Brain-CA Technologies

Brain-CA:
A Cellular Automata-Inspired Architecture for Energy-Efficient CPU Design

ISCA 2025 DCEE Workshop
June 2025

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Who is Brain-CA Technologies?

Founded by three former engineers with 70+ years in system design with the HP Enterprise team,

We are addressing the AI Energy Crisis.

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Our Progress:

ISCA 2024:
Presented theoretical approach to cut energy consumption *by orders of magnitude*.

Since:
Success in software simulations.
FPGA implementation.
Smaller models.

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Our Motivation:

You don’t need equations to play catch.

The same goes for learning.

Math can describe it—
but that doesn’t mean
it’s the best way to do it.

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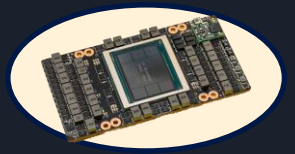
Comparing a mosquito brain to the H100



A mosquito brain is...

- ~40,000× smaller
- 1/400,000 the number of components
- ~700,000× more energy-efficient

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Re-think the lower levels of AI stack

- Application-Level Software (LLMs, Vision AI, etc.)
- Inference Logic (Prompting, APIs, etc.)
- Model Runtime (TensorRT, ONNX, etc.)
- Training Framework (PyTorch, TF, JAX)
- Hardware Interface Layer (CUDA, XLA, etc.)
- Compute Hardware (GPUs, TPUs — Von Neumann)

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331 Pages!

Von Neumann Architecture (JvN: 101 pages), Neural Networks (McCulloch & Pitts: 24 pages, Rosenblatt: 22 pages, Minsky: 136 pages), Backpropagation (Rumelhart, Hinton & Williams: 13 pages), Cuda & GPUs (Buck, Harris, Krizhevsky, Sutskever, Hinton: 35 pages)

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1. We invented the world’s simplest device that learns and predicts.

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1. We invented the world’s simplest device that learns and predicts.

2. We invented a scalable learning system using that elemental device.

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Re-think the Elemental Components

Element	Function
Bit	0 or 1
NAND Gate	Invert or Ignore
Transistor	Switch or Amplify
Estimator	Learn or Predict

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Re-think AI using Information Theory

- Shannon: Entropy defines the minimal message
- Redundancy enables perfect reconstruction from noise
- Estimation = compressed memory with structure
- AI, reframed: a compression + prediction problem
- Partial observations → compact model → accurate inference
- Redundancy fills in what was never seen
- Brain-CA builds AI from these first principles

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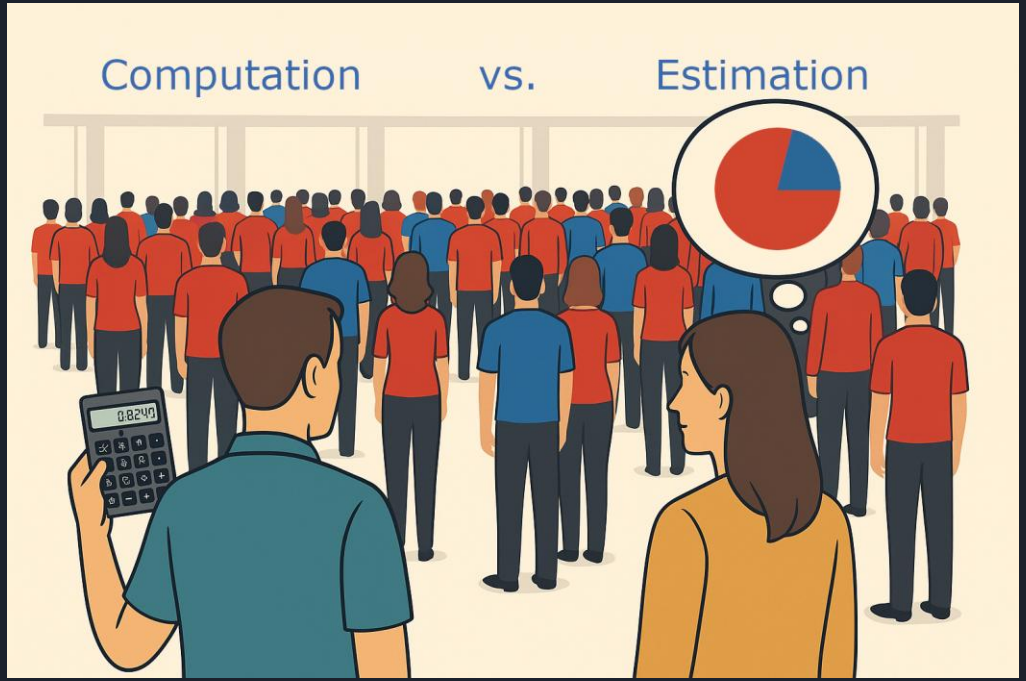
Estimation replaces Computation for Energy Savings



