Representation of high bandwidth sensory information by small circuits in the whisker system

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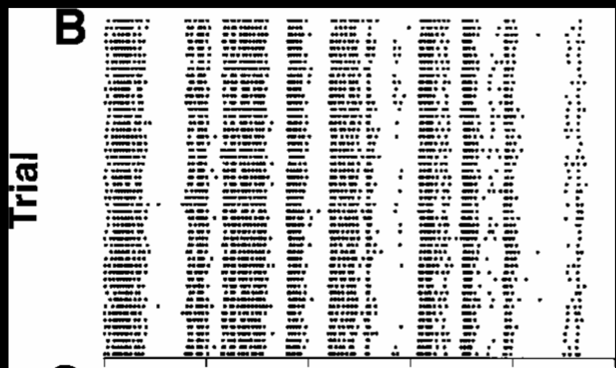
Two views of neural coding

- Low bandwidth

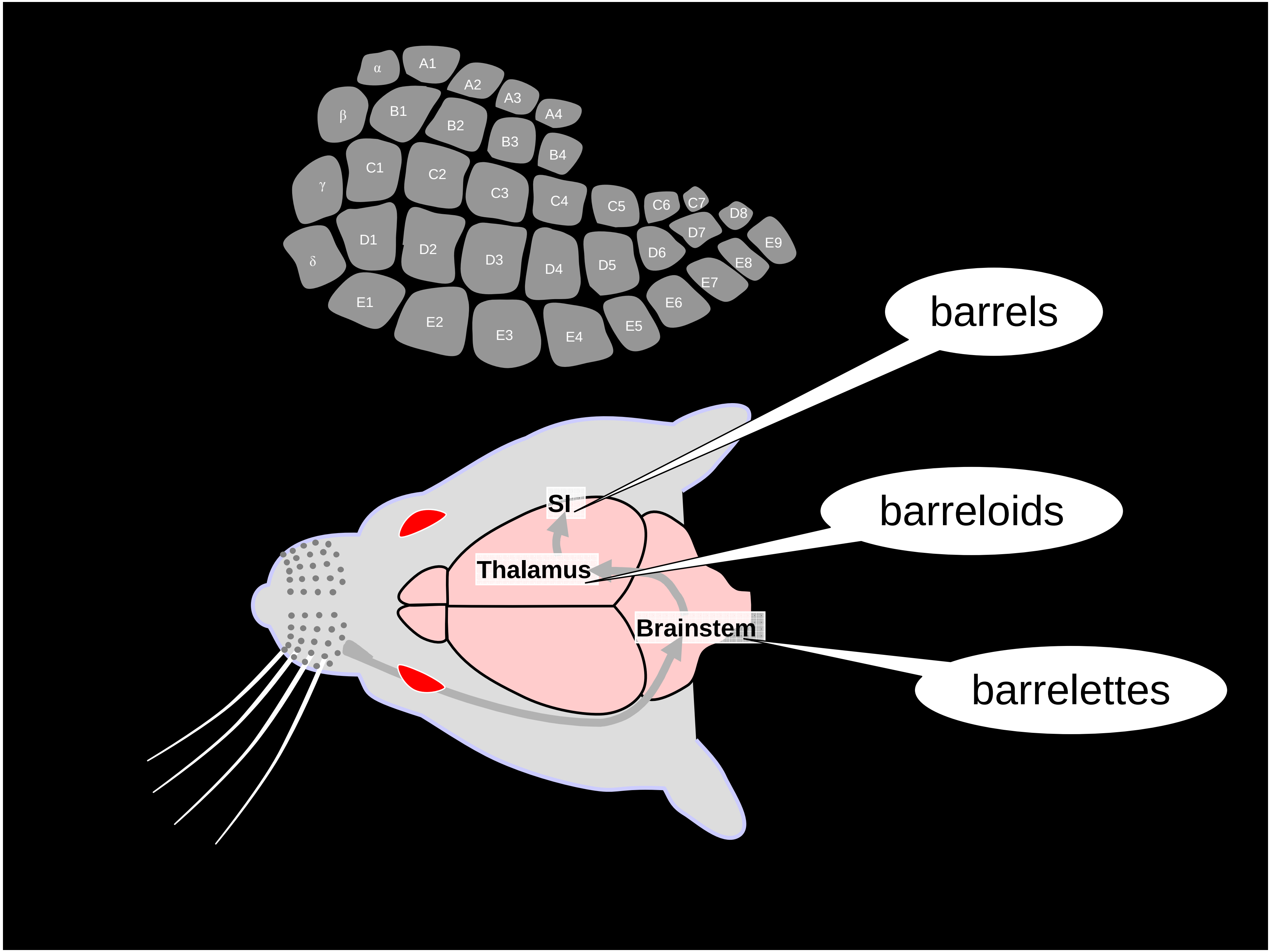
  e.g., visual cortex

- High bandwidth

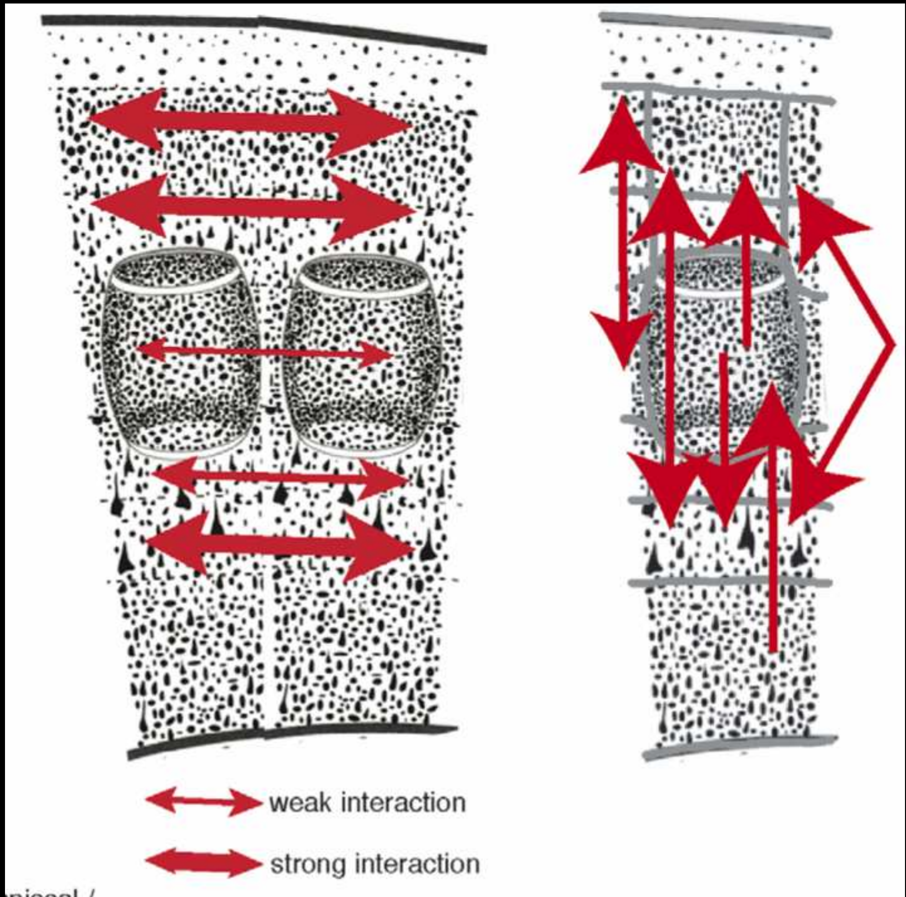
  e.g., fly H1

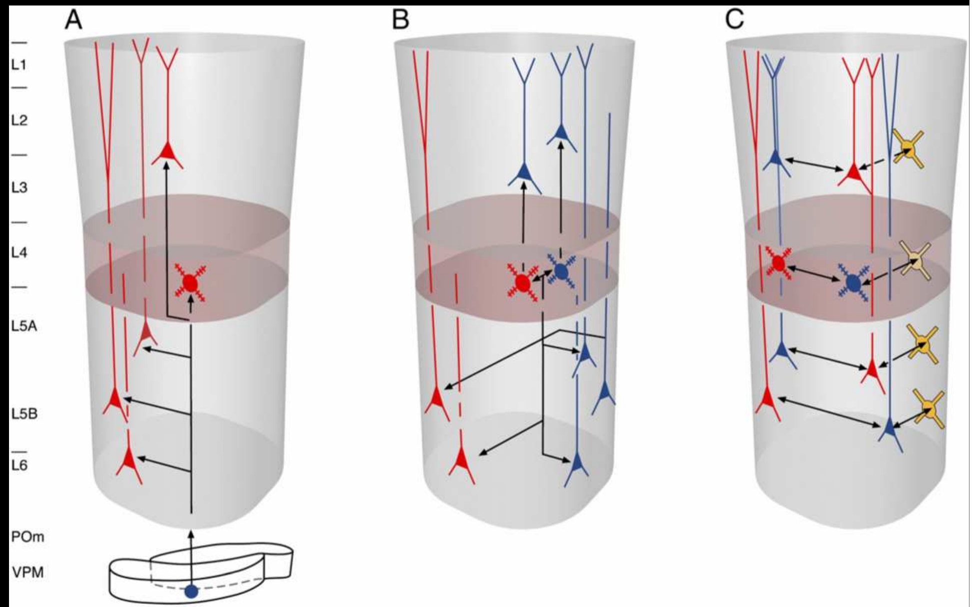


de Ruyter et al (1997)



