

Grid Cells

Kropff & Treves, 2008
Presented by dmac



Kropff & Treves, 2008

- Introduced a model of Grid Cells
- Model is conceptually similar to Spatial Pooler
 - But uses different notation and equations. This presentation will restate their work in terms of Numenta's HTM theory.



The Big Idea

- Grid cells assume you are moving
 - slow and steady
 - irregular movement -> irregular Grid Cells
- Assume that consecutive sensory inputs are physically adjacent
- Turn this into a small bias on the grid cells activity



Spatial Pooler Equations

- $y = f(\text{overlap}(\text{synapses}, \text{inputs}))$
- $\text{Active Cells}_{\text{note}} = \text{Maximum}(\text{sparsity}, y)$
- $f = \{ \text{Identity},$
- Low Pass Filter (LPF),
- LPF & High Pass Filter (HPF) $\}$

Note about terminology: in a regular Spatial Pool the cells are actually mini-columns.



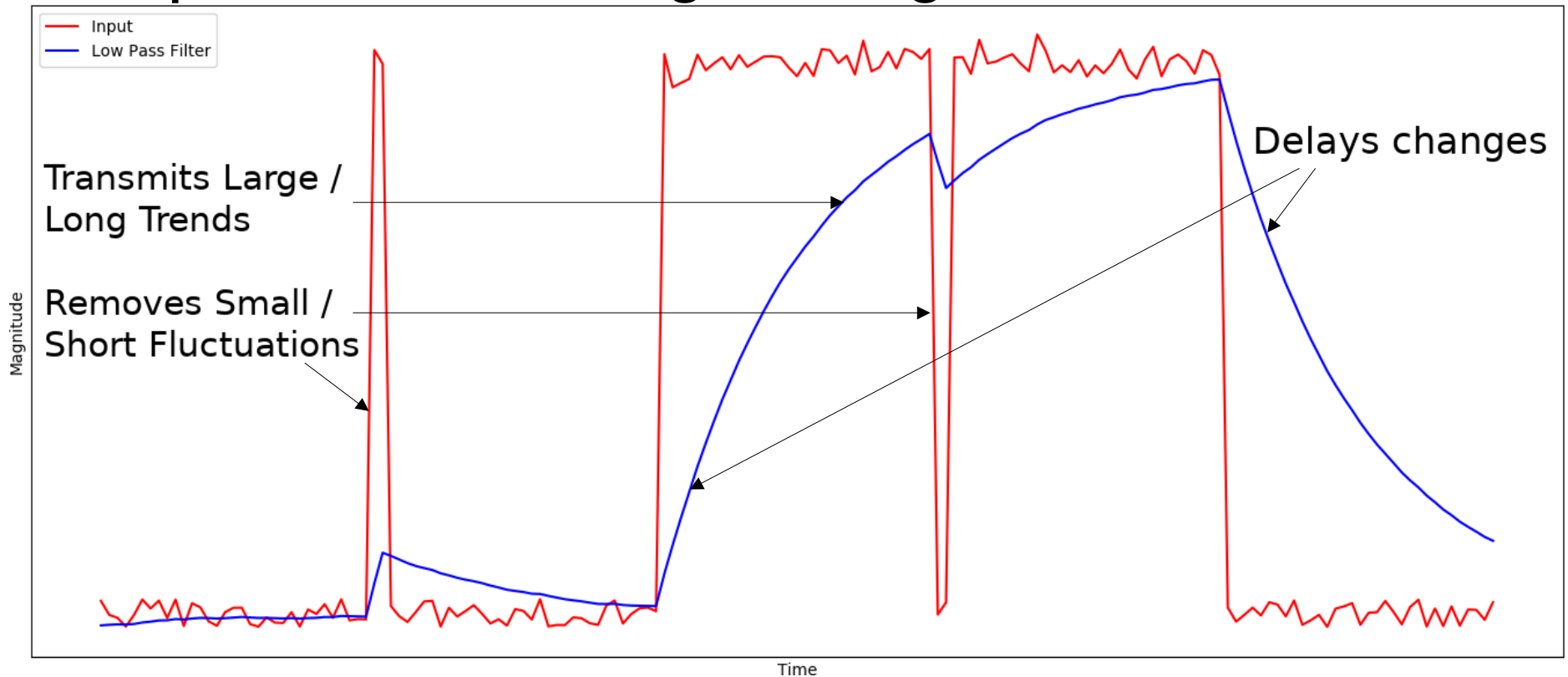
The function f

- Three options, each used by different cell types
- Identity function yields the regular Spatial Pooler which we all know and love
- Low Pass Filter is used by cells in Layers 2/3
 - Personal Conjecture
- Combined Low & High Pass Filters yield Grid Cells
 - Kropff & Treves, 2008



