

Brain Computer Interface for Communication and Control

Po T Wang
Nenadić Lab
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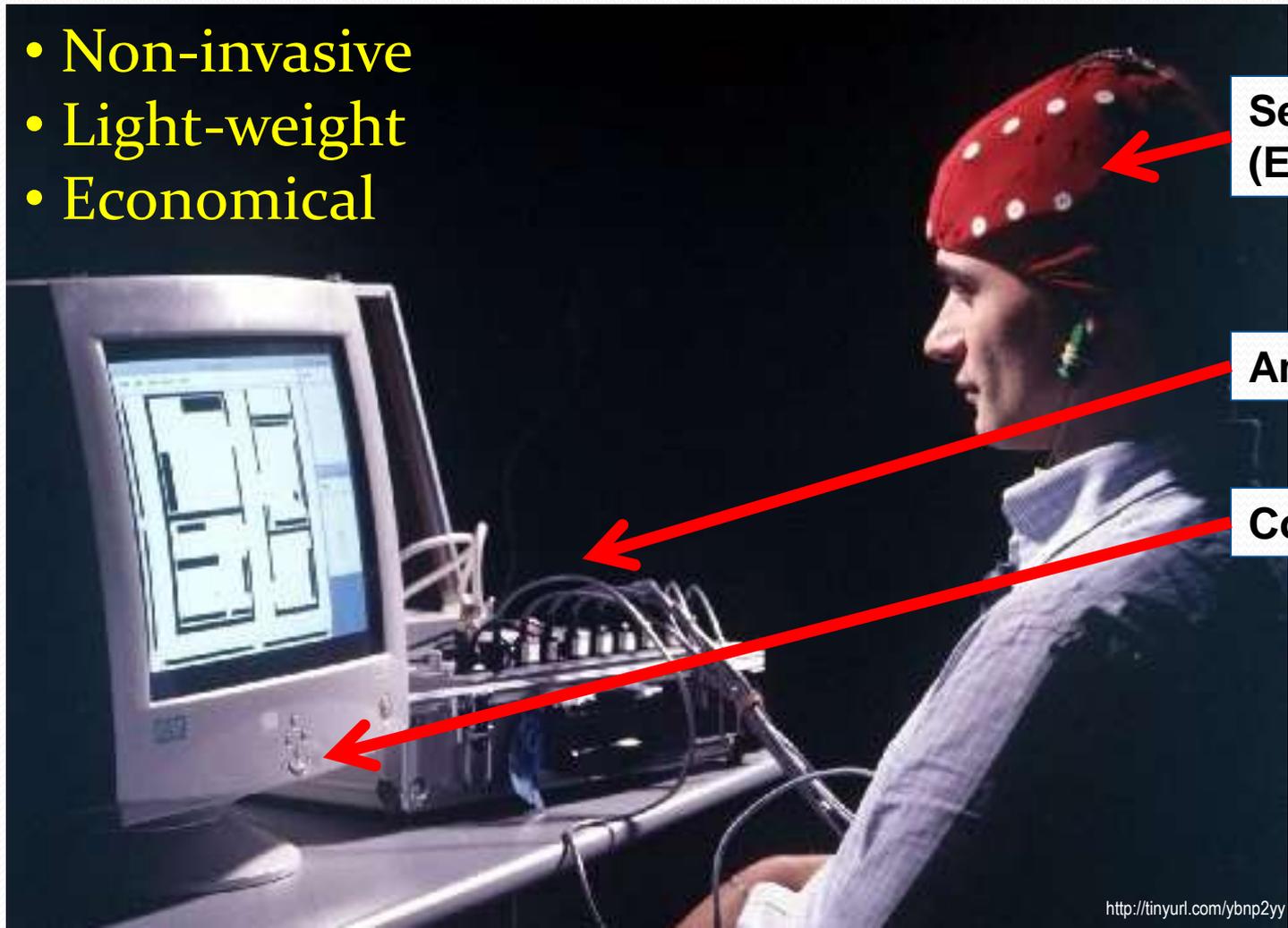


What is BCI and what can it do?