α
A1
A2
A3
A4
β
B1
B2
B3
B4
γ
C1
C2
C3
C4
C5
C6
C7
δ
D1
D2
D3
D4
D5
D6
D7
D8
E1
E2
E3
E4
E5
E6
E7
E8
E9
barrels
barreloids
barrelettes
SI
Thalamus
Brainstem

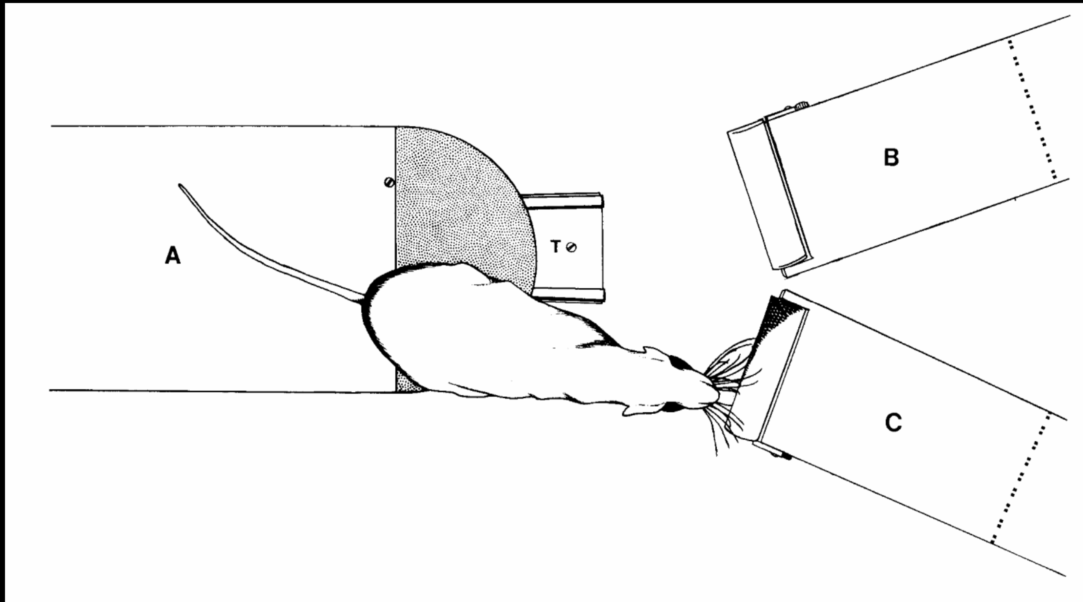


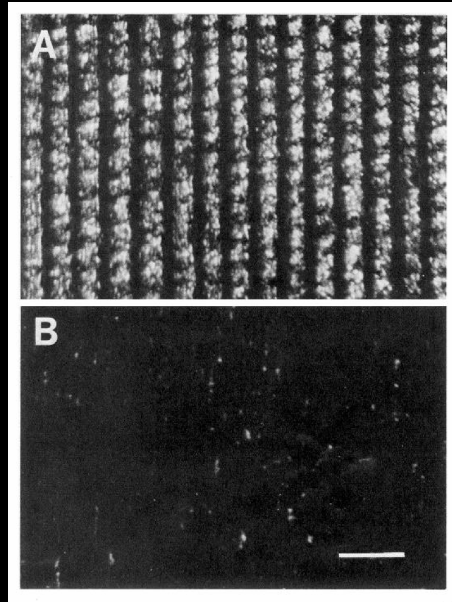


Brecht (2007) COIN

Helmstaedter et al. (2007) Br Res Rev

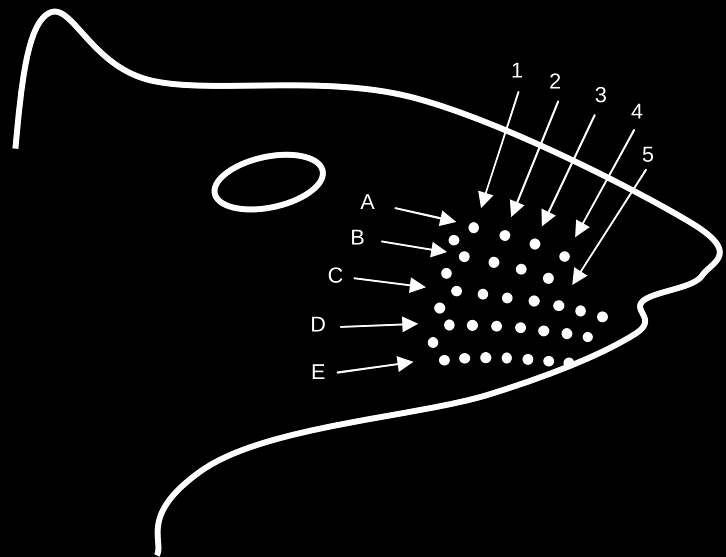