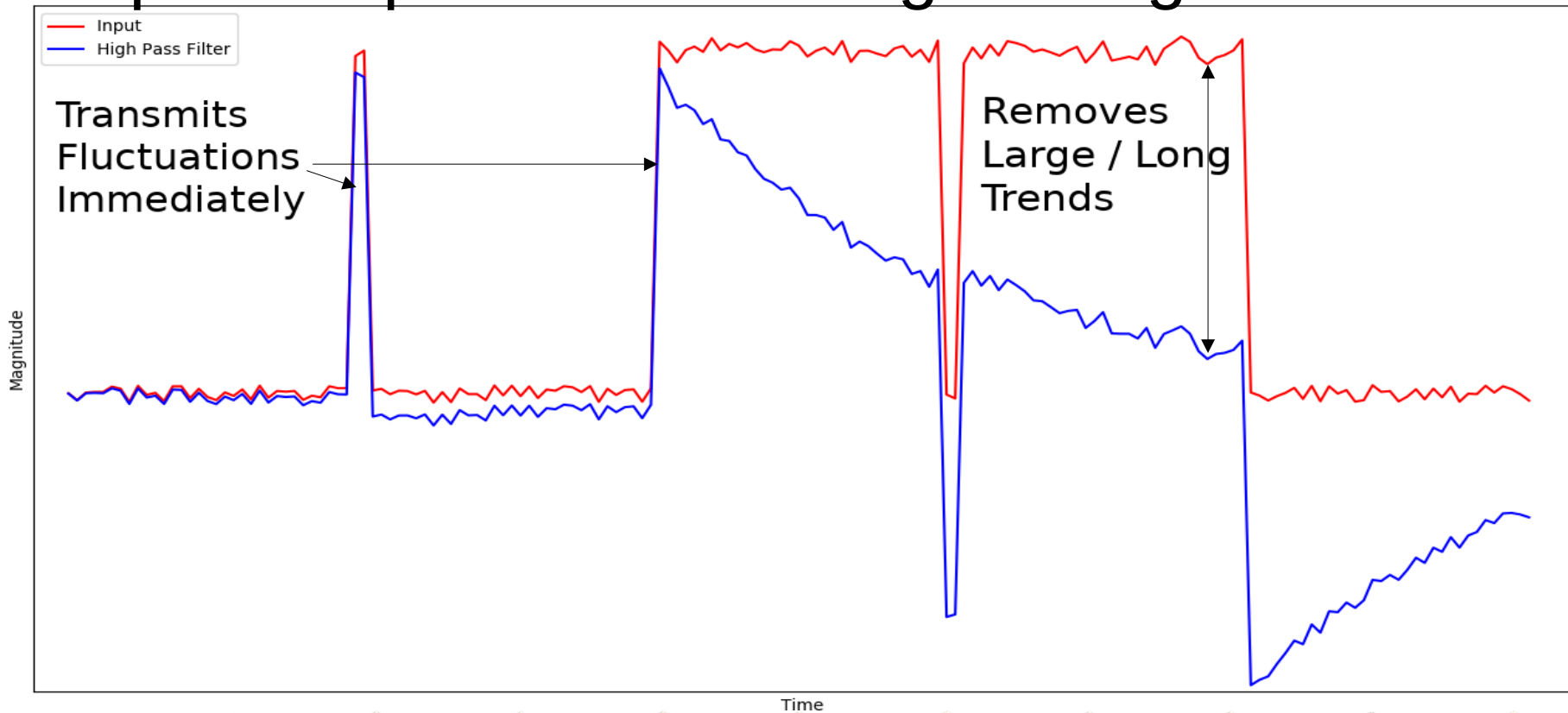
Low Pass Filter

- Exponential Moving Average



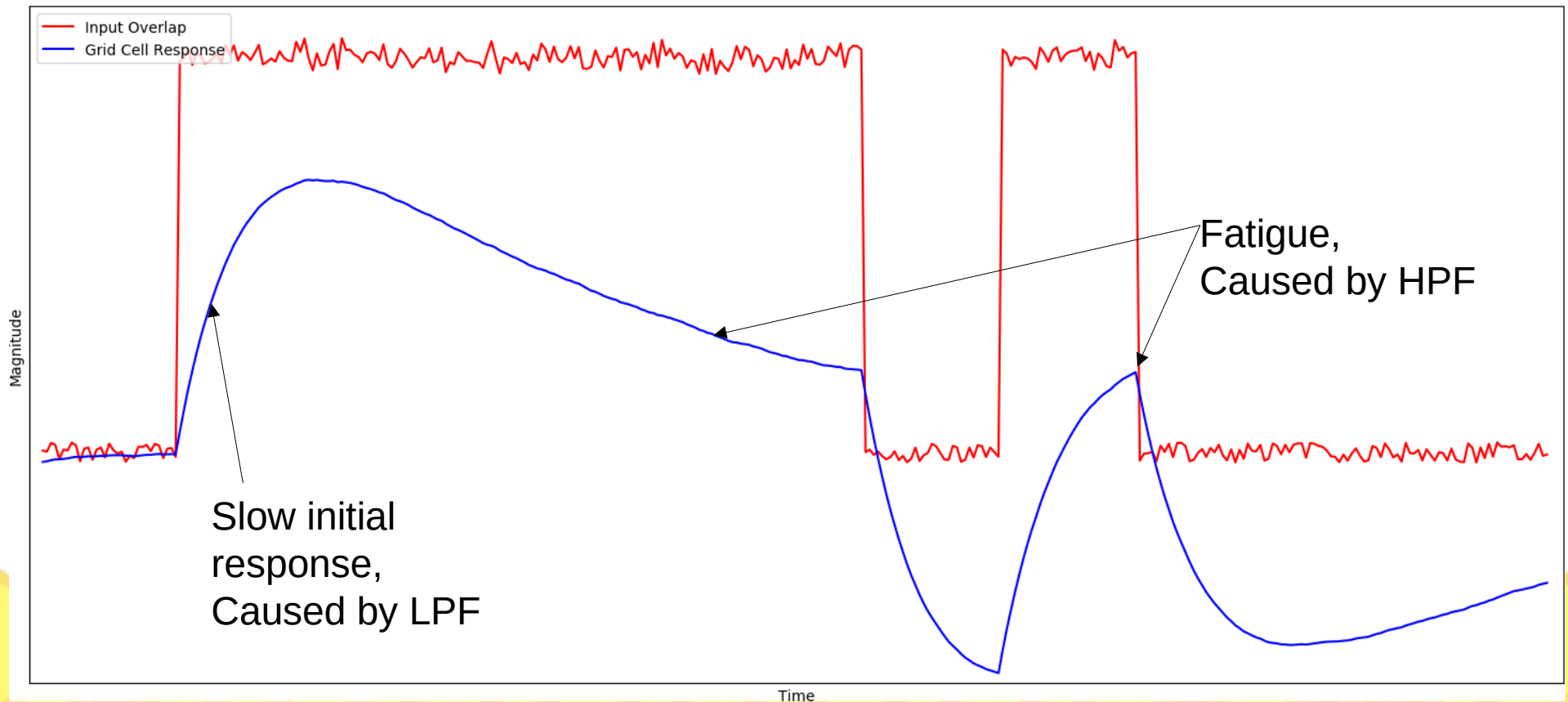
High Pass Filter

- Input - Exponential Moving Average



Combining HPF & LPF

- $y = \text{LPF}(\text{HPF}(\text{Overlap}))$
- Exponential period of HPF $>$ LPF



Low Pass Filter Discussion

- Some Grid Cells have large receptive fields
- LPF causes cells to respond to large contiguous areas of the world
 - Cells react slower than their inputs change
 - Cells will learn about multiple adjacent inputs







High Pass Filter Discussion

- Kropff & Treves call it “Fatigue”
- HPF turns off Grid Cells after you've moved through an area
- HPF controls the maximum size and minimum spacing of receptive fields
- When standing still, all Grid Cells are uniformly fatigued so their activity remains constant



