Brain-CA Technologies

Brain-CA:
A Dual-Speed, Low-Energy Architecture for Cognitive Learning via Cellular Automata

ISCA 2025 CogArch 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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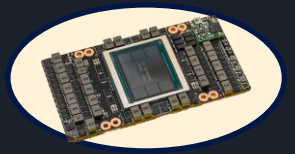
Comparing a mosquito brain to the H100



A mosquito brain is...

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

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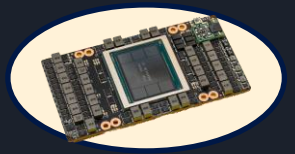
Comparing a mosquito brain to the H100



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Learn Fast. Spend Little. Or Die.™

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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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Technologies

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

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Technologies

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	At Scale
Bit	0 or 1	Integers, floating point, images, sound,…
NAND Gate	Invert or Ignore	Any logic circuit
Transistor	Switch or Amplify	Most electronic devices
Estimator	Learn or Predict	Most AI applications

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Re-think AI using Information Theory

- Claude 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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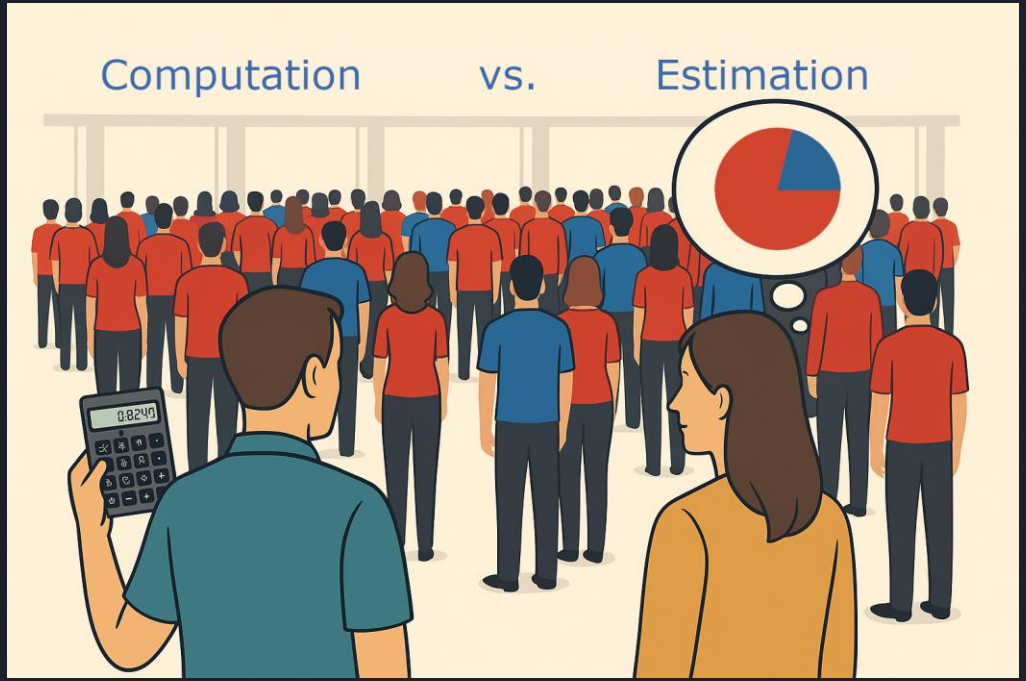
Estimation replaces Computation for Energy Savings



