Systems Neuroscience
& Neurotechnology Unit

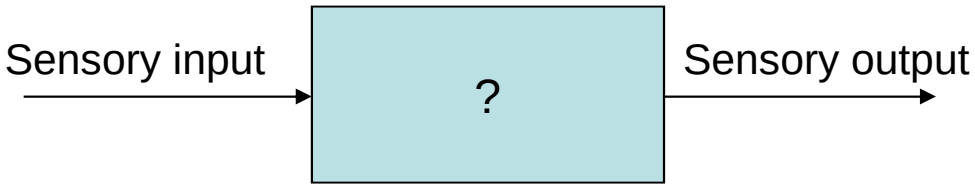
Compactly Supported Radial Basis Functions for the Multivariate Approximation of Neural Field Potentials in MEA Measurements

Overview

- Initial situation
- Objectives
- Support Vector machines (SVMs)
- Materials and Methods
- Results
- Summary and Outlook
- Bibliography

Initial situation

- Research, with regard to multiple scales of the structure of the human brain is meanwhile very advanced and largely investigated.
- But up to now, the relationship between signals at one scale and those at others is poorly understood.
- One of the most fascinating questions in neuroscience is the relationship between neural activity of individual neurons and their behavior or interaction within the neural system.
- The complete progress of understanding the functioning of the human brain can approximately be limited to the fact, that sensory input and output operations are playing the key role



- But little is known about the interactions and information process between this operations.

Objectives

- Mapping physiological features with in individual brain areas represents a powerful tool to understand how brain function is organized and how it takes place.

Support Vektor Maschinen (SVMs)
with compactly supported RBFs

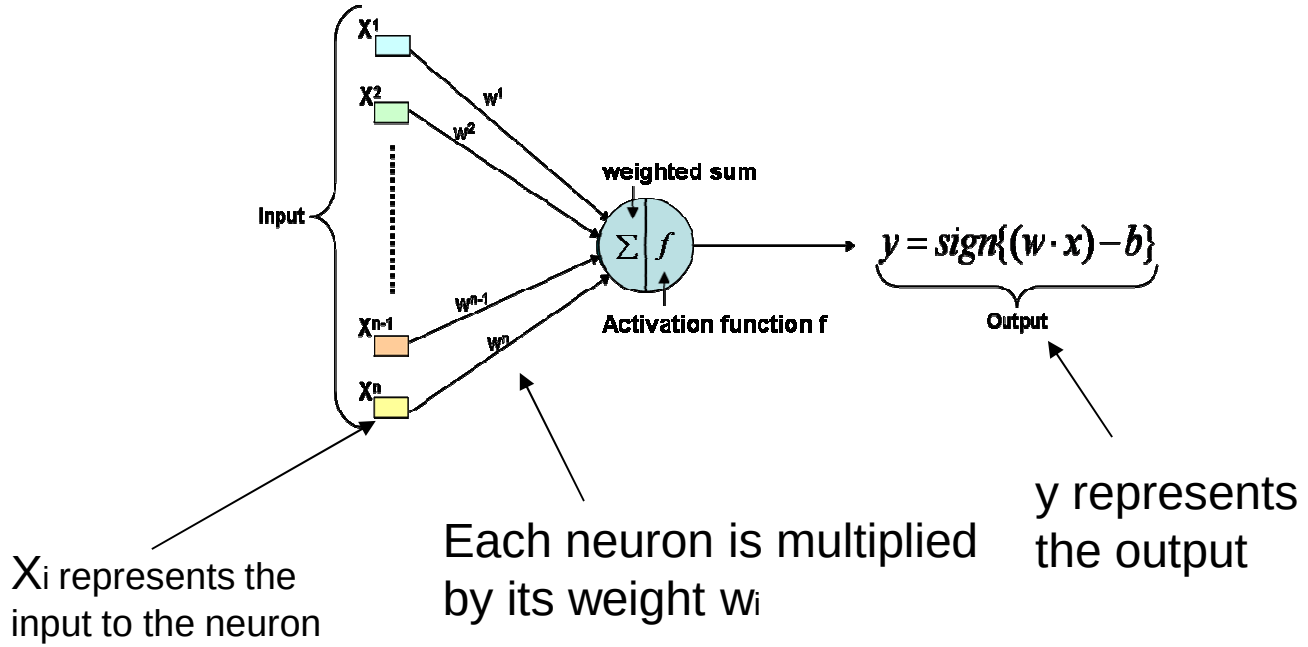
- 64-channel electrophysiological recordings by placing a flexible multielectrode array on the auditory cortex of a adult Wistar rat.

- Basically, when plotting or imaging recorded data the result will be a kind of a "snap-shot"

Intention
→„Dynamical map“
→ Each point is given a value
→ Transform the coarse grid into a **continuum**

Neural Networks - Forerunner

- In 1957 Frank Rosenblatt invented the first algorithmically described neural network (i.e. first model of a learning machine)
  →Rosenblatts perceptron
- This model is deemed to be the first model for learning with a *"teacher".*
- *Based on a "Binary threshold unit"*



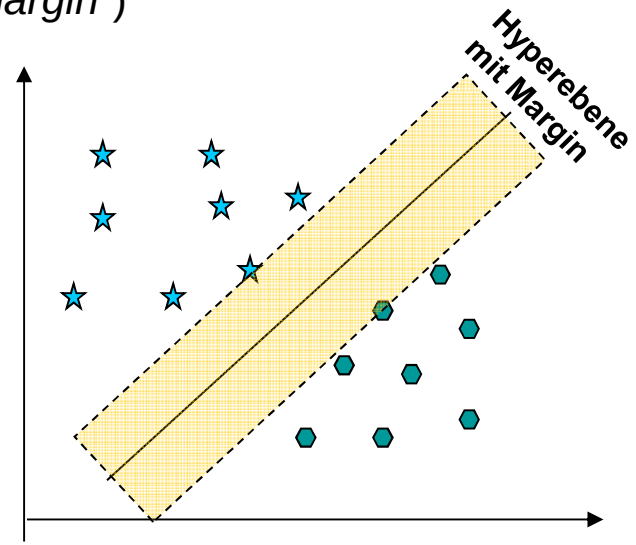
Support Vektor Machines - SVMs

- Developed by Vladimir Vapnik & Aleksei Chervonenkis in 1995
- Firmly grounded in the framework of statistical learning theory
- „Based on Support Vectors (SV)“
- Idea: Seperation of a dataset into two classes
  - ⇆ Hyperplane + Margin
    - High accuracy and low error probability („*Hard margin*“)

