CRACKING THE NEURAL CODE

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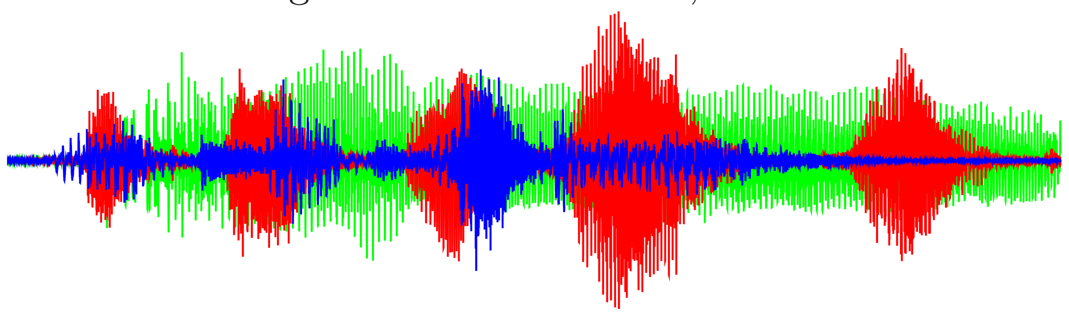
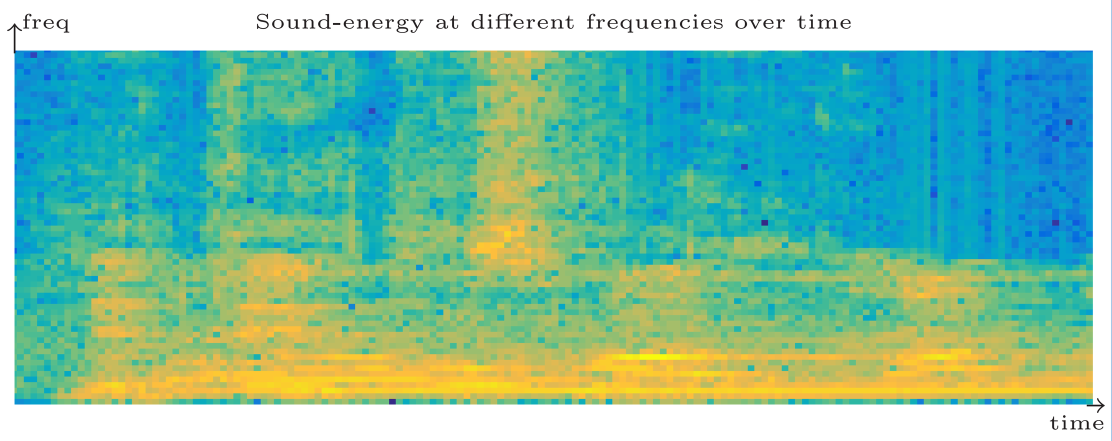
① SOUND: A MIX OF INDIVIDUAL OBJECTS

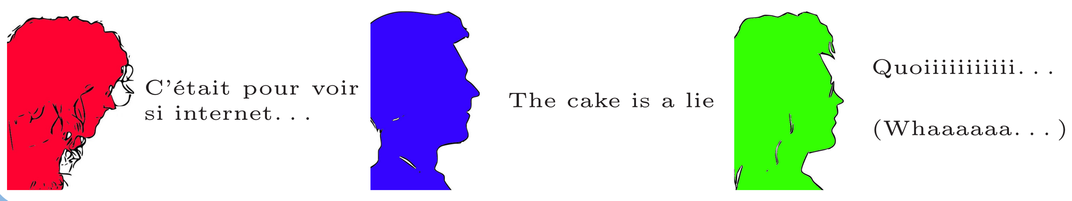
Sounds entering our ears are mixtures; it's not colour-coded!