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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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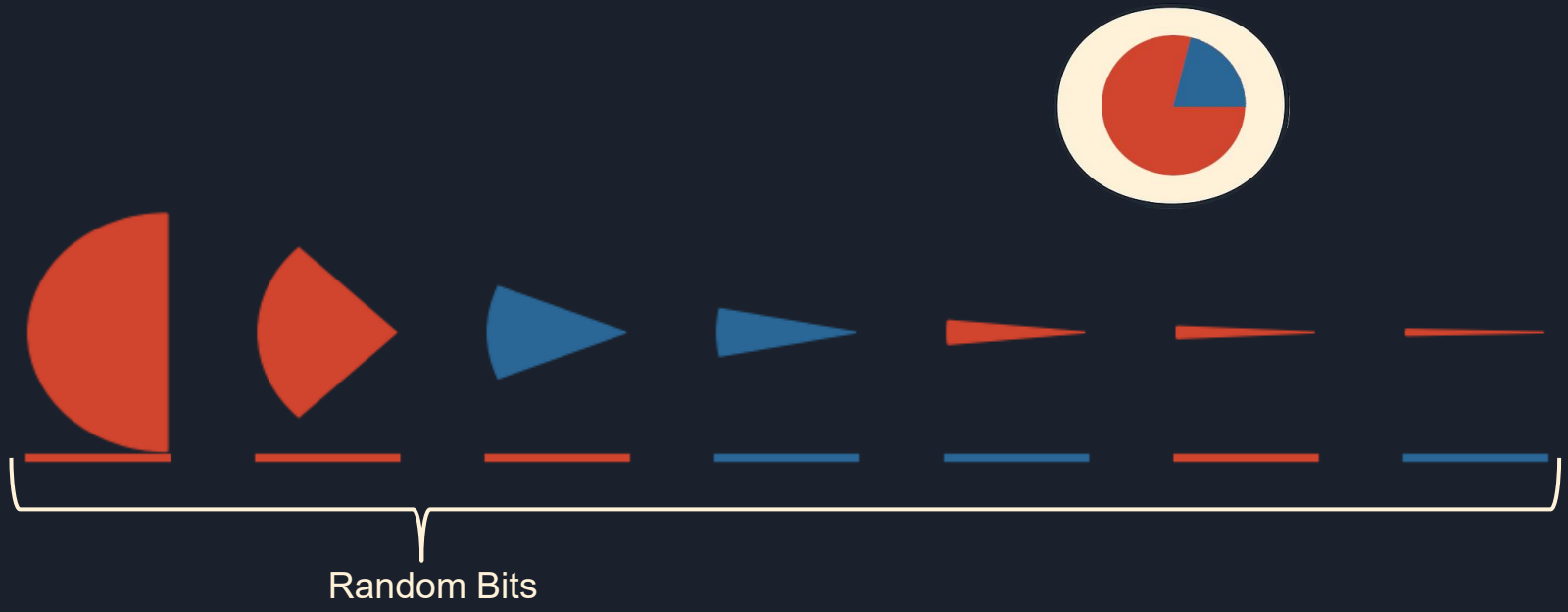
Re-think Memory: add Randomness



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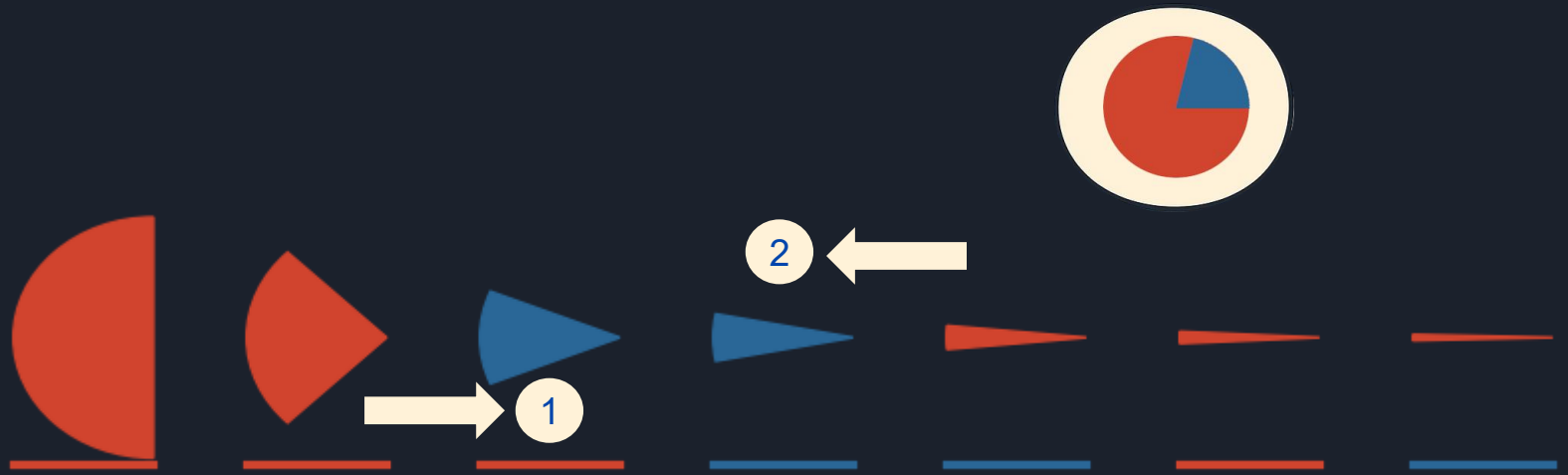
Prepare (off-cycle) to be ready for action



