

EMBEDDED SIGNAL PROCESSING



Spike Sorting

Presented by:

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3rd year ESYBIO

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OUTLINE

INTRODUCTION

PROBLEMATIC

CONCEPTUAL STUDY

TECHNICAL REALISATION

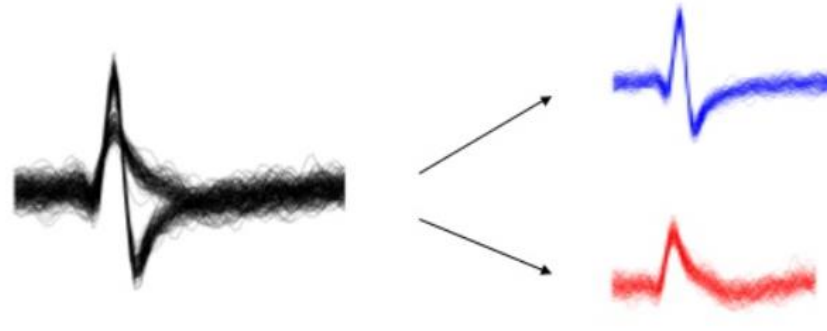
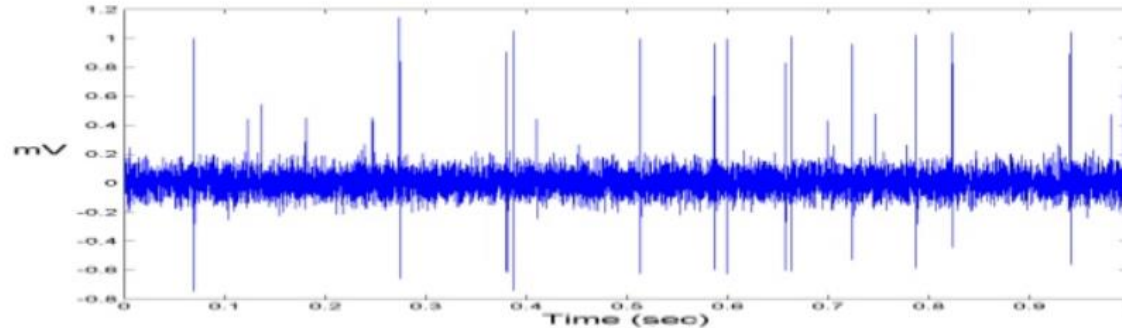
CONCLUSION

INTRODUCTION

- ▶ Neurons produce action potentials that are referred to as **“Spike”**
- ▶ Spike sorting is the grouping of spikes into clusters based on the similarity of their shapes.
- ▶ The end result of spike sorting is the determination of which spike corresponds to which of these neurons.

