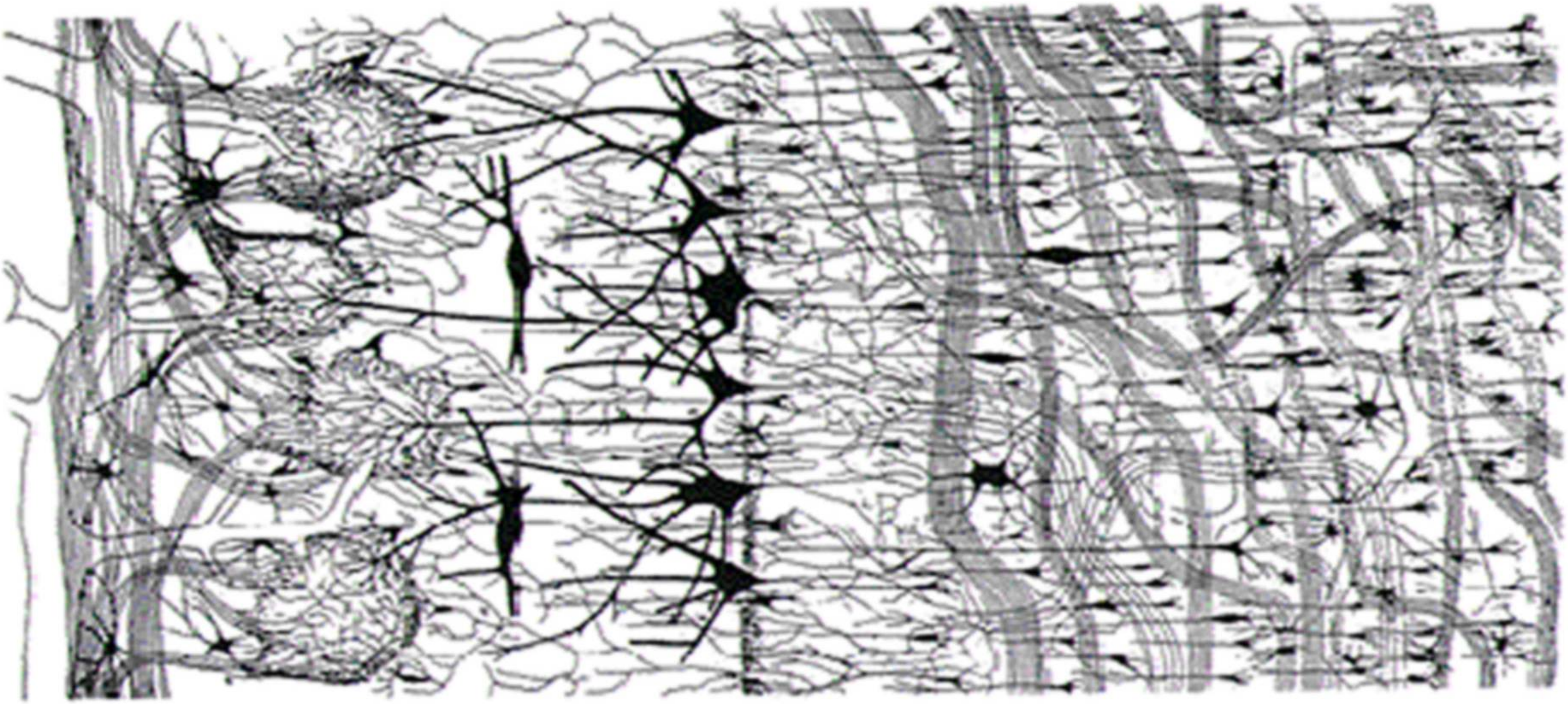
Dynamics and stable states in neuronal circuits of the olfactory system

Rainer Friedrich



Nose → Olfactory bulb ⇄ Telencephalic areas

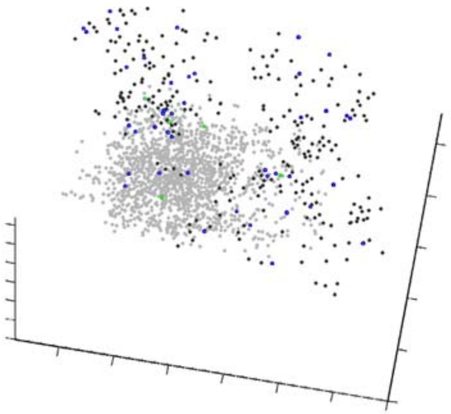
Golgi (1905)

Novartis Research Foundation; MPG; DFG; EU; Minna-James-Heinemann Foundation; Boehringer Ingelheim Fonds; SNF; EMBO

FMI Friedrich Miescher Institute for Biomedical Research

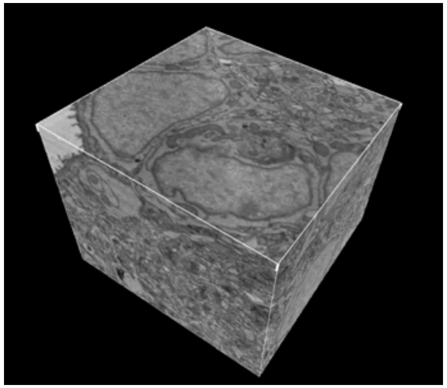
Size matters

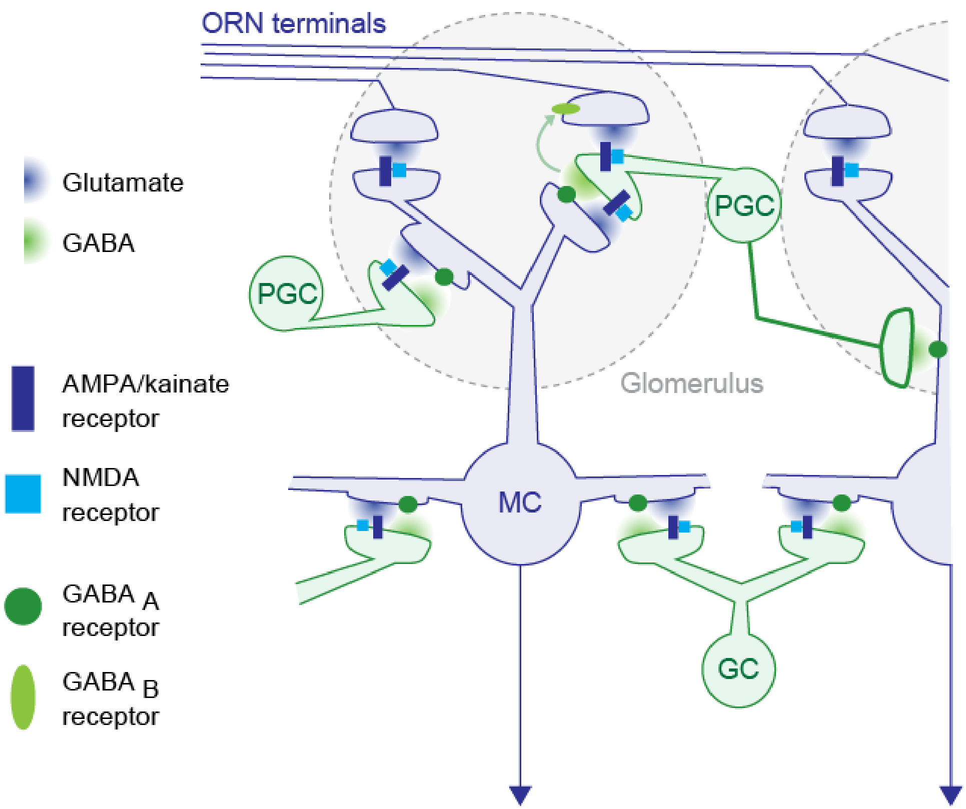
Measurement of neuronal activity patterns

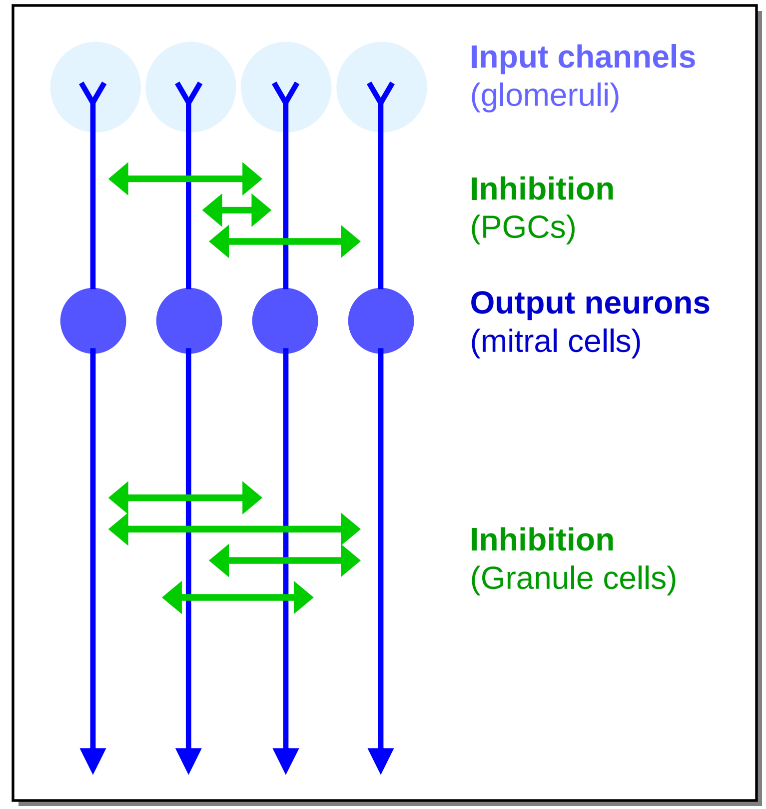


High-resolution optical manipulations

Exhaustive circuit reconstruction (EM)

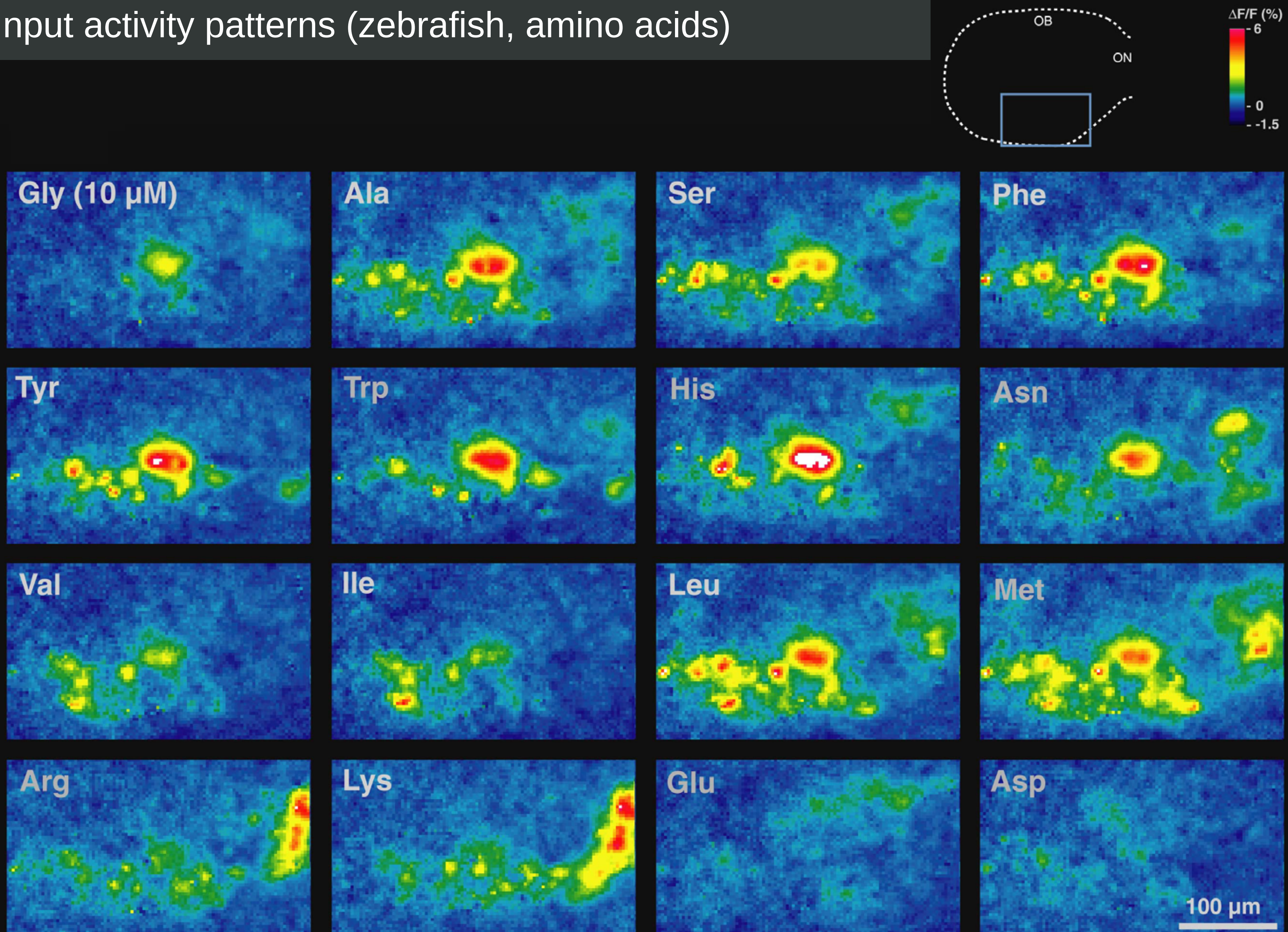






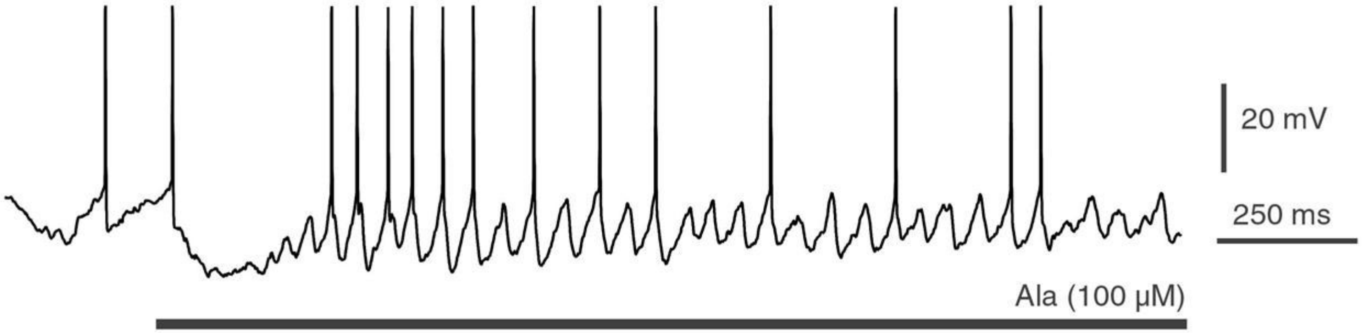
ORN: Olfactory Receptor Neuron; MC: Mitral Cell, GC: Granule Cell; PGC: Periglomerular Cell

