Standardized assessment of extracellular single unit isolation quality

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Introduction

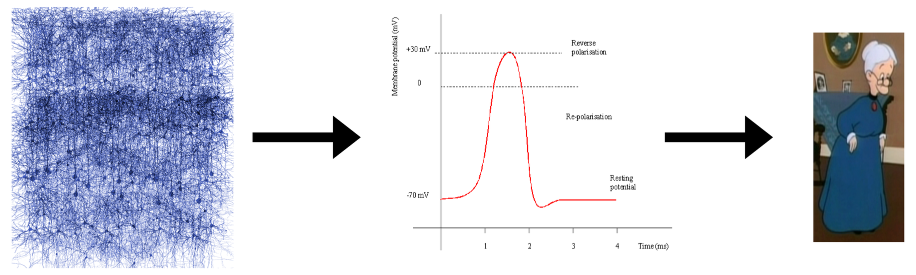
Why do we need to read spike identities?

Information processing in brain

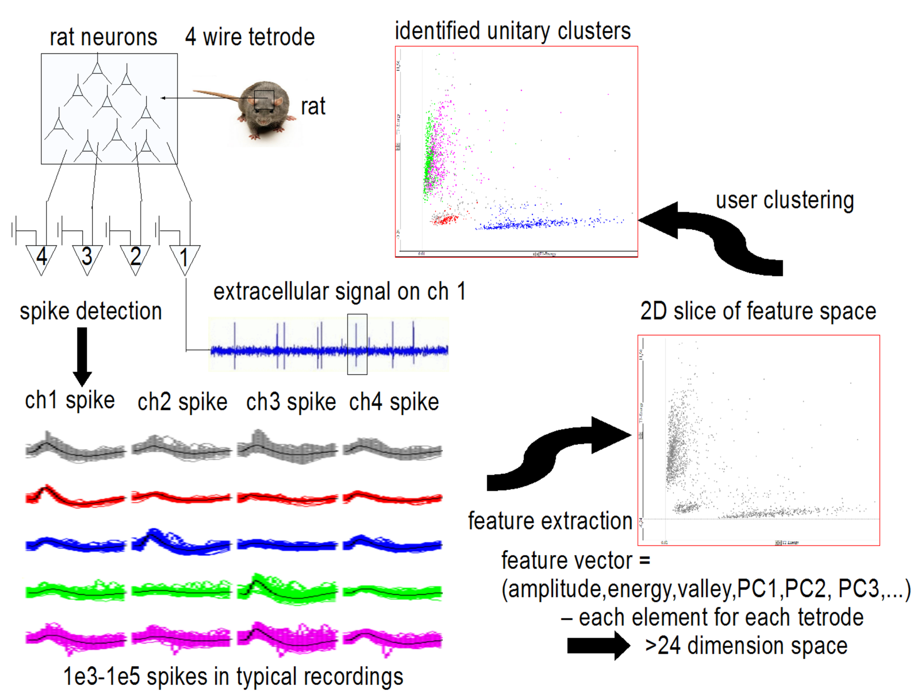
Ensemble codes

Dedicated coding

How do we "read" the codes?

