Spike sorting based on noise-assisted semi-supervised learning methodologies

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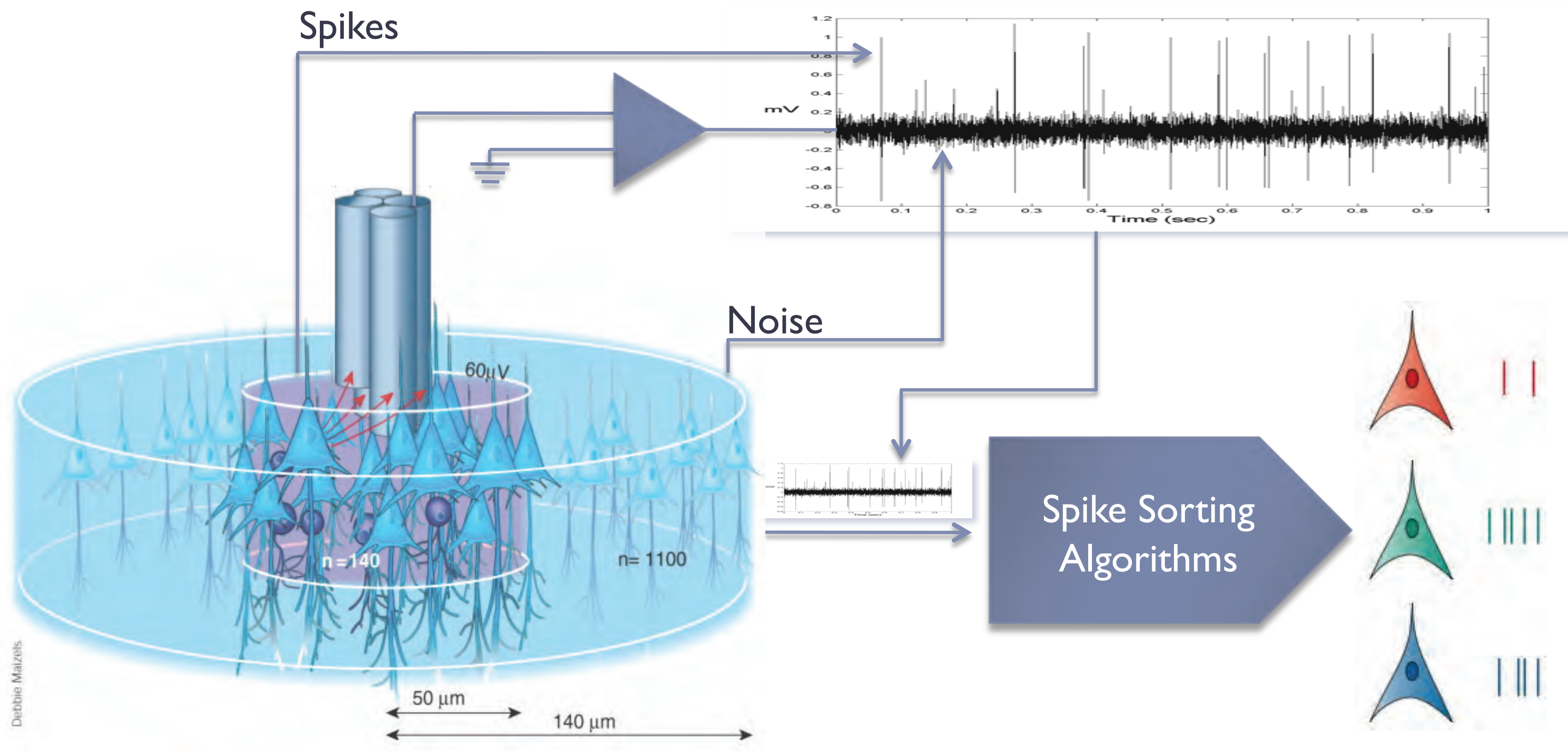
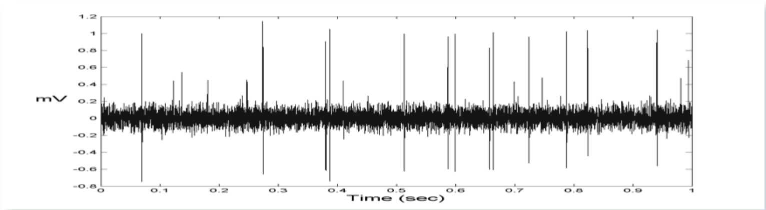
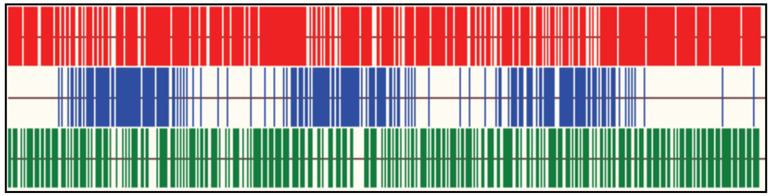
Extracellular recordings

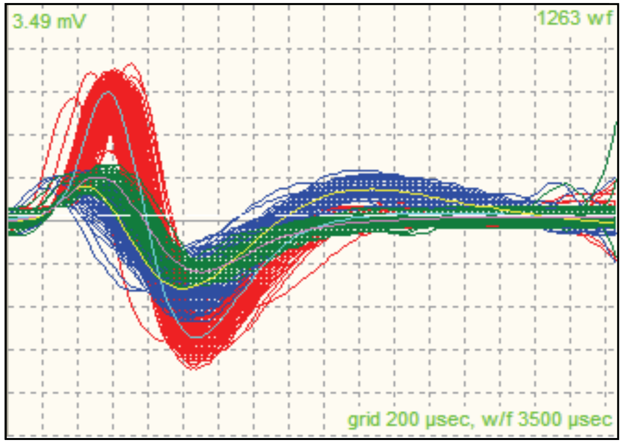


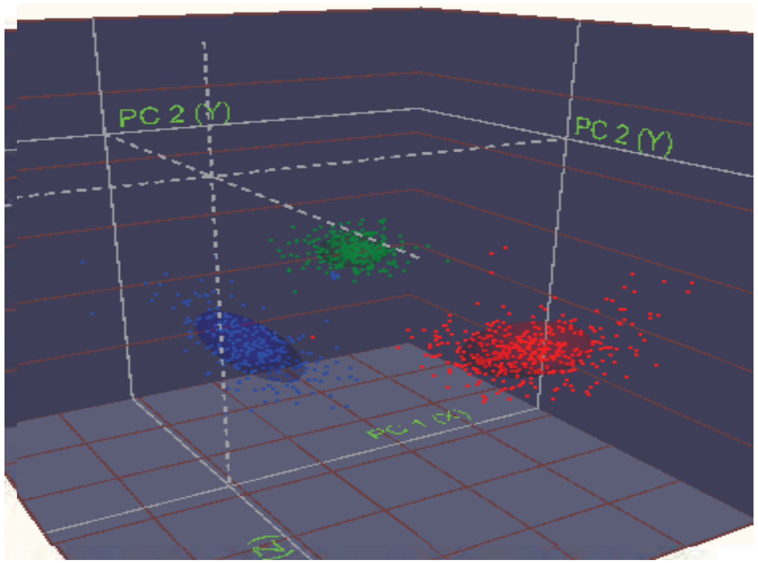
Buzsáki, G. (2004). *Large-scale recording of neuronal ensembles*. **Nature Neuroscience**

