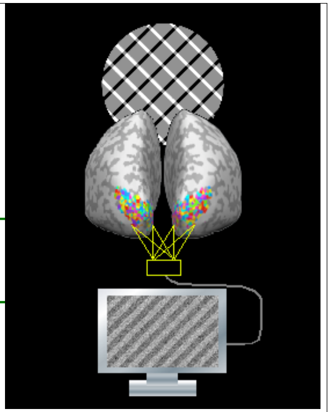
2. Decoding

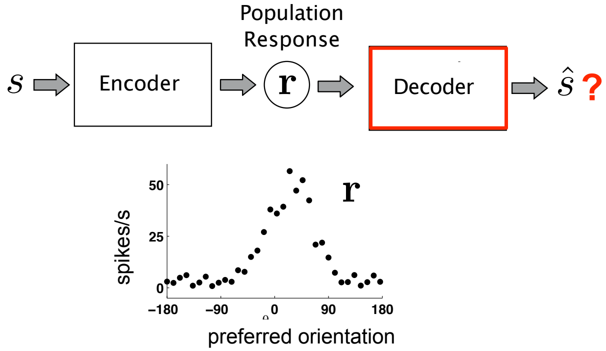
readings: Decoding D&A ch.3

Further readings:
Lebedev and Nicolelis, Brain-machine interfaces: past, present and future, TINS, 2006



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

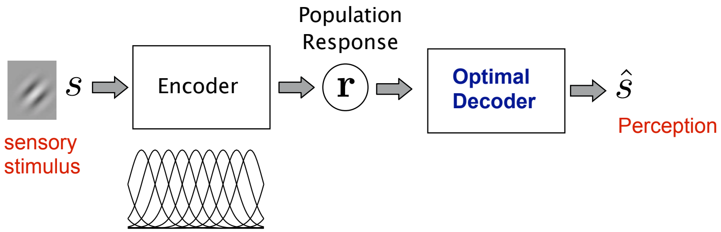
• Understanding the relationship between neural responses and performances of the animal:

• 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?

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

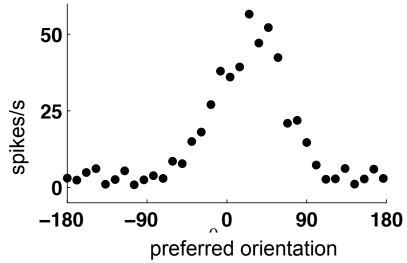
1. Optimal Decoding

- Maximum Likelihood:

  if we know P[**r**|s],

  choose the stimulus s that has maximal probability of having generated the observed response, **r**.

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



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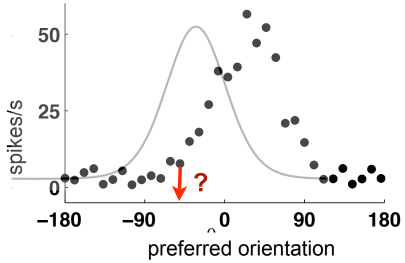


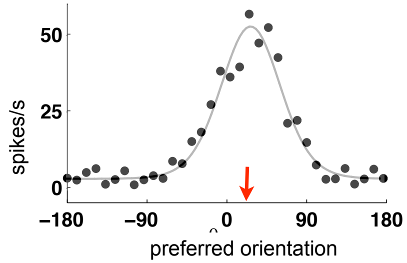
1. Optimal Decoding

- 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**.

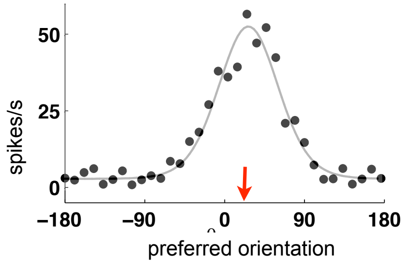
$$\hat{s} = \text{argmax}_s P(\mathbf{r}|s)$$



1. Optimal Decoding

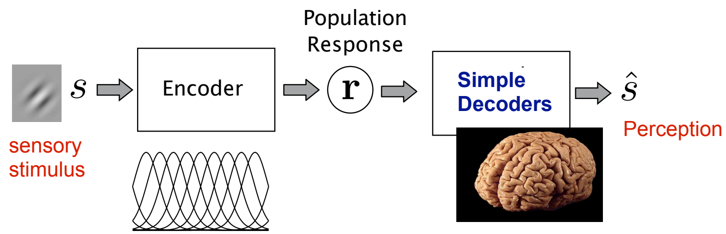
- Maximum a Posteriori:
  if we know P[**r**|s] and have a prior on s, P[s],
  choose the stimulus s that is most likely, given **r**.

