What Is Intelligence,
that a Machine Might Have Some?

N.I.C.E
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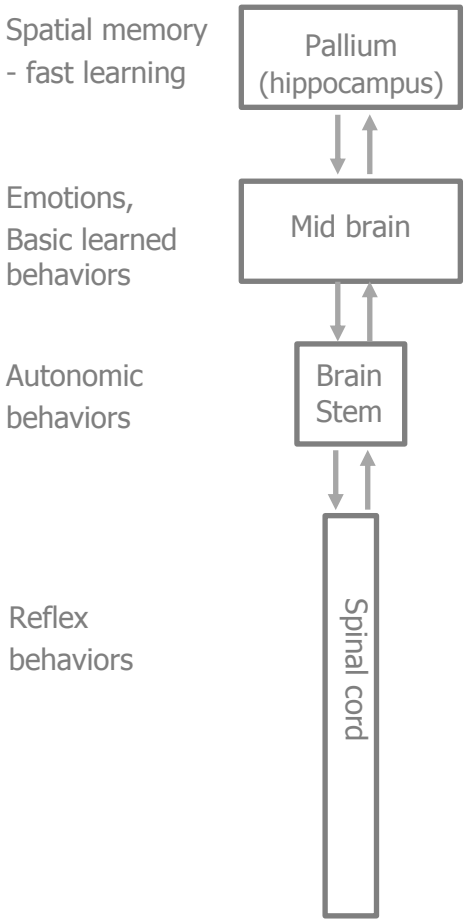
Numenta

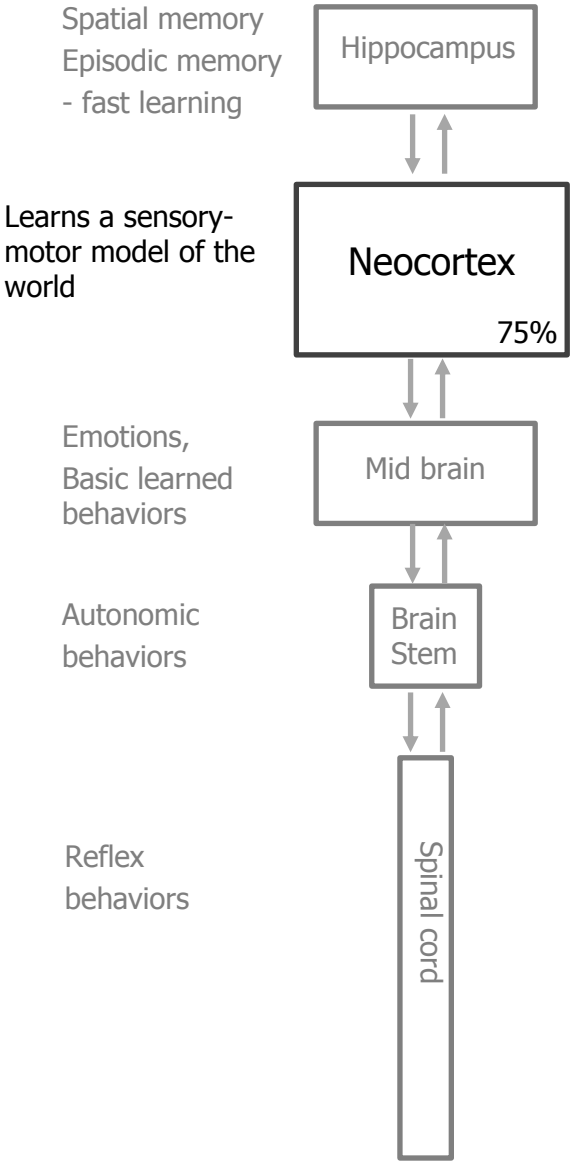
1) The Biological Components of Intelligence