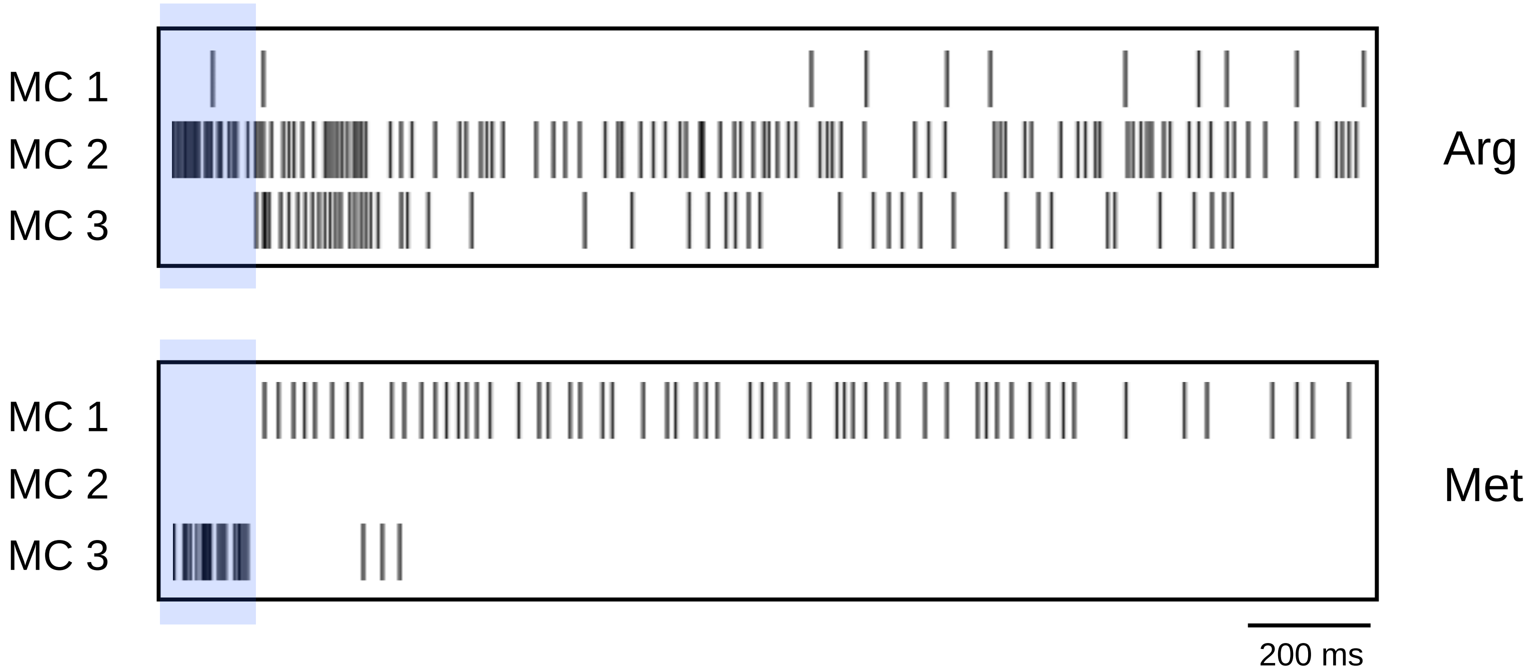
Input activity patterns (zebrafish, amino acids)



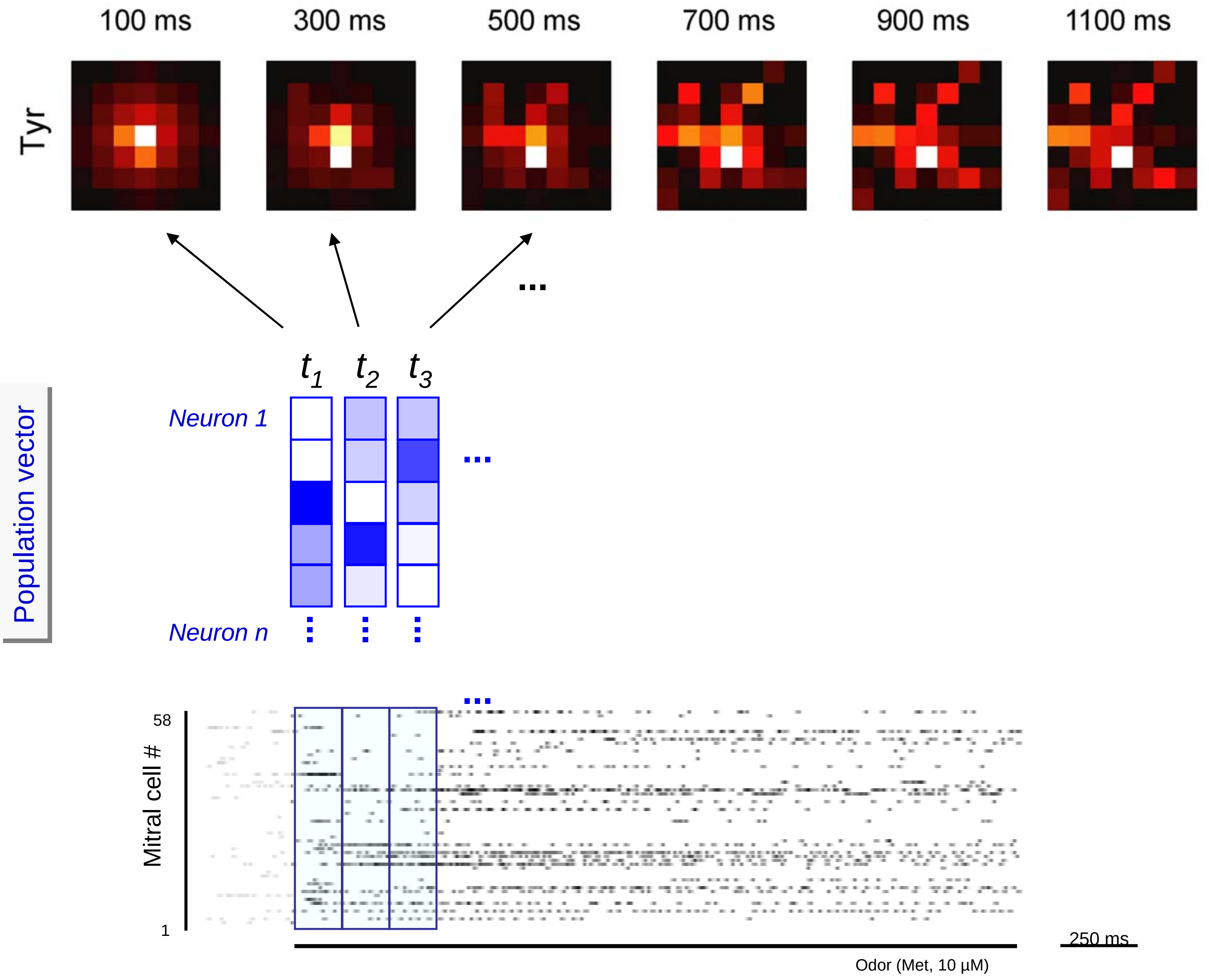
Friedrich and Korsching, Neuron (1997)

Output activity (mitral cells)

