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GUGER TECHNOLOGIES

Common Spatial Patterns 2 class BCI

V1.12.01

Introduction

This tutorial shows how to use Common Spatial Patterns (CSP) to run brain-computer interface (BCI) experiments. The tutorial explains the electrode montage, the amplifier setup, the usage of CSPs, parameter estimation and classification and shows also how to perform the user training. The model is able to deal with different numbers of EEG-electrodes, this example is done with a setup using 27 electrodes.

Required Components

To perform the tutorial the following components are required:

- 1 or several **g.HIamp** or **g.USBamp** biosignal acquisition device(s)
- **g.USBamp Highspeed** Online Processing for Simulink
- **g.BSanalyze** offline processing toolbox
- **g.RTanalyze** online and real-time biosignal processing library for use with SIMULINK
- EEG electrodes and an EEG cap
- Computer with USB connector
- MATLAB and Simulink Release 2012a

Install

Copy the folder gCSP to:

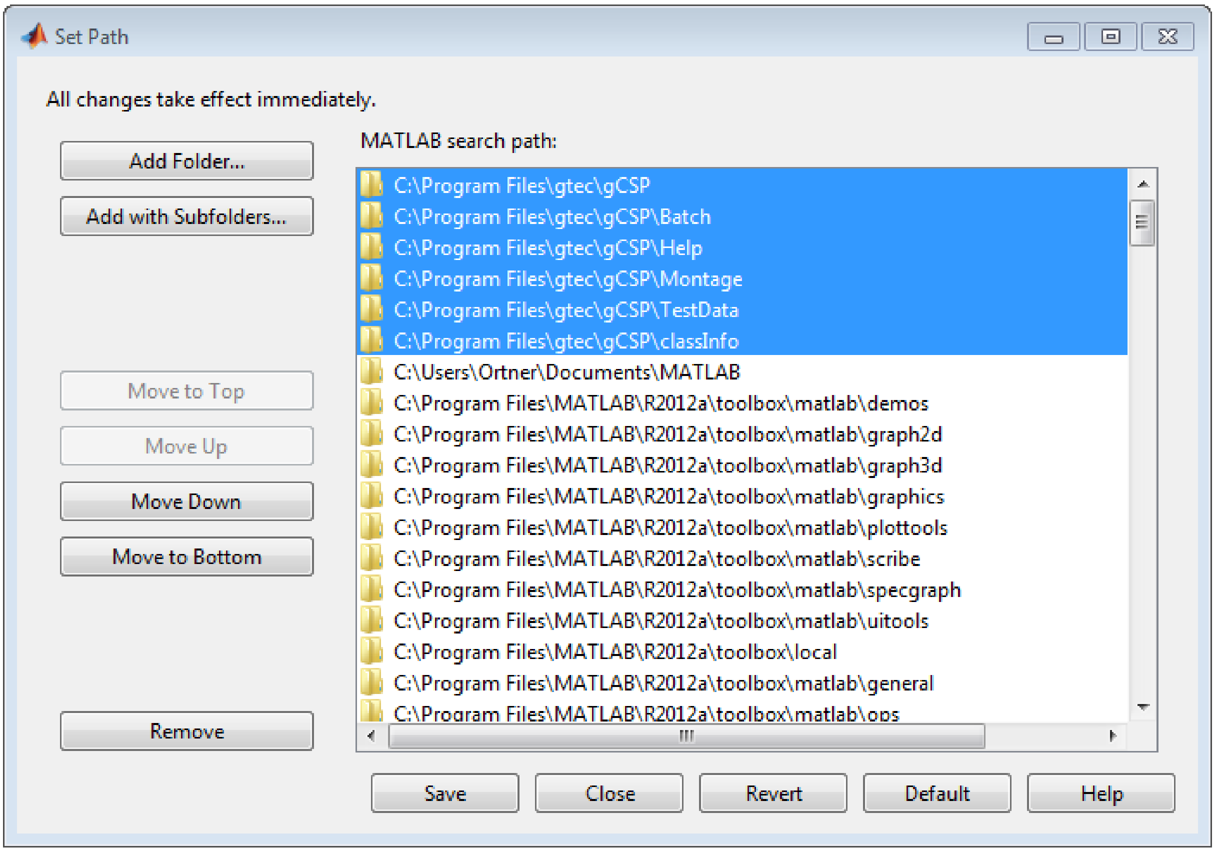
```
C:\Program Files\gtec
```

Setup

To make the path settings start MATLAB and open the Set Path window in the File menu. Then click on the Add with Subfolders button and select

```
C:\Program Files\gtec\gCSP
```

to add all subdirectories.



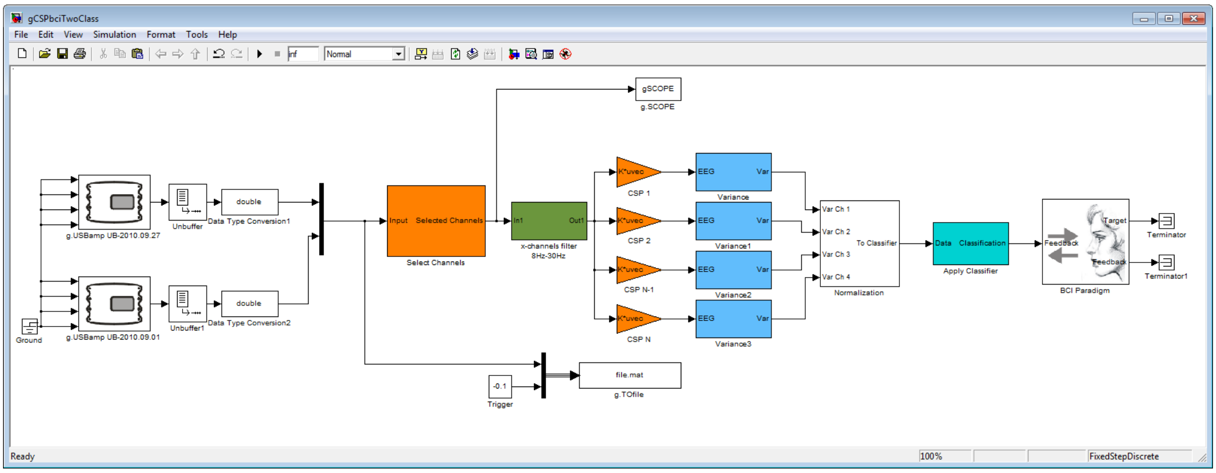
The corresponding Simulink model can be found under

```
C:\Program Files\gtec\gCSP
```

To start the g.USBamp two class BCI type into the MATLAB command line

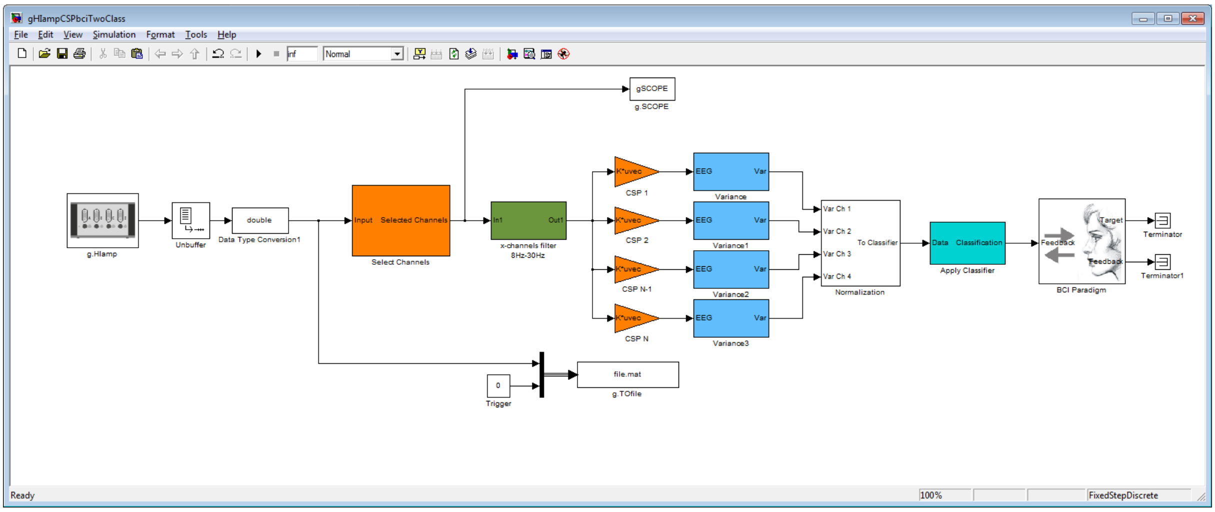
```
gUSBampCSPbci_TwoClass
```

to open the following Simulink model:



The model contains two amplifier blocks to read in data with g.USBamp over the USB ports of the computer. Each of the amplifiers has 16 channels and therefore the maximum channel number is 32. To be able to record from both devices the amplifiers have to be connected with the synchronization cable. One amplifier acts as MASTER device and the other amplifier acts as SLAVE device. For the BCI experiments with motor imagery and CSPs 27 electrodes will be used and the data will be sampled at 256 Hz. The ground and reference of the group D of both amplifiers have to be connected with jumper cables, to have the same ground and reference for both amplifiers.