2) The Functional Components of Intelligence

3) The Diversity of Intelligent Machines

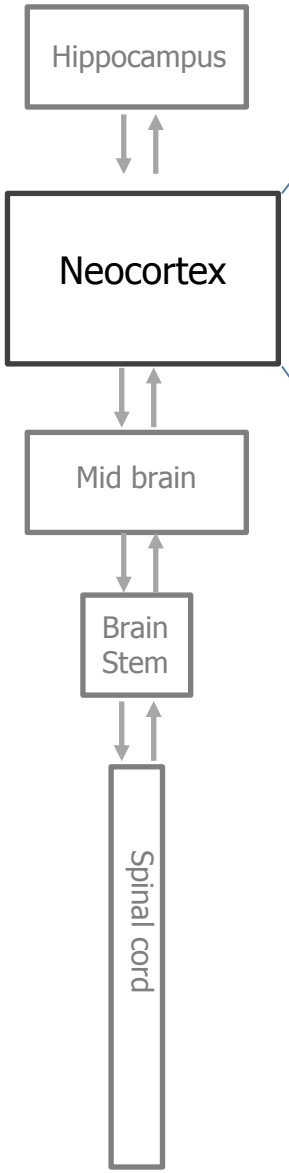


Reptile

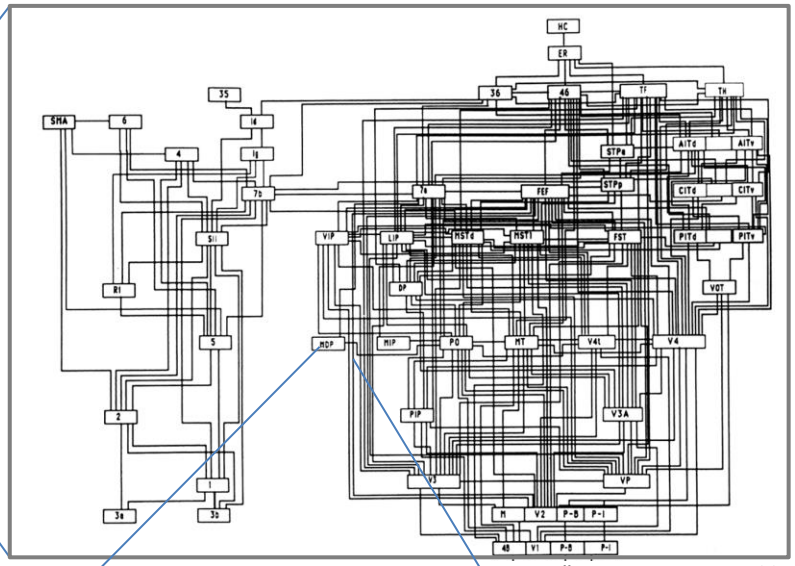


Mammal

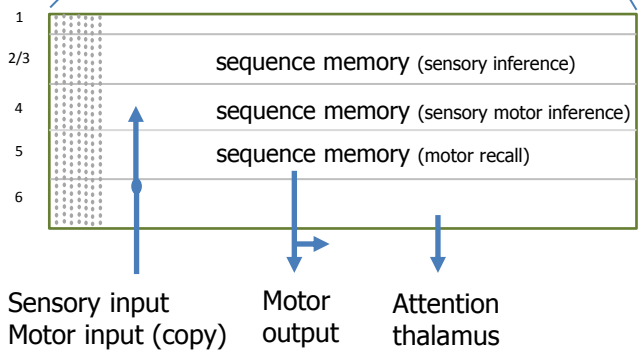
What is so valuable about the neocortex that overcomes its significant costs?



Mammal



Felleman, van Essen 1991



Hierarchy of Regions

1) Regions are remarkably similar across species and modalities.

Therefore, all regions perform similar functions.

2) Hierarchy varies across species.

Therefore, hierarchical graph is not critical. It is a design parameter.

All Regions:

1) Recognize sensory sequences
(e.g. spoken language, music, visual motion)

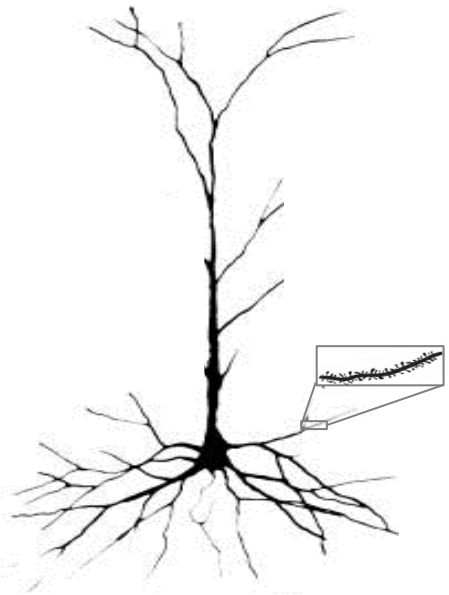
2) Recognize sensory-motor sequences
(e.g. limb movement, eye movement)

3) Generate motor sequences

Every region does what the entire hierarchy does. It learns a sensory-motor model of its world.

