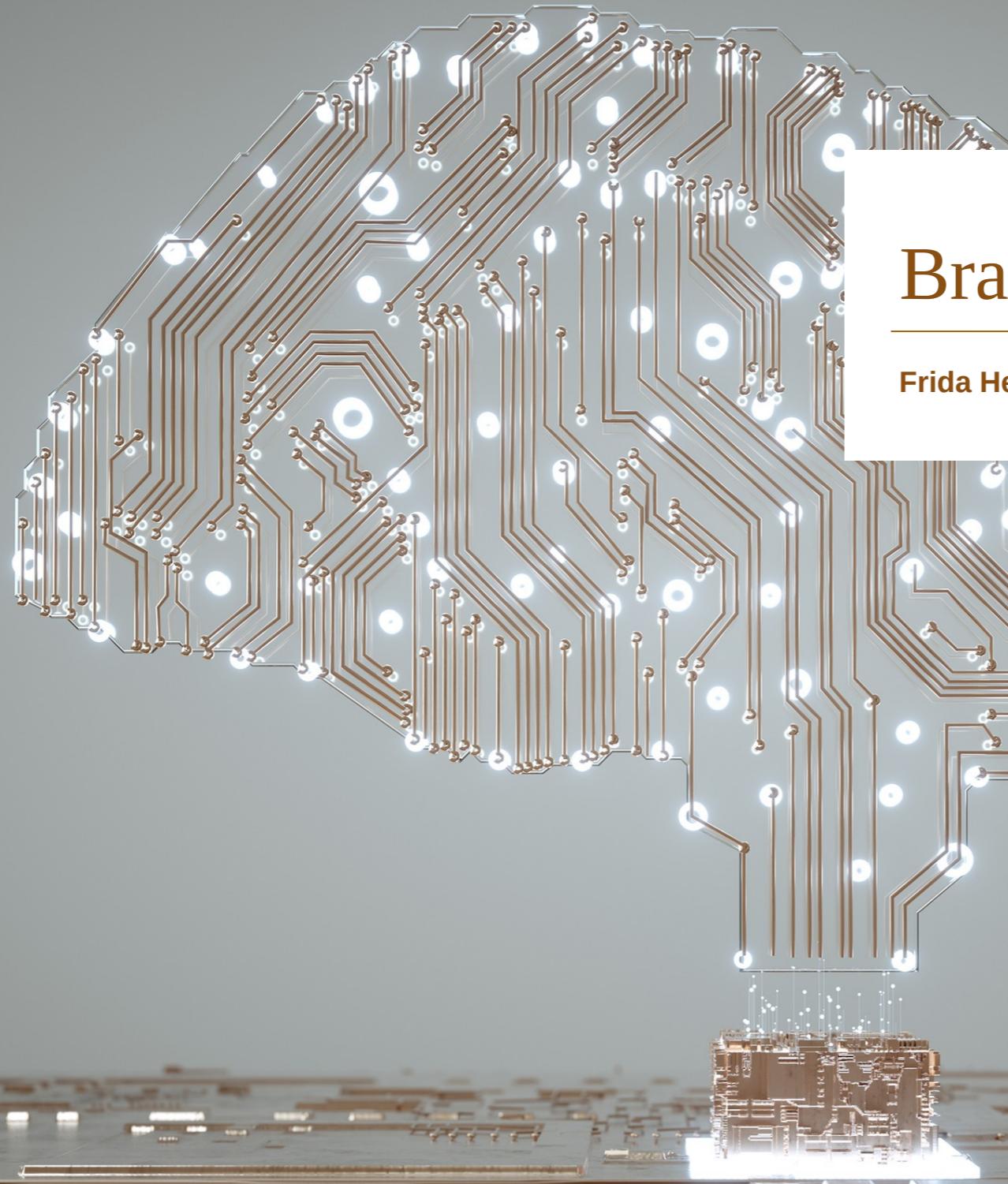




LUND  
UNIVERSITY



# Brain-Computer Interfaces

Frida Heskebeck, Frida(y) seminar, 2022-02-18



