Computing Like the Brain
The Path To Machine Intelligence

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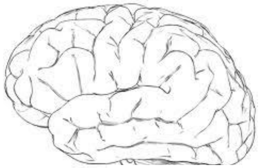
INTERNATIONAL
SOFTWARE DEVELOPMENT
CONFERENCE

1) Discover operating principles of neocortex



2) Build systems based on these principles

Artificial Intelligence - no neuroscience

Alan Turing

"Computers are universal machines" 1935

"Human behavior as test for machine intelligence" 1950

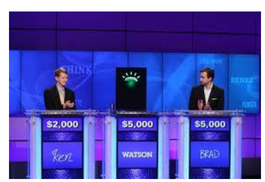
Major AI Initiatives

- MIT AI Lab
- 5th Generation Computing Project
- DARPA Strategic Computing Initiative
- DARPA Grand Challenge

AI Projects

- ACT-R
- Asimo
- CoJACK
- Cyc
- Deep Blue
- Global Workspace Theory
- Mycin
- SHRDLU
- Soar
- Watson

- Many more -



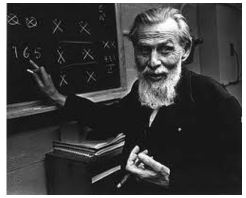
Pros: - Good solutions

Cons: - Task specific

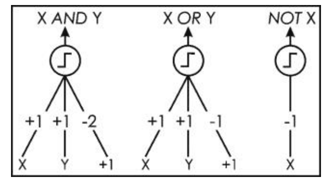
- Limited or no learning

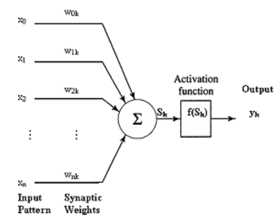
Artificial Neural Networks – minimal neuroscience

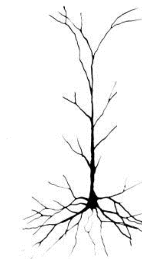
Warren McCulloch
Walter Pitts



"Neurons as logic gates" 1943
Proposed first artificial neural network



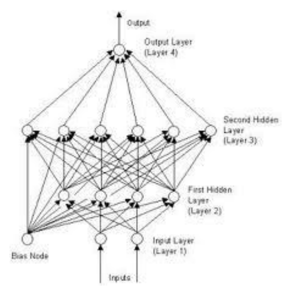


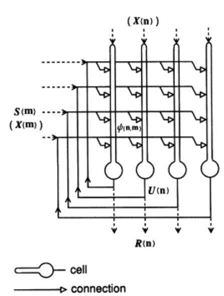


ANN techniques

- Back propagation
- Boltzman machines
- Hopfield networks
- Kohonen networks
- Parallel Distributed Processing

- Machine learning
- Deep Learning



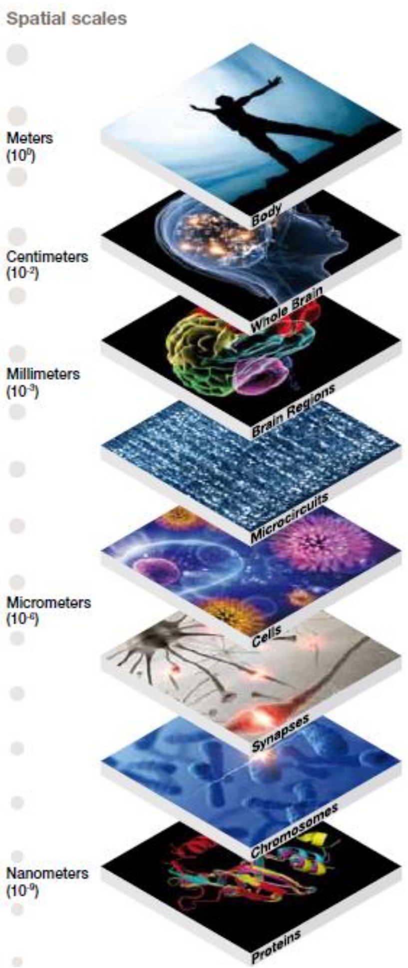


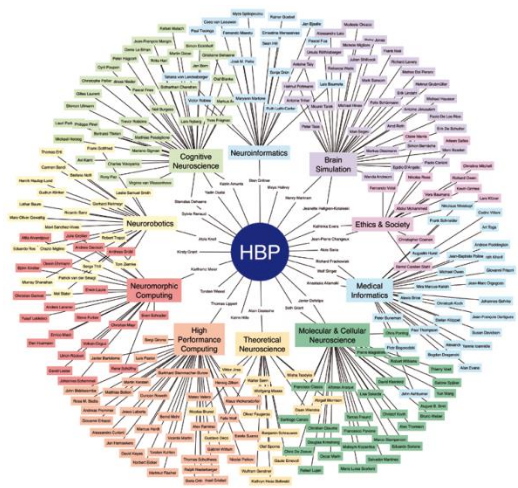
Pros: - Good classifiers
- Learning systems

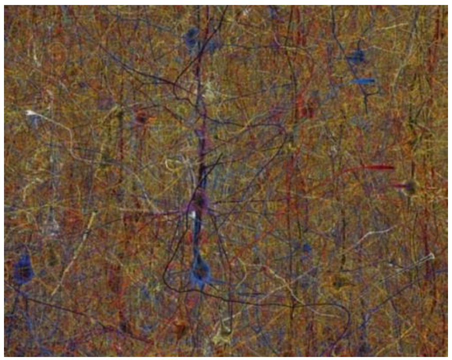
Cons: - Limited
- Not brain like

Whole Brain Simulator – maximal neuroscience

The Human Brain Project







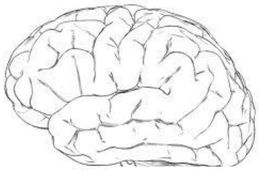
Blue Brain simulation

No theory

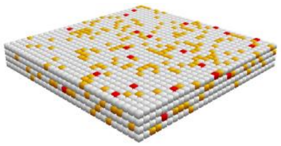
No attempt at Machine Intelligence

1) Discover operating principles of neocortex

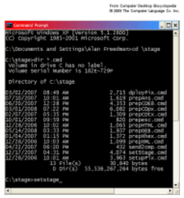
2) Build systems based on these principles



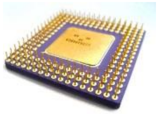
Anatomy,
Physiology



Theory



Software

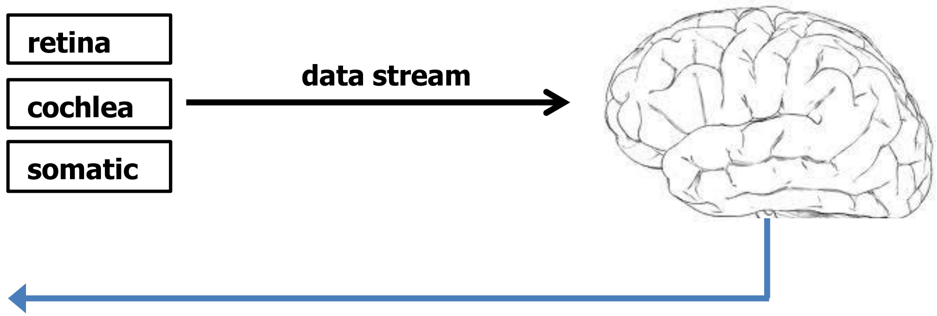


Silicon

Good progress is being made

1940s in computing = 2010s in machine intelligence

The neocortex is a memory system.



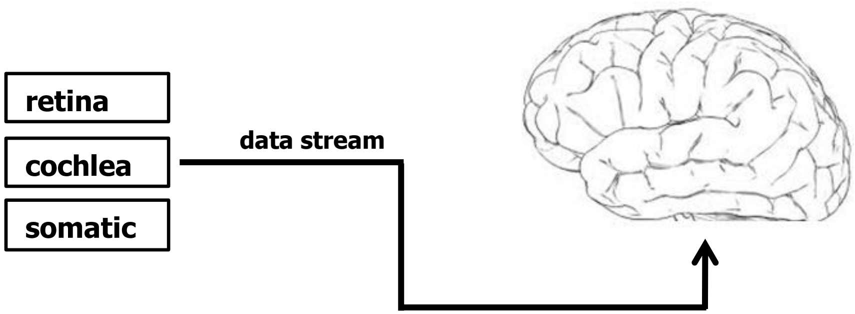
The neocortex learns a model from sensor data

- predictions
- anomalies
- actions

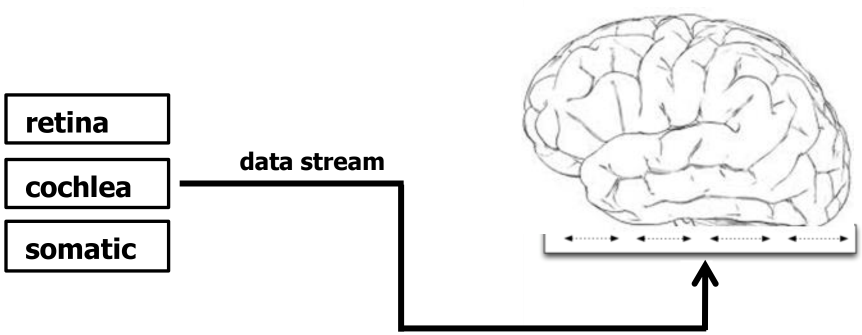
The neocortex learns a <u>sensory-motor model</u> of the world