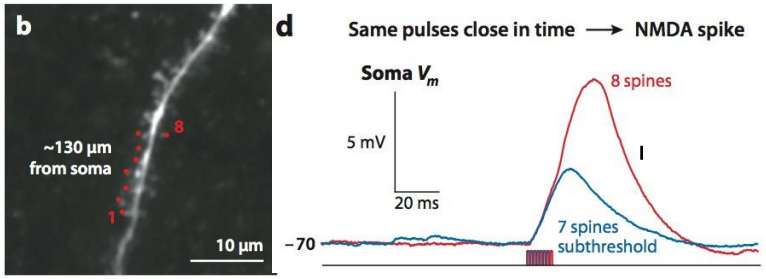
Deduction: Sequence memory is an important function of all regions.

Pyramidal Neuron

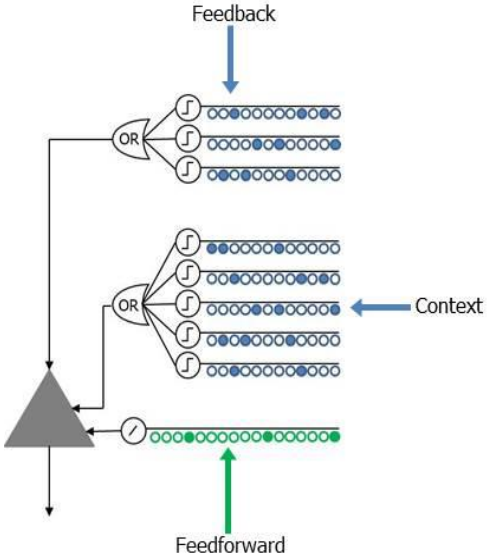


10K to 30K excitatory synapses
- 10% proximal
- 90% distal ?

Active dendrites act as pattern detectors



Major, Larkum and Schiller 2013



HTM neuron

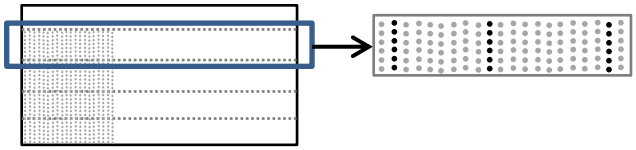
Each pyramidal neuron can recognize 100's of independent patterns.

Patterns recognized on basal distal dendrites will depolarize the soma but not cause an action potential.

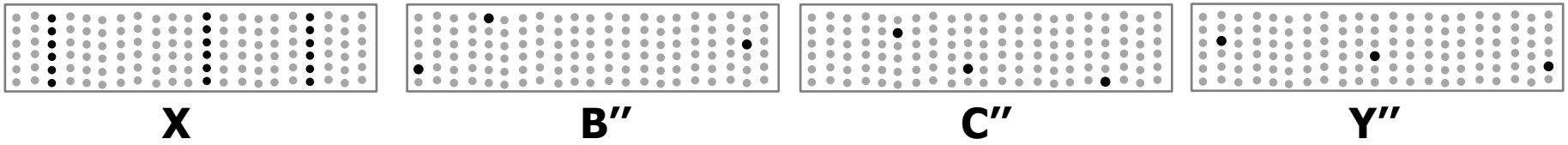
Hypothesis: Depolarization acts as a prediction, a depolarized cell fires sooner and disables nearby cells.