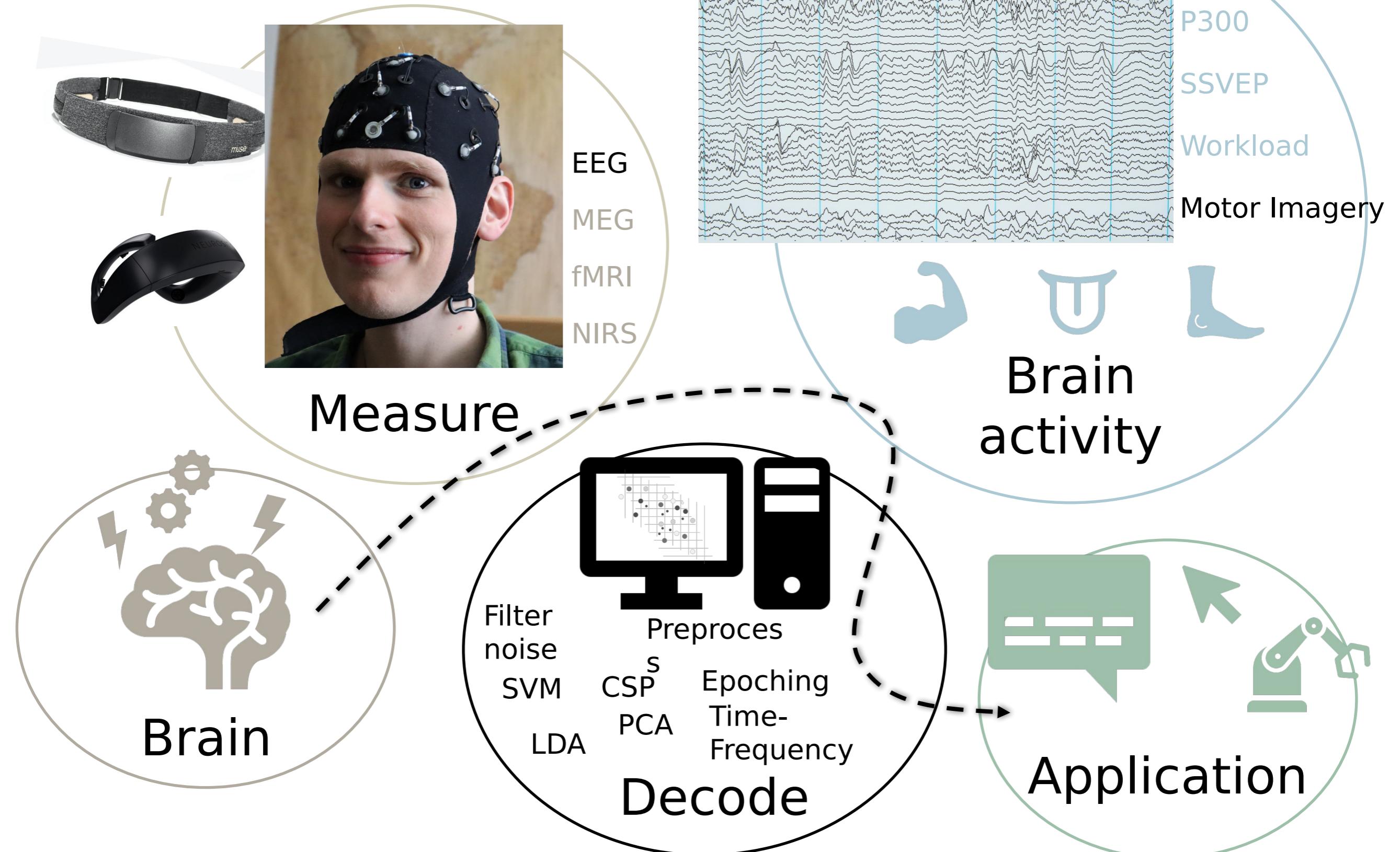
# Outline

- Introduction to Brain-Computer Interfaces
- BCI @ Automatic control
- My research