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

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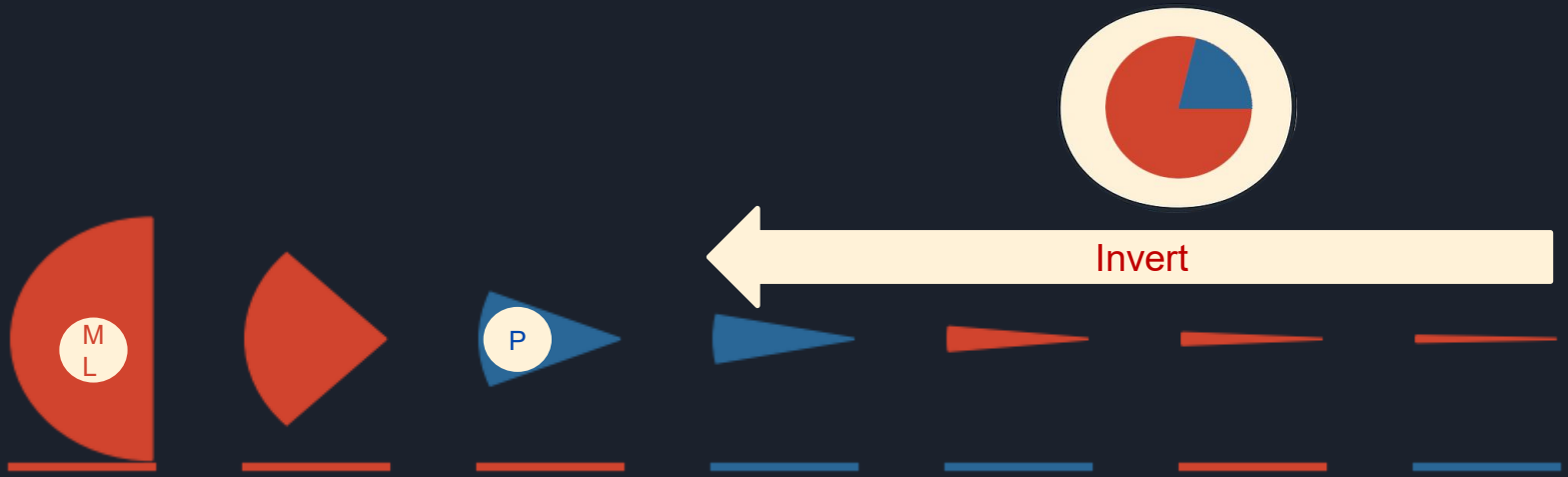
Designed to learn or predict instantly



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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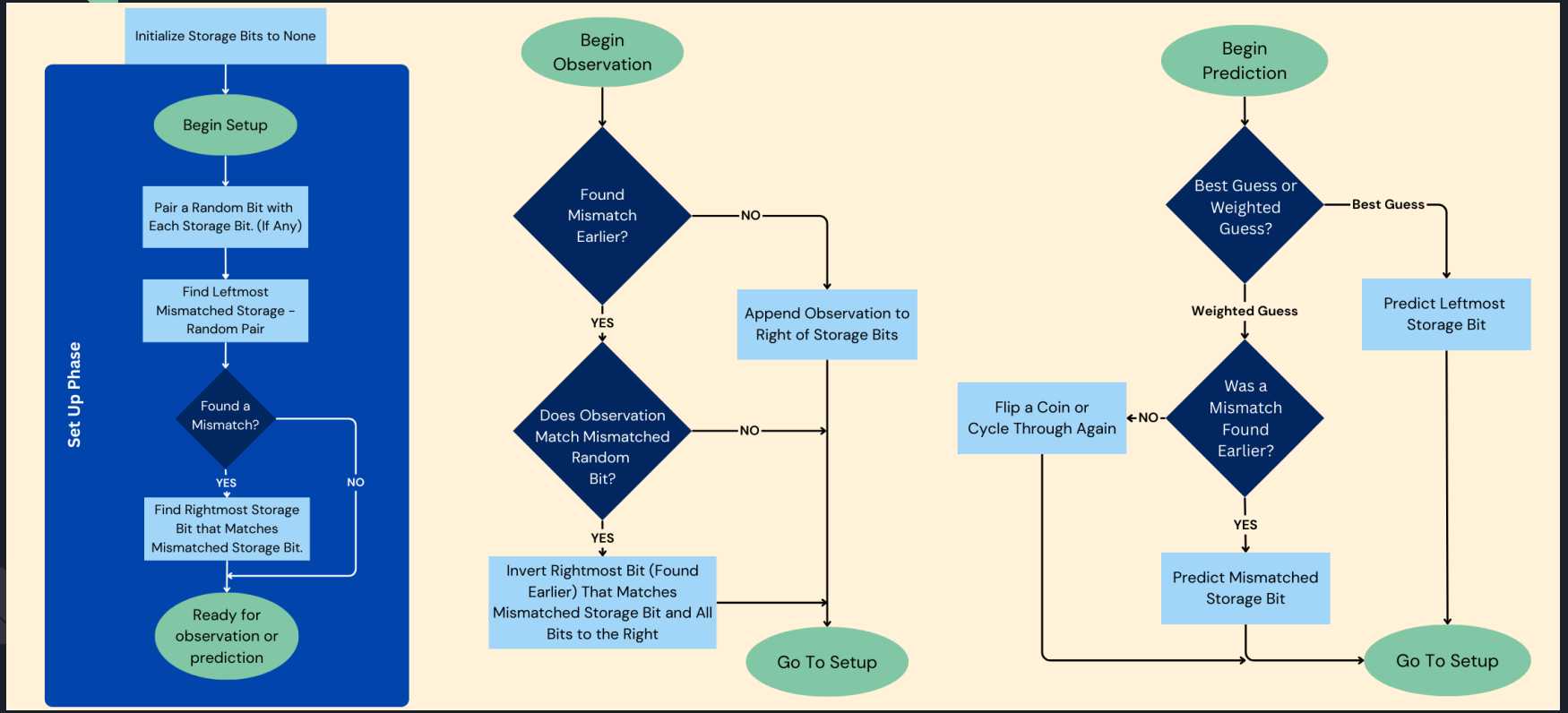
Simple Architecture: Estimator Logic



