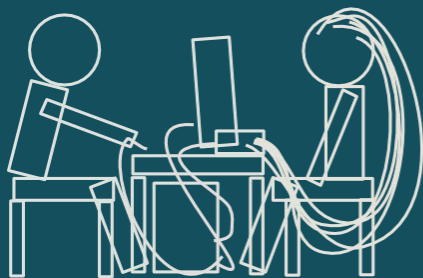
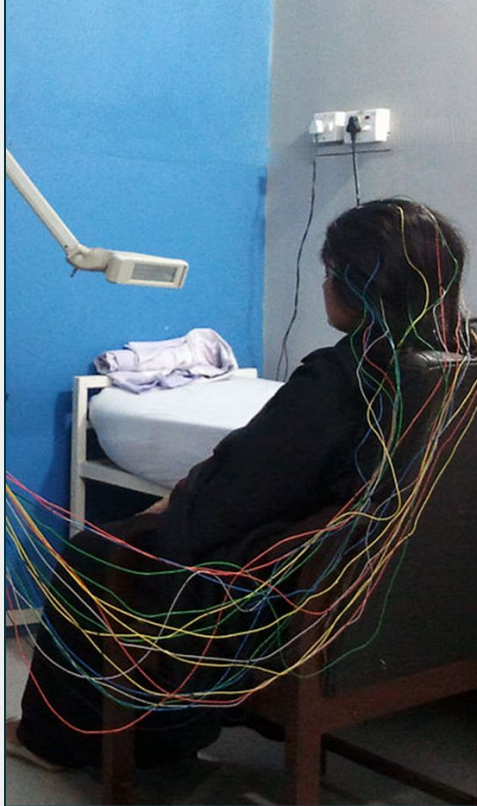


evolution of consumer brain-computer interfaces

towards open-source, high-quality devices
as an alternative to commercial products



evolution of BCIs



agenda

- basics
 - EEG / BCI / neurofeedback
- challenges, chances and risks
- consumer devices
 - overview
 - progress
- DIY / open-source
- security

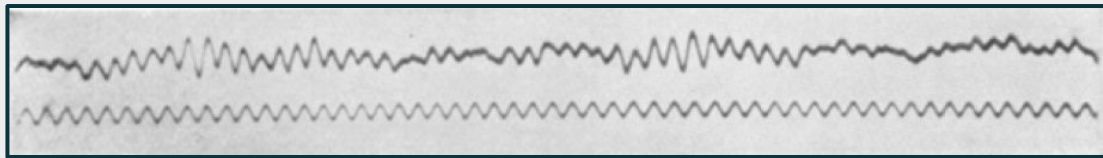
evolution of consumer brain-computer interfaces



basics (eeg & bci)

basics

EEG

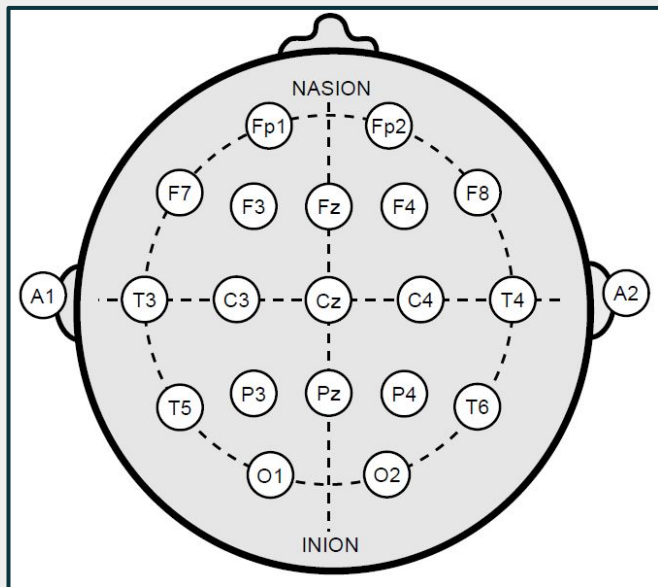


- electroencephalography
 - non-invasive method to measure brain waves
 - first detected in humans in 1924 (Berger et al. 1929)

