MSc in Artificial Intelligence and Robotics
MSc in Control Engineering
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Neuroengineering

Laura Astolfi, PhD
Department of Computer, Control and Management Engineering Antonio Ruberti
Sapienza University
E-mail: laura.astolfi@uniroma1.it

It is strictly related to the neural encoding

6- NEURAL DECODING

Learning objectives of the lesson

1. Understand the meaning and need for the neural decoding
2. Given a distribution of firing rates, illustrate how to perform a classification-based decoding
3. Given a Receiving Operator Characteristic curve, interpret its meaning in terms of accuracy, depending on:

   used to summarize the accuracy of the classification that we can achieve for a given neuron and in particular we use this curve to have info on the experimental conditions and classification choice

   a. The experimental conditions
   b. The classification choices
4. Describe what the Area Under the Curve means and the values it can assume

Neural decoding

this is the reverse operation of the neural encoding

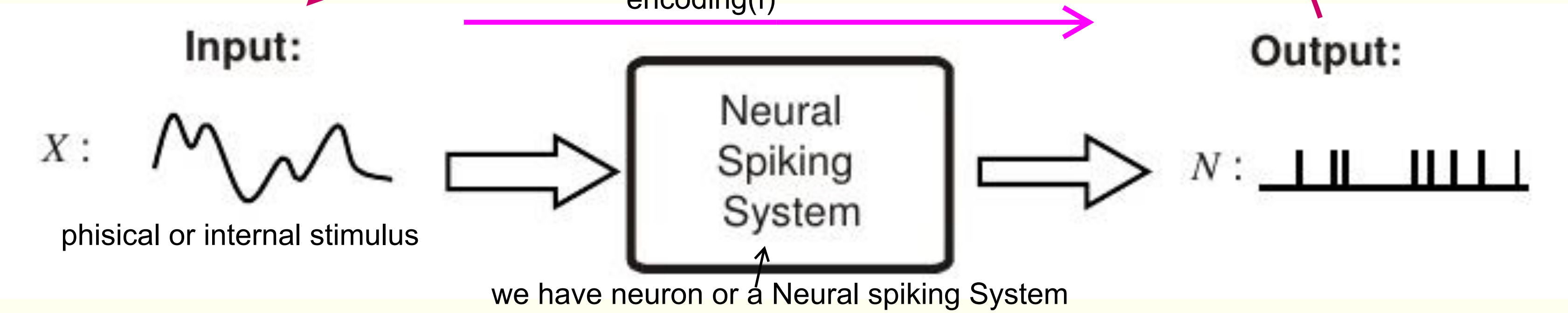
<u>From the neural response to the stimulus that induced it</u>

Stimulus = f^{-1}(neural response)

- *Aim:* to identify the stimulus (or its properties) that induced the neuronal spike train response

decoding(f^-1)

encoding(f)



phisical or internal stimulus

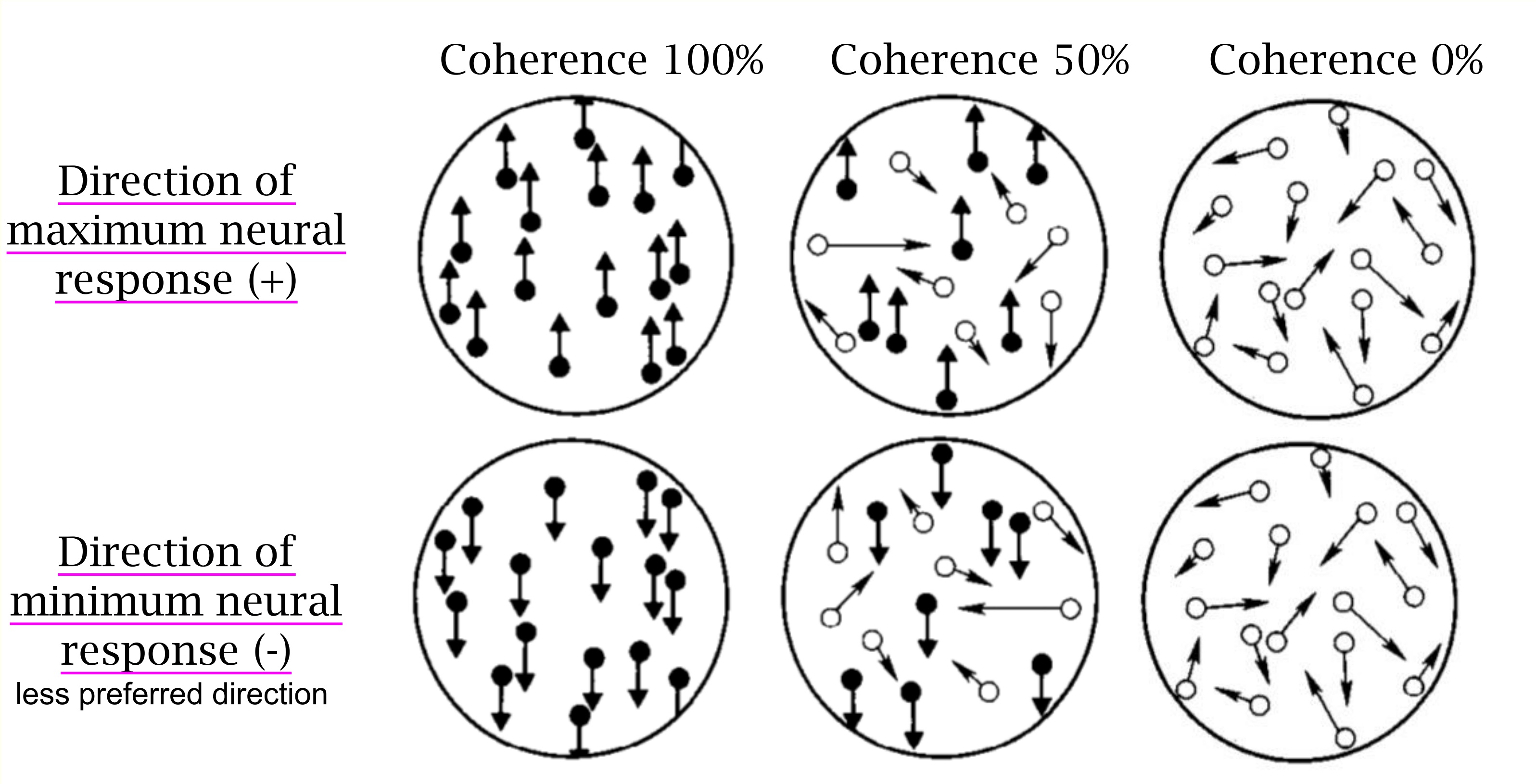
we have neuron or a Neural spiking System because the neurons are organized in groups