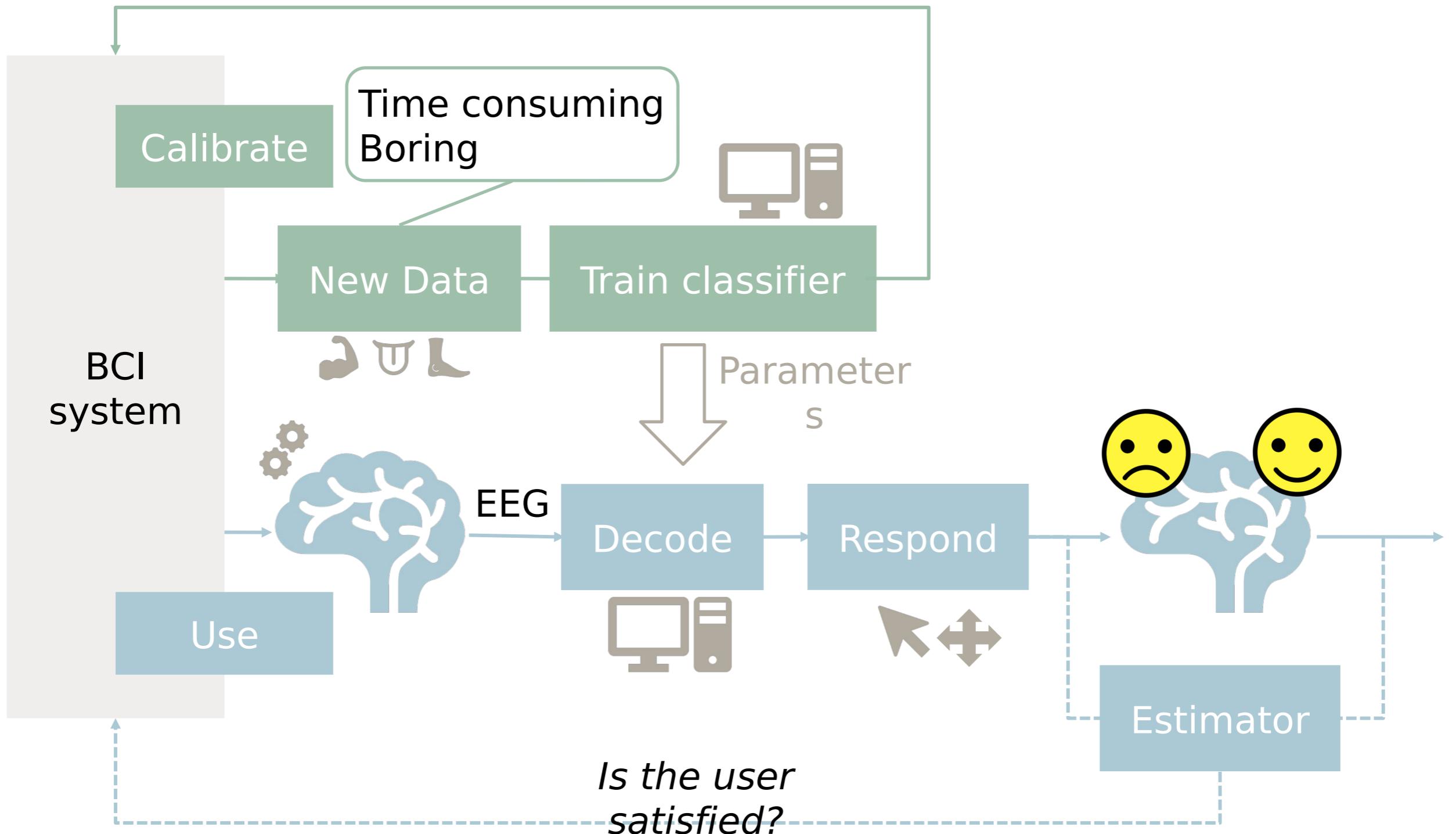
The image shows a hand-drawn silhouette of a human brain against a white background. Overlaid on the brain are numerous mathematical equations and diagrams, suggesting a connection between cognitive functions and mathematical concepts. Some of the visible equations include:

- $\int x = \frac{1}{2} x^2 - C \left( \frac{1}{2} x^2 + C \right)^{\frac{1}{2}} = \frac{1}{2} x^2 - \frac{1}{2} \left( \frac{a}{b} \right)^2 f(x) = \frac{a^m}{b^m} f(x)$
- $F = \frac{mv}{\sqrt{1-\mu^2/c^2}} + \frac{mv \cdot (u_0/c^2)}{(1-\mu^2/c^2)^2}$
- $Q = mc \Delta t$
- $\lim_{\Delta y \rightarrow 0} \frac{f(x_0, y_0 + \Delta y) - f(x_0, y_0)}{\Delta y}$
- $2+2=4$
- $\Delta = \sqrt{P(P-a)}$
- $AB = \sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}$
- $2x + bx + cx = 0$
- $h = \sqrt{a_x b_x} = \frac{a_x b_x}{c}$
- $E = mc^2$
- $a^2 - b^2 = (a-b)(a+b)$
- $f(x) = a(x-x_1)(x-x_2)$
- $C(x) = a(x-x_1)(x-x_2)$
- $S = \frac{a^m}{b^m} = \frac{b^m}{a^m}$
- $H_2O$
- $\cos \alpha + \cos \beta = 2 \cos \frac{\alpha+\beta}{2} \cos \frac{\alpha-\beta}{2}$
- $\log_b a = \frac{\log_c a}{\log_c b}$
- $\sin \alpha + \sin \beta = 2 \sin \frac{\alpha+\beta}{2} \cos \frac{\alpha-\beta}{2}$
- $Z = \frac{1}{\sqrt{2} \pi} e^{-\theta^2/2}$
- $\int_0^\infty \frac{\operatorname{erf}(\sqrt{x})}{e^x} dx = \frac{\sqrt{2}}{2}$
- $Q = mc \Delta t$
- $\sqrt{a^2 + b^2}$

