Chronic Recording, Stimulation, and Steering Control with Electrode Bundles

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Outline

- Introduction
  - Goals
  - Previous work
- Materials
  - Electrodes
  - Stimulator
- Experiments
  - Chronic recording
  - Stimulation
  - Current Steering
- The Future!
  - Ideas
  - Electrodes
  - Optimisation

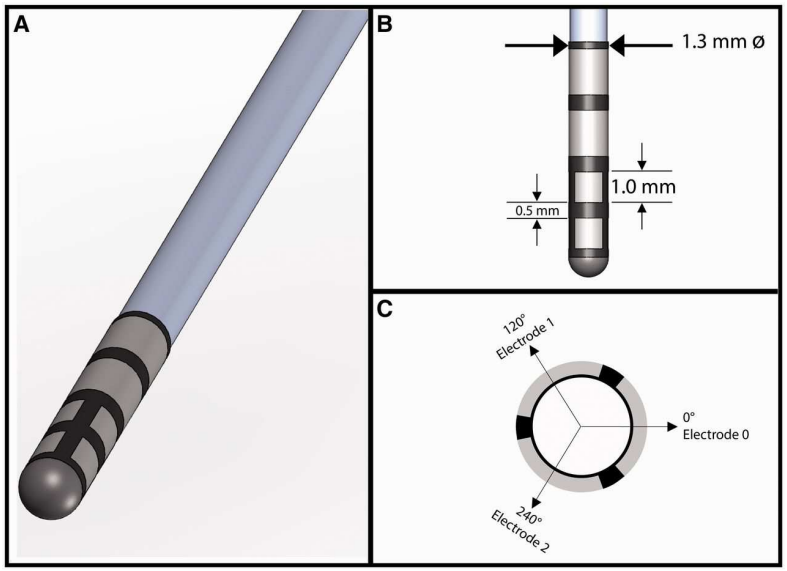
Controlling behaviour with chronically implanted electrodes

- Long-term stable recording
- Safe stimulation (despite small surface area)

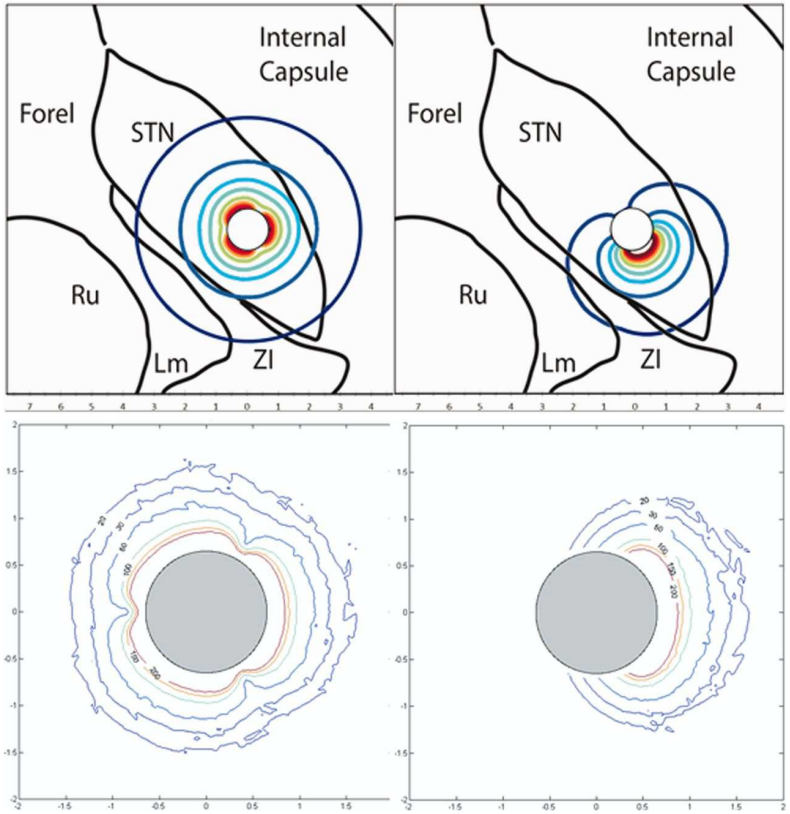
- Goal-directed modification of behaviour
  - Optimise stimulation parameters
    - Learn to produce desired output
    - Safety constraints...

Pollo. . . Schüpbach [2014]

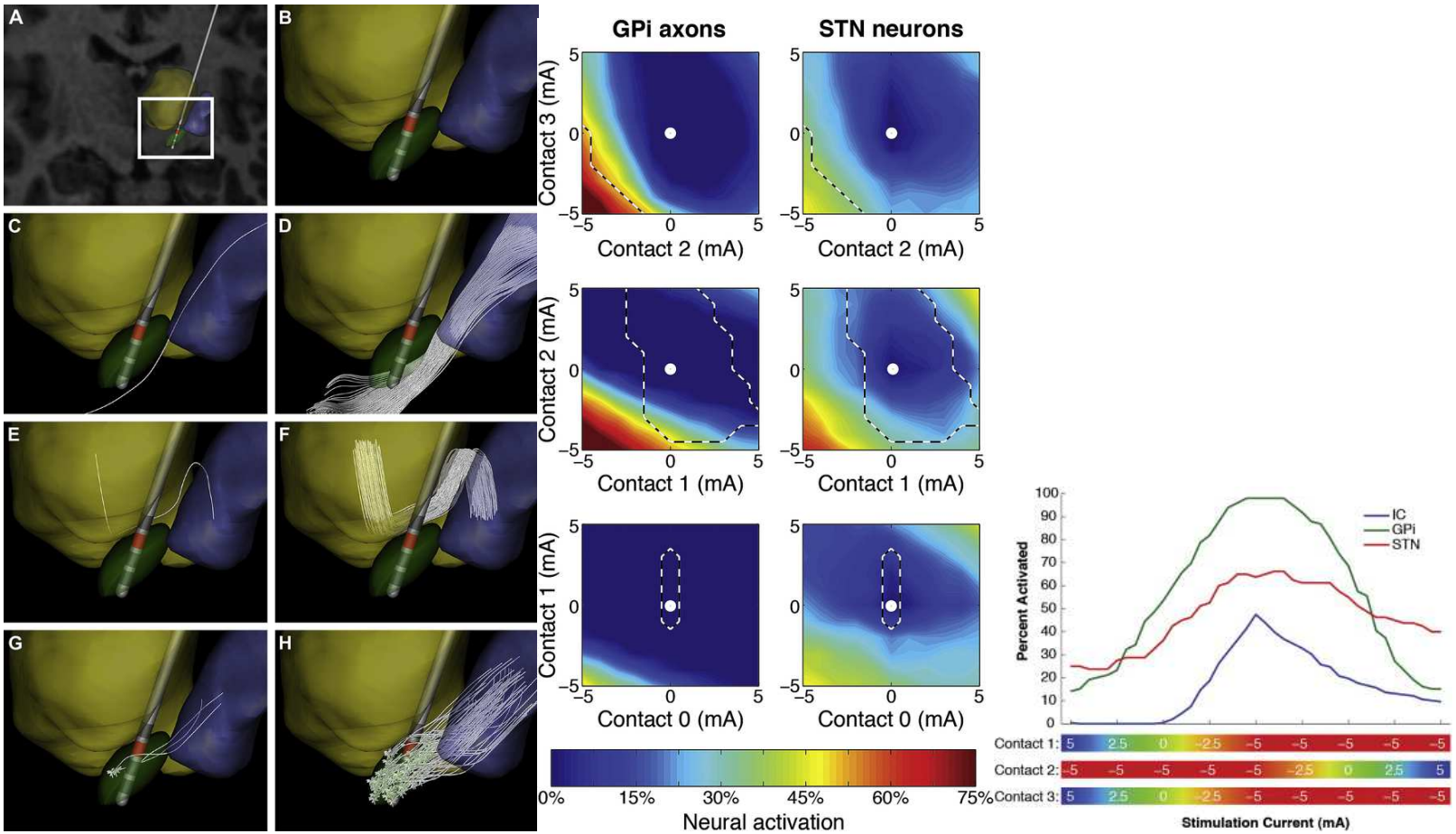
Slightly directional electrode



Finite element analysis



Chaturvedia, Foutza, McIntyre [2015]



Previous work

Current Steering using finite element analysis

- Faster than hand-tuning
- Some success
- Coarse-grained
- All models are wrong. Some models are useful.