- Classification
- Regression

Boolean value (true/false; 1/-1)

Real value or number



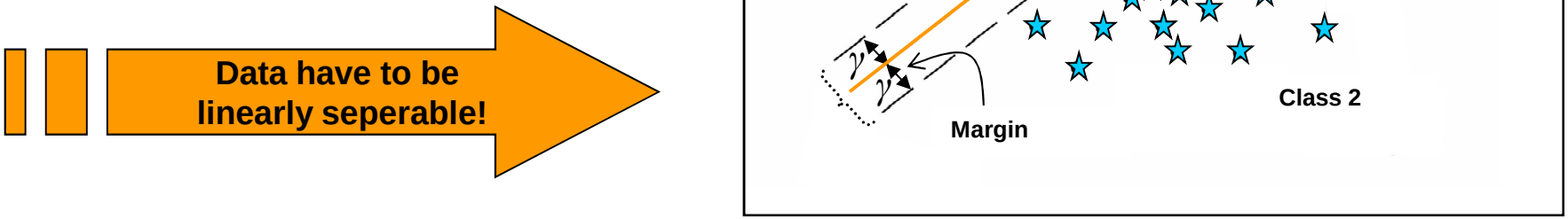
Principle - SVMs

- *Initial situation*: Trainingset / Examples as „*Learning-Input*“
  - Here the class membership is clear

  ↪ Creating the hyperplane for seperation

- Maximize the distance of those objects nearest to the hyperplane
  - → Large margin should reliably classify the data

- „Support Vectors (SVs)“
  - Define the orientation and position of the hyperplane

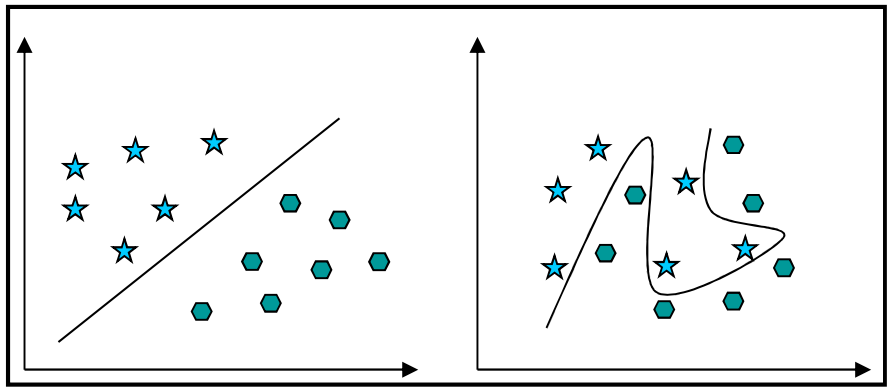


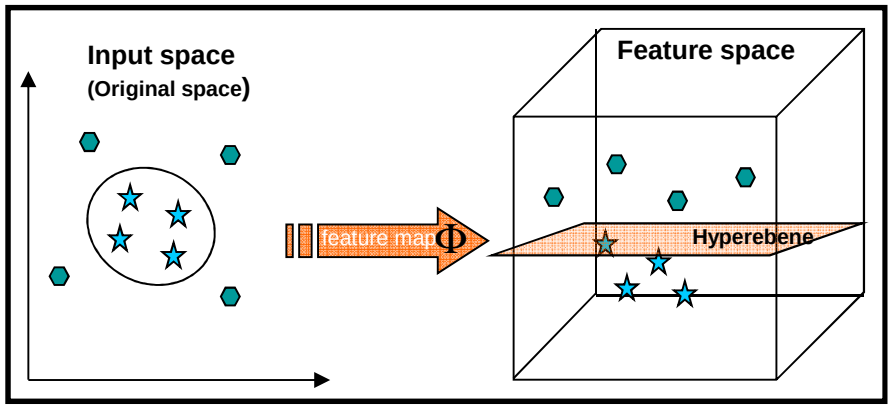
Principle - SVMs

- Linearly seperable would be desirable ≠ Real life applications

„Kernel – Trick“

- Requirement: Transform trainingdata into higher dimensional space
  - Non-linear (nL) → Linear (L)
  - Define the L hyperplane
  - Back-transformation→ nL hyperplane seperating the set into two classes.
  - Up-transformation
  - Back- transformation





