HEARLIGHT

Encoding algorithms for sensory rehabilitation implants

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Sensory rehabilitation: more and more devices

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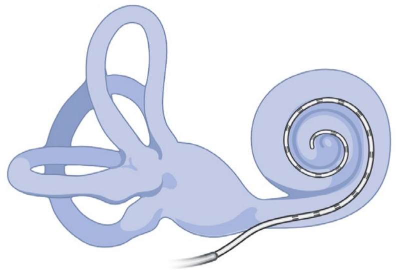
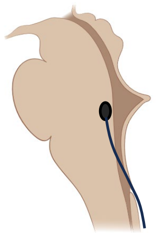
Hearing



Cochlear implants

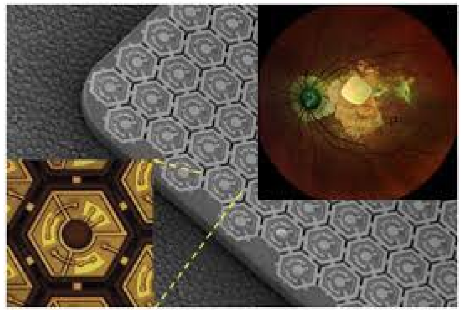
> 1,000,000 implantations



Brainstem implants

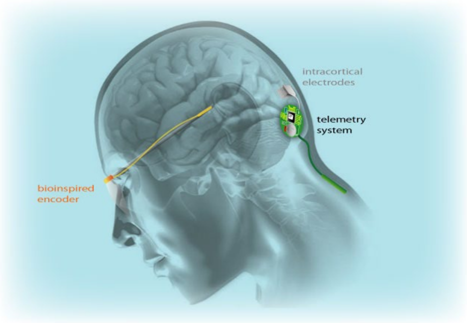
>1000 implantations

Vision



Retinal implants

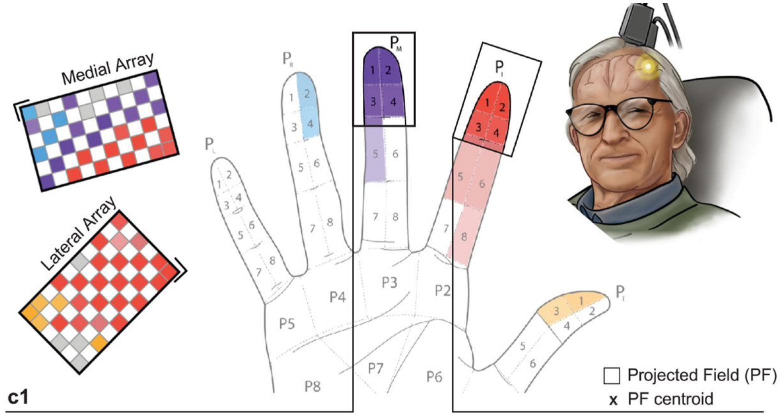
Pixium



Cortical implants

Cortivis

Touch



Valle et al. 2025
(Bensmaia lab)

more and more devices … most of the time “primitive”

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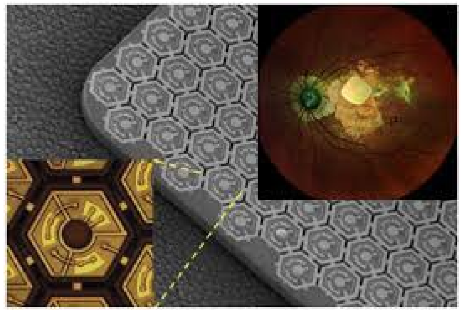
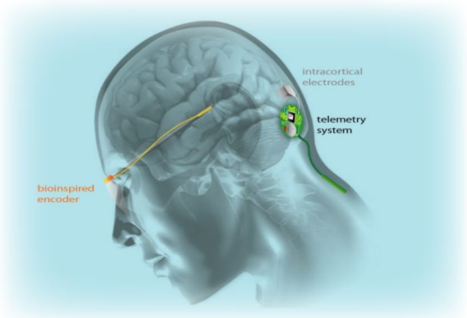
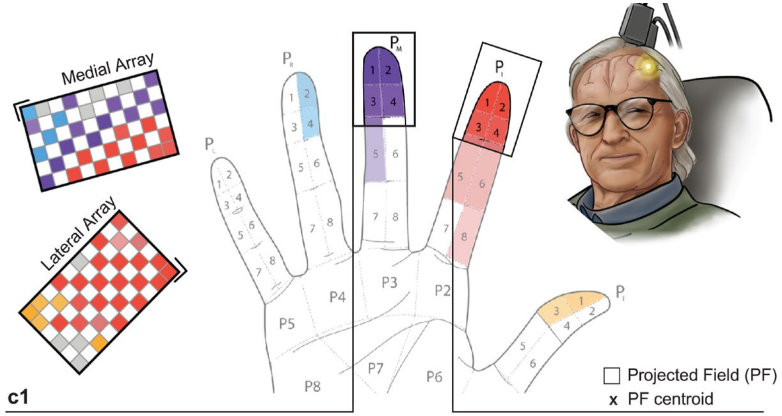
Vision **Touch**



Retinal implants
Pixium



Cortical implants
Cortivis



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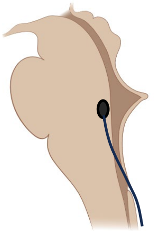
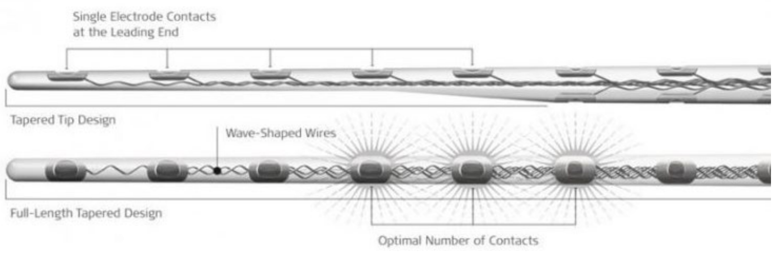


