Empirical estimates of STRFs are influenced by higher-order stimulus statistics

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Listening in Acoustic Scenes

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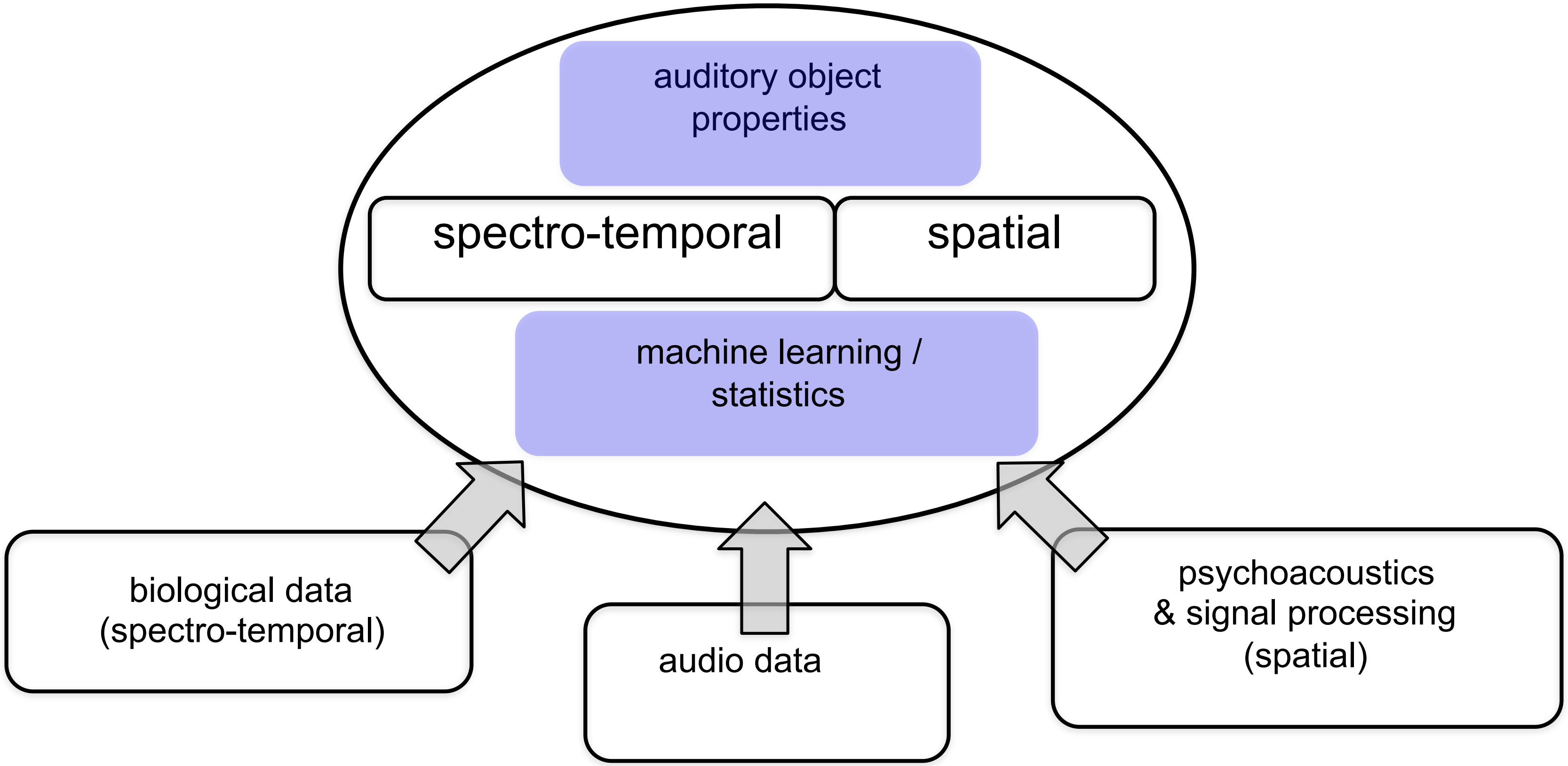
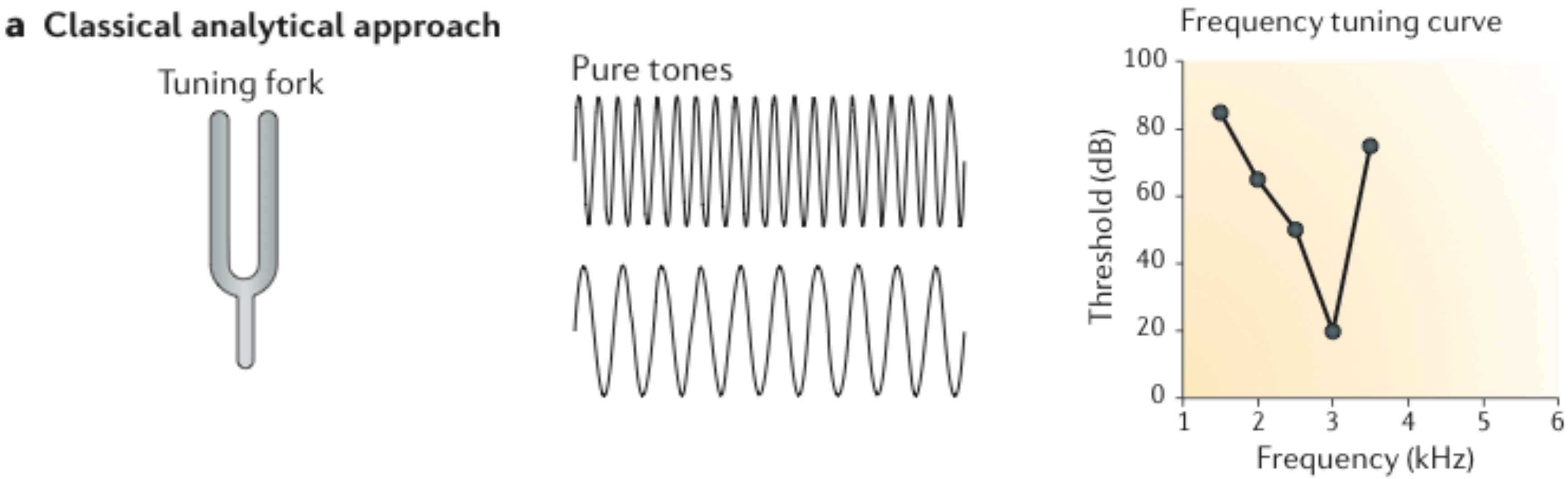
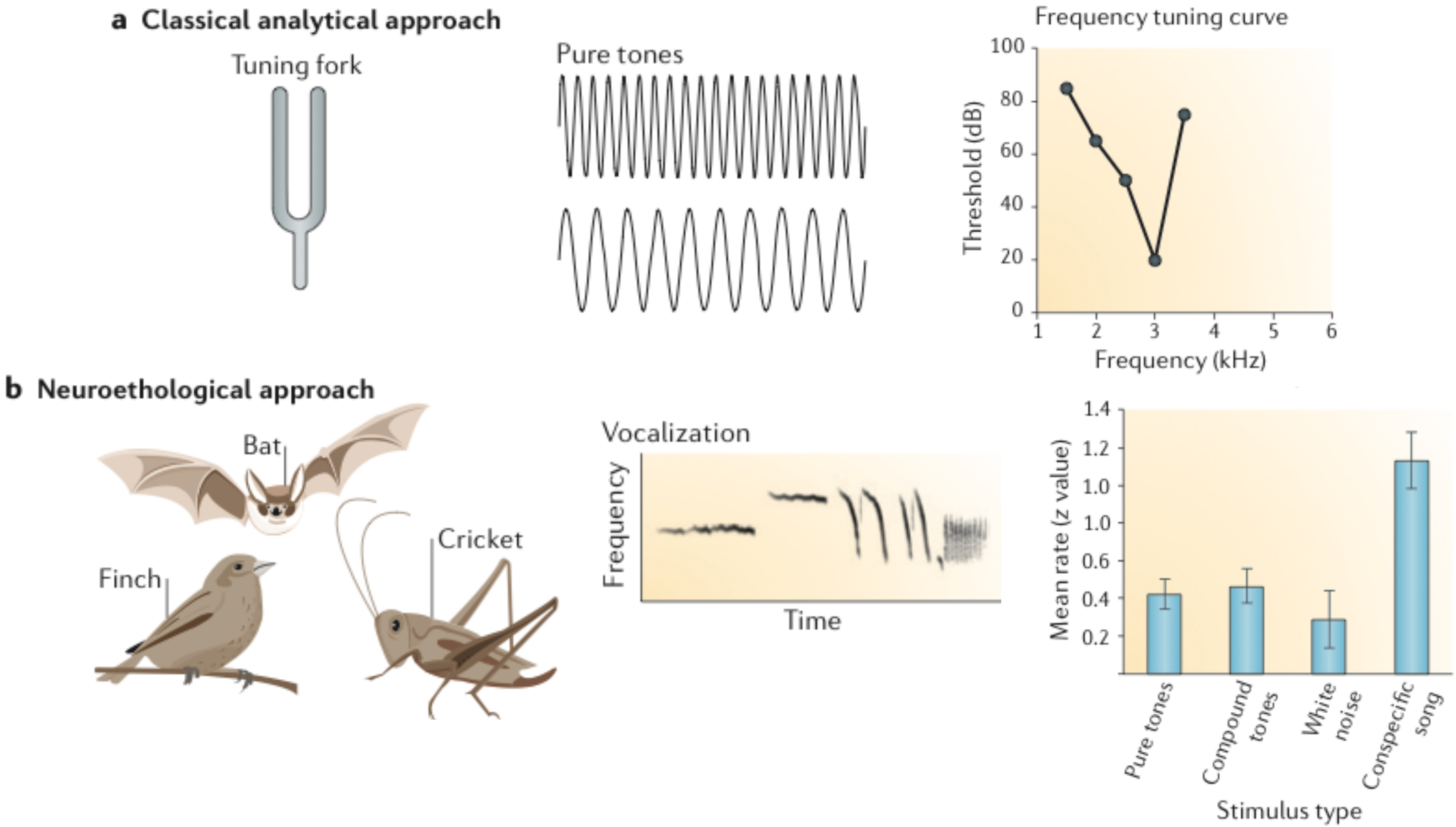

auditory object
properties
spectro-temporal
spatial
machine learning /
statistics
biological data
(spectro-temporal)
audio data
psychoacoustics
& signal processing
(spatial)

Historical approaches to neuron characterization



(Theunissen and Elie, 2014)

Historical approaches to neuron characterization



(Theunissen and Elie, 2014)

Hubel and Wiesel's visual receptive fields

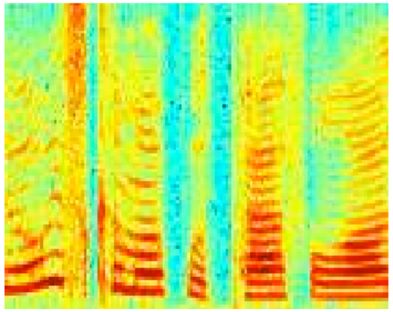
Hubel and Wiesel’s visual receptive fields

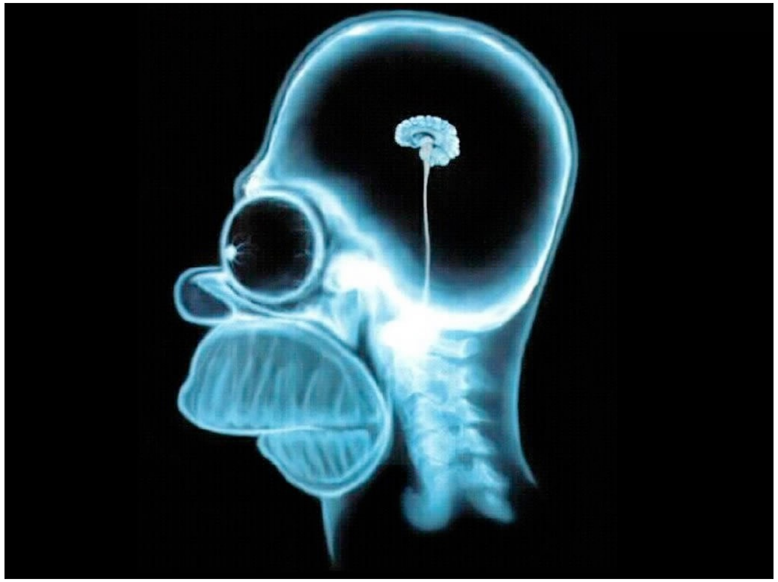
Statistical approach of neural characterization

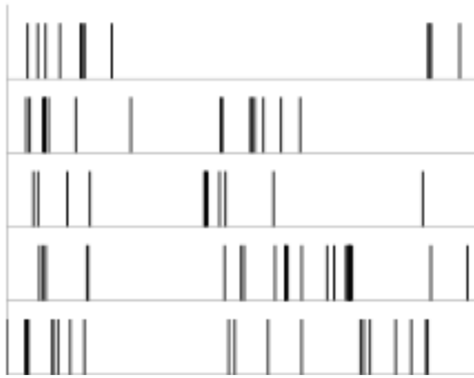
Sensory stimulus **s**

$p(r|\mathbf{s}) = ?$

Response **r**

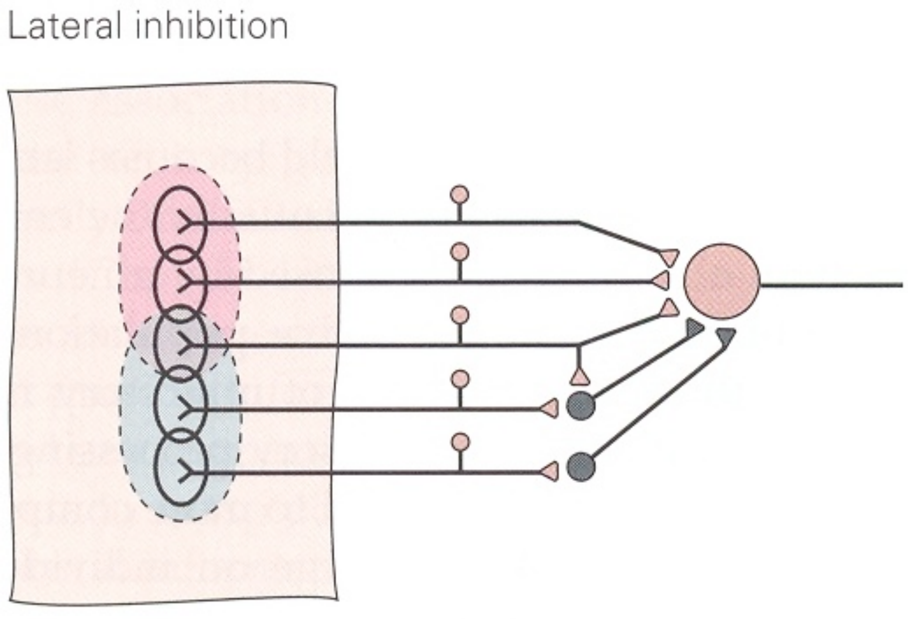






- Goal: infer response properties from stimulus and evoked response

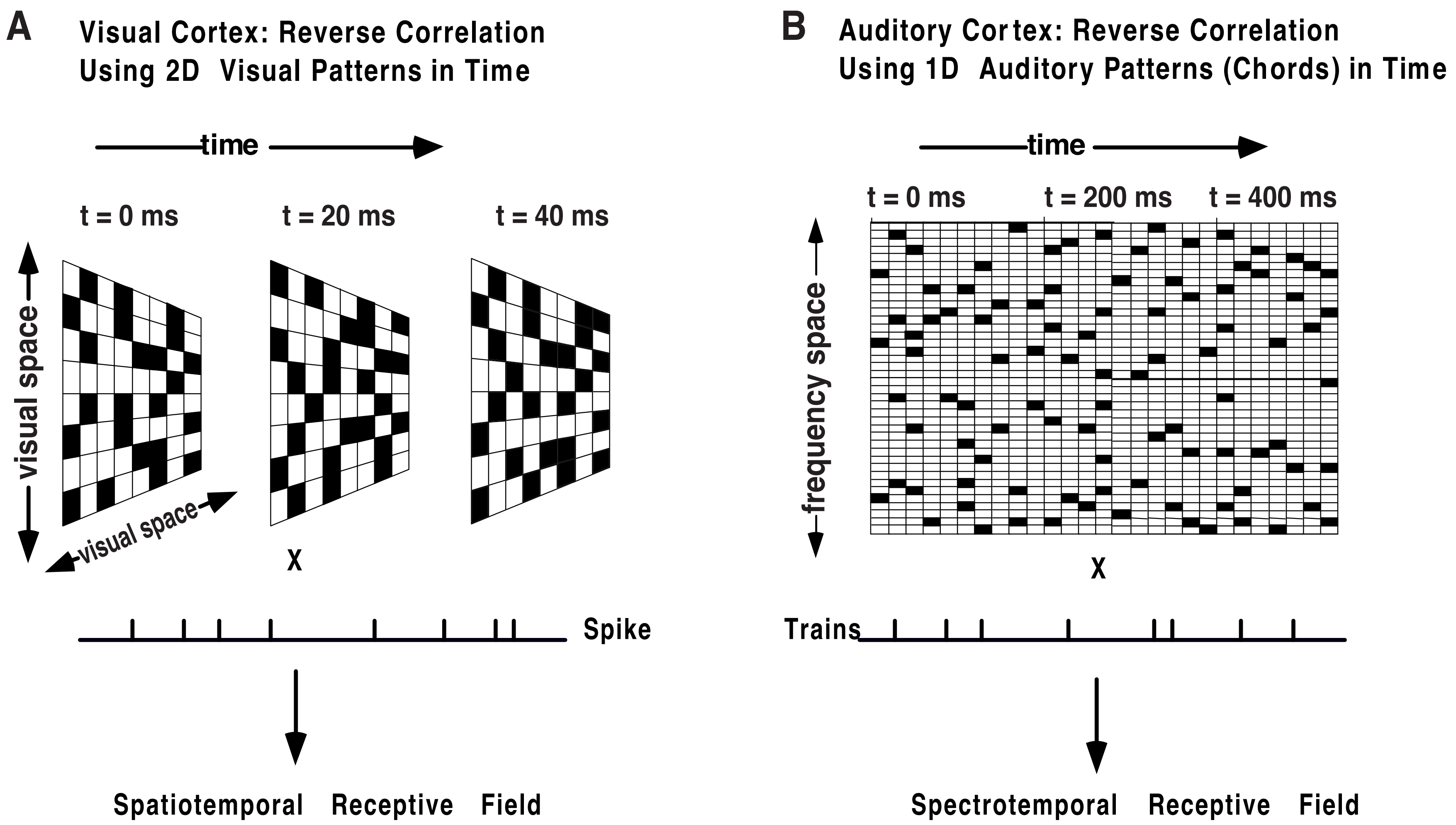
Simple cell linear receptive field model



$$y = g\left(\sum_{j=1}^{d} w_j x_j + w_0\right)$$

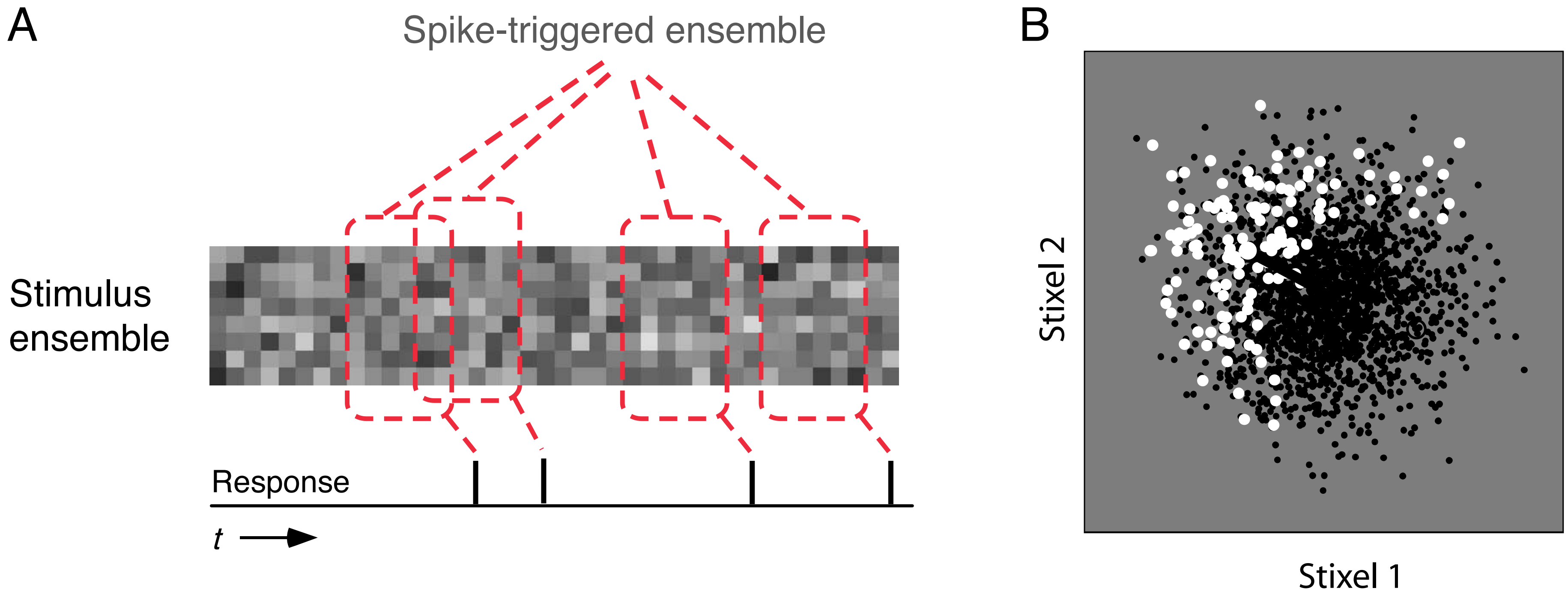
(Kandel et al., 2000)