Kernel-Trick

Use of kernel-functions (RBFs) for the description of the hyperplane

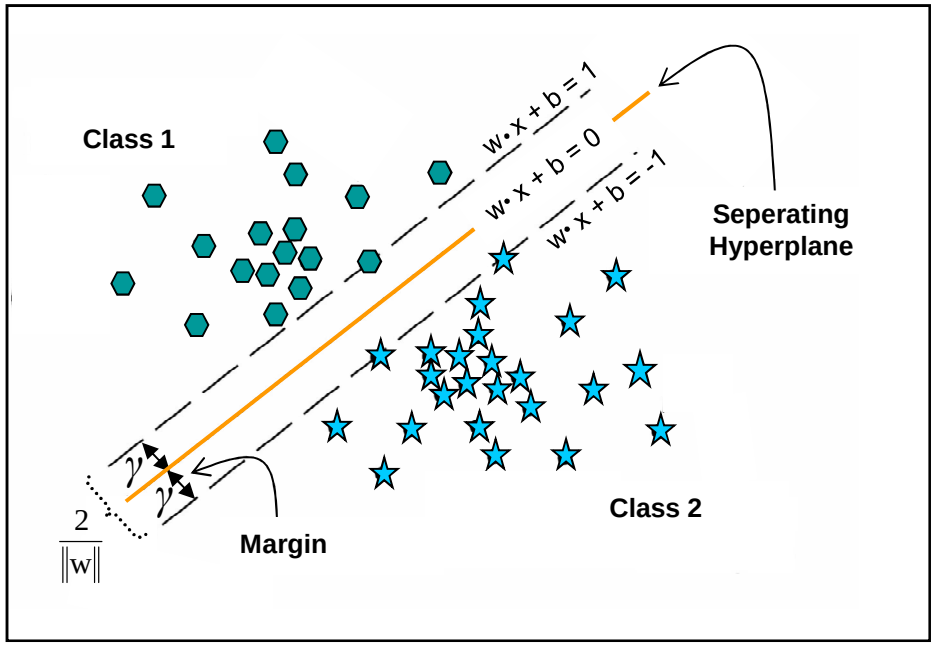
Theory - SVMs

- We are given empirical data

$$\{(x_1, y_1),\ (x_2, y_2), \ldots, (x_n, y_n)\}$$

wobei $y_i \in \{\pm 1\}$, $x_i \in R^d$

- SVM determines a hyperplane on the basis of the trainingdata, which divides the data
  - Maximize the smallest distance to the hyperplane



→*„Training“*

→Construct/estimate the hyperplane

→Serves as decicion-function

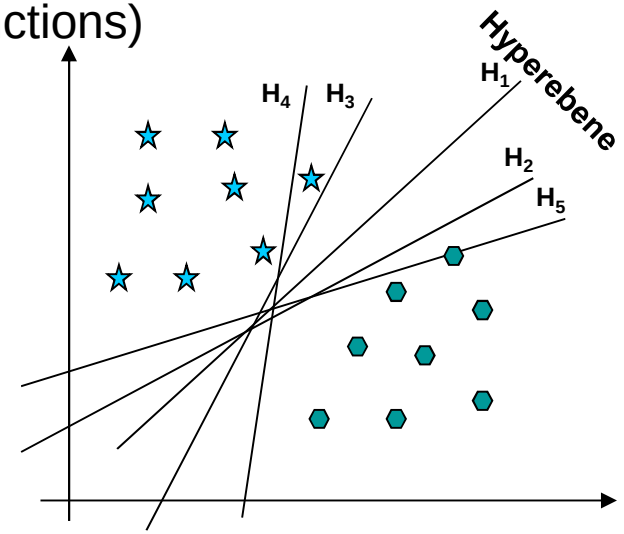
$$y_i = \operatorname{sgn}(\langle w \cdot x_i \rangle + b)$$

Depending on where the examples are- relative to the hyperplane (above or below)- the value is calculated.

$$\begin{cases} w \cdot x_i + b \geq +1 & \text{für } y_i = +1 \\ w \cdot x_i + b \leq -1 & \text{für } y_i = -1 \end{cases}$$

Theory – Linearly seperable Data

- Diverse learning algorithms use hyperplanes (linear functions)
  → ∞ Hyperplanes

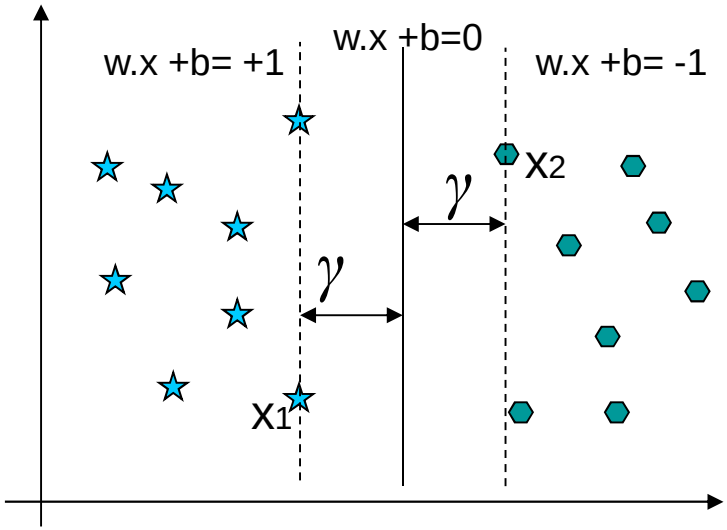


→ SVMs are searching for the one hyperplane with maximum margin ⇔

- Hyperplane with minimal quadratic norm

$$\|w\|^2 \quad , \quad y_i(\langle w \cdot x_i \rangle + b) \geq 1 \quad \text{für } \forall x_i$$

→ Maximization of γ ⇔ minimization of $\|w\|^2$



Optimization problem

minimize: $J(w,b) = \frac{1}{2}\|w\|^2$

subject to: $\forall i \, [y_i(w \cdot x_i + b) \geq 1]$

Theory – Non – linearly seperable Data

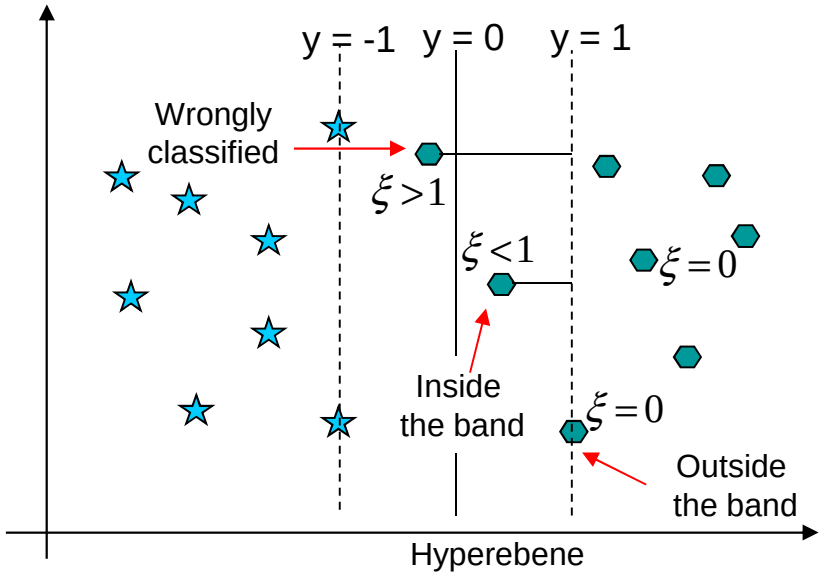
- In real : Trainingsset not linearly seperable