Spike sorting in a nutshell

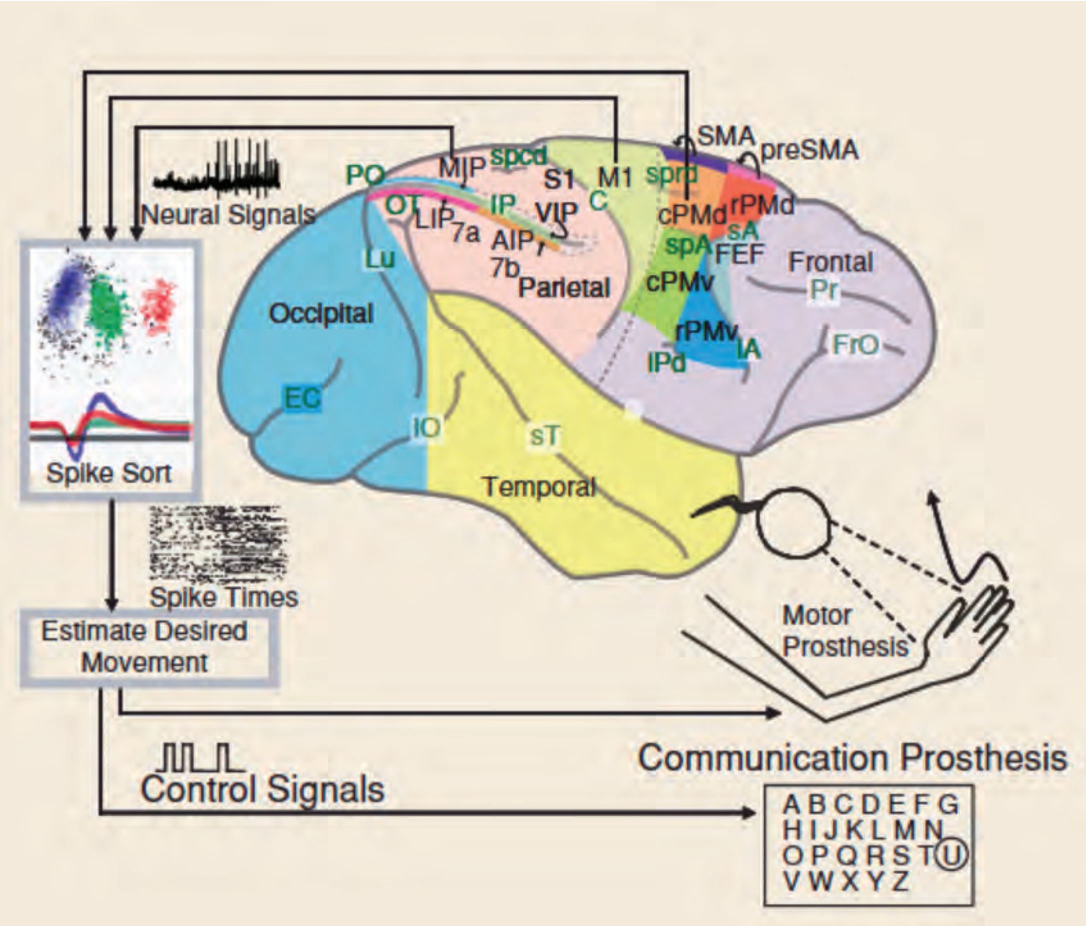






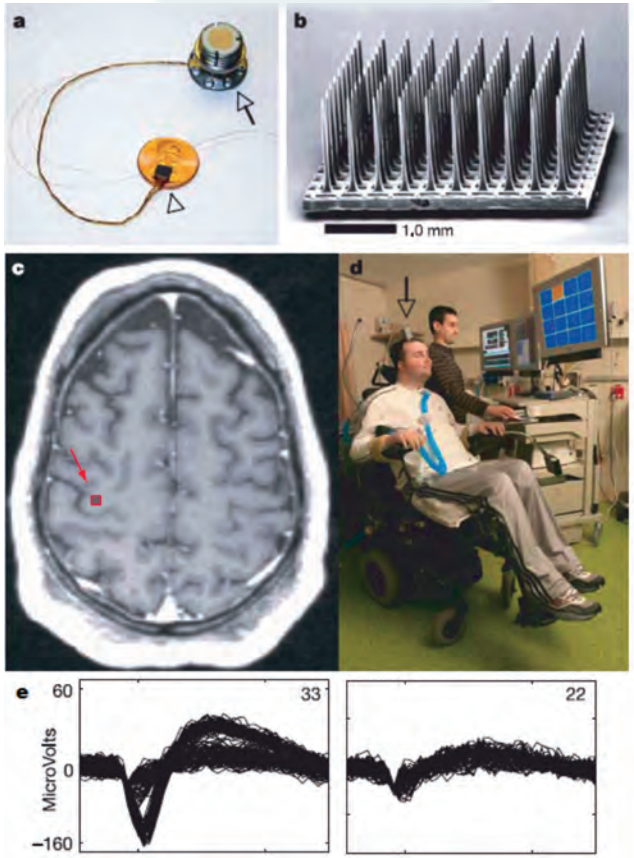


Spike sorting applications #1



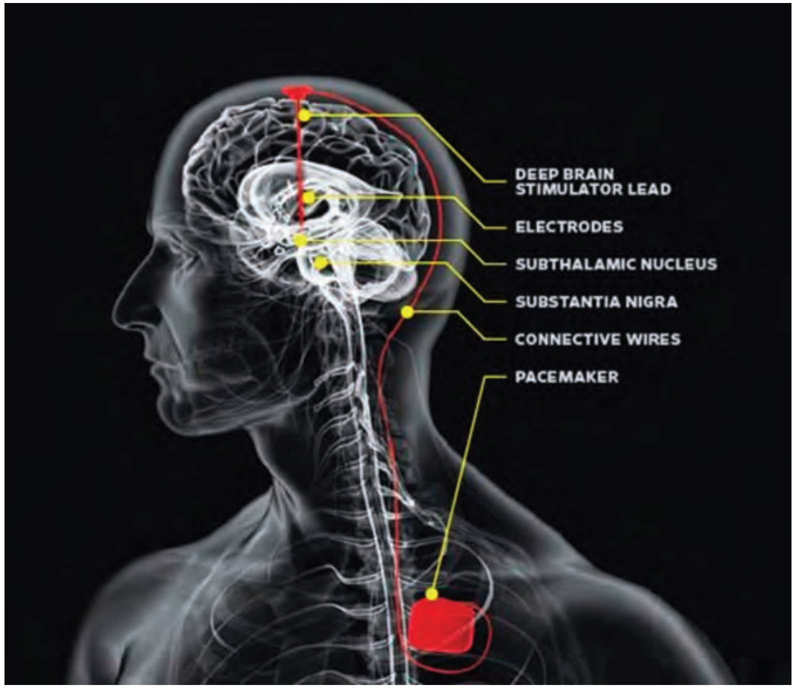
Linderman et al. (2008). *Signal processing challenges for neural prostheses.* ***IEEE Signal Processing Magazine***

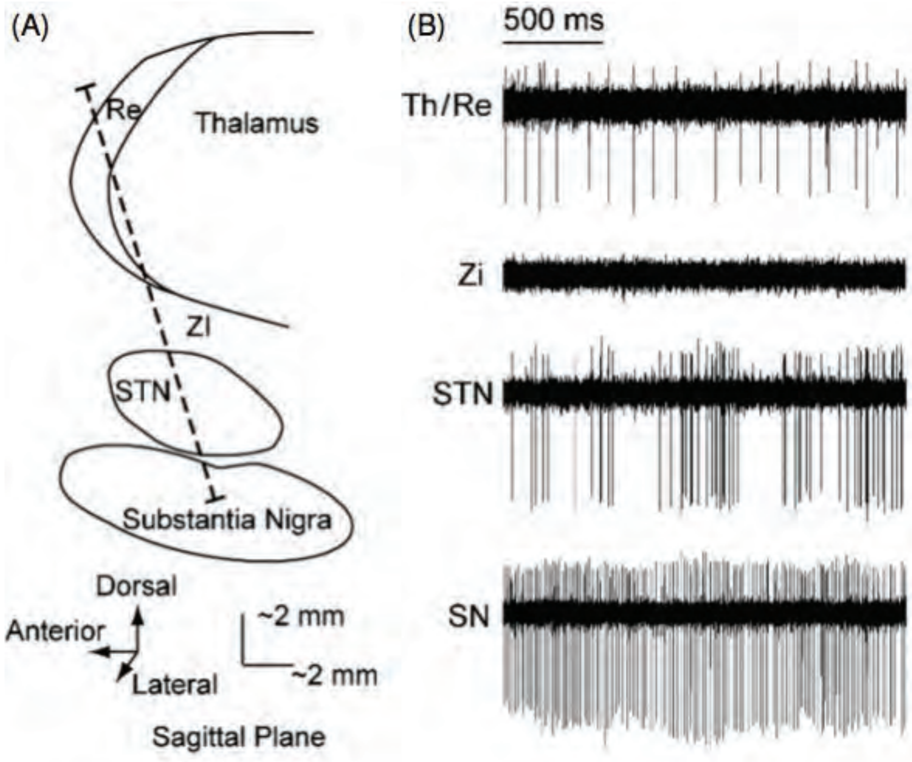
BrainGate



Hochberg et al. (2006). *Neuronal ensemble control of prosthetic devices by a human with tetraplegia.* ***Nature***