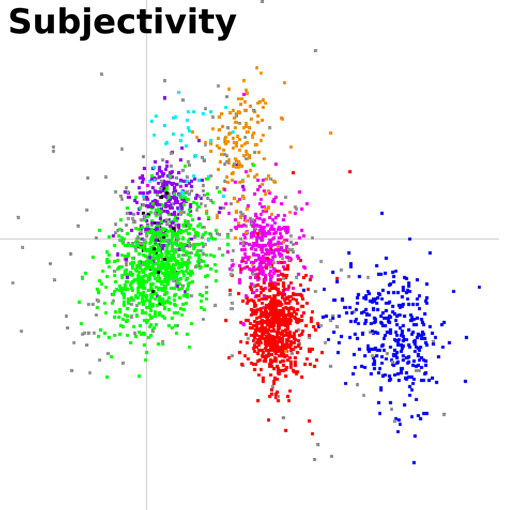


Recording & Clustering Overview

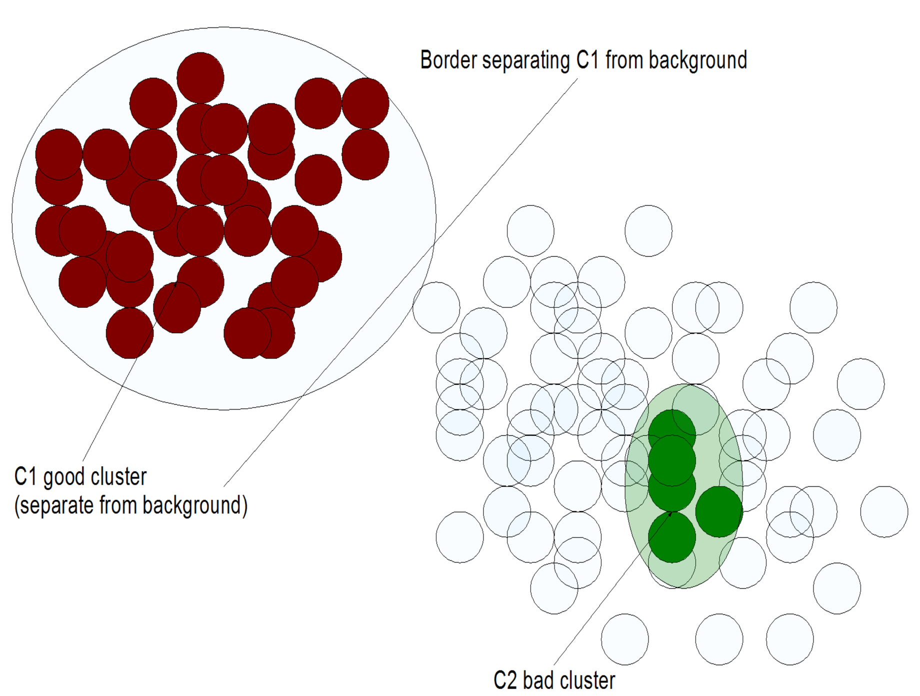


Real Clusters & Subjectivity

Monday: Alice says "Red Cluster Good"
Tuesday: Alice says "Red Cluster Bad"
Wednesday: Alice says "I'm just not sure about the red cluster."
Which Alice do we trust?



Good and Bad Clusters: Cartoon Example



Good = isolated from background, compact, unique

Bad= everything else

Methods

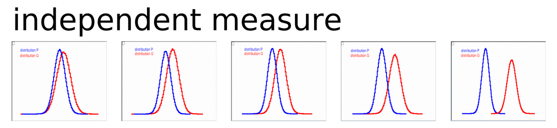
Kullback-Leibler Divergence (KLD)

Measures distinction between two distributions: cluster P from cluster Q:

$$\mathbf{D}_{KL}(P\|Q) = \sum_{i \text{ in } P} p(i)\cdot\log\left(\frac{p(i)}{q(i)}\right)$$

p(i)=probability of i in cluster P
q(i)=probability of i in cluster Q
Relative probabilities are key!!

KLD is a non-symmetric, parameter-independent measure

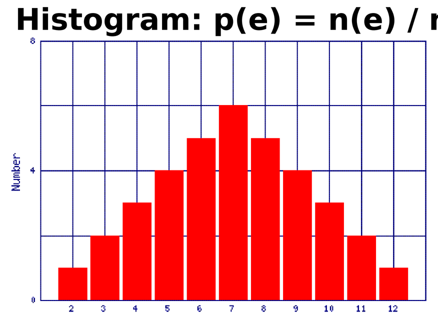


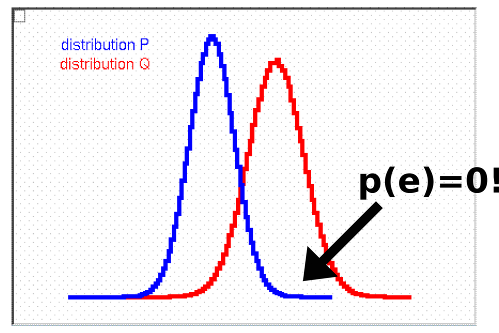
Increasing KLD

Symmetrize KLD into a distance measure with resistor average: $RA(P,Q) = \left(\frac{\mathbf{D}_{KL}(P\|Q)\cdot\mathbf{D}_{KL}(Q\|P)}{\mathbf{D}_{KL}(P\|Q)+\mathbf{D}_{KL}(Q\|P)}\right)$

How do we estimate probabilities?