Principles of Neocortical Function

1) On-line learning from streaming data



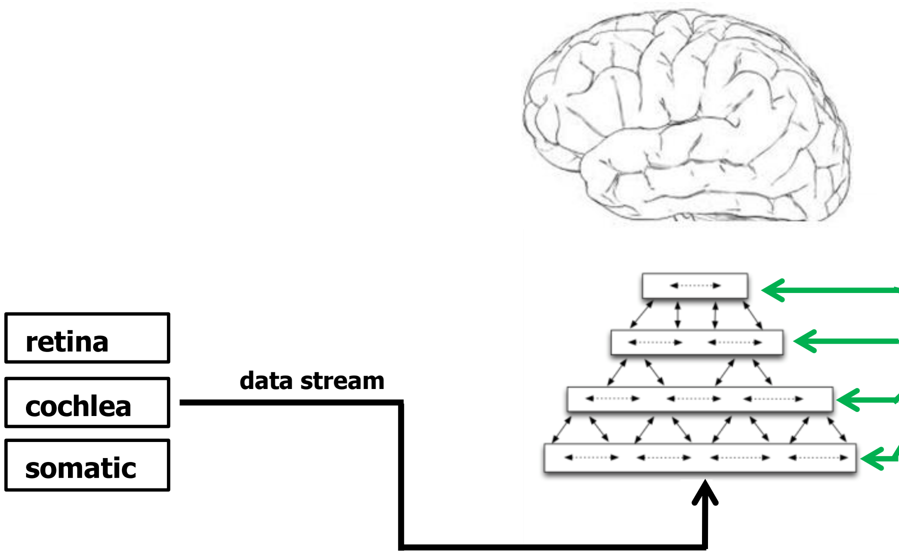
Principles of Neocortical Function



1) On-line learning from streaming data

2) Hierarchy of memory regions
- regions are nearly identical

Principles of Neocortical Function

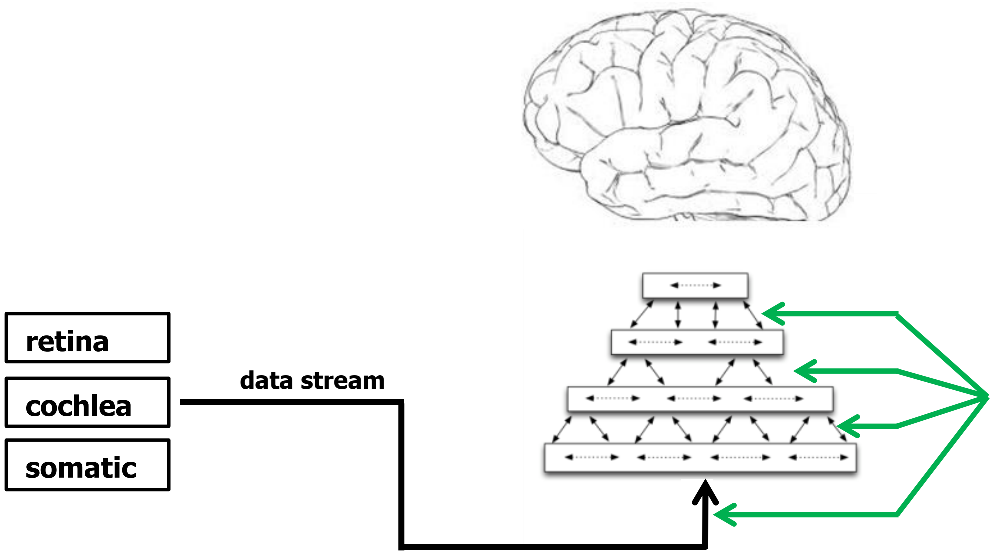


1) On-line learning from streaming data

2) Hierarchy of memory regions

3) Sequence memory
- inference
- motor

Principles of Neocortical Function



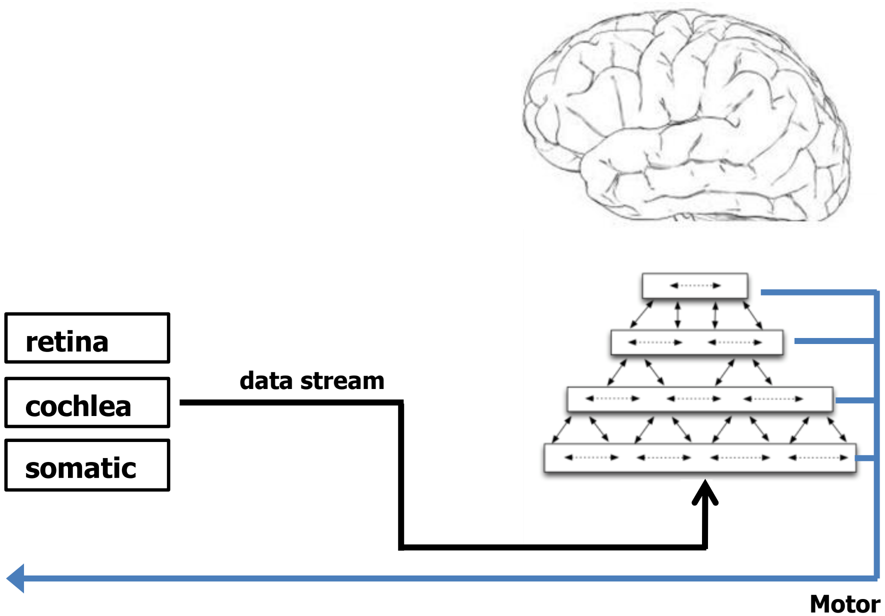
1) On-line learning from streaming data

2) Hierarchy of memory regions

3) Sequence memory

4) Sparse Distributed Representations

Principles of Neocortical Function



1) On-line learning from streaming data

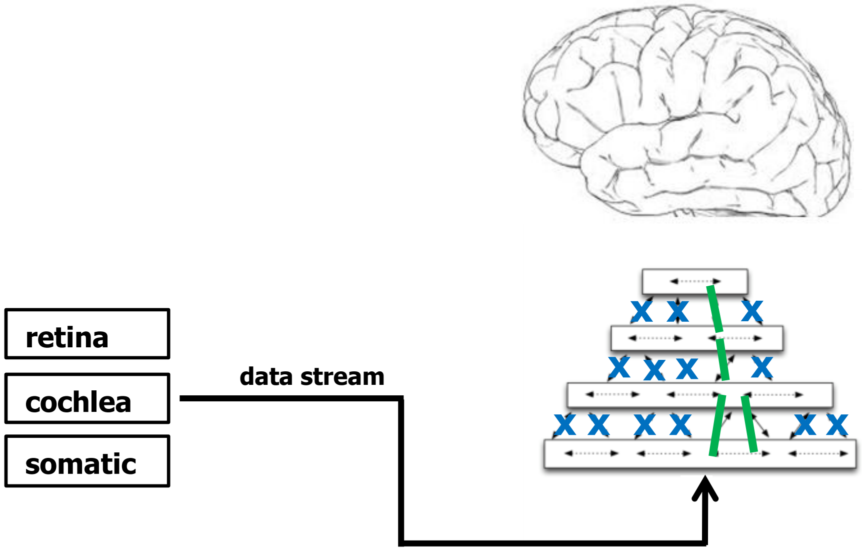
2) Hierarchy of memory regions

3) Sequence memory

4) Sparse Distributed Representations

5) All regions are sensory and motor

Principles of Neocortical Function



1) On-line learning from streaming data

2) Hierarchy of memory regions

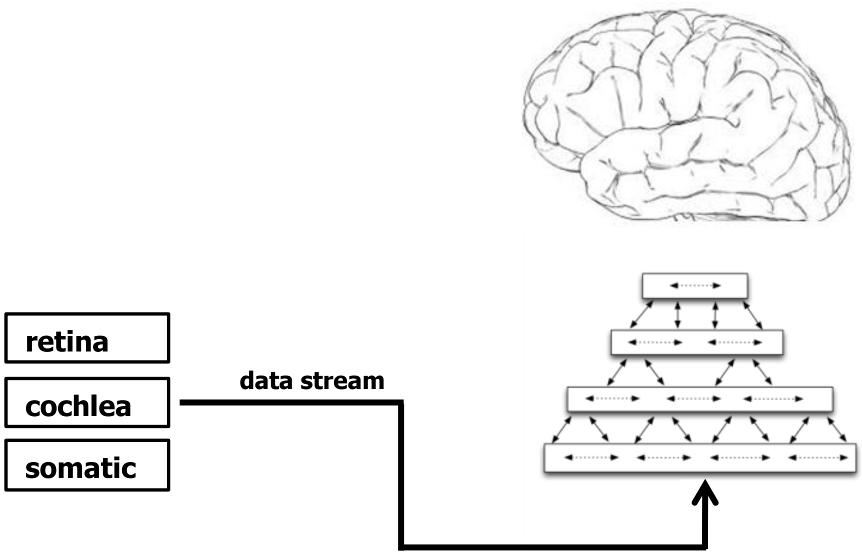
3) Sequence memory

4) Sparse Distributed Representations

5) All regions are sensory and motor

6) Attention

Principles of Neocortical Function

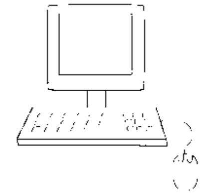


1) On-line learning from streaming data
2) Hierarchy of memory regions
3) Sequence memory
4) Sparse Distributed Representations
5) All regions are sensory and motor
6) Attention

These six principles are necessary and sufficient for biological and machine intelligence.

