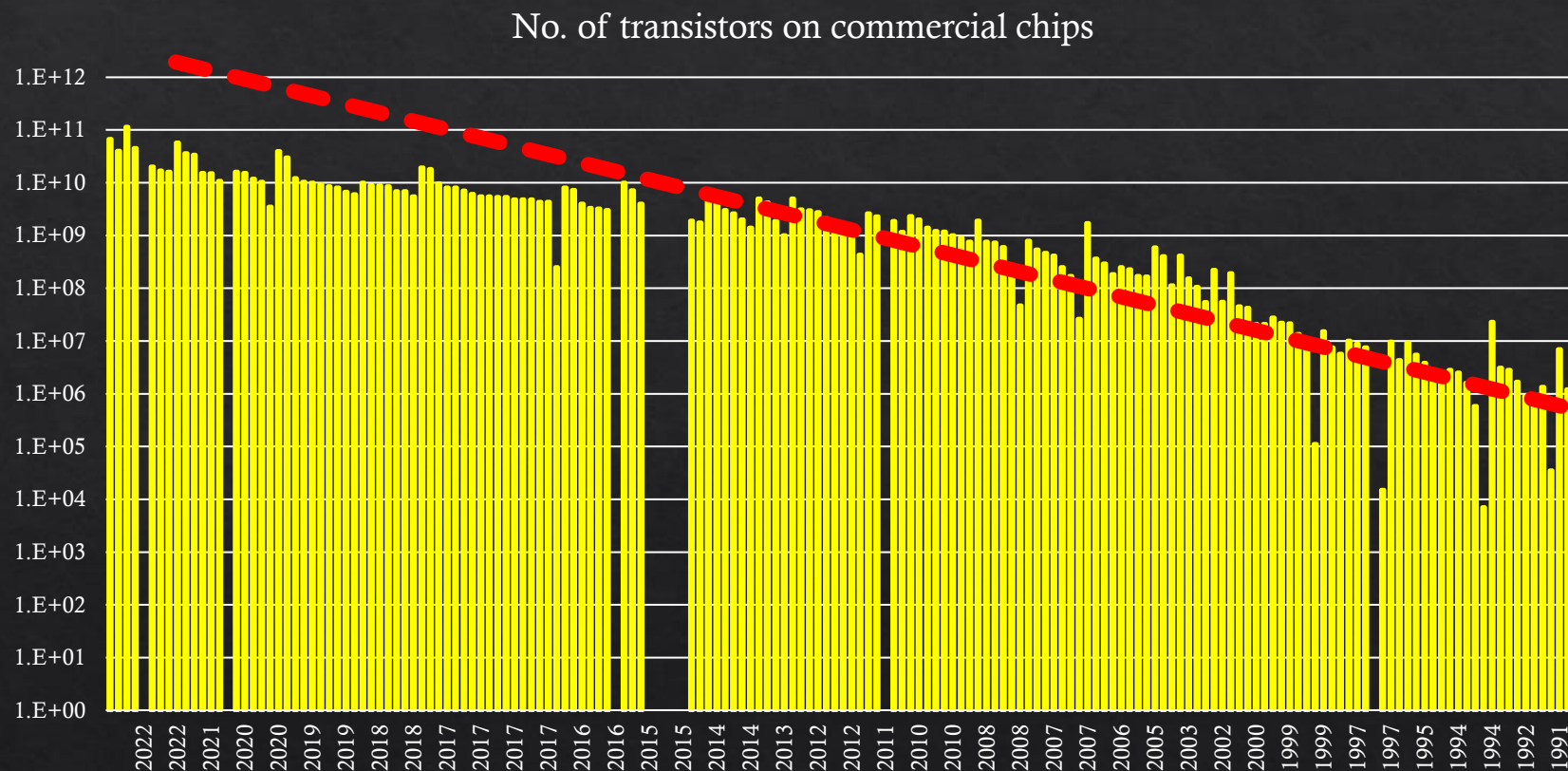
<https://www.forbes.com/sites/johnkoetsier/2023/02/10/chatgpt-ai-computer-scientists-make-ai-one-million-times-smarter/>

