MultiSpin.AI – a short introduction

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EIC Pathfinder Open

Funded by
the European Union

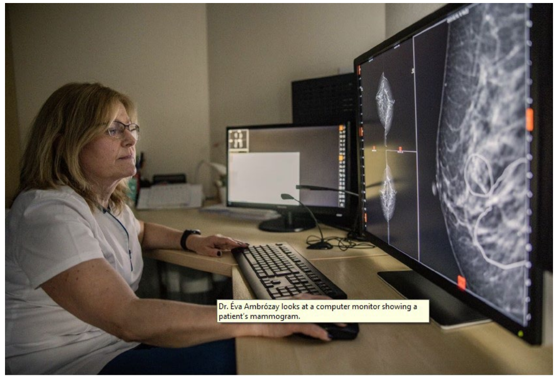
*MultiSpin.AI has received funding from the
European Union under grant agreement 101130046*

MULTISPIN.AI
AI Co-Processor Research Project

AI everywhere

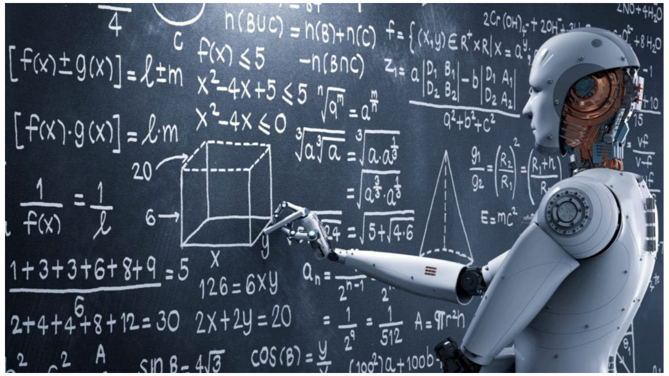
Natural language processing
ChatGPT, DeepSeek,…

Medical diagnosis and treatment

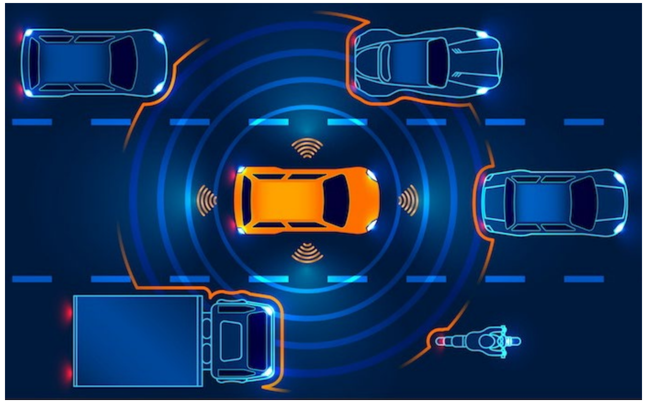


Dr. Éva Ambrózay looks at a computer monitor showing a patient's mammogram.

Personalized education



Autonomous vehicles



AI – computation challenges

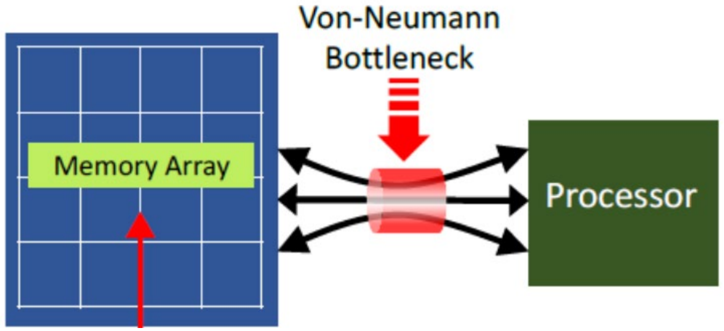
The end of Moore's law

Moore's Law: The number of transistors in a dense integrated circuit doubles about every two years

The end of the Dennard scaling law

Dennard scaling law: as transistors get smaller, their power density stays constant, so that the power use stays in proportion with area. Since around 2005–2007 Dennard scaling appears to have broken down

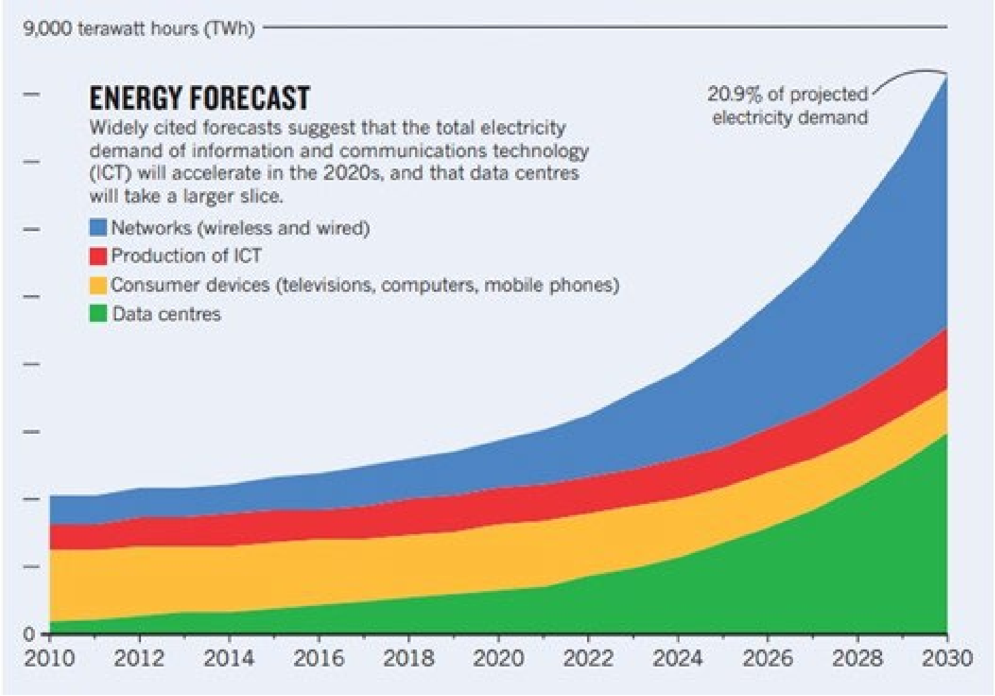
Von Neumann bottleneck



CPU execution time - a few nanoseconds or less

memory access times - tens to hundreds of nanoseconds

The hunger for power


ENERGY FORECAST

Widely cited forecasts suggest that the total electricity demand of information and communications technology (ICT) will accelerate in the 2020s, and that data centres will take a larger slice.