Brainstem implants
>1000 implantations

… and addressing very few patients

Cochlear implants



- 1 million implantations

- $2 billion / year market

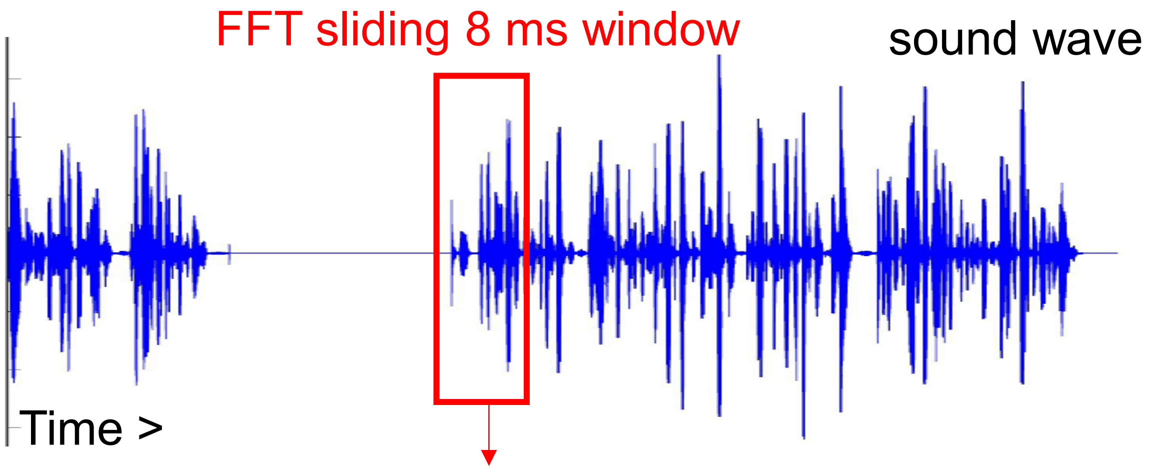
- Cost per device ~ $ 40k

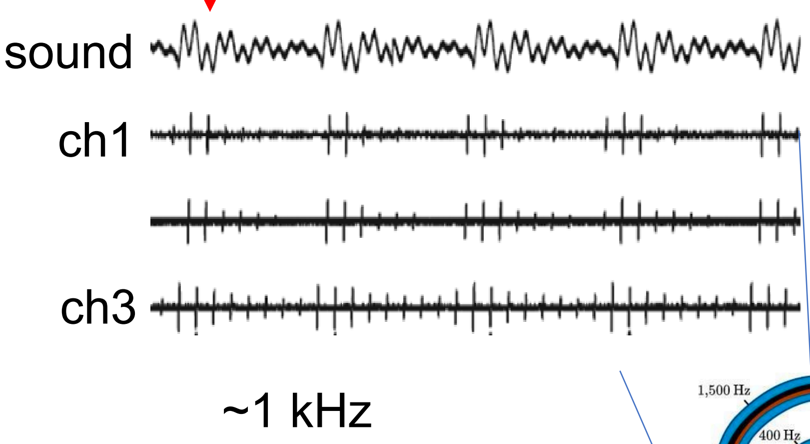
- 10 - 24 electrodes in the inner ear > auditory nerve stimulation
- **A full encoding model run by “the speech processor”**
- It provides patients with **good speech understanding** in favorable (not too noisy) environments but..

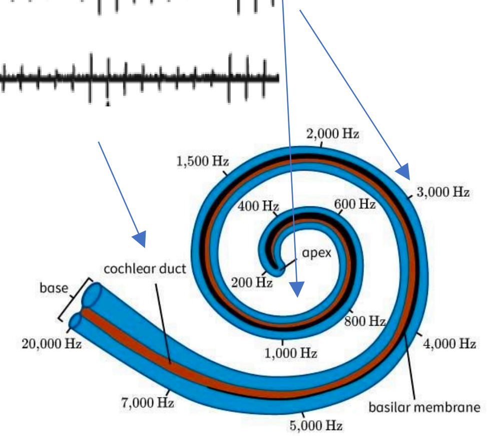
Reconstruction of encoded music
assuming 10-12 independent channels

original

Cochlear implant’s encoding limits







- Frequency info discretized into max 12 channels
  >> 90% of the spectral information is lost

- The timing of the signal has ~ few ms resolution
  >> temporal fine structure lost
  >> interaural time difference lost (very poor information direction)

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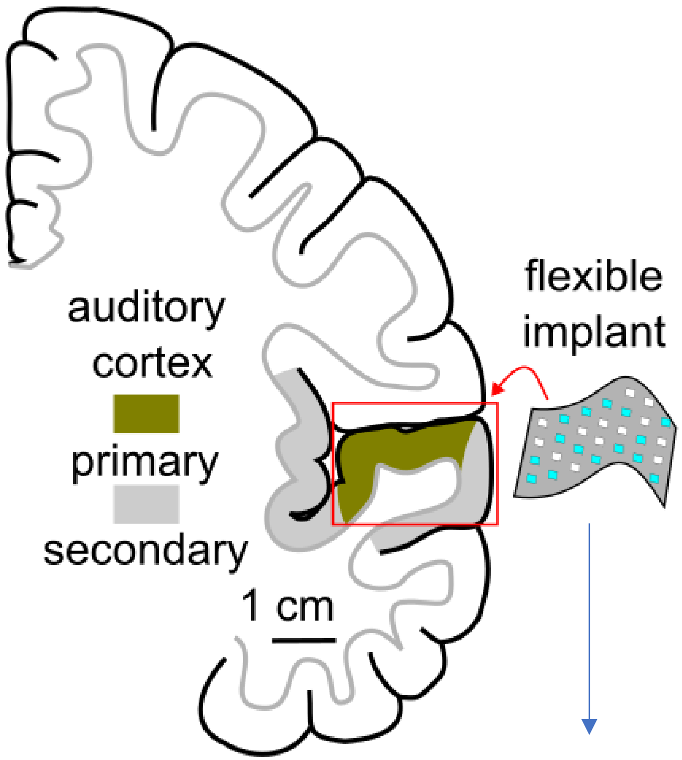
Advantages of auditory cortex targeting

Cortical implantation



High density stimulation device

- Upstream of the auditory nerve
- A surface area >10x larger than the cochlea i.e. potential for high throughput

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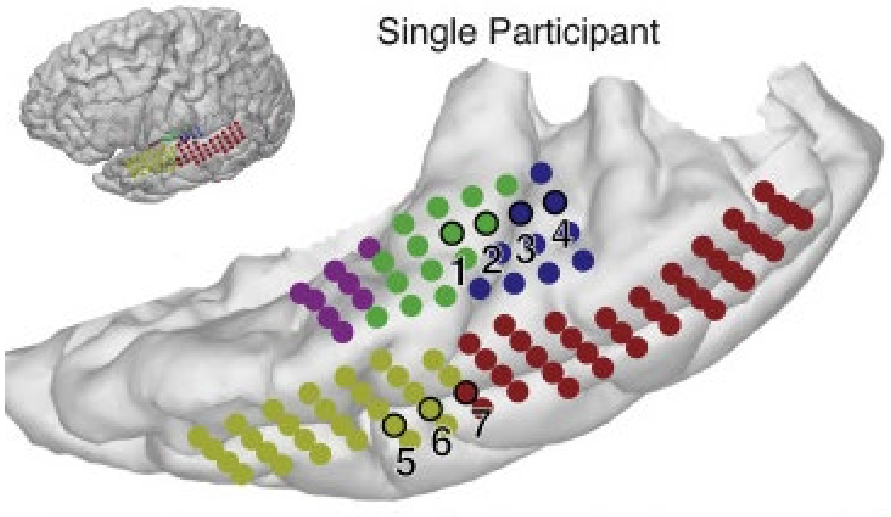
Auditory cortex stimulation triggers sound perception

e.g. recent work by Dr. Edward Chang at UCSF: electrical stimulation of primary auditory cortex leads to auditory preceptions

Hamilton et al. 2021



Bipolar stimulation with ECoG grids in epilepic patient

The Hearlight project (2021-2025)