Spike sorting applications #2



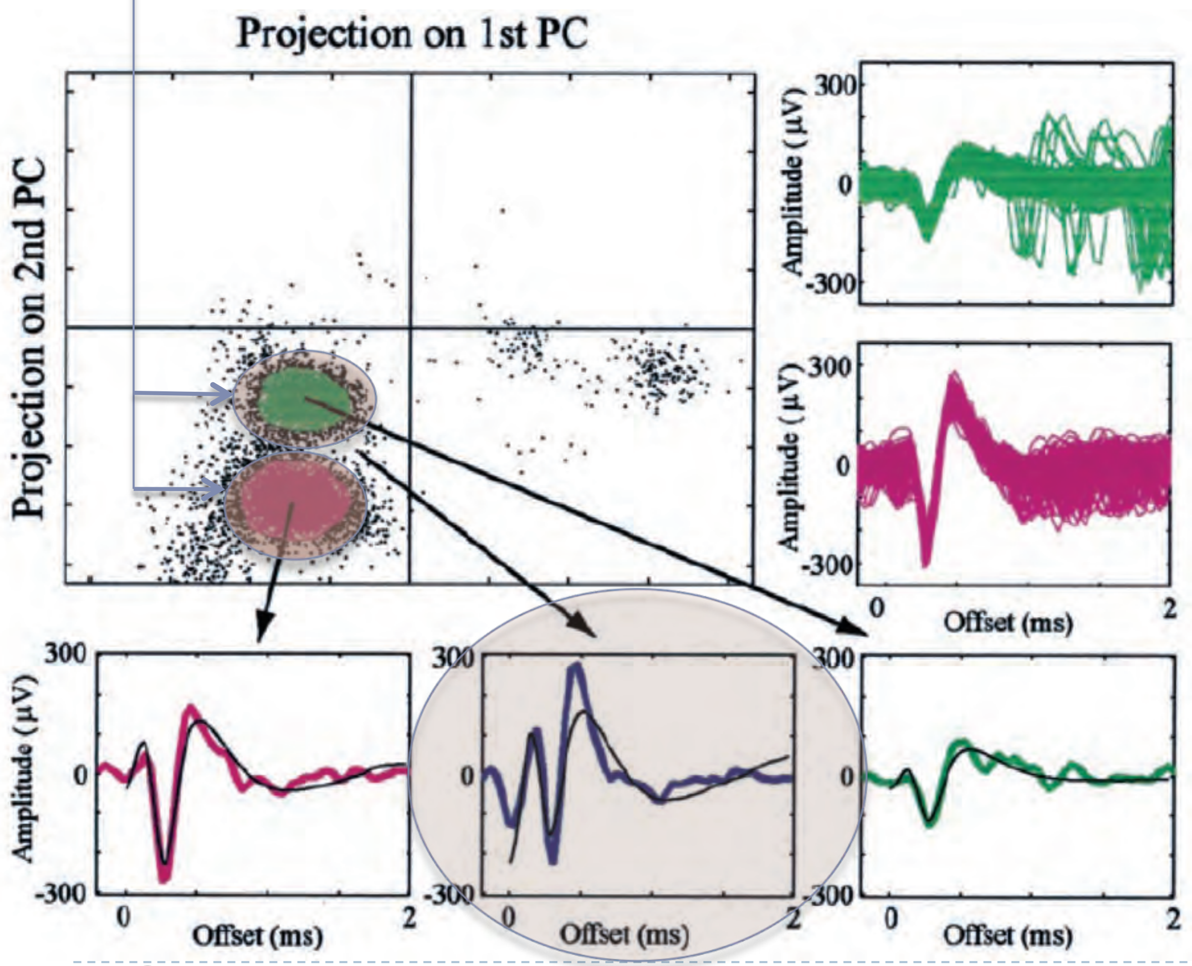


- Functional STN Targeting during DBS surgery

Wong et al. (2009). *Functional localization and visualization of the STN from microelectrode recordings acquired during DBS surgery with unsupervised machine learning*. **J Neural Eng**

Challenges in Spike sorting

- Clustering | Correct estimation of active neurons
- Overlapping spikes



Spike sorting of spikes from two neurons recorded on a single electrode

Bar-Gad et al. (2003). Functional correlations between neighboring neurons in the primate globus pallidus are weak or nonexistent. **J Neurosci**

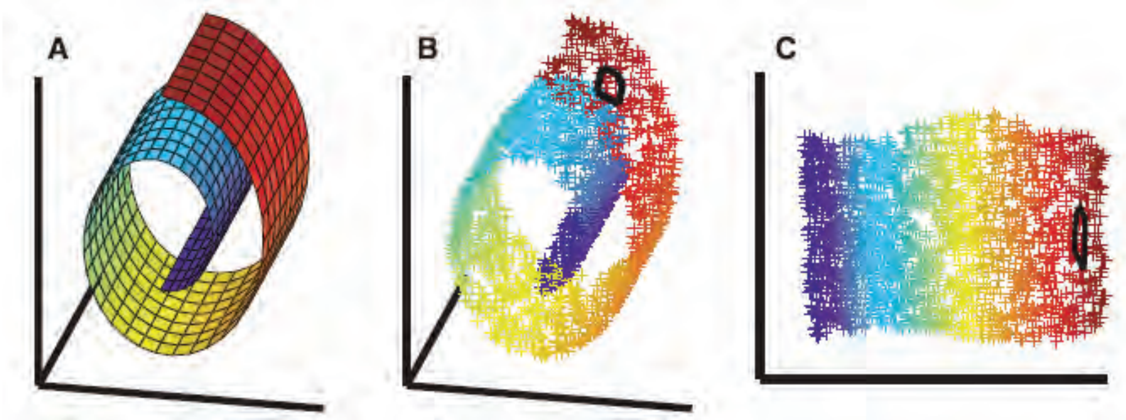
Bar-Gad et al. (2001). Failure in identification of overlapping spikes from multiple neuron activity causes artificial correlations. **J Neurosci Methods**

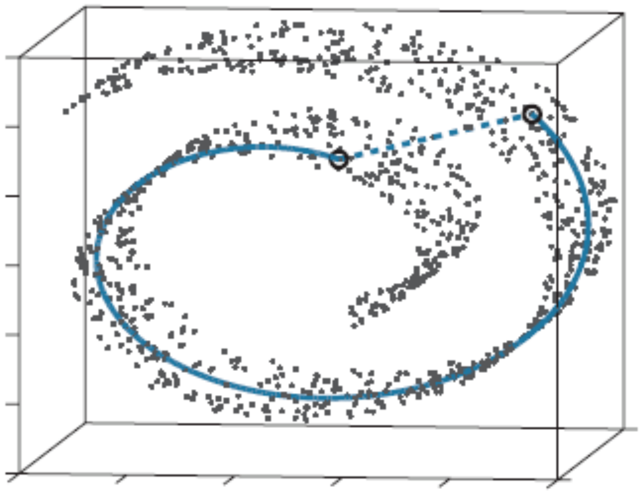
Identifying overlaps: the NASS algorithm

- Adamos DA, Laskaris NA , Kosmidis EK and Theophilidis G. NASS: An empirical approach to Spike Sorting with overlap resolution based on a hybrid Noise-Assisted methodology. **Journal of Neuroscience Methods** 2010;190(1):129-42

Non-linear low-dimensional representation

- Manifold learning: Isometric Feature Mapping (ISOMAP)





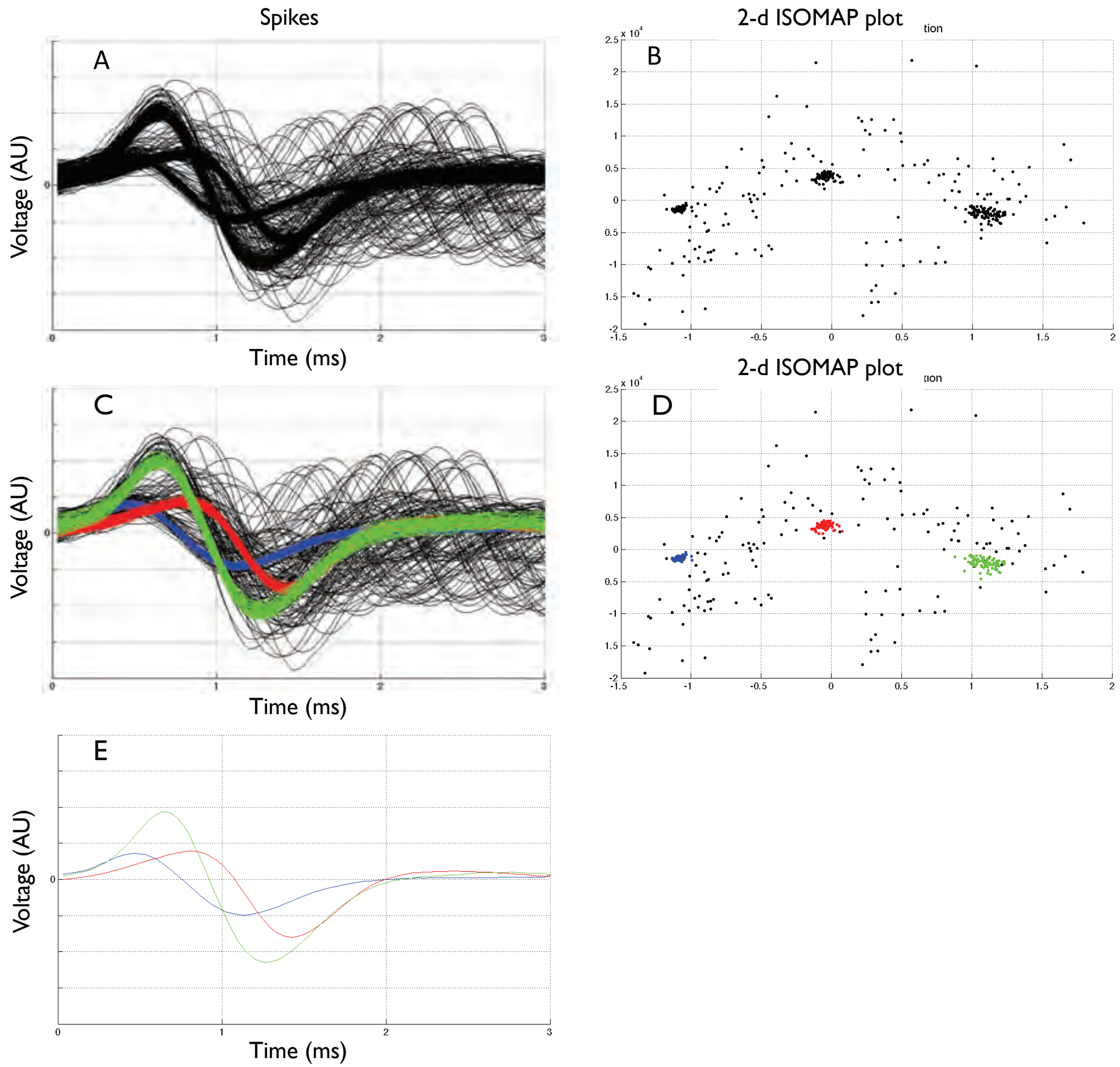
Noise Assisted Spike Sorting (NASS) Algorithm