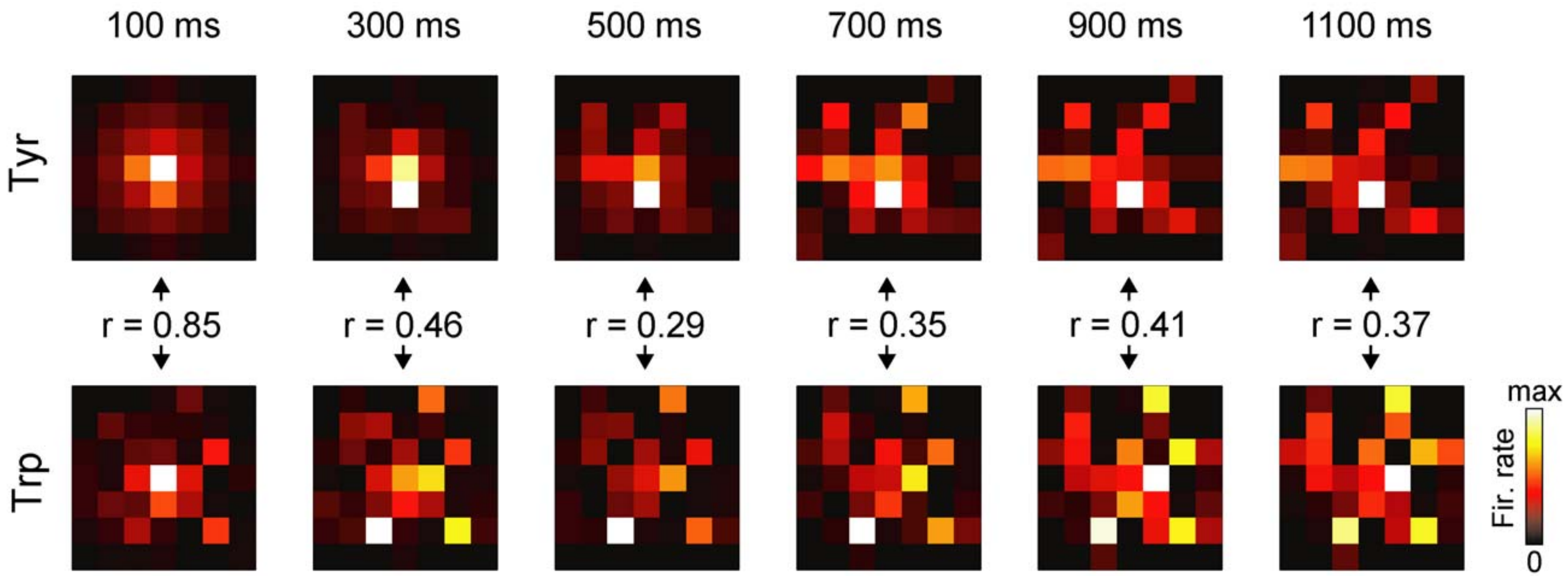


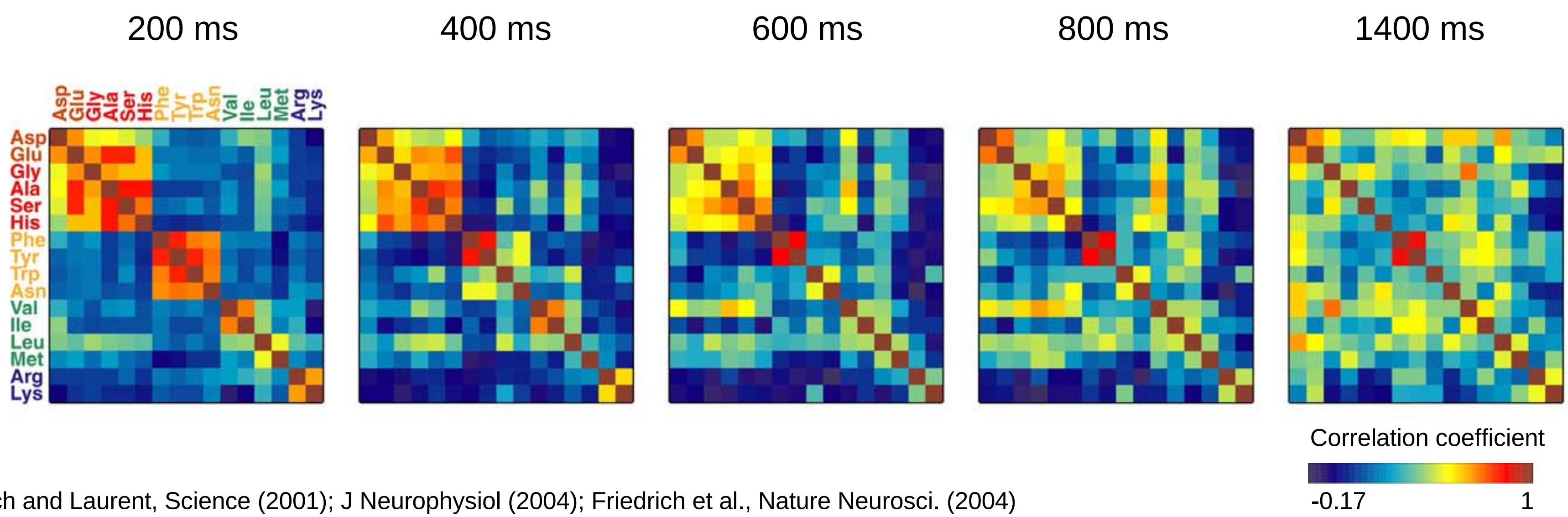


De-correlation of activity patterns



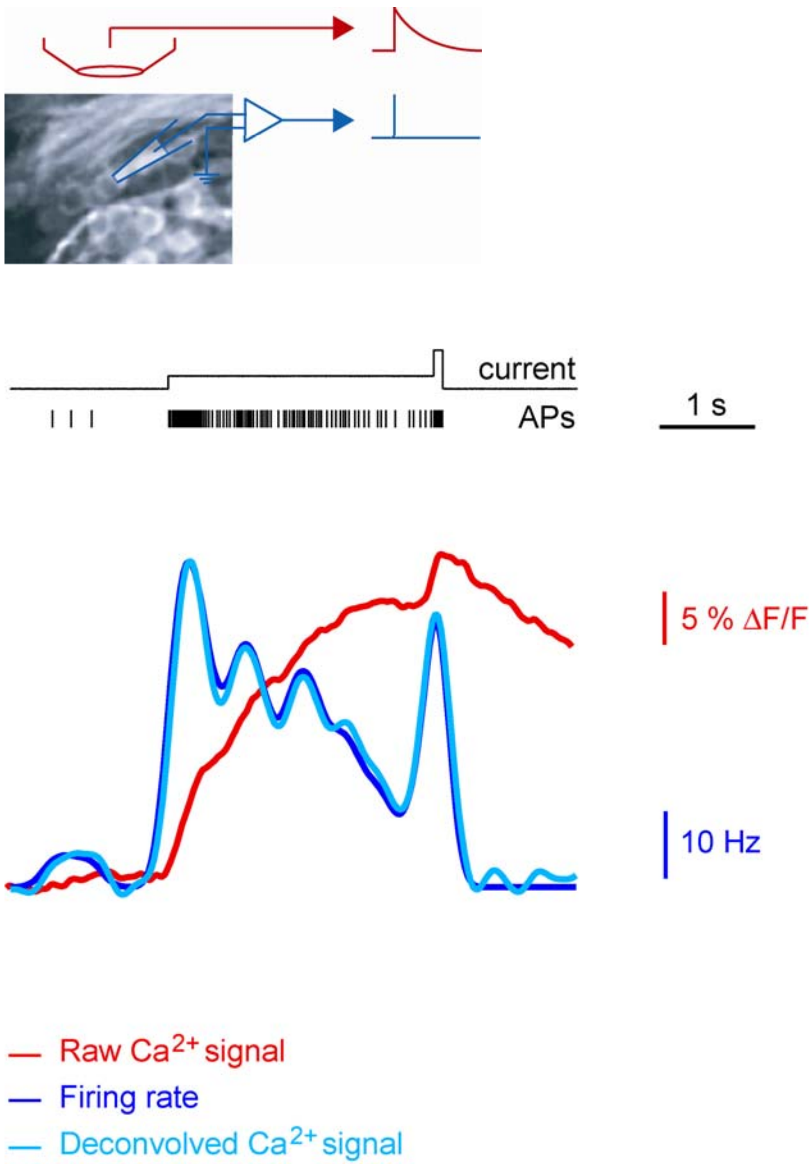
De-correlation of activity patterns

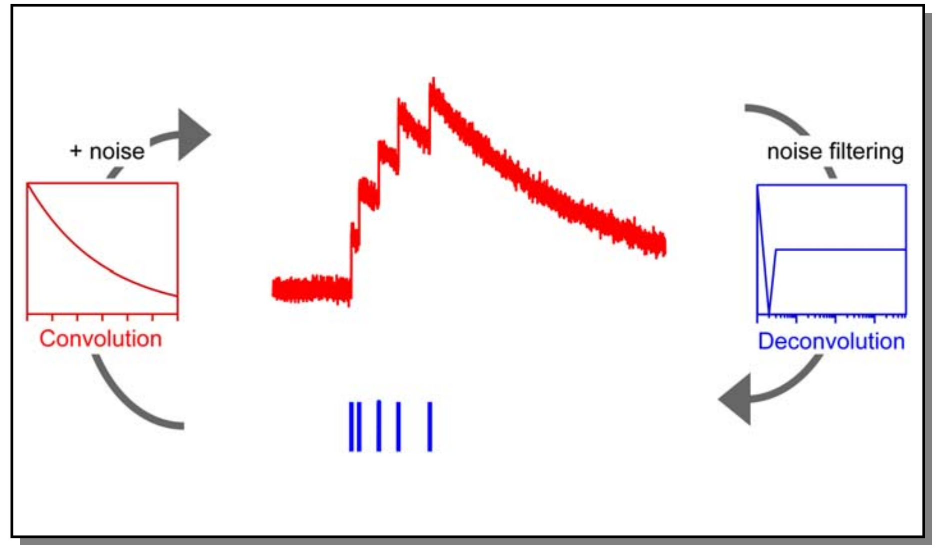


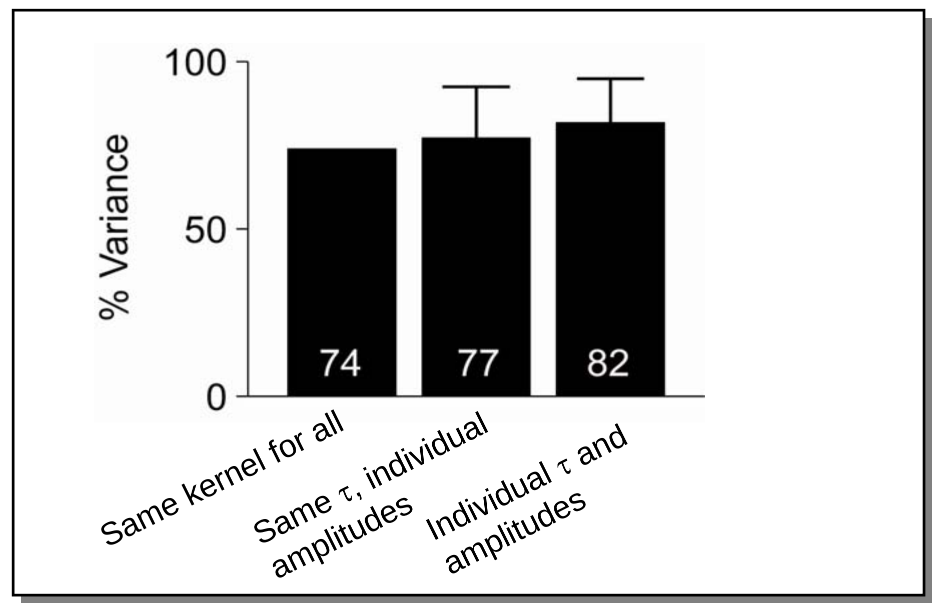


Friedrich and Laurent, Science (2001); J Neurophysiol (2004); Friedrich et al., Nature Neurosci. (2004)

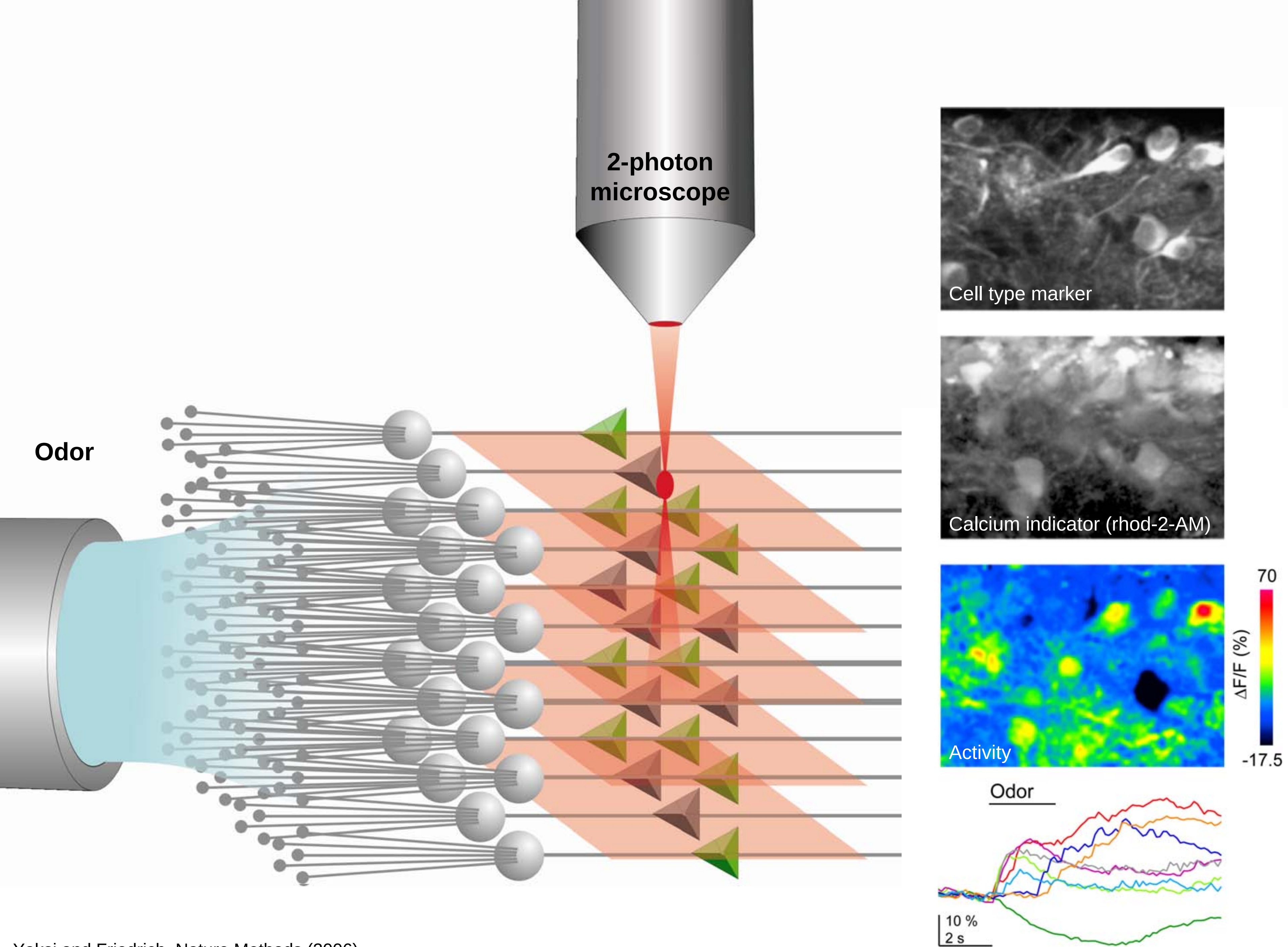
Reconstruction of electrical activity from Ca^{2+} signal by deconvolution



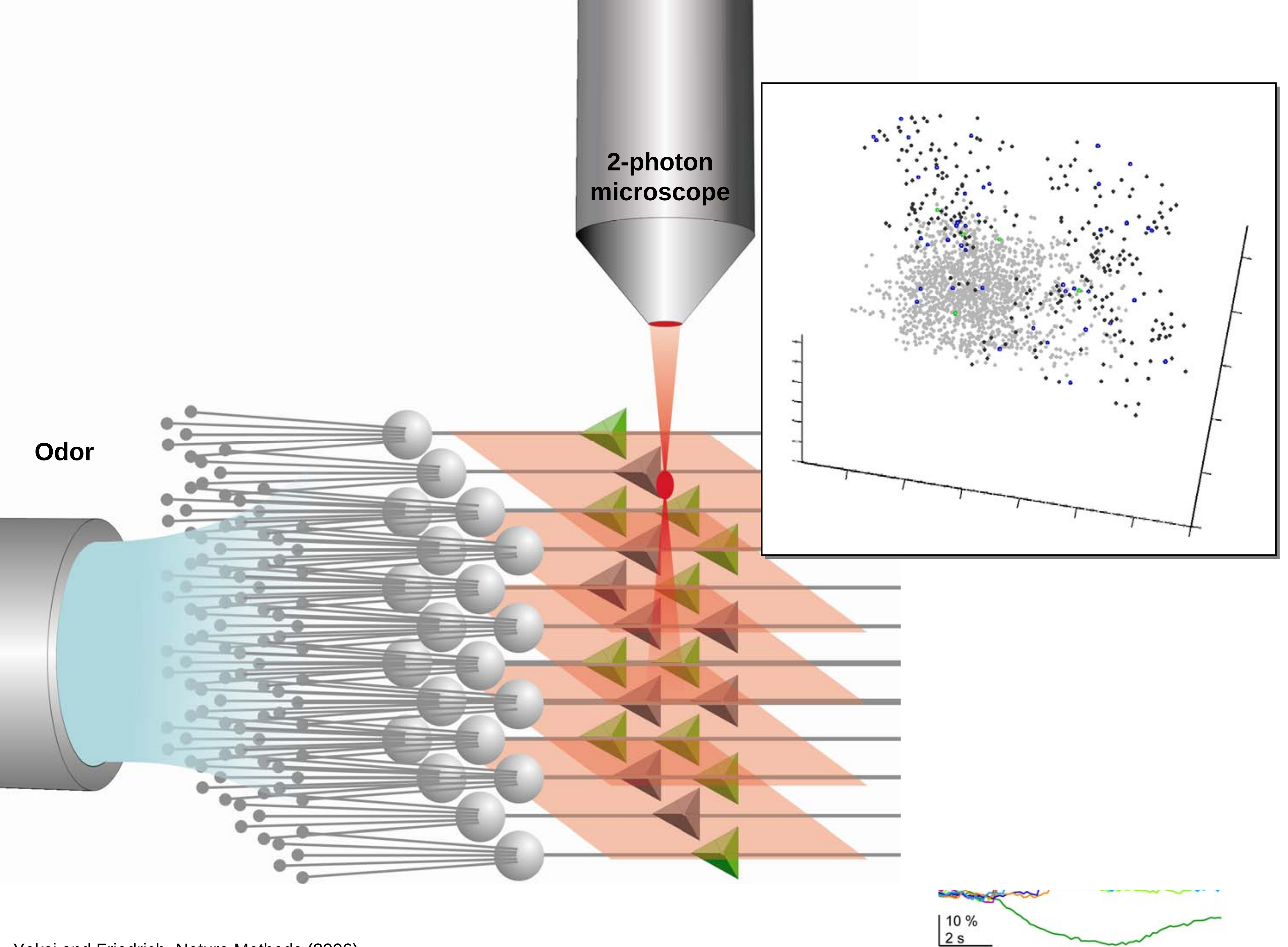




Yaksi and Friedrich, Nature Methods (2006)