- 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

- Non-invasive
- Light-weight
- Economical

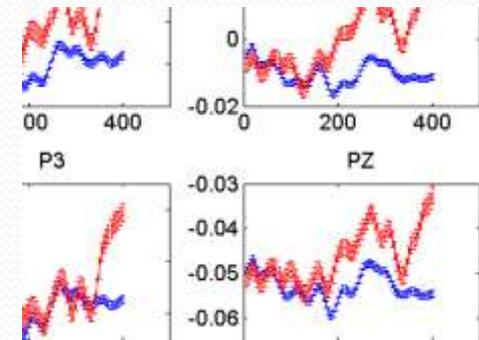
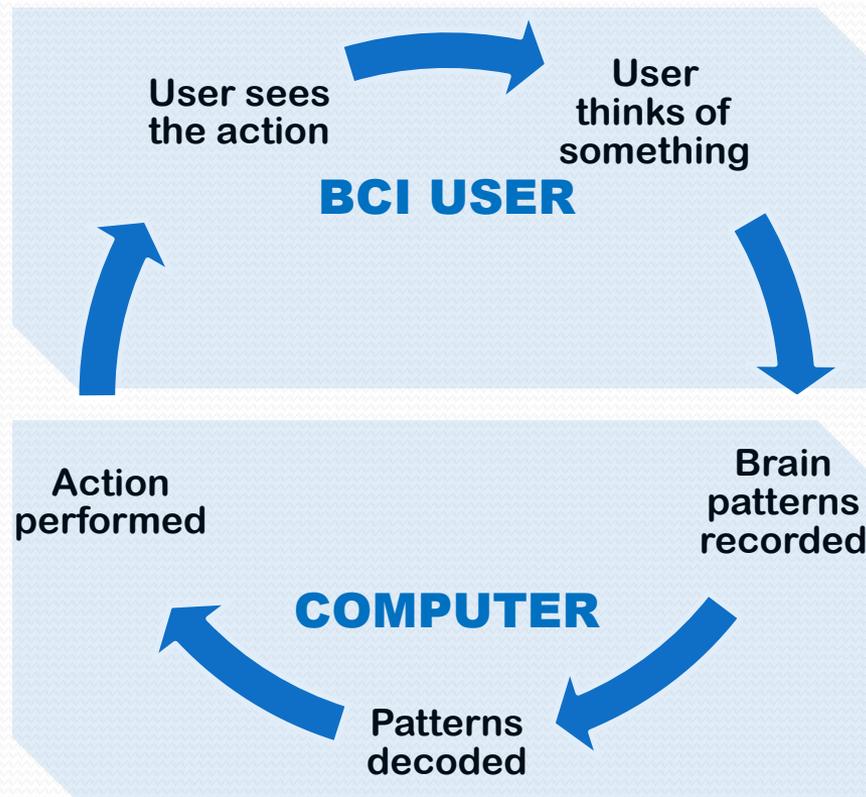


Sensors
(EEG cap)

Amplifiers

Computer

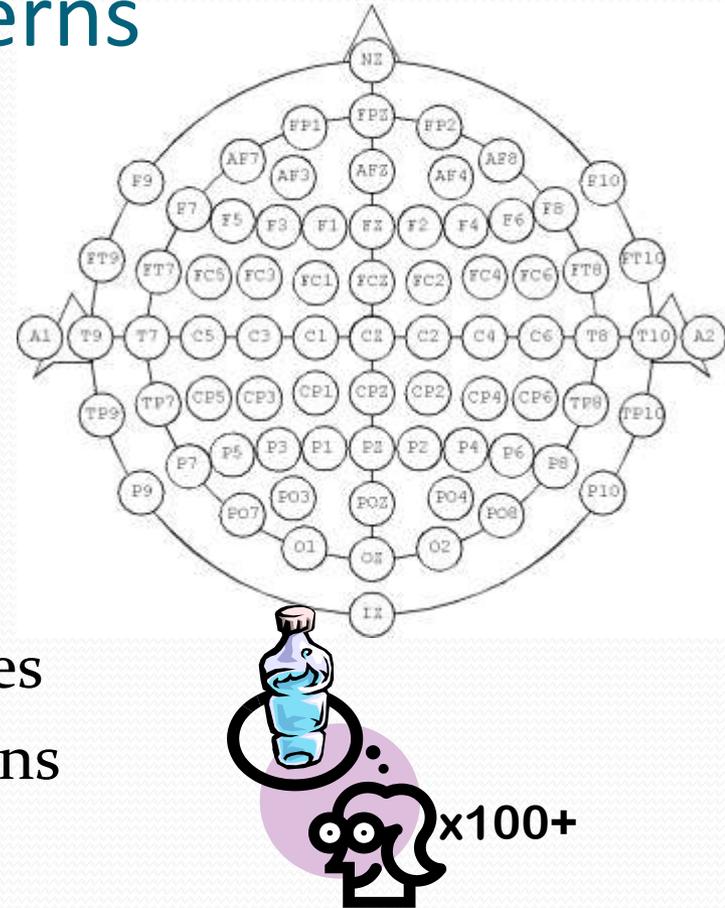
How does BCI work?



