

Introduction to Brain-Computer Interface Design: Practicum

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In the Meantime...

- ... please start unzipping your bcilab-1.01 file to some directory on your disk if you haven't done so already.
- You also find it at <ftp://sccn.ucsd.edu/pub/bcilab>
- Should take 5-10 minutes (if you're on Windows, try to use 7-zip or WinZip/WinRAR).
- Don't put it inside the EEGLAB folder (BCILAB includes an EEGLAB distribution).



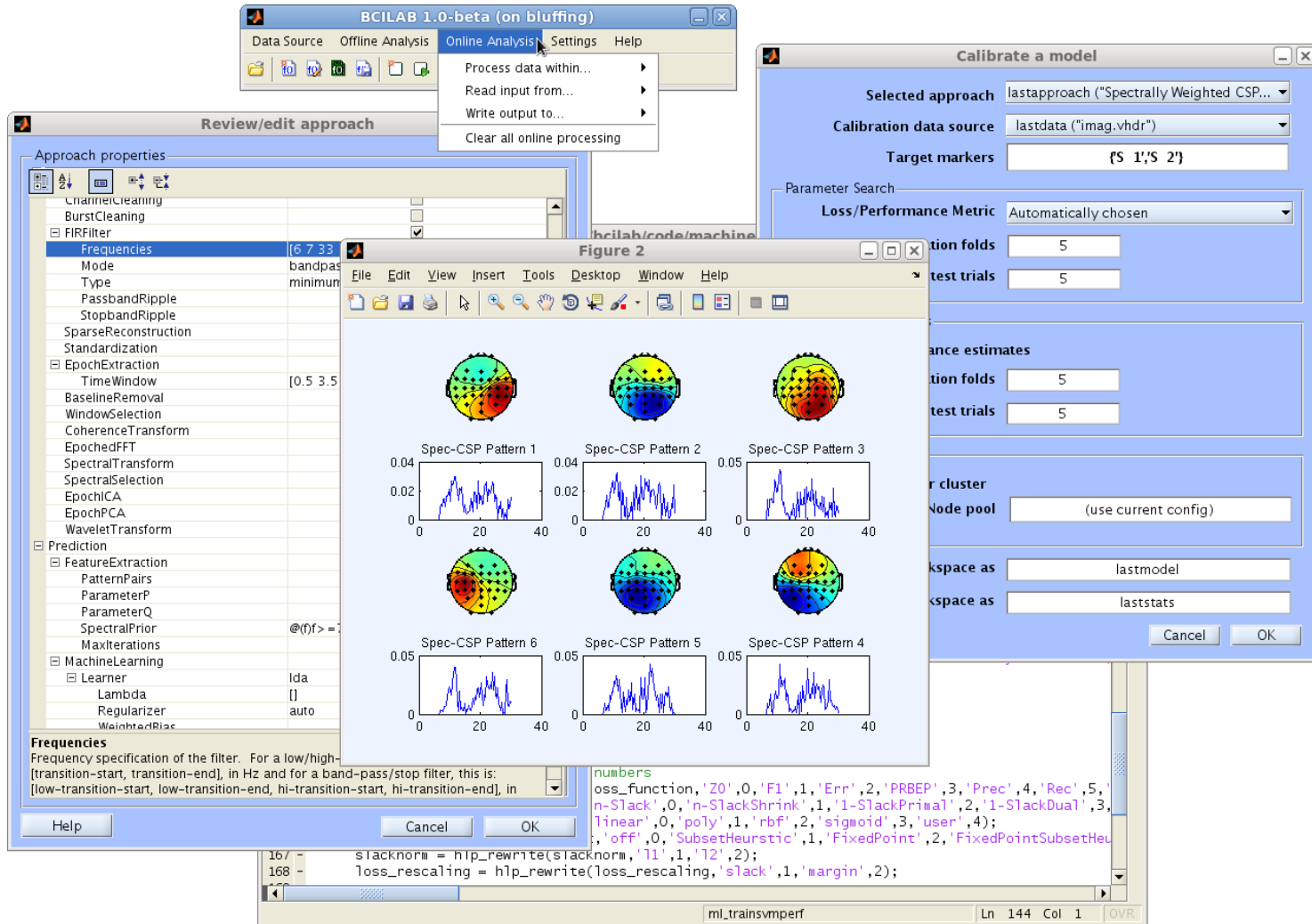
Outline

1. Toolbox Intro
2. Concepts and Components
3. Detailed GUI Walkthrough
4. Hands-On ERP Analysis
5. Hands-On Oscillatory Analysis



1 Toolbox Intro

The BCILAB Toolbox



The screenshot displays the BCILAB 1.0-beta software interface, which is running on a Windows operating system. The main window is titled "BCILAB 1.0-beta (on bluffing)" and has a menu bar with "Data Source", "Offline Analysis", "Online Analysis", "Settings", and "Help". A dropdown menu is open under "Online Analysis", showing options: "Process data within...", "Read input from...", "Write output to...", and "Clear all online processing".

Overlaid on the main window are several other windows:

- Review/edit approach:** This window shows a list of "Approach properties" with checkboxes for various processing steps. The "Frequencies" section is currently selected, showing a table with columns for "Frequencies" (value: [6 7 33]), "Mode" (value: bandpass), and "Type" (value: minimum). Other sections include "EpochExtraction", "Prediction", and "MachineLearning".
- Calibrate a model:** This window is used for configuring model calibration. It includes fields for "Selected approach" (set to "lastapproach"), "Calibration data source" (set to "lastdata"), and "Target markers" (set to "{S 1;S 2}"). It also has sections for "Loss/Performance Metric", "Performance estimates", and "Cluster" configuration.
- Figure 2:** This window displays six topographic maps of the head, each labeled "Spec-CSP Pattern" (1 through 6). Below each map is a line graph showing the power spectrum of that pattern, with the x-axis representing frequency (0 to 40 Hz) and the y-axis representing power (0 to 0.05).
- Code Editor:** A window at the bottom shows MATLAB code for training a support vector machine. The code includes:


```

numbers
loss_function, 'Z0',0,'F1',1,'Err',2,'PRBEP',3,'Prec',4,'Rec',5,'
n-Slack',0,'n-SlackShrink',1,'l1-SlackPrimal',2,'l1-SlackDual',3,'
linear',0,'poly',1,'rbf',2,'sigmoid',3,'user',4);
,'off',0,'SubsetHeuristic',1,'FixedPoint',2,'FixedPointSubsetHeu
stacknorm = hlp_rewrite(stacknorm,'l1',1,'l2',2);
loss_rescaling = hlp_rewrite(loss_rescaling,'slack',1,'margin',2);
      
```

<http://scn.ucsd.edu/wiki/BCILAB>

<ftp://scn.ucsd.edu/pub/bcilab>

Context

- Like EEGLAB, but for BCI (and/or cognitive state assessment)
 - Seeding a community
 - Strengthening links between BCI and Neuroscience
- SCCN's in-house tool for BCI problems
 - Main focus: Advanced cognitive monitoring
 - Part of a large US research program (CaN CTA)
 - Funded by ARL (and ONR, Swartz Foundation, ...)





Software Environment For:

- **Brain-Computer Interface Design** (Cognitive Monitoring)
- **Methods Research:**
 - Design & rapid prototyping of new methods & methods from literature
 - Offline testing, performance evaluation & batch comparison
 - Simulated online testing
- **Rapid Prototyping:**
 - Real-time use
 - Prototype deployment



Facts & Figures

- Developed since 2010 at SCCN, UCSD (primarily by me)
- Precursor was the PhyPA toolbox (Kothe & Zander, 2006-'09)
- Built on top of EEGLAB (Delorme & Makeig, 2004)
- Currently the largest open-source BCI toolbox by methods and algorithms (100+)
- Offline and online processing both in MATLAB, same code base, cross-platform, 32/64bit

Basic Goals

- Provide large array of existing methods to reproduce existing literature – e.g., in benchmarking and comparison studies
- Provide state-of-the-art and novel methods to rapidly set up well-performing BCIs
- Provide plugin frameworks and backend solvers to implement new methods quickly
- GUI for beginners & experimenters, scripting for experts and MATLAB veterans – largely the same feature set
- Allow for both conventional designs (e.g., data flow) and for radically new approaches



2 BCILAB Concepts and Details

Toolbox Layers

Framework

GUI / Scripting Interfaces

Approach
Definition

Online
Execution

Offline
Evaluation

Visualization

Plugins

Signal Processing

ICA

SSA

FIR

IIR

FFT

...

Machine Learning

LDA

QDA

DAL

GMM

SVM

...

BCI Paradigms

CSP

Spec-CSP

ERP

RSSD

...

Devices

TCP

OSC

BCI2000

...

Infrastructure

GUI
generation

cluster
computing

disk
caching

helper
functions

environment
services

Dependencies

CVX

BNT

EEGLAB

GUI utils

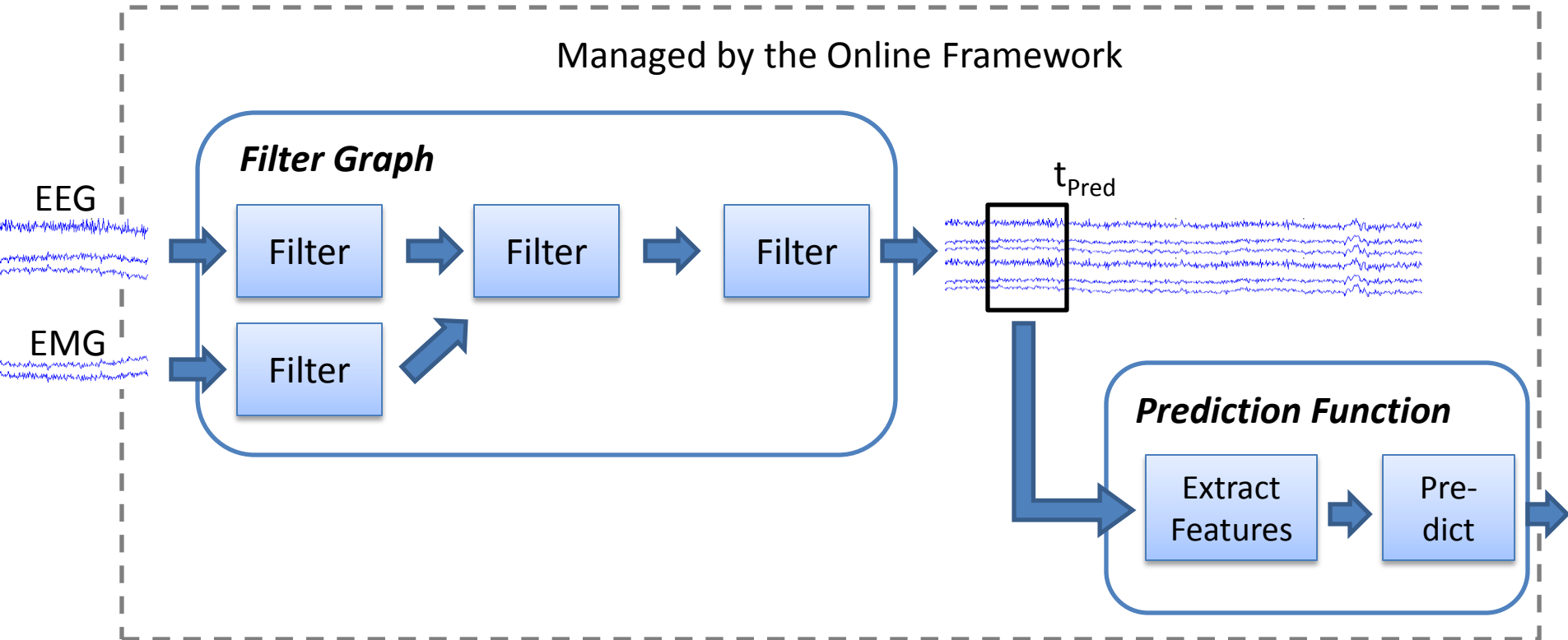
LIBSVM

GLMNET

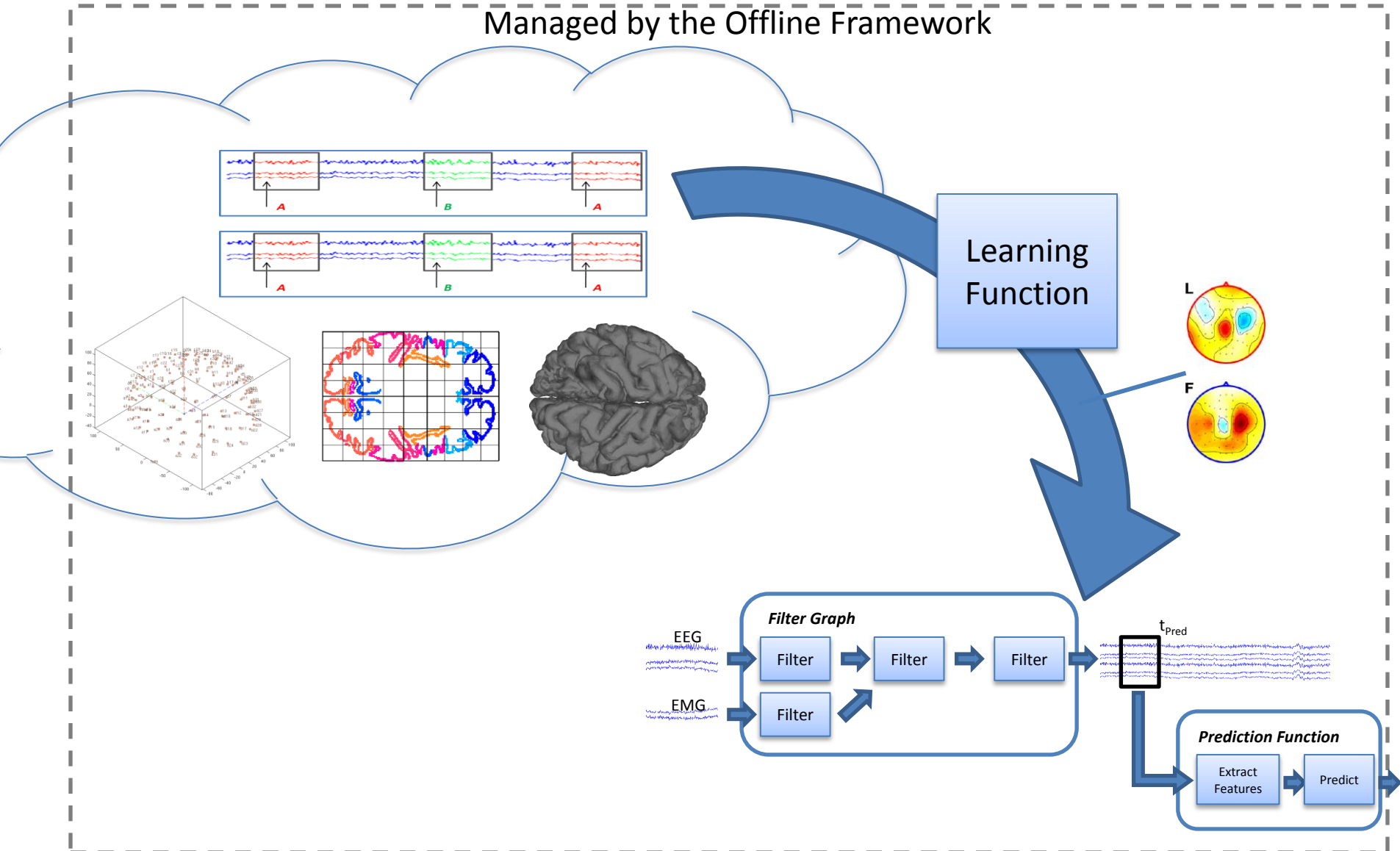
...

Driver
I/O

Scope of the Online Framework

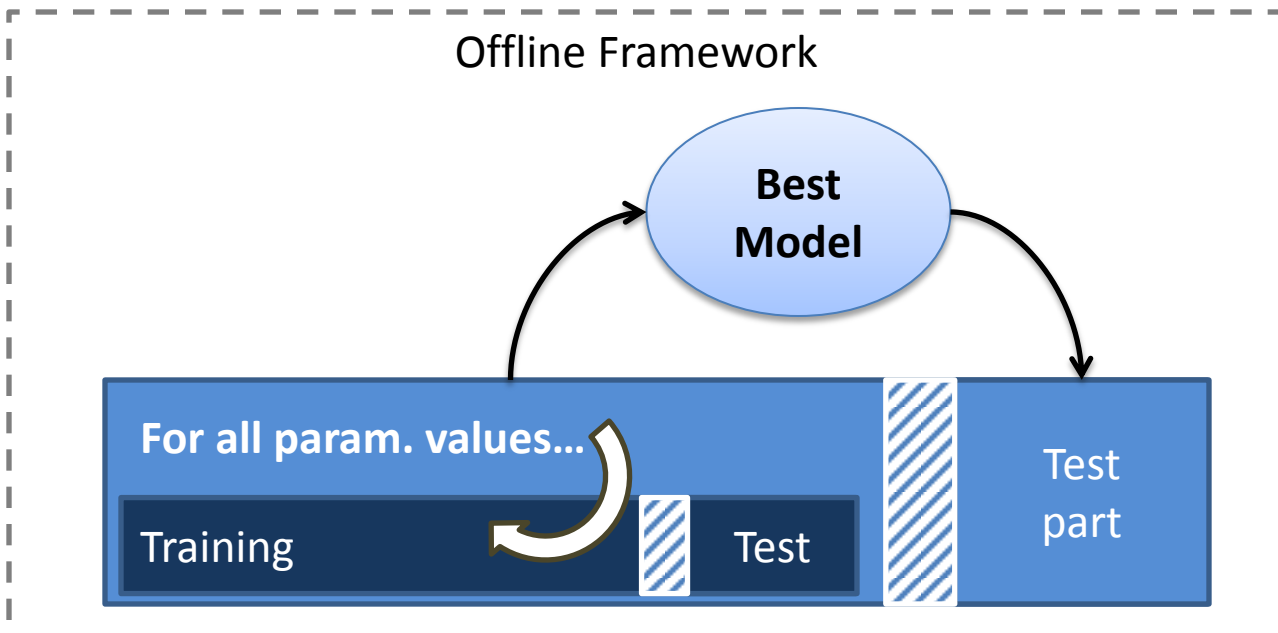


Scope of the Offline Framework



Scope of the Offline Framework

- **Also Covered:** Cross-validation, Grid Search, Nested Cross-Validation

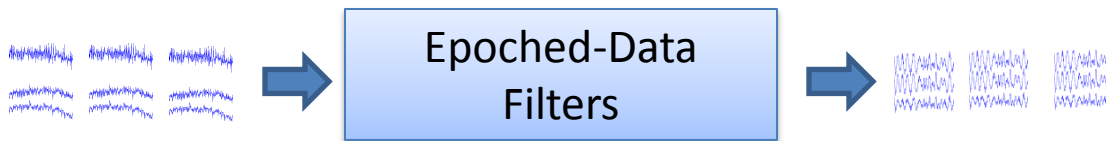


Filter Components

- Filters can operate on continuous signals...



- ... or on segmented (“epoched”) signals:



Machine Learning Components

- Machine learning functions come in pairs:

Machine Learning Method

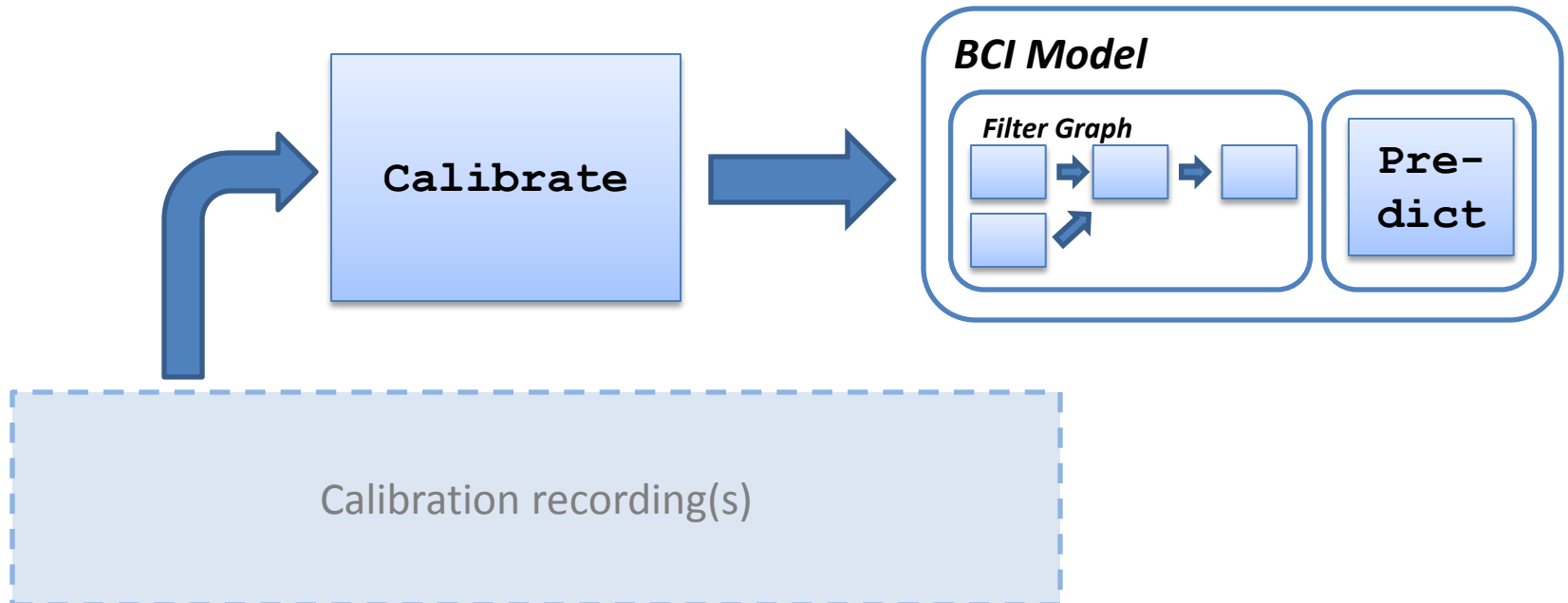


```
M = ml_trainlda(X,y)
```

```
p = ml_predictlda(Xnew,M)
```

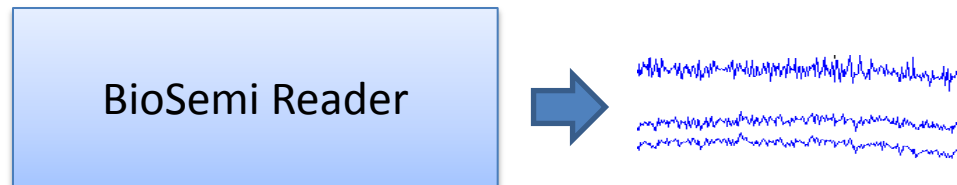

Paradigms Components

- **BCI paradigms** are the coarsest plugin type in BCILAB and *tie all parts of a BCI approach together* (signal processing, feature extraction, machine learning, ...)
- They are invoked by the offline/online framework



Online Reader Components

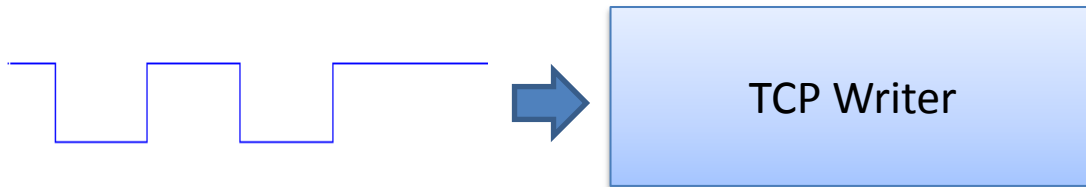
- Online reader plugins read signals from a source device and make them available in the MATLAB workspace:



- Example:
`run_readbiosemi();`

Online Writer Components

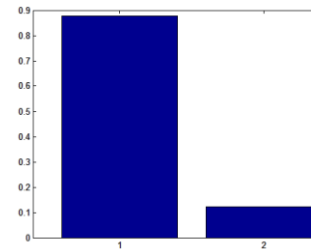
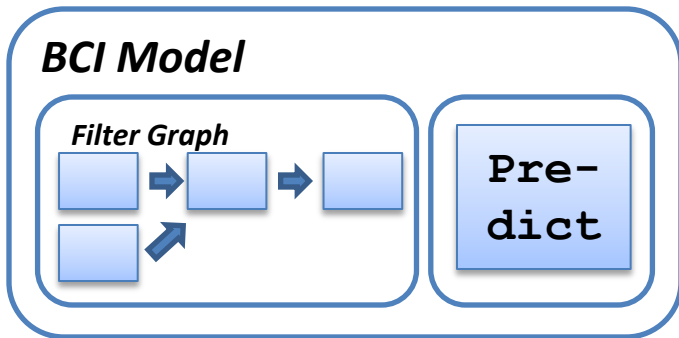
- Online writer plugins write BCI outputs (i.e., predictions) to some external destination:



- Example:

```
run_writetcp('mdl', 'strm', '192.168.1.5', 12467)
```

Data Representations



Probability Distributions

$$\begin{bmatrix} f_1 \\ f_2 \\ \vdots \end{bmatrix}$$

Feature Vectors

Symbolic Expression

@flt_fir

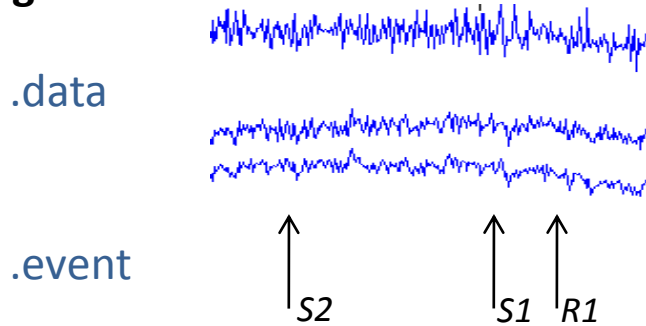
head

{ mydata, [0.5 1], 'highpass' }

parts

Data Representations

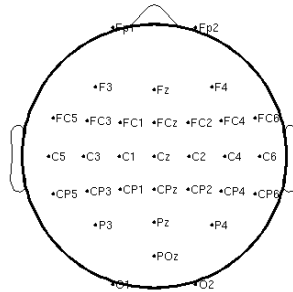
Signal



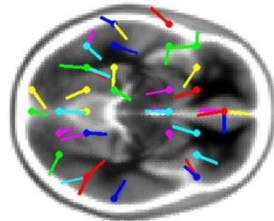
.srate
.xmin

200Hz
0.0s

.chanlocs



.dipfit



... (meta-data)

Signal Bundle

.streams

Signal 1

Signal 2

⋮

Signal n

... (meta-data)

Dataset Collection

Bundle 1

Bundle 2

⋮

Bundle n

Pipeline Notion

- BCILAB is a framework that resembles a processing pipeline: first configure everything, then apply it to one or more data sets
- **Configuration Inputs:**
 - Mapping between marker type strings and numeric class labels
 - Base BCI Paradigm to execute – “what to run?”
 - Custom parameters for the paradigm
 - Evaluation Scheme – “how to run it?”
(e.g., what type of cross-validation)



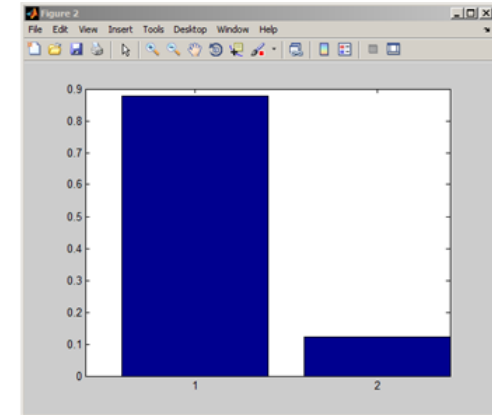
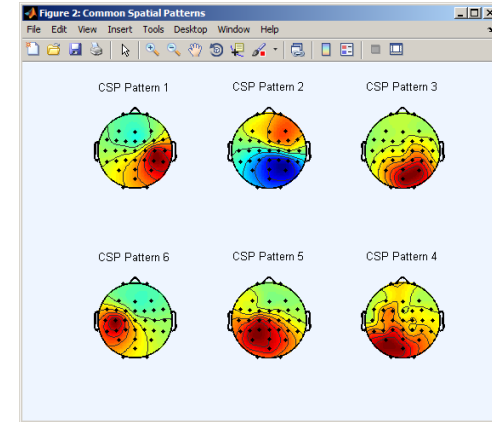
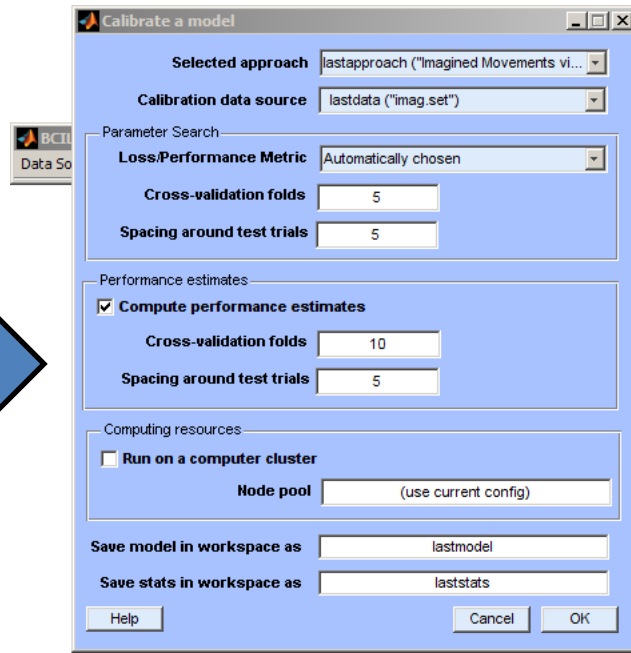
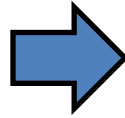
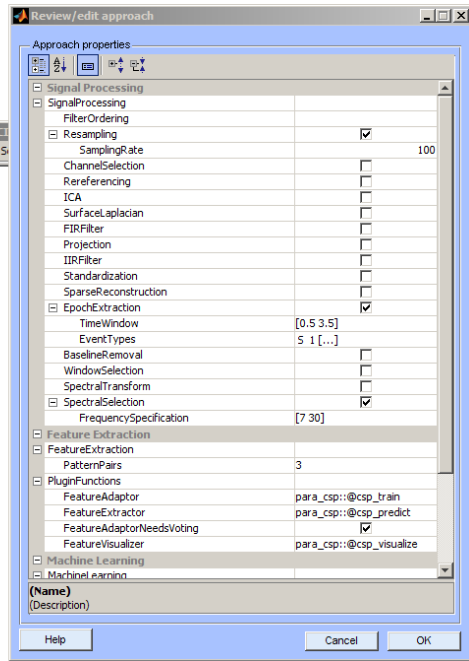
Pipeline Processes

- **Curate:** bring the input data into standard form
- **Design:** define the computational approach
- **Train:** invoke all steps necessary for training (calibrating) a BCI and estimates performance
- **Predict:** apply a BCI to some data offline
- **Visualize:** visualize BCI model internals
- **Run Online:** apply a BCI online / incrementally
- **Batch Analysis:** perform a series of processing steps, optionally in parallel



3 Detailed GUI Walkthrough

Detailed GUI Walkthrough





Getting Started

System requirements

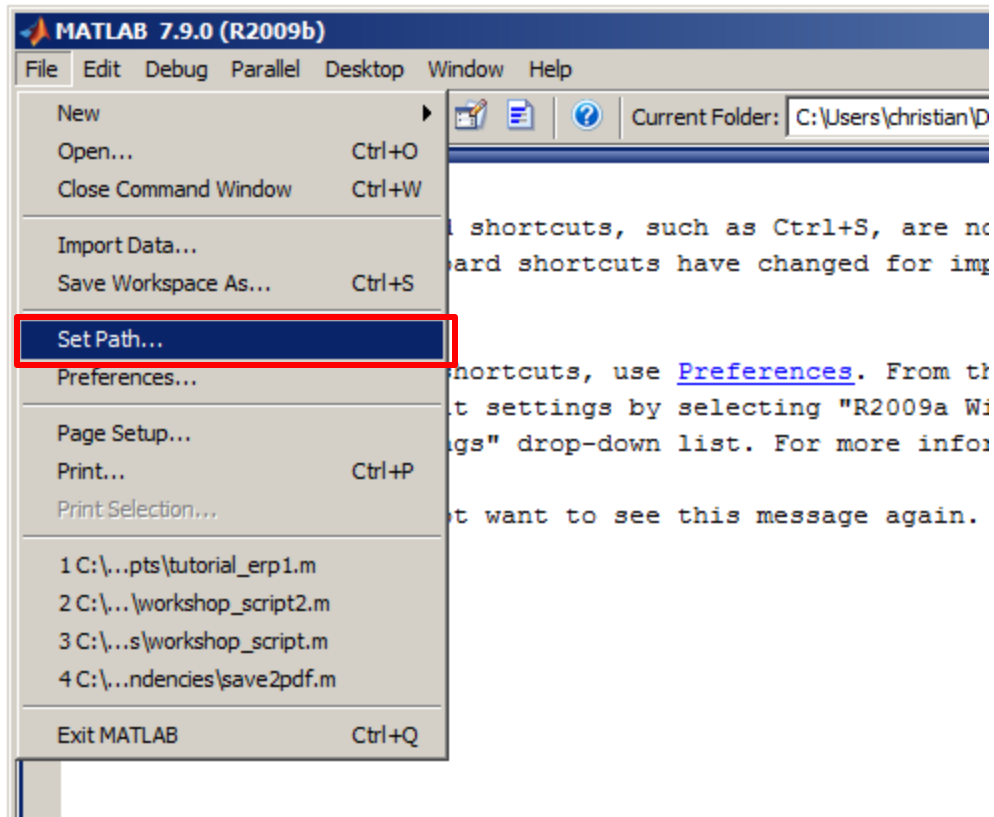
- MATLAB 2008a+
- 1GB+ RAM (better: 2GB+)
- Windows, Linux, or Mac
- For smooth workshop: **No** toolboxes in MATLAB path other than Mathworks toolboxes (or EEGLAB)
- To use certain additional features (not covered today):
Signal Processing Toolbox, Statistics Toolbox, Real-time experimentation environment (DataRiver, BCI2000, OpenViBE or your own)
- To use certain advanced features (also not covered today):
Correct MEX compiler setting (this requires Microsoft Visual C++ Express under Win64 and Xcode/gcc under Mac)



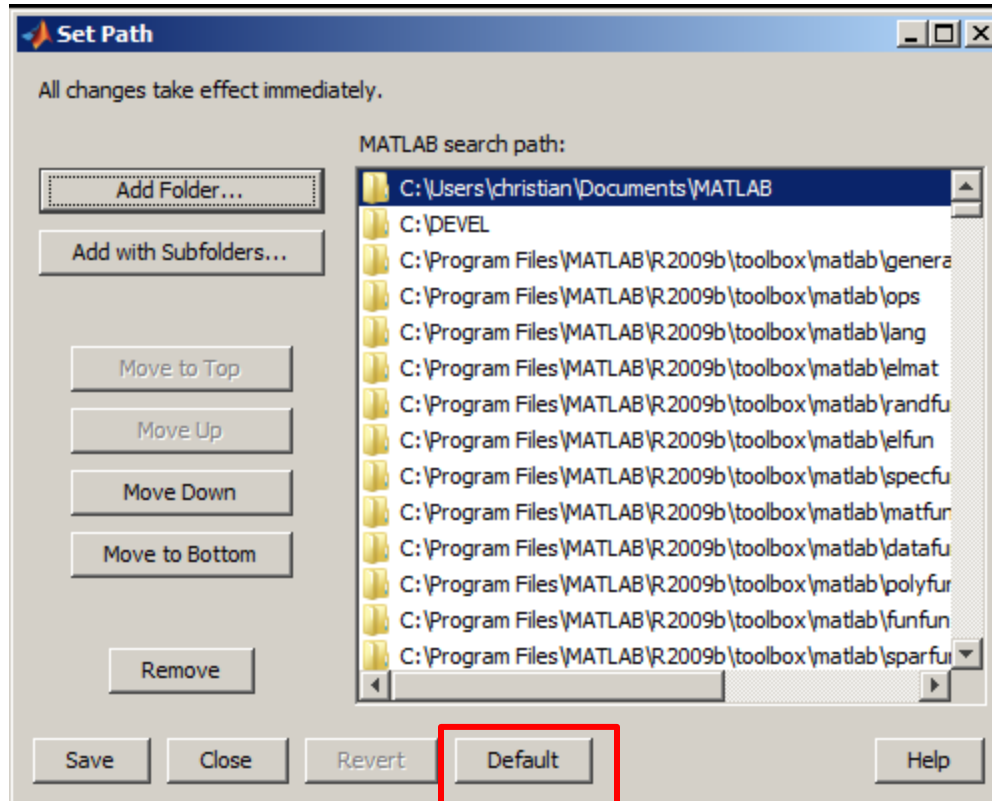
When Processing your own Data

- Note the following requirements:
 - You need proper channel labels (usually the 10-20 labels); 3d locations not necessary
 - You need event markers in your data for the time points with known target condition
 - BCILAB needs raw (unprocessed) data
 - Make sure you have a file format supported by EEGLAB
- Rawr!
-
- An arrow points from the word "Rawr!" at the bottom right to the word "raw" in the third list item, "BCILAB needs raw (unprocessed) data".