Tansu Celikel





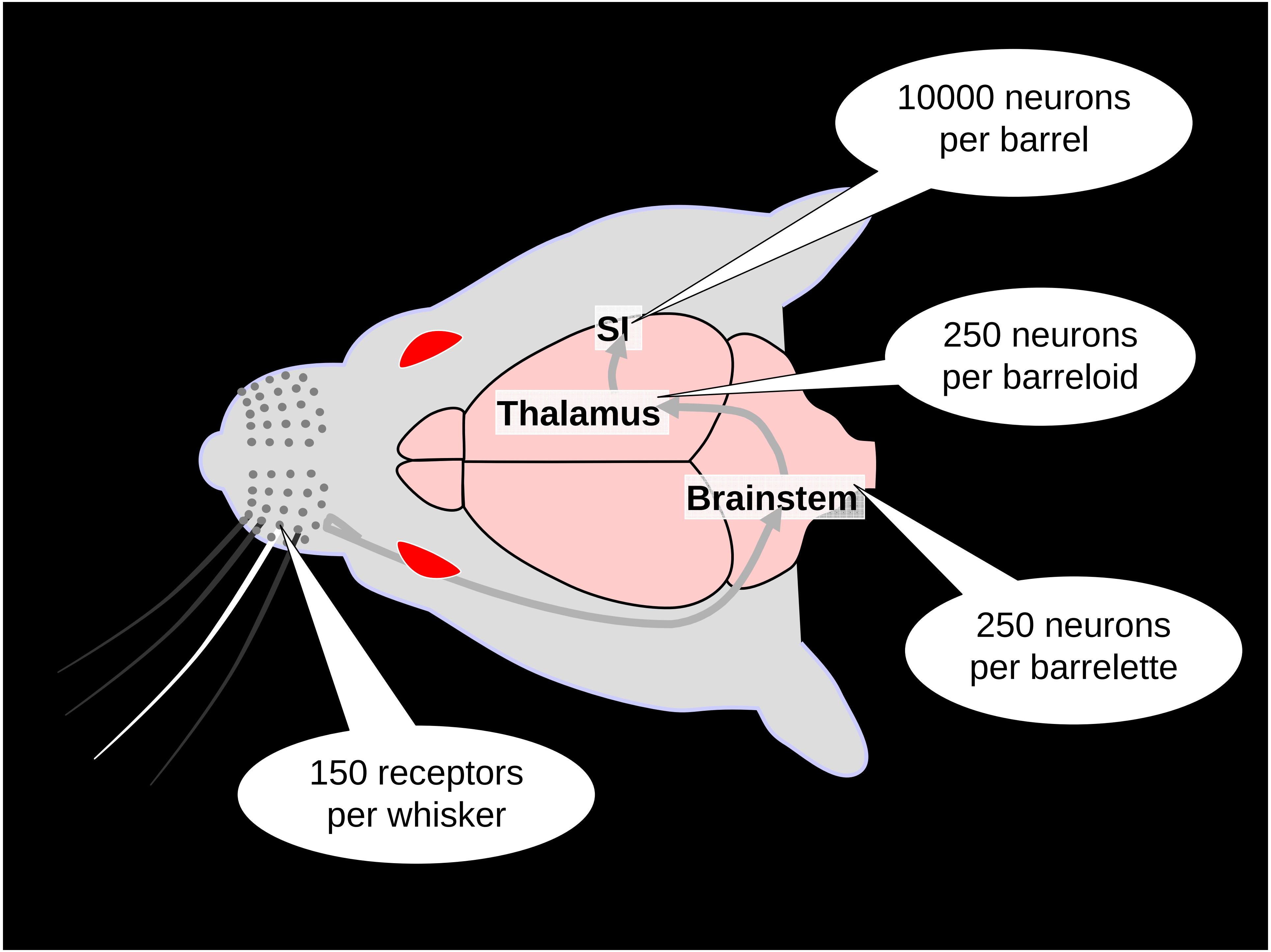
30 micron grooves

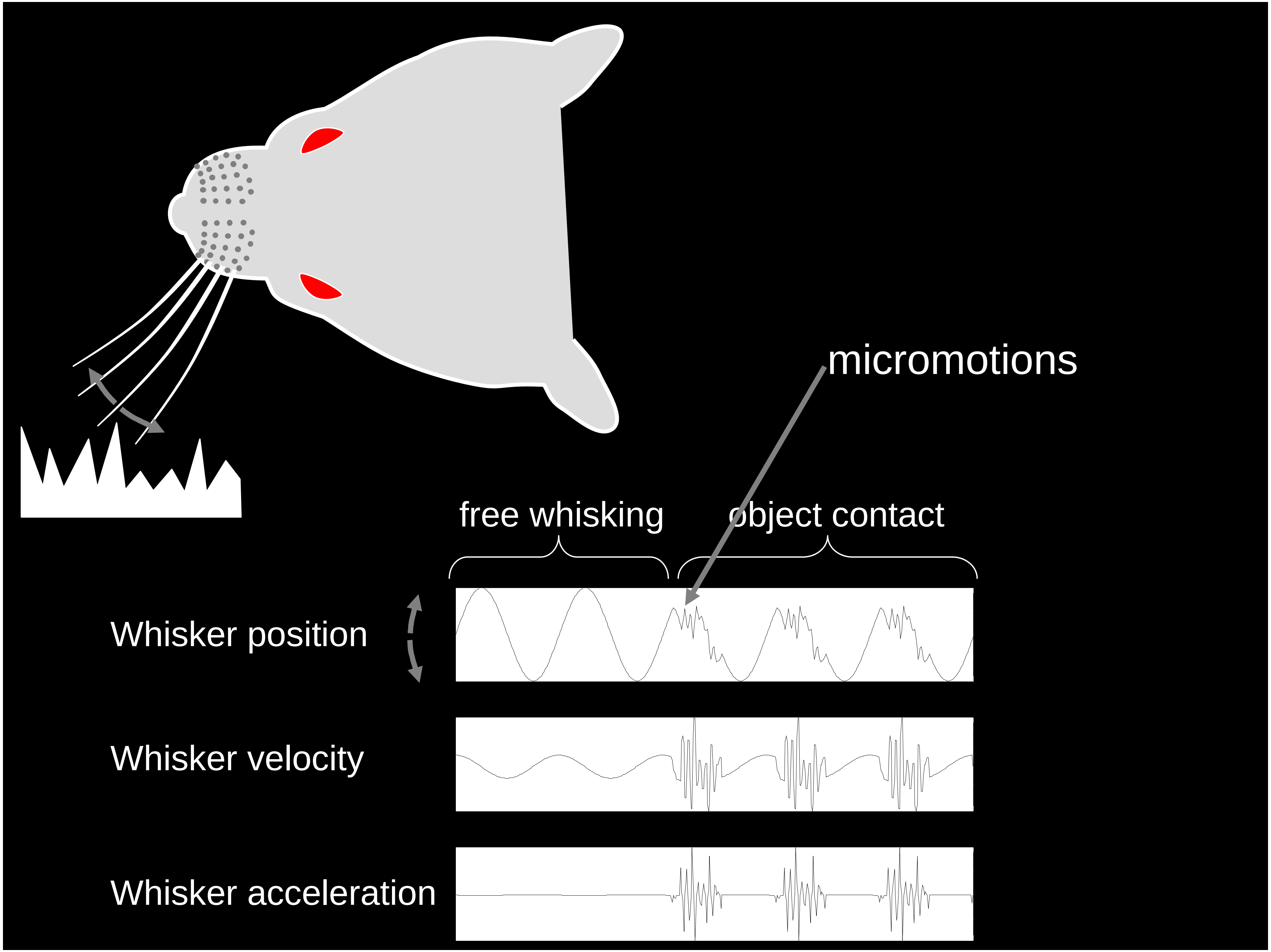
smooth

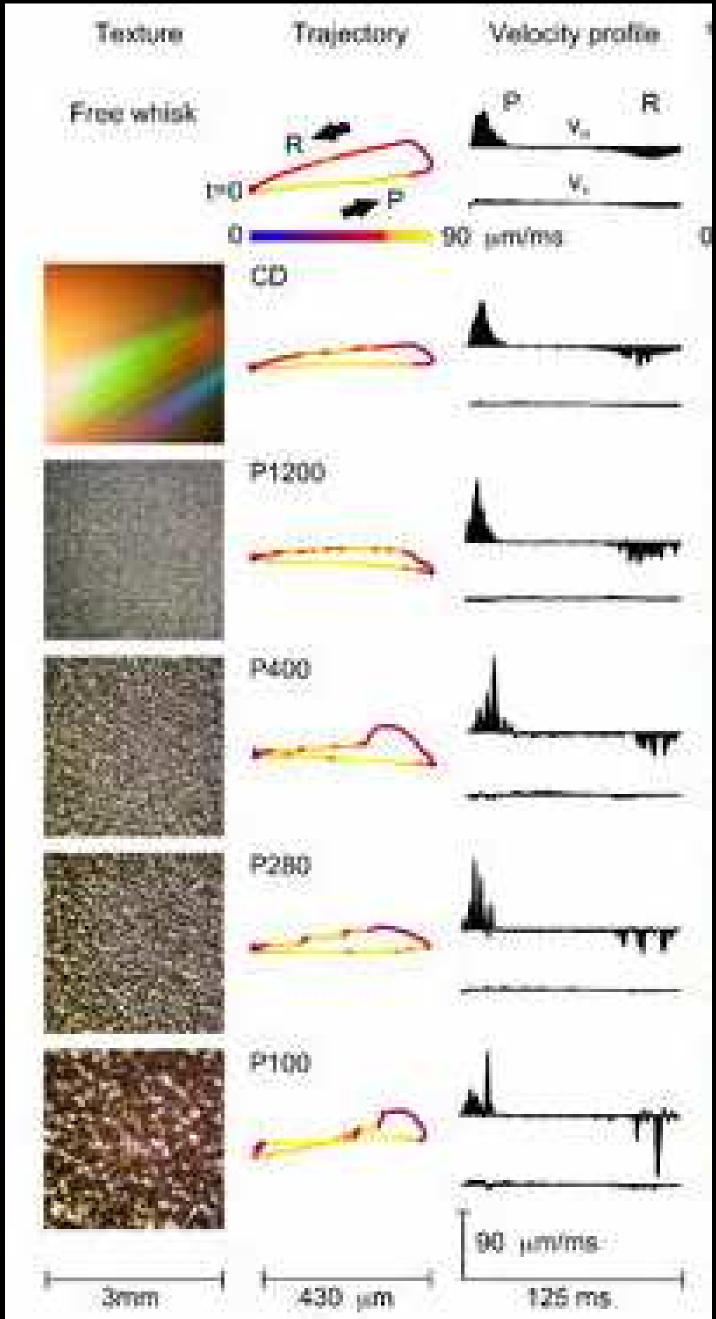


Single whisker discrimination

Carvell & Simons (1990)


10000 neurons per barrel
SI
250 neurons per barreloid
Thalamus
Brainstem
250 neurons per barrelette
150 receptors per whisker