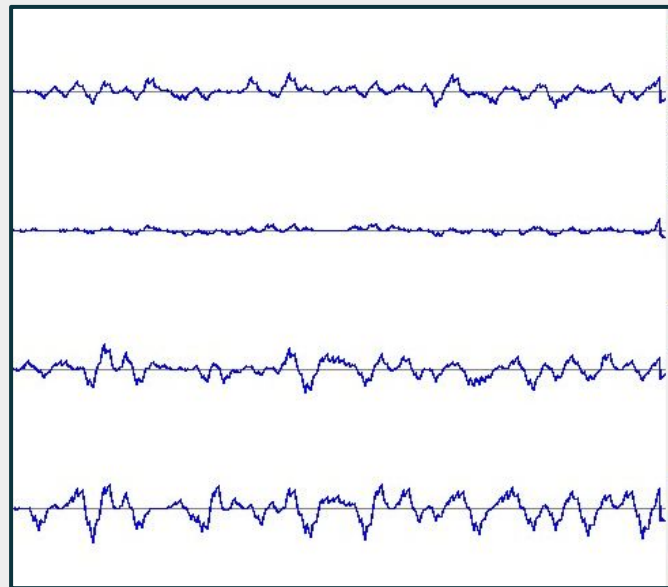


basics

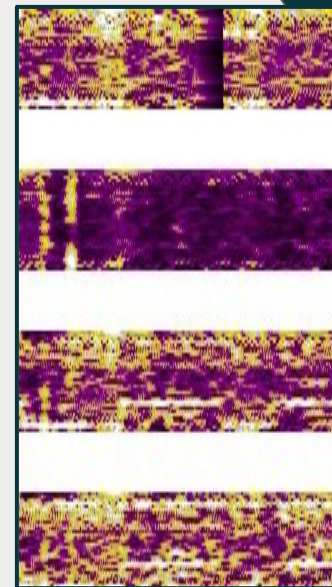
EEG



"10-20" electrode positions



raw data

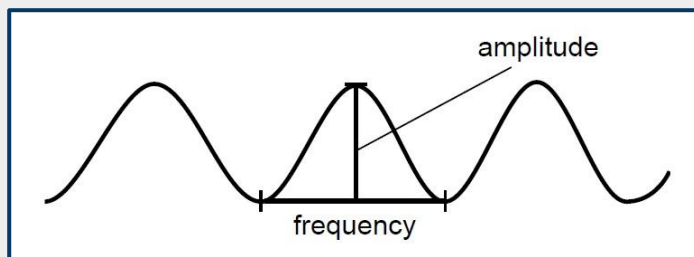


frequencies

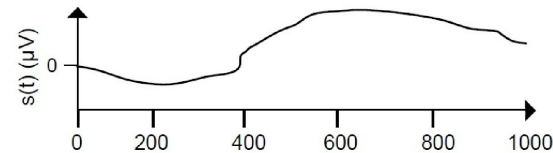
basics

EEG

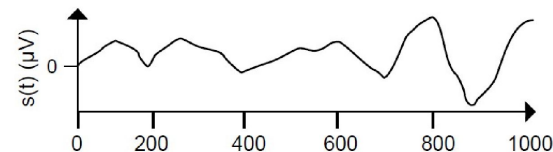
- unmix signals
 - spatially
 - frequency



