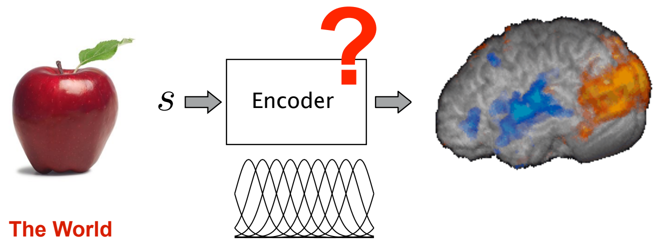
Encoding problem: $P[\mathbf{r}|s]$

Activity in the brain



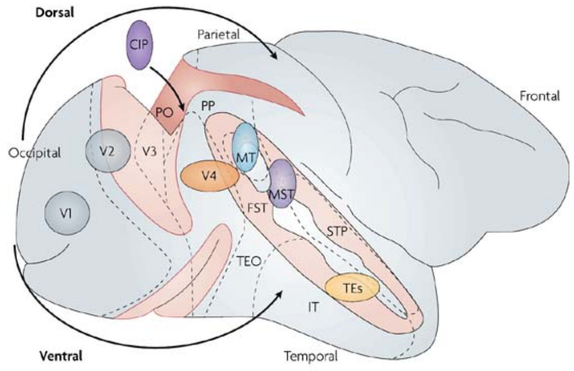
The World

properties of neurons

Overview of the visual cortex

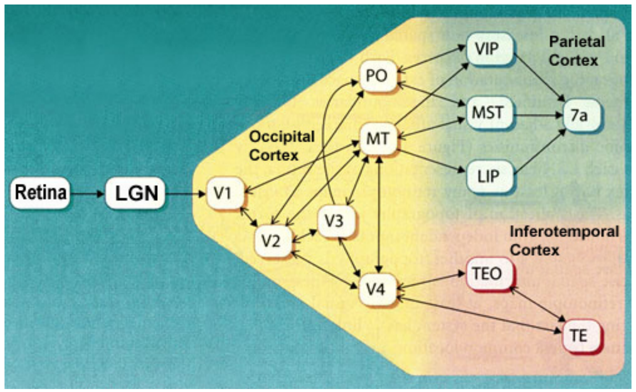
Two streams:

- **Ventral** 'What': V1,V2, V4, IT, form recognition and object representation
- **Dorsal** 'Where': V1,V2, MT, MST, LIP, VIP, 7a: motion, location, control of eyes and arms