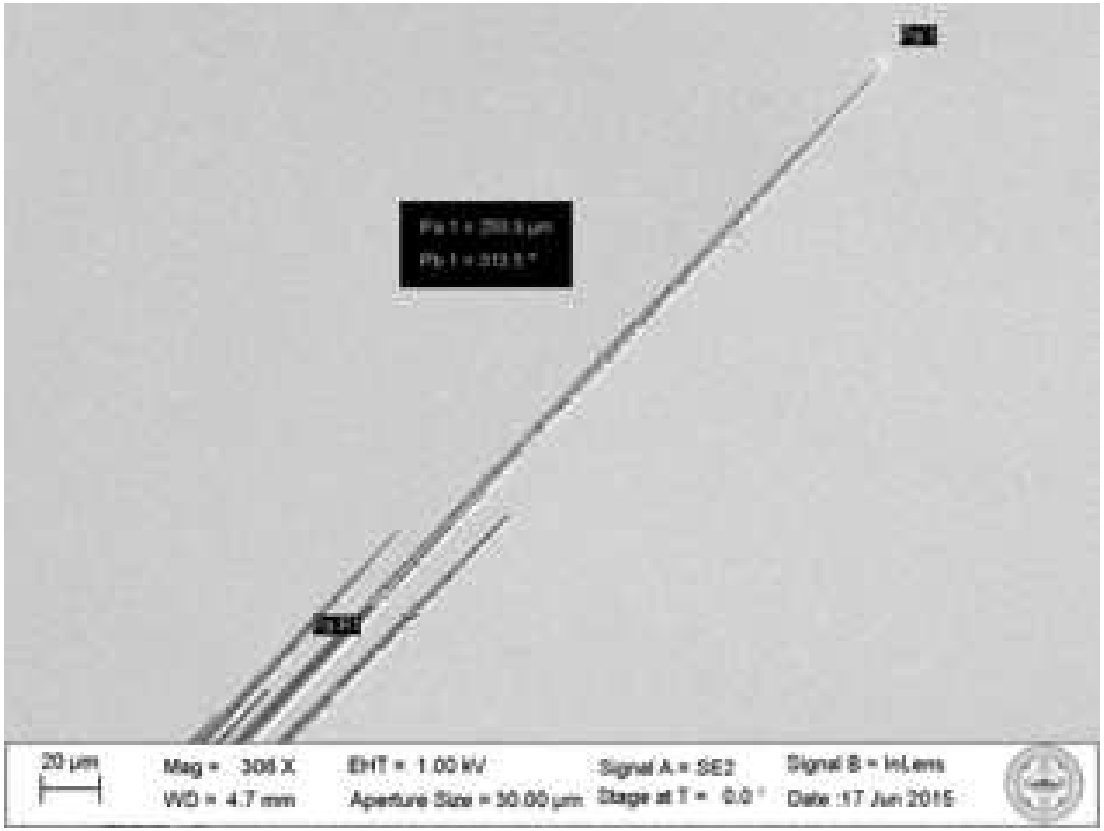
Recording for "closed-loop" therapy

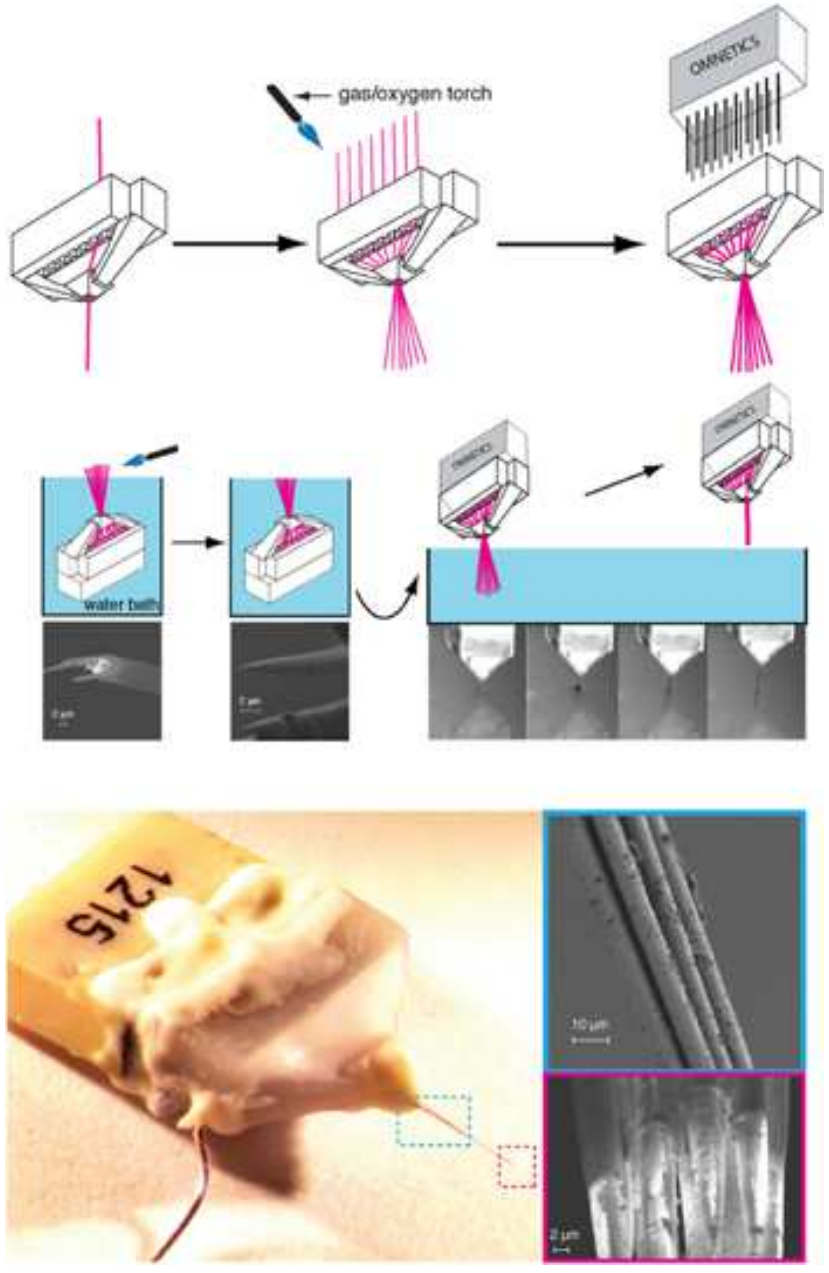
- Large populations
- Good luck

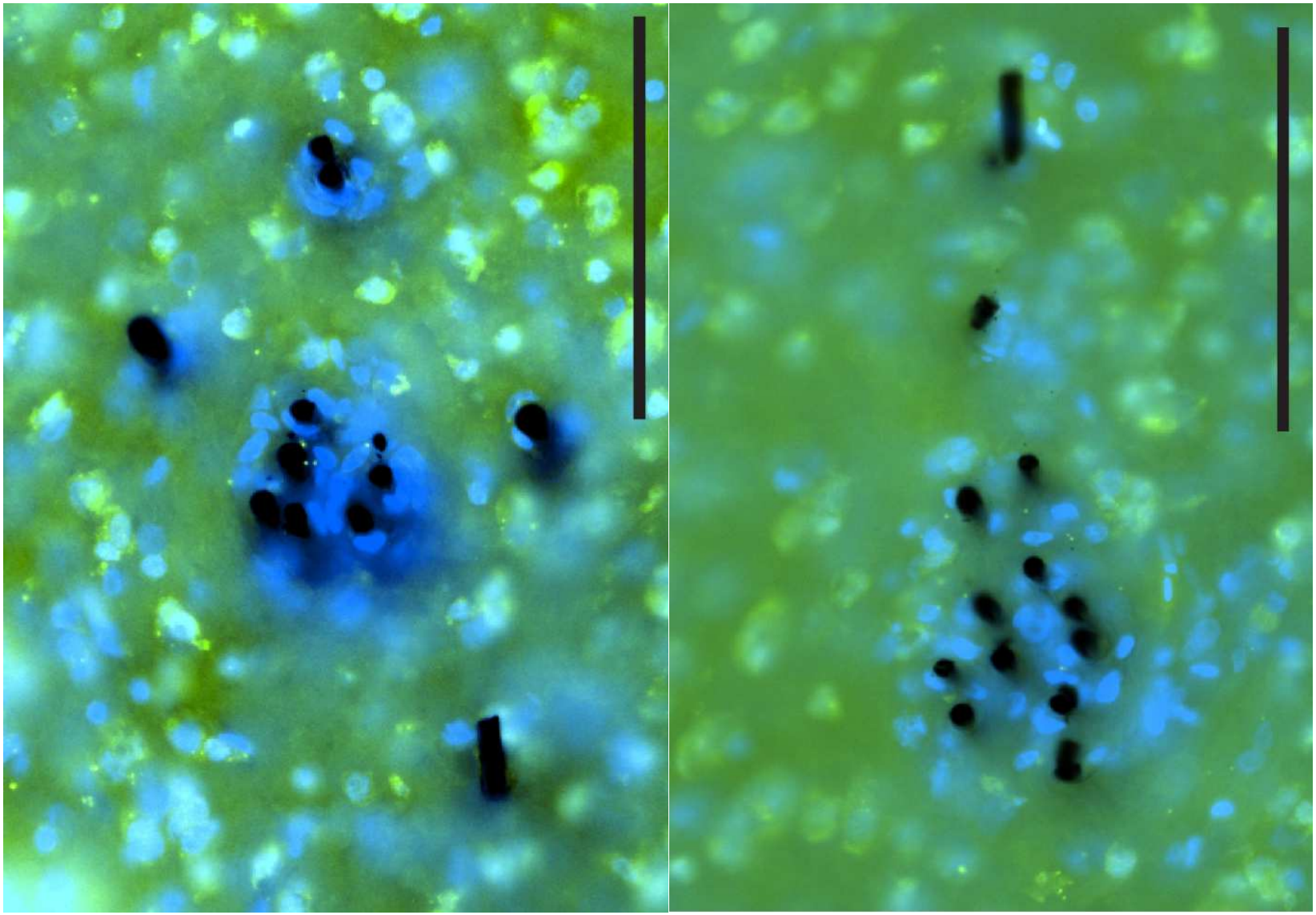
Electrodes

Chronic high-count high-impedance...

- Carbon fibres
- Silicon carbide
- Optical...?