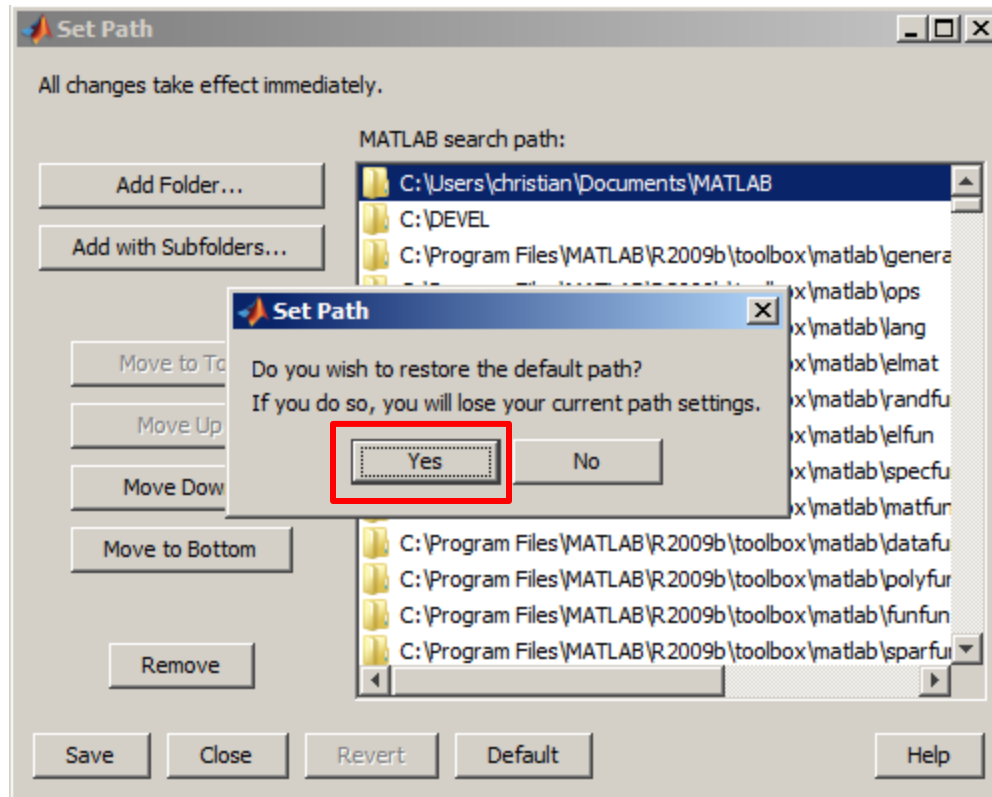
Clearing the Path



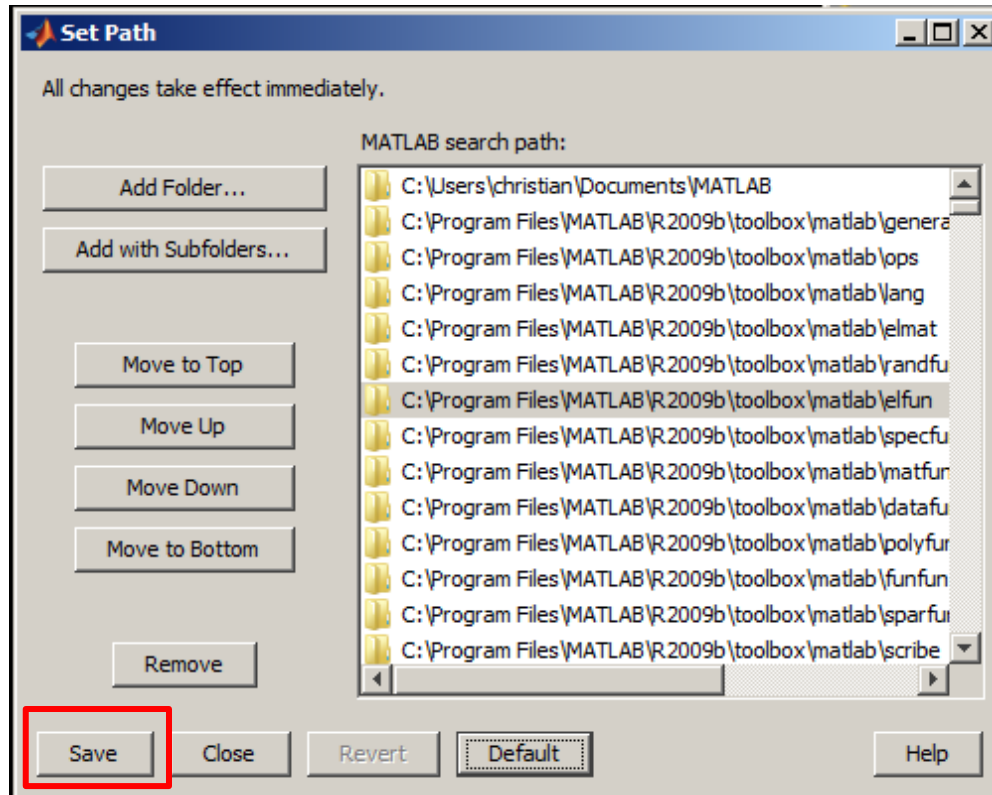
Clearing the Path



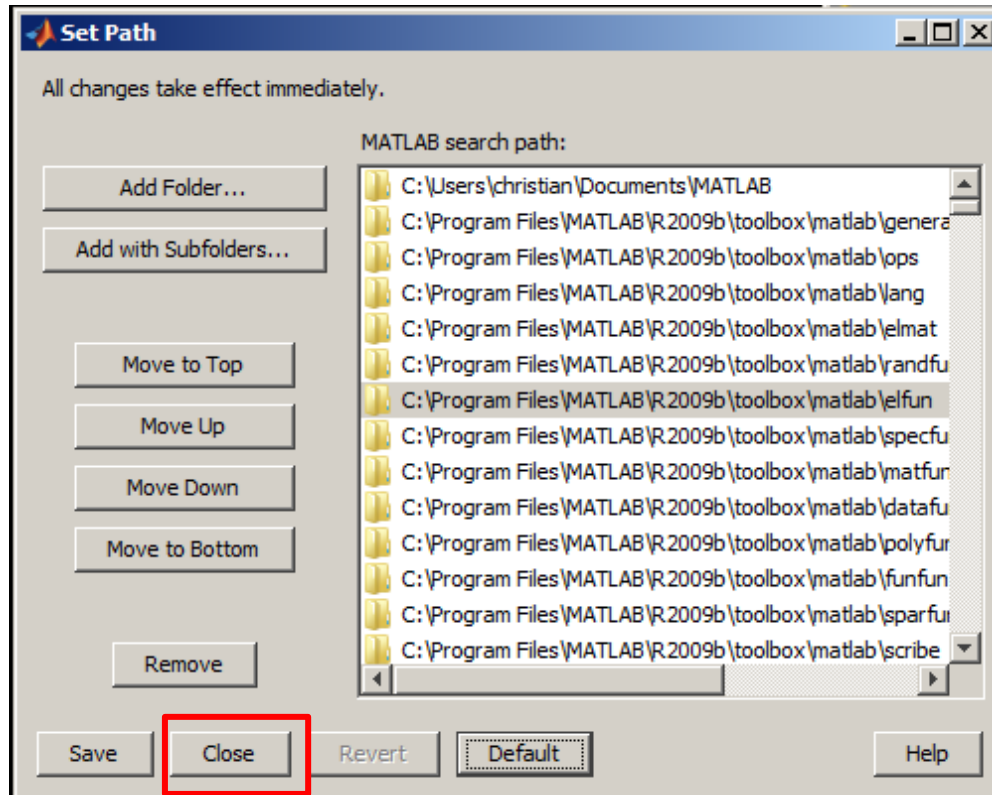
Clearing the Path



Clearing the Path

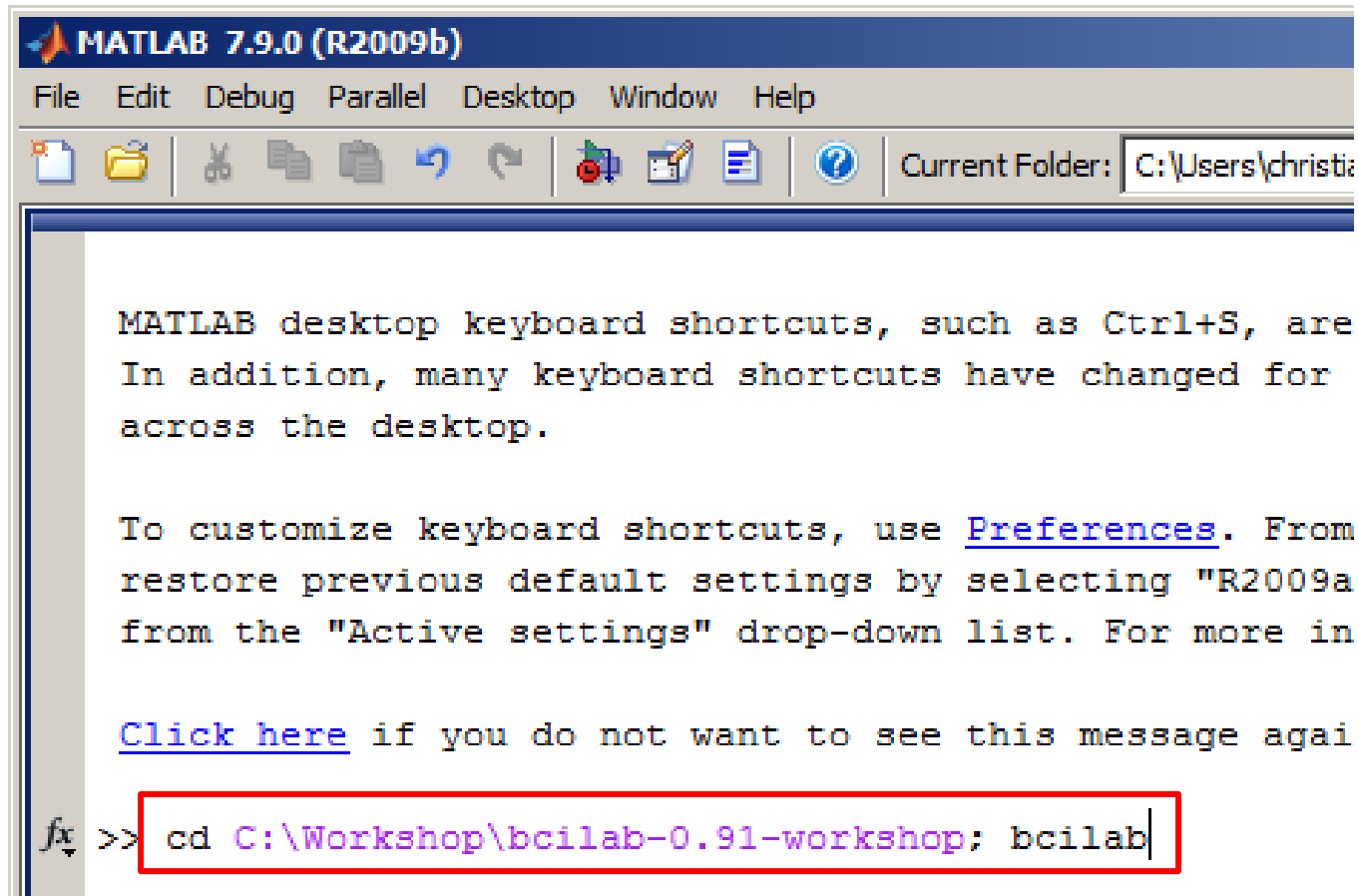


Clearing the Path



Starting the Toolbox

- Type: `cd C:\your\path\to\bcilab; bcilab`





Starting the Toolbox

- Or if your path contains spaces, type:
`cd('C:\your\path\to\bcilab'); bcilab`



Starting the Toolbox

- If you have an old (32-bit) Macintosh laptop, BCILAB might ask you some question about compiling functions
 - Just type n (for no) to continue
- If you have things on your MATLAB path that override BCILAB function names, you will get some warnings about it (it's best to remove them from the path)

Starting the Toolbox

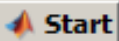
- You should now see the welcome message

```
temp directory \tmp\bcilab_temp does not exist and could not be created
Could not probe cache file system speed; reason: Error using ==> save
Unable to write file \tmp\bcilab_cache\_probe_cache_1450493820_.mat: 1

code is in C:\Workshop\bcilab-0.91-workshop\code
data is in C:\Workshop\bcilab-0.91-workshop\userdata
results are in C:\Workshop\bcilab-0.91-workshop\userdata
cache is in \tmp\bcilab_cache (location_1)
temp is in \tmp\bcilab_temp

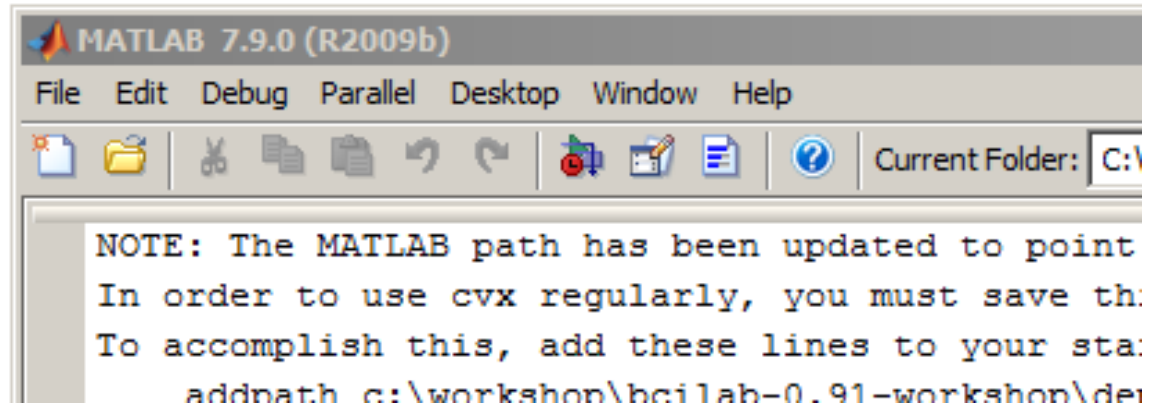
Welcome to the BCILAB toolbox!

fx >>
```

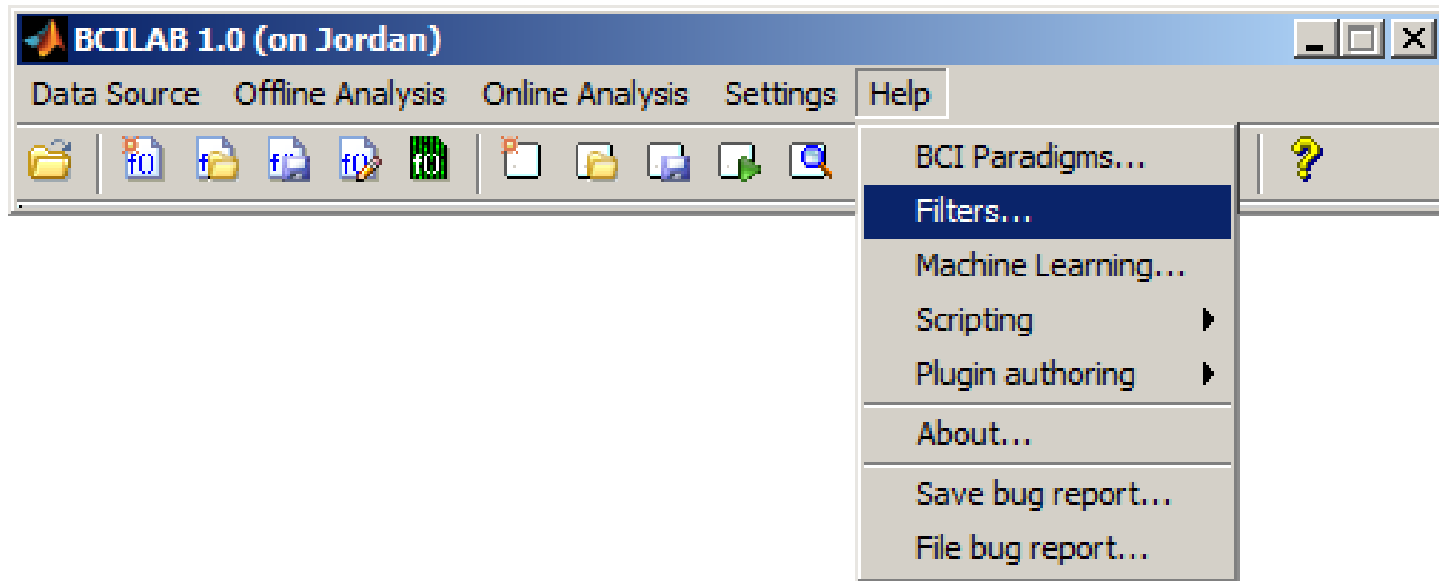


Starting the Toolbox

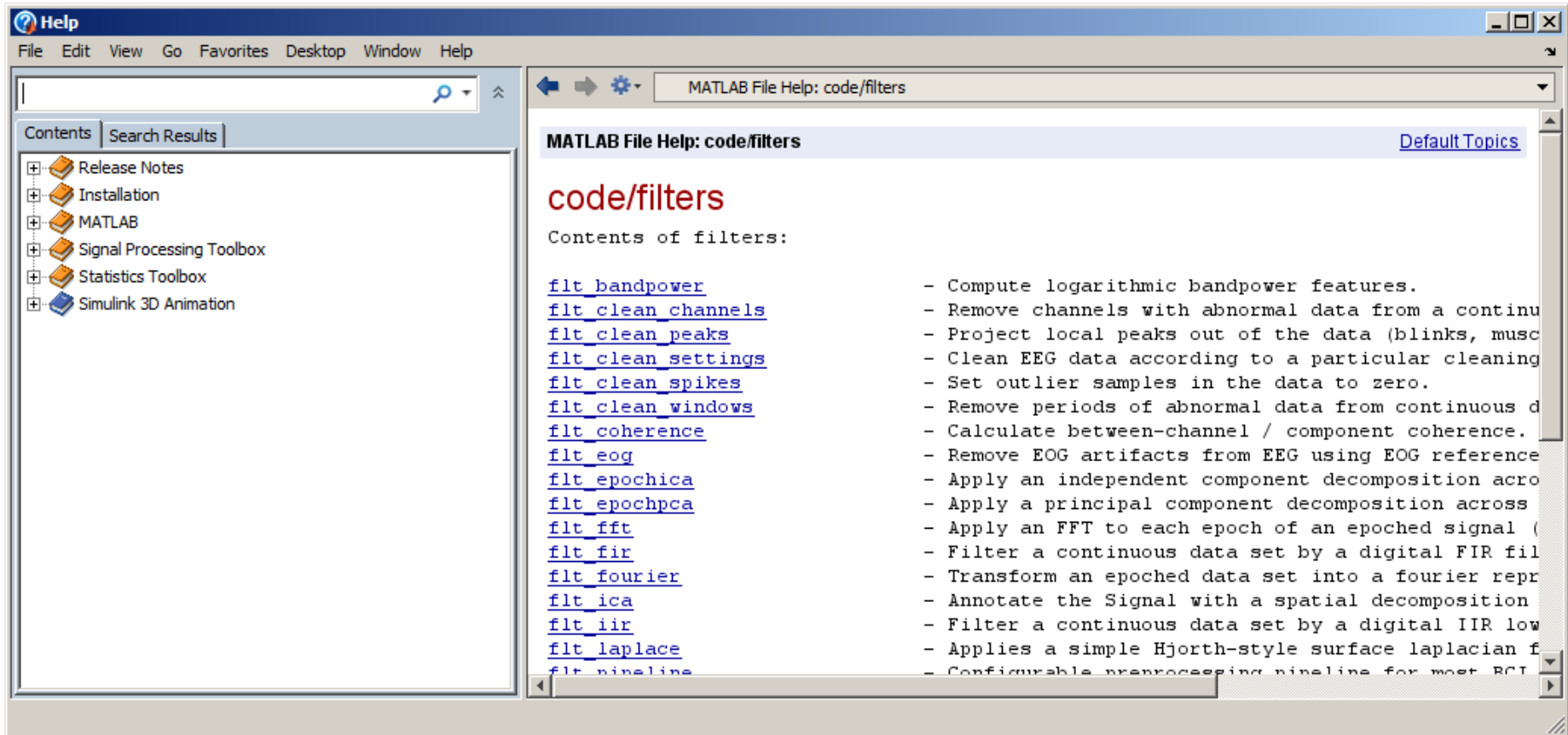
- ... and the main menu



Getting help (if needed)

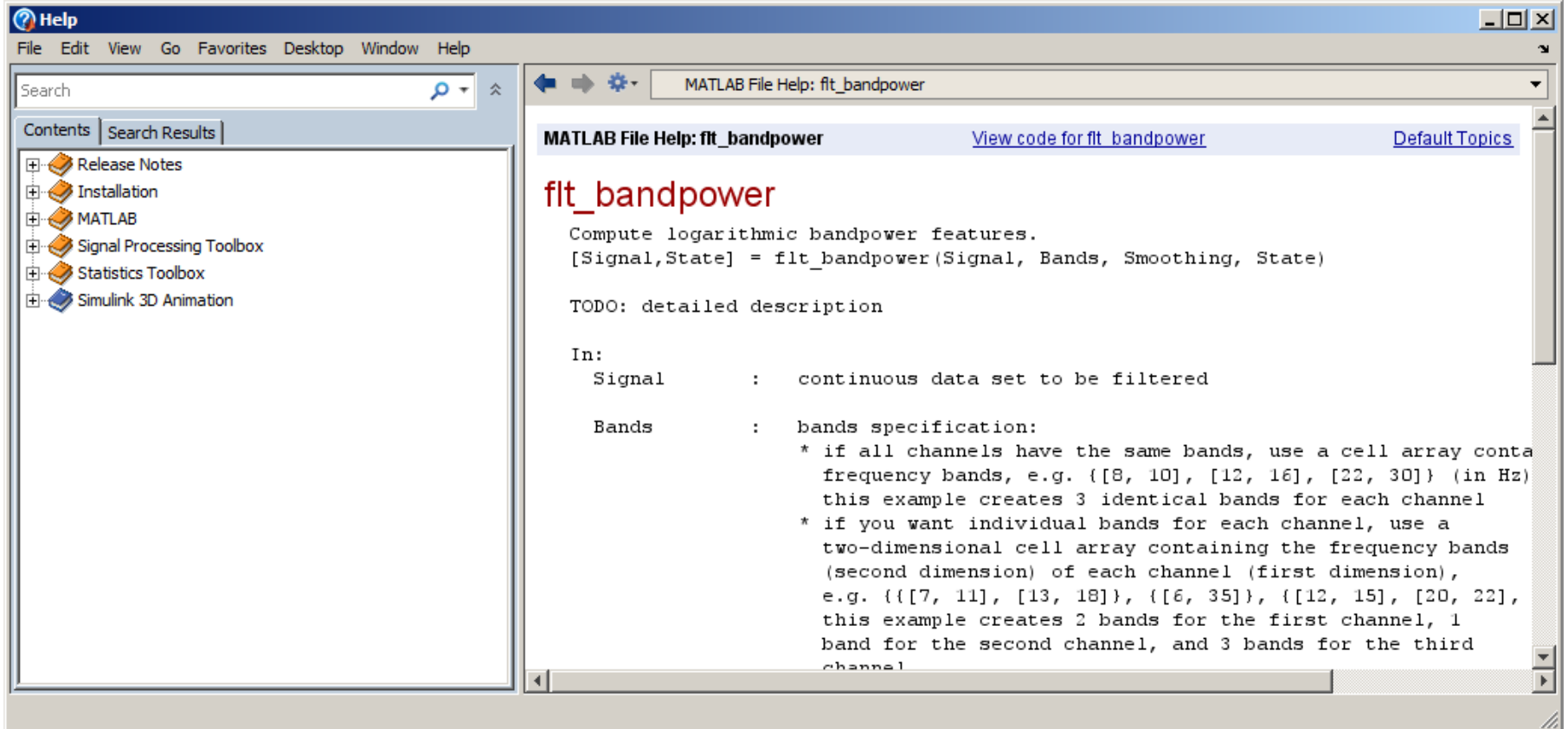


Getting help (if needed)



The screenshot shows the MATLAB File Help window. The title bar reads "MATLAB File Help: code/filters". The left sidebar contains a "Contents" pane with a tree view of help topics: Release Notes, Installation, MATLAB, Signal Processing Toolbox, Statistics Toolbox, and Simulink 3D Animation. The main content area displays the "code/filters" section, titled "MATLAB File Help: code/filters" with a "Default Topics" link. Below the title, it says "Contents of filters:" followed by a list of filter functions with blue underlined links: `flt_bandpower`, `flt_clean_channels`, `flt_clean_peaks`, `flt_clean_settings`, `flt_clean_spikes`, `flt_clean_windows`, `flt_coherence`, `flt_eog`, `flt_epochica`, `flt_epochpca`, `flt_fft`, `flt_fir`, `flt_fourier`, `flt_ica`, `flt_iir`, `flt_laplace`, and `flt_pipeline`. To the right of these links is a list of brief descriptions for each function, such as "Compute logarithmic bandpower features.", "Remove channels with abnormal data from a continu...", "Project local peaks out of the data (blinks, musc...", "Clean EEG data according to a particular cleaning...", "Set outlier samples in the data to zero.", "Remove periods of abnormal data from continuous d...", "Calculate between-channel / component coherence.", "Remove EOG artifacts from EEG using EOG reference...", "Apply an independent component decomposition across...", "Apply a principal component decomposition across...", "Apply an FFT to each epoch of an epoched signal (...", "Filter a continuous data set by a digital FIR fil...", "Transform an epoched data set into a fourier repr...", "Annotate the Signal with a spatial decomposition...", "Filter a continuous data set by a digital IIR low...", "Applies a simple Hjorth-style surface laplacian f...", and "Configurable preprocessing pipeline for most BCI..."

Getting help (if needed)



The screenshot shows the MATLAB Help window for the `fit_bandpower` function. The window title is "MATLAB File Help: fit_bandpower". The left sidebar shows a "Contents" pane with a tree view of MATLAB documentation topics: Release Notes, Installation, MATLAB, Signal Processing Toolbox, Statistics Toolbox, and Simulink 3D Animation. The main content area displays the function signature and description:

MATLAB File Help: fit_bandpower [View code for fit_bandpower](#) [Default Topics](#)

fit_bandpower

Compute logarithmic bandpower features.
`[Signal,State] = fit_bandpower(Signal, Bands, Smoothing, State)`

TODO: detailed description

In:

Signal : continuous data set to be filtered

Bands : bands specification:

- * if all channels have the same bands, use a cell array containing frequency bands, e.g. `{[8, 10], [12, 16], [22, 30]}` (in Hz) this example creates 3 identical bands for each channel
- * if you want individual bands for each channel, use a two-dimensional cell array containing the frequency bands (second dimension) of each channel (first dimension), e.g. `{{[7, 11], [13, 18]}, {[6, 35]}, {[12, 15], [20, 22]}}`, this example creates 2 bands for the first channel, 1 band for the second channel, and 3 bands for the third channel



3 Hands-On ERP Analysis



The Data

- Provided by Grainne McLoughlin
- Contains data from a Flanker task
- Two groups of markers:
 - S101, S102: person presses a button and **commits no error**
 - S201, S202: person presses a button and **commits an error**

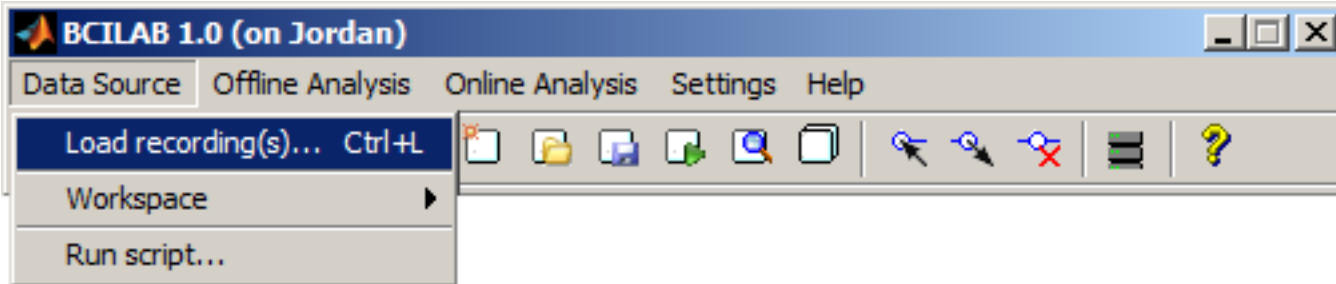
Experimental Task

- **Flanker Task:** The experiment consists of a sequence of ca. 330 trials with inter-trial interval of 2s +/- 1.5s
- At the beginning of each trial, an arrow is presented centrally (pointing either left or right)
- The arrow is flanked by congruent or incongruent “flanker” arrows:

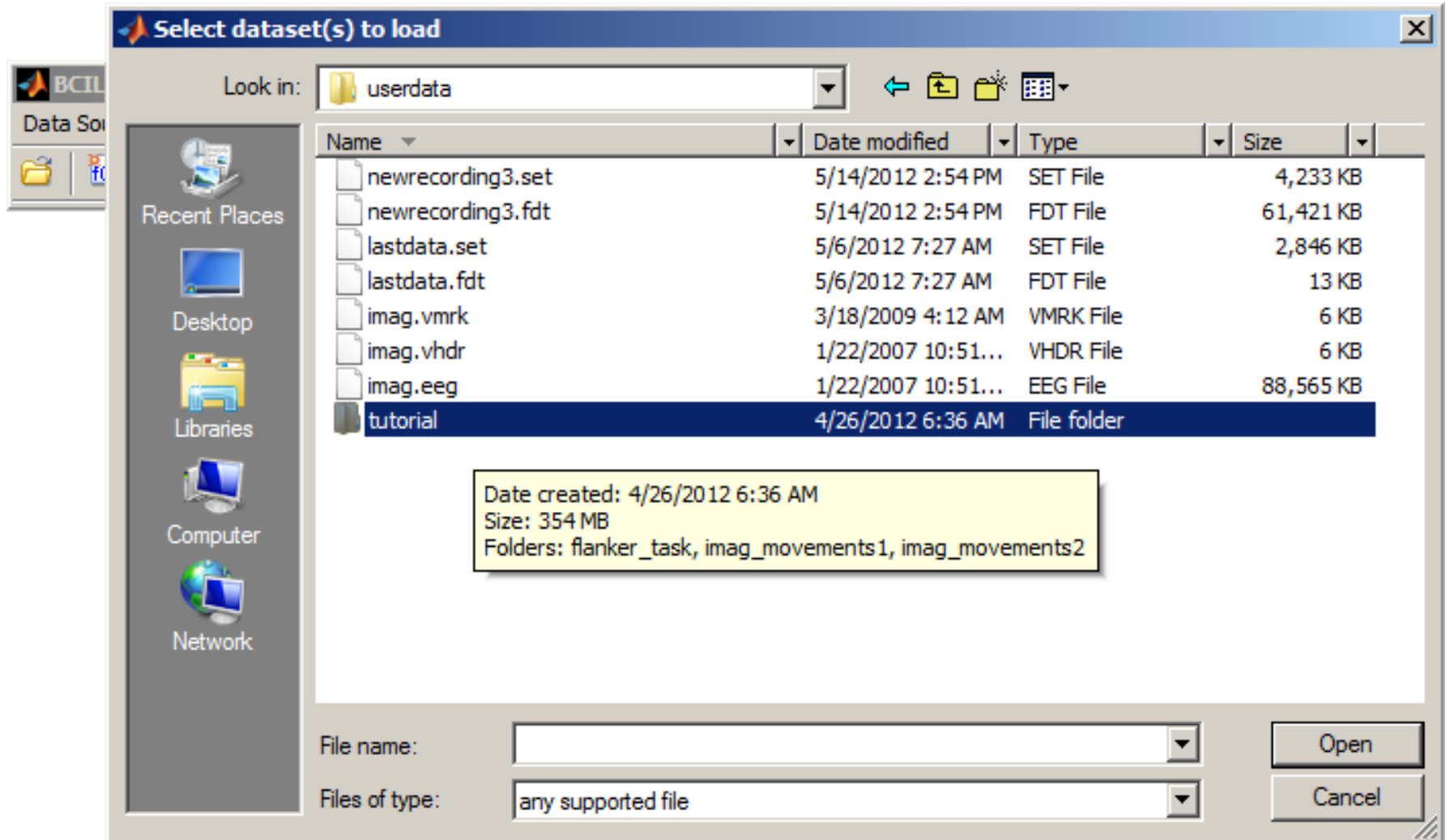


- The subject is asked to press the left/right button, according to the central arrow, and makes frequent errors (25%)