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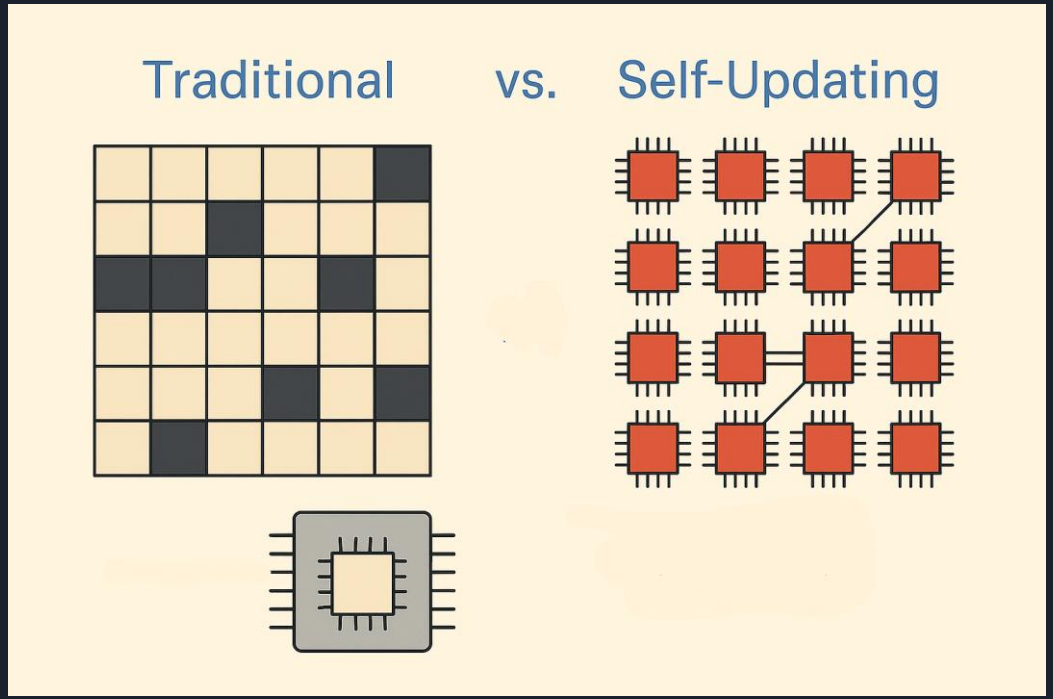
Re-think Cellular Automata