20.9% of projected electricity demand

The need for Edge computing

Data processing and analysis are performed on the devices or systems that generate the data, rather than sending all the data to a centralized location, such as a cloud server, for processing

Applications for edge computing include autonomous vehicles, industrial automation, smart cities, and healthcare monitoring systems

AI and edge computing are making CCTV more effective than ever

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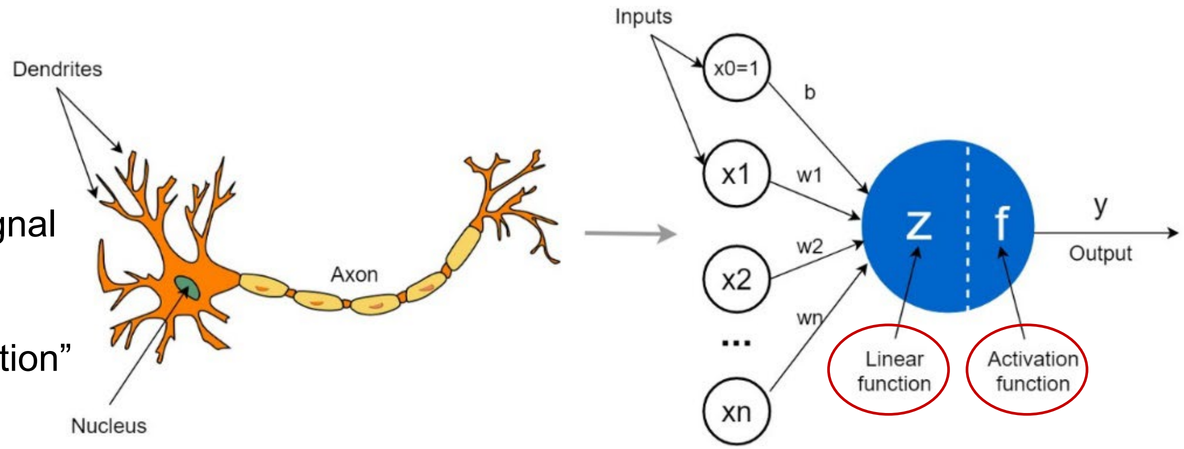
AI – Neuromorphic computing

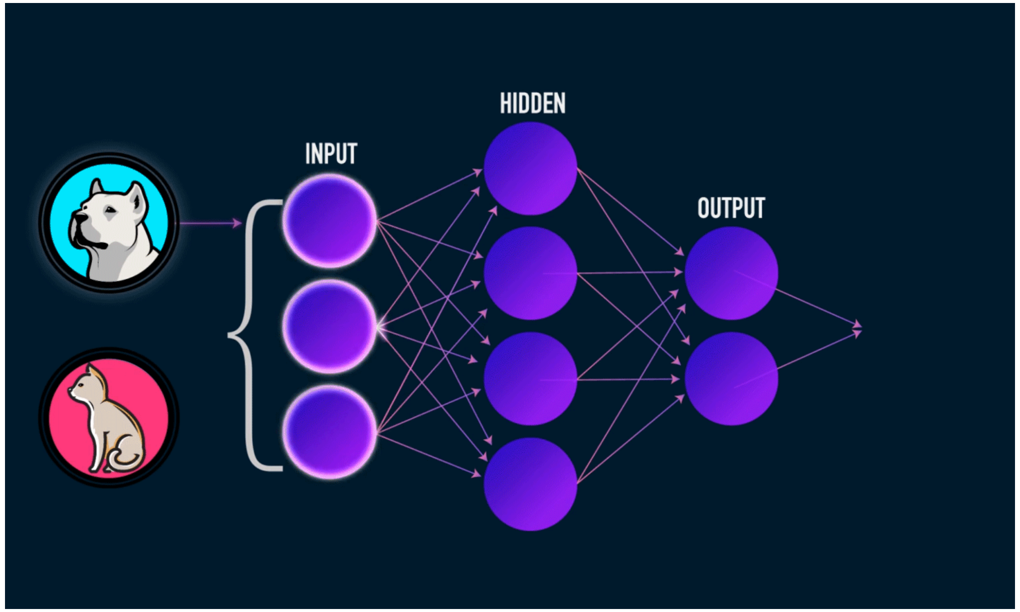
Visual perception

Stage 1:
Linear operation on the signal

Stage 2:
Non-linear “activation function”



Artificial neural network

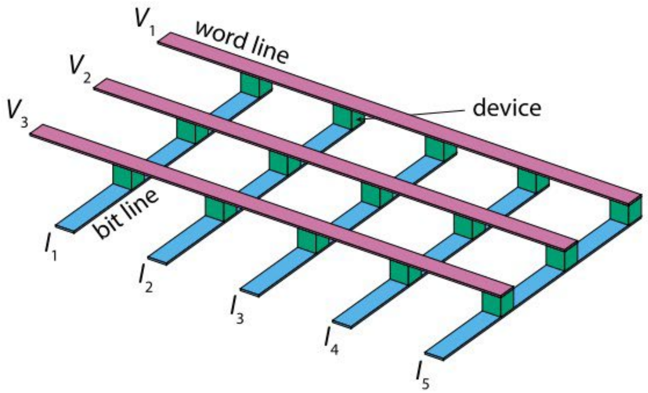


The crossbar –analogue multiplication and accumulation (MAC)

Analogue execution of the **linear** operations

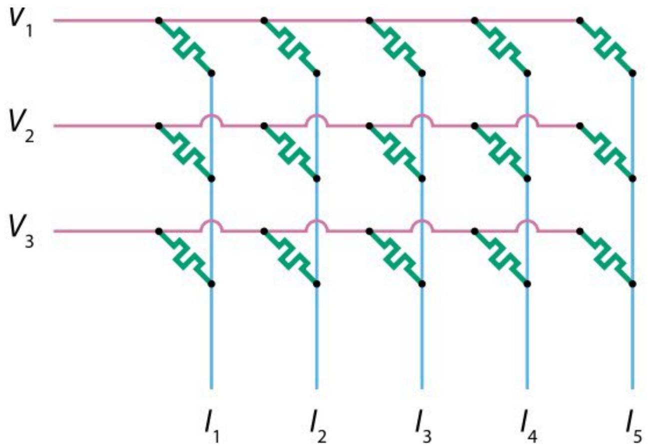
In memory processing:
fast and energy efficient

removes major computation barriers
particularly for AI at the edge



$$I_i = \sum_j G_{i,j} V_j$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} G_{1,1} & G_{1,2} & G_{1,3} & \cdots & G_{1,m} \\ G_{2,1} & G_{2,2} & G_{2,3} & \cdots & G_{2,m} \\ G_{3,1} & G_{3,2} & G_{3,3} & \cdots & G_{3,m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ G_{n,1} & G_{n,2} & G_{n,3} & \cdots & G_{n,m} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \vdots \\ V_m \end{bmatrix}$$