Loading the Data



Loading the Data



Select dataset(s) to load

Look in:

Name	Date modified	Type	Size
newrecording3.set	5/14/2012 2:54 PM	SET File	4,233 KB
newrecording3.fdt	5/14/2012 2:54 PM	FDT File	61,421 KB
lastdata.set	5/6/2012 7:27 AM	SET File	2,846 KB
lastdata.fdt	5/6/2012 7:27 AM	FDT File	13 KB
imag.vmrk	3/18/2009 4:12 AM	VMRK File	6 KB
imag.vhdr	1/22/2007 10:51...	VHDR File	6 KB
imag.eeg	1/22/2007 10:51...	EEG File	88,565 KB
tutorial	4/26/2012 6:36 AM	File folder	

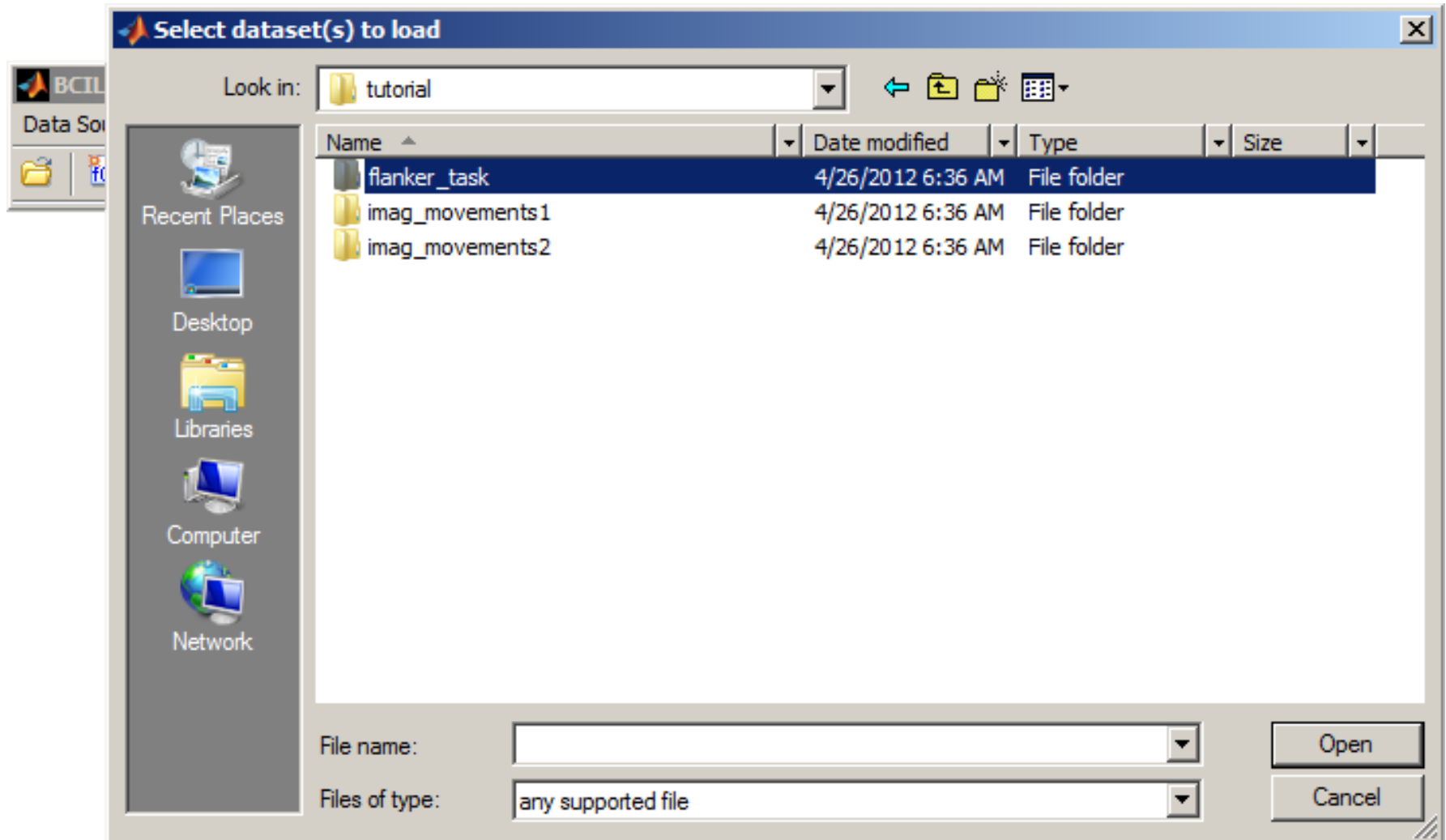
Date created: 4/26/2012 6:36 AM
 Size: 354 MB
 Folders: flanker_task, imag_movements1, imag_movements2

File name:

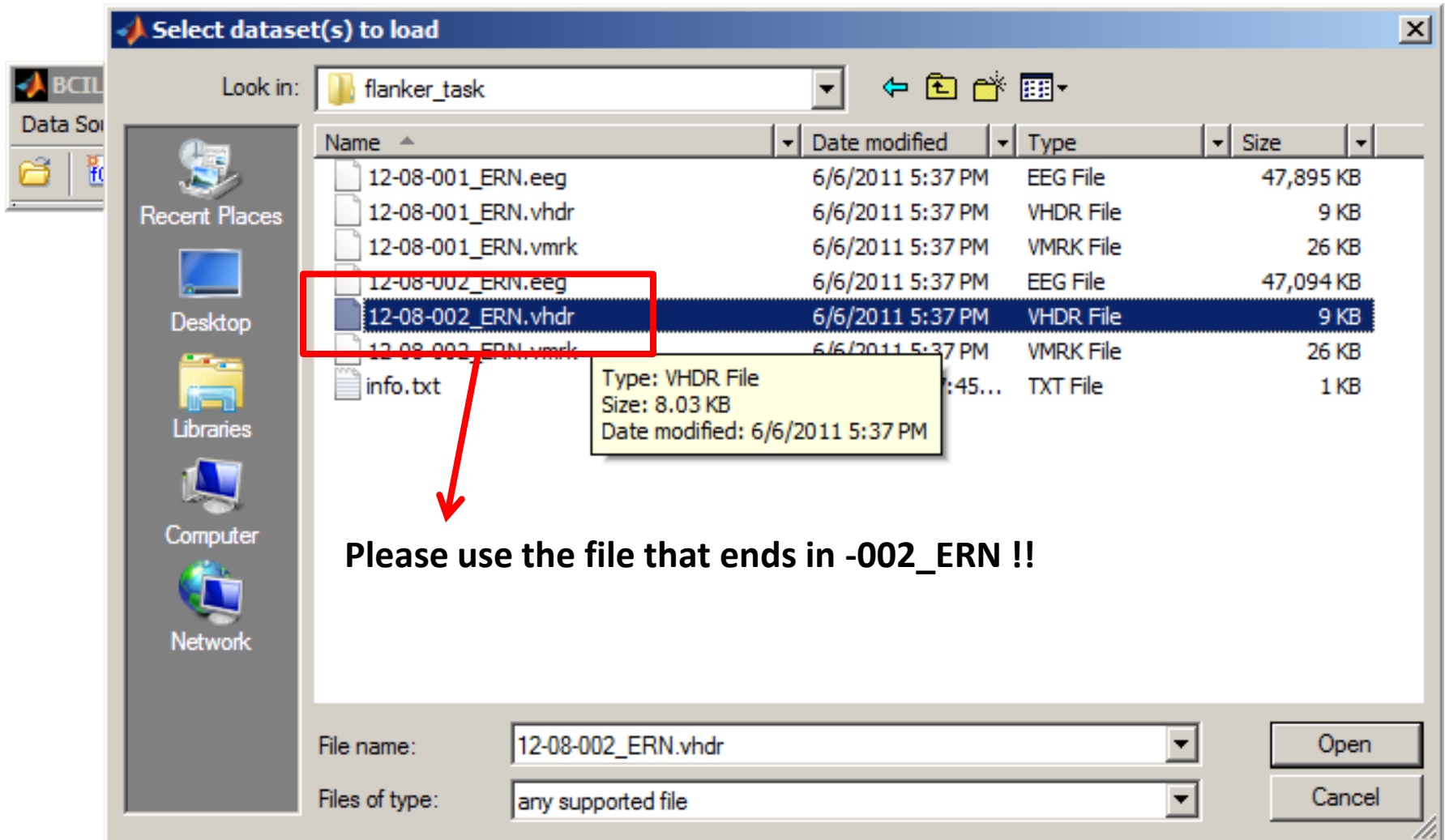
Files of type:

Open Cancel

Loading the Data



Loading the Data



BCIL
Data Source

Look in: flanker_task

Name	Date modified	Type	Size
12-08-001_ERN.eeg	6/6/2011 5:37 PM	EEG File	47,895 KB
12-08-001_ERN.vhdr	6/6/2011 5:37 PM	VHDR File	9 KB
12-08-001_ERN.vmrk	6/6/2011 5:37 PM	VMRK File	26 KB
12-08-002_ERN.eeg	6/6/2011 5:37 PM	EEG File	47,094 KB
12-08-002_ERN.vhdr	6/6/2011 5:37 PM	VHDR File	9 KB
12-08-002_ERN.vmrk	6/6/2011 5:37 PM	VMRK File	26 KB
info.txt		txt	1 KB

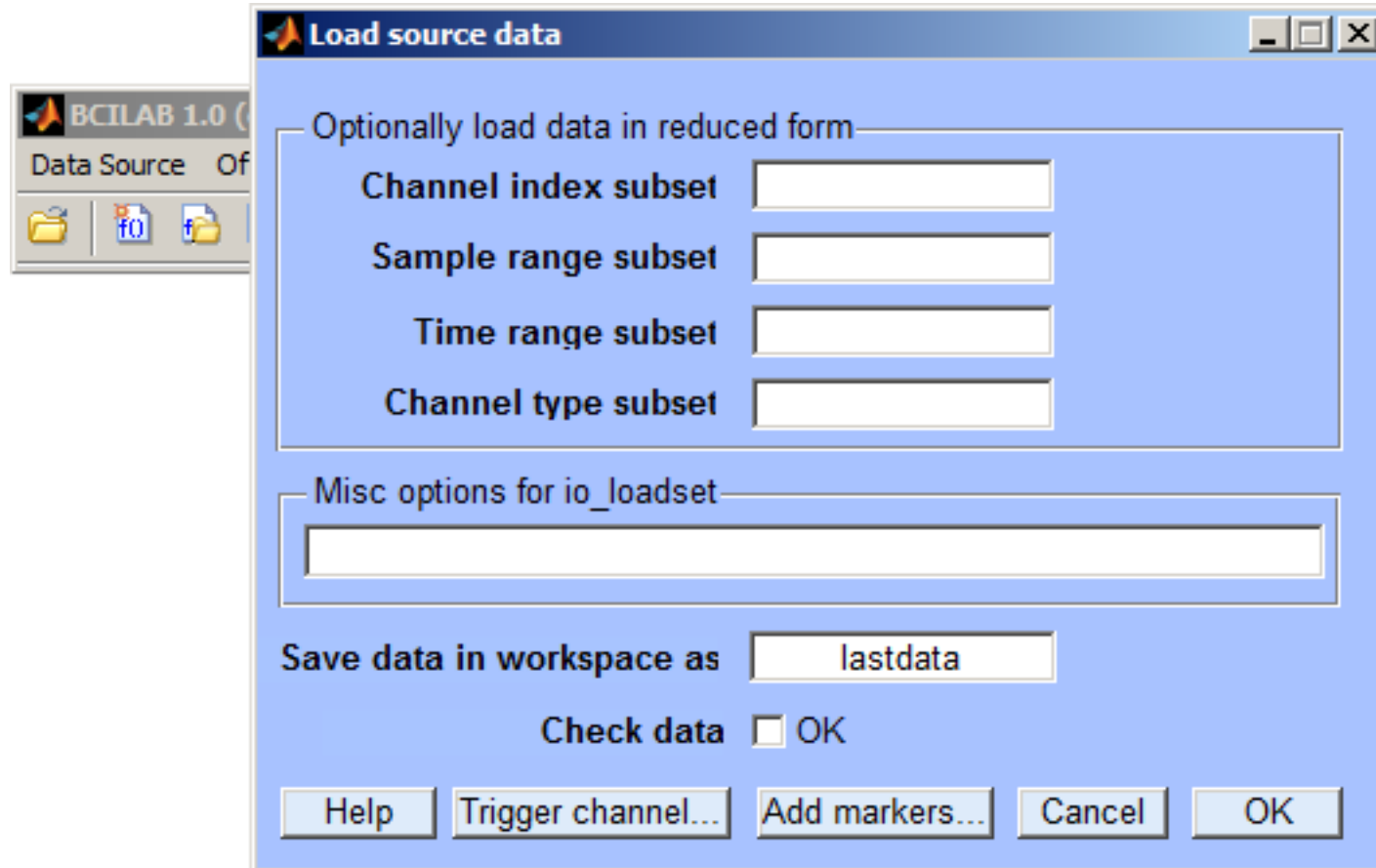
Type: VHDR File
Size: 8.03 KB
Date modified: 6/6/2011 5:37 PM

Please use the file that ends in -002_ERN !!

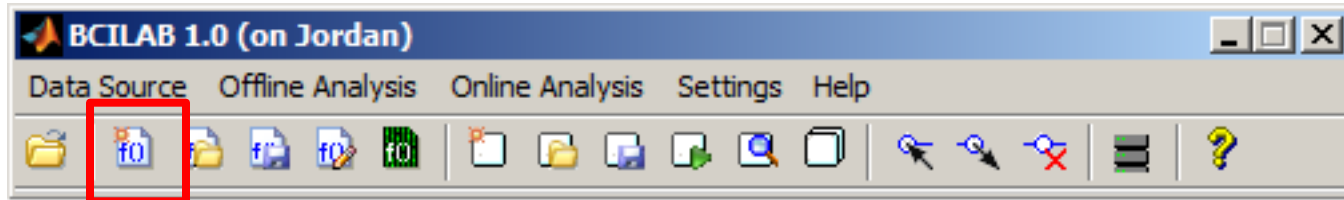
File name: 12-08-002_ERN.vhdr
Files of type: any supported file

Open
Cancel

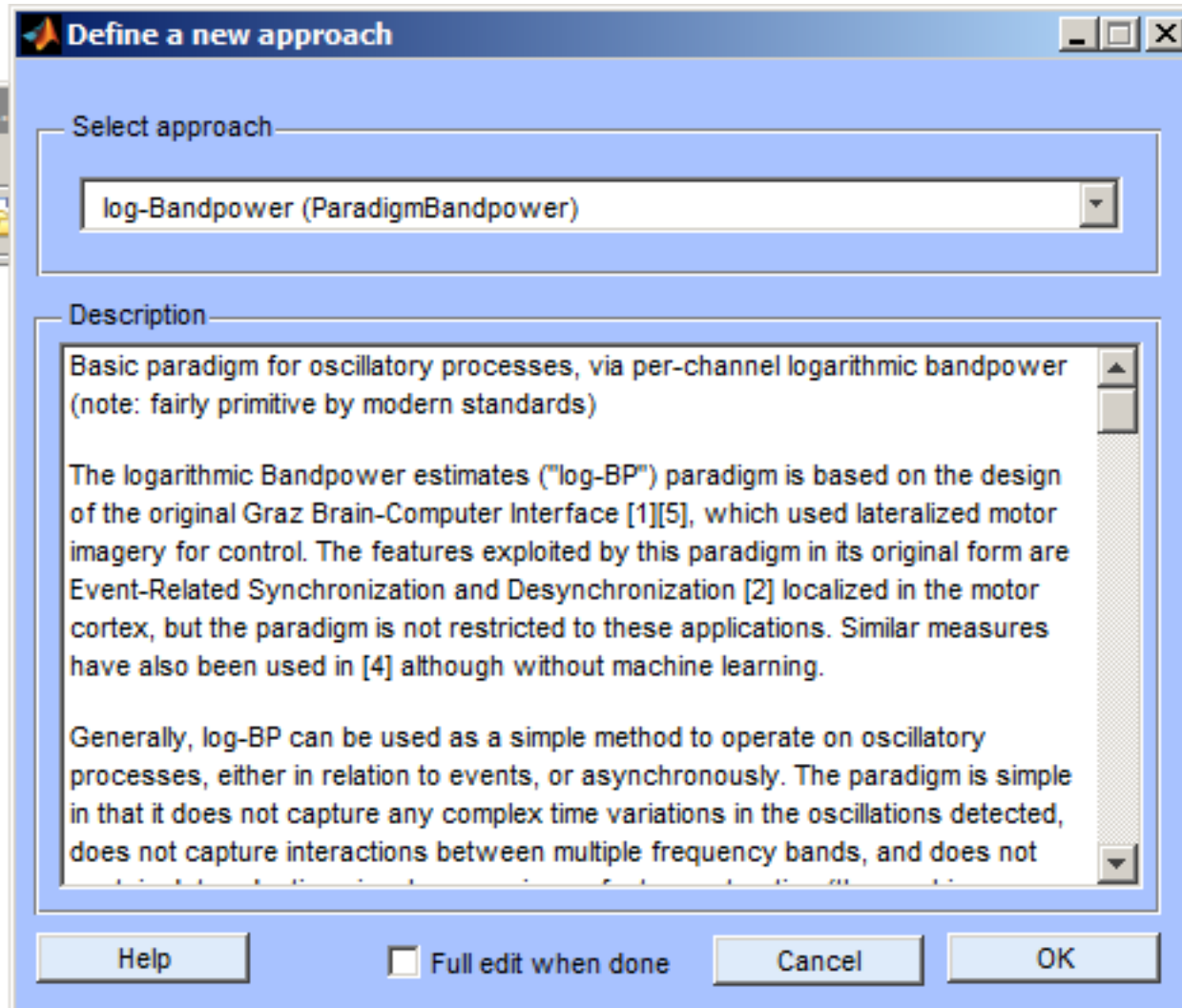
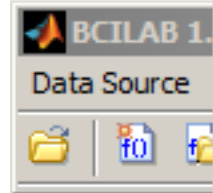
Confirming Import Options



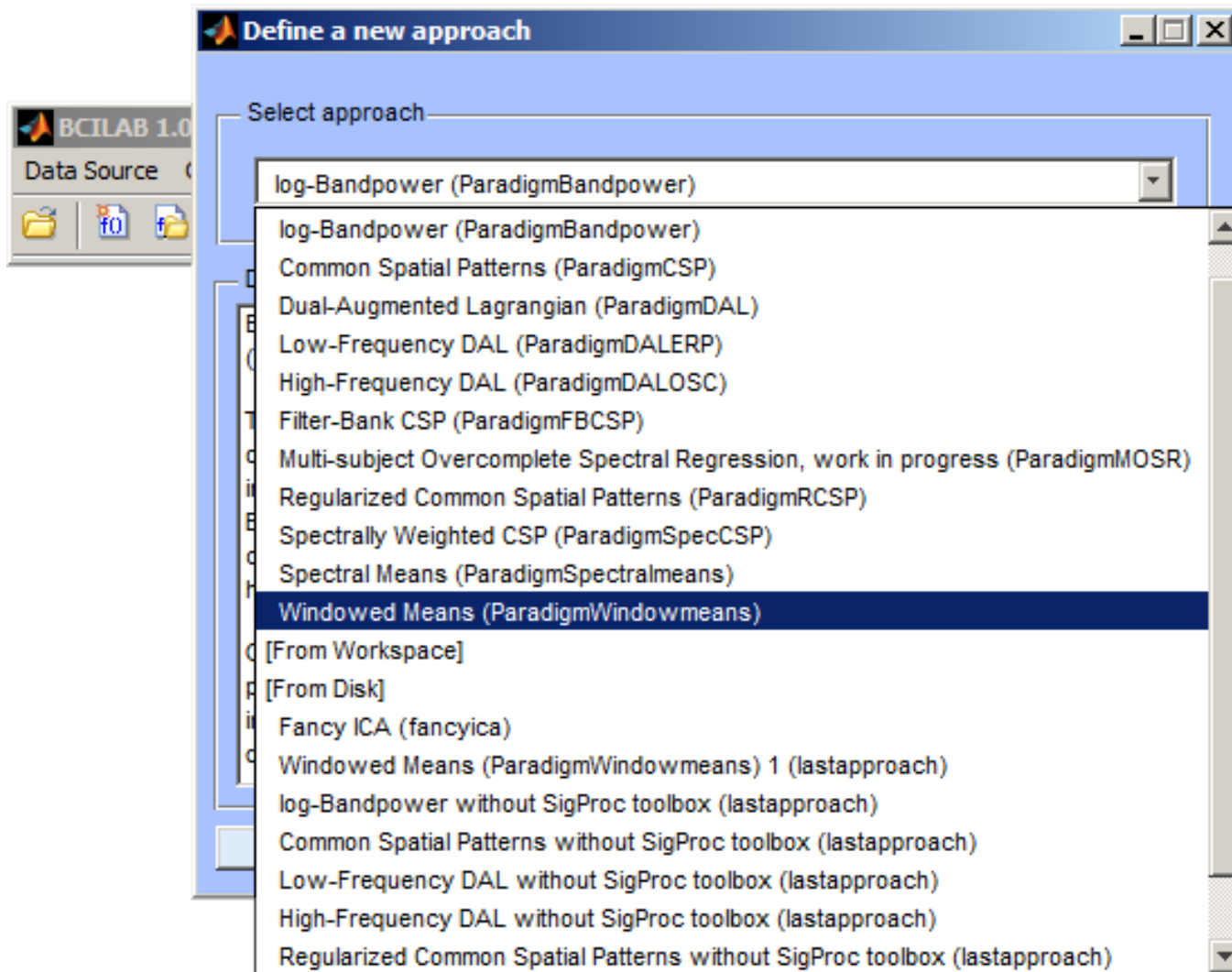
Creating a New Approach



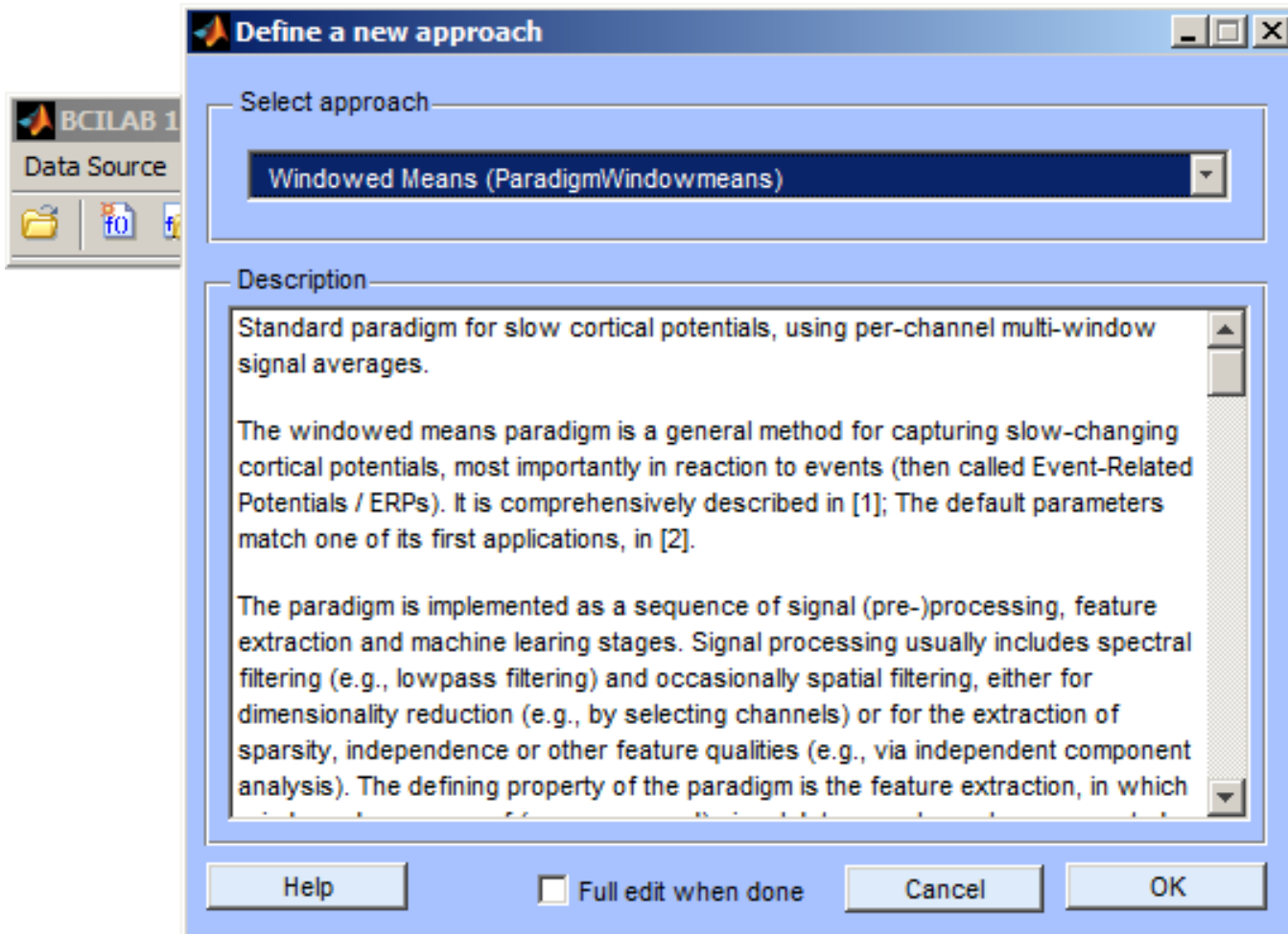
Creating a New Approach



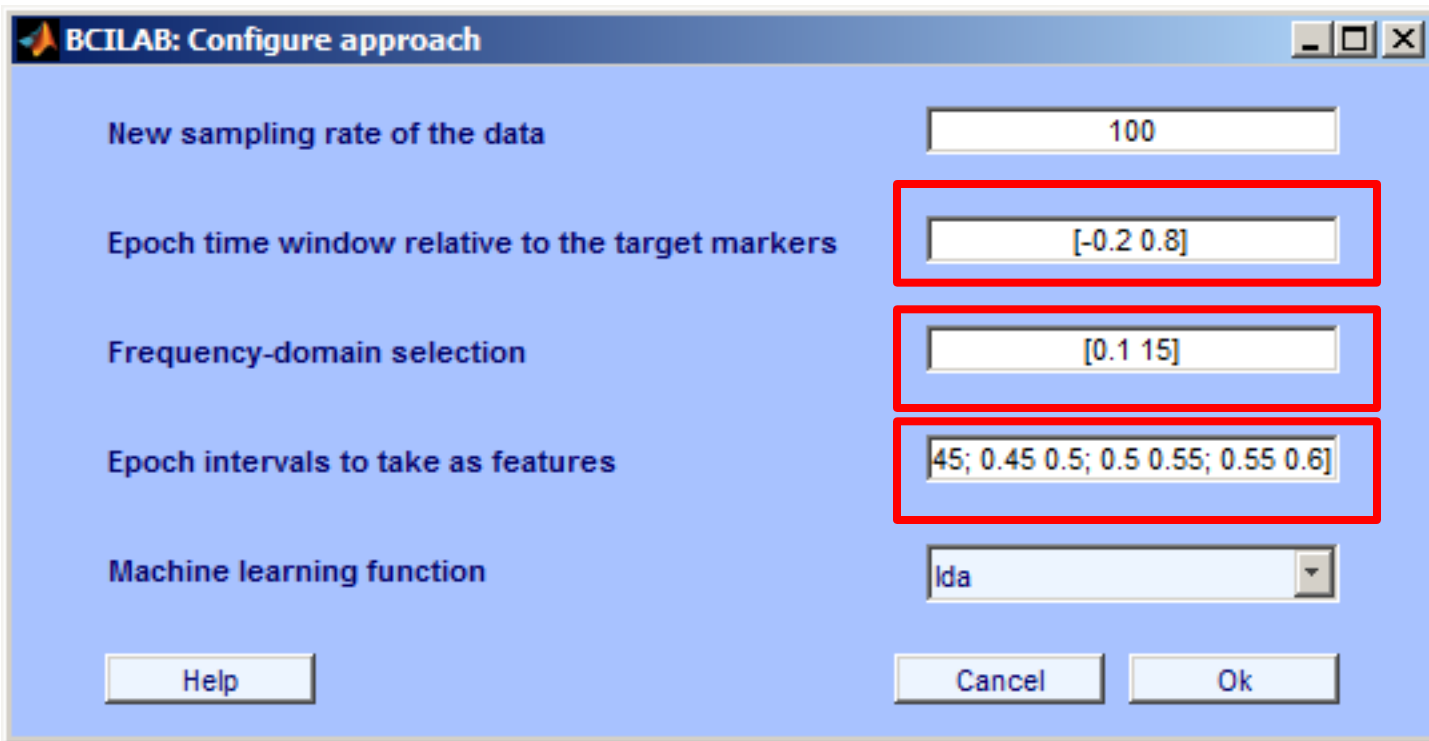
Select an ERP Paradigm



Select an ERP Paradigm



Configuring the Approach



The screenshot shows a dialog box titled "BCILAB: Configure approach" with a light blue background. It contains several configuration options, each with a text input field. Three of these fields are highlighted with red rectangular boxes:

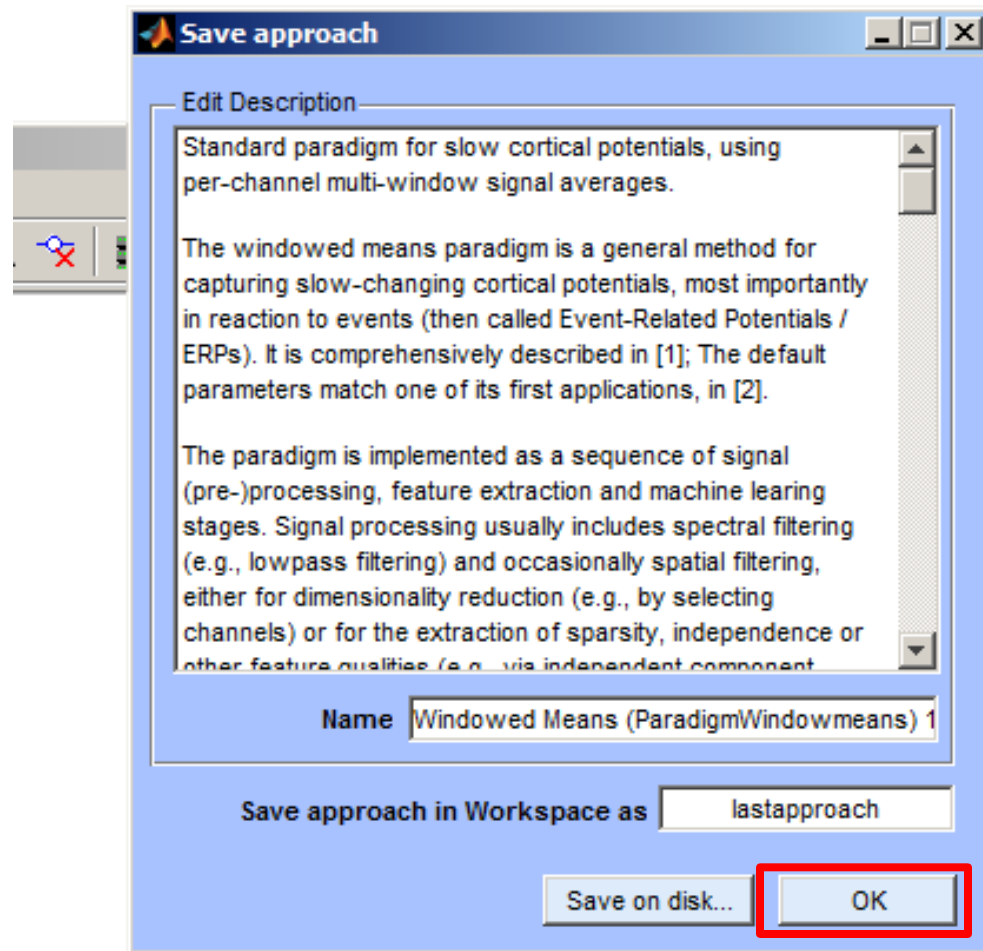
- New sampling rate of the data:** Input field contains "100".
- Epoch time window relative to the target markers:** Input field contains "[-0.2 0.8]".
- Frequency-domain selection:** Input field contains "[0.1 15]".
- Epoch intervals to take as features:** Input field contains "[45; 0.45 0.5; 0.5 0.55; 0.55 0.6]".
- Machine learning function:** A dropdown menu showing "lda".

At the bottom of the dialog box, there are three buttons: "Help", "Cancel", and "Ok".