Encoding and decoding as conditional probabilities

- Encoding consists of determining $P[r/s]$, i.e. the probability of a response with firing rate r given a stimulus with property s
- Decoding consists of determining $P[s/r]$, i.e. the probability of a stimulus with property s, given that the neural response has firing rate r
- Determining what is going on in the real world from neuronal spiking patterns (neural decoding) is the natural aim of the nervous system → we need this to interface an external device with the brain

this experiment is a little complicated. It is based on visual discrimination task where t is a task in which the subject has to recognize or distinguish between 2 different stimuli.

Example of decoding – visual discrimination task

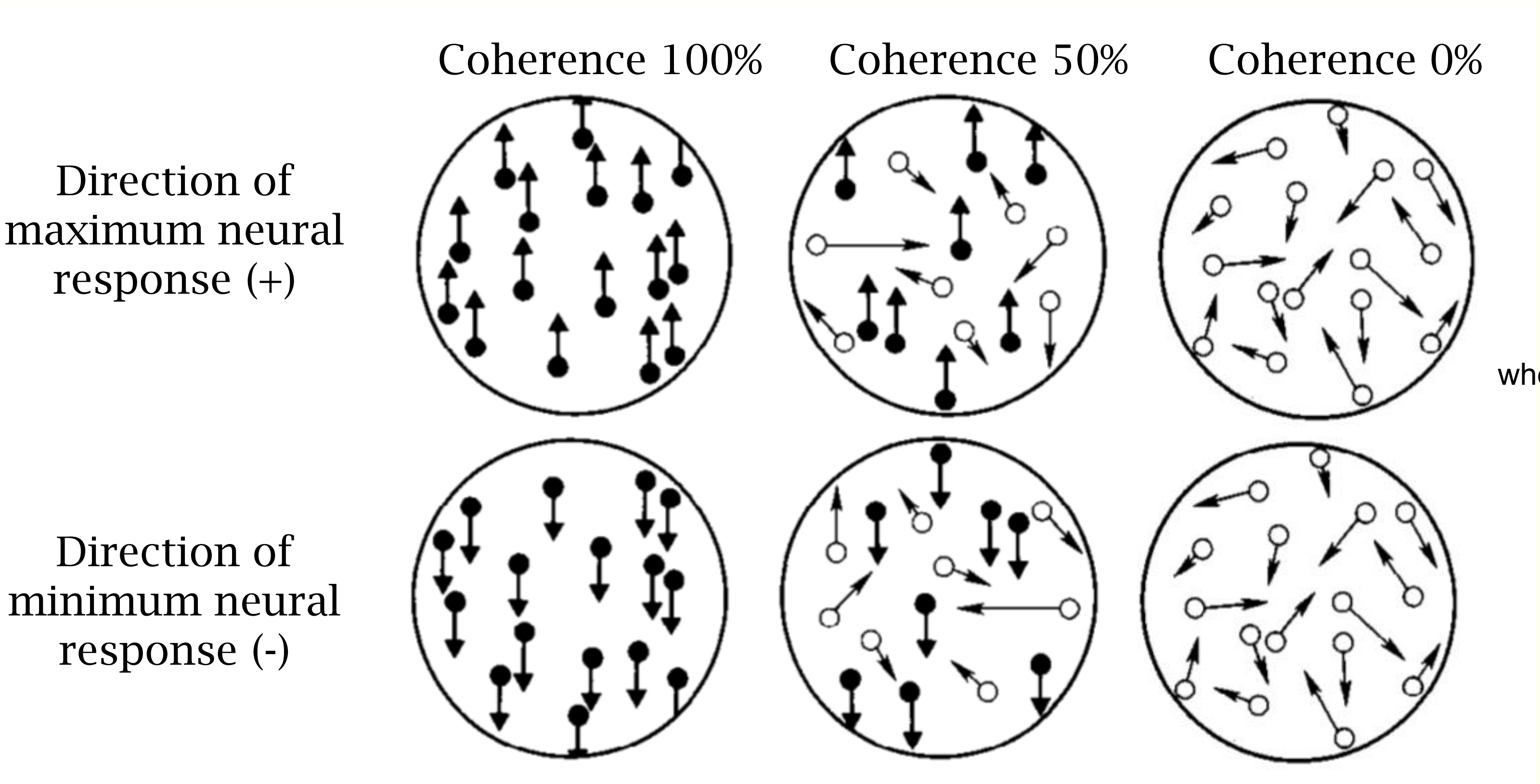


1° Factor: direction

Levels: [+, -]