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



Is the brain able to do ML or MAP estimation ?

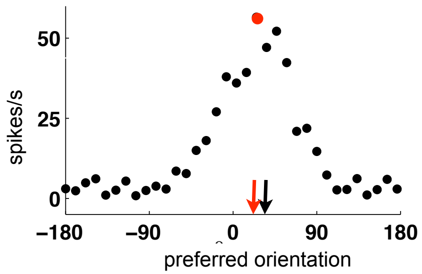
- Unknown
- It is argued that realistic architectures could perform ML
[Deneve, Latham, Pouget al 2001, Ma, Pouget et al 2006, Jazayeri and Movshon 2006]



2. Simpler Decoding Strategies

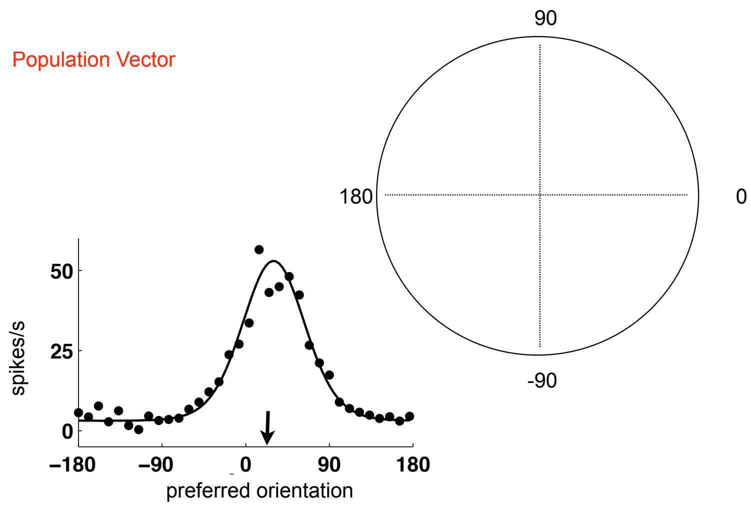
Winner Take All :

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



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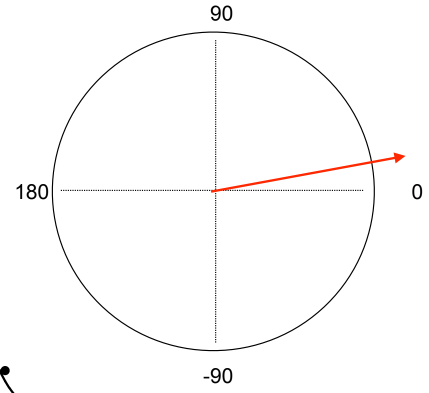

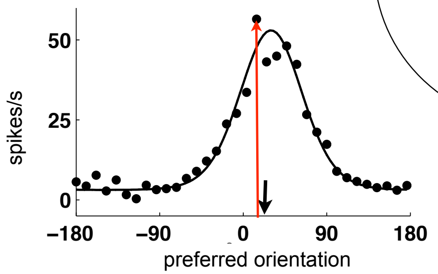

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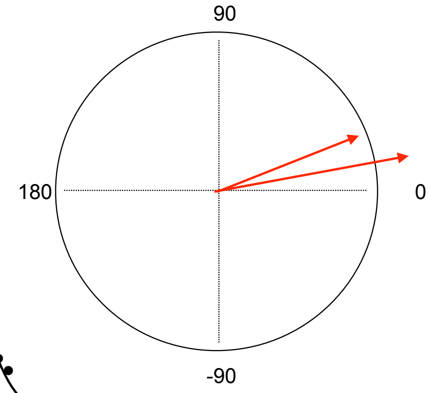