Type into the lowest of the 3 highlighted fields:

[0.25 0.3; 0.3 0.35; 0.35 0.4; 0.4 0.45; 0.45 0.5; 0.5 0.55; 0.55 0.6]

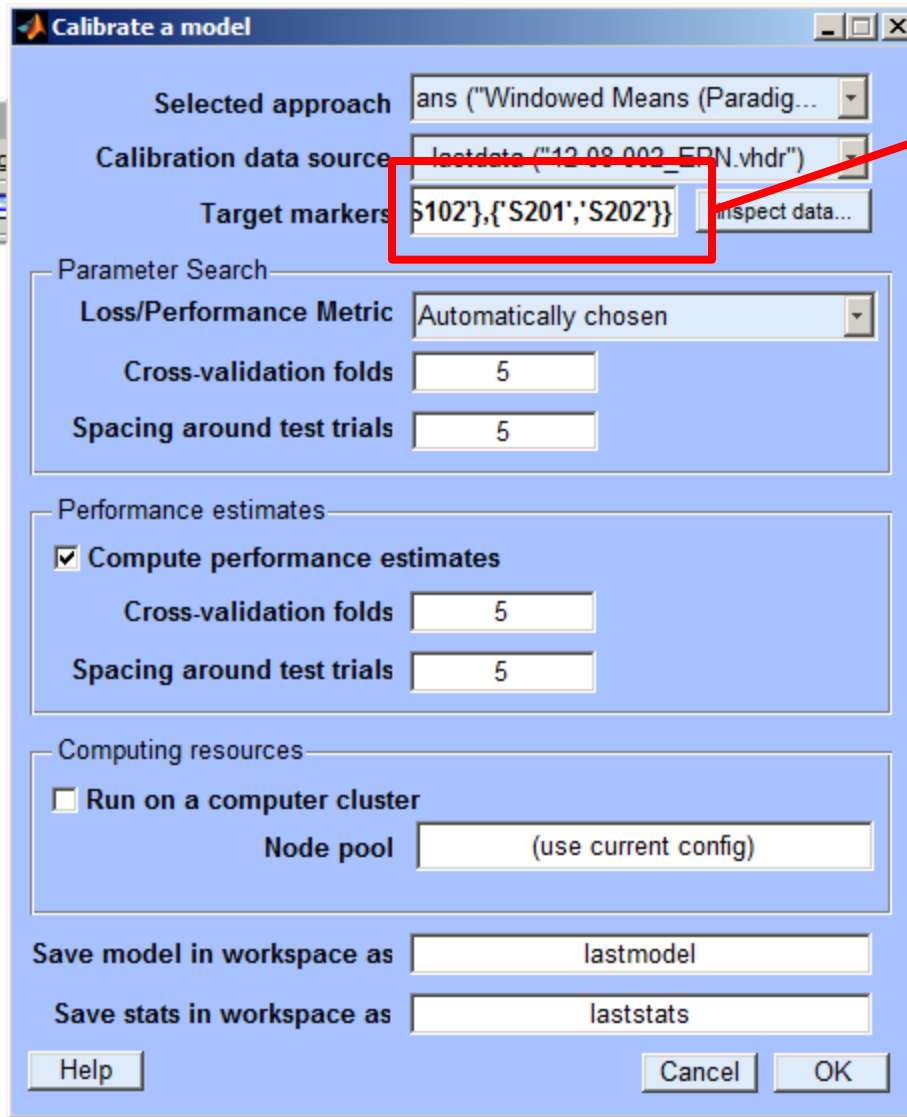
Saving to the Workspace



Calibrating a New Model



Calibrating a New Model



Calibrate a model

Selected approach: ans ("Windowed Means (Paradig...)

Calibration data source: lastdata ("12-08-002_FPN.vhdr")

Target markers: **`{'S102'}, {'S201', 'S202'}}`**

Parameter Search

Loss/Performance Metric: Automatically chosen

Cross-validation folds: 5

Spacing around test trials: 5

Performance estimates

Compute performance estimates

Cross-validation folds: 5

Spacing around test trials: 5

Computing resources

Run on a computer cluster

Node pool: (use current config)

Save model in workspace as: lastmodel

Save stats in workspace as: laststats

Buttons: Help, Cancel, OK

This is the set of marker labels that determine our two possible error conditions. For each of the two conditions, there is a group of multiple markers (different types of errors and non-errors).

Type the following here:
`{{'S101', 'S102'}, {'S201', 'S202'}}`

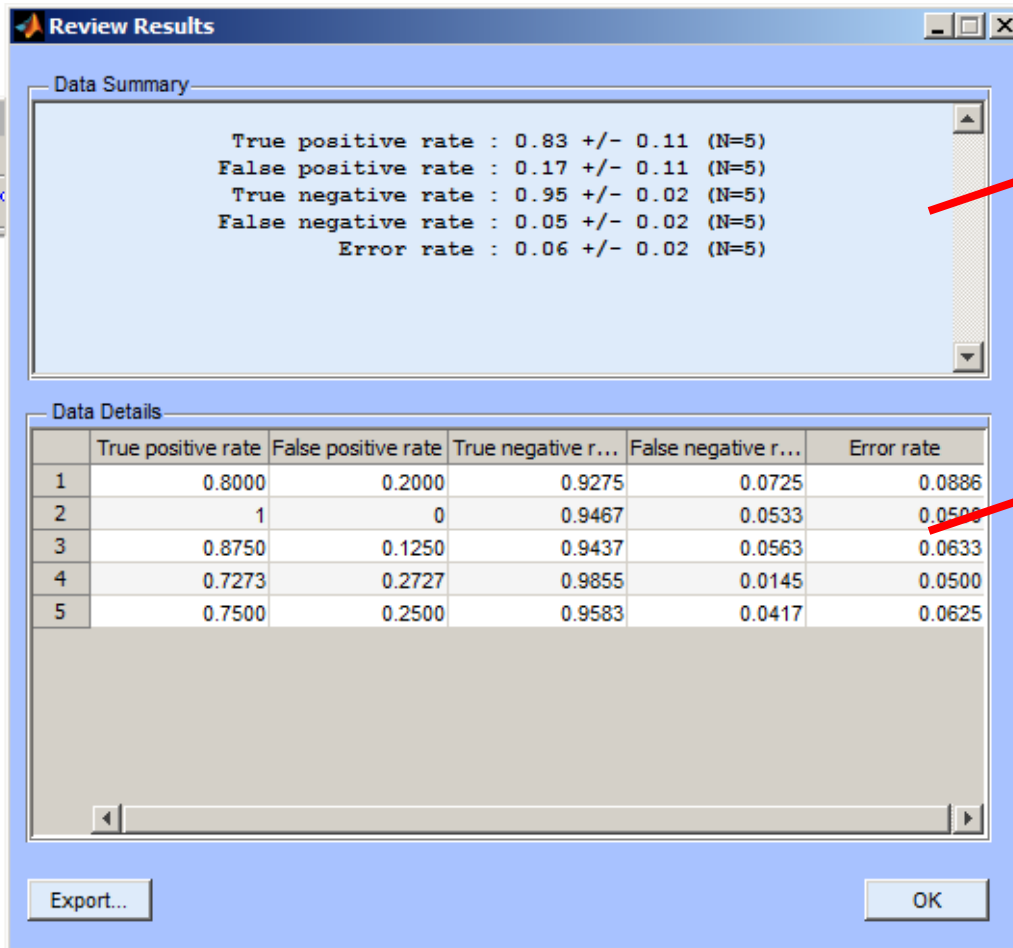
Watching the Computation...

```
io_loadset(): loading C:\DEVEL\bcilab-1.0\userdata\tv
pop_loadbv(): reading header file
pop_loadbv(): reading EEG data
pop_loadbv(): scaling EEG data
pop_loadbv(): reading marker file
readlocs(): 'sfp' format assumed from file extension
Channel lookup: no location for RE,LE,VEOG
Send us standard location for your channels at eeglab
Radius values: 0.0999117 (mean) +/- 4.20252e-005 (std)
Note: automatically convert XYZ coordinates to spherical
pop_epoch():408 epochs selected
Epoching...
pop_epoch():408 epochs generated
eeg_checkset: found empty values for field 'target'
                filling with values of other events in
pop_epoch(): checking epochs for data discontinuity
Extra common reference electrode location detected

beginning new computation...
fx >>
```

OVR

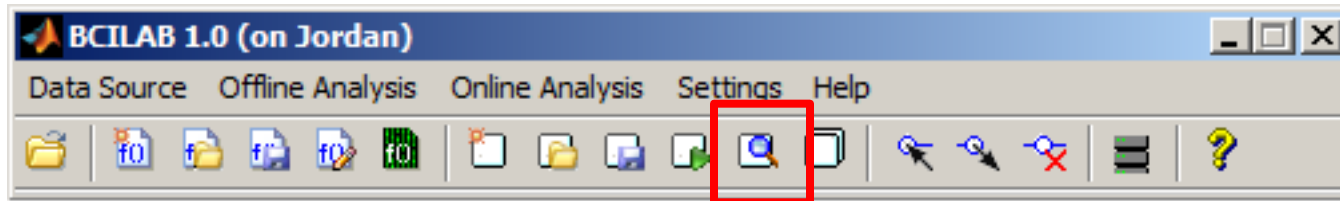
Reviewing Results



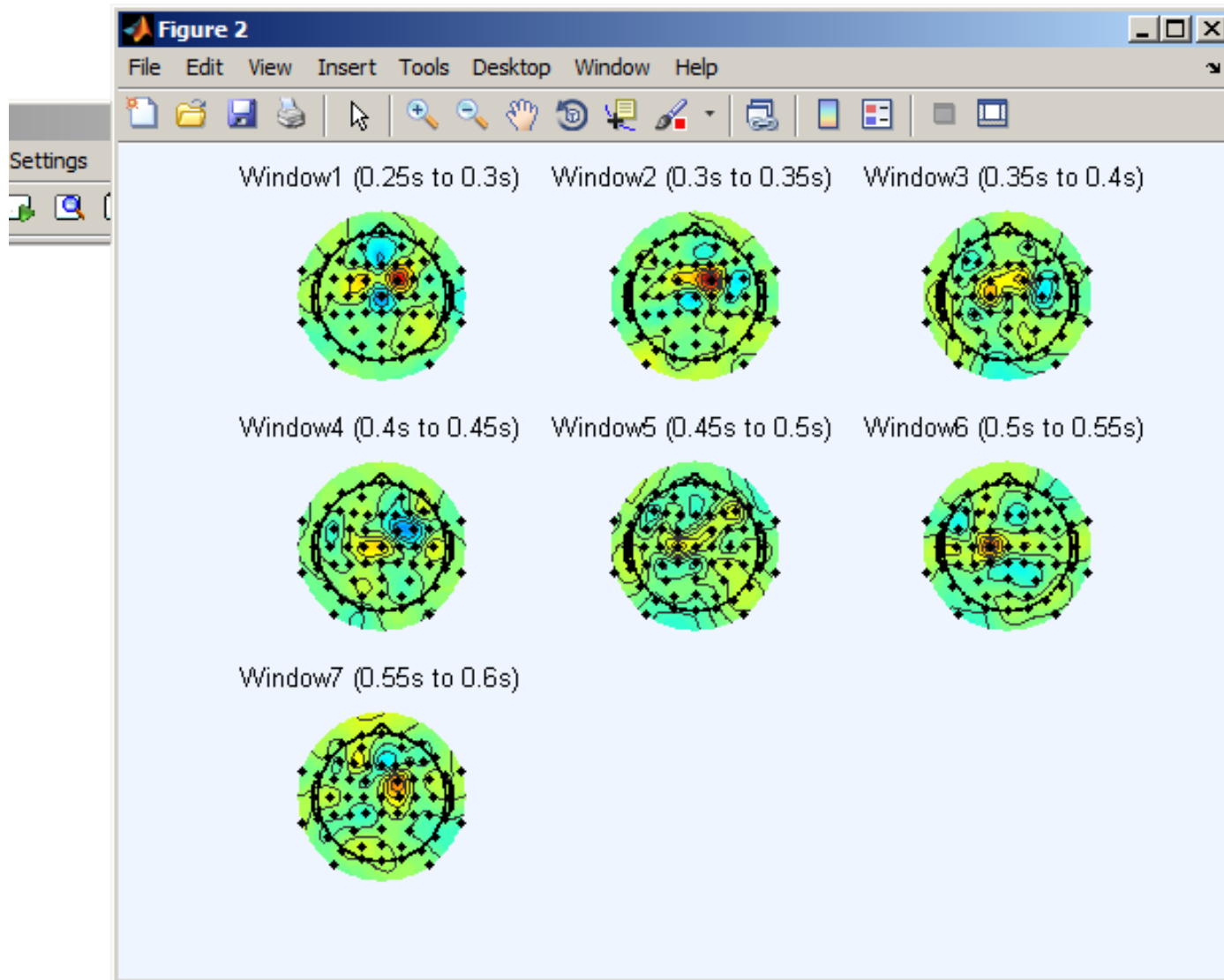
Summary Statistics

Statistics for each fold of the Cross-Validation (here 5x).

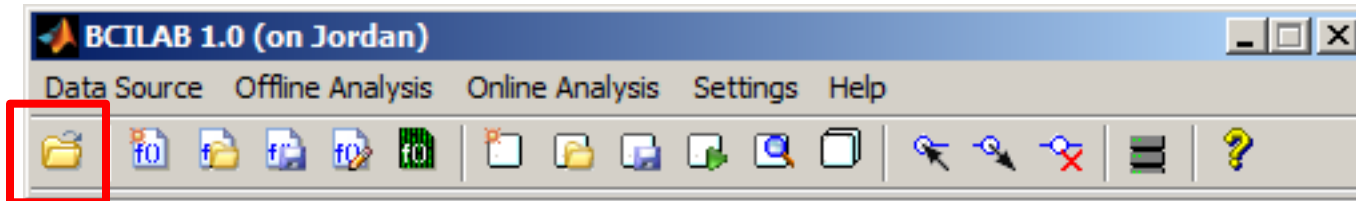
Visualizing the Model



Visualizing the Model

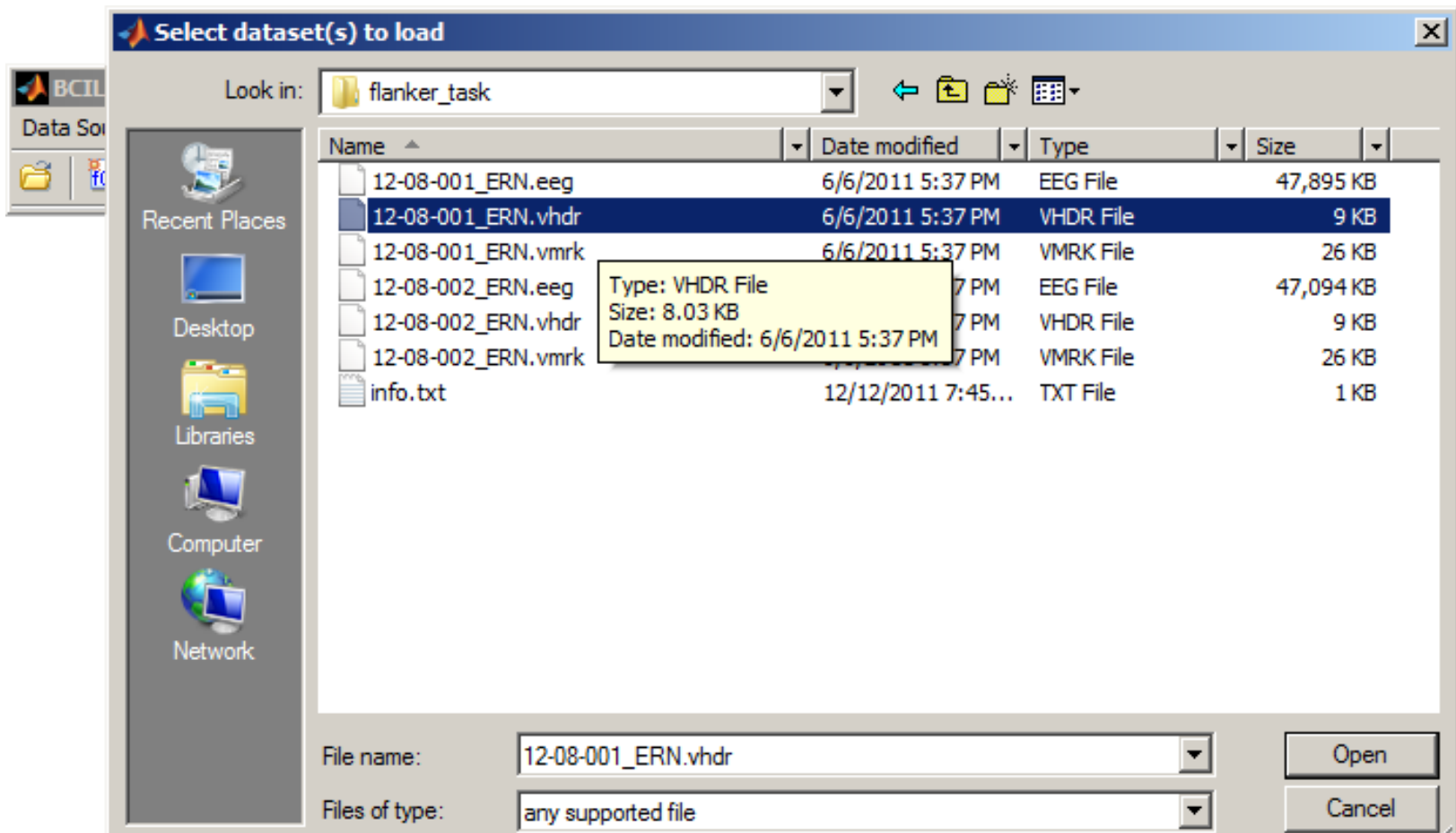


Loading a Separate Test Set



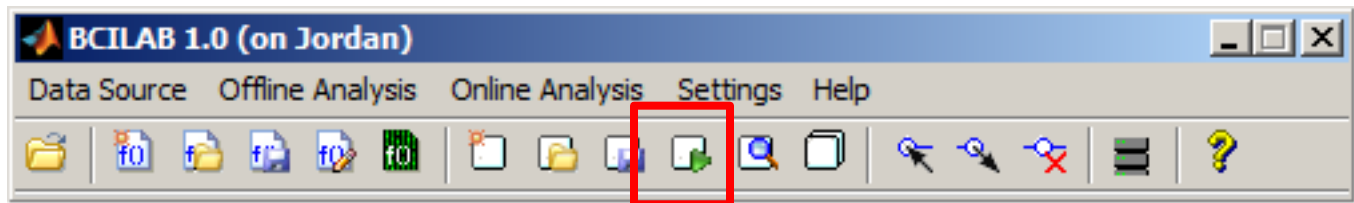
Loading a Separate Test Set

Note: This data set is from an identical twin doing the same task.

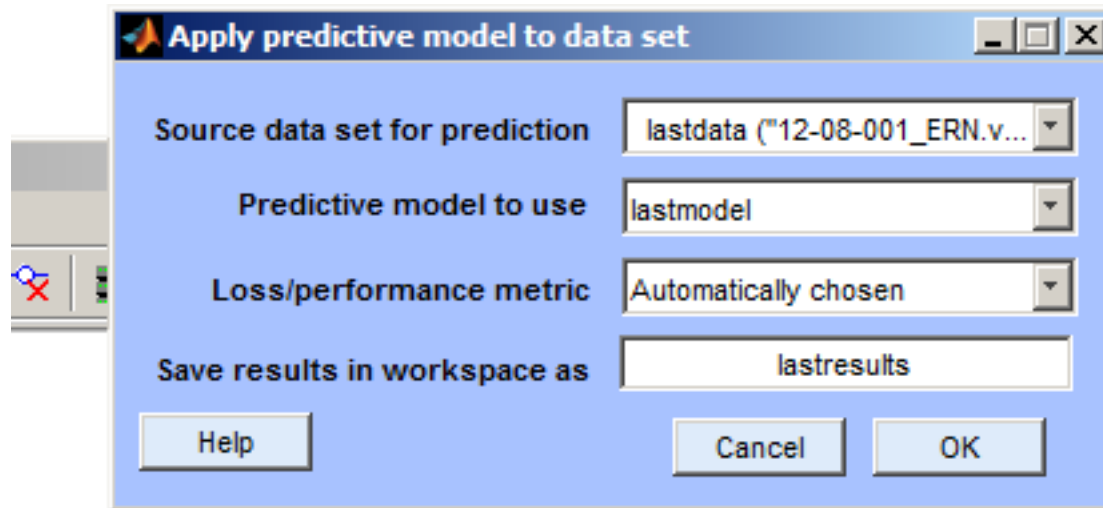




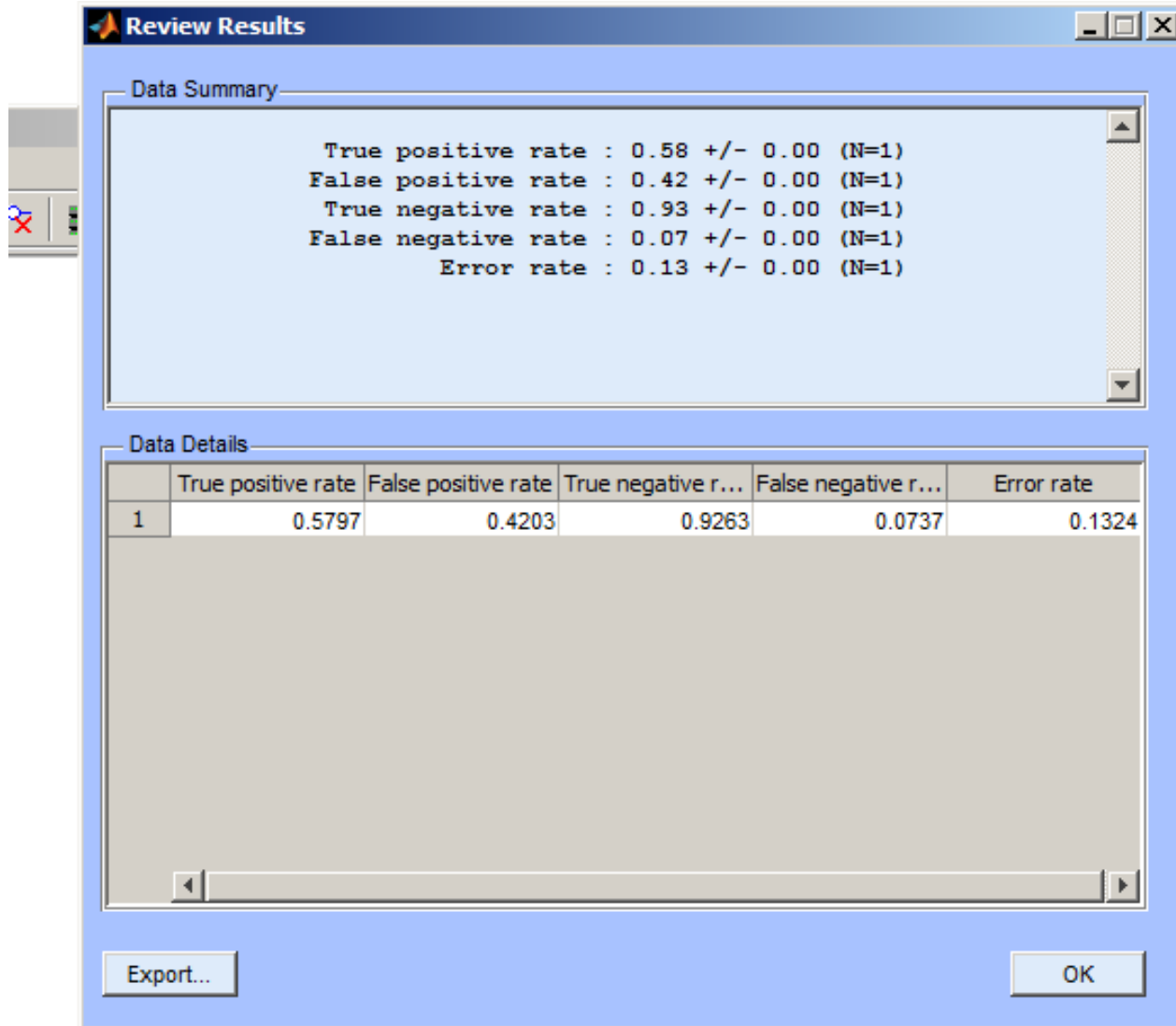
Applying the Model to Test Data



Applying the Model to Test Data



Reviewing Statistics



The screenshot shows a software window titled "Review Results" with a blue title bar. The window is divided into two main sections: "Data Summary" and "Data Details".

Data Summary

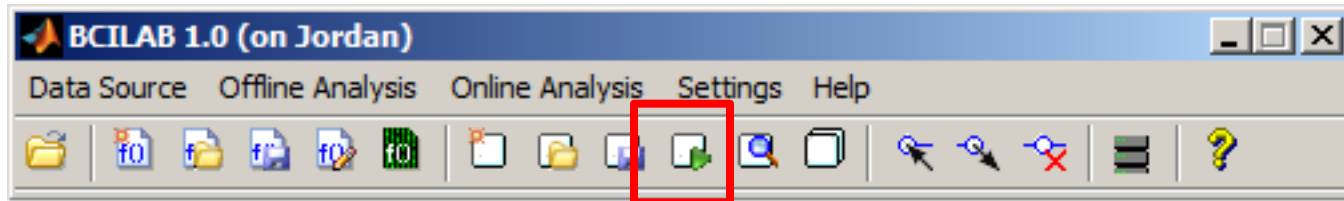
```
True positive rate : 0.58 +/- 0.00 (N=1)
False positive rate : 0.42 +/- 0.00 (N=1)
True negative rate : 0.93 +/- 0.00 (N=1)
False negative rate : 0.07 +/- 0.00 (N=1)
Error rate : 0.13 +/- 0.00 (N=1)
```

Data Details

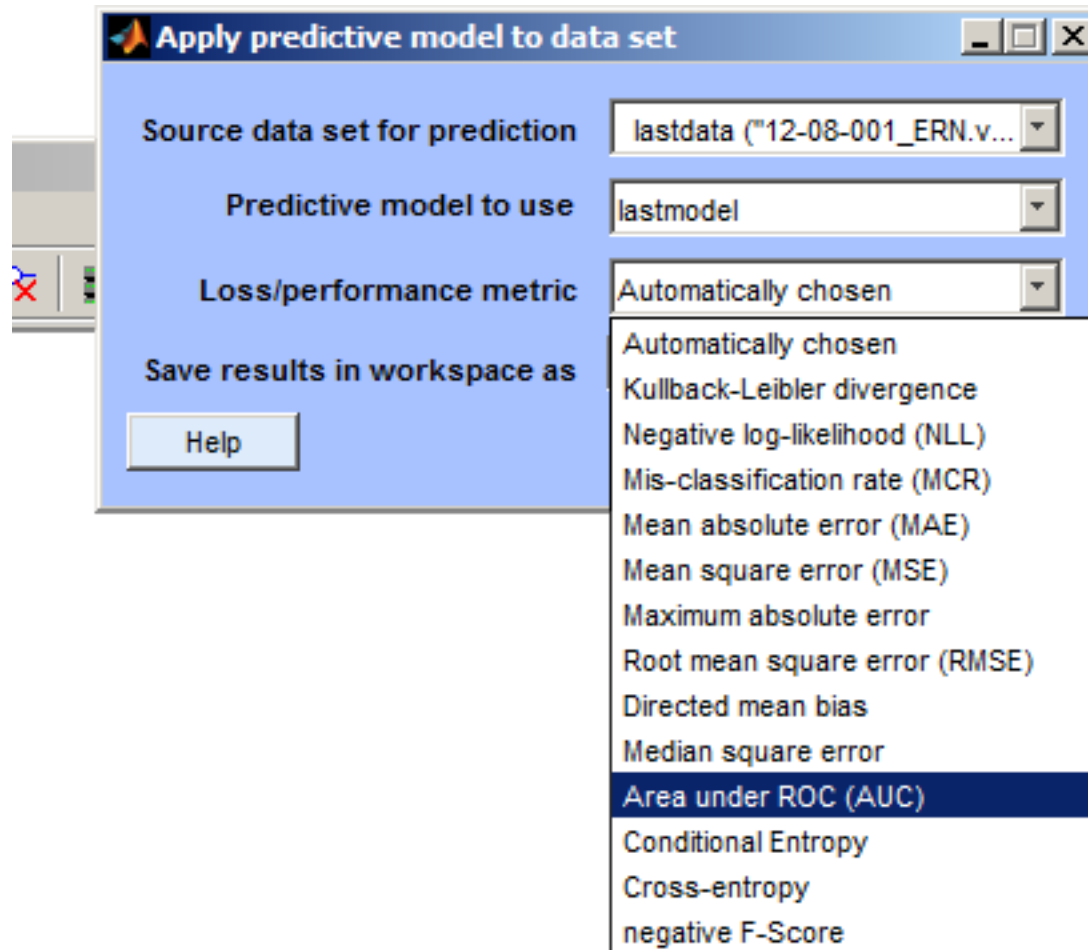
	True positive rate	False positive rate	True negative r...	False negative r...	Error rate
1	0.5797	0.4203	0.9263	0.0737	0.1324

At the bottom of the window, there are two buttons: "Export..." on the left and "OK" on the right.

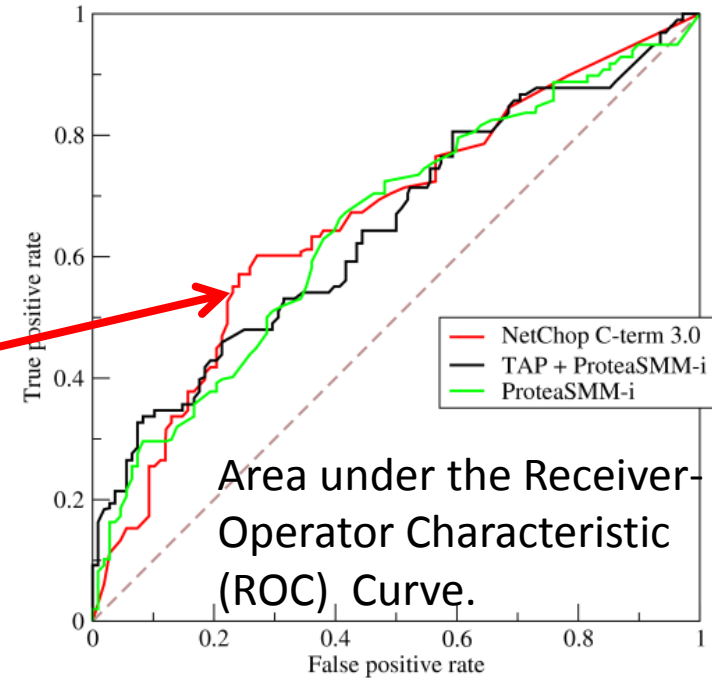
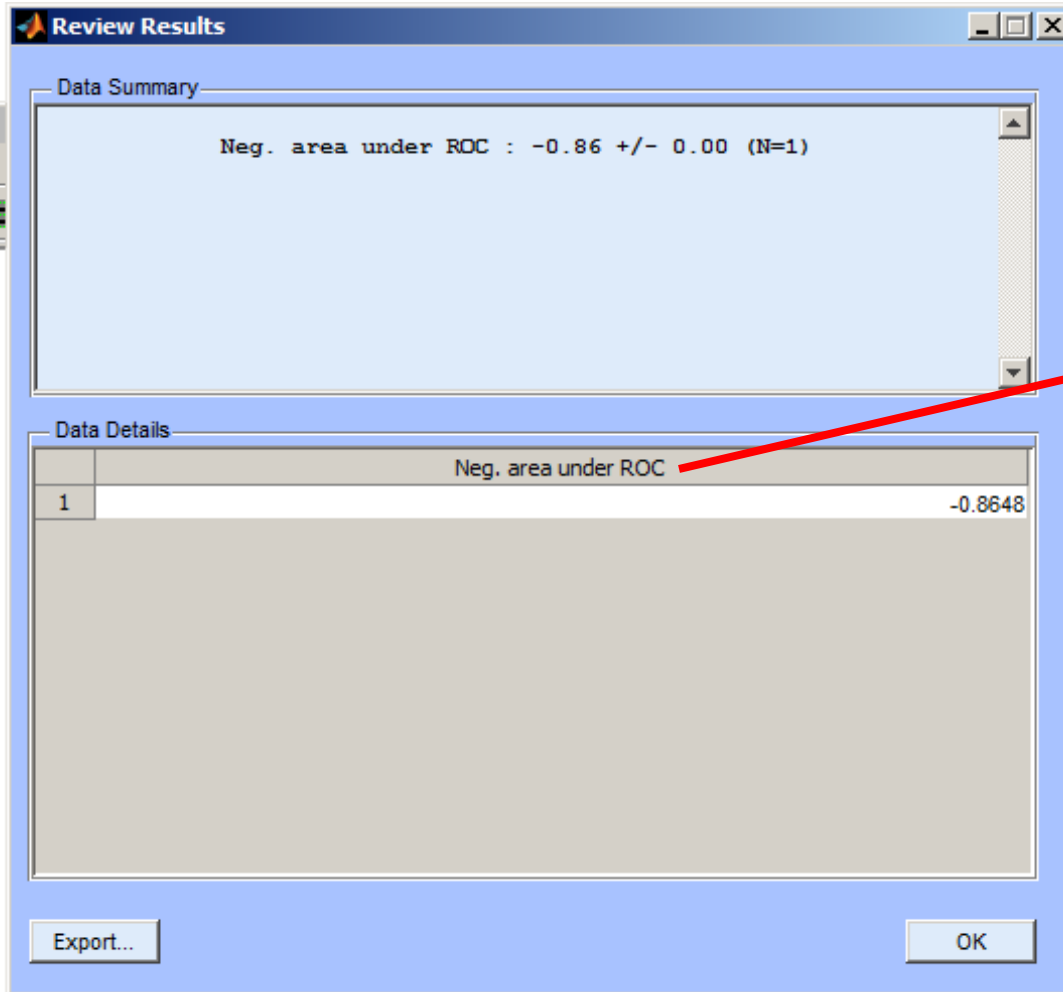
Using Another Loss Measure



Using Another Loss Measure



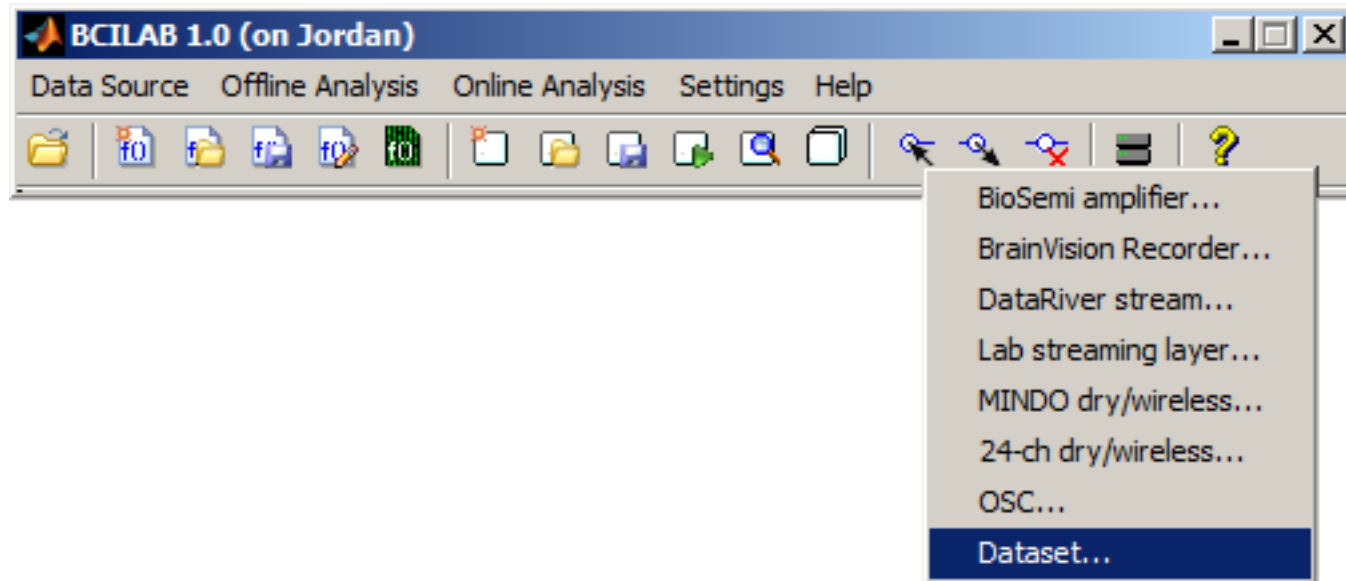
Using Another Loss Measure





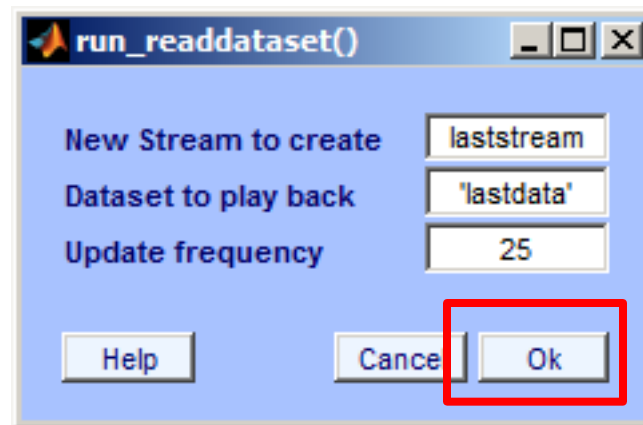
Online Analysis

Starting an Online Data Stream



The selected stream will be played back in the background.
In this course we'll be playing back the test data set in real time
(instead of reading from an actual device).