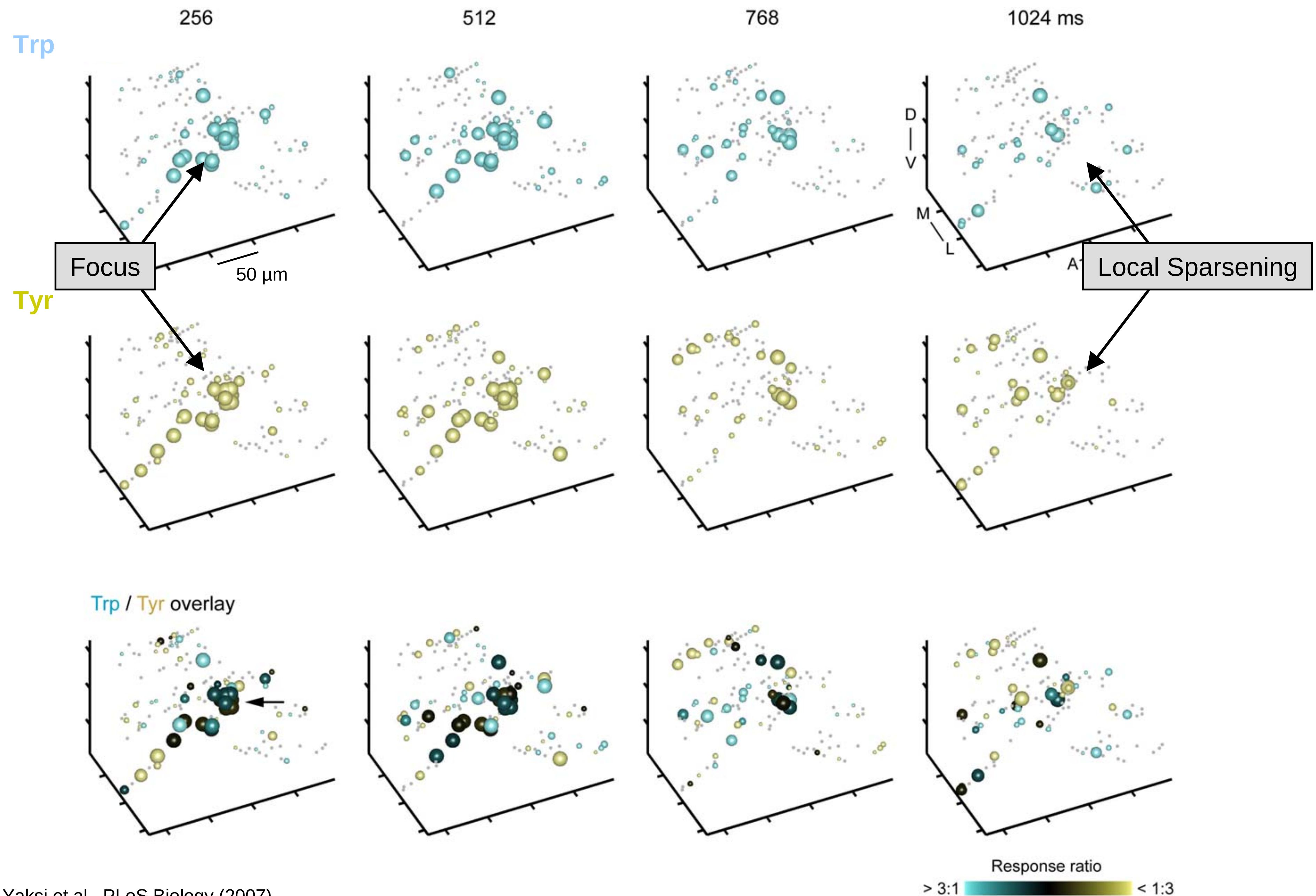


Yaksi and Friedrich, Nature Methods (2006)



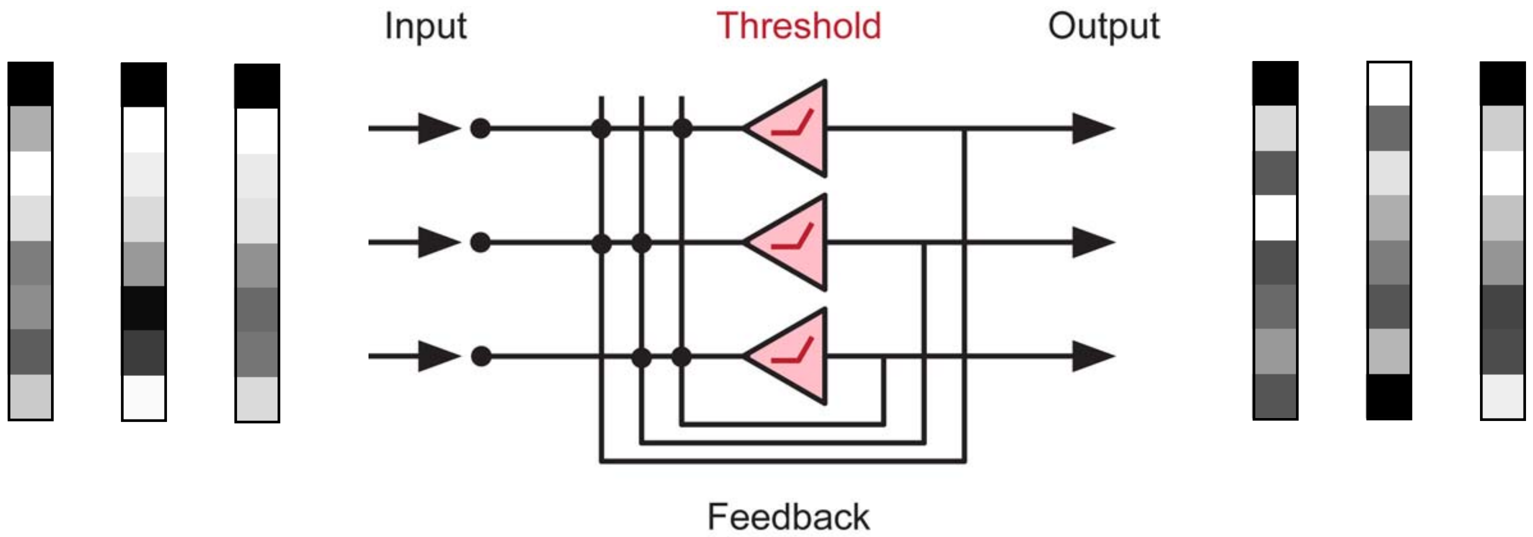
Yaksi and Friedrich, Nature Methods (2006)

Pattern decorrelation by local sparsening



Yaksi et al., PLoS Biology (2007)

Decorrelation



Channel decorrelation:
→ „Efficient“ coding

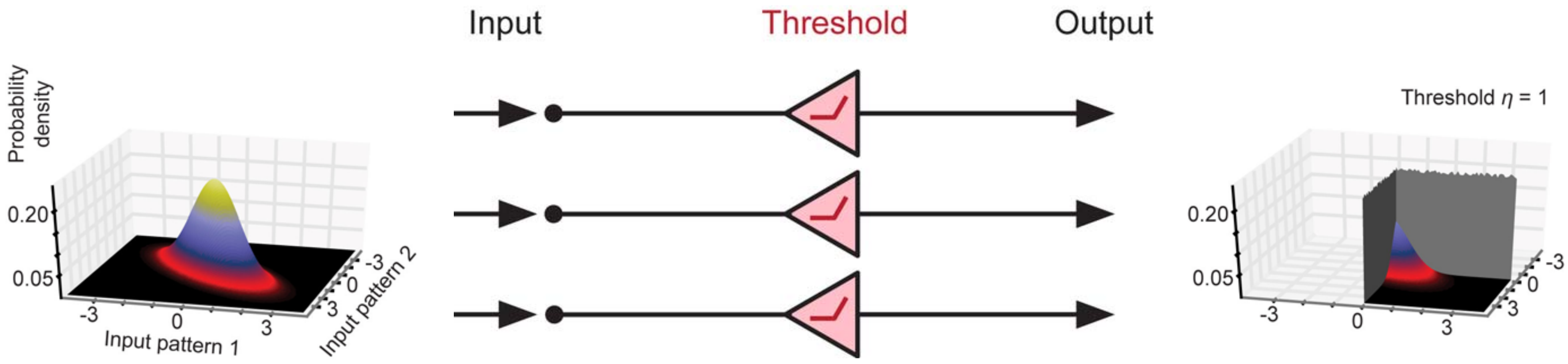
- Minimizes neuron number required for transmission

Pattern decorrelation:
→ „Informative“ coding

- Facilitates discrimination
- Important for storage by associative networks

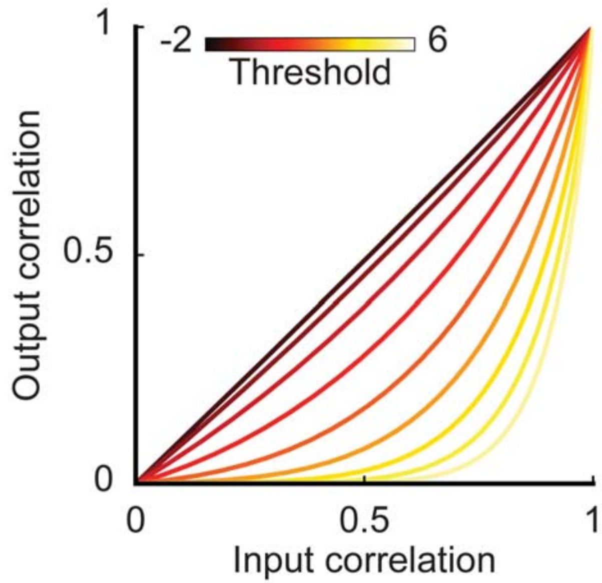
<u>Known strategies are:</u>

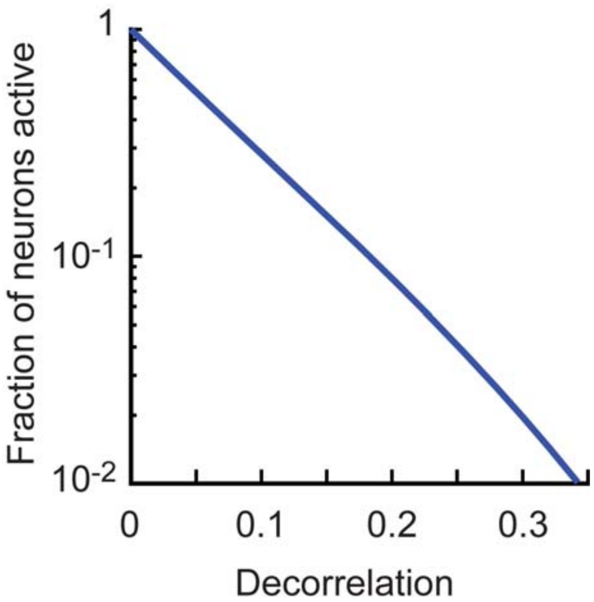
- adaptive (require prior knowledge and training)
- no obvious neuronal implementation



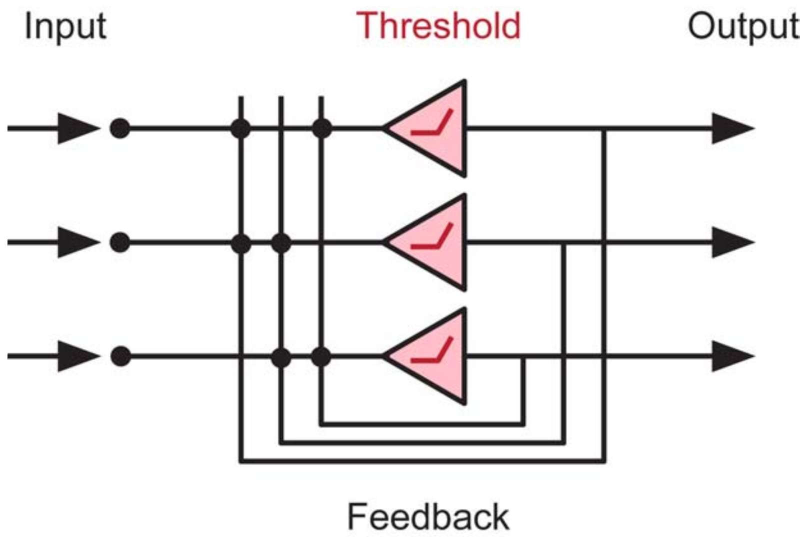
Theorem 1

Thresholding alone invariably causes decorrelation

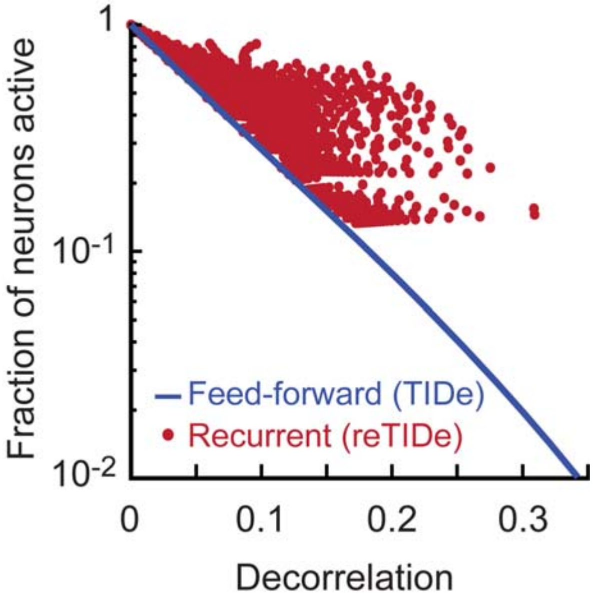




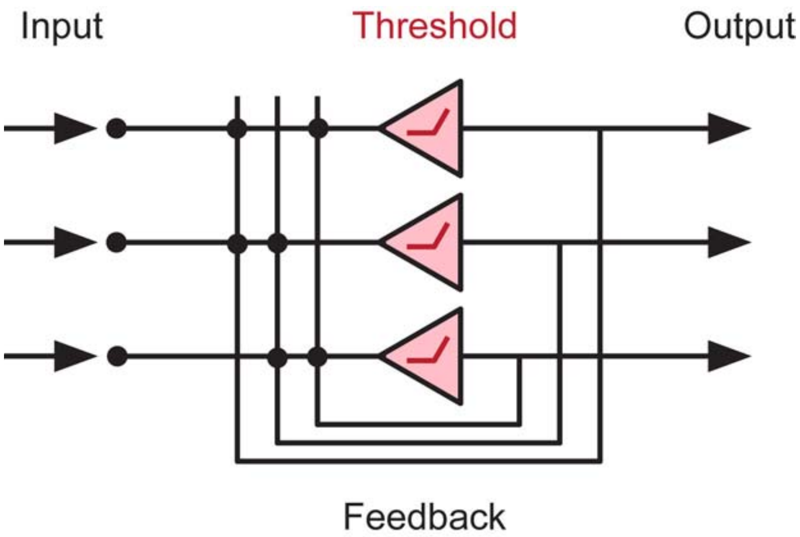
Decorrelation by recurrent networks: mathematical analysis



Theorem 1	Theorem 2
Thresholding alone invariably causes decorrelation	Recurrent connectivity amplifies threshold-induced decorrelation