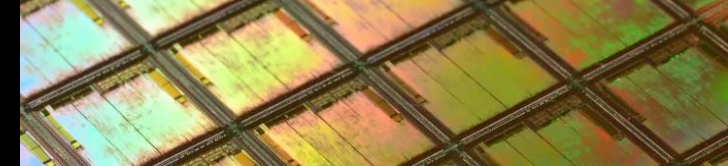
## Data centres and data transmission networks are responsible for nearly 1% of energy-related GHG emissions

<https://www.iea.org/reports/data-centres-and-data-transmission-networks>

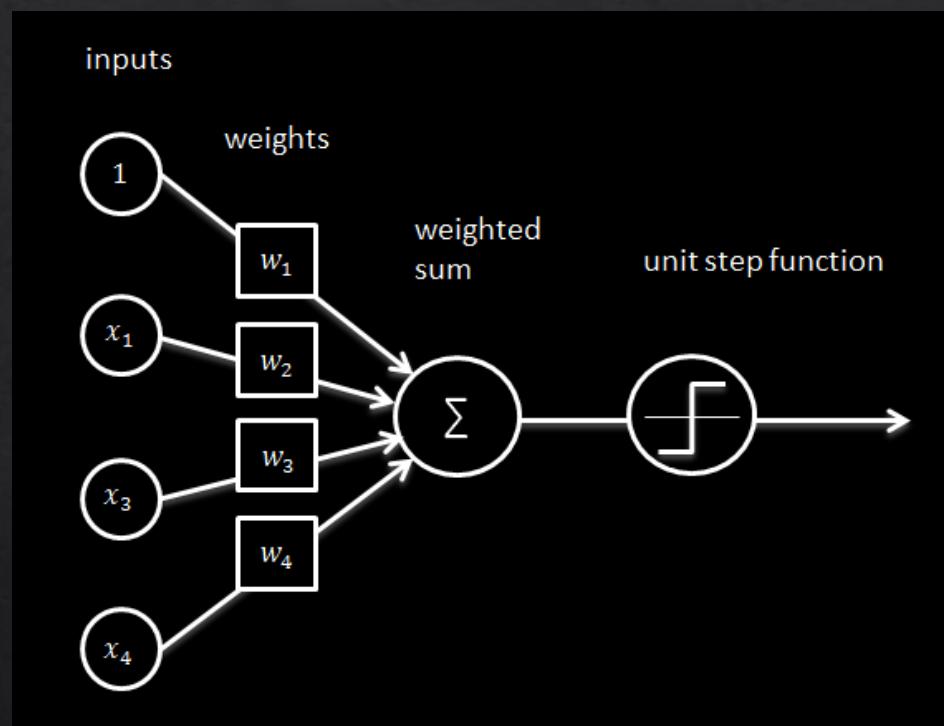


# Conventional solutions are beginning to falter

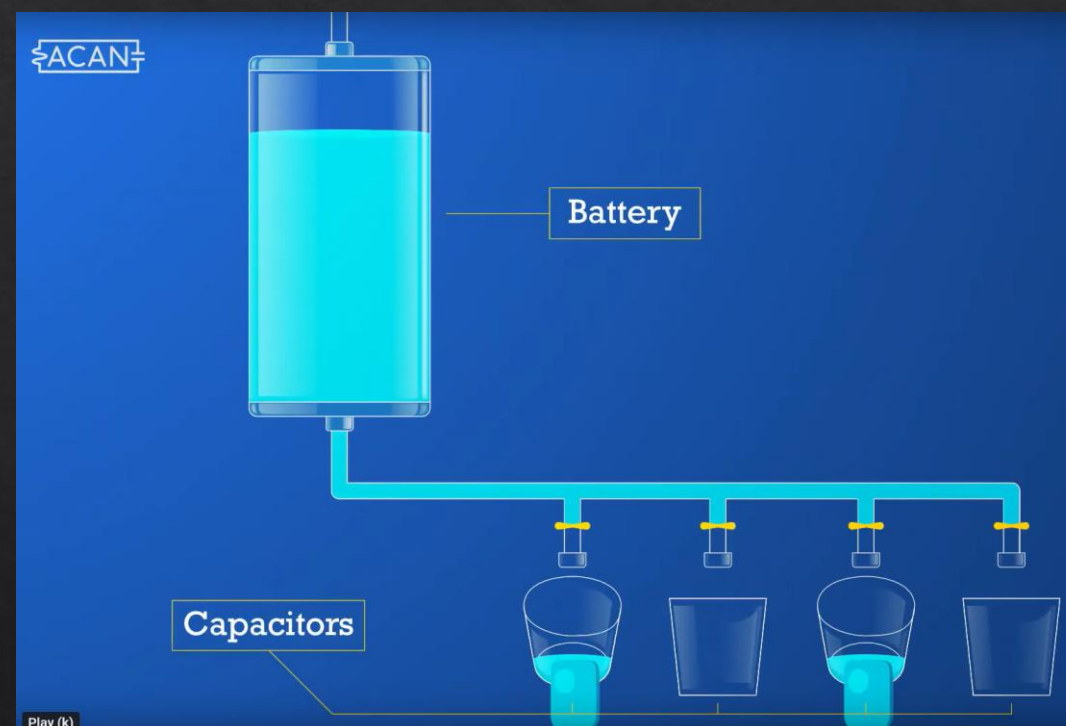




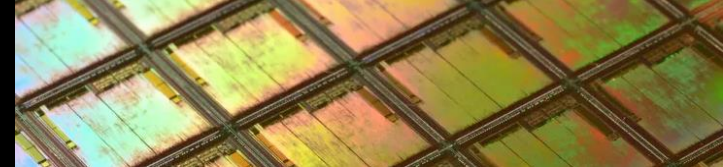
