Biological Prediction

We know the brain has an expectation of what it will sense at a given moment. How?

Agenda

Topics Covered

01 Structure of the Neocortex

02 Learning Criteria

03 Dendritic Predictions

04 Applications

Basis

https://www.frontiersin.org/article/10.3389/fncir.2016.00023

CrossMark

Why Neurons Have Thousands of Synapses, a Theory of Sequence Memory in Neocortex

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OPEN ACCESS

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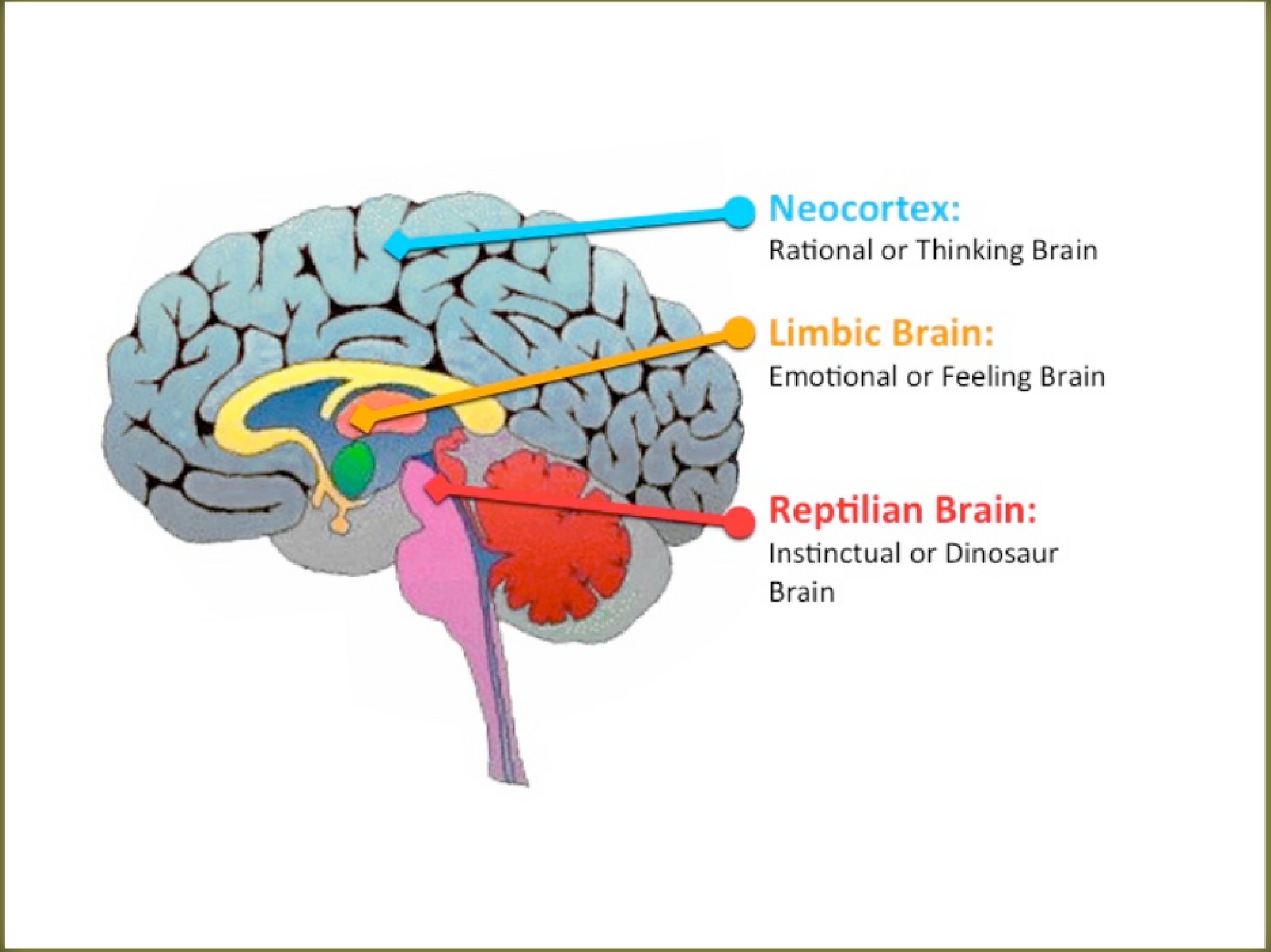
Pyramidal neurons represent the majority of excitatory neurons in the neocortex. Each pyramidal neuron receives input from thousands of excitatory synapses that are segregated onto dendritic branches. The dendrites themselves are segregated into apical, basal, and proximal integration zones, which have different properties. It is a mystery how pyramidal neurons integrate the input from thousands of synapses, what role the different dendrites play in this integration, and what kind of network behavior this enables in cortical tissue. It has been previously proposed that non-linear properties of dendrites enable cortical neurons to recognize multiple independent patterns. In this paper we extend this idea in multiple ways. First we show that a neuron with several thousand synapses segregated on active dendrites can recognize hundreds of independent patterns of cellular activity even in the presence of large amounts of noise and pattern variation. We then propose a neuron model where patterns detected