- Subject trained to recognize the motion direction of dots on the screen
- Two possible directions: one corresponding to the maximum neural response (+), the other corresponding to a minimum neural response (-)

Example of decoding – visual discrimination task



2° Factor: coherence

Levels: [0%, ..., 100%]

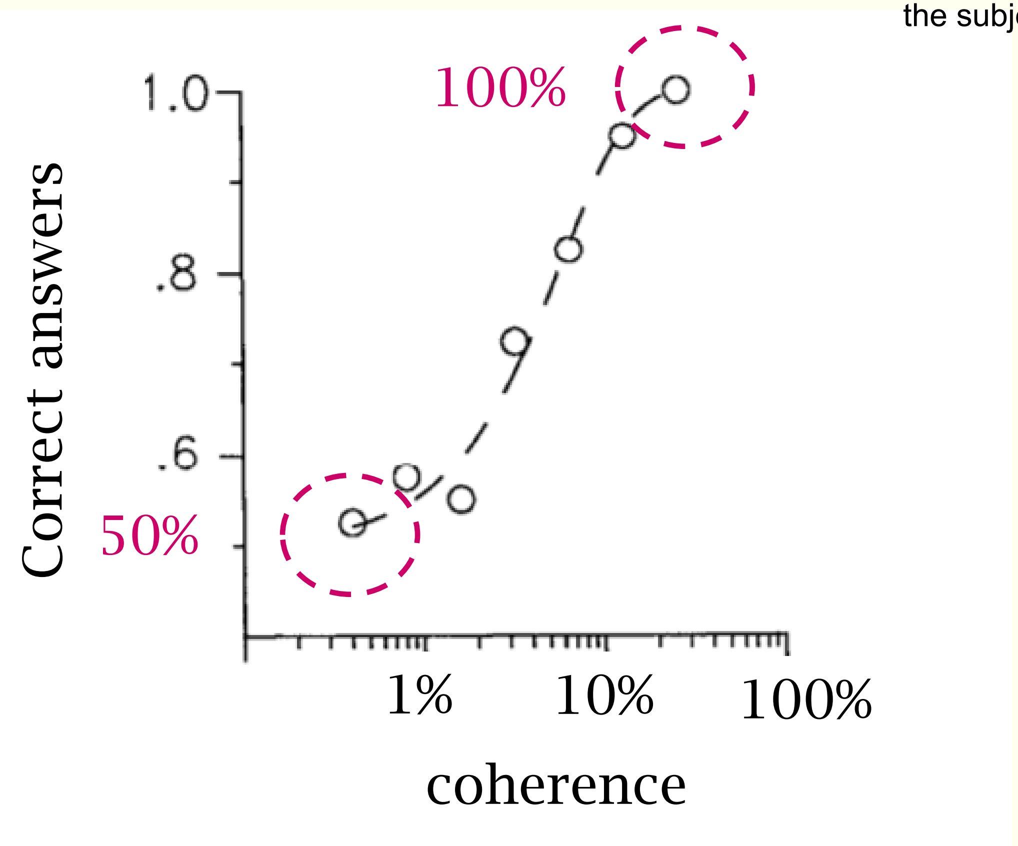
when the coherence is zero there are no differences

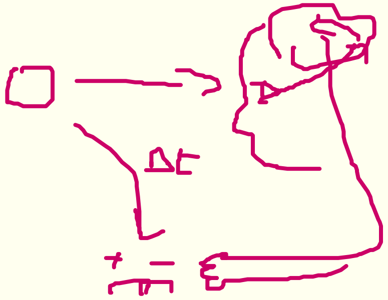
- Coherence level: percentage of dots moving in the same direction
- Changing the coherence level means controlling noise
- Zero coherence → dots move randomly

Behavioural data

it collects the responses collected by the subject not the neuron

the subject has to answer if the stimulus is + or -(directions)





