Encoding: Summary

- Spikes are the important signals in the brain.
- What is still debated is the code: number of spikes, exact spike timing, temporal relationship between neurons' activities?

- Experimentalists have characterized the activity of neurons all over the brain and in particular in sensory cortex, motor cortex etc .., mainly in terms of tuning curves and response curves. A variety of well-specialized areas. Detailed wiring and mechanisms at the origins of these responses are largely unknown.

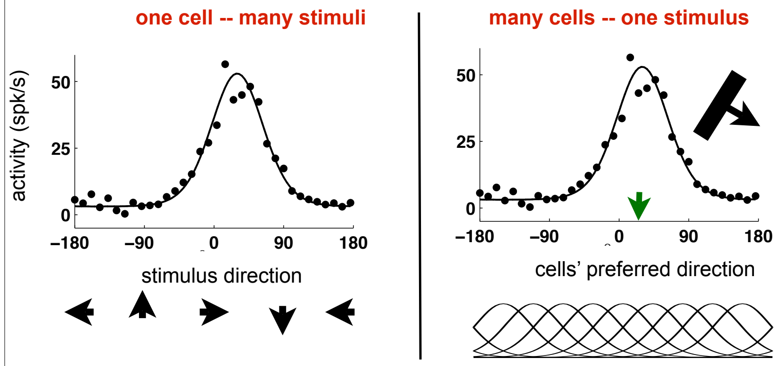
- Other techniques to predict activity (when stimulus is changing) : STA, reverse correlation.

- The large variability (in ISI, number of spikes) is often well described by a Poisson or Gaussian model.

Single cell tuning curves vs population response

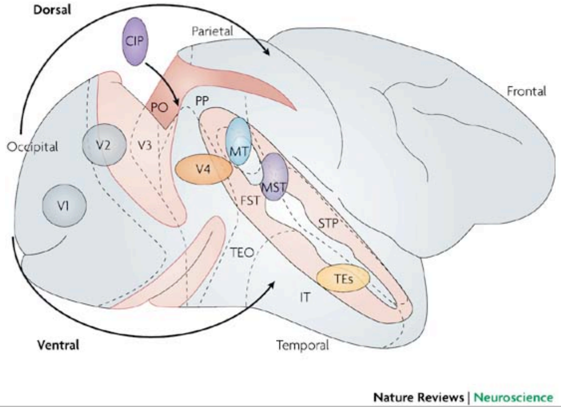
Single cell tuning curve: change stimulus, record spike count for every stimulus

Population response: keep stimulus fixed, record spike count of every neuron in the population