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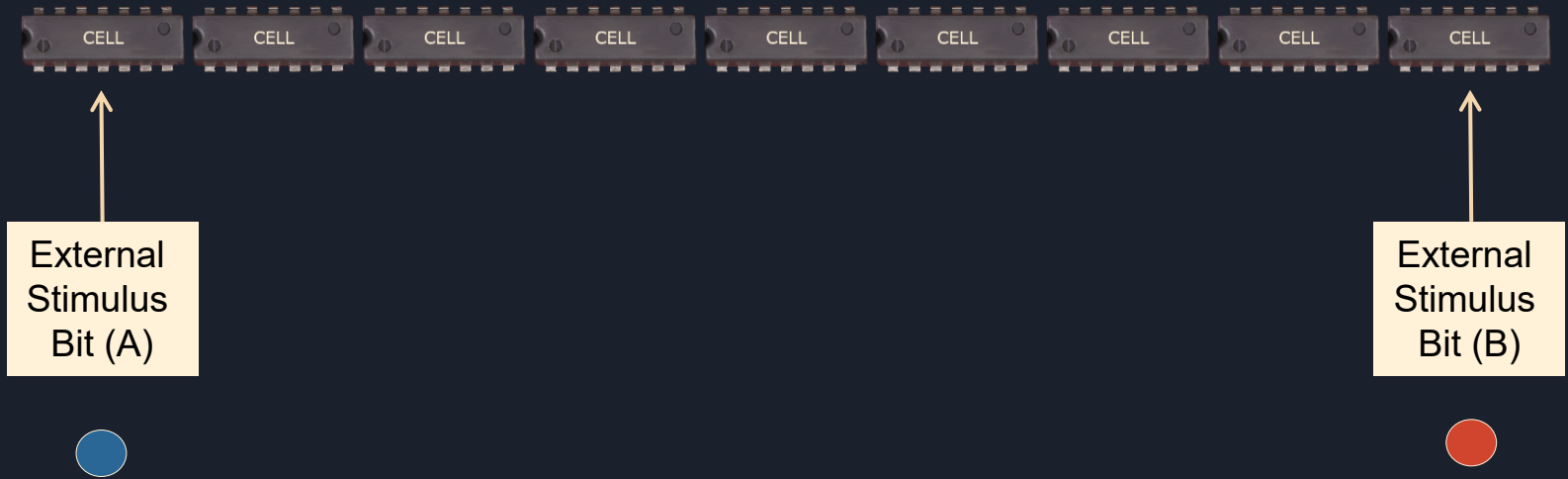
One-dimensional view



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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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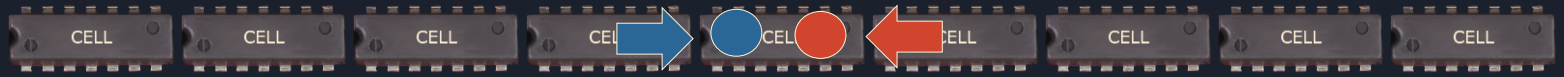
Collision Cells can track relationships



Communication to Memory Logic:

- When signals collide, bifurcate and remember relationship

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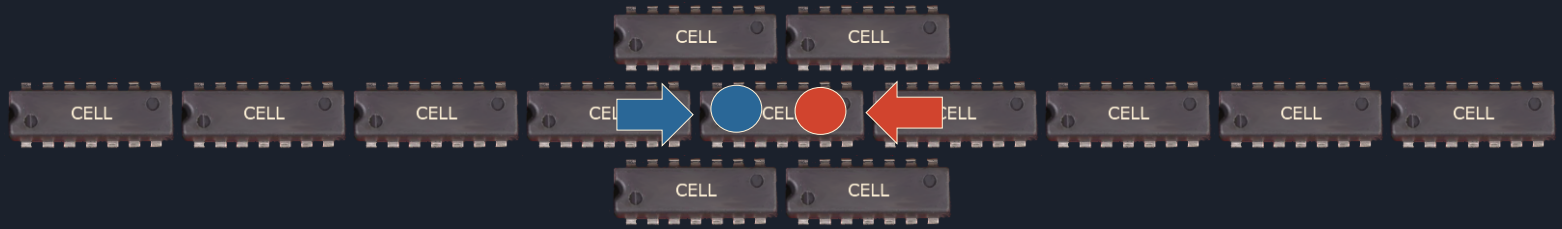
Collision Cells can track relationships



Communication to Memory Logic:

- When signals collide, bifurcate and remember relationship

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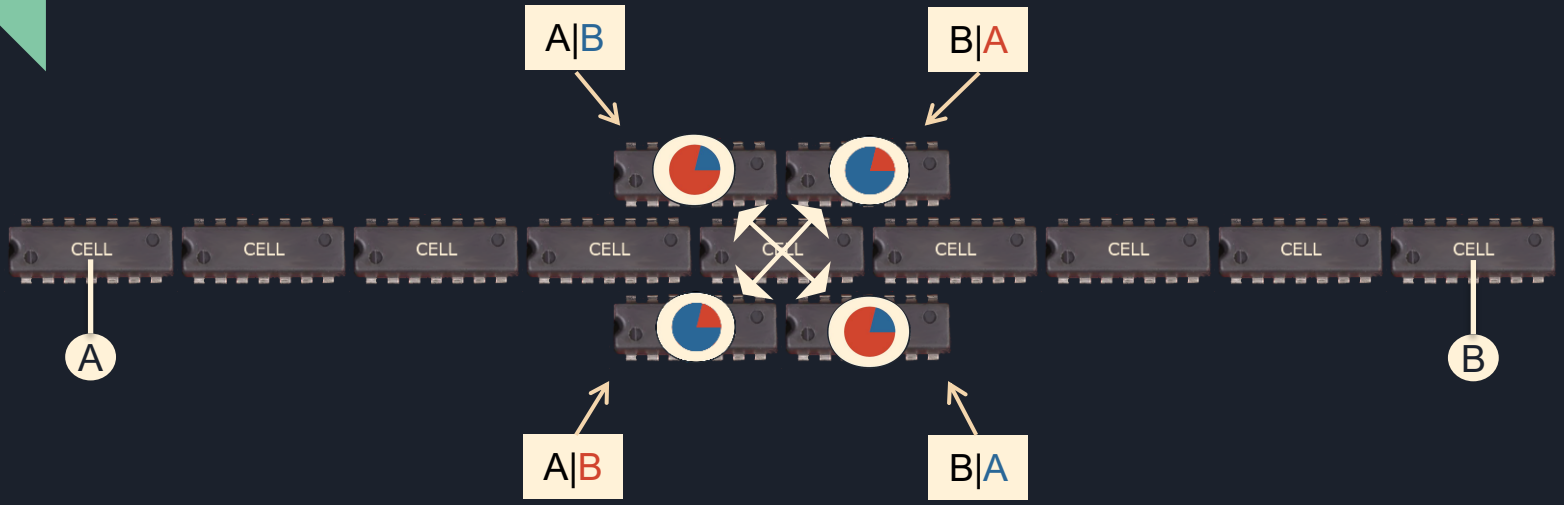
Use Neighbors to track conditional relationships



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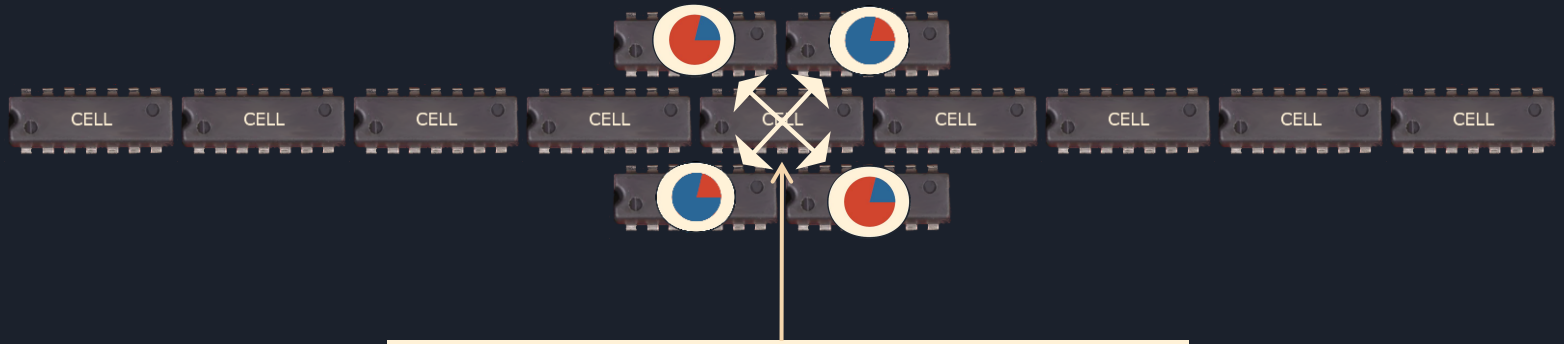
Collision Cells coordinate the memory



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

Slight problem: the cellular propagation delay.

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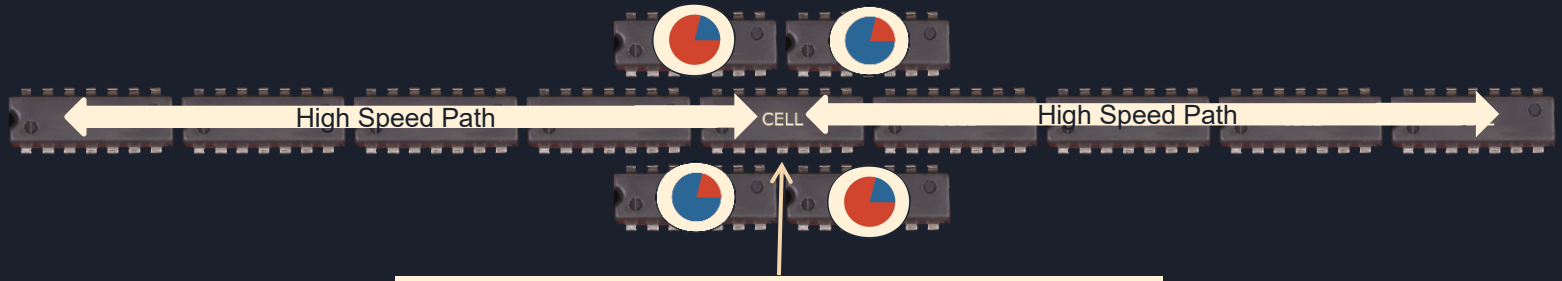
Dual Speed Architecture