Histogram: p(e) = n(e) / n

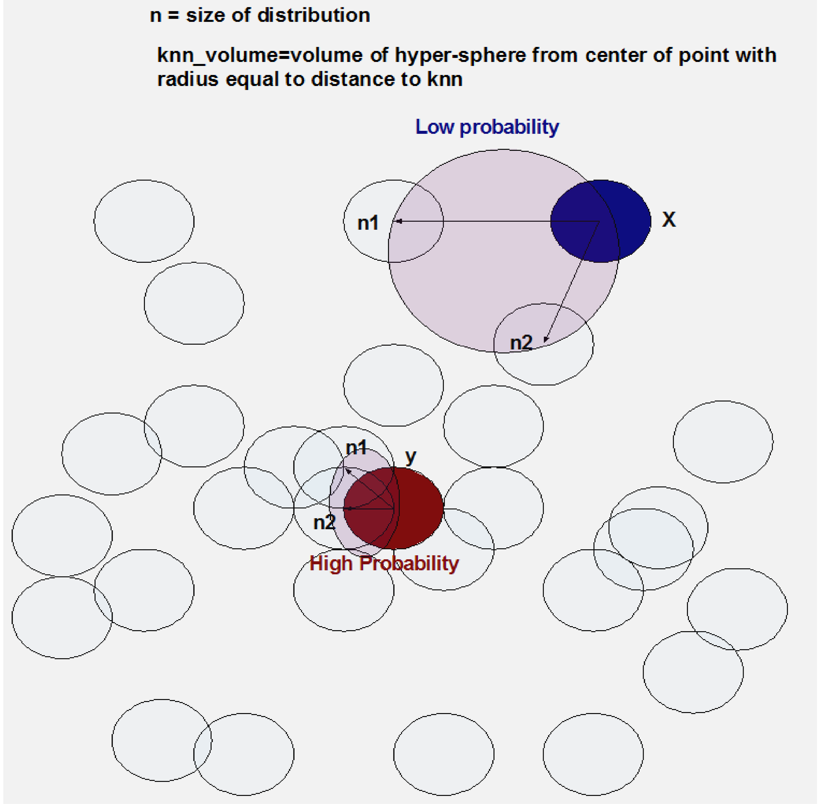




Histograms can have p(e)=0 -> KLD undefined!!

Solution: use k-nearest neighbor (KNN) estimates

KNN Probability estimates
p(x) ~ (k/n)/knn_volume



KNN-based KLD Estimator for clusters P,Q:

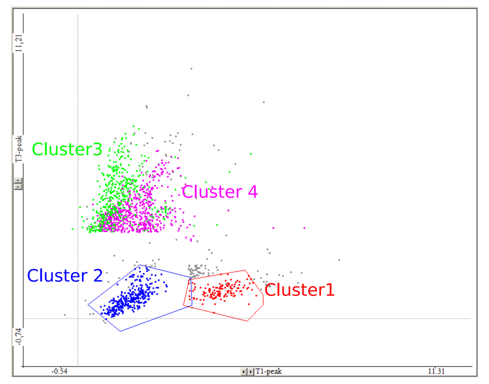
$$\frac{d}{|P|}\sum_{P_i\in P}\log\frac{\min\left(dist\left(q_j\in Q, P_i\right)\right)}{\min\left(dist\left(P_j\in P\setminus P_i, P_i\right)\right)} + \log\frac{|Q|}{|P|-1}$$

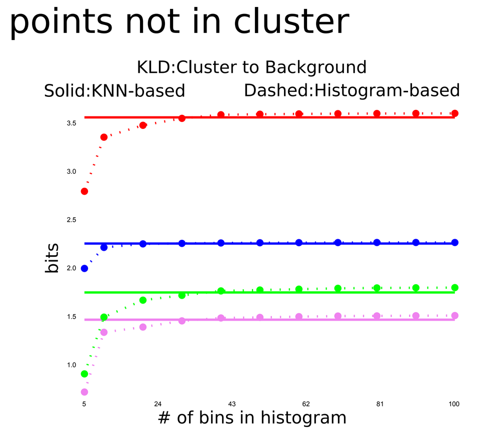
min(dist(Qj,Pi))=min. distance of an element in Q to Pi
min(dist(Pj,Pi))=min. dist. of other element in P to Pi
ratio of these distances is key!!
d=number of features, |P|=# elements in P
|Q|=# elements in Q

(Adopted from "A Nearest-Neighbor Approach to Estimating Divergence between Continuous Random Vectors",Wang. et al, 2006)

Compare: Histogram-based KLD vs KNN-based KLD

Background (BG) = all points not in cluster





Results - properties

Symmetric KLD between clusters as Isolation-Information (ISO-I)