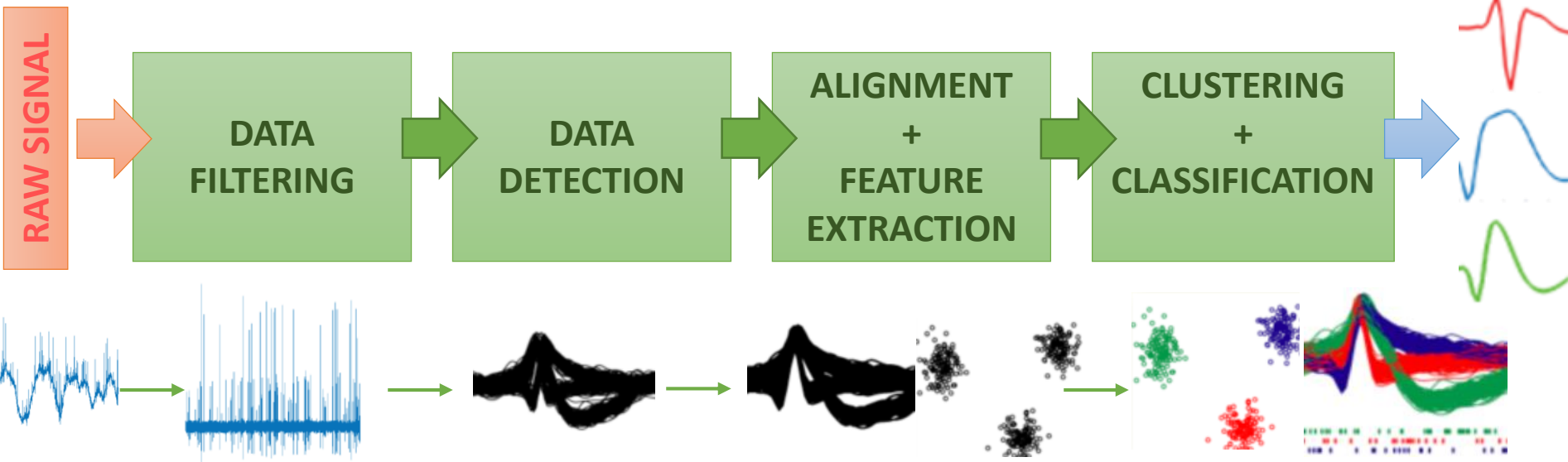
PROBLEMATIC

Problem: detect and separate spikes corresponding to different neurons



CONCEPTUAL STUDY

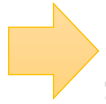
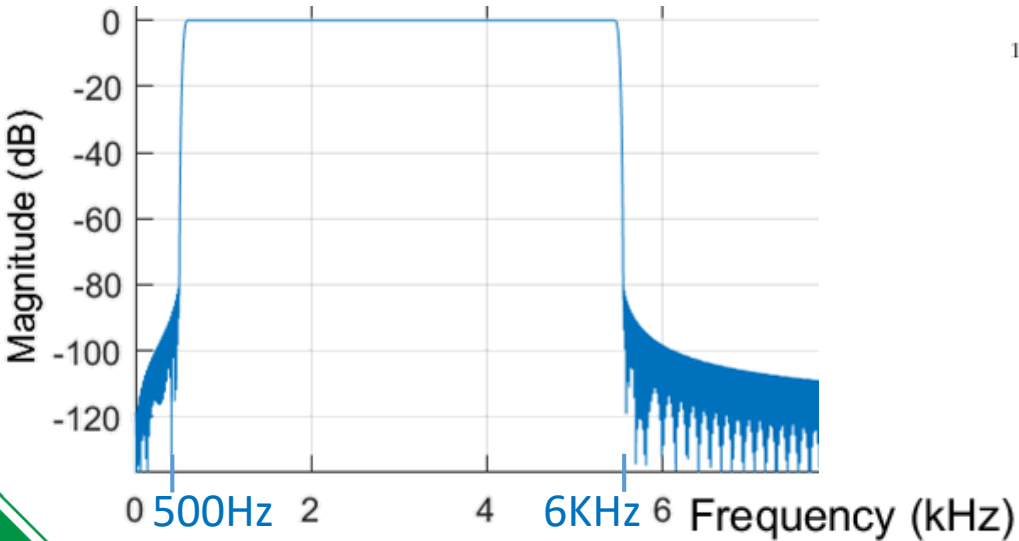
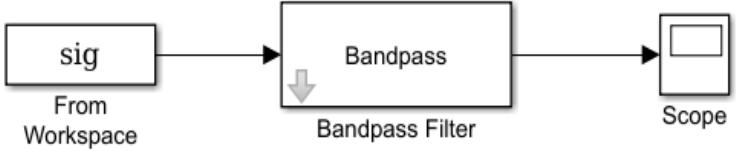
Basic steps for Spike sorting