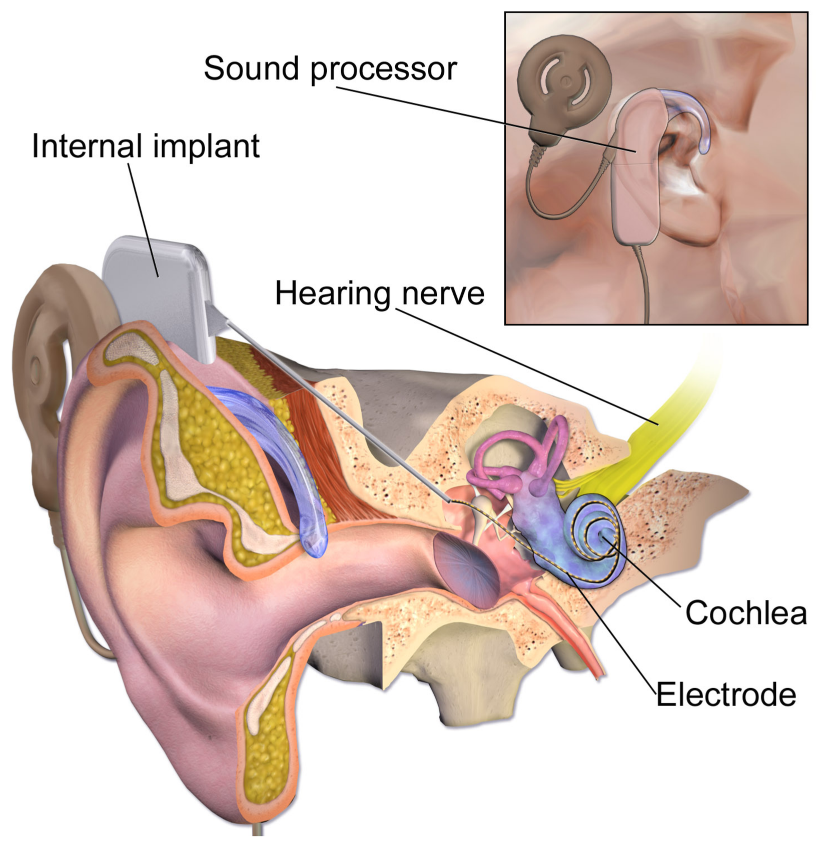
Different speakers often use the same range of **frequencies**.



Still we can **perceive** the different objects as being separate.



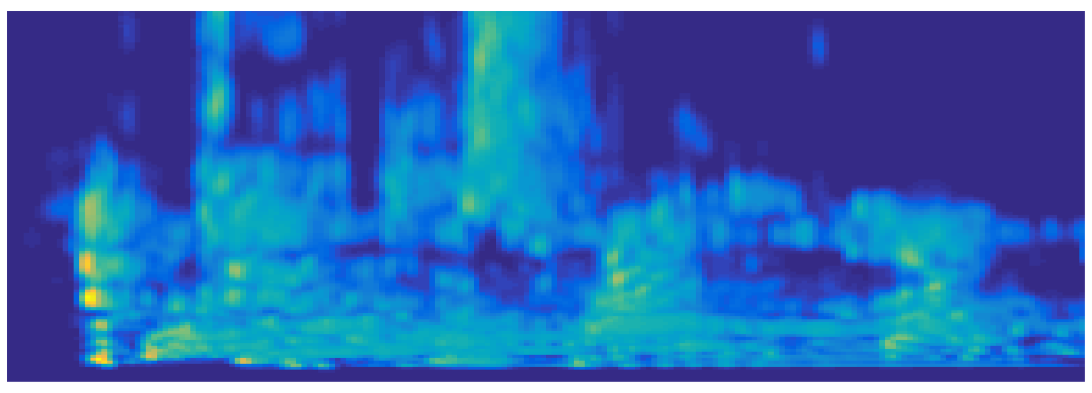
② EAR & COCHLEAR IMPLANT



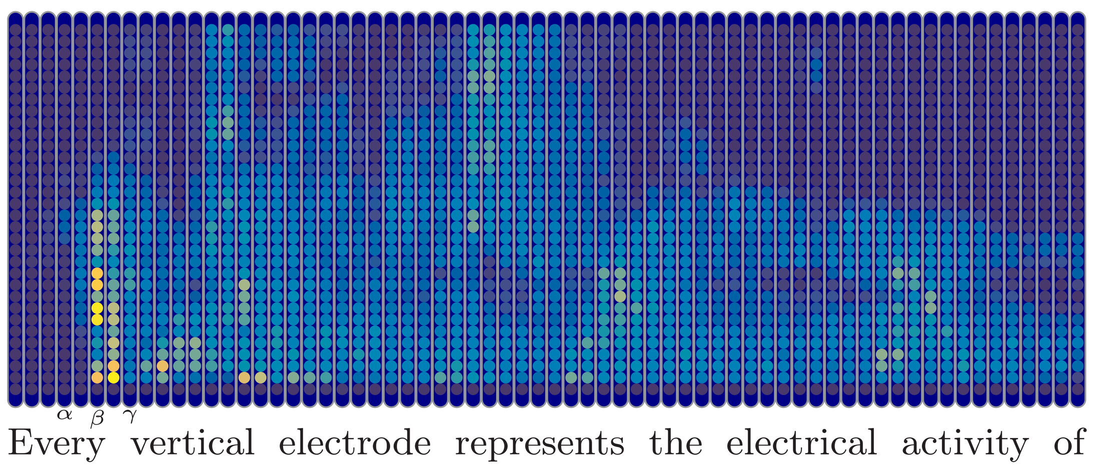
[1]