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

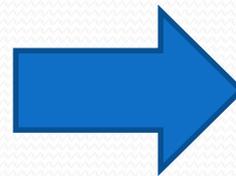
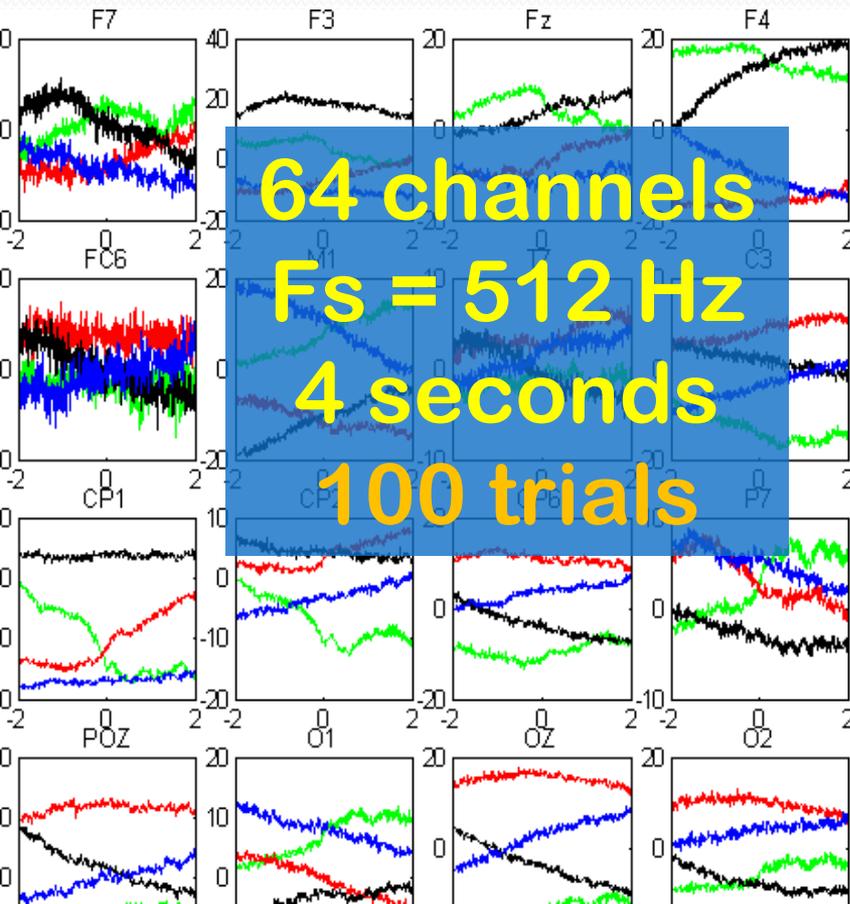
Discovering new useful patterns