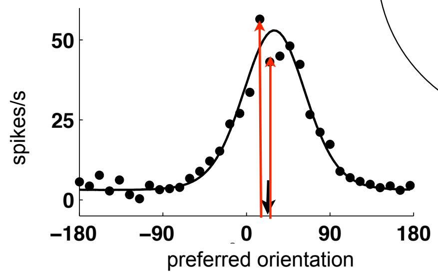

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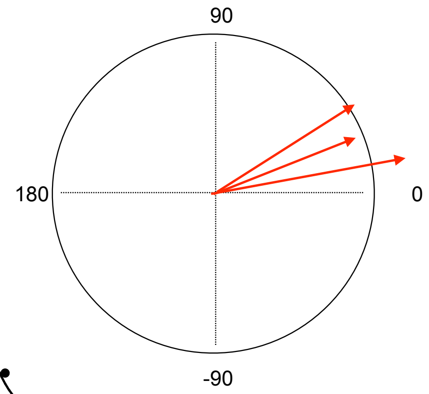

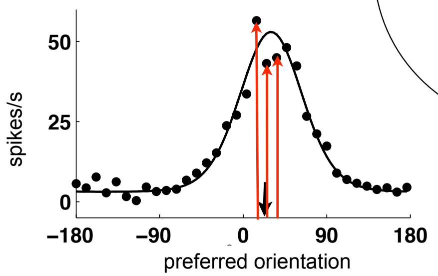

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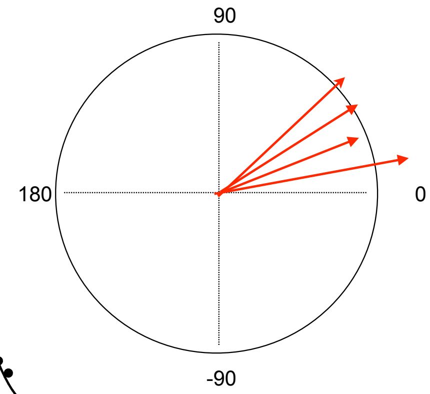

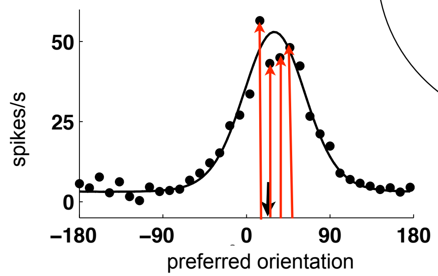

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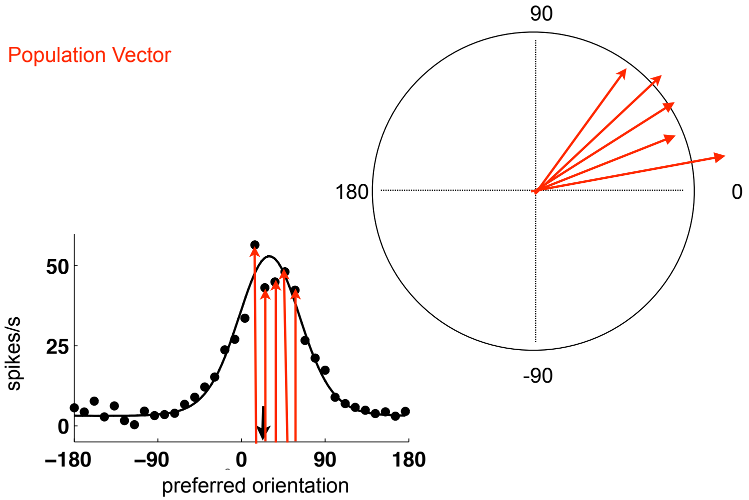