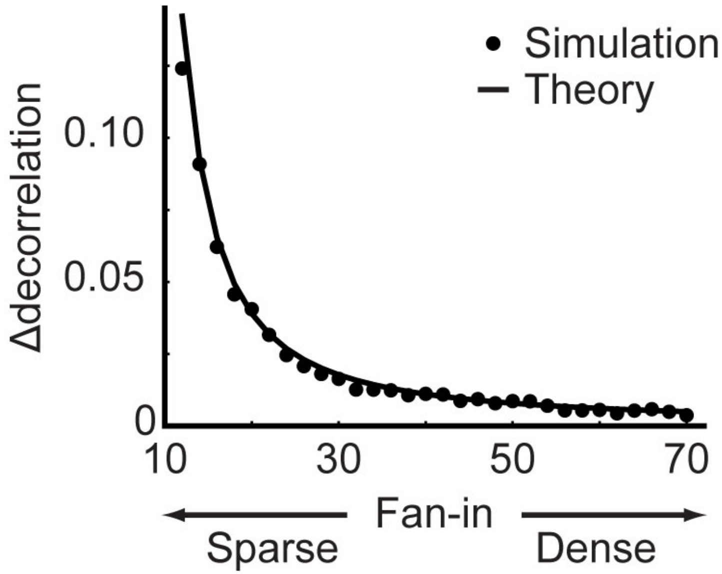


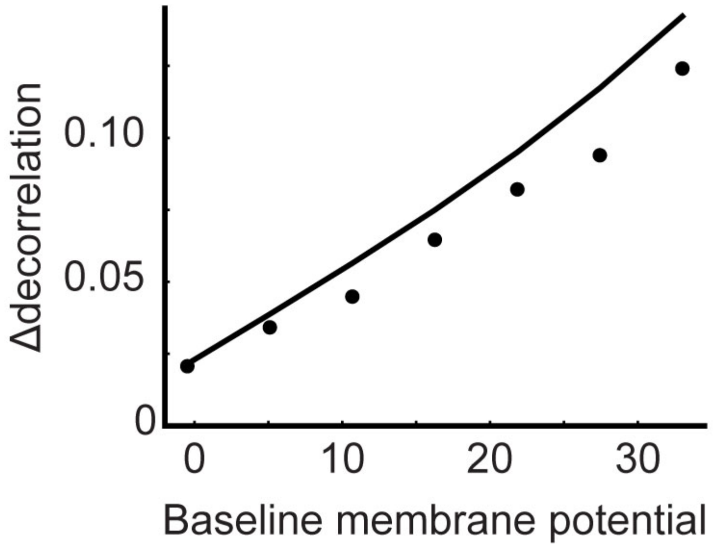
Decorrelation by recurrent networks: mathematical analysis



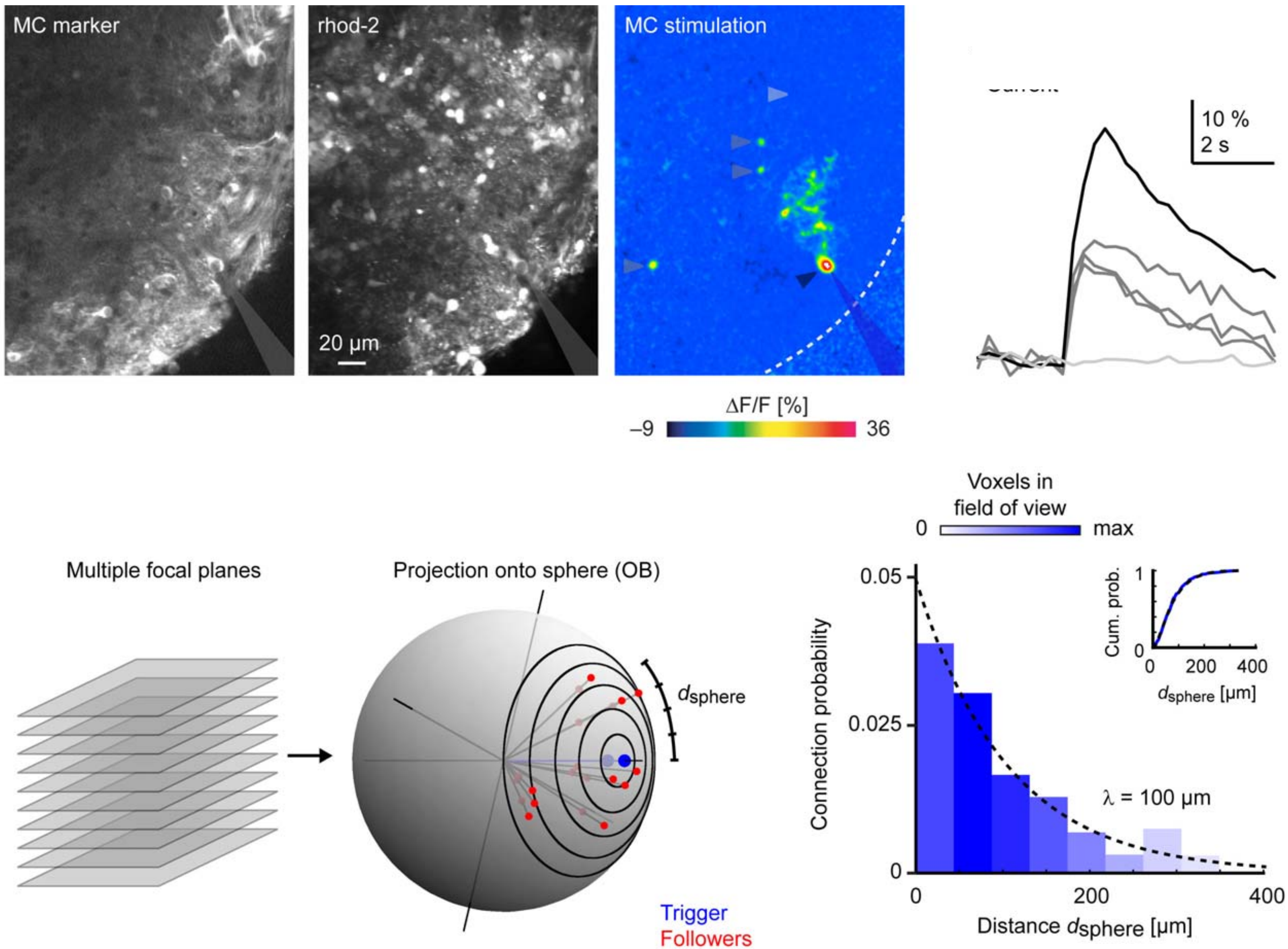
Theorem 1	Theorem 2	Theorem 3
Thresholding alone invariably causes decorrelation	Recurrent connectivity amplifies threshold-induced decorrelation	Recurrent-enhanced decorrelation increases with: • Sparse connectivity • High baseline activity (when „sufficiently coupled“)

Theoretical predictions and simulation results





Forward optical probing of neuronal connectivity in the olfactory bulb



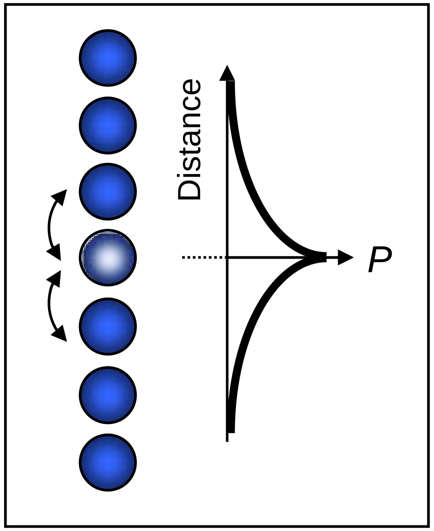
Overall connection probability: 0.0034

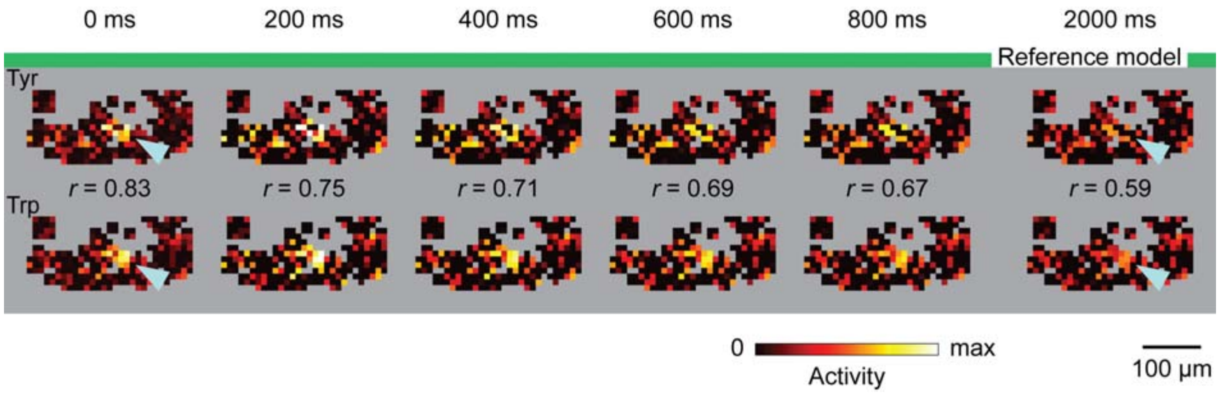
Benjamin Judkewitz

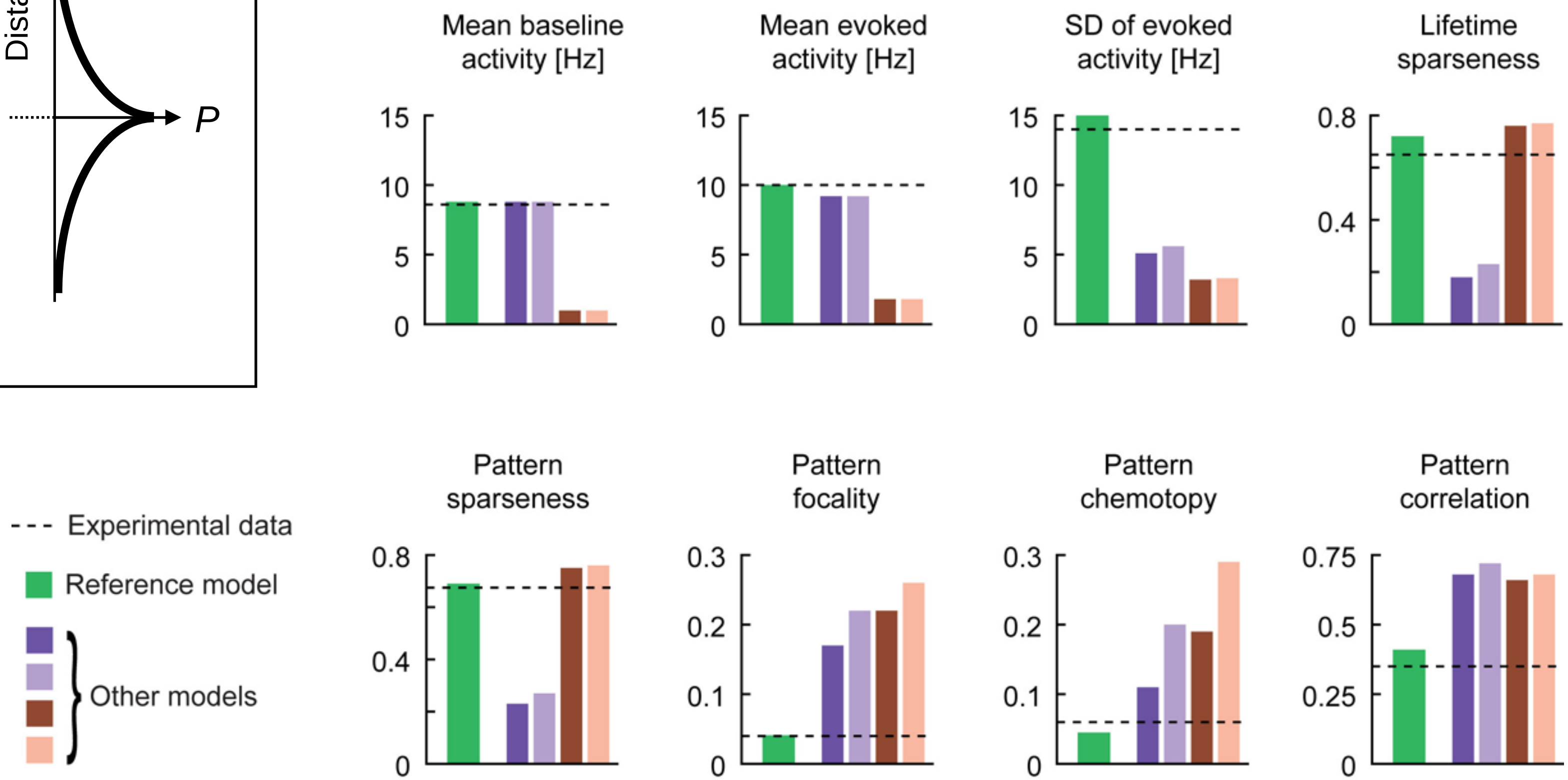
Olfactory bulb circuit model

Olfactory bulb model:

- Recurrent inhibitory connections
- Reciprocal connectivity
- Topographic connectivity
- Naturalistic inputs