- All mammals from mouse to human have them
- We can build machines like this

Dense Representations

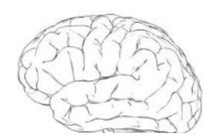


- Few bits (8 to 128)
- All combinations of 1’s and 0’s
- Example: 8 bit ASCII

  01101101 = m

- Individual bits have no inherent meaning
- Representation is arbitrary

Sparse Distributed Representations (SDRs)



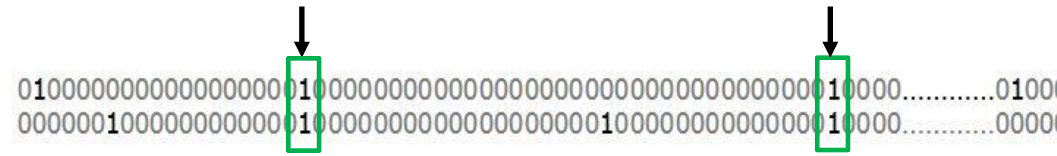
- Many bits (thousands)
- Few 1’s mostly 0’s
- Example: 2,000 bits, 2% active

  0100000000000000000100000000000000000000000000000000000010000…........01000

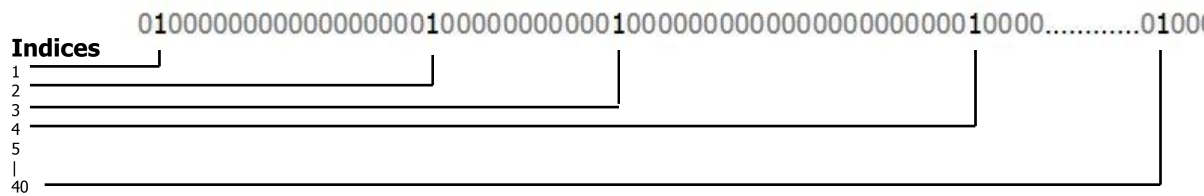
- Each bit has semantic meaning (learned)
- Representation is semantic

SDR Properties

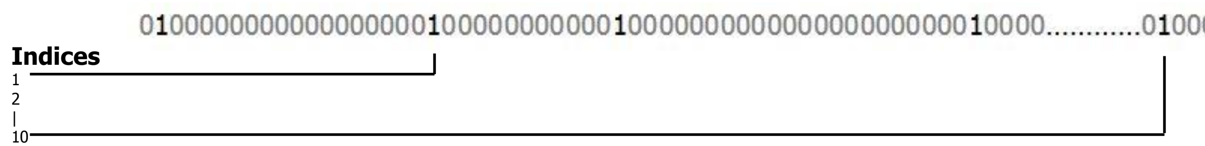
1) **Similarity**:
shared bits = semantic similarity



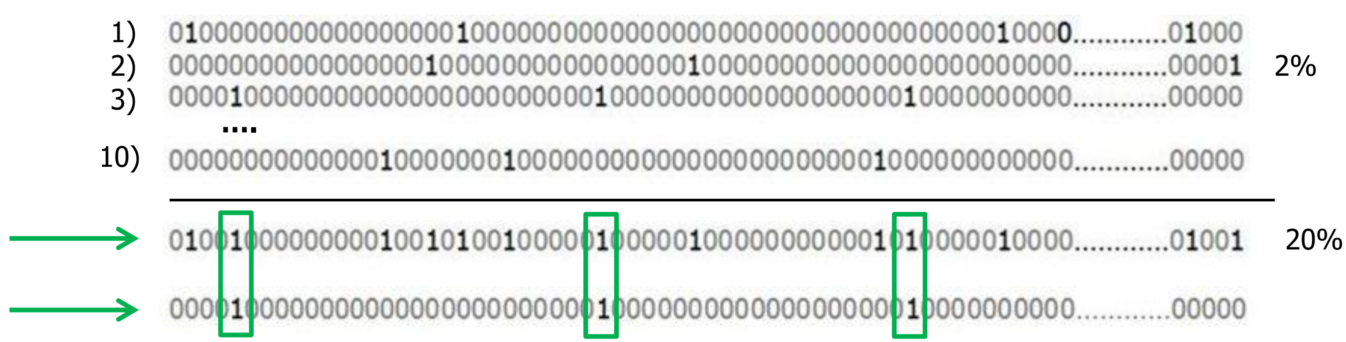
2) **Store and Compare**:
store indices of active bits



subsampling is OK



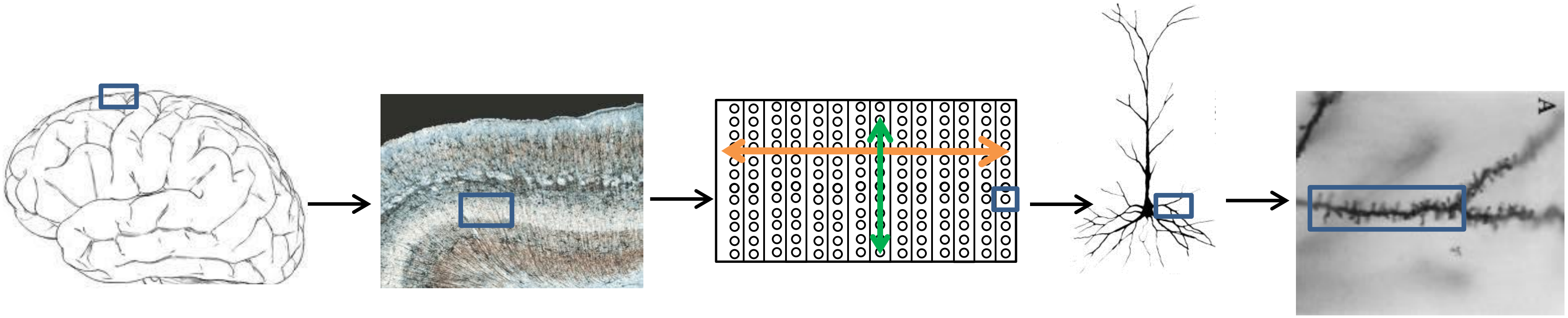
3) **Union membership**:

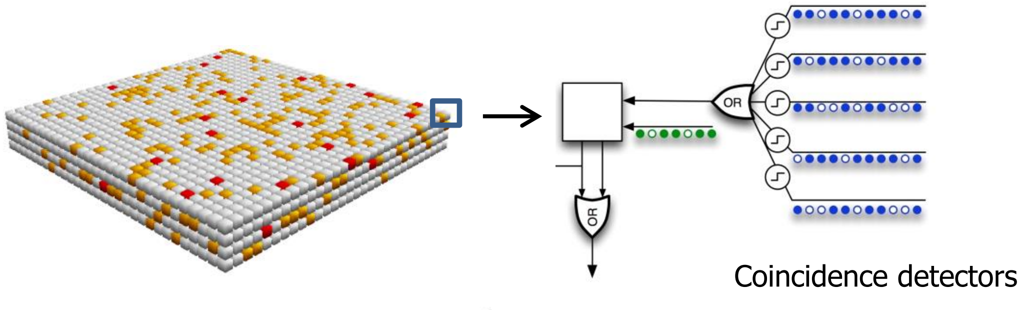


Union

Is this SDR
a member?

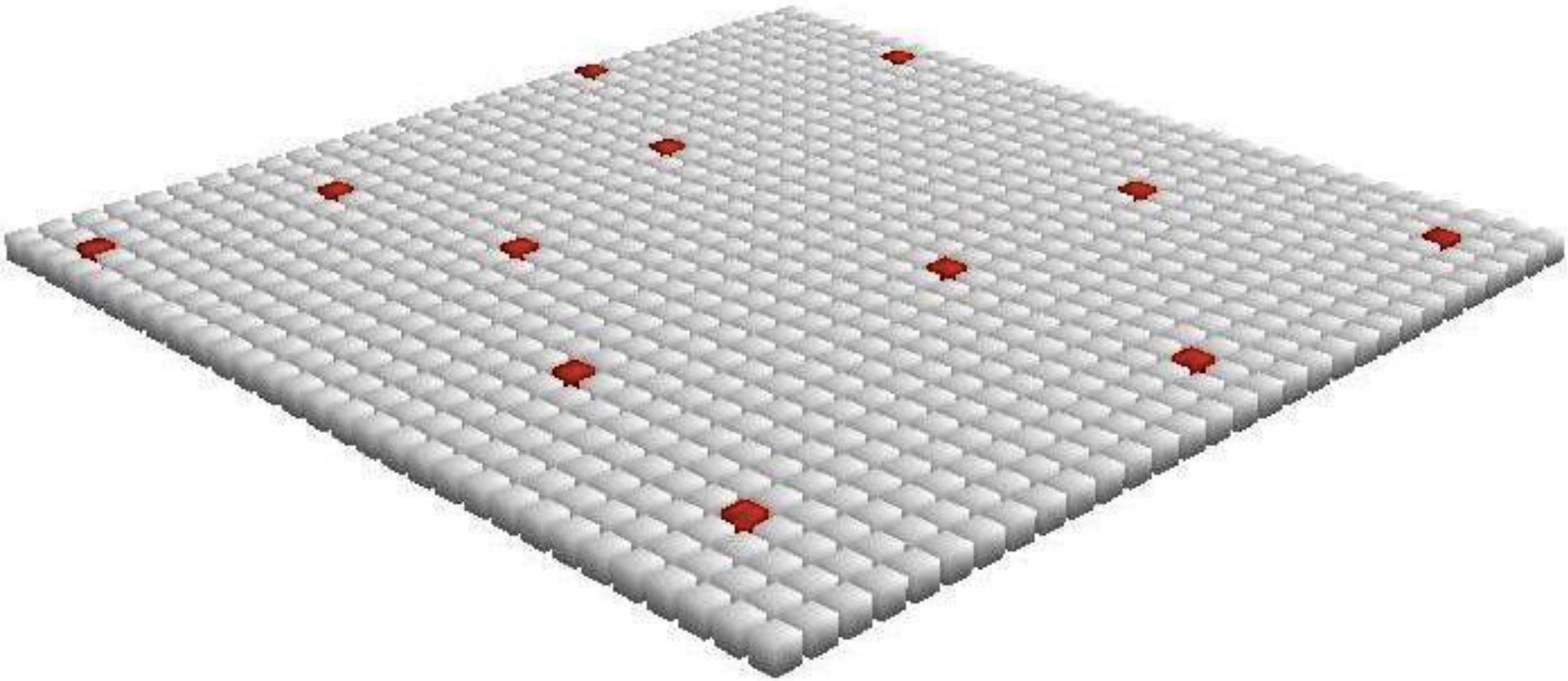
Sequence Memory (for inference and motor)





How does a layer of neurons learn sequences?