- 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

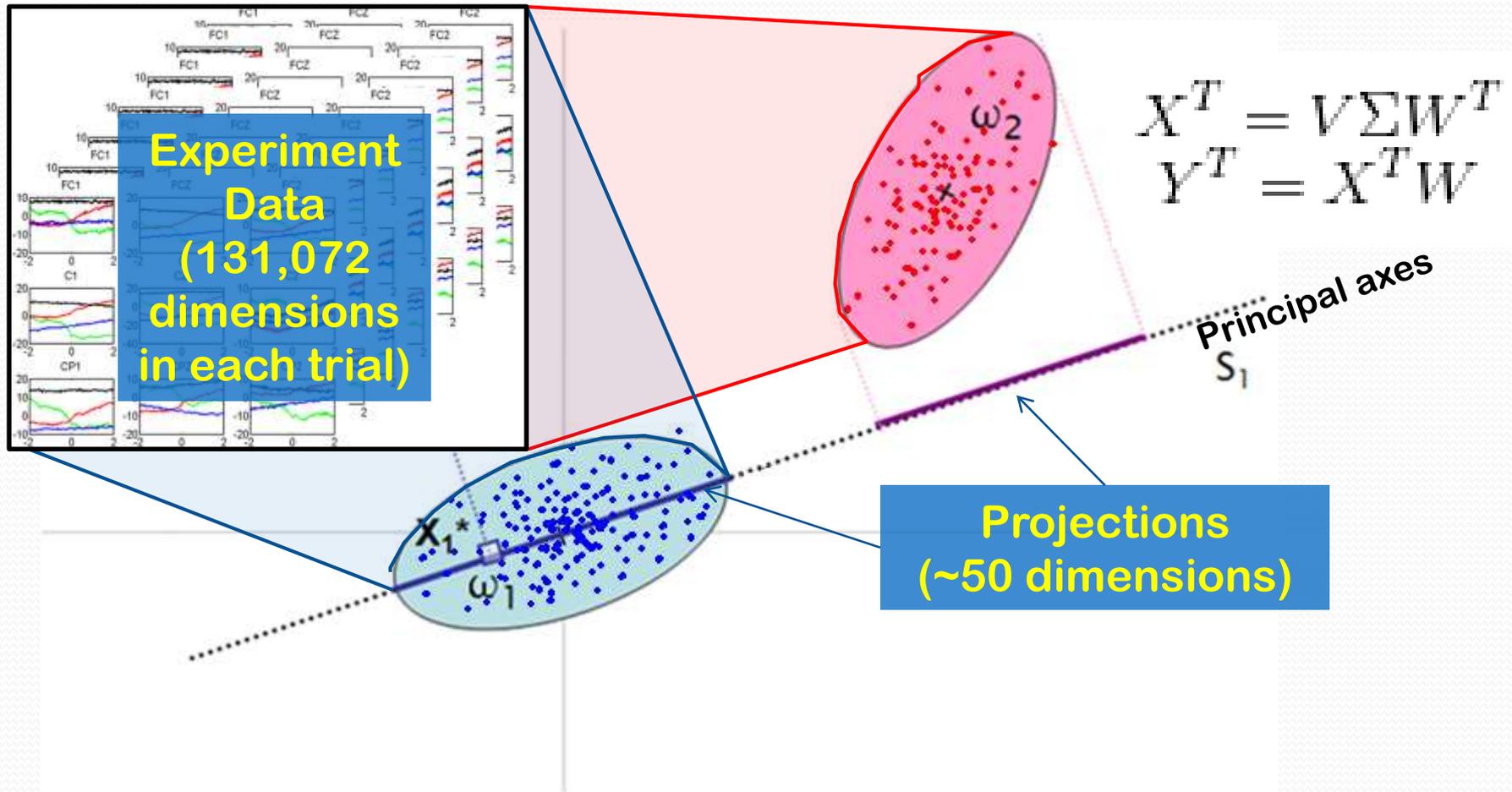
- Recorded signals have extremely high dimensions