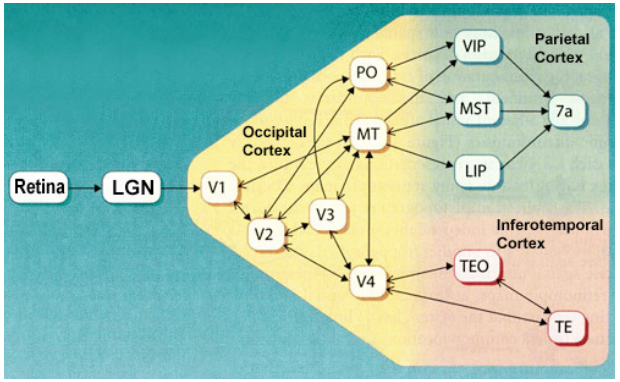


Overview of the visual cortex

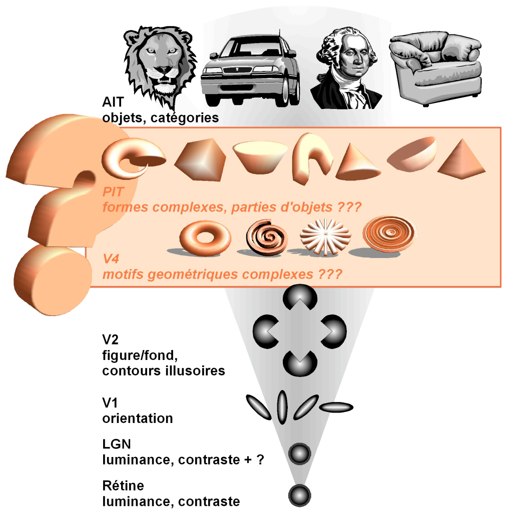
Two streams:
- **Ventral** 'What': V1,V2, V4, IT, form recognition and object representation
- **Dorsal** 'Where': V1,V2, MT, MST, LIP, VIP, 7a: motion, location, control of eyes and arms



Overview of the visual cortex



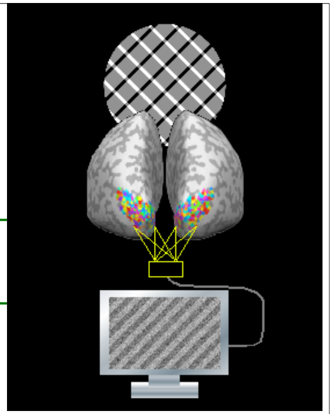
Ventral pathway



Dorsal pathway

- **MT: MOTION.** stimulus of choice: random dot patterns
http://monkeybiz.stanford.edu/movies/30coh_circle.qt
- **MST**: linear, radial, circular motion.
- **LIP**: spatial position in head-centered coordinates. spatial attention, spatial representation. saliency map -- used by oculomotor system (saccade). spatial memory trace and anticipation of response before saccade.
- **VIP**: spatial position in head-centered coordinates, multisensory responses. speed, motion.
- **7a:** large receptive fields, encode both visual input and eye position.

2. Decoding

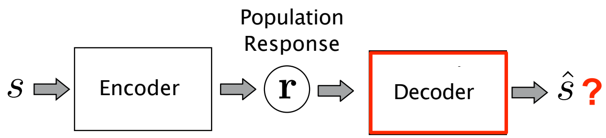


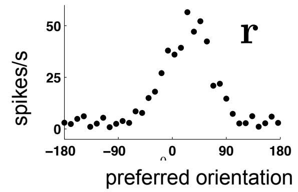
readings: Decoding D&A ch.3

Further readings:
Lebedev and NicolelisBrain-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?:

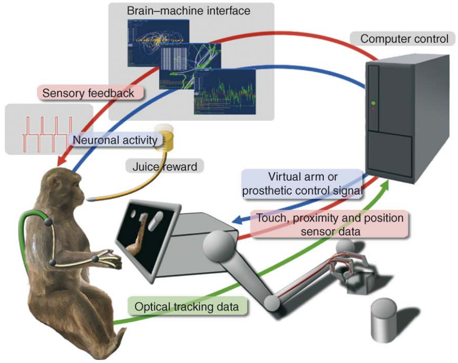
1 - Point of view of the experimentalist or Neuro-Engineering. Seeking the most effective method (e.g. prosthetics) to read out the code.

- ✤ 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: for Neuro-Prosthetics (a.k.a. Brain-machine interfaces)



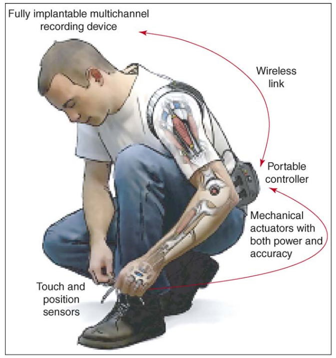


Figure 3. How a fully-implantable BMI could restore limb mobility in paralyzed subjects or amputees. Although the details of this system have to be worked out through future research, it is clear that the BMI for human clinical applications should be encased in the patient's body as much as possible. Wireless telemetry offers a viable solution for this purpose. The prosthesis not only should have the functionality of the human arm in terms of power and accuracy of the actuators, but also should be equipped with the sensors of touch and position from which signals can be transmitted back to the subject's brain.