Configuring the Online Stream



Meanwhile in the MATLAB Workspace...

If you type **whos** you could see the data structure (laststream) that is updated in the background.

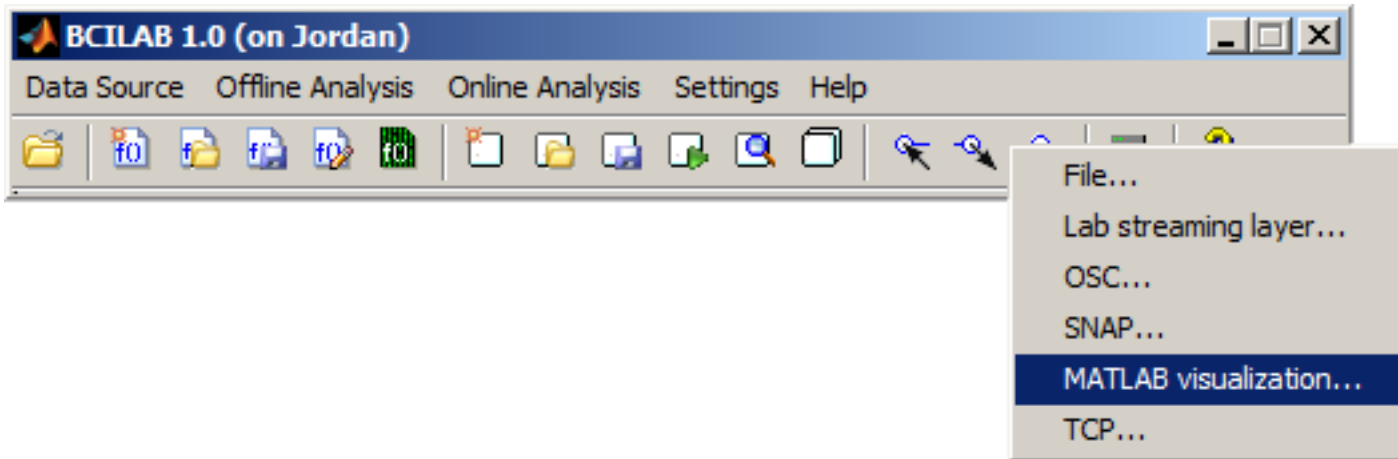
```
beginning new computation...
beginning evaluation...
Extra common reference electrode location detected
>> whos
```

Name	Size	Bytes	Class
ans	1x1	38164	struct
f	1x1	8	double
lastapproach	1x1	38164	struct
lastchunk	64x15	3840	single
lastdata	1x1	874	struct
lastmodel	1x1	356657	struct
lastresults	1x1	12543	struct
laststats	1x1	418464	struct
laststream	1x1	7804880	struct
y	1x2	16	double

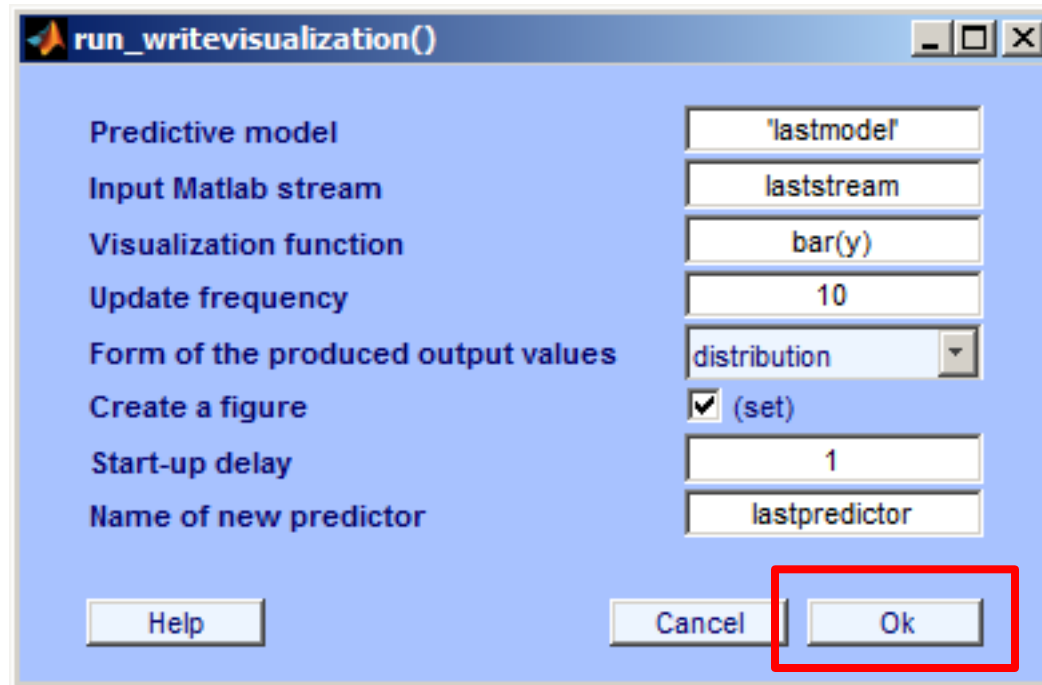
```
fx >> |
```

OVR

Selecting the Destination for BCI Outputs



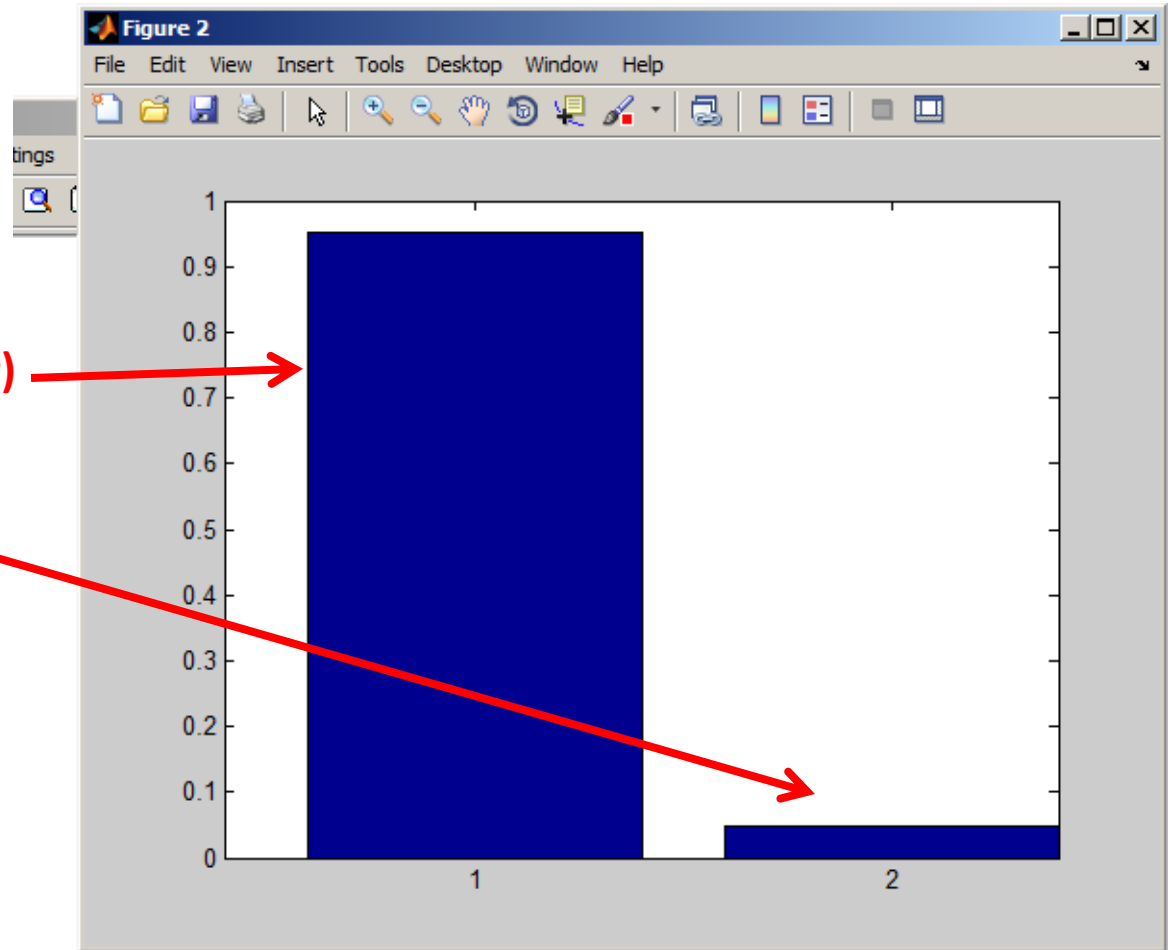
Selecting the Destination for BCI Outputs



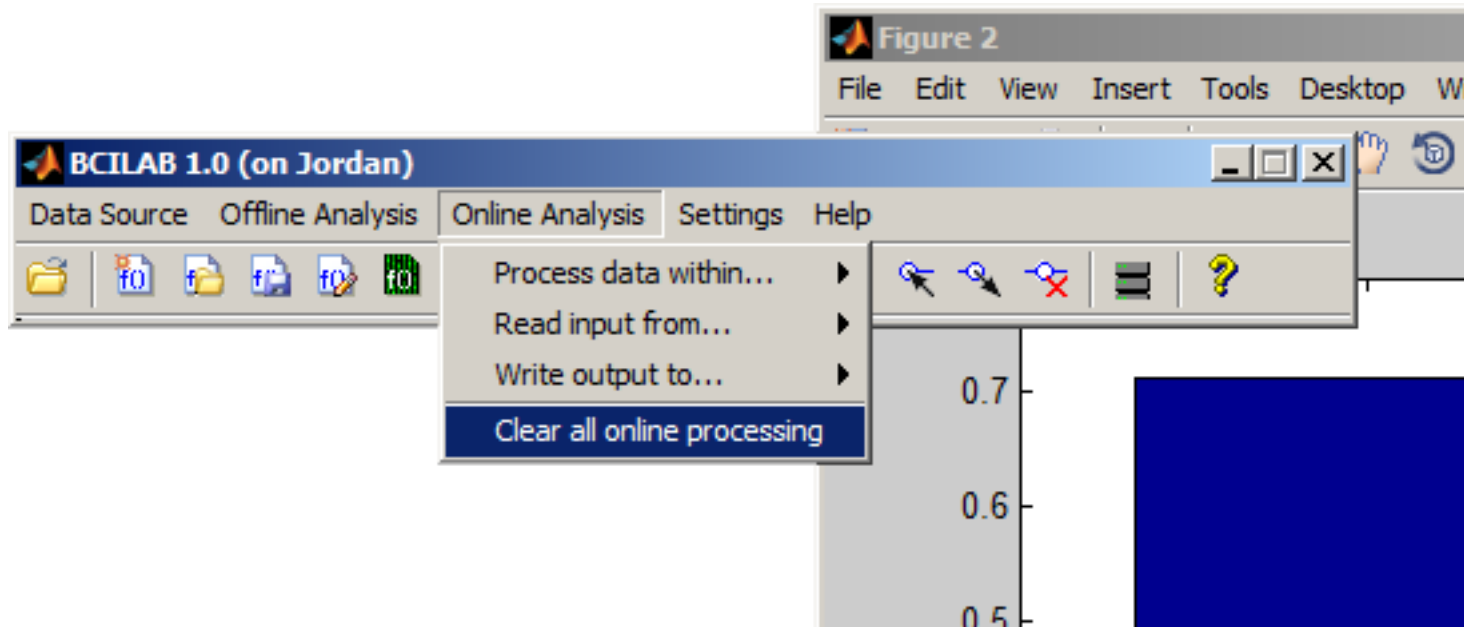
Visualized Real-Time Outputs

Probability of class 1 (no error)

Probability of class 2 (error)



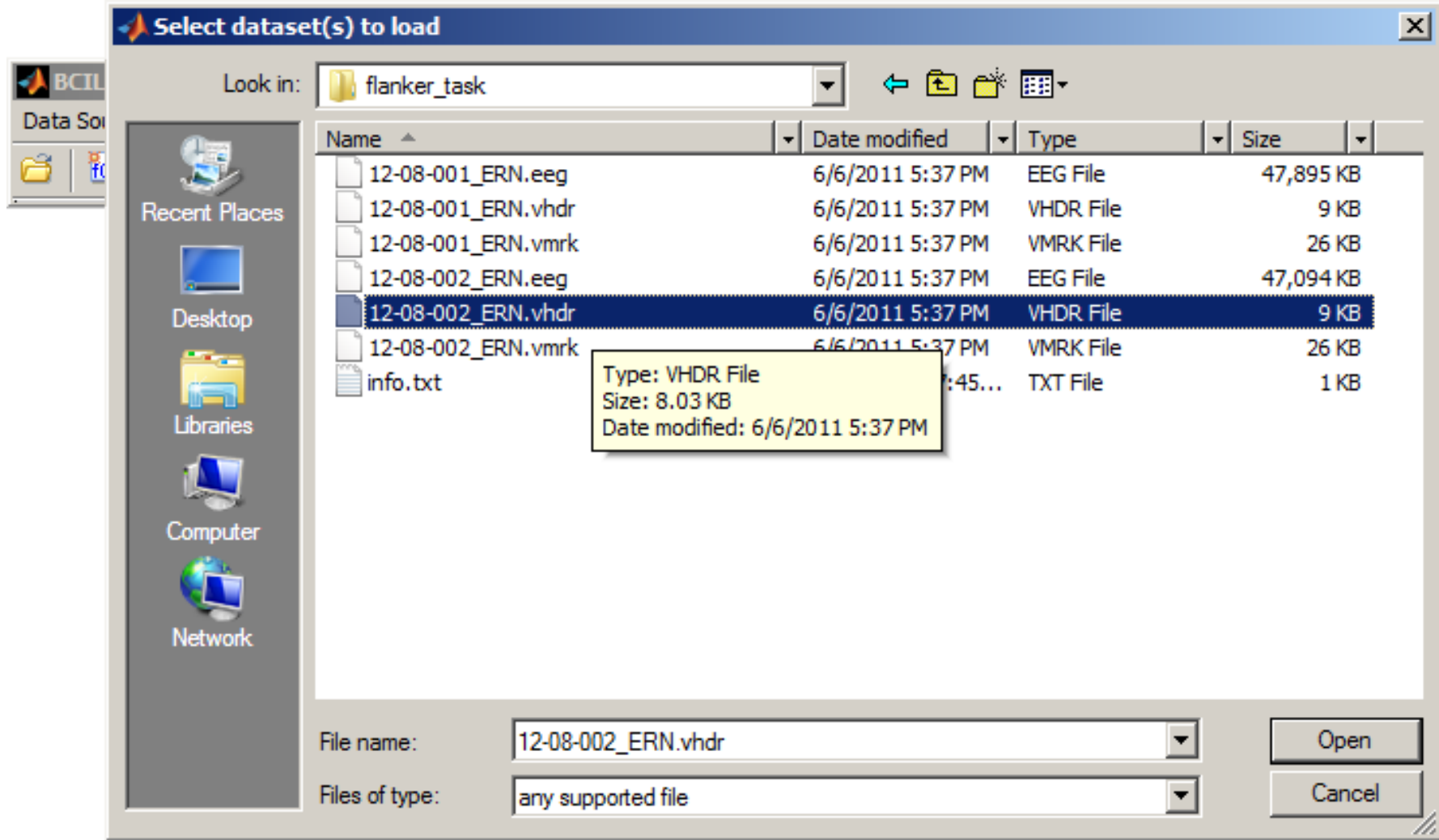
Stopping the Online Processing





Customizing Approaches

Loading the Training Data Again



Look in:

Name	Date modified	Type	Size
12-08-001_ERN.eeg	6/6/2011 5:37 PM	EEG File	47,895 KB
12-08-001_ERN.vhdr	6/6/2011 5:37 PM	VHDR File	9 KB
12-08-001_ERN.vmrk	6/6/2011 5:37 PM	VMRK File	26 KB
12-08-002_ERN.eeg	6/6/2011 5:37 PM	EEG File	47,094 KB
12-08-002_ERN.vhdr	6/6/2011 5:37 PM	VHDR File	9 KB
12-08-002_ERN.vmrk	6/6/2011 5:37 PM	VMRK File	26 KB
info.txt		TXF File	1 KB

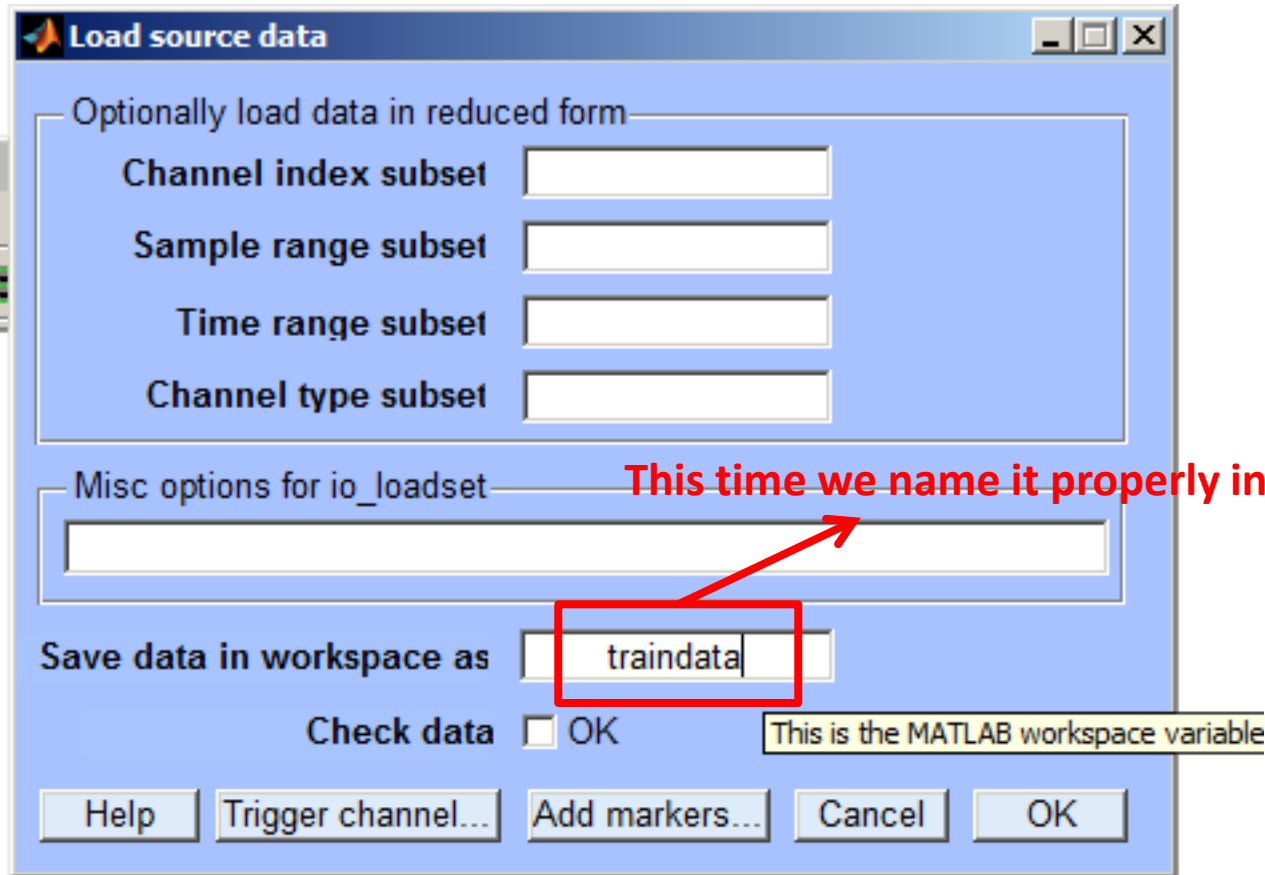
Type: VHDR File
Size: 8.03 KB
Date modified: 6/6/2011 5:37 PM

File name:

Files of type:

Open Cancel

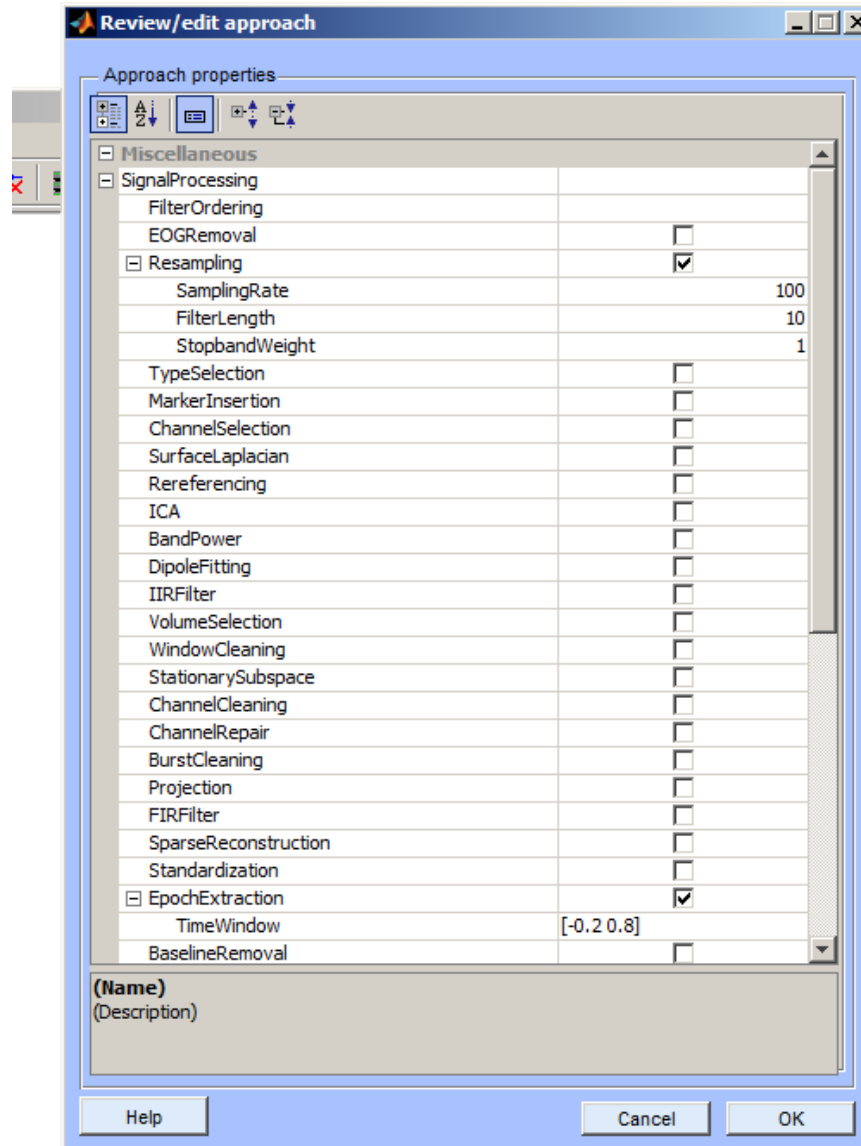
Loading the Training Data Again



Editing the Previous Approach In Detail

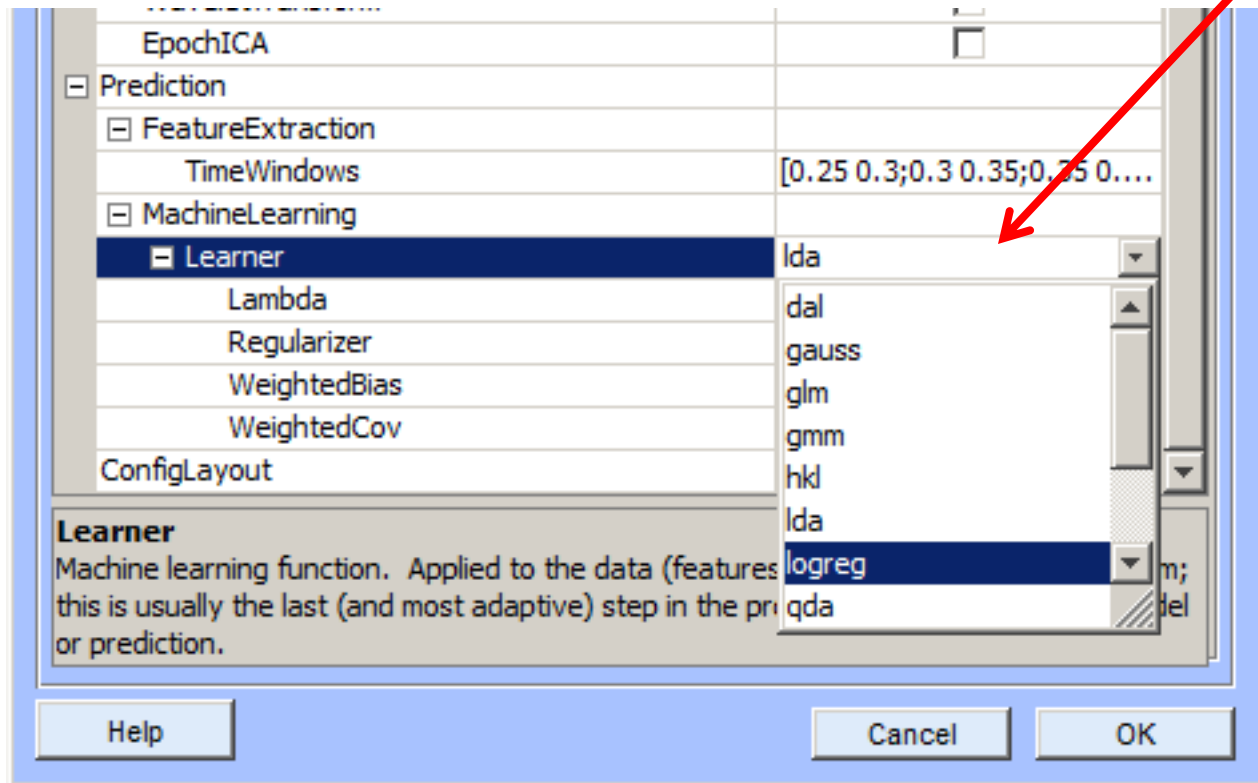


Editing the Previous Approach In Detail



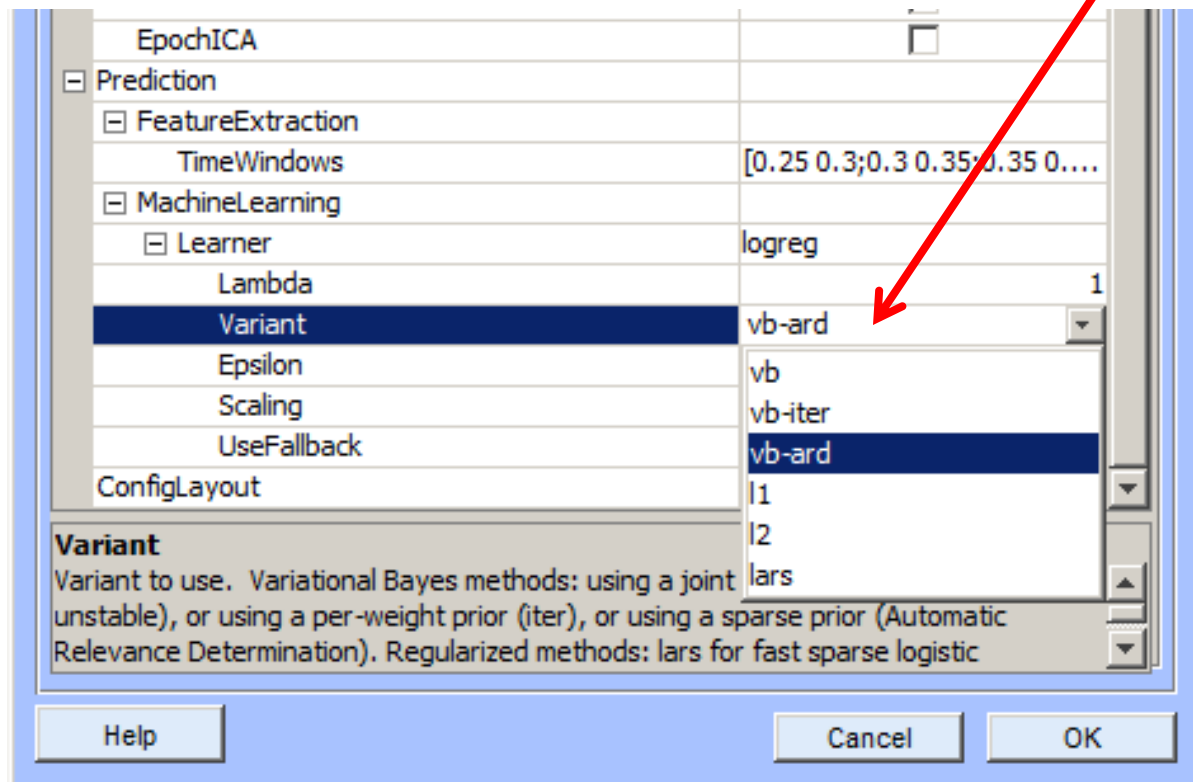
Changing the Classifier

Instead of LDA we choose logistic regression.

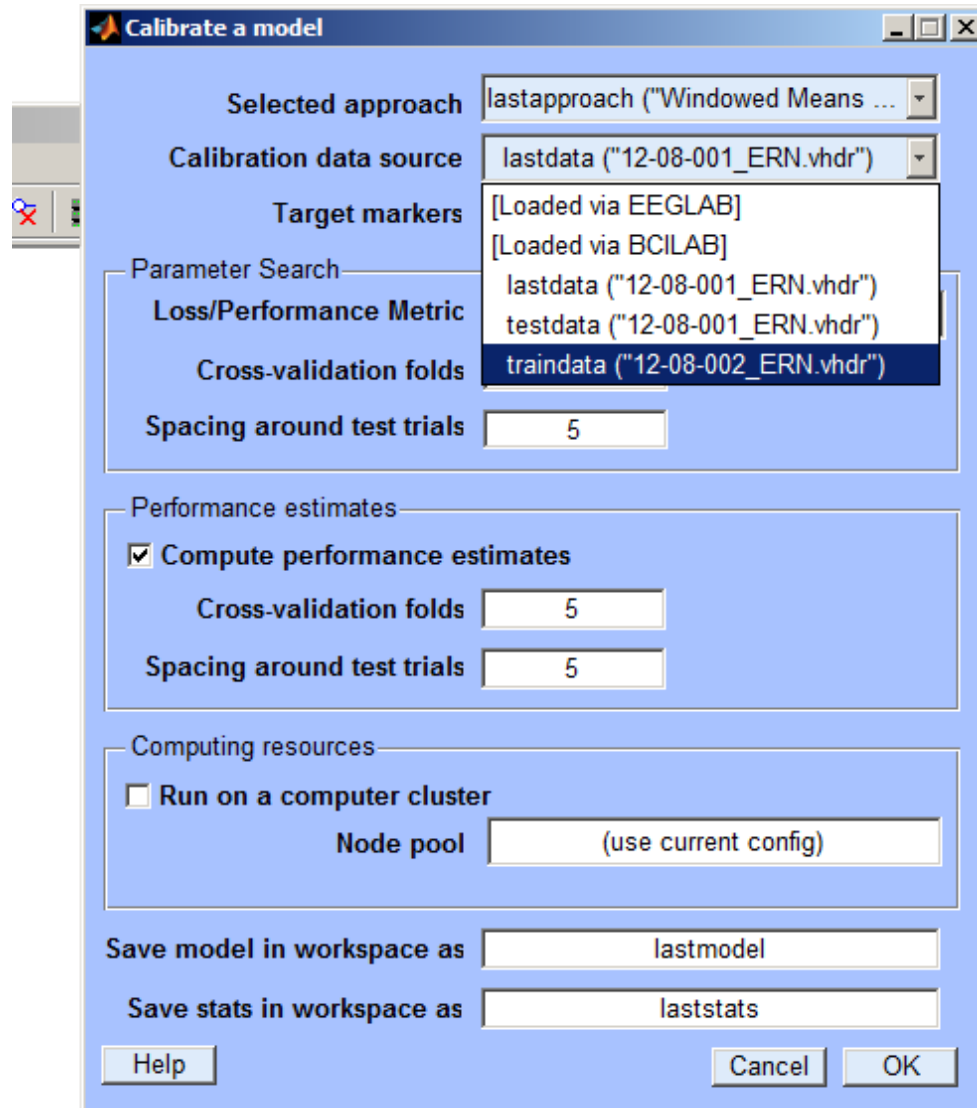


Changing the Classifier

We don't use the VB (Variational Bayes) variant but the sparse version (with Automatic Relevance Determination).



