Brain Computer Interface for Communication and Control

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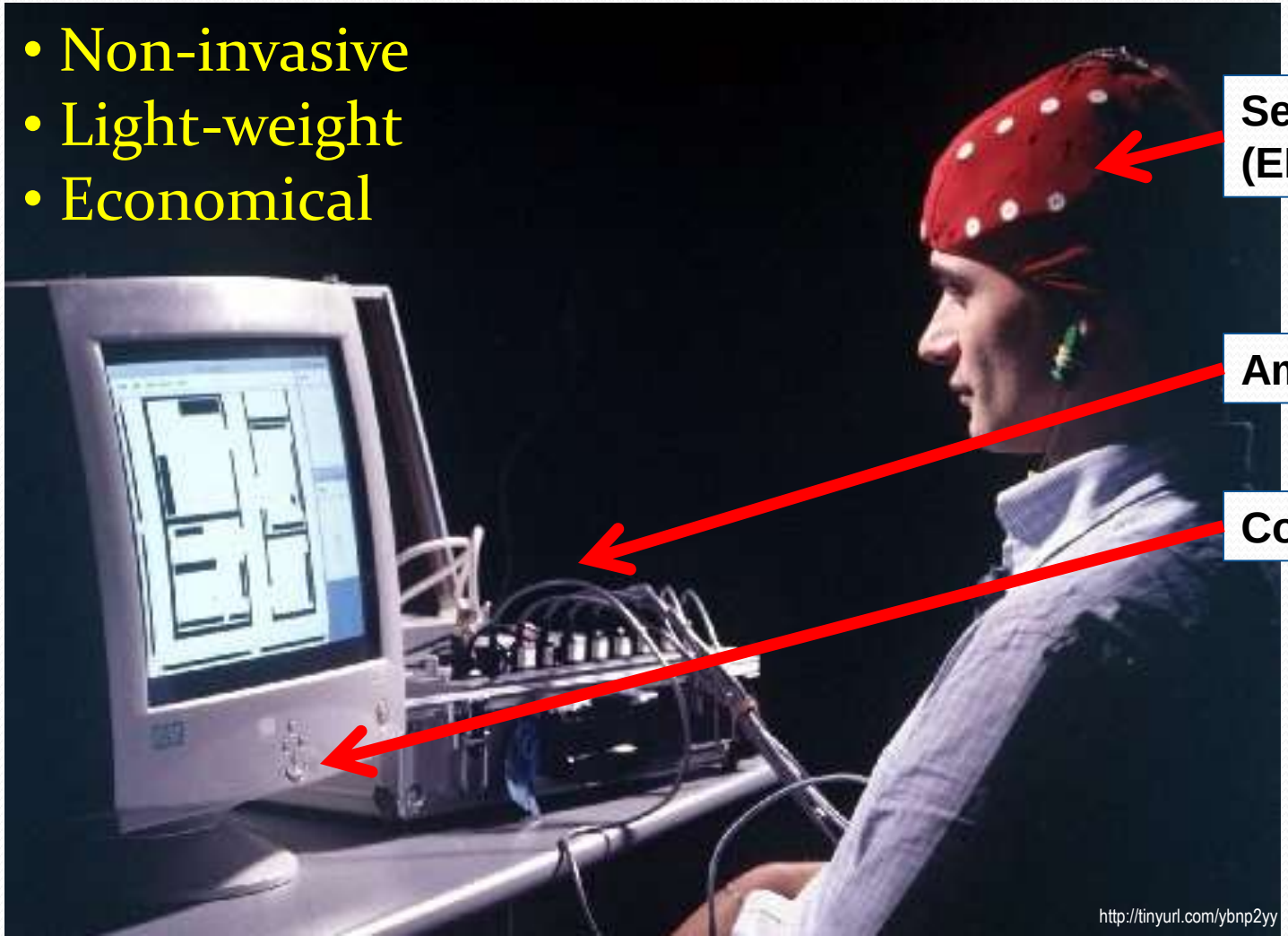
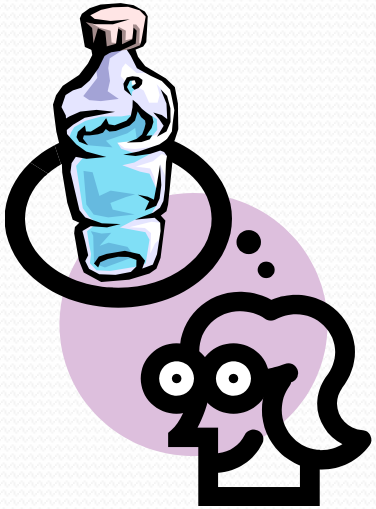
What is BCI and what can it do?