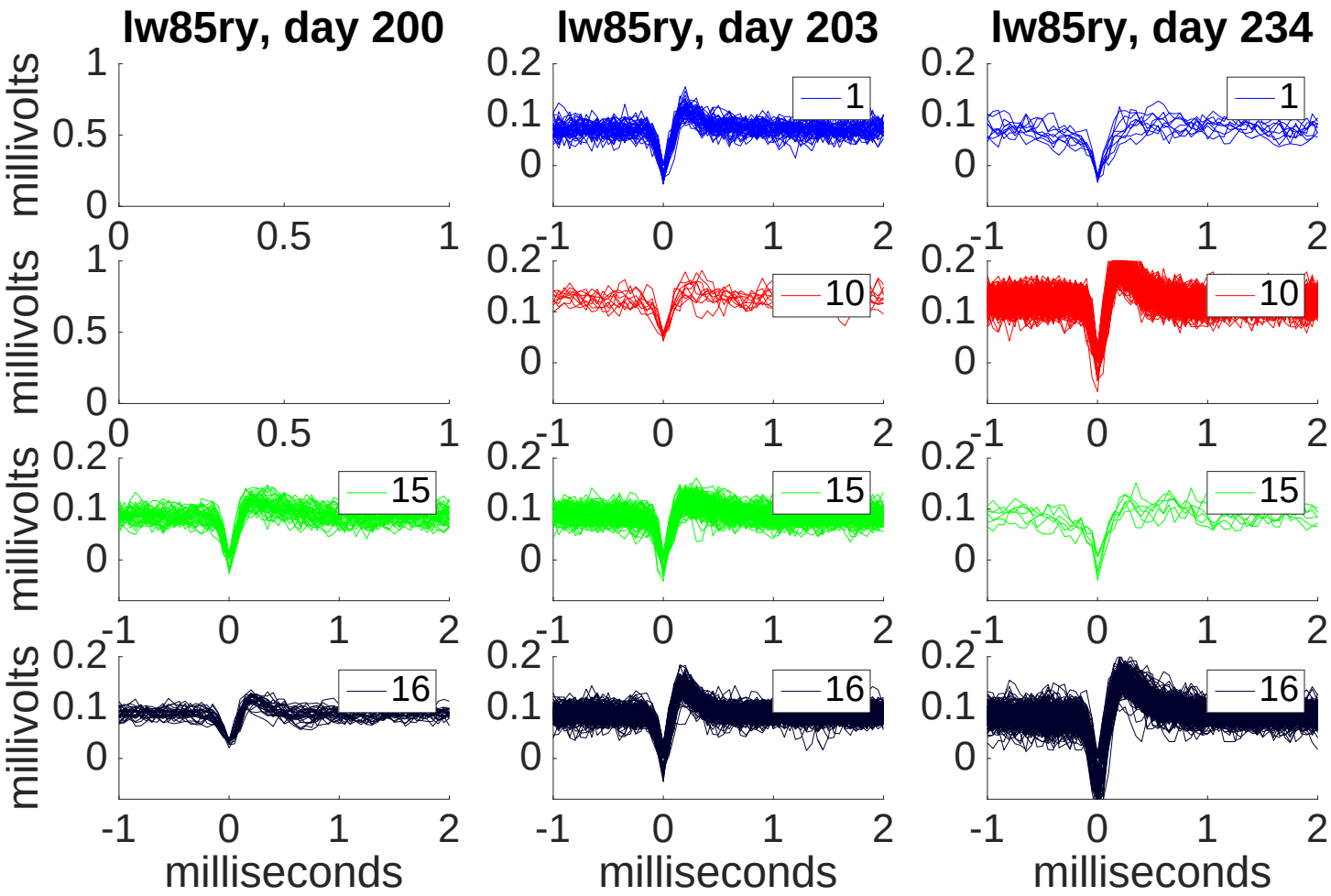

gas/oxygen torch
OMNETICS
water bath
12 15
10 µm
2 µm



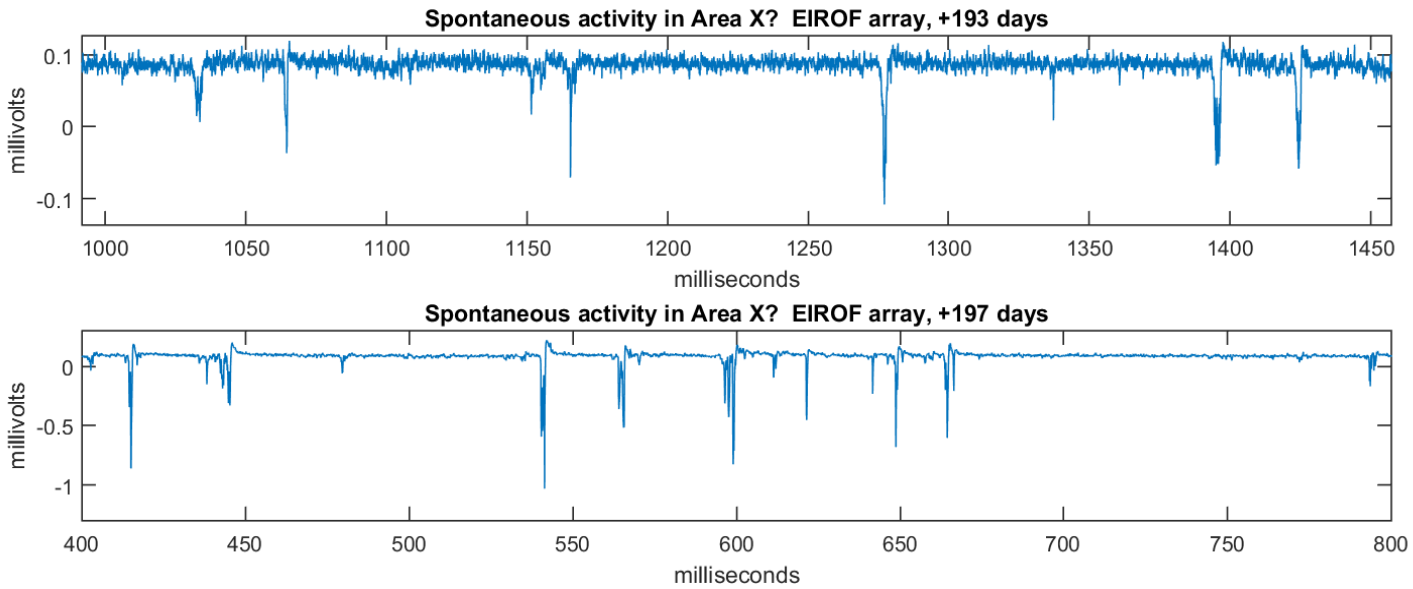
Plexon stimulator

- 16 channels
- Current-controlled
- Externally triggered
- Arbitrary pulse waveforms
- Resolution: 30 nA $\times 1\mu$s
- Matlab API
- Reprogramming time $\approx$ 0.2s/channel
- Voltage monitoring is expensive!