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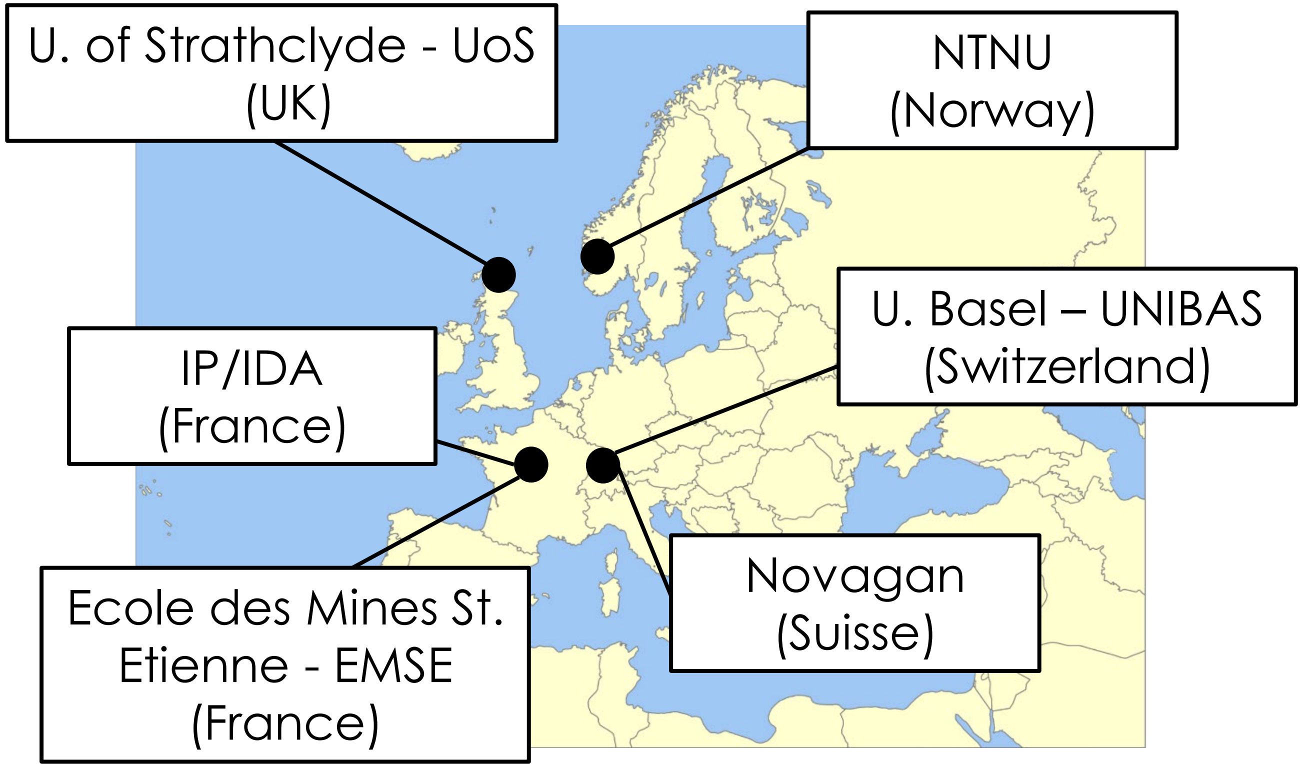


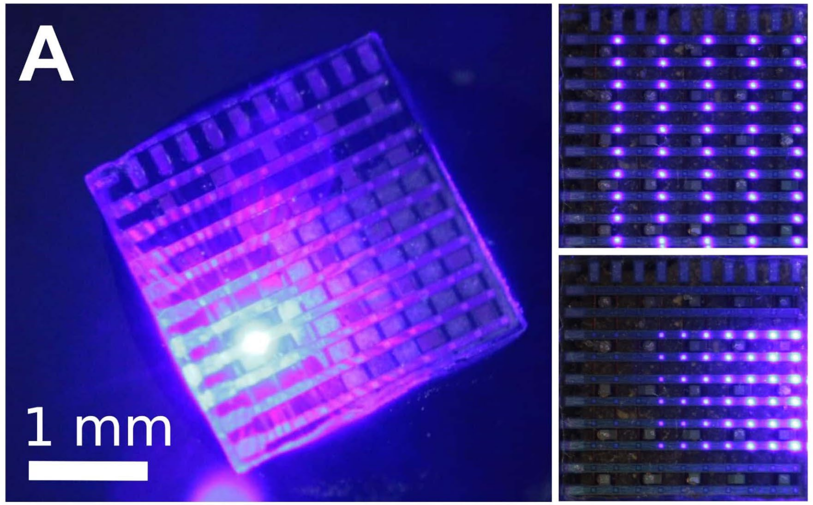
Goal: Pre-clinical evaluation of auditory cortical implants in mice

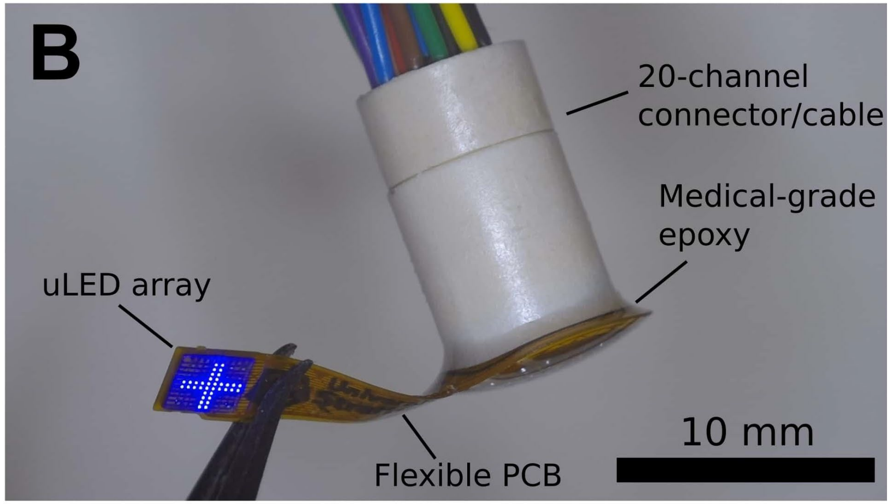
High-density implant design and evaluation
- Surface electrode arrays
- LEDs arrays (optogenetics)

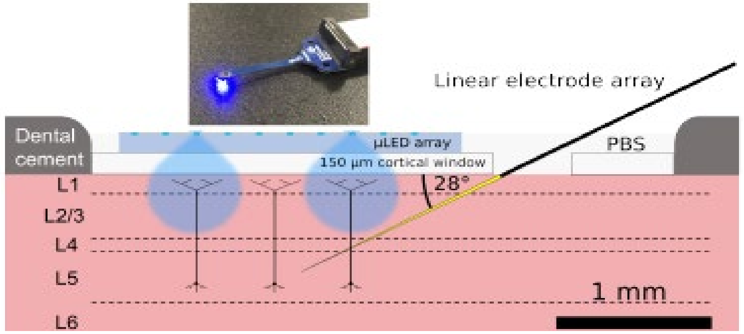
Encoding algorithms design and evaluation

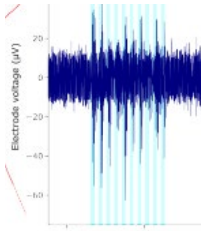
Optogenetic cortical implant

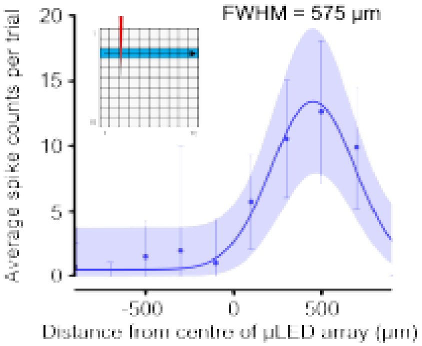
Design Mathieson lab, university of Strathclyde (2X2 mm, 10 x 10 = 100 LEDs)