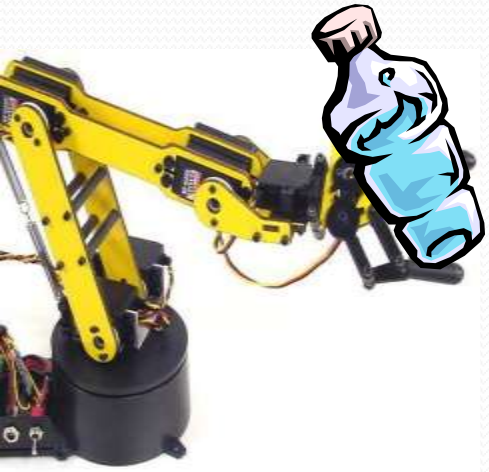
- Brain computer interface (BCI) is a direct communication pathway between human brain and a computer device.
- Often used for restoring lost bodily functions
  - Amyotrophic lateral sclerosis (ALS) patients
  - Spinal cord injury (SCI) patients
- Can help
  - Communicate with people
  - Control assistive/prosthetic devices

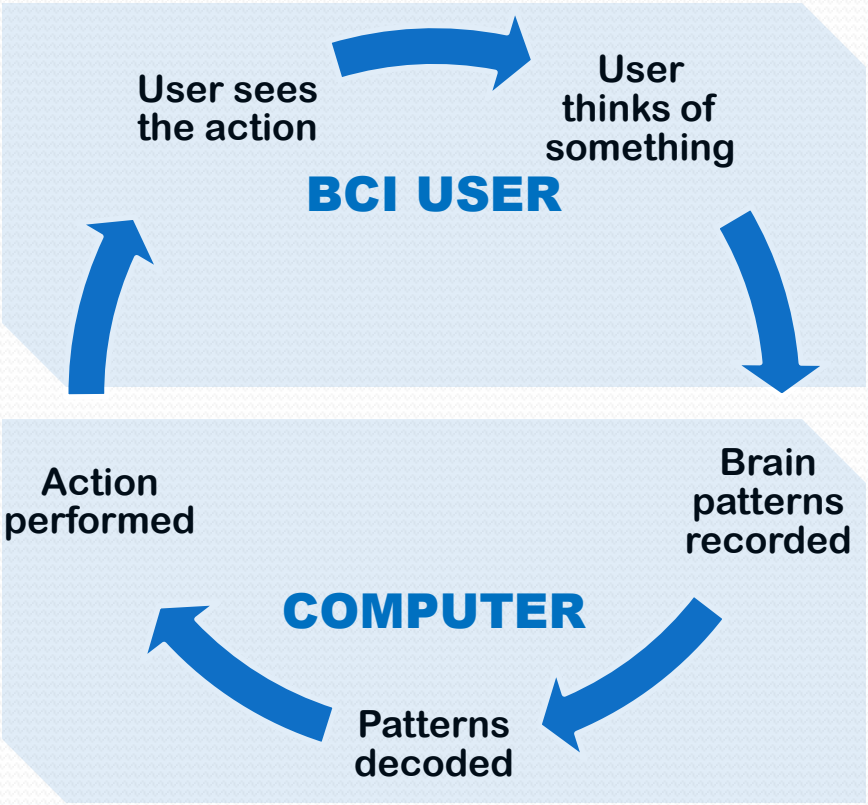
Electroencephalography (EEG)-based BCI

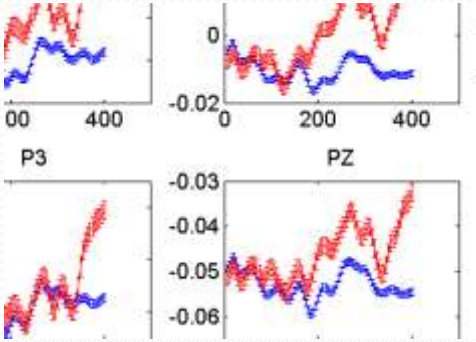


How does BCI work?