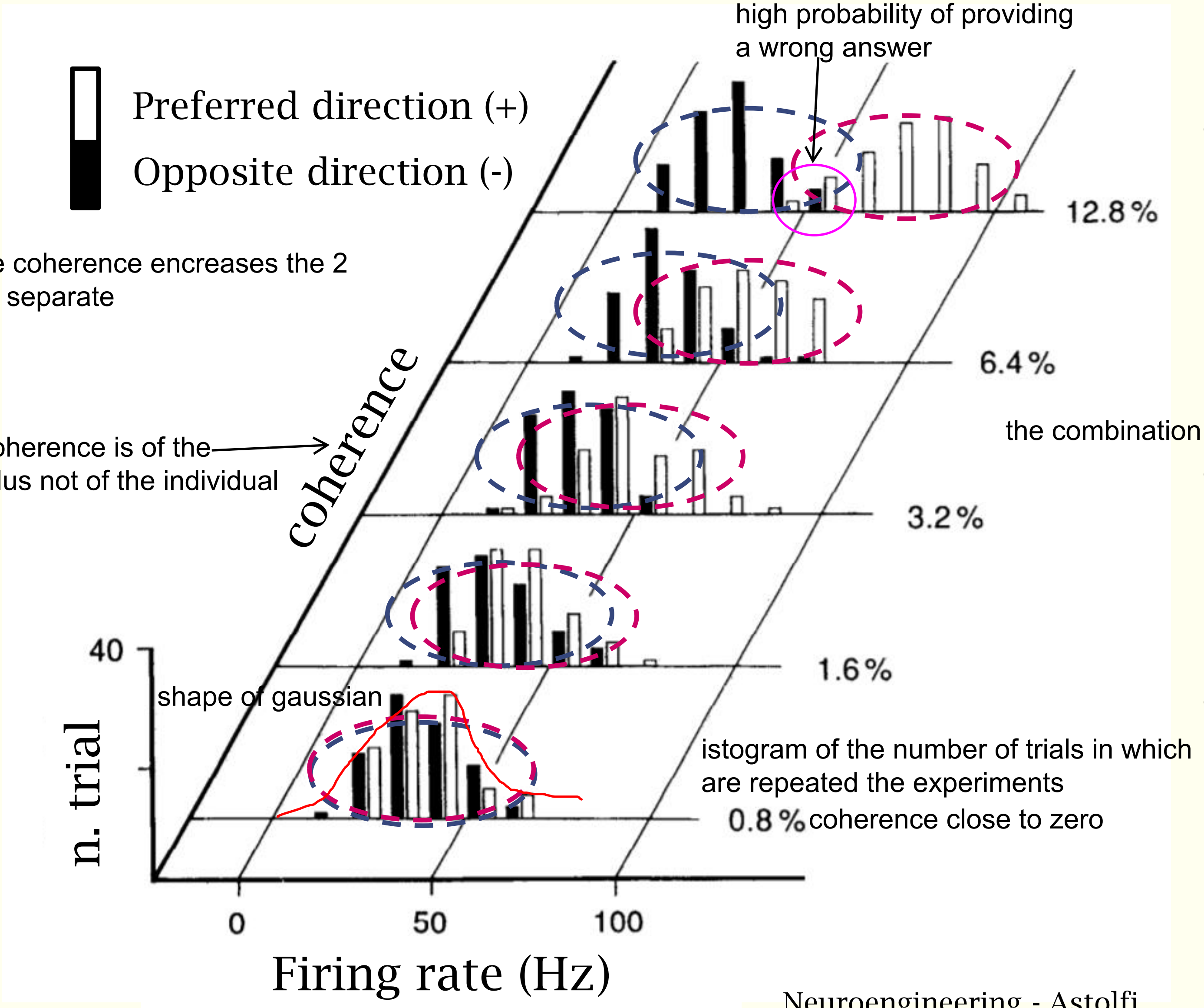
if the stimulus is noisy the correct answer could not always occur

if you move from 1% to 10% of coherence we don't have significant decreases of the perfomances. It means that even when the percentage of coherence dots is very low, our brain is perfectly able to tell the direction

Percentage of correct recognition of the motion direction (between + and -) as a function of coherence

In order to be able to decode the neuronal output we need to know how the neurons work.

Distribution of the firing rate (r)



- Combination of the two factors:
  - movement direction (+, -)
  - coherence level with many levels between 0 and 100%

the combination of these 2 factors produces the stimulus which is given to the subject

- Hystogram built on 60 trials for each combination of the two factors
- Two Gaussians $P[r/s]$ with the same variance σ_r^2 and means $\langle r \rangle_+$ and $\langle r \rangle_-$

Threshold classification

index of how good we are in distinguish positive and negative direction

Discriminability: $d' = \dfrac{\langle r\rangle_{+} - \langle r\rangle_{-}}{\sigma_r}$

Given a threshold z between the two distributions:

If $r \geq z$ the inferred direction is (+)

dedotta

firing rate

If r $< z$ the inferred direction is (-)

- The probability to discriminate between the two directions (classification performance) is increased with increased coherence (because the two distributions are more separate)
- It depends on the choice of z

Evaluation of the classification accuracy

2 conditions

$P[r \geq z|+] = \beta(z)$ (true positive)

$P[r \geq z|-] = \alpha(z)$ (false positive)

correct direction

$P[r < z|+] = 1\text{-}\beta(z)$ (false negative)

$P[r < z|-] = 1\text{-}\alpha(z)$ (true negative)

	probability	
stimulus	correct	incorrect
+	β	$1-\beta$
−	$1-\alpha$	α

The ideal z is such that:

$$\begin{cases} \beta(z)=1 \\ \alpha(z)=0 \end{cases}$$

it provides a way of evaluating how test performace depends on the choice of the threshold z