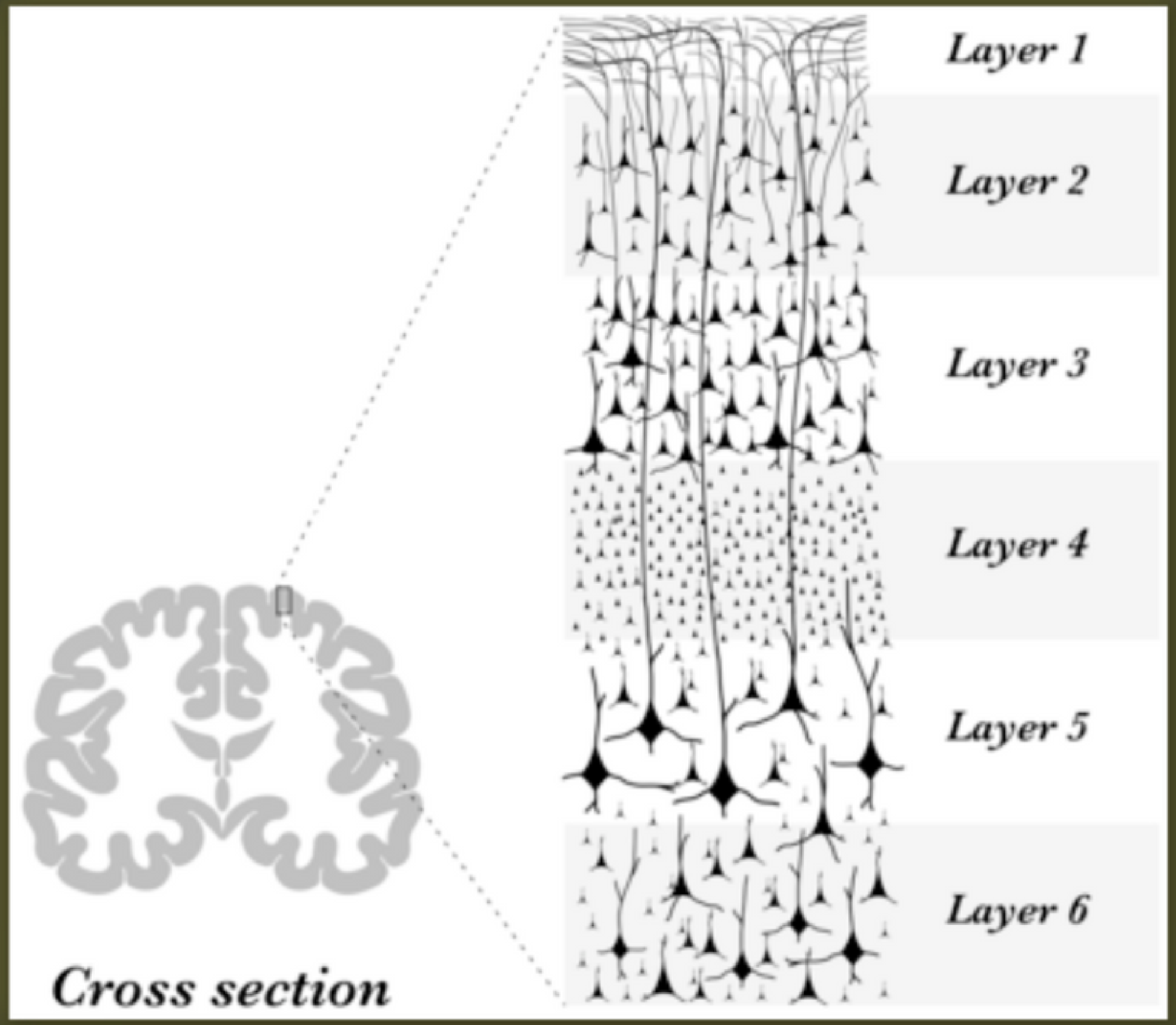
The Neocortex

- 'Higher order' intelligent thinking, planning, prediction, consciousness
- Composed of ~150,000 cortical columns
  - Thousands of neurons each
- Six layers