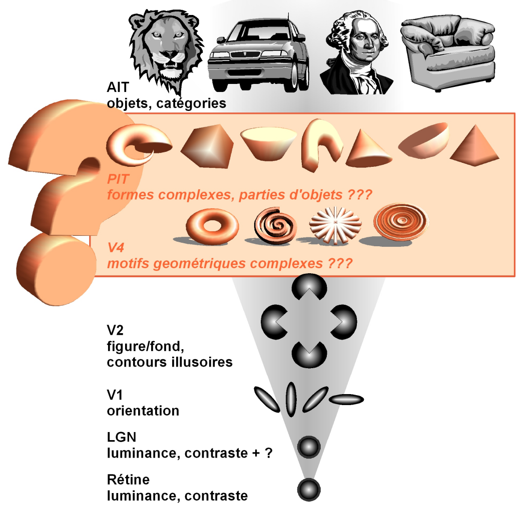


Nature Reviews | Neuroscience

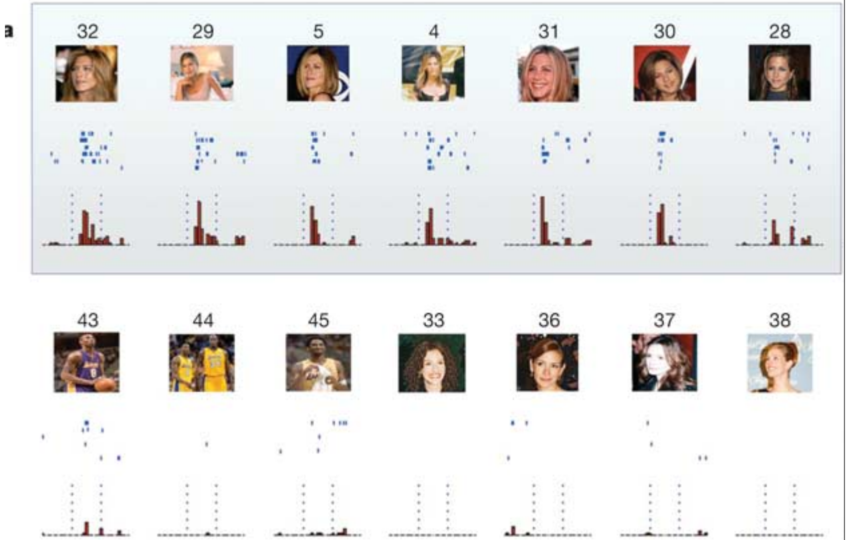
Overview of the visual cortex



Ventral pathway



Quiroga et al, *Nature*, 2005 -- Invariant visual representation by single neurons in the human brain (MTL), a.k.a the Jennifer Aniston Neuron.



https://www.youtube.com/watch?v=635Ntur8K2s

Dorsal pathway

- **MT: MOTION.** stimulus of choice: random dot patterns.

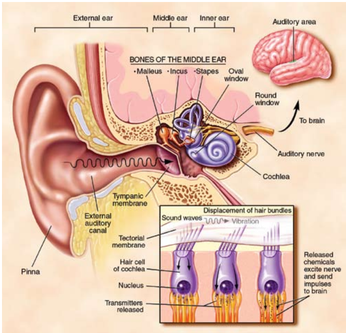
Dorsal pathway

- **MST**: linear, radial, circular motion (flow field).
- **LIP**: spatial position in head-centered coordinates. spatial attention, spatial representation. saliency map -- used by oculo-motor system (the "saccade planning area"). spatial memory trace and anticipation of response before saccade.
- **VIP**: spatial position in head-centered coordinates, multi-sensory responses. speed, motion.
- **7a:** large receptive fields, encode both visual input and eye position.

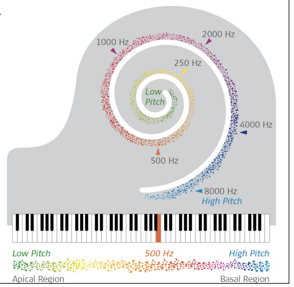
Encoding applications: Cochlear implants ('bionic ears')

https://www.youtube.com/channel/UCkN8E4D0Gs9y-QgUcWc-gMQ?v=LhSpb36_1s4

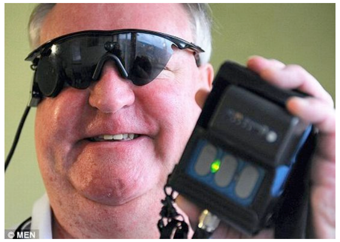
- surgically implanted electronic device that provides a sense of sound to a person who is profoundly deaf or severely hard of hearing.
- 324,000 people worldwide in 2012 have an implant.
- a set of electrodes stimulating neurons in the cochlea.



People hearing for the first time: https://www.youtube.com/watch?v=mbe7x8GP2Ds



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 -currently 60-100 channels.

https://www.youtube.com/watch?v=CiyGOUHD2nI

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

Review

Cell PRESS

Visual prostheses for the blind

Robert K. Shepherd[1,2], Mohit N. Shivdasani[1,2], David A.X. Nayagam[1,2,3], Christopher E. Williams[1,2], and Peter J. Blamey[1,2]

[1] Bionics Institute, 384-388 Albert St East Melbourne, 3002, Victoria, Australia
[2] Medical Bionics Department, University of Melbourne, 384-388 Albert St East Melbourne, 3002, Victoria, Australia
[3] Department of Pathology, University of Melbourne, Parkville, 3010, Victoria, Australia

After more than 40 years of research, visual prostheses are moving from the laboratory into the clinic. These devices are designed to provide prosthetic vision to the blind by stimulating localized neural populations in one of the retinotopically organized structures of the visual pathway – typically the retina or visual cortex. The long gestation of this research reflects the many significant technical challenges encountered including surgical access, mechanical stability, hardware miniaturization, hermetic encapsulation, high-density electrode arrays, and signal processing. This review provides an introduction to the pathophysiology of blindness; an overview of existing visual prostheses, their advantages and drawbacks; the perceptual effects evoked by electrical stimulation; as well as the role played by plasticity and training in clinical outcomes.