③ COCHLEA: WAVEFORM TO ACTIVITY

Cochleogram: Firing of different auditory nerves over time, carrying information about different frequencies [3]. Around 50000 nerve fibres transmit sound information to the brain.



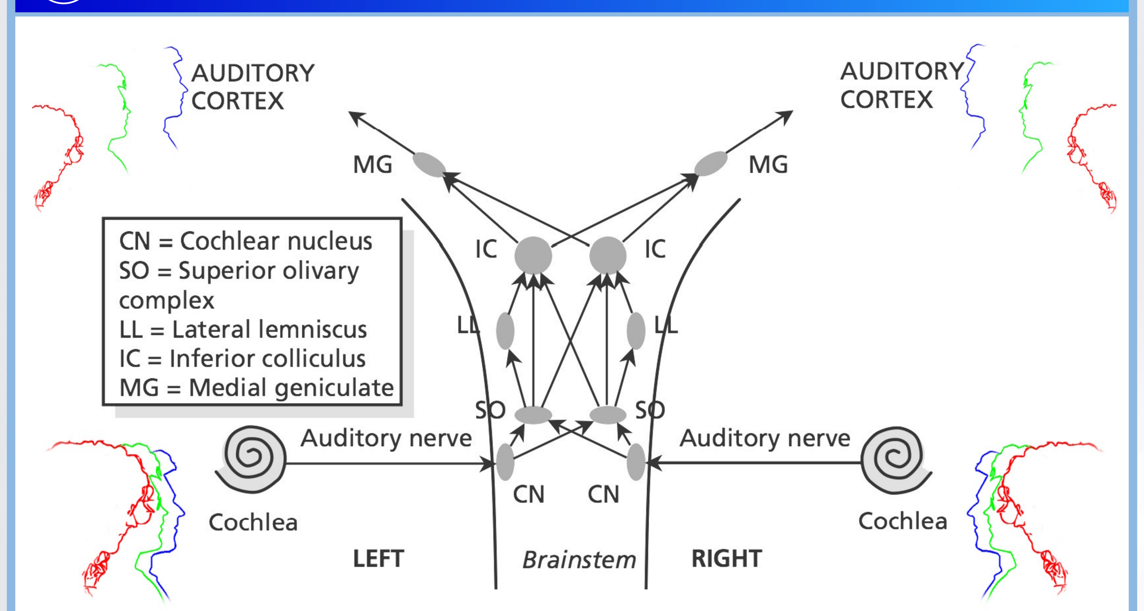
Electrode array: Sequence of activation of a cochlear implant. With a cochlear implant, the information is a fraction ($\sim$1%) of normal. Still, speech can be understood in quiet environment.



Every vertical electrode represents the electrical activity of the cochlear implant at a given moment, encoding input sounds:

time = 0.06s time = 0.09s time = 0.12s

④ AUDITORY PATHWAY: SOUND TO SENSE



Spikes from the auditory nerve pass into the brain where they are processed in a number of discrete brain nuclei. Somehow, this pathway groups and segregates sounds [4].

