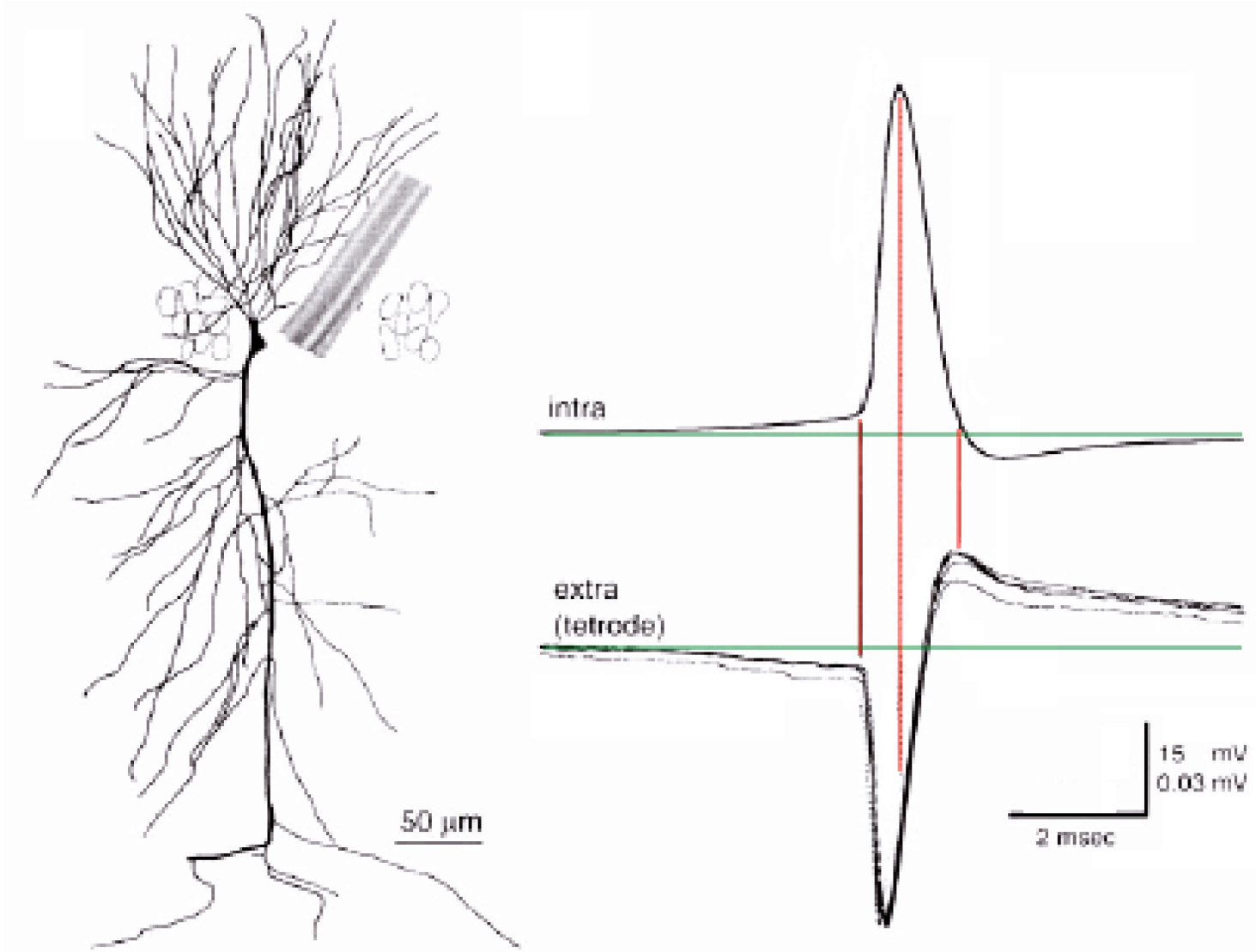
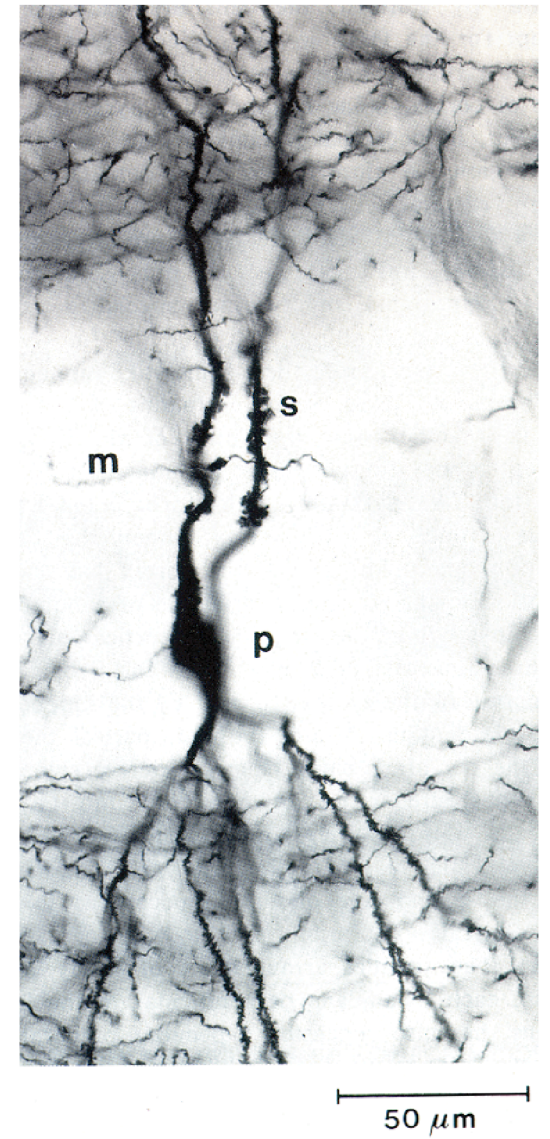
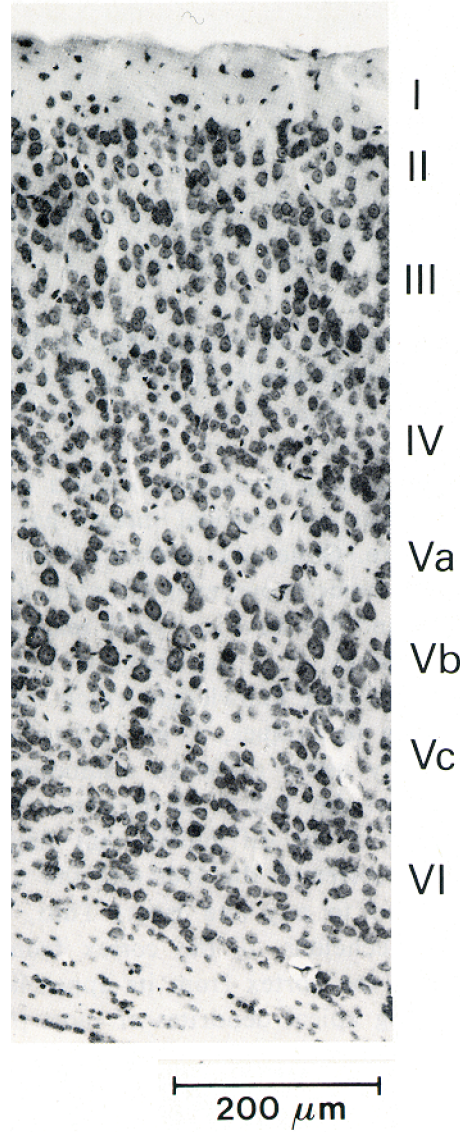