⇨ Change the Optimization problem

  - Constraints can be infringed allowing for some errors (*Soft Margin*)
  - Slack variables ξ_i

Three possible cases

- Vector outside the band (correct classified) $y_i(w \cdot x_i + b) \geq 1$
- Vector inside the band (correct classified) $0 \leq y_i(w \cdot x_i + b) < 1$
- Vector wrongly classified $y_i(w \cdot x_i + b) < 0$



Optimization problem

minimize: $J(w,b) = \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{m}\xi_i$

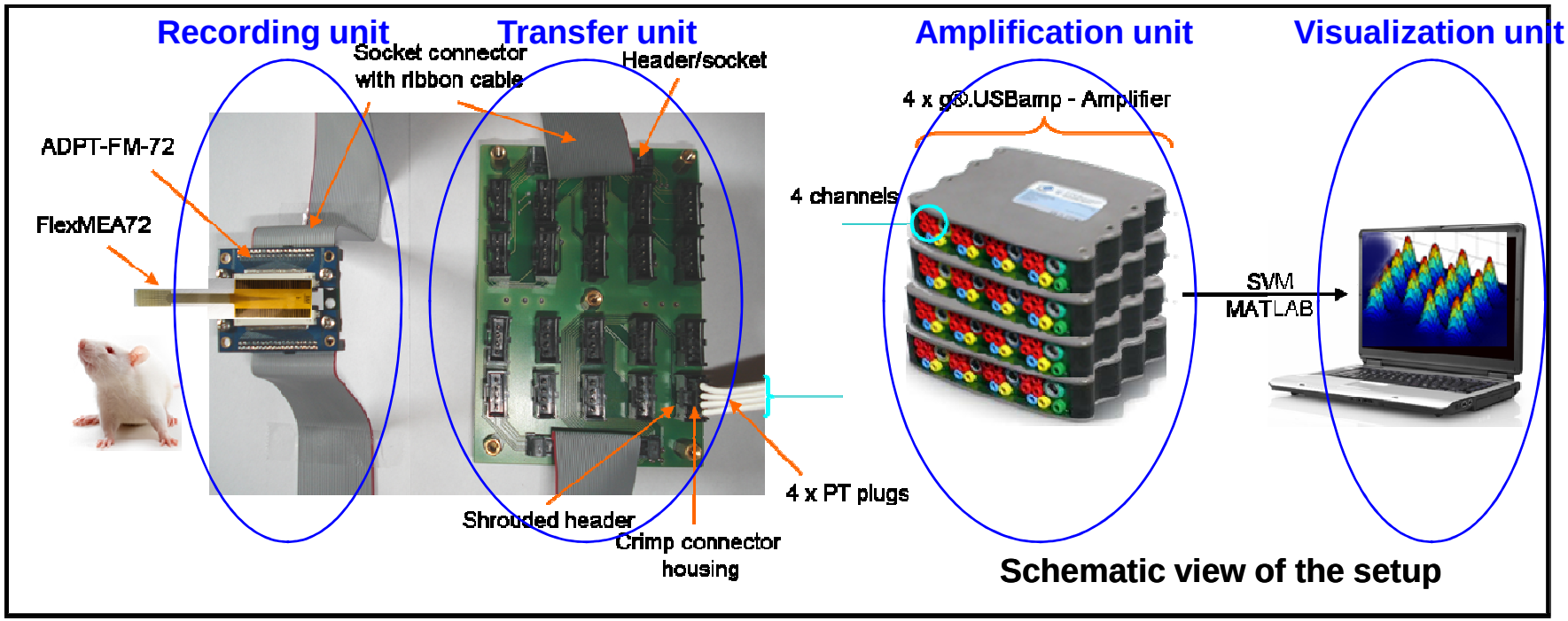
subject to: $\forall i \left[y_i(w \cdot x_i + b) \geq 1 - \xi_i\right]$

To keep the infringements to the minimum

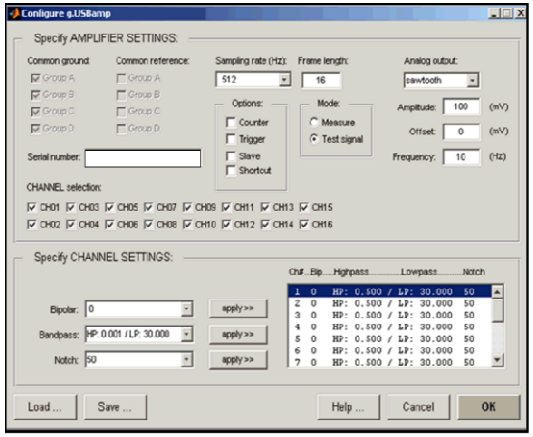
- Add the sum of the error
- Multiply by a positive constant C to regulate the balance between the minimization of the quadratic norm and the correct classified training examples

Materials and Methods

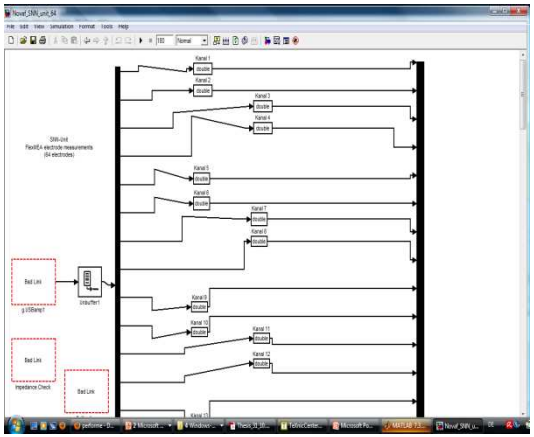
- To carry out an electrophysiological study, with respect to animals, no ubiquitous experimental setup is available.
- Intention
  - Place a flexible multielectrode array (FlexMEA72) onto the auditory cortex of a rat and performe electrophysiological recordings.
  - Provide the data to the support vector machine (SVM) for generating a „dynamical map“ of the cortex-area.