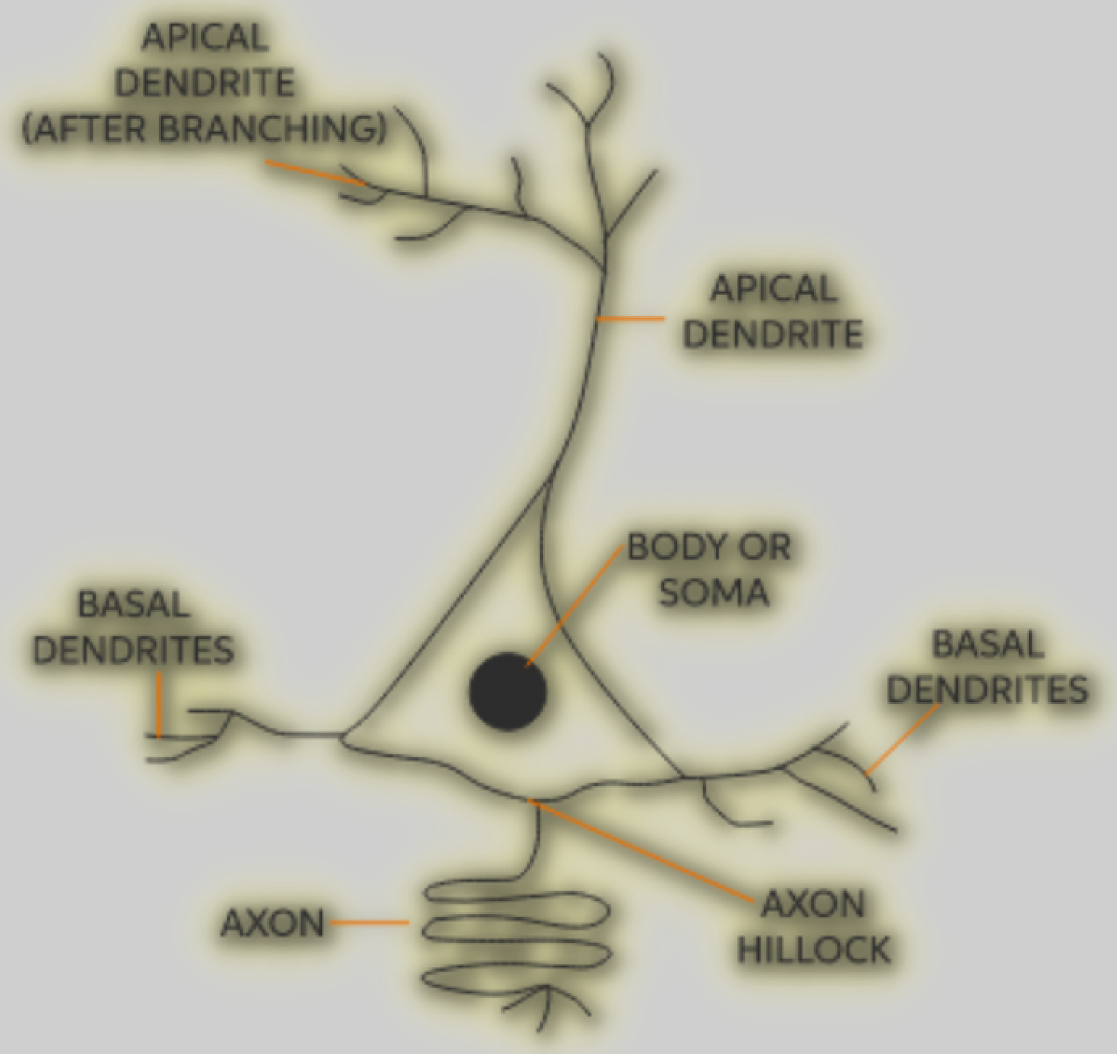
A Cortical Column

- **"Mini-columns** are small groups of pyramidal neurons that exist within one layer of each cortical column. The input layer of each cortical column are arranged in mini-columns. In our simulations, there are typically 150-250 mini-columns per cortical column, with 16 cells per mini-column."
- Hawkins' Claim: if the cortex has the same structure everywhere and learns, then there exists a general learning algorithm from this structure



A Neuron

- Each pyramidal neuron has thousands of inputs from other neurons on synapses
- Synapses line each dendrite
- Input on dendrites further away is not enough to cause an action potential
- Input to proximal dendrites largely responsible for action potentials



Learning

Input

Prediction

Next Input

Adjust Model

Predictive Coding Model:
Update less when you correctly predict the next input, update more when it was unexpected

Learning Criteria and Constraints

1) Local Learning Rules

2) Continuous Learning
   (the environment changes)

3) Contextual Info and Prior Experience

4) Multiple Simultaneous Predictions

5) Robust to Noise

What biological mechanisms meet these?

Predictions Thought Experiment

You hear a key turn in the door to your house, and you generally expect your roommate to get back from classes soon
Due to your prior experience with the sound of the key that have been followed by the door opening, you unconsciously anticipate it will open

Either
1) The door does not open, you become conscious of the unmet prediction
OR
2) The door opens and you may not have even looked up

Predictions Thought Experiment

In no case can you tell your brain to stop receiving the sensory input of hearing the door open or not, but in different scenarios we become conscious of it or not.

Dendritic Predictions

Key Idea

Predictions are encoded when an actively firing neuron connects to distal dendrites of another neuron that is predicted to come next.

1) When I hear the key turn, first, the minicolumn(s) encoding the sound of the key turning fire.
2) They also connect to basal dendrites of neurons that encode the sound of the door opening
3) The basal dendritic spikes do not cause these neurons to fire (otherwise you would hallucinate the sound of the door opening)
4) Instead, the basal dendritic spikes depolarize the neurons expecting the sound of the door opening