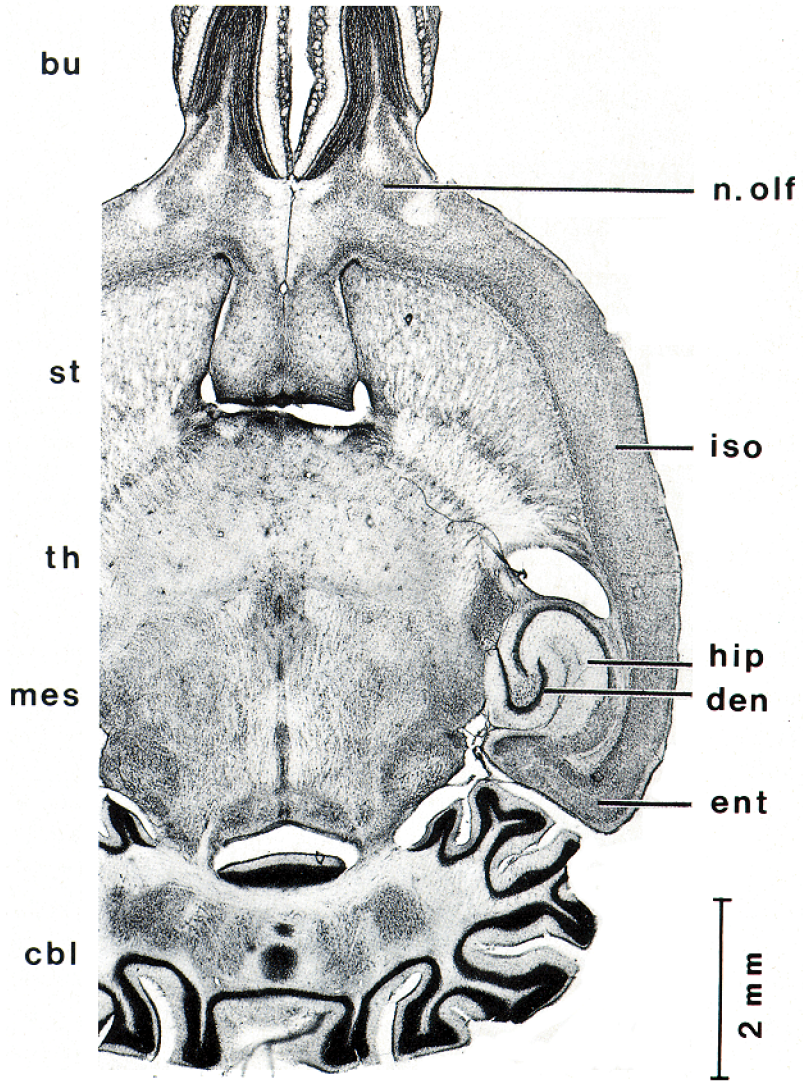
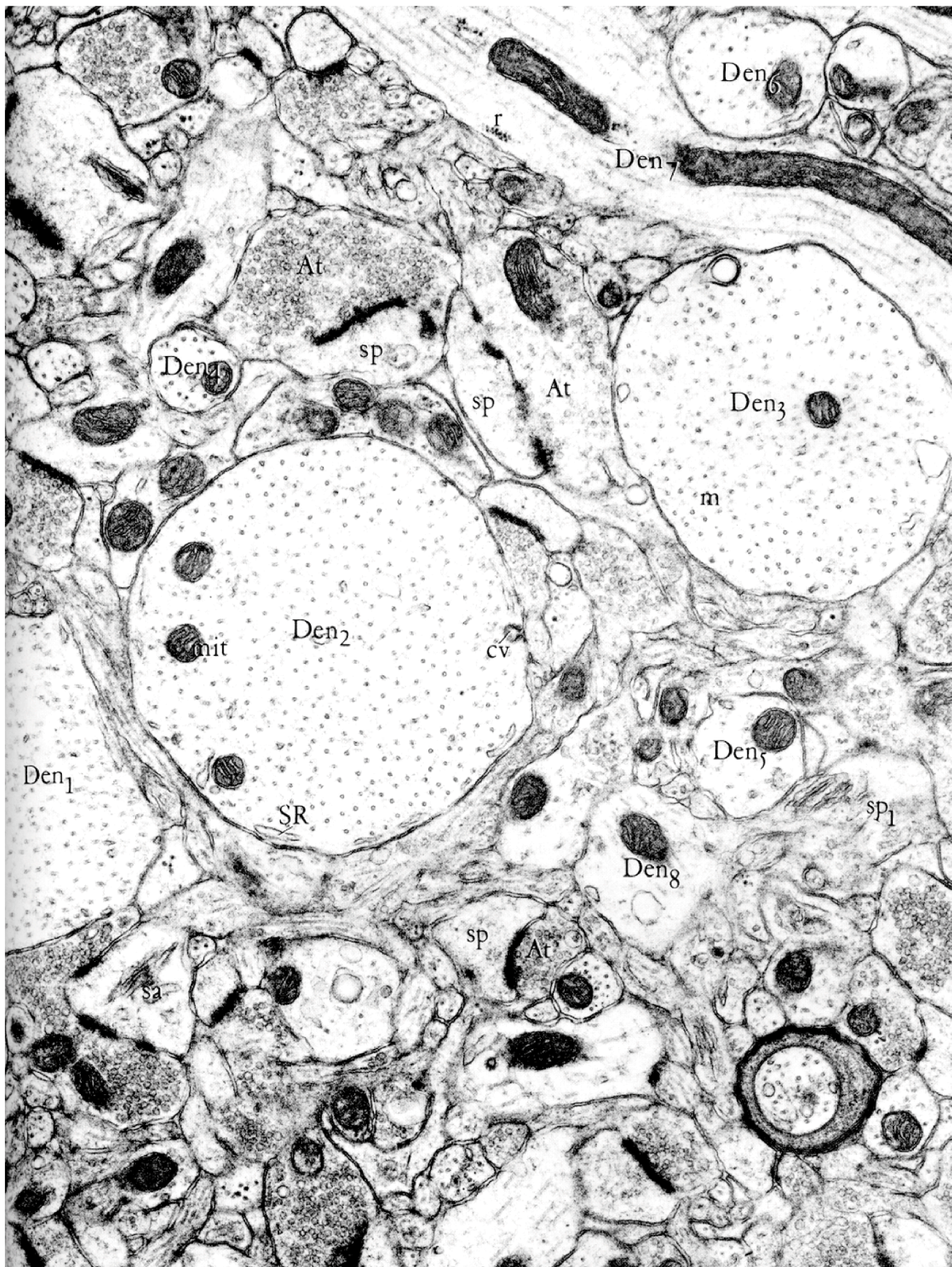