# Adiabatic computing: counting charge buckets



<https://towardsdatascience.com/everything-you-need-to-know-about-neural-networks-and-backpropagation-machine-learning-made-easy-e5285bc2be3a>

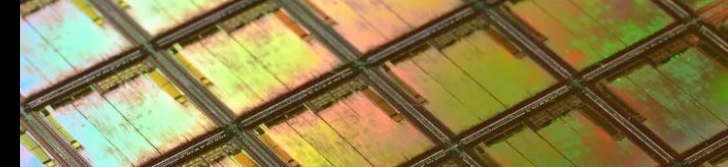


<https://www.youtube.com/watch?v=Uw2qMSRAMS4>



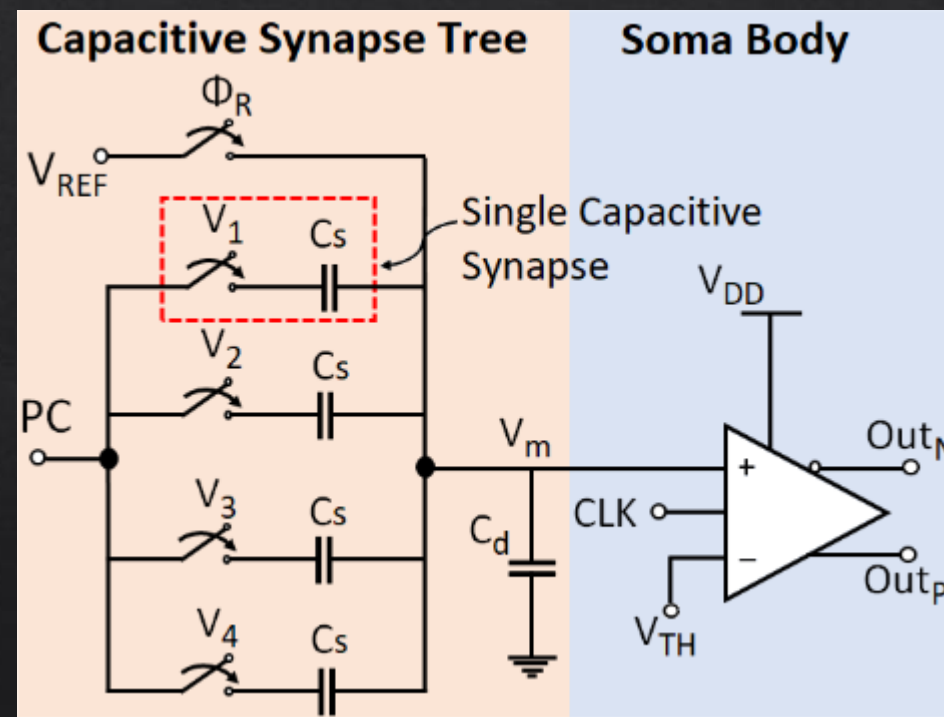
<https://www.youtube.com/watch?v=Uw2qMSRAmS4>