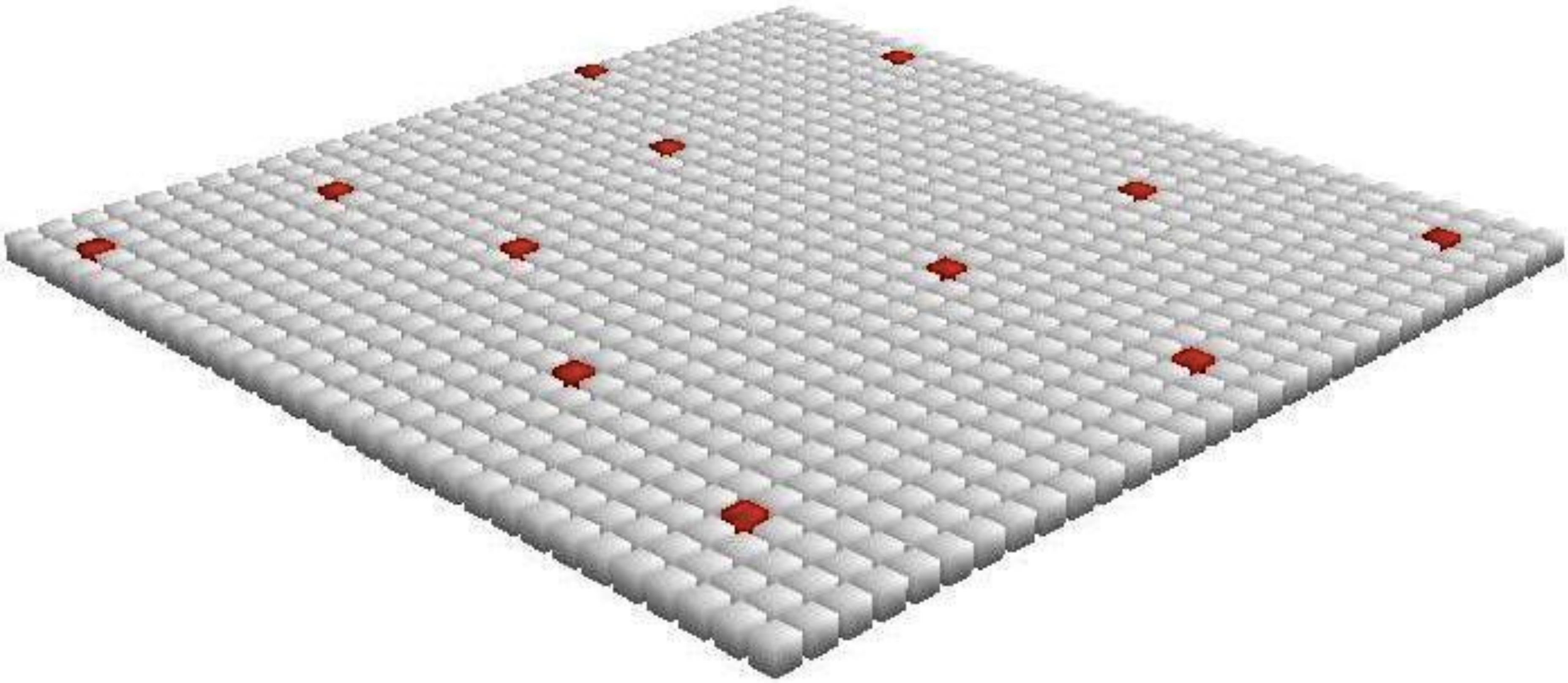
Each cell is one bit in our Sparse Distributed Representation



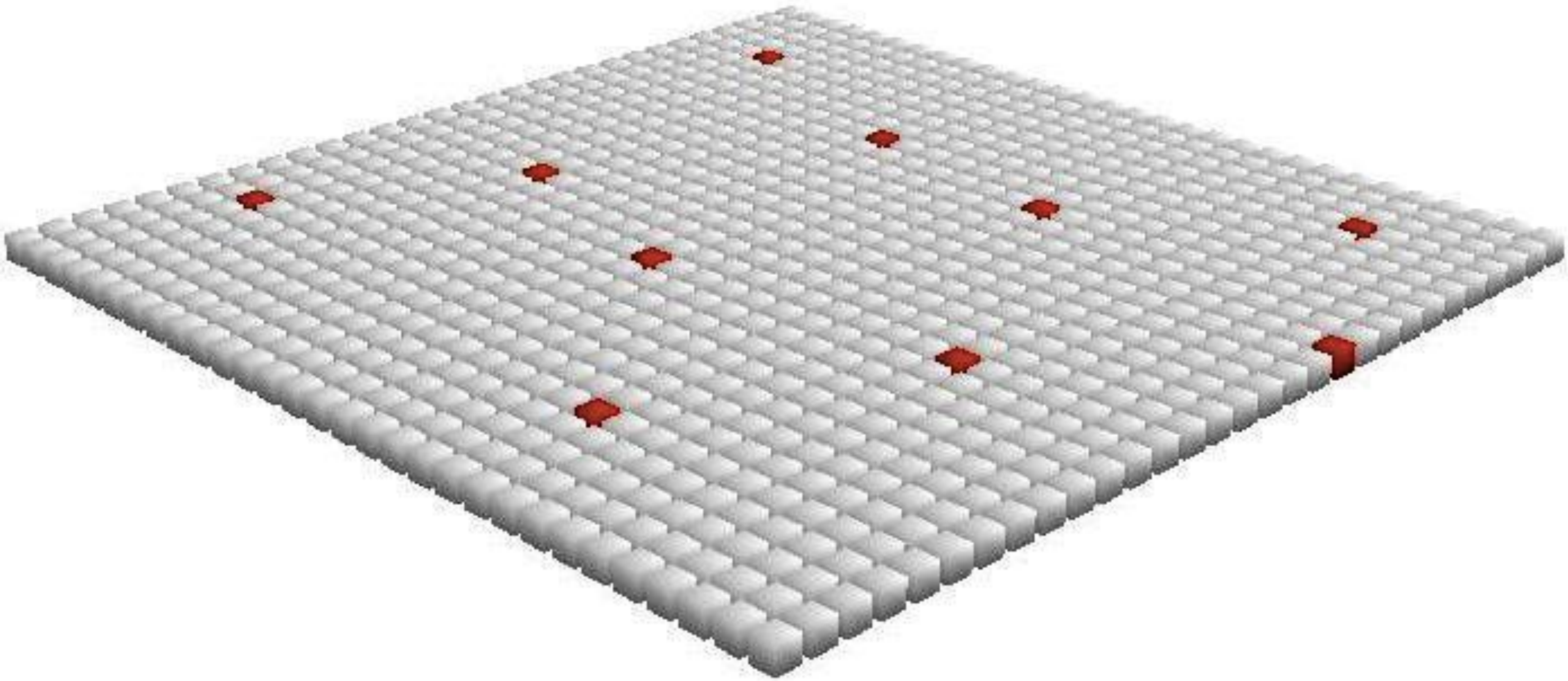
SDRs are formed via a local competition between cells.

All processes are local across large sheets of cells.

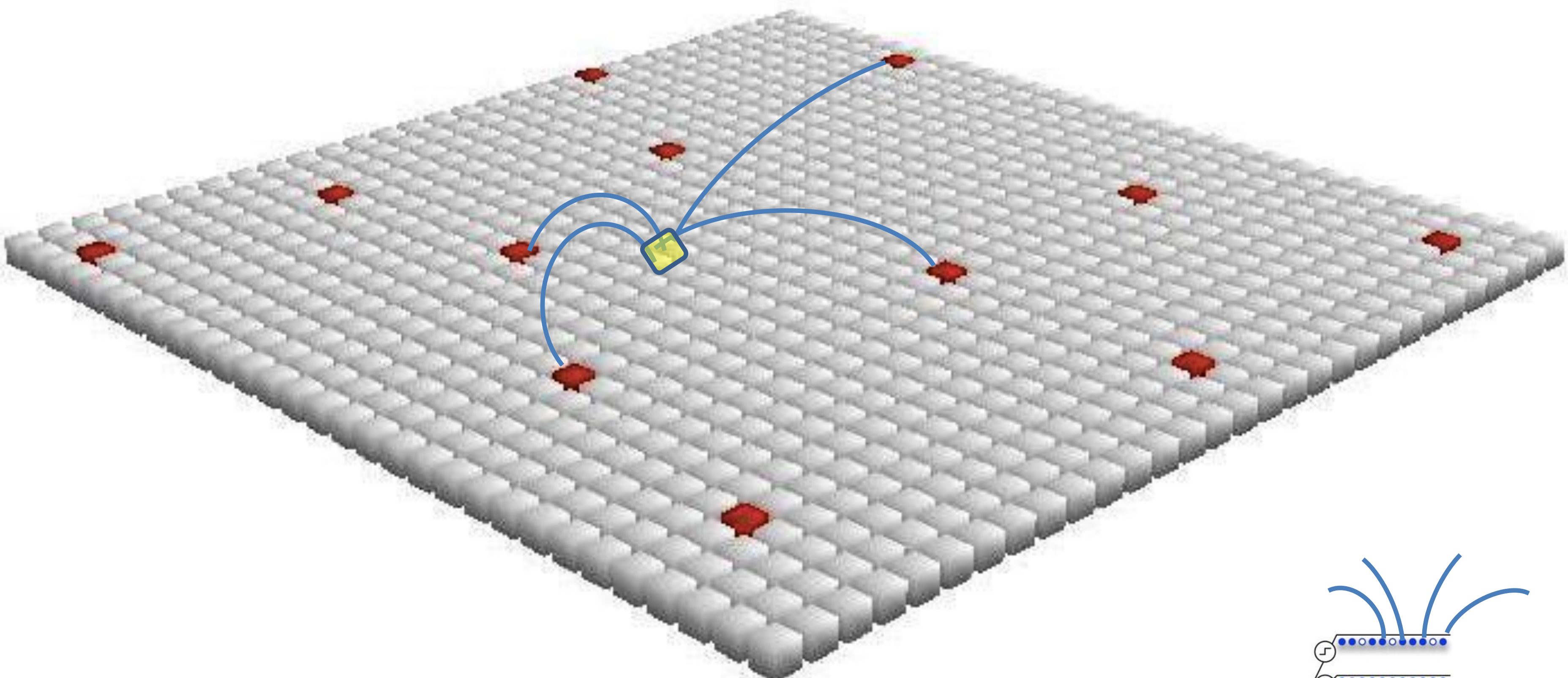
SDR (time =1)

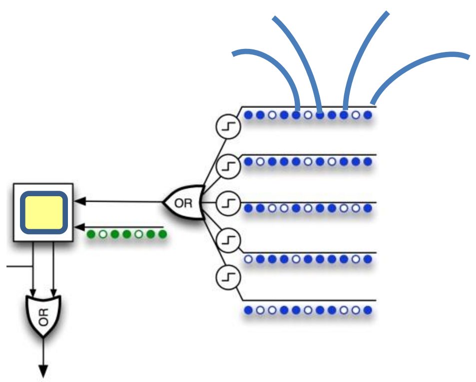


SDR (time =2)