To open the g.HIamp two class BCI type
`gHIampCSPbci_TwoClass`

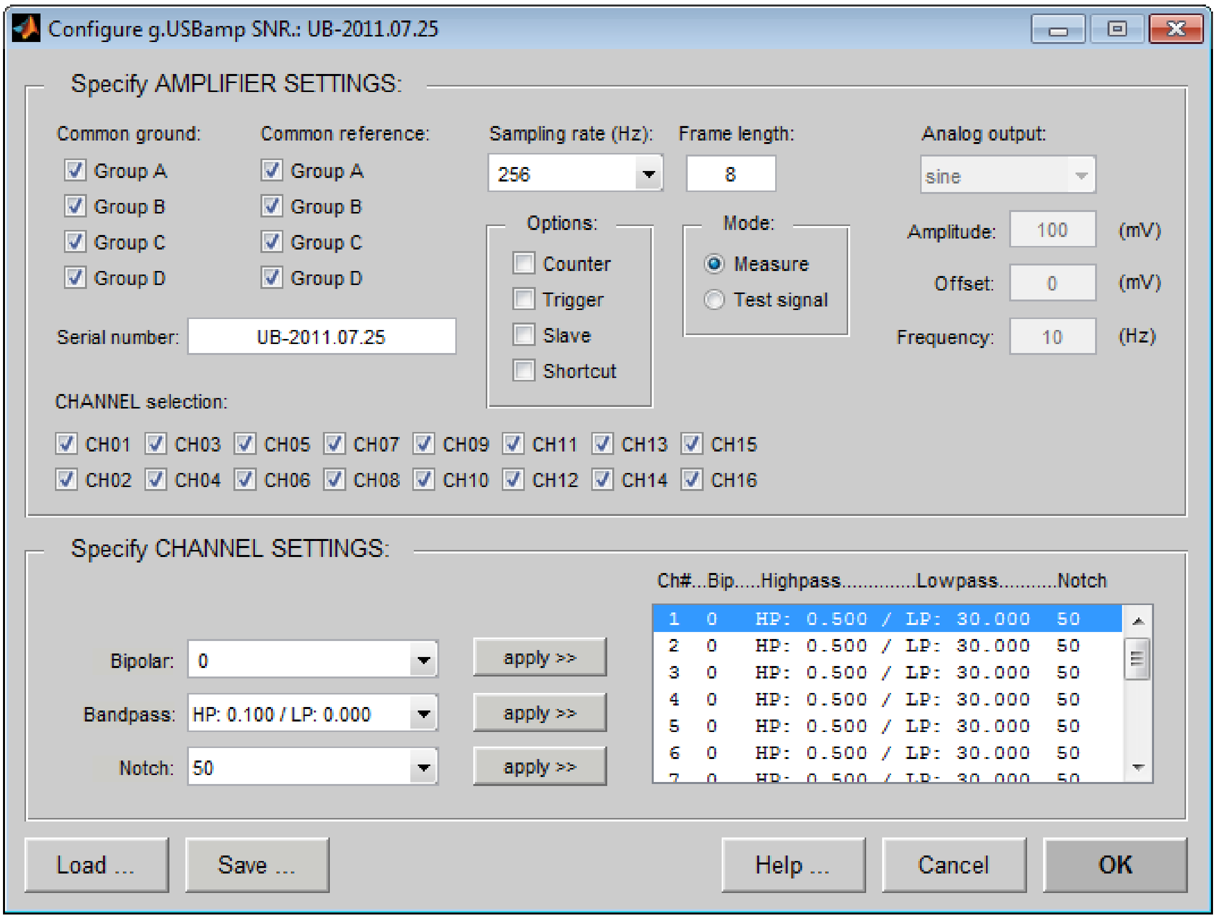


Instead of the two g.USBamp block it contains one g.HIamp block, the rest of the model is the same as before.

Driver Configuration

g.USBamp

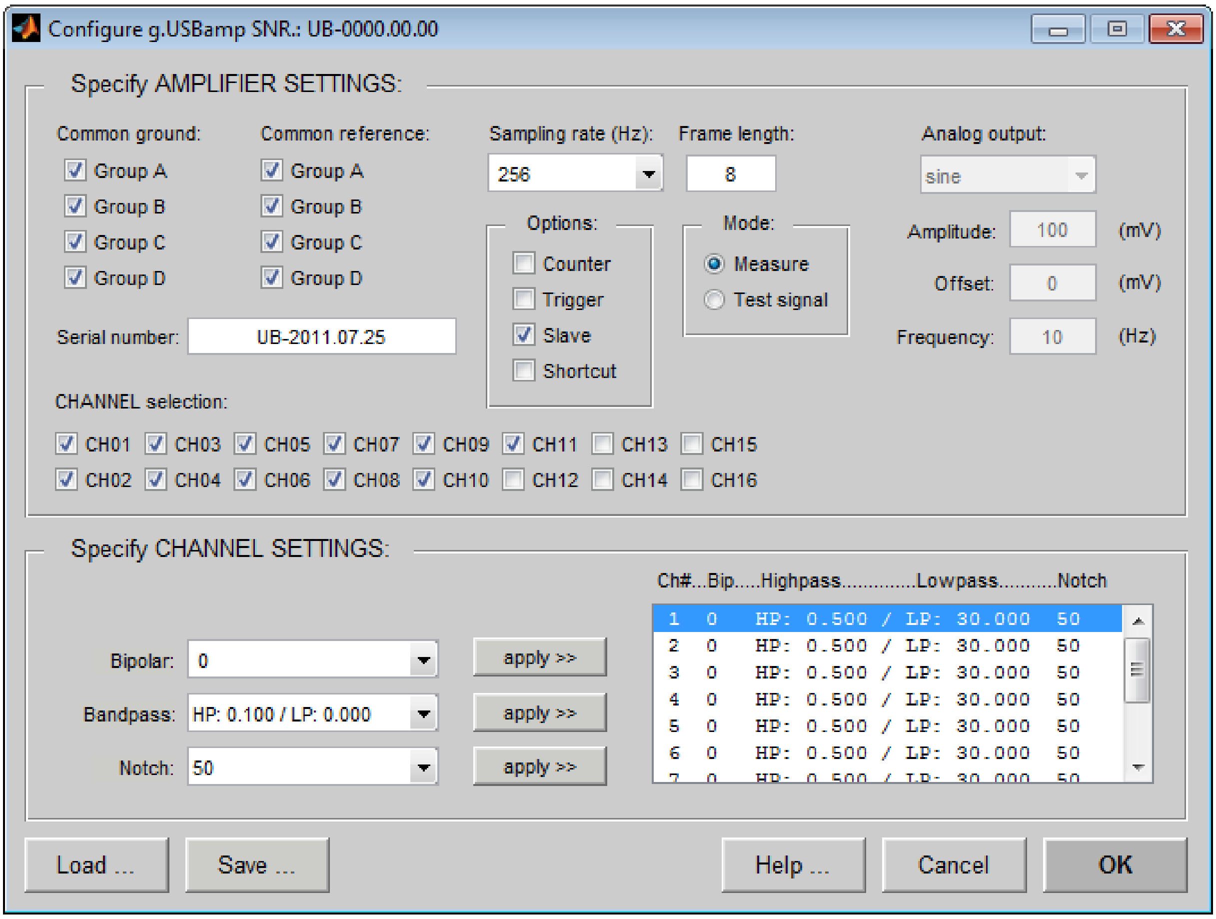
Double click on the MASTER **g.USBamp** block to open the following window:



First enter the **Serial number** of the amplifier and then select a **Sampling rate** of `256 Hz` with a **Frame length** of `8` to read in the data from the amplifier sample by sample. Select all 16 channels, use a **Bandpass** filter from `0.5 to 30 Hz` and enable a **Notch** filter with `50 Hz`. The configuration can be saved by clicking onto the **Save…** button.

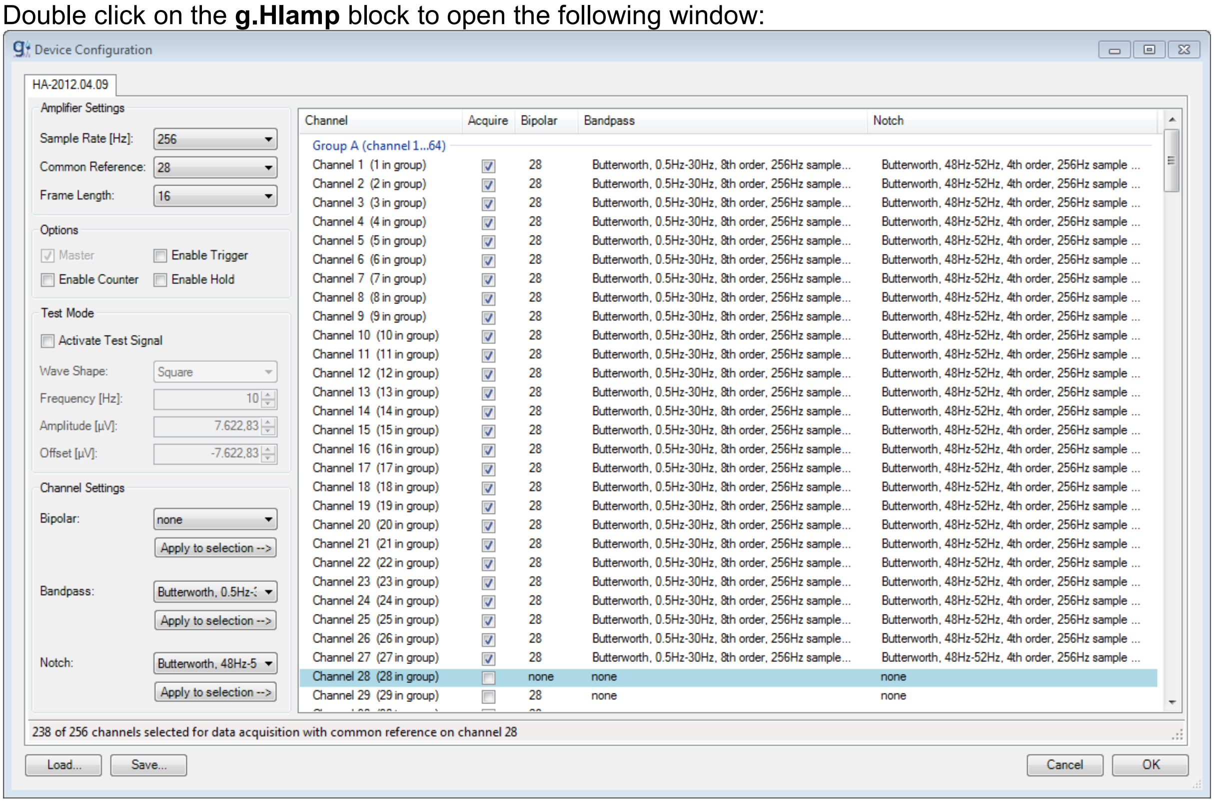
Note: For active electrodes using the g.GAMMAbox system from g.tec it is not necessary to connect **Common ground** and **Common reference**.