Recording — bare carbon in X



Questionable recording — IrO_2 in X



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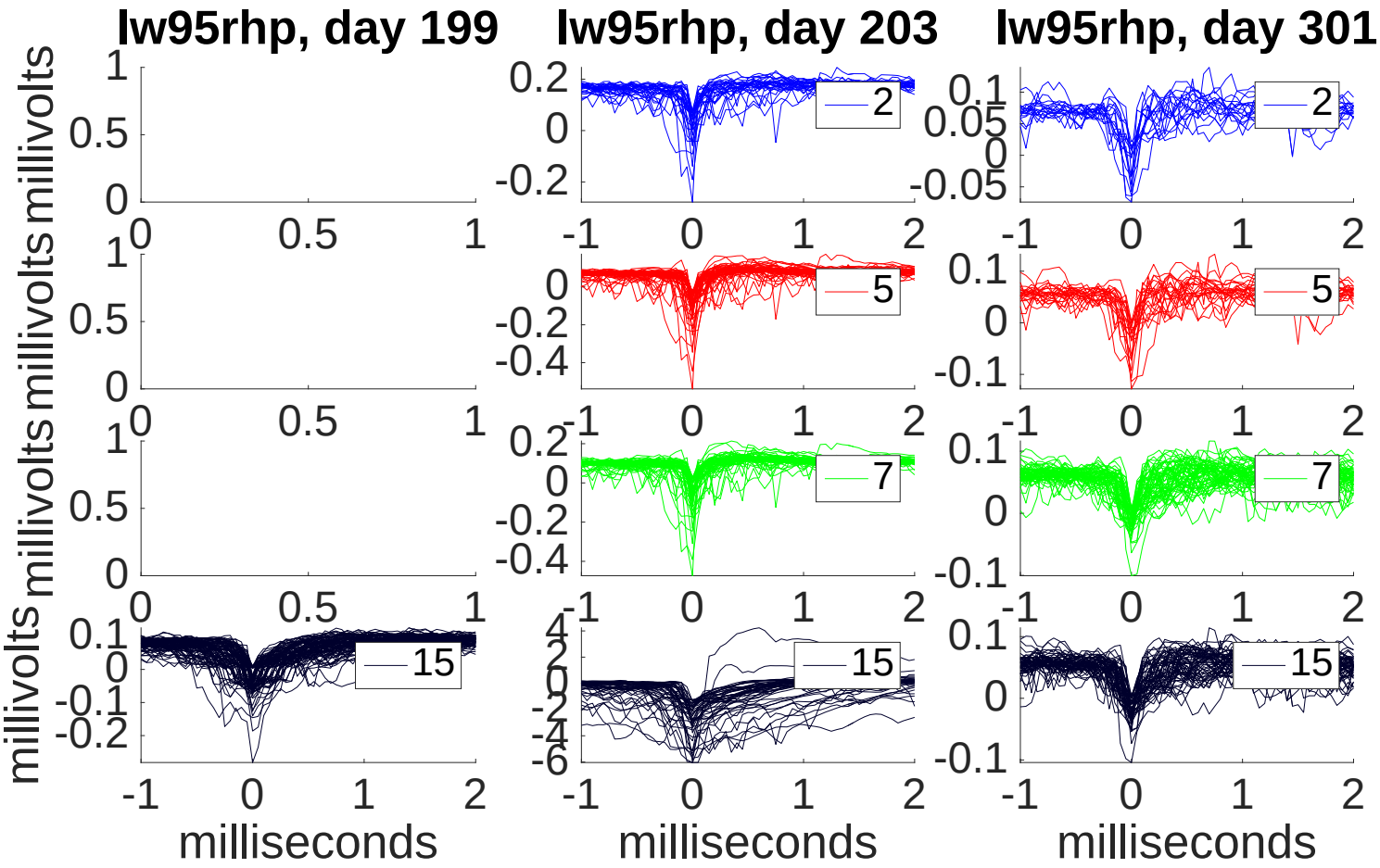
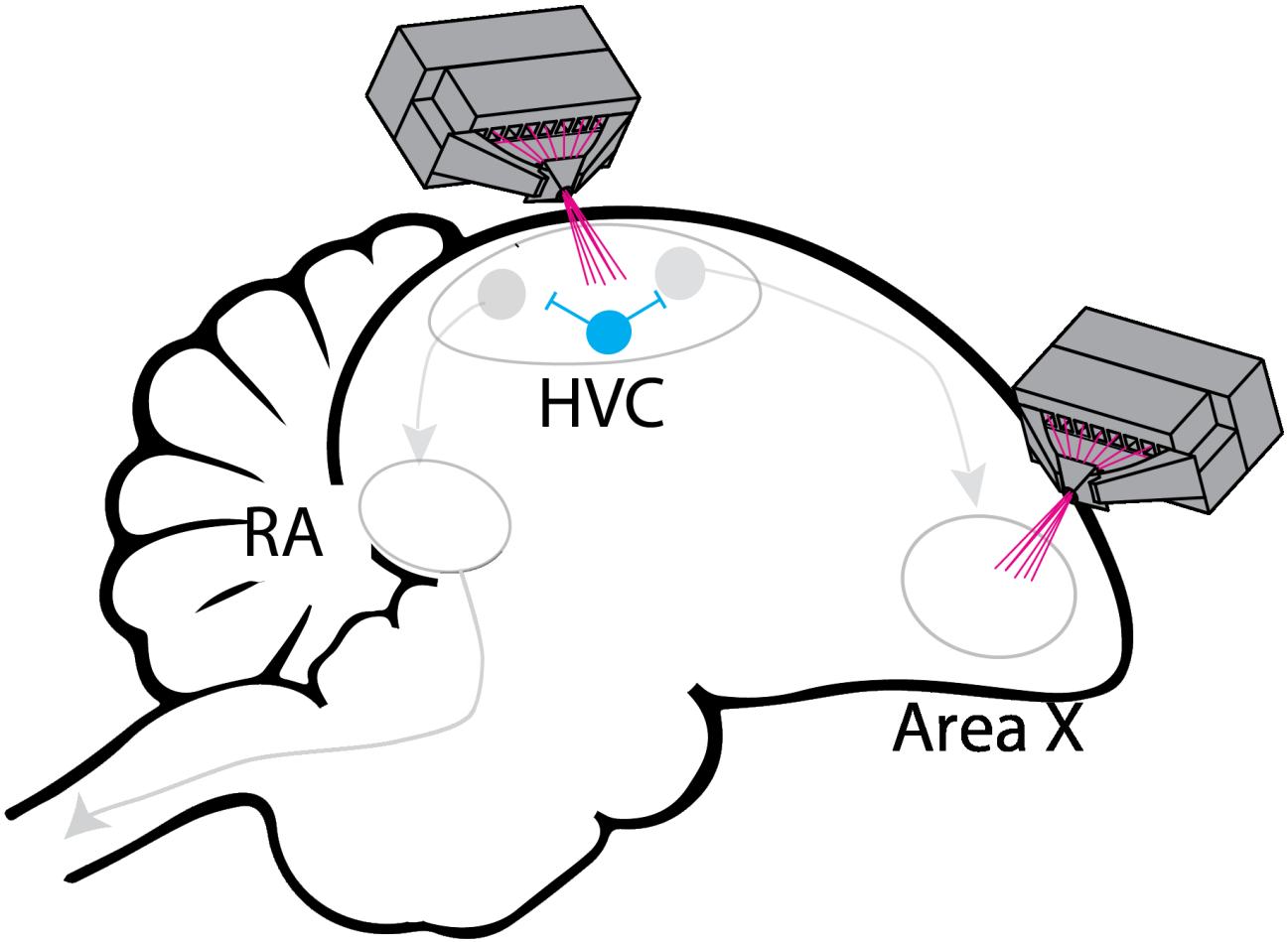
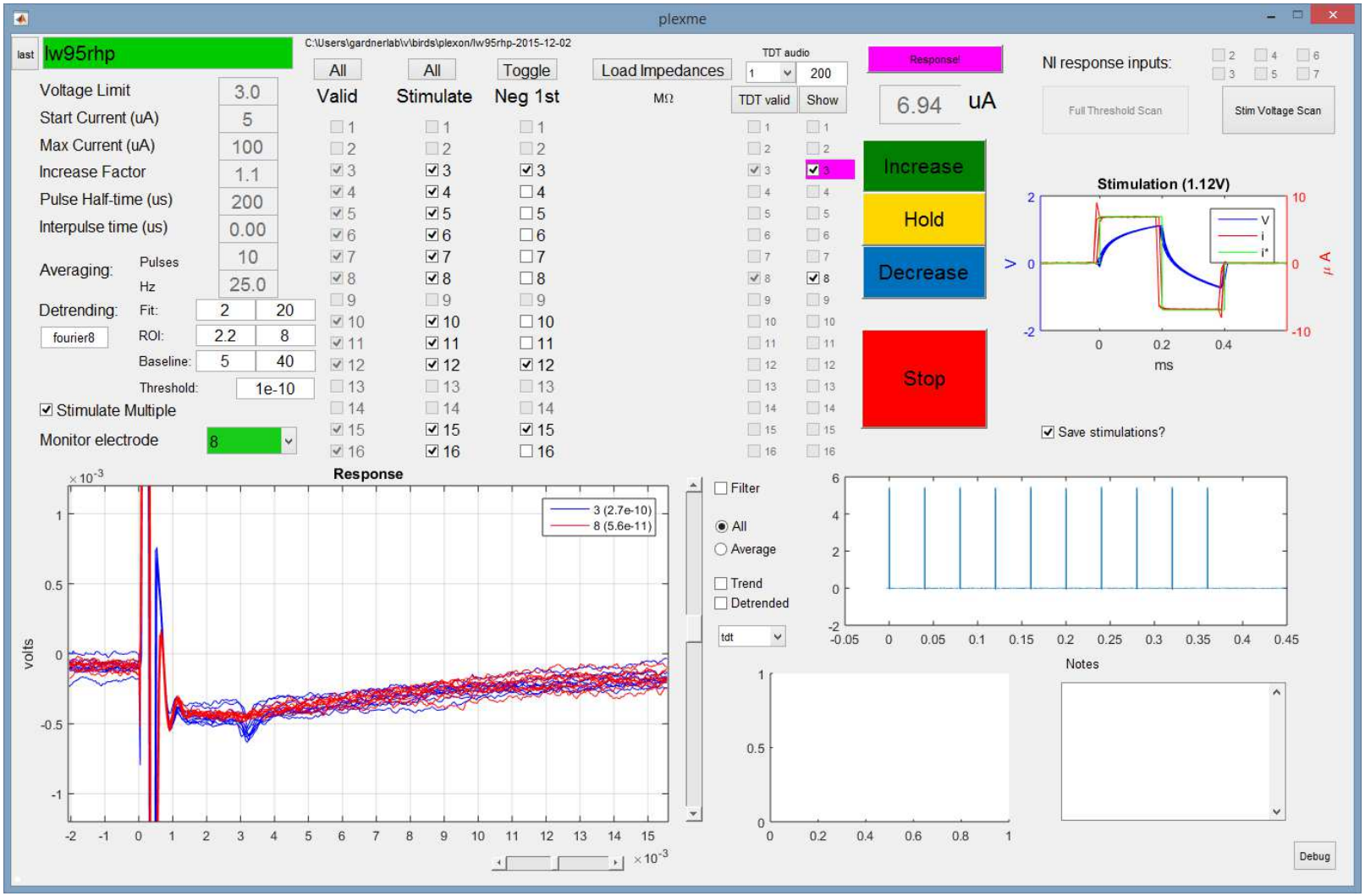