# What is a BCI?



# Control loop



# Outline

- Introduction to Brain-Computer Interfaces
- BCI @ Automatic control
- My research

The image contains a complex web of handwritten mathematical formulas and diagrams, heavily obscured by black ink. Key elements include:

- A large integral at the top left:  $\int x = \frac{1}{2} x^2 - C \left( \frac{1}{2} x^2 + C \right)^{\frac{1}{2}} = \frac{1}{2} x^2 - \frac{1}{2} \left( \frac{a}{b} \right)^2 f(x) = \dots$
- An equation for force:  $F = \frac{m a}{\sqrt{1 - \mu^2/c^2}} + \frac{m \cdot (\mu a)/c^2}{(-\mu^2/c^2)^2}$
- A diagram of a right-angled triangle with legs  $a$  and  $b$ , hypotenuse  $c$ , and height  $h$ . It includes the formula  $h = \sqrt{a \cdot b} = \frac{a \cdot b}{c}$ .
- A limit definition of a derivative:  $\lim_{\Delta y \rightarrow 0} \frac{f(x_0, y_0 + \Delta y) - f(x_0, y_0)}{\Delta y}$ .
- A Pythagorean theorem application:  $AB = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$ .
- A quadratic equation:  $ax^2 + bx + cx = 0$ .
- The mass-energy equivalence formula:  $E = mc^2$ .
- A chemical structure with labels H, Cl, N, OH, and H<sub>2</sub>O.
- Trigonometric identities:  $\cos \alpha + \cos \beta = 2 \cos \frac{\alpha + \beta}{2} \cos \frac{\alpha - \beta}{2}$  and  $\sin \alpha + \sin \beta = 2 \sin \frac{\alpha + \beta}{2} \cos \frac{\alpha - \beta}{2}$ .
- A formula involving a circle with radius  $r$ :  $Z = \frac{1}{\sqrt{2} \pi} \theta r^2$ .
- A definite integral:  $\int_0^\infty \frac{\operatorname{erf}(\sqrt{x})}{e^x} dx = \frac{\sqrt{2}}{2}$ .
- The mass-energy equivalence formula again:  $Q = mc^2 t$ .

# BCI @ LU

Bo Bernhardsson



Department of  
Automatic  
Control

Maria Sandsten



Department of  
Mathematical  
Statistics

Mikael Johansson

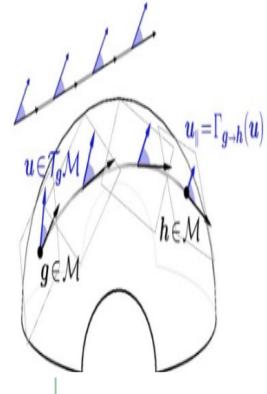


Department of  
Psychology

# BCI @ Automatic control



# BCI @ Automatic control



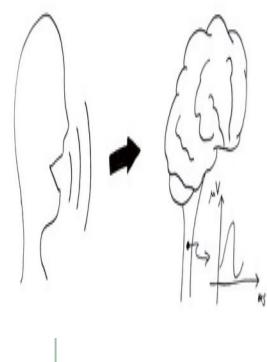
## Domain Adaptation for Attention Steering

- Johanna Wilroth
- 2020



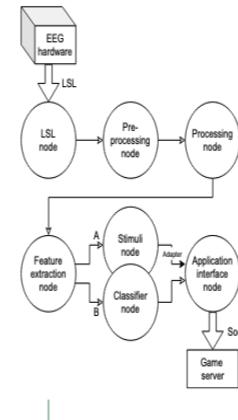
## Audiovisual processing in the wild by using video-based lip reading software