Connection Logic:

- Build high speed paths between correlated cells

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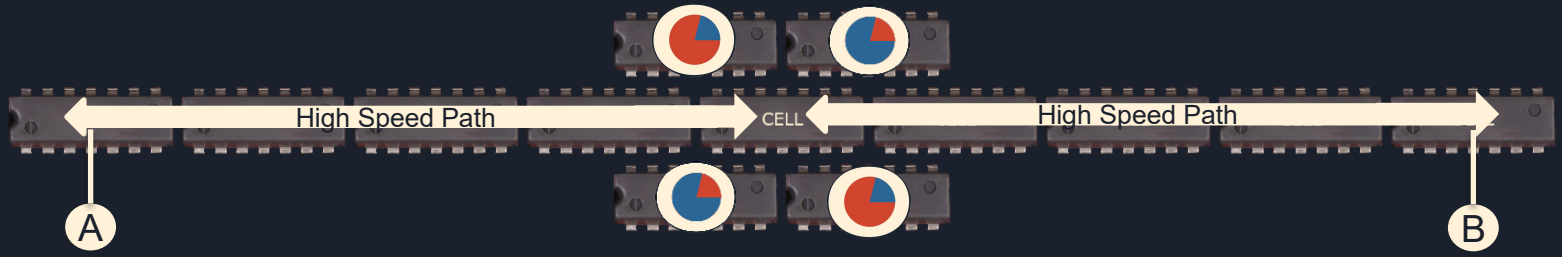
Inference with concurrent signals



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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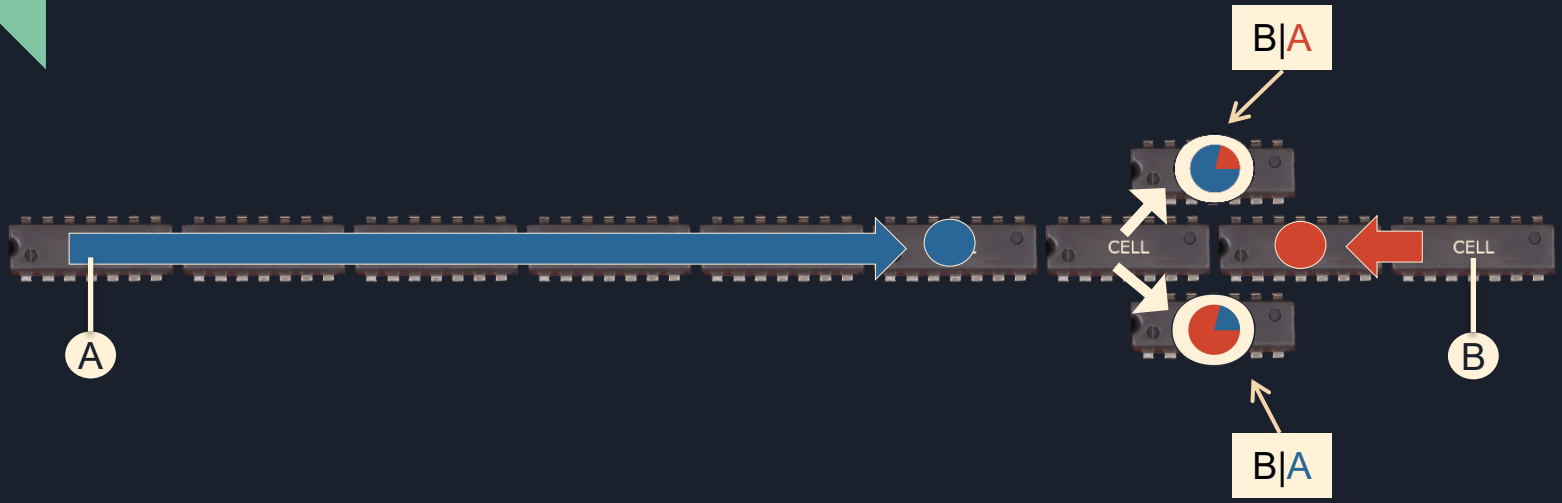
Learning with temporal offsets