Learning a New Model...

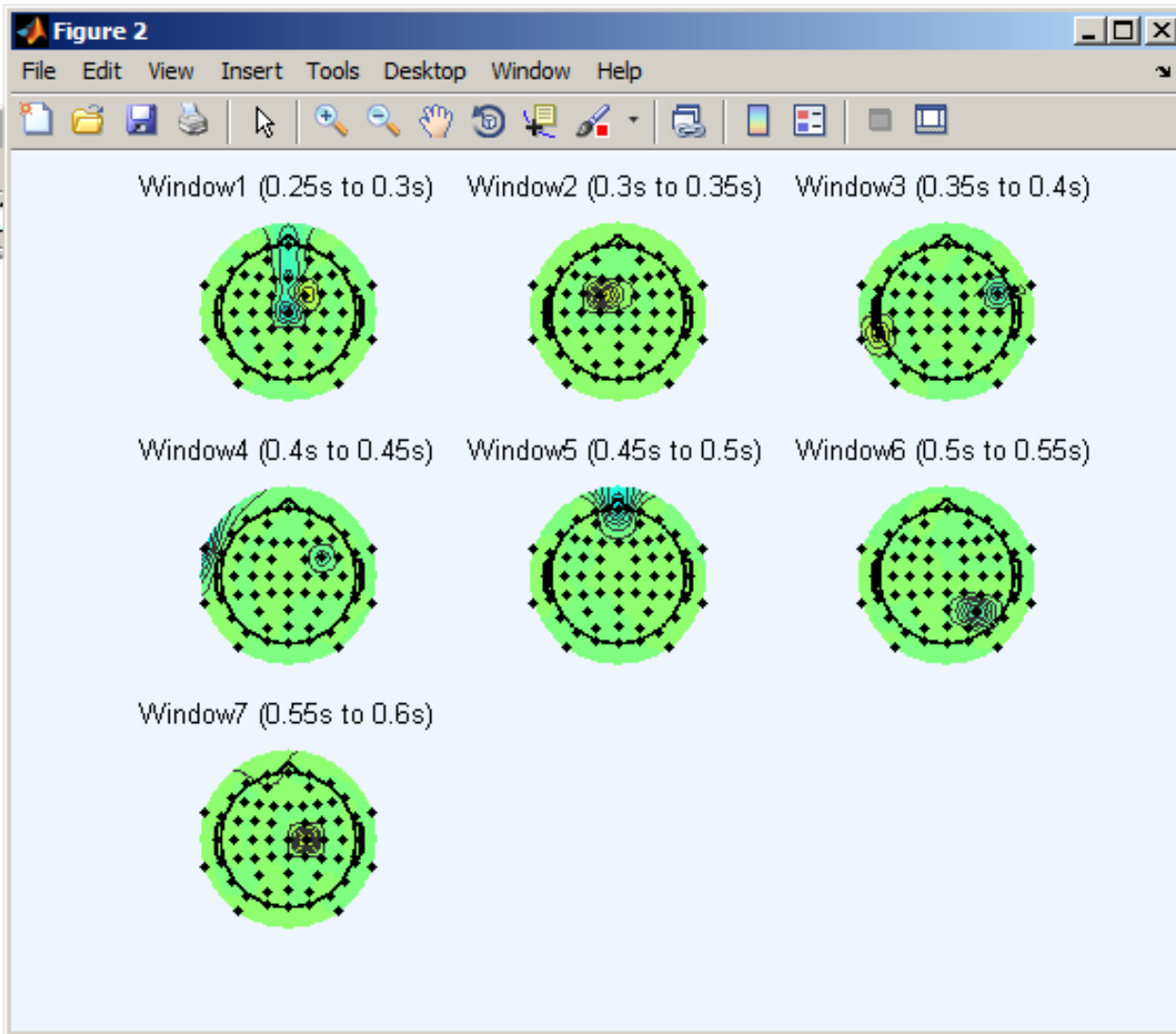


The screenshot shows the 'Calibrate a model' dialog box with the following settings:

- Selected approach:** lastapproach ("Windowed Means ...")
- Calibration data source:** lastdata ("12-08-001_ERN.vhdr")
- Target markers:** [Loaded via EEGLAB], [Loaded via BCILAB], lastdata ("12-08-001_ERN.vhdr"), testdata ("12-08-001_ERN.vhdr"), traindata ("12-08-002_ERN.vhdr")
- Parameter Search:**
 - Loss/Performance Metric:** (empty)
 - Cross-validation folds:** (empty)
 - Spacing around test trials:** 5
- Performance estimates:**
 - Compute performance estimates**
 - Cross-validation folds:** 5
 - Spacing around test trials:** 5
- Computing resources:**
 - Run on a computer cluster**
 - Node pool:** (use current config)
- Save model in workspace as:** lastmodel
- Save stats in workspace as:** laststats

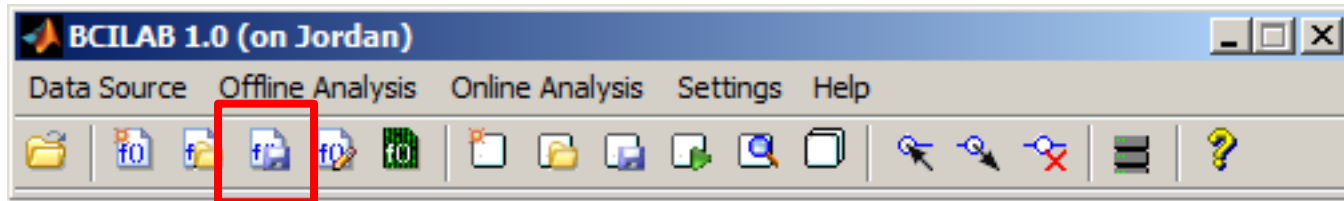
Buttons: Help, Cancel, OK

Visualizing The Model

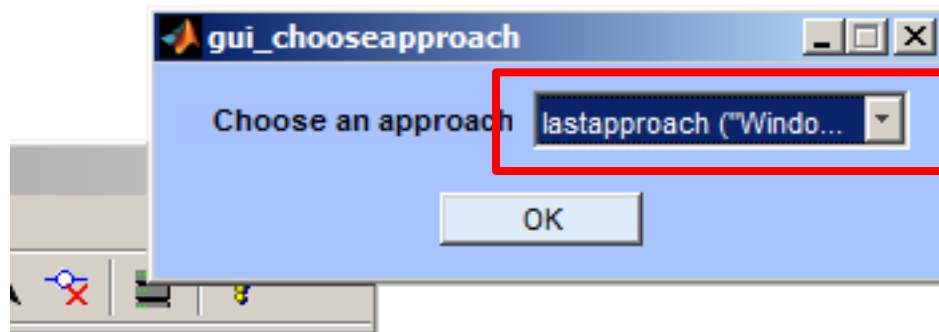


**This model uses
a minimal
subset of
channels.**

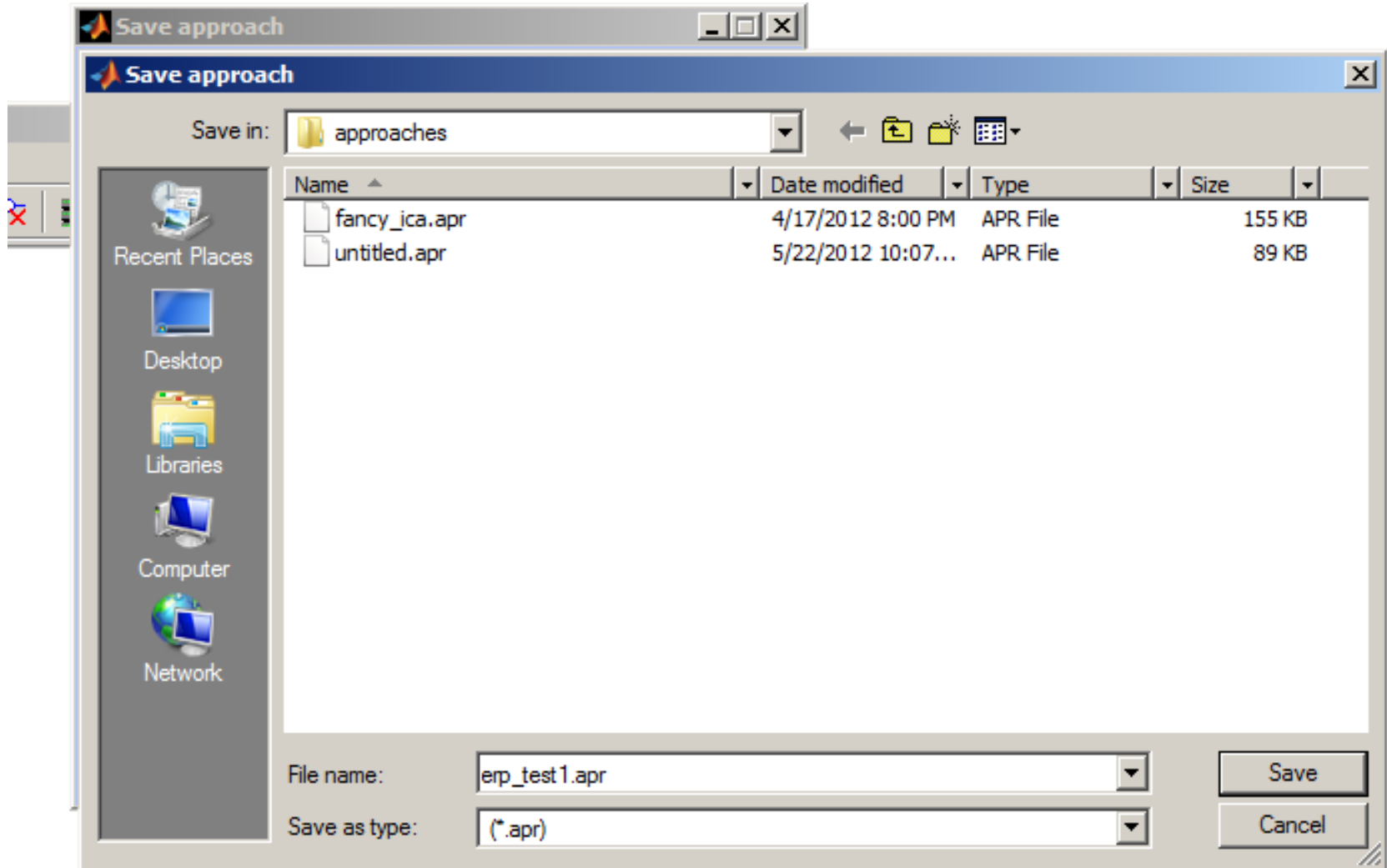
Saving the Approach for Later



Saving the Approach for Later



Saving the Approach for Later

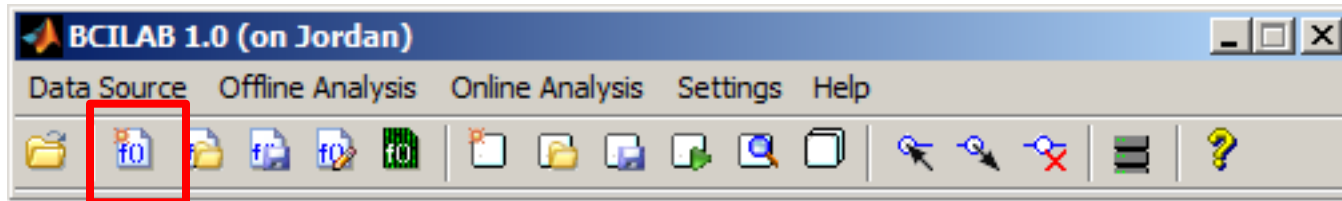




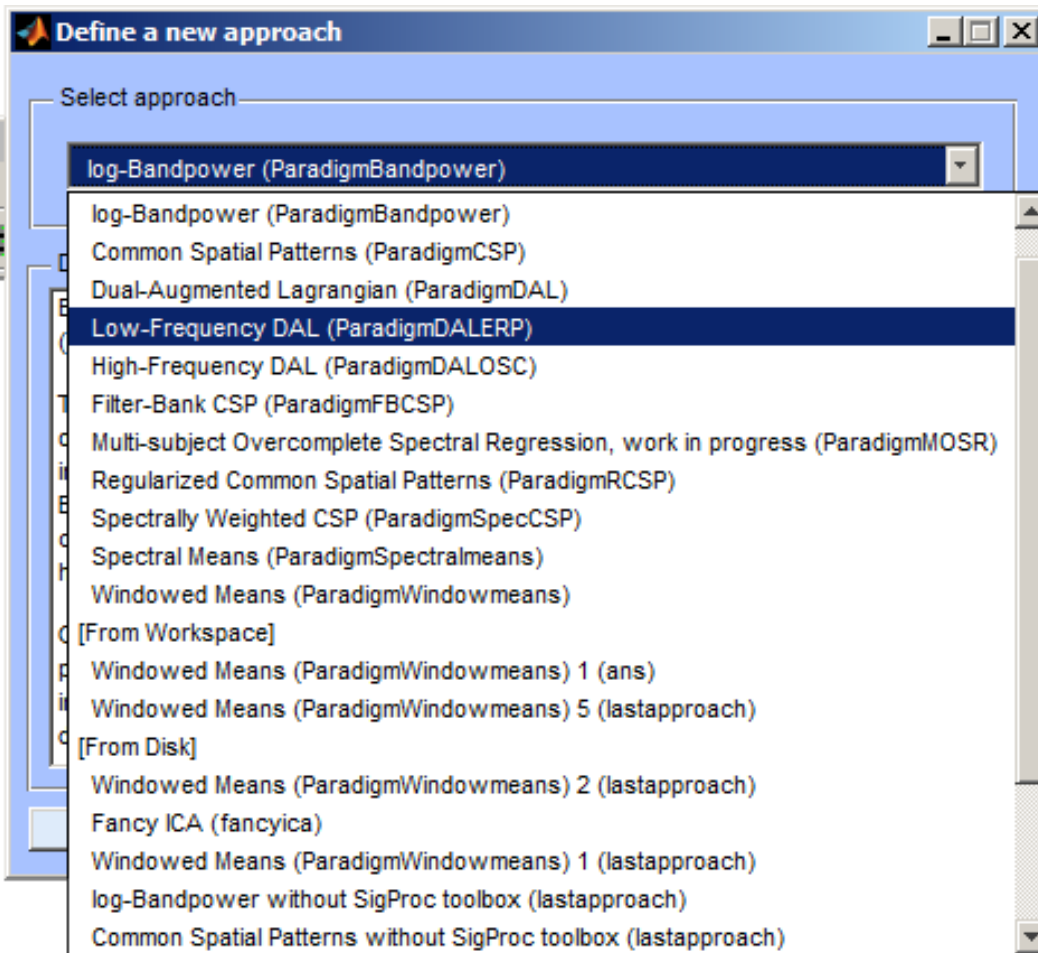
Using a Different BCI Paradigm

(state of the art – this is optional for people with a fast computer)

New Approach....

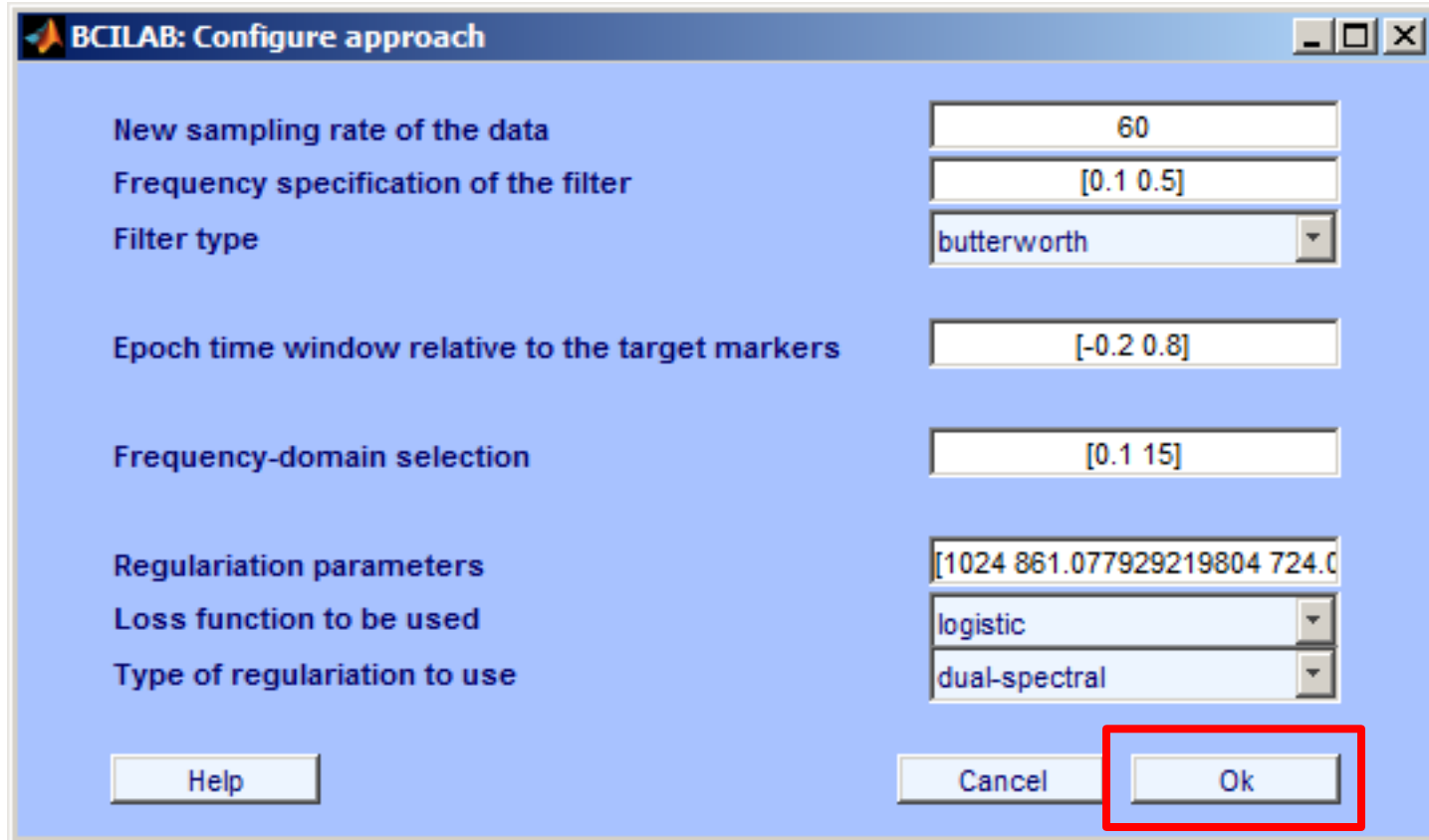


Selecting DAL-ERP



This is one of the best known approaches for ERP-based BCIs. It assumes that there is a small set of latent spatial sources with their own characteristic time course weights, and learns *both simultaneously*.

Configuring DAL-ERP

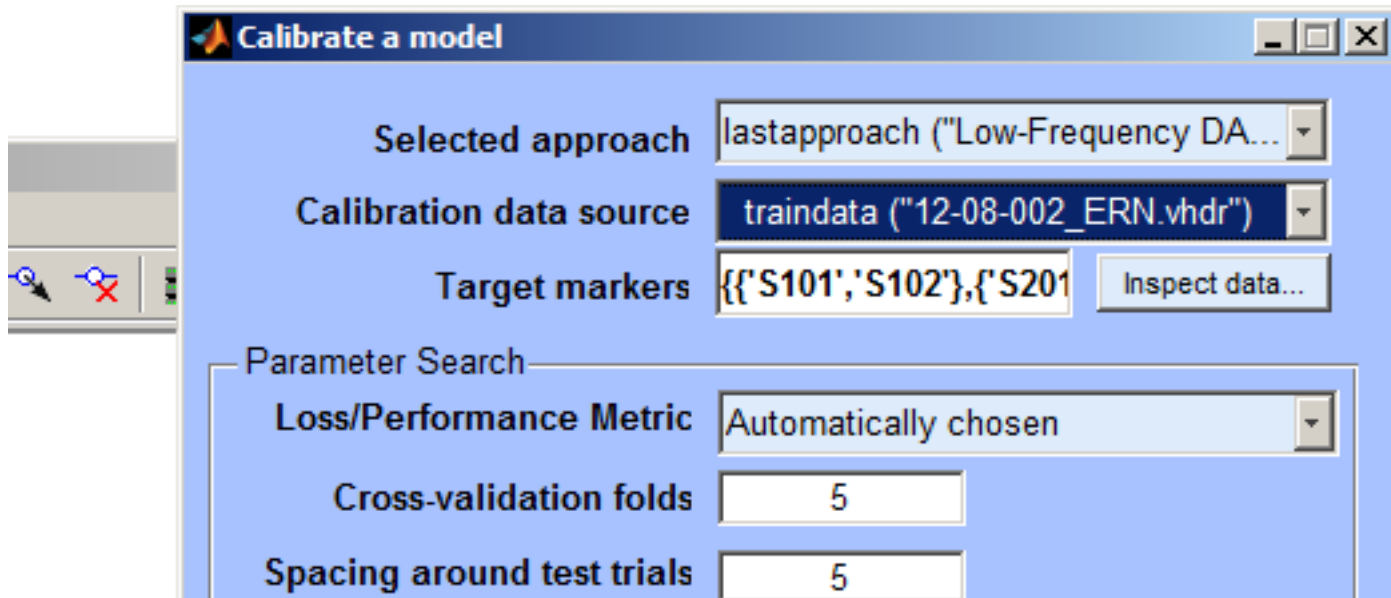


BCILAB: Configure approach

New sampling rate of the data	<input type="text" value="60"/>
Frequency specification of the filter	<input type="text" value="[0.1 0.5]"/>
Filter type	<input type="text" value="butterworth"/>
Epoch time window relative to the target markers	<input type="text" value="[-0.2 0.8]"/>
Frequency-domain selection	<input type="text" value="[0.1 15]"/>
Regularisation parameters	<input type="text" value="[1024 861.077929219804 724.0]"/>
Loss function to be used	<input type="text" value="logistic"/>
Type of regularisation to use	<input type="text" value="dual-spectral"/>

Help Cancel **Ok**

Calibrate Model...



The image shows a software dialog box titled "Calibrate a model". It contains several configuration options for model calibration:

- Selected approach:** lastapproach ("Low-Frequency DA...")
- Calibration data source:** traindata ("12-08-002_ERN.vhdr")
- Target markers:** {'S101','S102'},{'S201'} (with an "Inspect data..." button)
- Parameter Search:**
 - Loss/Performance Metric:** Automatically chosen
 - Cross-validation folds:** 5
 - Spacing around test trials:** 5

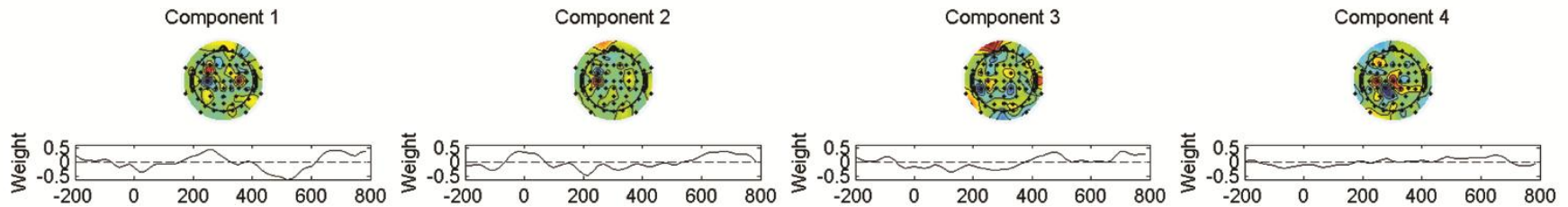
Wait for a Few Minutes...

```
beginning evaluation...

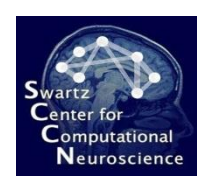
beginning new computation...
pop_epoch():398 epochs selected
Epoching...
pop_epoch():398 epochs generated
eeg_checkset: found empty values for field 'target'
              filling with values of other events in
pop_epoch(): checking epochs for data discontinuity
learning ensemble...
  scanning lambda = 1024.000000... model rank = 0
  scanning lambda = 861.077929... model rank = 0
  scanning lambda = 724.077344... model rank = 0
  scanning lambda = 608.874043... model rank = 0
  scanning lambda = 512.000000... model rank = 0
  scanning lambda = 430.538965... model rank = 1
  scanning lambda = 362.038672... model rank = 1
  scanning lambda = 304.437021... model rank = 1
  scanning lambda = 256.000000... model rank = 1
  scanning lambda = 215.269482... model rank = 1
  scanning lambda = 181.019336... model rank = 1
  scanning lambda = 152.218511... model rank = 1
  scanning lambda = 128.000000... model rank = 2
  scanning lambda = 107.634741... model rank = 3
  scanning lambda = 90.509668... model rank = 3
  scanning lambda = 76.109255... model rank = 3
  scanning lambda = 64.000000... model rank = 3
  scanning lambda = 53.817371... model rank = 3
  scanning lambda = 45.254834... model rank = 4
  scanning lambda = 38.054628... model rank = 6
  scanning lambda = 32.000000...>> |
```

OVR.

Some of the Resulting Components



Note that these are the spatial filters rather than the forward projections!



5 Hands-On Oscillatory Process Analysis

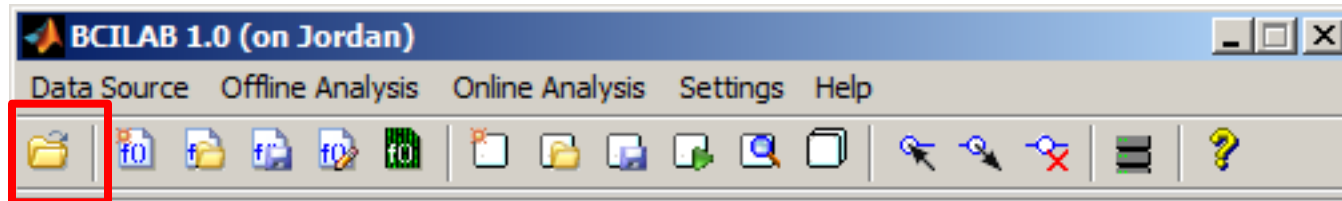
The Data

- The experiment consists of 160 trials (pause at $\frac{1}{2}$ the experiment) . Each trial begins with a letter (either L or R) displayed for 3s. The subject is instructed to subsequently **imagine either a left-hand or a right-hand movement**. Each trial ends with a blank screen displayed for 3.5s.

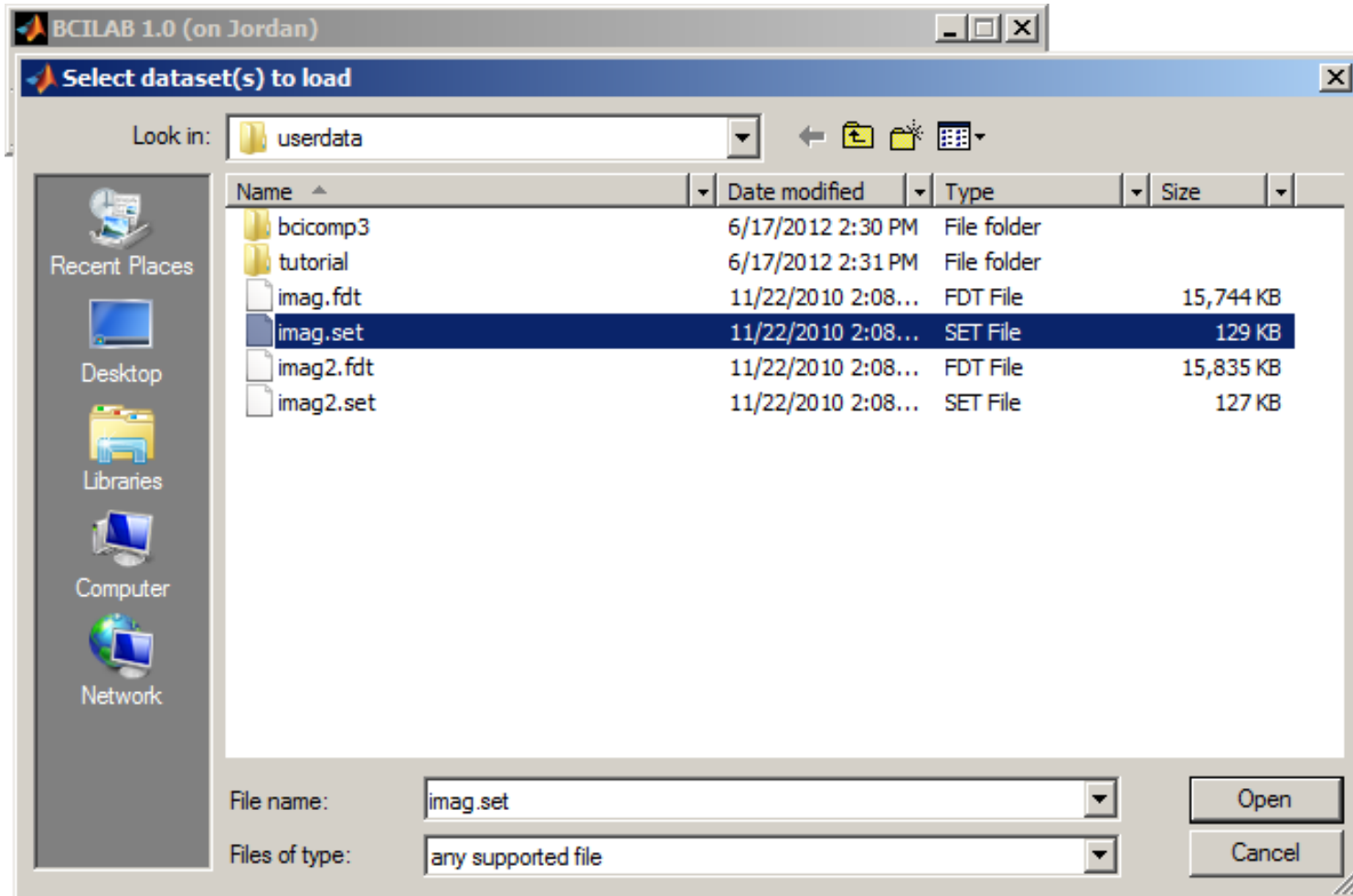


R

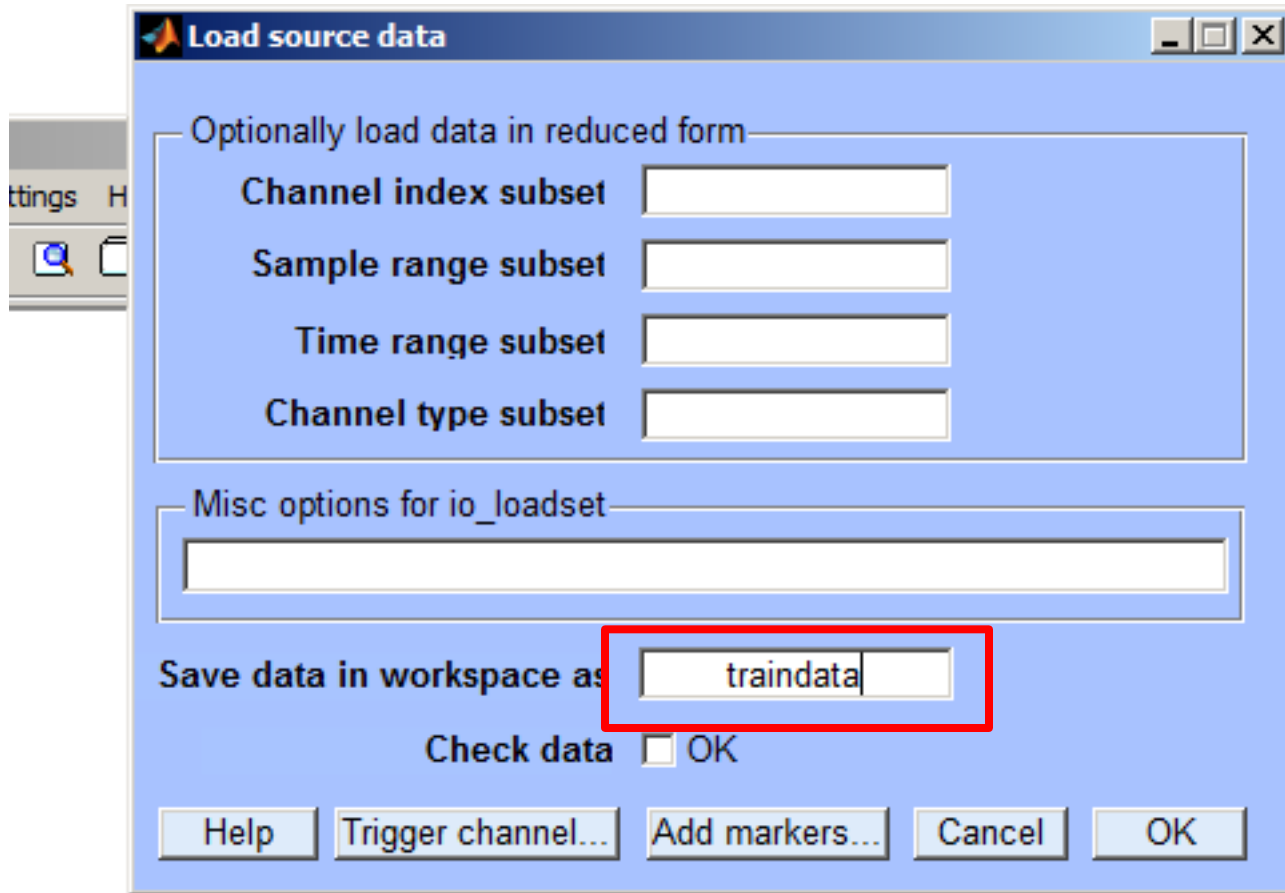
Loading the Data....