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Re-think the Pie Chart

1/2 1/4 1/8 1/16 1/32 1/64 1/128

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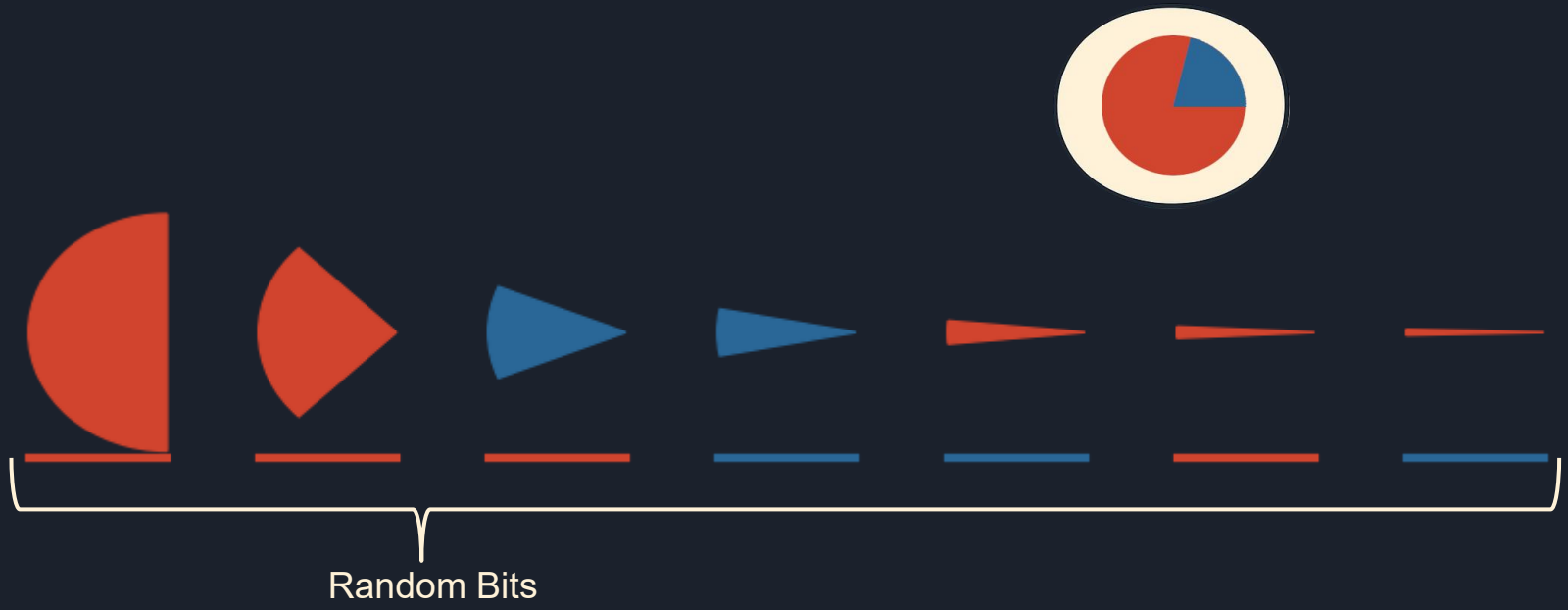
Re-think Memory: add Randomness



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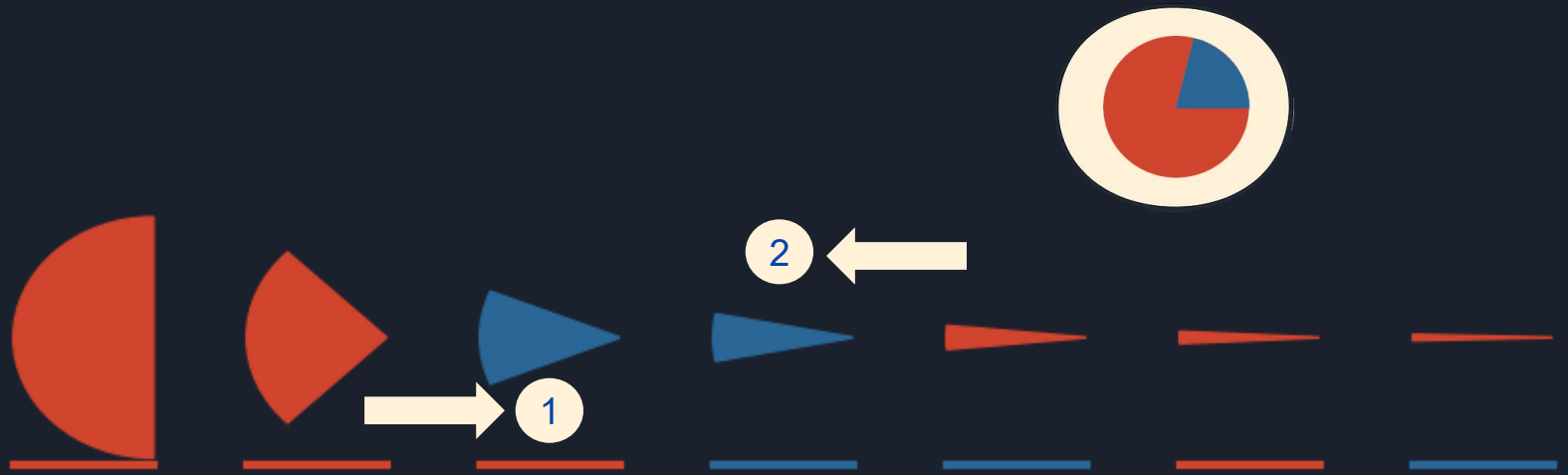
Prepare (off-cycle) to be ready for action