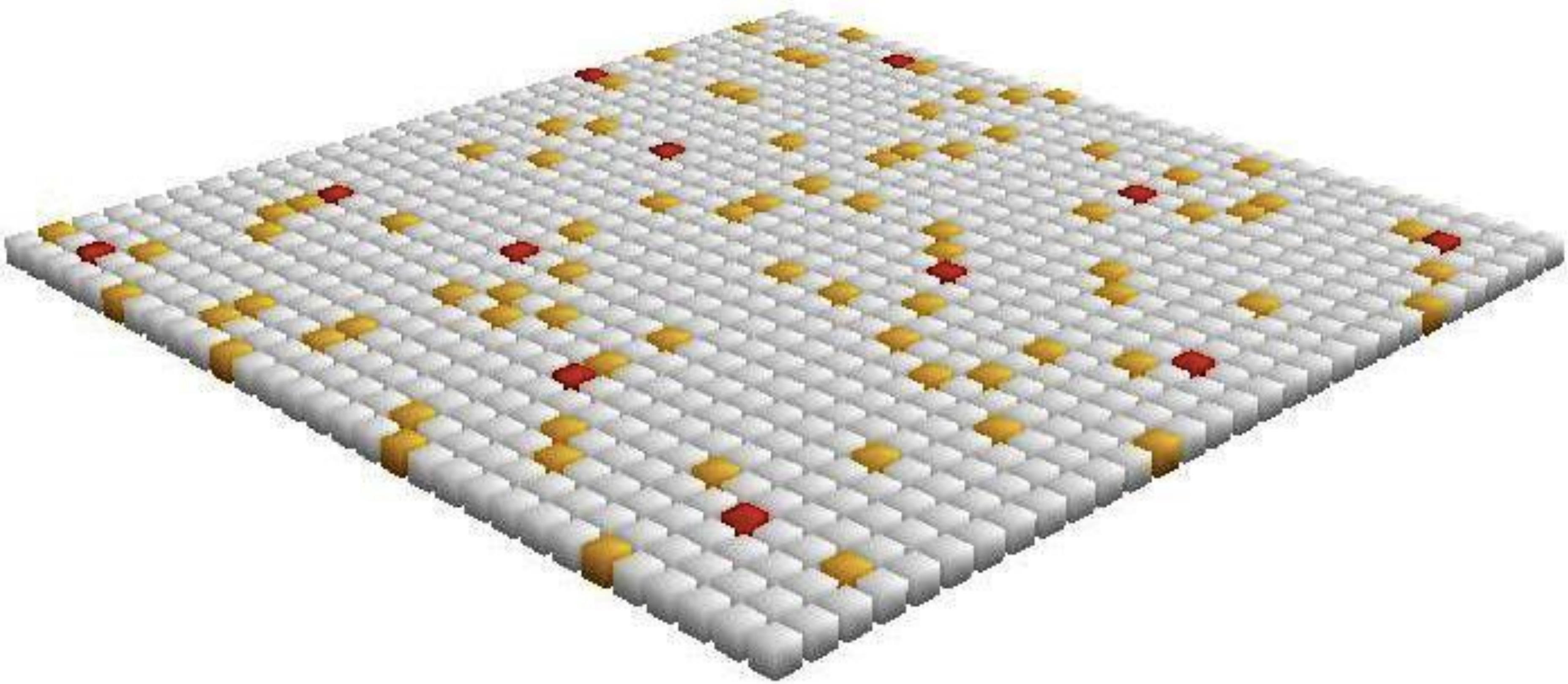


Cells connect to sample of previously active cells
to predict their own future activity.



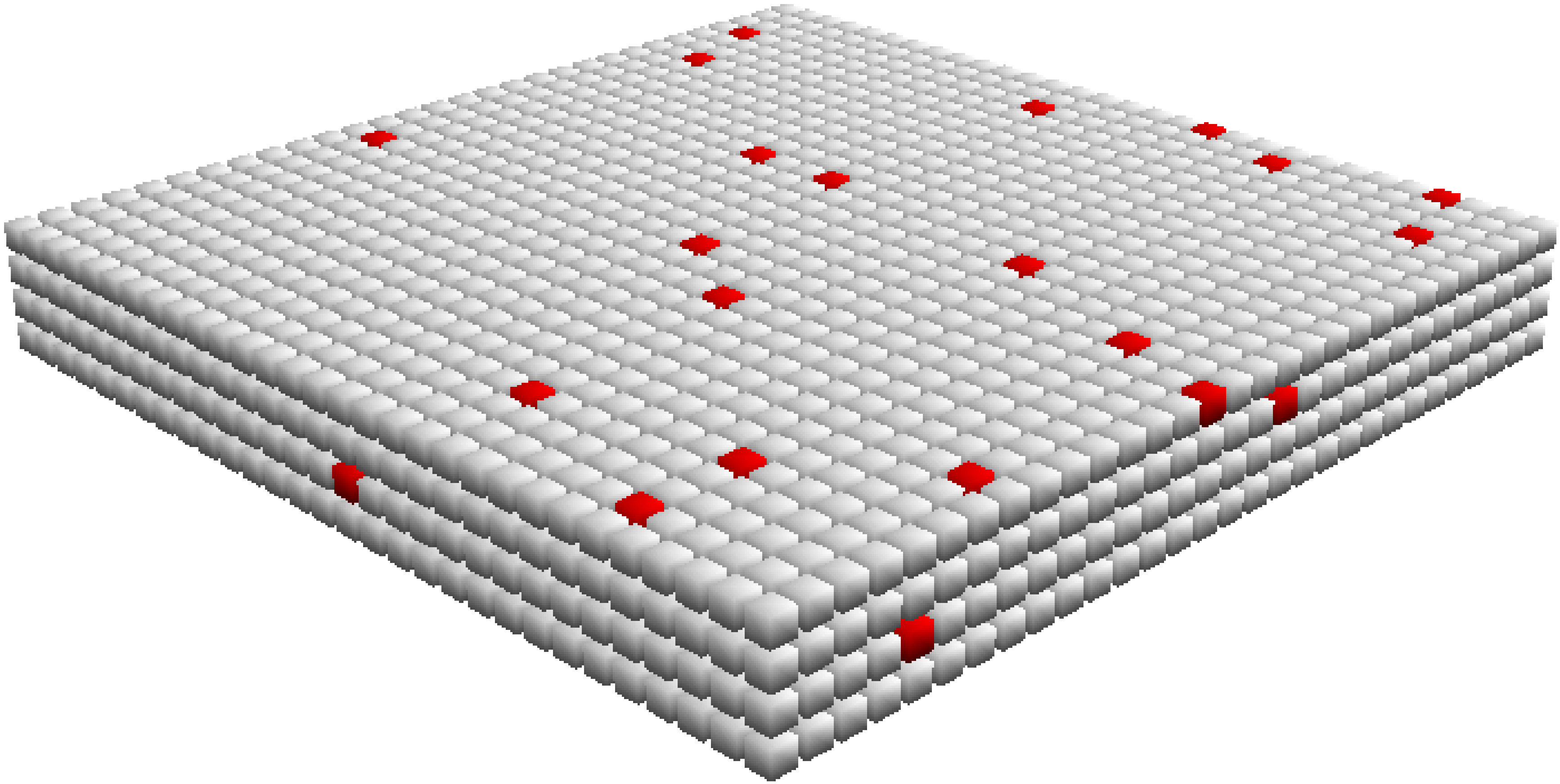


Multiple Predictions Can Occur at Once.

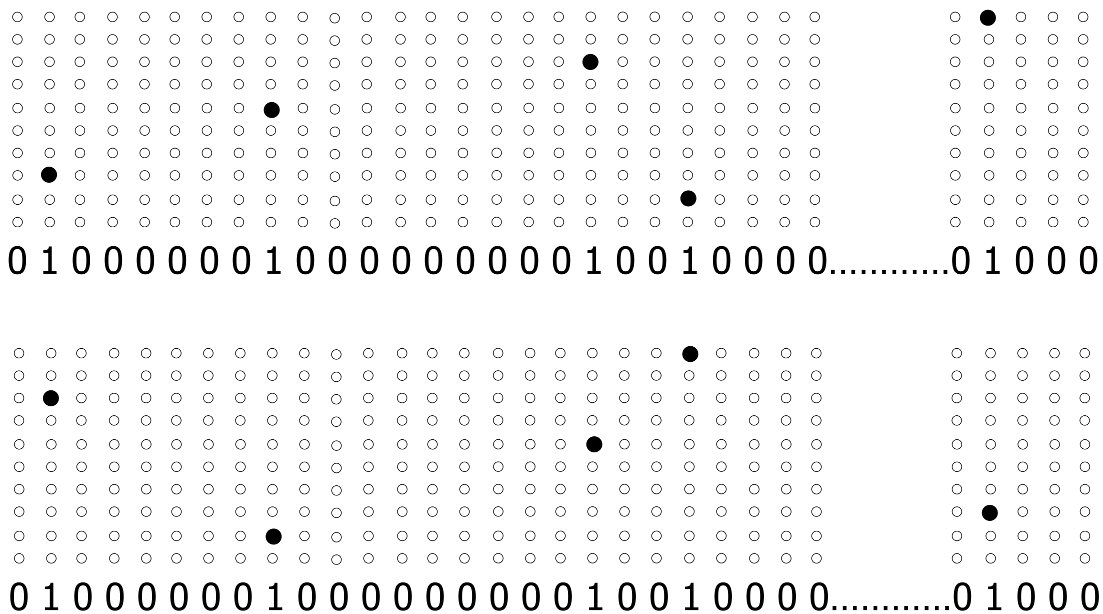


This is a 1st order memory.
We need a high order memory.

High order sequences are enabled with multiple cells per column.