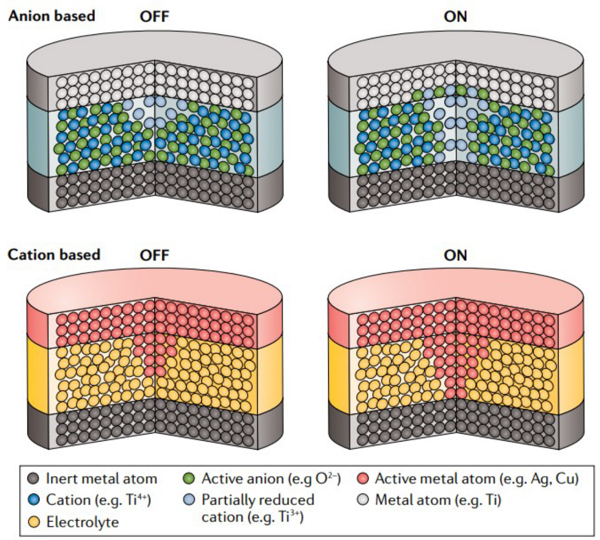


Ohm’s law for crosspoint multiplication
Kirchhoff's law for summation

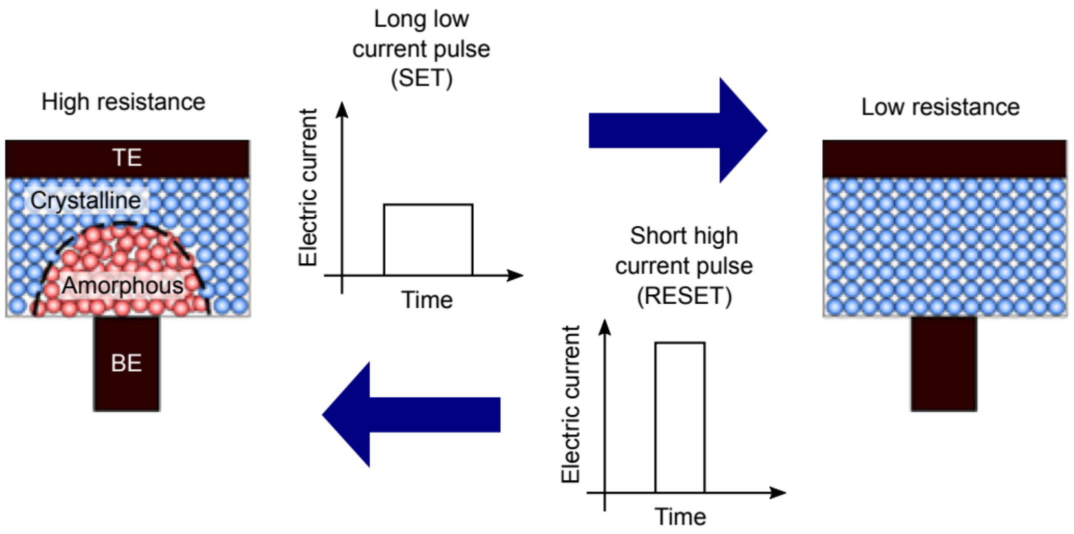
Advantages in speed and energy efficiency

The crossbar – material options

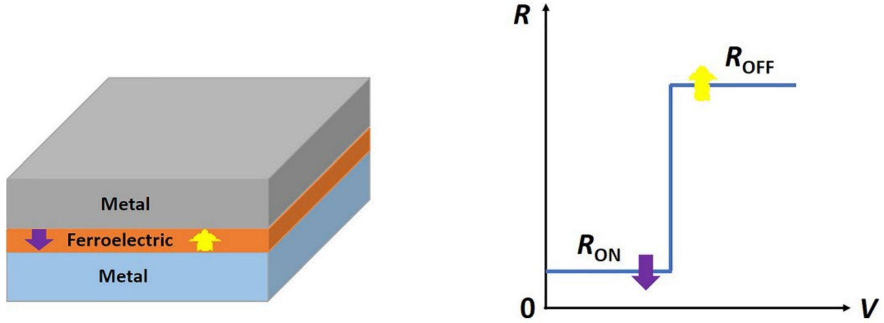
Redox (reduction oxidation) materials



Phase change materials



Ferroelectric tunnel junctions



Magnetoresistance (spintronics)

low resistance

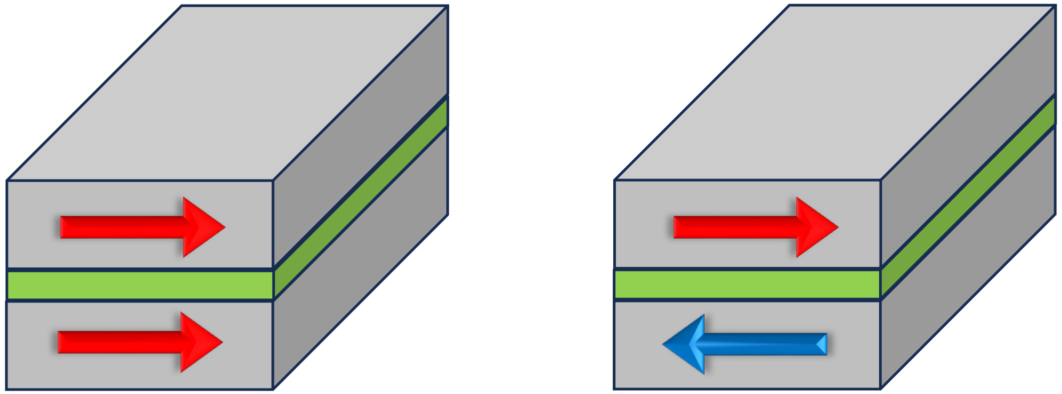
high resistance

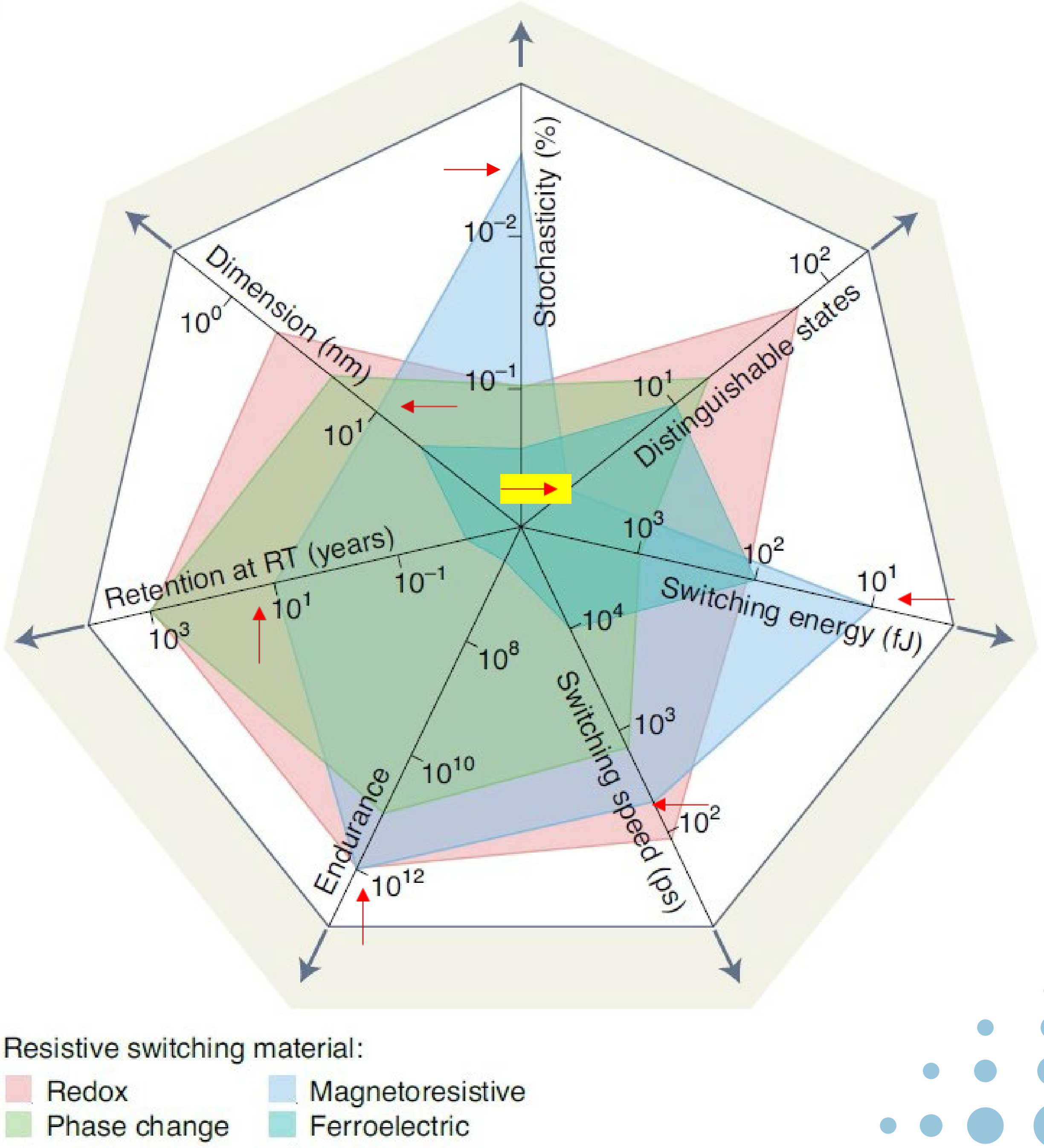
The crossbar – material options

The weak spot of the magnetoresistance option

Distinguishable States

Spintronic configurations





Wang et al. Nature Reviews 5, 173 (2020)