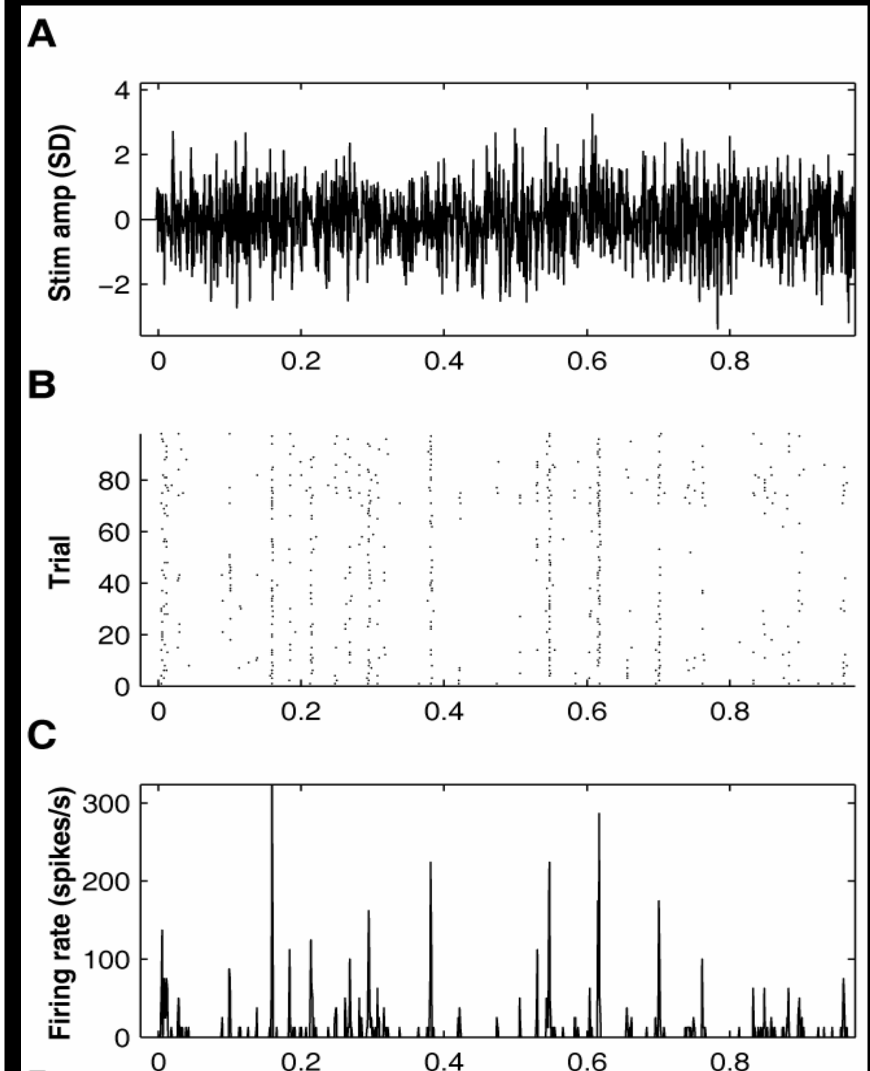

micromotions
free whisking
object contact
Whisker position
Whisker velocity
Whisker acceleration

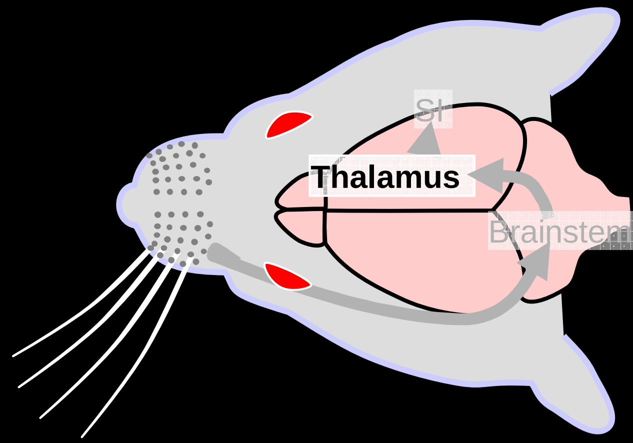


- Experimentally measured micromotions
- Importance of temporal domain

Arabzadeh et al. (2005)

Coding temporal signals



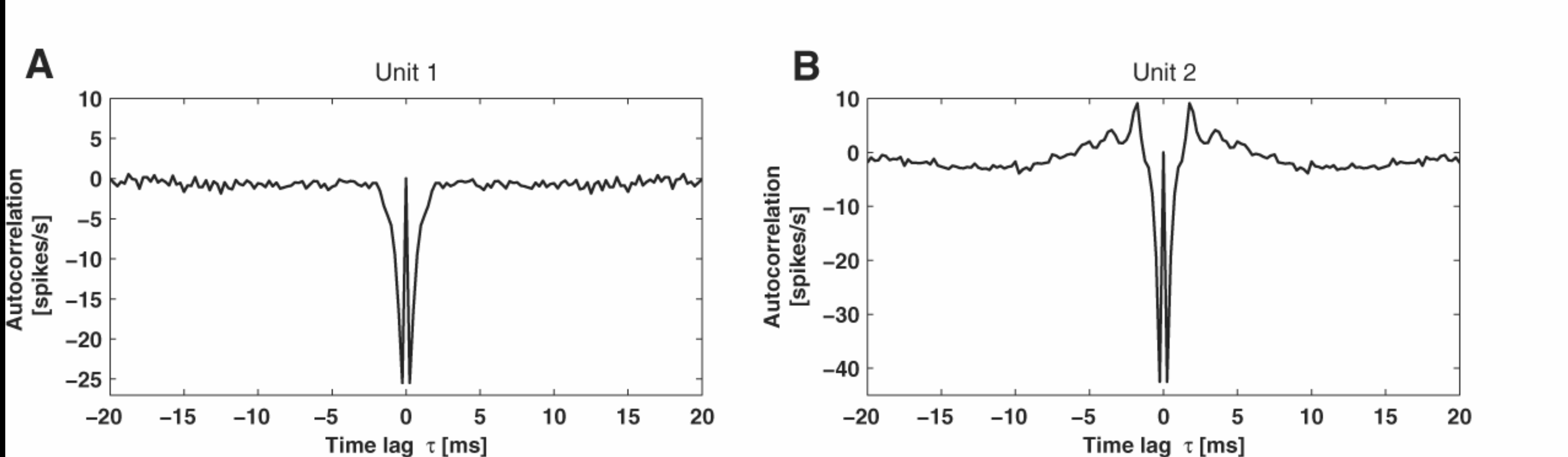


1. **Response question**:
   What is the 'information-bearing element' of the neuronal response?
2. **Stimulus question**:
   What stimulus features do the information-bearing elements signify?

The information-bearing element of a spike train

Hypothesis 1. Firing rate

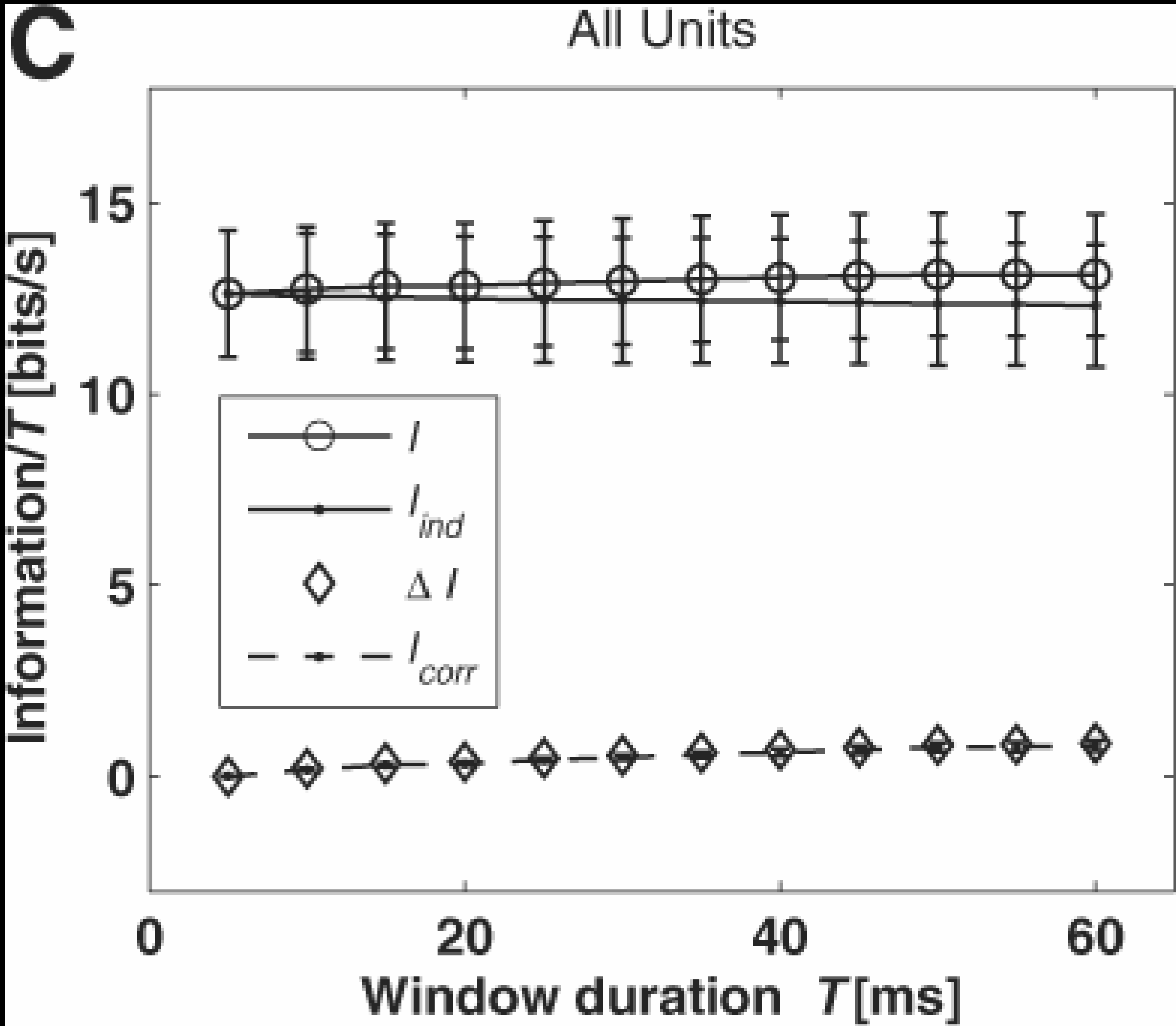
Hypothesis 2. Correlations between spikes