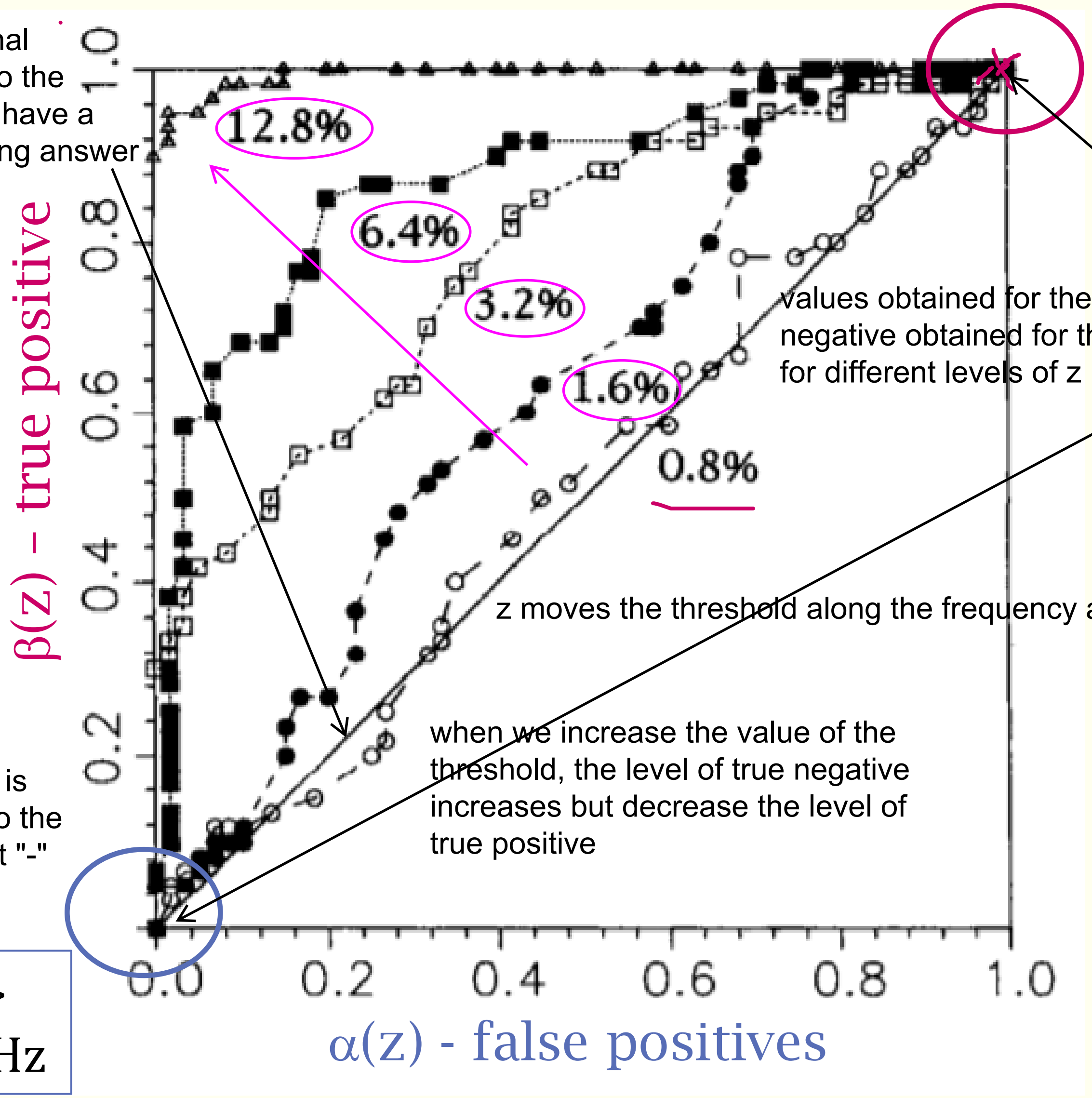
ROC (Receiver Operating Characteristic) curves

binary discrimination is very useful

z=0

the firing rate is always > z, so the decoding procedure gives the answer "+"

on the diagonal alpha=beta so the probability to have a right and wrong answer are the same



values obtained for the false positive and negative obtained for the same dataset for different levels of z

z moves the threshold along the frequency axis

when we increase the value of the threshold, the level of true negative increases but decrease the level of true positive

the firing rate is always < z, so the test will report "-"