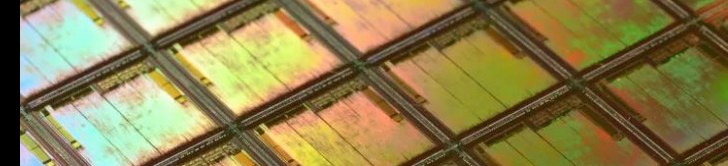


# An adiabatic neuron in practice

- ◇ Adiabatic component...
  - ◇ Synapses made of capacitors.
  - ◇ Switches made of TGs.
  - ◇ “Reset to reference” path.
  - ◇ May include a damping capacitor.
- ◇ ...and non-adiabatic component.
  - ◇ Contains a neural soma...
    - ◇ ...which is a strong-arm comparator.
- ◇ Note that “PC” terminal on the left...

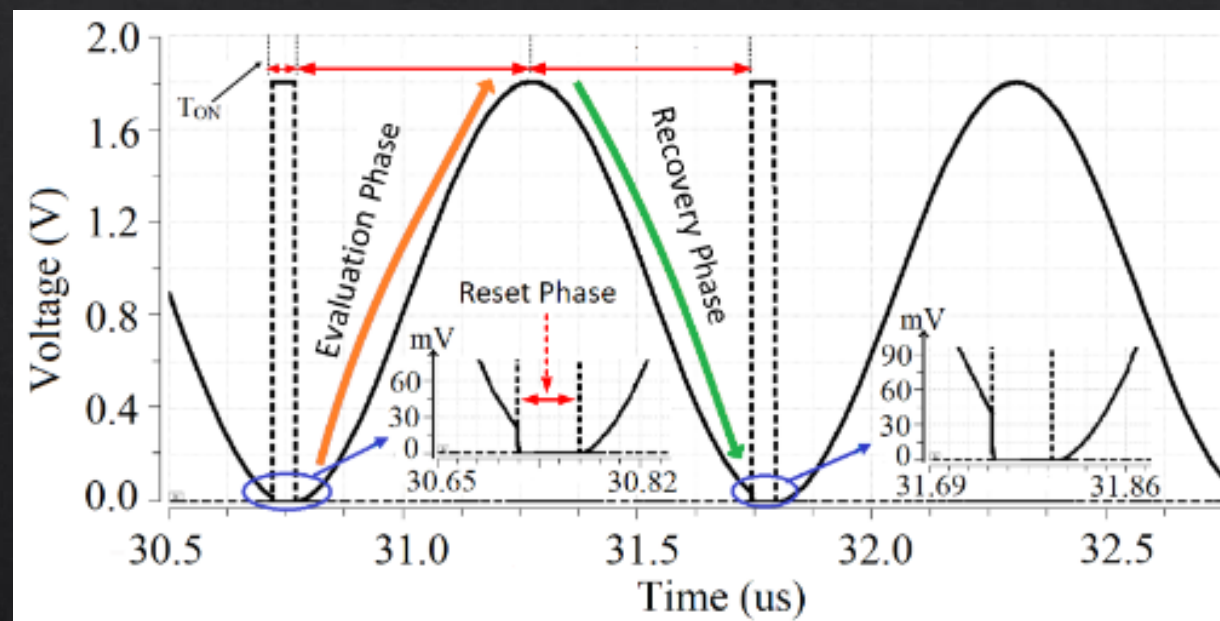


<https://ieeexplore.ieee.org/abstract/document/9799538>

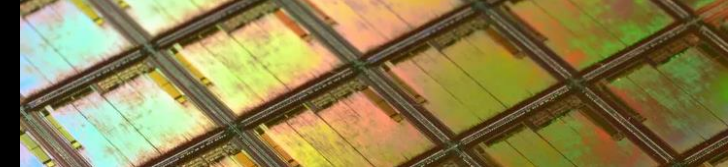


# A closer look at adiabatic operation

- ◇ 3x-phase operation:
- ◇ Evaluation phase:
  - ◇ “The tide flows”.
  - ◇ System samples comparator at peak.
- ◇ Recovery phase:
  - ◇ “The tides ebbs”.
  - ◇ At the stroke of the clock reset triggers.
- ◇ Reset phase:
  - ◇ The power clock is hard-reset.