Martin Wiechert

Olfactory bulb circuit model

Olfactory bulb model:
- Recurrent inhibitory connections
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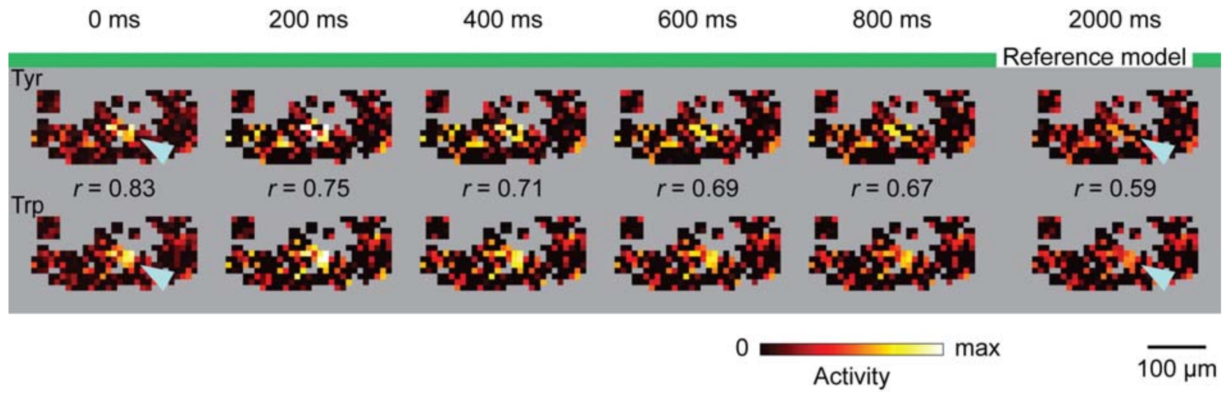
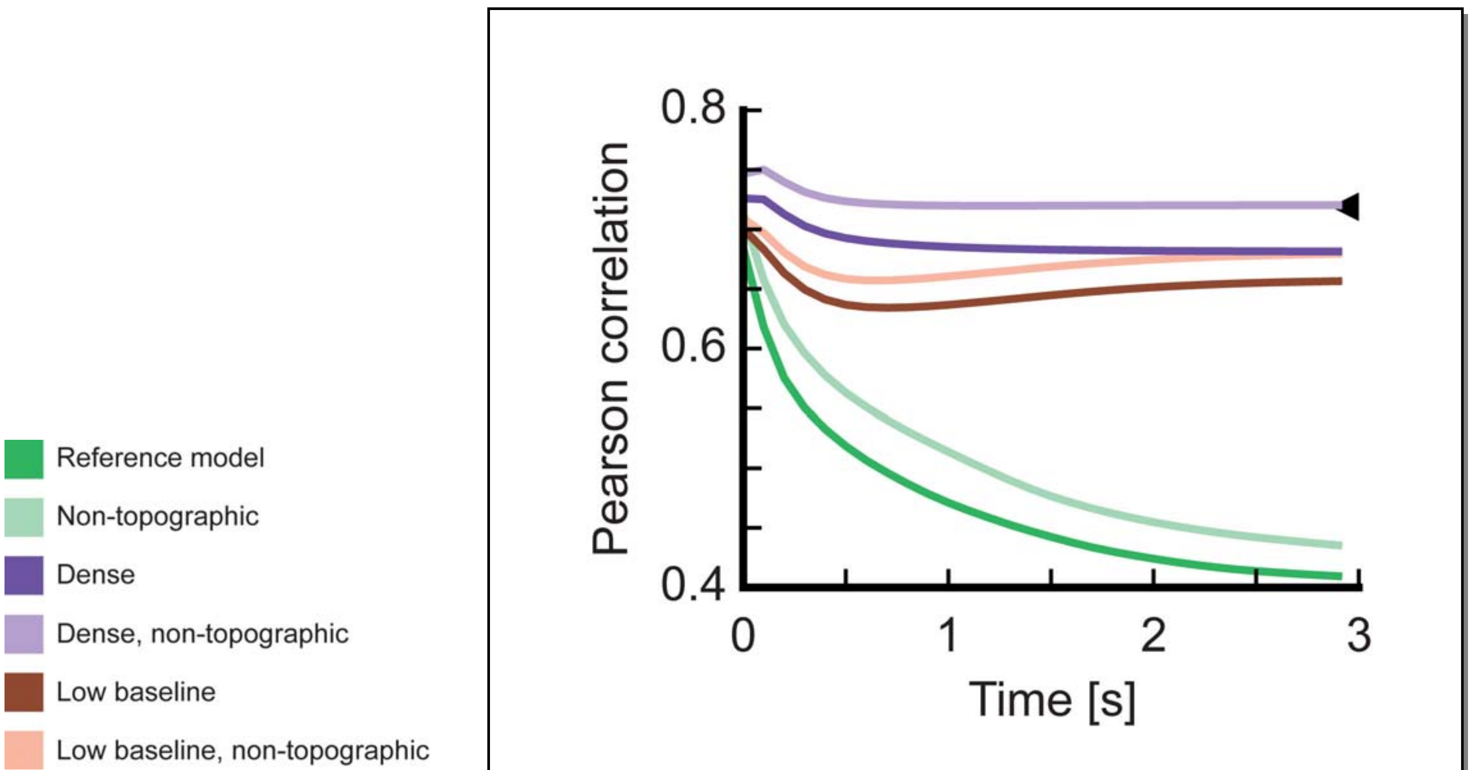
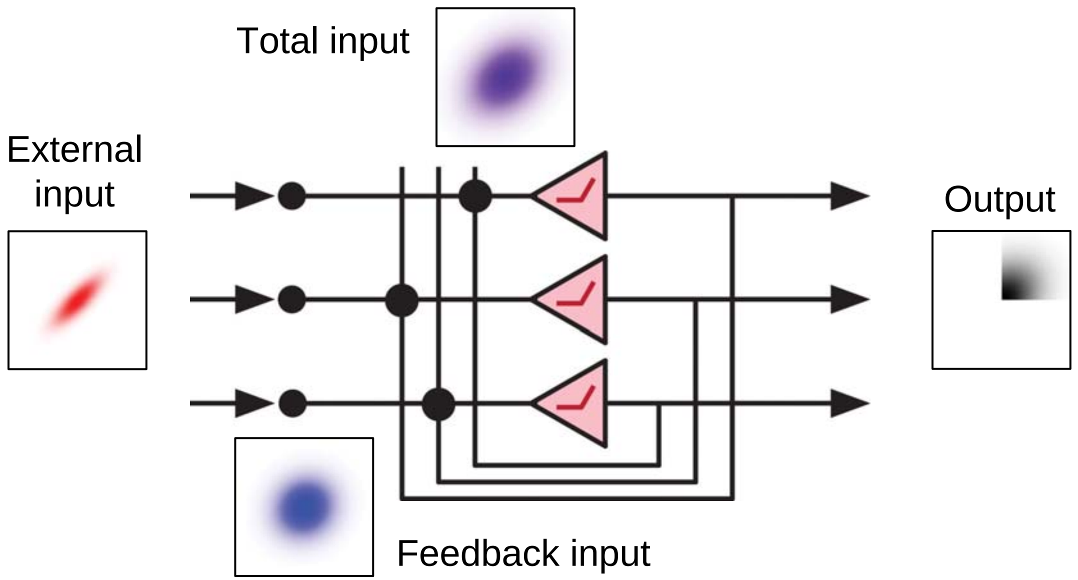




Decorrelation

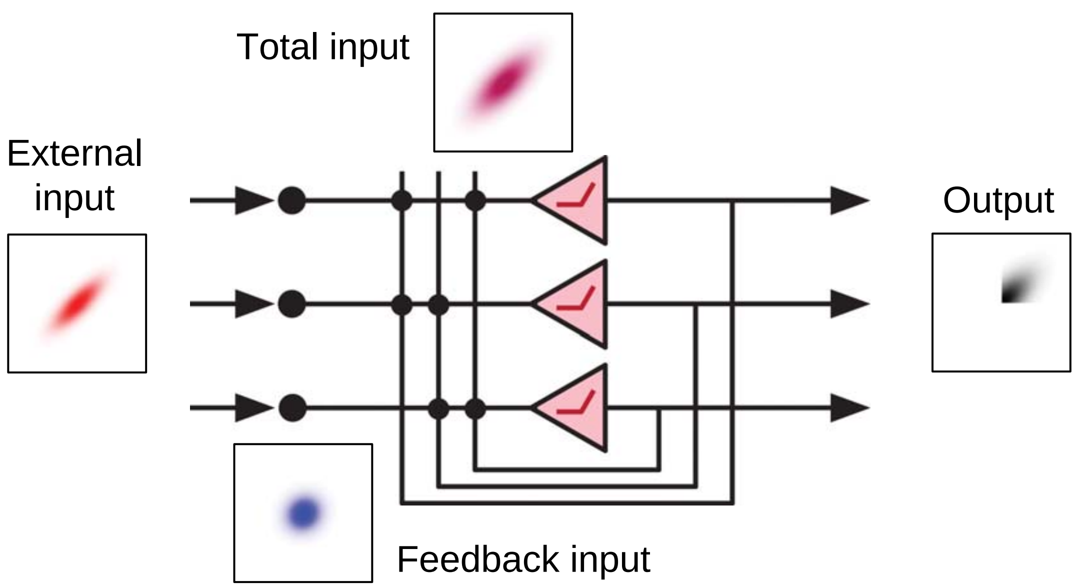
Sparse circuit:

Few but strong connections

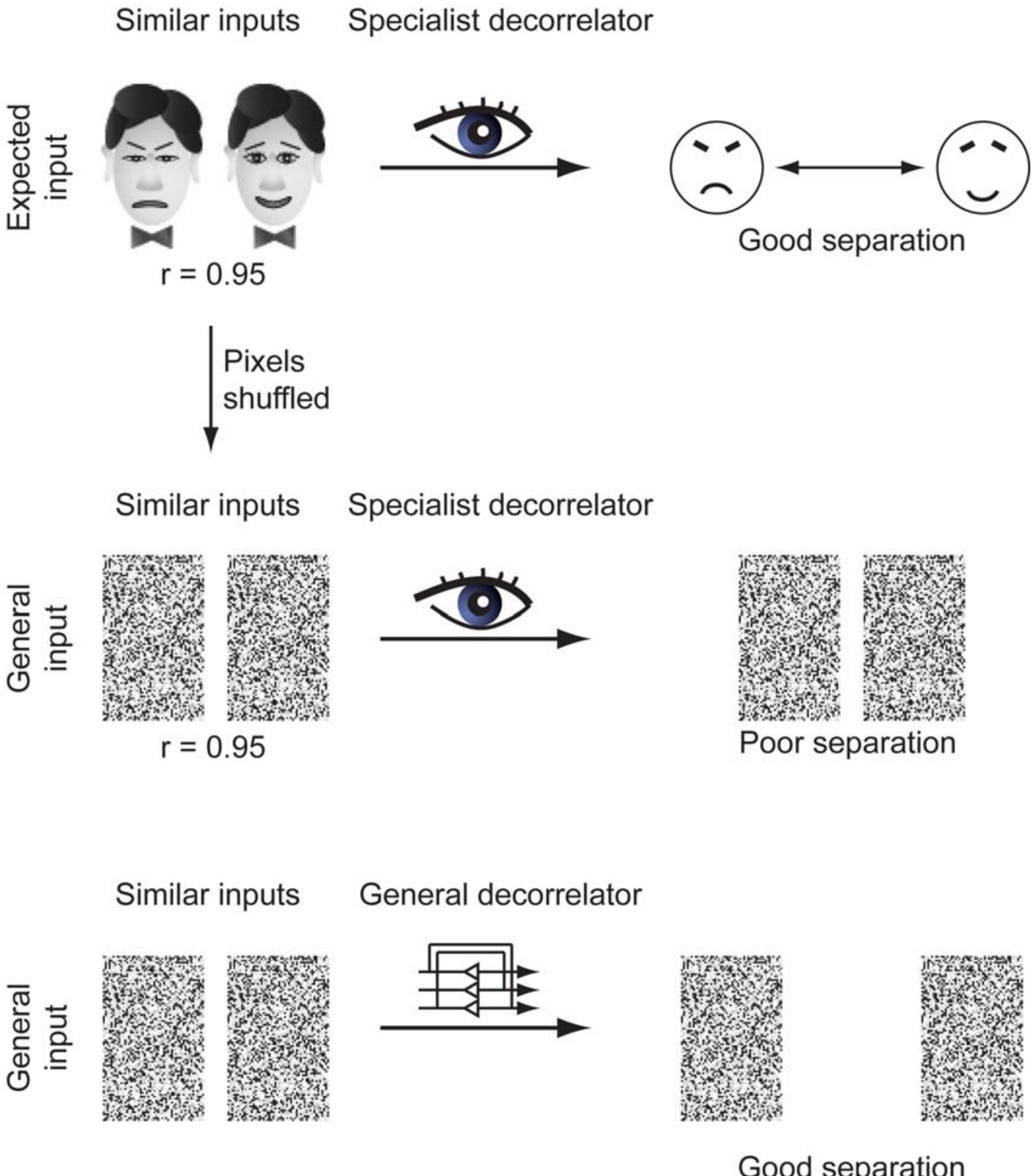


Dense circuit:

Many but weak connections

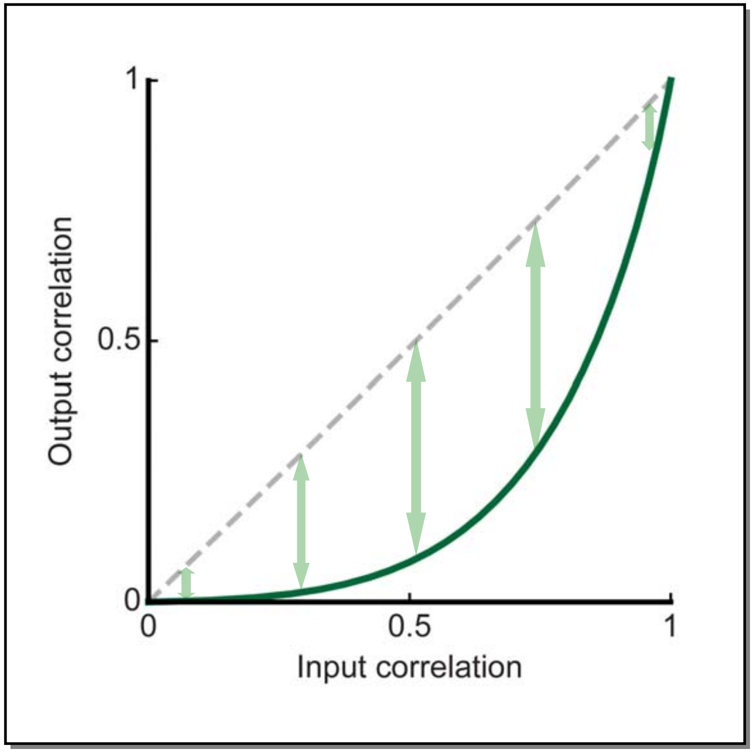


Recurrent networks act as general pattern decorrelators



Wiechert et al., Nature Neurosci. (2010)

Pattern decorrelation by recurrent networks is not chaotic



Pattern classification: generalization vs. separation

Neuronal representations are discontinuous:

- Decision-making: abrupt switching of neuronal output
- Sensory processing: generalization vs. separation
- ...

Hypothesis: aprupt switching between network states?