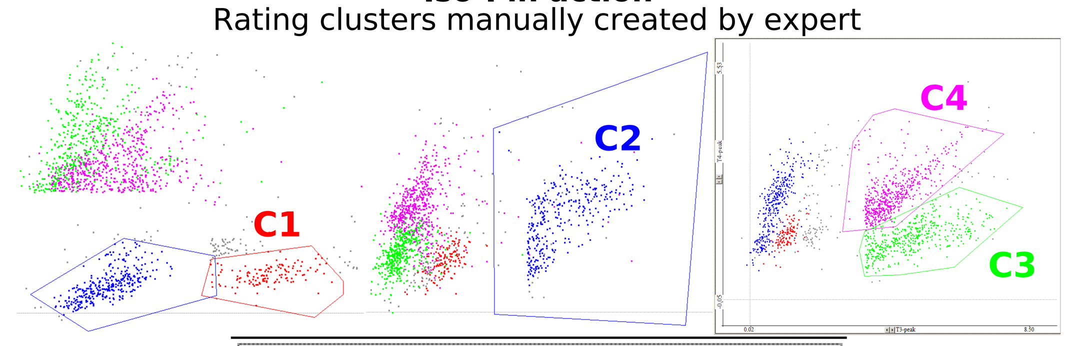
ISO-I(BG) Measures distance from cluster C to background distribution (BG) - measures isolation & compactness

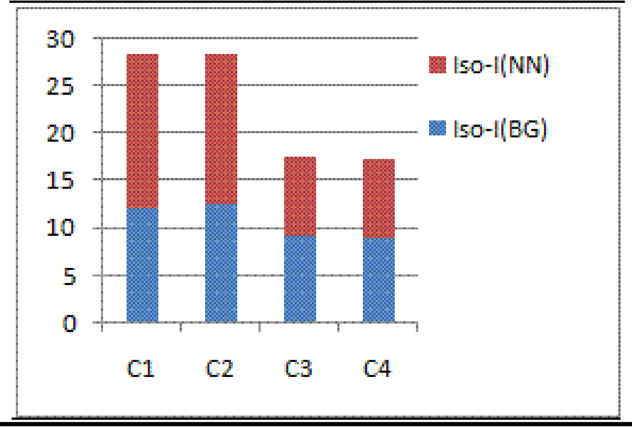
ISO-I(NN) Measures distance from cluster C to nearest neighboring cluster - measures uniqueness and compactness

Both use units of information(bits): intuitive and feature-independent

Iso-I in action

Rating clusters manually created by expert



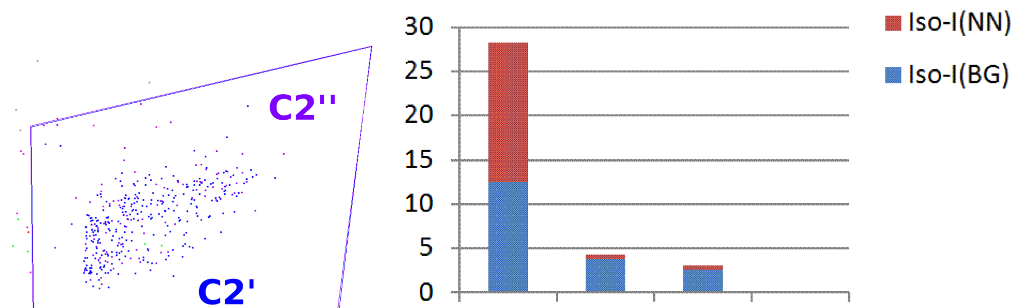


Iso-I Sensitivity to perturbations

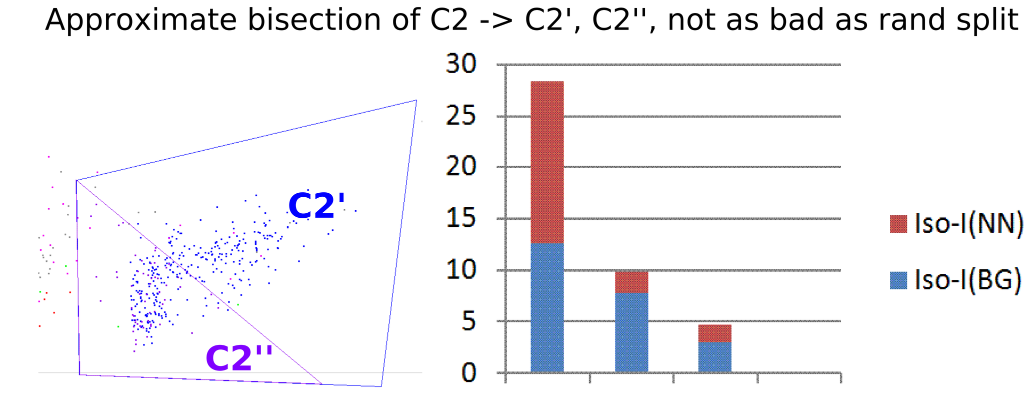
Apply degradations/enhancements to clusters ,track changes in Iso-I

Demonstrate that when we damage a cluster, the information content of the clustering decreases.