High Order Sequence Memory



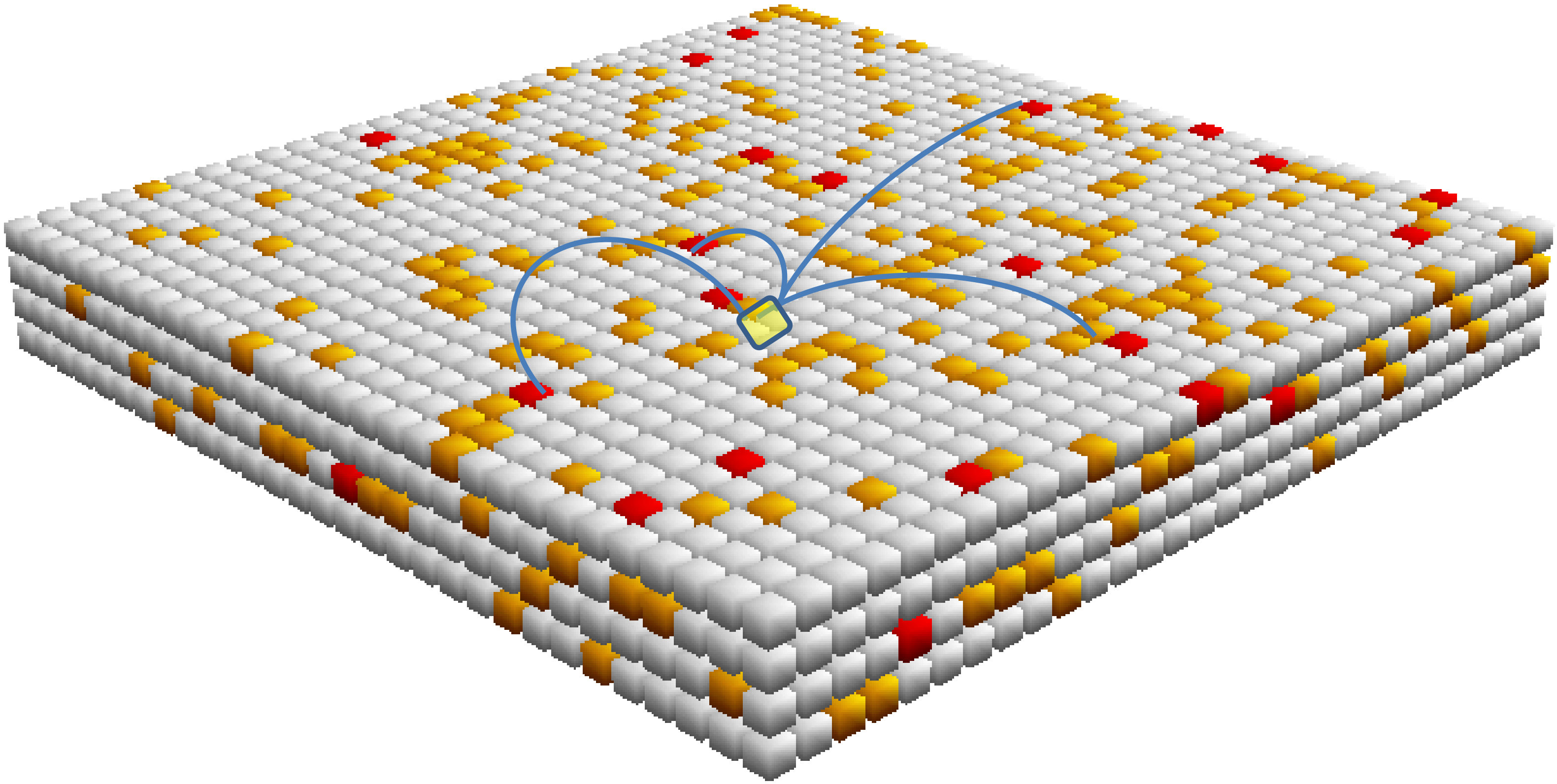
40 active columns, 10 cells per column

= 10^{40} ways to represent the same input in different contexts

A-B-C-D-E

X-B’-C’-D’-Y

High Order Sequence Memory



Distributed sequence memory

High order, high capacity

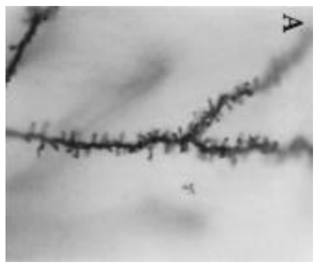
Noise and fault tolerant

Multiple simultaneous predictions

Semantic generalization

Online learning

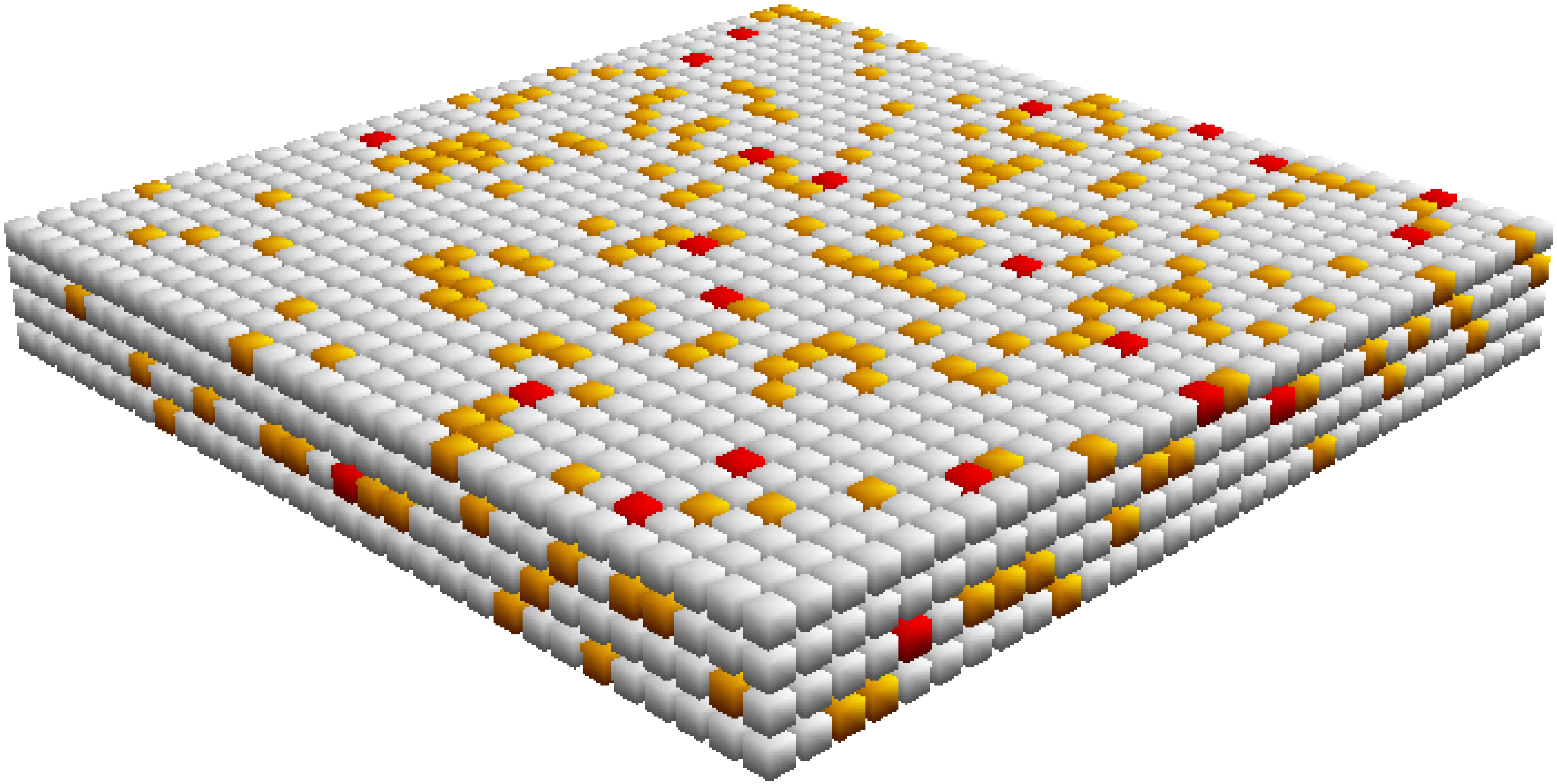
- Learn continuously, no batch processing
- If pattern repeats, reinforce, otherwise forget it



Learning is the growth of new synapses.

Connection strength is binary
Connection permanence is a scalar
Training changes permanence

“Cortical Learning Algorithm” (CLA)



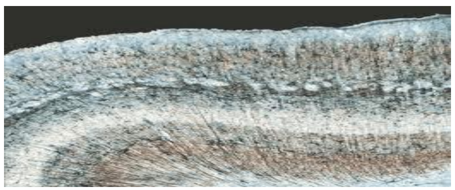
Not your typical computer memory!

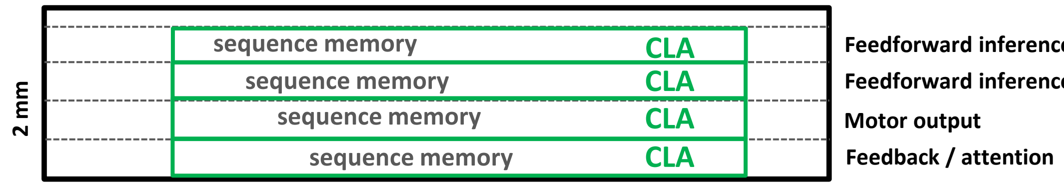
A building block for

- **neocortex**
- **machine intelligence**

Cortical Region

2 mm





Evidence suggests each layer is implementing a CLA variant

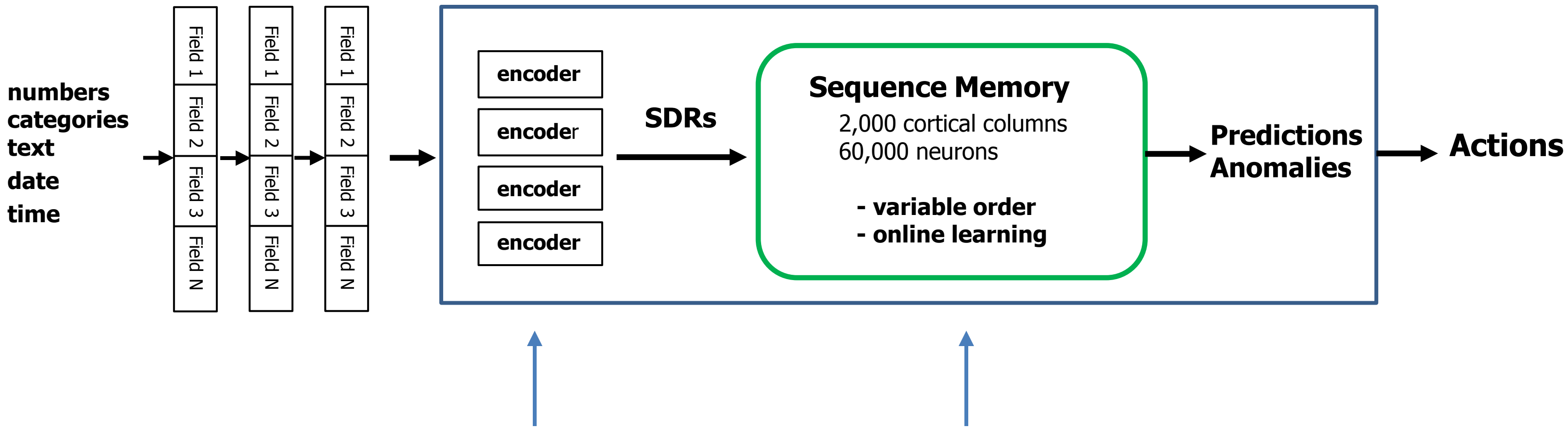
What Is Next? Three Current Directions

1) **Commercialization**
   - GROK: Predictive analytics using CLA
   - Commercial value accelerates interest and investment