Representing High-Order Sequences

A-B-C-D vs. **X-B-C-Y**

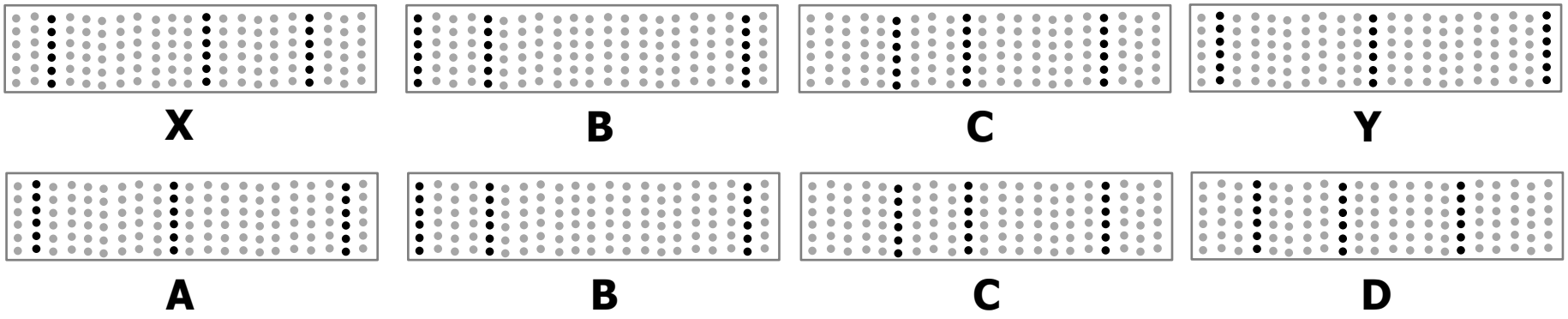


After learning

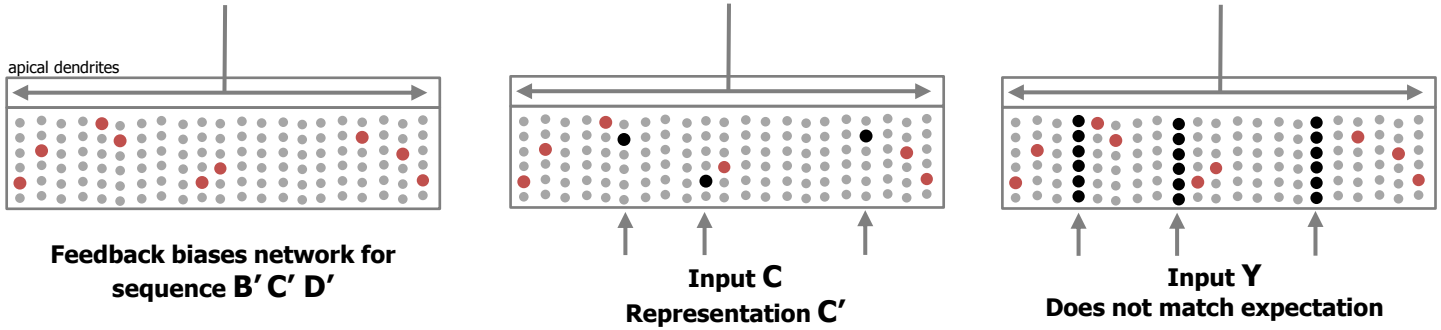


Same columns,
but only one cell active per column.