This is a prediction

Dendritic Updates

Key Idea

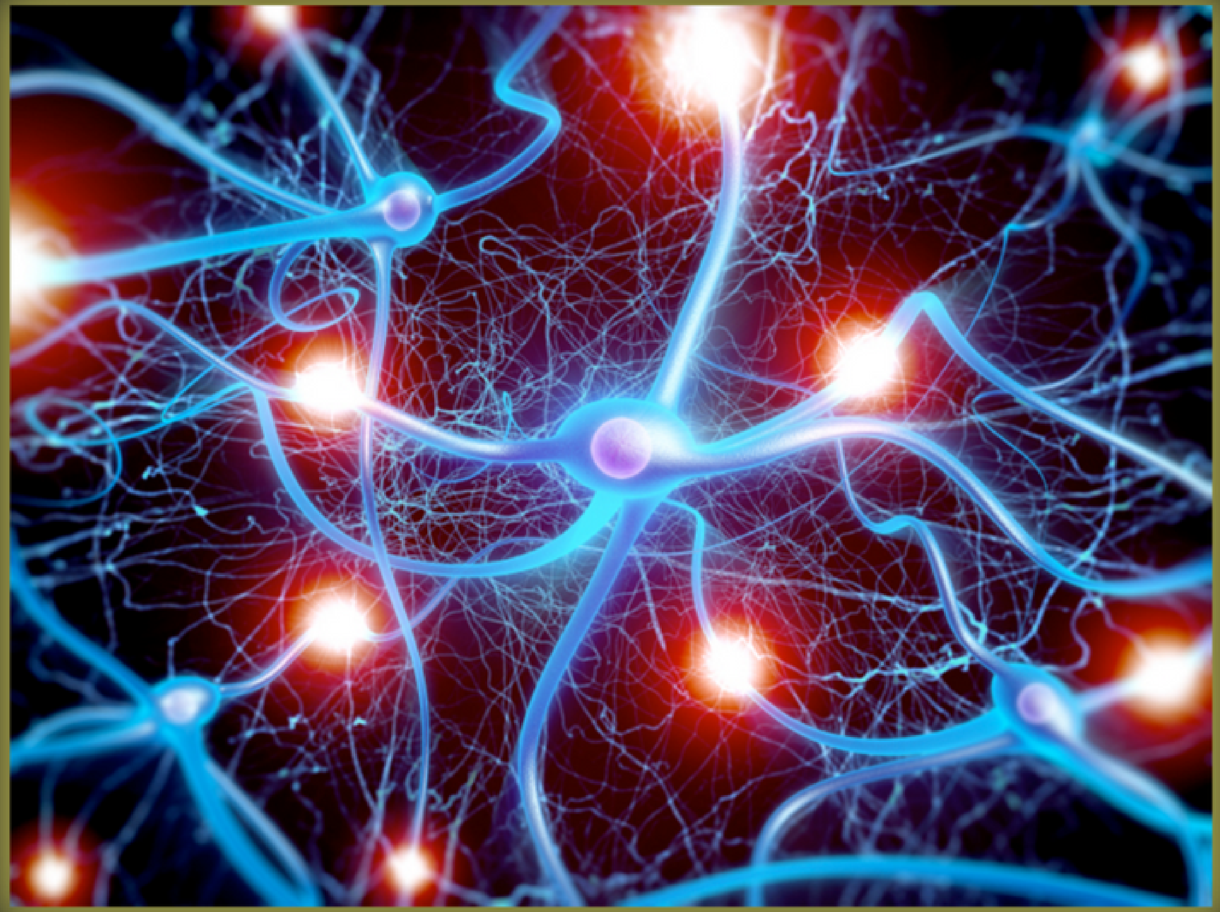
When the next input is received, if it sends signals to the expected neurons, they will fire **faster** than unpredicted possibilities, causing local **inhibition**

1) The minicolumn(s) representing the door opening receive the excitatory signal as I hear the door opening
2) The neurons of this column that were depolarized by the noise of the key fire **first** and **faster**
3) This inhibits the other neurons of the column from firing that weren't primed by the noise of the key
4) The prediction was met, and fewer neurons fired because of it (maintaining sparsity)

Dendritic Updates

Key Idea

Otherwise, if the next input was **unexpected**, the primed neurons do not fire faster, and all the neurons encoding the unexpected input fire



1) The excitatory input is directed to neurons that were not depolarized by a prior input
2) They all fire at the same rate and there is no local inhibition
3) The prediction was not met and more neurons fired because of it

Sparsity and Combinatorics

Key Idea

It is important that only a few neurons fire at once in order to represent a given input. If a dense amount of neurons fire, then this pattern can be easily confused with other patterns.

If I have 1,000 Skittles total and I can arrange them in different locational patterns, but every time I must arrange 999 of the Skittles, then I can make fewer patterns than if I could change one Skittle at a time to make a different pattern.