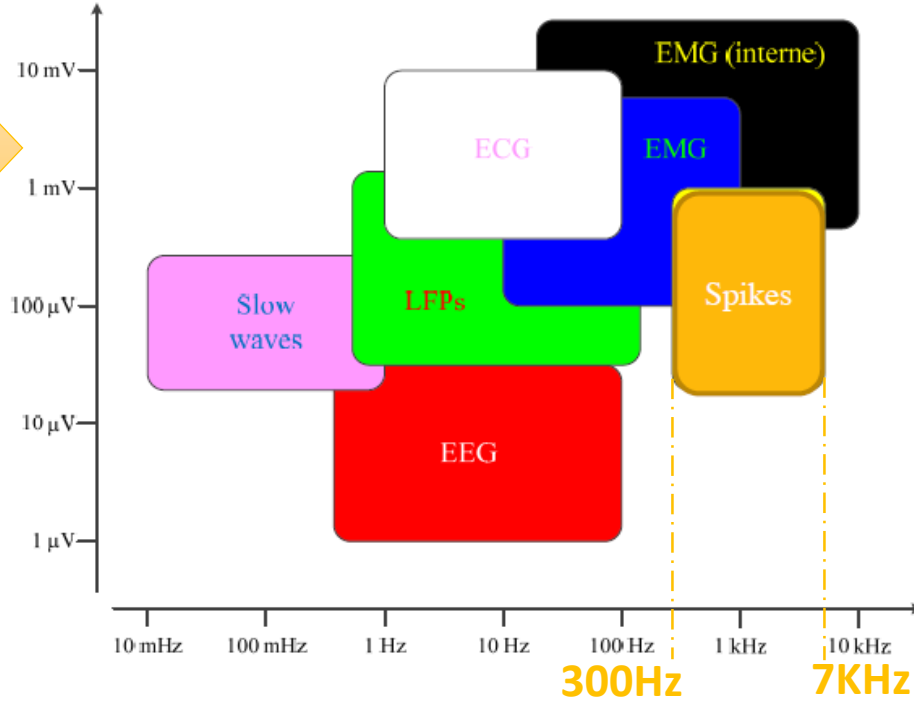
CONCEPTUAL STUDY

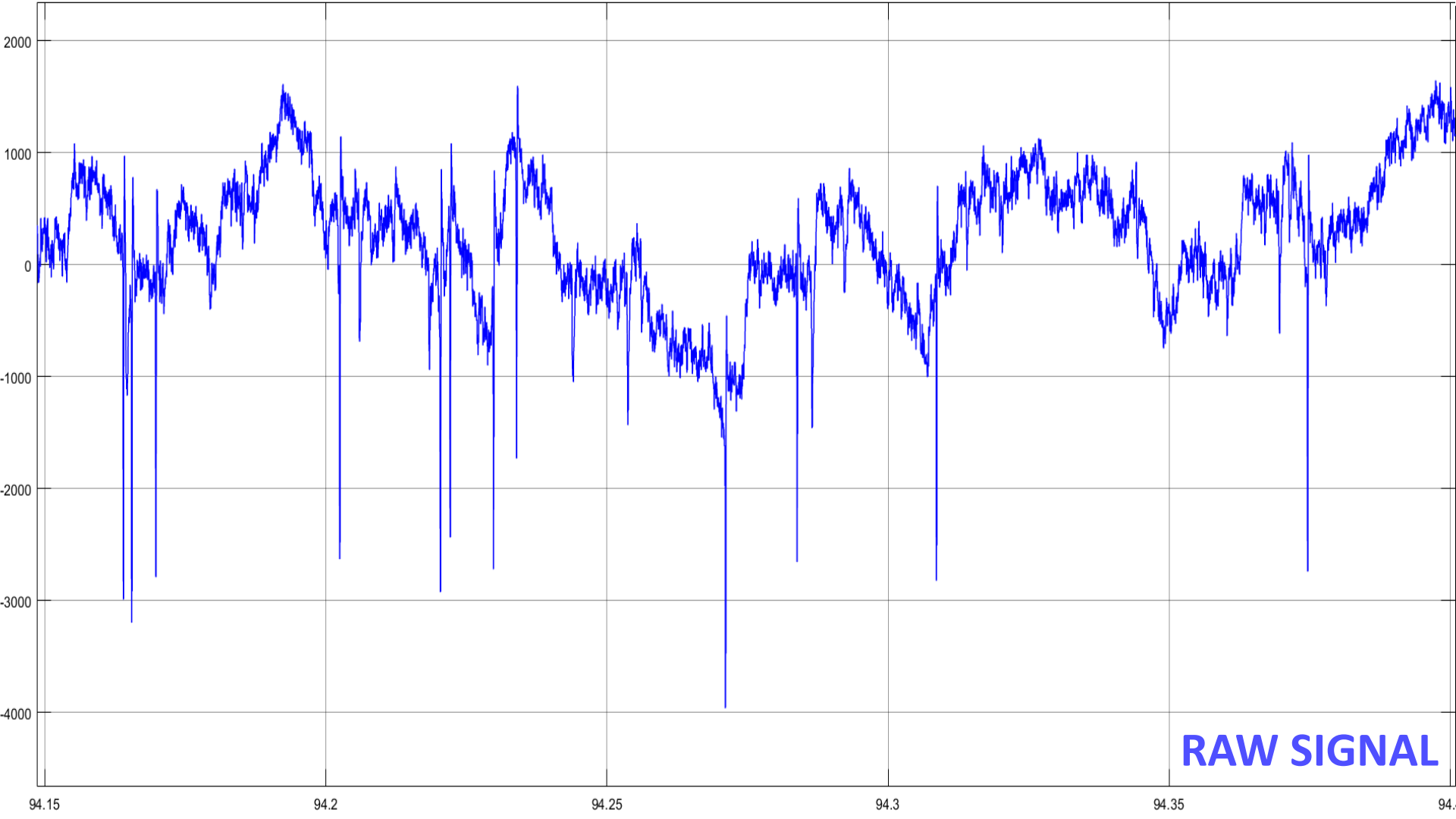
FILTERING

► Range of Strike frequency : 300Hz → 7KHz

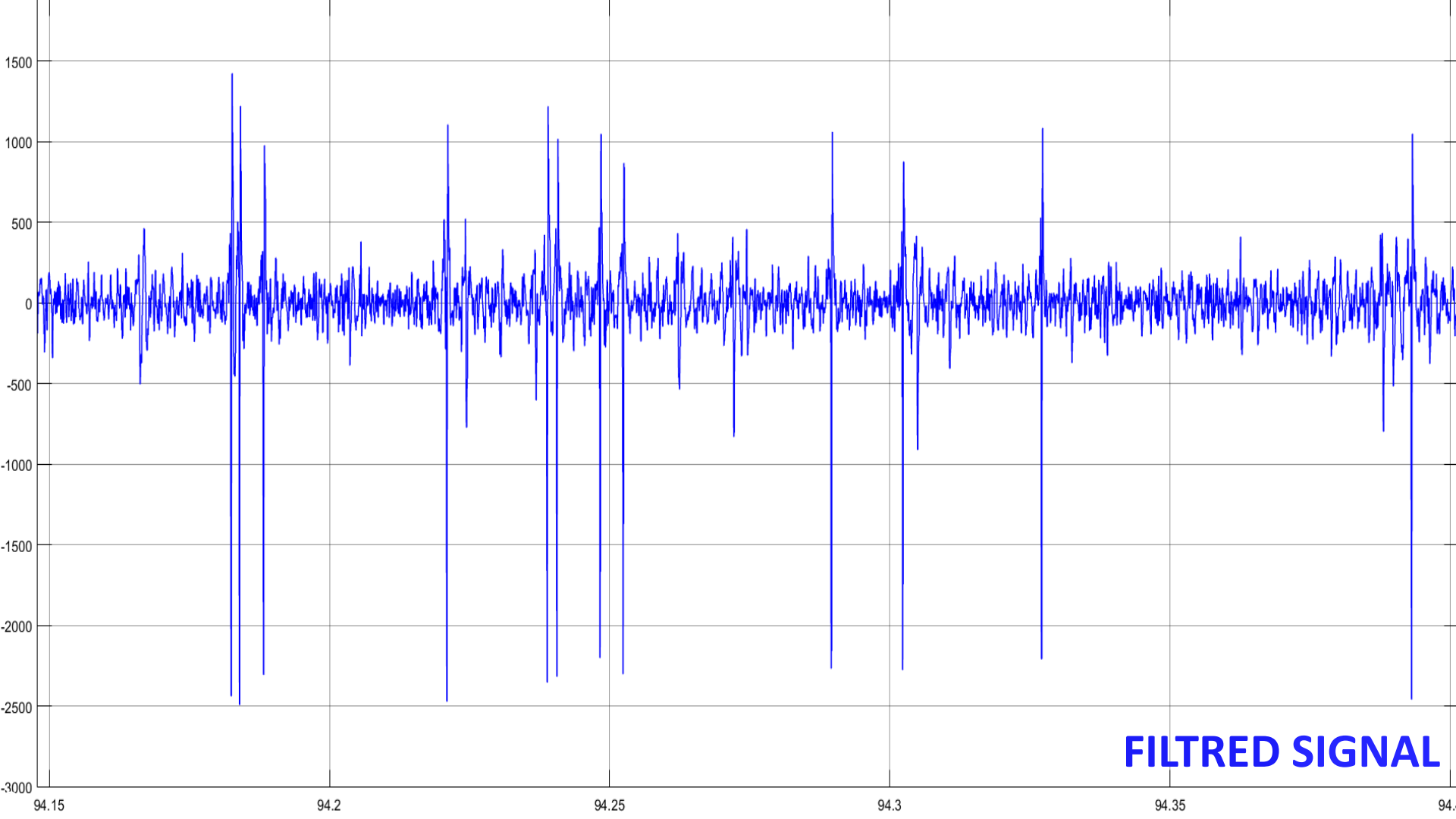


Electrophysiological signals





RAW SIGNAL



FILTRED SIGNAL

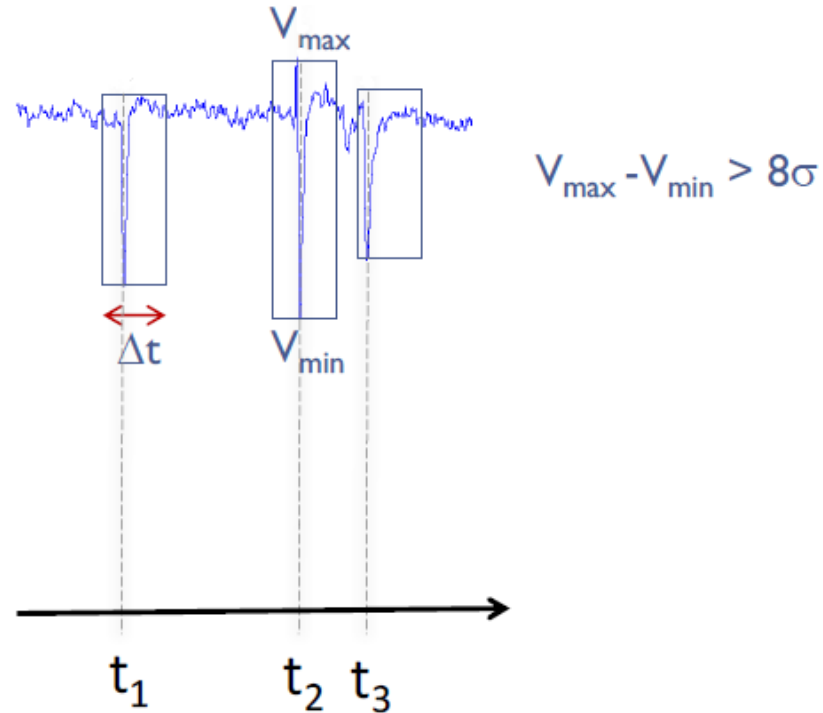