Stimuli: White noise



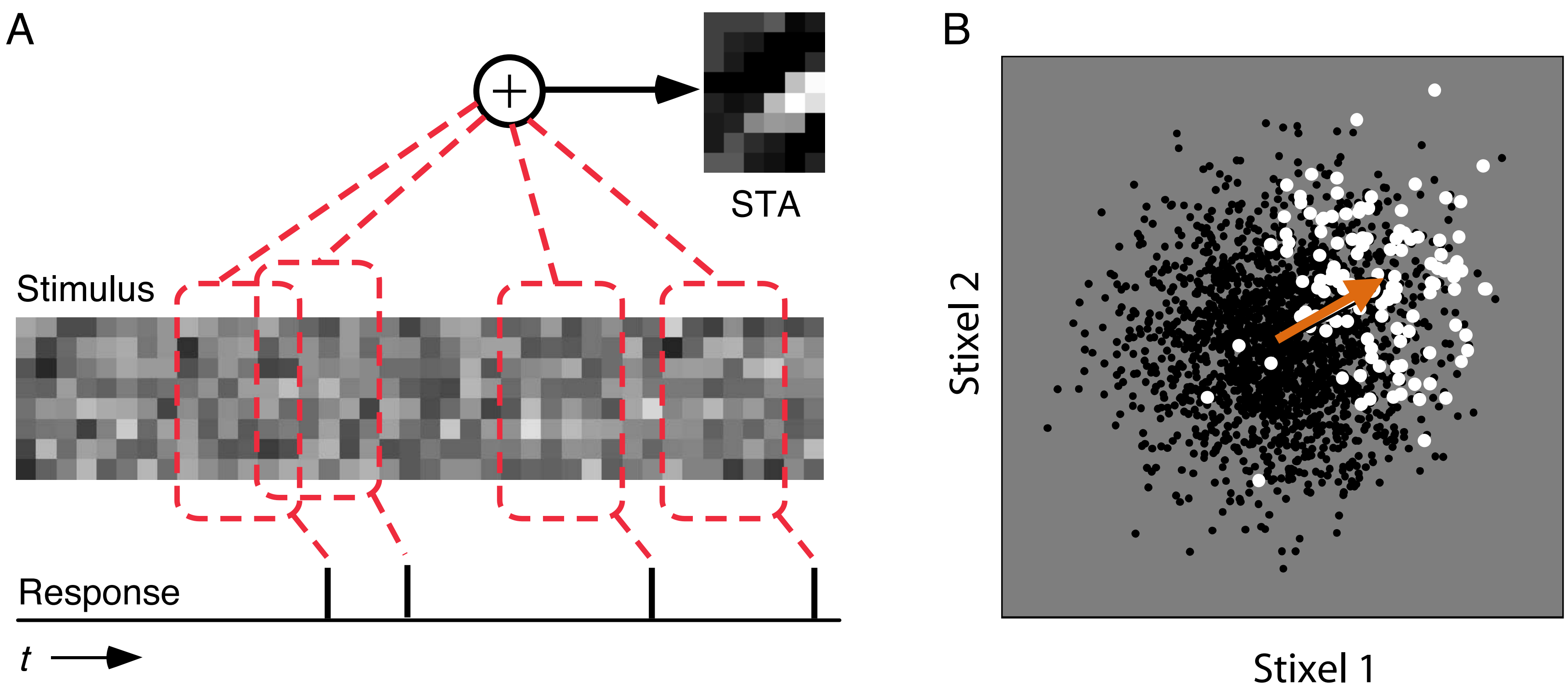
deCharms, Blake, Merzenich (1998)

Stimulus = Point in feature space



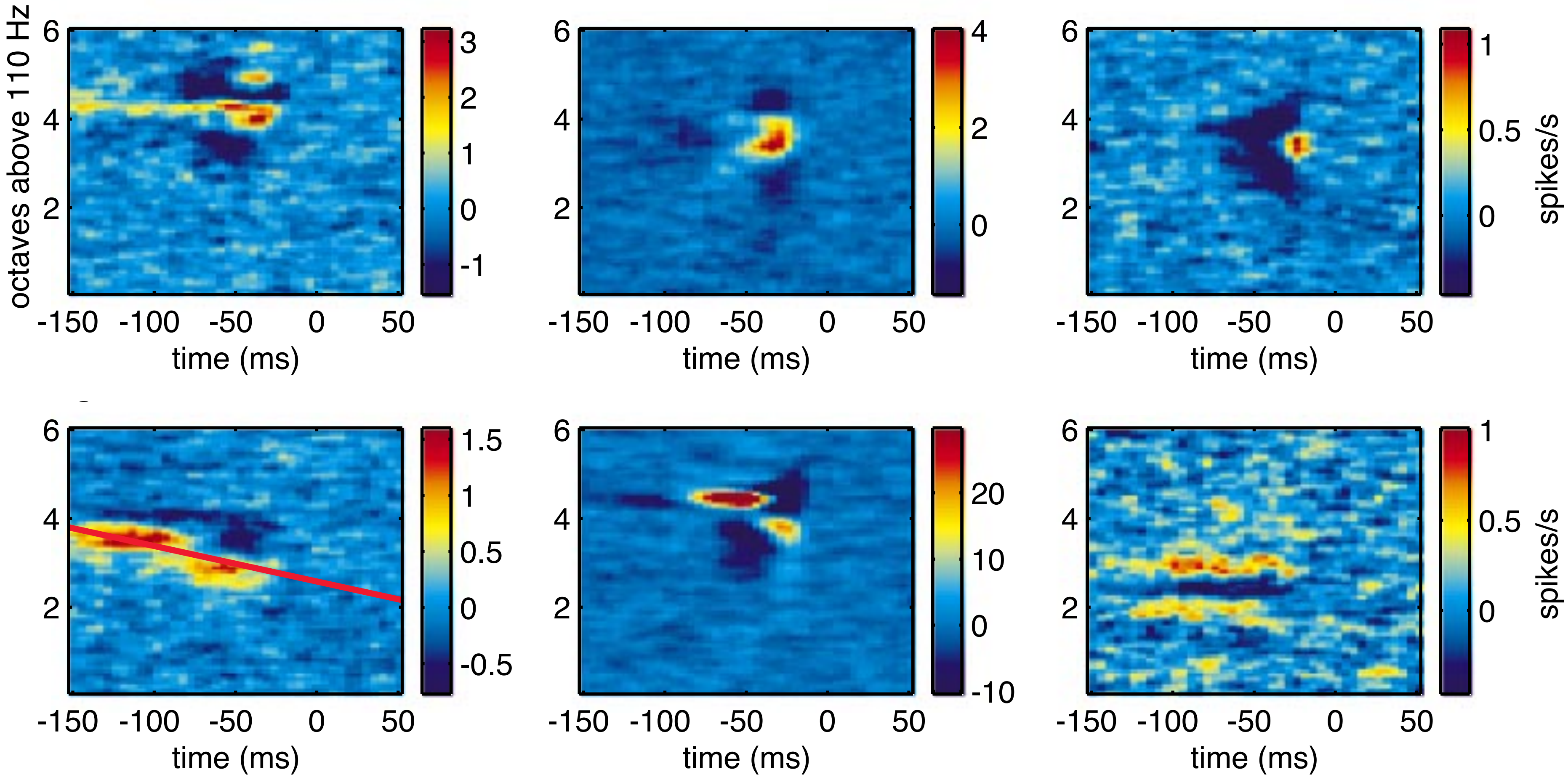
Eggermont, Johannesma, Aertsen (1983)
Schwartz, Pillow, Rust, Simoncelli (2006)

Spike triggered average (STA)



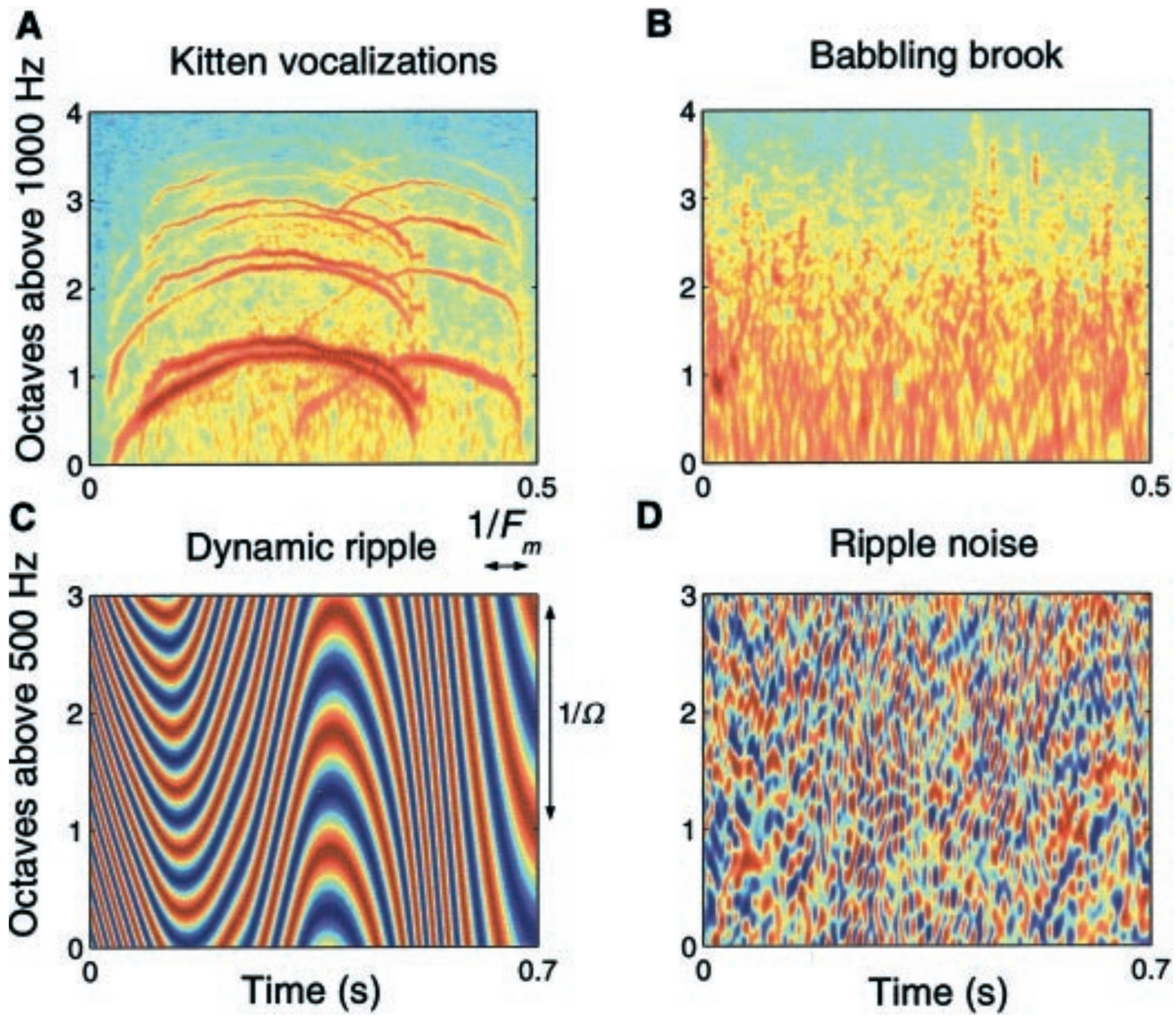
Eggermont, Johannesma, Aertsen (1983)
Schwartz, Pillow, Rust, Simoncelli (2006)

Response characteristics in A1



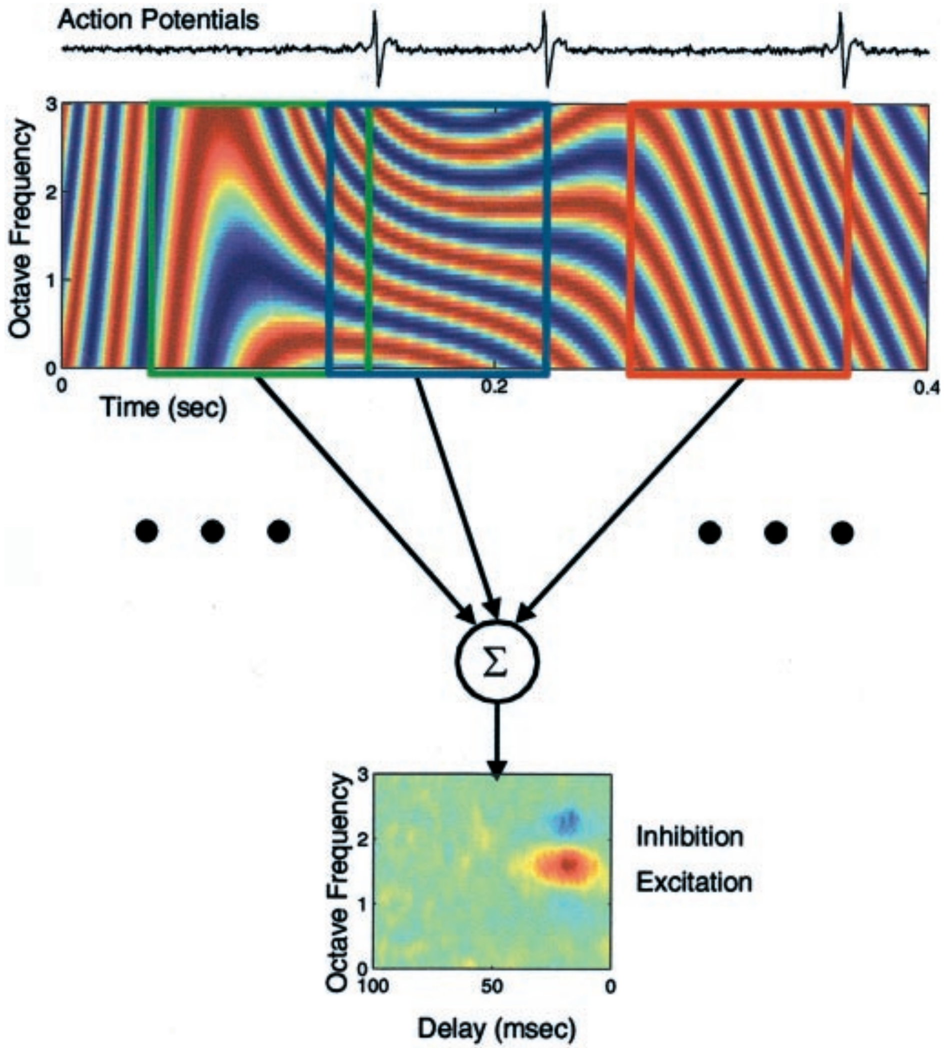
deCharms, Blake, Merzenich (1998)

Stimuli: Dynamic moving ripples (DMR) and ripple noise



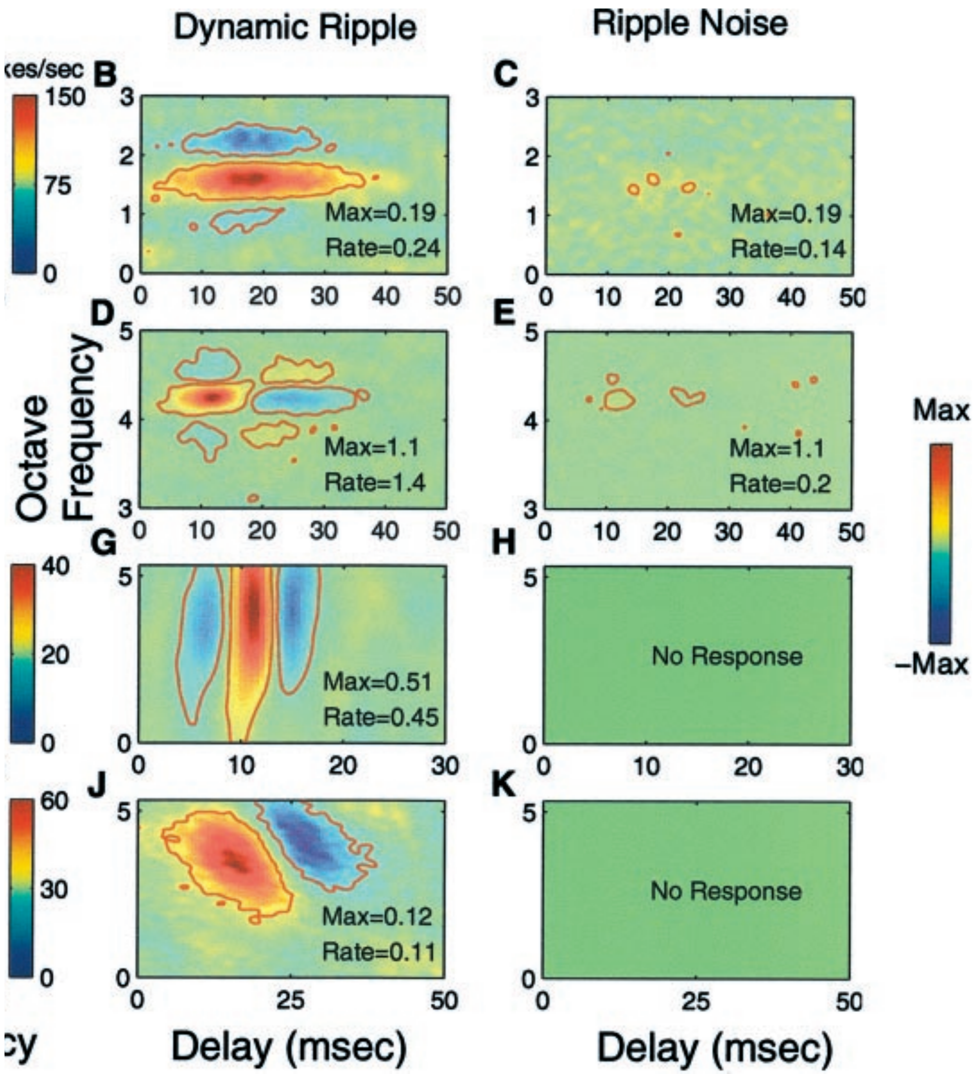
Escabi, Schreiner (2002)

STRF estimation with STA



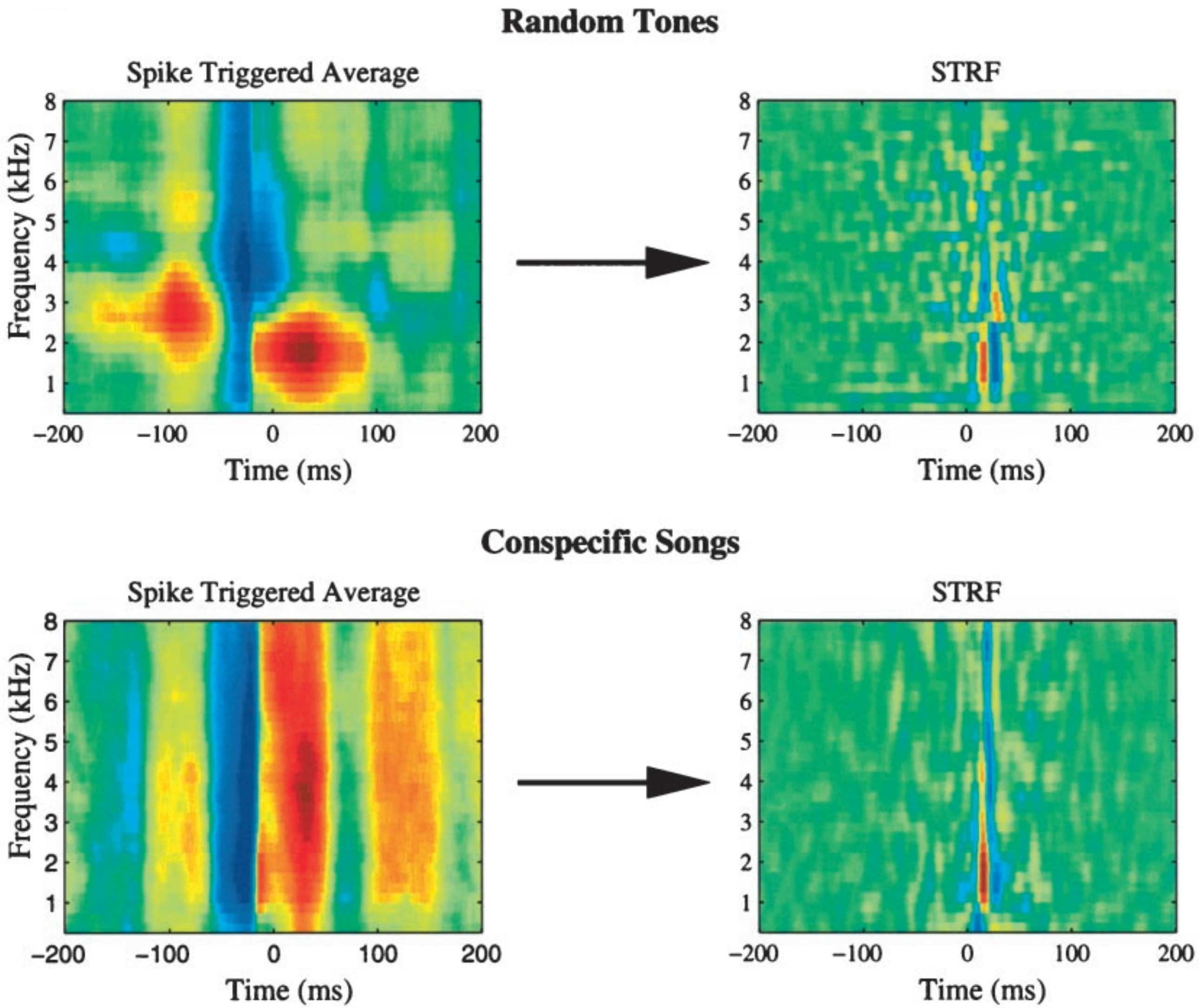
Escabi, Schreiner (2002)