Randomly split C2 into C2' , C2''. C2',C2'' have negligible Iso-I(NN) values.



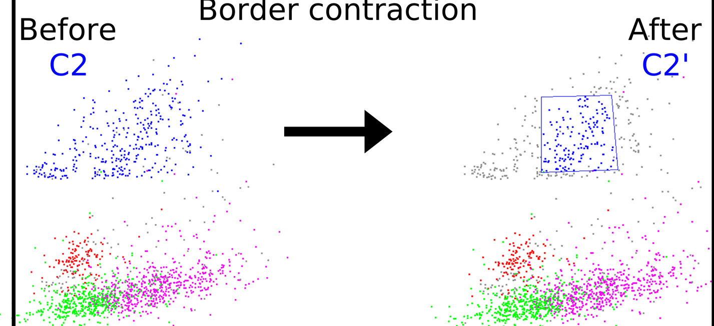
Approximate bisection of C2 -> C2', C2'', not as bad as rand split

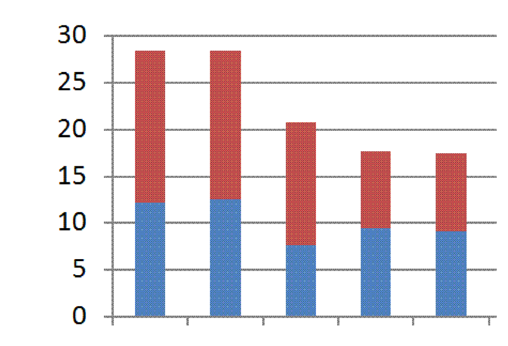


Border contraction

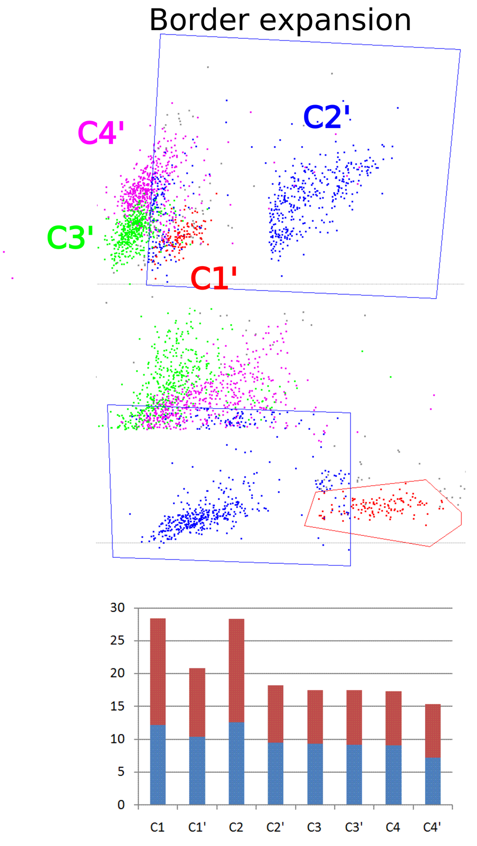
Before

After





Border expansion



Results - compare Iso-I with other cluster quality measures

Isolation distance (Iso-D) :
Calculates Nth largest squared mahalanobis distance (MD) of spikes not in cluster to cluster center, where N is size of cluster. Large value indicates good separation of cluster from background.

L-ratio: $L(C) = \sum_{i\notin C} 1 - CDF\chi^2_{df}(D^2_{i,C})$

Estimates separation of cluster from surrounding noise with the summation above using Chi-squared cumulative distribution function with 8 degrees of freedom and the squared MD: (Di)^2, for all points in the noise distribution. Then normalizes by N. Small values indicate a "moat" around the cluster.

Standard Iso-D and L-ratio operate in feature space of 1st principal component of energy-normalized spikes and energy of each spike on each microwire of a tetrode (8 features). (Quantitative Measures Of Cluster Quality For Use In Eextracellular Recordings, Schmitzer-Torbert et. al, 2005)

