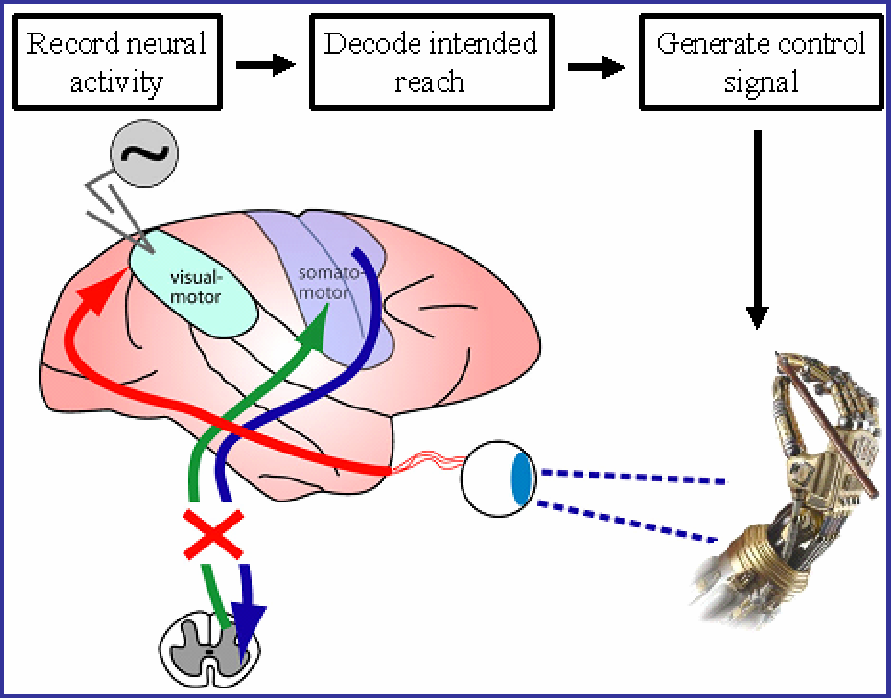
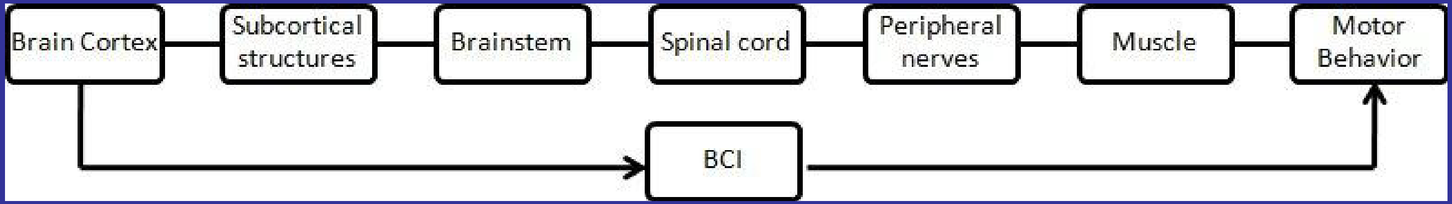
BME 195/295 MICRO IMPLANTS

Guest lecturer: Zoran Nenadic, D.Sc.

02/26/2009

Brain-Computer Interface (BCI)





BCIs can be *noninvasive* or *invasive.*

Noninvasive BCIs:

Electroencephalogram (EEG)

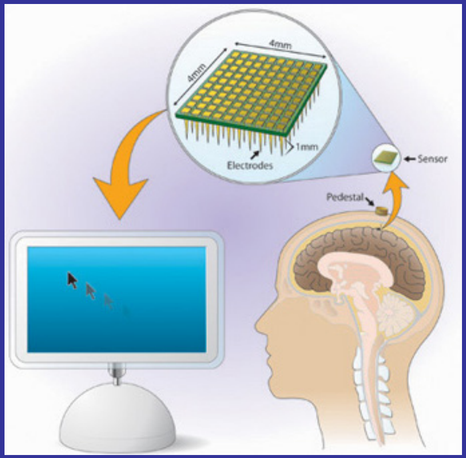
Magnetoencephalogram (MEG)

Near Infrared Spectroscopy (NIRS)

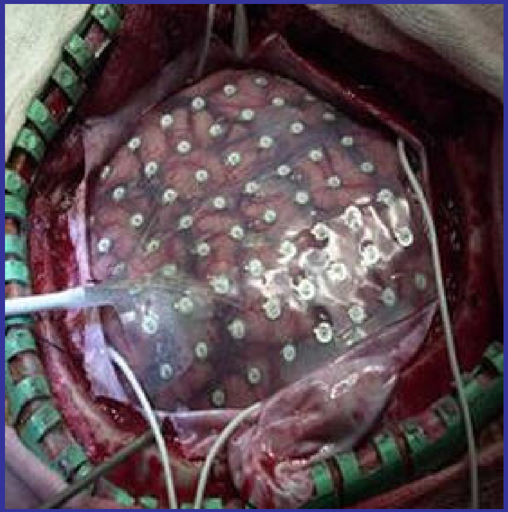
Function magnetic resonance imaging (fMRI)

