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.

Spatial Pooler Equations

- Active Cells[note] = Maximum(sparsity, y)
- y = f(overlap(synapses, inputs))
- f = { Identity,

  Low Pass Filter (LPF),

  LPF & High Pass Filter (HPF) }

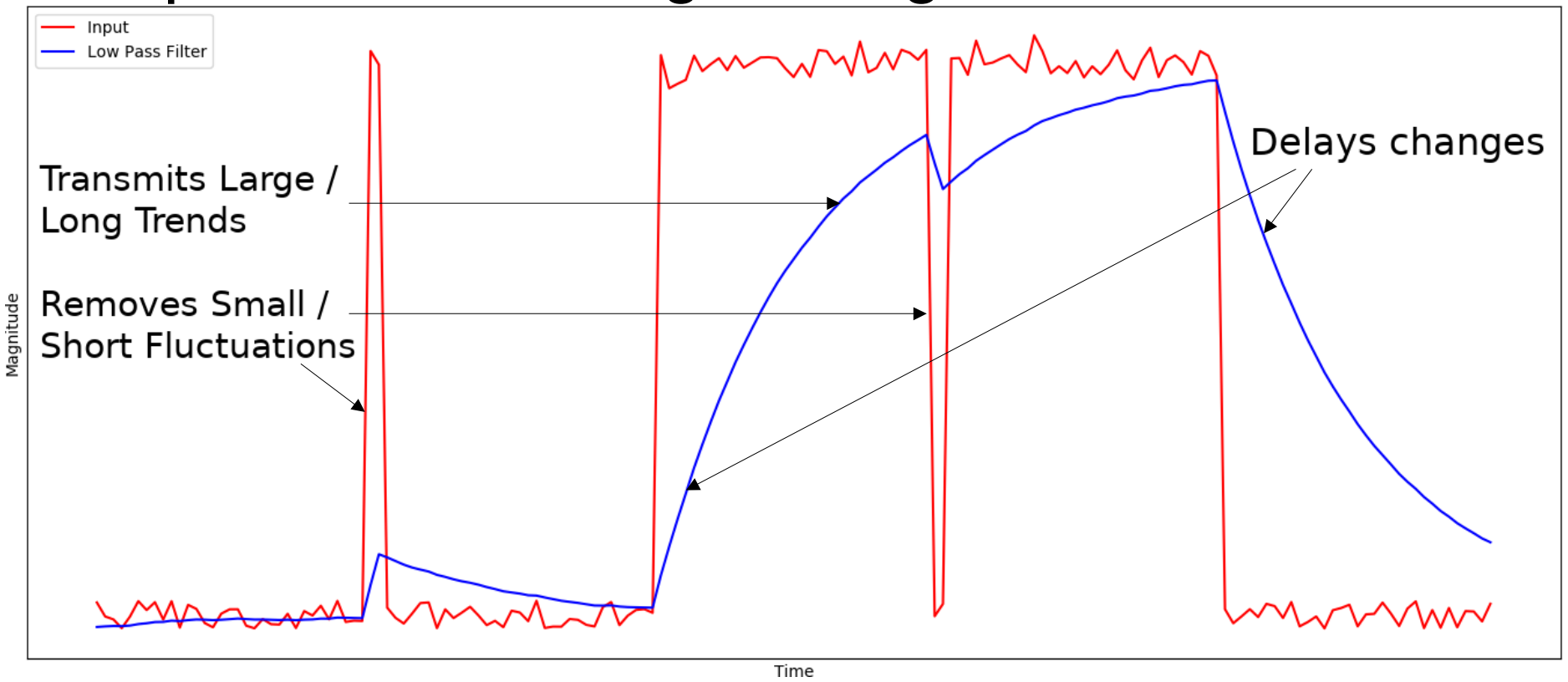
Note about terminology: in a regular Spatial Pool the cells are actually mini-columns.