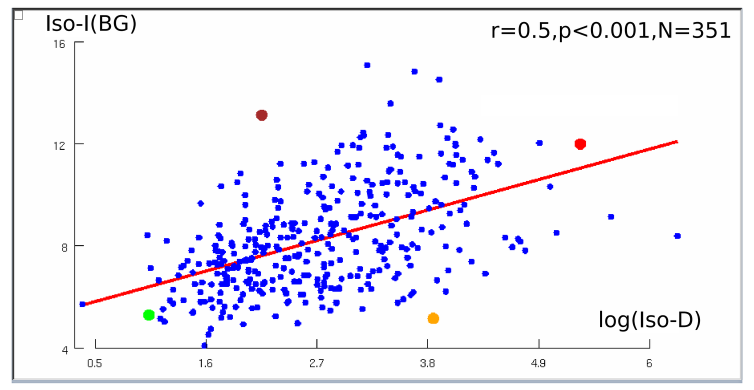
Silhouette-Width(SW): $s(i) = \frac{b(i)-a(i)}{\max\{a(i),b(i)\}}$

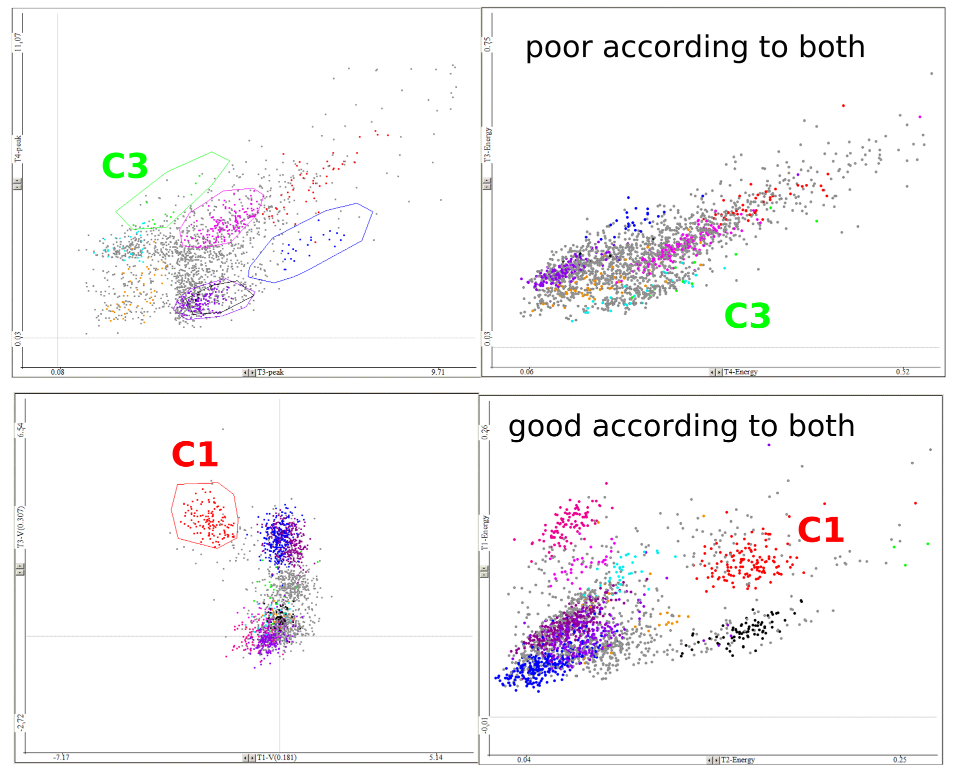
Given a(i) as distance of nearest neighbor(nn) of element i in cluster A and b(i) as distance of nn of element i in cluster B, average s(i) for elements in cluster A, measures confidence of points belonging to cluster A. Values [-1,1] are [bad,good]. Operates in arbitrary feature space.
(Graphical aid to cluster analysis, Rousseeuw PJ,1987)

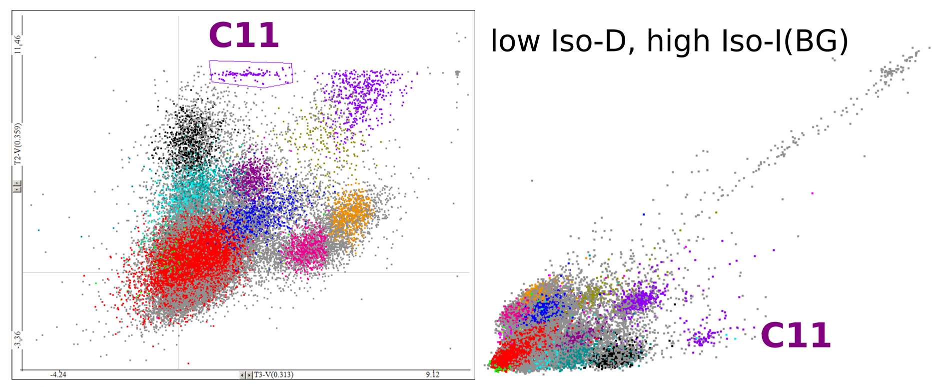
	Iso-I(BG)	Iso-I(NN)	log(Iso-D)	log(L-Ratio)	SilhouetteWidth
Iso-I(BG)	•	▪	▪	▪	▪
Iso-I(NN)	0.55	•	▪	▪	▪
log(Iso-D)	0.5	0.47	•	▪	▪
log(L-Ratio)	-0.57	-0.46	-0.91	•	▪
SilhouetteWidth	0.27	0.63	0.43	-0.44	•
Spikes	-0.02	0.21	0.37	-0.26	0.07

Table of correlations between different measures and number of spikes in a cluster.