1. Find first mis-match Memory / Random from left
2. Find first matching Memory #1 / Memory from right

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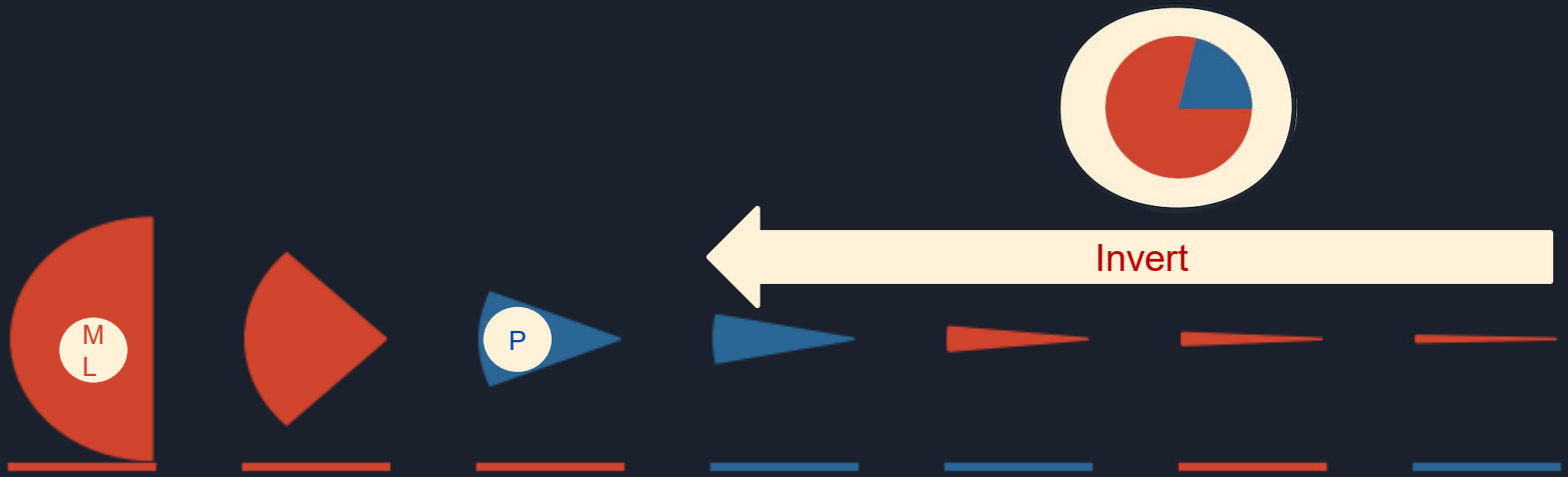
Designed to learn or predict instantly



Learn: Red → Invert last four Blue → Ignore

Predict: M L Most Likely → Red P Probabilistic → Blue

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Estimator converges on actual ratio