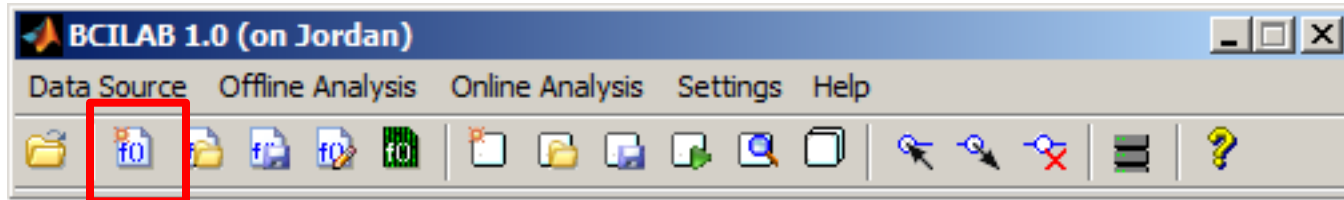
Loading the Data...



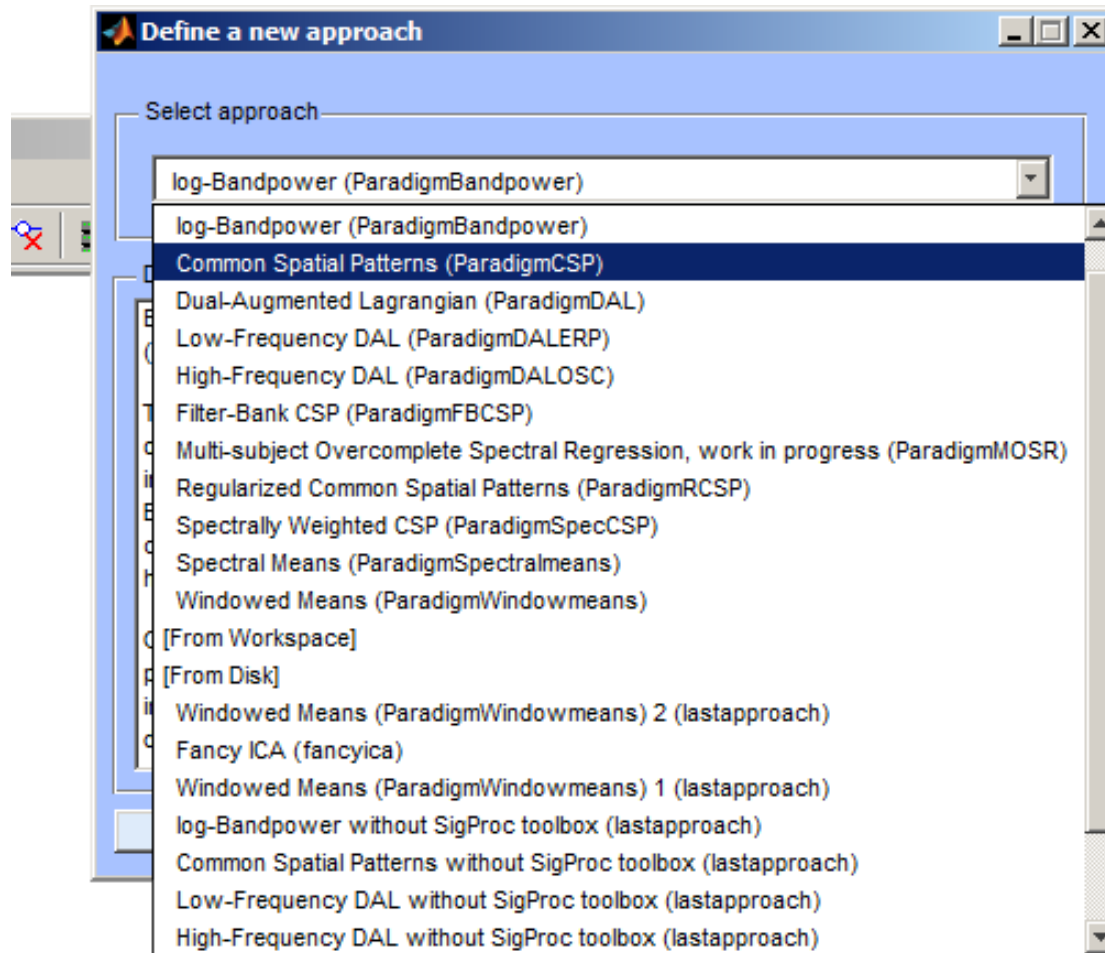
Name It



New Approach

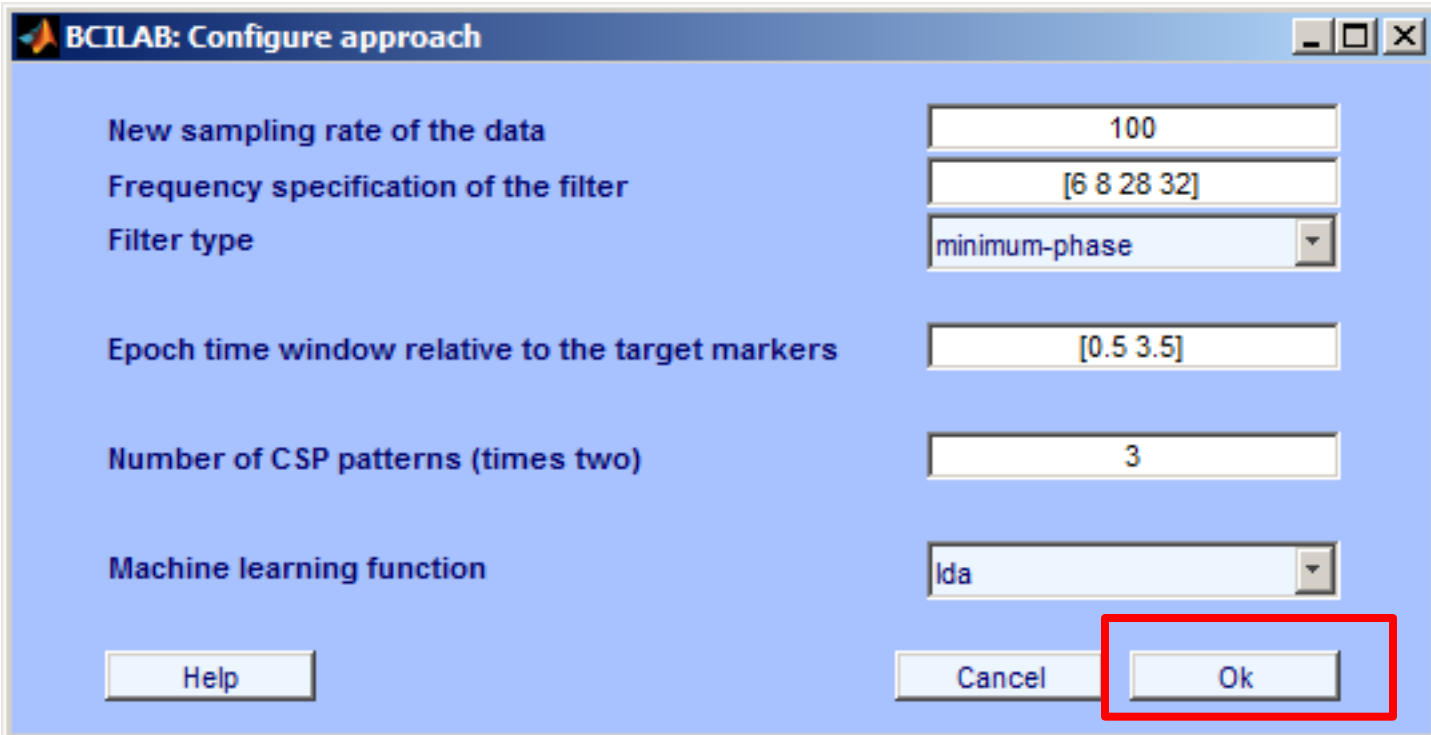


Selecting the Common Spatial Patterns Paradigm



Note: If you don't have a signal processing license, try instead the method "Common Spatial Patterns without SigProc toolbox" at the bottom.

Configuring the Approach



BCILAB: Configure approach

New sampling rate of the data: 100

Frequency specification of the filter: [6 8 28 32]

Filter type: minimum-phase

Epoch time window relative to the target markers: [0.5 3.5]

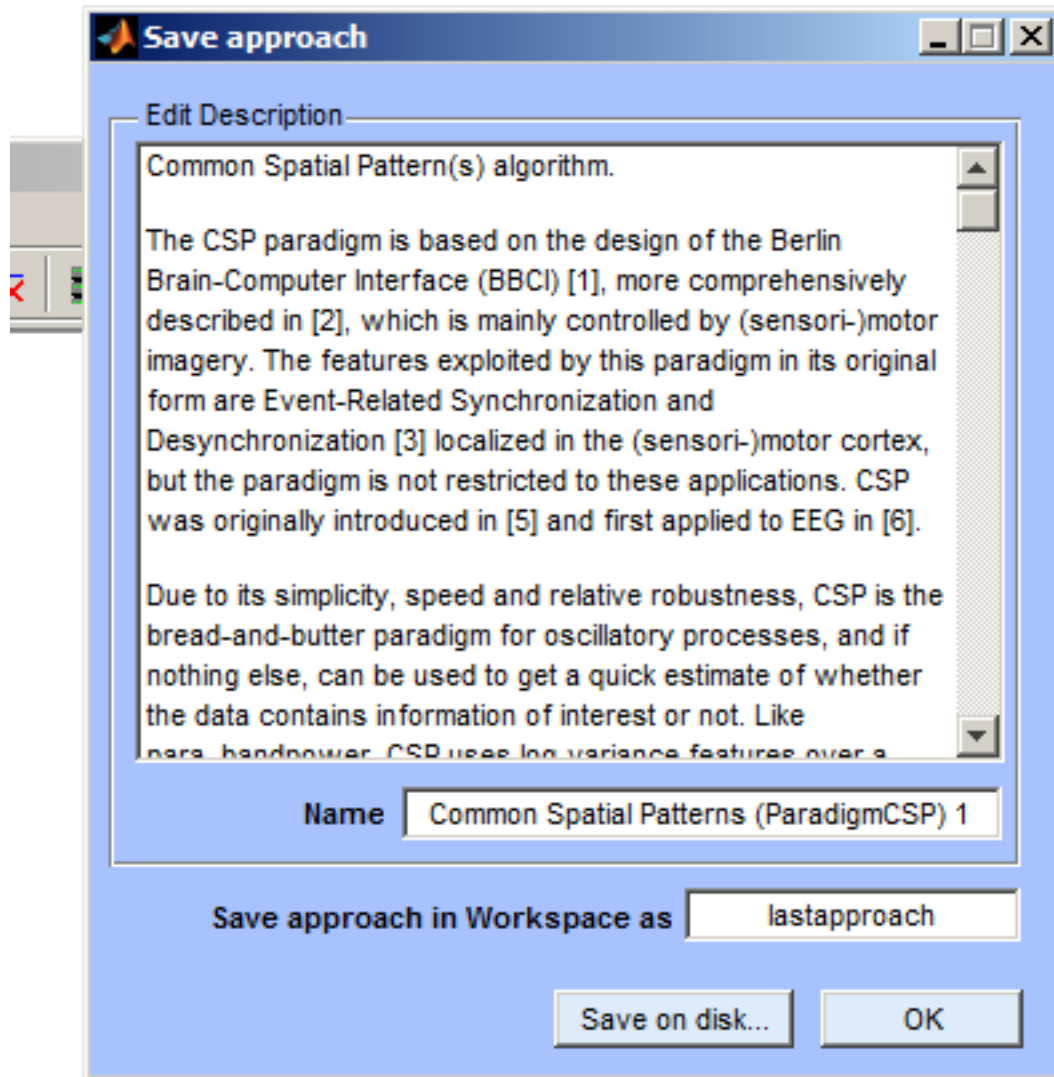
Number of CSP patterns (times two): 3

Machine learning function: lda

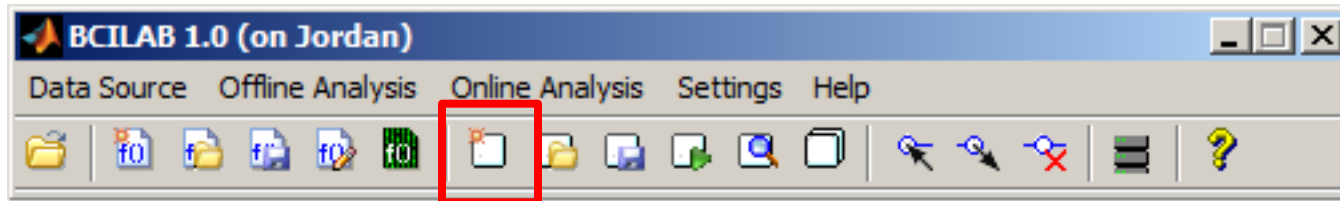
Buttons: Help, Cancel, Ok

The 'Ok' button is highlighted with a red rectangle.

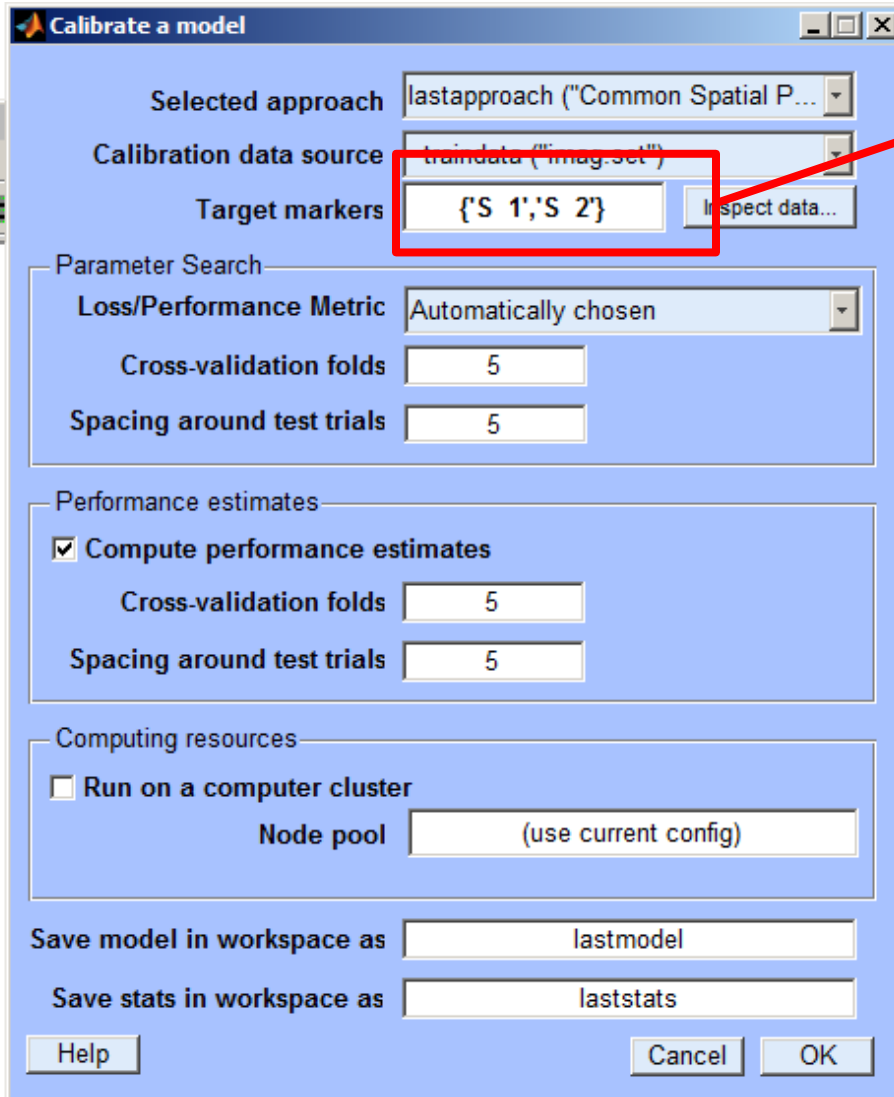
Save Approach to Workspace



Calibrating a New Model



Calibrating a New Model



Calibrate a model

Selected approach: lastapproach ("Common Spatial P...")

Calibration data source: traindata ("imag.set")

Target markers: **{S 1';S 2'}** [Inspect data...]

Parameter Search

Loss/Performance Metric: Automatically chosen

Cross-validation folds: 5

Spacing around test trials: 5

Performance estimates

Compute performance estimates

Cross-validation folds: 5

Spacing around test trials: 5

Computing resources

Run on a computer cluster

Node pool: (use current config)

Save model in workspace as: lastmodel

Save stats in workspace as: laststats

Help Cancel OK

There are only two markers here, one per condition (no sub-groups). Type the following here: **{S 1';S 2'}**

IMPORTANT: There are 2 space characters between the S and the number!

The marker "S 1" indicates the moment when the subject is instructed to imagine a left-hand movement, and the marker "S 2" indicates the moment when a right-hand movement should be imagined.

Watching the Computation...

```
beginning new computation...
>> clc
io_loadset(): loading C:\DEVEL\bcilab-1.0b\userdata\i
pop_loadset(): loading file C:\DEVEL\bcilab-1.0b\user
Reading float file 'C:\DEVEL\bcilab-1.0b\userdata\ime
The loaded EEGLAB set is lacking an online expressio
If it contains filtered data, however, BCI models der
pop_epoch():160 epochs selected
Epoching...
pop_epoch():160 epochs generated
eeg_checkset: found empty values for field 'target'
             filling with values of other events in
pop_epoch(): checking epochs for data discontinuity
pop_epoch():160 epochs selected
Epoching...
pop_epoch():160 epochs generated
eeg_checkset: found empty values for field 'target'
             filling with values of other events in
pop_epoch(): checking epochs for data discontinuity
```

fx

OVR

Reviewing Results

Review Results

Data Summary

```

True positive rate : 0.92 +/- 0.09 (N=5)
False positive rate : 0.08 +/- 0.09 (N=5)
True negative rate : 0.93 +/- 0.08 (N=5)
False negative rate : 0.07 +/- 0.08 (N=5)
Error rate : 0.07 +/- 0.06 (N=5)
  
```

7% mis-classification rate is pretty good!

Data Details

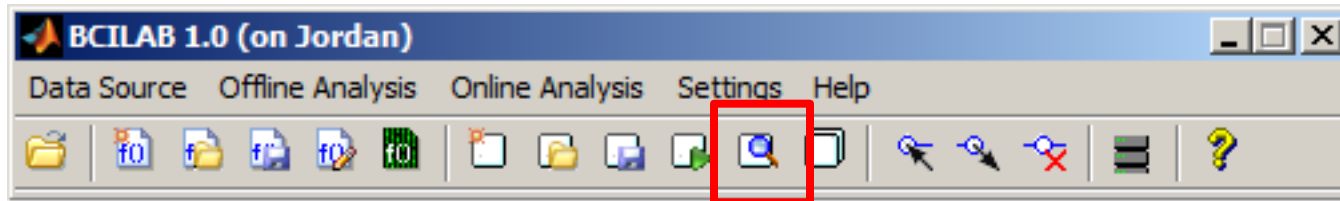
	True positive rate	False positive rate	True negative r...	False negative r...	Error rate
1	0.8824	0.1176	0.8000	0.2000	0.1563
2	0.9474	0.0526	0.9231	0.0769	0.0625
3	0.7778	0.2222	1	0	0.1250
4	1	0	0.9286	0.0714	0.0313
5	1	0	1	0	0

Export... OK

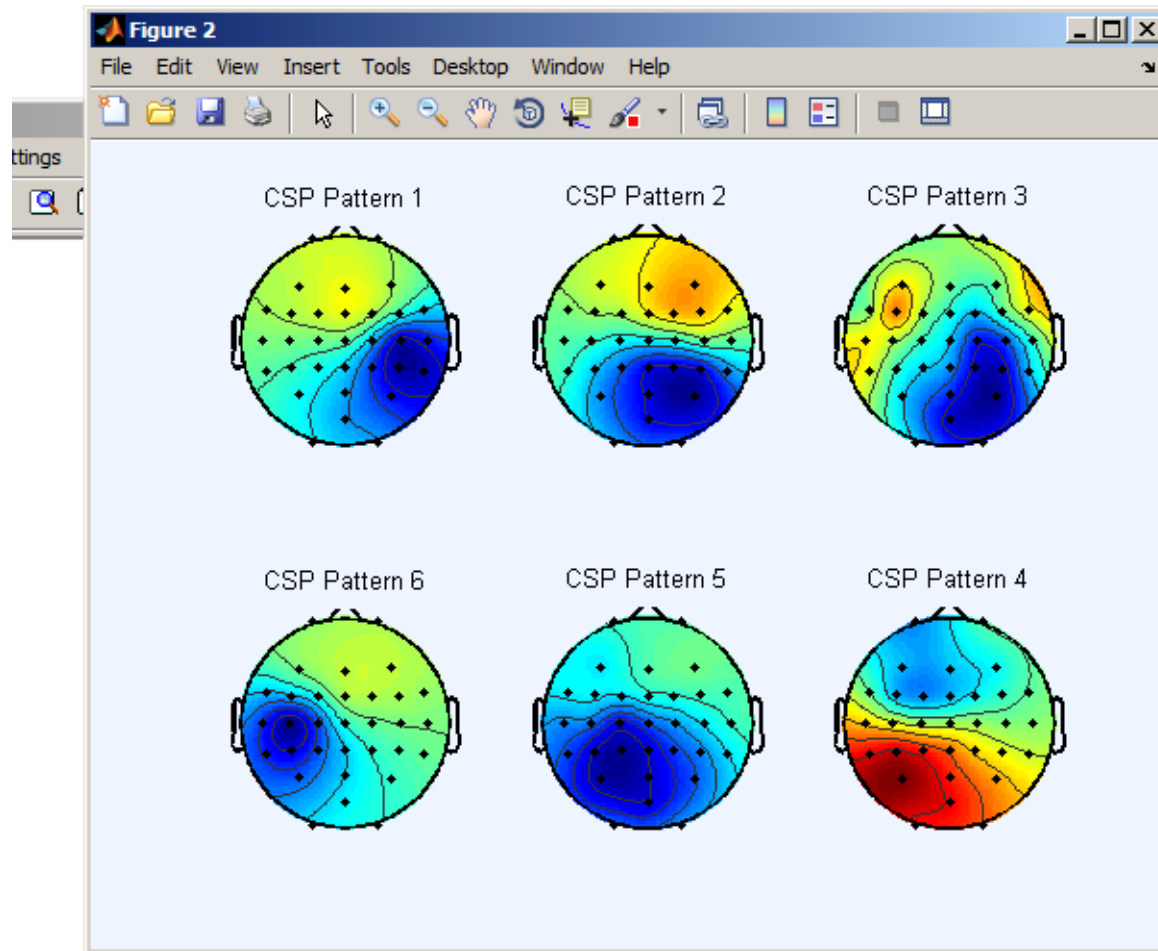
Save stats in workspace as

Help Cancel OK

Visualizing the Model

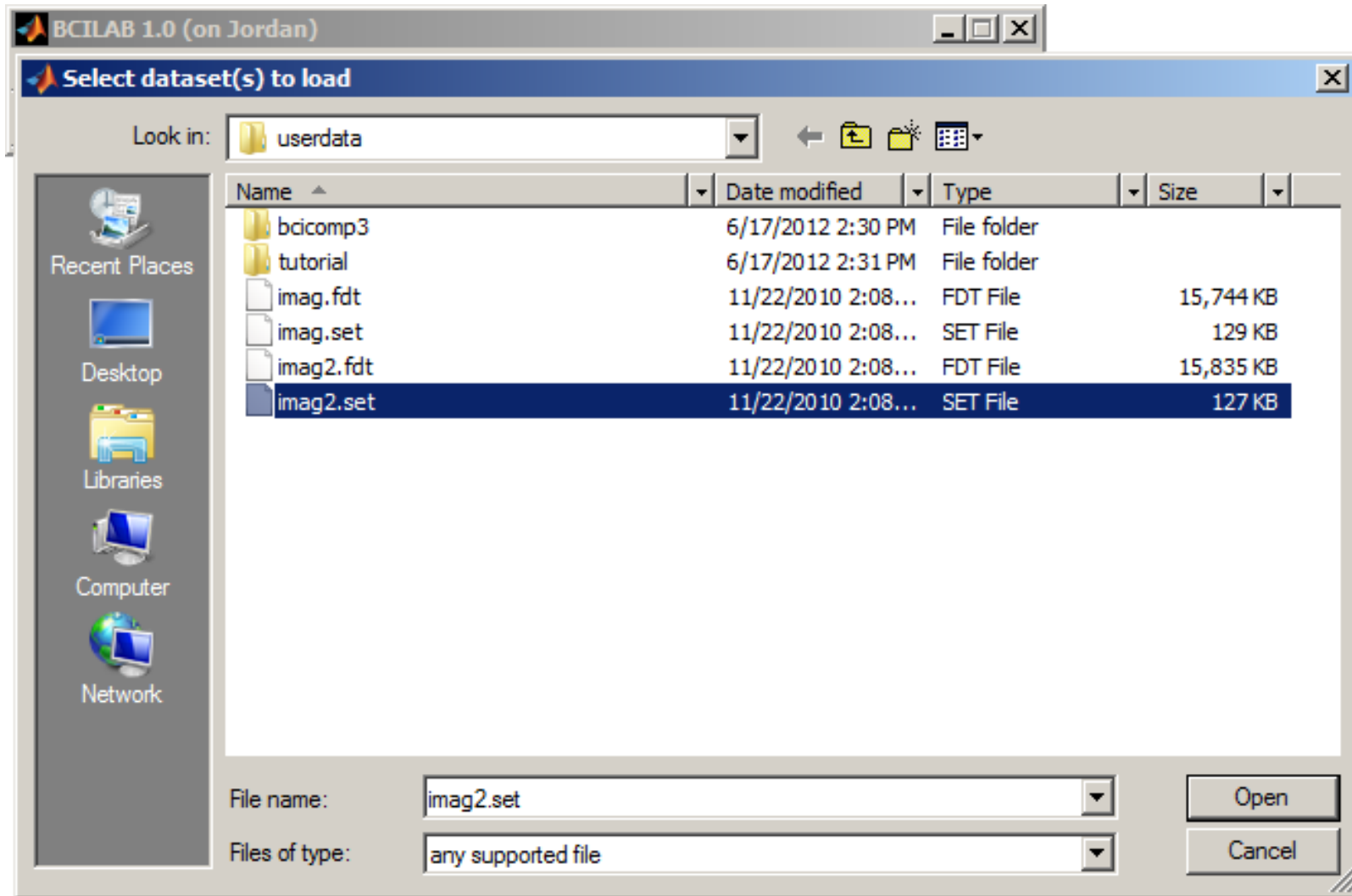


Visualizing the Model

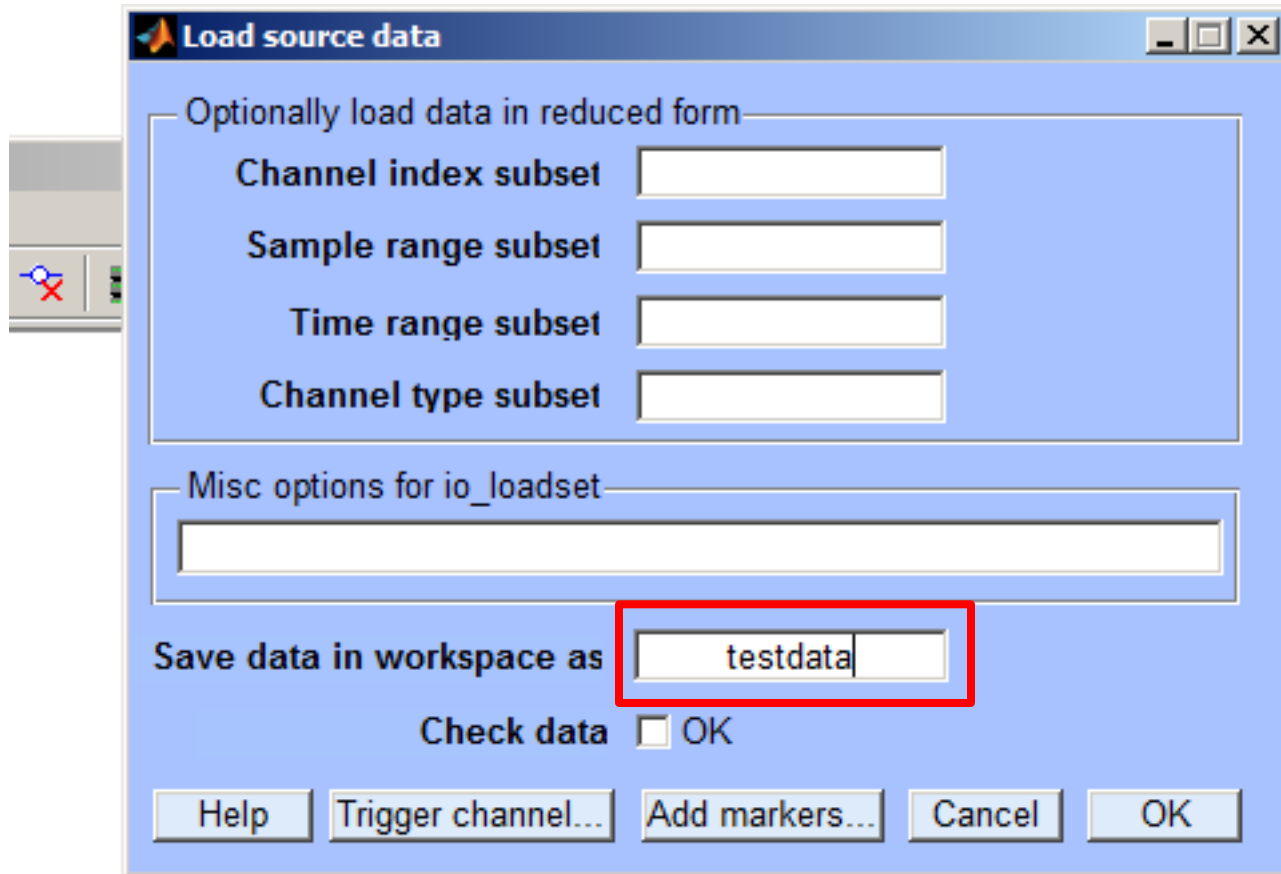


Note: these are not the spatial filters but the source forward projections .

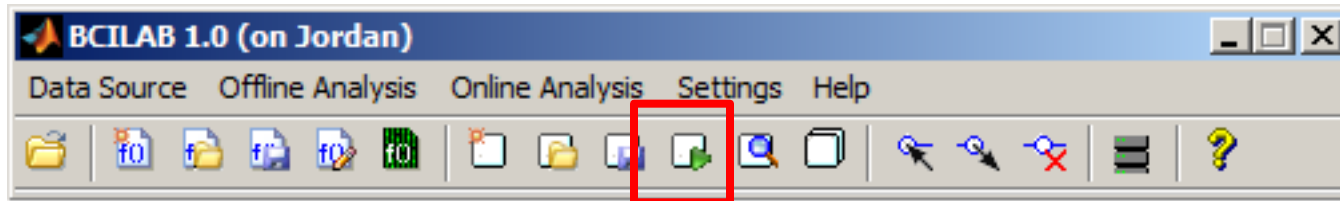
Loading A Separate Test Set



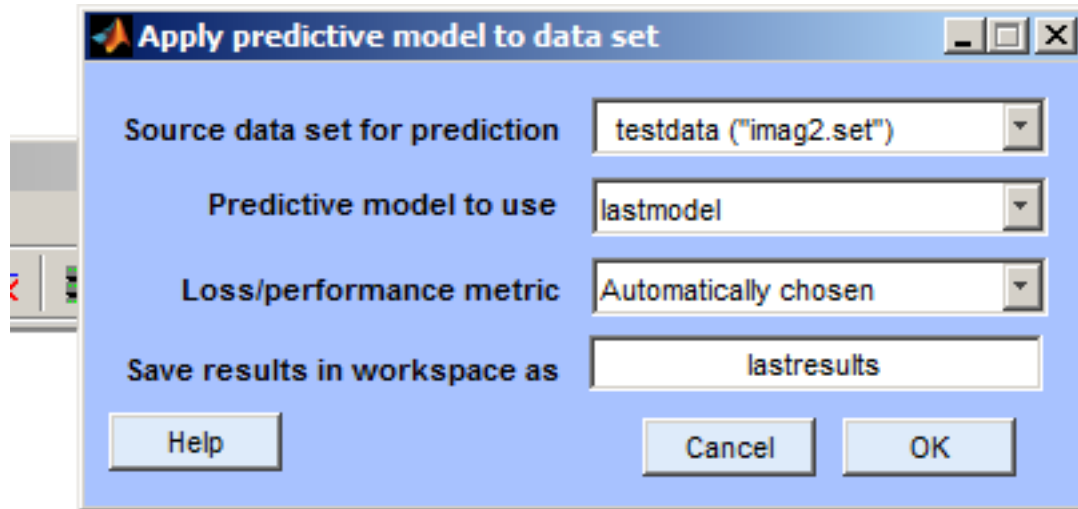
Naming the Test Set



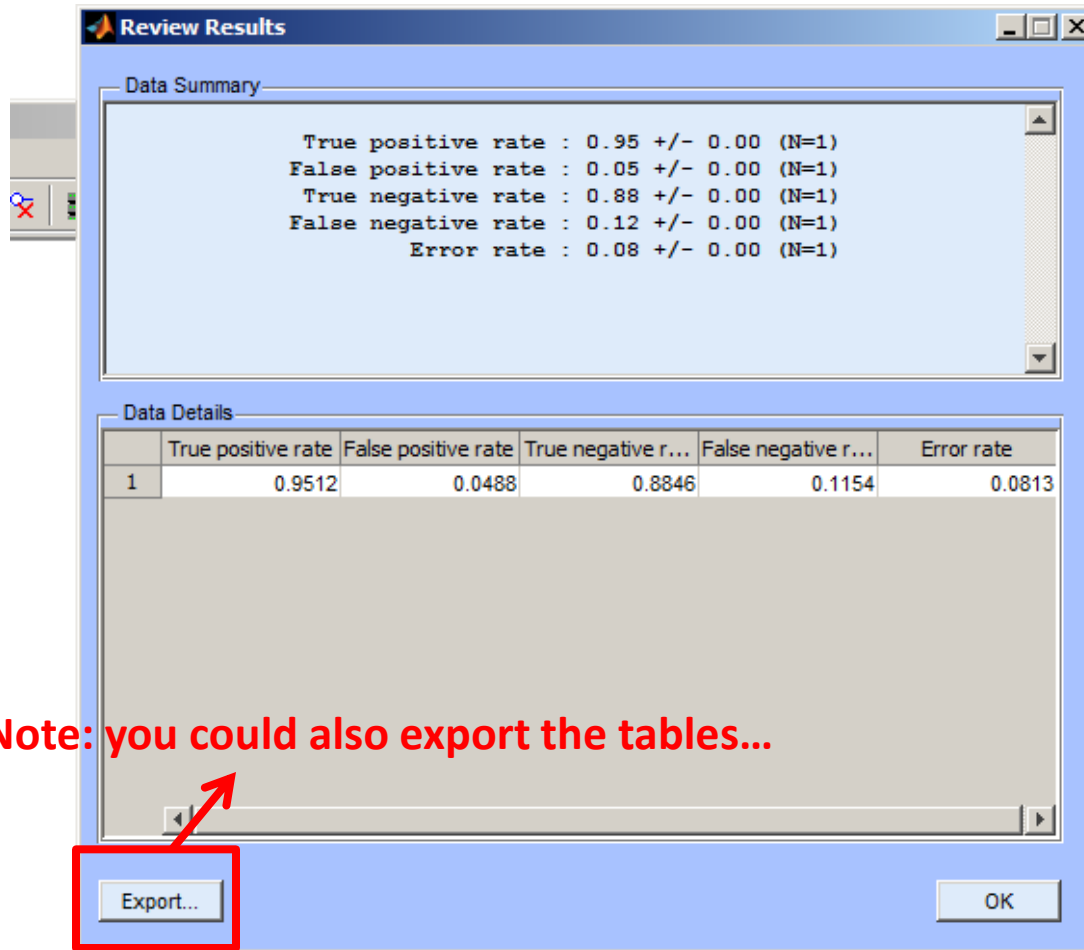
Applying the Model to the Test Data



Applying the Model to the Test Data



Reviewing Results



The screenshot shows a software window titled "Review Results" with a blue border. It contains two main sections: "Data Summary" and "Data Details".