CONCEPTUAL STUDY

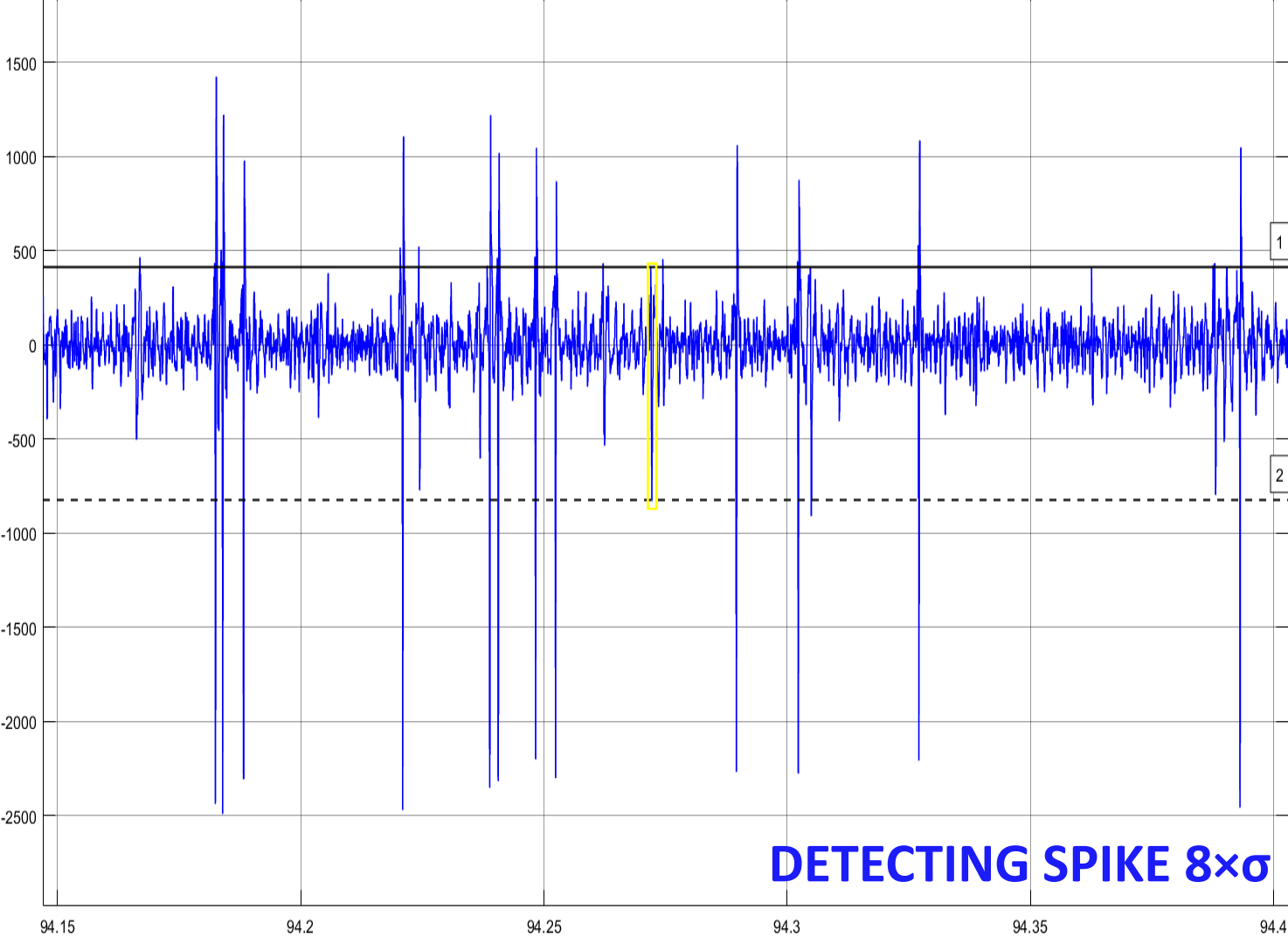
DETECTION

Differential threshold

- SDDT
Spike Detection Differential Threshold

- PTSD
Precision Timing Spike Detection





▼ Settings

- Screen cursors
 - Horizontal Vertical
- Waveform cursors
- Lock cursor spacing
- Snap to data