Invasive BCIs:

Single neuron activities



Electrocorticogram (ECoG)

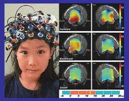


Noninvasive BCIs (pros and cons):

1) EEG 

Strengths: good temporal resolution (milliseconds), relatively cheap, relatively easy to set up, wearable

Weaknesses: poor spatial resolution (2-3 cm), sensitive to artifacts (muscle activity, eye movements, blinks), limited information can be extracted from brain (~1 bit/s)

2) NIRS 

Strengths: good spatial resolution (millimeters), wearable

Weaknesses: poor temporal resolution (seconds), limited information can be extracted from brain (<<1 bit/s)

3) MEG 

Strengths: good spatial (millimeters) and temporal (milliseconds) resolution

Weaknesses: bulk, price, limited information can be extracted from brain (~1 bit/s)

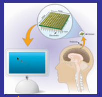
4) fMRI 

Strengths: good spatial (millimeters) resolution

Weaknesses: bulk, price, limited information can be extracted from brain (<<1 bit/s)

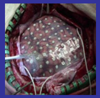
Invasive BCIs (pros and cons):

1) Single neuron activities



Strengths: good spatial (microns) and temporal (<milliseconds) resolution, higher information transfer rates (up to 6.5 bits/s in monkeys)
Weaknesses: poor long-term signal stability, risk of infections (wireless communication may be needed in the future)

2) ECoG

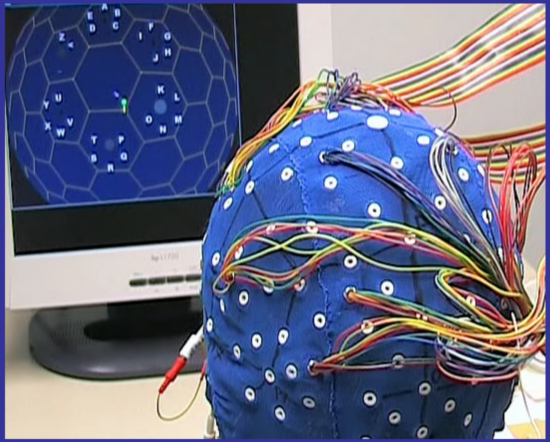


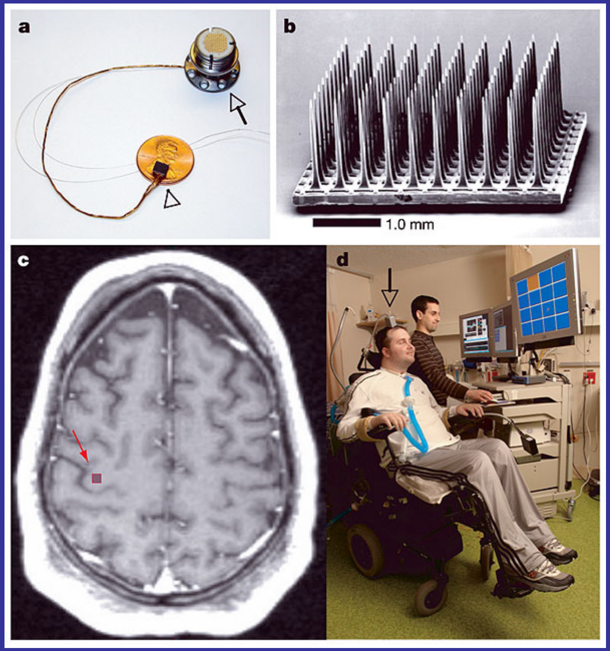
Strengths: ?
Weaknesses: risk of infections (wireless device may be needed)

Facts:
- temporal resolution better than that of EEG and inferior to that of single neuron activity
- spatial resolution (1 cm), better than EEG, inferior to single neuron activity
- information transfer rates so far comparable to EEG (more data needed)
- long-term stability—clinical data suggests that it may be better than that of single-neuron activity.

For both of these invasive signal modalities only a limited data is available
For ECoG very limited data exists with paralyzed individuals, most studies focused on epileptic patients.