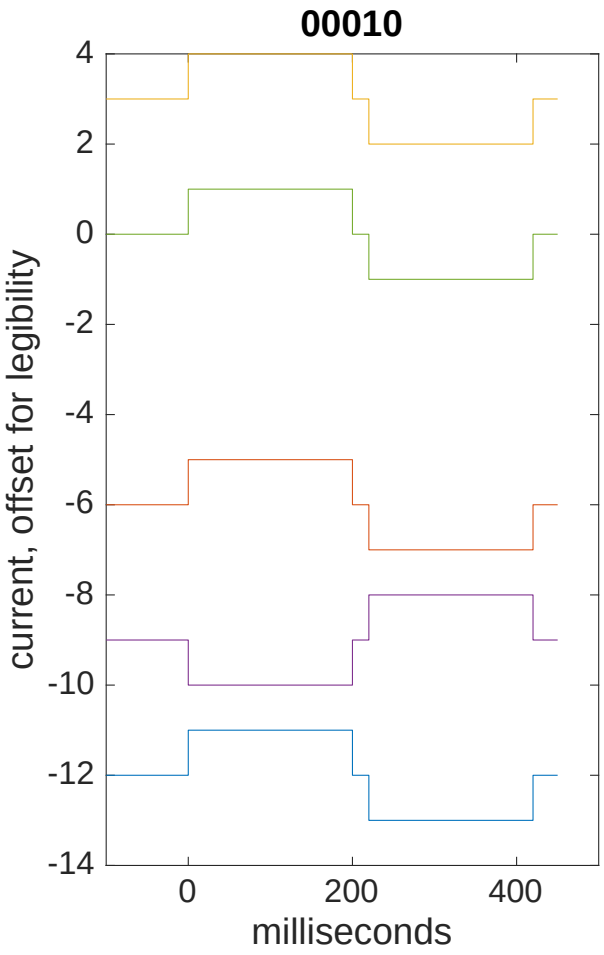
Antedromic HVC ← X response

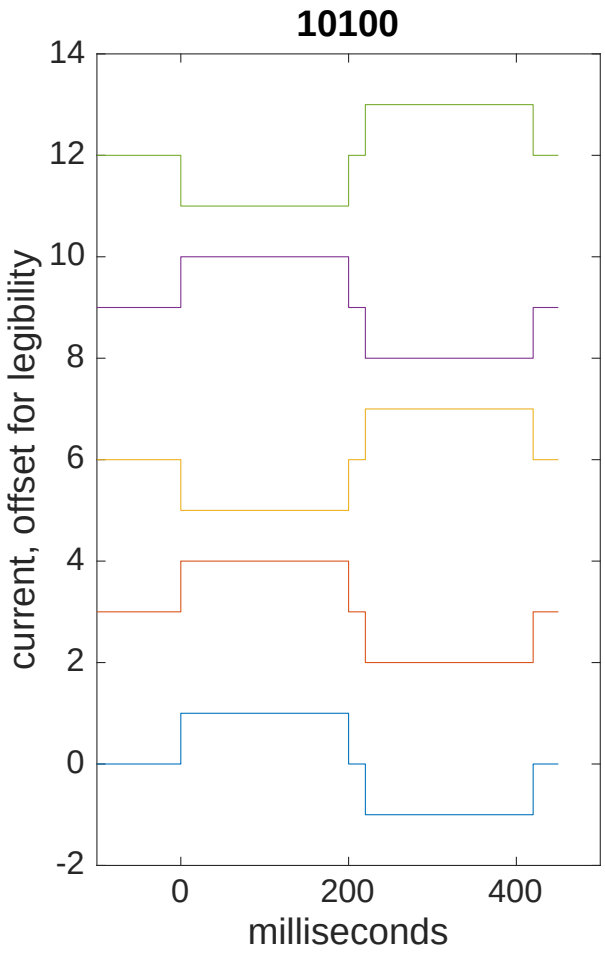


Antedromic HVC ← X response

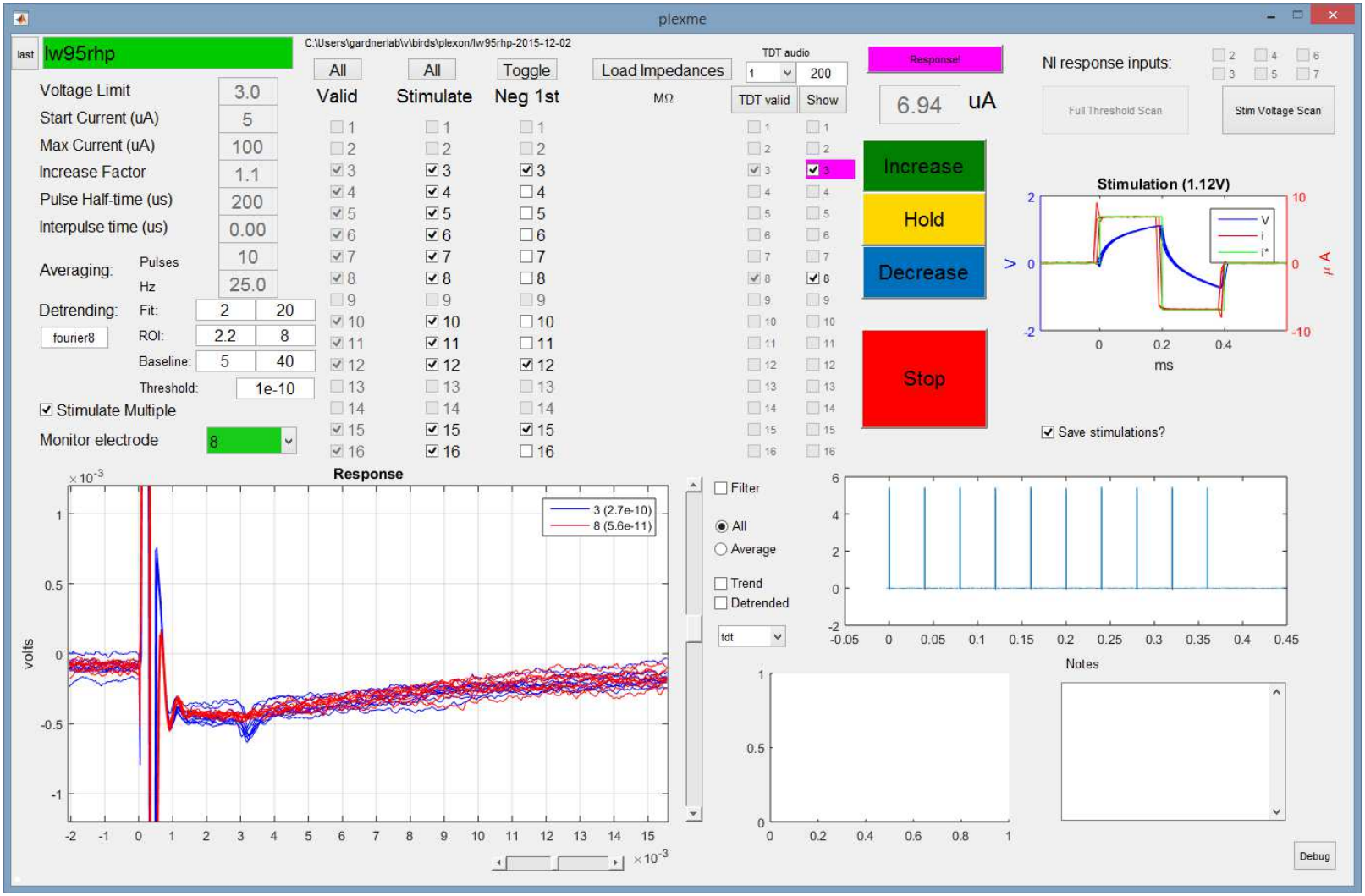


Combinatorial optimisation