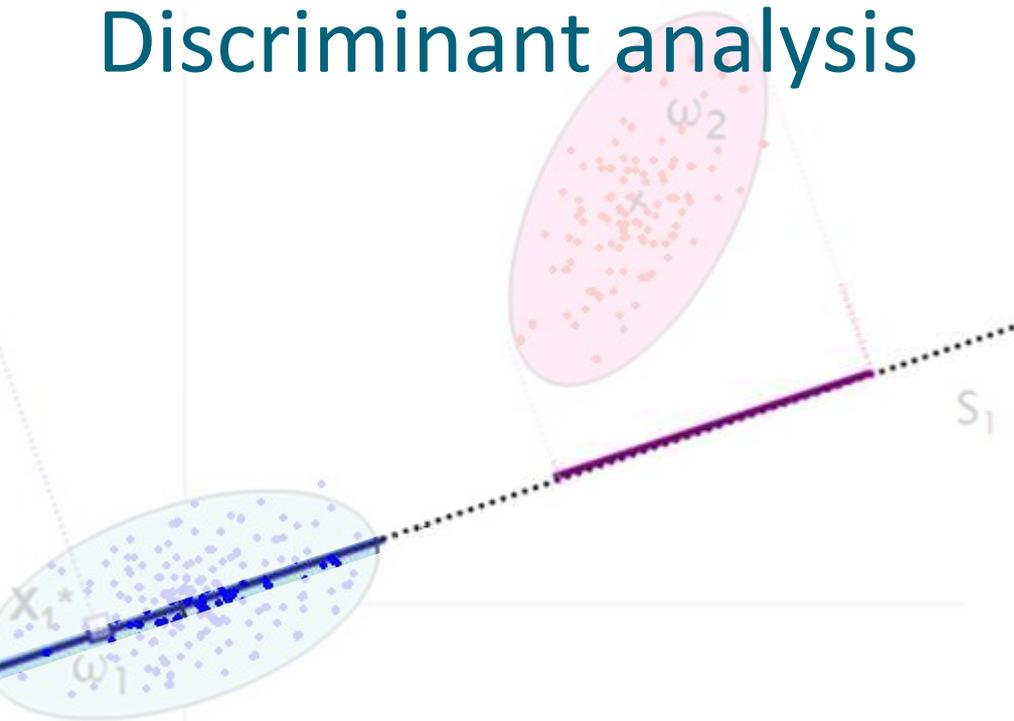
columns 1 through 7

0.0028	-0.0079	-0.0392	-0.0377	-0.0514	0.0623	0.0363
0.0036	-0.0074	-0.0383	-0.0370	-0.0507	0.0637	0.0370
0.0046	-0.0062	-0.0363	-0.0359	-0.0495	0.0655	0.0370
0.0049	-0.0055	-0.0348	-0.0354	-0.0488	0.0664	0.0381
0.0035	-0.0067	-0.0352	-0.0364	-0.0499	0.0651	0.0370
0.0014	-0.0089	-0.0360	-0.0381	-0.0515	0.0631	0.0351
-0.0001	-0.0104	-0.0381	-0.0394	-0.0525	0.0620	0.0338
-0.0006	-0.0108	-0.0385	-0.0398	-0.0522	0.0623	0.0334
0.0001	-0.0101	-0.0380	-0.0393	-0.0511	0.0634	0.0338
0.0016	-0.0087	-0.0369	-0.0376	-0.0497	0.0649	0.0344
0.0031	-0.0075	-0.0366	-0.0373	-0.0485	0.0658	0.0346
0.0044	-0.0059	-0.0353	-0.0359	-0.0477	0.0662	0.0344
0.0051	-0.0052	-0.0341	-0.0347	-0.0469	0.0662	0.0342
0.0052	-0.0053	-0.0328	-0.0372	-0.0493	0.0656	0.0339
0.0047	-0.0065	-0.0338	-0.0378	-0.0505	0.0644	0.0336
0.0040	-0.0079	-0.0358	-0.0383	-0.0517	0.0629	0.0332
0.0039	-0.0081	-0.0358	-0.0383	-0.0517	0.0629	0.0330
0.0047	-0.0079	-0.0358	-0.0383	-0.0517	0.0629	0.0338
0.0051	-0.0079	-0.0358	-0.0383	-0.0517	0.0629	0.0340
0.0044	-0.0065	-0.0367	-0.0341	-0.0491	0.0643	0.0354
0.0024	-0.0079	-0.0363	-0.0354	-0.0498	0.0643	0.0350
0.0001	-0.0102	-0.0367	-0.0373	-0.0513	0.0636	0.0342
-0.0018	-0.0127	-0.0389	-0.0399	-0.0527	0.0620	0.0336
-0.0030	-0.0144	-0.0399	-0.0409	-0.0537	0.0623	0.0337
-0.0037	-0.0152	-0.0406	-0.0416	-0.0547	0.0618	0.0336
-0.0037	-0.0140	-0.0390	-0.0404	-0.0544	0.0616	0.0335
-0.0029	-0.0135	-0.0384	-0.0399	-0.0544	0.0621	0.0331
-0.0016	-0.0131	-0.0380	-0.0390	-0.0542	0.0623	0.0326
0.0004	-0.0090	-0.0360	-0.0367	-0.0520	0.0652	0.0322
0.0023	-0.0073	-0.0343	-0.0349	-0.0513	0.0673	0.0320
0.0040	-0.0065	-0.0331	-0.0342	-0.0514	0.0692	0.0319
0.0047	-0.0054	-0.0304	-0.0337	-0.0494	0.0699	0.0316
0.0040	-0.0050	-0.0305	-0.0340	-0.0506	0.0692	0.0301
0.0026	-0.0069	-0.0315	-0.0369	-0.0524	0.0675	0.0277
0.0016	-0.0078	-0.0325	-0.0390	-0.0536	0.0656	0.0246
0.0015	-0.0077	-0.0332	-0.0405	-0.0537	0.0646	0.0217
0.0028	-0.0063	-0.0331	-0.0411	-0.0524	0.0648	0.0190
0.0046	-0.0040	-0.0324	-0.0408	-0.0504	0.0659	0.0186
0.0064	-0.0016	-0.0313	-0.0400	-0.0479	0.0675	0.0184
0.0070	0.0004	-0.0301	-0.0390	-0.0450	0.0690	0.0180
0.0081	0.0012	-0.0292	-0.0386	-0.0447	0.0697	0.0193
0.0078	0.0015	-0.0285	-0.0388	-0.0442	0.0697	0.0196
0.0073	0.0017	-0.0280	-0.0395	-0.0443	0.0693	0.0199
0.0066	0.0017	-0.0278	-0.0407	-0.0448	0.0688	0.0201
0.0062	0.0018	-0.0279	-0.0417	-0.0453	0.0683	0.0204
0.0061	0.0022	-0.0279	-0.0422	-0.0455	0.0682	0.0208
0.0070	0.0033	-0.0272	-0.0417	-0.0448	0.0690	0.0210