▼ Measurements

	Time	Value
1	--	413.594
2	--	-823.616
ΔT	--	ΔY 1.237e+03
1 / ΔT		--
$\Delta Y / \Delta T$		--

Standard Deviation

$\sigma = 111,5478$

$8 \times \sigma = 892,3824$

$V_{max} - V_{min} = 1237$

➔ $V_{max} - V_{min} > 8 \times \sigma$

CONCEPTUAL STUDY

DETECTION

UNIVERSAL THRESHOLD (Donoho, 1995)

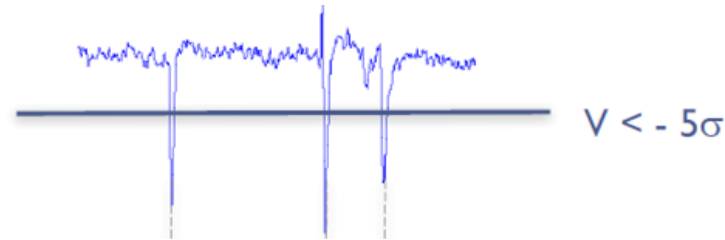
$$T = \sigma * \sqrt{2 * \log(N)}$$

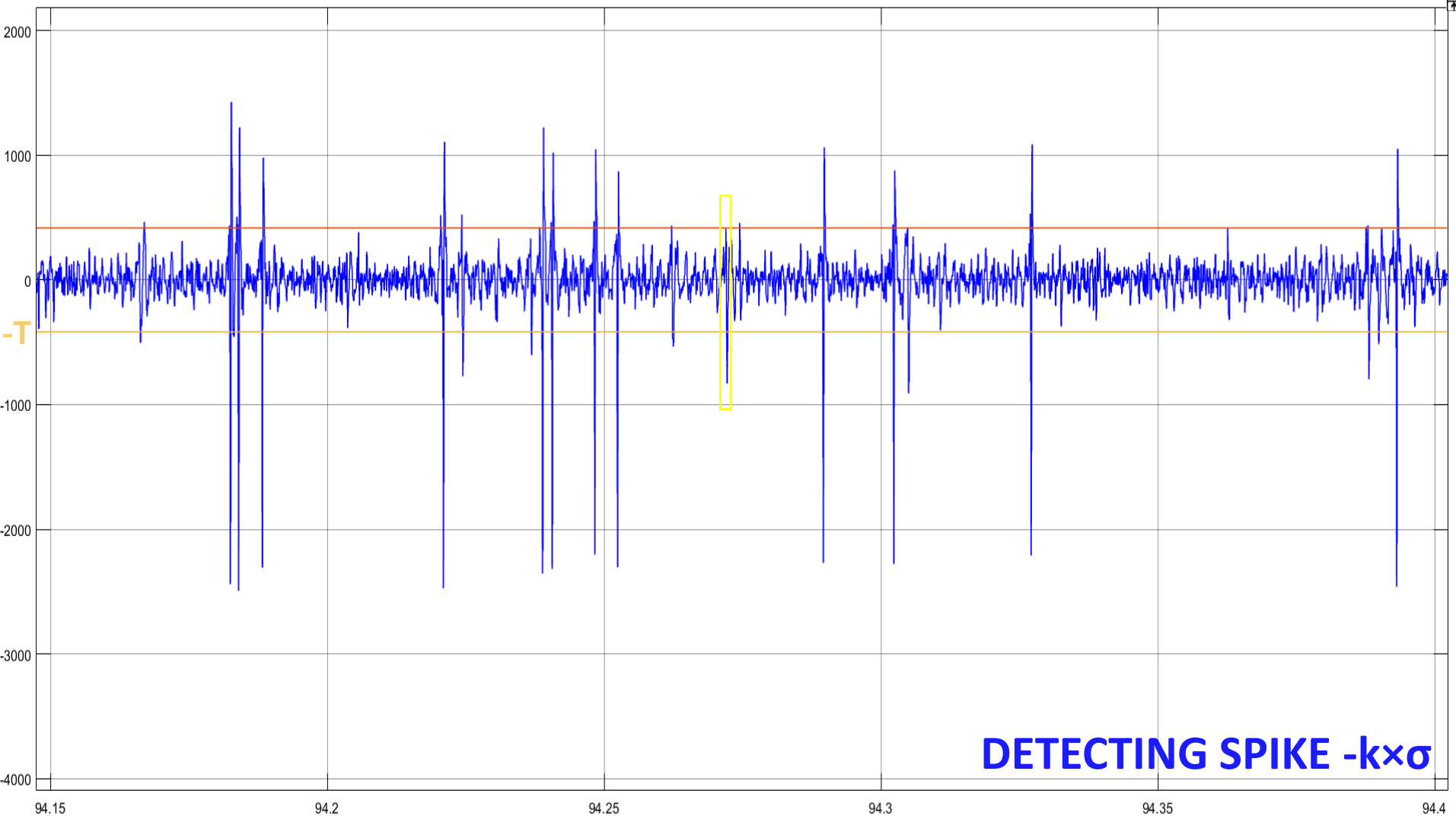
The white Gaussian noise can be fully described by its standard deviation σ