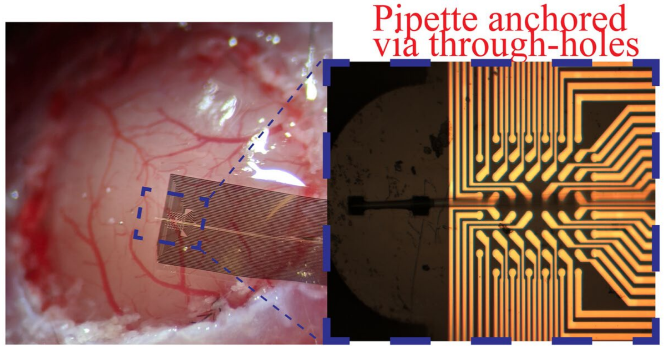




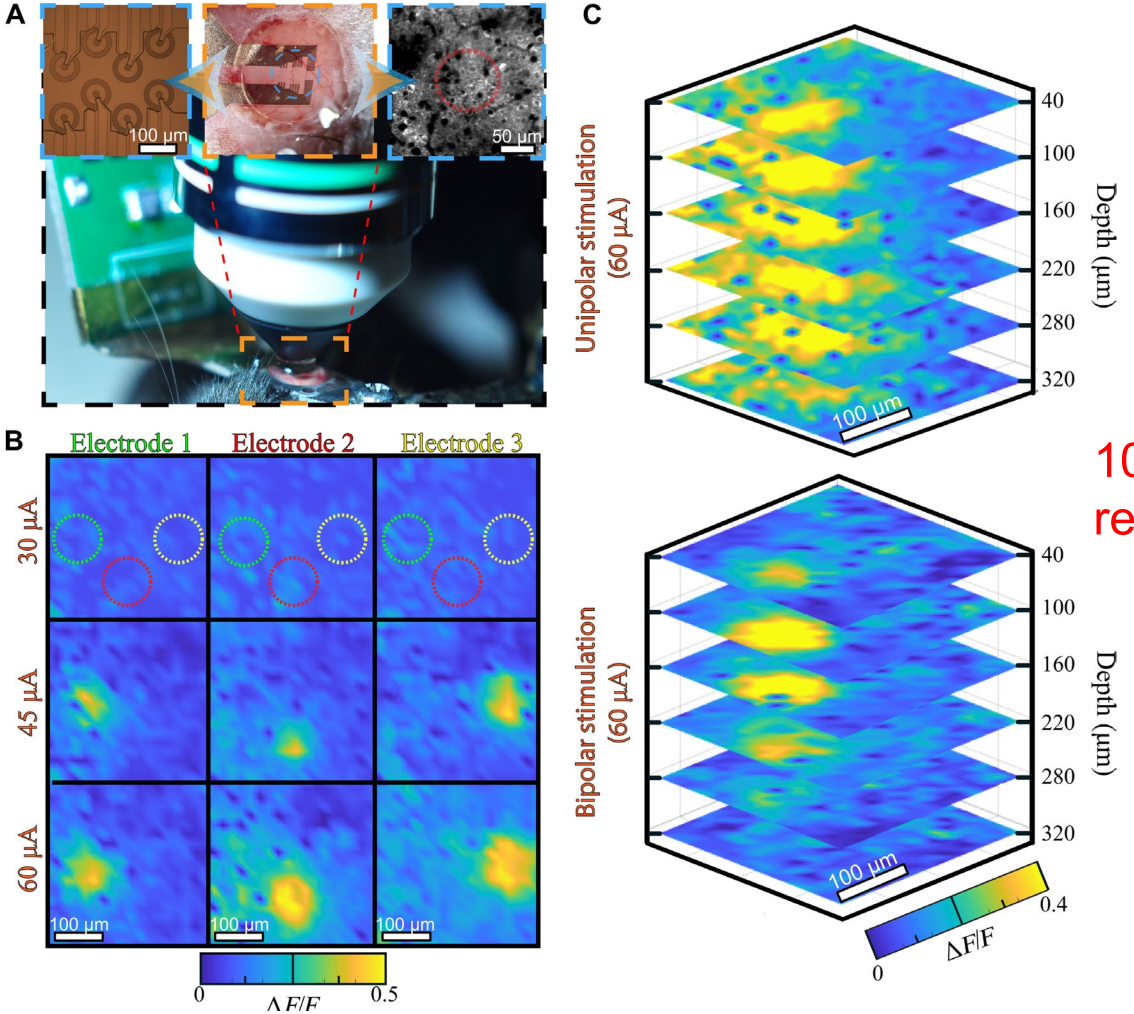


500 µm resolution

Surface electrical stimulation can be highly resolved



Uguz et al. 2022, Shepard lab



100-200 µm resolution

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High density surface stimulation is feasible

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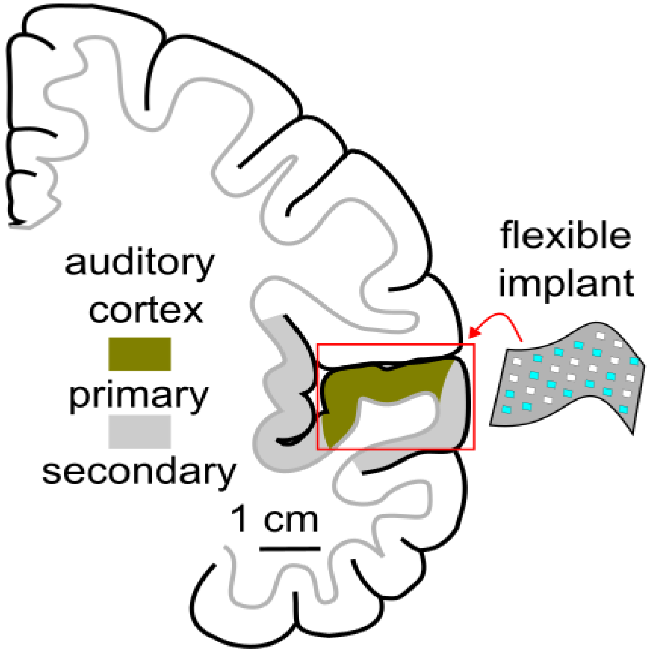

On the human auditory cortex, there is space for >5,000 independant stimulation sites and potentially even many more

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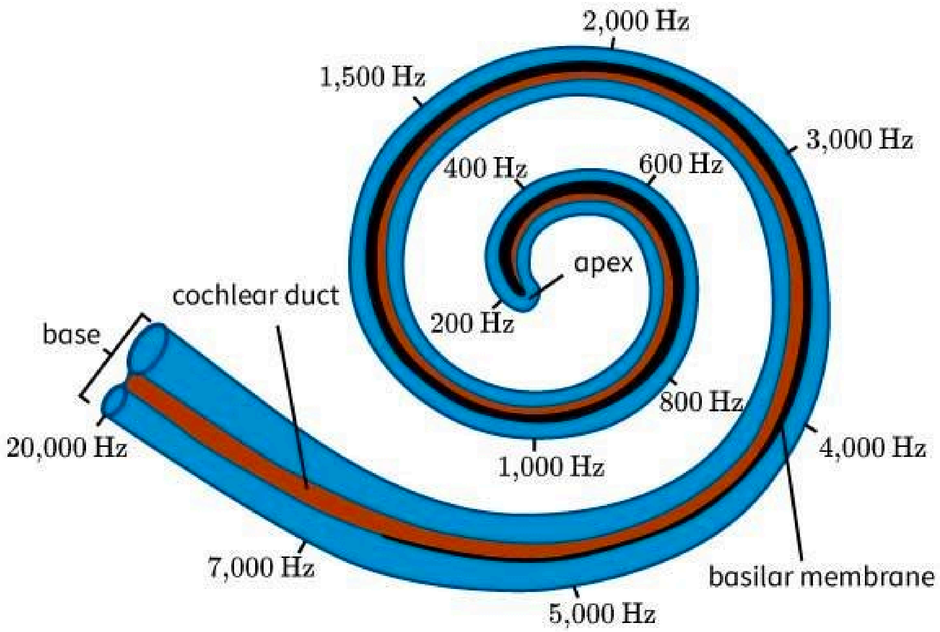
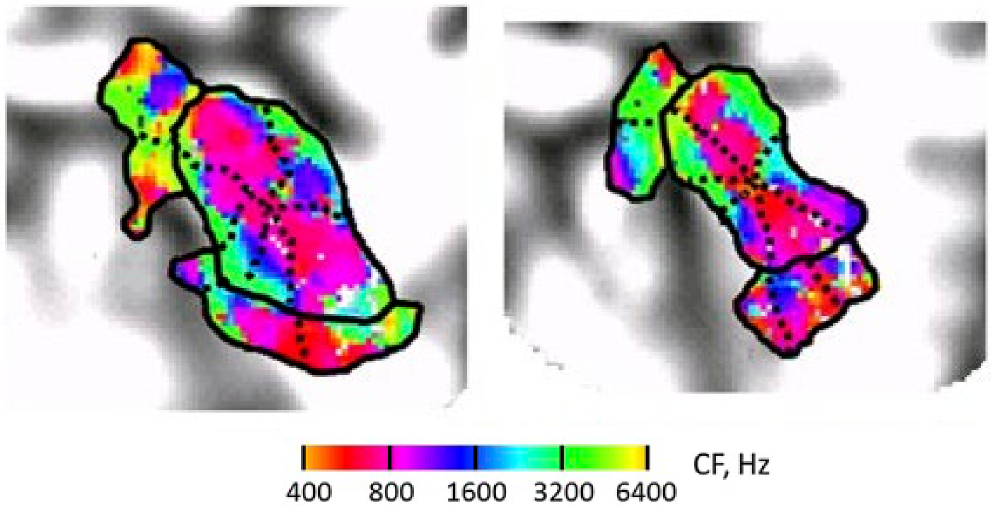
Efficient encoding algorithm for a cortical implant?