Simultaneous Extracellular and Intracellular Records



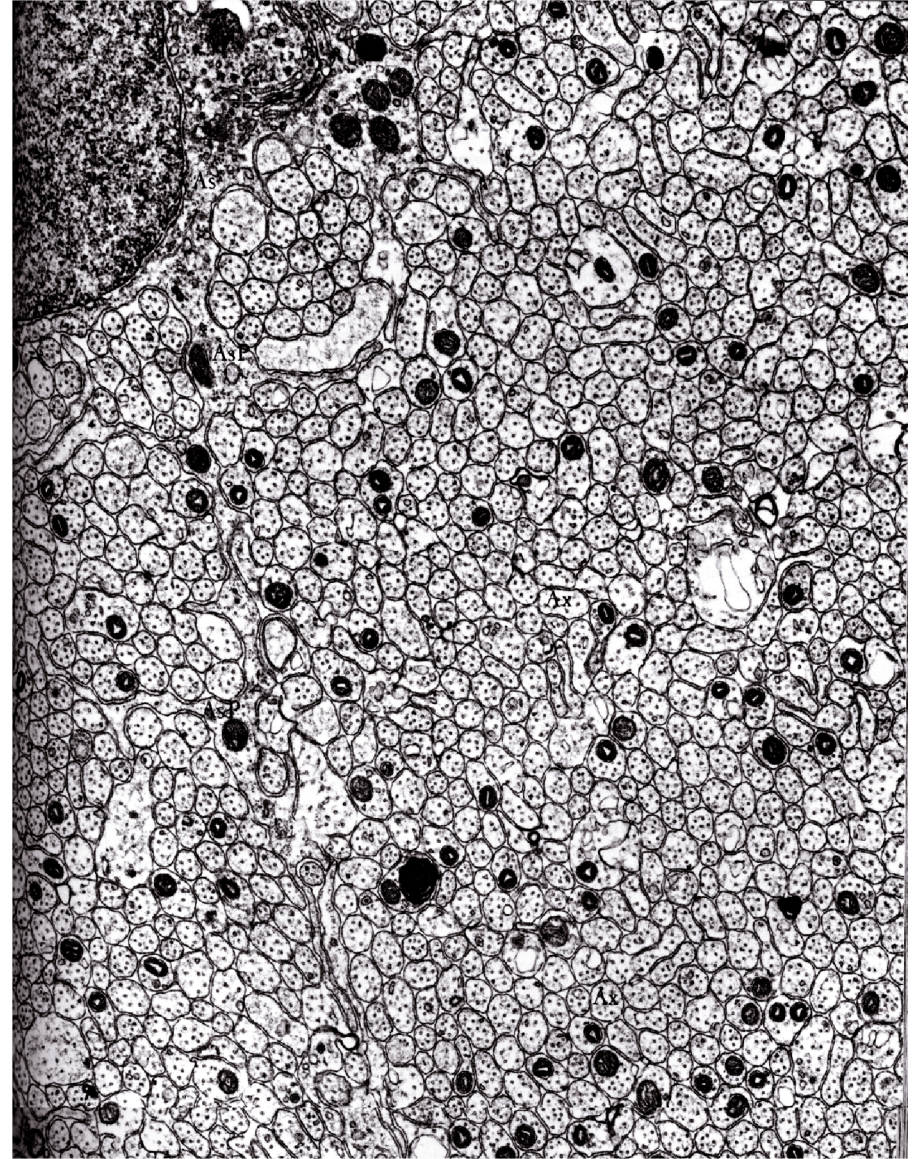


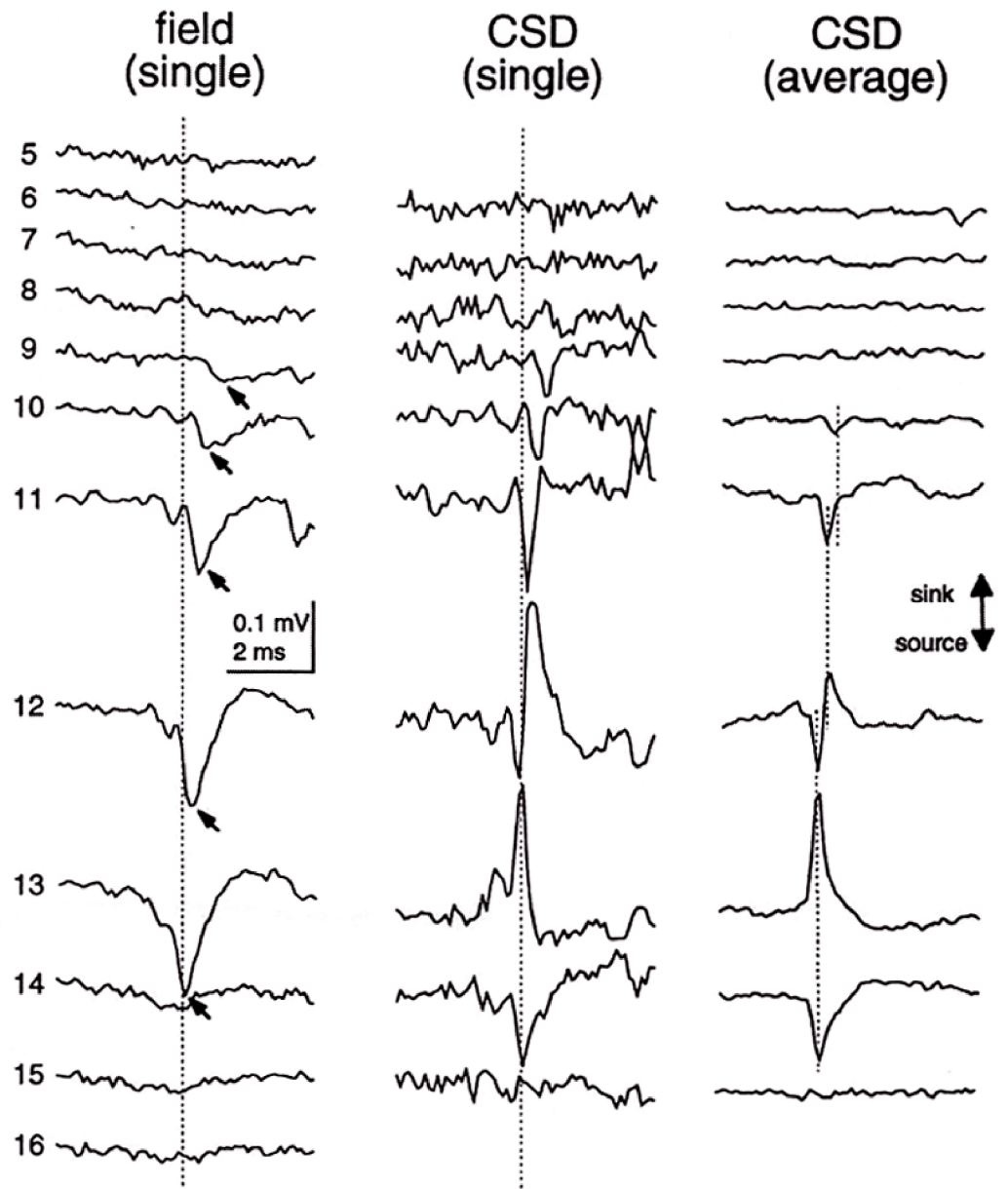
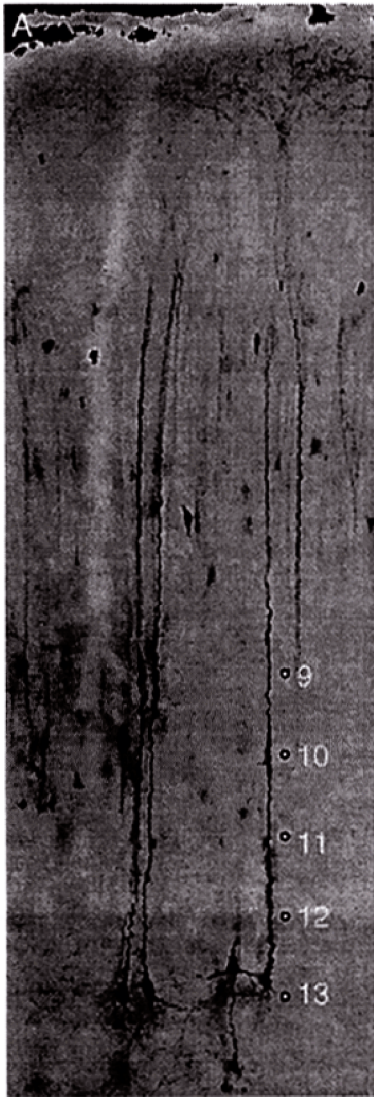


Pyramidal axon and axon hillock



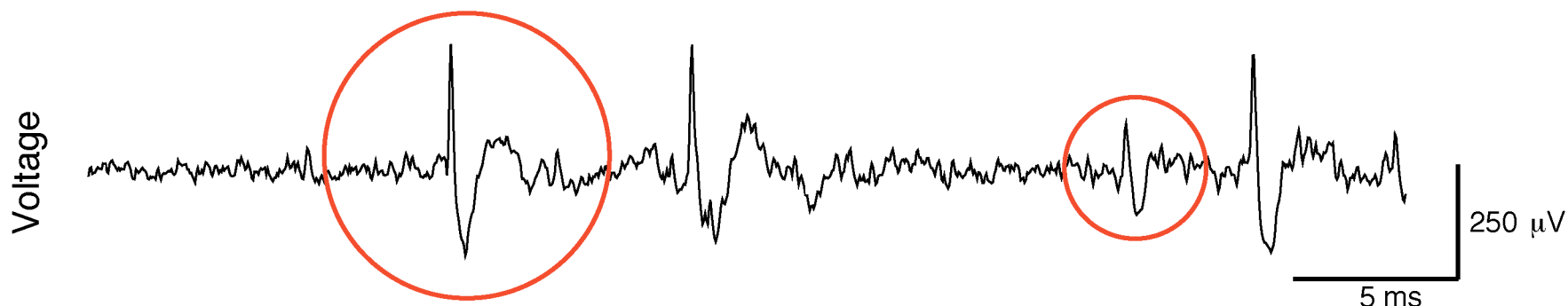
Olfactory nerve axons





Why Sort? - Three Issues

- 1- Detection of Candidate Extracellular Waveforms
- 2- Separation of these Waveforms as Spike-based versus Artifacts
- 3- Classification of Candidate Spikes into Different Clusters (Underlying Neurons)



Our Mantras

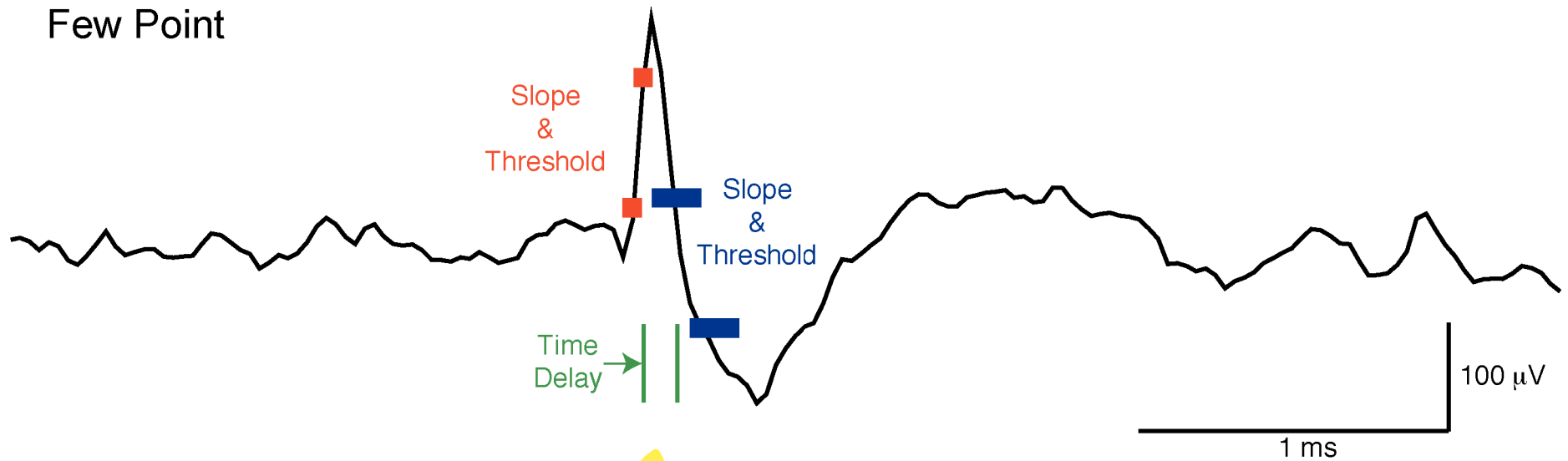
Sort in the Full Feature Space of the Spike Waveform