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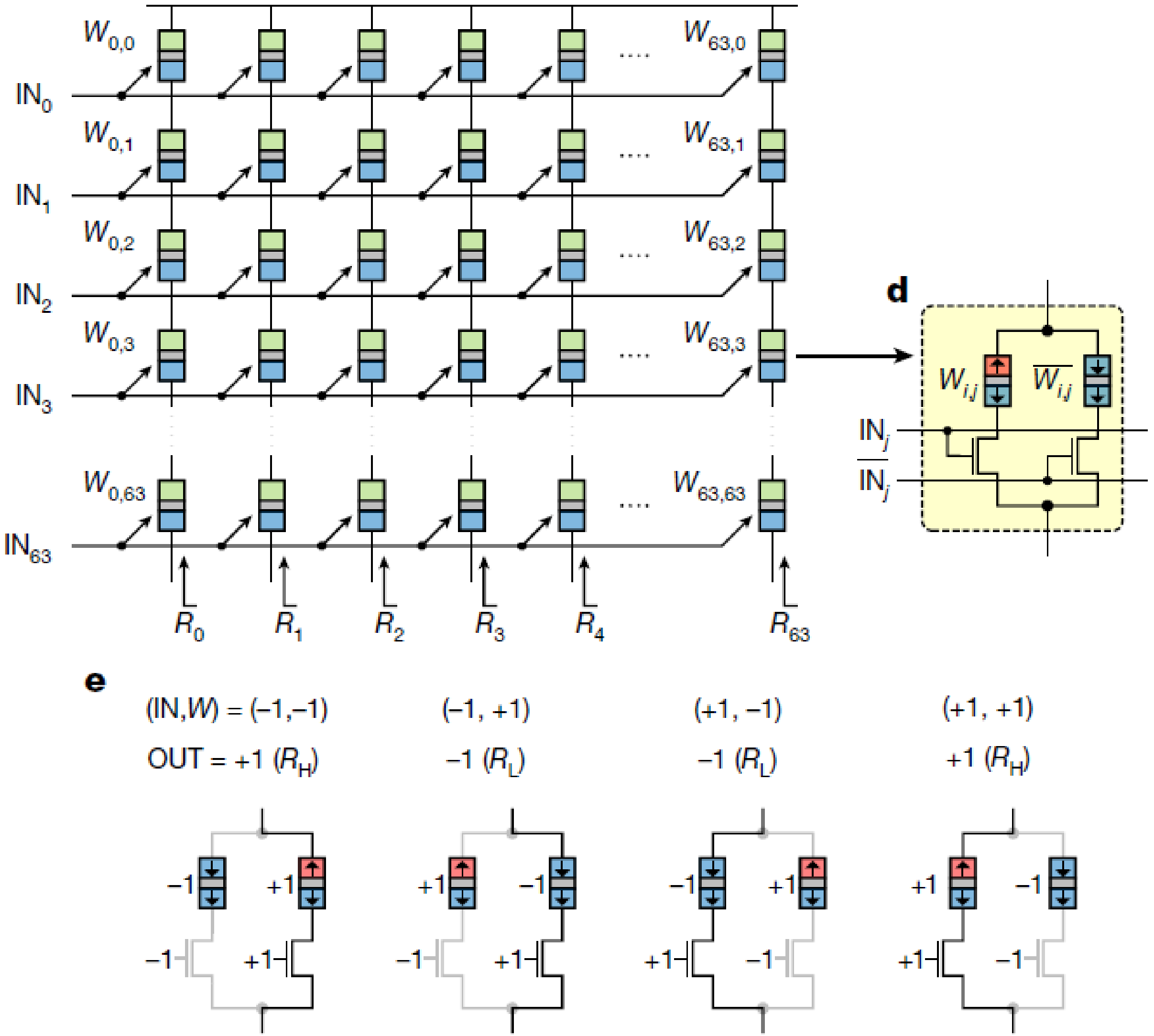
Samsung’s Spintronic Crossbar with binary MTJs

64x64 crossbar



S. Jung et al. Nature 601, 2011 (2022)

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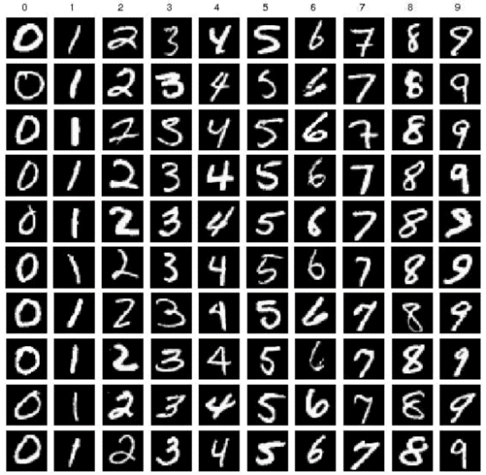
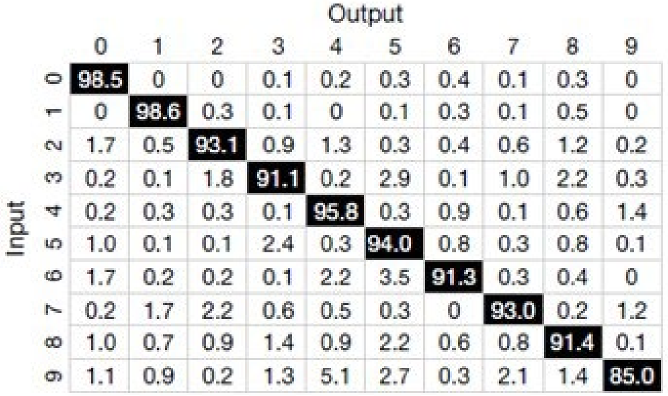
The performance of MTJ-based Crossbar