Response characteristics in IC



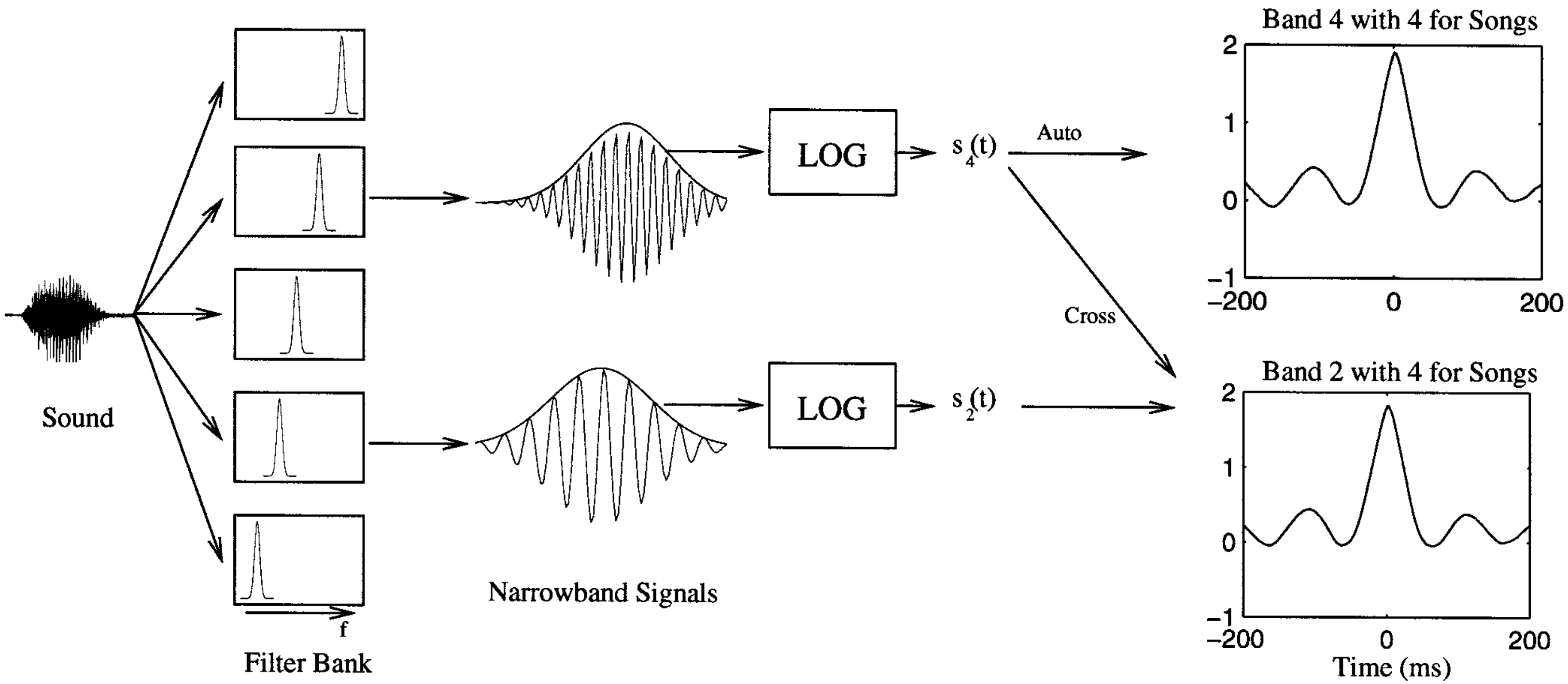
Escabi, Schreiner (2002)

STRF for natural stimuli



Theunissen, Sen, Doupe (2000)

STA not optimal for correlated stimuli



Theunissen, Sen, Doupe (2000)

Correcting for stimulus correlations

- Normalized reverse correlation (NRC)

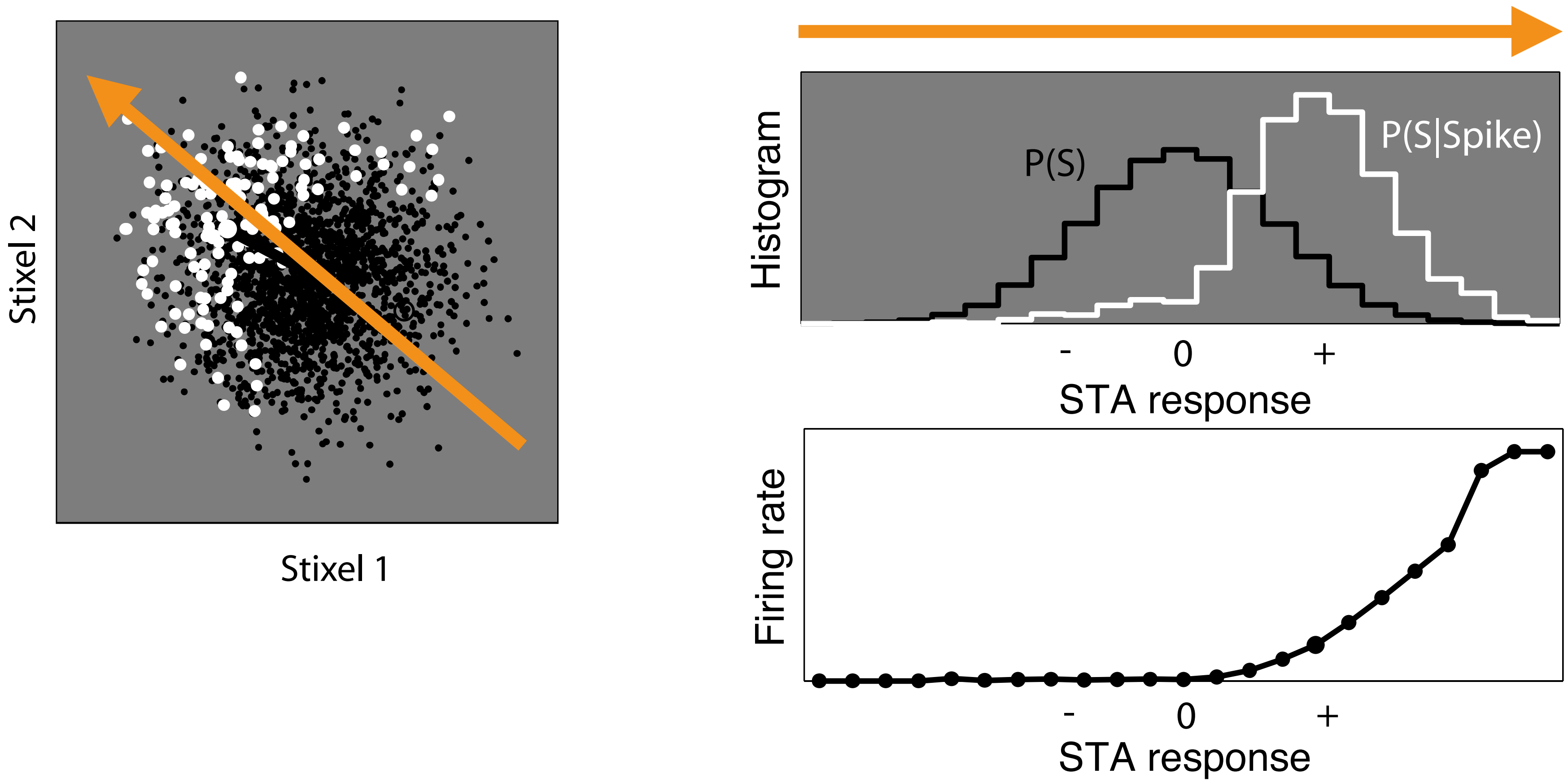
$$r = Sh + e$$

$$h_{\text{ideal}} = \frac{1}{T} C_{ss}^{-1} S^T r \qquad C_{ss} = S^T S / T$$

- Ridge Regression
  Regularize C_{SS} with additive diagonal term
  (Often done on spike rate)

Machens, Wehr, Zador (2004); David, Mesgarani, Shamma (2007); Park, Pillow (2011)

Linear-nonlinear Poission (LNP) model



Chichilniski, 2001; Schwartz, Pillow, Rust, Simoncelli (2006)

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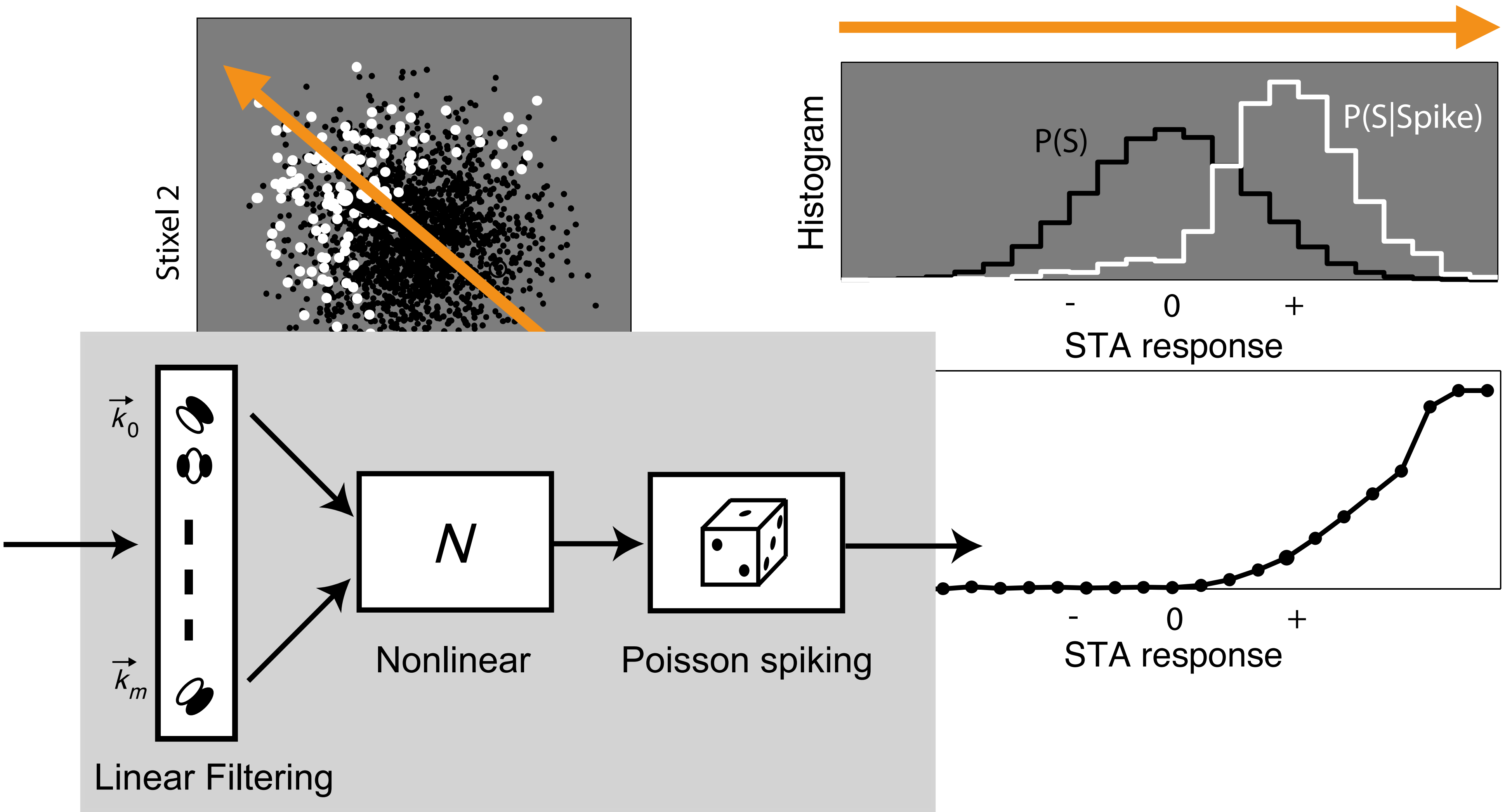
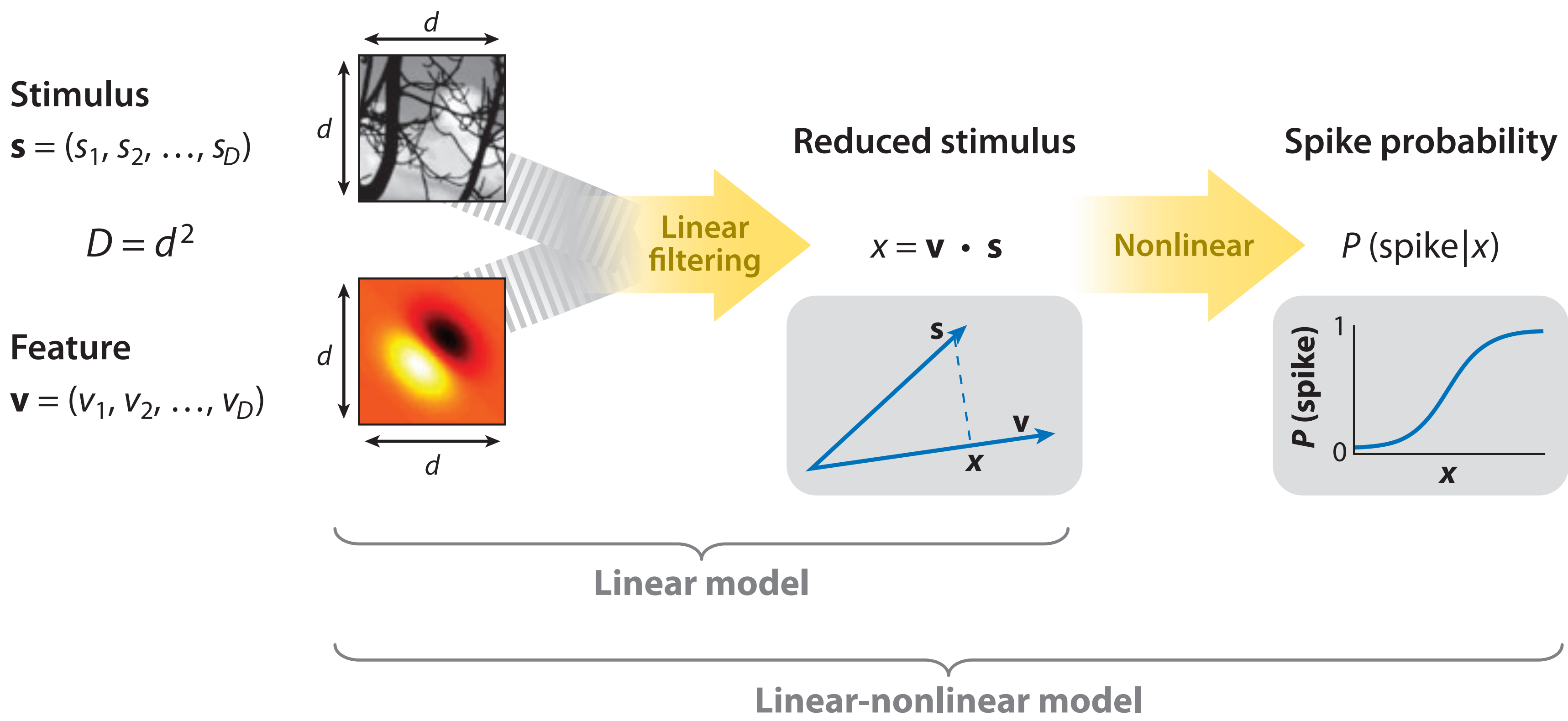


Chichilniski, 2001; Schwartz, Pillow, Rust, Simoncelli (2006)

LNP estimation: generalized linear models (GLM) and maximally informative dimensions (MID)



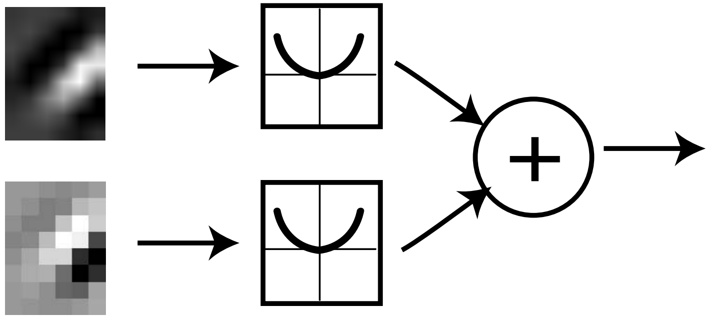
GLM: maximize likelihood based on prior distribution

MID: search for directions that preserve stimulus information

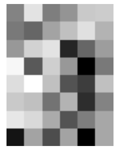
Sharpee, Rust, Bialek (2003), Sharpee (2013)

Subspace approach:
Spike-triggered covariance (STC)

Model neuron:



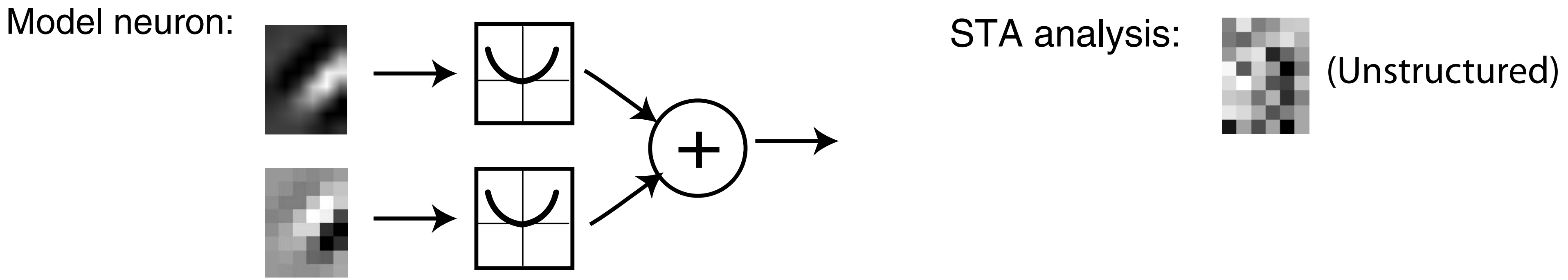
STA analysis:

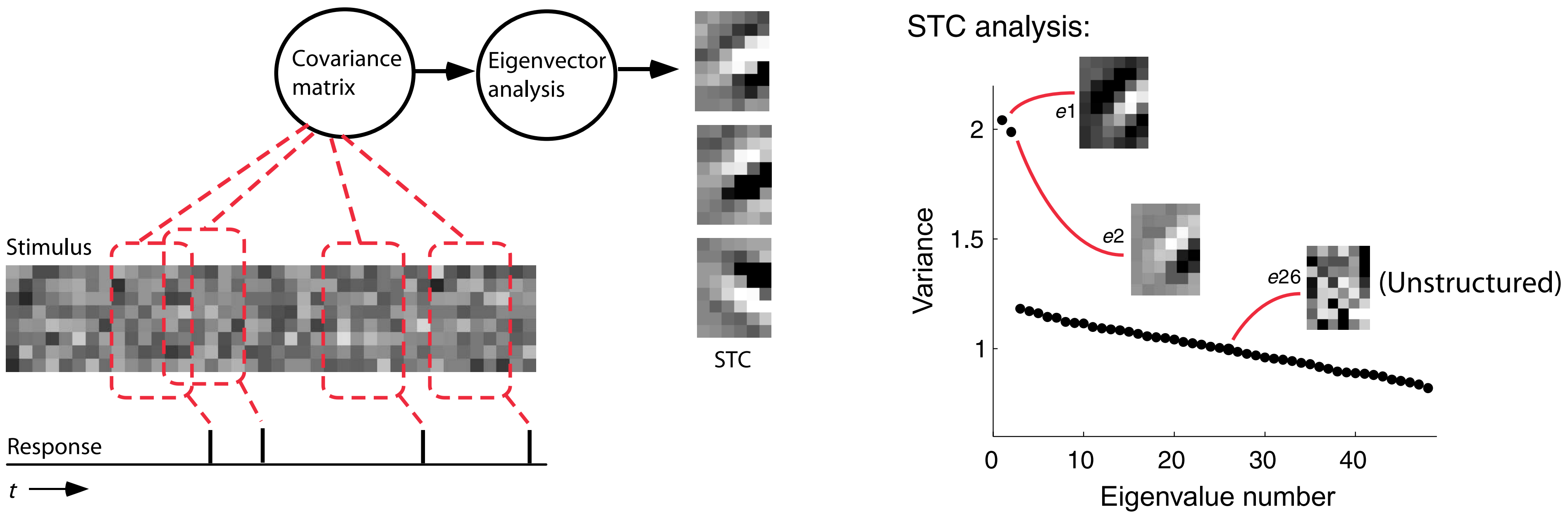


(Unstructured)

Schwartz, Pillow, Rust, Simoncelli (2006)

Subspace approach:
Spike-triggered covariance (STC)