Combinatorial optimisation

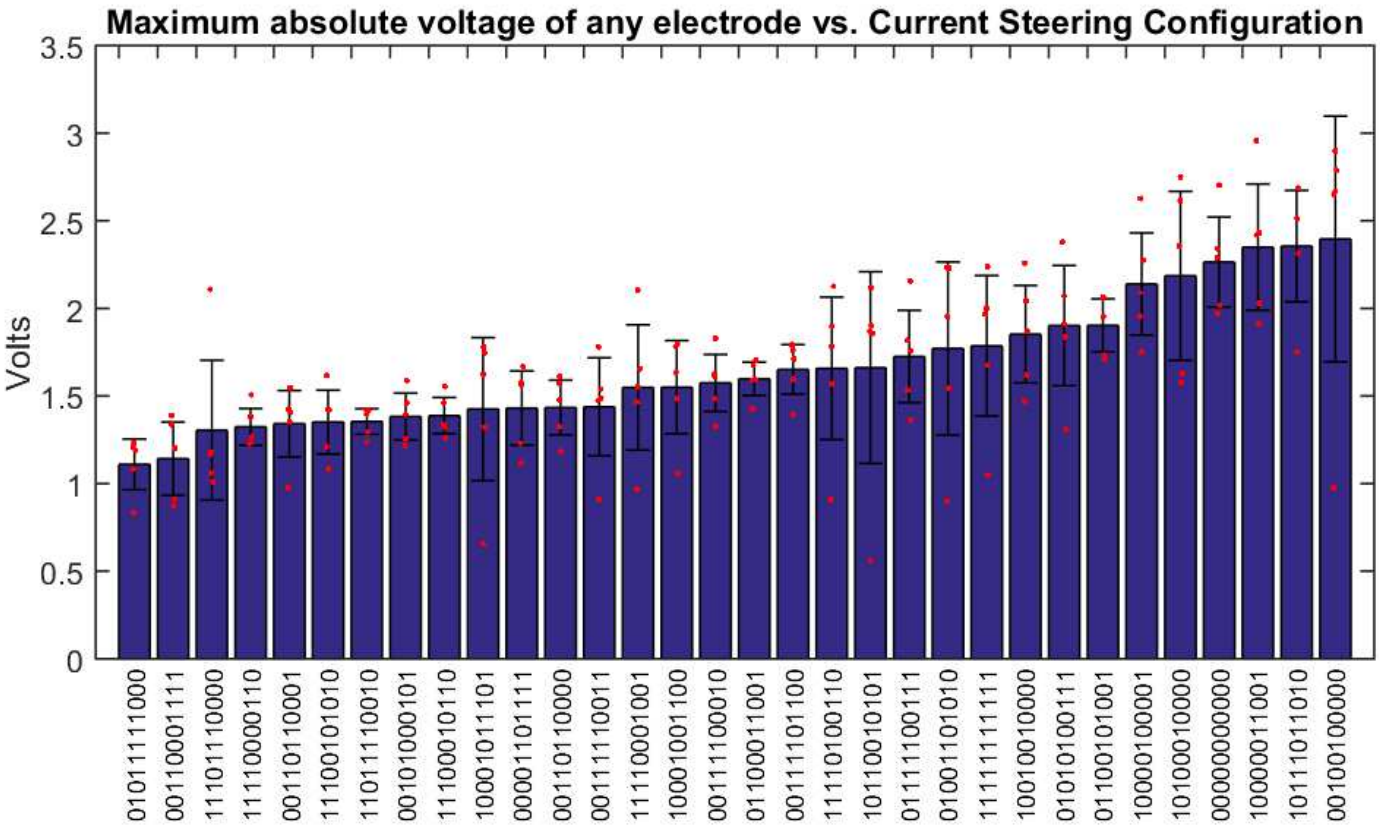


Combinatorial optimisation

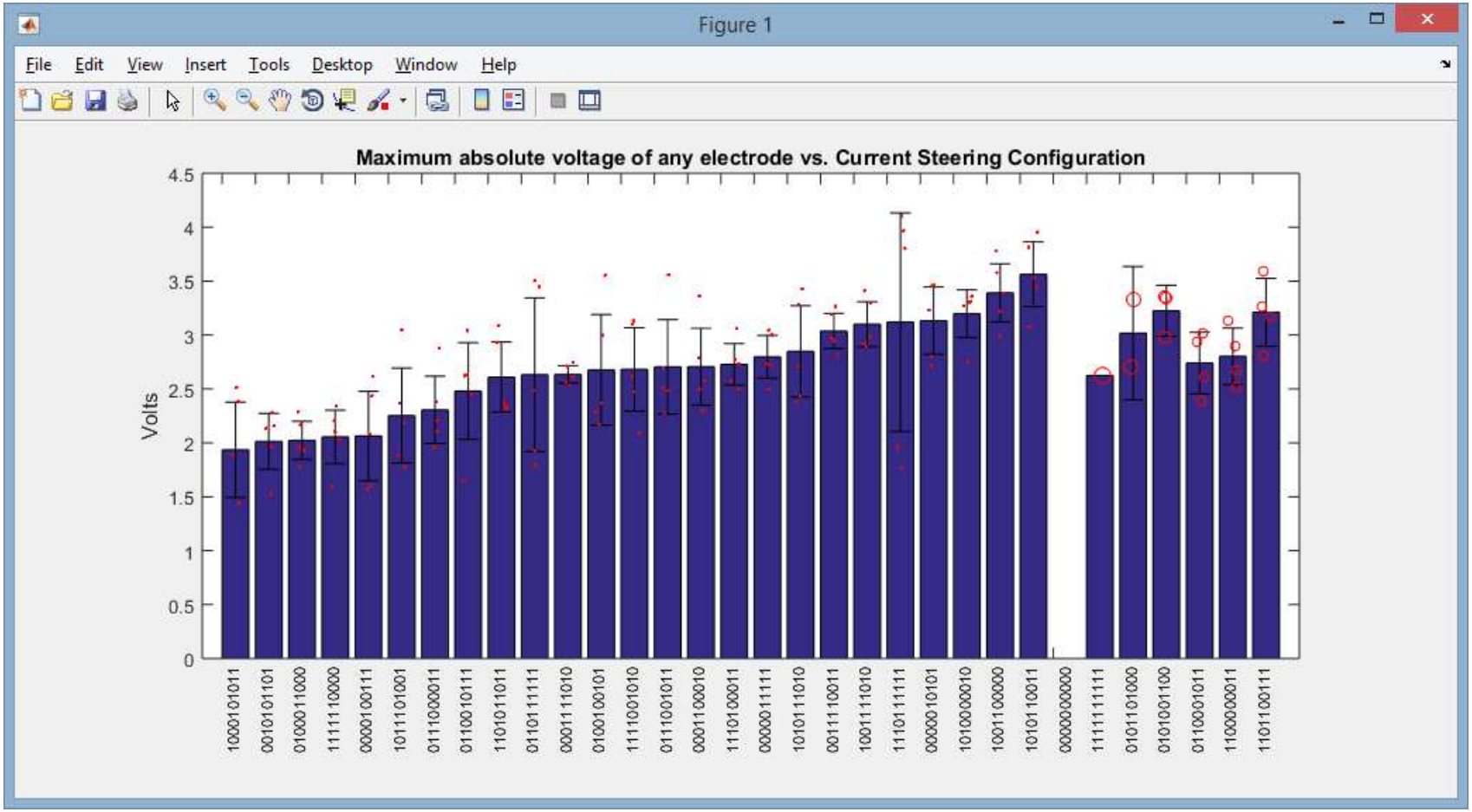
Can current steering minimise stimulation voltage?