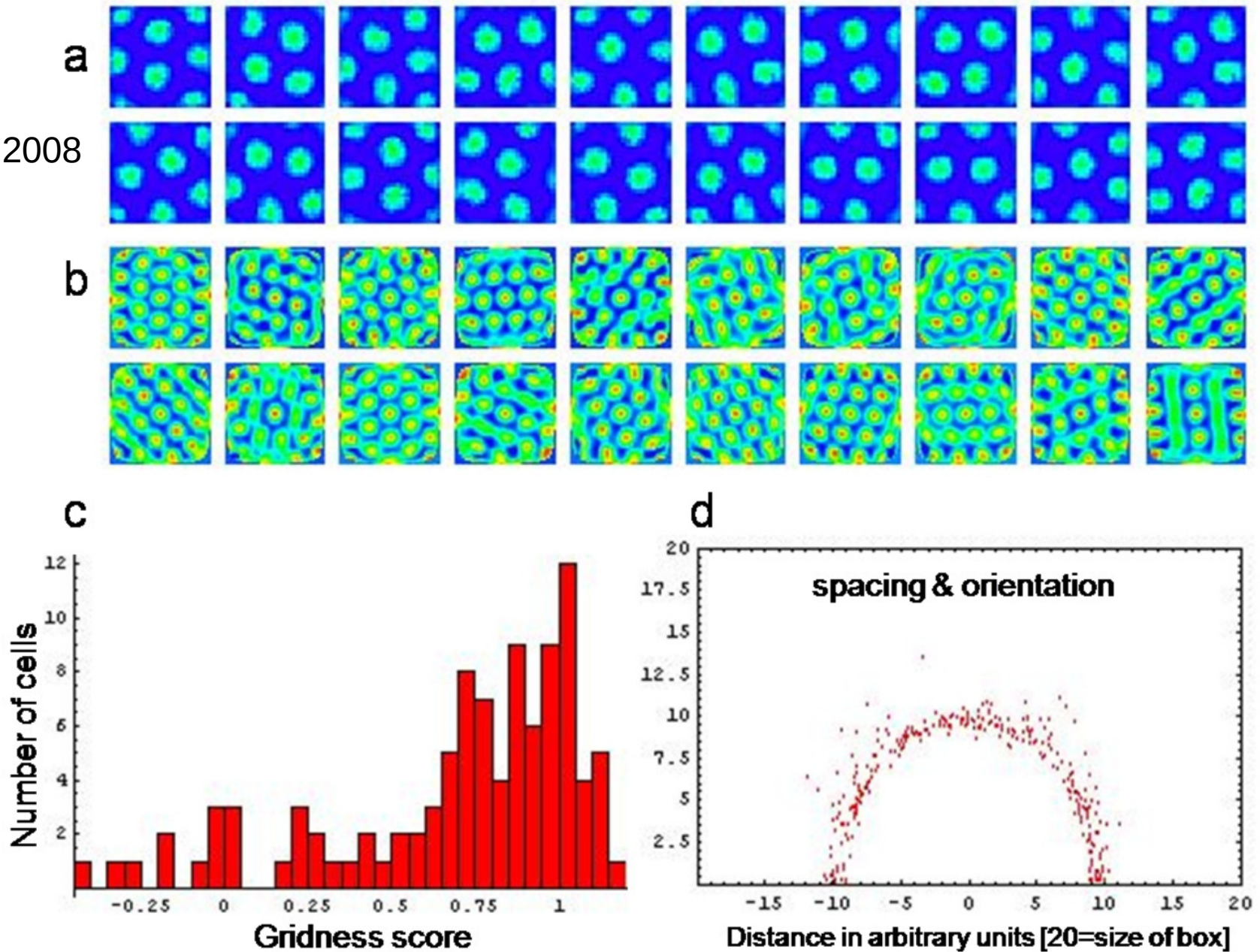
Competition

- The competition to activate controls how many Grid Cells respond to a location
- Competitive pressure helps pack the Grid Cell receptive fields into a hexagonal lattice.
- Grid Cell sparsity is ~30%