Then double-click onto the SLAVE **g.USBamp** block and perform the settings like above, but use only the first 11 channels and enable the **Slave** checkbox.



g.HIamp

Double click on the **g.HIamp** block to open the following window:

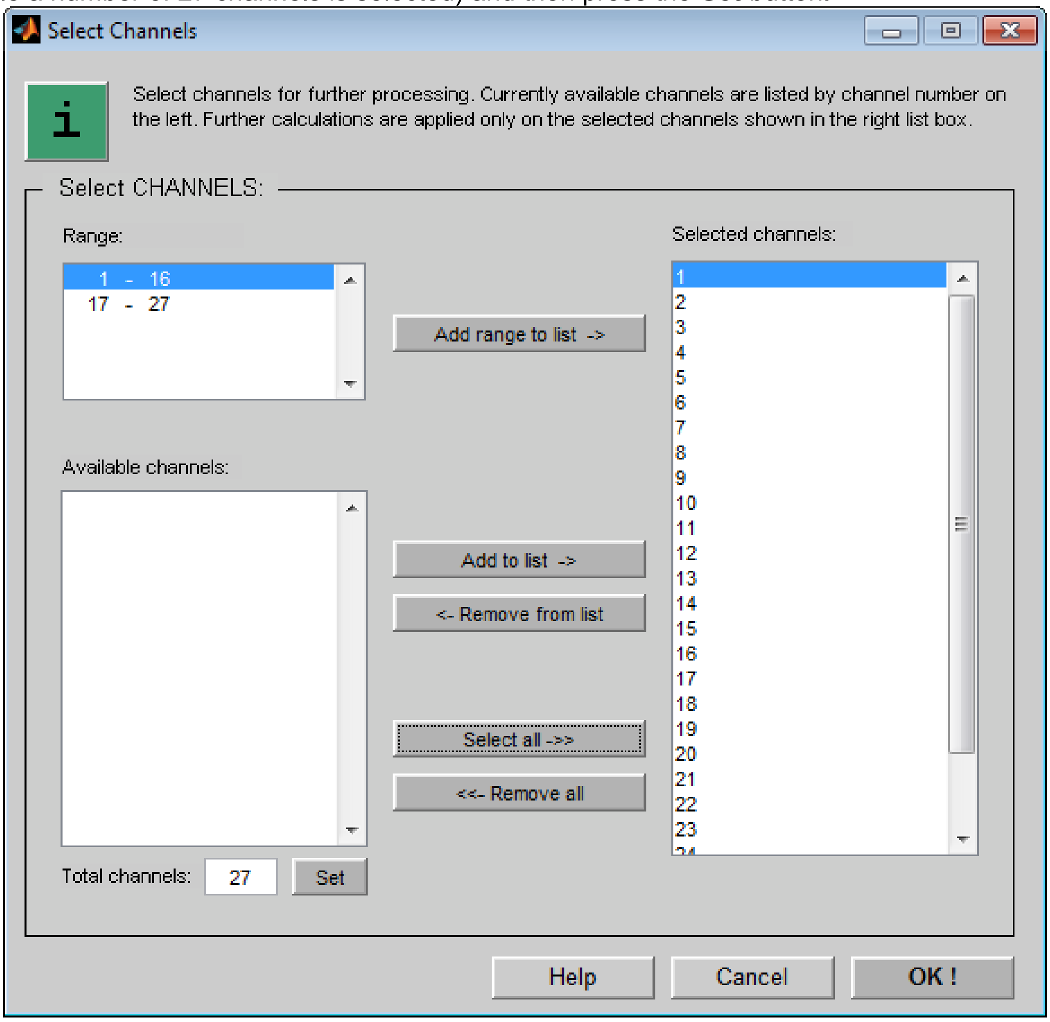


Select a **Sampling rate** of 256 Hz with a **Frame length** of 16 to read in the data from the amplifier sample by sample. Select as **Common Reference** the number 28 (reference electrode).
Use a **Bandpass** filter from 0.5 to 30 Hz and enable a **Notch** filter between 48Hz-52Hz. The configuration can be saved by clicking onto the **Save** button.

Signal Processing

The **Select Channels** block allows you to select different number of channels for the recordings. In this way, you can use one or several g.USBamps for the experiment, or a g.HIamp, which allows you to record the EEG on several channels (up to 256).
Double click on **Select Channels** block.

In the **Total channels** field type the number of channels you want to use for the recordings (in this example a number of 27 channels is selected) and then press the **Set** button.

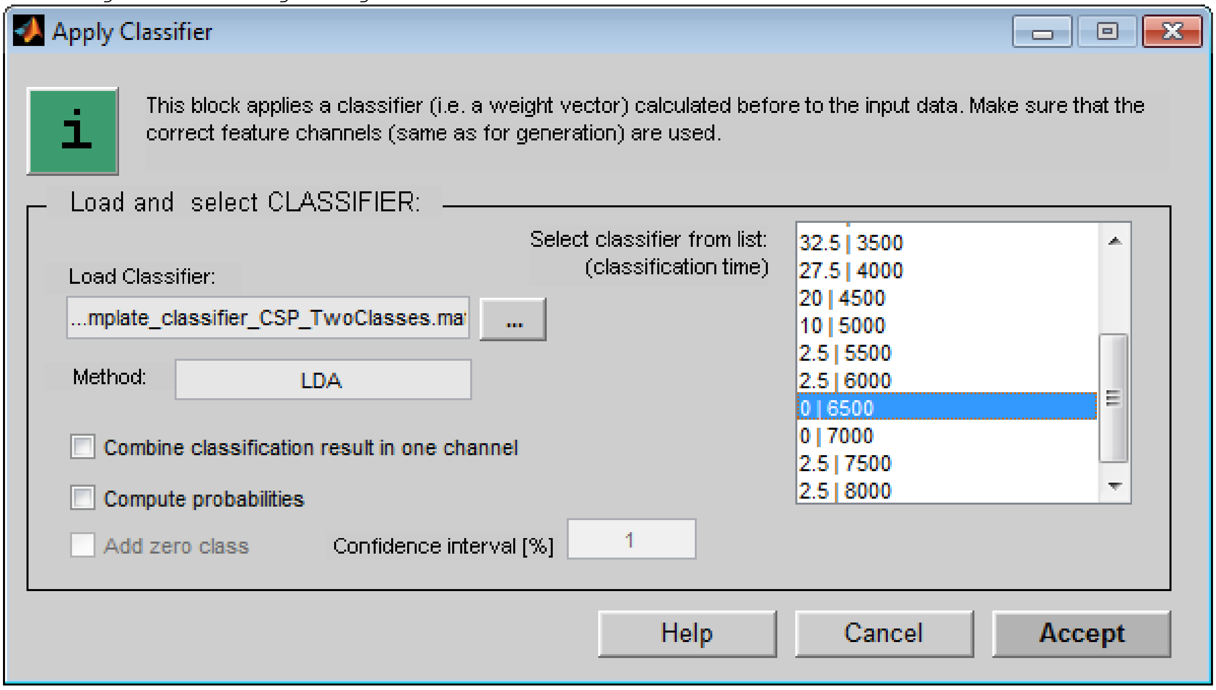


A list of channel numbers will be displayed in the **Available channels** field.

Click on **Select all ->>** button. All the channels previously listed in the **Available channels** field are now listed in the **Selected channels** field.

Classifier selection

For running the model you need to load a classifier. If no own classifier is already created you can select a template file. Click on the **Apply Classifier** block and select the file `template_classifier_CSP_TwoClasses_27Ch.mat` that is stored under `C:\Program Files\gtec\gCSP\TestData.`

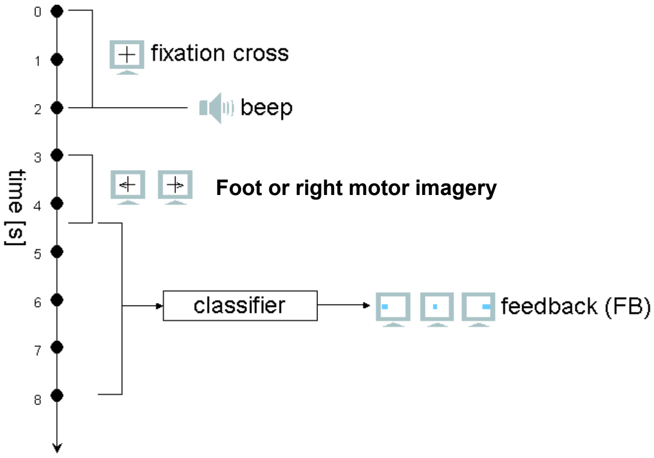


In the window on the right select the timepoint with the lowest error rate (the first number is the error the second number the timepoint in ms). Deselect the checkboxes at **Combine classification result in one channel**, and **Compute probabilities.** Click on **Accept** to confirm.

Experimental Paradigm

The first step in order to run the BCI experiment is to acquire EEG data to train the BCI system. First the experiment is performed without feedback presentation to the user to train a classifier. After the training it is possible to give feedback (e.g. in form of a cursor) to the user to increase the performance.
In general the EEG data-set used for the training of the BCI can be acquired during a brain-computer interface experiment with or without feedback. For the first run, the experiment can only be started without feedback.

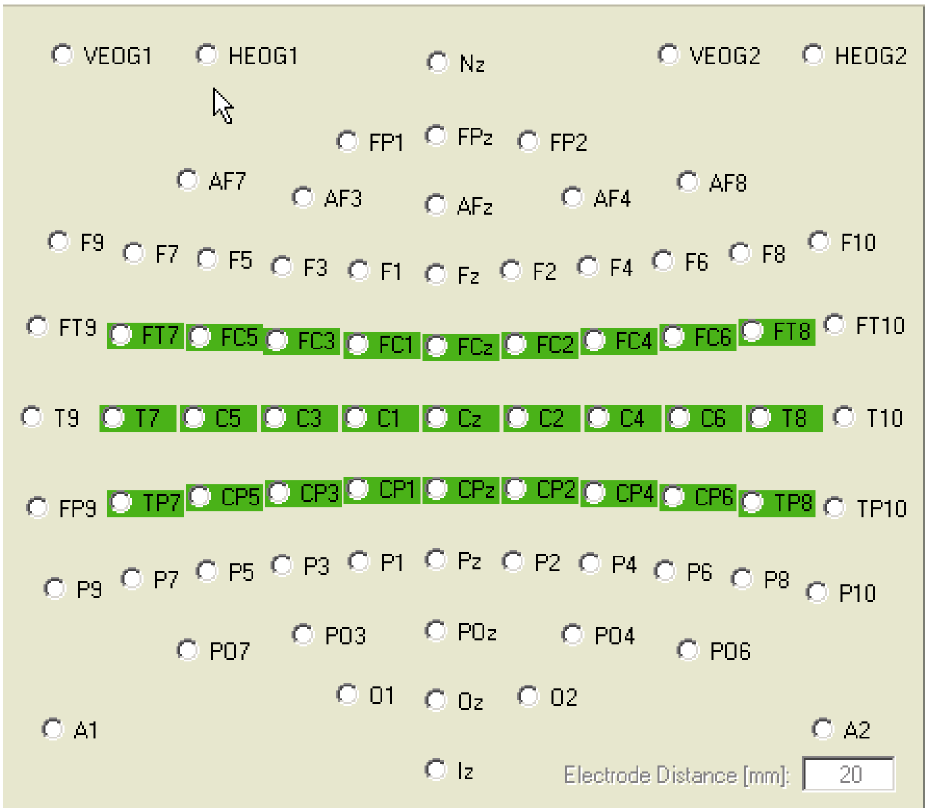
In this example the sessions are divided into 4 experimental runs of 40 trials with randomized directions of the cues (20 left and 20 right) and last about 1 hour (including electrode application, breaks between runs and experimental preparation). The subject sits in a comfortable armchair 1 meter in front of a computer-monitor and should not move, keep both arms and hands relaxed and should maintain the fixation at the center of the monitor throughout the experiment.