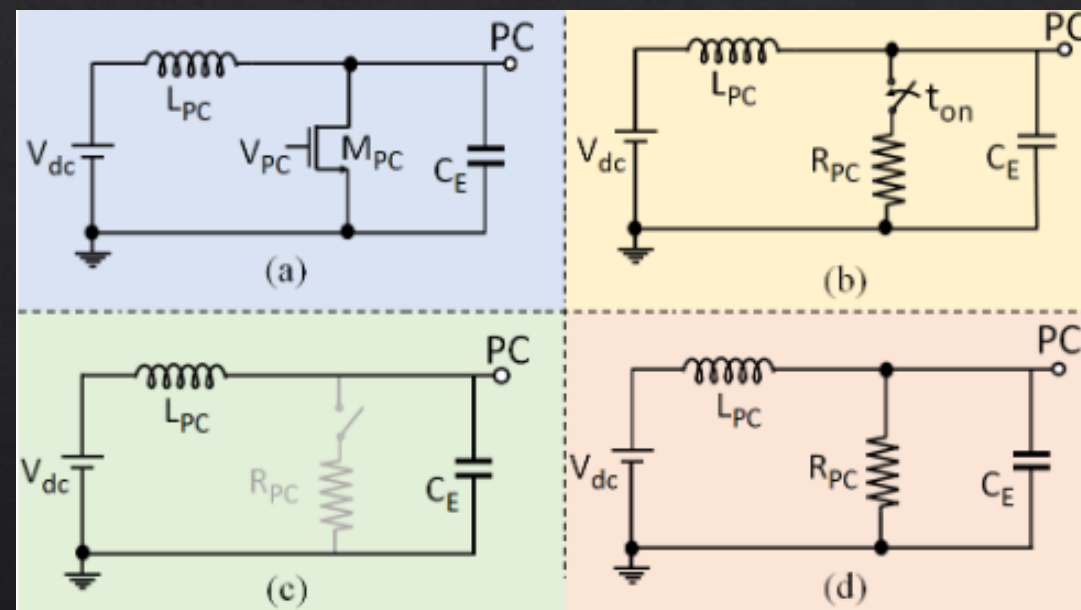


<https://ieeexplore.ieee.org/abstract/document/9799538>



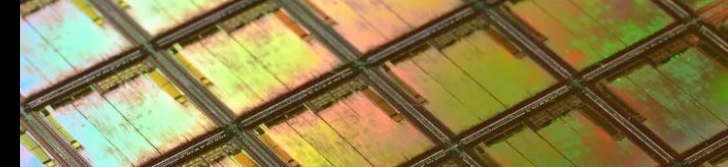
# Outside the chip: the power supply

- ◆ Adiabatic circuits require adiabatic power supplies...
- ◆ Easiest approach: an LC resonator with a by-pass switch.
- ◆ During evaluation and recovery phases behaves as LC tank...
- ◆ ...and during reset the RC dominates and discharges “quickly”.