Firing rate vs temporal correlations

- **Effect of correlations on encoded information (I_{corr})**
  How much does the presence of noise correlations change the information compared to a hypothetical neural system where the neuron has identical mean firing rate but zero noise correlations? (eg Schneidman et al., 2003)

- **Effect of correlations on decodable information (ΔI)**
  If a hypothetical downstream decoding circuit attempts to decode using a model that includes mean firing rates but ignores noise correlations, how much information will be lost? (Nirenberg et al., 2001)

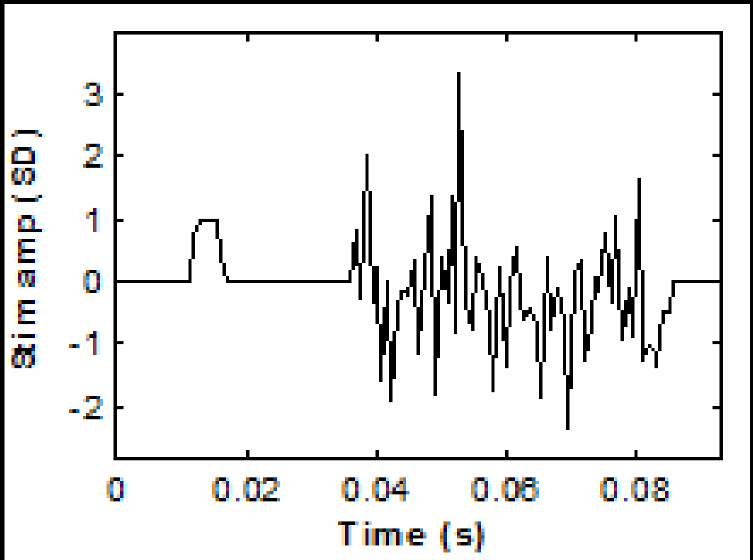


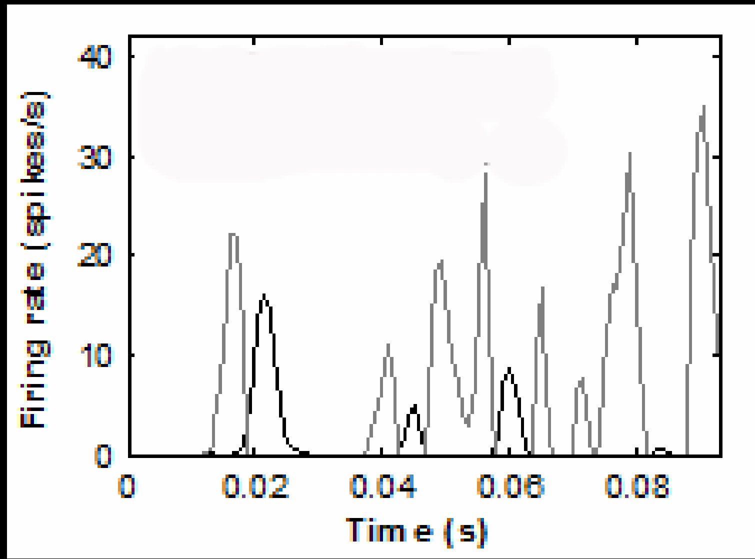
Montemurro et al (2007) *J Neurophysiol*

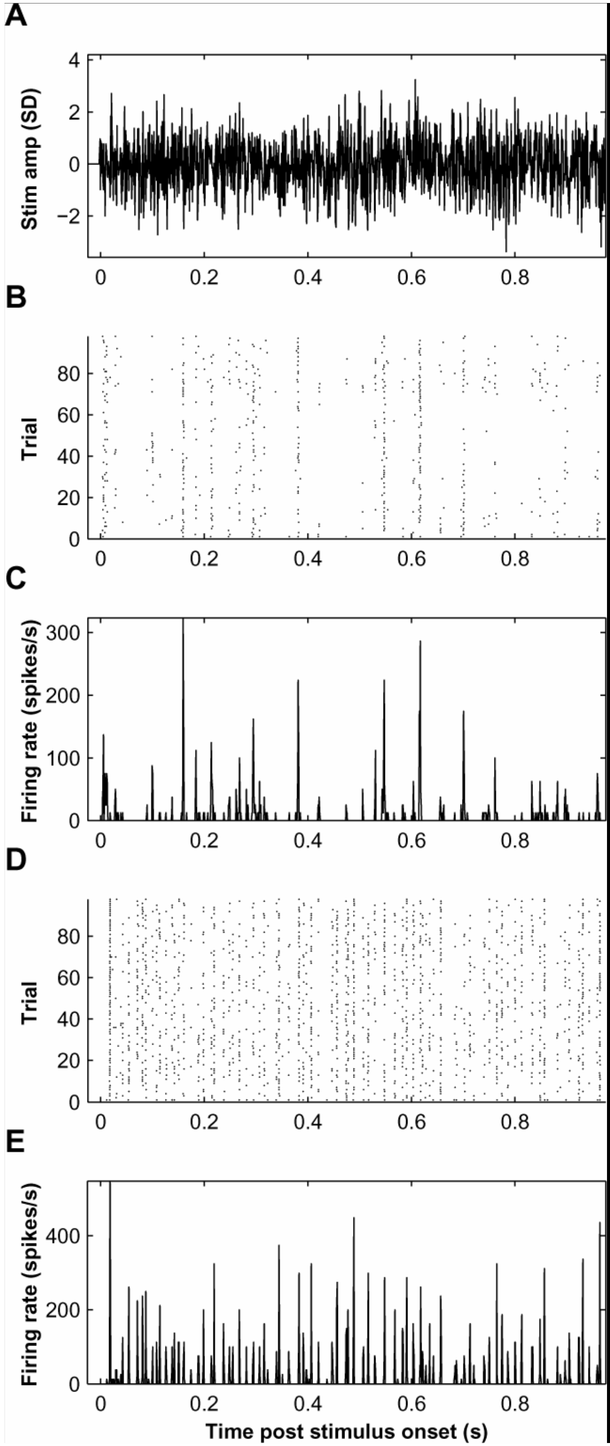
Summary

- For VPM neurons stimulated by white noise, key “information-bearing element” is firing rate
- For most VPM neurons, higher order temporal correlations have minor impact

What stimulus features does the firing rate signify?







Approaches:
- Pseudolinear model:
  - Spike-triggered averaging
- Non-linear models:
  - Spike feedback (Paninski) model
  - Spike-triggered covariance analysis

Linear Nonlinear Poisson (LNP) Model

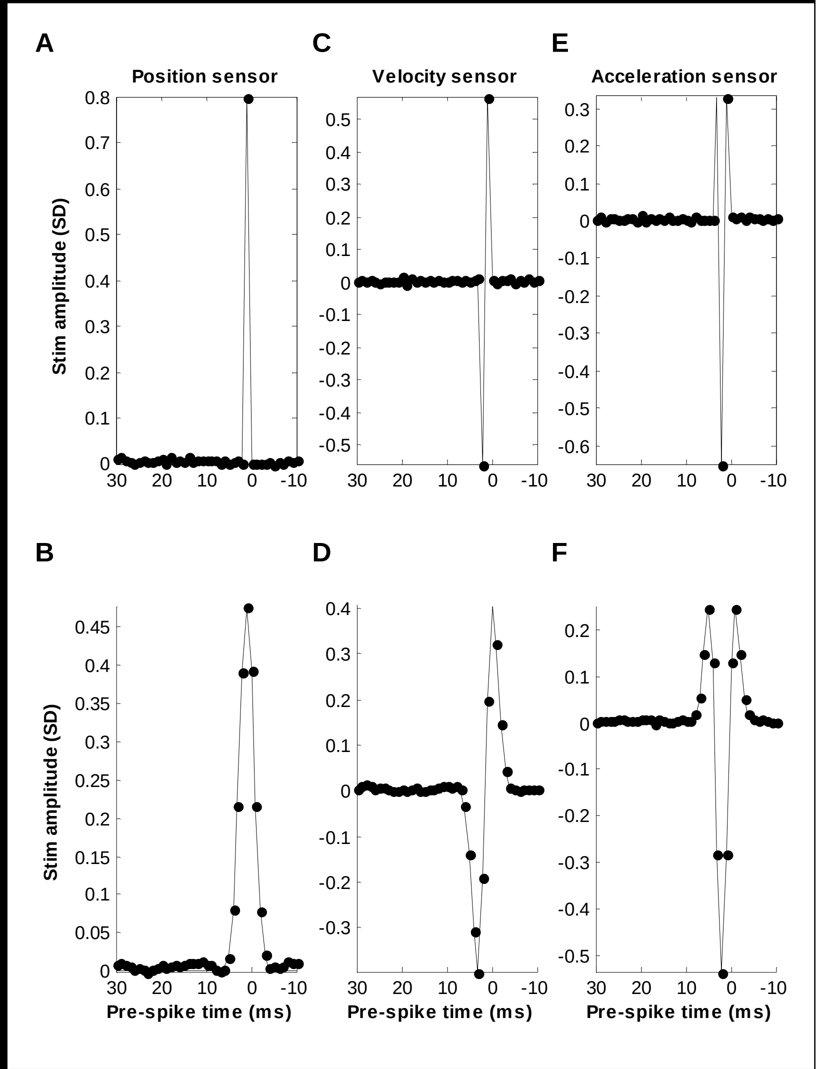
$$k(t) = \sum_{i=0}^{i=T/\delta t} s(t - i\delta t) f(i\delta t)$$