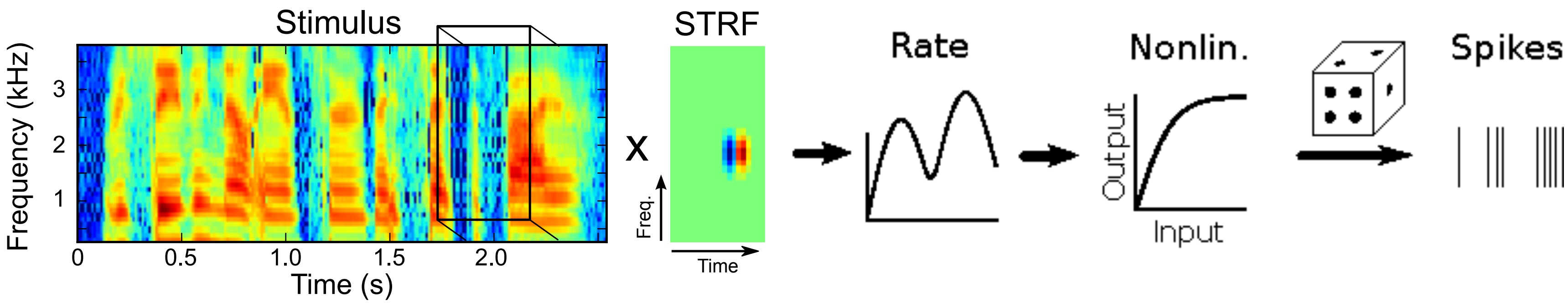




Schwartz, Pillow, Rust, Simoncelli (2006)

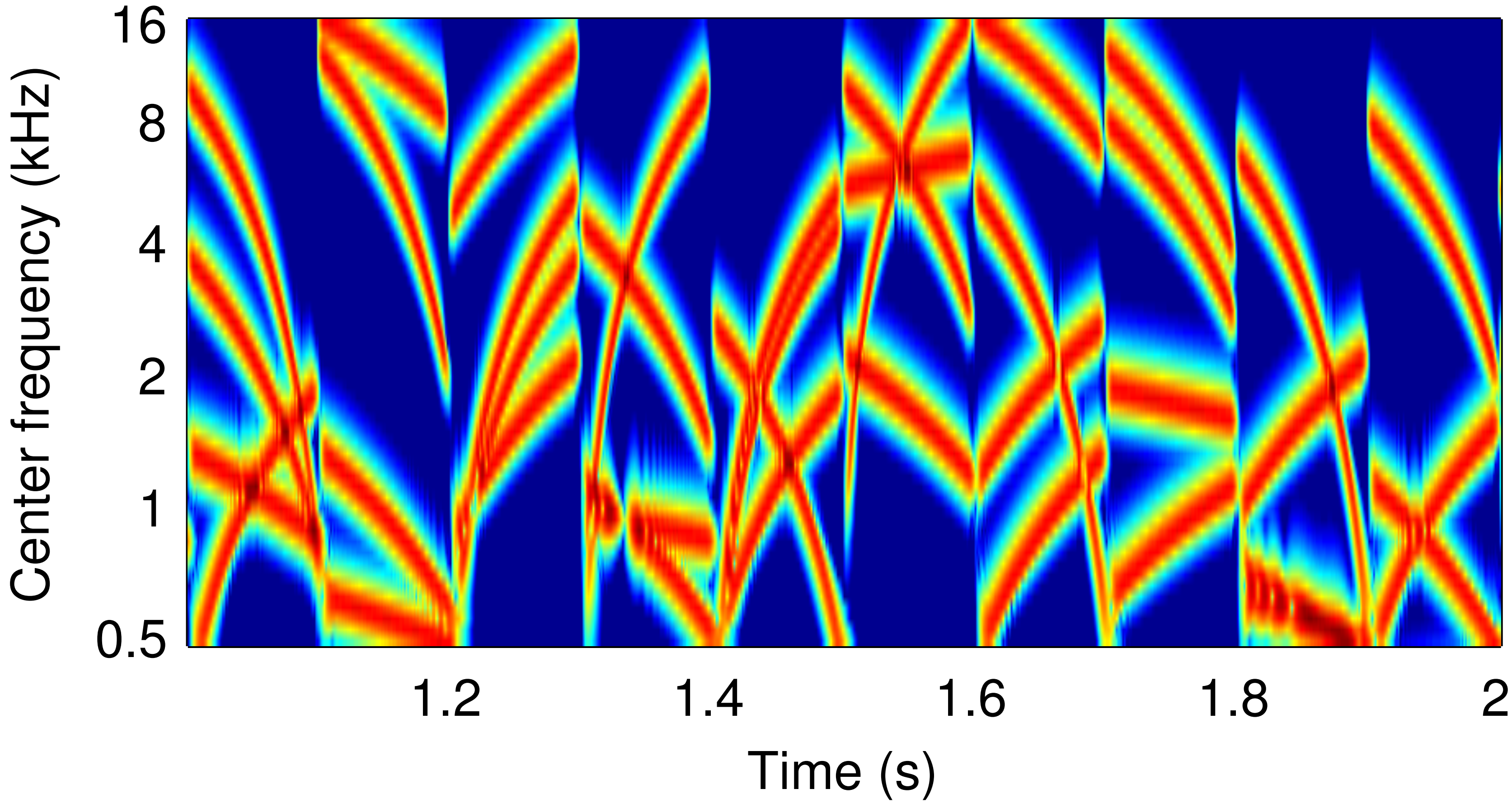
From sounds to spikes

Classic STRF model:



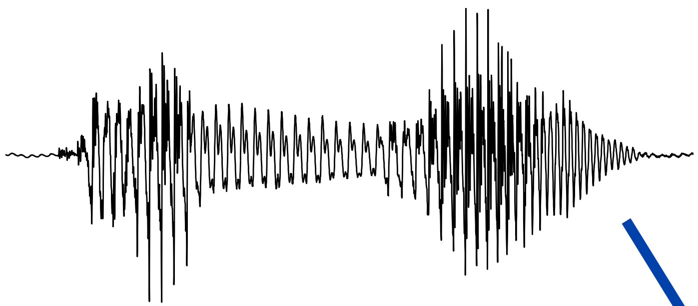
- Separation into **linear part** (= receptive field or kernel **k**) and **static memoryless nonlinearity** (Chichilnisky 2001)
- Once we know **k** estimation of the nonlinearity is quite simple!
- White noise approach: Estimation of linear part using (normalized) reverse correlation method (Bussgang Theorem 1952)
- BUT: need Gaussian (symmetric) stimuli!

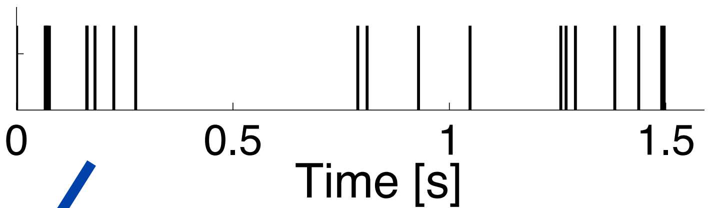
Stimuli: Bank of frequency-modulated tones (FM-Bank)



Meyer, Diepenbrock, Happel, Ohl, Anemüller (2014)

Classification-based receptive field (CbRF) estimation
Training a classifier to predict spike trains

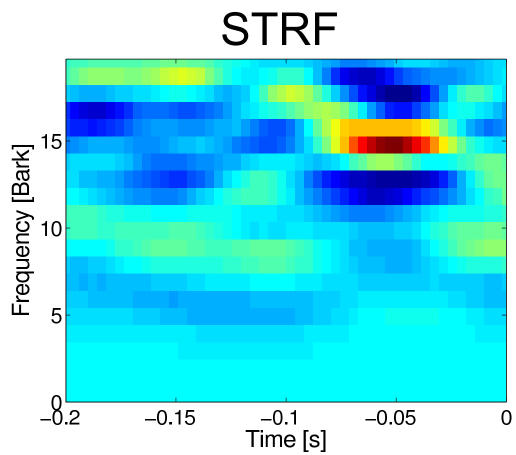




Cooperation with F. Ohl
- Experiments
- Statistical modeling
- Experimental paradigma for
  influence of stimulus changes

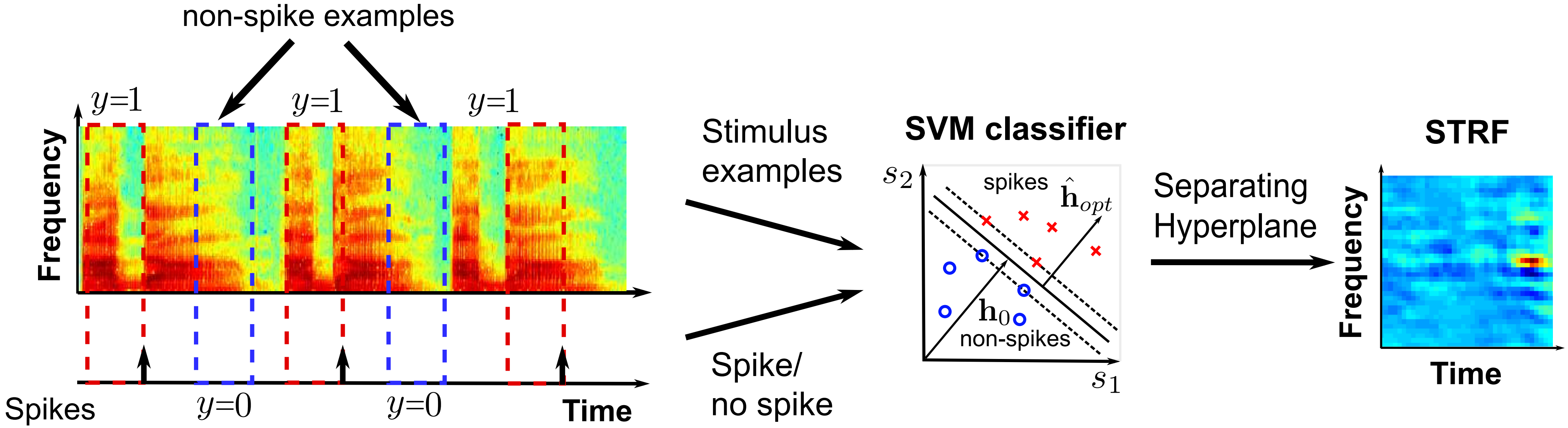
Black Box
SVM Classifier

Spike ?
yes / no



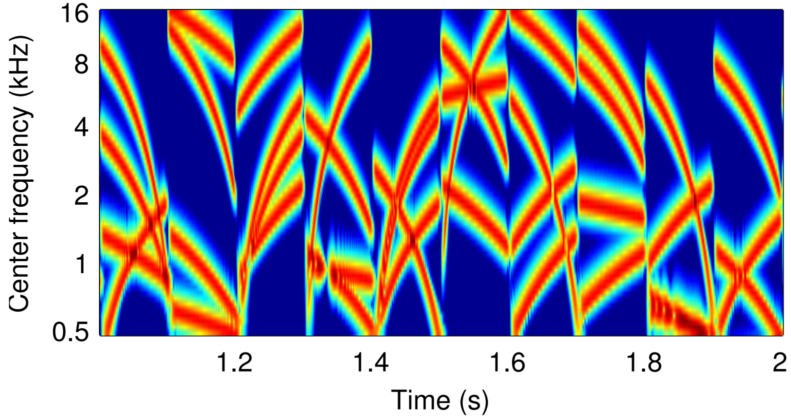
Classification-based receptive field estimation (CbRF)

Spectro-temporal receptive field (STRF) estimation

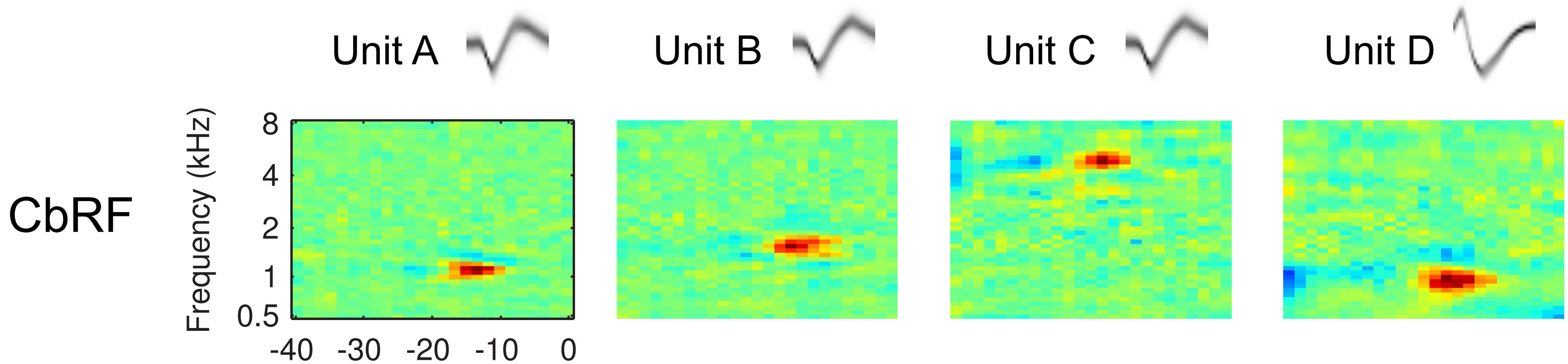


Meyer, Diepenbrock, Happel, Ohl, Anemüller (2009, 2014)

STRF estimation from gerbil neurons



stimulation with
frequency-modulated
tone complexes



Meyer, Diepenbrock, Happel, Ohl, Anemüller (2014)

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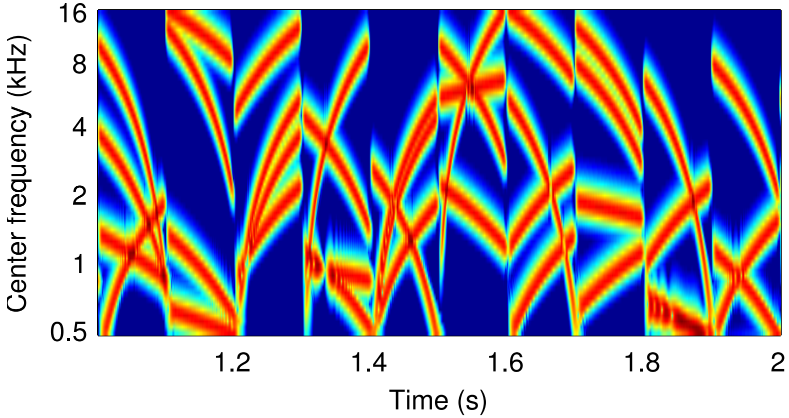
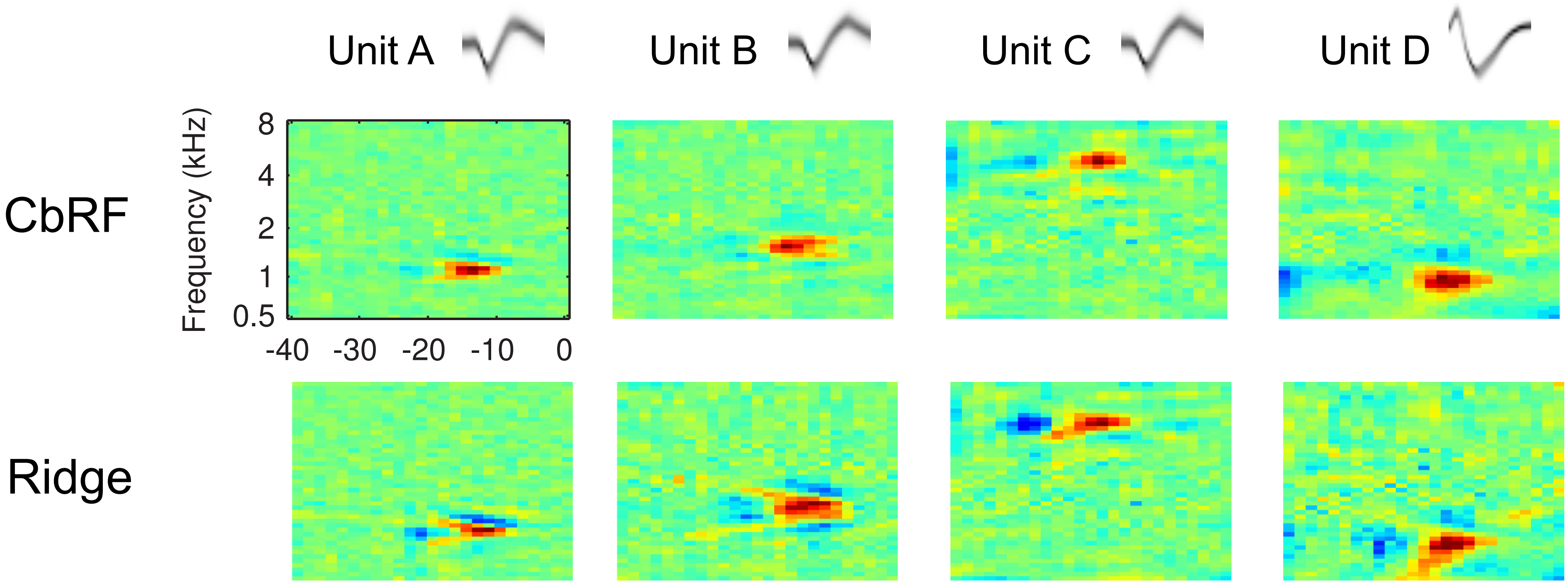
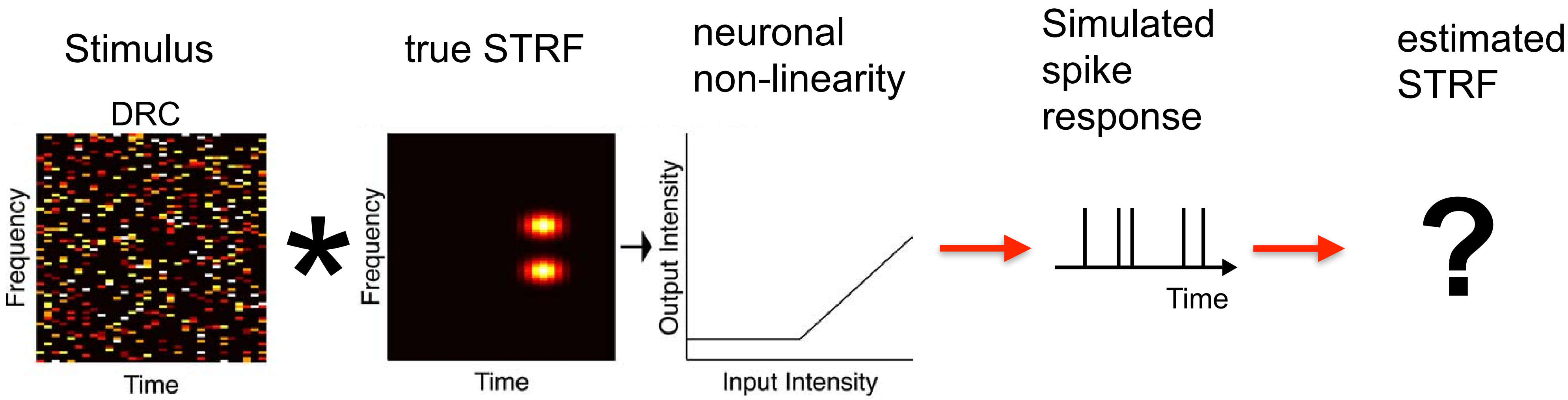


stimulation with frequency-modulated tone complexes



Meyer, Diepenbrock, Happel, Ohl, Anemüller (2014)

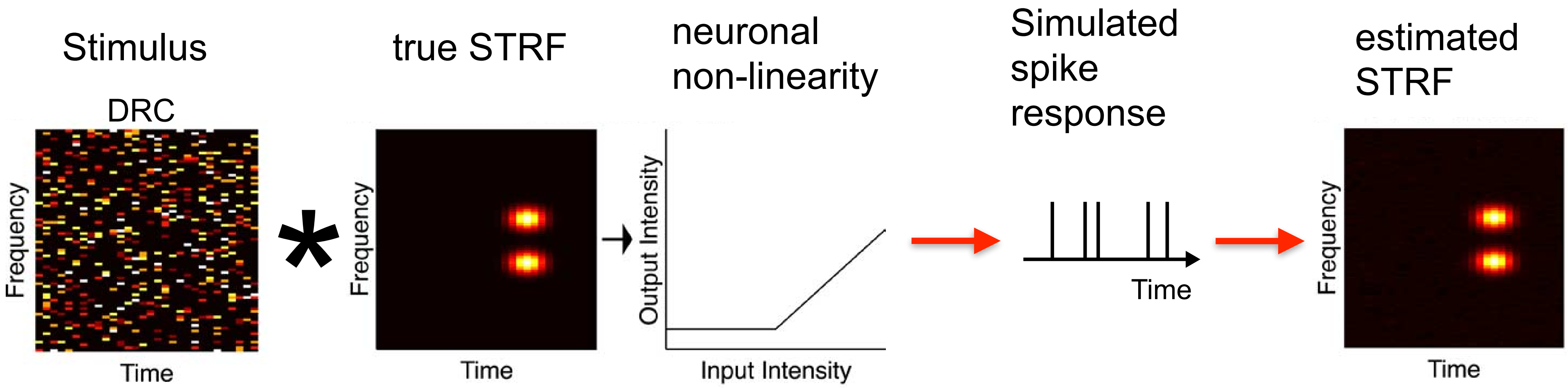
Higher-order stimulus statistics influences STRF estimation results