1.0 Model: tonotopy



Tonotopy on auditory cortex



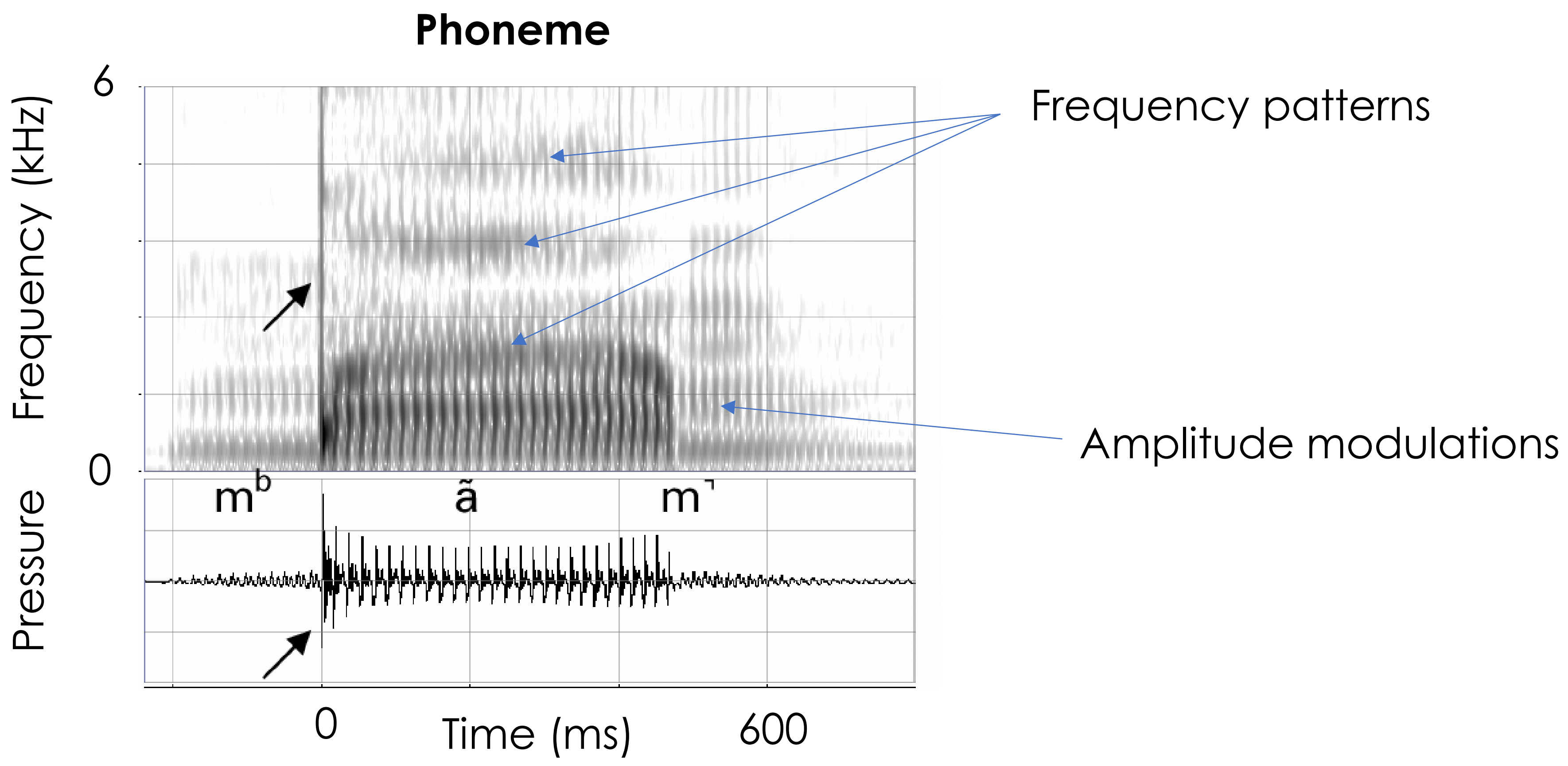
Cochlea = single axis

… but cortex is not cochlea

- 2D map

- encode sound features

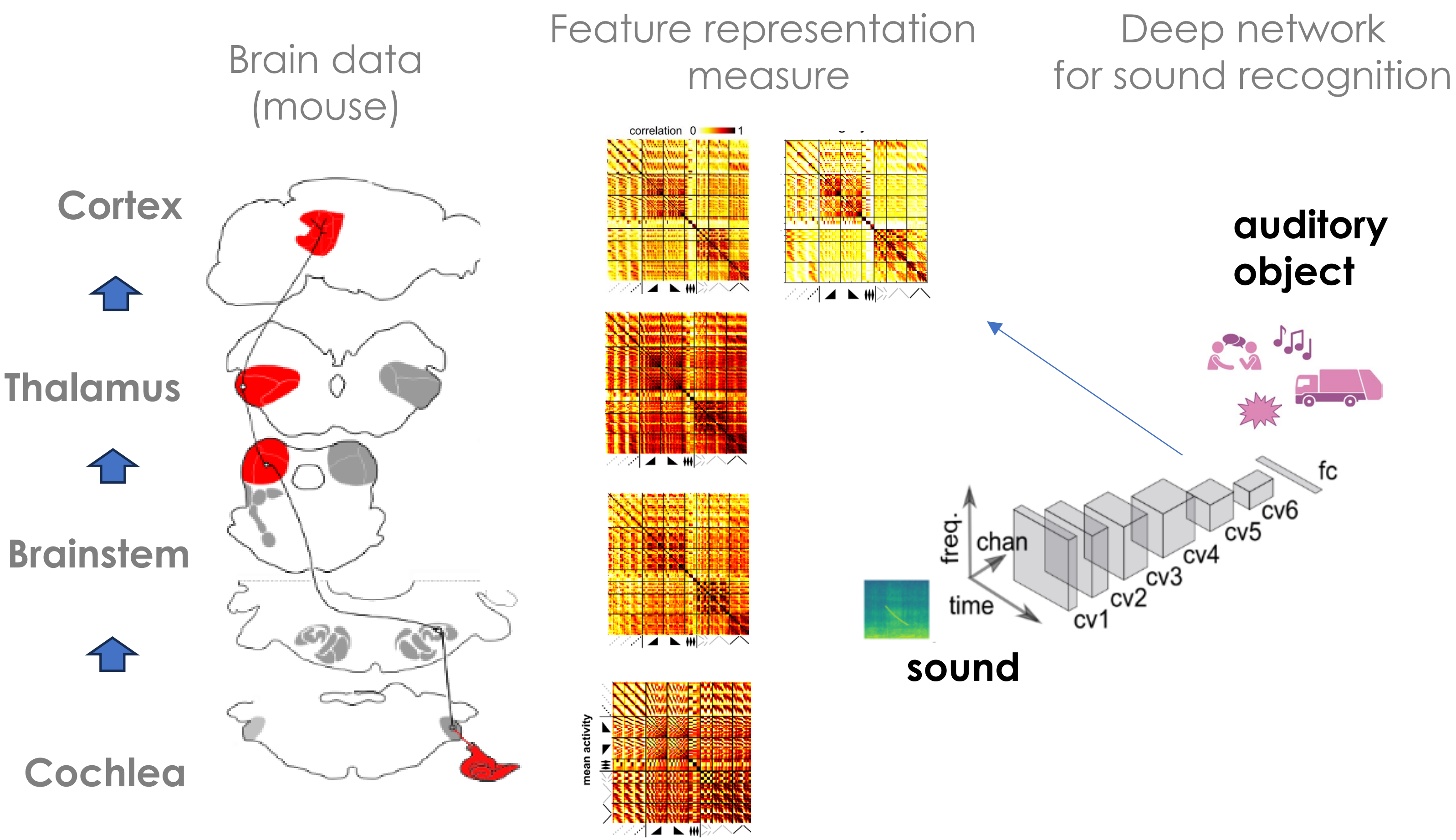
Example of features in sounds



Specific spatial patterns of neurons code for different sound features, even temporal features

Bagur et al. Science Adv 2025, Fox et al. Elife 2020

Sound feature representations are necessary for sound categorization.