Classwise principal component analysis (cPCA)



Discriminant analysis



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

Sample covariance of class means:

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

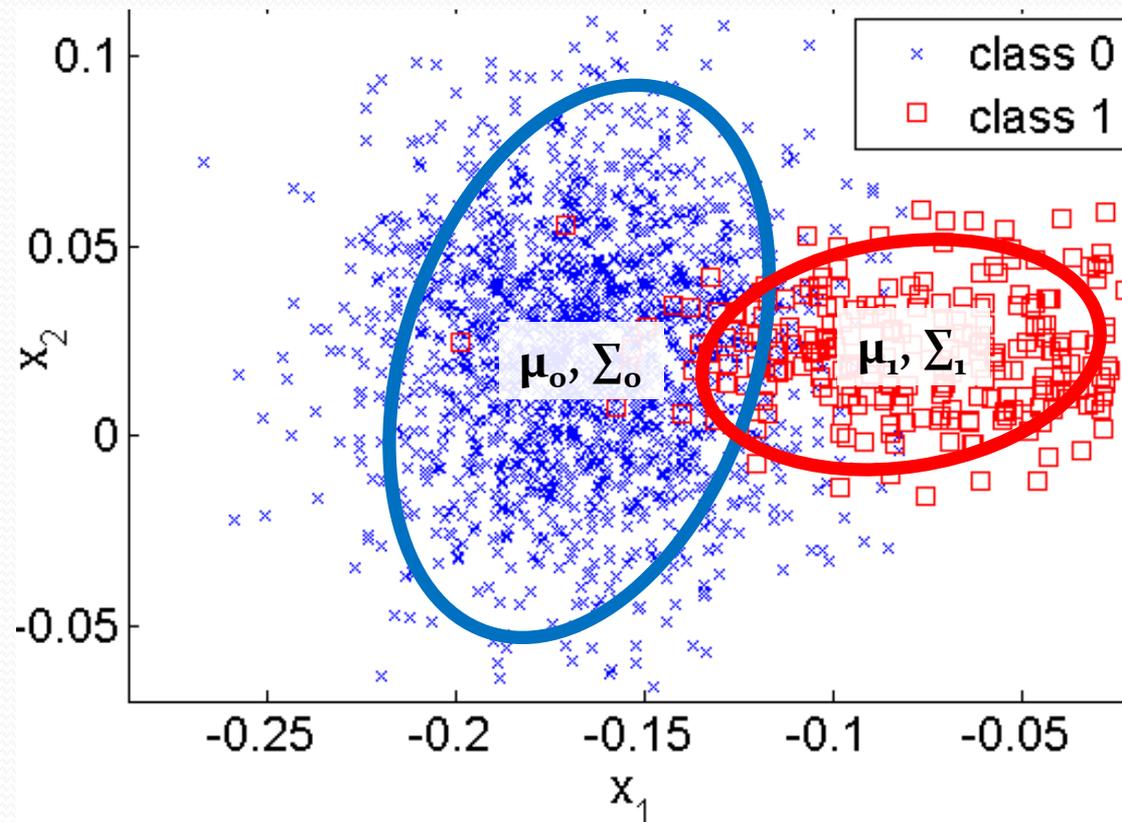
Class separation:

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

Optimal separation:

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

Classification: Where do new data belong?



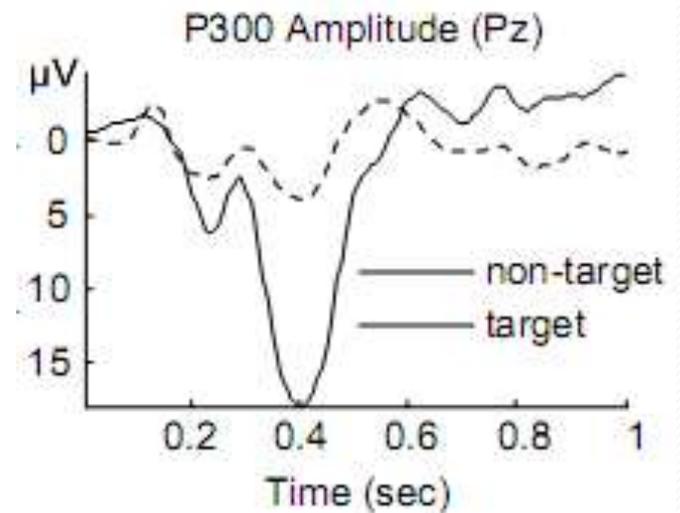
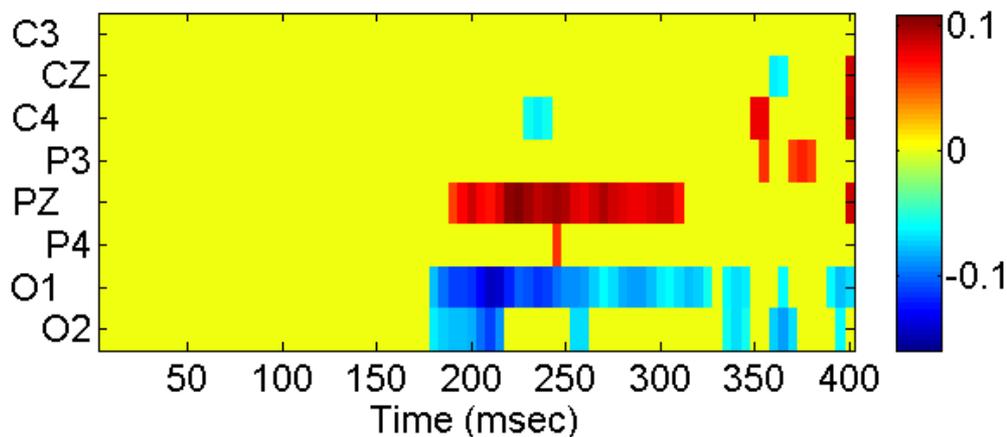
$$p(\omega_i|D) = \frac{p(D|\omega_i)p(\omega_i)}{p(D)}$$
$$= \frac{N(\mu_i, \Sigma_i, D)p(\omega_i)}{\sum_i N(\mu_i, \Sigma_i, D)p(\omega_i)}$$

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

P300 spelling system

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

Filter Image, dimension 1 of 1, thresholded at 1x std dev



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

V W X Y Z , .