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

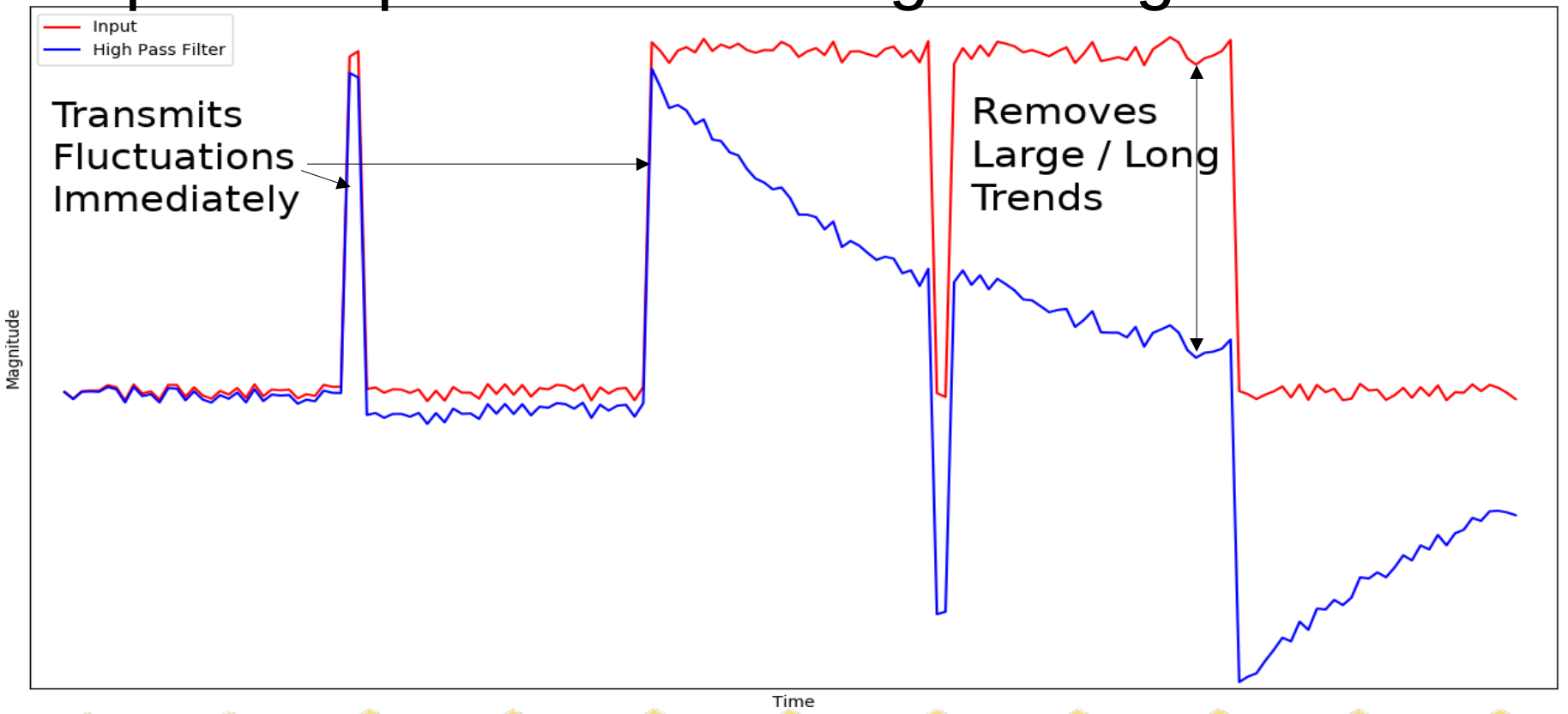
Low Pass Filter

- Exponential Moving Average



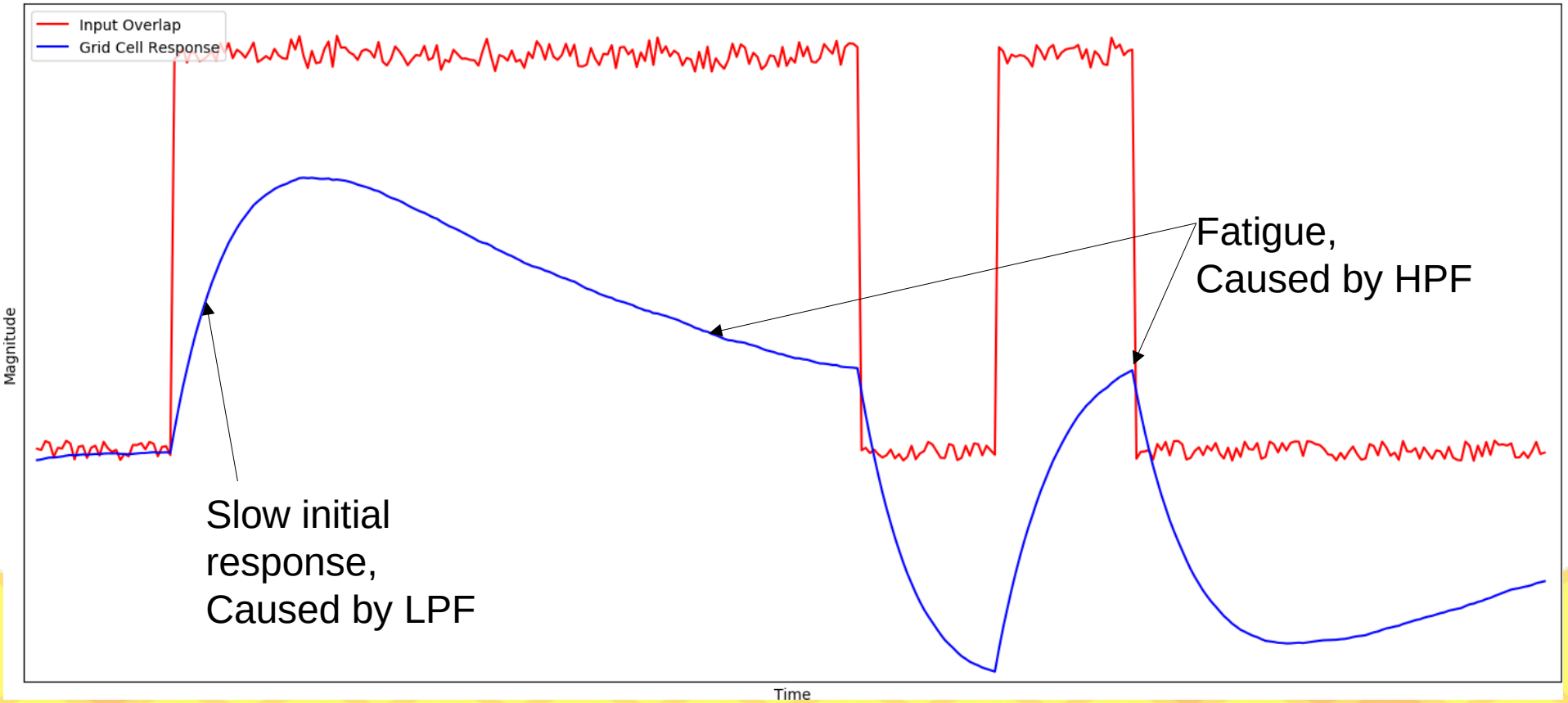
High Pass Filter

- Input - Exponential Moving Average



Combining HPF & LPF

- y = LPF(HPF(Overlap))
- Exponential period of HPF > LPF



LPF Discussion

- Some Grid Cells have large receptive fields
- LPF causes cells to respond to large contiguous areas of the world
  - It does this by making cells react slower than their inputs change
  - Cells will learn about multiple adjacent inputs
  - Movement is required
    - And irregular movement -> irregular Grid Cells