Applications:





check out: Hochberg LR et al. (2006) Neuronal ensemble control of prosthetic devices by a human with tetraplegia. Nature 442: 164–171 to find out what can be done

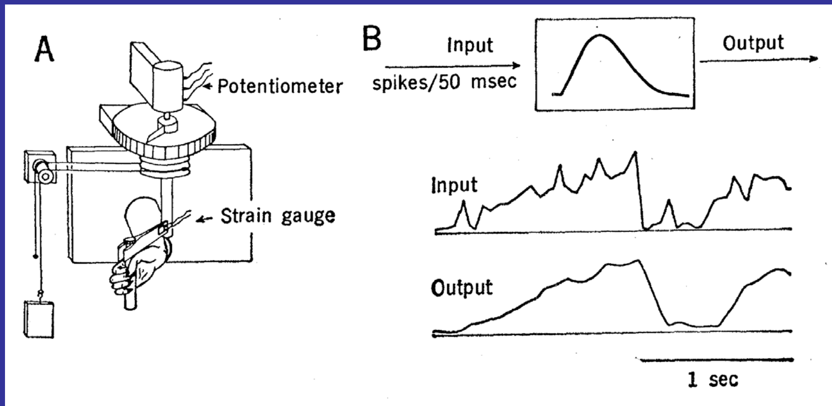
Historical Remarks

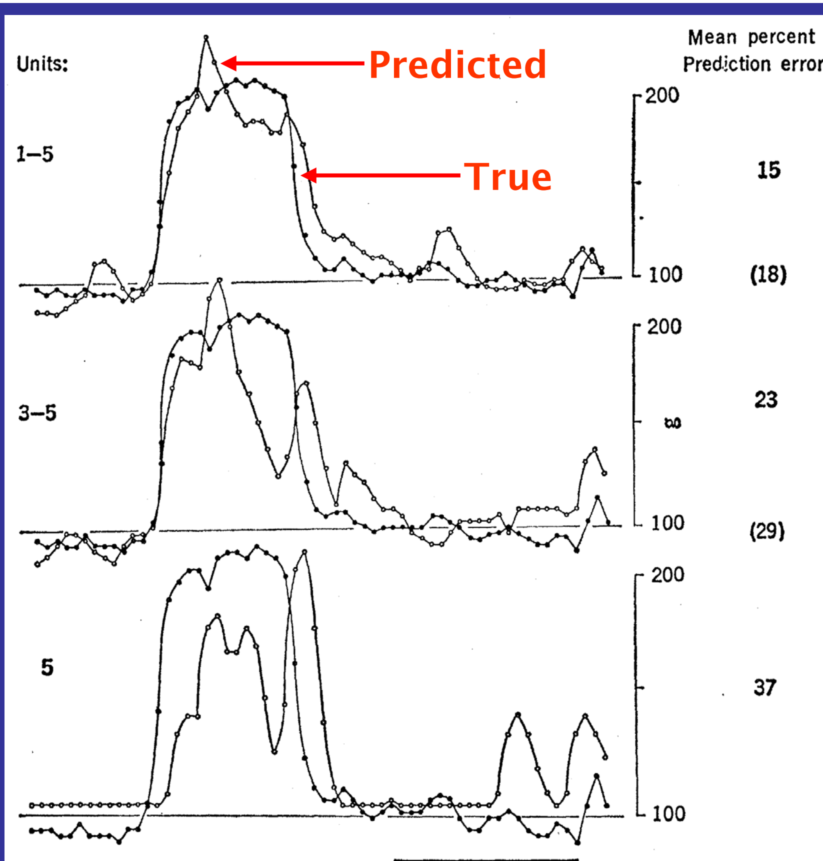
"We will be engaged in the development of principles and techniques by which information from the nervous system can be used to control external devices such as prosthetic devices, communications equipment, teleoperators [· · ·] and ultimately perhaps even computers."

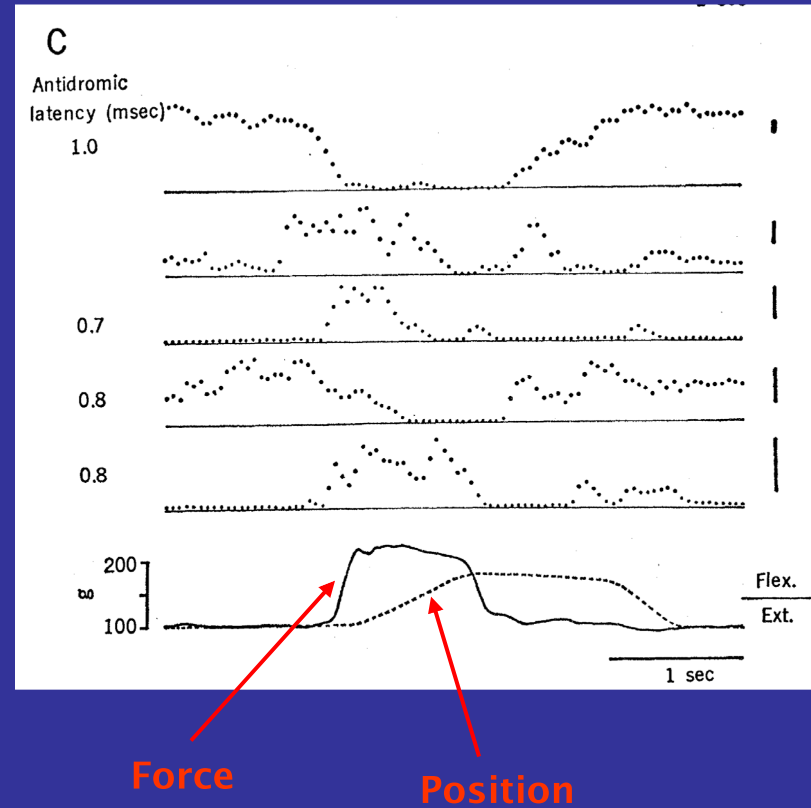
Karl Frank, Founder of the Laboratory of Neural Control at the NINDS, [1].