1 2 3 4 5 6 7

< 8 9 0 ? ! >

ONLINE STAGE

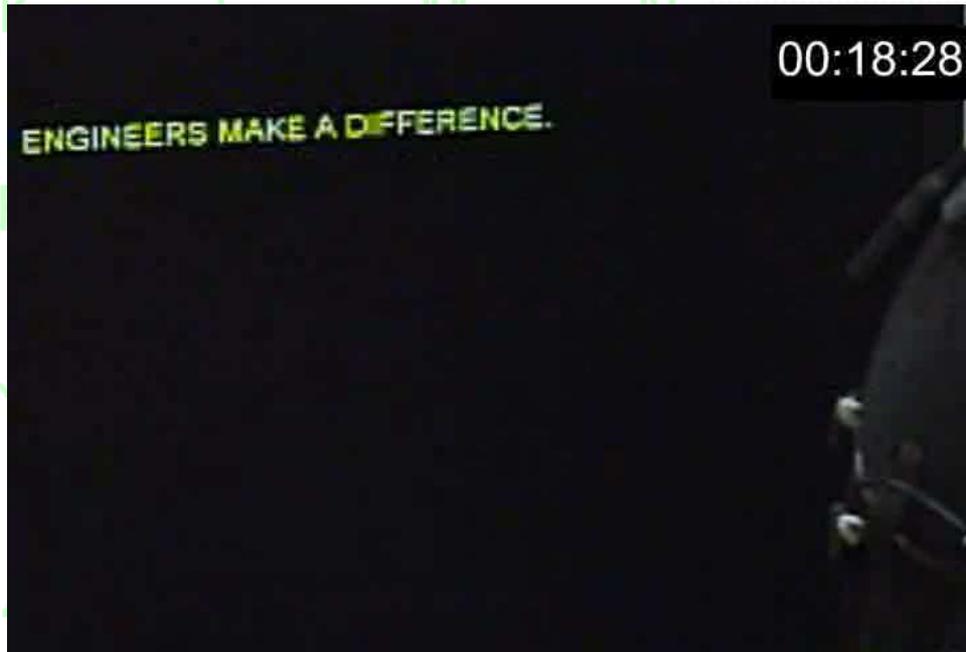
C
H L
V W 7



```
Posterior=0.99847, thebomb=1  
You entered: E  
likelyletters =  
|.YES  
Posterior=0.99676, thebomb=1  
You entered: -  
Elapsed time is 291.113805 seconds.  
>> p300speller1(11:8) (1) TrainDB /  
BIOFAC API Library HYDEV.DLL loaded OK  
Connected to BIOFAC HF150 device.  
Highest letter: 7 score=0.094675 mean=0.0135 std=0.0335
```

P300 spelling is easy to use

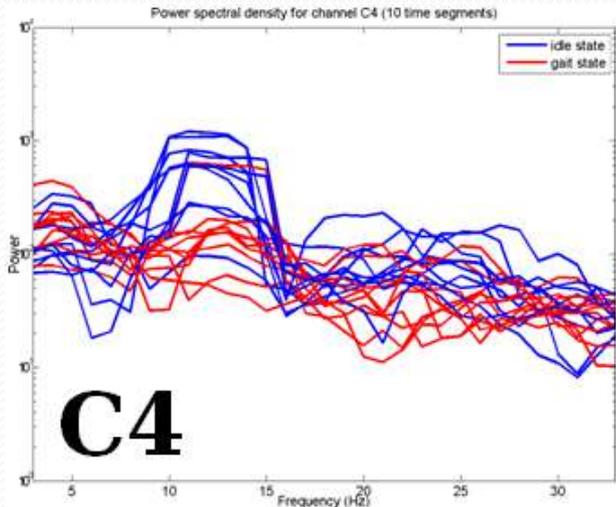
- P300 signal is natural: 97% of population^[1] responds to the oddball.
- Users in our lab can achieve 80-100% accuracy with less than 15 minutes training.



[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%)
	5.0% (2.0%)	1.7% (2.3%)	99.4% (1.1%)	1.0% (0.0%)

Acknowledgements

- Principal investigator
 - Zoran Nenadic, DSc
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