1. Pick a current-steering configuration
2. Find response threshold
3. Check each channel for voltage

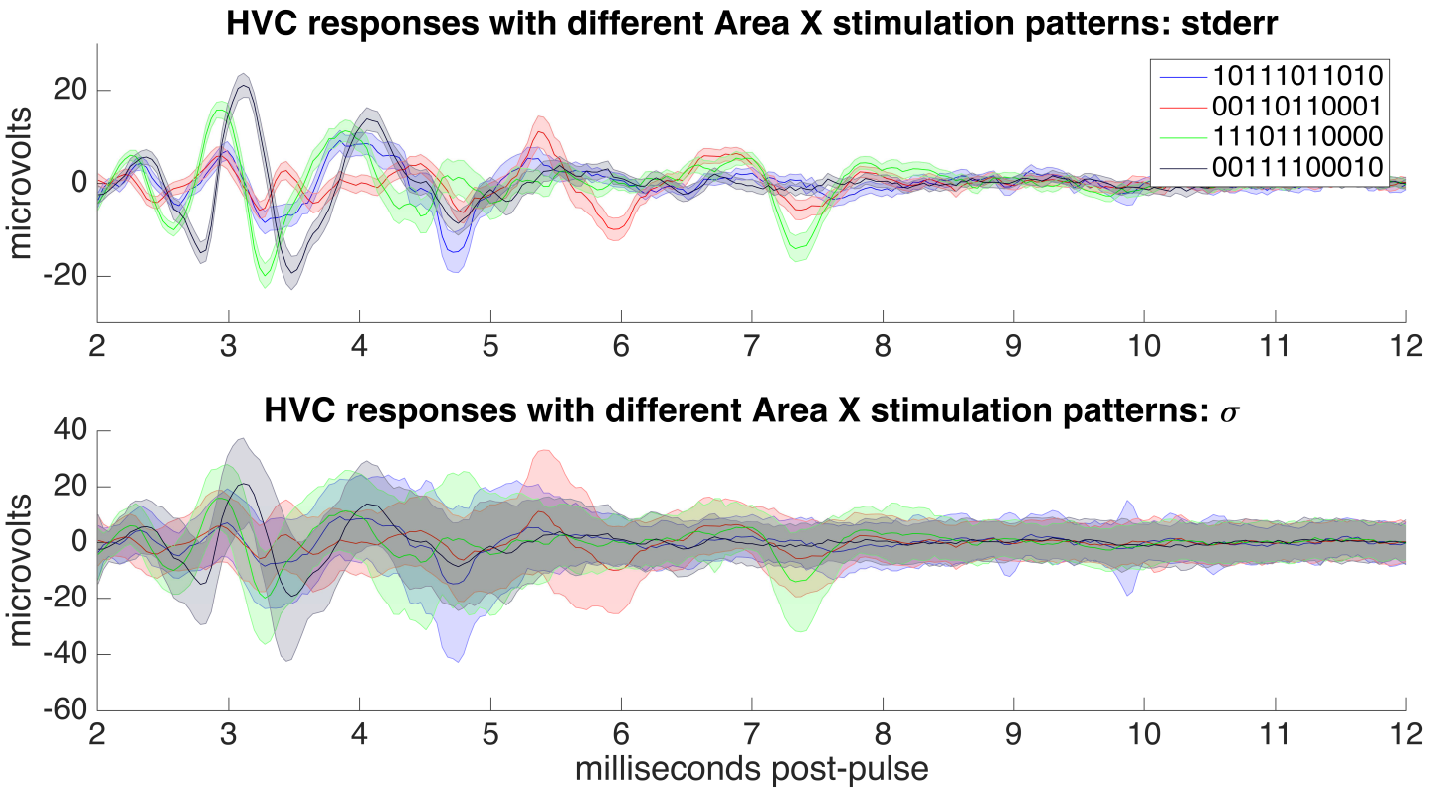
Voltage minimisation



Voltage minimisation



Response shaping in HVC



Policy optimisation

Criteria

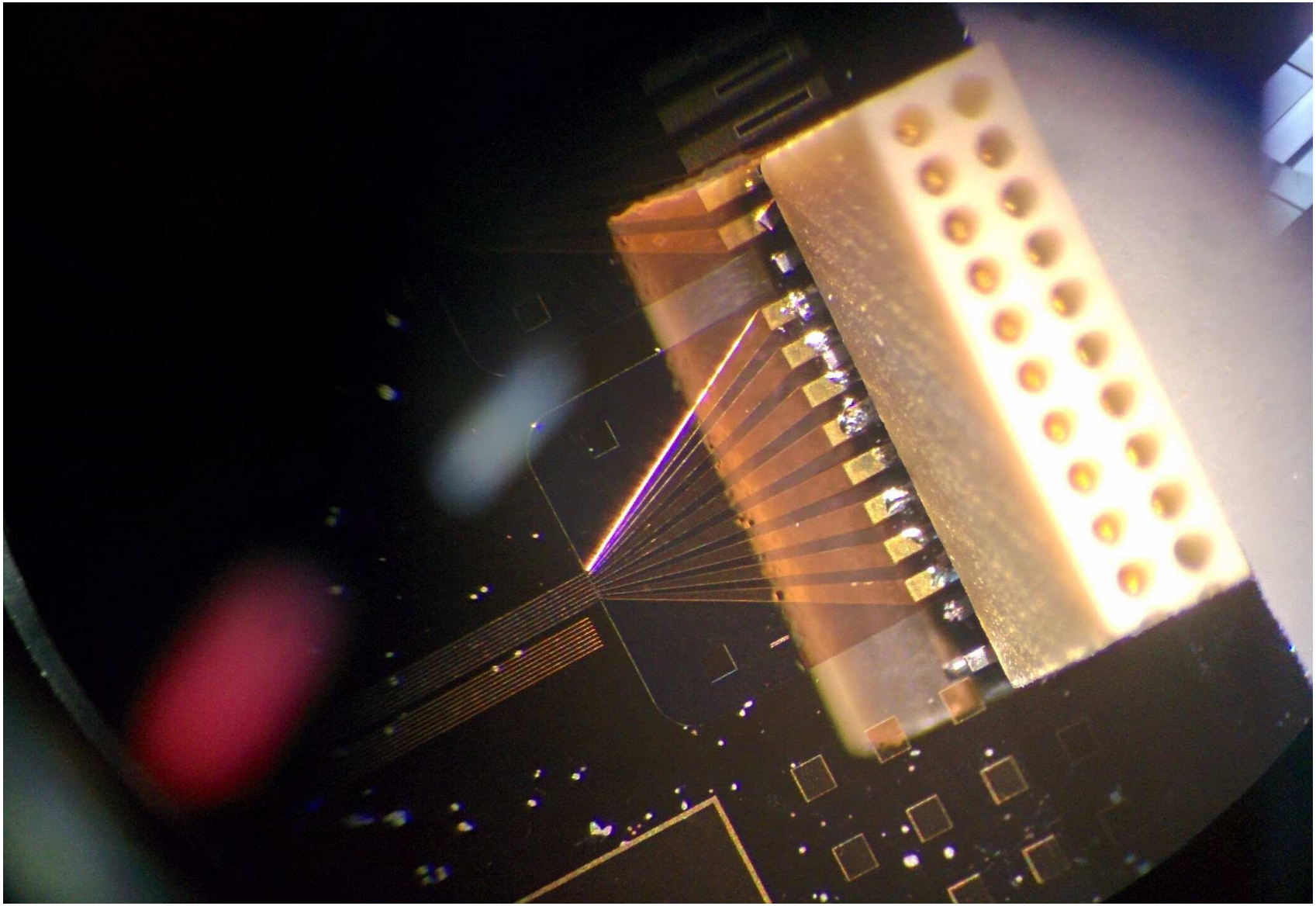
- See response
- Maximise response
- Minimise voltage
- Separate responses
- Directed change to song
  - Acute
  - Chronic

Policy outputs

- Pulse train timing
- Channel timing
- Arbitrary pulse shape
- *Optical!*

Policy inputs

- Vocalisation
- Neural activity
- Other motor output?



Gradient estimation: eR / Stochastic Approximation

Policy:

$$\pi(s, u; \theta) = \Pr(u|s; \theta)$$

Gradient:

$$\widehat{\nabla_\theta J(\theta)} = \widehat{g_\theta} = \left\langle \left(\sum_{k=0}^{H} \nabla_\theta \log \Pr(u_k|s_k; \theta) \right) \cdot (r - b) \right\rangle$$

Learning:

$$\theta_{e+1} = \theta_e + \alpha \frac{\nabla_\theta J(\theta)}{|\nabla_\theta J(\theta)|}$$

Gradient estimation: eR / Stochastic Approximation

Reward:

$$r(d, m) = -\left(d + \eta \sum_{j=1}^{n} \left(\max\left[0, \quad \left(\frac{\mu D}{m_j}\right)^2 - 1\right]\right)\right)$$

Eligibility:

$$\begin{aligned} u &= \theta + \mathcal{N}(0, \Sigma) \\ \nabla_\theta \log \Pr(u|s;\theta) &= \frac{1}{2}\left(\Sigma^{-1} + \Sigma^{-1\,T}\right)(u - \theta) \end{aligned}$$