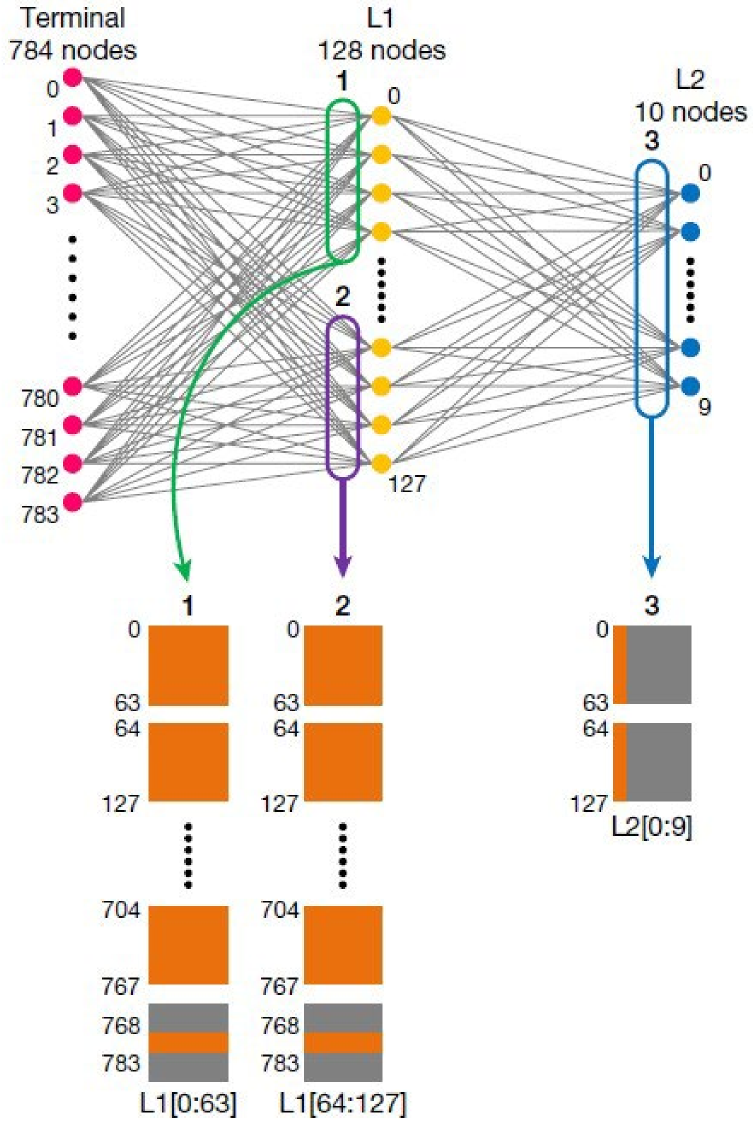
28x28 pixel image



Limitation – only 2 weights per junction



	Output									
Input	0	1	2	3	4	5	6	7	8	9
0	98.5	0	0	0.1	0.2	0.3	0.4	0.1	0.3	0
1	0	98.6	0.3	0.1	0	0.1	0.3	0.1	0.5	0
2	1.7	0.5	93.1	0.9	1.3	0.3	0.4	0.6	1.2	0.2
3	0.2	0.1	1.8	91.1	0.2	2.9	0.1	1.0	2.2	0.3
4	0.2	0.3	0.3	0.1	95.8	0.3	0.9	0.1	0.6	1.4
5	1.0	0.1	0.1	2.4	0.3	94.0	0.8	0.3	0.8	0.1
6	1.7	0.2	0.2	0.1	2.2	3.5	91.3	0.3	0.4	0
7	0.2	1.7	2.2	0.6	0.5	0.3	0	93.0	0.2	1.2
8	1.0	0.7	0.9	1.4	0.9	2.2	0.6	0.8	91.4	0.1
9	1.1	0.9	0.2	1.3	5.1	2.7	0.3	2.1	1.4	85.0

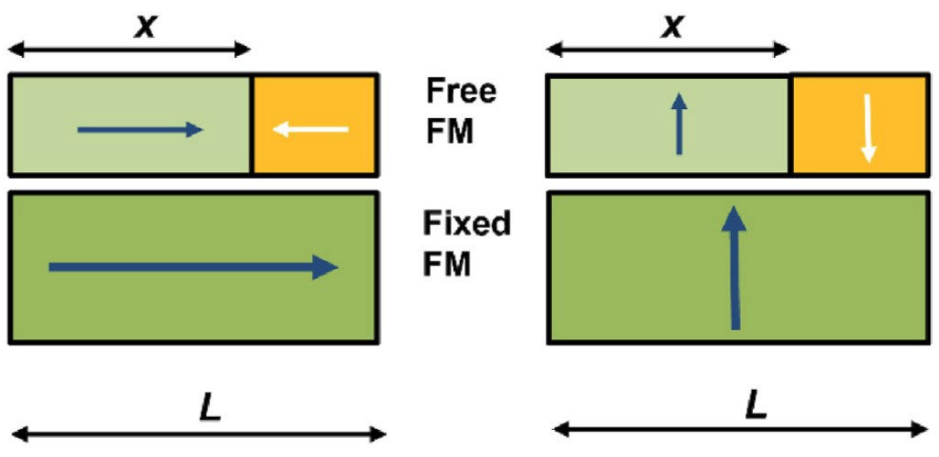


S. Jung et al. Nature 601, 2011 (2022)

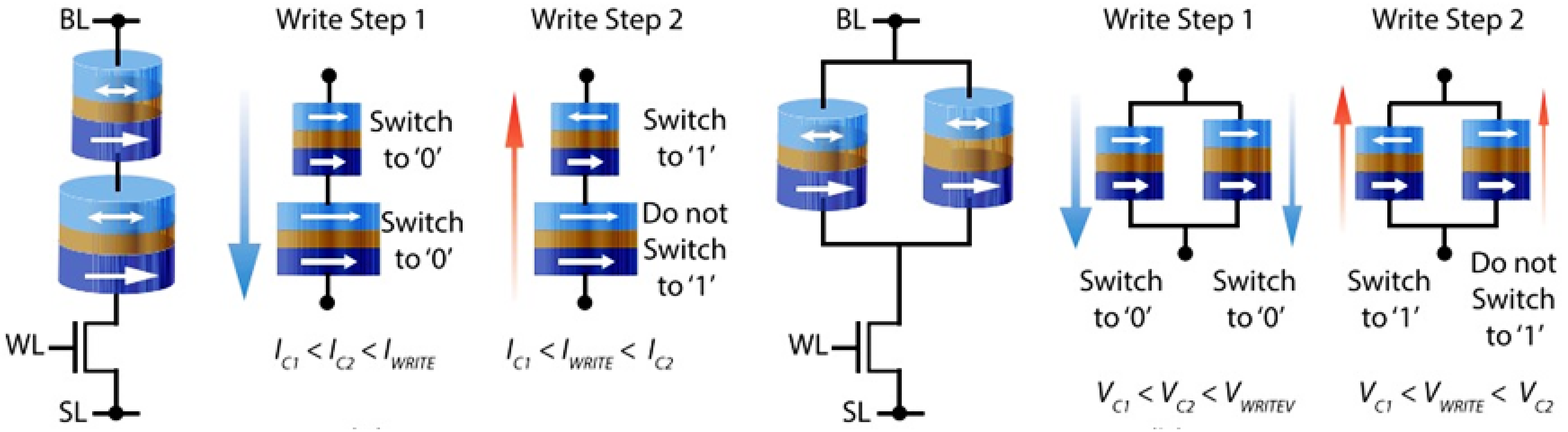
The binary spintronic crossbar has limitations

From binary to multi-state

Increasing the number of resistance states



Sci Rep 6, 31510 (2016)



Proceedings of the IEEE, vol. 104, no. 7, 1449, July 2016

Using a new angle – the M^{2}TJ

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Private, non-for-profit research institute