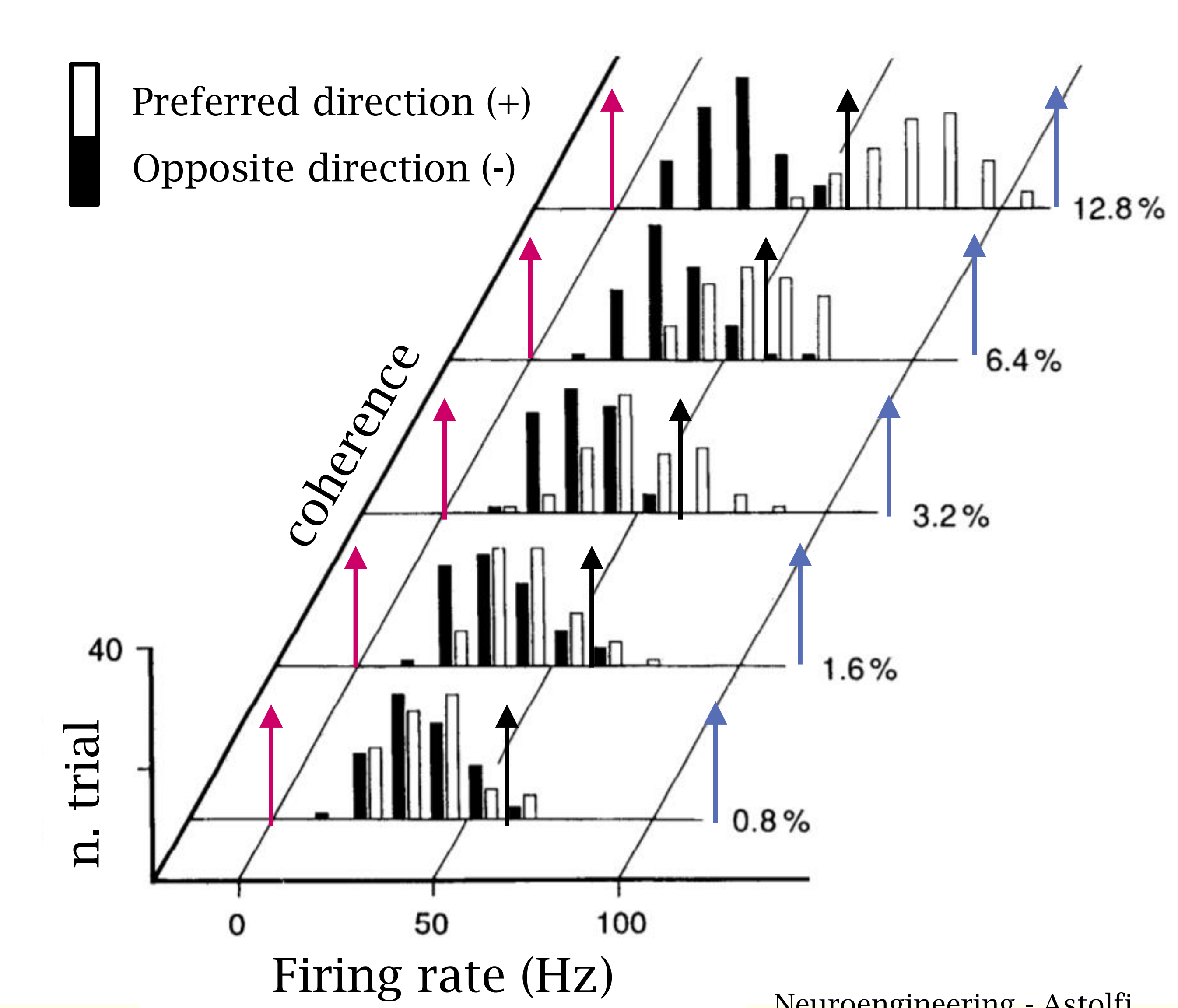
z > 100 Hz

x:size of the test for this value of z

y: power of the value of z

- A **dot** for each **z: [α(z),β(z)]**
  - $z = 0 \rightarrow \alpha(z)=1,\ \beta(z)=1$
  - $z > 100\ Hz \rightarrow \alpha(z)=0,\ \beta(z)=0$
- A **curve** for each **coherence level**
- **Area Under the Curve (AUC)**
  - % of correct classifications
  - between 0.5 (chance level) and 1