The experimental paradigm starts with the display of a fixation cross in the center of the monitor. After two seconds a warning stimulus is given in form of a "beep". From second 3 until 4.25 an arrow (cue stimulus), pointing left or right is shown on the monitor. The subject is instructed to imagine a left or right hand movement depending on the direction of the arrow. Between seconds 4.25 and 8, the EEG is classified on-line and the classification result is translated into a feedback stimulus in form of a horizontal bar that appears in the center of the monitor in the feedback mode. If the person imagines a right movement the bar, varying in length, extends to the right and vice versa (correct classification assumed). The subject's task is to extend the bar to the left or right boundary of the monitor as indicated by the arrow cue. One trial lasts 8 seconds and the time between two trials is randomized in a range of 0.5 to 2.5 seconds to avoid adaptation.

EEG Recording

Connect 27 electrodes overlaying the sensori-motor area to the subject's head as indicated in the Figure (the figure is just a visualization of the EEG-positions and not part of the software) below. Attach the ground electrode to the forehead and the reference electrode to the right earlobe.



Then connect the electrode wires according to the following scheme to the biosignal amplifiers:

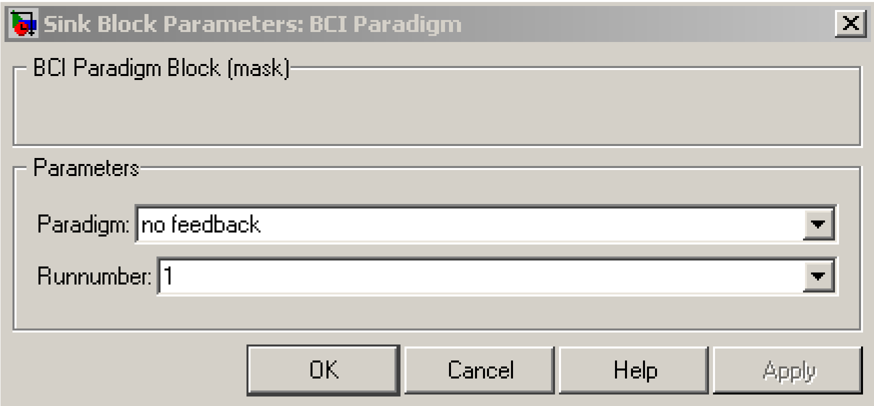
MASTER device
FT7 to channel 1
FC5 to channel 2
FC3 to channel 3
FC1 to channel 4
FCz to channel 5
FC2 to channel 6
FC4 to channel 7
FC6 to channel 8
FC8 to channel 9
T7 to channel 10
C5 to channel 11
C3 to channel 12
C1 to channel 13
Cz to channel 14
C2 to channel 15
C4 to channel 16

SLAVE device
C6 to channel 17 = channel 1 SLAVE
T8 to channel 18 = channel 2 SLAVE
TP7 to channel 19 = channel 3 SLAVE
CP5 to channel 20 = channel 4 SLAVE
CP3 to channel 21 = channel 5 SLAVE
CP1 to channel 22 = channel 6 SLAVE
CPz to channel 23 = channel 7 SLAVE
CP2 to channel 24 = channel 8 SLAVE
CP4 to channel 25 = channel 9 SLAVE
CP6 to channel 26 = channel 10 SLAVE
TP8 to channel 27 = channel 11 SLAVE

Training without Feedback

First EEG data must be acquired during a session without feedback to calculate CSPs and the weight vector with the linear discriminant analysis (LDA).

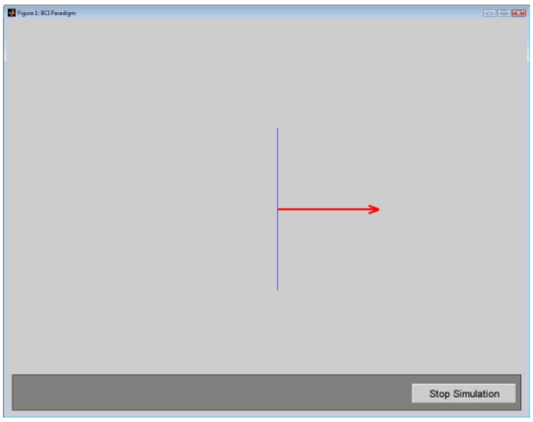
Therefore double-lick onto the **BCI Paradigm** block and select under **Paradigm** `no feedback`.

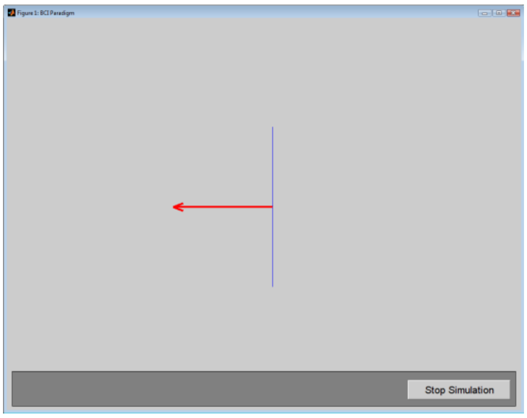


It is possible to choose from 4 different runs with a different order of left and right trials. Every single run consists of 40 trials. Start with the first run.

Double-click onto the **g.TOfile** block and enter the filename to store the EEG data in MATLAB format. Beside the EEG data the block also stores a trigger signal indicating second 2 of each trial.

Then start the Simulink model to run the experiment. After 10 seconds a beep sounds and an arrow pointing to the right or left side will appear. The whole experiment will last about 6 minutes and terminates automatically after 40 trials.





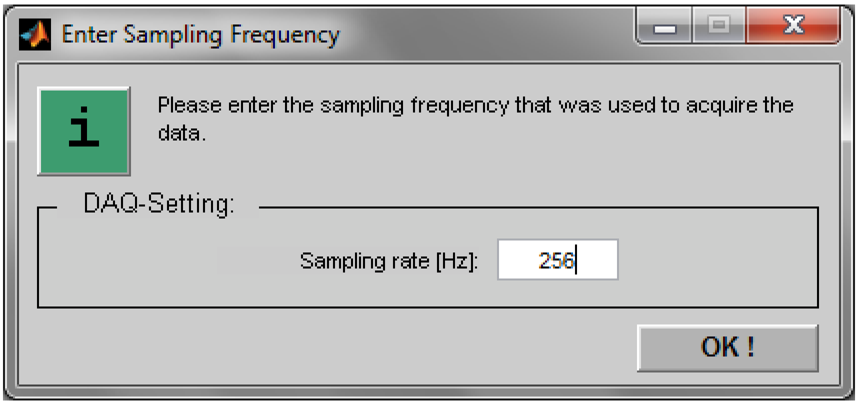
Analyzing the Data

Type into the MATLAB command window

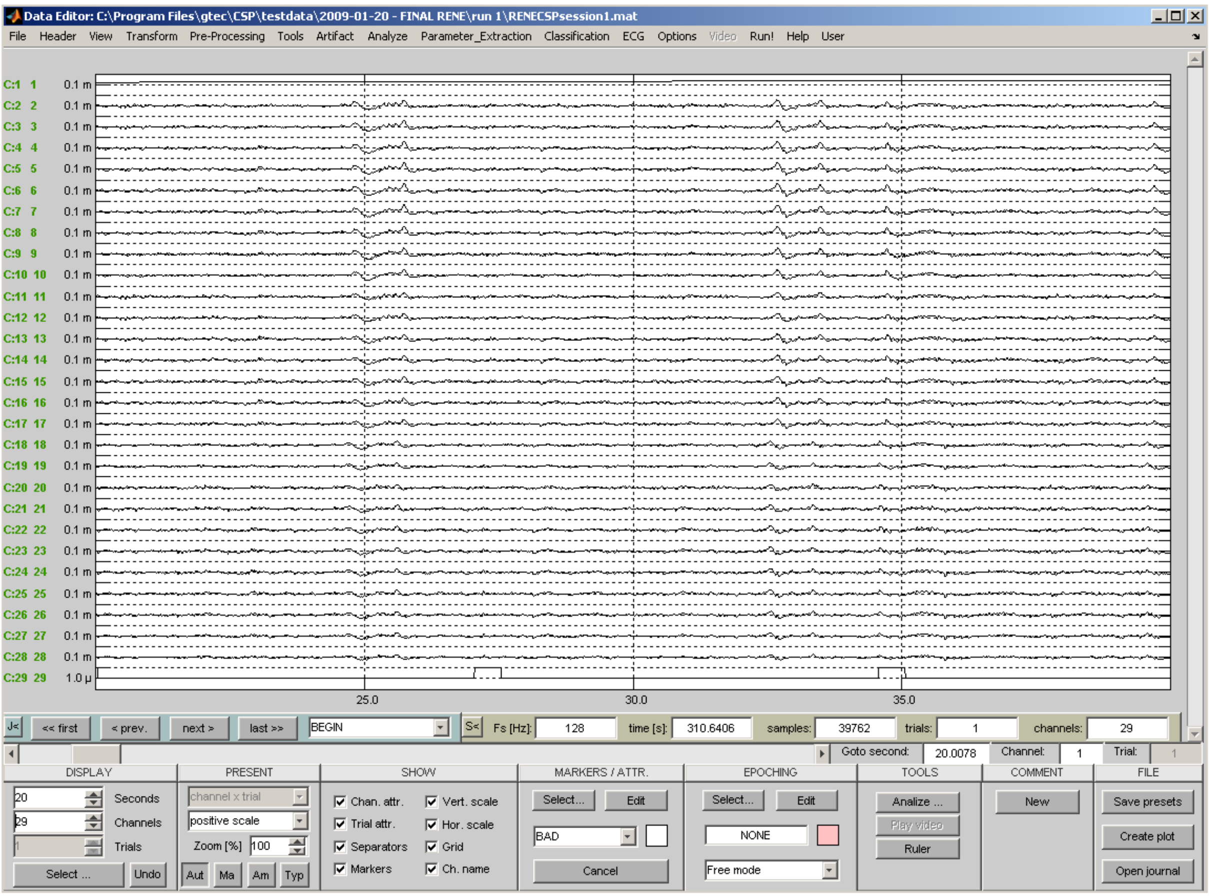
```
gbsanalyze
```

to start the Data Editor.

Load the acquired data file `session1.mat` for the calculation of the CSPs and of a new weight vector for the on-line experiment with feedback. If you are asked, enter a sampling frequency of `256` Hz in the window.