Hardware and Software

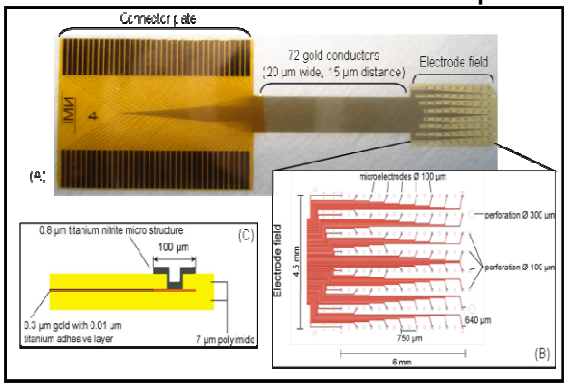


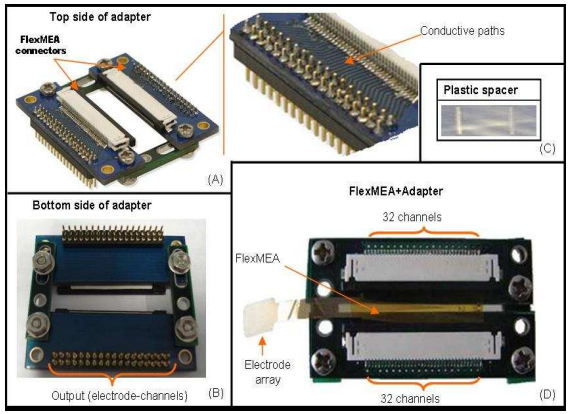
MATLAB and Simulink

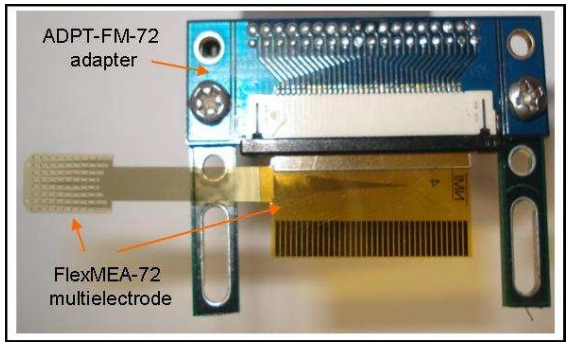


g.USBamp amplifier

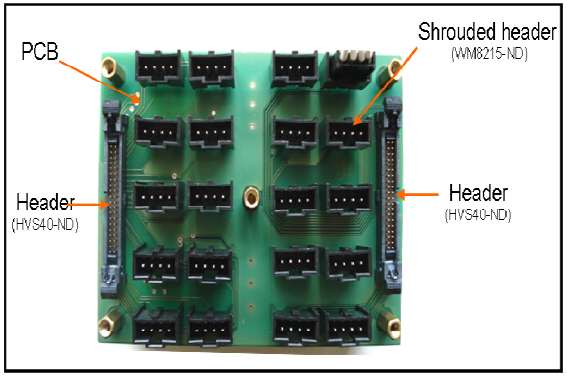
FlexMEA72 and ADPT-adapter

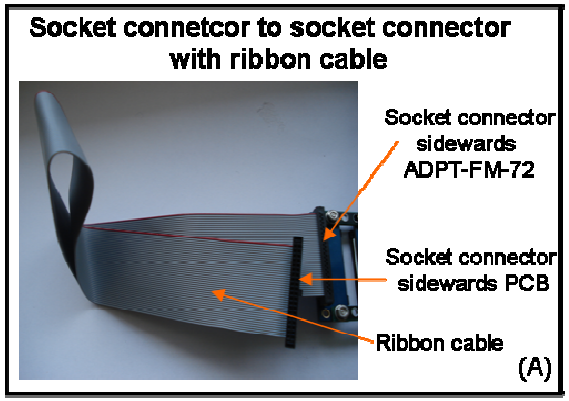


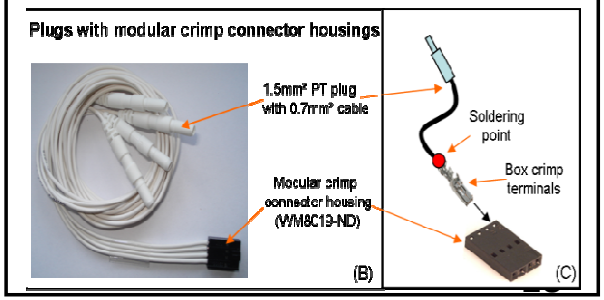




PCB and accessoiries

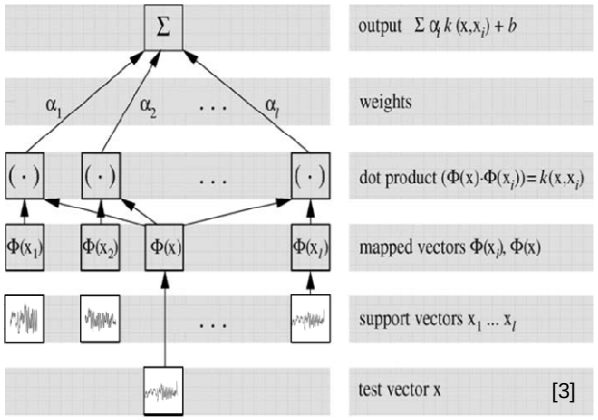






Methods

Support vector machine



- „Teach“ the machine (training set)
- Construct hyperplane (Support vectors (SVs))
- Map input vectors into the feature space (*„Kernel-Trick“*)
- Compute the dot products under the map (*“Gaussian-kernel”*)
- By adding the dot products, plus the constant term b the machine computes the final prediction output