Respect the Form of the Noise

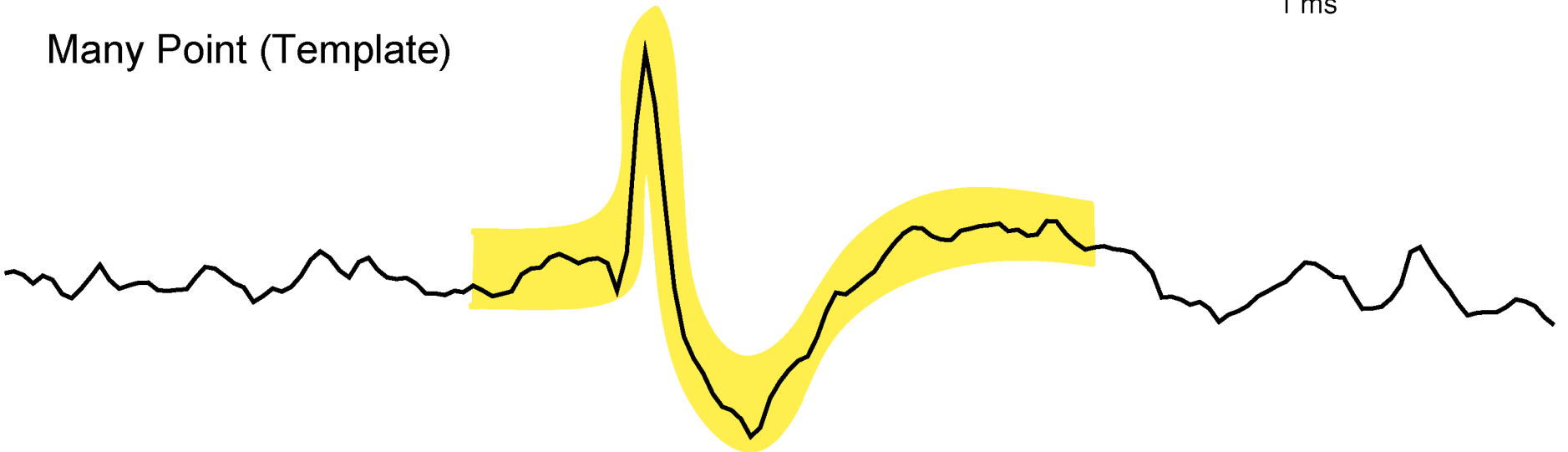
How to Sort

Naive Methods (very appropriate with physically small electrodes and non-bursting cells)

Few Point



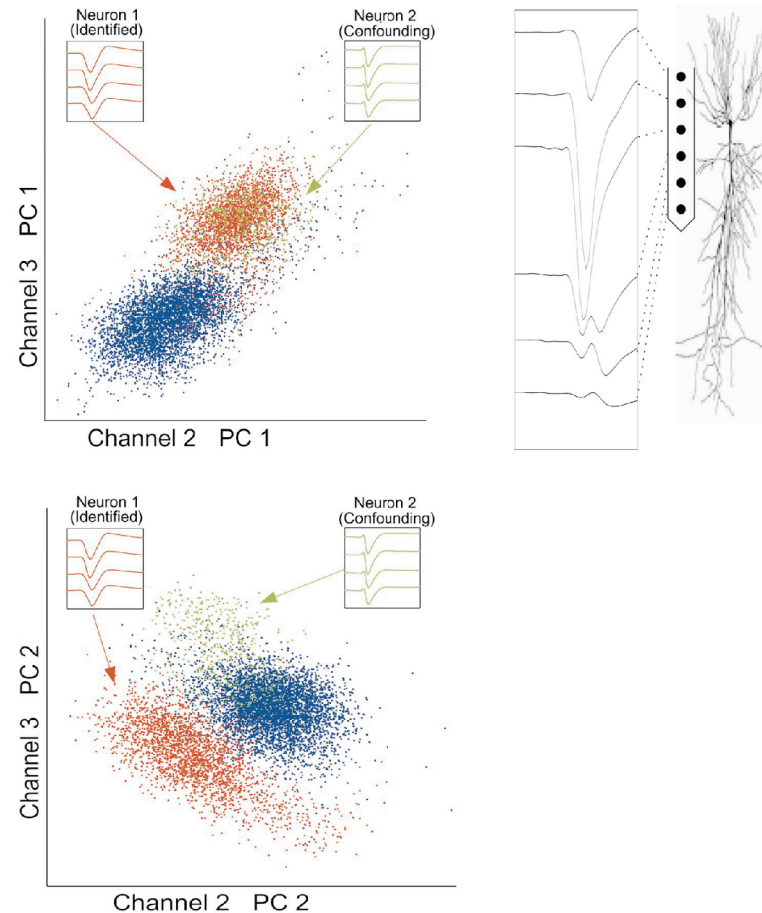
Many Point (Template)



Typically Used in Real Time - Requires Robust Model of Spike and Stable Recording

Decomposition of Putative Spike Waveforms into Their Natural Basis Set

Case 1 - Use Concomitant Intracellular Recordings so that Principal Components (PC) Basis can be Accurately Calculated for One Cell

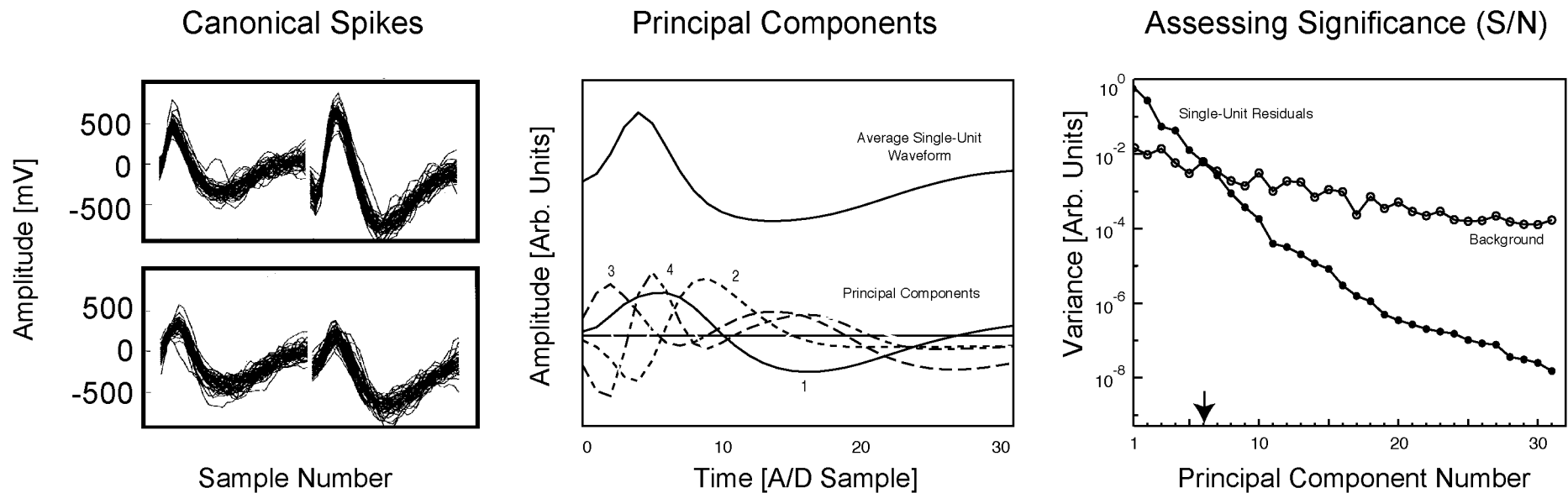


BUZSAKI, PENTTONEN, NADASDY and BRAGIN (1996)
HENZE, BORHEGYI, CSICSVARI, MAMIYA, HARRIS and BUZSAKI (2000)
HARRIS, HENZE, CSICSVARI, HIRASE and BUZSAKI (2000)

Lesson: Spikes Exist in High (> 3-D) Dimensional Space

Decomposition of Putative Spike Waveforms into Their Natural Basis Set

Case 2 - Use Canonical Library of Spikes to Calculate PC Basis for One Brain Area
(program started by Abeles and Goldstein, 1977)