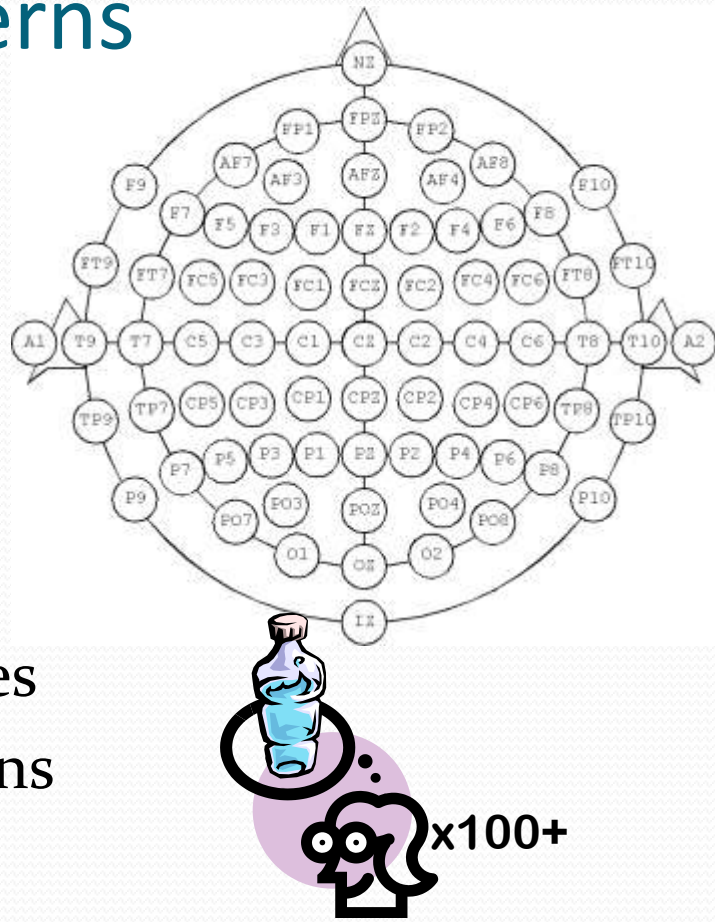


$$P(\omega_{i1}\,|\,x_1^*) = \frac{p(x_1^*\,|\,\omega_{i1})P(\omega_i)}{p(x_1^*)}$$