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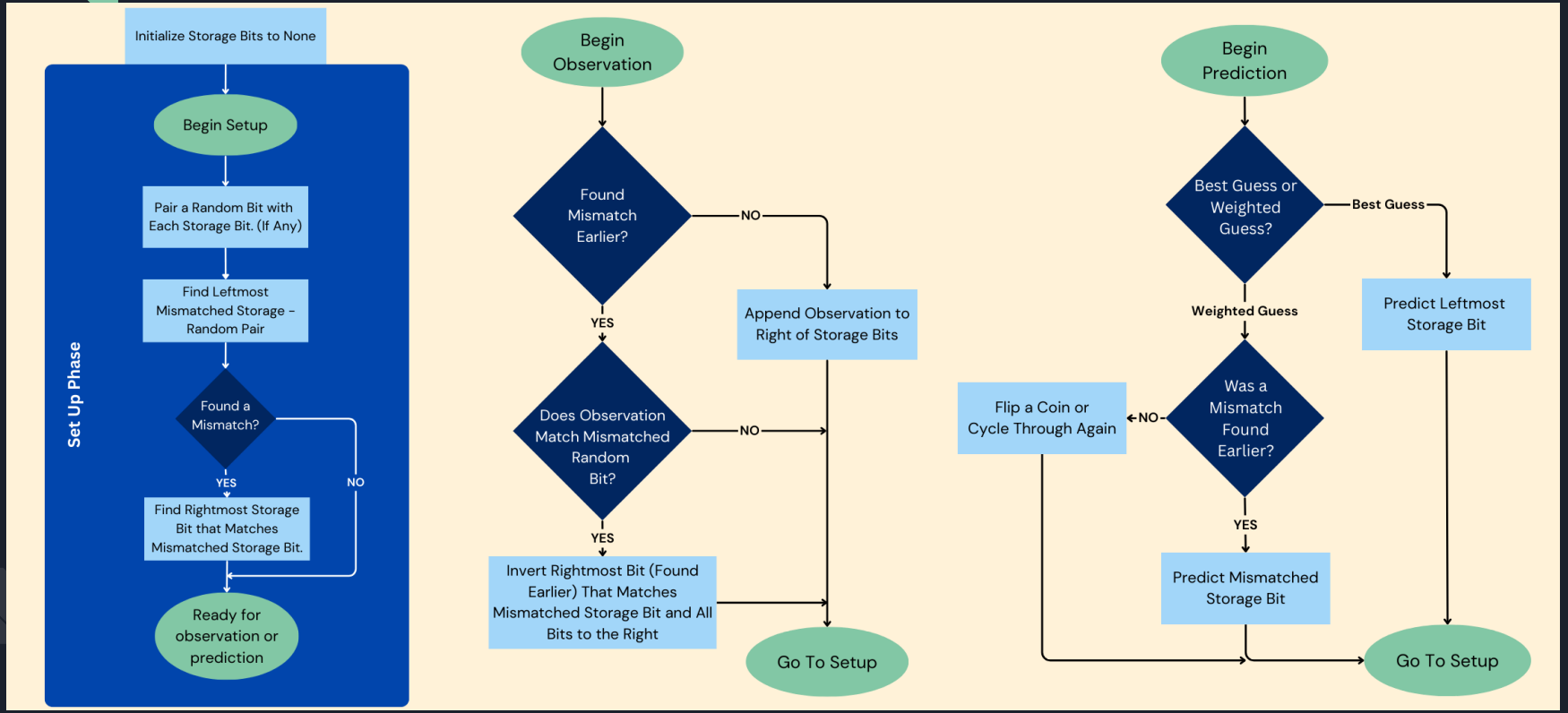
Simple Architecture: Estimator Logic



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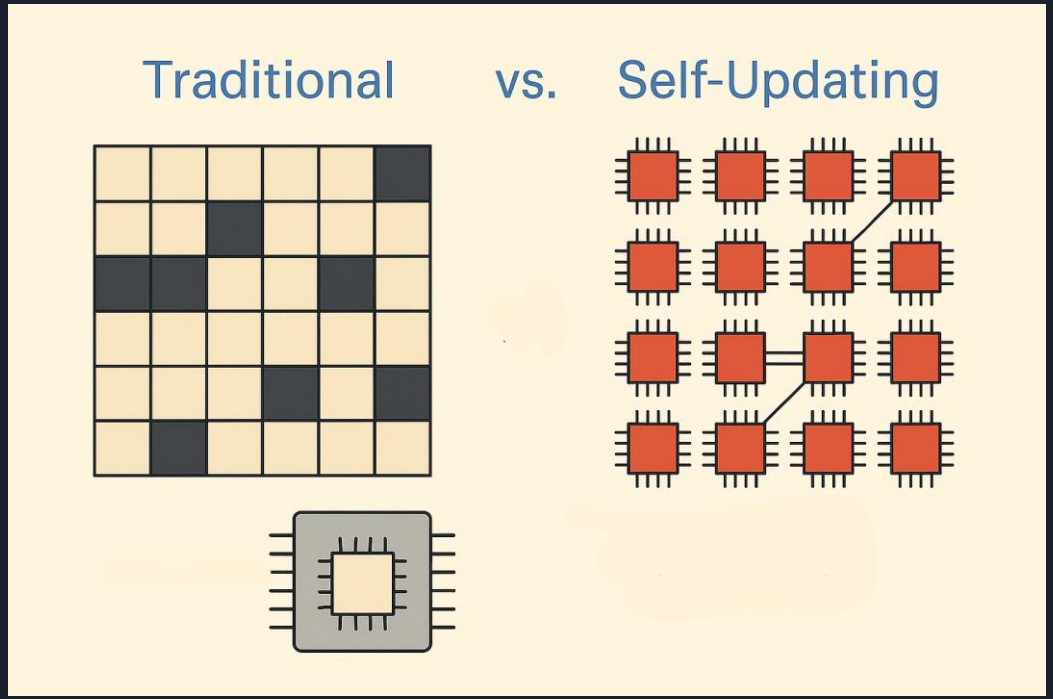
Re-think Cellular Automata