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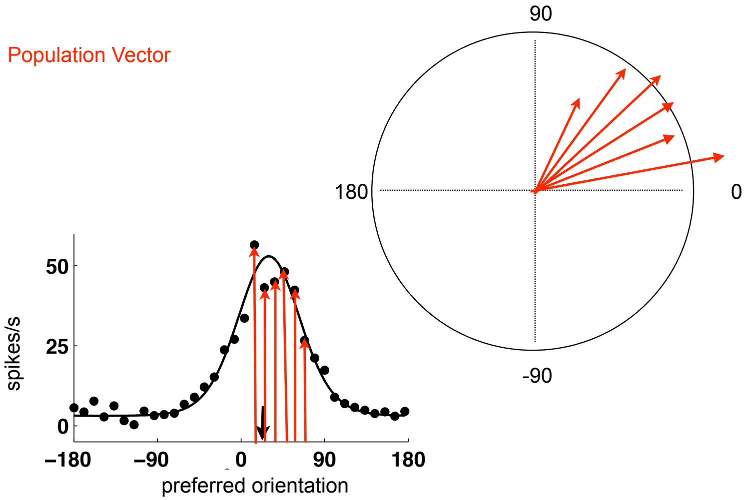

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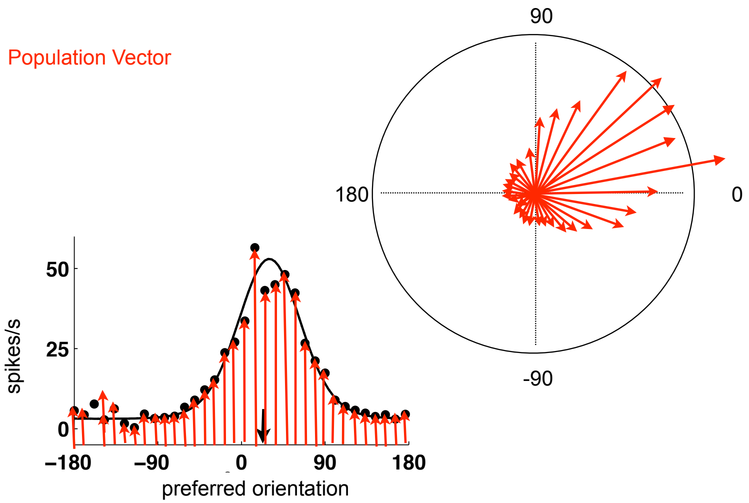

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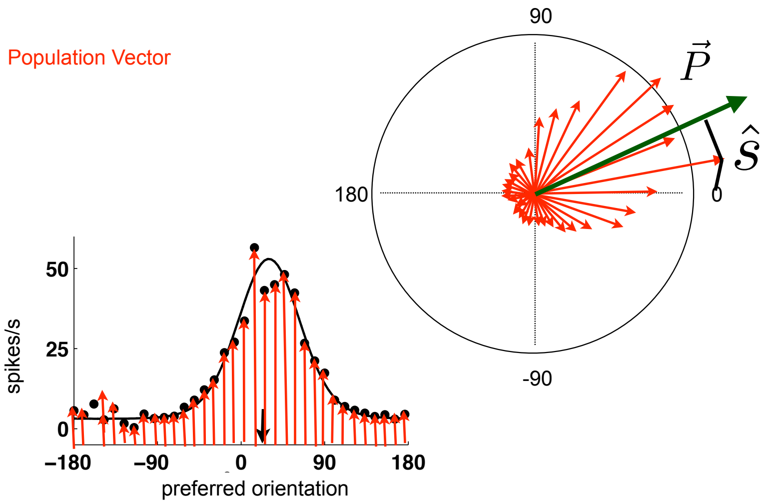


2. Simpler decoding strategies: Optimal Decoders within a class

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

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

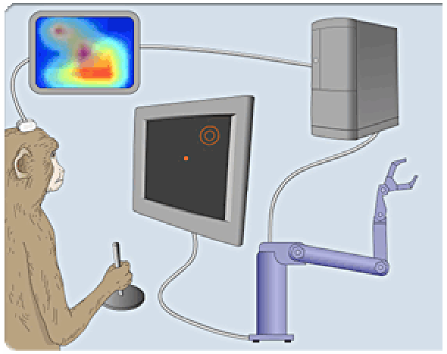
Use of simple decoding methods for prosthetics

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=sm2d0w87wQE

http://www.youtube.com/watch?v=7-cpcoIJbOU



Decoding in humans

Decoding from fMRI -- classification techniques

‘reading your mind’
http://www.youtube.com/watch?v=Cwda7YWK0WQ

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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