Lesson: The Dimension of the "Spike-Space" can be Quantified (~ 6-D above)

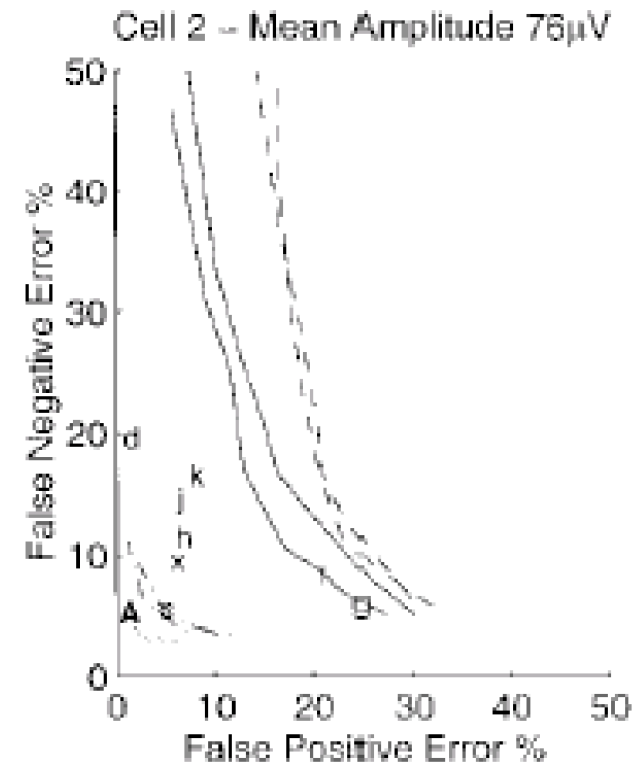
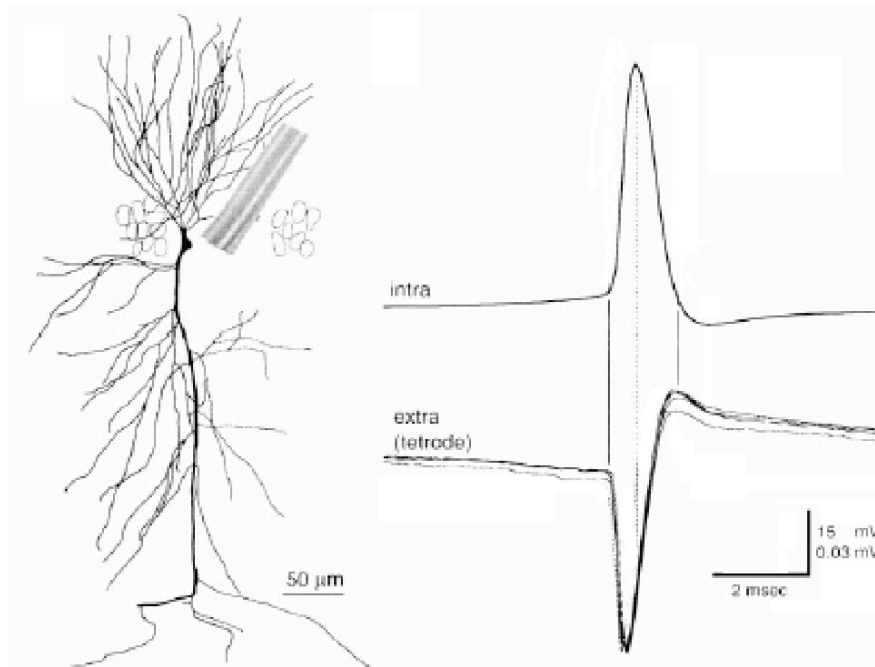
How to Classify Putative Spike Waveforms

Consider Sorting Based on Projections in 4x3-D Space of PC₁, PC₂, and PC₃

Manual ("Chi by Eye")

versus

Bayesian Clustering Algorithm (AutoClass; Cheeseman & Stutz 1996)

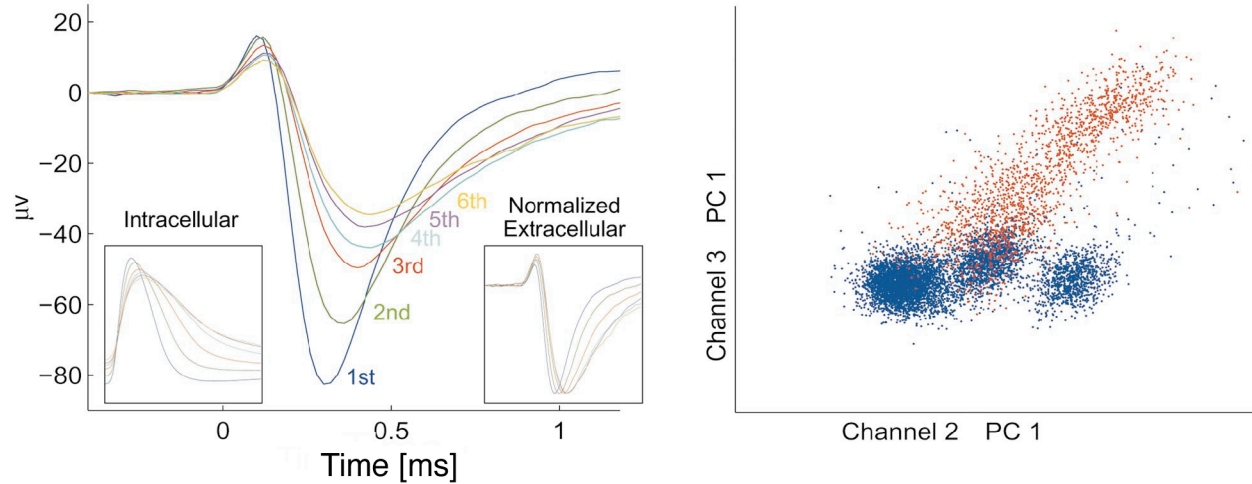


HENZE, BORHEGYI, CSICSVARI, MAMIYA, HARRIS and BUZSAKI (2000)
HARRIS, HENZE, CSICSVARI, HIRASE and BUZSAKI (2000)