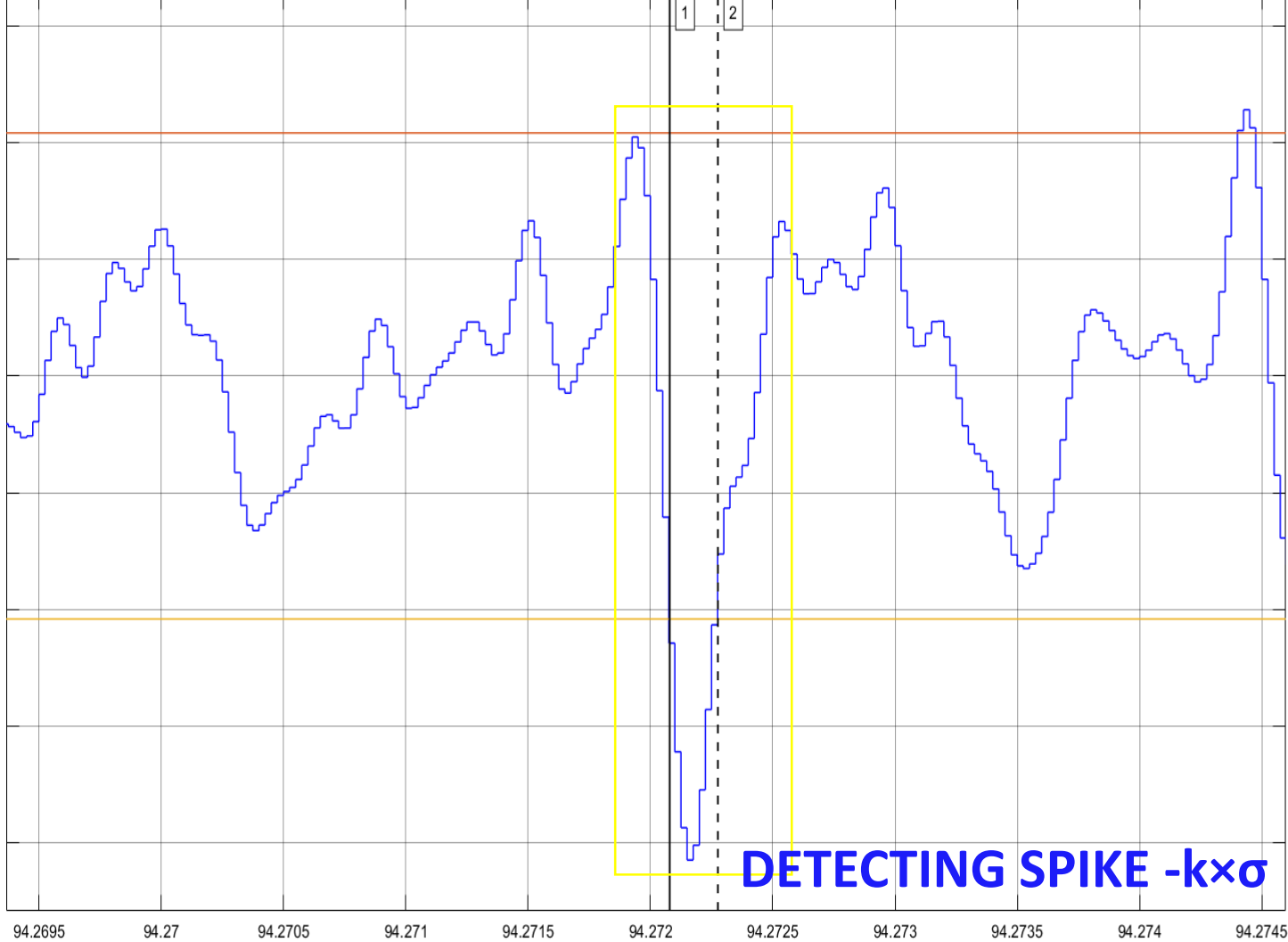
HOWEVER Noise from neuronal or pancreatic signals can be assimilated to white Gaussian noise

We choose the multiplication coefficient (K) in order to set the threshold plus or minus near the noise level.

Hard threshold







Trace Selection

Lowpass Filter

Cursor Measurements

Settings

- Screen cursors
 - Horizontal
 - Vertical
- Waveform cursors
 - 1 | Lowpass Filter
 - 2 | Lowpass Filter
- Lock cursor spacing
- Snap to data

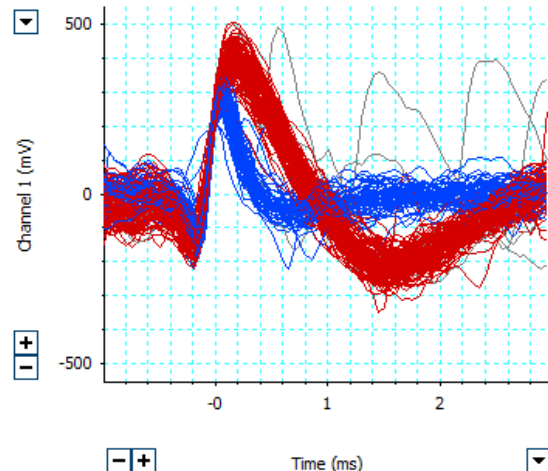
Measurements

	Time		Value
1	94.272		--
2	94.272		--
ΔT	196.993 μs	ΔY	--
1 / ΔT			5.076 kHz
$\Delta Y / \Delta T$			--