Flavio Abreu Araujo

UCLouvain

University

SpinEdge

SpinEdge AI accelerator – Spintronic analog instant AI

Konstantin Zvezdin

I-FEVS

Developing fully electric vehicles for sustainable urban mobility

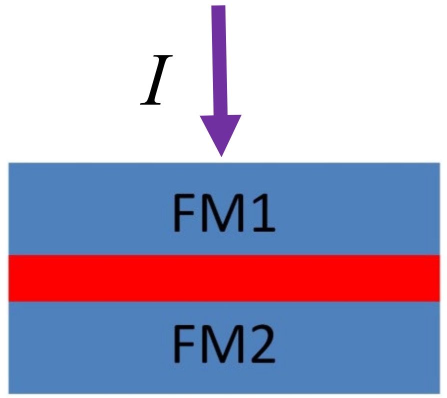
Pietro Perlo

AMIRES

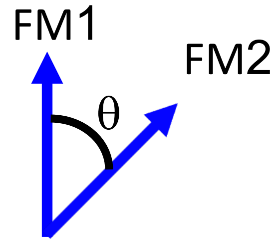
Supporting strategically oriented innovation for business and societal impact

Marina de Souza Faria

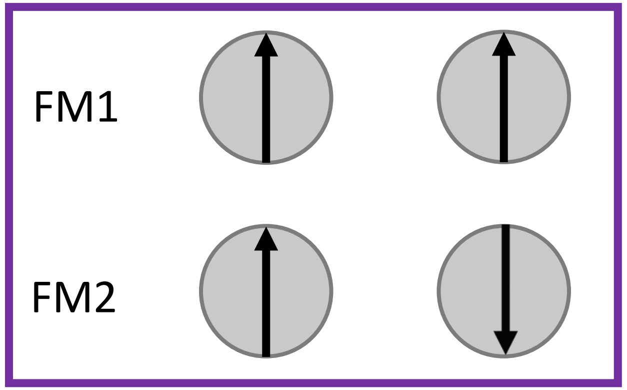
M²TJ - the *angular* degree of freedom



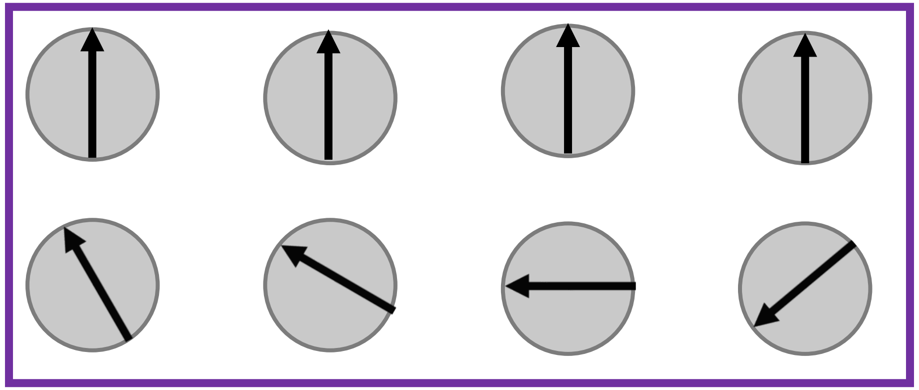
$$R_{junction} = R_{av} - \frac{1}{2}\Delta R \cos\vartheta$$



NOW



Our approach



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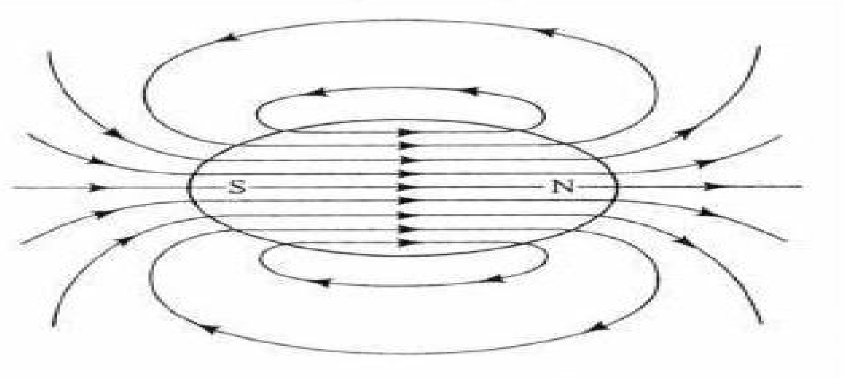
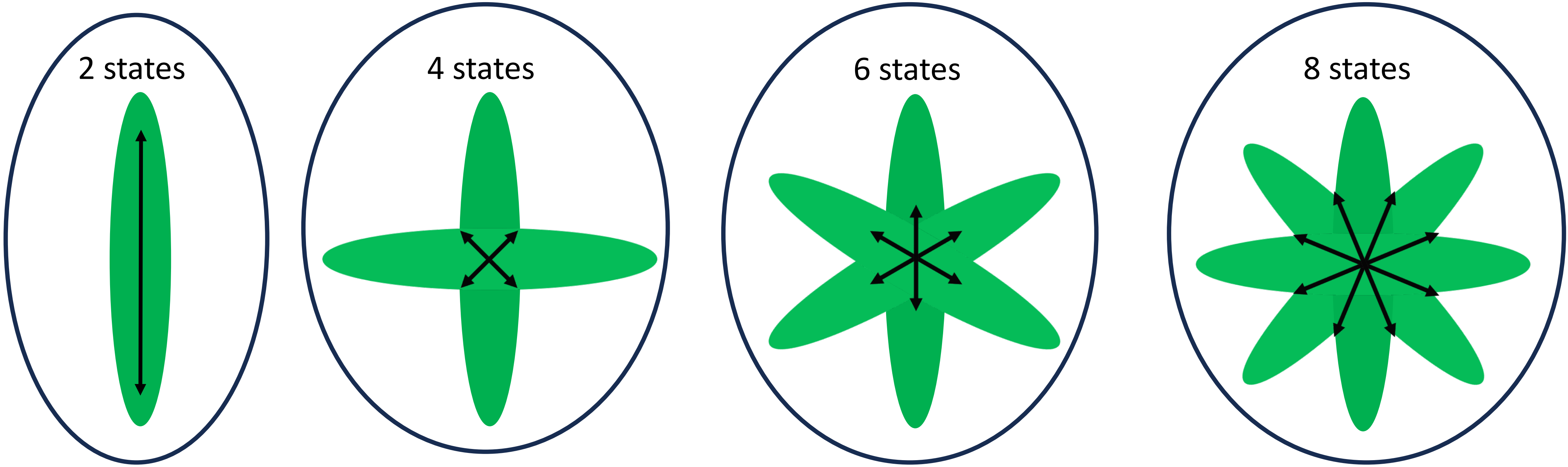
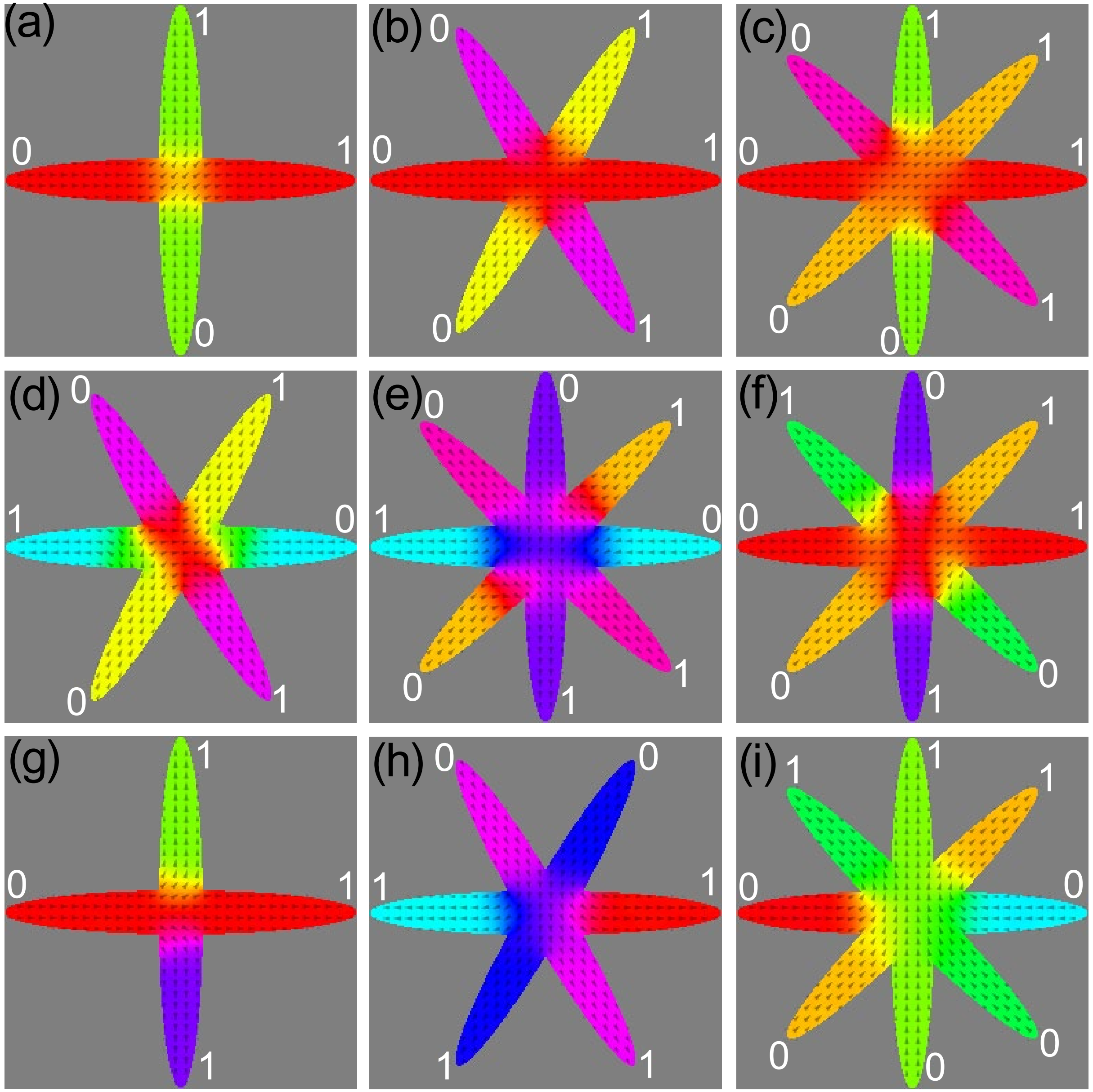
High-order magnetic anisotropy induced by shape