Lessons: Automation Wins and 3 PCs beats 2 PCs beats 1 PC and Minimum Error ~10%

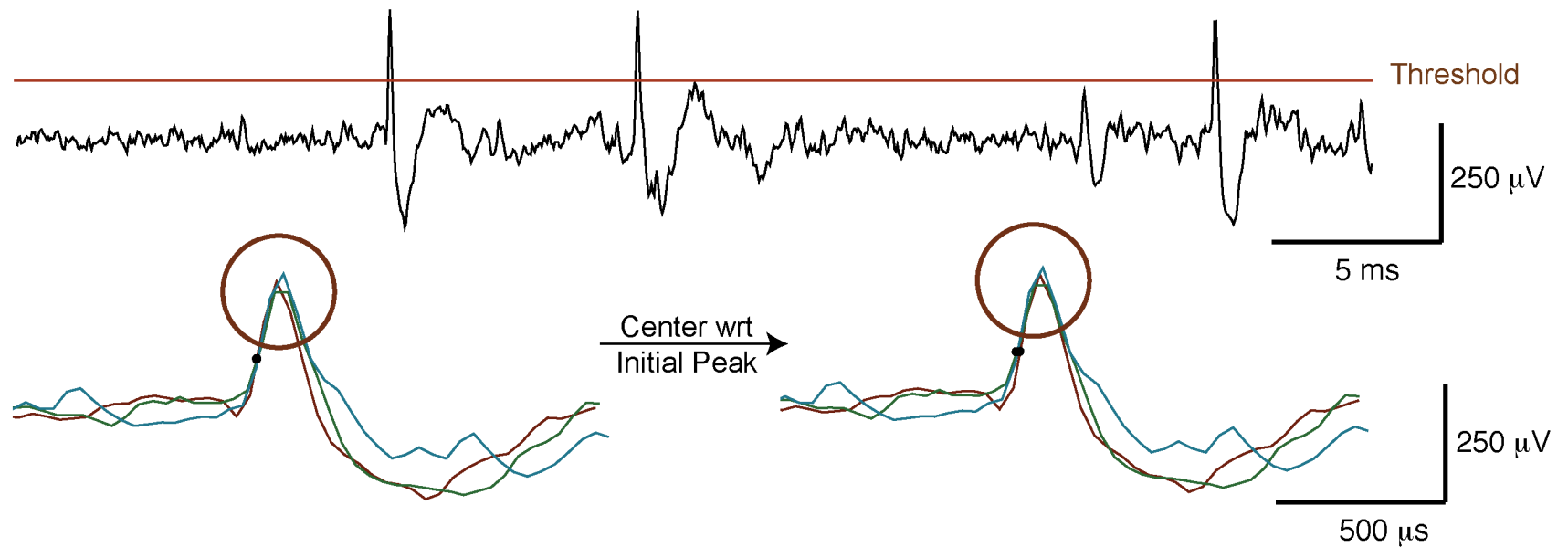
Critical Side Issues

1 - Multiple μ wires (n-trodes) for Better Separation



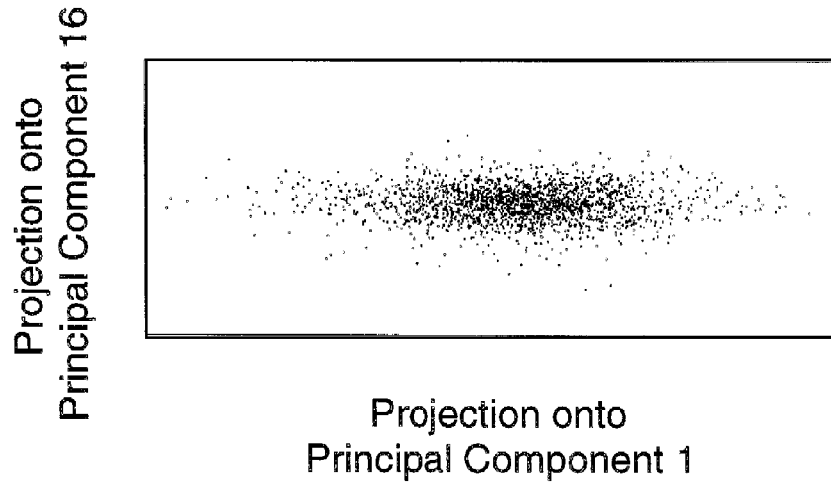
HARRIS, HENZE, CSICSVARI, HIRASE and BUZSAKI (2000)

2 - Center Spikes to Remove Artificial Jitter - Otherwise $\text{PC}_2 \sim dV/dt$ with $\text{PC}_1 \sim V(t)$

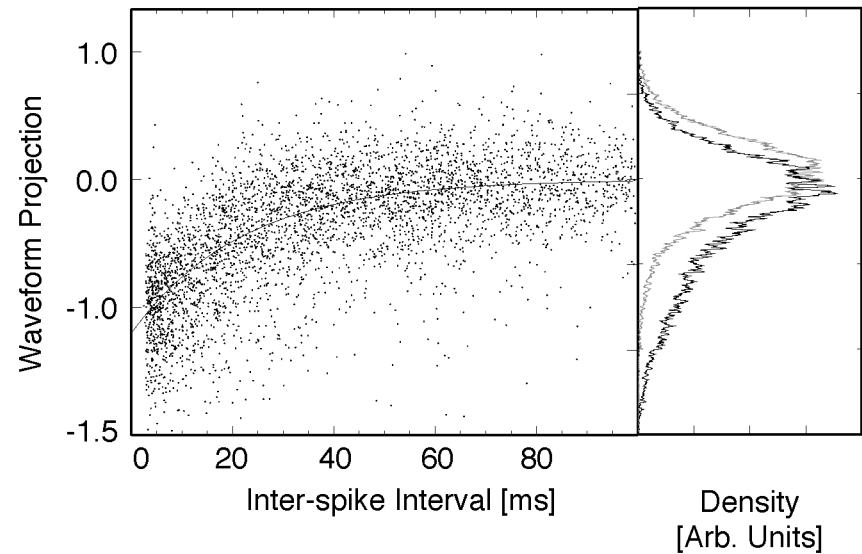
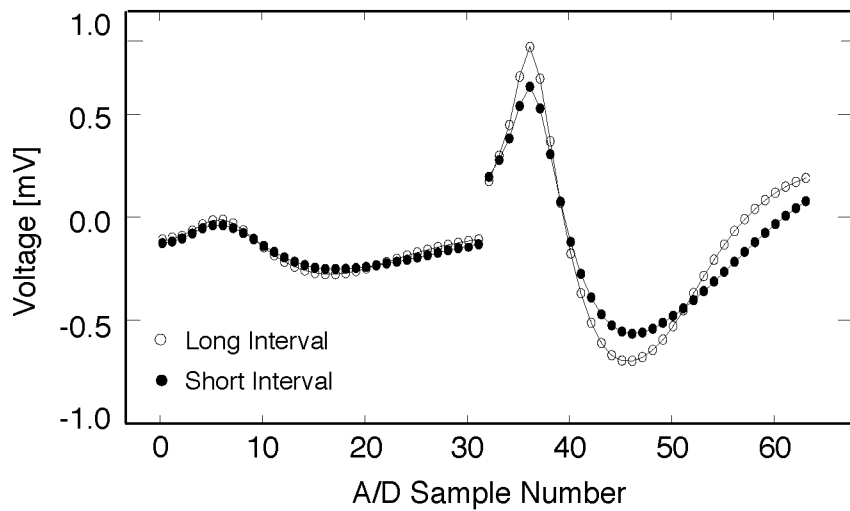


Fee, Mitra and Kleinfeld (1996)

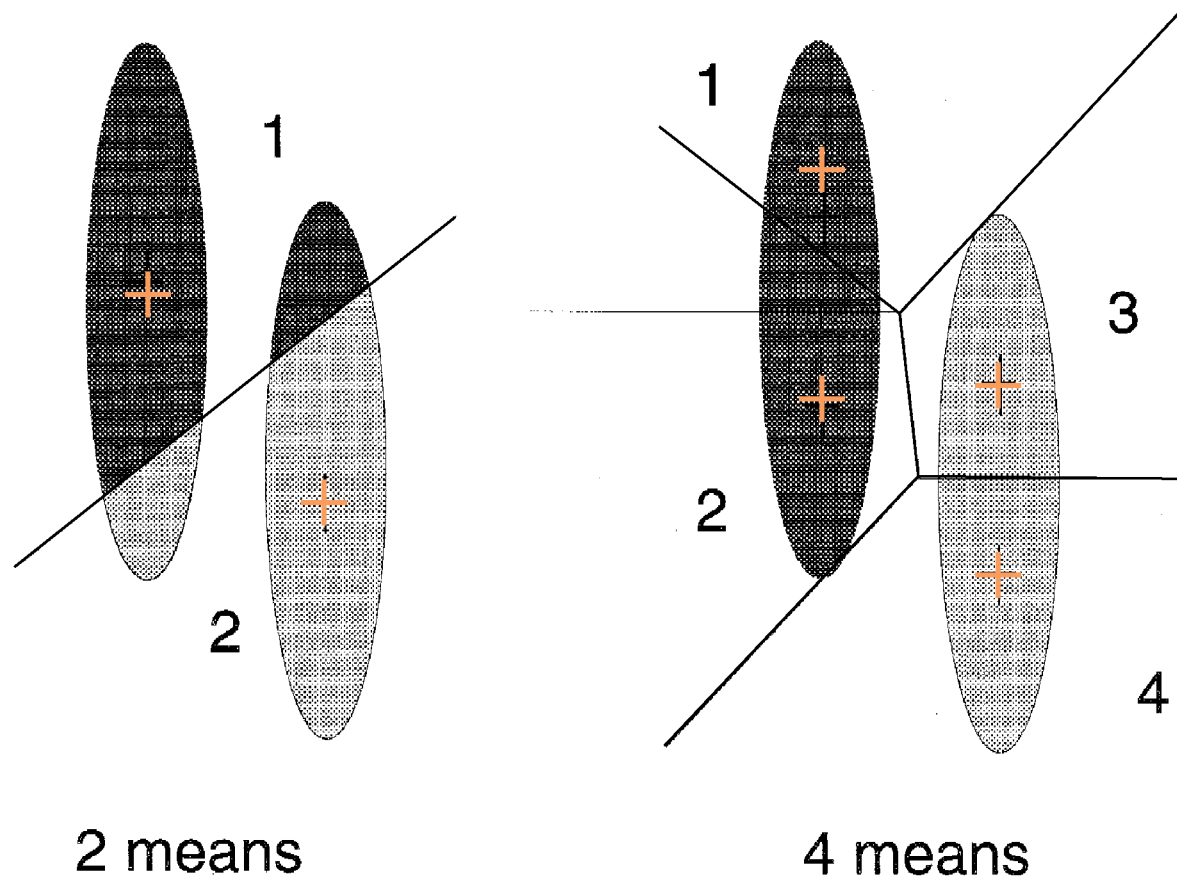
Waveforms Have Anisotropically Distributions in "Spike-Space"