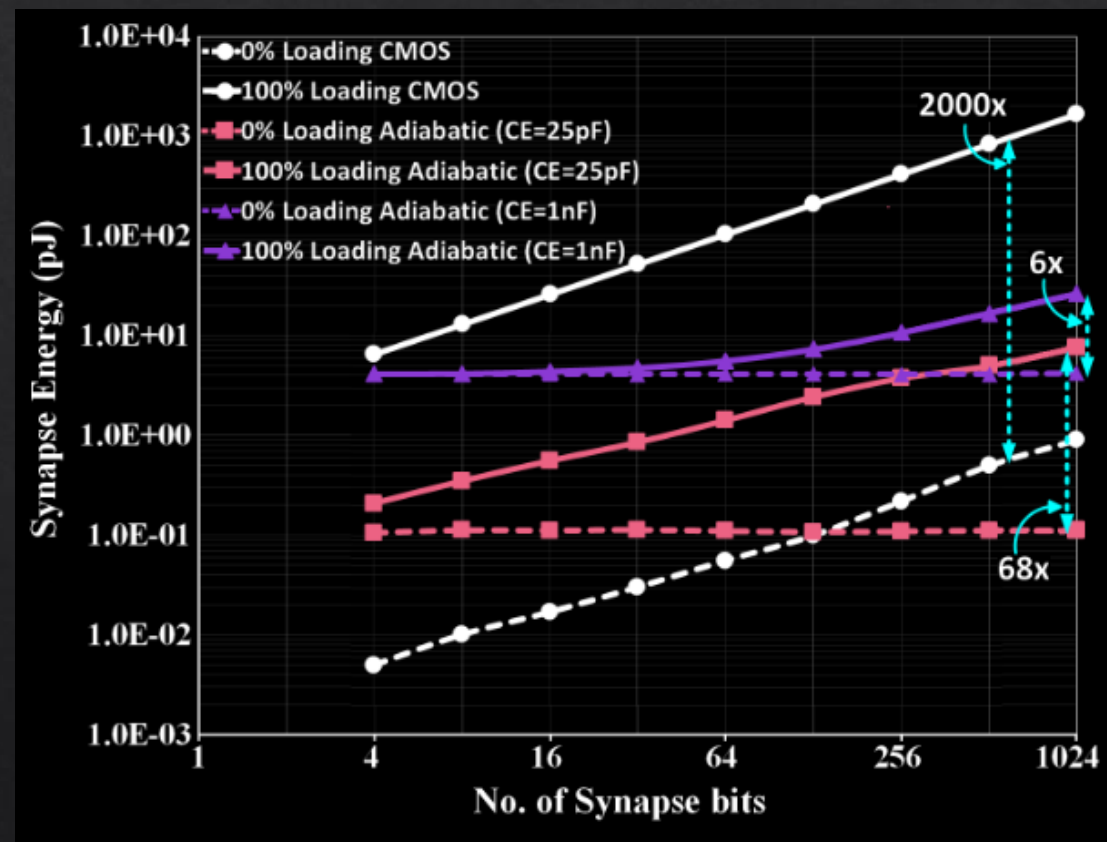
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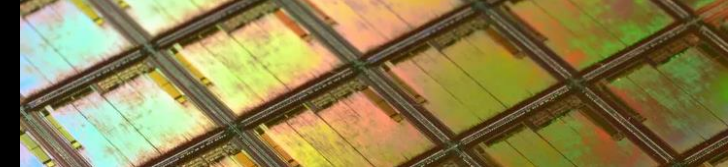


# What can the technology do?

- ◇ Ideally suited for artificial neural networks
- ◇ Up to 90% power reduction vs. like-for-like non-adiabatic circuit
- ◇ “Makes 180nm CMOS look like 65nm”
- ◇ Working on a proof-of-concept demonstrator (in 180nm technology)
- ◇ How well do these techniques downscale to 22nm and below?
- ◇ What is the actual saving in a full-size ANN?