Low-dimensional ISOMAP representation

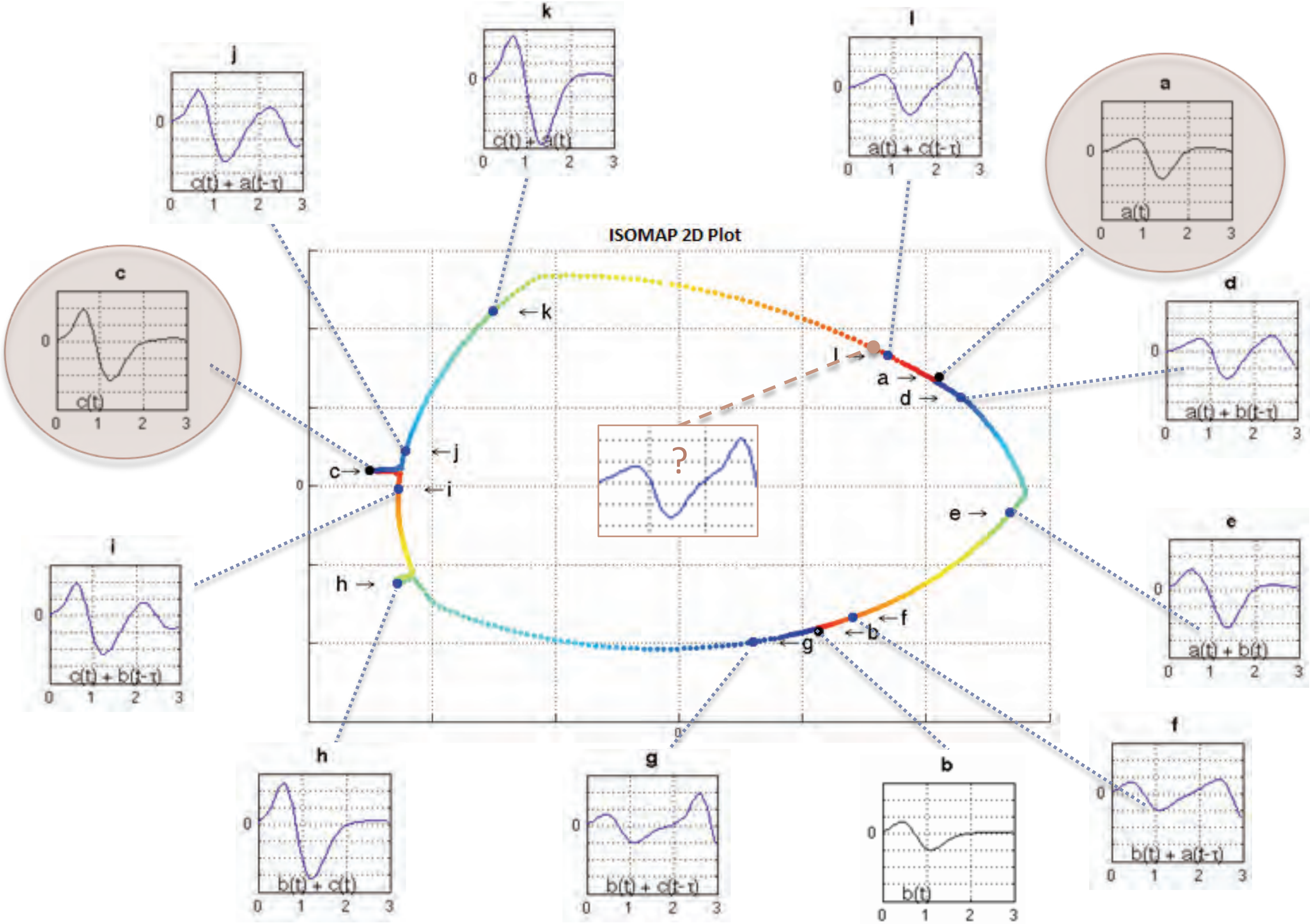
FCM (Fuzzy C-means) clustering

Spikes in black are left **unclassified** for further processing

Spikes in color are used to estimate (using weighted averaging) **prototype waveforms** for each cluster



NASS algorithm: Identifying overlapping spikes



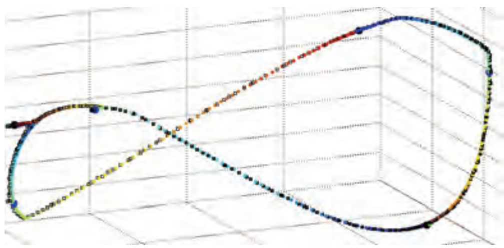
NASS algorithm: Identifying overlapping spikes

