Encoding applications: retinal implants (‘bionic eyes’)

- in development
- meant to partially restore vision to people with degenerative eye conditions such as macular degeneration
- stimulating the retina with array of electrodes.

http://www.dailymotion.com/video/xfreg4_retinal-implants-allow-blind-to-see-shapes-news

TED Ideas worth spreading
Sheila Nirenberg: A prosthetic eye to treat blindness
http://www.ted.com/talks/sheila_nirenberg_a_prosthetic_eye_to_treat_blindness.html

Encoding applications: Cochlear implants (‘bionic ears’)

- surgically implanted electronic device that provides a sense of sound to a person who is profoundly deaf or severely hard of hearing.
- 188 000 people worldwide in 2009.
- a set of electrodes stimulating neurons in the cochlea.

http://www.youtube.com/watch?v=-WA7-k_UcWY&feature=related

**Encoding problem:** $P[r|s]$

Activity in the brain

The World

Encoder

properties of neurons

**Encoding applications: retinal implants (‘bionic eyes’)**

**Decoding populations of neurons**

In response to a stimulus with unknown orientation $s$, we observe a pattern of activity $r$ (e.g. in V1). What can we say about $s$ given $r$?

Population Response

S $\Rightarrow$ Encoder $\Rightarrow$ R $\Rightarrow$ Decoder $\Rightarrow$ $\hat{S}$ ?
Decoding populations of neurons

An estimation problem (detecting signal in noise).
- **Tools**: estimation theory, bayesian inference, machine learning

When does the problem occur?

1. **Point of view of the experimentalist** or Neuro-Engineering. Seeking the most effective method (e.g. prosthetics) to read out the code.
   - Statistical optimality
   - considering the constraints (e.g. real time?)

2. **Model of the brain’s decoding strategy**
   e.g. mapping from sensory signals to motor response and understanding the relationship between physiology and psychophysics
   - statistical optimality?
   - optimality within a class?
   - or simplicity/ arbitrary choice? (what are the biological constraints?)

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1. Optimal Decoding

- **s** \rightarrow Encoder \rightarrow \text{Population Response} \rightarrow \text{Optimal Decoder} \rightarrow \hat{s} \rightarrow \text{Perception}

- **optimality criterion?**
  
  \[ \text{MSE}(s) = \langle (\hat{s} - s)^2 \rangle \]

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Decoding: to understand the link between Physiology and Psychophysics

- Understanding the relationship between neural responses and performances of the animal:
  - **Detection Task**: e.g. can you see the target? Measure Detection threshold.
  - **Estimation Task**: e.g. What is the angle of the bar? The contrast of the grating? Measure Estimation errors (bias -- illusions).
  - **Discrimination Task**: e.g. What is the minimal difference you can see?

- **Maximum Likelihood:**
  if we know \( P[r|s] \) (the encoding model), choose the stimulus \( s \) that has maximal probability of having generated the observed response, \( r \).
  \[
  \hat{s} = \text{argmax}_s P(r|s)
  \]
1. Optimal Decoding

**Maximum Likelihood:**
if we know $P[r|s]$ (the encoding model),
choose the stimulus $s$ that has maximal probability of having generated the observed response, $r$.

$$\hat{s} = \arg\max_s P(r|s)$$

1. Optimal Decoding

**Maximum a Posteriori:**
if we know $P[r|s]$ and have a prior on $s$, $P[s]$,
choose the stimulus $s$ that is most likely, given $r$.

$$\hat{s} = \arg\max_s P(s|r) = \arg\max_s P[r|s]P[s]$$

Is the brain able to do ML or MAP estimation?
- Unknown
- It is argued that realistic architectures could perform ML.

$\hat{s}$
2. Simpler Decoding Strategies

Winner Take All:

If we know the preferred orientation of all neurons, choose the preferred orientation of the neuron that responds most.
2. Simpler Decoding Strategies

Population Vector

spikes/s

preferred orientation

Population Vector

spikes/s

preferred orientation

Population Vector

spikes/s

preferred orientation

Population Vector

spikes/s

preferred orientation
2. Simpler Decoding Strategies

Optimal decoders often require much too much data (full model $P[r|s]$), seem too complex:

The question then is the cost of using non-optimal decoders.

- Linear Decoders, eg. OLE, [Salinas and Abbott 1994]

- Decoders that ignore the correlations (decode with the "wrong model" which assumes independence) [Nirenberg & Latham 2000, Wu et al 2001, Series et al 2004]

Use of simple decoding methods for prosthetics

Brain-machine interface usually use very simple decoding techniques ... and they show promising results (as well as surprising learning effects).

See eg. lab of M. Nicolelis @ Duke, and A. Schwartz @ Pittsburg

http://www.youtube.com/watch?v=7kctOHNryuM&feature=related

http://www.youtube.com/watch?v=me20x87yQfE

Decoding in humans

http://www.youtube.com/watch?v=6FsH7RK152E

Jack Gallant -- decoding the movie you’re viewing from your fMRI scan

Neural Prosthetics: Krishna Shenoy at TEDxStanford

http://www.youtube.com/watch?v=ZuATvhlcUU4

ARTICLES

Neuronal ensemble control of prosthetic devices by a human with tetraplegia

Leigh R. Hochberg1,2,3,4, Miguel D. Serruya5, Gerhard M. Friehs6, Jon A. Mulik7,2, Maryam Soleymanian7,8, Abraham H. Caplan1, Ahmed Bramer1, David Chen1, Richard D. Penn1,9 & John P. Donoghue1

Neurorotor prostheses (NRP) aim to replace or restore lost motor functions in paralyzed humans by creating movement-related signals from the brain, around damaged parts of the nervous system, to external effectors. To translate practical results from intact animals to a clinically useful NRP, movement signals must persist in cortex after spinal cord injury and be engaged by movement intent when sensory inputs and limb movement are long absent. Furthermore, NRP would require that intention-driven neural activity be converted into a control signal that enables useful tasks. Here we show initial results for a tetraplegic human (MN) using a pilot NRP. Neuronal ensemble activity recorded through a five-lead microelectrode array implanted in primary motor cortex demonstrated that intended hand motion modulates cortical spiking patterns three years after spinal cord injury. Decoders were created, providing a ‘neural cursor’ with which MN operated simulated e-mail and operated devices such as a television, even while conversing. Furthermore, MN used neural control to open and close a prosthetic hand, and perform rudimentary actions with a multi-jointed robotic arm. These early results suggest that NRP based upon intracortical neuronal ensemble spiking activity could provide a valuable new neurotechnology to restore independence for humans with paralysis.

http://www.braingate2.org/60mins.html

fMRI

http://videolectures.net/fmri06_mitchell_odmsp/

classification techniques; a machine learning problem
Decoding: Summary of previous slides

- Decoding: for neuro-prostheses and/or for understanding the relationship between the brain’s activity and perception or action

- Different strategies are possible: optimal decoders (e.g. ML, MAP) vs simple decoders (e.g. winner take all, population vector), depending on what we know about the encoding model, and constraints.

![Diagram of decoding process](image_url)

![Diagram of spike and preferred orientation](image_url)