Using such structures for multi-level MRAM US Patent 10,204,678



Ordinary states

2N states

Staggered states

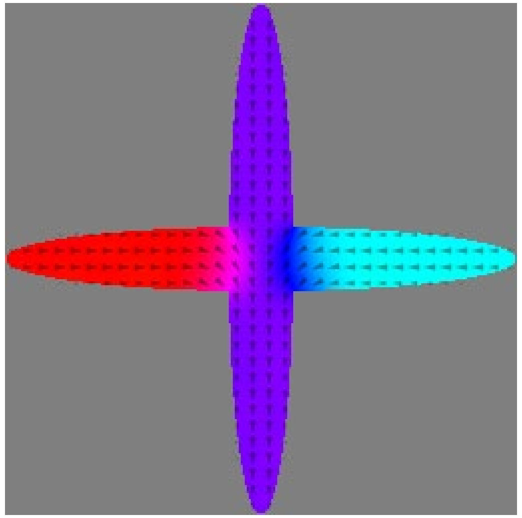
2^N states

Neel states

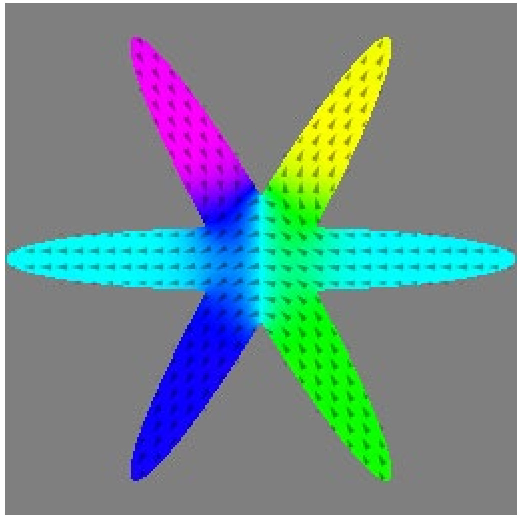
2^{2N} states

*S. Das et al., Appl. Phys. Lett. **116,** 262405 (2020).*

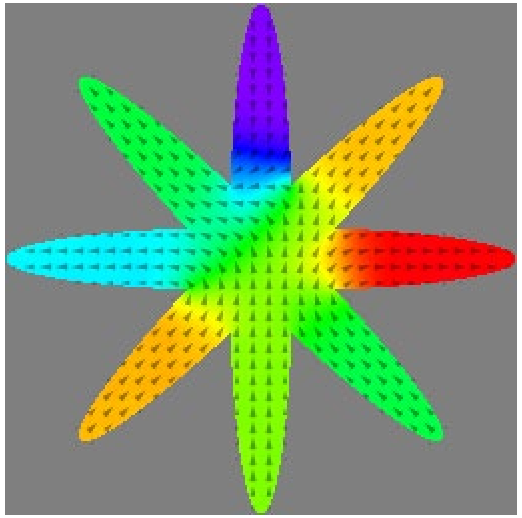
Exponential number of magnetic configurations



$2^{2*2} = 16$



$2^{2*3} = 64$



$2^{2*4} = 256$

Note: this is the number of distinct magnetic configurations.
The number of resistance states is smaller.