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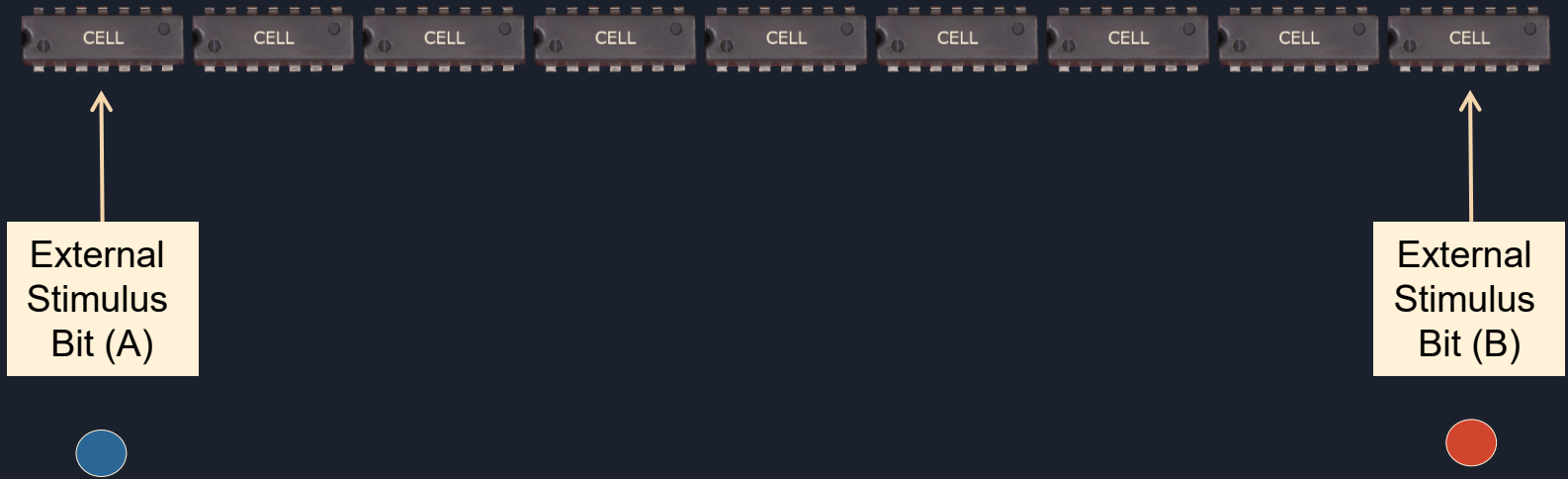
One-dimensional view



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Learn through observation

How does “A” behave?

How does “B” behave?

External Stimulus Bit (A)

External Stimulus Bit (B)

Memory Logic:

- Remember the characteristics of external stimuli

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Discovering Relationships

Communication Logic:

- Pass any external stimulus to neighbor(s)
- If something is passed from the left, pass it to the right (and vice versa)

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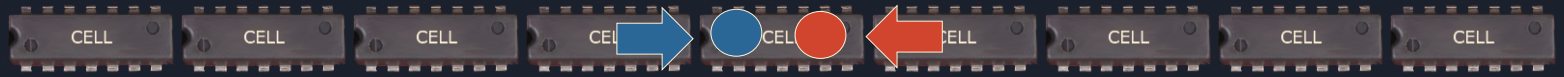
Collision Cells can track relationships



Communication to Memory Logic:

- When signals collide, bifurcate and remember relationship

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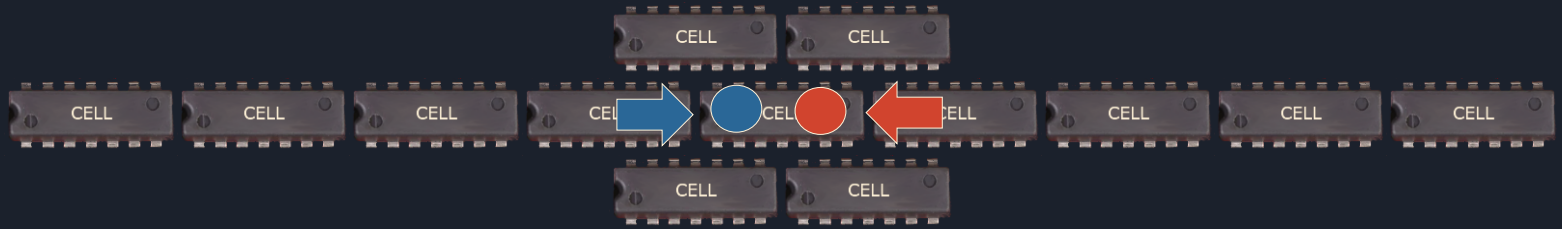
Collision Cells can track relationships



Communication to Memory Logic:

- When signals collide, bifurcate and remember relationship

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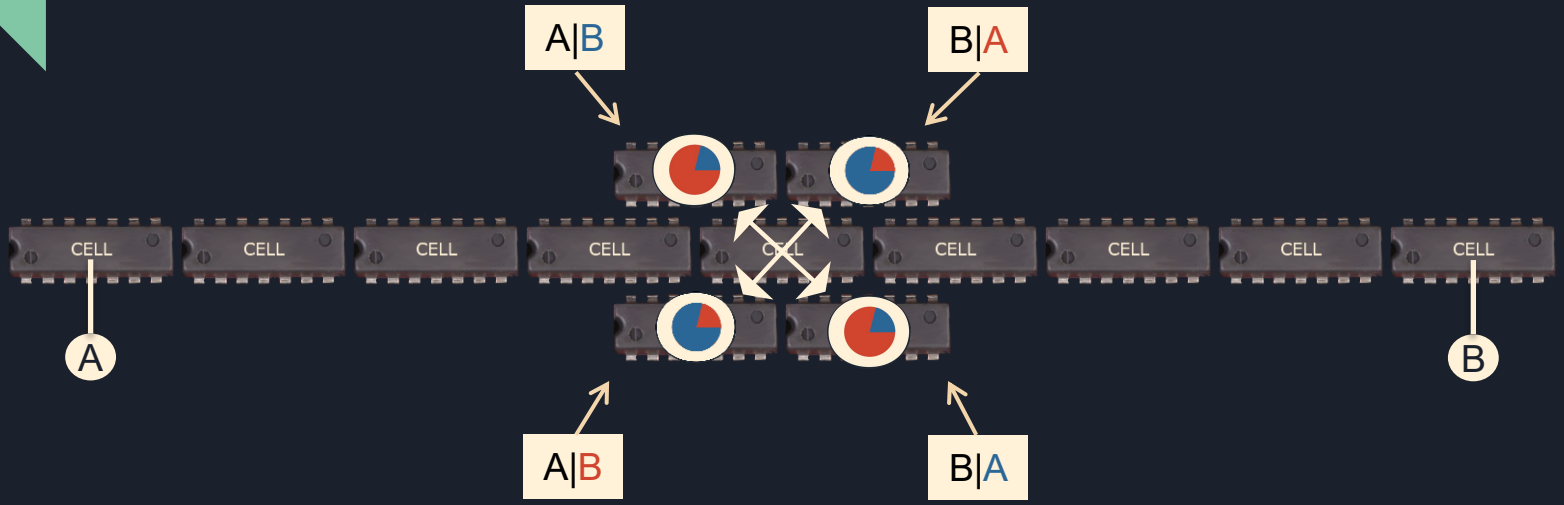
Use Neighbors to track conditional relationships



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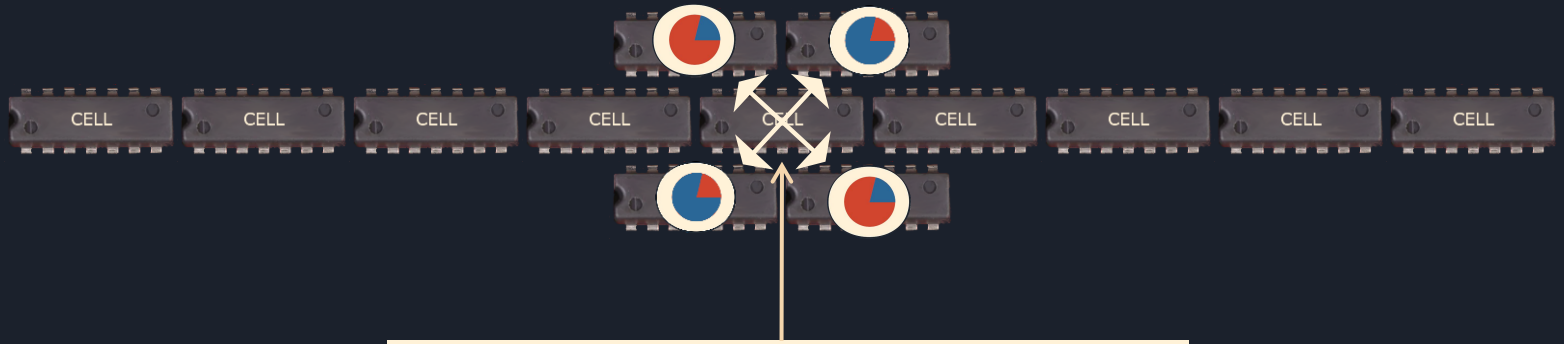
Collision Cells coordinate the memory



This cell can now predict A|B and B|A.

Slight problem: the cellular propagation delay.

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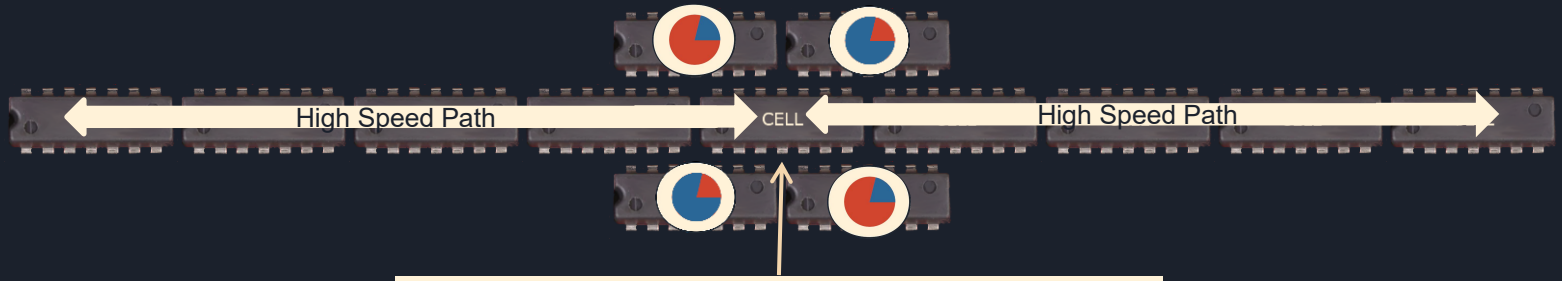
Dual Speed Architecture