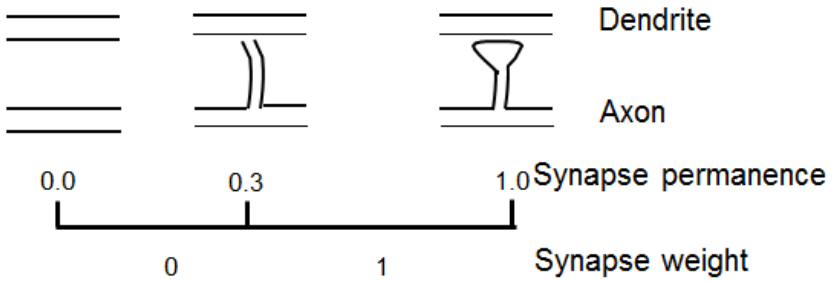
Before learning



Apical Synapses Predict Sequences



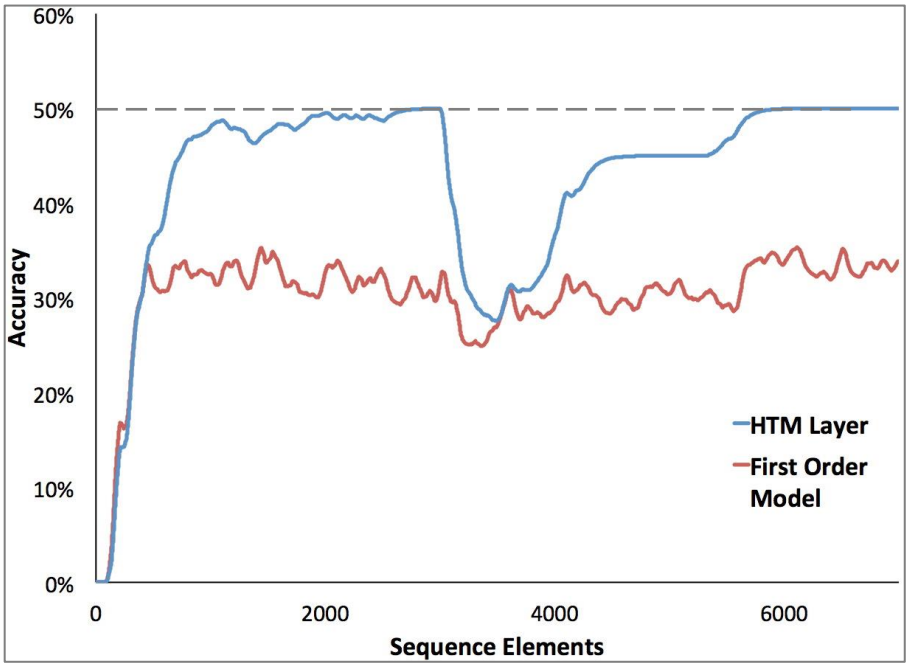
Learning Via Synaptogenesis



Chklovskii, Mel, and Svoboda 2004

Holtmaat and Svoboda 2009

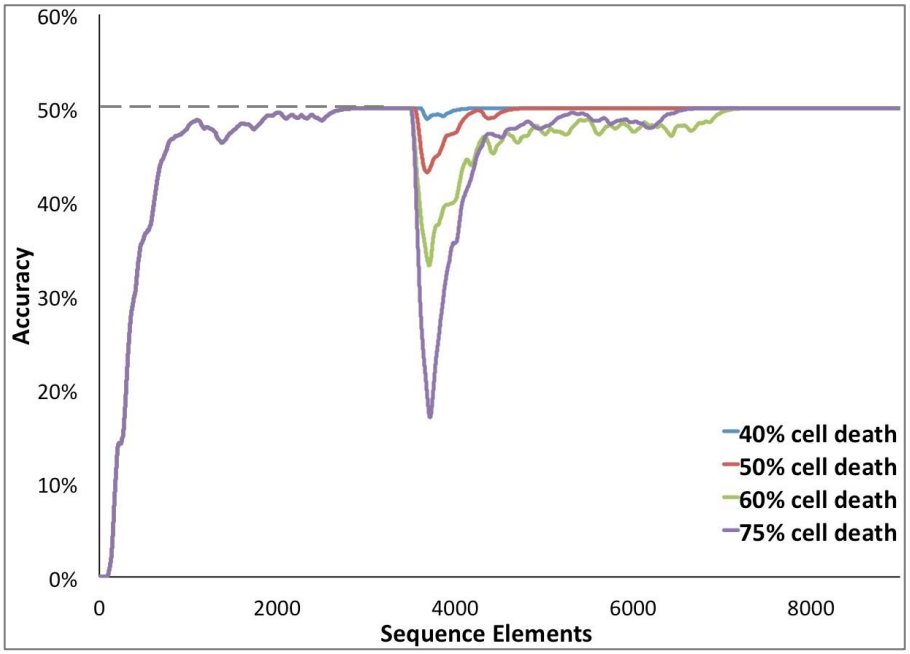
A



HTM Sequence Memory

- Learns continuously
- No batch training
- Adjusts as patterns change

B



- Robust to cell death

1) The Biological Components of Intelligence

2) The Functional Components of Intelligence

3) The Diversity of Intelligent Machines

Hawkins' List of the Functional Components of Intelligence

1) Networks of neurons that learn and recall sequences (required)

- Continuous learning, not batch (required)
- Many simultaneous predictions (required)
- Robust (required)

HTM: active dendrites, synaptogenesis, no spikes

2) Regions that use sequence memory for:

- sensory inference (required)
- sensory-motor inference (required)
- motor generation (required)

3) Hierarchy of regions (required)

- number of regions (parameter)
- size of regions (parameter)
- connectivity graph (parameter)

4) Embodiment (required)

- sensors (parameter)
- built-in behaviors (parameter)
- emotions/motivations (parameter)
- episodic/spatial memory (parameter)

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