Why?: E.g. - The Distribution of Spike Waveform Amplitudes is NOT Gaussian



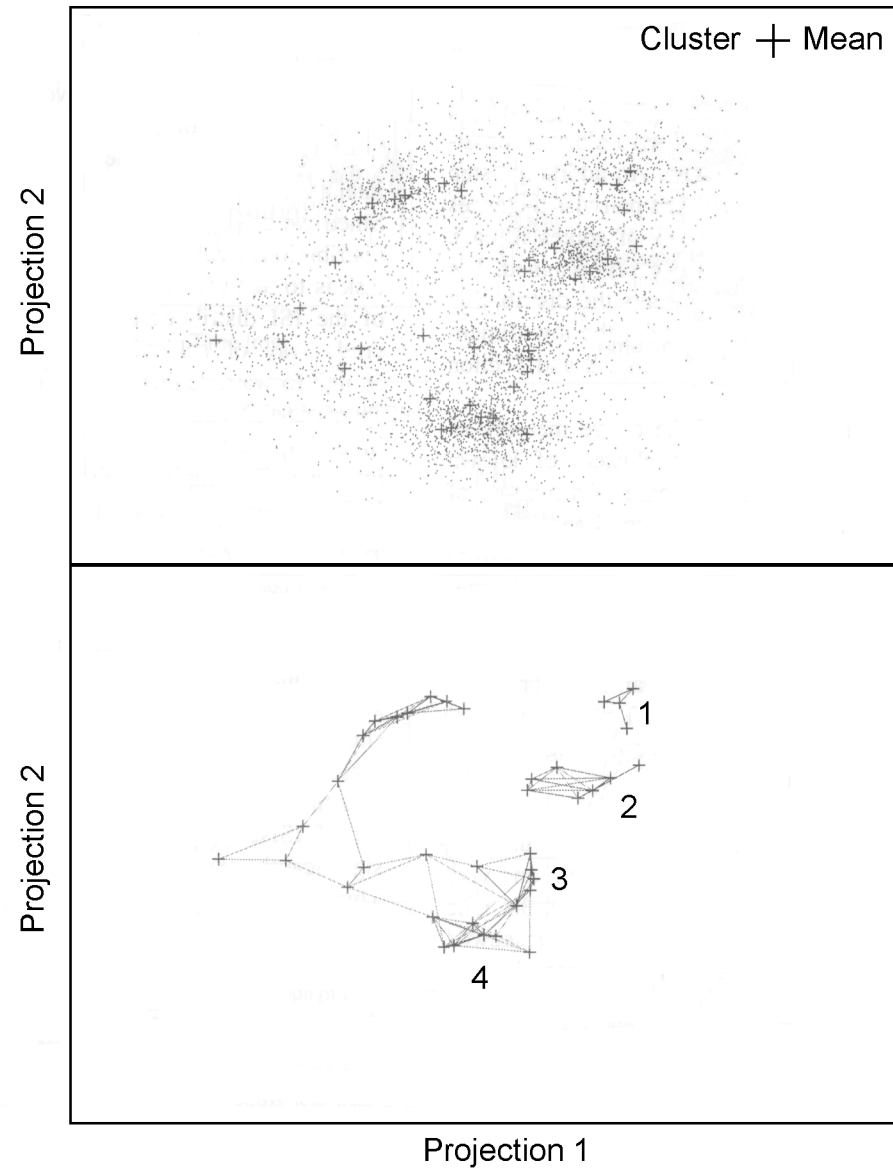
How to Work with a Distribution of Spike Waveform Amplitudes that is NOT Isotropic in "Spike-Space"



Lesson: Multiple Means are Required to Describe Clusters
(Over Cluster Data with Isotropic Clusters - and Agglomerate Clusters)

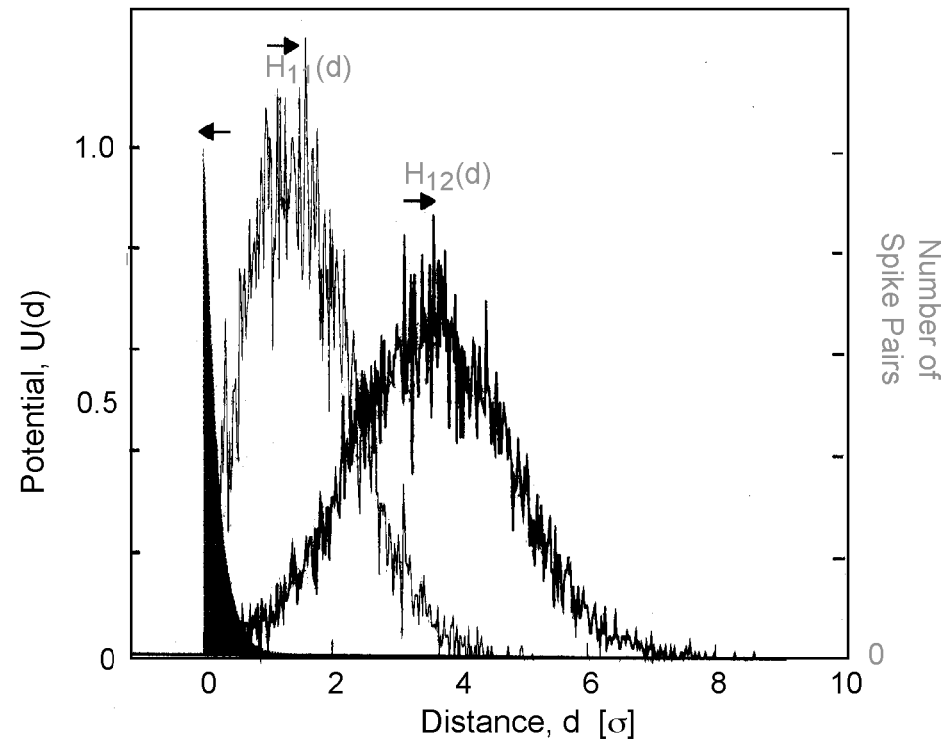
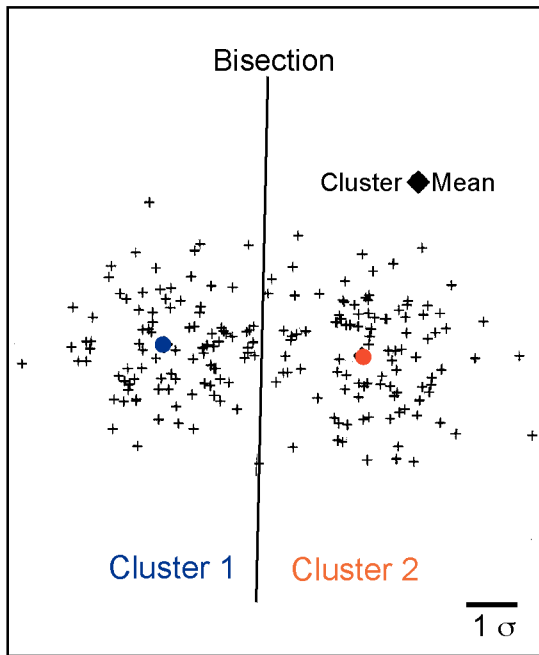
How to Implement "Our Mantras"

Start by Heavily Over Clustering the Data



How to Implement "Our Mantras"

Calculation of Cluster Overlaps - "Surface Energy" - Prior to Possible Agglomeration