Introduction

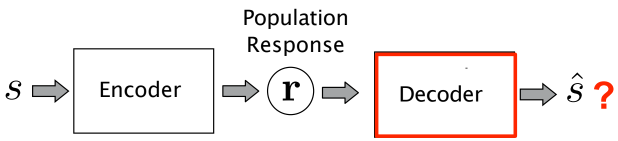
It is estimated that 285 million people are visually impaired worldwide; 39 million of whom are blind [2]. Although uncorrected refractive errors are the main cause of visual impairment, diseases associated with degeneration of the retinal photoreceptors result in severe visual loss with few or no therapeutic options for ongoing clinical management. Importantly, significant numbers of RGCs are spared following the loss of photoreceptors. Although there are major alterations to the neural circuitry of these surviving neurons [3], their presence provides the potential to restore vision using electrical stimulation delivered by an electrode array located close to the retina (Box 1). The clinical management of other forms of blindness, including

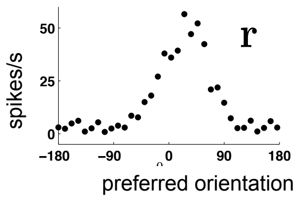
Glossary

Age-related macular degeneration (AMD): damage to the photoreceptors of the macula region of the retina leading to central blindness.

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**?





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 ?)

Decoding: to understand the link between Physiology and Psychophysics

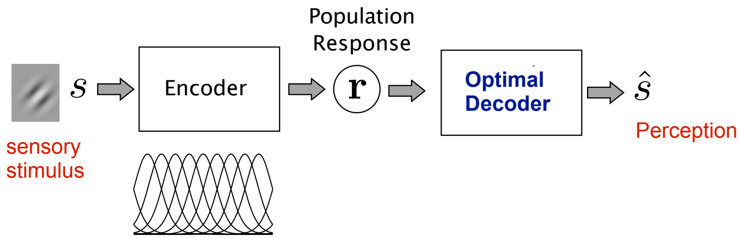
• Understanding the relationship between neural responses and performances of the animal:

• 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?

1. Optimal Decoding



✤ optimality criterion?

$MSE(s) =< (\hat{s} - s)^2 >$

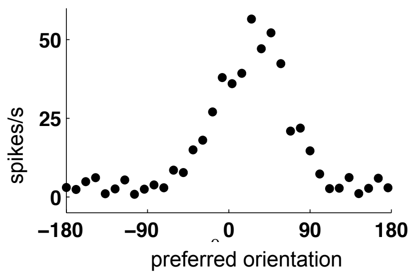
1. Optimal Decoding

✤ 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**.

$\hat{s} = \mathrm{argmax}_s P(\mathbf{r}|s)$



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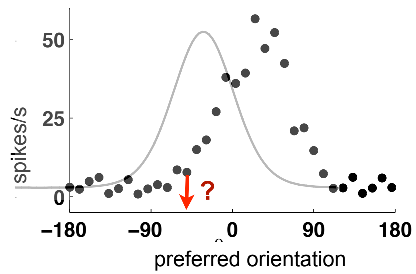

1. Optimal Decoding

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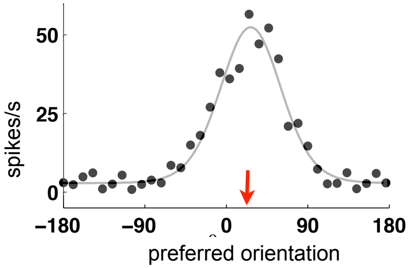
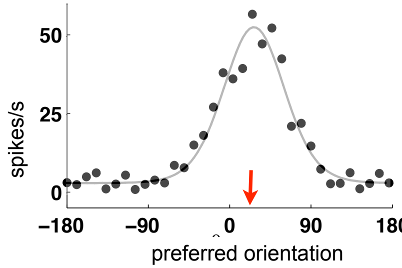


1. Optimal Decoding

- Maximum a Posteriori:

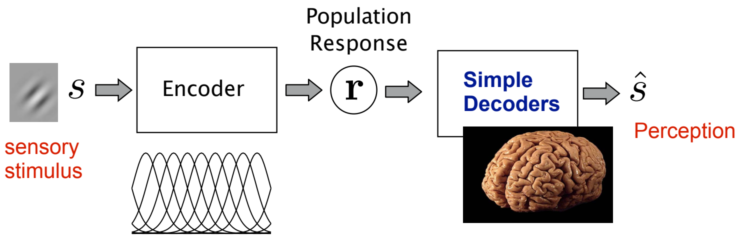
  if we know P[**r**|s] and have a prior on s, P[s],
  choose the stimulus s that is most likely, given **r**.

$$\hat{s} = \text{argmax}_s P(s|\mathbf{r}) = \text{argmax}_s P[\mathbf{r}|s]P[s]$$



Is the brain able to do ML or MAP estimation ?

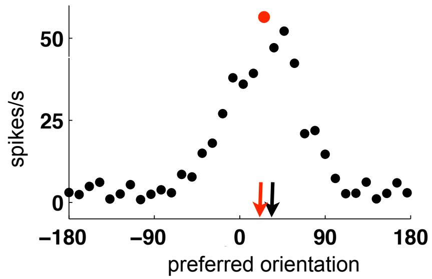
- Unknown
- It is argued that realistic architectures could perform ML [Deneve, Latham, Pouget al 2001, Ma, Pouget et al 2006, Jazayeri and Movshon 2006]



2. Simpler Decoding Strategies

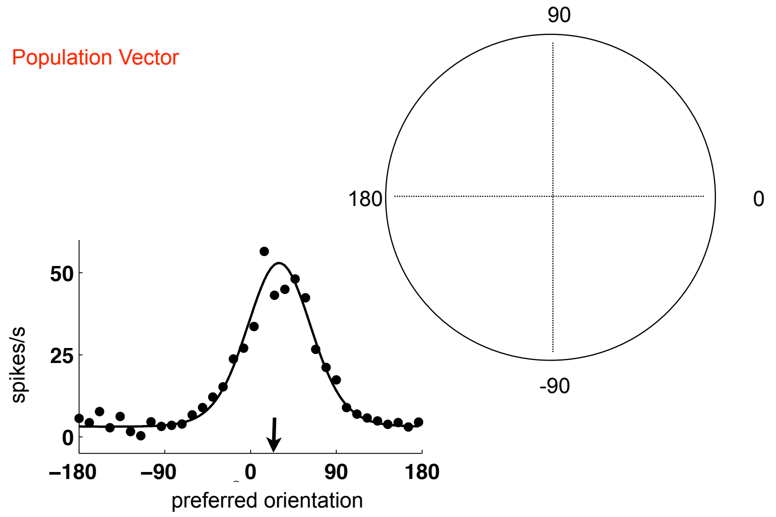
Winner Take All :