Synthetic overlaps and noisy synthetic overlaps are projected to ISOMAP space

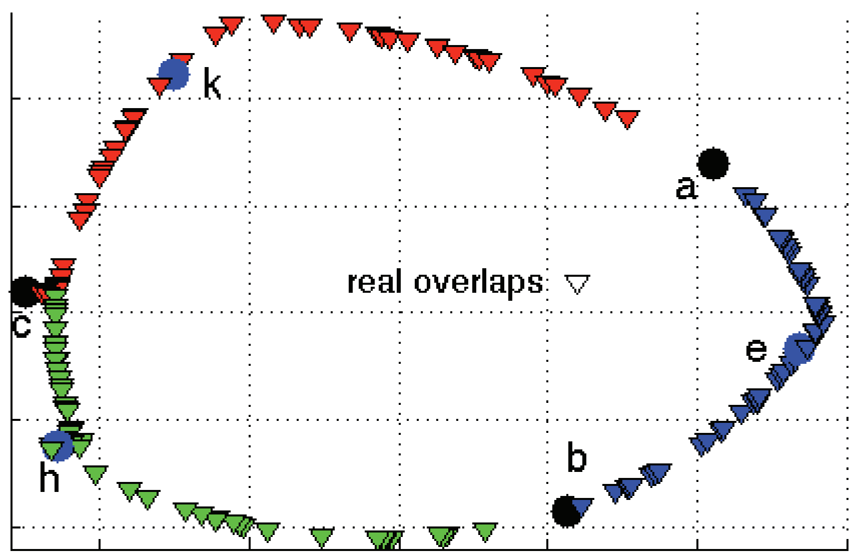
Extreme Learning Machine is trained

Real waveforms left unclassified are projected on the same ISOMAP space

The trained Extreme Learning Machine algorithm classifies the real waveforms



2-d ISOMAP Plot



Synthetic overlaps

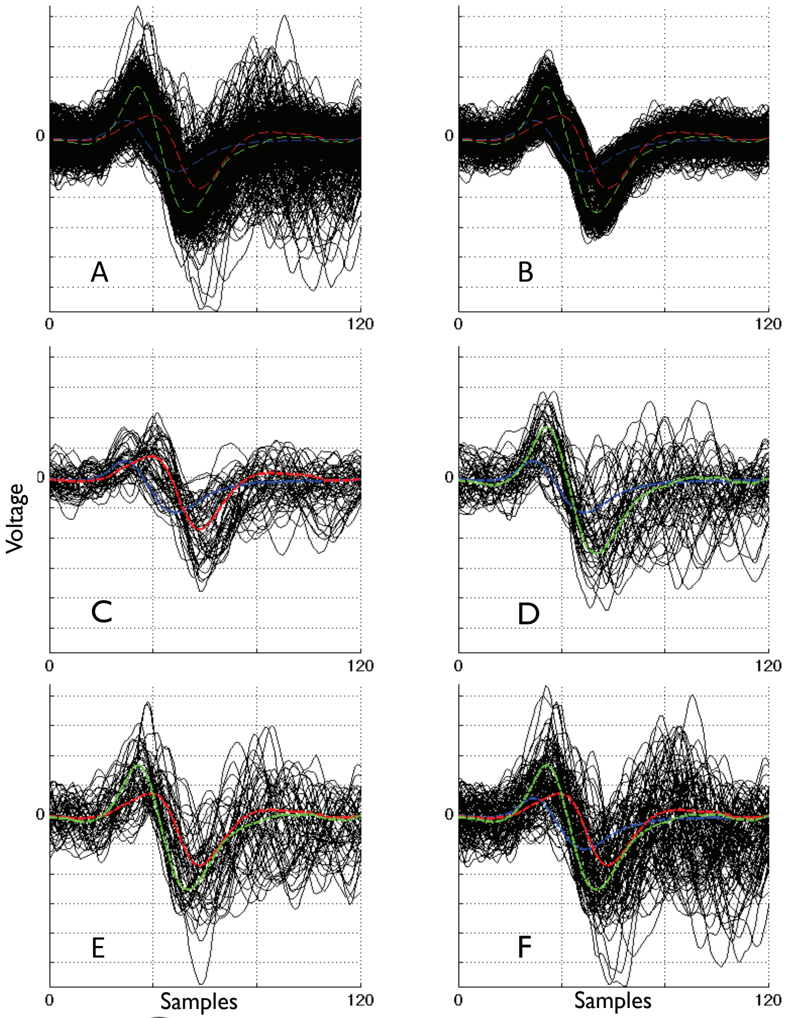
Synthetic 'noisy' overlaps

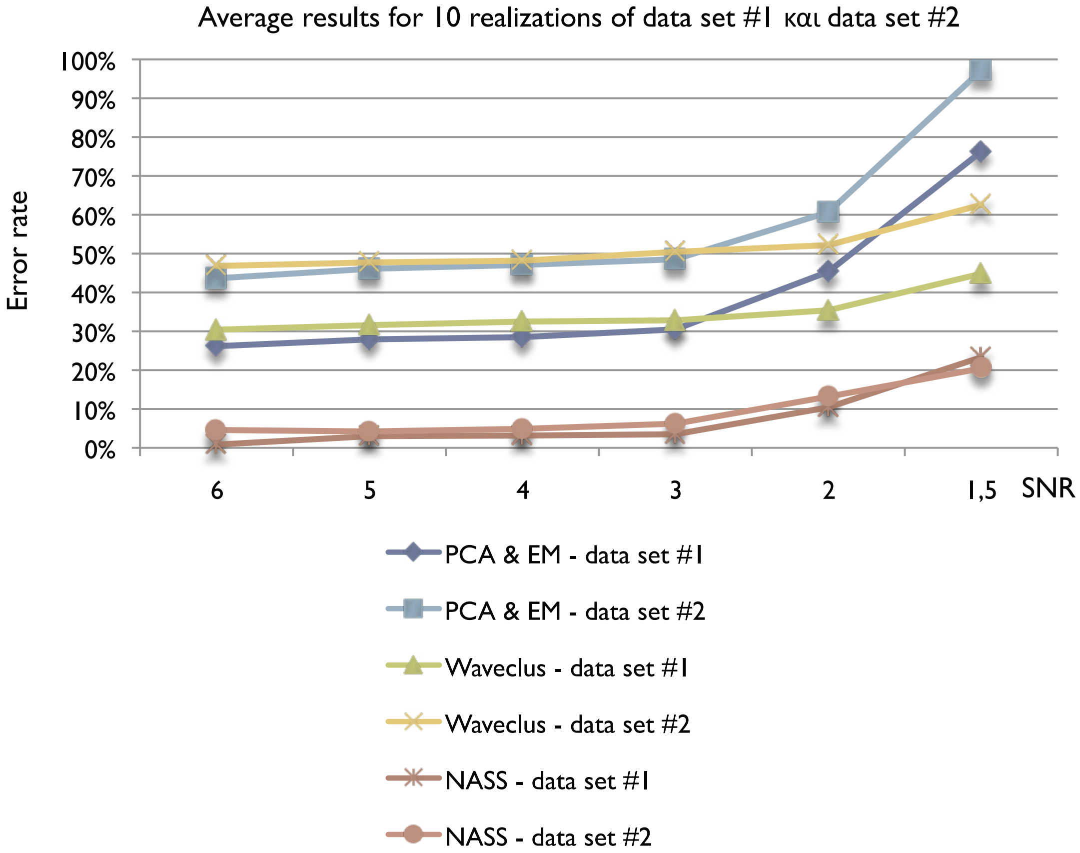
Real overlaps

NASS algorithm: Identifying overlapping spikes

- Comparative evaluation using simulated spikes from 3 neurons
  - Other methods: [PCA-EM] , [Waveclus*]
  - Signal-to-Noise Ratio (SNR) 6 – 1.5

* Quian Quiroga R et al. *Unsupervised spike detection and sorting with wavelets and superparamagnetic clustering*. **Neural Computation**, 2004.

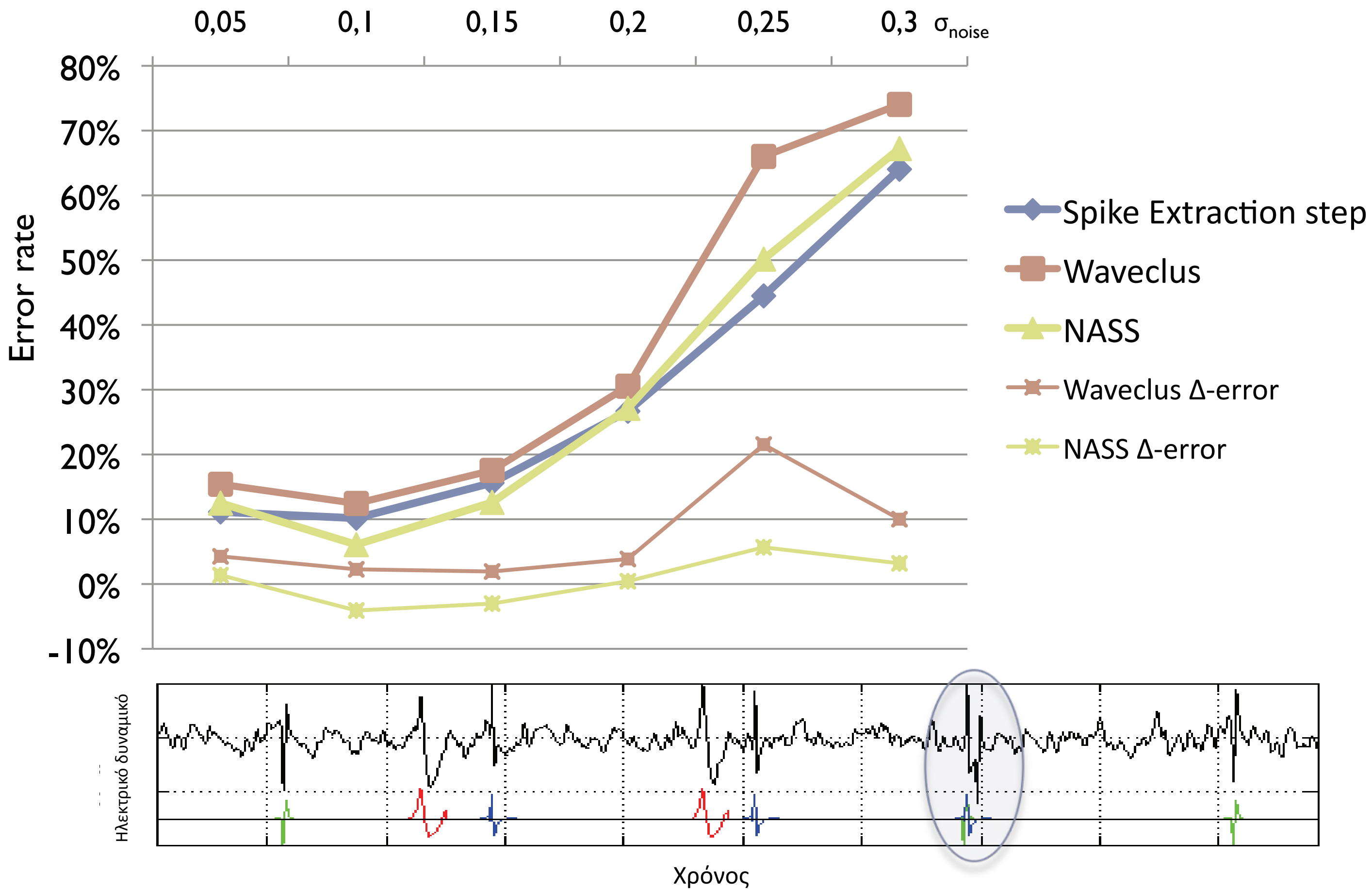




NASS algorithm: Identifying overlapping spikes

Comparative evaluation using simulated neural recordings*, featuring real action potential traces from the cortex and the basal ganglia.