[1] K. Frank. Some approaches to the technical problem of chronic excitation of peripheral nerve. Ann Otol Rhinol Laryngol,77(4):761–771, Aug 1968.

D. R. Humphrey, E. M. Schmidt, and W. D. Thompson. Predicting measures of motor performance from multiple cortical spike trains. Science, 170(959):758–762, Nov 1970.

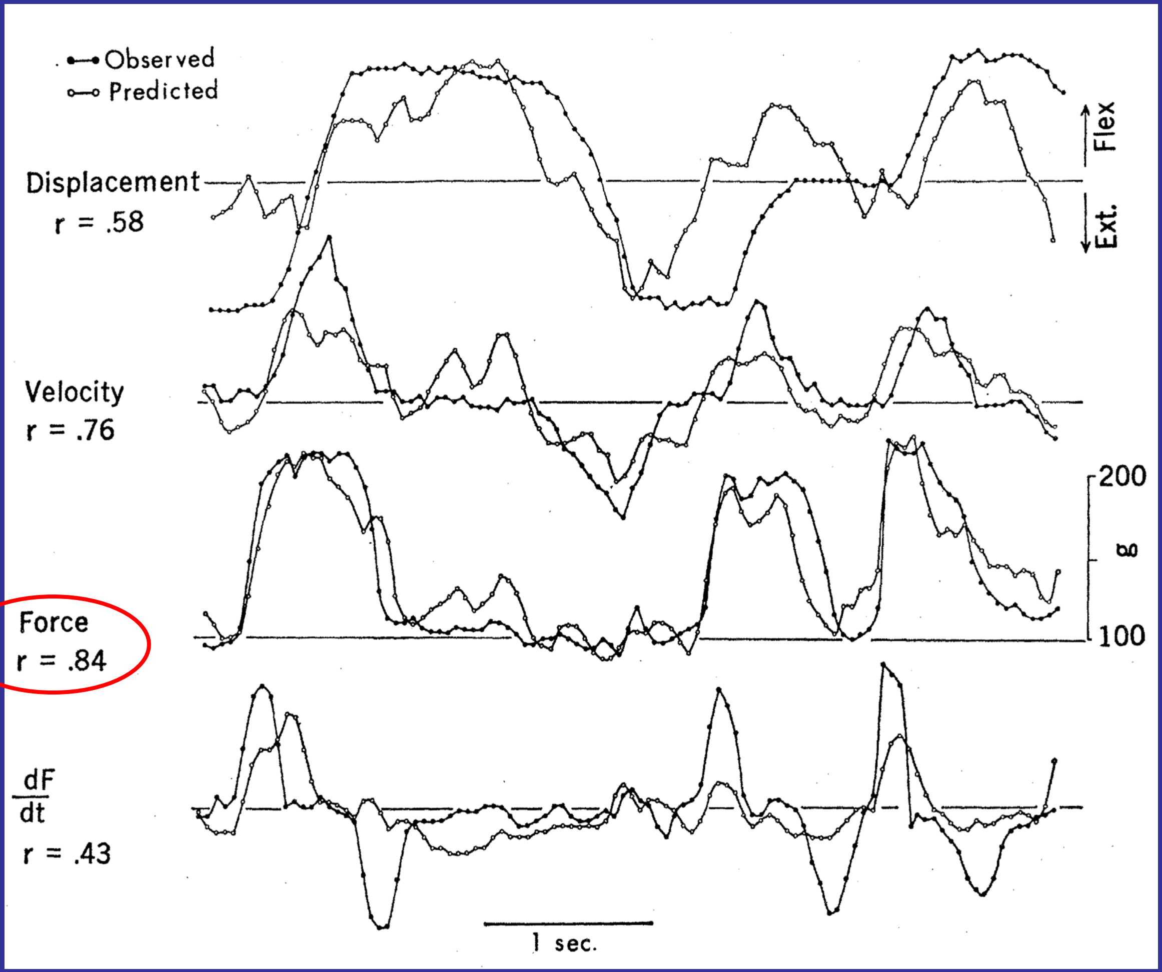






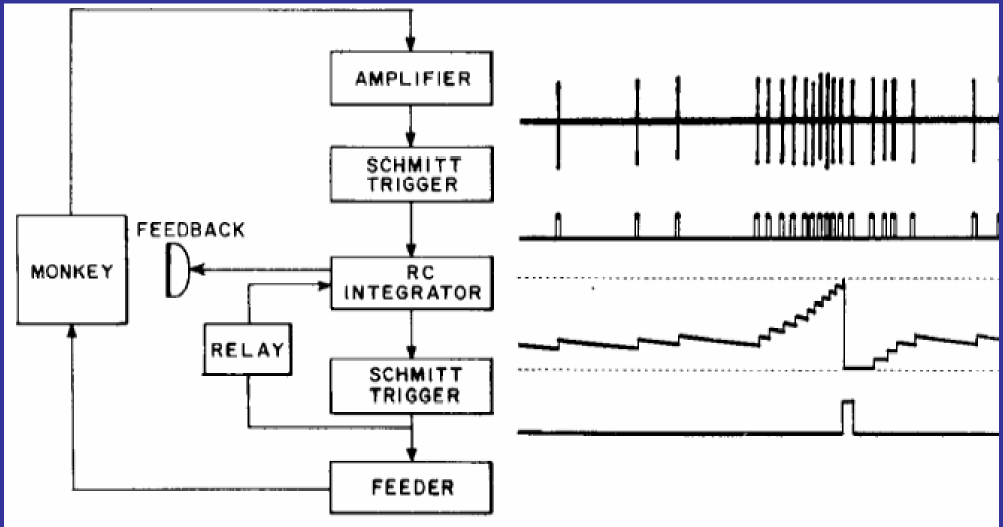
$$\underbrace{\phi(t)}_{\text{prediction}} = a_0 + \sum_i a_i \underbrace{U_i(t)}_{\text{firing rate}}$$

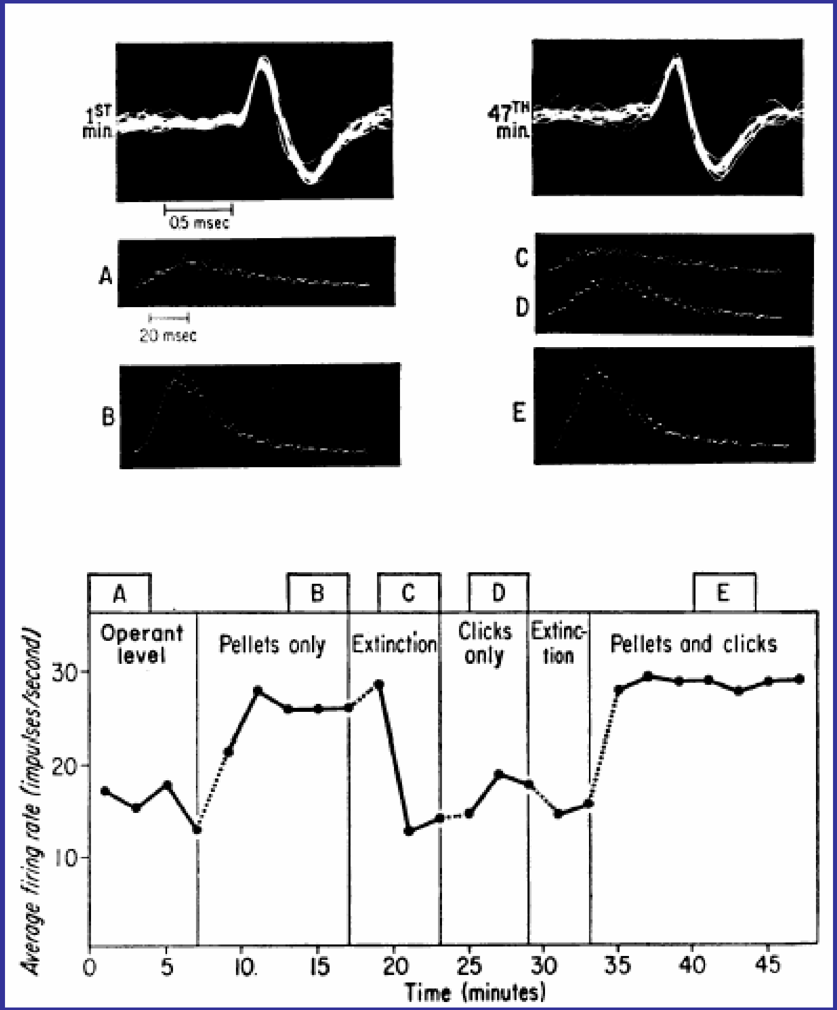
Humphrey et al., 1970 (cont'd)