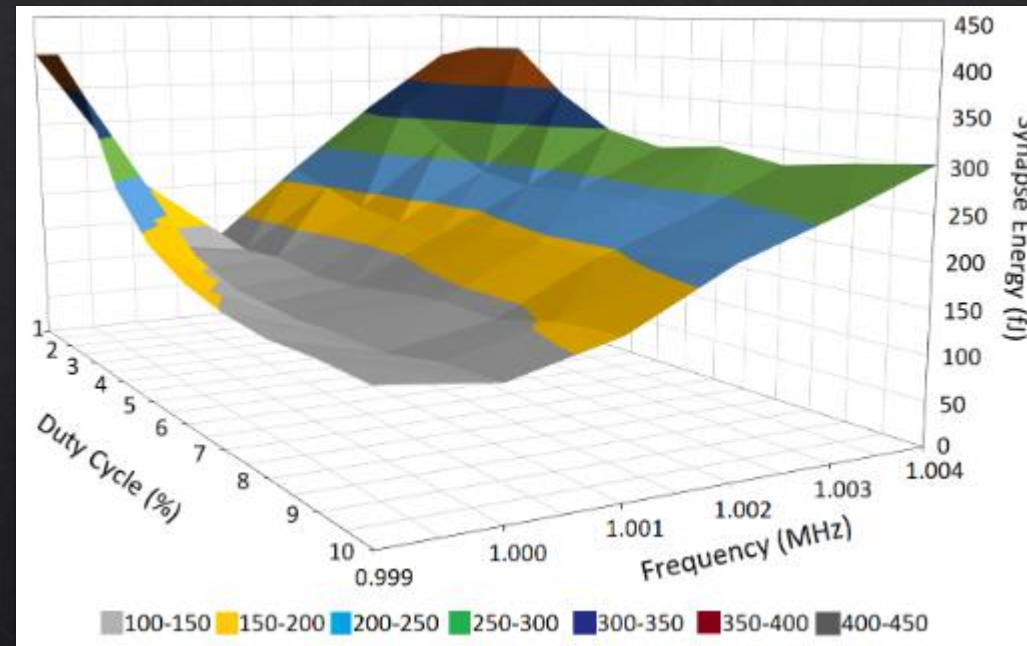


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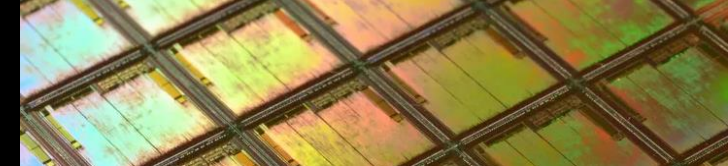
# A closer look at key results

- ◇ Some important considerations:
  - ◇ This version of ACNNs requires a fine balance between operating frequency and reset duration.
  - ◇ Sensitivity is much higher to frequency than to reset duration.
  - ◇ Operating frequency depends on loading.
  - ◇ It is possible to get the system to “hunt” for the best frequency as the load varies.



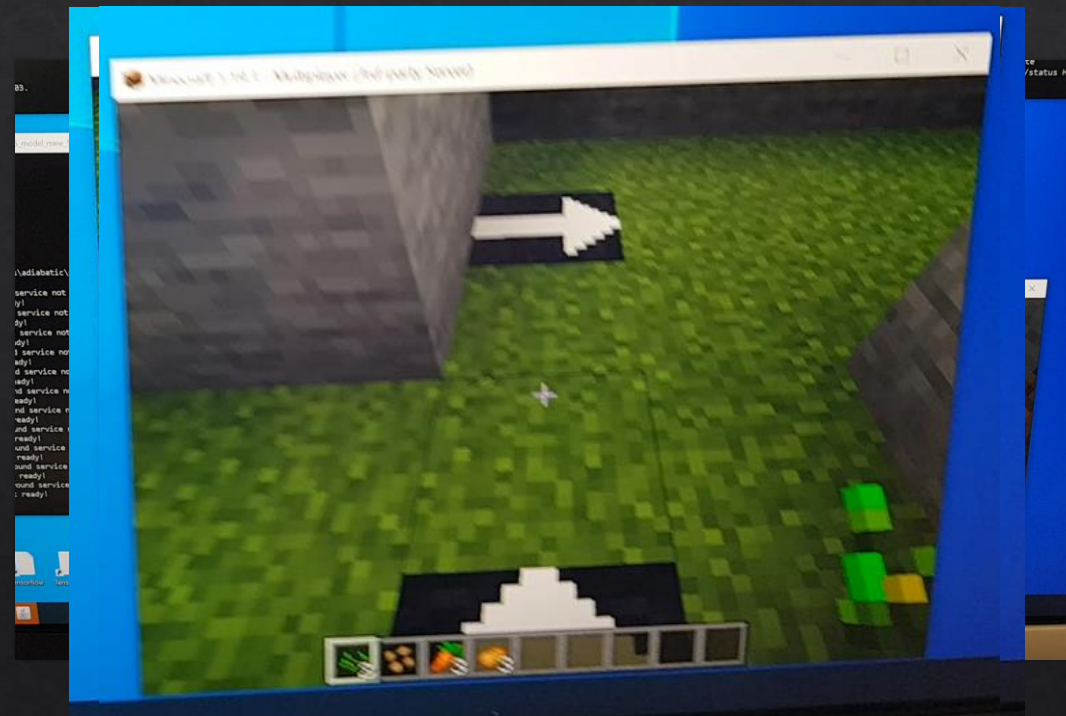
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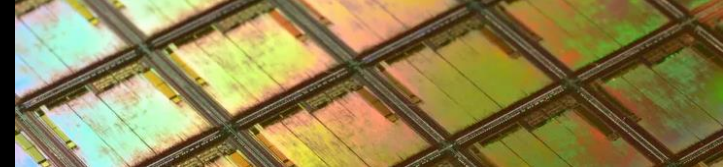