* Quian Quiroga R et al. (2004). *Unsupervised spike detection and sorting with wavelets and superparamagnetic clustering.* **Neural Computation**



What about clustering?

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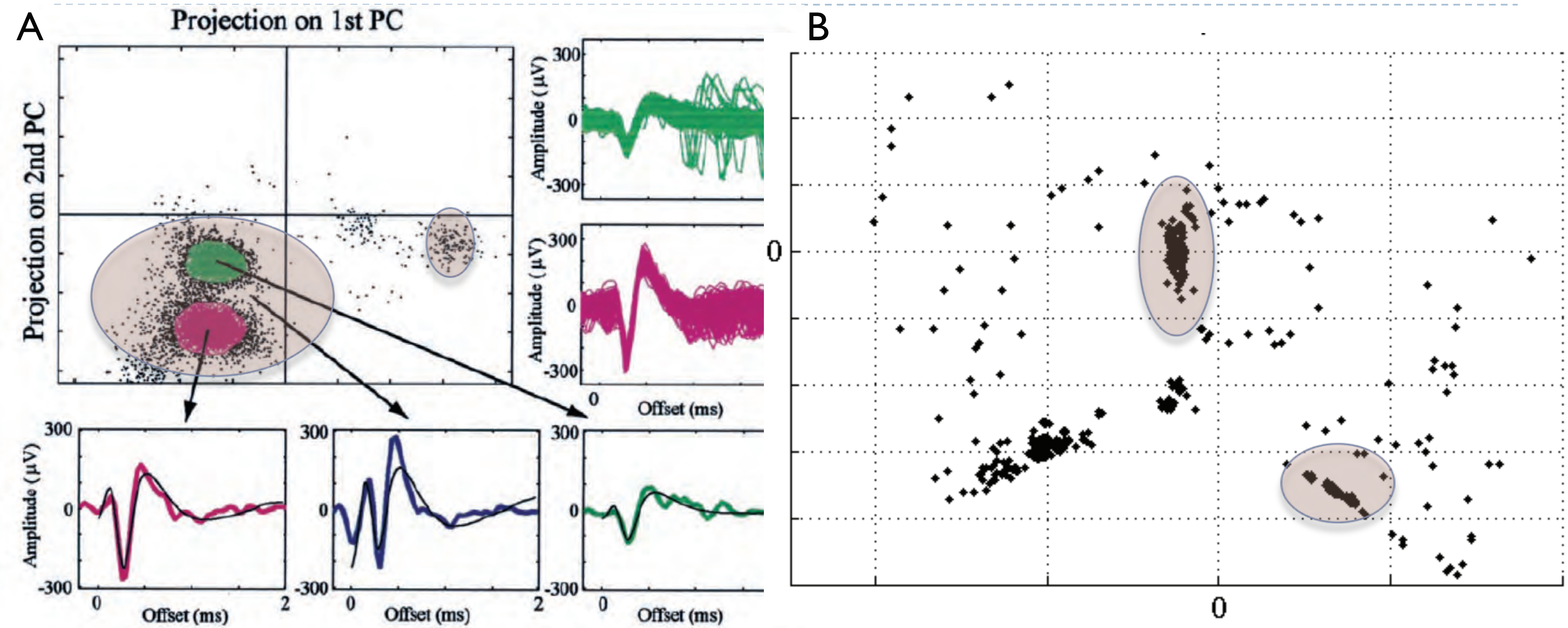
What about clustering?



- Background noise cannot be modelled with a stationary Gaussian profile [1 – 2]
- Gaussianity is not carried over non-linear representations
- Sparse-firing neurons are usually neglected, as contemporary clustering algorithms target the activity of dominating “hyperactive” neurons.

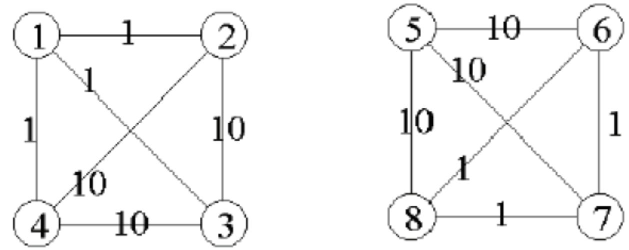
[1] Fee et al. (1996) Variability of extracellular spike waveforms of cortical neurons, **J Neurophysiol**

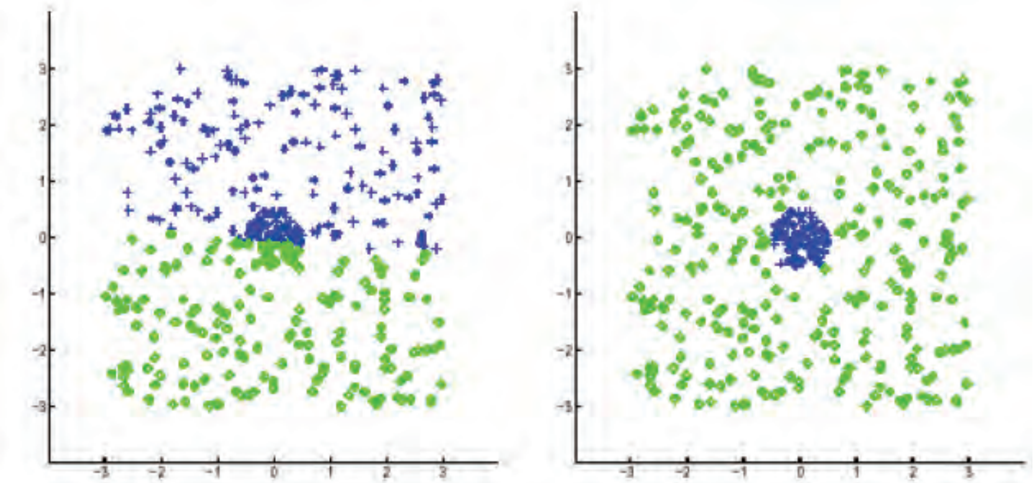
[2] Quian Quiroga R et al. (2004). Unsupervised spike detection and sorting with wavelets and superparamagnetic clustering. **Neural Computation**

Methods #2: Graph-Theoretic Clustering

Pavan M and Pelillo M, (2007). Dominant sets and pairwise clustering. **IEEE Transactions on Pattern Analysis and Machine Intelligence**

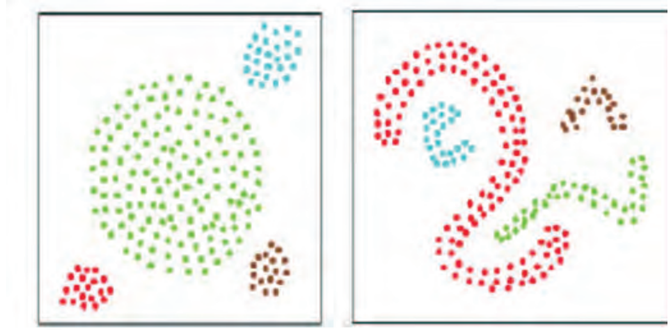
- **Dominant-Sets** clustering
  - **Internal criterion**: all objects *inside* a cluster should be highly similar to each other
  - **External criterion**: all objects *outside* a cluster should be highly dissimilar to the ones inside
  - **Similarity** is represented by weights:





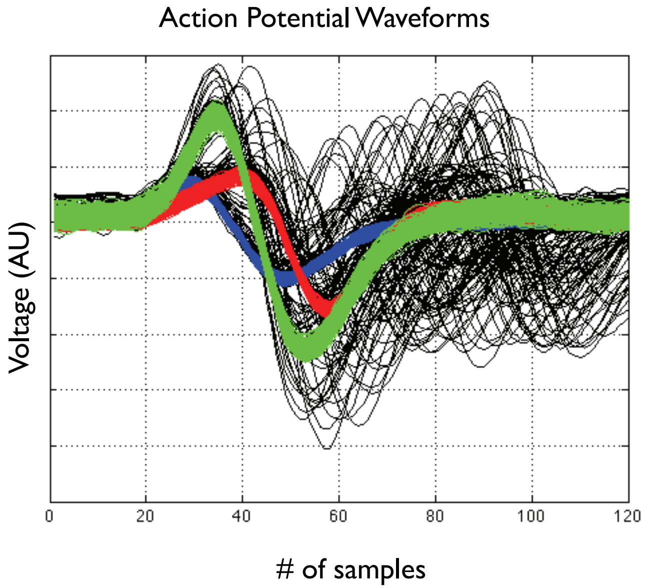
K-means

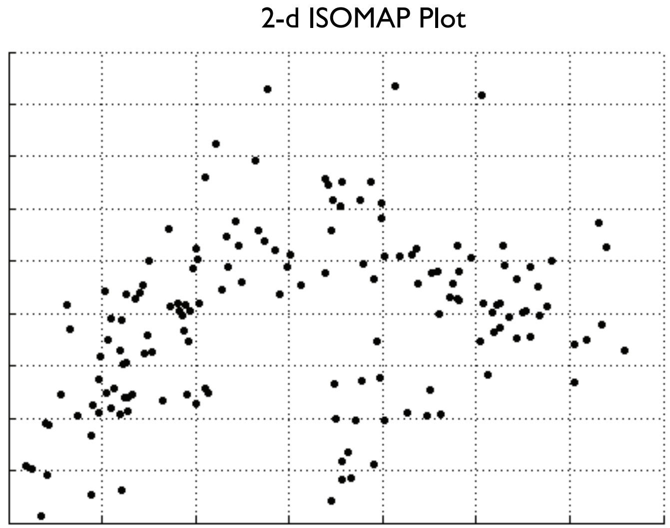
Dominant-Sets

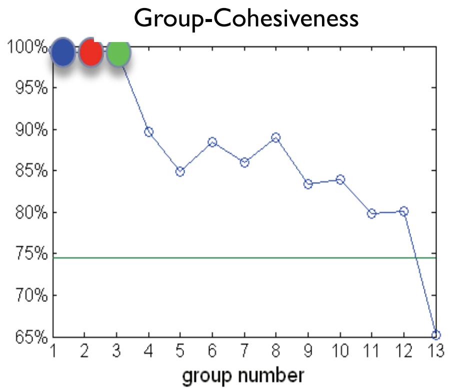


Estimating the number of active neurons

- Replicator Dynamics approach

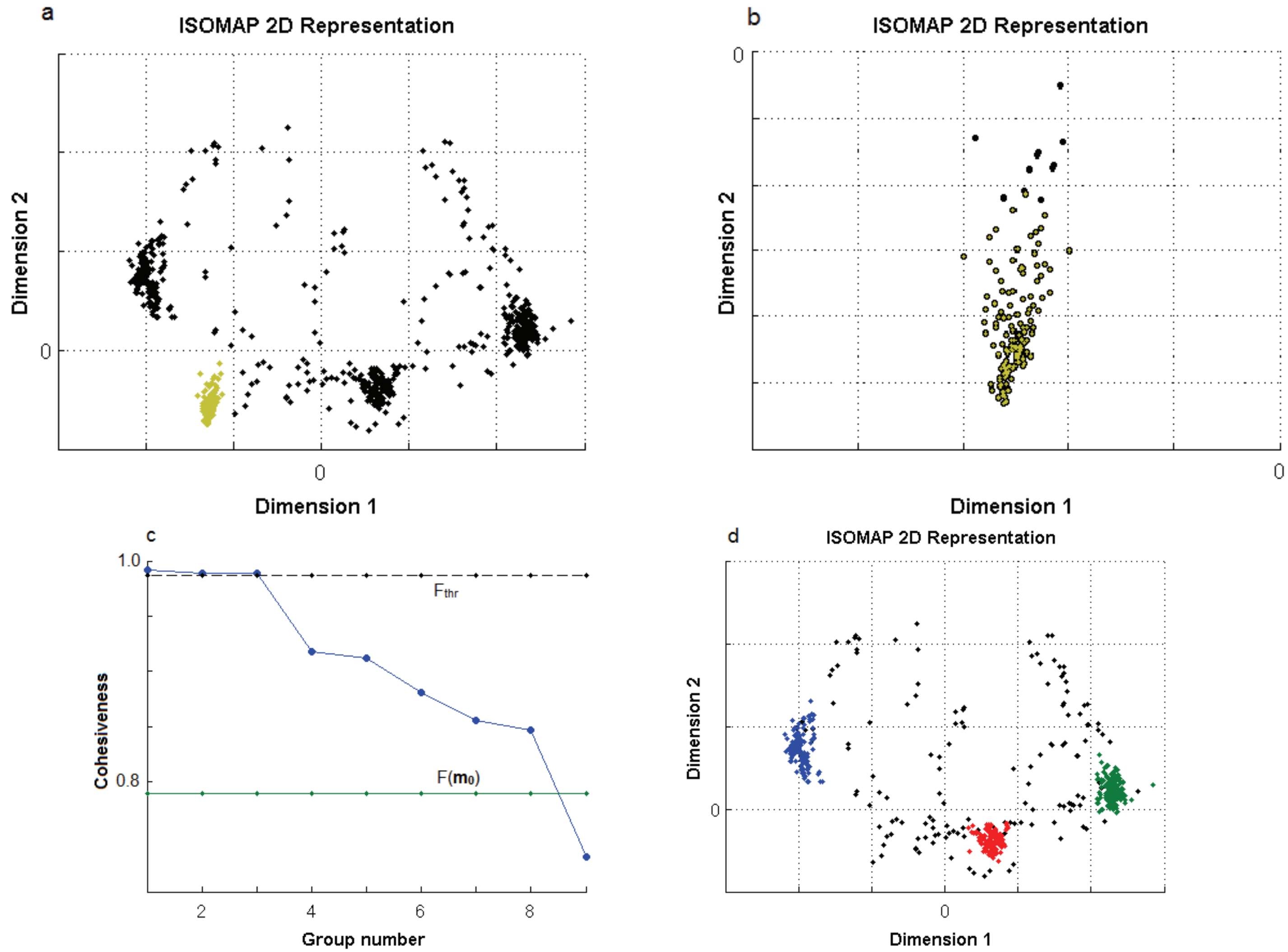






Estimating the number of active neurons

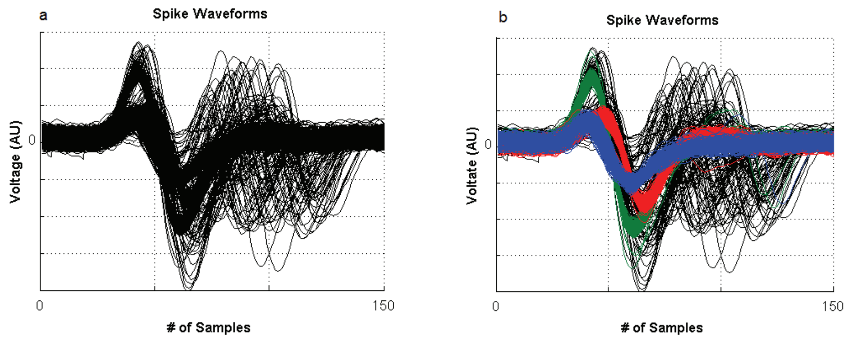
- Noise-assisted adaptation of the algorithm to the data set

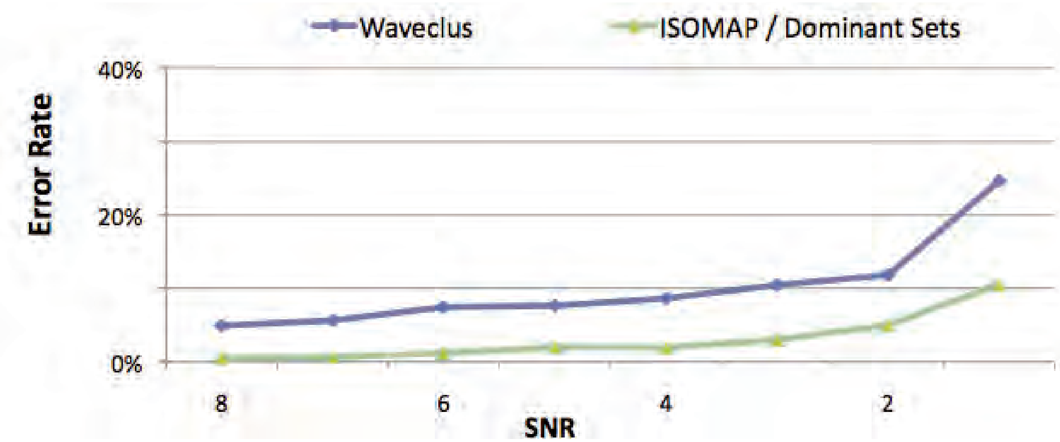


Estimating the number of active neurons

- Comparative evaluation with Waveclus* for 10 realizations of Data Set #2

  * Quian Quiroga R et al. Unsupervised spike detection and sorting with wavelets and superparamagnetic clustering. **Neural Computation**, 2004.