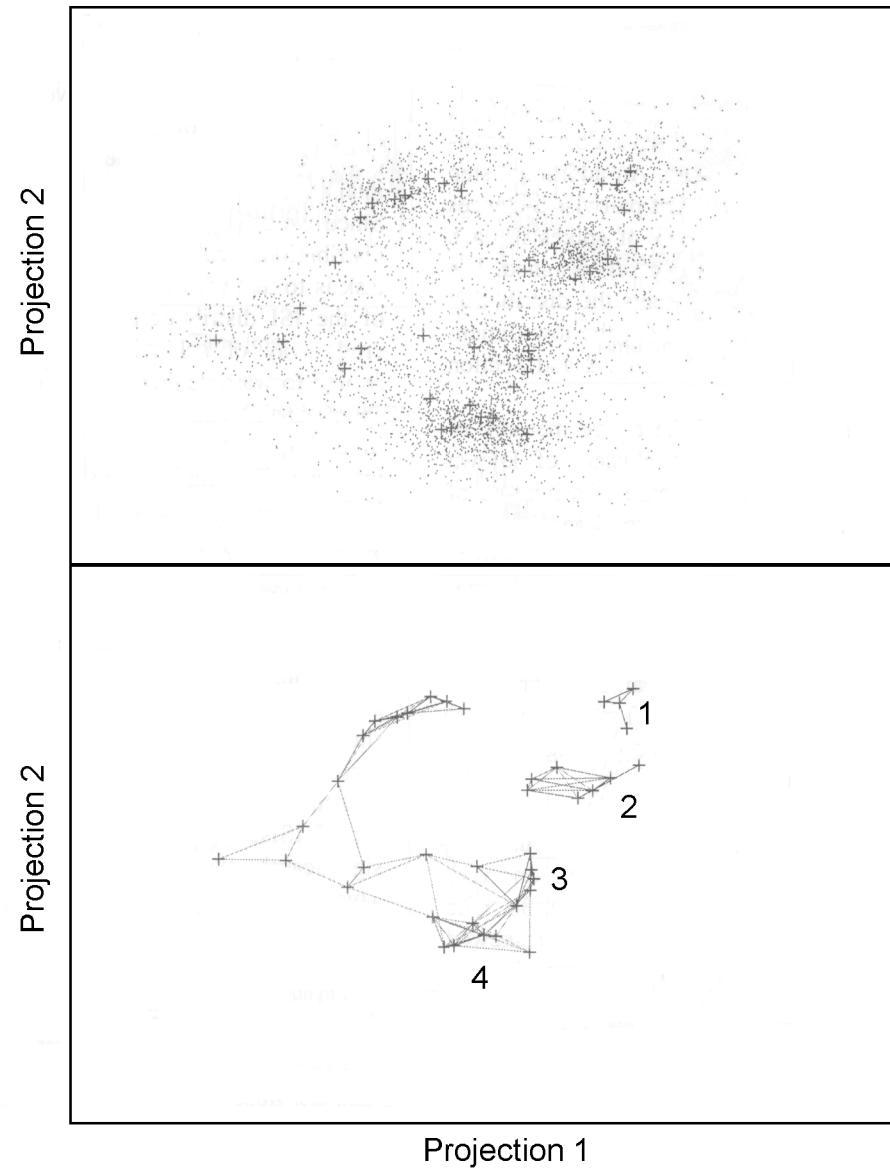


$$J_{ab} \sim \sum_{d_i=1}^{d_{\max}} U(d_i) H_{ab}(d_i)$$

$$U(d_i) \equiv e^{-d/d_0}$$

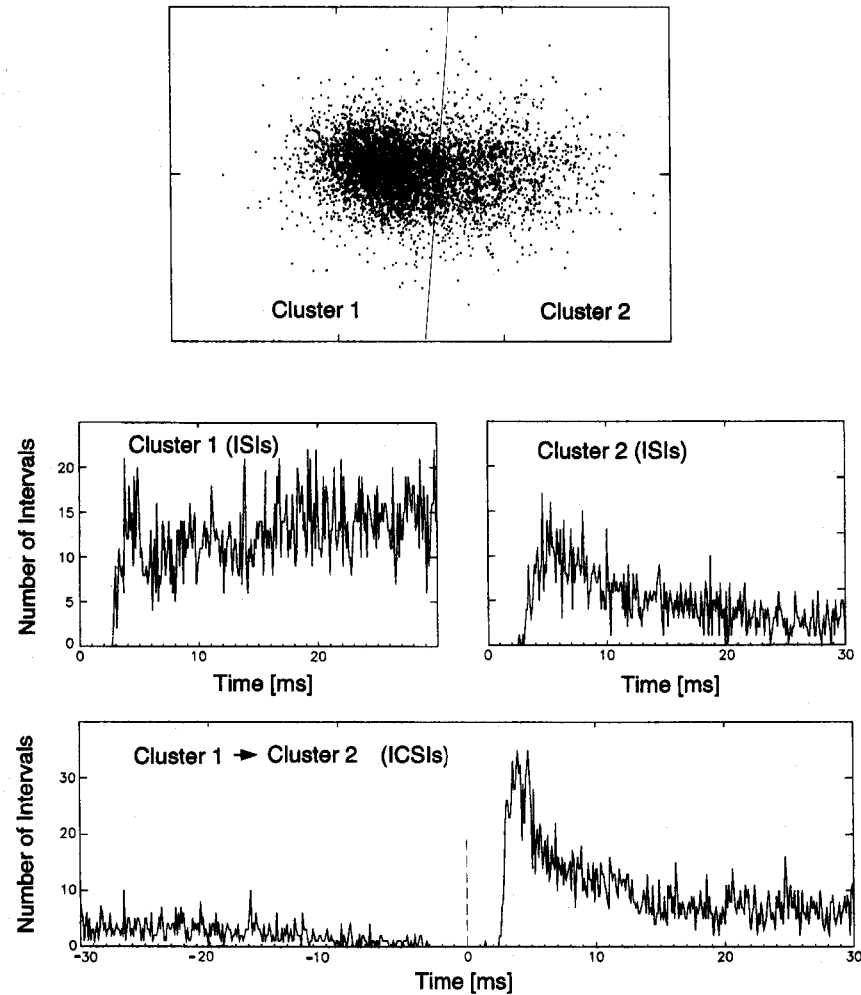
How to Implement "Our Mantras"

Agglomeration of Clusters Based on Ranked List of J_{ab} 's and Single-Unit Statistics



How to Implement "Our Mantras"

Evaluation of Single-Unit (Refractory Period) Statistics

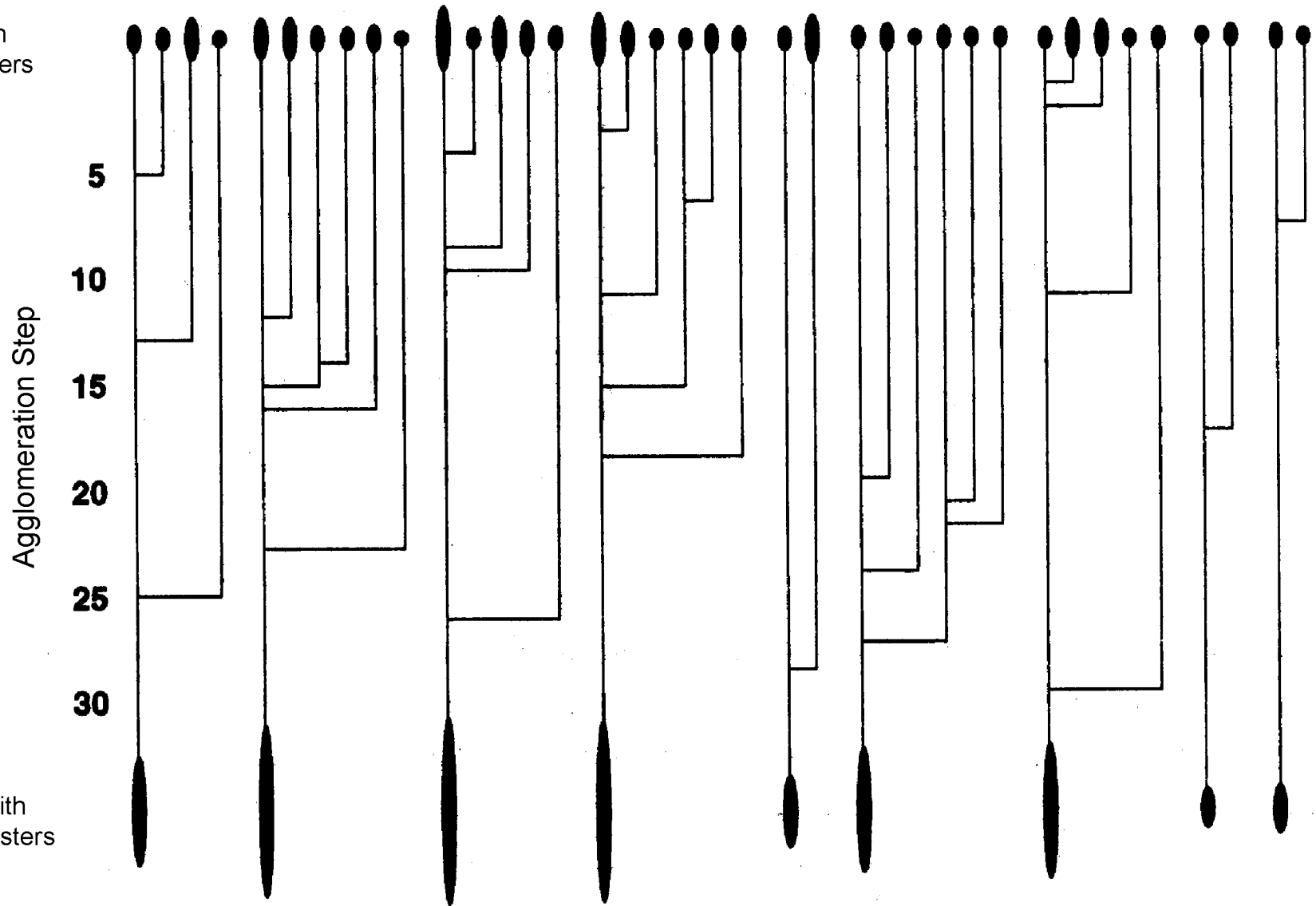


Use Kolmogorov-Smirnoff Statistic to Test if Agglomeration Degrades ISI Distribution

How to Implement "Our Mantras"

Dendrogram of Agglomeration

Start with
Initial Clusters



Stop Agglomeration Based on Single-Unit Statistics - or Other Measure like High Surface Energy

How to Implement Our Mantras

Evaluate Fidelity of Single Units (Still Open)