AUDITORY NEUROSCIENCES: HEARING, IMPLANTS & NEUROSCIENCES IN A NUTSHELL

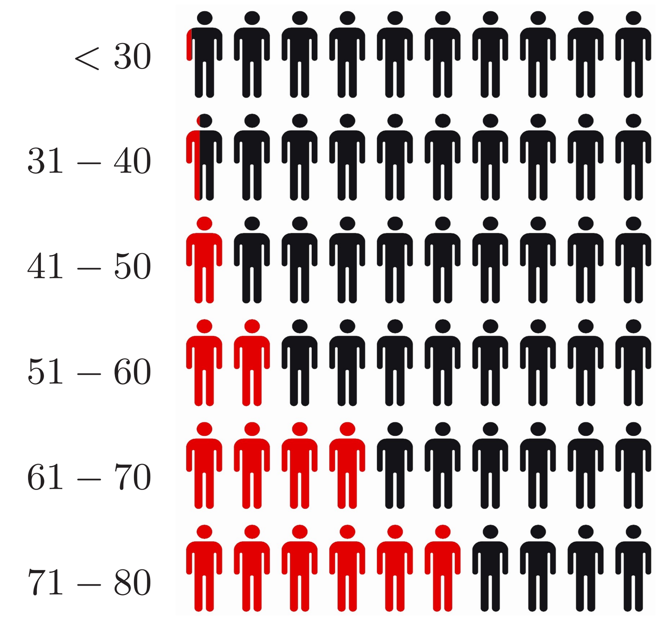
OUR ULTIMATE GOAL IS TO

Understand how our brains are able to **segregate and group elements of sound** to form perceptual objects.

1. We hear mixtures of **sounds** from individual objects. Still, we can understand speech even when several people are speaking at the same time.
2. The cochlea **transduces** vibrations in the air into electrical impulses, **spikes**, along the hearing nerve fibres.
3. A **cochlear implant** can be used to excite an impaired cochlea.
4. The spikes from the auditory nerve pass into the brain where they are **processed** in a number of discrete brain nuclei.
5. Neurons use spikes in some secret Morse code Biology decided long ago: the **neural code**, inherently containing **randomness**. Since neurons transmitting sounds also process it, by building **computational models** that simulate this processing we can test and develop our understanding of how the code is made.
6. A main goal of Neuroscience is to **decipher** this code. This requires heavy Maths and **statistics** machinery.

WHY WE CARE: IT AFFECTS MANY PEOPLE

In ageing populations, hearing impairment is a problem affecting the quality of life [2].



· The major problem for the hearing impaired or cochlear implantees is communicating in difficult environments.

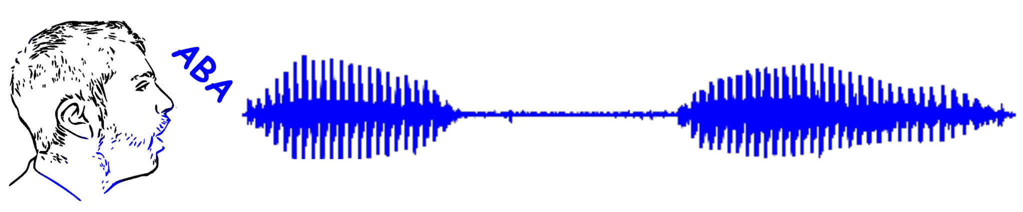
· We do not understand how the brain segregates and groups sounds, nor how to restore normal hearing.

⑤ DATA: MODELLING & EXPERIMENT

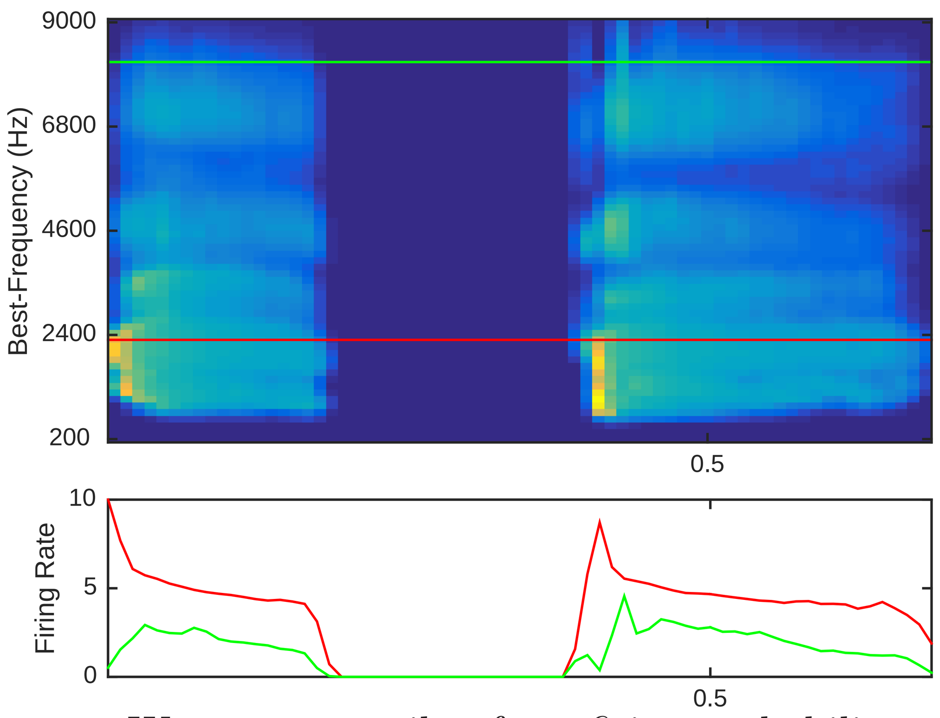
Data can be simulated - using computational models - or obtained from experiments. Each has advantages and limitations:

Modelling

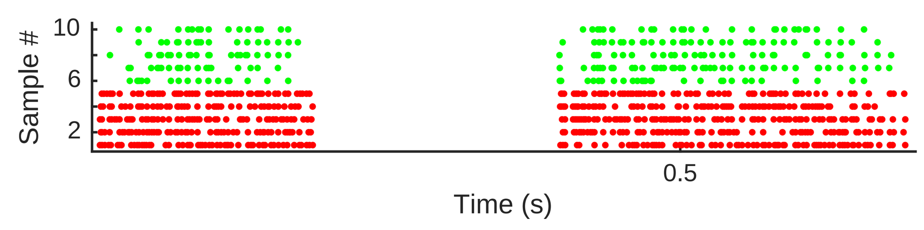
· Speech as input to cochlear model



· Algorithm generates neurons' spiking probabilities



· We generate spikes from firing probability

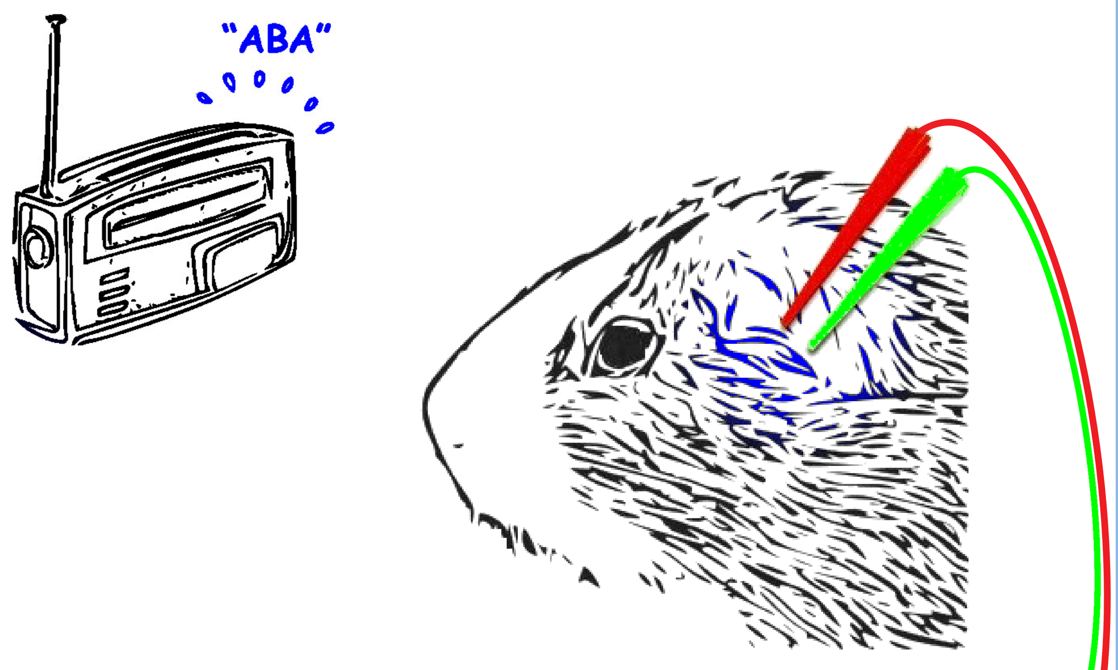


+ Data can be simulated anytime
+ Can be computed in big quantities
+ Parameters can be varied
+ Intermediate steps are interpretable
- Each model is based on assumptions