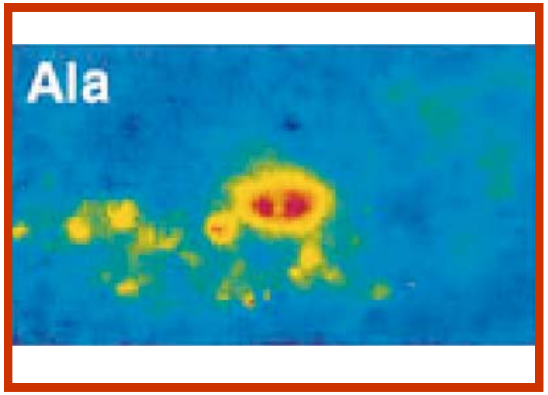
George

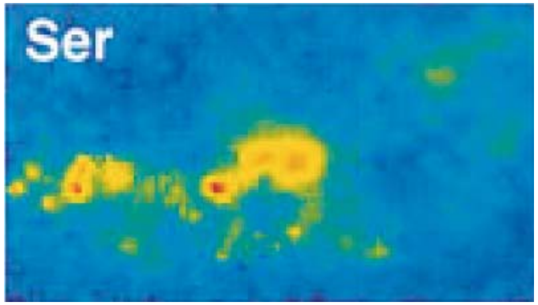
Almost George

Pattern generalization

Pattern separation

Pattern classification: generalization vs. separation

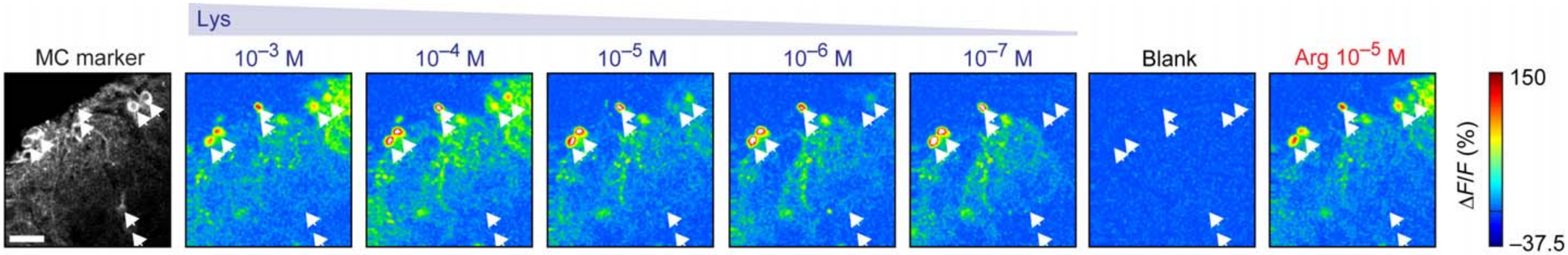


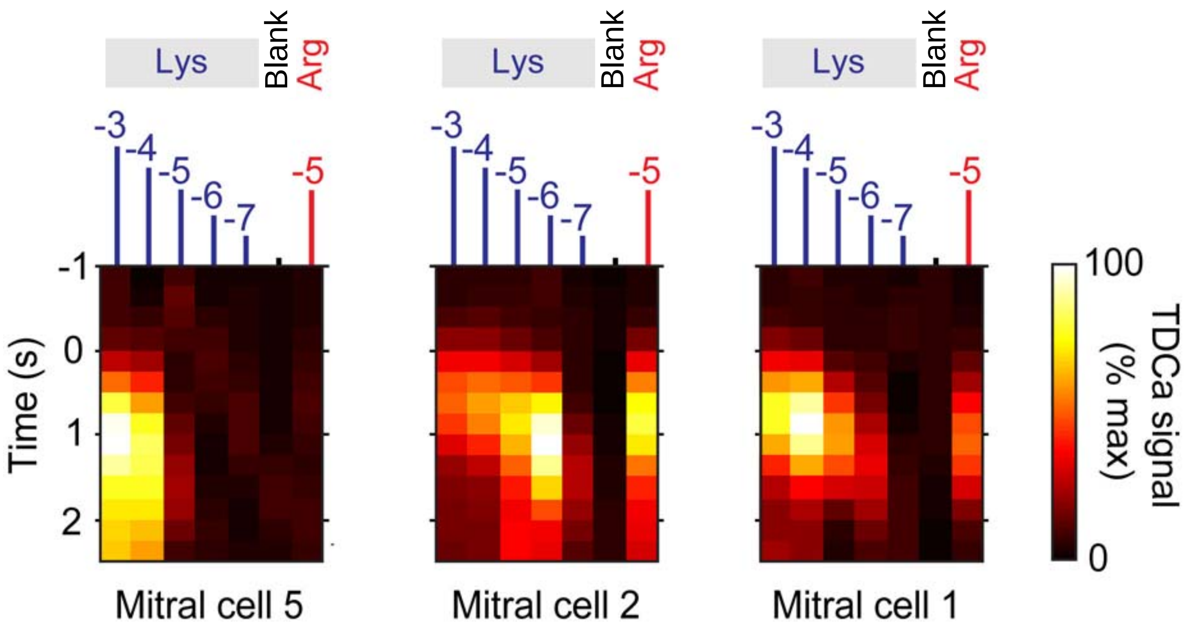


Pattern generalization

Pattern separation

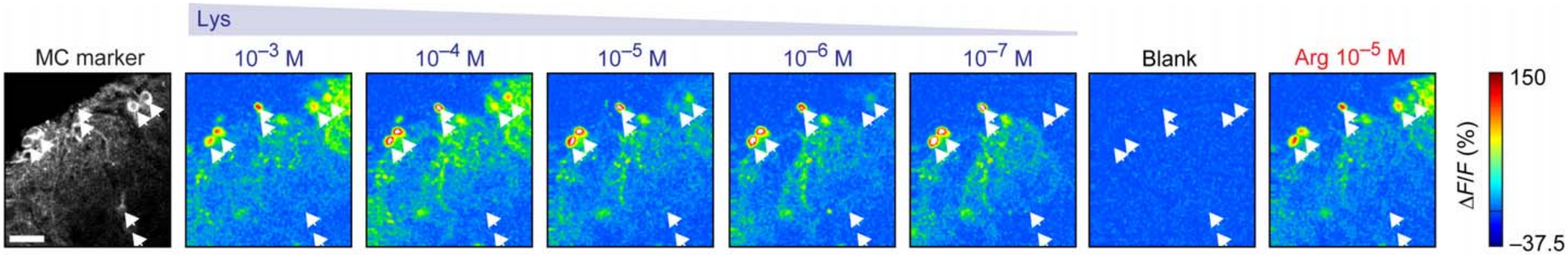
Concentration-invariance of mitral cell response patterns



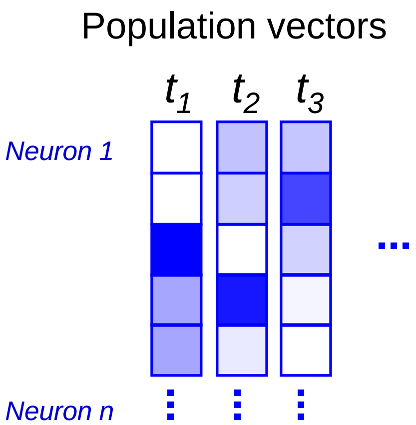


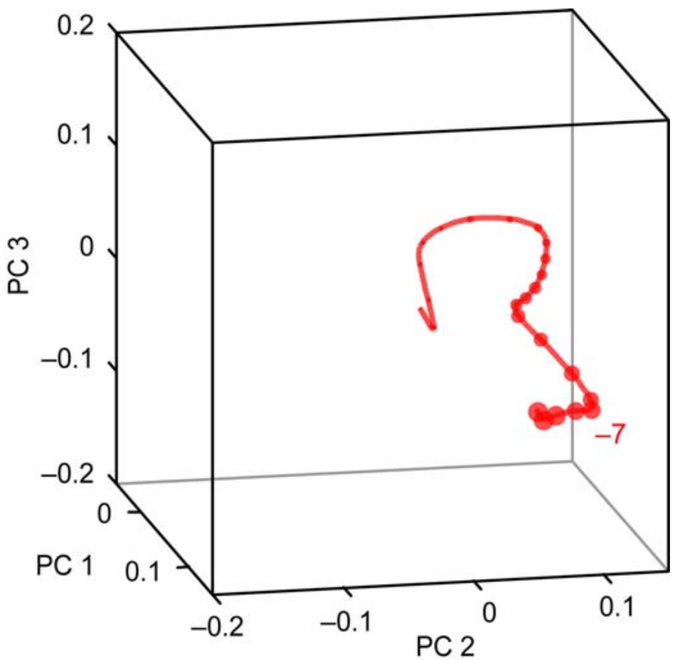
Jörn Niessing

Concentration-invariance of mitral cell response patterns

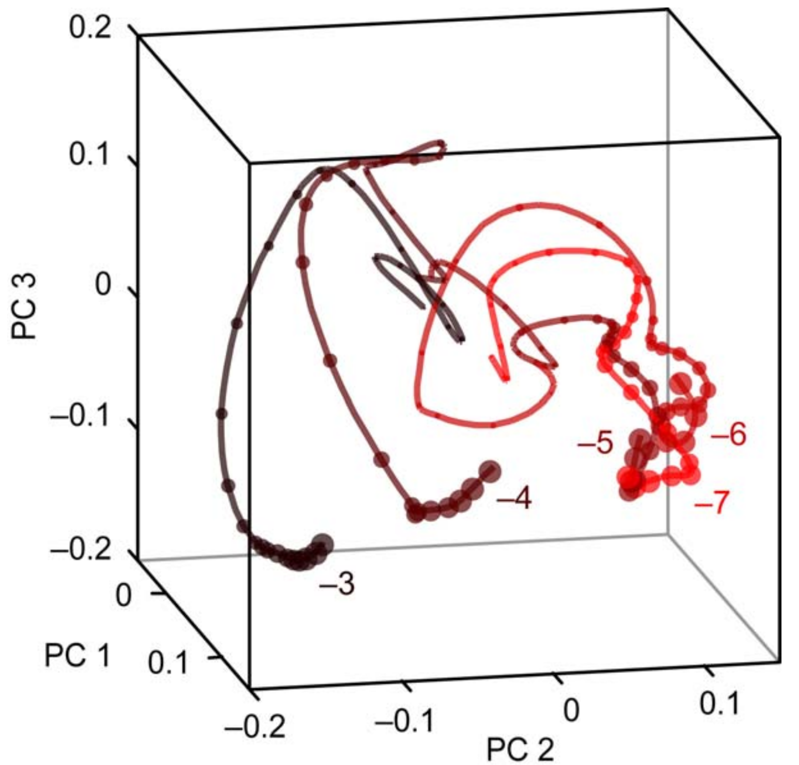


Principal component analysis





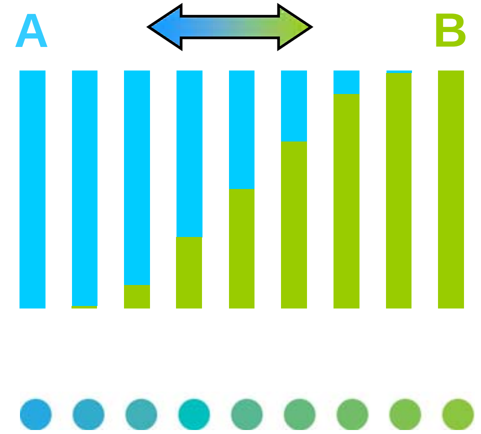
Concentration-invariance of mitral cell response patterns



Lys

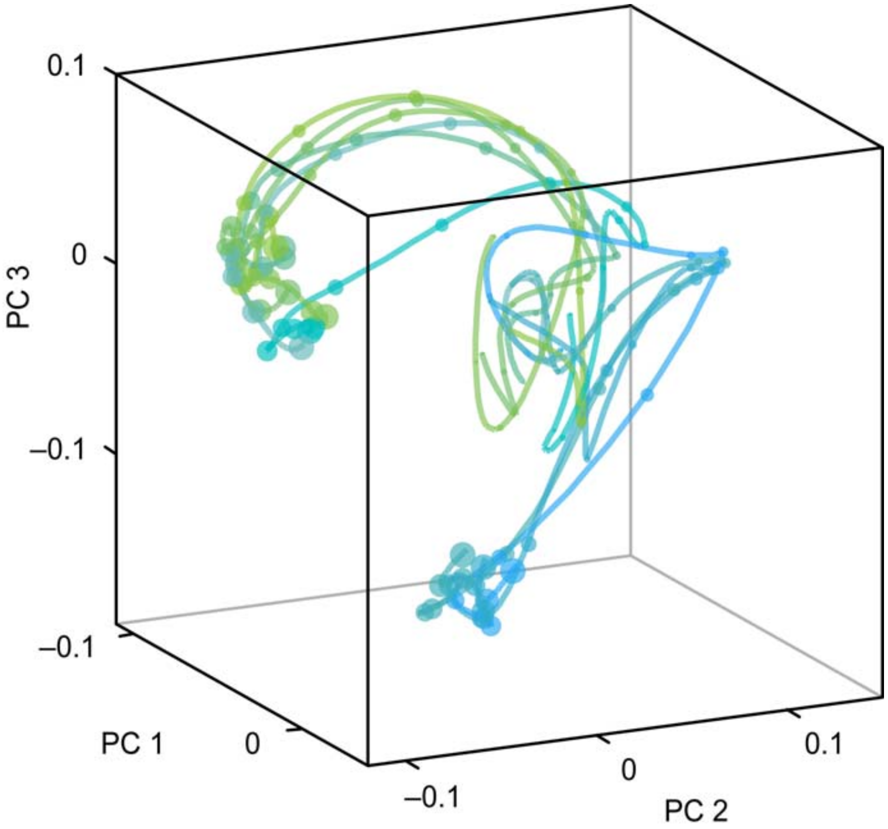
Output patterns are largely invariant within a range of concentrations