Bagur et al. Science Adv 2025, see also works by McDermott and DiCarlo labs in humans & NHP

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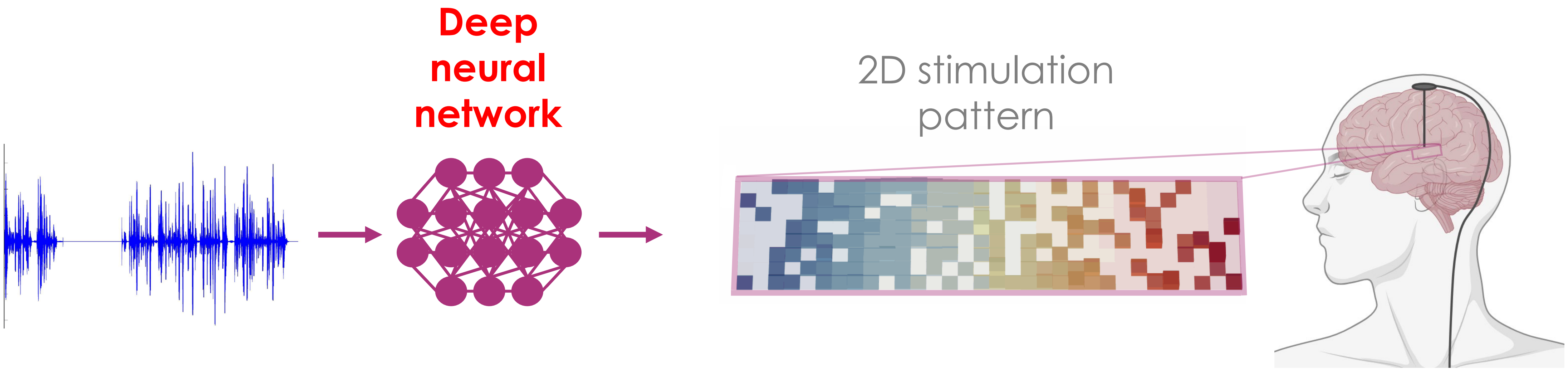
End-to-end strategy for cortical implant encoding



- **Constraint 1**: Must accurately reconstruct sounds to preserve information
- **Constraint 2**: Must accurately identify sound categories to generate biologically encoded sound features
- **Constraint 3**: Must reproduce known spatial organization of sound feature (e.g. tonotopy)