Connection Logic:

- Build high speed paths between correlated cells

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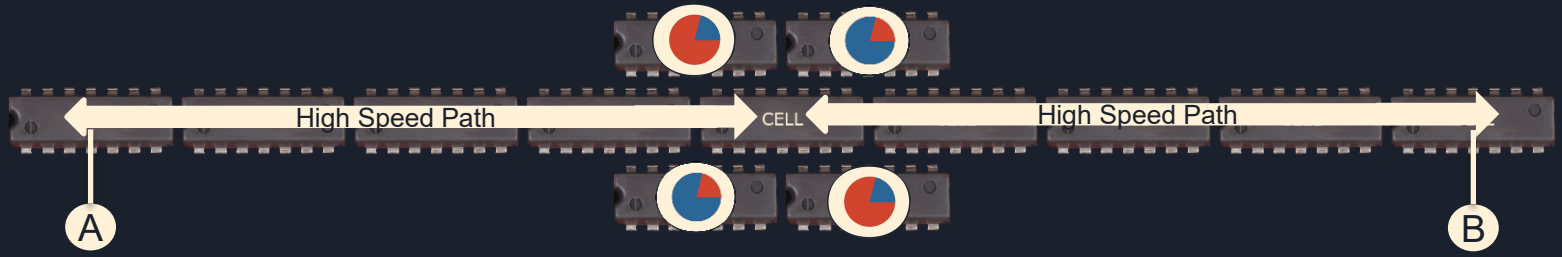
Inference with concurrent signals



1. If “A” is stimulated, the signal is immediately sent to the collision cell.
2. “B” can be predicted based on the value of “A”.
3. The prediction is rapidly sent to “B”.

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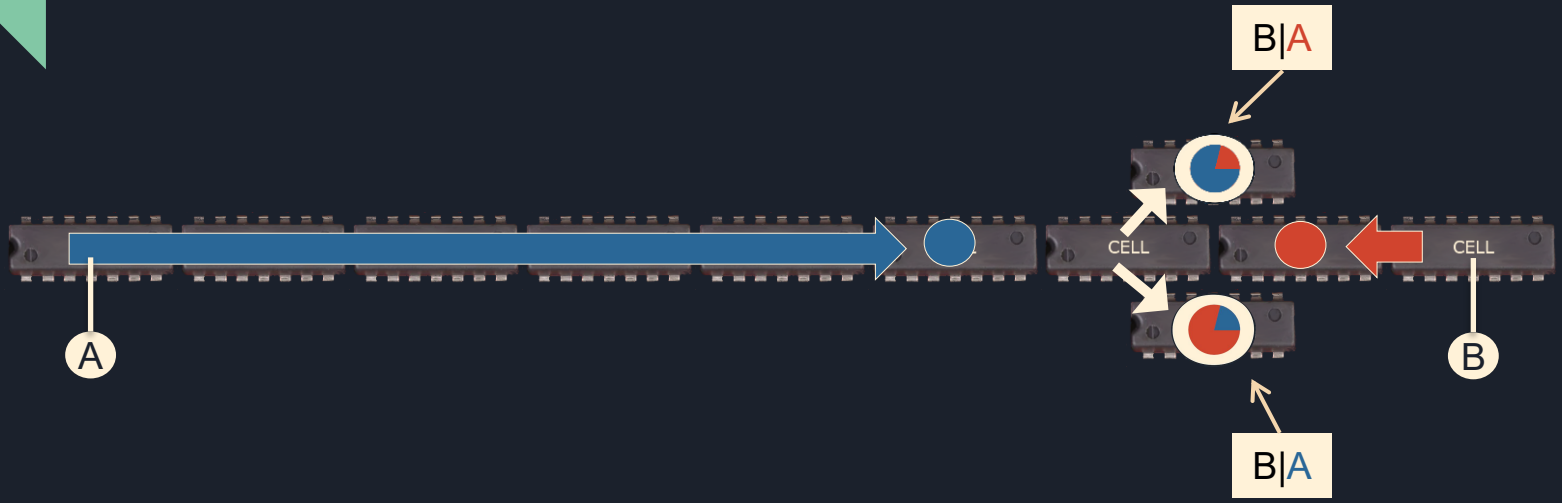
Learning with temporal offsets



“A” was stimulated four clock ticks earlier than “B”.