Odor morphing: similar odors

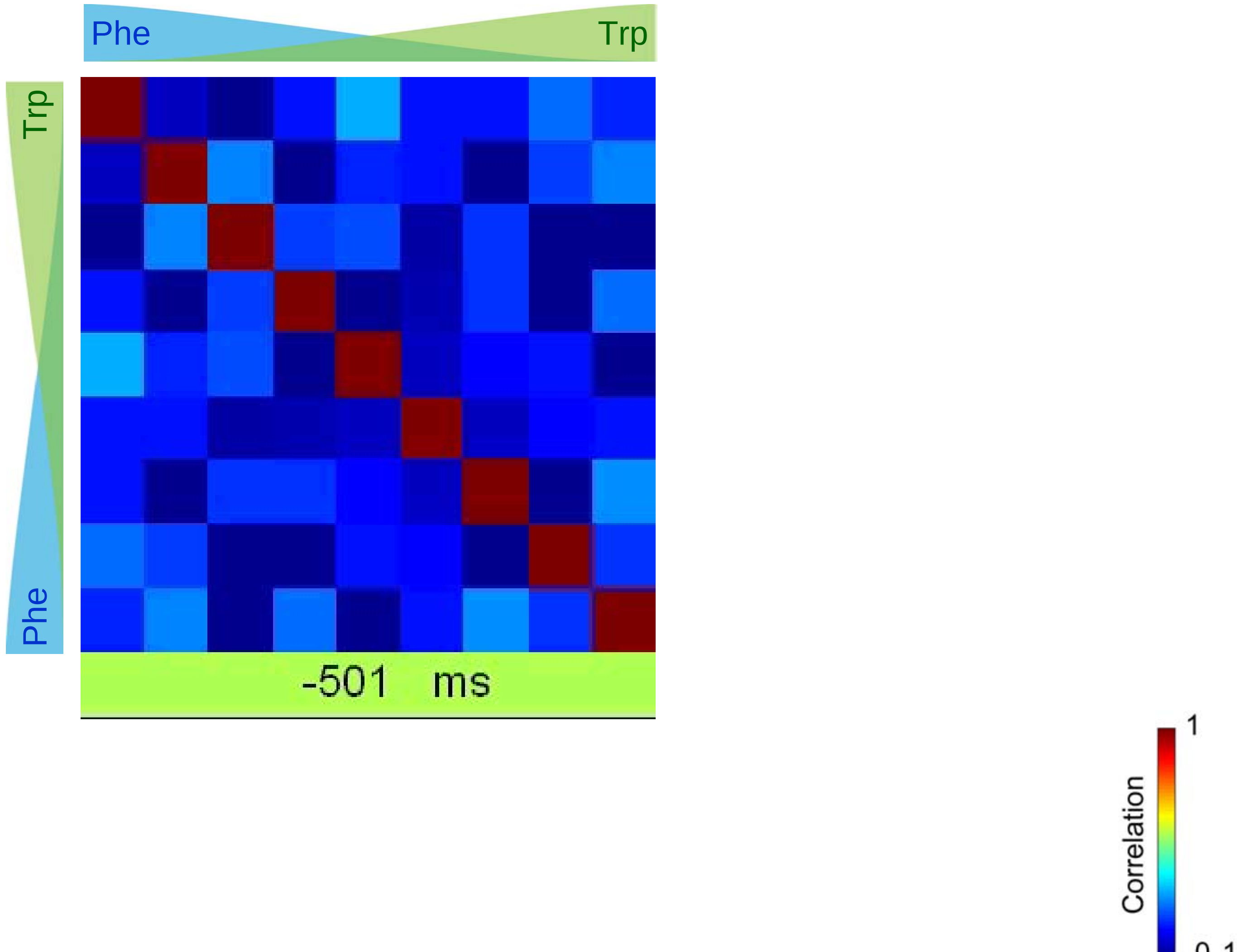


Jörn Niessing

Odor morphing: similar odors



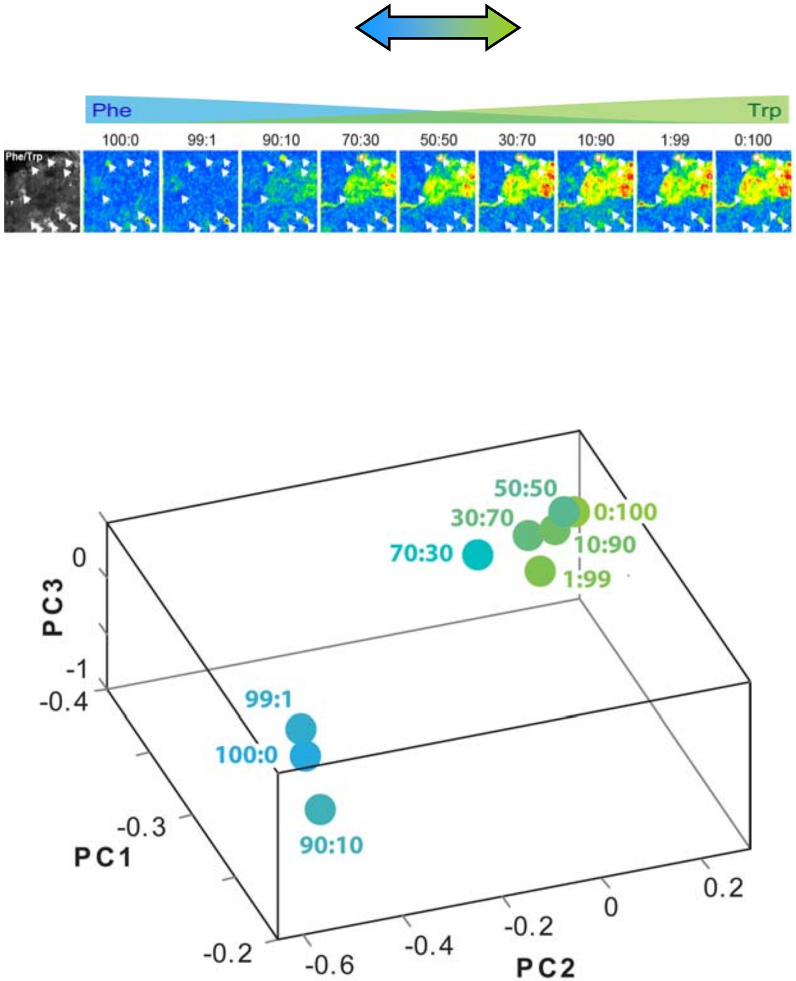
Odor morphing: similar odors



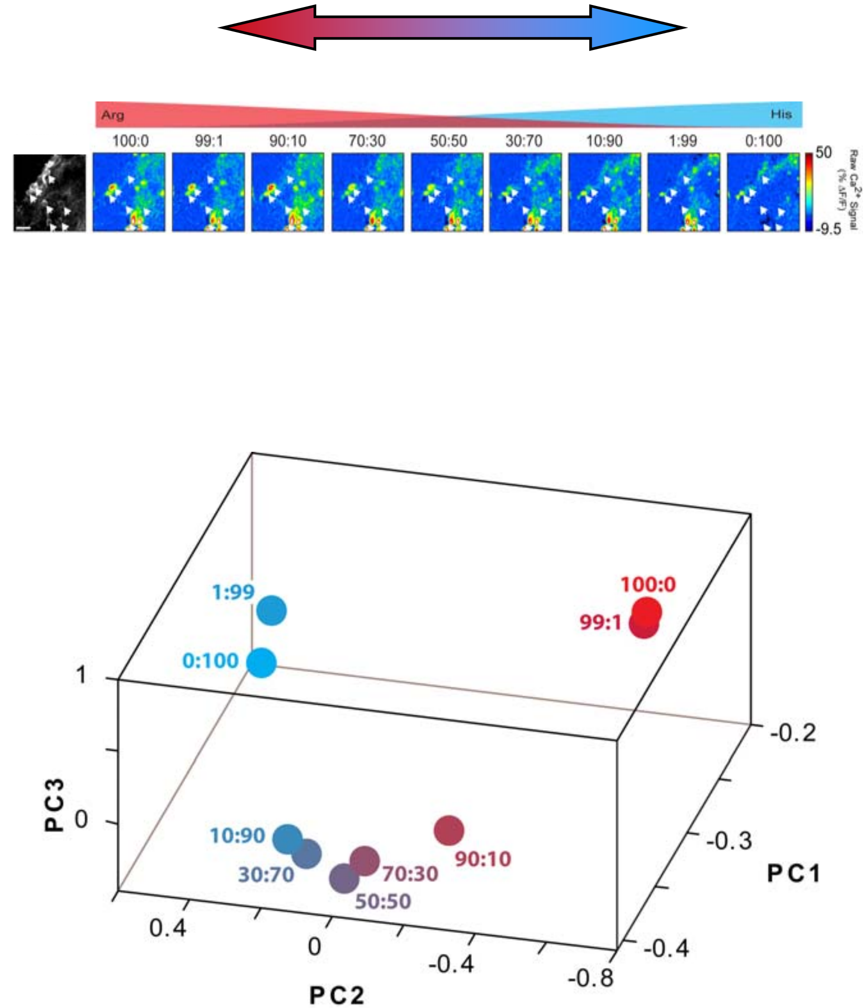
Jörn Niessing

Odor morphing: discrete transitions

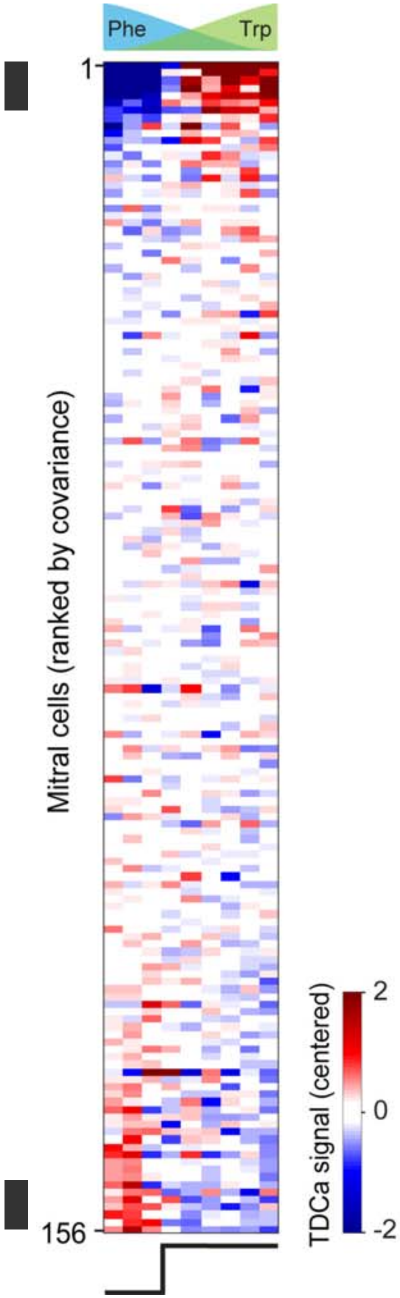
Similar odors



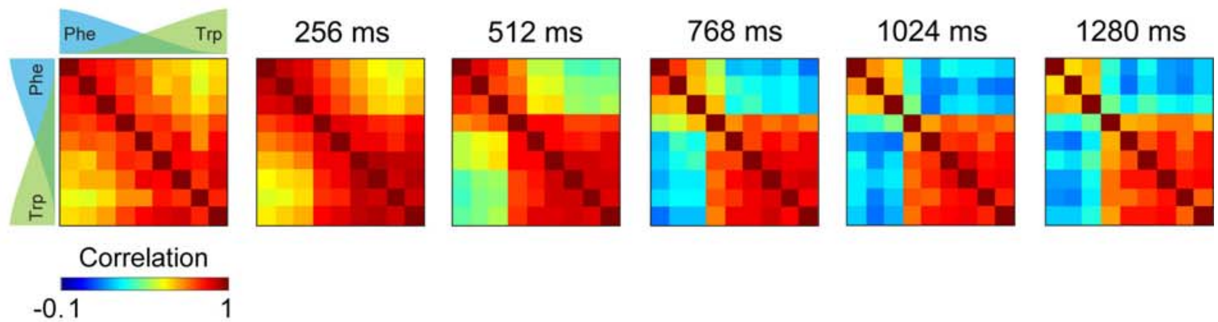
Dissimilar odors



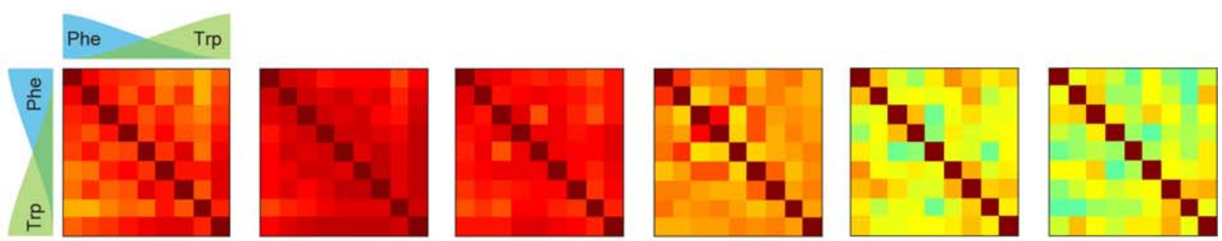
Pattern transitions are mediated by small, coordinated ensembles



All mitral cells:

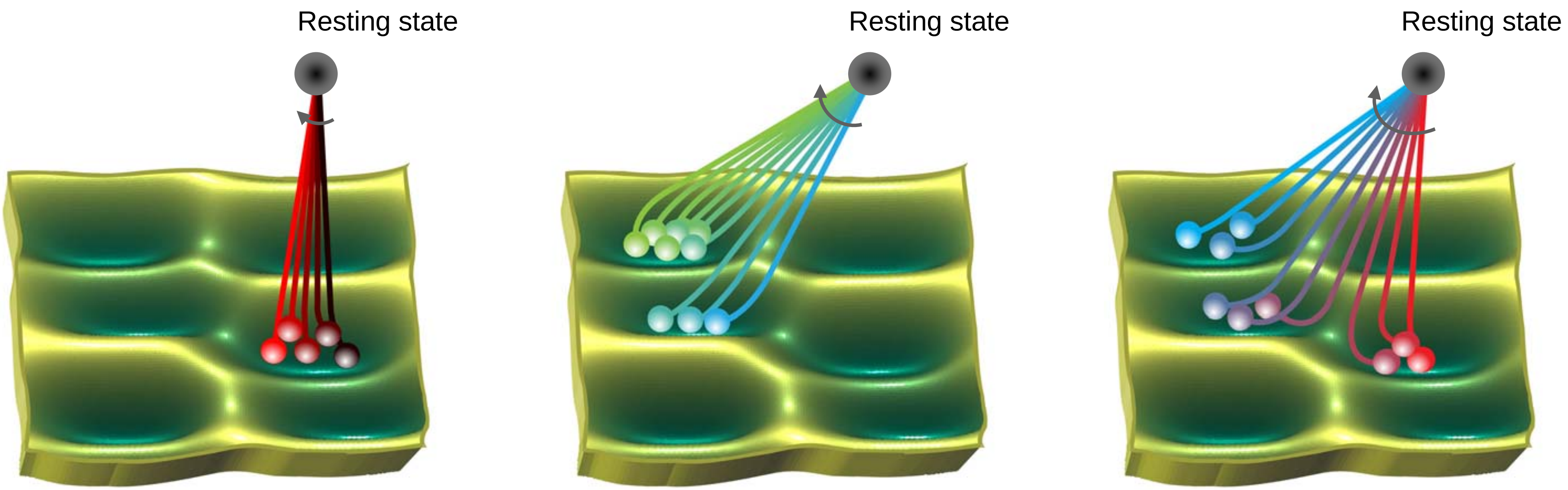


“Switching” cells (10 %) removed:



Jörn Niessing

Discrete pattern classification: summary



- Discretization of coding space
- Noise-tolerance vs resolution
- Sensory filter → invariances.
- Coordinated switching of responses in small ensembles.

- Consistent with psychophysics.
- Consistent with attractor networks.

Niessing and Friedrich, Nature (2010)