Braincodec: generic cortical implant encoder for natural sounds

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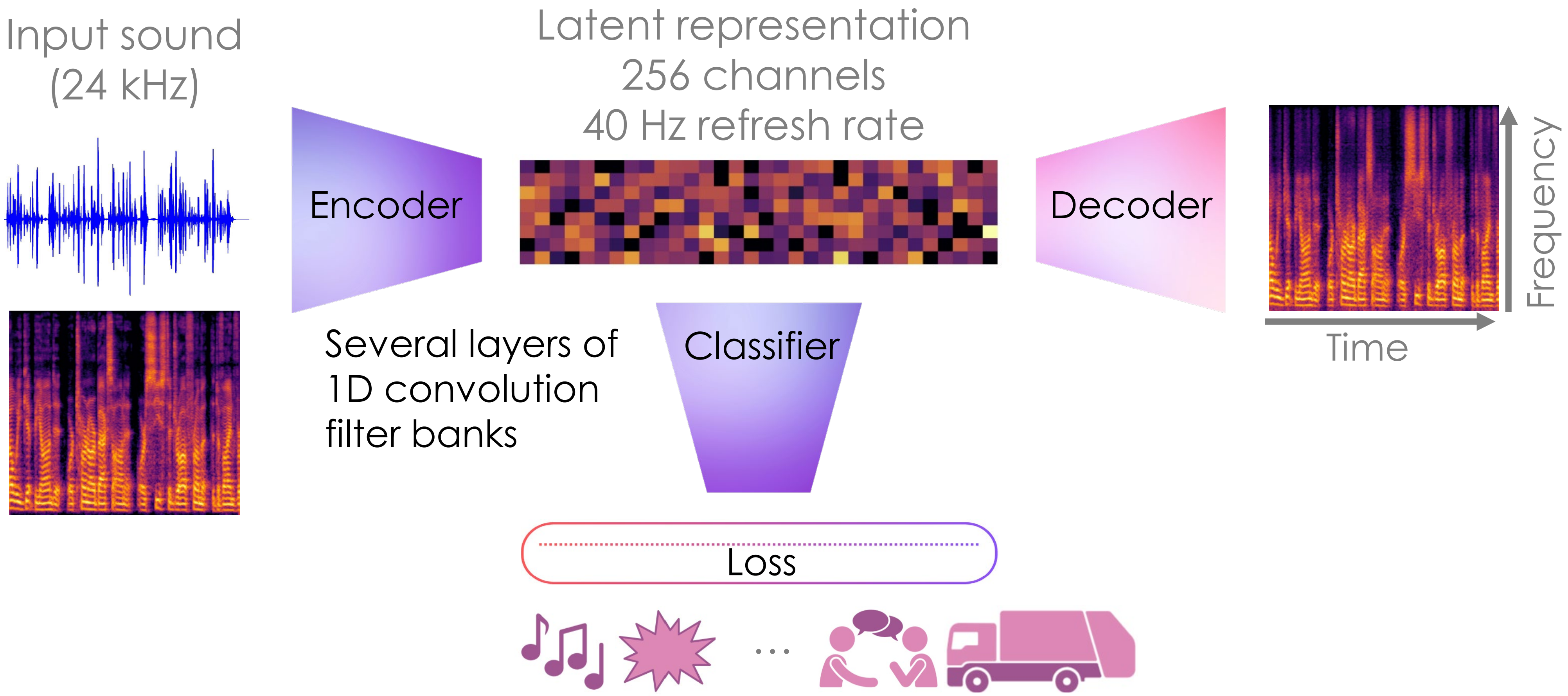
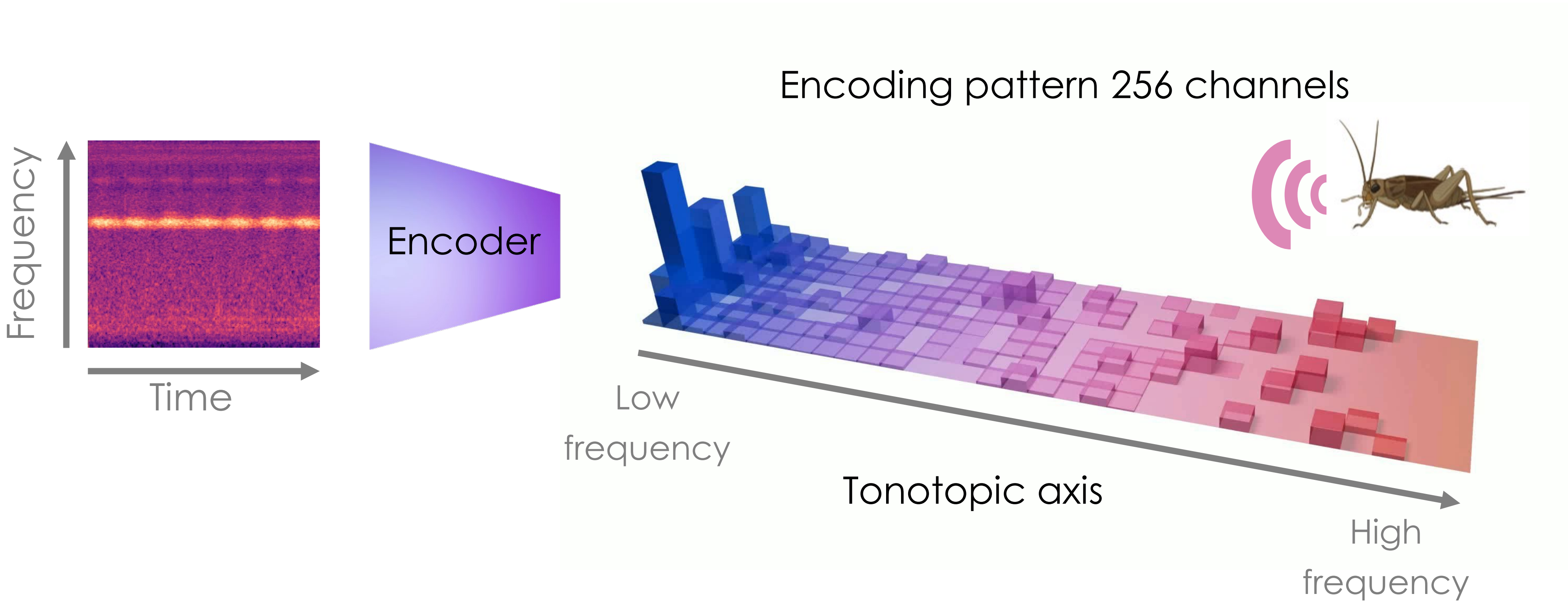


Patent EP24199347.6 (2024)
Derived from Encodec (Meta resesearch)

Performance of the model: tonotopy



Playing the reconstructed sound

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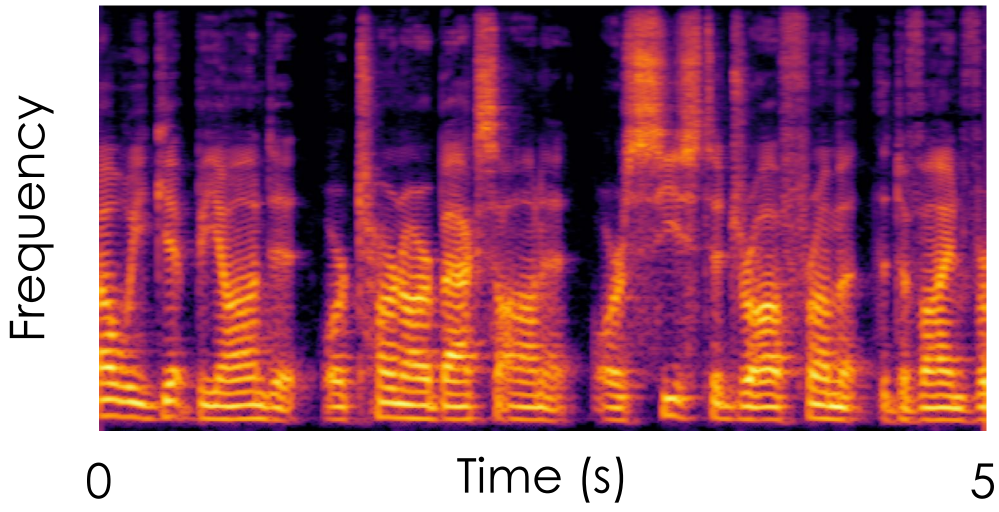
Performance of the model: reconstruction

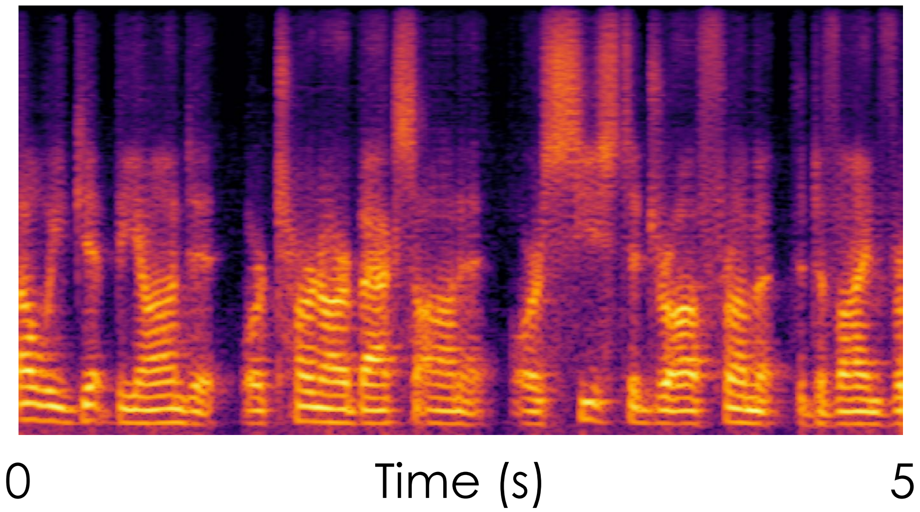
Original music

Braincodec reconstruction

Original speech

Braincodec reconstruction





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Performance of the model: sound features