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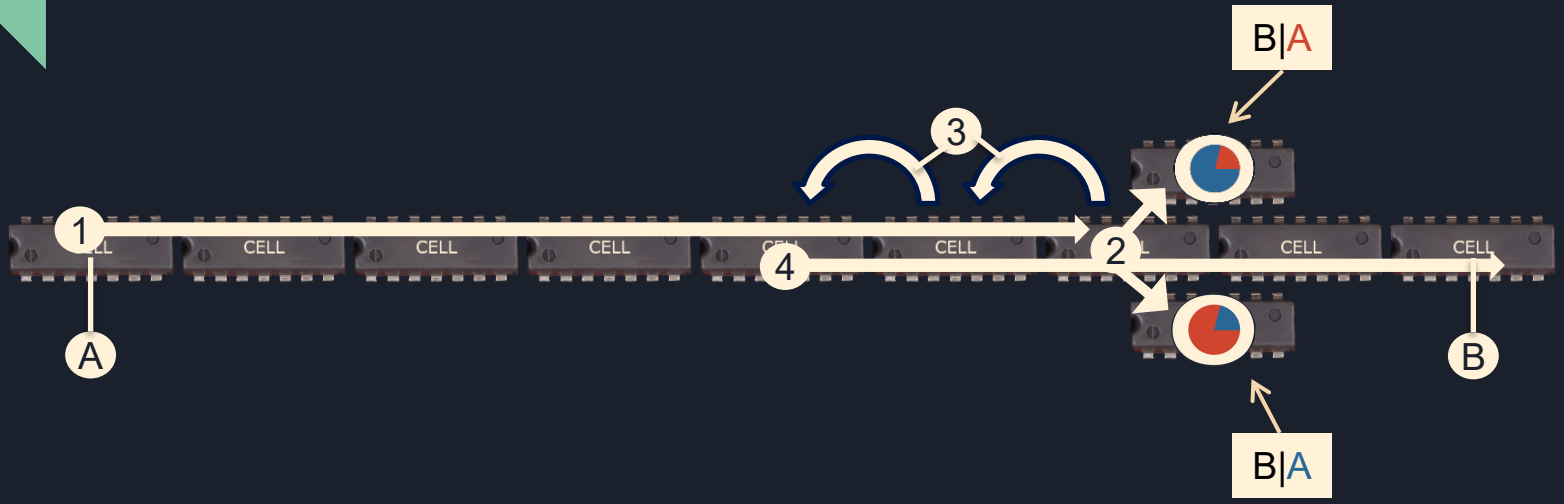
Inference with temporal offsets



1. If “A” is stimulated, the signal is immediately sent to the collision cell.
2. “B” can be predicted based on the value of “A”.
3. The prediction can is slowly routed to the mid-point.
4. The prediction is rapidly sent to “B”. Right place, right time.

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All cells run the same logic

- Waves encode time and distance using quantized values
- Relationships are discovered at collision points of waves
- Fast Paths are built between related stimulus points
- Predictions are easy

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Each cell participates in three Subsystems

Communication: Broadcast signals

Memory: Remember relationships

Connection: Build Inference fast paths

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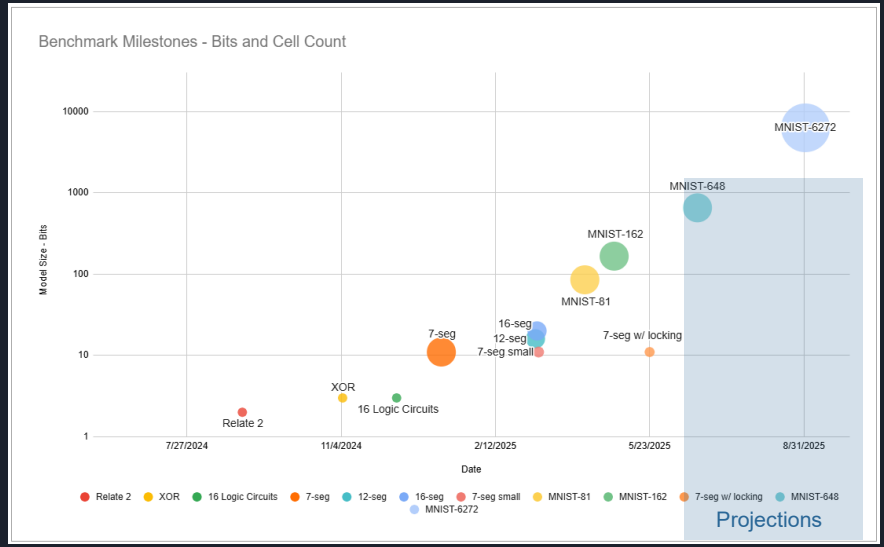
Progress to date

Successful simulations on small models

FPGA implementation underway

MNIST expected to be first public results



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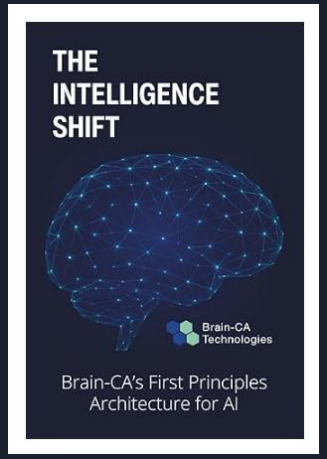
Learn More

5:20 – 6:00 Today – Poster Presentation for MLArchSys
1:45 – 2:10 Tomorrow – Presentation for CogArch

Book, Papers, Videos at brain-ca.com/isca



amazon

brain-ca.com/isca