Data aquisition and analysis

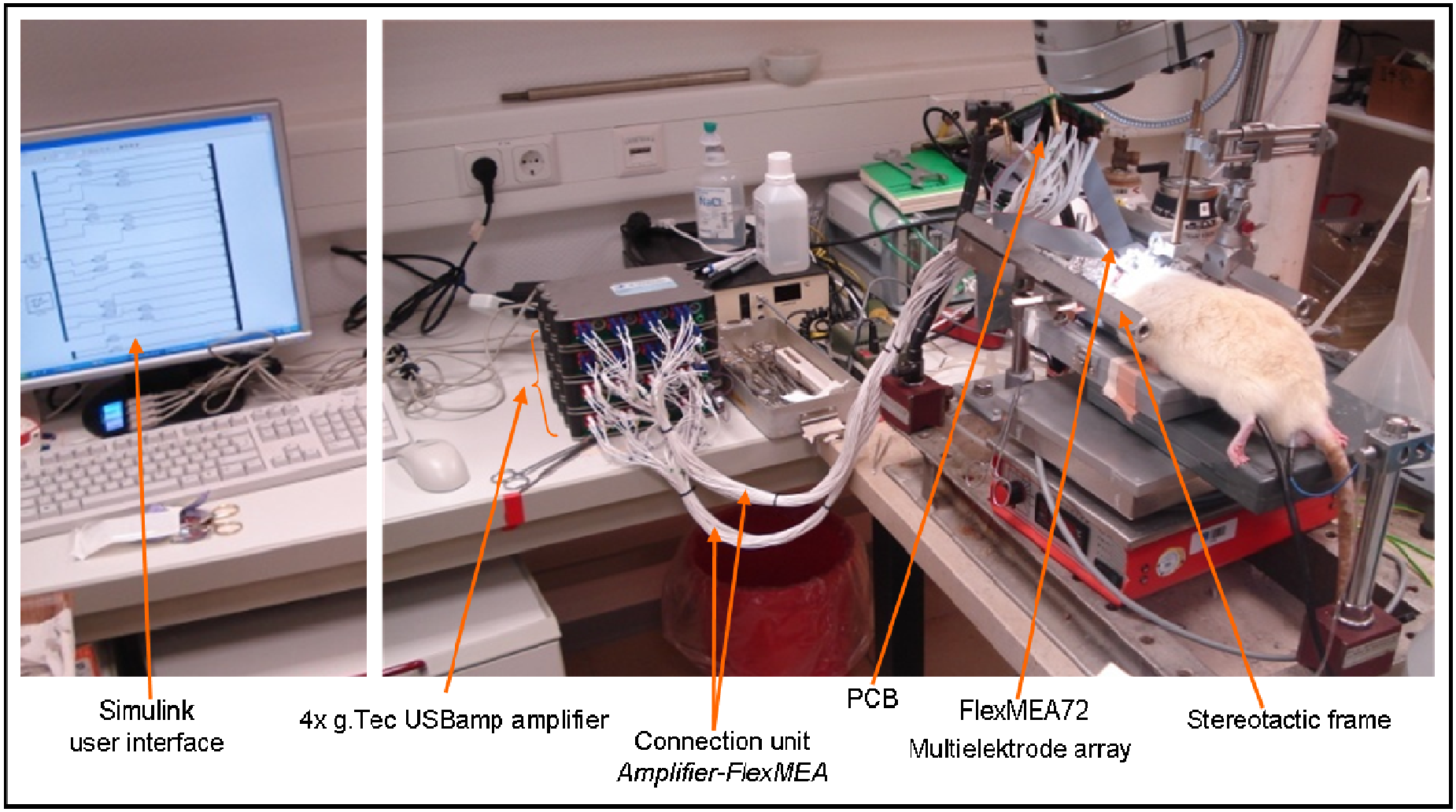
- For recording settings Simulink was used.
- Sampling frequency 19,2 kHz. (Important to fulfill the Nyquist-theorem f(s) > 2 f(c))
- Recording of neural field potentials (NFPs)
- NFPs contain local field potential (LFPs) and multi unit activities (MUA)
- Extract LFPs (30-200 Hz)
  - Low pass filtering at 300 Hz
- Since the collected amount of data prevented the usage of MATLAB - for analysis and SVM regression estimation - we also decided to decimate, and thereby reducing the length of the available signals.

Animal preperation

- Experimental procedures were approved by the Saarland University Ethics Committee and in accordance with section 5 TierSchG.
- Anesthesia was given by inhalation of the anesthetic agent isoflurane.
- The rat was placed in a stereotaxic frame, the head stabilized and the corneas were covered with ophthalmic ointment.
- A heating pad maintained a body temperature between 37-38℃.
- The skull was surgically exposed and a craniotomy was perforemd.