Robotic arm from Lynxmotion

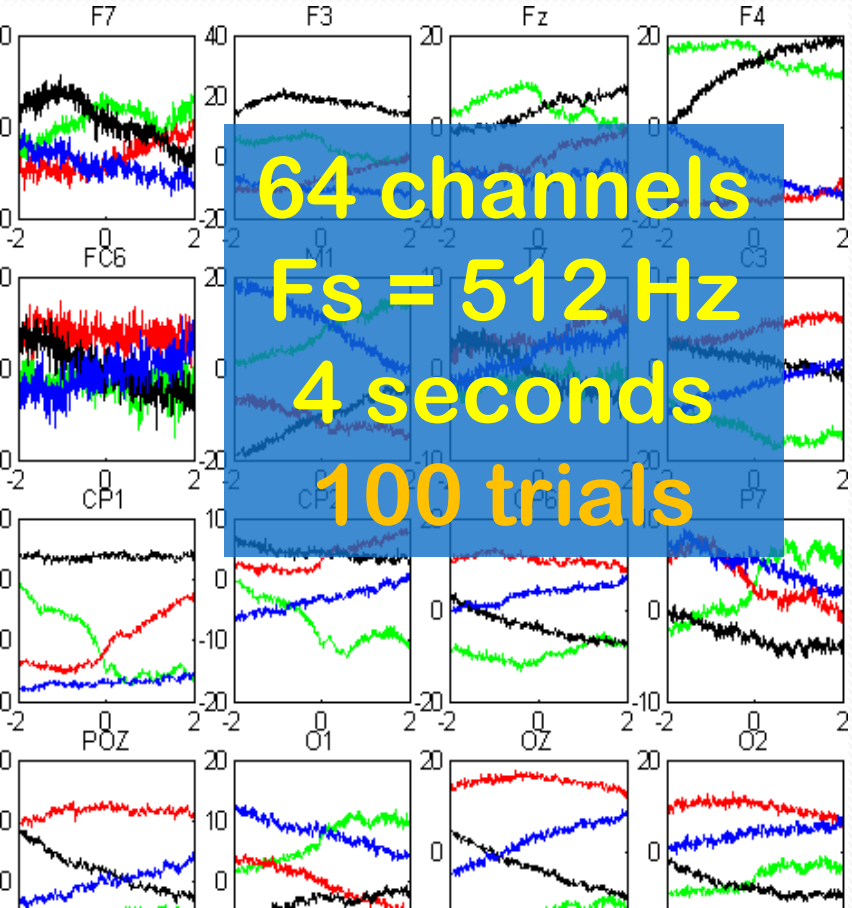
Discovering new useful patterns

- BCI relies on consistent mental patterns to work
- Where are the useful patterns, in which sensors, at what time?
  - Record all sensors for as long as feasible.
  - Repeat the mental tasks many times
  - Data can be over 100,000 dimensions per trial for just a few seconds of recording



Problem of high dimensionality

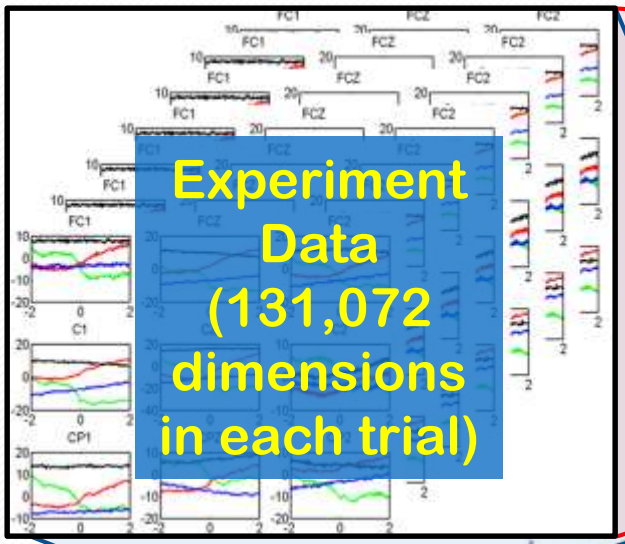
- Recorded signals have extremely high dimensions