Lebedev & Nicolelis, TINS, 2005

Decoding: to understand the link between physiology and psychophysics

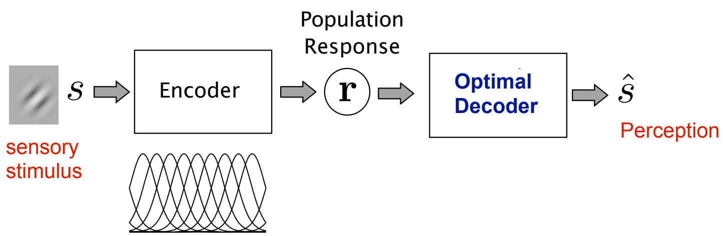
• Detection Task: e.g. can you see the target ?
Measure Detection threshold.

• 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?

Mapping between visual responses, eg in V1, and response of subject?

1. Optimal Decoding



✤ optimality criterion?

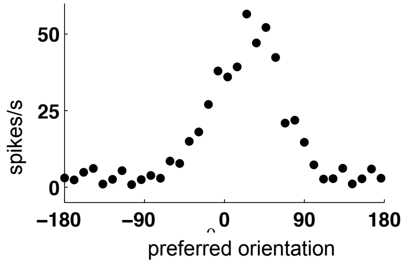
$$MSE(s) =< (\hat{s} - s)^2 >$$

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**.

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



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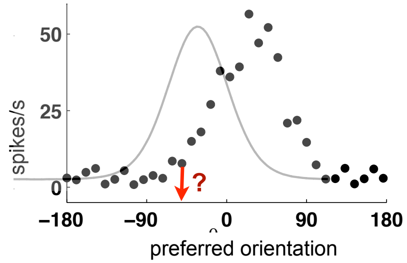

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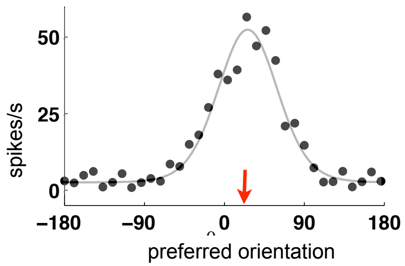
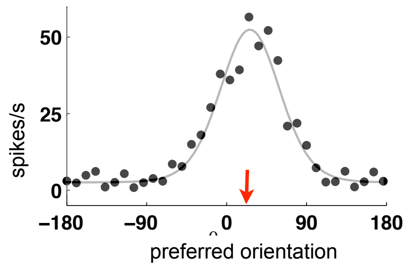


1. Optimal Decoding

- 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**.

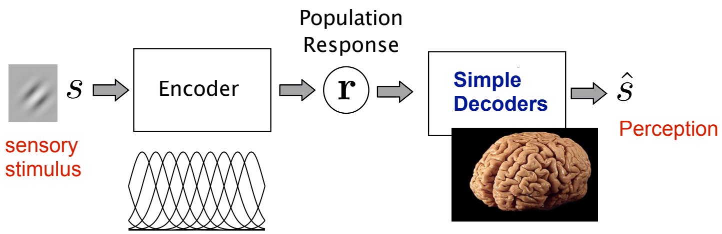
  $$\hat{s} = \mathrm{argmax}_s P(s|\mathbf{r}) = \mathrm{argmax}_s P[\mathbf{r}|s]P[s]$$



Is the brain able to do ML or MAP estimation ?