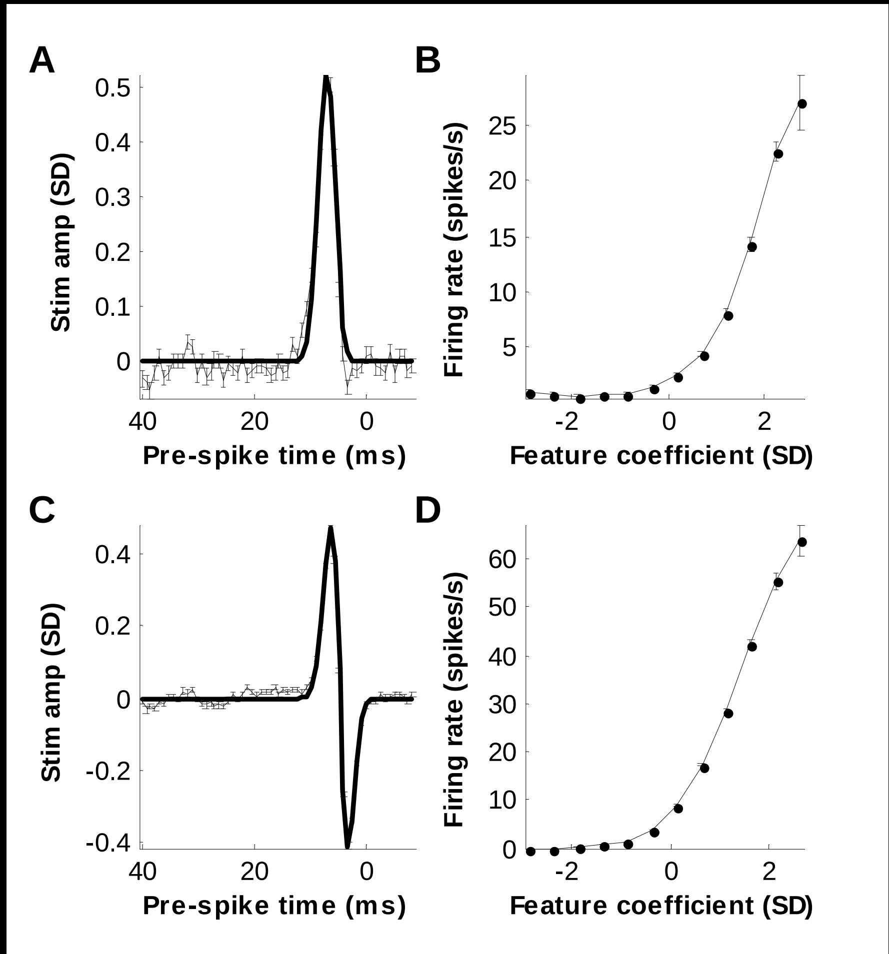
$$r(t) = g[k(t)]$$

Position $\quad r(t) = g[s(t)]$

Velocity $\quad r(t) = g[s(t) - s(t - \delta t)]$

Acceler. $\quad r(t) = g\left[\frac{1}{2} s(t) - s(t - \delta t) + \frac{1}{2} s(t - 2\delta t)\right]$