Ripple

Christianson, Sahani, Linden, J. Neurosci., 2008

Higher-order stimulus statistics influences STRF estimation results



Ripple

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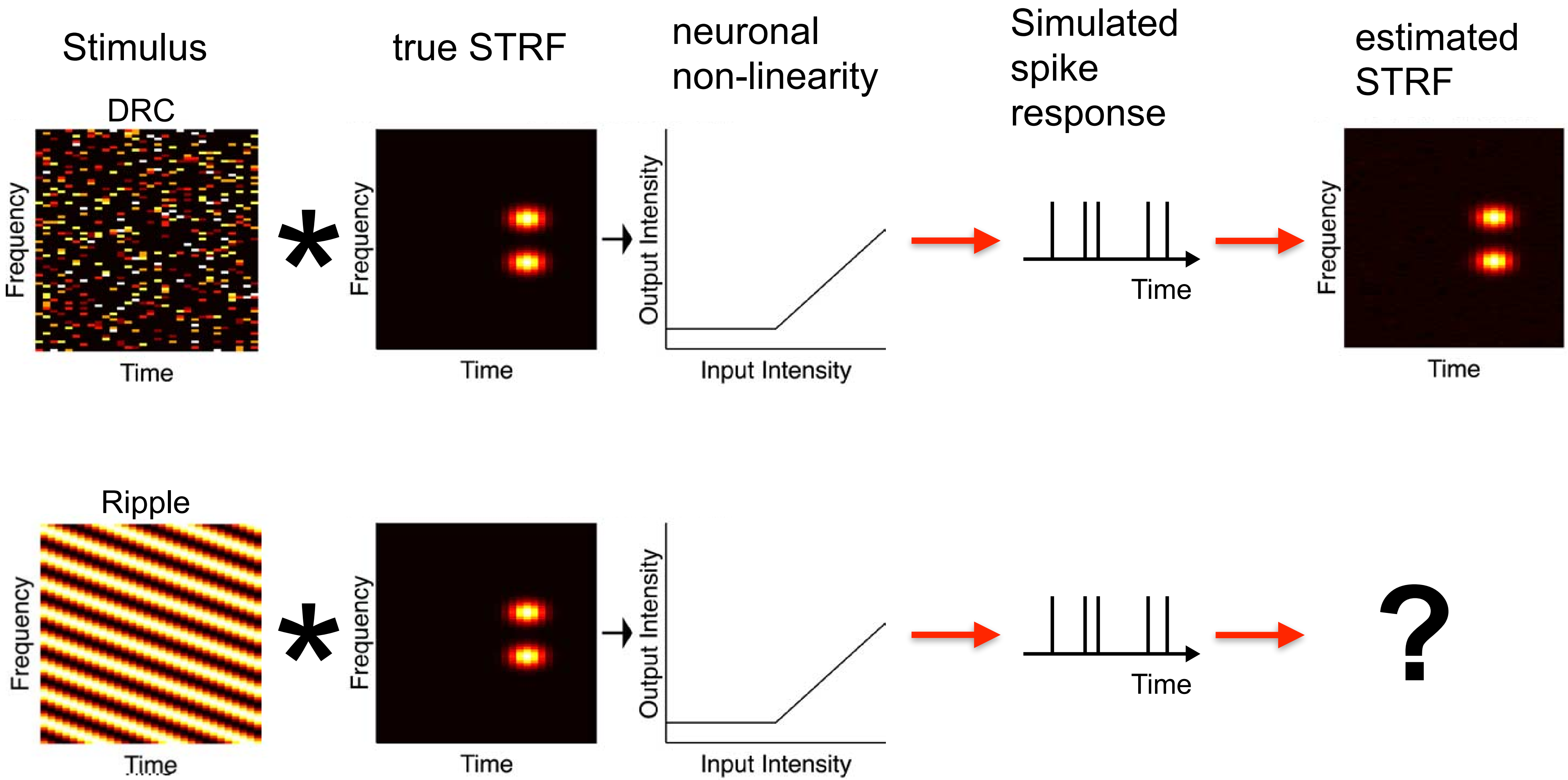

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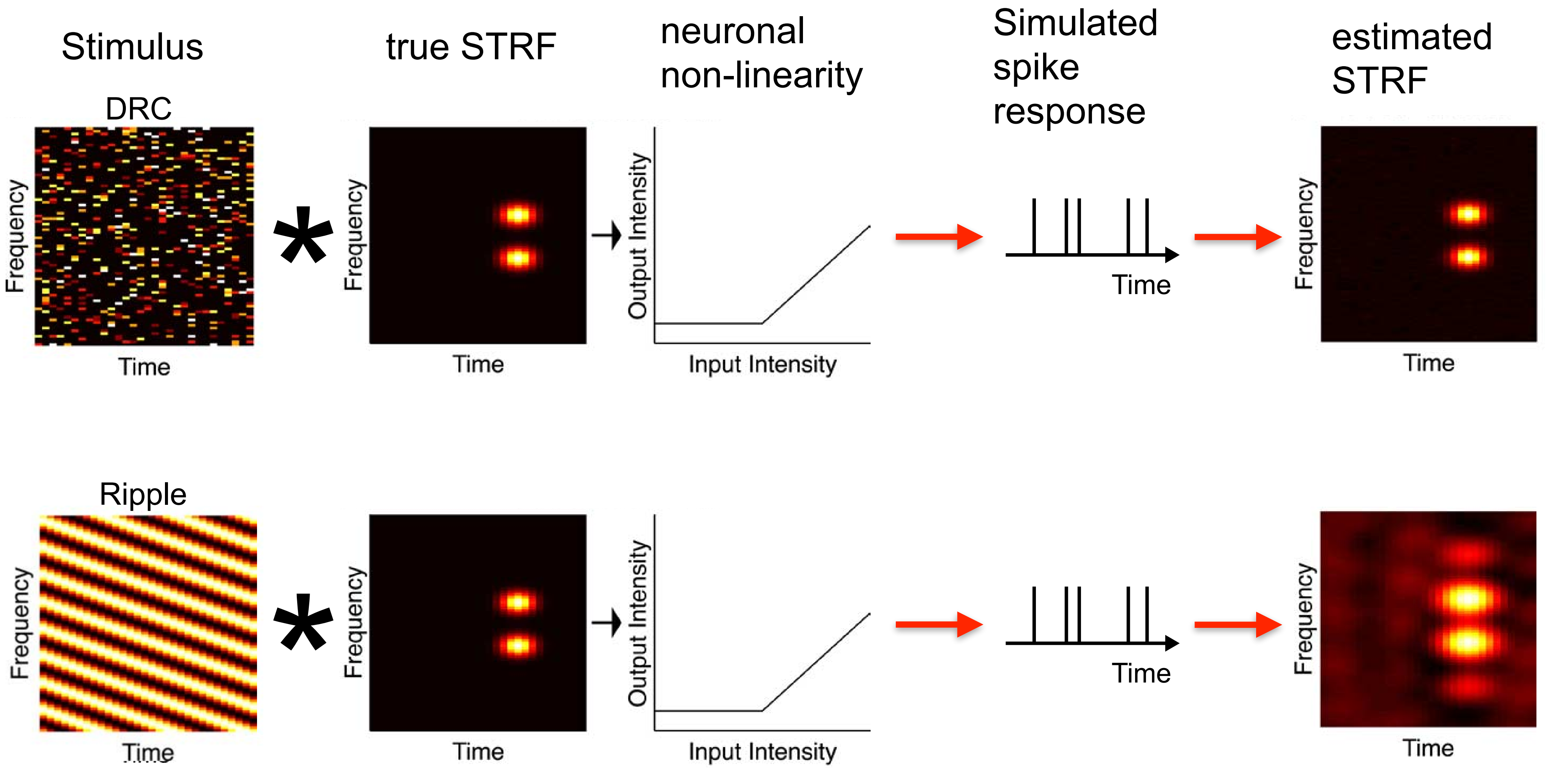
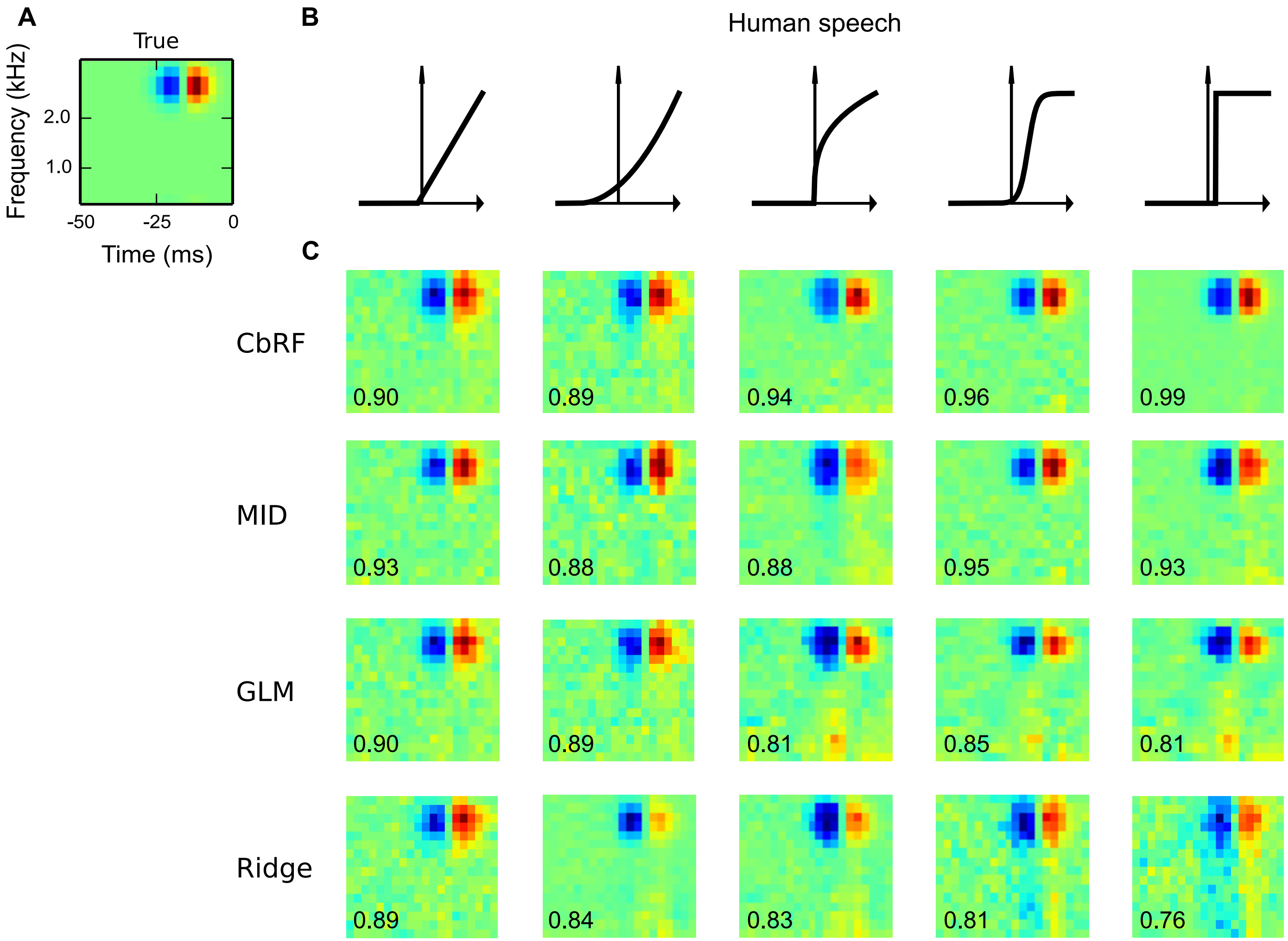


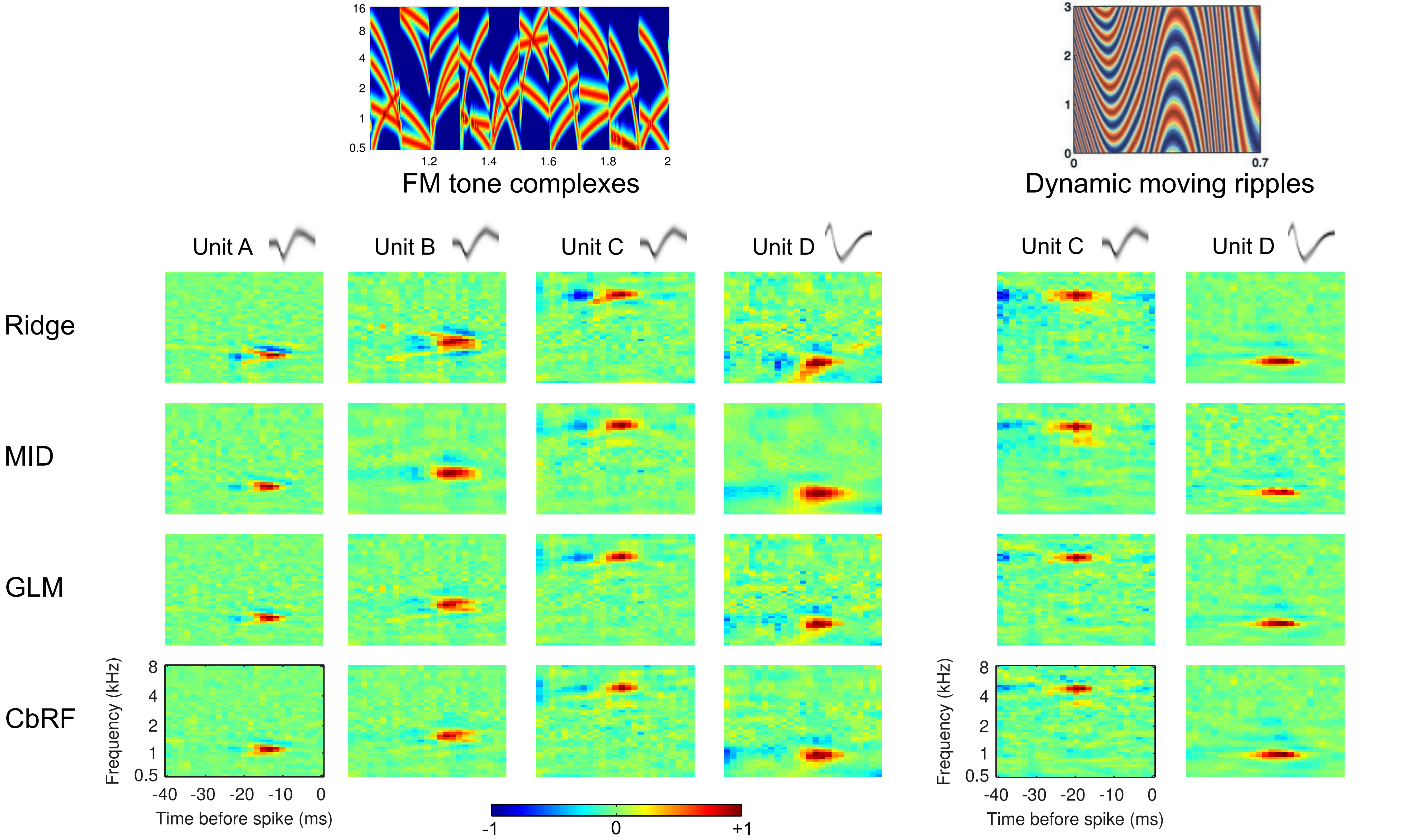
Christianson, Sahani, Linden, J. Neurosci., 2008

STRF estimation with speech stimul input

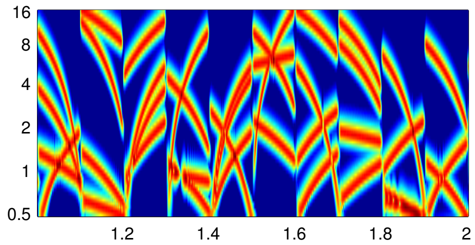


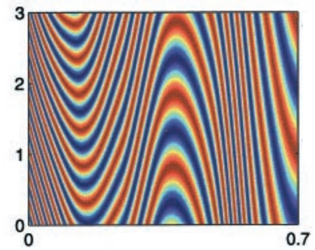
Classification-based method best matches ground-truth

STRF estimation from gerbil IC neurons



Influence of stimulus ensemble on STRF in gerbil IC recordings

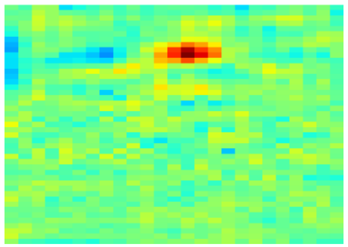


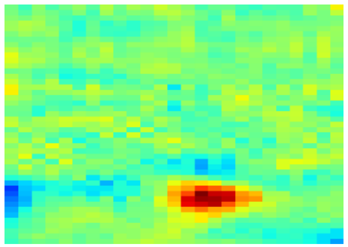


FM tone complexes

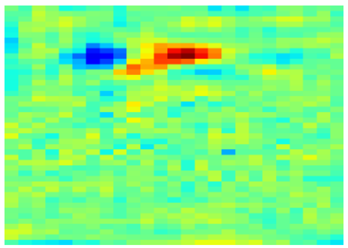
Unit C  Unit D 

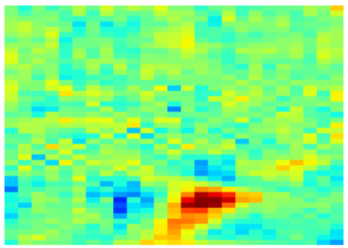
CbRF





Ridge





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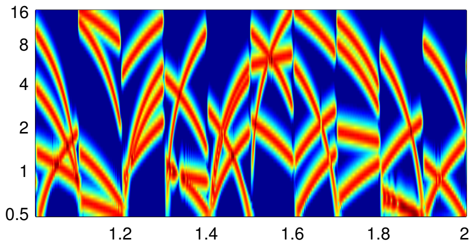

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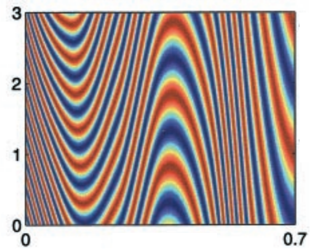
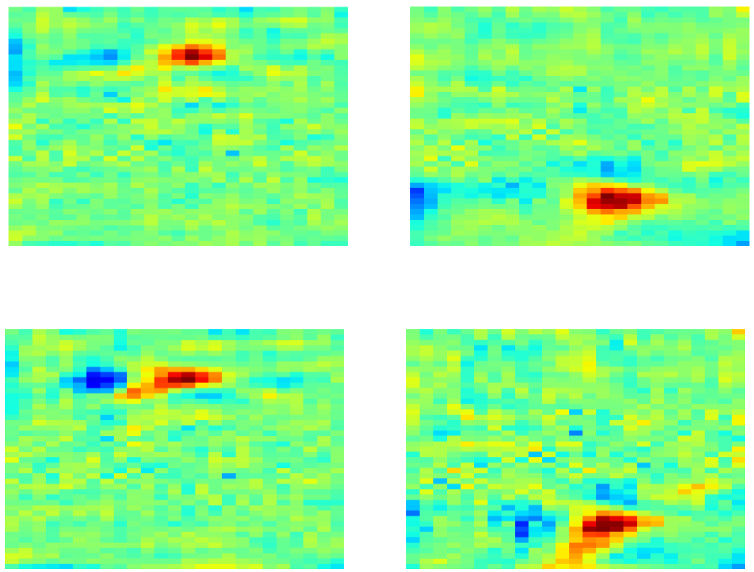


Dynamic moving ripples

Unit C  Unit D  Unit C  Unit D 

CbRF

Ridge



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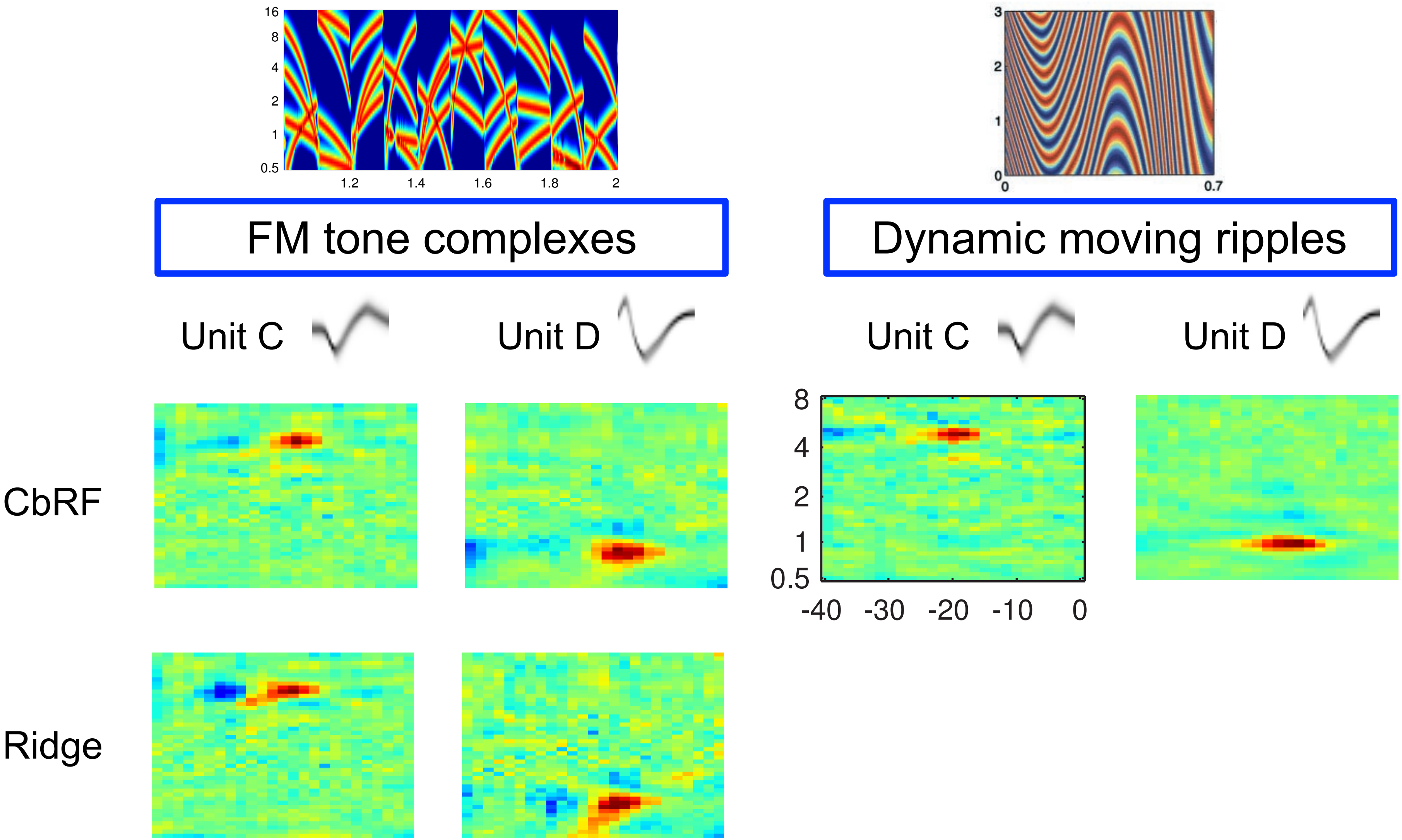