- Unknown
- It is argued that realistic architectures could perform ML

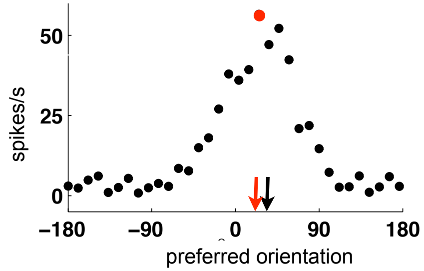
[Deneve, Latham, Pouget al 2001, Ma, Pouget et al 2006, Jazayeri and Movshon 2006]



2. Simpler Decoding Strategies

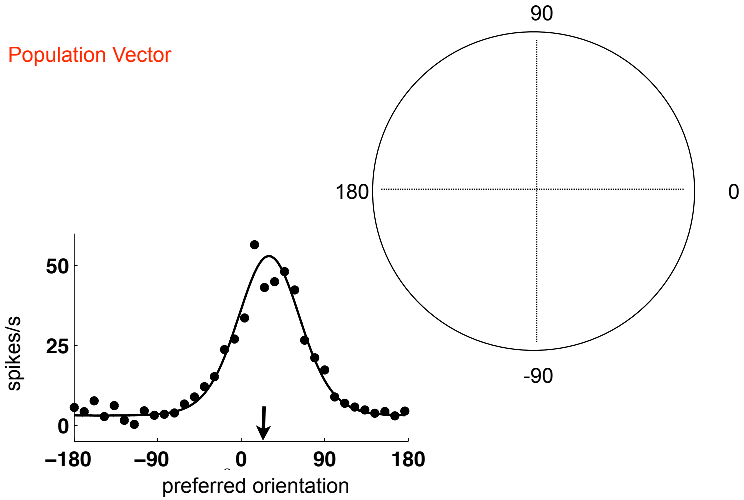
Winner Take All :

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



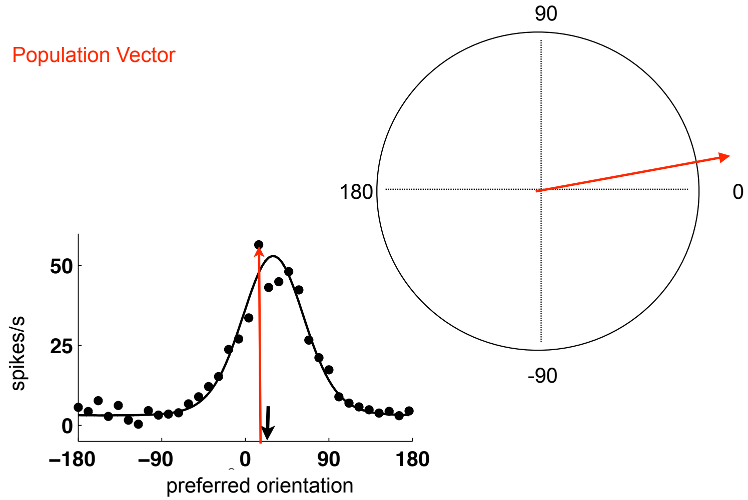
2. Simpler Decoding Strategies

Population Vector



2. Simpler Decoding Strategies

Population Vector



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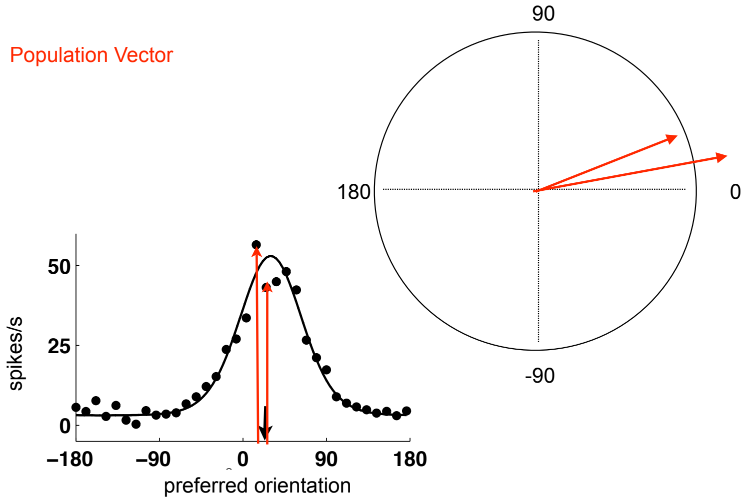