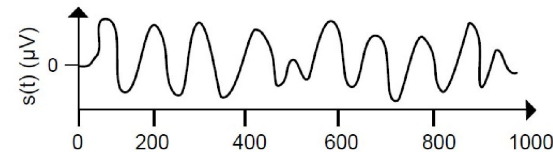
delta
0.5-4 Hz
deep sleep



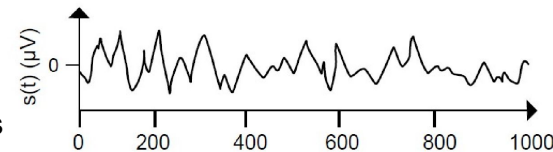
theta
4-8 Hz
sleep /
hypnagogia



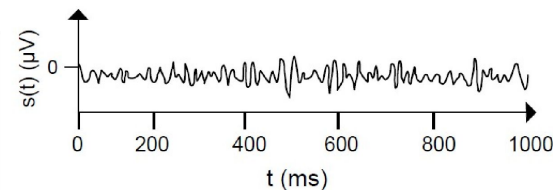
alpha
8-15 Hz
relaxed /
inner focus



beta
15-40 Hz
awake / focus



gamma
40-100 Hz
heightened
perception



basics

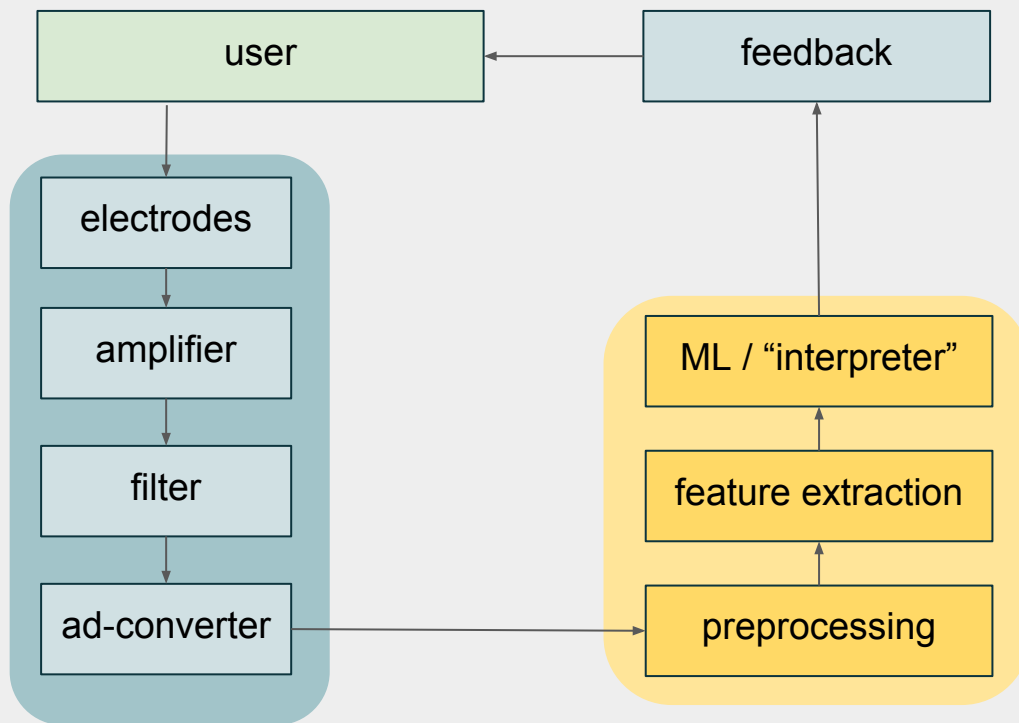
BCI

- Brain-Computer Interfaces
 - control devices by thought
 - **active** → directly controlled by the user
 - **reactive** → in reaction to external stimuli
 - **passive** → enhance user experience

[Zander et. al, 2010]