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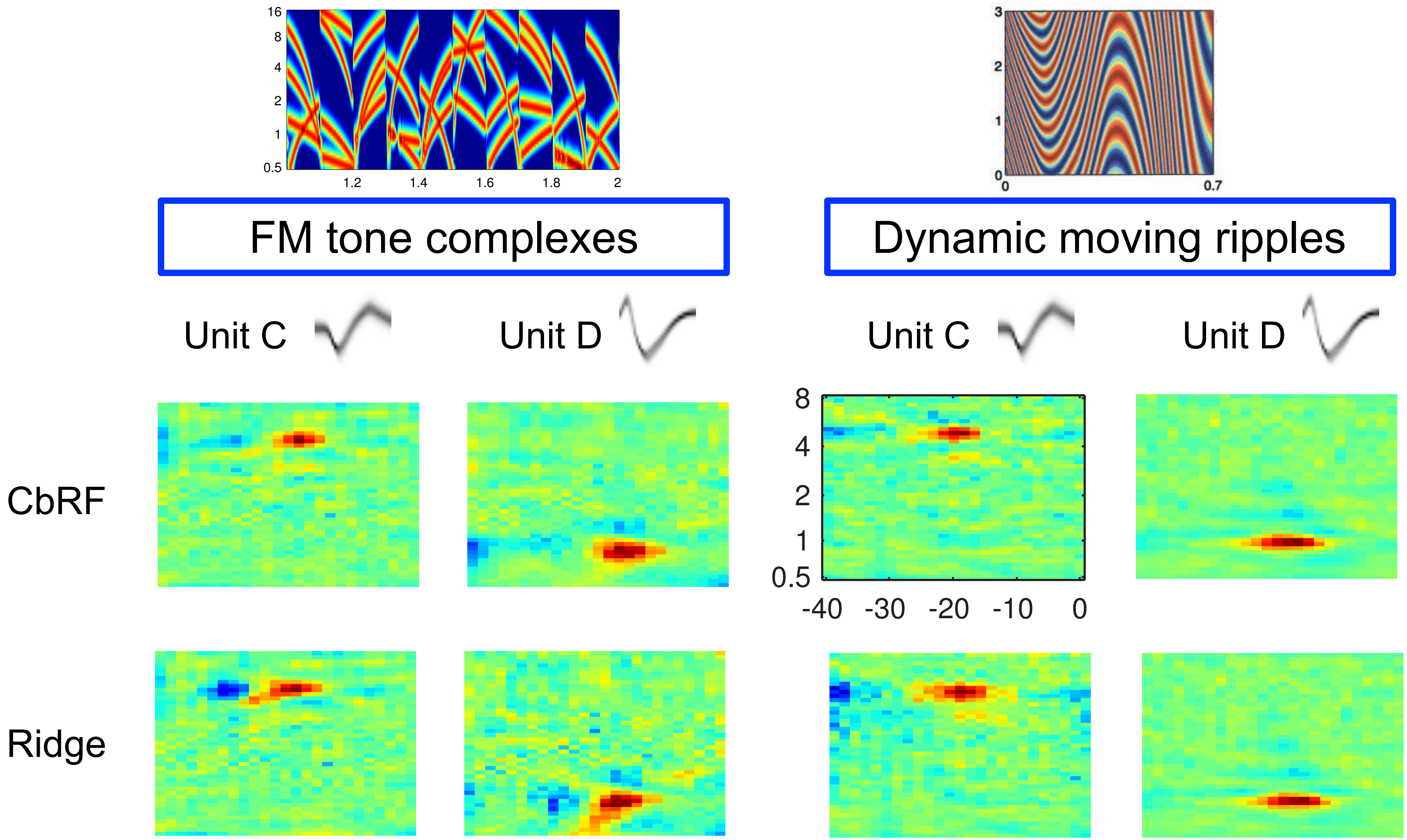
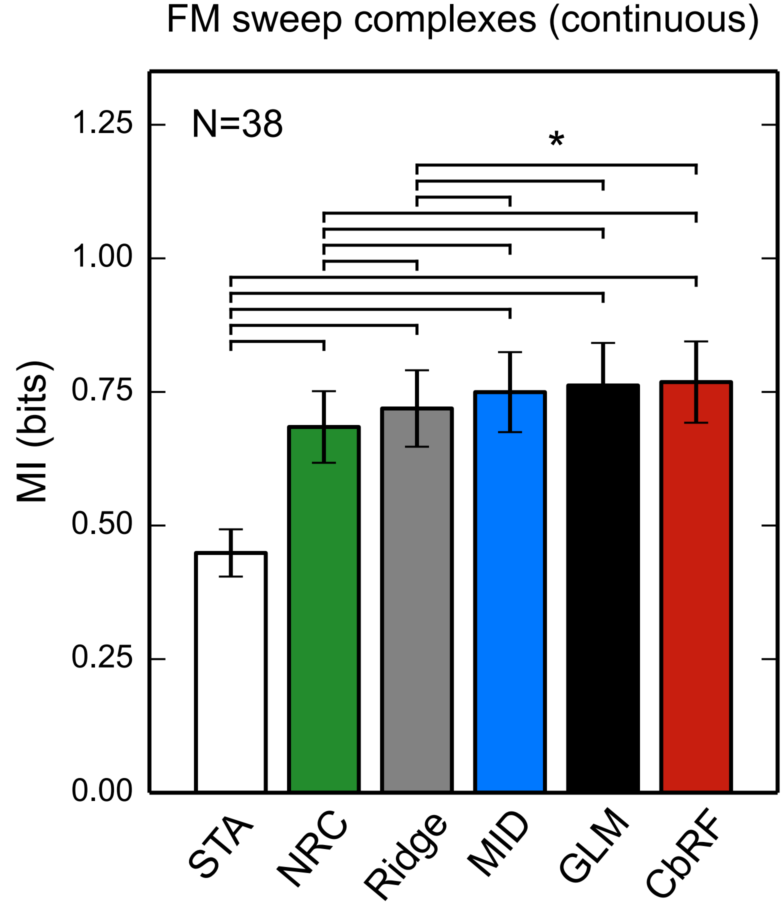


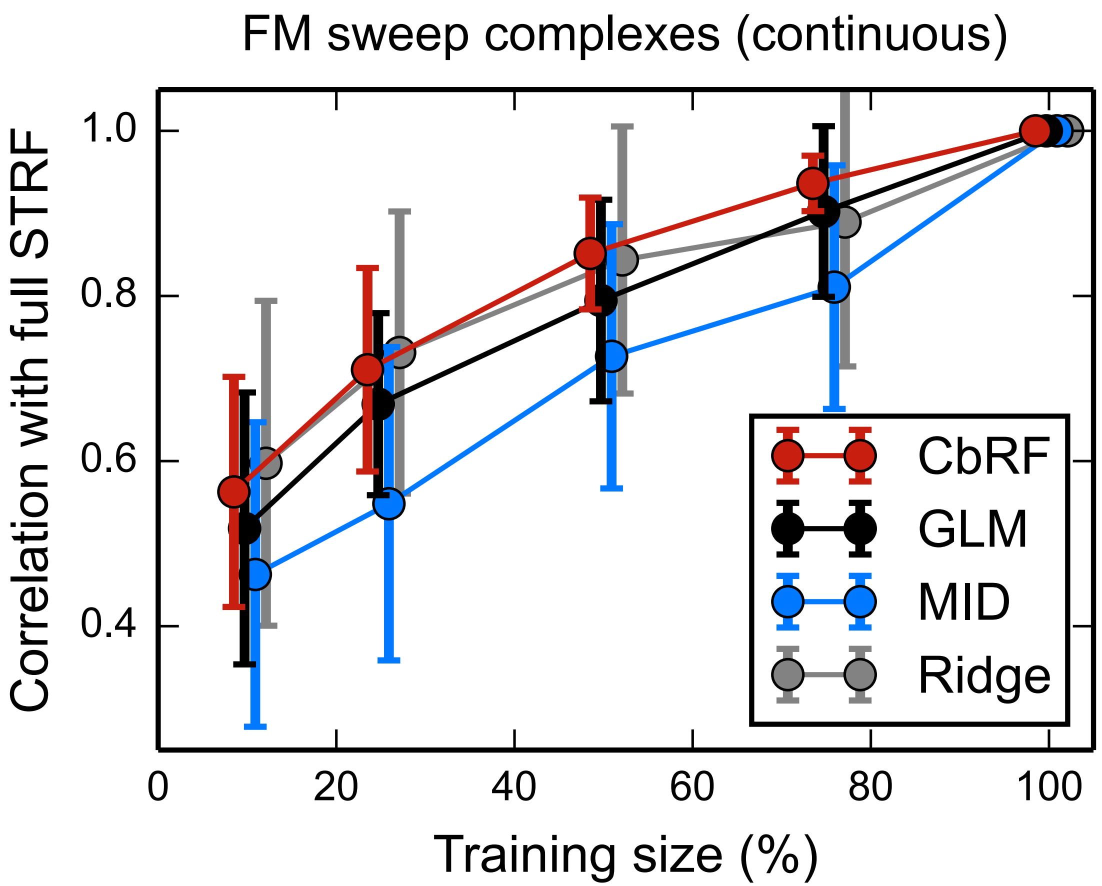
STRF estimation from gerbil IC neurons: Mutual information analysis



Non-linear methods (CbRF, GLM, MID) show highest information-transfer rates for non-Gaussian stimuli

Meyer, Diepenbrock, Happel, Ohl, Anemüller (2014)

STRF estimation from gerbil IC neurons: speed of convergence

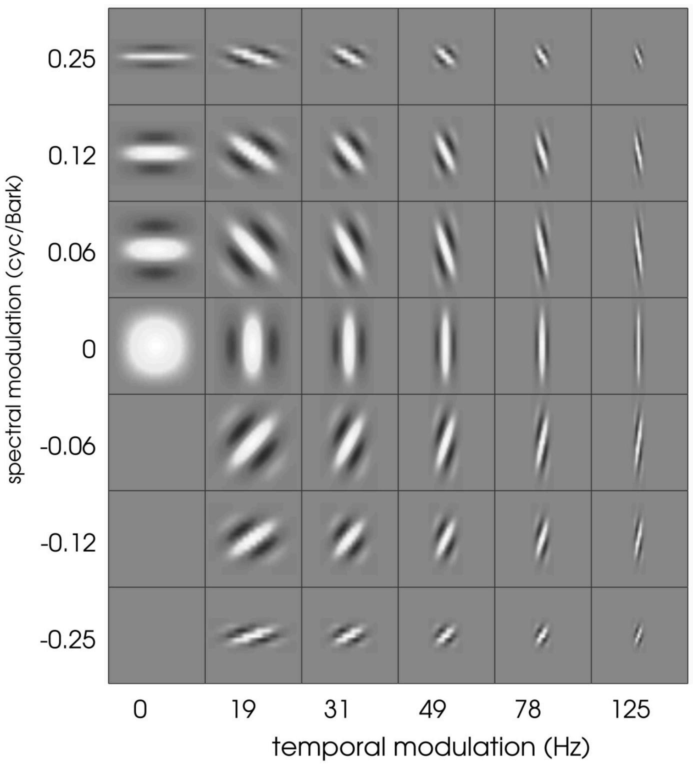


Classification-based method converges quickly and with relatively small estimation variance

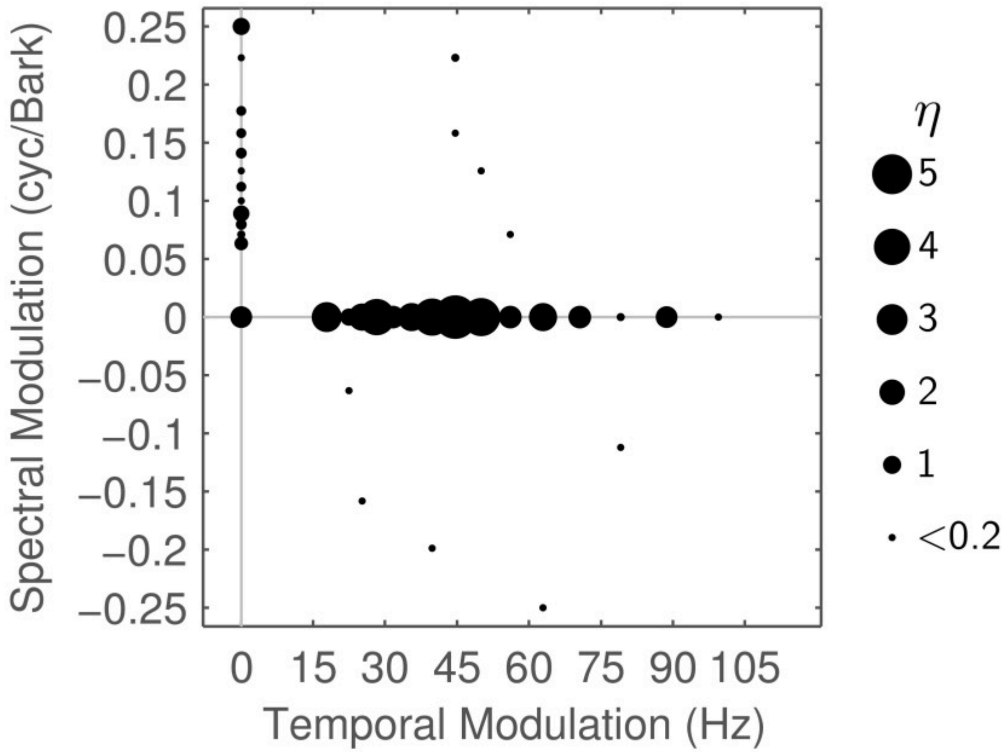
Meyer, Diepenbrock, Happel, Ohl, Anemüller (2014)

Matching pursuit (MP) analysis of spectral, temporal and spectra-temporal characteristics

Gabor basis functions as MP-atoms



Spectro-temporal distribution of MP-selected atoms



Data from Gill, Zhang, Woolley, Fremouw, Theunissen (2006) + ridge regression

Bach, Kollmeier, Anemüller (2017)

Summary STRF estimation

STRF estimation algorithms need to go beyond second order statistics (e.g., GLM, MID, CbRF)

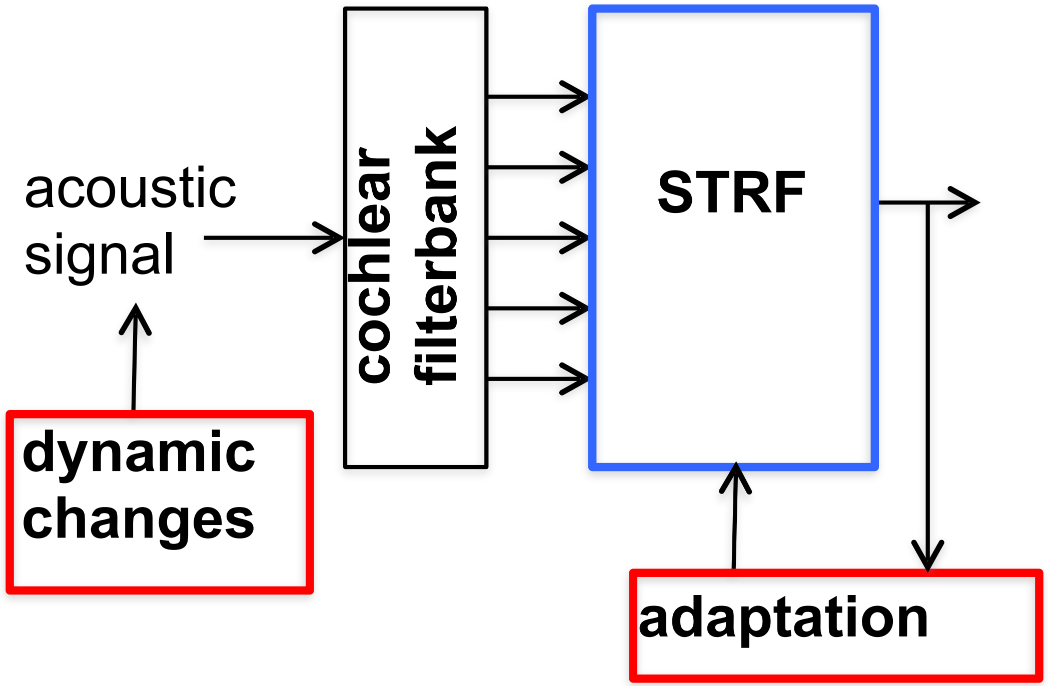
Data show that estimation algorithm influences obtained STRF pattern *qualitatively*

FM-bank stimuli to mimic speech-like t-f-transients

Joint spectra-temporal STRFs appear to be rare, even on FM-bank stimuli

Beyond the linear time-invariant STRF model

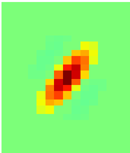
Cue selection under dynamic stimulus changes



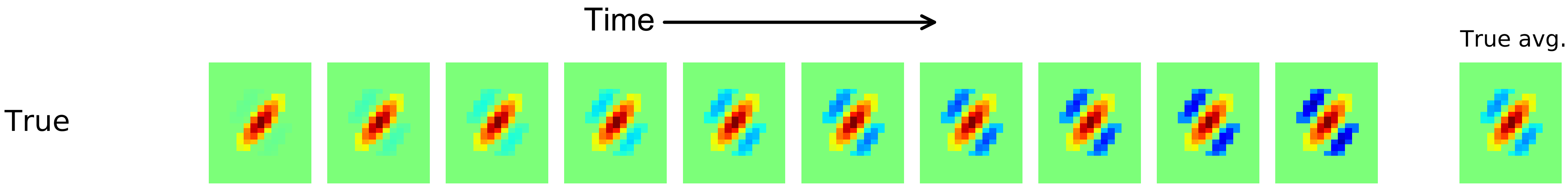
Beyond the linear time-invariant STRF model

Time

True



Beyond the linear time-invariant STRF model



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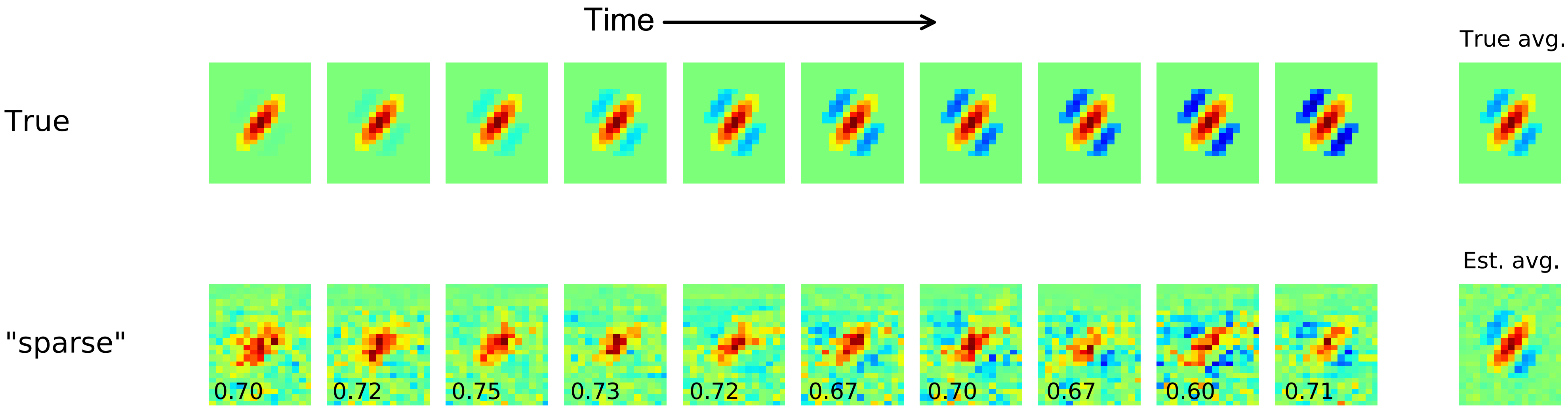
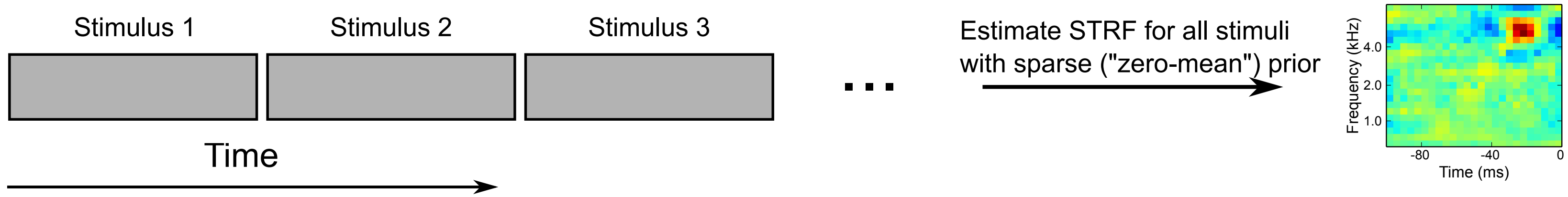