HPF Discussion

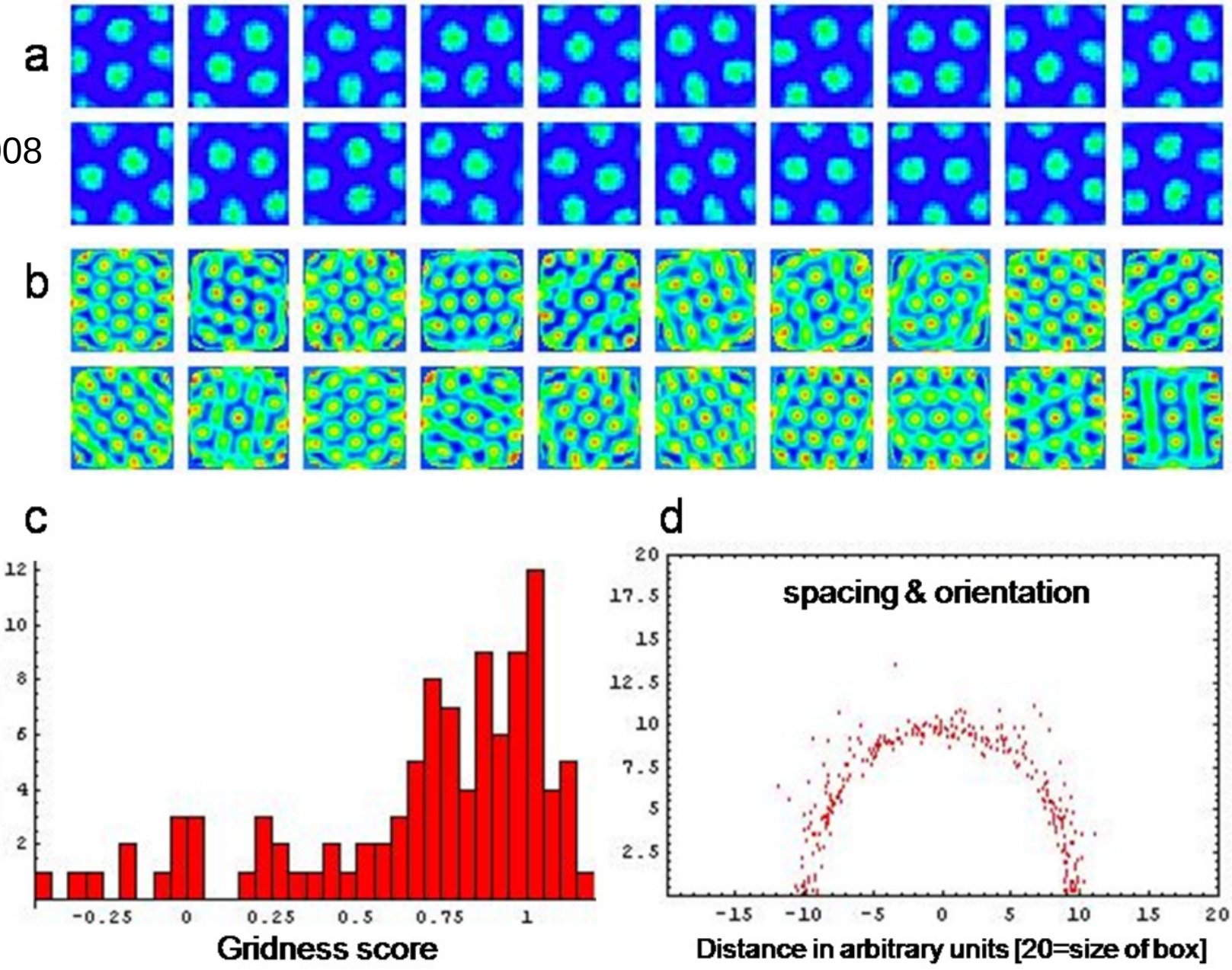
- Kropff & Treves call it “Fatigue”
- HPF controls the maximum size and minimum spacing of receptive fields
- When standing still, all Grid Cells are uniformly fatigued so their activity remains constant