It works in simulation

Kropff & Treves, 2008
Figure 3



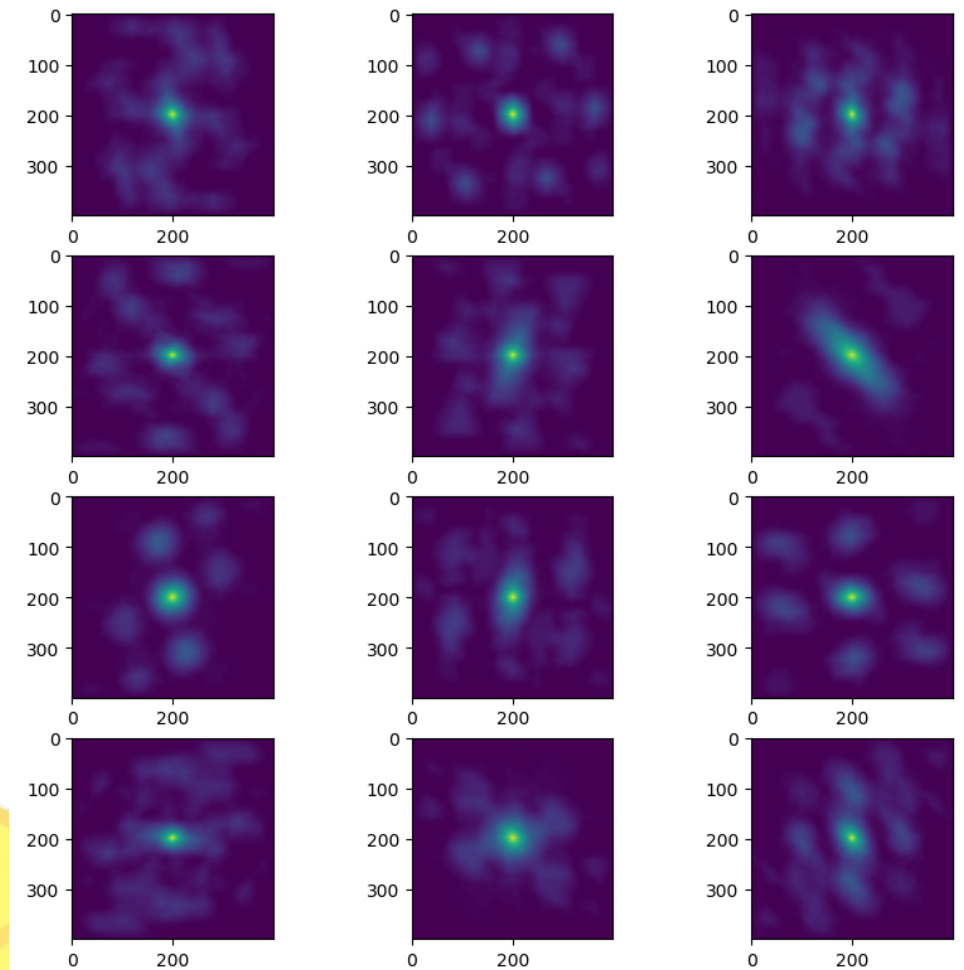
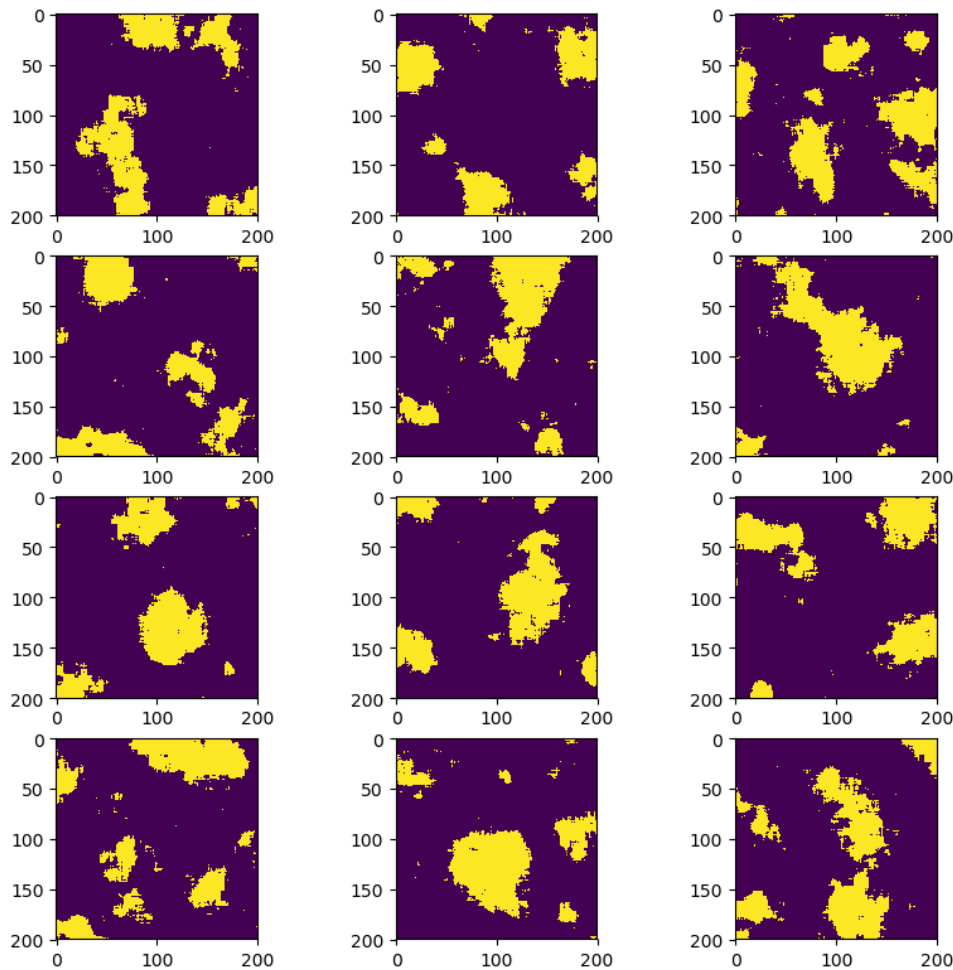
Explanation of Previous Slide