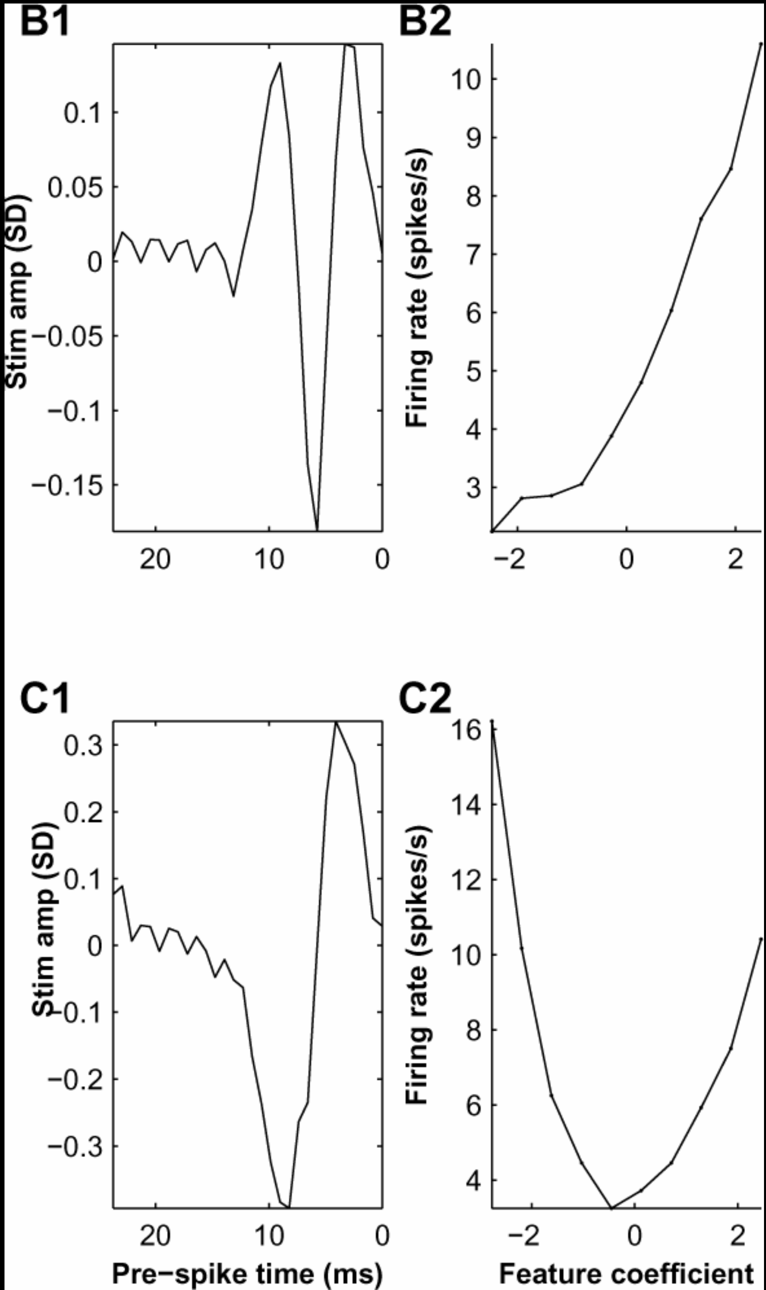


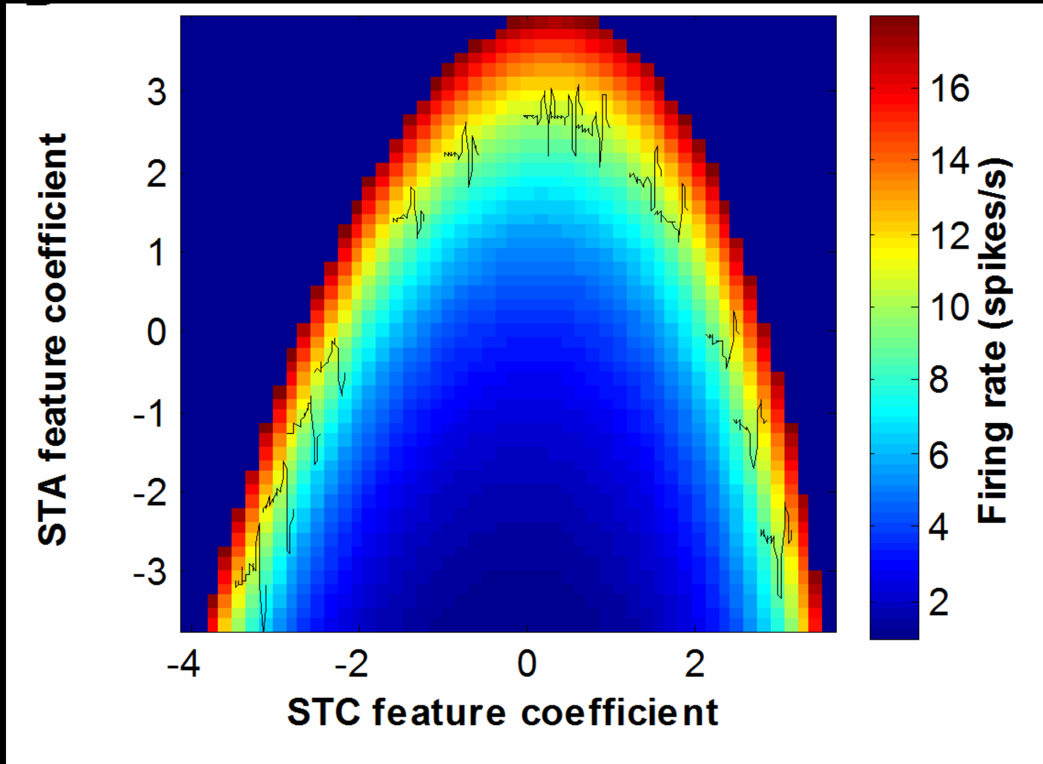


Petersen et al (in press) *Neuron*

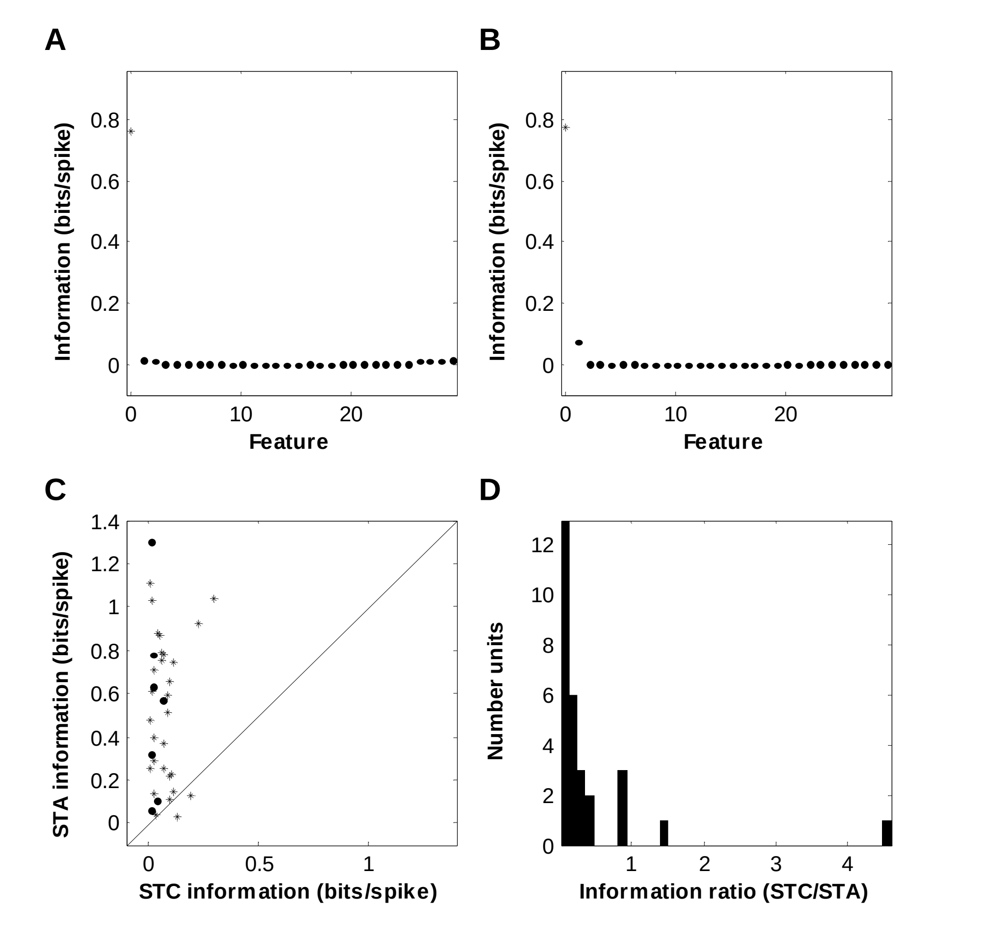
How accurate is the LNP model?

- Non-linear approaches:
  - Maximum likelihood fitting of spike feedback (Paninski) model
  - Spike-triggered covariance analysis