64 channels
Fs = 512 Hz
4 seconds
100 trials

131,072 dimensional vectors, 100 trials

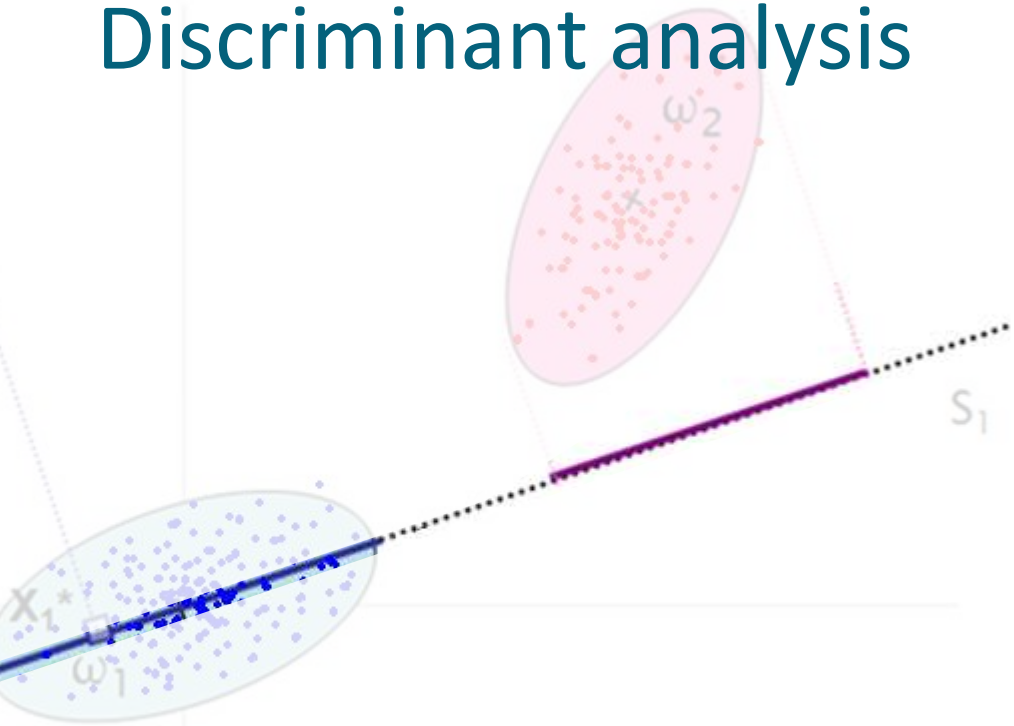
Classwise principal component analysis (cPCA)



$$X^T = V\Sigma W^T$$
$$Y^T = X^T W$$

K. Das, S. Osechinskiy, Z. Nenadic. *Conf Proc IEEE Eng Med Biol Soc, (2007)* 6520-6523

Discriminant analysis



- Finds combinations of features that best separate the classes
- Brings down to 1 – 3 dimensions

Sample covariance of class means:

$$\Sigma_b = \frac{1}{C}\sum_{i=1}^{C}(\mu_i - \mu)(\mu_i - \mu)^T$$

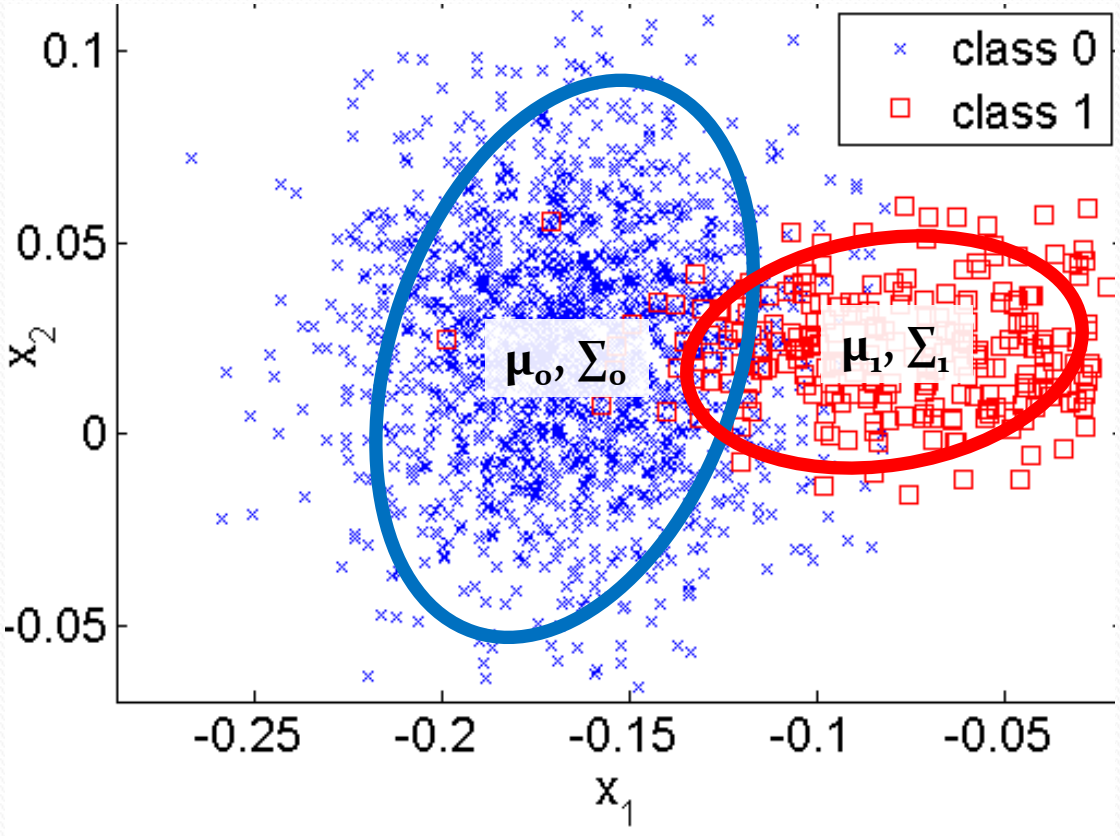
Class separation:

$$S = \frac{\vec{w}^T \Sigma_b \vec{w}}{\vec{w}^T \Sigma \vec{w}}$$

Optimal separation:

$$(\Sigma^{-1}\Sigma_b)\vec{\omega} = \Lambda\vec{\omega}$$

Classification: Where do new data belong?



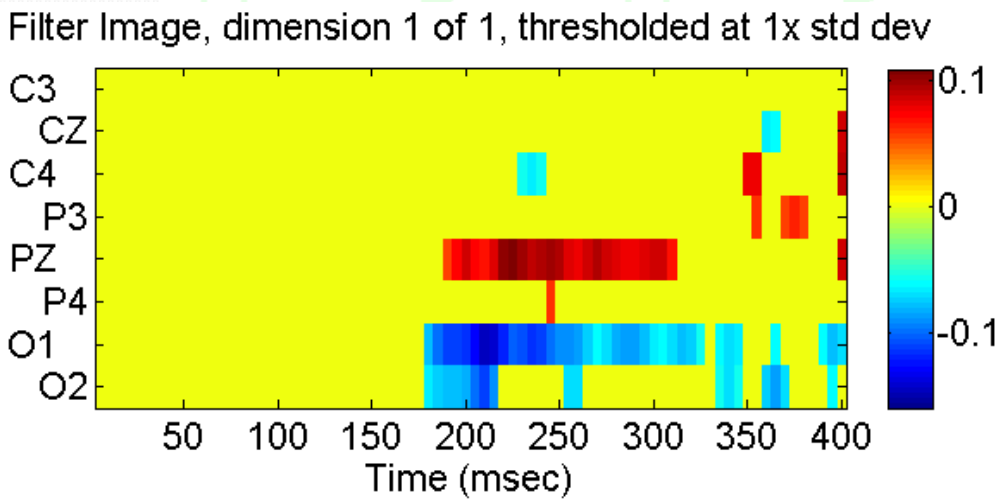
$$p(\omega_i|D) = \frac{p(D|\omega_i)p(\omega_i)}{p(D)} = \frac{N(\mu_i, \Sigma_i, D)p(\omega_i)}{\sum_i N(\mu_i, \Sigma_i, D)p(\omega_i)}$$

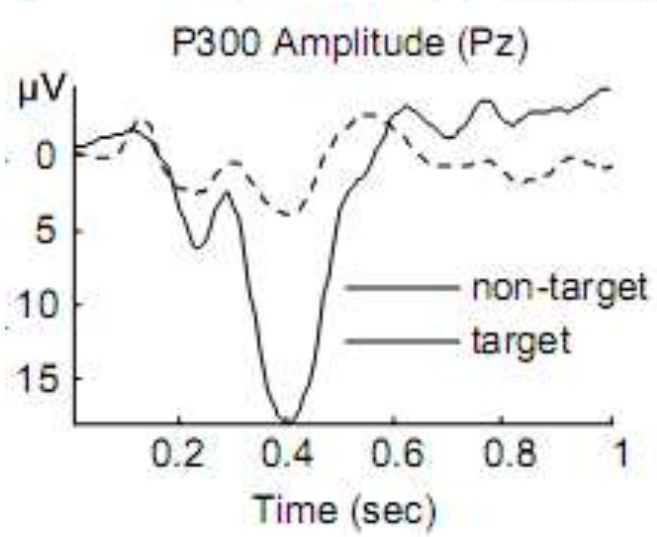
Class decision = $\max_i(p(\omega_i|D))$