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



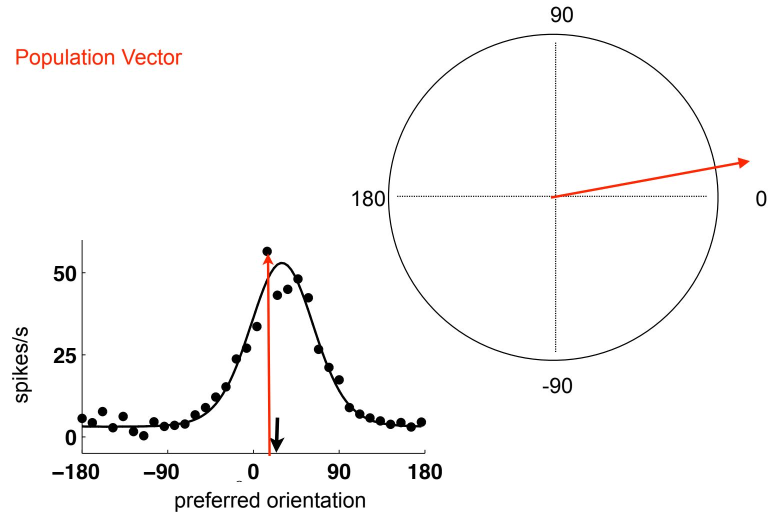
2. Simpler Decoding Strategies

Population Vector



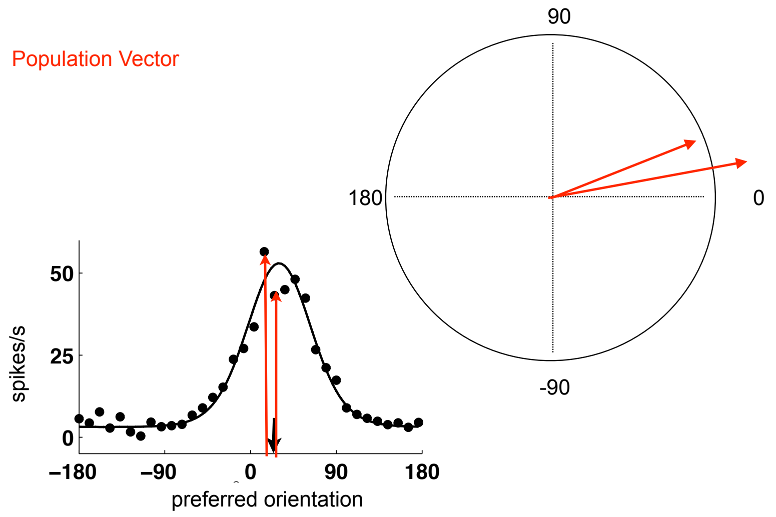
2. Simpler Decoding Strategies

Population Vector



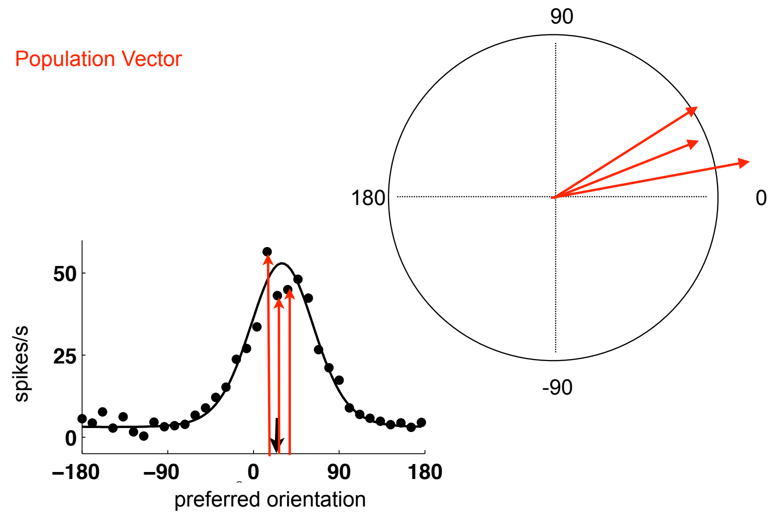
2. Simpler Decoding Strategies

Population Vector



2. Simpler Decoding Strategies