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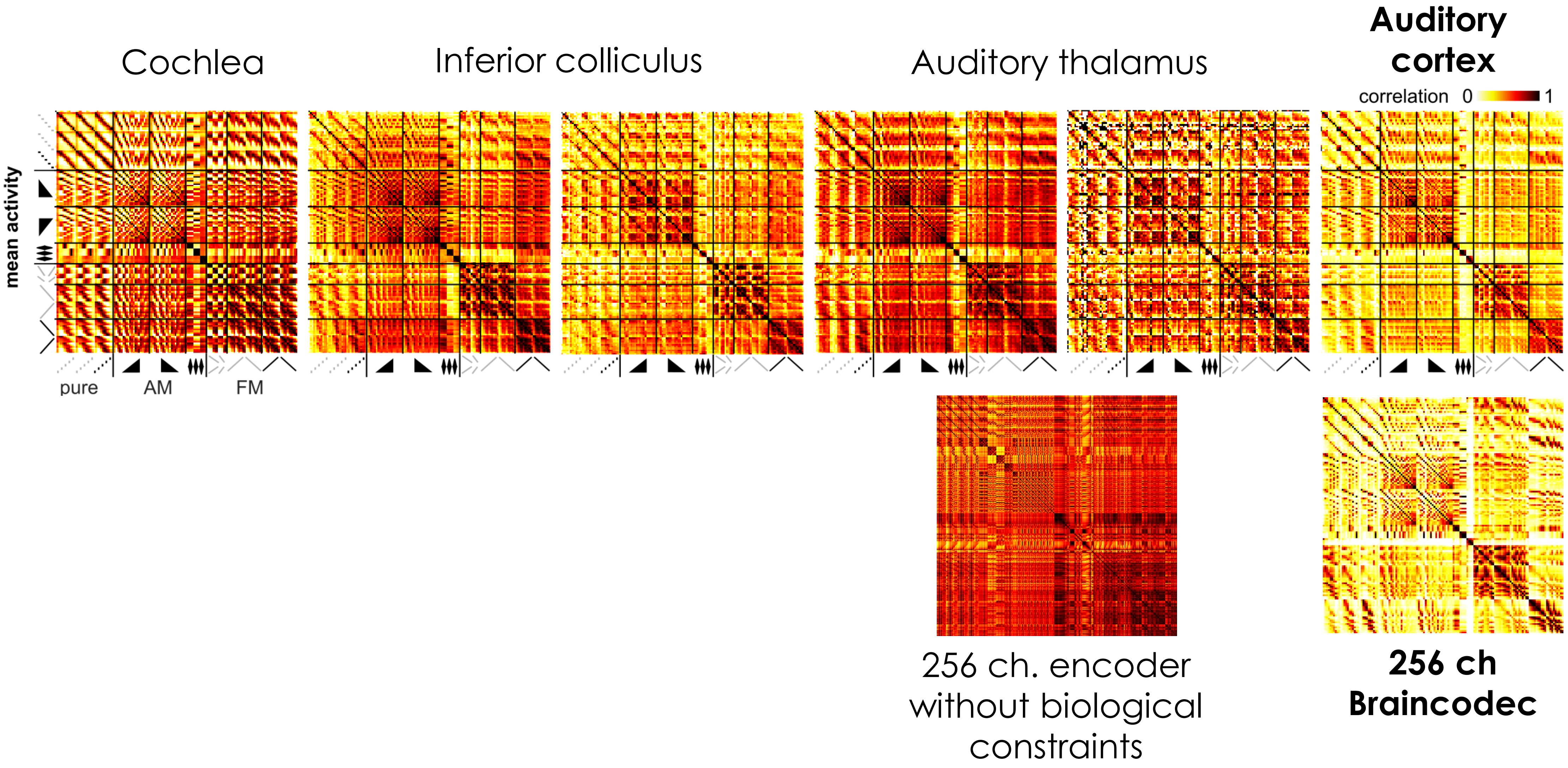
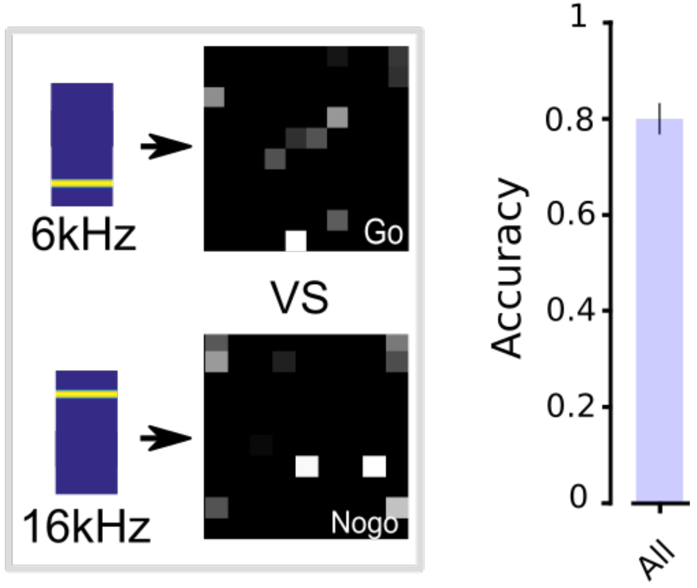
Sound feature similarity matrices accross the auditory system (mouse data)

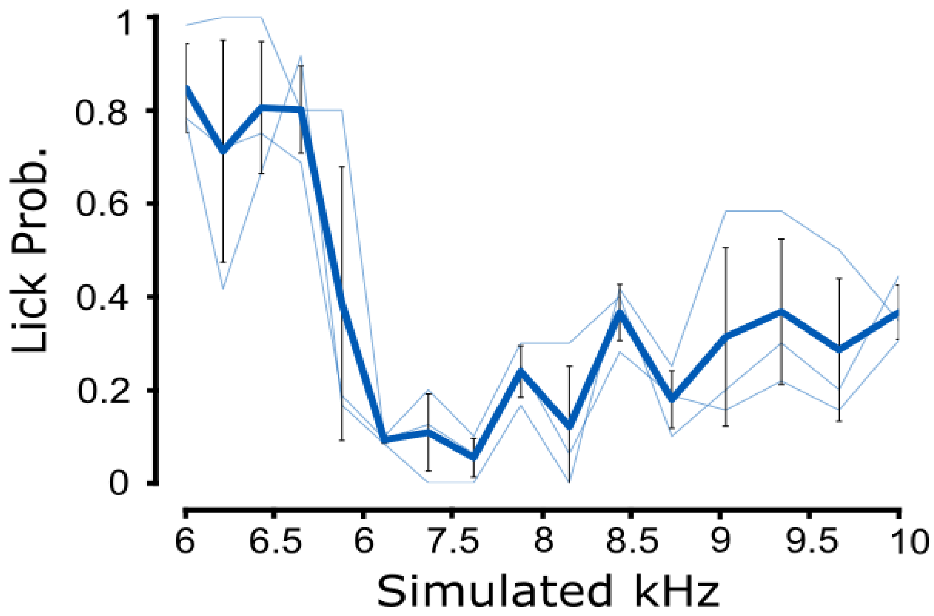


Mice discriminate AI-generated patterns



Discrimination behavior

Simulated pure tones
100 channels model for mice



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Conclusions

- High density surface stimulation seems highly feasible
  - Transposing to the human auditory cortex remains a challenge
  - CE marked / FDA approved devices for >100 channels don't exist yet.

- Deep-learning based models can be used to compress sounds into efficient bio-compatible cortical stimulation patterns
  - It is urgent to develop technologies to integrate them into the processors of brain implants
  - Low power technologies are needed (or high efficiency wireless communication to externalize)

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Perspectives for Braincodec technology

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- Extension to tactile, visual processing or other modalities
  - The same concepts as in hearing apply to other sensory modalities
  - Applications to limb prostheses for sensory feedback
  - Applications to visual prostheses

- Application to binaural cochlear implants
  - Braincodec is not based on FFT
  - Rather it uses 1D temporal filters of adjustable temporal precisions
  - Won't solve the low channel count of cochlear implant but
    - May help to provide high-resolution temporal cues to cochlear implant provided that the electronic is upgraded
    - May be useful for improving sound localization
    - May be useful to deal with amplitude compression

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Companies
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