- **Kropff & Treves, 2008**
- **Figure 3.** Numerical simulations where mEC units receive inputs from place units and self-organize feedforward weights based on adaptation dynamics alone, leading to grids broadly similar to experimentally observed ones.
- **a** Fields of a random set of 20 out of 100 mEC neurons;
- **b** the corresponding autocorrelograms;
- **c** histogram with the distribution of the gridness score across the entire mEC population;
- **d** orientation and spacing of the maxima (the position with respect to the center of the autocorrelogram of each of the first 3 maxima is plotted as an individual point), showing similar spacing, but random orientation of the grids across the population.



It works in simulation

- Spatial Pooler Augmented for Grid Cells



Conjecture for L2/3

- A Theory of How Columns in the Neocortex Enable Learning the Structure of the World
- Model requires cells which are “stable with sensor movement”
- But does not explain how to make such cells
- The Low Pass Filter can make cells stable with sensor movement



Experiment for L2/3

- Modified Numenta's 2-Layer model with a Low Pass Filter on the output layer
 - Output layer has no distal dendrites
- Input is stream of characters
 - No spaces, No punctuation, No resets
- Task is to identify the boundaries between words

Source:

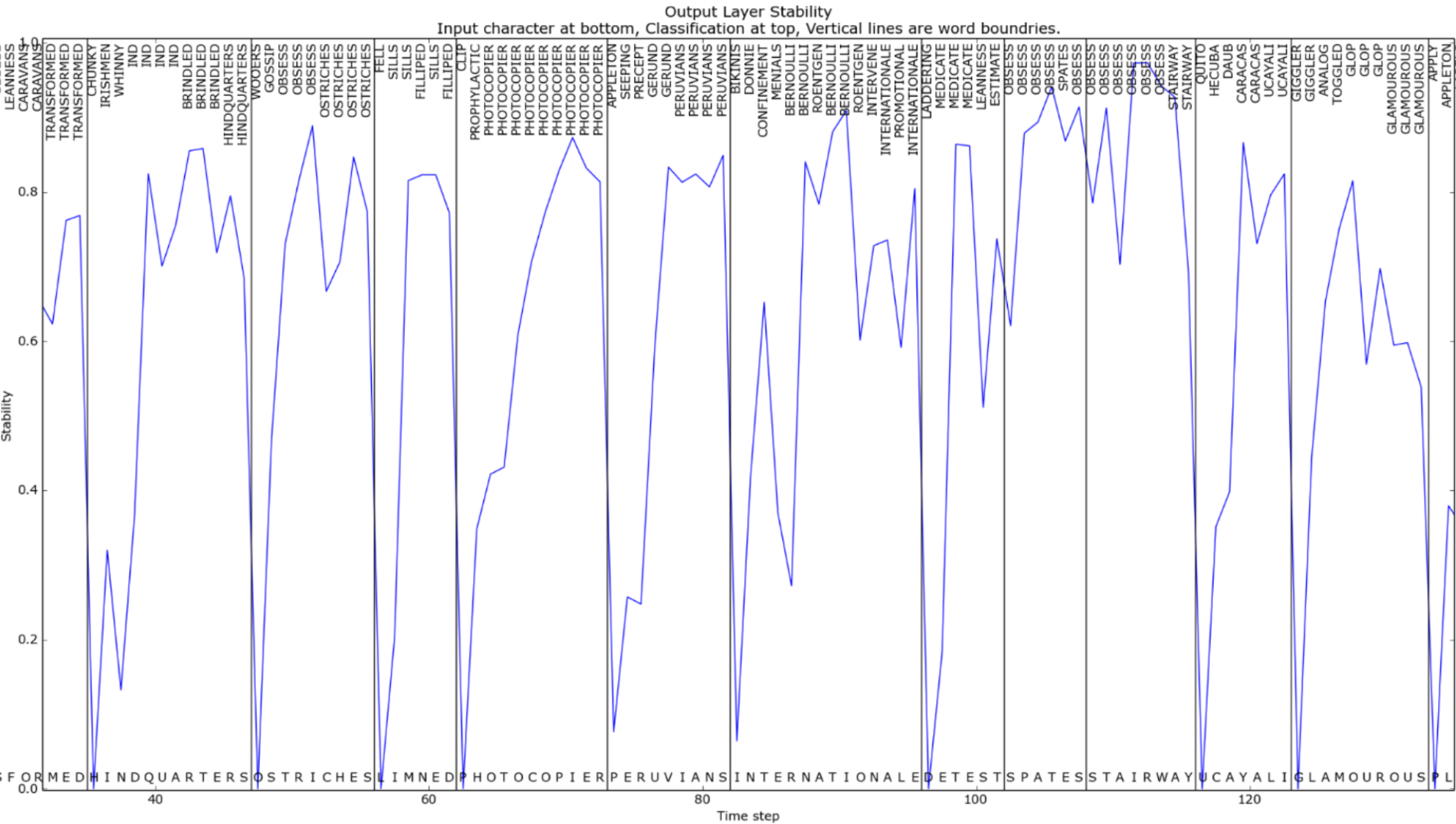
https://github.com/ctrl-z-9000-times/sdr_algorithms/blob/master/ascii_stability.pdf