Population Vector



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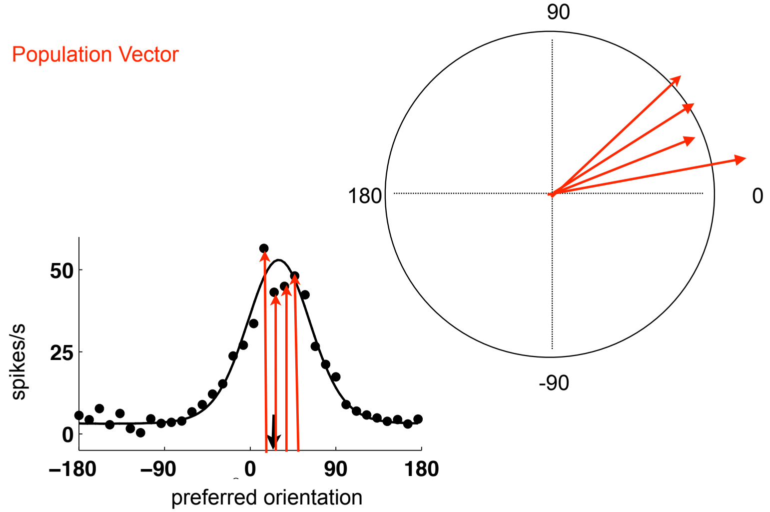
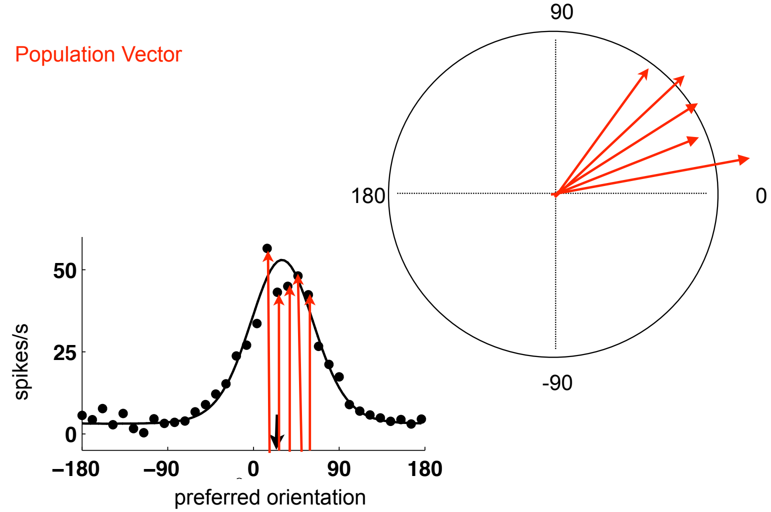
Population Vector



2. Simpler Decoding Strategies

Population Vector



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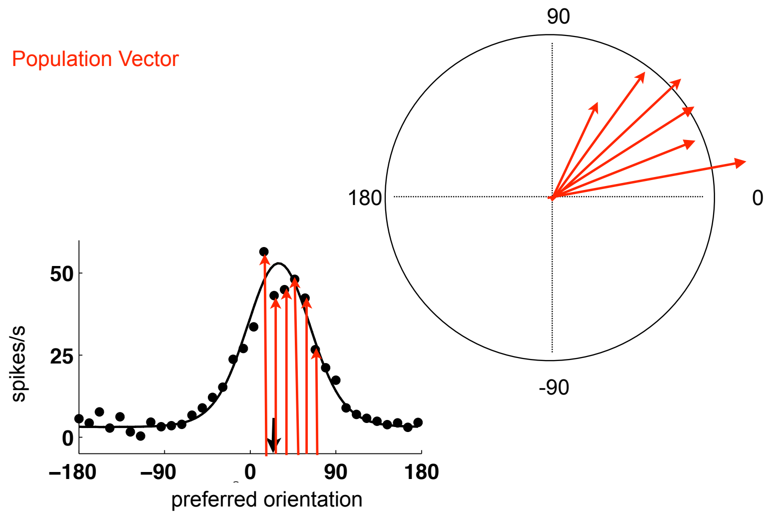
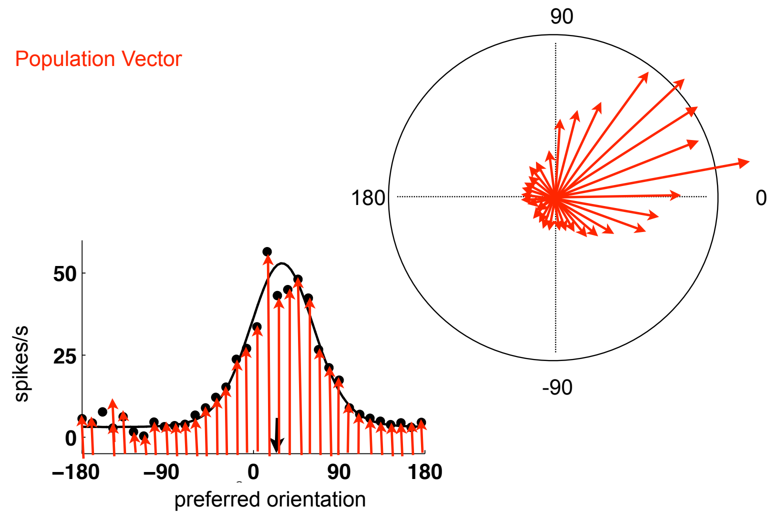
Population Vector