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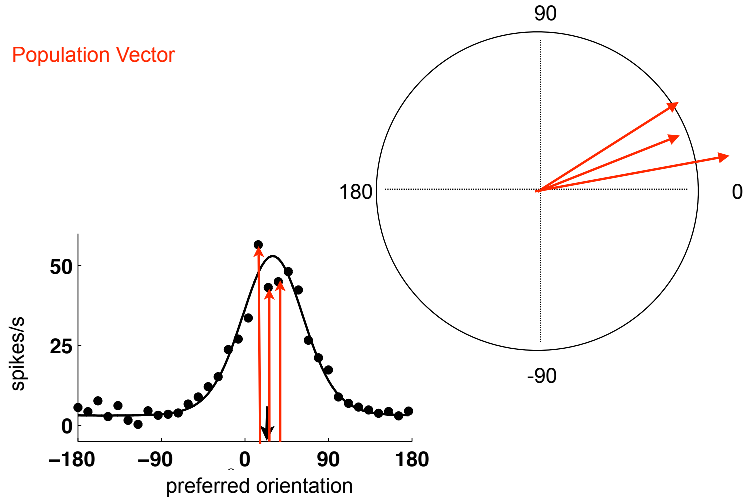

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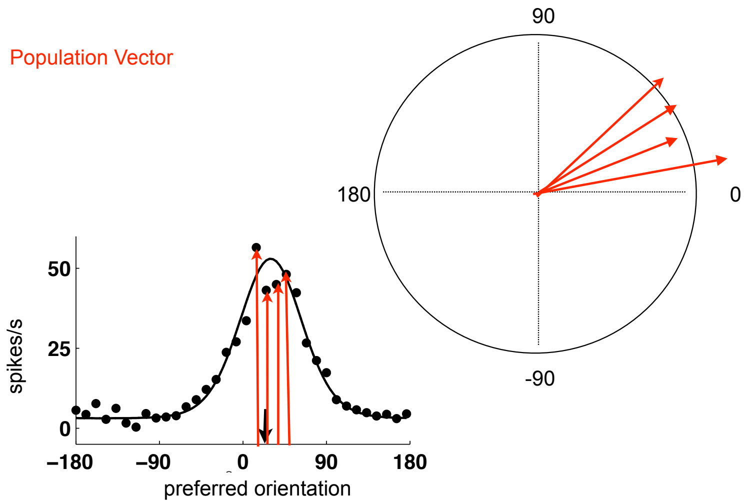

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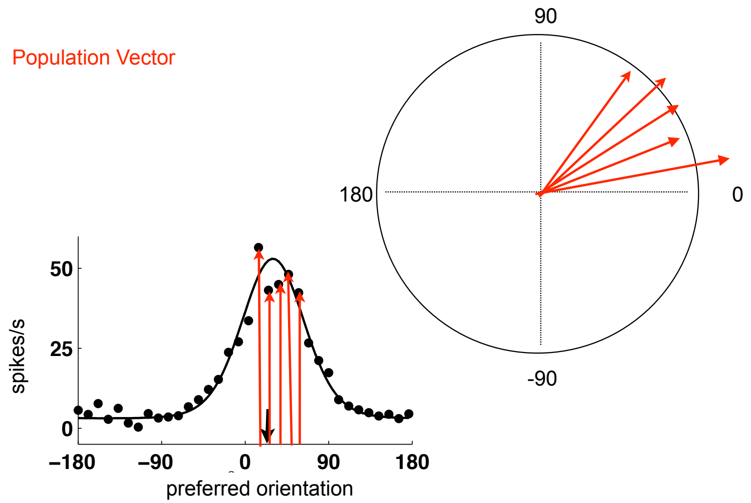