Petersen et al (in press) *Neuron*

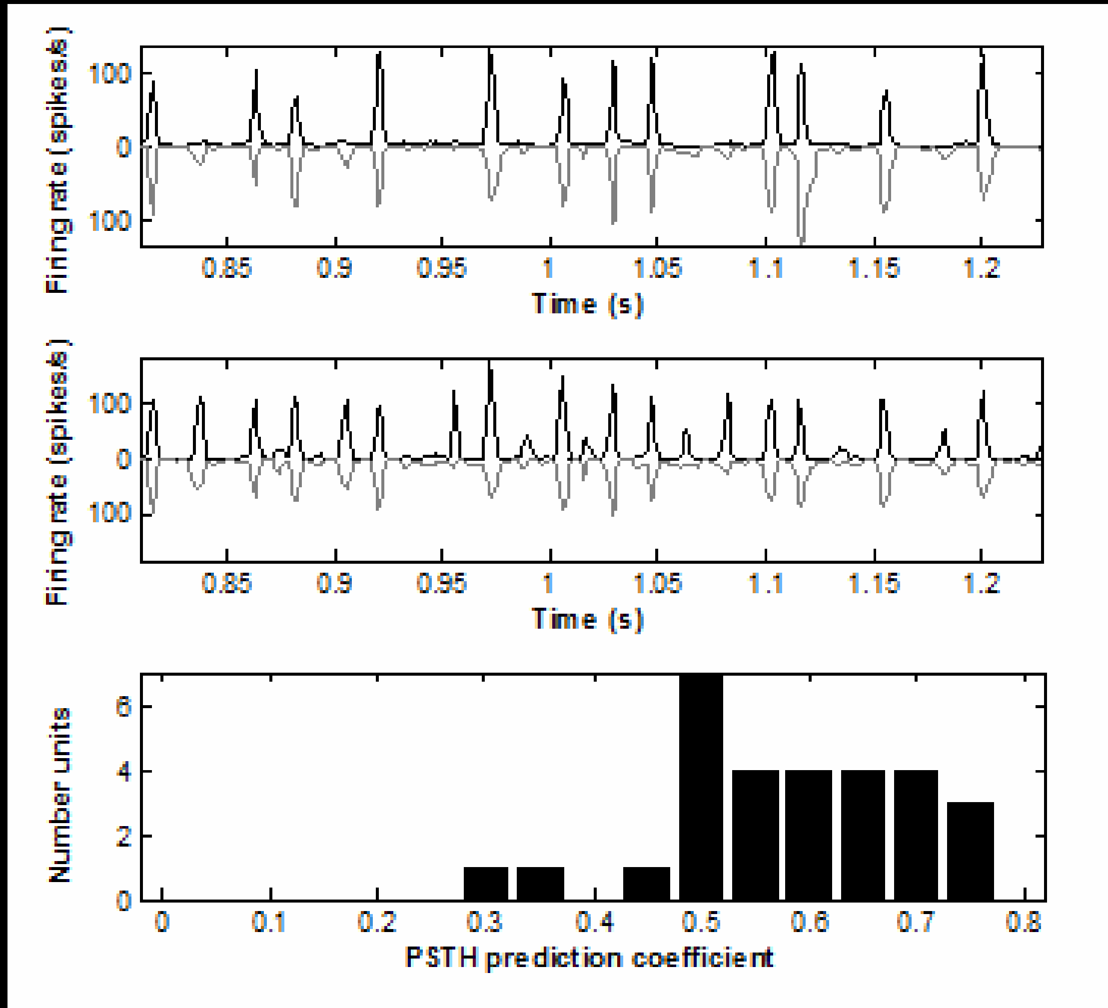


Petersen et al (in press) *Neuron*

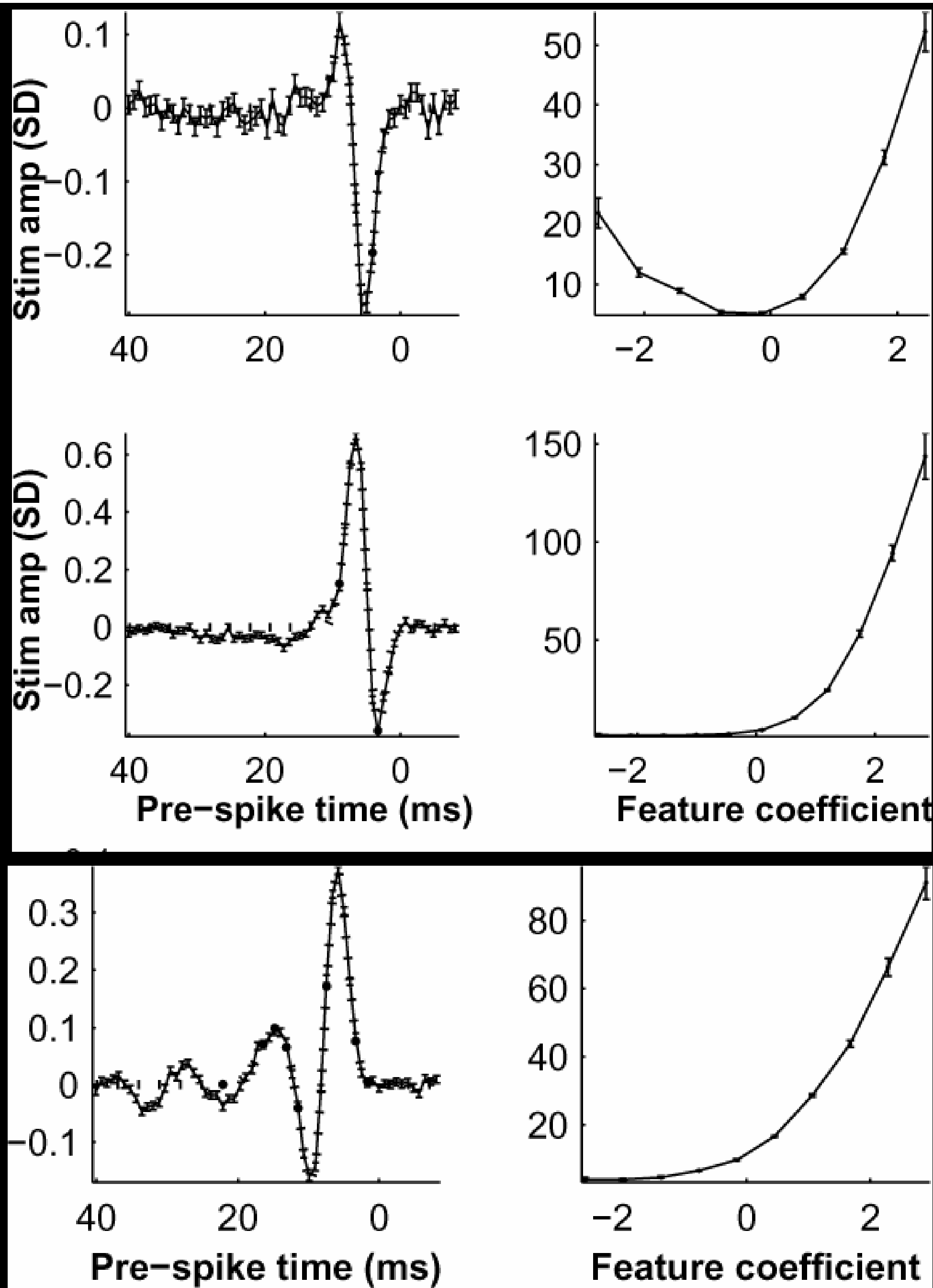
LNP model

$$k(t) = \sum_{i=0}^{i=T/\delta t} s(t - i\delta t) f(i\delta t)$$

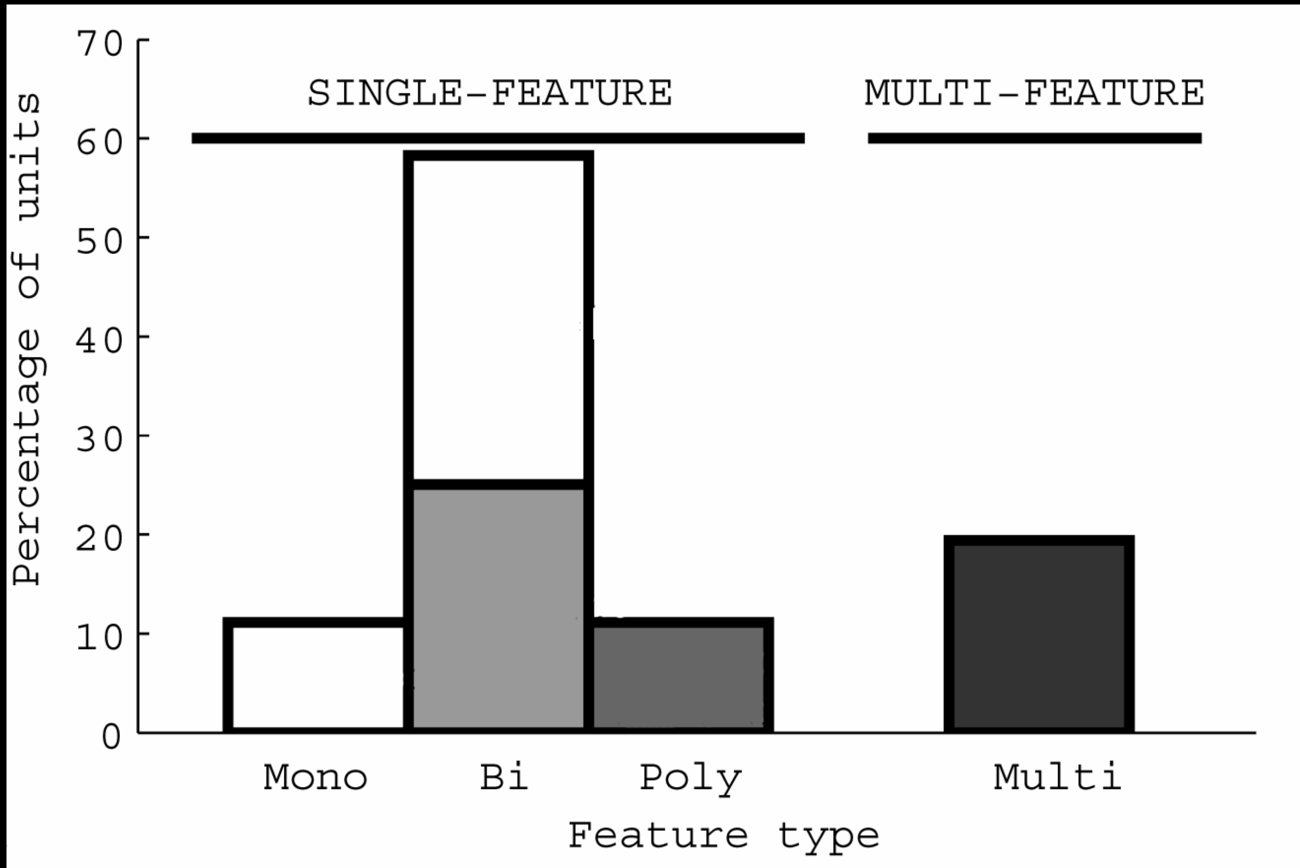
$$r(t) = g[k(t)]$$



Petersen et al (in press) *Neuron*



Petersen et al (in press) *Neuron*



Petersen et al (in press) *Neuron*

Conclusions

- VPM neurons reliably encode complex whisker motion
- Key information-bearing element of response is firing rate on millisecond time-scale
- High reliability permits small subcortical circuits to support demanding sensory processing
- Most VPM neurons can be described by LNP models
- VPM exhibits a distributed code for whisker motion

Acknowledgements

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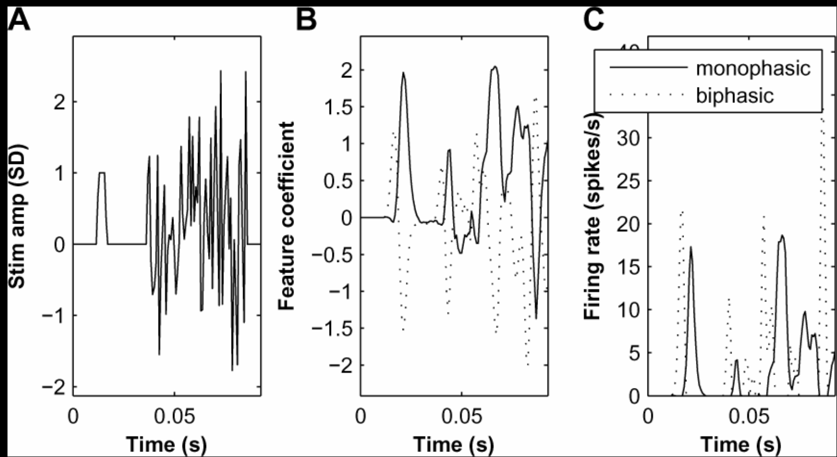
EXTRA


A
B
C
Stim amp (SD)
Feature coefficient
Firing rate (spikes/s)
Time (s)
Time (s)
Time (s)
monophasic
biphasic