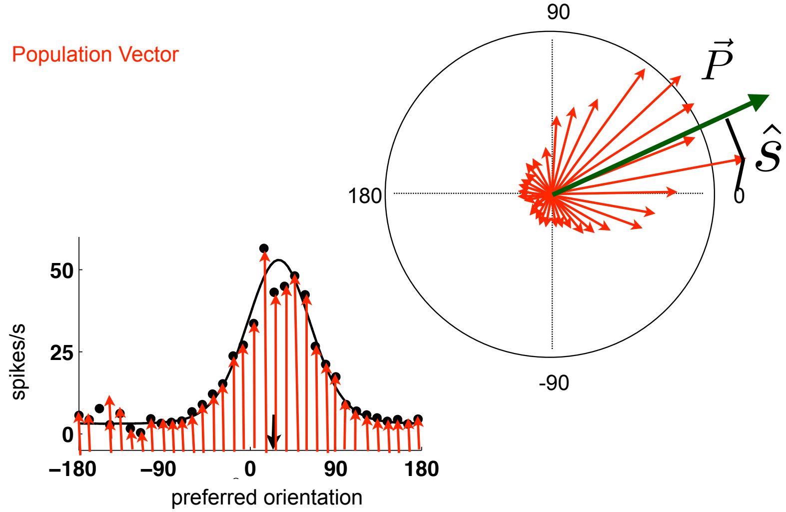
2. Simpler Decoding Strategies

Population Vector



2. Simpler Decoding Strategies

Population Vector



2. Simpler decoding strategies: Optimal Decoders within a class

Optimal decoders often requires 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, Seriès et al 2004]

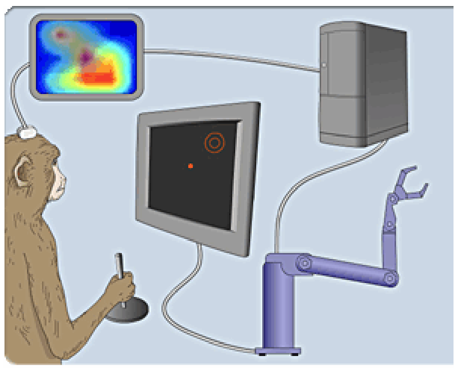
$$\hat{s} = \sum_i w_i r_i$$

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=7kctOHnrvuM&feature=related



nature Vol 442|13 July 2006|doi:10.1038/nature04970

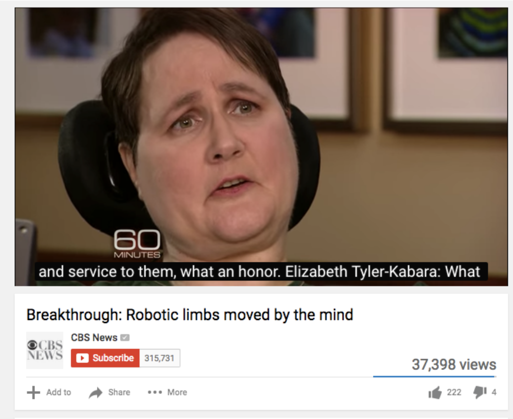
ARTICLES

Neuronal ensemble control of prosthetic devices by a human with tetraplegia

Leigh R. Hochberg[1,2,4], Mijail D. Serruya[2,3], Gerhard M. Friehs[5,6], Jon A. Mukand[7,8], Maryam Saleh[9]†, Abraham H. Caplan[9], Almut Branner[10], David Chen[11], Richard D. Penn[12] & John P. Donoghue[2,9]

Neuromotor prostheses (NMPs) aim to replace or restore lost motor functions in paralysed humans by routeing movement-related signals from the brain, around damaged parts of the nervous system, to external effectors. To translate preclinical results from intact animals to a clinically useful NMP, 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, NMPs would require that intention-driven neuronal activity be converted into a control signal that enables useful tasks. Here we show initial results for a tetraplegic human (MN) using a pilot NMP. Neuronal ensemble activity recorded through a 96-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 opened 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 NMPs 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



https://www.youtube.com/watch?v=Z3a5u6djGnE

TED Ideas worth spreading

Miguel Nicolelis: A monkey that controls a robot with its thoughts.