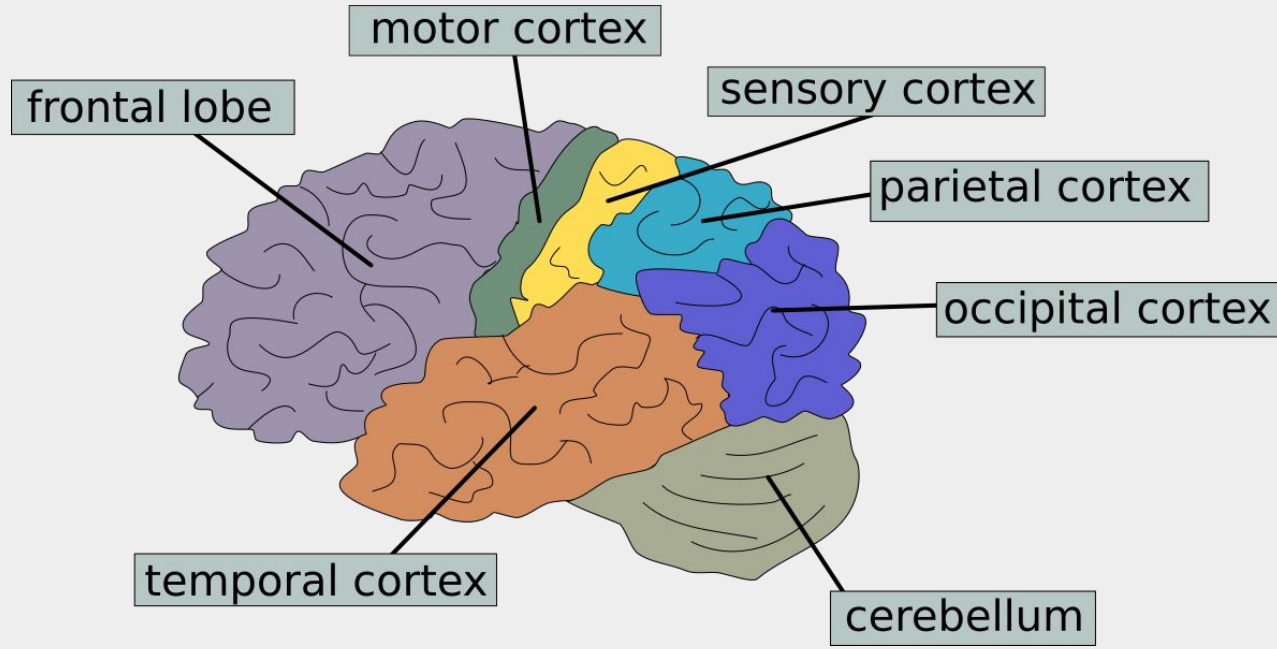
basics

BCI



basics

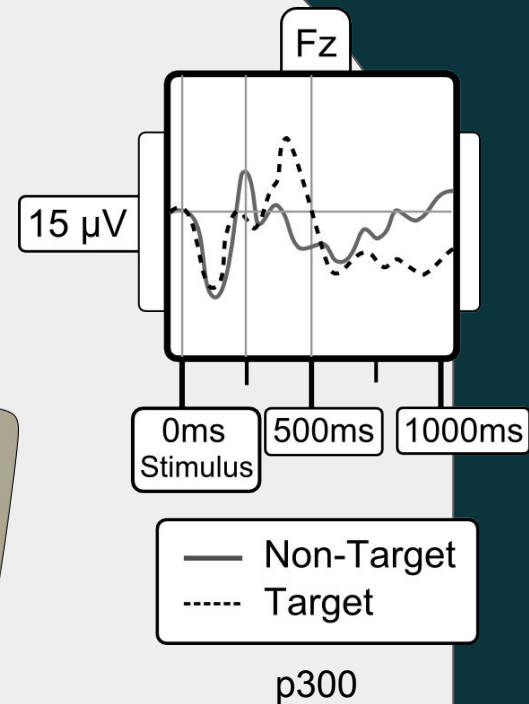
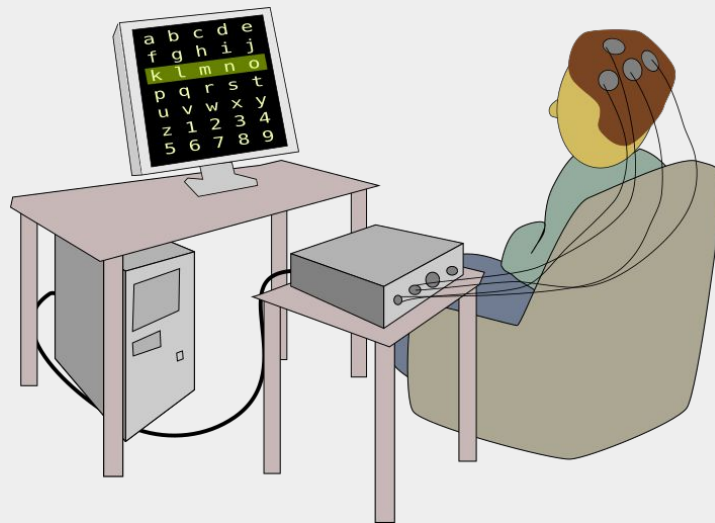
EEG / BCI