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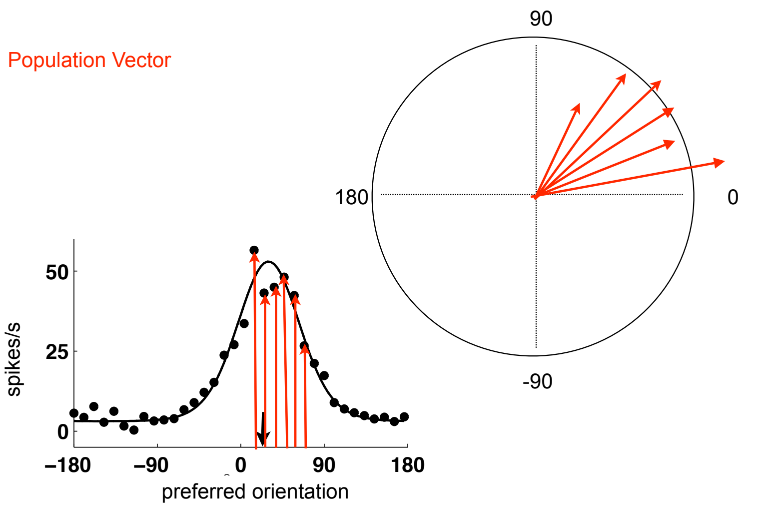

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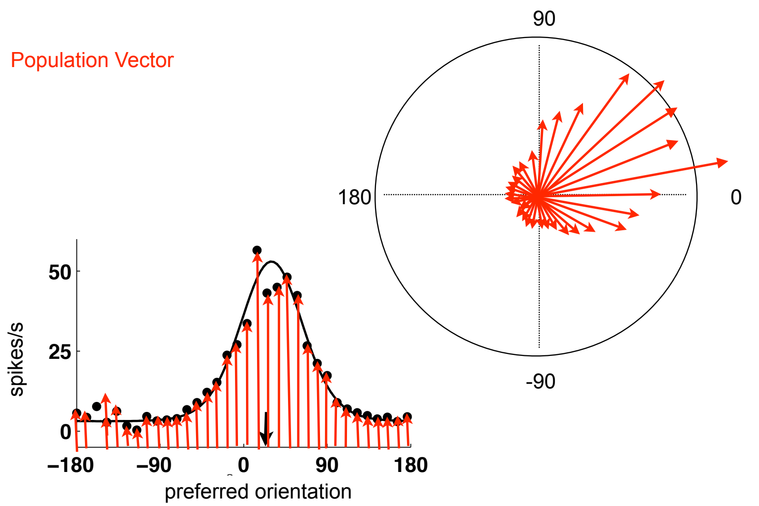

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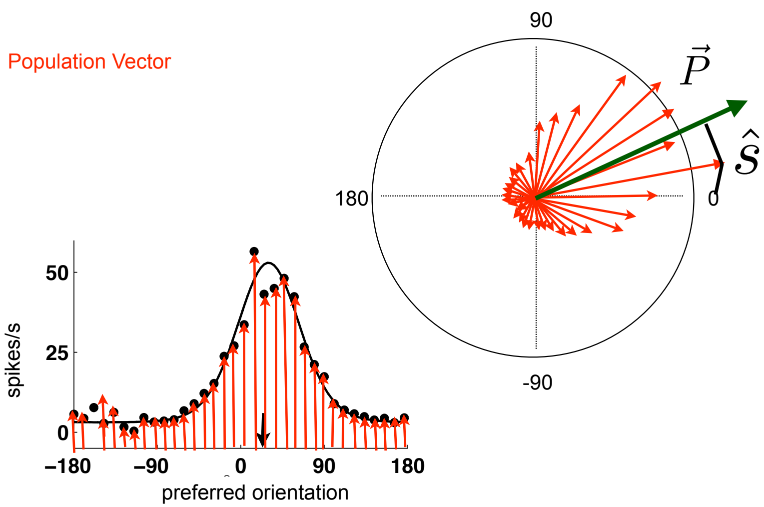

3. Optimal Decoders within a class

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]