CONCEPTUAL STUDY

ALIGNMENT + FEATURE EXTRACTION

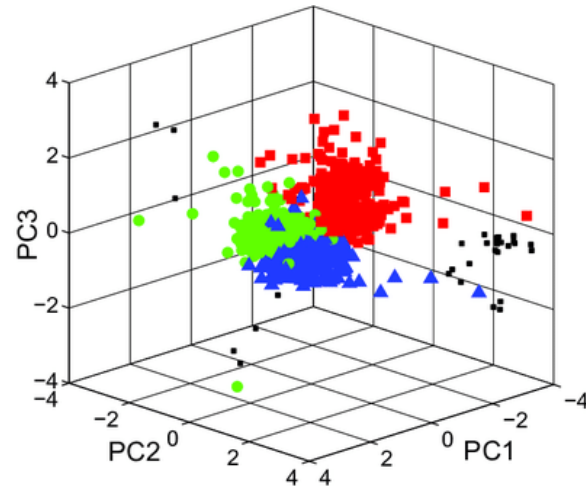
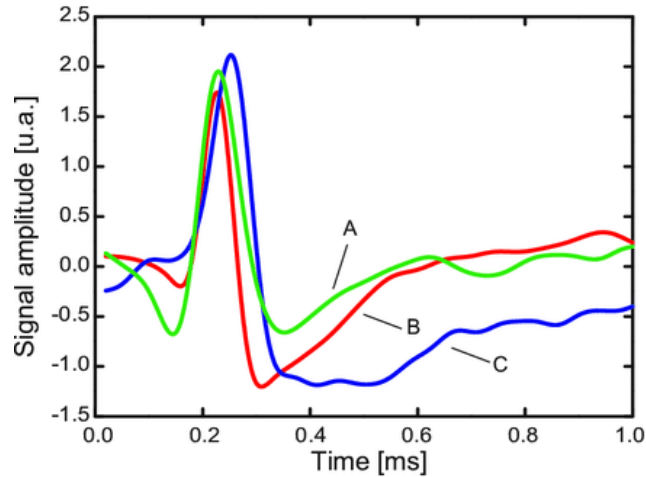
- ▶ Separating units based on the amplitude of the spikes + “window discriminators”.
- ▶ implemented in a fast and simple way
- ▶ The windows should be set (and readjusted) manually



CONCEPTUAL STUDY

ALIGNMENT + FEATURE EXTRACTION

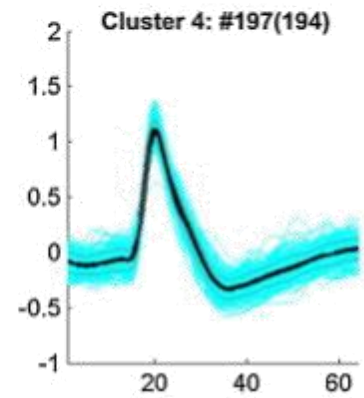
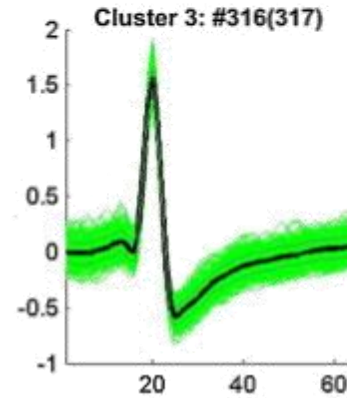
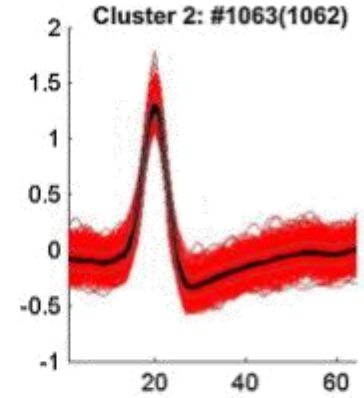
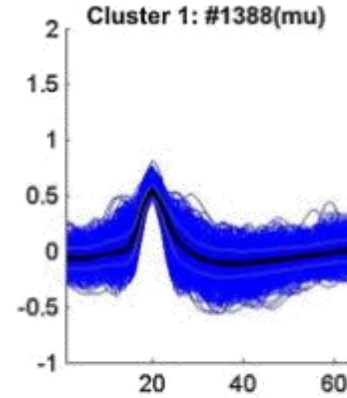
- ▶ PCA : principal component analysis