basics

BCI applications

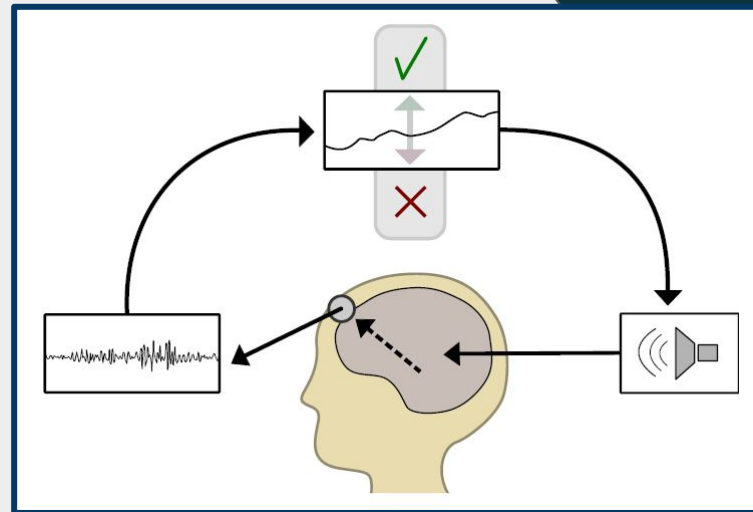
- spell computers
- exoskeletons
- prosthetics



basics

neurofeedback

- presenting interpreted EEG data back to its user → operant conditioning
- typically used to treat
 - seizures (Sterman et. al 2005)
 - anxiety disorders / stress (Hammond et. al 2005)
 - autism (Jarusiewicz et. al 2002)
 - ADD (Arns et. al 2009)



audio feedback loop

EEG / BCI

non-clinical applications

- art installations
 - interactive audio-visual feedback
 - collective neurofeedback

[Kovacevic et al., 2015]

- neurogaming
 - gamification of neurofeedback

[Berka et al., 2010]