Nenadic Lab, unpublished work (2009)

P300 spelling system

- P300 is a positive-deflecting brain wave pattern occurring 300 ms after an oddball object is presented





Nenadic Lab, unpublished work (2009)

Sellers & Donchin, Clinical Neurophysiology 117 (2006) 538–548

A B C D E F G

P300 spelling system

- Spelling software flashes groups of alphabets and waits for the P300 signal
- Each P300 signal narrows down the choices of alphabets, until one is chosen

P300 speller 2009-06-21

Online Stage

00:19:23

C

H L

V W

7

```
posterior=0.99847, thebomb=1
You entered: E
likelyLetters =
...YES
posterior=0.99676, thebomb=1
You entered: .
Elapsed time is 291.113805 seconds.
>> p300speller1([1:8],[],TrainDS);
BIOPAC API Library MPDEV.DLL loaded OK
Connected to BIOPAC MP150 device.
Highest letter: 7 score=0.094675 mean=0.0135 std=0.0335
```

CBMSPC

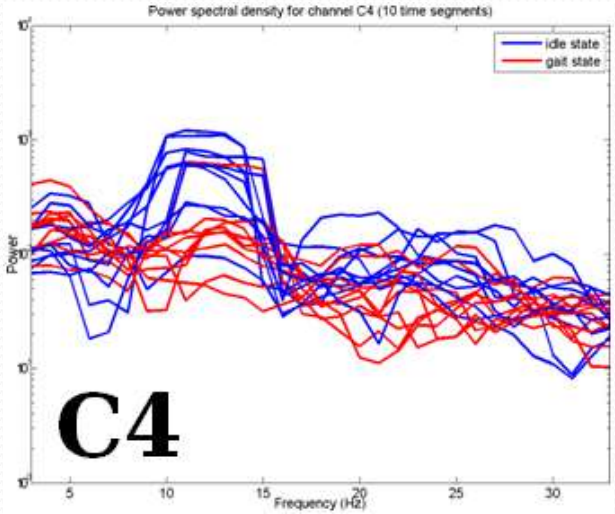
P300 spelling is easy to use

- P300 signal is natural: 97% of population[1] responds to the oddball.
- Users in our lab can achieve 80-100% accuracy with less than 15 minutes training.

[1] C Guger, et al. Neuroscience Letters 462 (2009) 94–98

Future works

- Computer mouse system
- Frequency based decoding
- Combining multiple events
- Continuous trajectory decoding



4.0% (2.0%)	1.3% (1.2%)	91.1% (0.0%)	4.0% (3.4%)
11.6% (4.6%)	15.3% (4.2%)	2.0% (0.0%)	63.7% (4.1%)
aida(3) line,	81.0% (1.7%)	(#1)	
85.8% (5.7%)	1.3% (1.2%)	5.9% (0.0%)	16.8% (2.0%)
0.0% (0.0%)	82.7% (2.3%)	1.0% (0.0%)	15.8% (2.0%)
4.0% (2.0%)	1.3% (1.2%)	91.4% (1.1%)	3.3% (2.3%)
10.2% (4.1%)	14.7% (3.1%)	1.7% (1.1%)	64.0% (5.0%)
aida(2) line,	79.9% (2.6%)	(#4)	
83.8% (1.1%)	0.3% (1.2%)	5.6% (1.1%)	15.8% (3.4%)
1.7% (1.1%)	81.3% (4.6%)	0.0% (0.0%)	18.2% (2.3%)

Nenadic Lab, unpublished work (2009)

Acknowledgements

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