- Louise Karsten & Sara Enander
- 2022



## Optimal signal processing of brain signals used for automatic control of a hearing device

- Julia Adlercreutz
- 2022



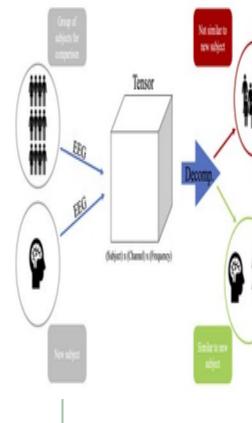
## Implementation of a Simple Asynchronous Pipeline Framework (SAPF) for construction of real-time BCI systems

- Tom Andersen
- 2021



## Audiovisual processing in the wild by using video-based lip reading software

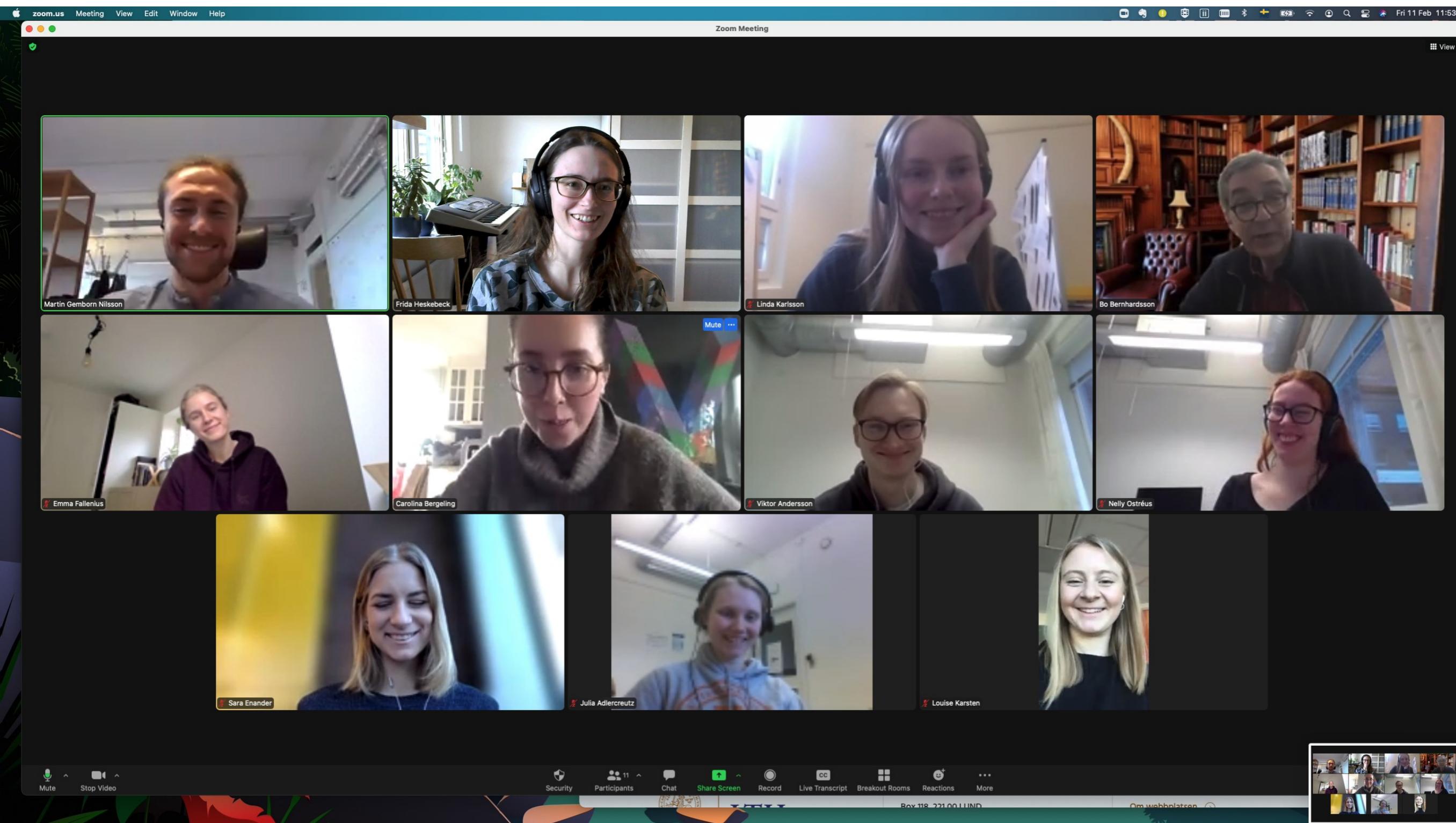
- Nelly Ostreus & Viktor Andersson
- 2022