Force is best predicted!
(r-correlation coefficient)

E. E. Fetz. Operant conditioning of cortical unit activity. Science, 163(870):955-958, Feb 1969.





"After several training sessions, monkeys could increase the activity of newly isolated cells by 50 to 500 percent above rates before reinforcement"

Milestones in Human-operated BCIs

1. Person spells words by using EEG (Farwell and Donchin, 1988).
2. An ALS patient communicates (spelling) through visually-induced activity measured by ECoG (Sutter, 1992)
3. Human operates a computer cursor in 1D with EEG signals (Wolpaw and McFarland, 1994)
4. An ALS patient communicates through a single electrode by modulating the neuronal firing rate (Kennedy and Bakay, 1998).
5. Paralyzed human operates a computer cursor in 2D with EEG signals (Wolpaw and McFarland, 2004)
6. Paralyzed human implanted with Utah array and able to operate various interfaces: move cursor, flip TV channels, draw a circle, etc. (Hochberg et al. 2006)
7. Paralyzed human operates a computer cursor in 2D with ECoG signals (Schalk et al., 2008)

L. A. Farwell and E. Donchin, “Talking off the top of your head: A mental prosthesis utilizing event-related brain potentials,” Electroencephalogr. Clin. Neurophysiol., vol. 70, pp. 510–523, 1988.

E.E. Sutter. The brain response interface: communication through visually-induced electrical brain responses. J. Microcomput. Appl., 15(1):31–45, 1992.

J. R. Wolpaw and D. J. McFarland. Multichannel eeg-based brain-computer communication. Electroencephalogr Clin Neurophysiol, 90(6):444–449, Jun 1994.

P. R. Kennedy and R. A. Bakay. Restoration of neural output from a paralyzed patient by a direct brain connection. Neuroreport, 9(8):1707–1711, Jun 1998.

J.R. Wolpaw and D.J. McFarland. Control of a two-dimensional movement signal by a noninvasive brain-computer interface in humans. Proc Natl Acad Sci U S A, 101(51):17849–17854, Dec 2004

L.R. Hochberg, M.D. Serruya, G.M. Friehs, J.A. Mukand, M. Saleh, A.H. Caplan, A. Branner, D. Chen, R.D. Penn, and J.P. Donoghue. Neuronal ensemble control of prosthetic devices by a human with tetraplegia. Nature, 442(7099):164–171, Jul 2006.

G. Schalk, K.J. Miller, N.R. Anderson, J.A. Wilson, M. D. Smyth, J. G. Ojemann, D. W. Moran, J. R. Wolpaw, and E. C. Leuthardt. Two-dimensional movement control using electrocorticographic signals in humans. J Neural Eng, 5(1):75–84, Mar 2008.

How did I get into this?