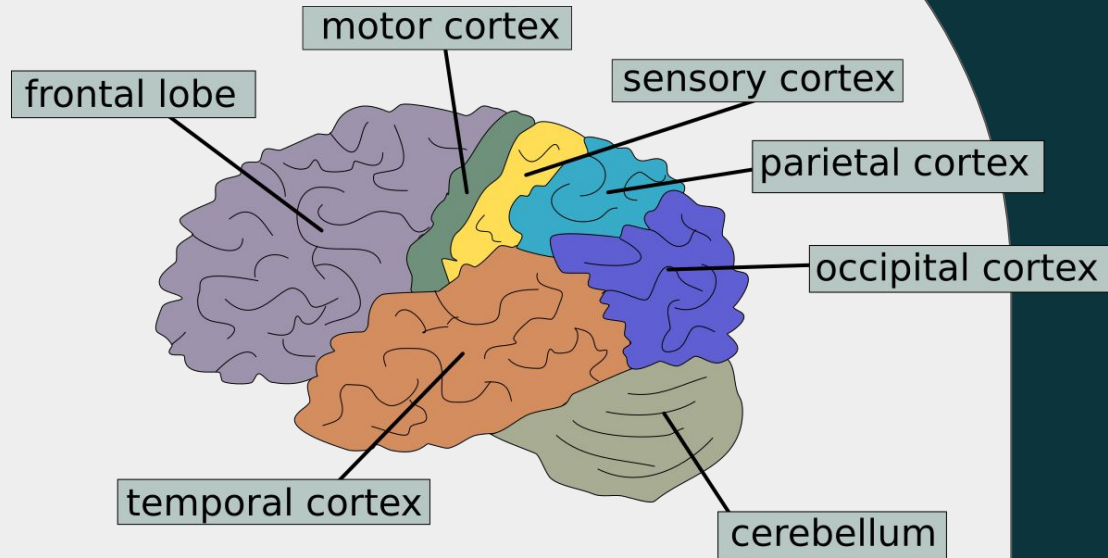


EEG / BCI

non-clinical applications

- combine with tDCS / tACS
 - extreme caution is advised

(Davis 2014)



BCI methods

overview

method	learning	locations	choices	bci type
P300 / P3a / P3b (Polich et. al, 2007)	no	occipital, parietal	many	reactive
SSVEP (Jeffreys et. al, 1972)	no	occipital	many	reactive
SCP (Elbert et. al, 1980)	weeks	parietal	1-2	active
SMR / motor imagery (Pfurtscheller et. al, 2006)	hours - weeks	frontal	2, more with training	active

evolution of consumer
brain-computer interfaces



consumer devices

consumer BCIs

criteria

- cost
- specificity & **reliability** / robustness
 - **signal to noise ratio**
 - electrodes
- hardware & software DOF / hackability
 - exchange parts, electrodes
 - raw data access
- ergonomics
- **product safety & security**

consumer BCIs

overview

device	channels	hackability	cost
NeuroSky MindWave	1	Hardware DIY guide	\$79.99
Emotiv Epoc / Epoc+	14	- guide to build cap - emokit raw data hack	\$399 - \$499 + \$300 for SDK
Emotiv Insight	5	tbd	\$358,95 \$658,95 for SDK
Interaxon Muse	4	SDK	\$299
Melon	not publishing a data sheet yet ;-)		\$99

sources: neurosky.com ; emotiv.com ; choosemuse.com ; melon kickstarter // dec 2015

consumer BCIs

progress

- dry electrodes
 - high impedance, sensitive montage
 - more efficient and accurate algorithms
 - temporal, spatial filters
 - machine learning
- but good signal quality remains essential!