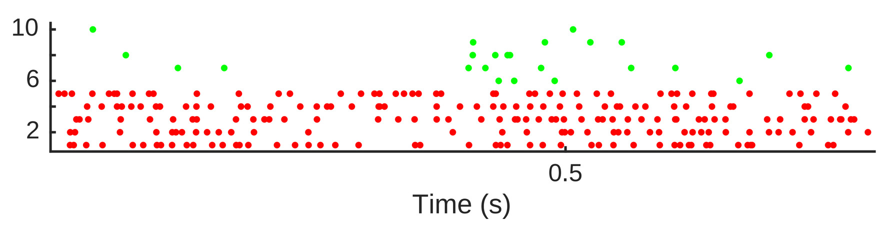
Experiment

· Speech played to anaesthetised animal

· Auditory system generates spikes along Auditory pathway



· We record spiking IC activity from electrodes



+ **This** is the data we ultimately want
- Limitations from legislation (3 R's) [5]
- Experiments are slow and costly
- Cannot predict the quality of data
- Requires training and licenses

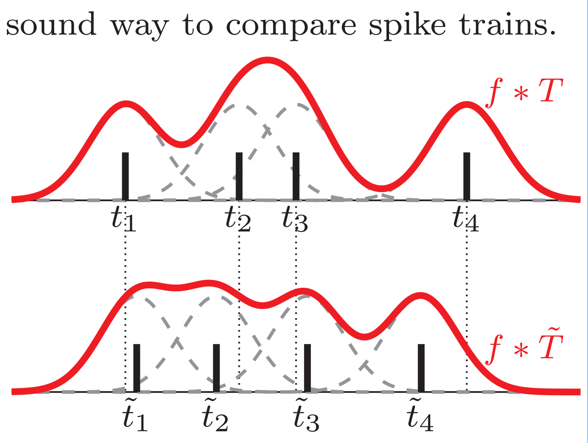
One Sentence Summary: We develop and test computational and statistical models to improve artificial recognition of sounds in complex scenes from auditory neuronal activity, in order to probe how the brain itself separates sound sources.

⑥ CHALLENGE: SPIKE TRAIN CLASSIFICATION

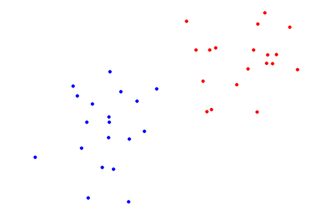
We present here a theoretically sound way to compare spike trains.

We represent a given spike train $T = [t_1, \dots, t_f]$ as a function from the Hilbert space $L^2(\mathbb{R})$:

$$\kappa(T,t) := f * T(t) = \sum_{k=1}^{f} \exp\left(-\frac{(t-t_k)^2}{\sigma^2}\right)$$



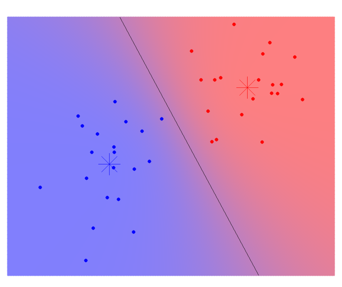
where $f(t) = e^{-t^2/\sigma^2}$ is the kernel we convolve spike trains with. This '**Kernel Trick**' allows one to perform signal processing on neural data, as shown in this example of classification: From two sets of spike trains $T_1 \dots$ and $\tilde{T}_1 \dots$ coming from an experiment with two different setups, how can we build a model to guess the setup associated with a new spike trains?



$$y_1 := f * T_1$$
$$y_2 := f * T_2$$
$$\vdots$$
$$x_1 := f * \tilde{T}_1$$
$$x_2 := f * \tilde{T}_2$$
$$\vdots$$

$$y_{Mean} = \frac{1}{M}\sum_{j=1}^{M} y_j$$

$$x_{Mean} = \frac{1}{N}\sum_{i=1}^{N} x_i$$



Classification: For $z = [t_1, t_2 \cdots, t_K]$ a new spike train, we colour it depending on the sign of

$$||y_{Mean} - \kappa(z,\cdot)|| - ||x_{Mean} - \kappa(z,\cdot)||$$

CONCLUSION

Hearing is an interdisciplinary problem related to Big Data/Data Science challenges. The development of new technologies, computational models and statistical techniques will be necessary to solve its mysteries and improve hearing aids.

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