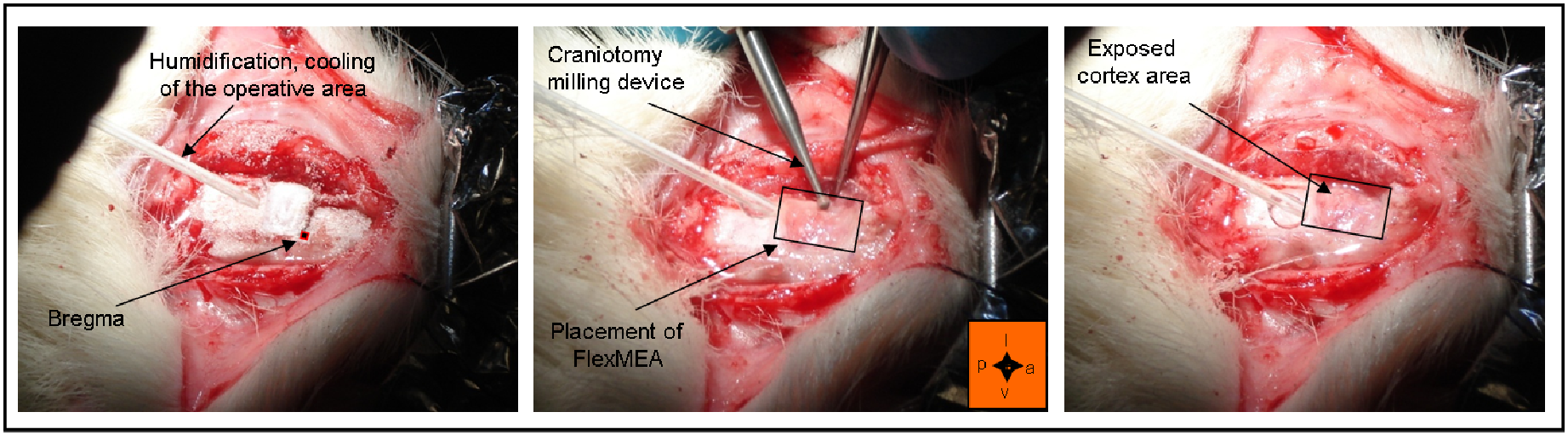
Results

Experimental setup

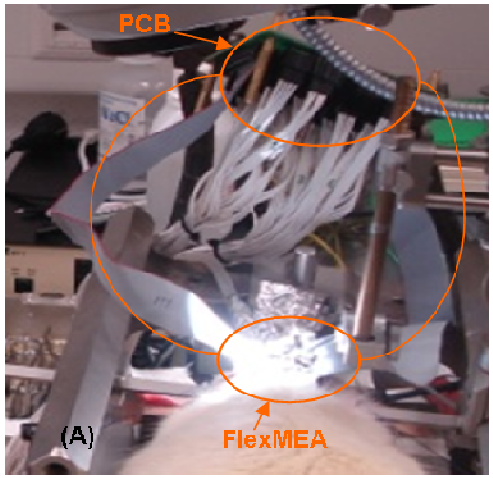


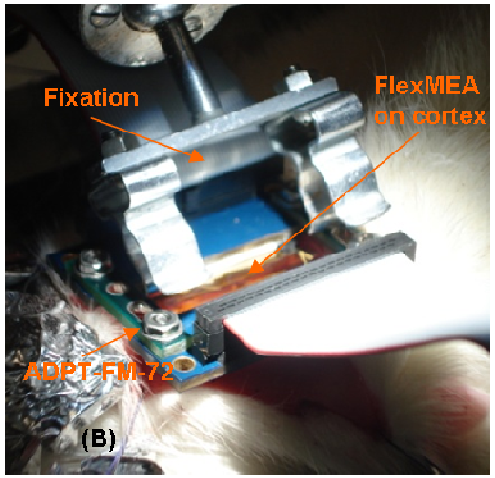
Results

Animal preperation



- Skull was surgically exposed in a sterile procedure
- The *Bregma* was identified, serving as a reference point for stereotactic surgery.
- A drilling a milling device was used to „remove“ the skull (0.4 mm lateral and 0.2 mm anterior to posterior, relative to Bregma).
- The „Recording Unit“ was then placed on the cortex with the bottom side pointing upwards and the FlexMEA array lying underneath.