evolution of consumer
brain-computer interfaces



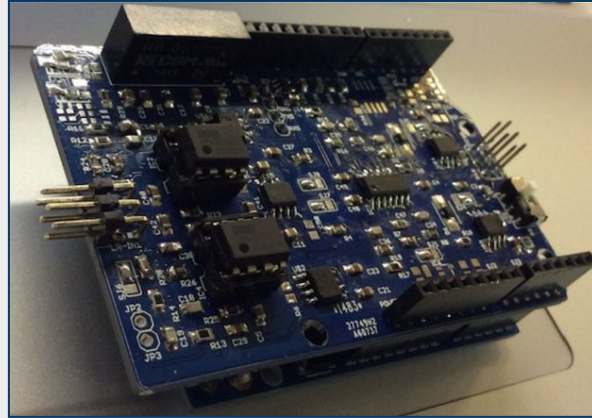
open-source / DIY

open-source BCIs

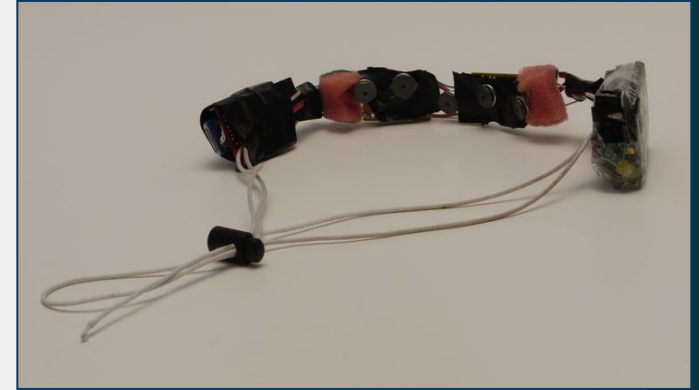
amplifier / adc overview



2011 Maker's DIY 28c3 CCC edition
(source: open-bci.org dec/2015)



Brain-Duino v 0.2



Brain-Duino v 0.3 24 bit

open-source BCIs

amplifier / adc overview

project / device	electrodes	cost	µc / adc
openEEG / SF modularEEG tutorial	2-6	\$200-400	ATMega8
olimex openEEG EEG SMT	5 (active)	€99	ATMega16
openbci.com kit / addon / ganglion	8 16 4	\$499.99 \$899.99 \$99.99	PIC32MX250F128B / TI ADS1299
open-bci.org / psychiclab.net brain-duino	2 (stackable, active)	\$150 / \$299	arduino uno, teensy / analog devices AD7173

SOURCES: openeeg.sourceforge.net ; openbci.com ; open-bci.org ; psychiclab.net // dec 2015

consumer BCIs

electrodes

- material: silver, gold, tin
- types: passive, active (/w amplifier)
- dry
 - pins, discs, bendable
- wet / gel
 - disposable, cup



(source: openeeg.sourceforge.net dec/2015)



(source: open-bci.org dec/2015)

open-source / DIY software

- OpenVibe for linux / win / osx
- BrainBay for win
- Neuromore for linux / osx

evolution of consumer
brain-computer interfaces



privacy issues

consumer BCIs

privacy issues

Brainwave privacy standard “is needed” to prevent spying on EEG scan data, researchers warn

source: <http://www.welivesecurity.com/2014/03/14/brainwave-privacy-standard-is-needed-to-prevent-spying-on-eeeg-scan-data-researchers-warn/> / dec 2015

Security

Boffins propose brainwave privacy standard

EEG data can predict illness, and app-makers are storing it in the cloud ...

source: www.theregister.co.uk/2014/03/14/boffins_propose_brainwave_privacy_standard/ / dec 2015

consumer BCIs

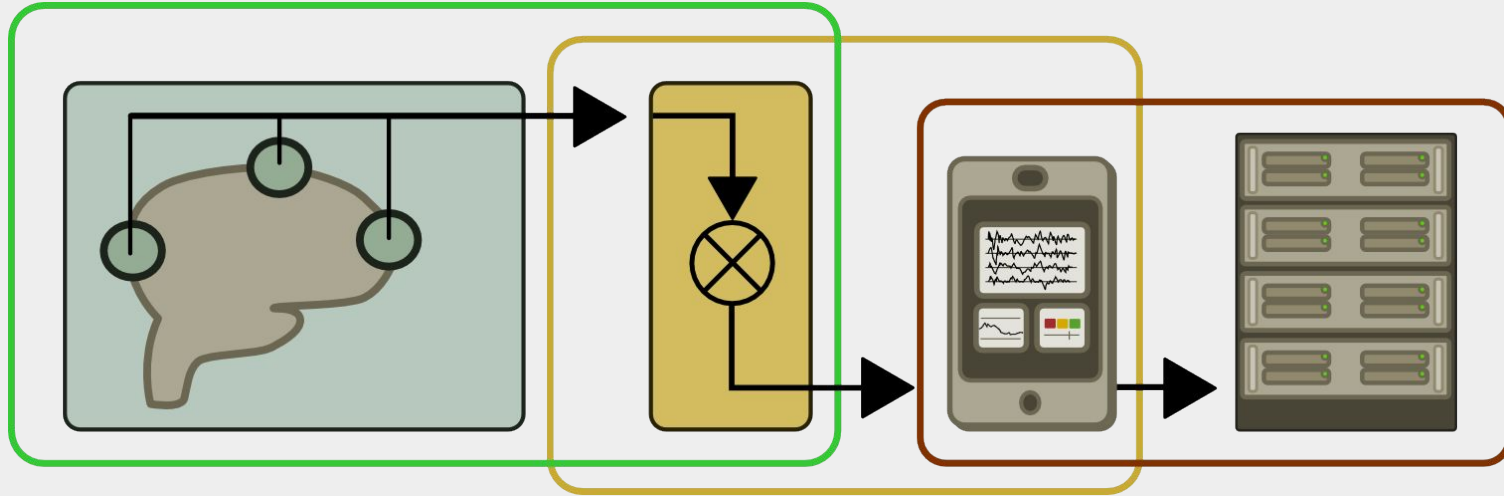
privacy issues

leaking sensitive user information

- health conditions / cognitive performance
→ comparison to normative databases / qEEG, P300
et al. 2009)
- PIN-codes, month of birth, locations, known people
→ P300 (Martinovic et al. 2012)