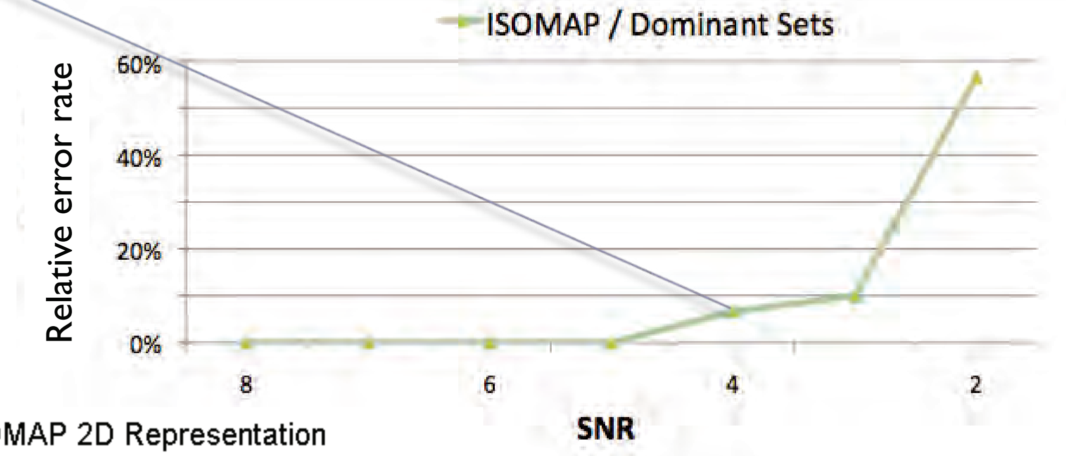


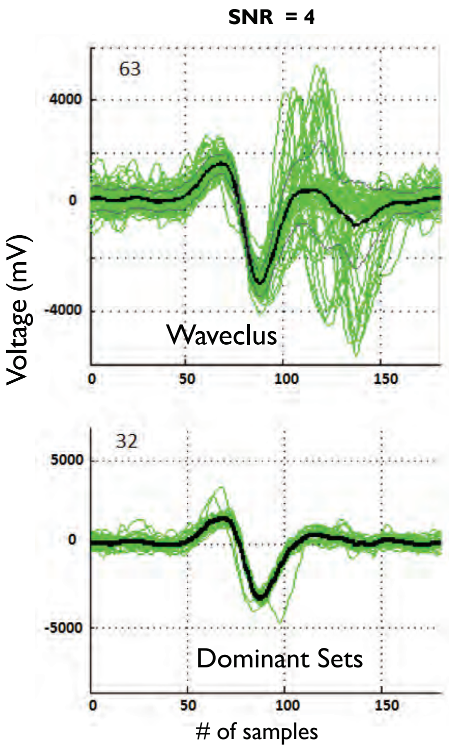


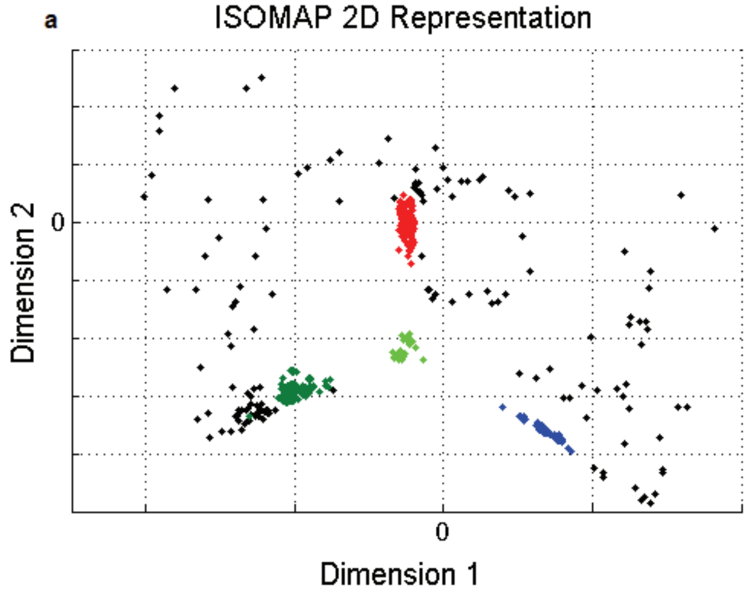
Estimating the number of active neurons

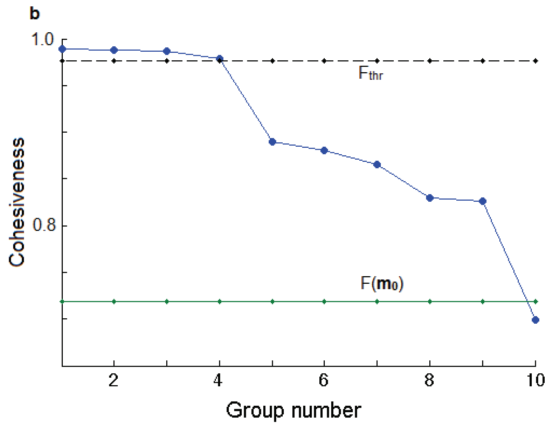
- Simulating a sparse-firing neuron
  - Same data set
  - Additional neuron with 30 spikes

Waveclus relative error rate exceeds 100% when SNR drops to 4





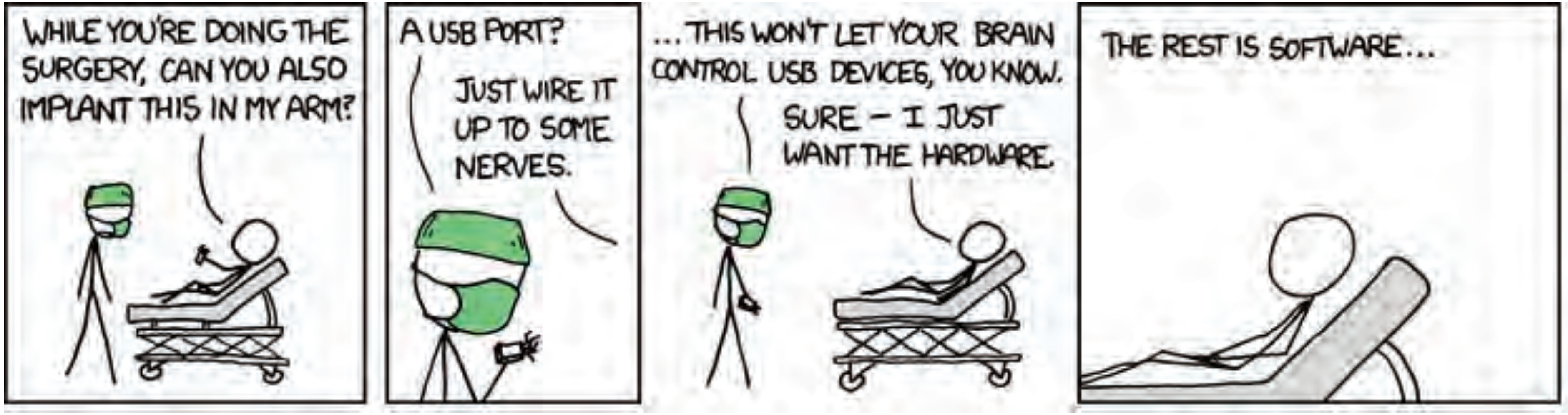




More info: http://neurobot.bio.auth.gr

Conclusions

- Problem:
  - Identifying overlapping waveforms
  - Estimating the number of active neurons
- Methods
  - Methods from the graph-theoretic domain
  - Incorporation of noise in the algorithm adaptation (training) stage
- Results
  - Semi-supervised classification of spike overlaps using a bottom-up design approach
  - Semi-supervised clustering approach with relative ranking of groups
    - High ranking: active neurons, Medium ranking: overlapping and noisy spikes that need further treatment, low ranking: background noise
- Future
  - Incorporation of both approaches in a single algorithm


WHILE YOU'RE DOING THE SURGERY, CAN YOU ALSO IMPLANT THIS IN MY ARM?
A USB PORT?
JUST WIRE IT UP TO SOME NERVES.
...THIS WON'T LET YOUR BRAIN CONTROL USB DEVICES, YOU KNOW.
SURE – I JUST WANT THE HARDWARE.
THE REST IS SOFTWARE...

Thank you