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

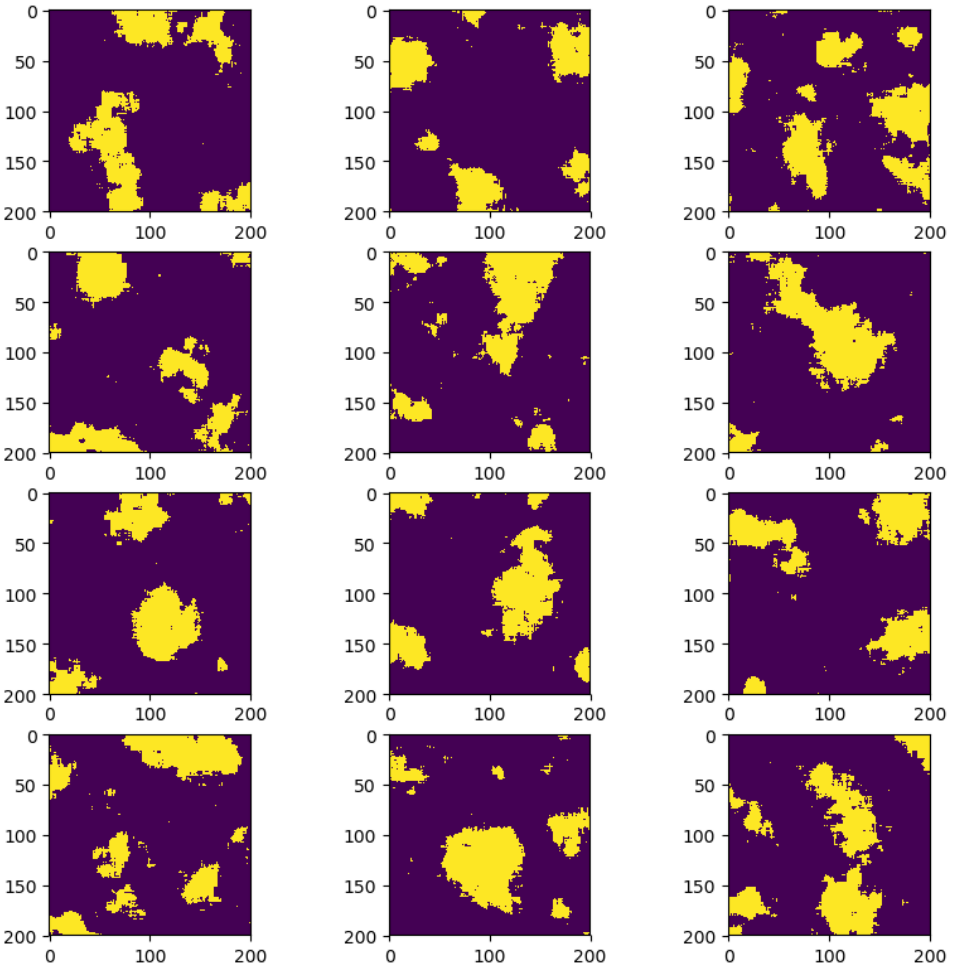
Kropff & Treves, 2008

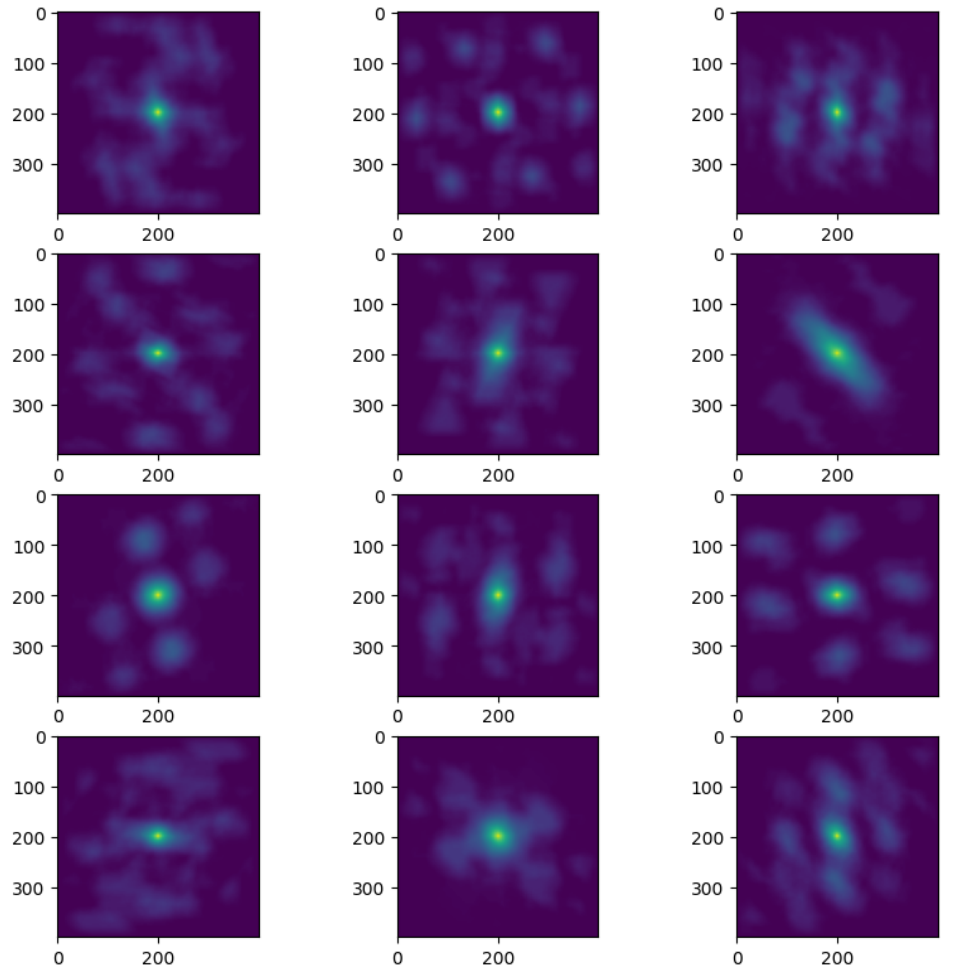
Figure 3. Numerical simulations where mEC units receive inputs from place units and self-organize feedforward weights based on adaptation dynamics alone, leading to grids broadly similar to experimentally observed ones.