consumer BCIs

privacy issues

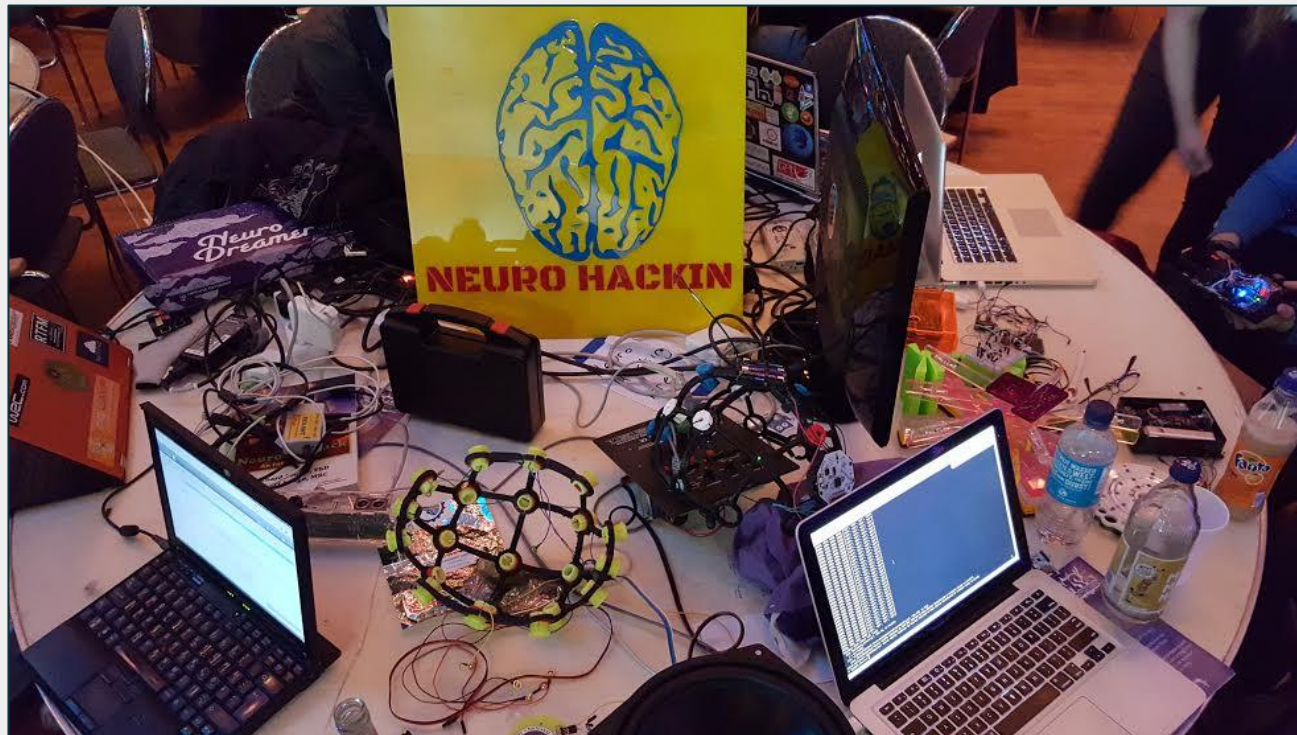


consumer BCIs

countermeasures?

- privacy standard is needed
 - ideas for communication protocols
- raw data encryption
- offline pre-processing of raw data
- openPDS
- ... ?

call for participation!
discuss, try out, test, develop



thank you for listening!

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