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

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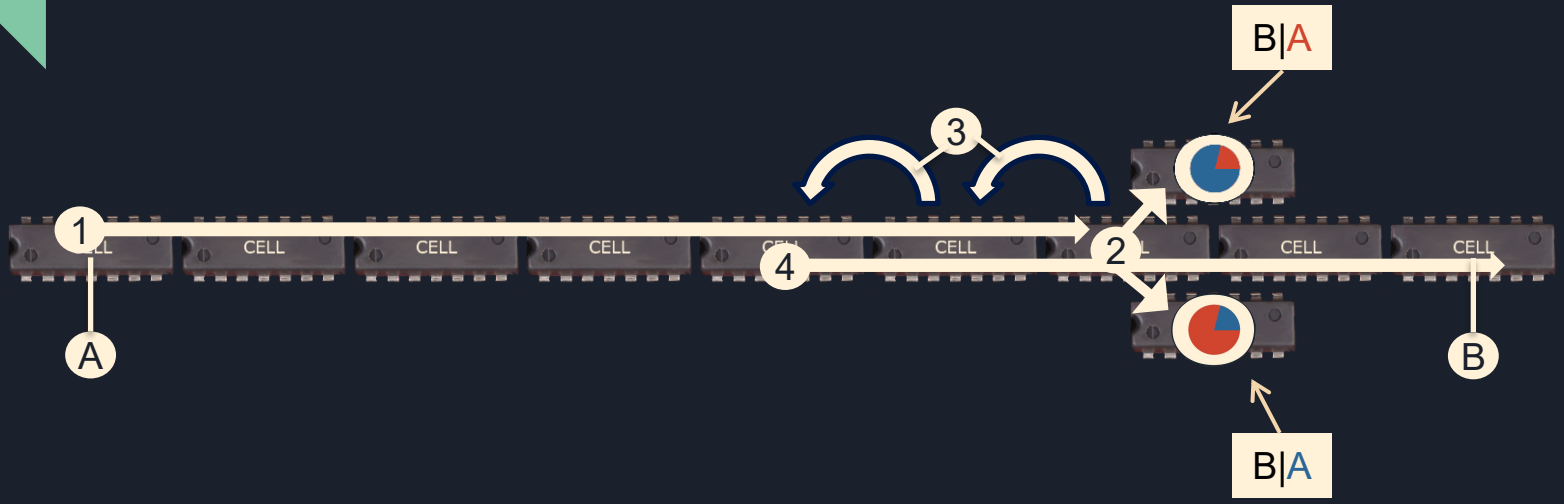
Inference with temporal offsets



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 instant and 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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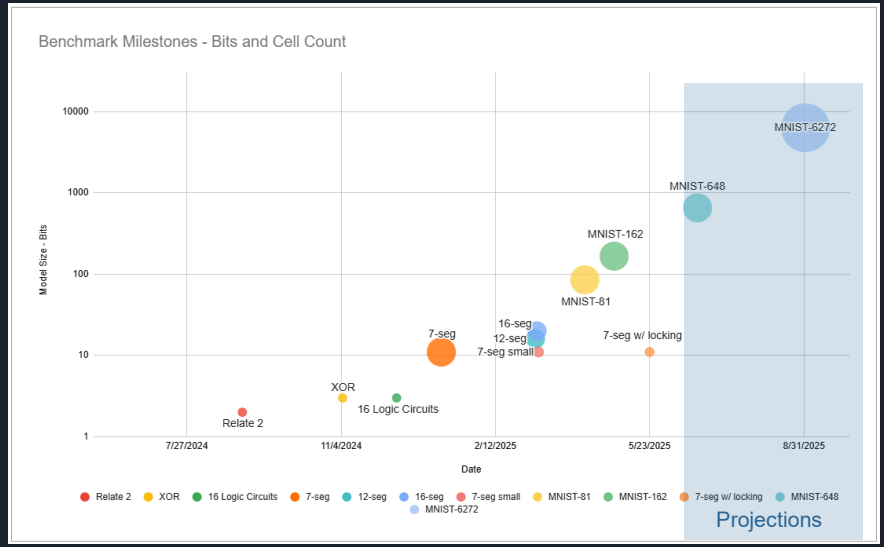
Progress to date

Successful simulations on small models

FPGA implementation underway

MNIST expected to be first public results



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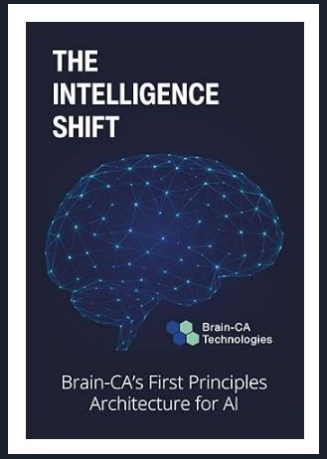
Learn More

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



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