## Tensor Decomposition of EEG signals

- Emma Fallénius & Linda Karlsson
- 2022

# BCI @ Automatic control



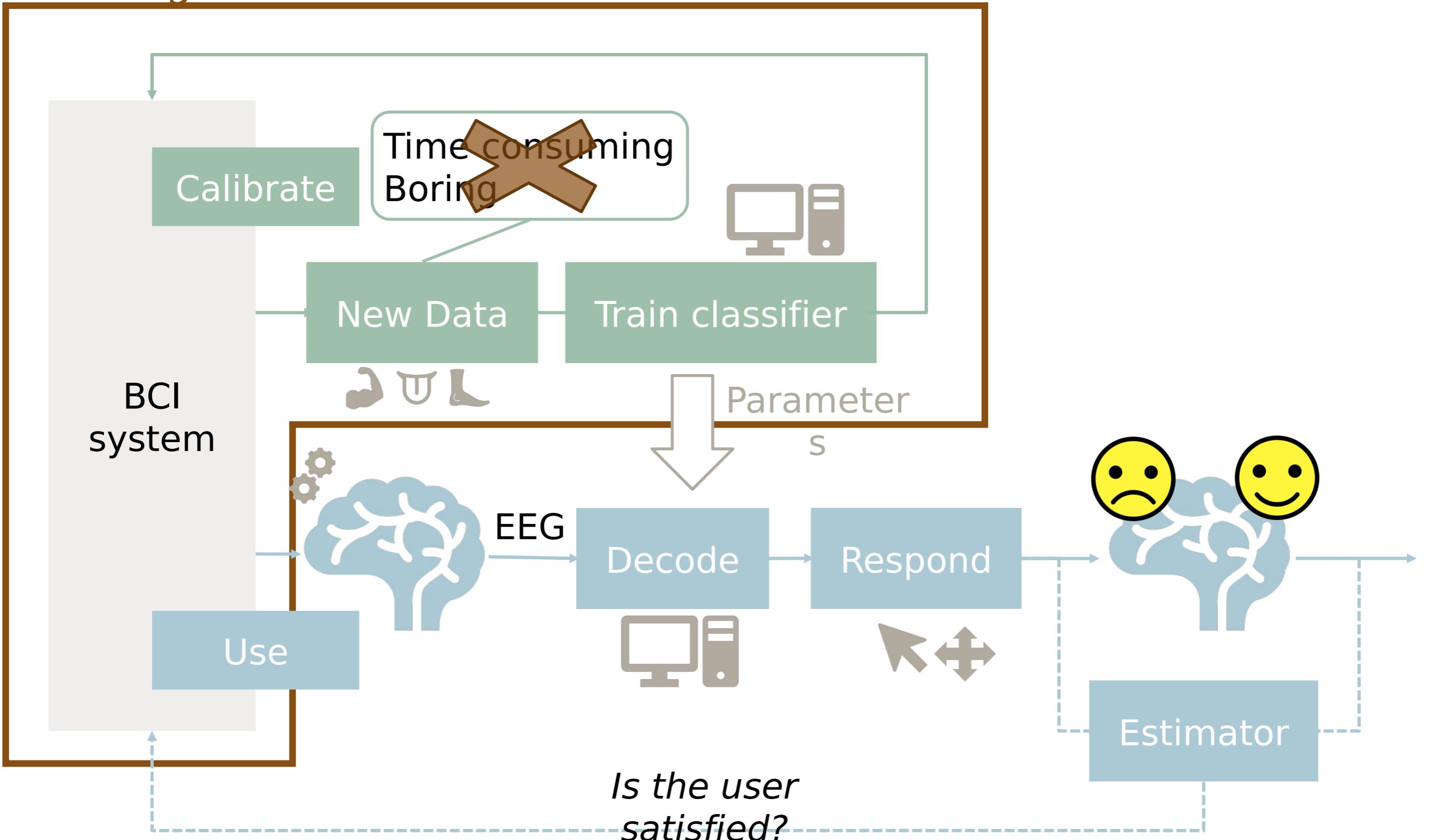
# Outline

- Introduction to Brain-Computer Interfaces
- BCI @ Automatic control
- My research