The Data Editor shows the 27 EEG electrodes and the trigger channel. Scroll through the data-set to investigate the data quality.

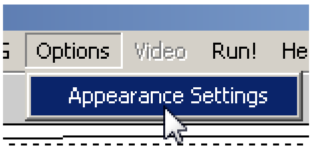


Calculation of CSPs and Weight Vector

The Simulink model first bandpass filters the data between 8 and 30 Hz before the data is filtered with the CSP filters. The model uses the four most important CSP filters (index 1, 2, 26, 27: for 27 channels) for each imagination task. Then the variance is calculated from the CSP time series. A log operation is applied and the weight vector obtained with the LDA is used to discriminate between left, right and foot movement imagination. Finally the **Classification** block outputs a signal that is used to control the cursor on the screen.

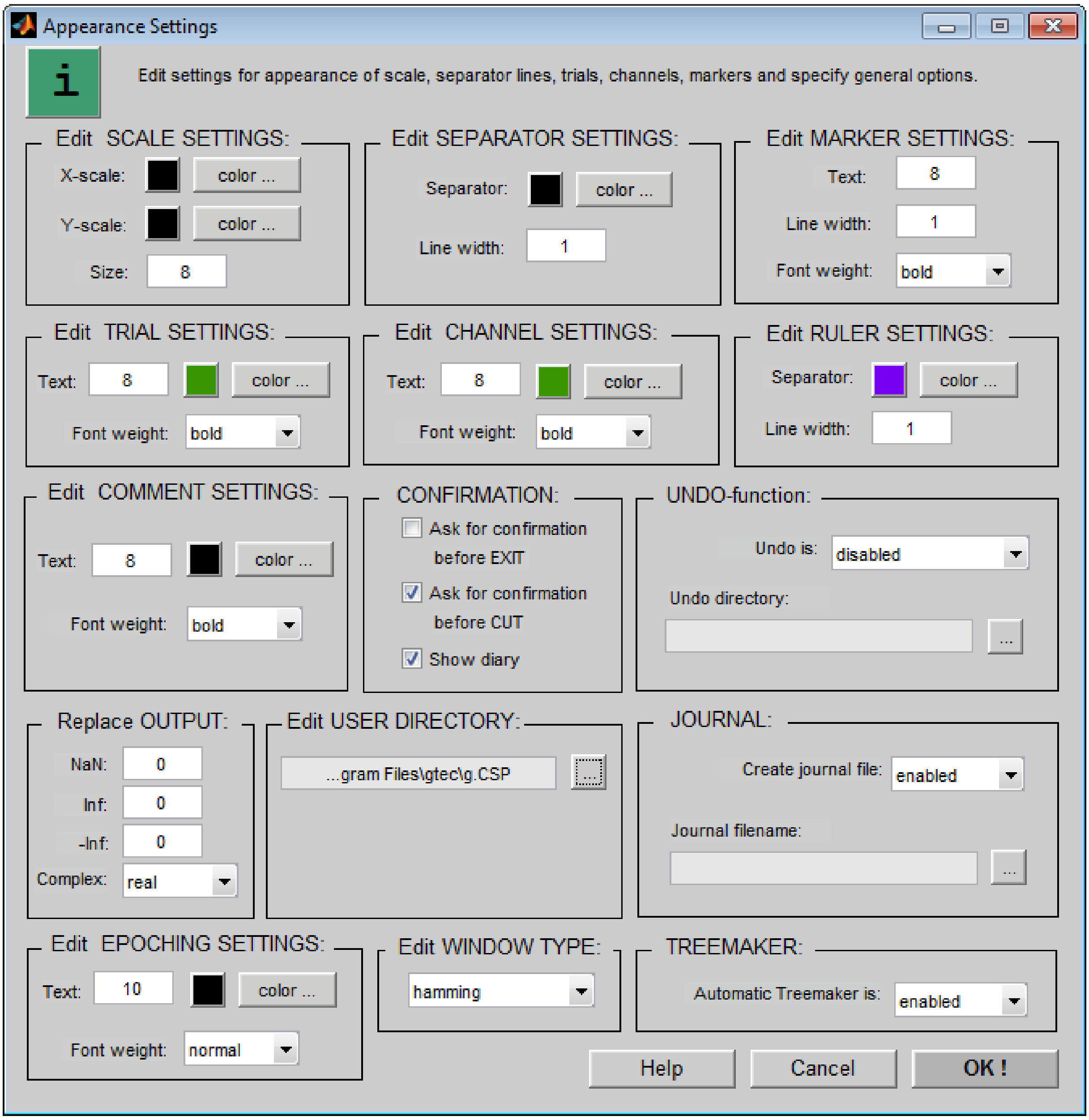
In order to calculate the CSP filters and the LDA perform the following steps:

Open the **Appearance Settings** window from the **Options** menu.

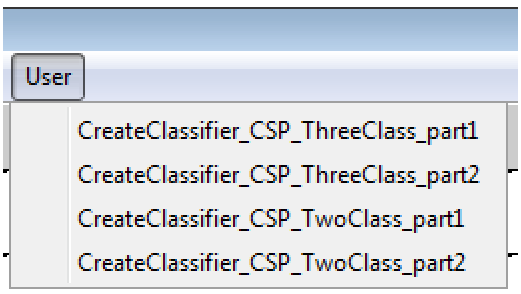


Then select the following directory under **Edit USER DIRECTORY**.

`Program Files\gtec\g.CSP\Batch`



Now the **User** menu of g.BSanalyze is populated and contains a list of batches.



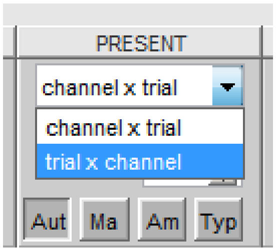
The `CreateClassifier_CSP_TwoClass_part1` batch automatically triggers the loaded EEG data and saves it as `CreateClassifier_TwoClass_part1_saved.mat` file in the Current Folder.

Click on `CreateClassifier_CSP_TwoClass_part1`.

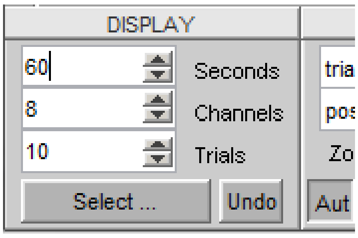
After a few seconds, the "`createClassifierPart1 done`" message is displayed in the command window, meaning that the data is triggered and saved.
In g.BSanalyze, load the `CreateClassifier_ThreeClass_part1_saved.mat` from the current folder.

Because the CSP method is very sensitive to artifacts, all trials must be visually checked and those containing artifacts in the 3-8 seconds time period must be discarded.

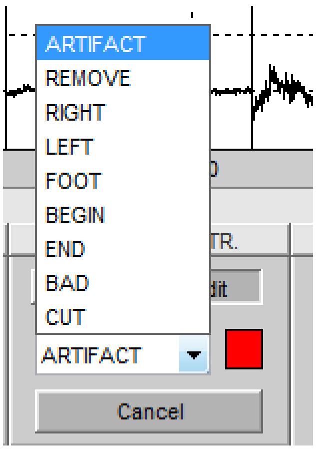
In the **PRESENT** field, select **trial x channel** in order to view the channels as rows and trials as columns and press the **Aut** button to enable the auto-scaling mode.



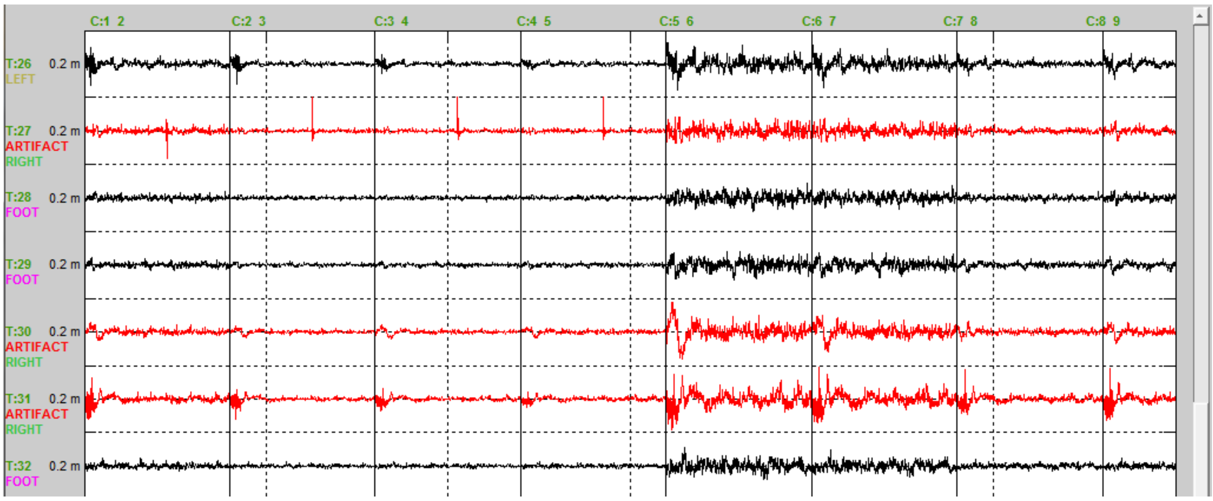
Select 60 seconds to be visible on the screen under the **DISPLAY** field.



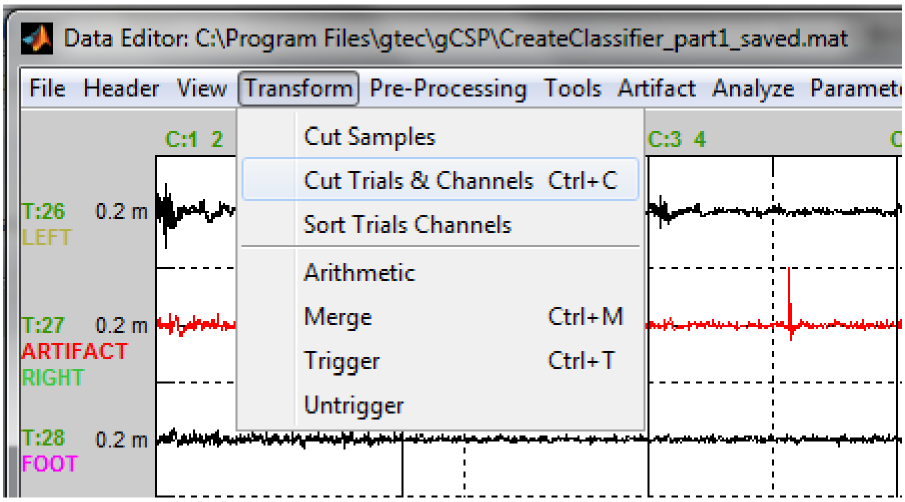
In order to mark the trials containing artifacts, select **ARTIFACT** attribute under the **MARKERS / ATTR.** field.