- **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

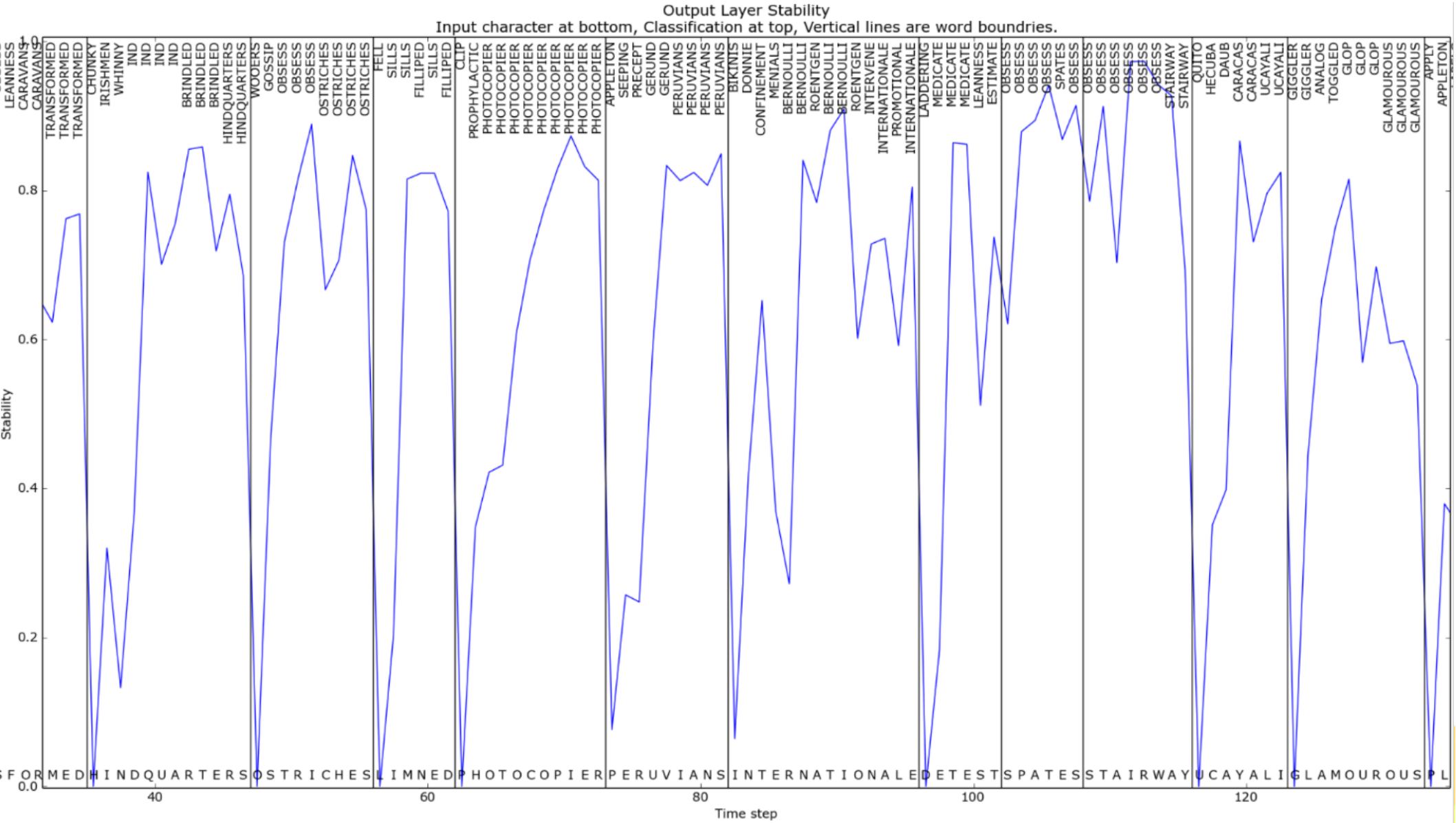
- Modified Numenta's 2-Layer model with a Low Pass Filter on the output layer
  - Output layer has no distal dendrites
- Input is stream of characters
  - No spaces, No punctuation, No resets
- Task is to identify the boundaries between words

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
- Dataset is 500 random words

Success!


Output Layer Stability
Input character at bottom, Classification at top, Vertical lines are word boundries.
Stability
Time step
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
FORMED HINDQUARTERS OSTRICHES LIMNED PHOTOCOPIER PERUVIANS INTERNATIONALE DETEST SPATES STAIRWAY UCAYALI GLAMOUROUS PL

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: CA+ dependent NMDA receptor desensitization

Open Questions

- How do distal dendrites effect grid cells?
  - In theory distal dendrites should cause Grid Cells to Align, Integrate Movement, and Tessellate

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