CONCEPTUAL STUDY

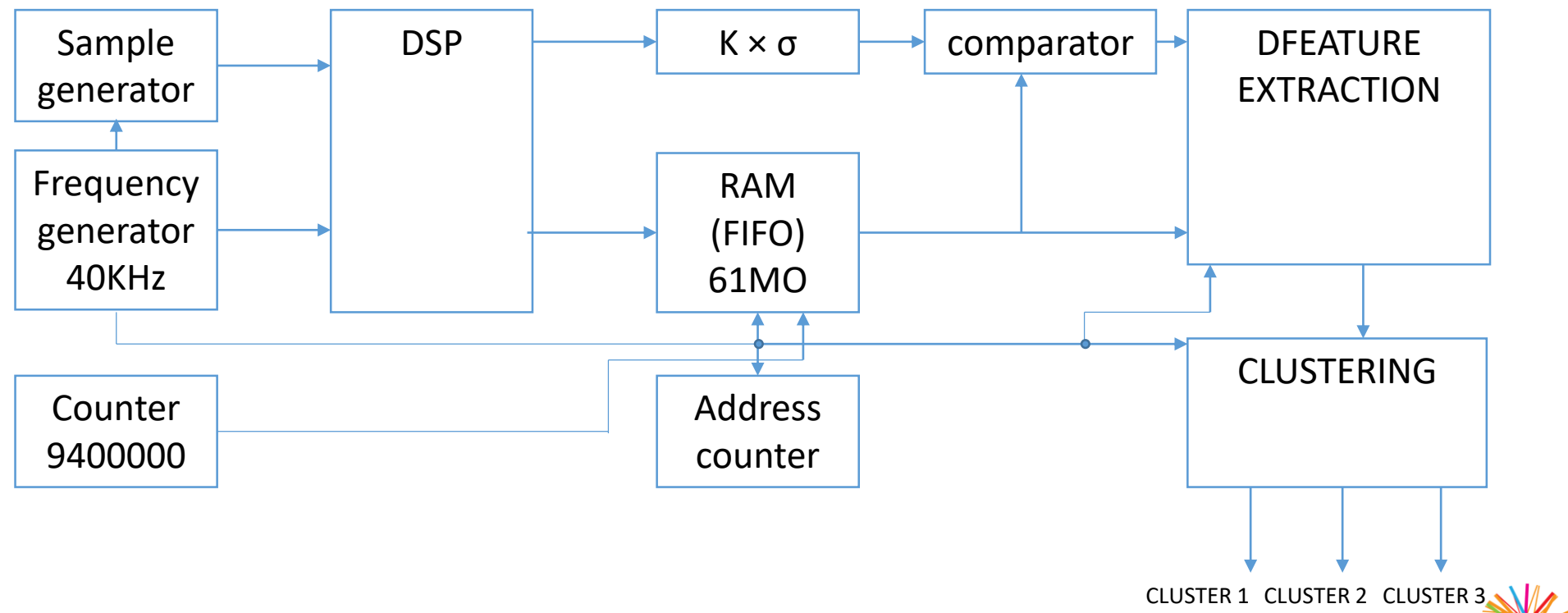
CLUSTERING + CLASSIFICATION

- ▶ ARTIFICIAL NEURAL NETWORK, ANN + SUPPORT VECTOR MACHINE, SVM



TECHNICAL REALISATION

STRUCTURAL MODEL



TECHNICAL REALISATION

DSP IMPLEMENTATION

IP Symbol Freq. Response **Implementation Details** Coefficient Reload

Resource Estimates

DSP slice count:	1
BRAM count:	2

Information

Start-up Latency:	1014
Calculated Coefficients:	2009
Coefficient front padding:	0
Processing cycles per output:	1005

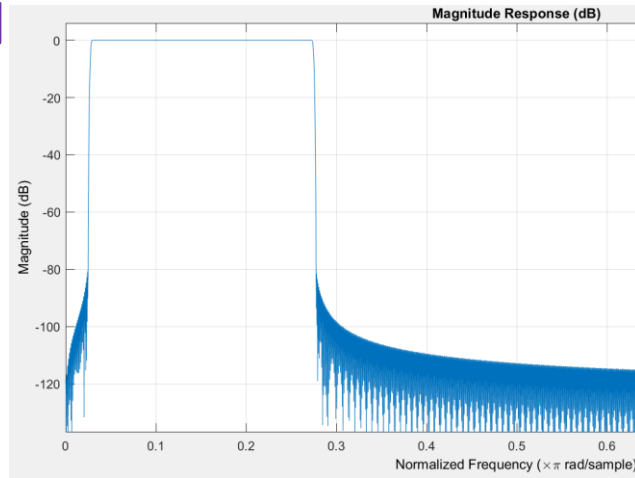
AXI4 Stream Port Structure

S_AXIS_DATA - TDATA

Transaction	Field	Type
0	REAL(15:0)	fix16_0

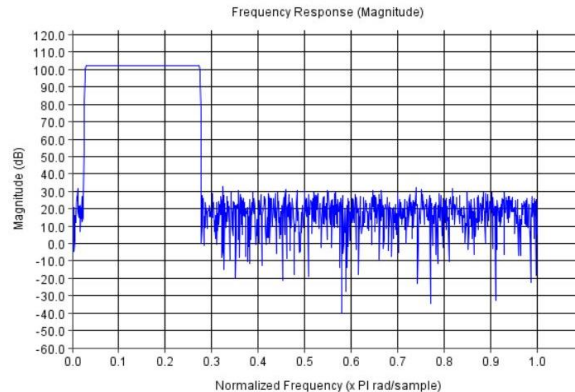
M_AXIS_DATA - TDATA

Transaction	Field	Type
0	REAL(34:0)	fix35_0



IP Symbol **Freq. Response** Implementation Details Coefficient Reload

Integer



```
>> filterDesigner
>> BP
```

```
BP =
```

```
FilterStructure: 'Direct-Form FIR'
Arithmetic: 'fixed'
Numerator: [1x2009 double]
PersistentMemory: false
```

```
CoeffWordLength: 16
CoeffAutoScale: true
Signed: true
```

```
InputWordLength: 16
InputFracLength: 15
```

```
FilterInternals: 'FullPrecision'
```

```
>> set(BP, 'arithmetic', 'fixed');
>> coewrite(BP, 10, 'mycoeffile');
```

TECHNICAL REALISATION

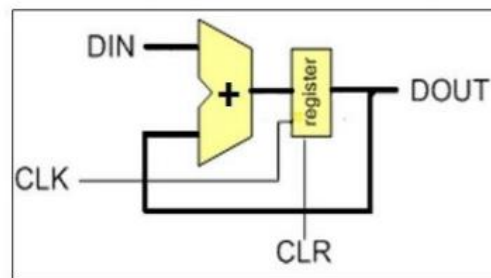
STANDARD DEVIATION CALCULATE

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2}$$



$$s^2 = \frac{1}{n-1} \left[\sum_{i=1}^n X_i^2 - \frac{1}{n} \left(\sum_{i=1}^n X_i \right)^2 \right]$$

$$\frac{1}{N-1} * \frac{N+1}{N+1} = \frac{N+1}{N^2-1} * \frac{N^2+1}{N^2+1} = \frac{N^3+N^2+N+1}{N^4-1} \cong \frac{1}{N} + \frac{1}{N^2} + \frac{1}{N^3} + \frac{1}{N^4}$$



Square Root Component

CONCLUSION

- ▶ Spike sorting is a very challenging mathematical problem that has attracted the attention of scientists from different fields.
- ▶ The use of machine learning methods opens the room for more improvement and more innovation in the matter

THANK YOU FOR YOUR ATTENTION



ANY QUESTIONS ?