http://www.youtube.com/watch?v=CR_LBcZg_84

Neural Prosthetics: Krishna Shenoy at TEDxStanford

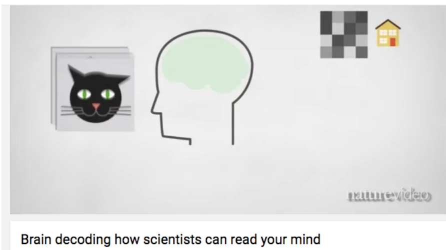
http://www.youtube.com/watch?v=ZuATvhlcUU4

Decoding in humans

http://www.youtube.com/watch?v=6FsH7RK1S2E

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

https://www.youtube.com/watch?v=1_yaQTR3KHI

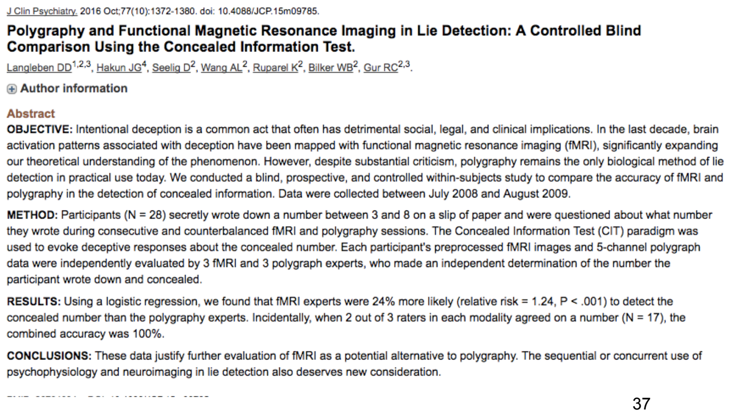


fMRI

http://videolectures.net/fmri06_mitchell_odmsp/

classification techniques : a machine learning problem

lie detection: fMRI now better than polygraphs?



J Clin Psychiatry. 2016 Oct;77(10):1372-1380. doi: 10.4088/JCP.15m09785.

Polygraphy and Functional Magnetic Resonance Imaging in Lie Detection: A Controlled Blind Comparison Using the Concealed Information Test.

Langleben DD[1,2,3], Hakun JG[4], Seelig D[2], Wang AL[2], Ruparel K[2], Bilker WB[2], Gur RC[2,3].

⊕ Author information

Abstract

OBJECTIVE: Intentional deception is a common act that often has detrimental social, legal, and clinical implications. In the last decade, brain activation patterns associated with deception have been mapped with functional magnetic resonance imaging (fMRI), significantly expanding our theoretical understanding of the phenomenon. However, despite substantial criticism, polygraphy remains the only biological method of lie detection in practical use today. We conducted a blind, prospective, and controlled within-subjects study to compare the accuracy of fMRI and polygraphy in the detection of concealed information. Data were collected between July 2008 and August 2009.

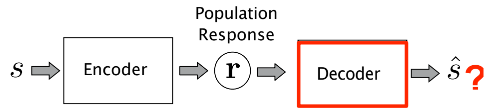
METHOD: Participants (N = 28) secretly wrote down a number between 3 and 8 on a slip of paper and were questioned about what number they wrote during consecutive and counterbalanced fMRI and polygraphy sessions. The Concealed Information Test (CIT) paradigm was used to evoke deceptive responses about the concealed number. Each participant's preprocessed fMRI images and 5-channel polygraph data were independently evaluated by 3 fMRI and 3 polygraph experts, who made an independent determination of the number the participant wrote down and concealed.

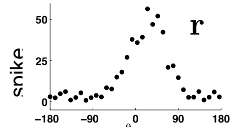
RESULTS: Using a logistic regression, we found that fMRI experts were 24% more likely (relative risk = 1.24, P < .001) to detect the concealed number than the polygraphy experts. Incidentally, when 2 out of 3 raters in each modality agreed on a number (N = 17), the combined accuracy was 100%.

CONCLUSIONS: These data justify further evaluation of fMRI as a potential alternative to polygraphy. The sequential or concurrent use of psychophysiology and neuroimaging in lie detection also deserves new consideration.

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.





preferred orientation