Applications

HTM Network

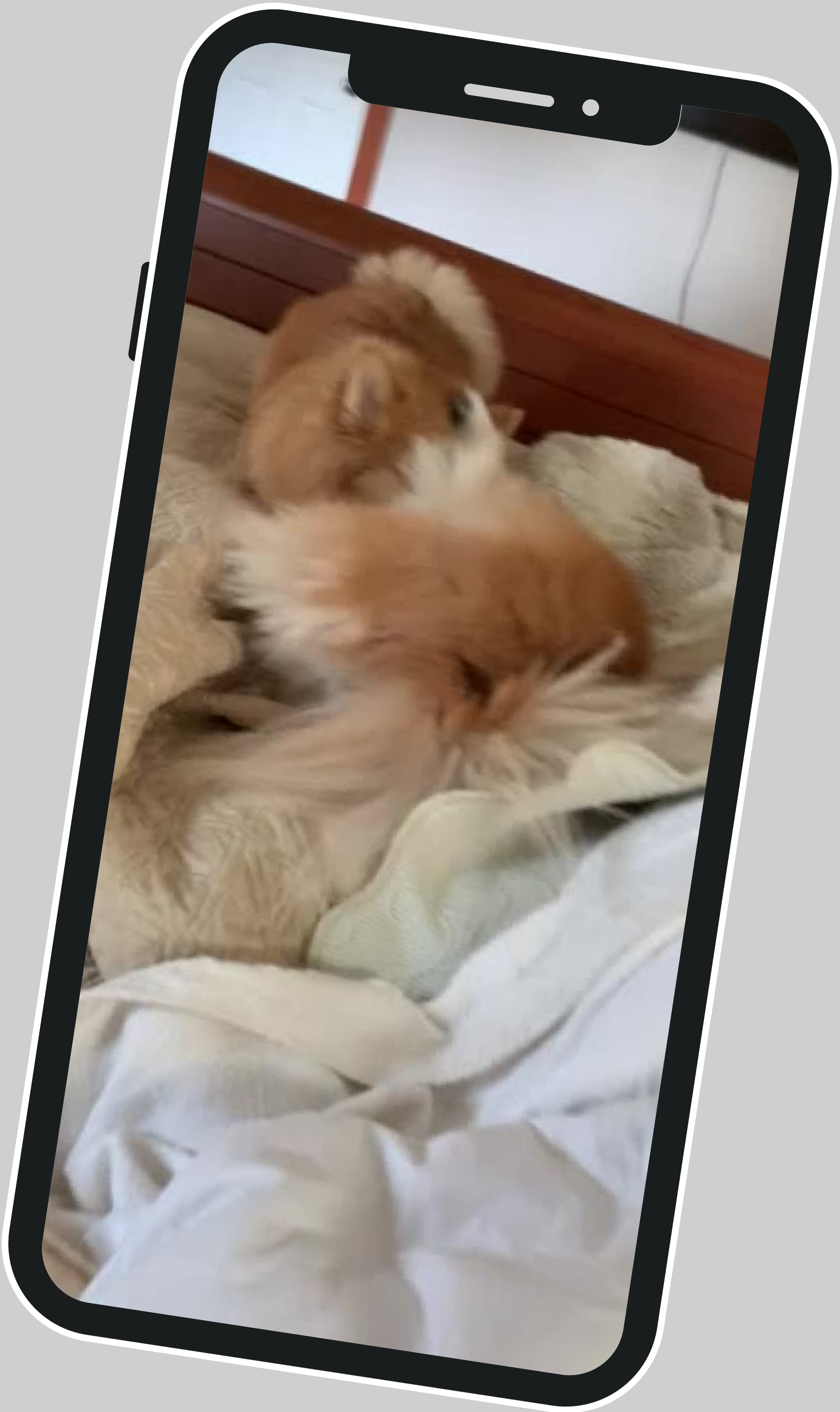
The group who wrote this paper, Numenta, simulated this model using neural networks. It learned sequences of characters well and was robust to perturbations of the data.

Could we add a depolarization mechanism to our networks?

Could we add an inhibitory mechanism to encourage sparse representation of seen patterns?

Other thoughts?

And now, my dogs



Bonus Slides!!!

STEPHEN GROSSBERG

Adaptive Resonance Theory

Top down expectations are compared to bottom up inputs.

Matches cause excitatory cycles.

These cycles are called resonant states