2) **Open Source Project**
   - NuPIC: CLA open source software and community
   - Improve algorithms, develop applications

3) **Custom CLA Hardware**
   - Needed for scaling research and commercial applications
   - IBM, Seagate, Sandia Labs, DARPA

GROK: Predictive Analytics Using CLA



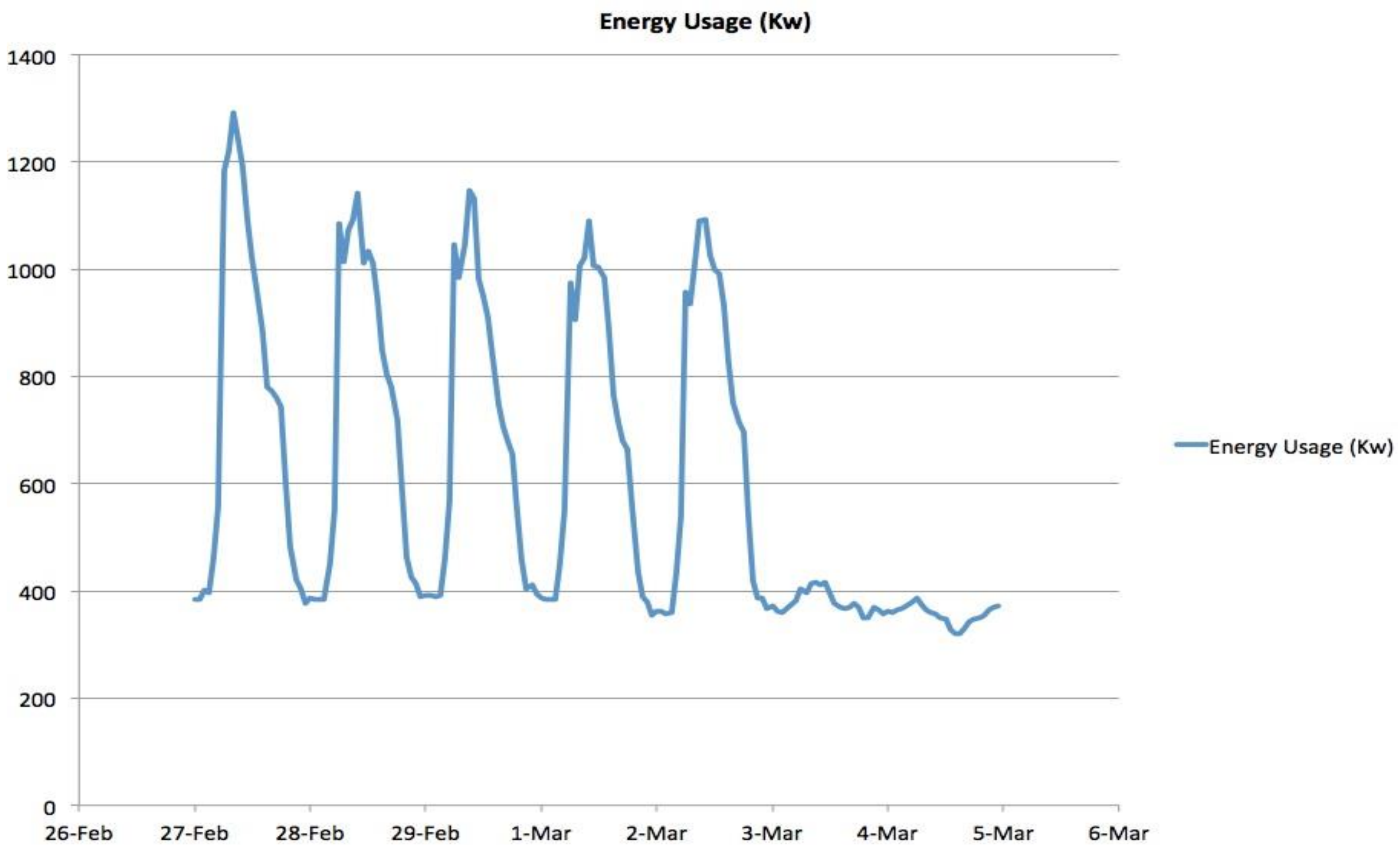
Encoders

Convert native data
type to SDRs

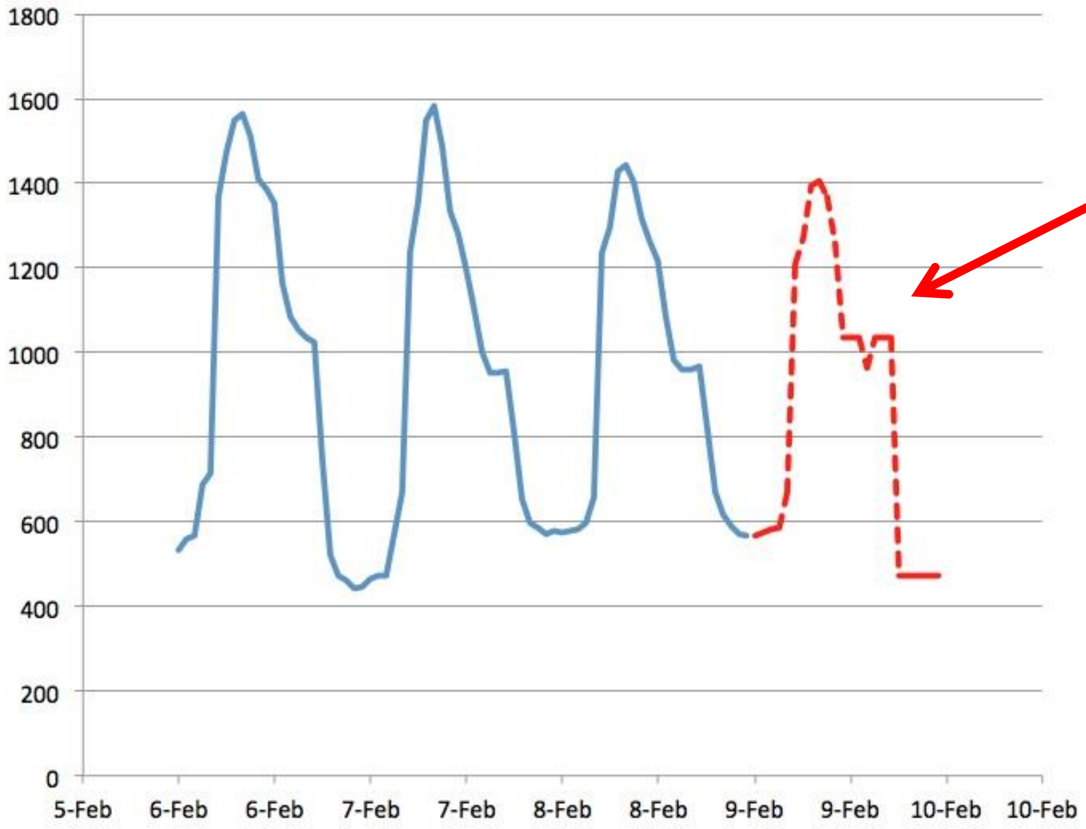
CLA

Learns spatial/temporal patterns
Outputs
- predictions
  anomalies

GROK example: Factory Energy Usage

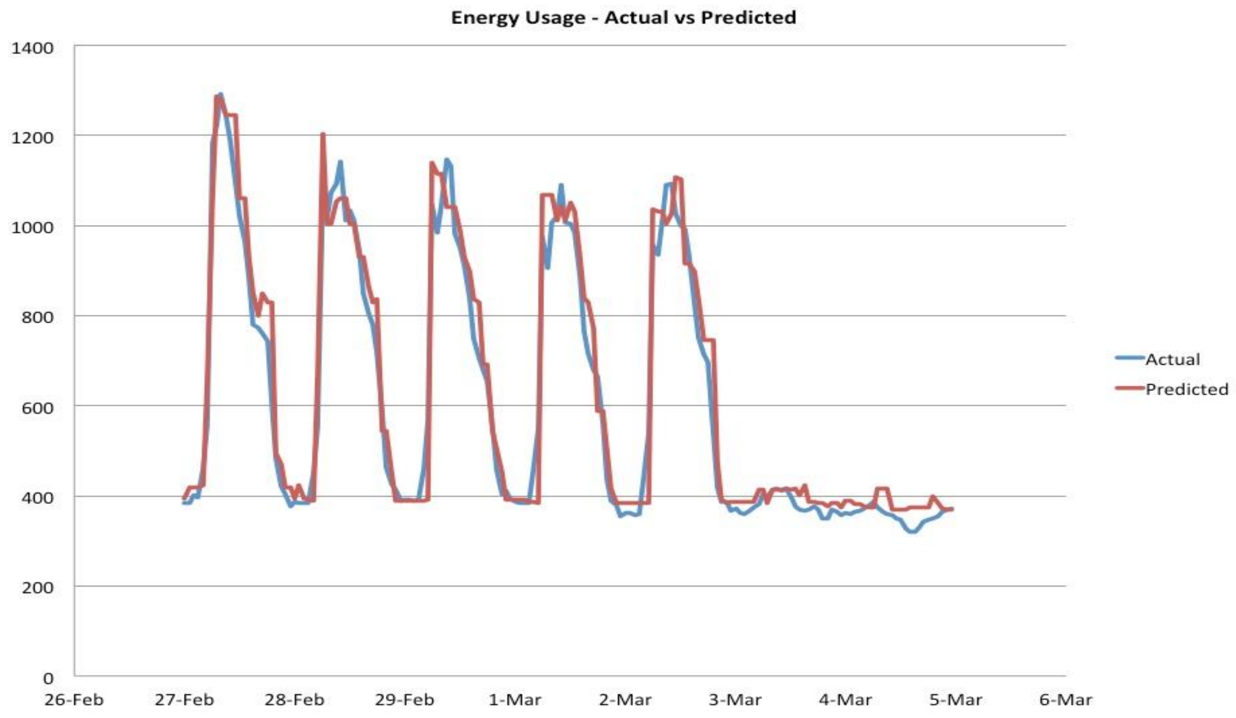


Customer need



At midnight, make 24 hourly predictions

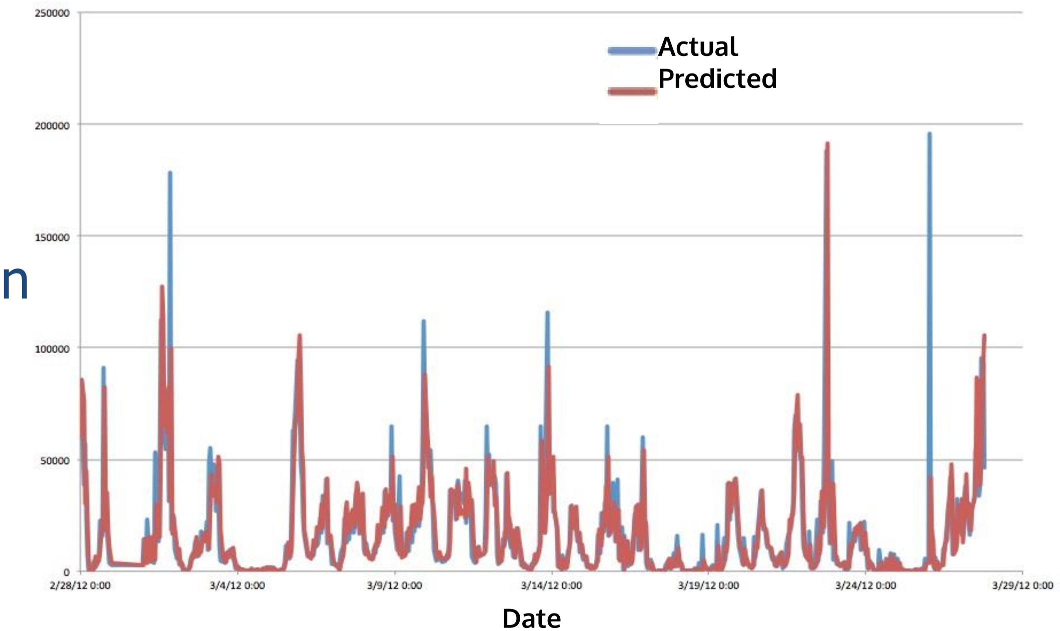
GROK Predictions and Actuals



GROK example: Predicting Server Demand

Grok used to predict server demand

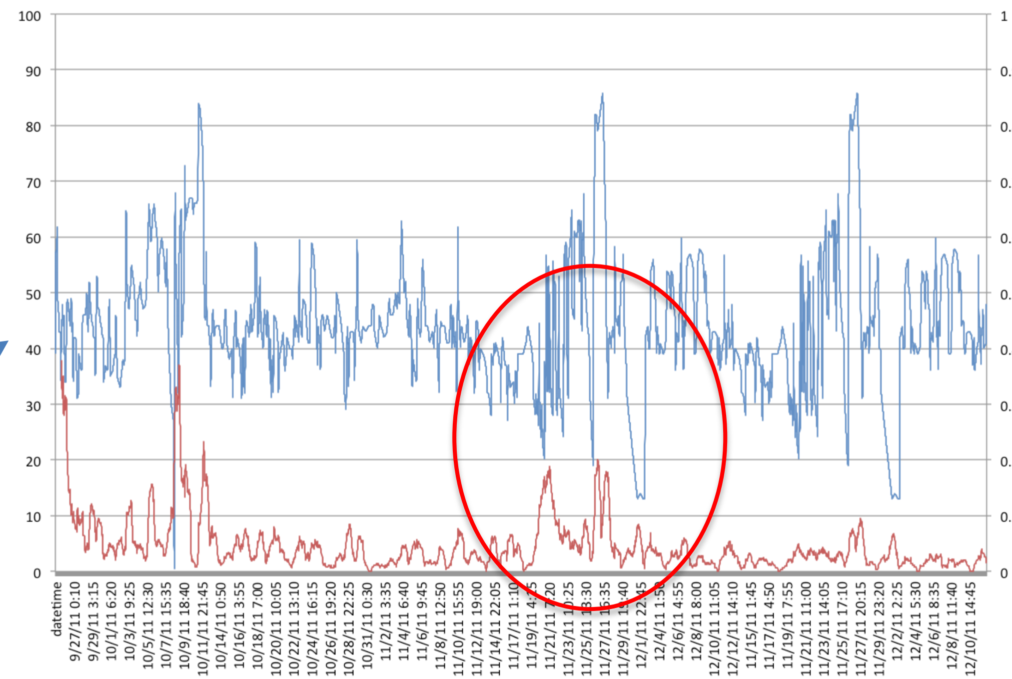
Approximately 15% reduction in AWS cost



Server demand, Actual vs. Predicted

GROK example: Detecting Anomalous Behavior

Grok builds model of data, detects changes in predictability.



Gear bearing temperature & Grok Anomaly Score

GROK going to market for anomaly detection in I.T. 2014

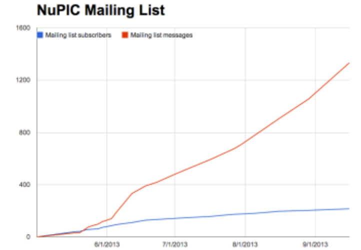
2) Open Source Project

NuPIC: www.Numenta.org

- CLA source code (single tree), GPLv3
- Papers, videos, docs