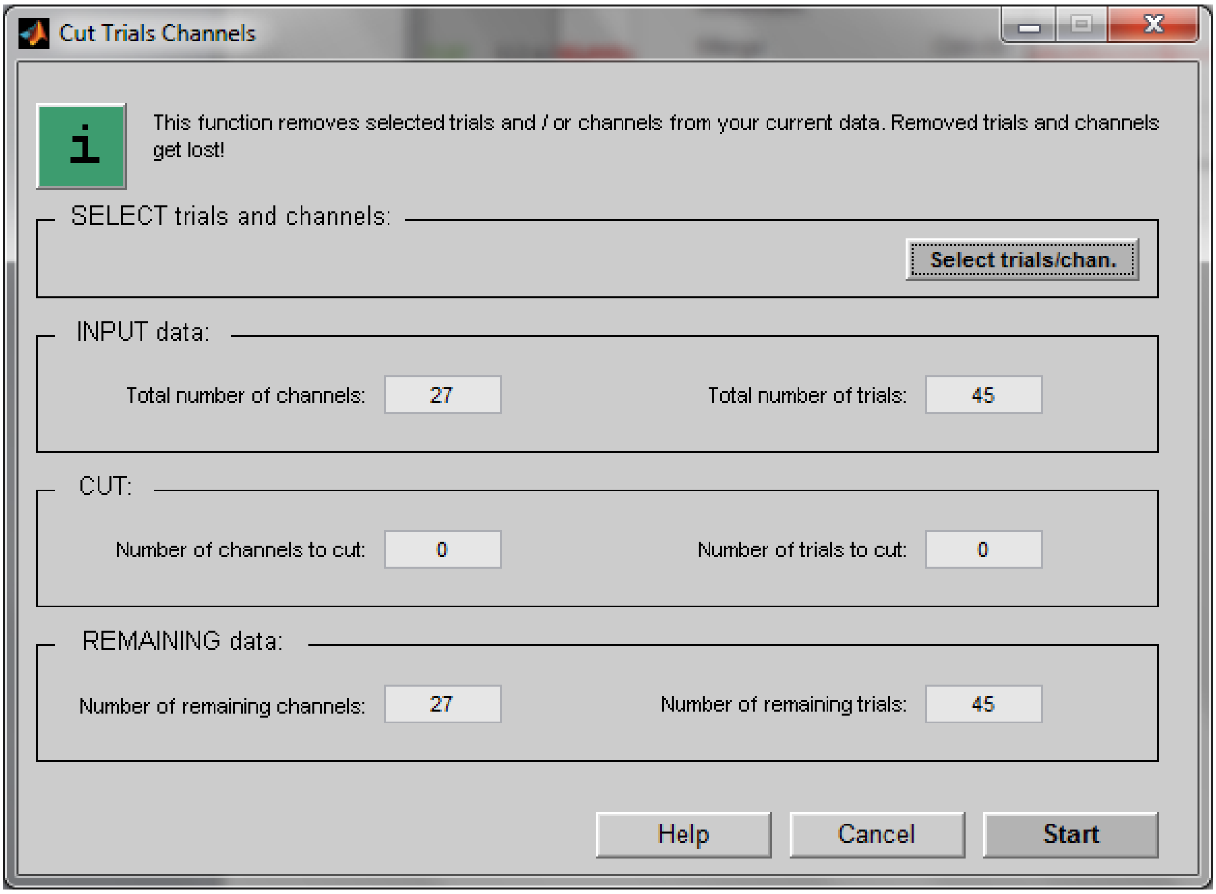
Now scroll through the entire data-set and click on the trials containig artifacts. The selected trials color will change to red and the label **ARTIFACT** will appear under the trial number in the left side of the screen.



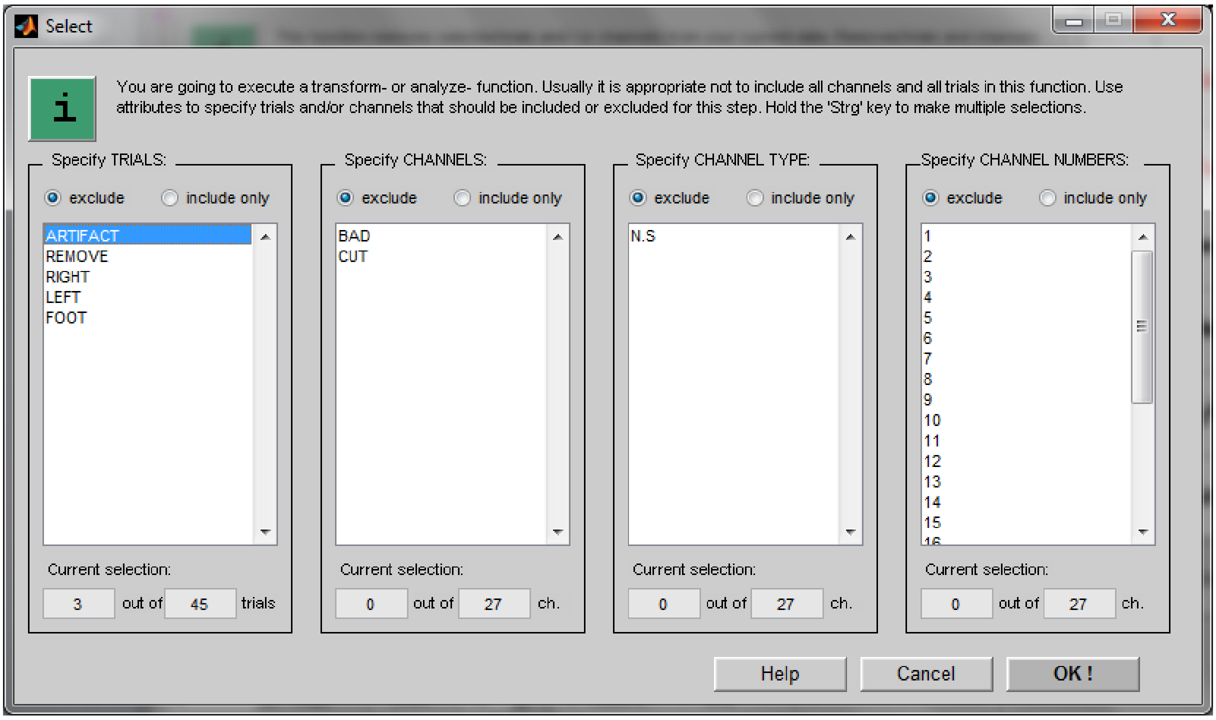
After visually inspecting the entire data-set and marking the trials containing artifacts, select **Cut trials & Channels** under **Transform** menu.



Click on **Select trials/chan.** button.



In the **Specify TRIALS** field click on the **exclude** radiobutton and mark the **ARTIFACT** attribute. Click on the **OK** button to confirm the selection.



In the **Cut Trials Channels** window press the **Start** button in order to start removing the trials containing artifacts.

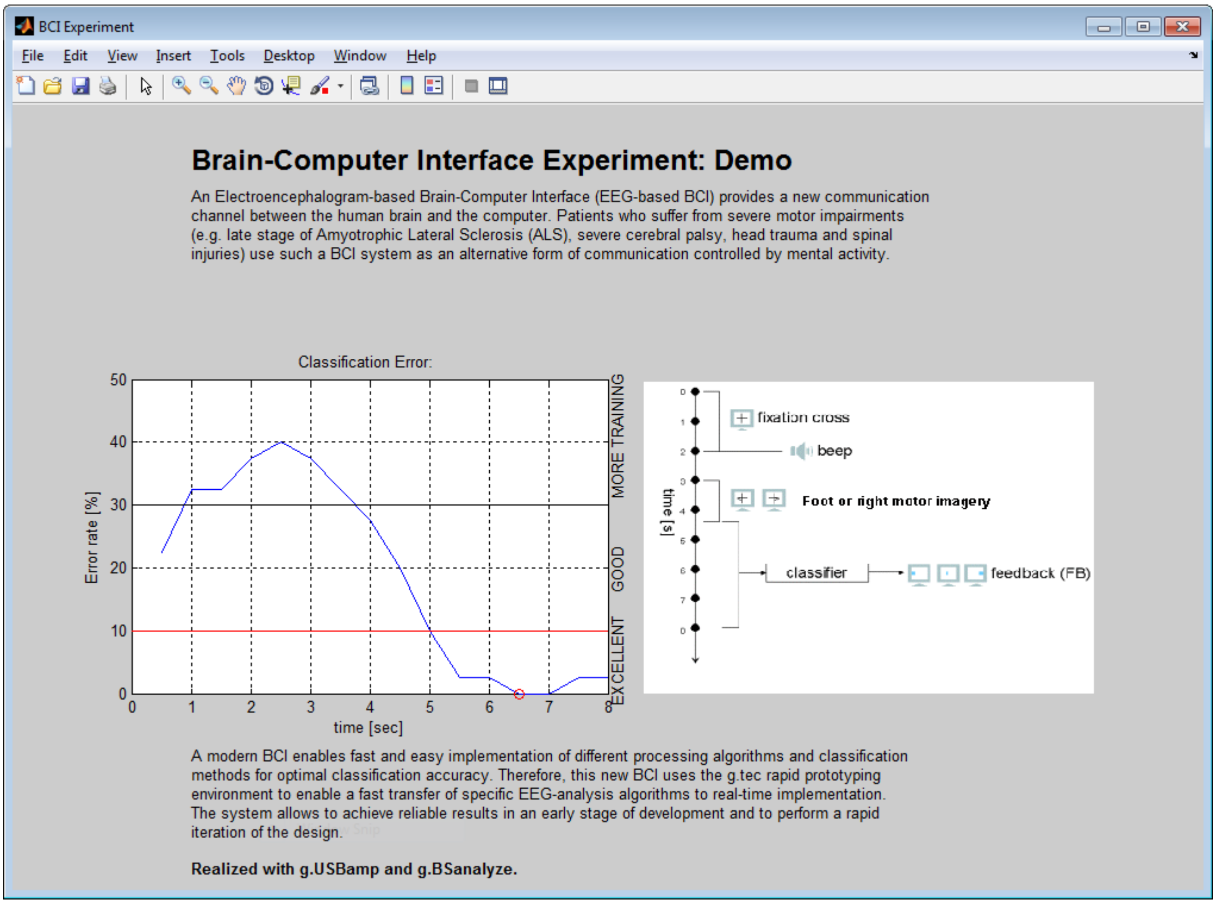
Also, it could happen that the whole data of one channel is too noisy (e.g. if no gel was inserted into the electrode). To mark such a channel select the **BAD** attribute under the **MARKERS / ATTR.** field. Click on the affected channel to mark it as bad, it will then not be further considered in the calculations. Deselect this channel also in the **Select Channels** block in the online model.