MultiSpin.AI – the final goal

A spintronic crossbar where binary MTJs are replaced by M^2TJ

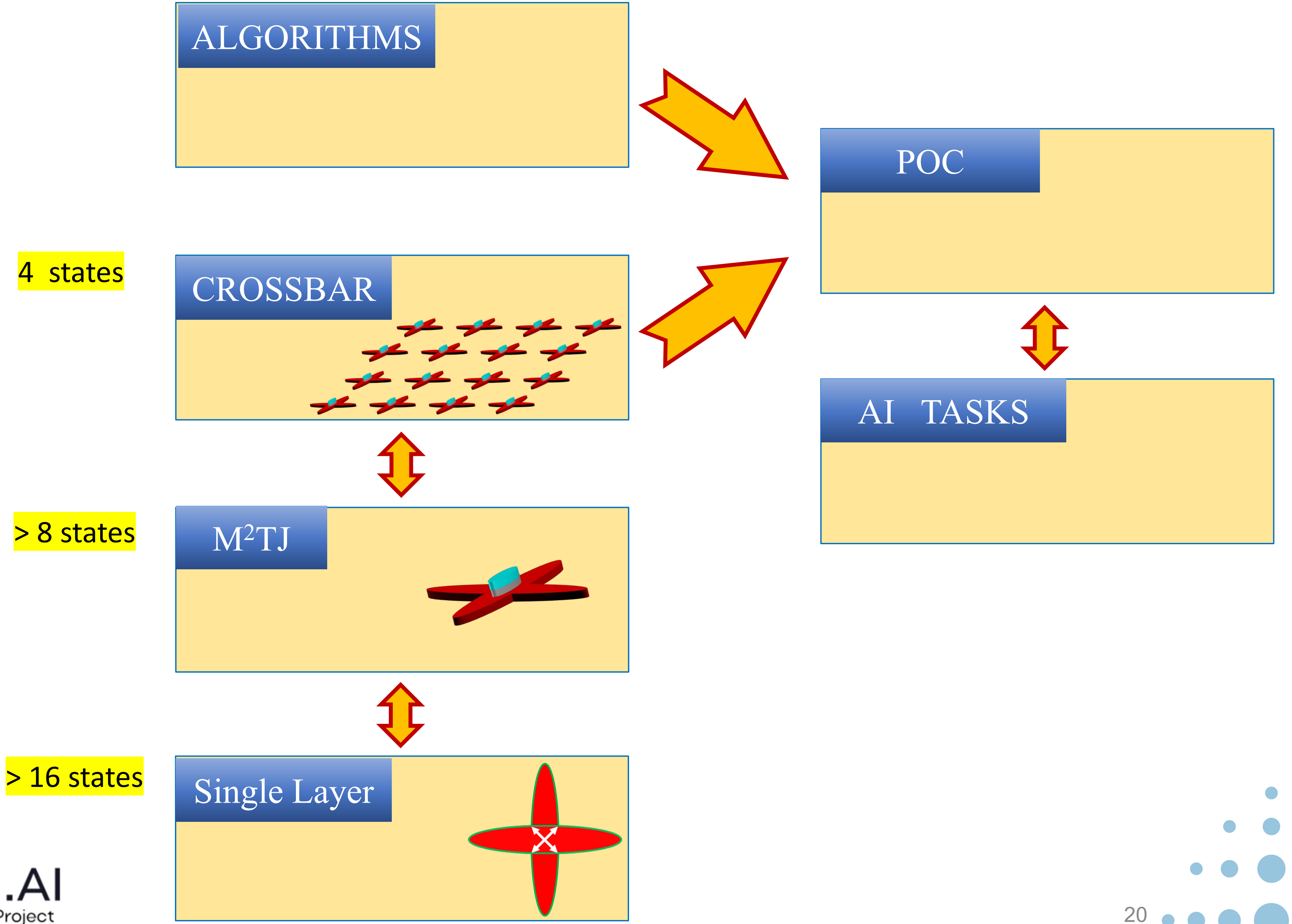
with multiple discrete magnetic states

We plan to

- Fabricate
- Operate
- Test

MultiSpin.AI

The strategy



ALGORITHMS

POC

AI TASKS

4 states

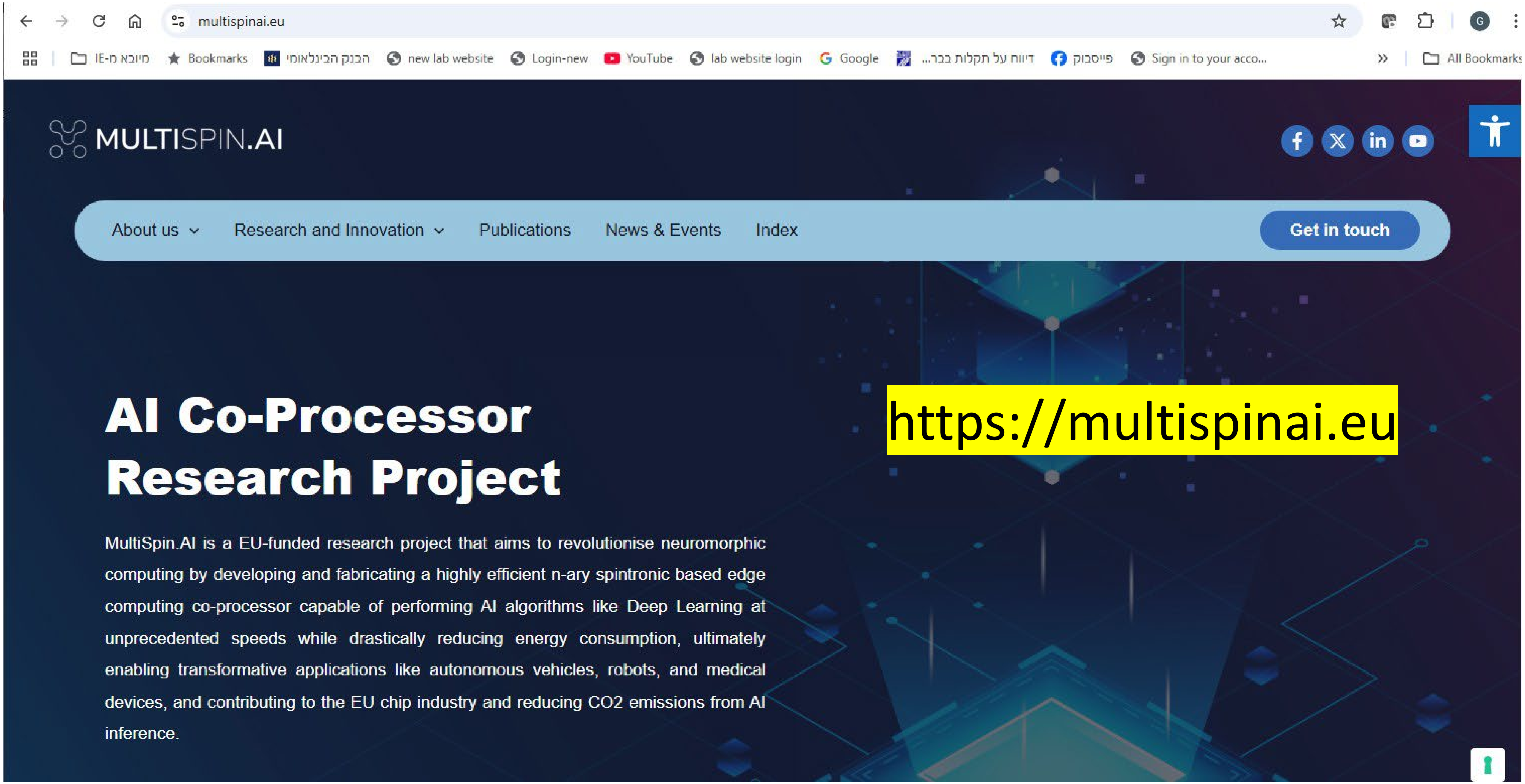
CROSSBAR

> 8 states

M^2TJ

> 16 states

Single Layer



https://multispinai.eu

AI Co-Processor Research Project

MultiSpin.AI is a EU-funded research project that aims to revolutionise neuromorphic computing by developing and fabricating a highly efficient n-ary spintronic based edge computing co-processor capable of performing AI algorithms like Deep Learning at unprecedented speeds while drastically reducing energy consumption, ultimately enabling transformative applications like autonomous vehicles, robots, and medical devices, and contributing to the EU chip industry and reducing CO2 emissions from AI inference.

MultiSpin.AI – expectations and challenges

What are the Constraints and limitations tackled by Multispin.AI?

Spintronic crossbars are promising - hundreds of tera-operations per second per watt (Samsung) – MultiSpin.AI can improve significantly their accuracy by overcoming the binary constraints

How to expedite implementation?

The fabrication challenge is considerable; therefore, the most efficient way to expedite implementation is by partnership with European chips companies