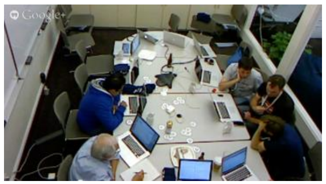
Community

- 200+ mail list subscribers, growing
- 20+ messages per day
- full time manager, Matt Taylor



What you can do

- Get educated
- New applications for CLA
- Extend CLA: robotics, language, vision
- Tools, documentation



2nd Hackathon November 2,3 in San Francisco

- Natural language processing using SDRs
- Sensory-motor integration discussion
- 2014 hackathon Ireland?

3) Custom CLA Hardware

HW companies looking "Beyond von Neumann"

- Distributed memory
- Fault tolerant
- Hierarchical

New HW Architectures Needed

- Speed (research)
- Cost, power, embedded (commercical)

IBM

- Almaden Research Labs
- Joint research agreement

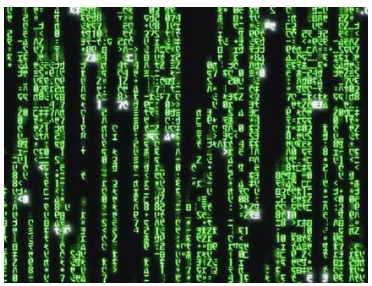
DARPA

- New Program called "Cortical Processor"
- HTM (Hierarchical Temporal Memory)
- CLA is prototype primitive

Seagate

Sandia Labs

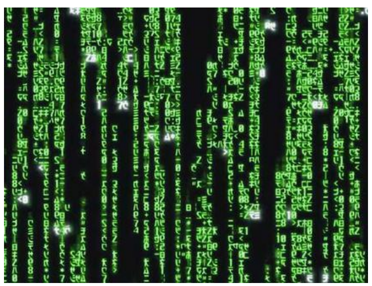
Future of Machine Intelligence



Future of Machine Intelligence

Definite

- Faster, Bigger
- Super senses
- Fluid robotics
- Distributed hierarchy



Maybe

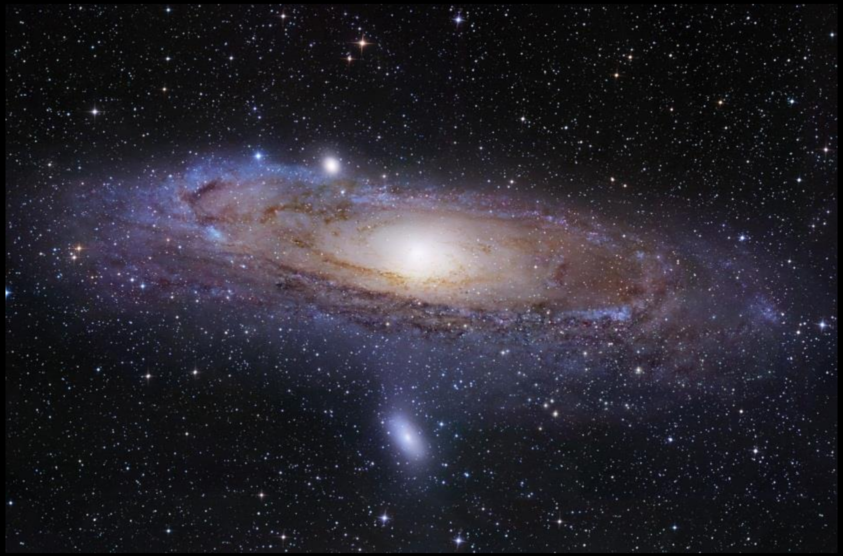
- Humanoid robots
- Computer/Brain interfaces for all

Not

- Uploaded brains
- Evil robots

Why Create Intelligent Machines?

Live better



Learn more

Thank You