The `CreateClassifier_CSP_TwoClass_part2` batch displayed in the **User** menu list automatically calculates the CSP filters and LDA from the artifact corrected data.

Click on `CreateClassifier_CSP_TwoClass_part2`.

After a few seconds the analysis batch automatically shows the classification error rates for all three classes and a total error. The best time point to evaluate the experiment is indicated by the point where the total error reaches the lowest value. In the example below the user reached an error of about 0% at second 6. This means that 3 seconds after the arrow appeared on the screen the minimum error was reached.

NOTE: The CSP filters were calculated for a time window in the feedback period, which is specified in the batch, and therefore producing best results for this time point. To investigate other CSP filters the time window in the batch must be modified. If more than one window is defined, the batch evaluates all of them and selects the window with the lowest error rate.



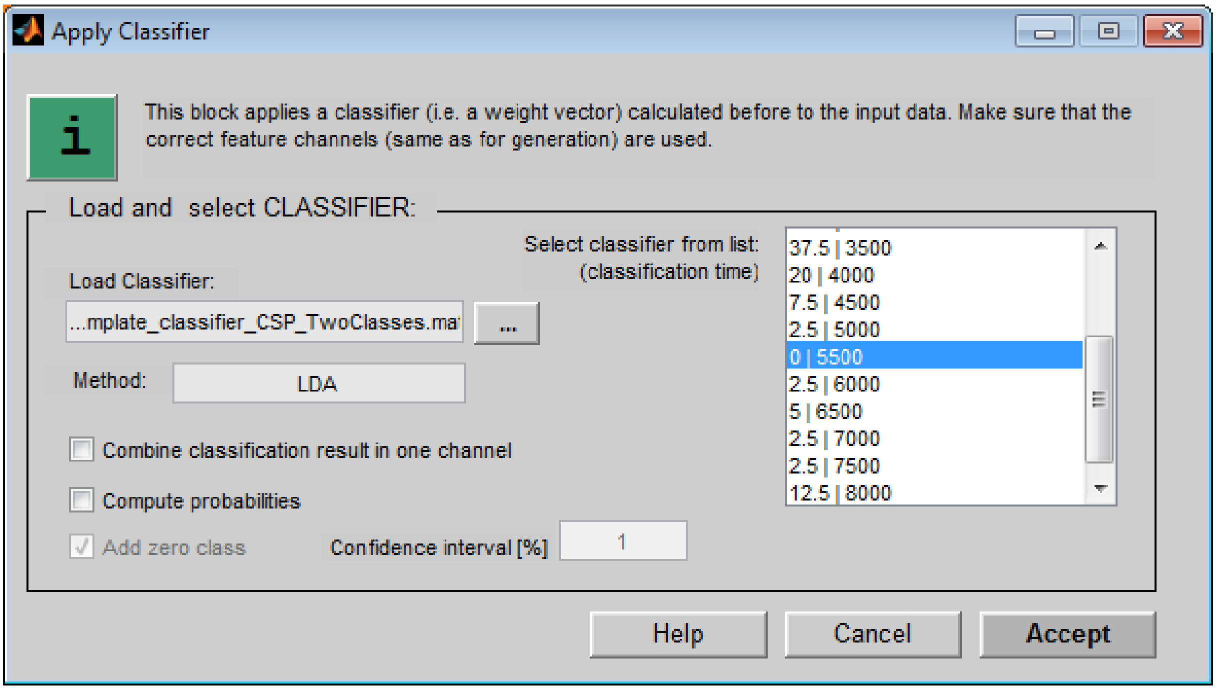
The batch automatically stores the calculated CSP filters `W_CSP` into the MATLAB global workspace. The classifier is stored automatically as `classifier_CSP_TwoClasses.mat` file in the MATLAB **Current folder** and must be manually loaded in the next steps.

`W_CSP` is of size Channels x Channels if one or several channels were marked as bad this number is reduced. Please be sure that the bad channels are also deselected in the **Select Channels** block in the online model.

Experiment with Feedback

Once the classifier is calculated, you can run the same experiment, but this time with providing feedback to the BCI user.

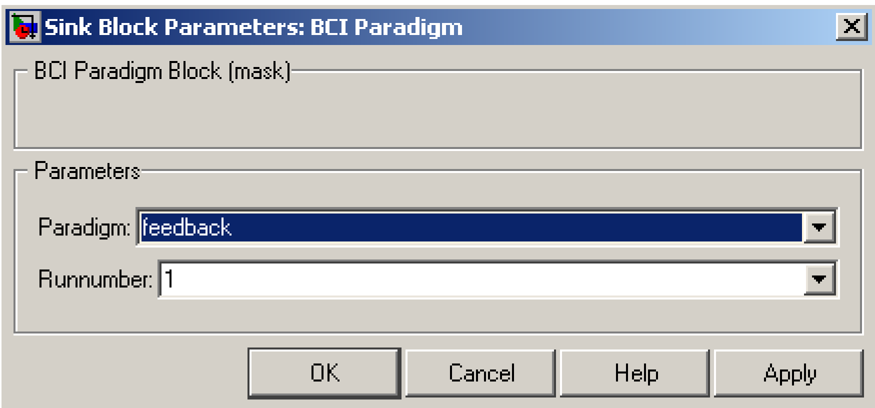
In the Simulink model double click on the **Apply Classifier** block to load the classifier.



Load Classifier: select the `classifier_CSP_TwoClasses.mat` file saved previously in MATLAB **Current folder.**

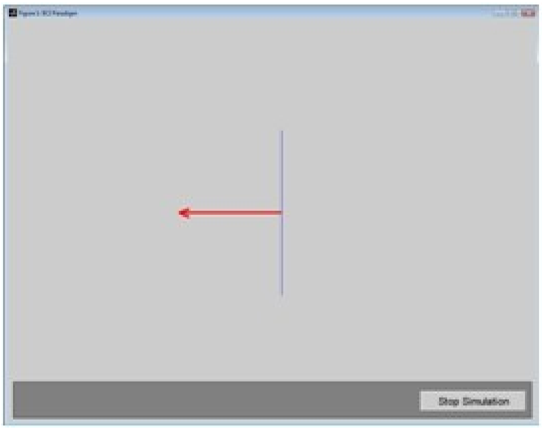
Select classifier from list: select the classifier which should be used for the online classification. The left value is the classification error and the right value the time point the error was observed.

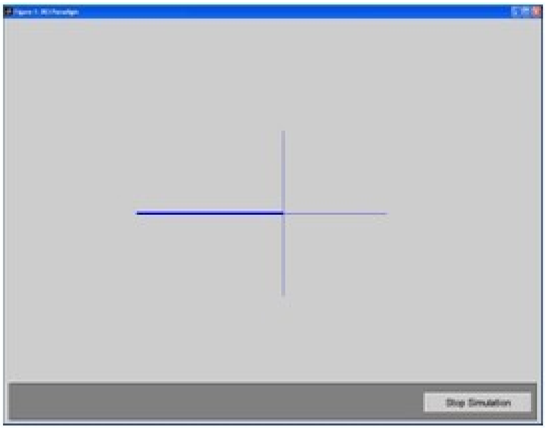
Double-click onto the **BCI Paradigm** block and select the feedback mode.



Then change the filename to `run_1` at the **To File** block and start the Simulink model.

The paradigm now displays after the arrow a bar which moves to the right or to the left depending on the type of imagination. The goal is to extend the bar as far as possible to the right or left because this corresponds to a better discrimination.





Repeat the feedback paradigm for all 4 runs.

A whole session (`run1_TwoClass.mat`, `run2_TwoClass.mat`, `run3_TwoClass.mat`, `run4_TwoClass.mat`) of prerecorded EEG data and a classifier (`template_classifier_CSP_TwoClasses.mat`) calculated from these merged runs, are stored under the following directory:

`Program Files/gtec/gCSPbci/TestData`

and can be used as examples for the off-line analysis.

Off-line Processing of 4 Runs

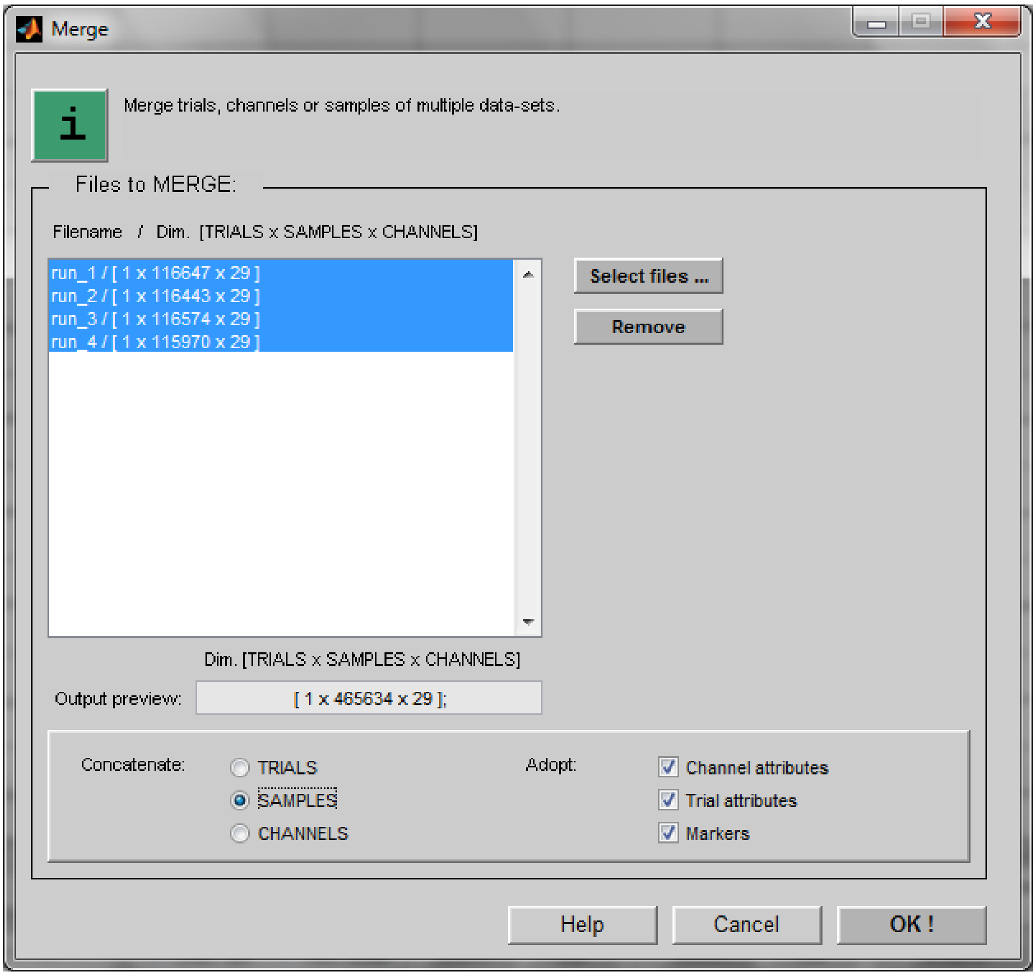
After 4 runs with 40 trials each (runs 1, 2, 3 and 4) were recorded, the data must be merged to be able to analyze the whole data set.