# Towards real applications

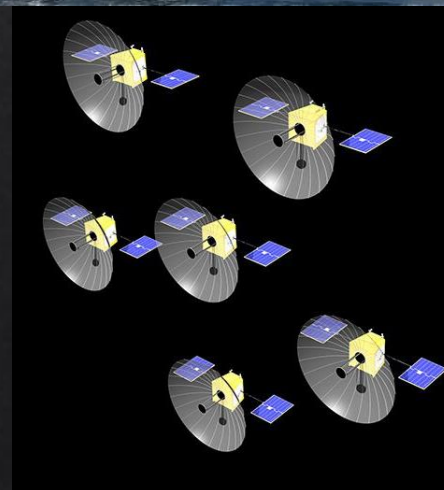
- ◇ Begin with a simulator in Minecraft.
- ◇ Fixed camera angle, player follows arrows.
- ◇ Achieved using 16x neurons and 816 synapses with appropriately quantised weights.
- ◇ Correct answers 99% of the time.
- ◇ Requires  $\sim 3.7k$  minimum capacitances.
- ◇ Next challenge: implement this on-chip.



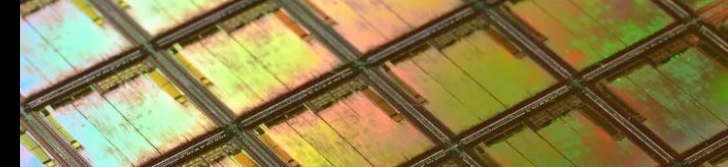




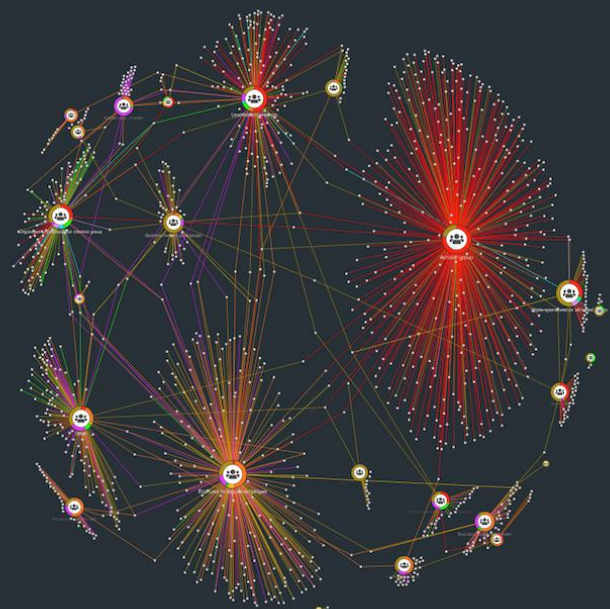
# Adiabatic computing in defence



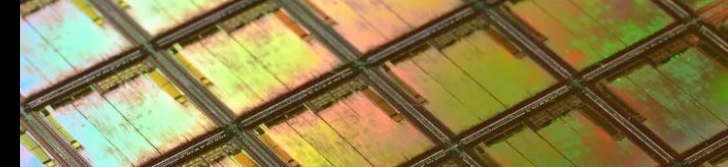




# Adiabatic computing around defence







# Thank you for your attention



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