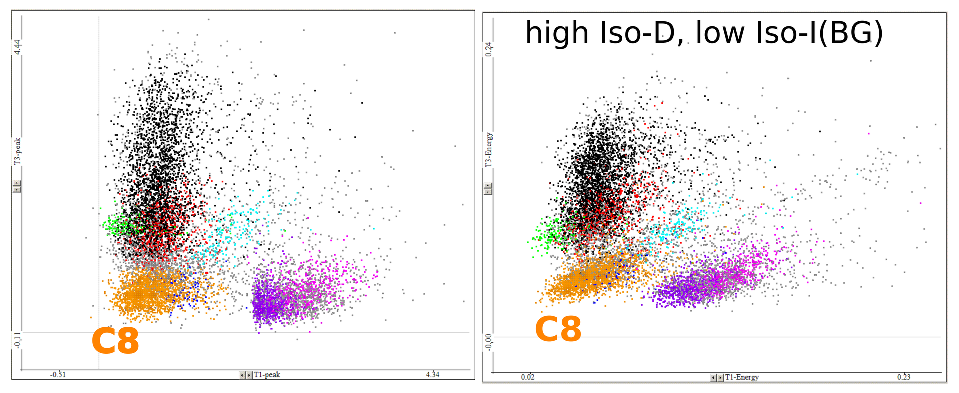
Iso-I(BG) less sensitive to cluster size than Iso-D