Quantifying Stability

- Stability (blue line) measures the overlap between sequential time-steps
- Statistical classifier trained on output layer
 - Only trains on the final character in each word
- Intra/Inter category overlap
 - Sample the output layer activity for each object
 - Compute overlap between samples of the same object versus different objects



Success!



Standing Still

- Synapses only learn when either the presynaptic or postsynaptic side changes its activity state. This filters out duplicate updates on sequential time steps.
 - Protects synapses from deleterious effects of looking at one object for too long
 - Motion is required for learning
- See also: CA²⁺ dependent NMDA receptor desensitization



Open Questions

How do distal dendrites effect grid cells?

In theory distal dendrites should cause Grid Cells to Align, Tessellate, and Integrate Movement



References

- The emergence of grid cells: intelligent design or just adaptation? Emilio Kropff and Alessandro Treves, 2008. DOI 10.1002/hipo.20520
- Cui Y, Ahmad S and Hawkins J (2017), The HTM Spatial Pooler—A Neocortical Algorithm for Online Sparse Distributed Coding. Front. Comput. Neurosci. 11:111. doi: 10.3389/fncom.2017.00111
- A Theory of How Columns in the Neocortex Enable Learning the Structure of the World, Hawkins Jeff, Ahmad Subutai, Cui Yuwei, 2017. DOI: 10.3389/fncir.2017.00081