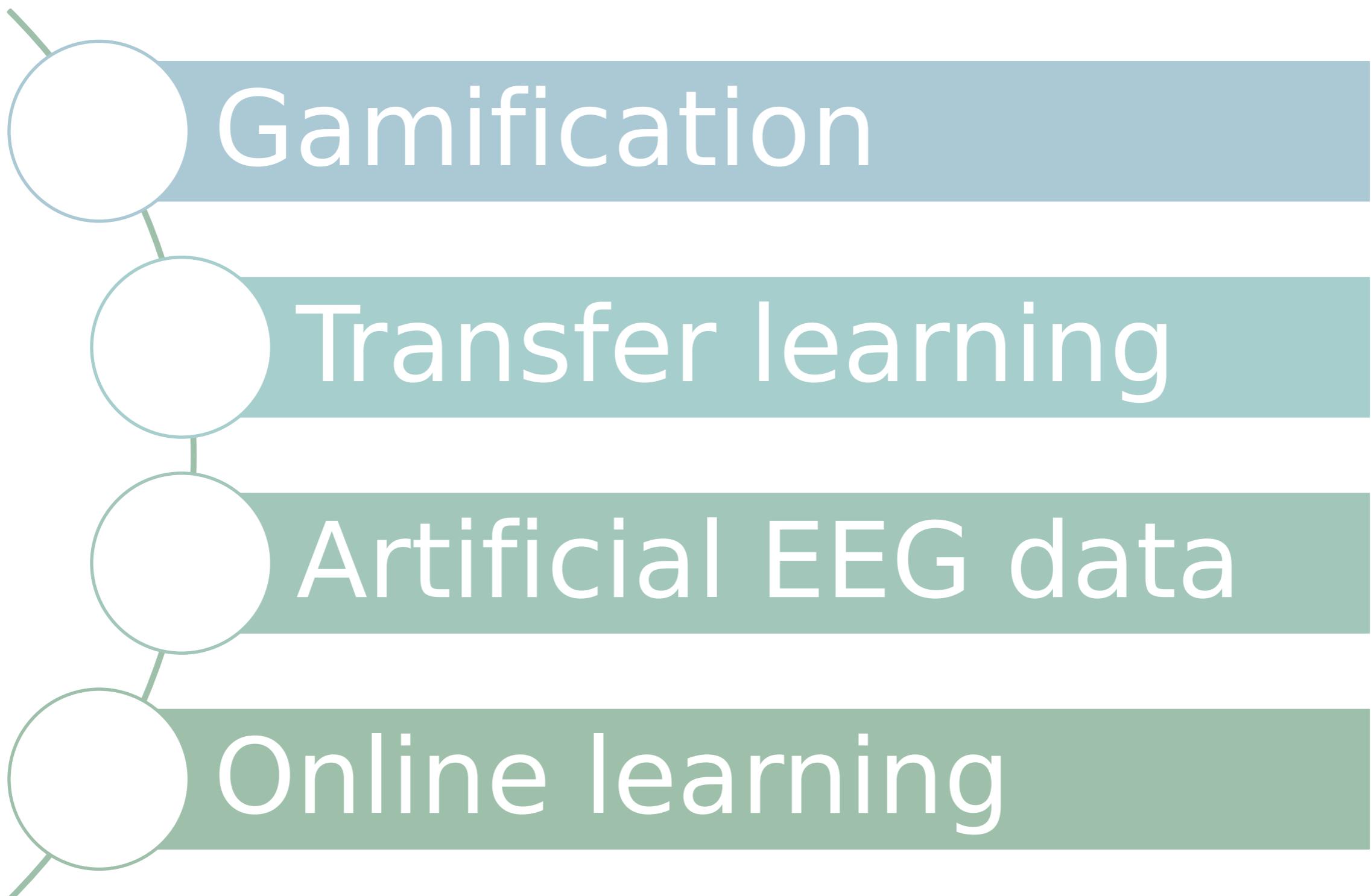
The image contains a complex web of handwritten mathematical formulas and diagrams, heavily obscured by black ink. Key elements include:

- A large integral at the top left:  $\int x = \frac{1}{2} x^2 - C \left( \frac{1}{2} x^2 + C \right)^{\frac{1}{2}} = \frac{1}{2} x^2 - \frac{1}{2} \left( \frac{a}{b} \right)^2 f(x) = \dots$
- A formula for force:  $F = \frac{m a}{\sqrt{1 - \mu^2/c^2}} + \frac{m \cdot (\mu a)/c^2}{(-\mu^2/c^2)^2}$
- A diagram of a right-angled triangle with legs  $a$  and  $b$ , hypotenuse  $c$ , and height  $h$ . It includes the Pythagorean theorem:  $a^2 + b^2 = c^2$ .
- A limit definition of a derivative:  $\lim_{\Delta y \rightarrow 0} \frac{f(x_0, y_0 + \Delta y) - f(x_0, y_0)}{\Delta y}$ .
- A distance formula:  $AB = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$ .
- A quadratic equation:  $ax^2 + bx + cx = 0$ .
- The mass-energy equivalence formula:  $E = mc^2$ .
- A chemical structure with a chlorine atom: Clc1ccc(cc1)N(C)c2cc(O)cc(Cl)c2.
- A diagram of a circle with radius  $r$  and circumference  $2\pi r$ .
- A trigonometric identity:  $\cos \alpha + \cos \beta = 2 \cos \frac{\alpha + \beta}{2} \cos \frac{\alpha - \beta}{2}$ .
- A logarithmic equation:  $\log_a b = \frac{\log_c b}{\log_c a}$ .
- A trigonometric identity:  $\sin \alpha + \sin \beta = 2 \sin \frac{\alpha + \beta}{2} \cos \frac{\alpha - \beta}{2}$ .
- A formula for  $Z$ :  $Z = \frac{1}{\sqrt{2\pi}} e^{-\theta^2/2}$ .
- An integral involving the error function:  $\int_0^\infty \frac{\operatorname{erf}(\sqrt{x})}{e^x} dx = \frac{\sqrt{2}}{2}$ .
- The mass-energy equivalence formula again:  $Q = mc^2$ .

# My focus



# Calibration reduction



# Multi-Armed Bandits



- Stationary bandits
- Non-stationary bandits
- Mortal bandits
- Sleeping bandits
- ...

???



Exploration vs Exploitation

# Multi-Armed Bandits in BCI

Keyboard

- Which is the fastest way to find the correct key?

BCI button

- What is the best class to use to push the button?

Our thoughts

- Attention steering
- Transfer learning
- What new data to collect in calibration?



LUND  
UNIVERSITY

# References

- [gamification] Flatla, D. R., Gutwin, C., Nacke, L. E., Bateman, S., & Mandryk, R. L. (2011, October). Calibration games: making calibration tasks enjoyable by adding motivating game elements. In *Proceedings of the 24th annual ACM symposium on User interface software and technology* (pp. 403-412).
- [MAB, BCI-button] Fruitet, J., Carpentier, A., Munos, R., & Clerc, M. (2012). Bandit Algorithms boost Brain Computer Interfaces for motor-task selection of a brain-controlled button. In *Advances in Neural Information Processing Systems* (Vol. 25, pp. 458-466). Neural Information Processing Systems (NIPS) Foundation.
- [Online learning] Grizou, J., Iturrate, I., Montesano, L., Oudeyer, P. Y., & Lopes, M. (2014, June). Calibration-free BCI based control. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 28, No. 1).
- [Calibration, artificial EEG data] Lotte, F. (2015). Signal processing approaches to minimize or suppress calibration time in oscillatory activity-based brain–computer interfaces. *Proceedings of the IEEE*, 103(6), 871-890.
- [Transfer learning] Lotte, F., Bougrain, L., Cichocki, A., Clerc, M., Congedo, M., Rakotomamonjy, A., & Yger, F. (2018). A review of classification algorithms for EEG-based brain–computer interfaces: a 10 year update. *Journal of neural engineering*, 15(3), 031005.
- [MAB, keyboard] Ma, T., Huggins, J. E., & Kang, J. (2021, December). Adaptive Sequence-Based Stimulus Selection in an ERP-Based Brain-Computer Interface by Thompson Sampling in a Multi-Armed Bandit Problem. In *2021 IEEE International Conference on Bioinformatics and Biomedicine (BIBM)* (pp. 3648-3655). IEEE.