Perform the following steps:

Load the data-set `run1_TwoClass.mat` into the Data Editor

Select **Merge** in the menu **Transform**

Press **Select files …** and choose `run2_TwoClass.mat`



Enter a sampling frequency of `256 Hz` in the **Enter Sampling Frequency** window

Repeat Steps 3 and 4 also for `run3_TwoClass.mat and run4_TwoClass.mat`

Select **Concatenate SAMPLES**. **Output preview** shows the expected result of the merging process.

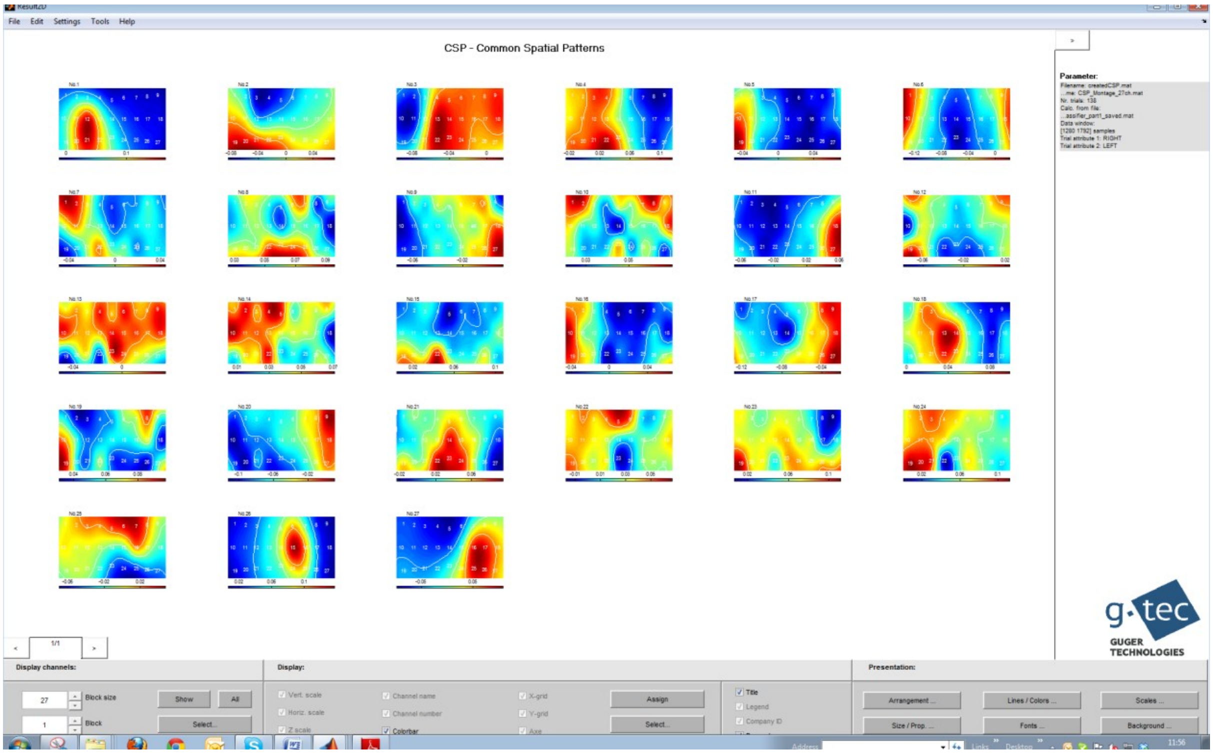
Press the button **OK**.

The new data-set consists of 1 trial and 4 times more samples as a single data-set.

From now one, perform the following steps:

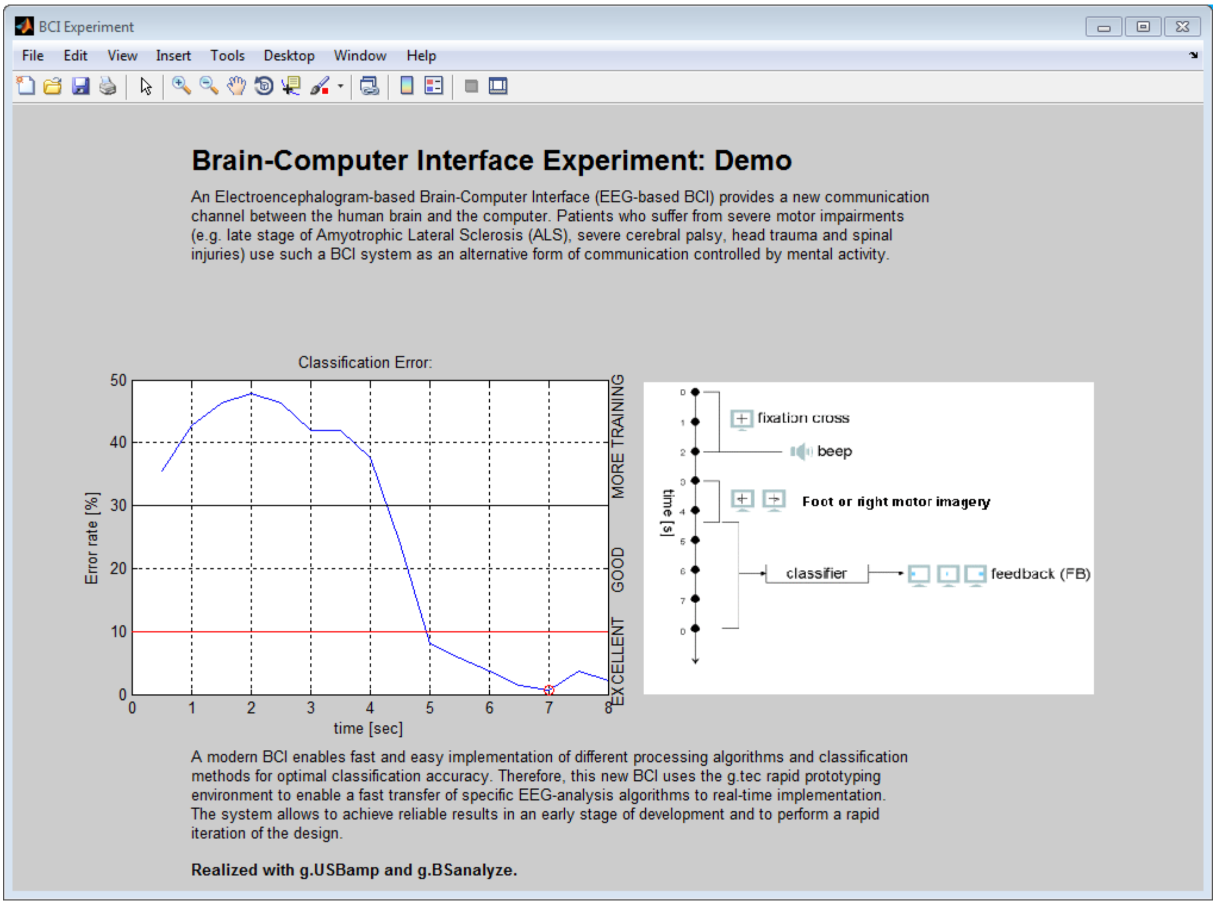
- run the `CreateClassifier_CSP_TwoClass_part1` batch;
- load the created `CreateClassifier_part1_saved.mat` file from the MATLAB **Current folder.**
- Perform the artifact correction as mentioned before.
- Run the `CreateClassifier_CSP_TwoClass_part2` batch.

A few seconds later, 27 CSP filters are shown with the correct topographic arrangement.



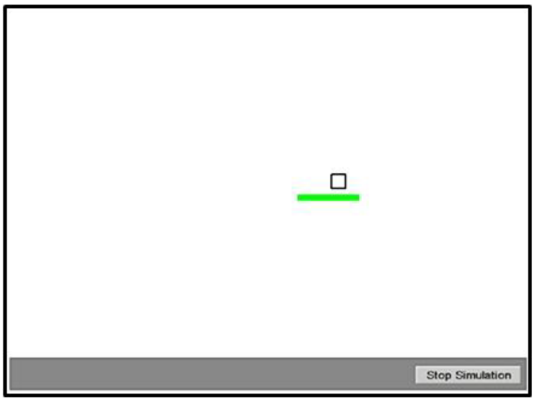
The two most important CSP filters 1 and 27 show peaks around the most important positions C3 and C4 according to the physiology. The second most important filters 2 and 26 already have different spots.

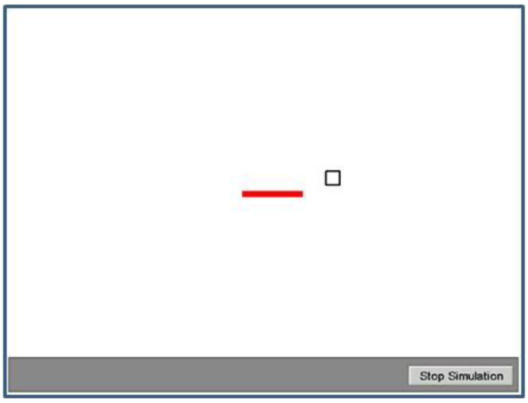
Finally the accuracy of the whole experiment is displayed. In this example the best classification was possible at second 4.5. The user reaches almost 0 % error.



Mental tracking

This paradigm shows a rectangle on the screen that is moving to the left and right border of the screen. The task of the user is to follow the rectangle with the paddle. The paddle is shown in green if it is close to the rectangle, otherwise it becomes red.





Switch to the ball paradigm in the **BCI Paradigm** block:
The speed of the rectangle increases every 50 seconds and therefore it can be tested if the user is able to follow the item fast enough. Finally the accuracy will be plotted for 8 different speeds.
HAVE FUN.
Your g.tec team.

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