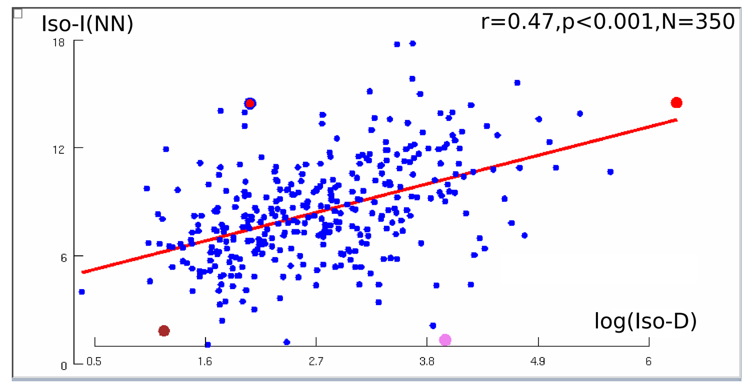


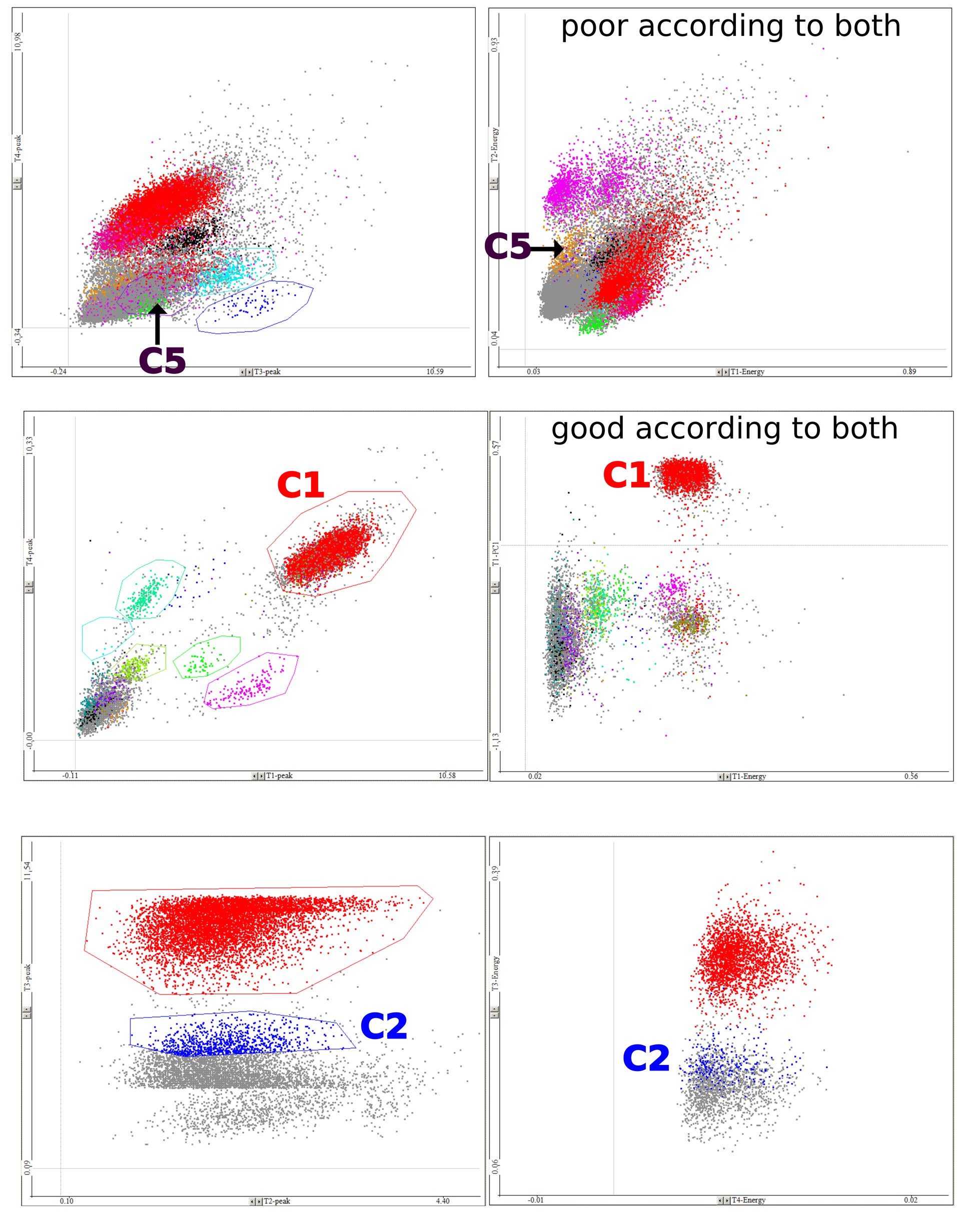
C11, reasonable separation, but few elements, -> low Iso-D



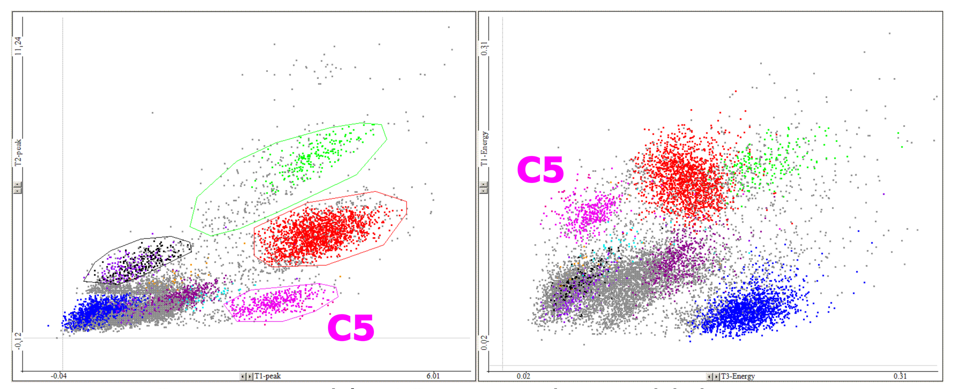
C8, poor separation, but many elements (~28% of spikes) -> inflated Iso-D

Iso-I(NN) sensitive to uniqueness of cluster compared to Iso-D





C2, poor background separation -> low Iso-D, Iso-I(BG)
C2, good inter-cluster separation -> high Iso-I(NN)
Iso-I(NN) AND Iso-I(BG) can detect different types of problems.



C5, reasonable BG separation -> high Iso-D
C5, poor inter-cluster separation (low uniqueness) -> low Iso-I(NN)

Conclusions

Cluster assessment critical for quality control of spike sorting.

Various cluster quality measures are useful for detecting different types of cluster features/errors.

Information measures are feature independent and show good concordance with intuitive sense of quality.

Standard Iso-D is oversensitive to number of elements in a cluster, limited to specific features, redundant with L-ratio, and not sensitive to uniqueness of clusters.

Iso-I(BG),Iso-I(NN) are less redundant cluster quality measures that can detect cluster background-separation, uniqueness, and compactness.

We invite submissions of spike cluster data for evaluation.

Acknowledgments

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