Effects of the choice of z



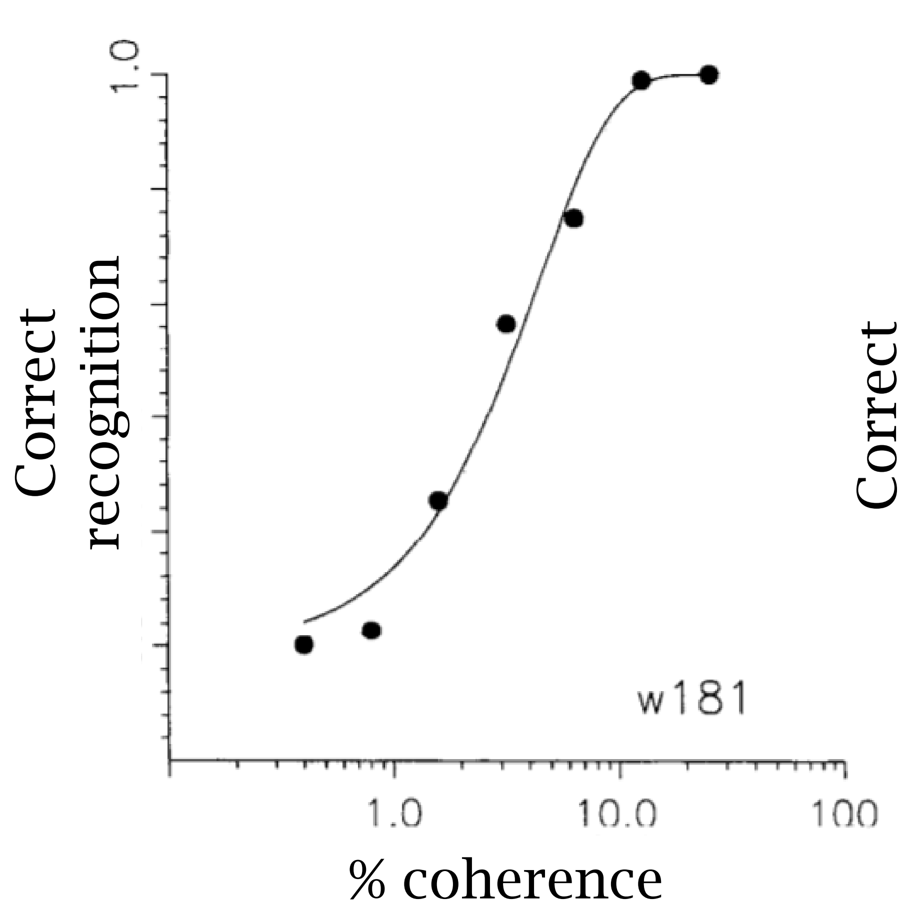
z=0 starting point

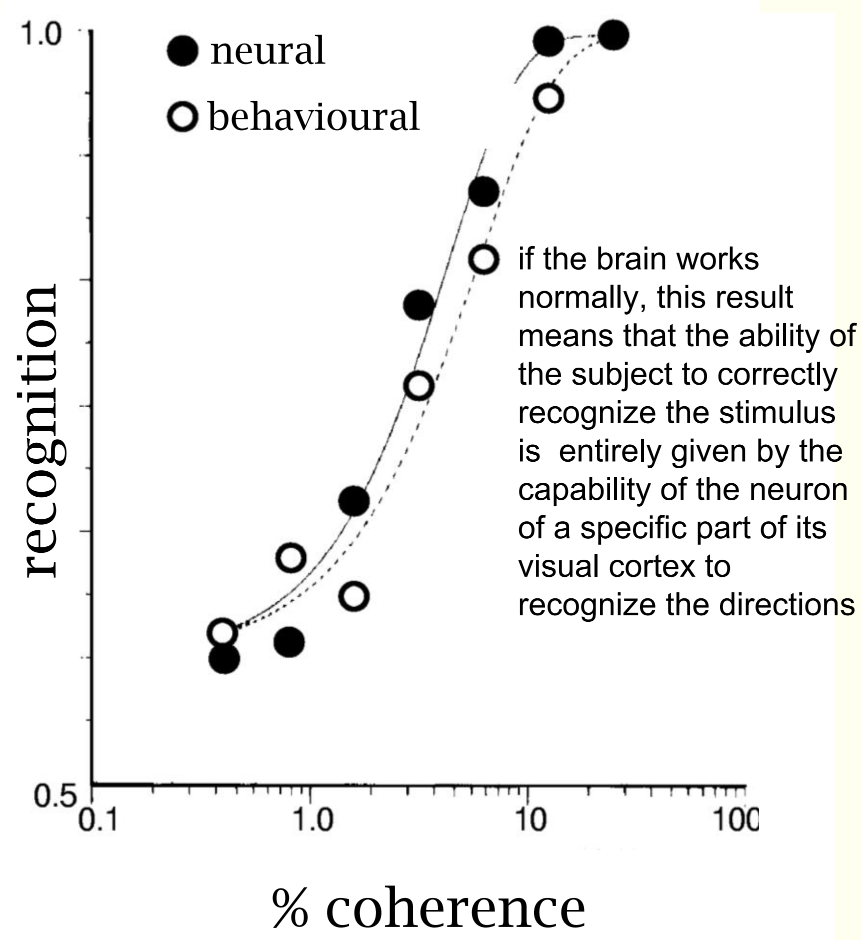
z>100 Hz

0<z<100 Hz

of the classifier

Subject and classification performances

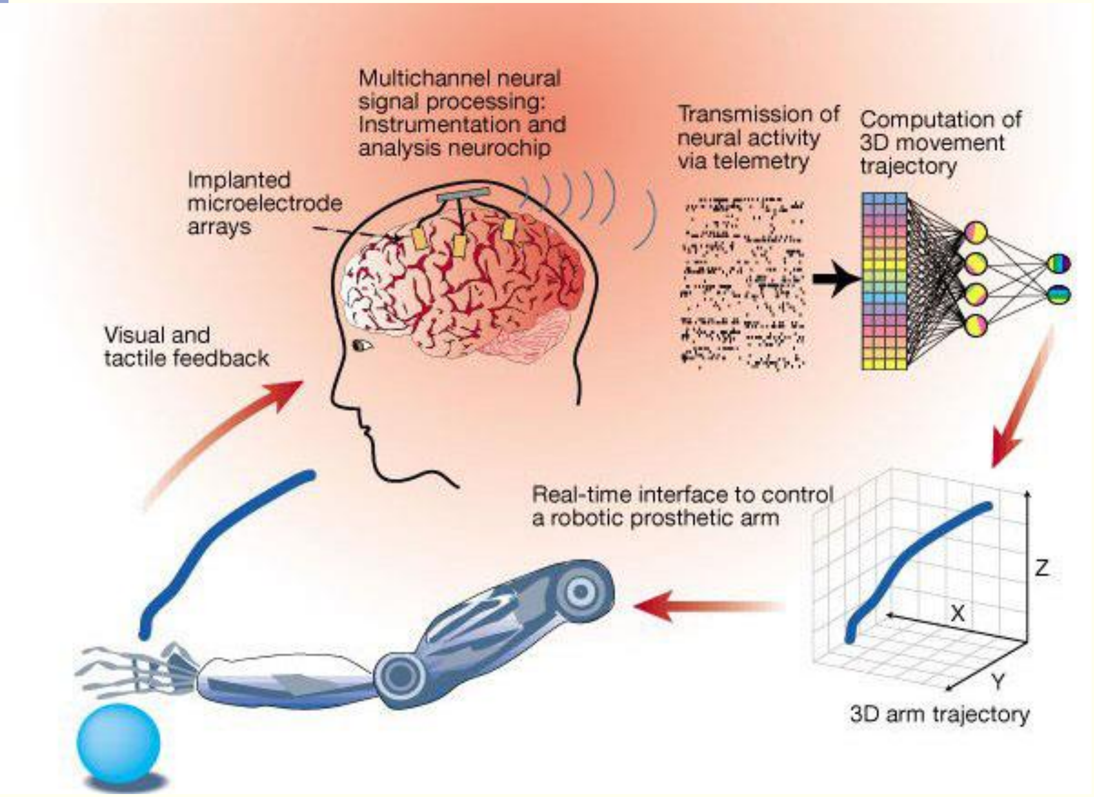




For this family of neurons, we can hypothesize that a threshold mechanism can correctly describe the neuronal information processing

The classifier performances are close to the subject performances

Applications of neural decoding



Brain Computer Interfaces

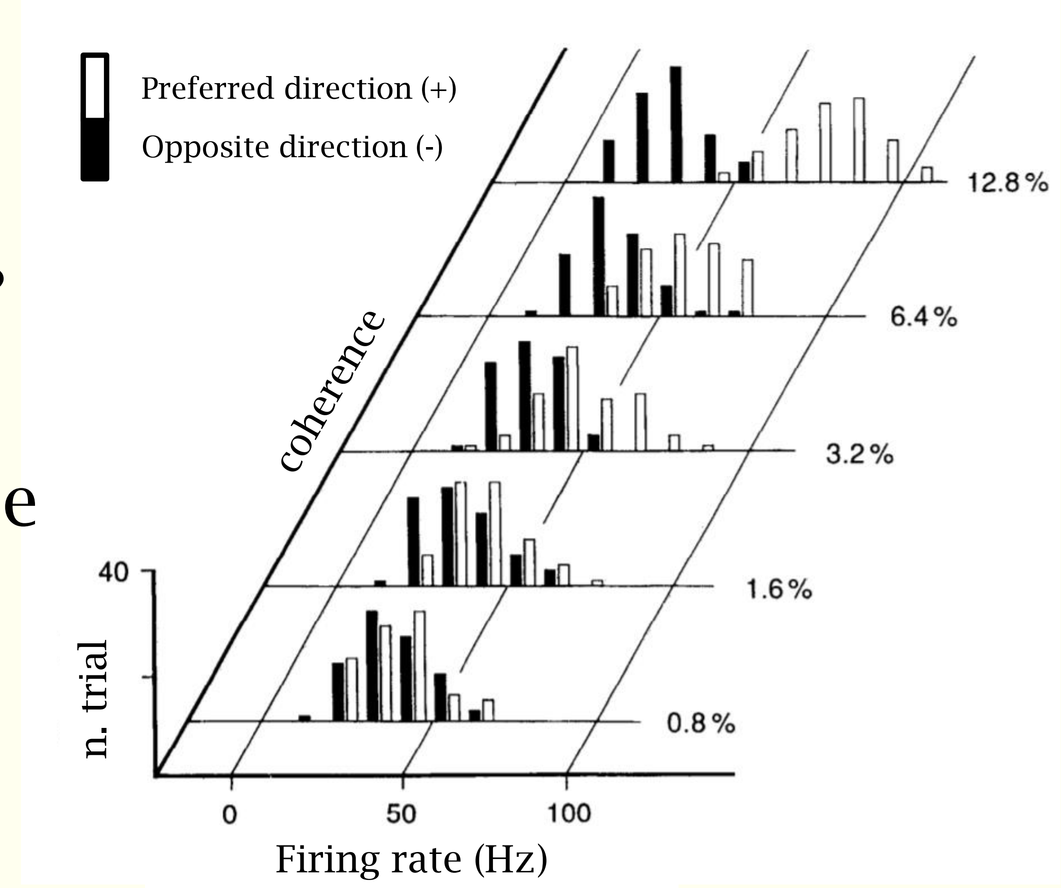
Neuroprosthesis

References

- Dayan & Abbott:
  - Chapter 3.1 (Encoding and decoding)
  - Chapter 3.2 (Discrimination; ROC curves; ROC Analysis of Motion Discrimination)

Self-evaluation

1. Explain why we perform the neural decoding (two reasons)
2. Given the distribution of firing rates in the figure:
   A. Is the discriminability *d'* higher when the coherence=1.6 or =6.4?
   B. Is there any optimal value of z that can be used for all coherence levels?
   C. Which of the two distributions (r_+ or r_-) is affected by the coherence level?



Self-evaluation

3. Given the ROC curves in the figure, indicate if the following statements are **true or false**:
   A. The related AUC is between [0,1]
   B. The classification performances do not depend on z
   C. The classification performances depend on the experimental conditions
   D. The ideal curve is the one closer to the diagonal