EEG/ECoG signals are spatio-temporal and high-dimensional

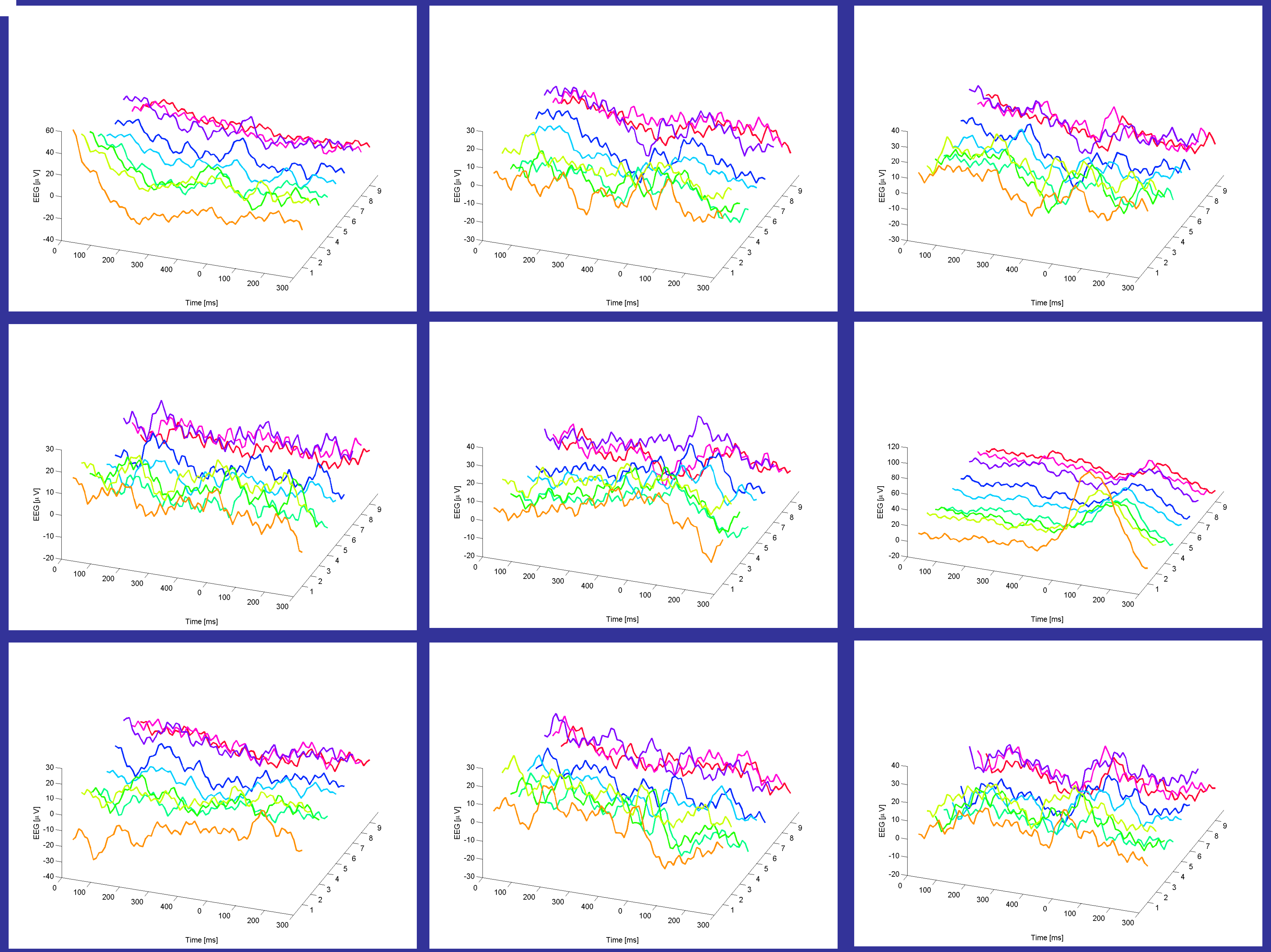
The number of experimental trials is typically small