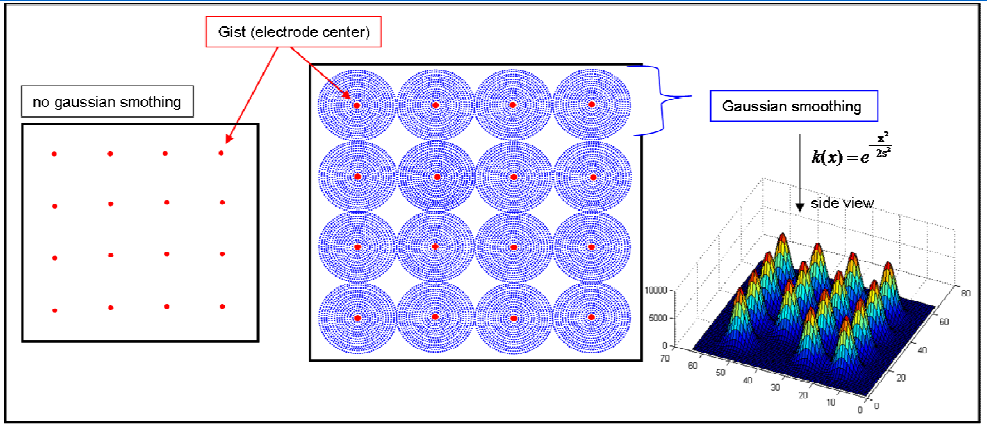


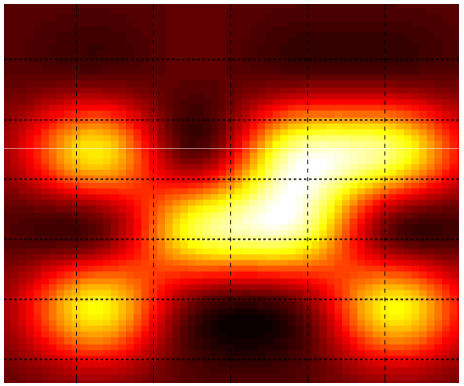


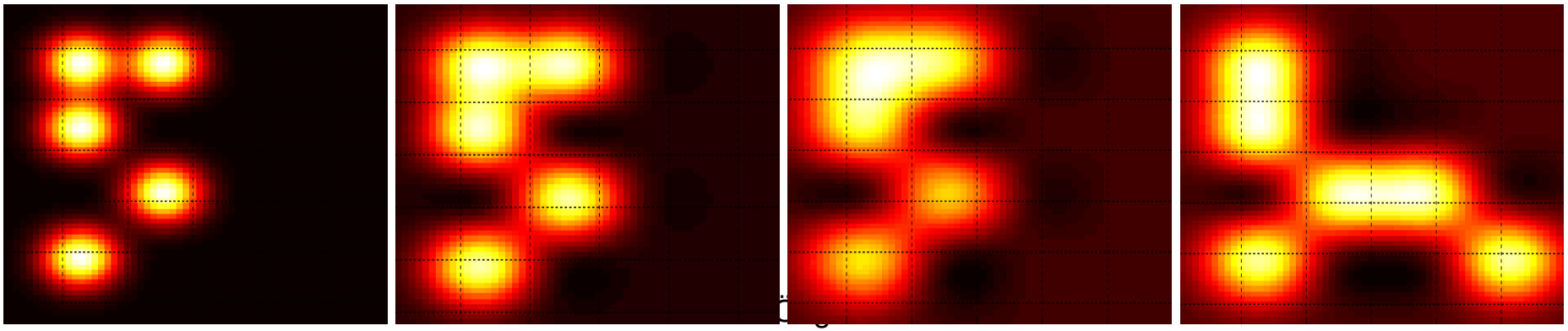
Results

SVM

- First, the recorded data was preprocessed (filtering, decimating)
- Afterwards the available data was provided to the SVM for regression estimation
- Generating a „dynamical map“ of the data recorded from the surface, picturing the possible "ongoing-actions“.
- Applying a Gaussian RBF- for smoothing

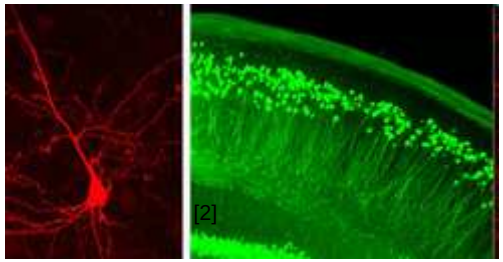






Summary and Outlook

- This work represents an attempt to understand cortical functioning in terms of a computational model.
- Electrophysiological data was recorded by placing a flexible multielectrode array (FlexMEA72) on the cortex of a adult Wistar rat.
- In this way our intention was to generate a "dynamical map" of the underlying electrophysiological data belonging to the surface, picturing the possible "ongoing-actions".
- Basically a great deal of work and efforts still requires to be undertaken in understanding the behavioral role of the "10 billion" neurons in the mammalian brain.
- Nevertheless, our results have shown that it is feasible in teaching a machine (SVM), using electrophysiological data, for constructing a "functional map" in a dynamic manner.
- Moreover, in addition to computer modeling techniques, optical recording methods such as voltage sensitive dye imaging (VSDI) can be used for measuring brain activity
- Thus, in future work both techniques could be compared with each other and mutually complete themselves.



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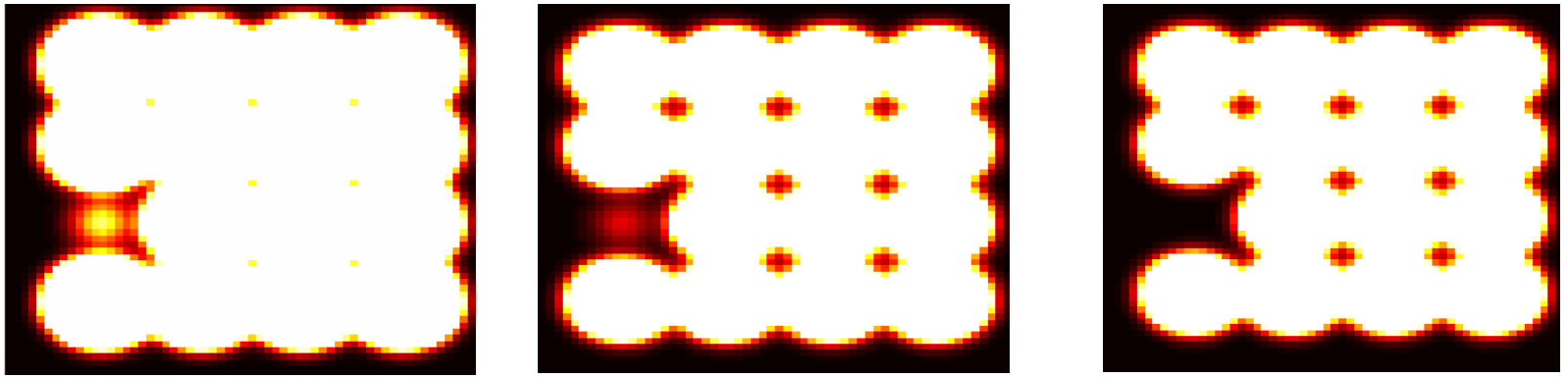
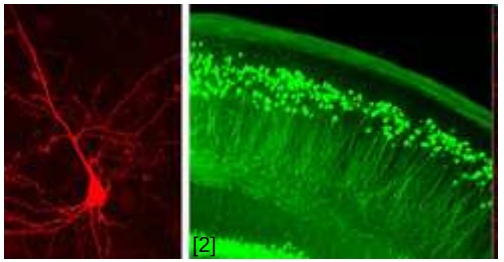
Thank you for
your attention!

Resultate und Ausblick

Resultat SVM kultivierter Zellen



- Erste Schritte vielversprechend
- Vergleich mit Voltage sensitive dyes (VSD)
  - Bildgebendes verfahren zur Darstellung der Veränderungen des Flusses elektrischer Nervenzellaktivität in Hirnschaltkreisen
  - Ergebnisse vergleichbar
  - Zellen können durch Farbstoffe geschädigt werden
  - Oft gelangen Farbstoffe nicht zum Zielort



- Abstand zwischen kanonischen Hyperebenen ergibt sich durch Projektion von $x_1 - x_2$ auf den Einheitsnormalenvektor $\frac{w}{\|w\|}$: $2\gamma = \frac{2}{\|w\|}$