Adaptive STRF estimation model

Step 1 "global"

Average STRF

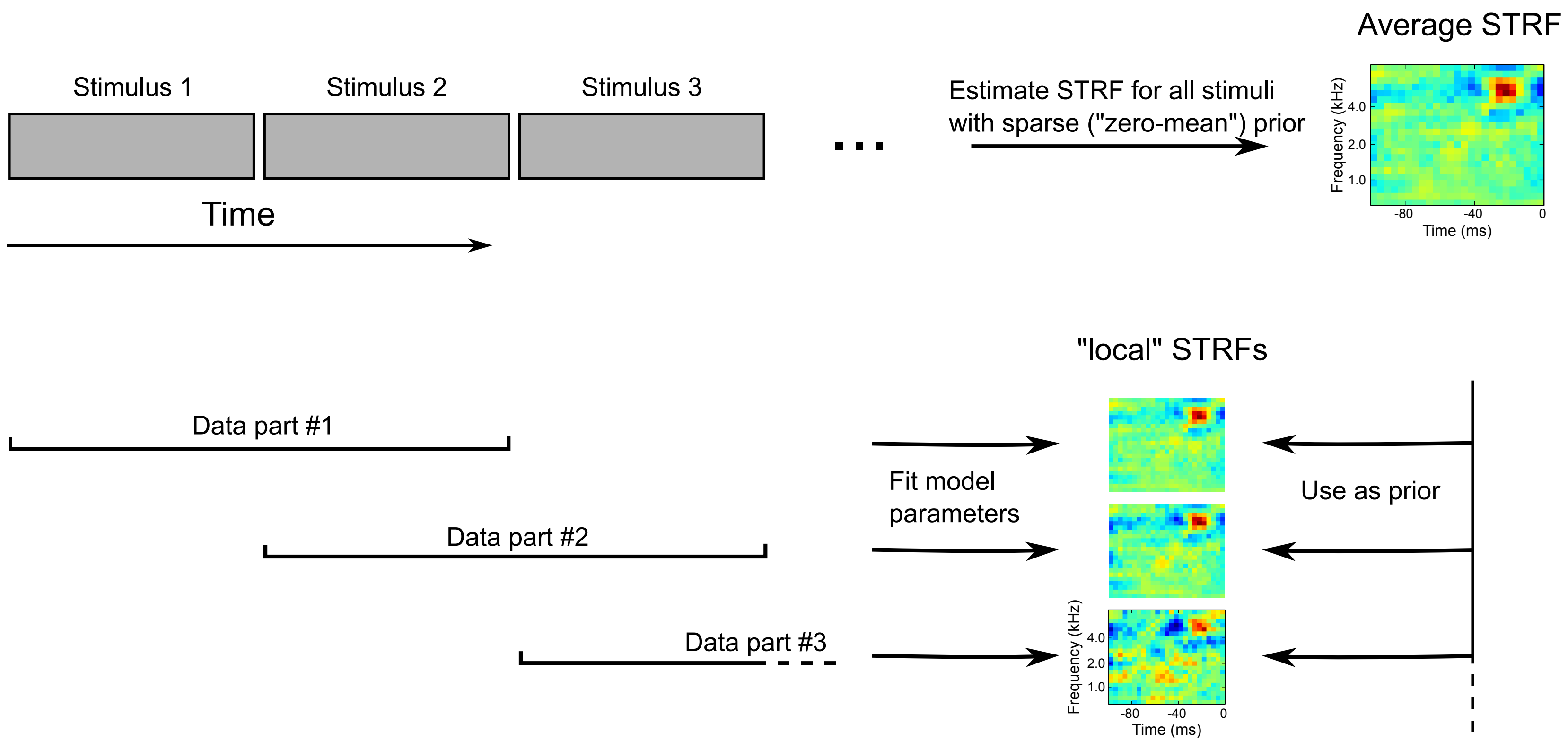


Meyer, Diepenbrock, Ohl, Anemüller (2014)

Adaptive STRF estimation model

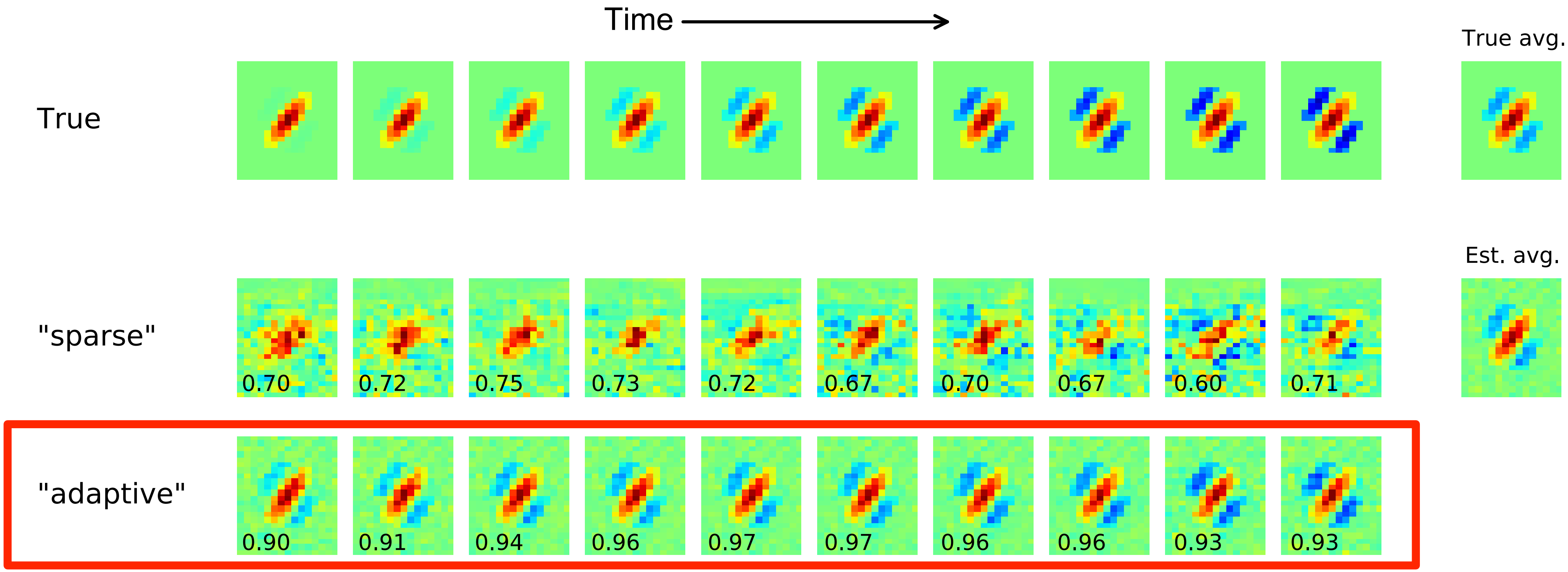
Step 1
“global”

Step 2
“local”

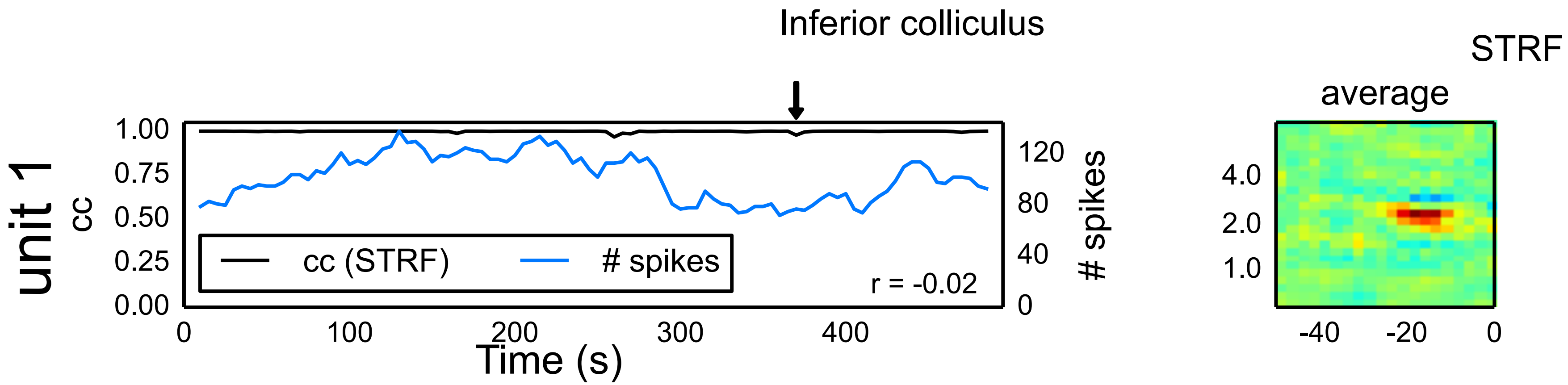


Meyer, Diepenbrock, Ohl, Anemüller (2014)

Adaptive STRF estimation model

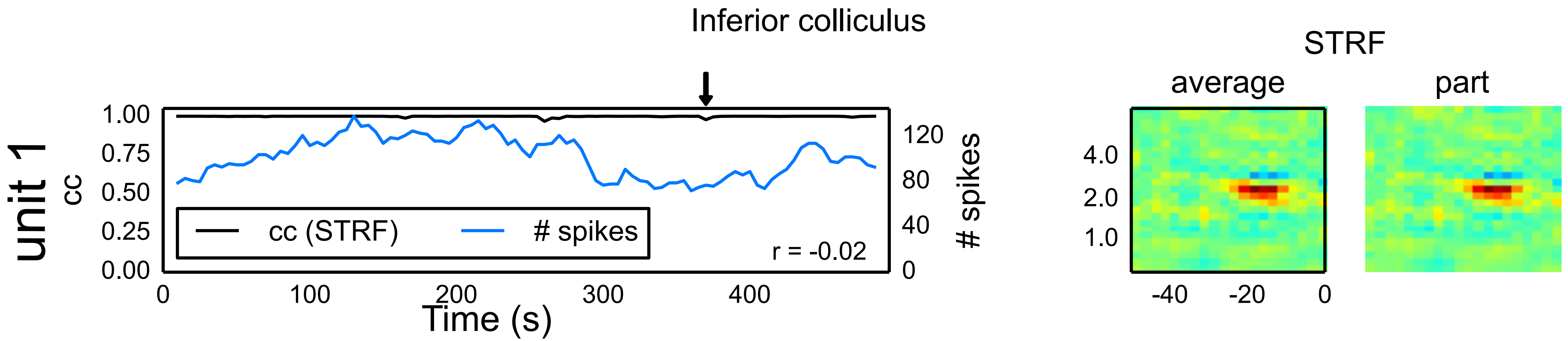


STRF variability across time: Gerbil inferior colliculus



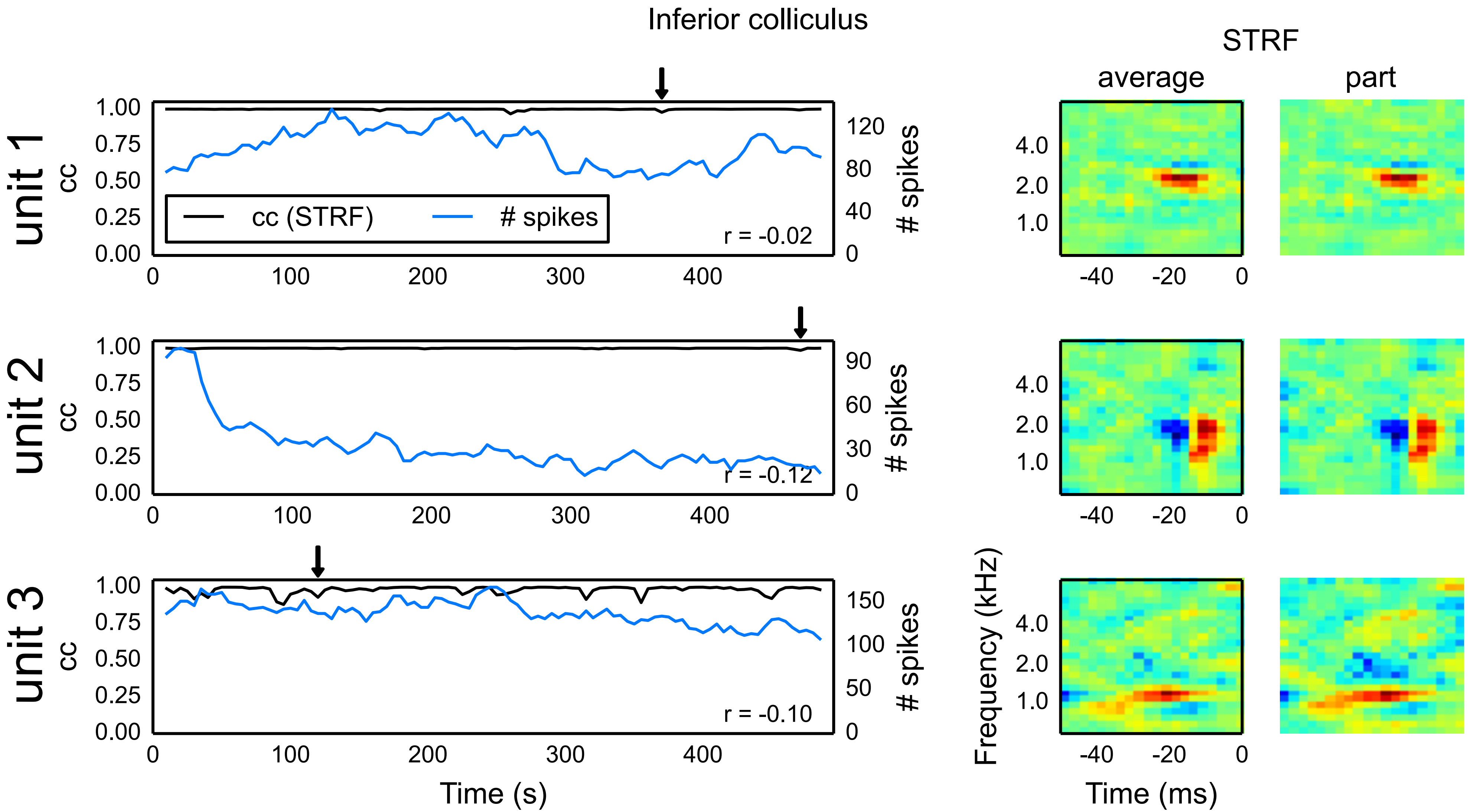
Meyer, Diepenbrock, Ohl, Anemüller (2014)

STRF variability across time: Gerbil inferior colliculus



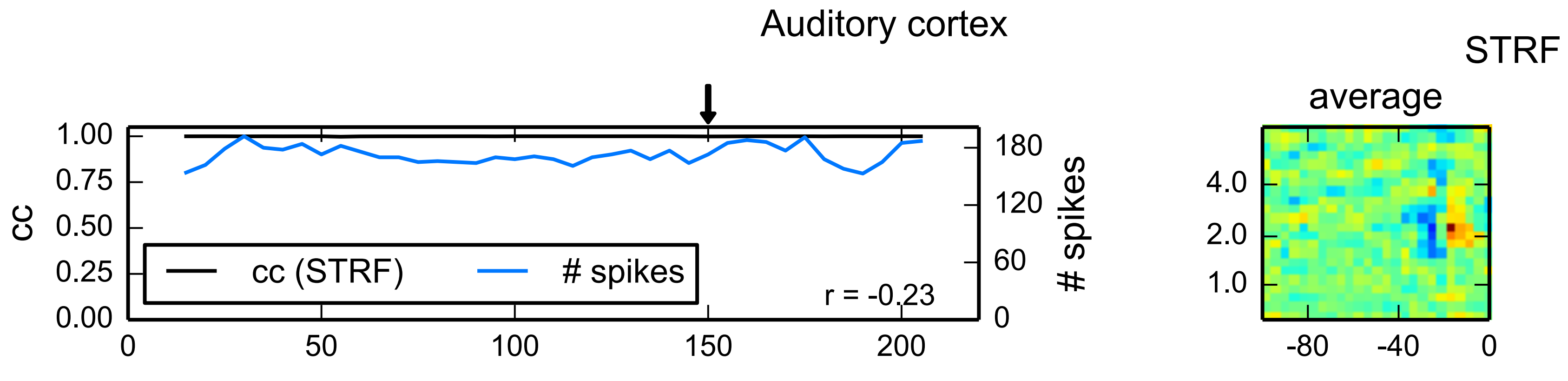
Meyer, Diepenbrock, Ohl, Anemüller (2014)

STRF variability across time: Gerbil inferior colliculus



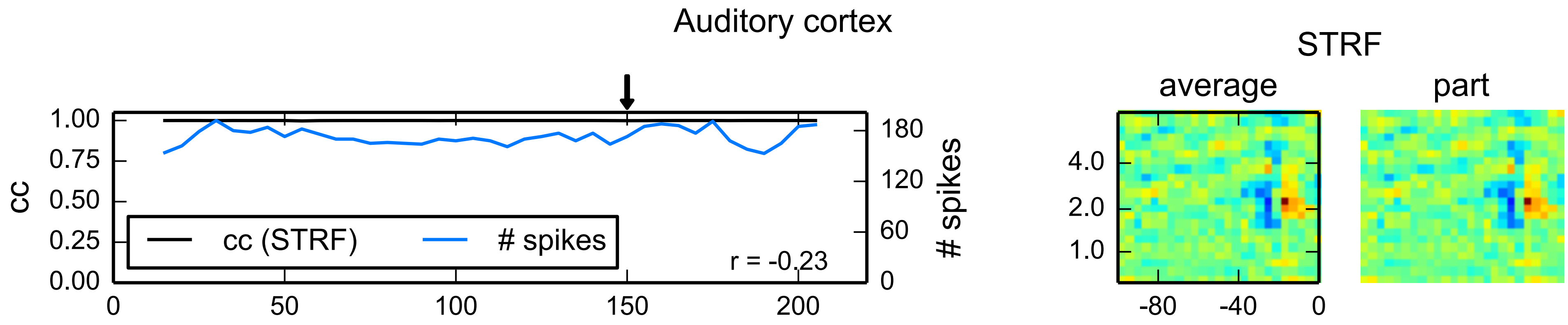
Meyer, Diepenbrock, Ohl, Anemüller (2014)

STRF variability across time: Gerbil auditory cortex



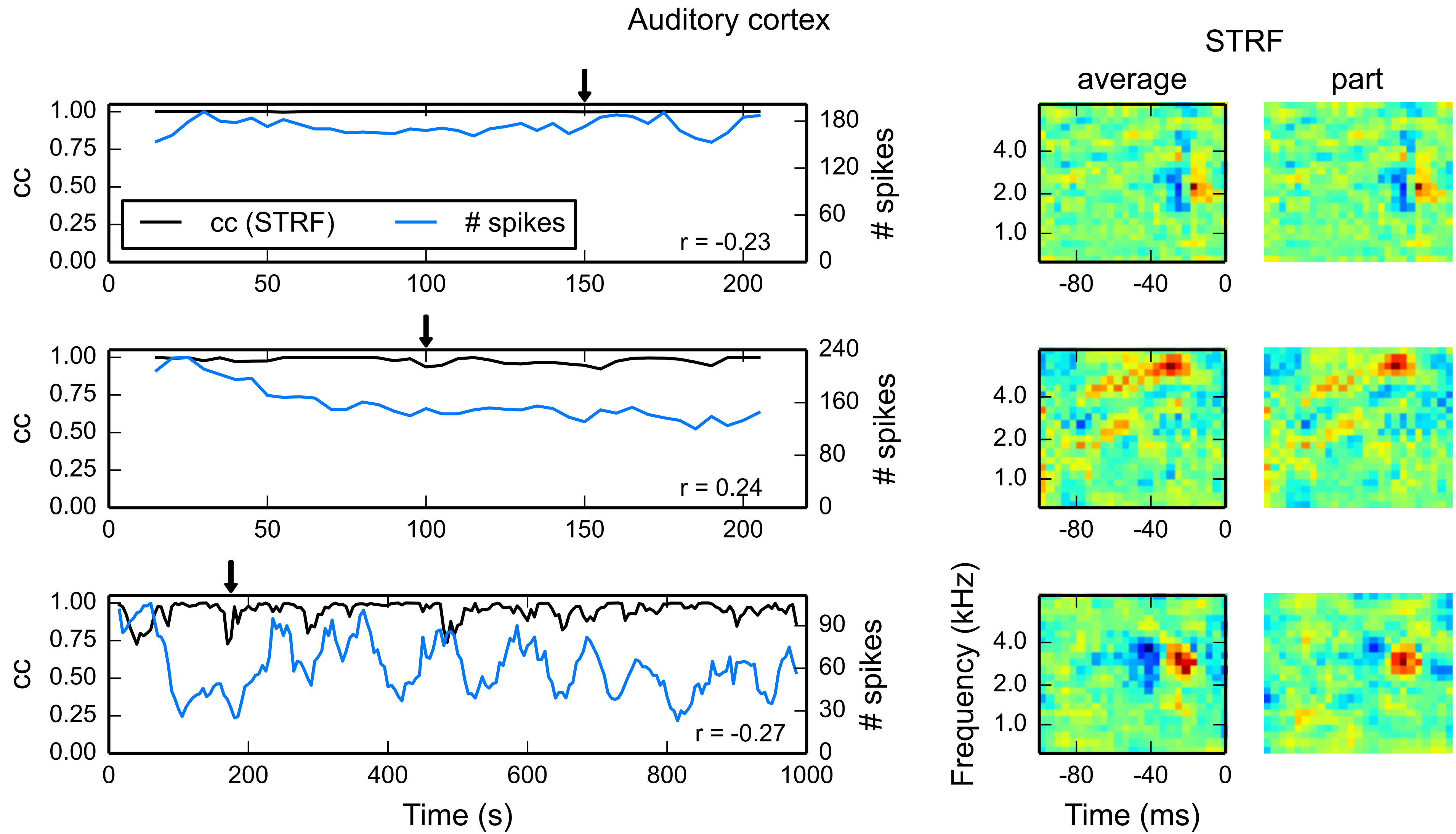
Meyer, Diepenbrock, Ohl, Anemüller (2014)