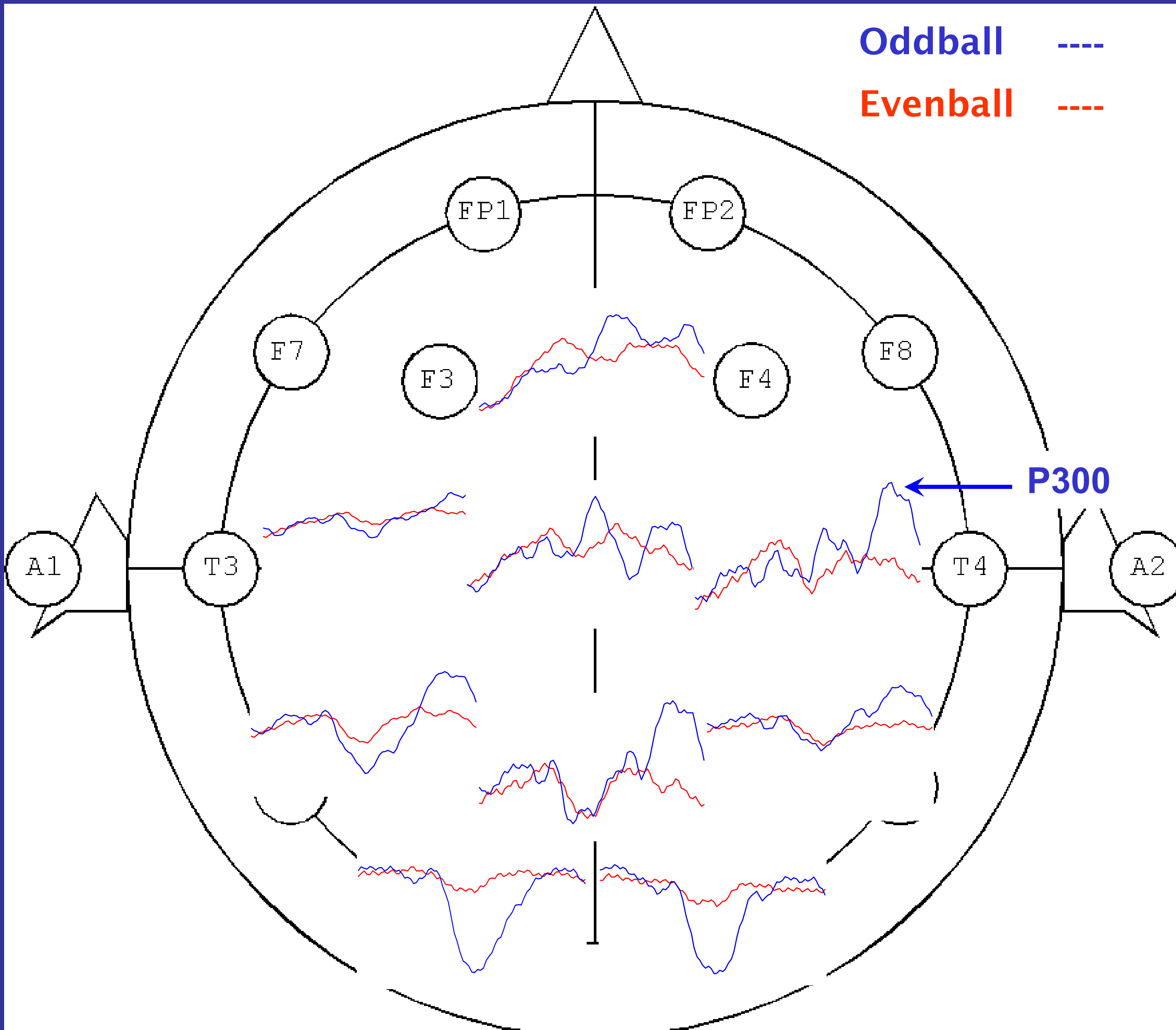
The data is very noisy

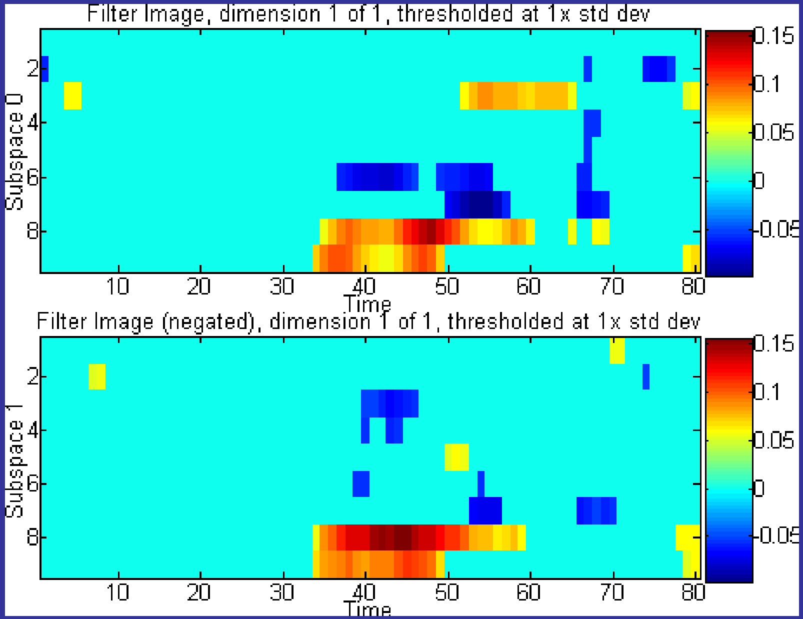
It is a challenging signal processing/data analysis problem

Example:
9 electrodes
400 ms @ 200 Hz=80 points
size of data vector: 80 x 9 = 720

← **one trial**


EEG [μ V]
Time [ms]


Oddball ----
Evenball ----
P300
FP1
FP2
F7
F3
F4
F8
A1
T3
T4
A2



Offline analysis:

CPCA, AIDA(1), Linear density

Channels	Times	Evenball rate	Oddball rate	Pcorrect
1:9	1:100	92.2% ± 0.5%	85.7% ± 1.0%	89.0% ± 0.527%
1:9	21:80	93.0% ± 0.6%	86.7% ± 1.6%	89.9% ± 0.936%
1:9	41:80	92.6% ± 0.5%	84.1% ± 0.9%	88.4% ± 0.385%
1:9	34:70	93.3% ± 0.4% 92.9% leave-one-out	87.7% ± 1.0% 88.6% leave-one-out	90.5% ± 0.408% 90.8% leave-one-out
2:9 (no FZ)	34:70	94.1% ± 0.4% 94.6% leave-one-out	88.2% ± 1.3% 88.6% leave-one-out	91.1% ± 0.733% 91.6% leave-one-out
1:7 (no O1, O2)	34:70	85.3% ± 0.6%	75.0% ± 1.4%	80.1% ± 0.679%
2:7 (no FZ, O1, O2)	34:70	85.4% ± 0.6%	77.4% ± 1.0%	81.4% ± 0.46%
8:9 (O1, O2 only)	34:70	82.5% ± 0.7%	79.9% ± 1.6%	81.2% ± 0.975%

A	B	C	D	E	F	G
H	I	J	K	L	M	N
O	P	Q	R	S	T	U
V	W	X	Y	Z	,	.
1	2	3	4	5	6	7
<	8	9	0	?	!	>