STRF variability across time: Gerbil auditory cortex



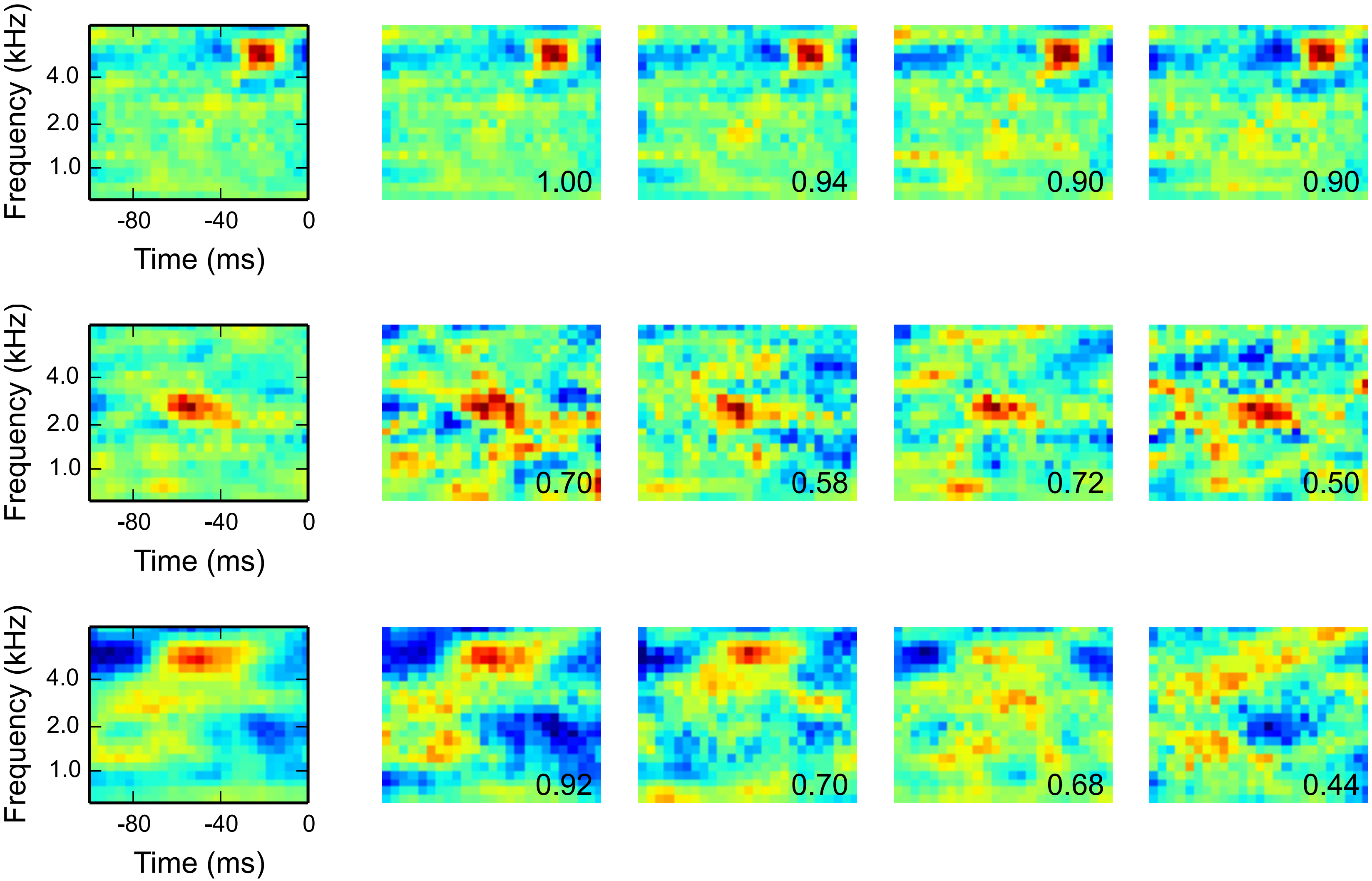
Meyer, Diepenbrock, Ohl, Anemüller (2014)

STRF variability across time: Gerbil auditory cortex

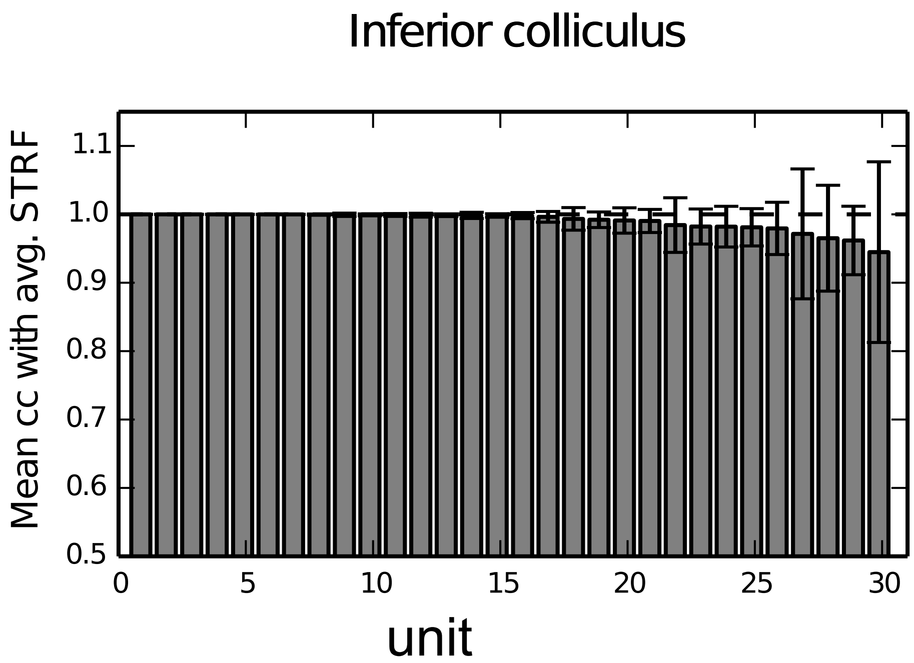


Meyer, Diepenbrock, Ohl, Anemüller (2014)

STRF variability across time:
3 units, moderate to strong fluctuation

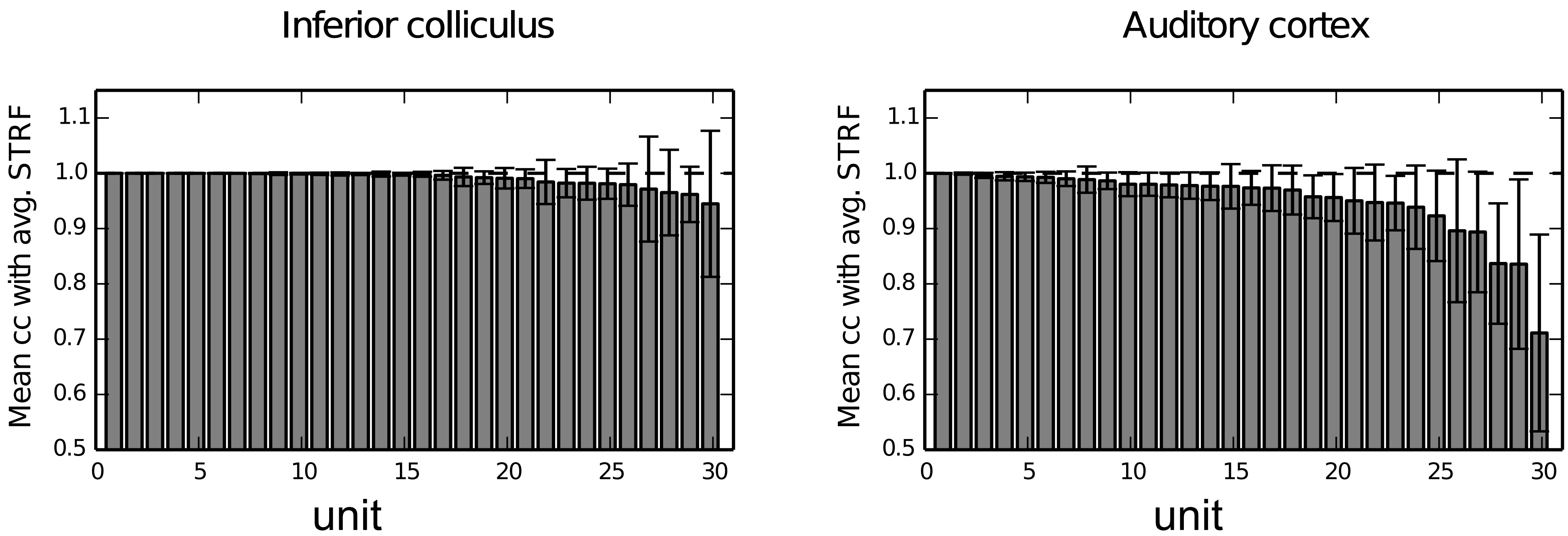


STRF variability across time: Summary statistics



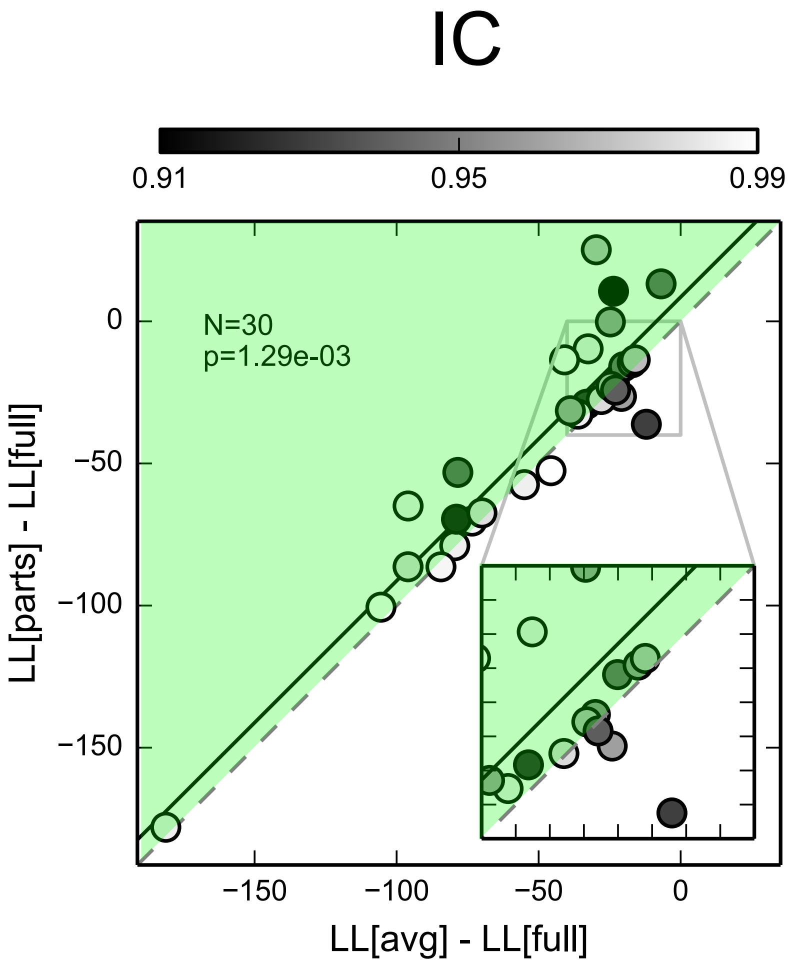
Meyer, Diepenbrock, Ohl, Anemüller (2014)

STRF variability across time: Summary statistics



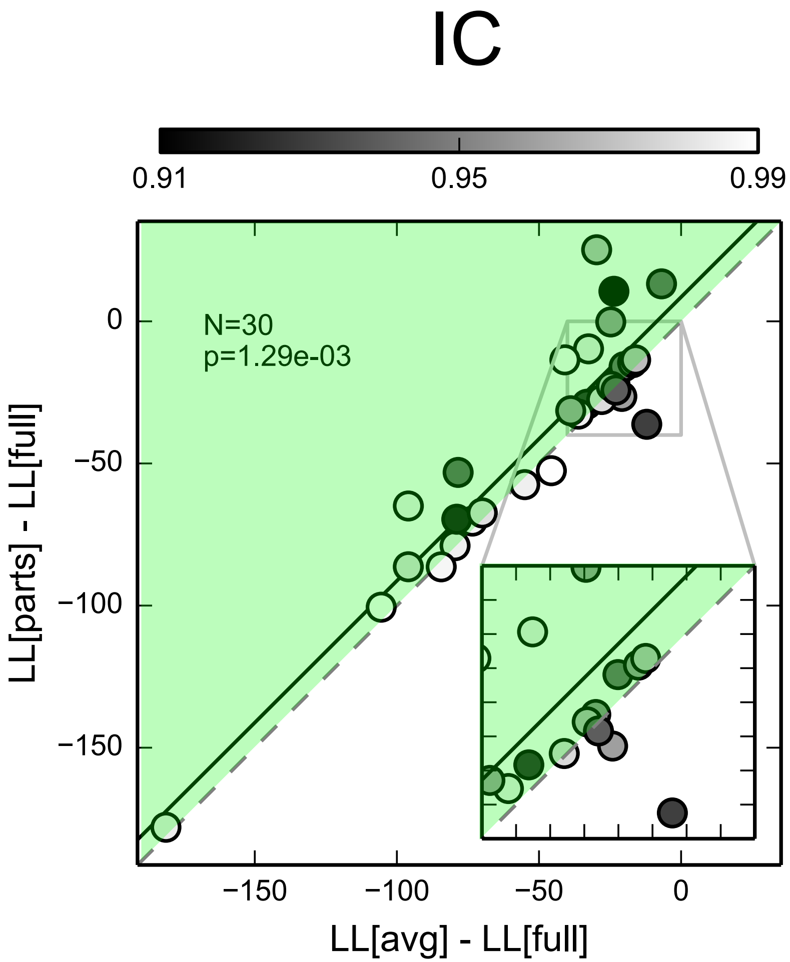
Meyer, Diepenbrock, Ohl, Anemüller (2014)

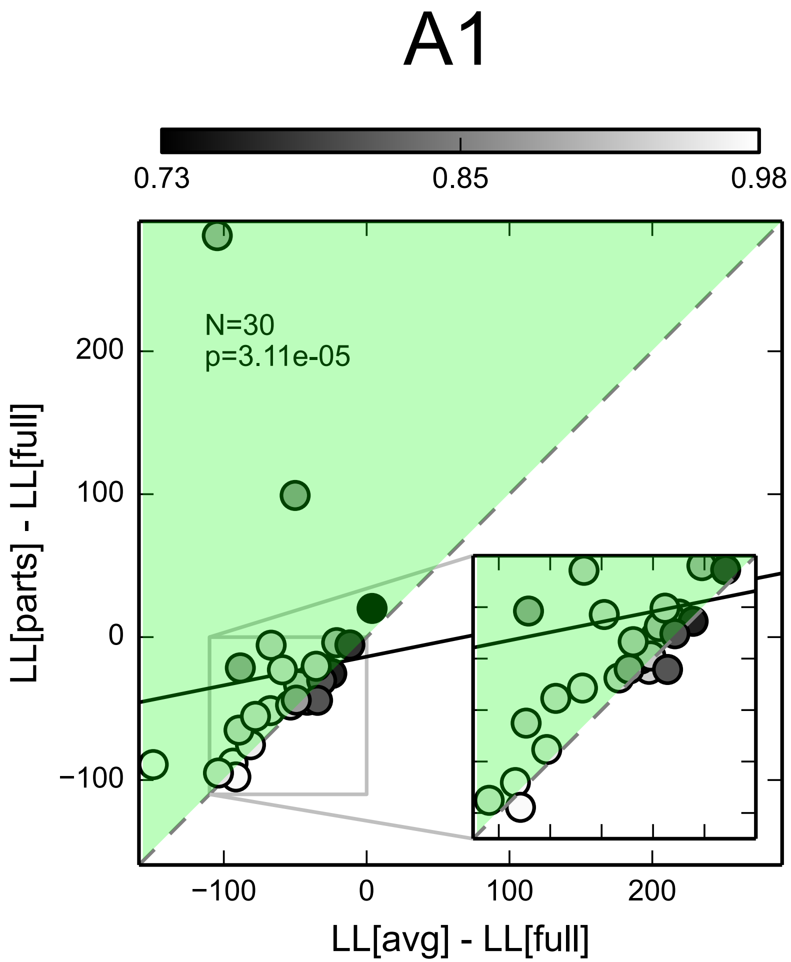
Likelihood evidence of static vs. adaptive STRF model



Meyer, Diepenbrock, Ohl, Anemüller (2014)

Likelihood evidence of static vs. adaptive STRF model

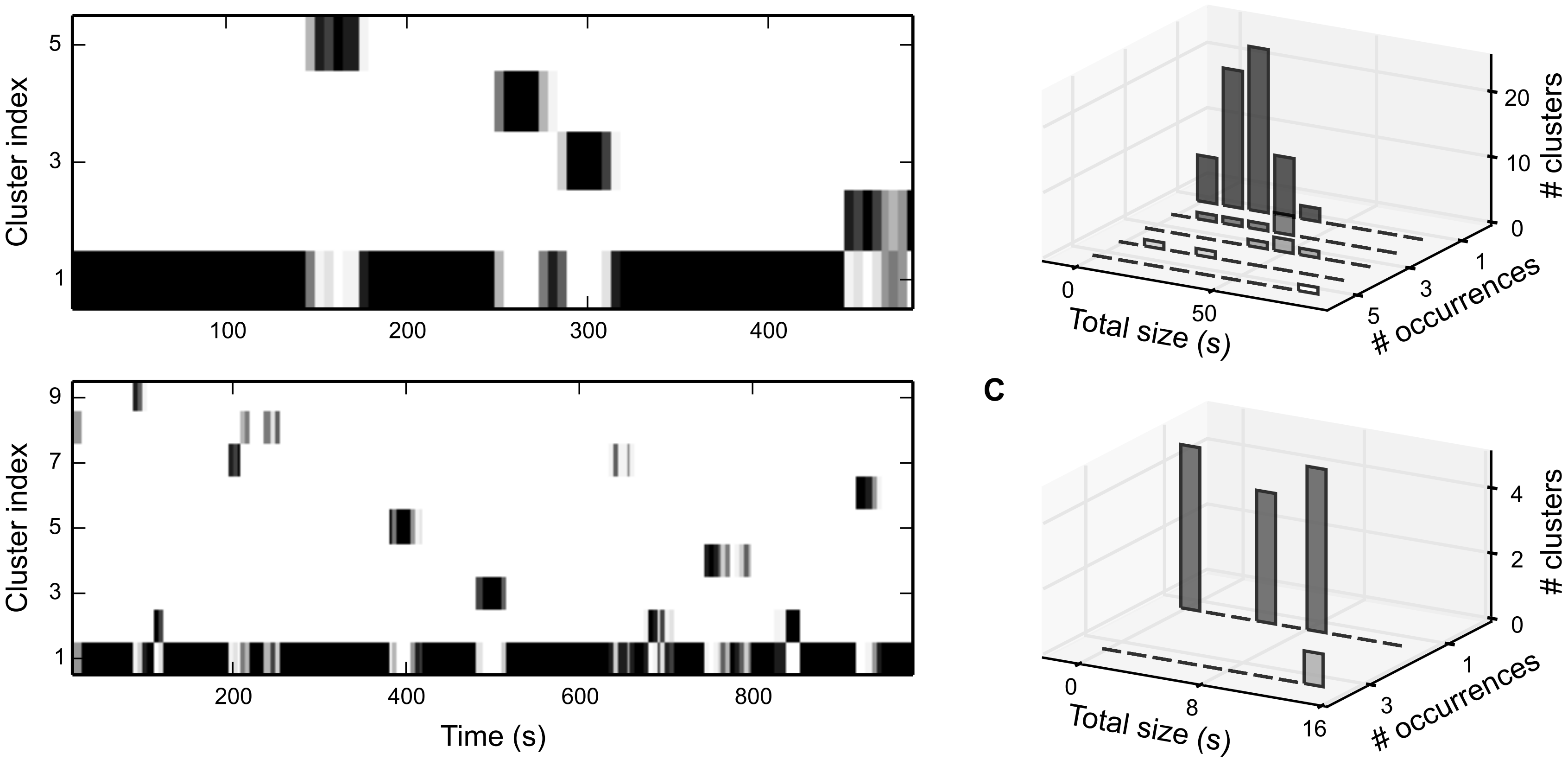




Meyer, Diepenbrock, Ohl, Anemüller (2014)

Cluster analysis:
Do the neurons “revisit” discrete states?

Cluster analysis of two A1 units



Summary dynamic STRF model

- dynamic variability in STRF seems unrelated to spike count
- STRF variability higher in A1 than IC (shown quantitatively)
- quality of STRF variability:
  - parts of STRF change dynamically
  - even spectral BF changes in some cases
- dynamic STRF model supported by higher likelihood than static model

- Origin of fluctuations unclear. Randomly on timescale ~10s? Linked to stimuli?