Data Summary

```
True positive rate : 0.95 +/- 0.00 (N=1)
False positive rate : 0.05 +/- 0.00 (N=1)
True negative rate : 0.88 +/- 0.00 (N=1)
False negative rate : 0.12 +/- 0.00 (N=1)
Error rate : 0.08 +/- 0.00 (N=1)
```

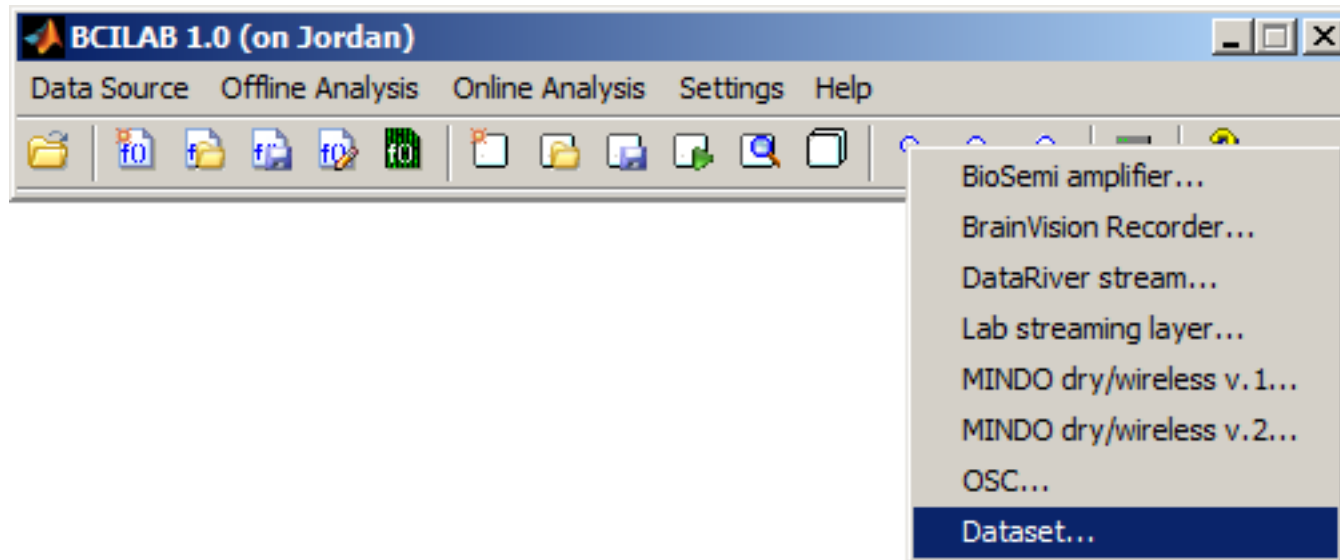
Data Details

	True positive rate	False positive rate	True negative r...	False negative r...	Error rate
1	0.9512	0.0488	0.8846	0.1154	0.0813

At the bottom of the window, there is an "Export..." button highlighted with a red box and an "OK" button. A red arrow points from the "Export..." button to the text "Note: you could also export the tables..." located to the left of the window.

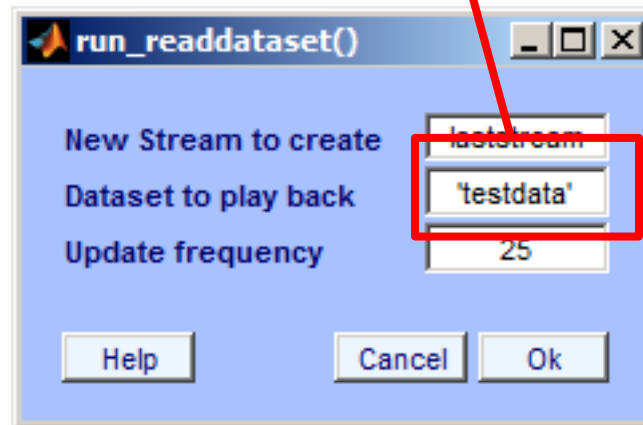
Note: you could also export the tables...

Starting Online Analysis

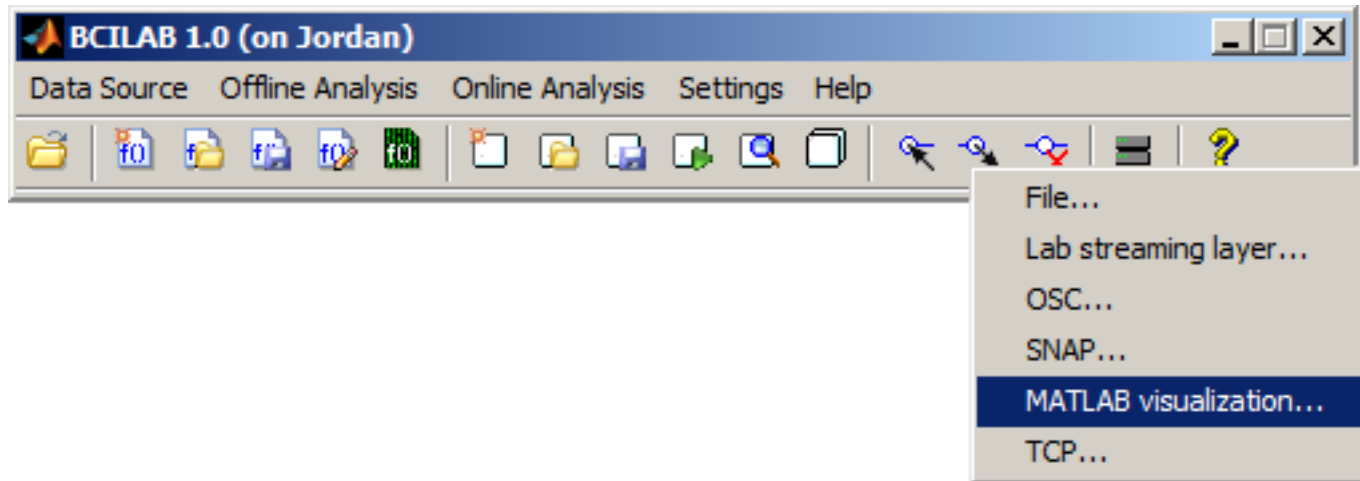


Starting Online Analysis

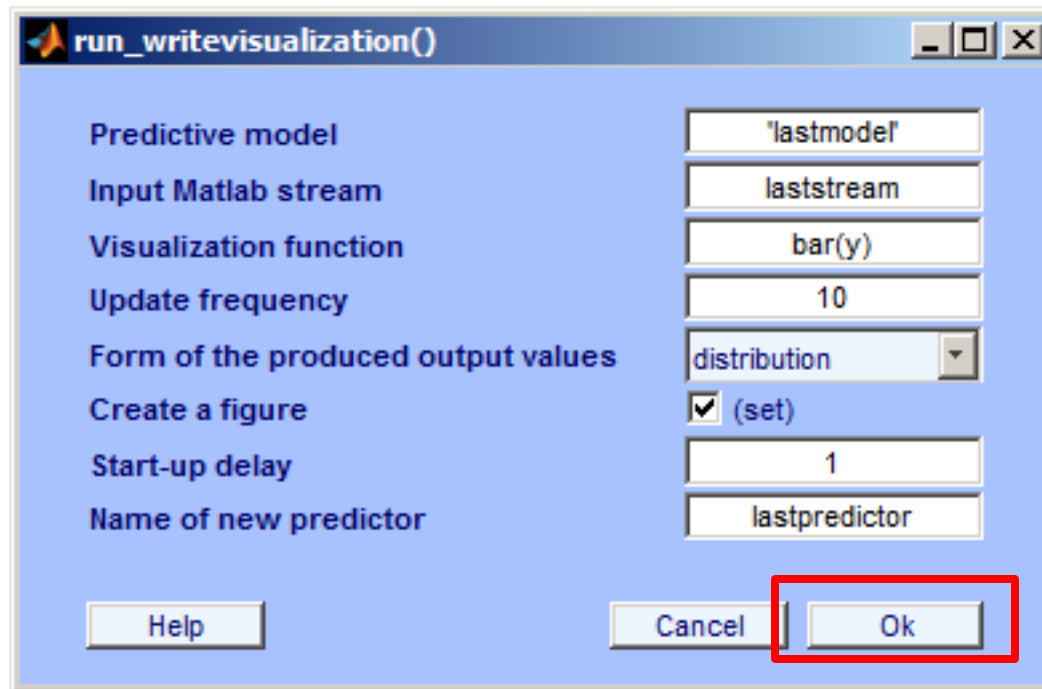
IMPORTANT: Put the name of your test data set here!



Select Output Destination



Configure/Confirm

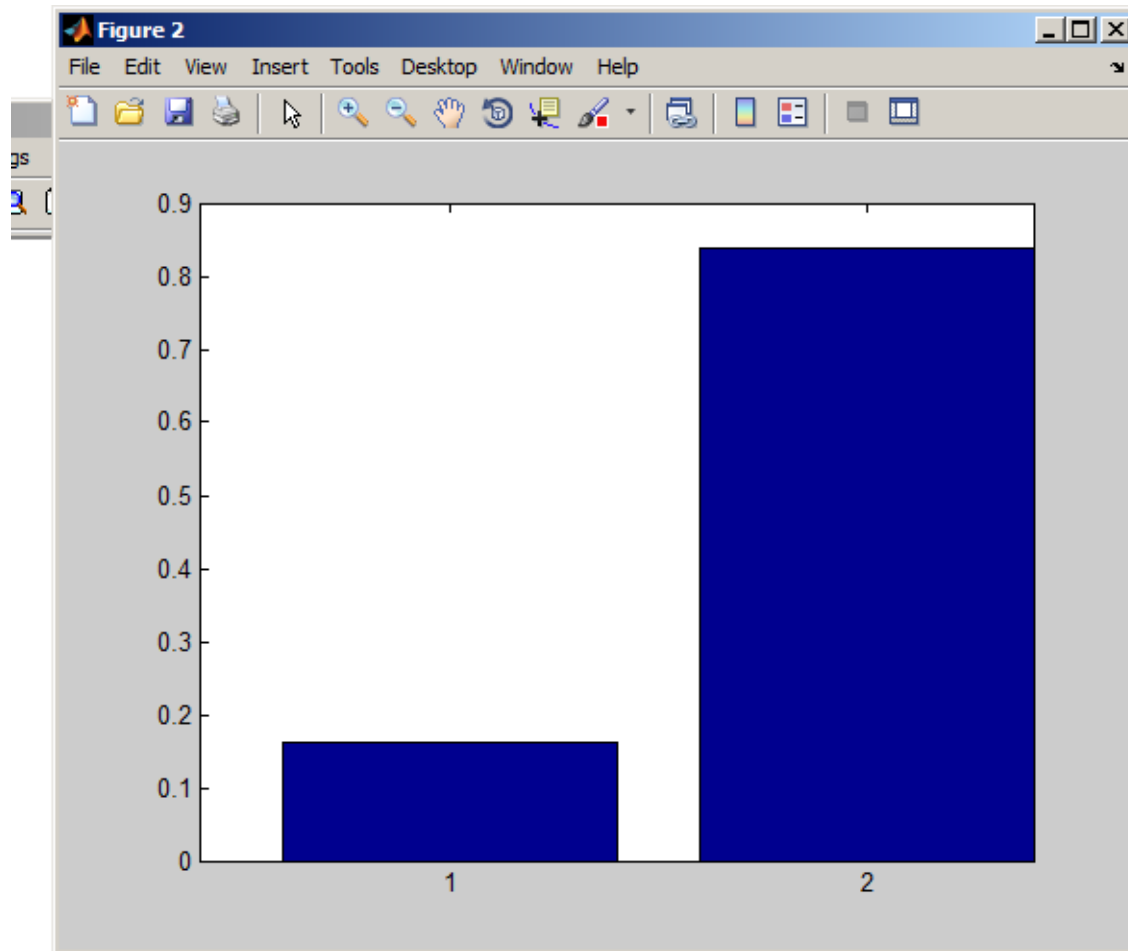


The image shows a MATLAB dialog box titled "run_writevisualization()". It contains several configuration options with corresponding input fields:

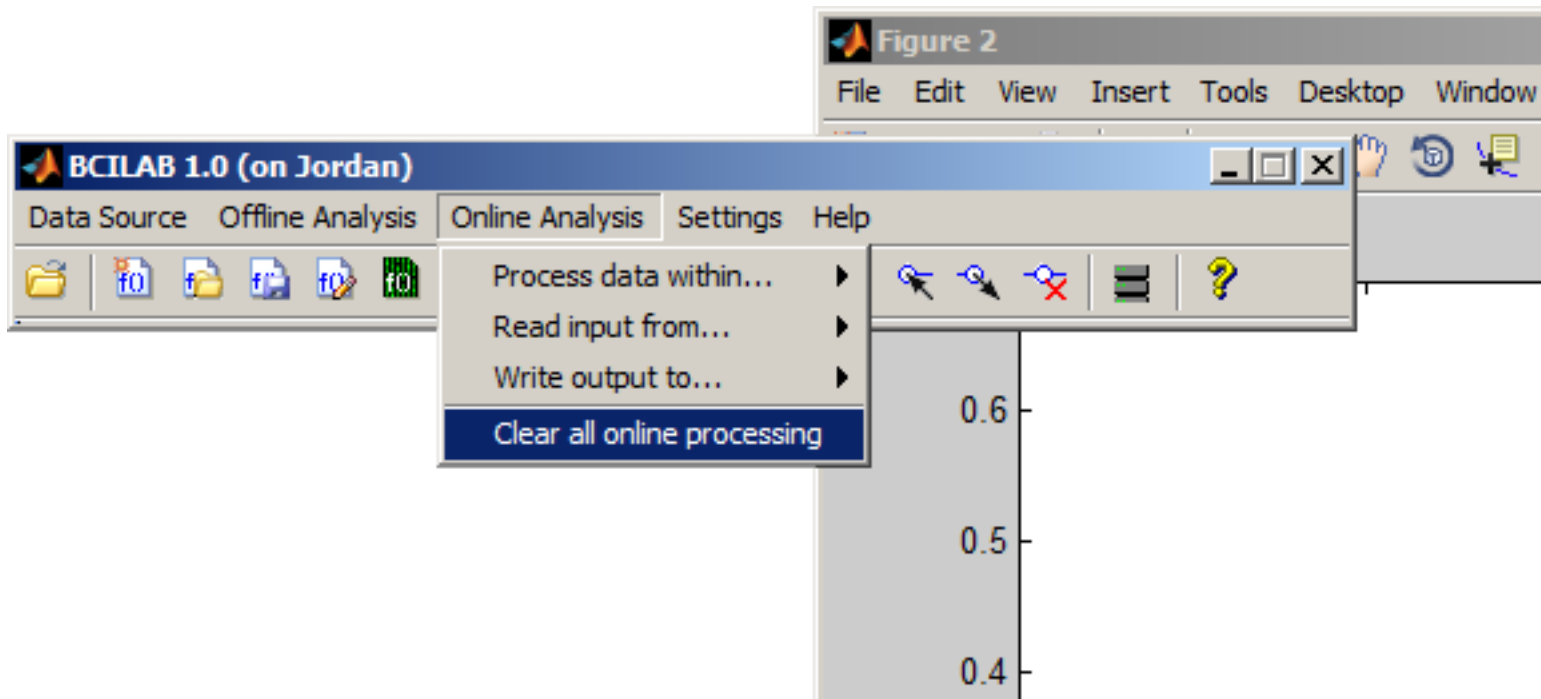
- Predictive model:** 'lastmodel'
- Input Matlab stream:** laststream
- Visualization function:** bar(y)
- Update frequency:** 10
- Form of the produced output values:** distribution (dropdown menu)
- Create a figure:** (set)
- Start-up delay:** 1
- Name of new predictor:** lastpredictor

At the bottom of the dialog, there are three buttons: "Help", "Cancel", and "Ok". The "Ok" button is highlighted with a red rectangular box.

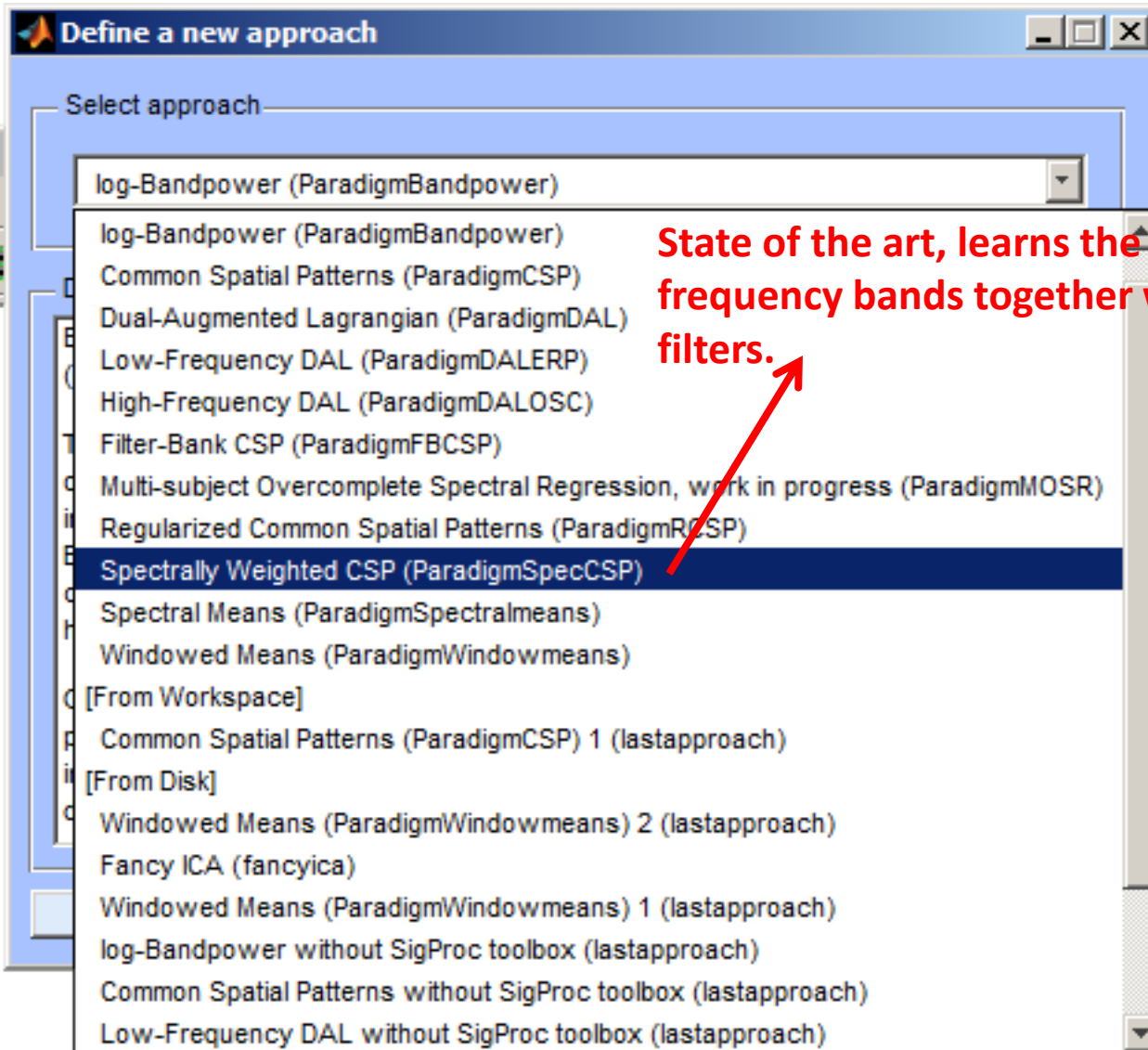
Online Output



Clear Online Processing



Alternative Paradigms: Spec-CSP



State of the art, learns the correct frequency bands together with spatial filters.

Alternative Paradigms: Spec-CSP

Review Results

Data Summary

```

True positive rate : 0.95 +/- 0.05 (N=5)
False positive rate : 0.05 +/- 0.05 (N=5)
True negative rate : 0.93 +/- 0.04 (N=5)
False negative rate : 0.07 +/- 0.04 (N=5)
Error rate : 0.06 +/- 0.01 (N=5)
  
```

Data Details

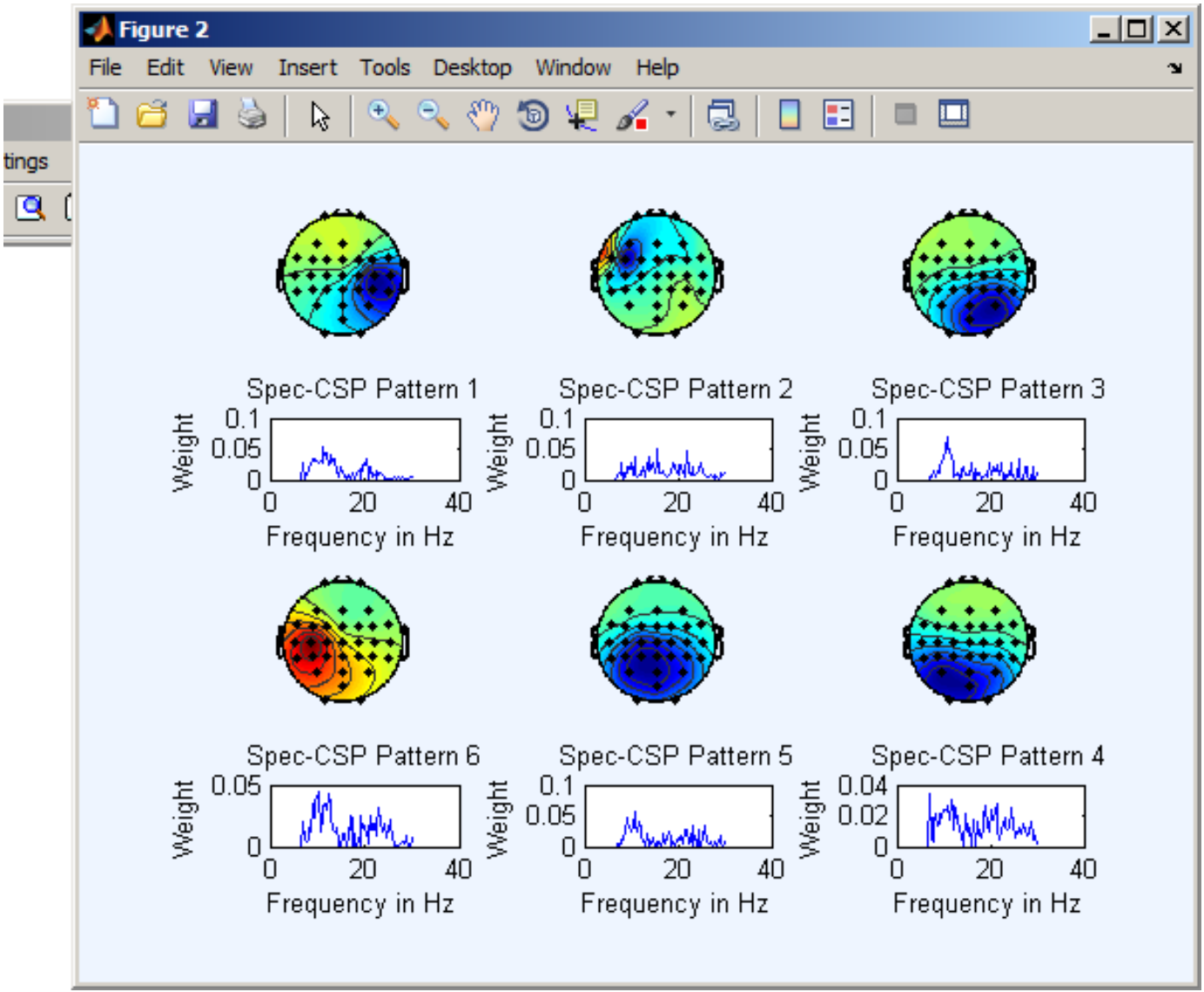
	True positive rate	False positive rate	True negative r...	False negative r...	Error rate
1	1	0	0.8824	0.1176	0.0625
2	0.9474	0.0526	0.9231	0.0769	0.0625
3	0.8667	0.1333	1	0	0.0625
4	0.9500	0.0500	0.9167	0.0833	0.0625
5	1	0	0.9474	0.0526	0.0313

Export... OK

Save stats in workspace as

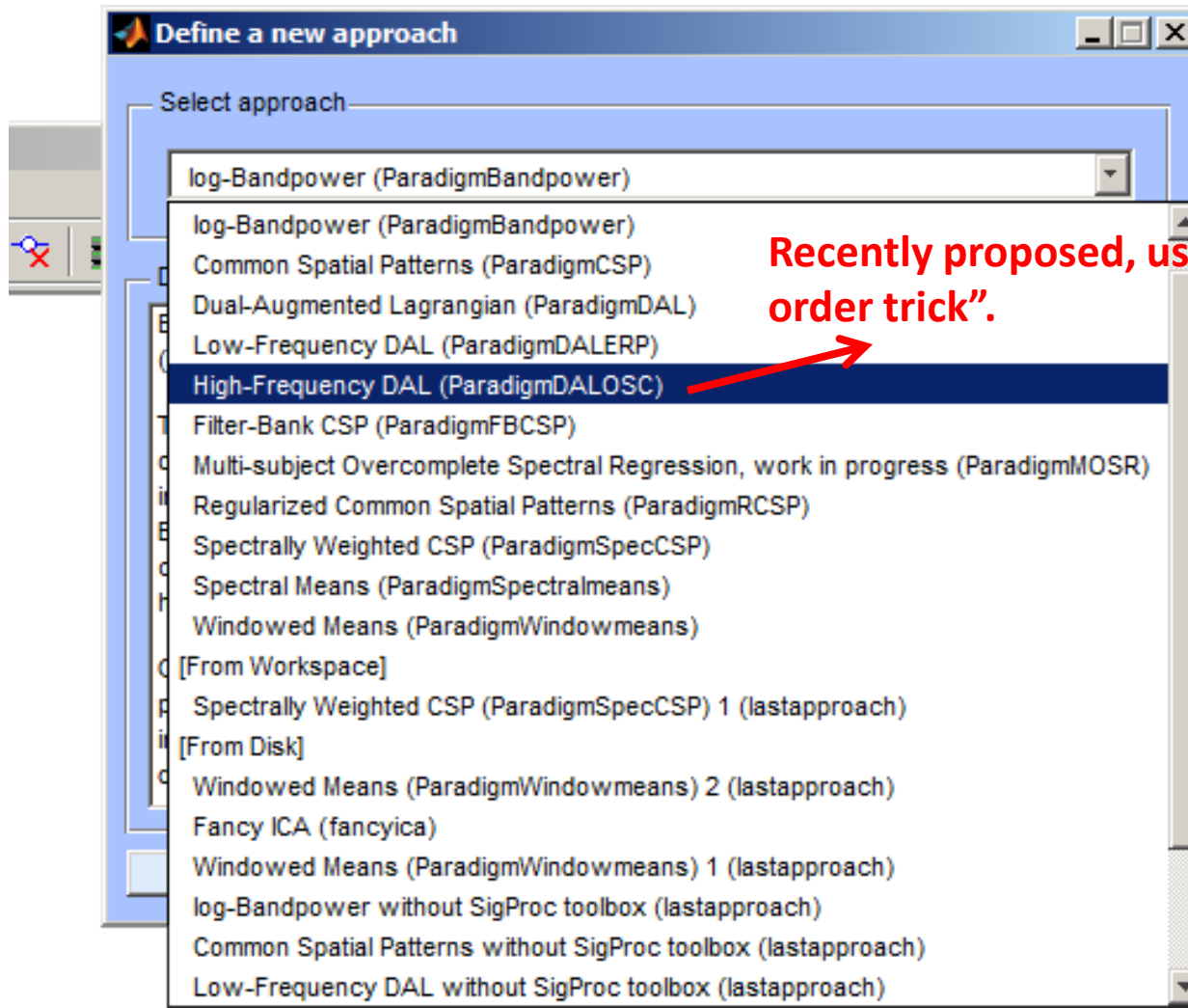
Help Cancel OK

Alternative Paradigms: Spec-CSP



Alternative Paradigms: DAL-OSC

Note: this takes several minutes of computation – only for fast computers!



Recently proposed, uses the “second-order trick”.

Alternative Paradigms: DAL-OSC

- Watching the computation...

```
scanning lambda = 861.077929... model rank = 0
scanning lambda = 724.077344... model rank = 0
scanning lambda = 608.874043... model rank = 0
scanning lambda = 512.000000... model rank = 0
scanning lambda = 430.538965... model rank = 0
scanning lambda = 362.038672... model rank = 0
scanning lambda = 304.437021... model rank = 0
scanning lambda = 256.000000... model rank = 1
scanning lambda = 215.269482... model rank = 2
scanning lambda = 181.019336... model rank = 2
scanning lambda = 152.218511... model rank = 2
scanning lambda = 128.000000... model rank = 2
scanning lambda = 107.634741... model rank = 2
scanning lambda = 90.509668... model rank = 2
scanning lambda = 76.109255... model rank = 2
scanning lambda = 64.000000... model rank = 2
scanning lambda = 53.817371... model rank = 2
scanning lambda = 45.254834... model rank = 2
scanning lambda = 38.054628... model rank = 3
scanning lambda = 32.000000... model rank = 3
scanning lambda = 26.908685... model rank = 4
scanning lambda = 22.627417... model rank = 4
scanning lambda = 19.027314... model rank = 5
scanning lambda = 16.000000... model rank = 5
scanning lambda = 13.454343...>>
```

OVR



Alternative Paradigms: DAL-OSC

- No visualization yet, but can apply to test-set data or run online

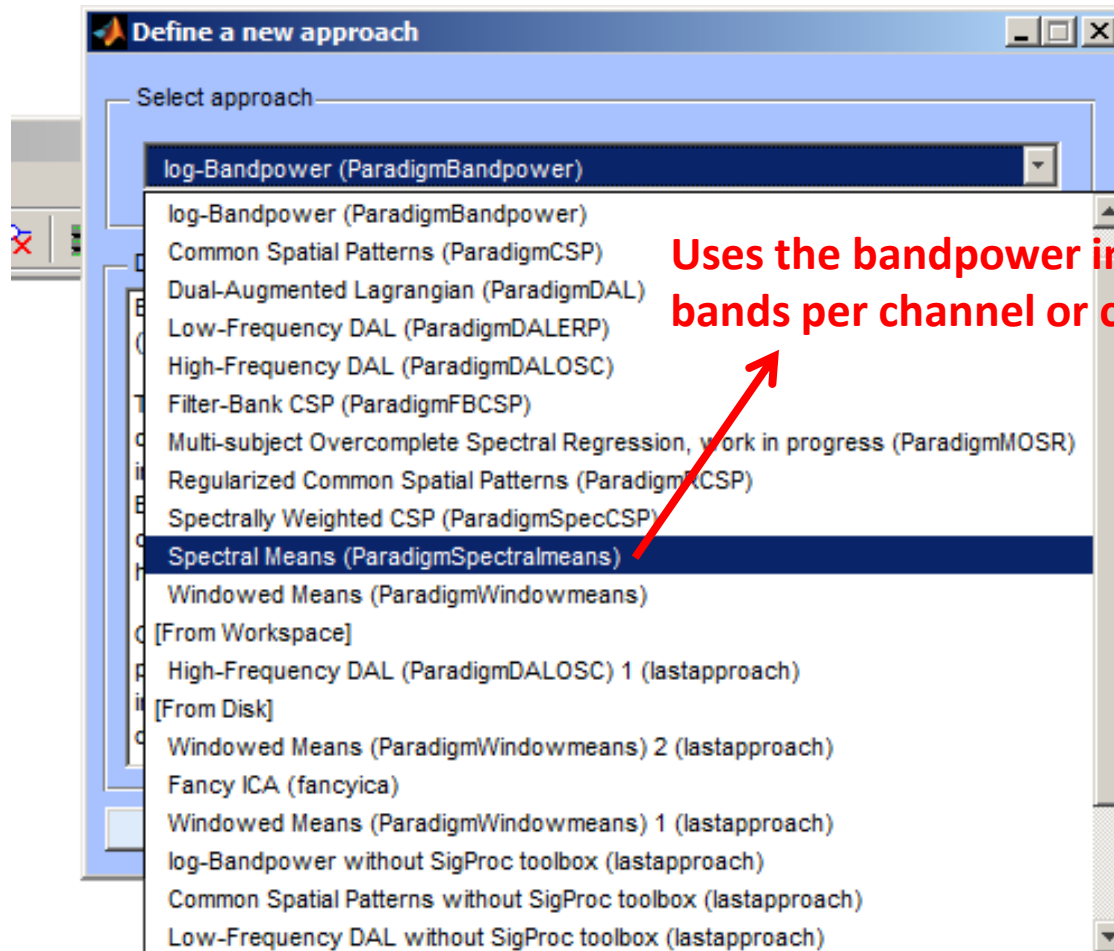


Creating an Entirely Customized Approach

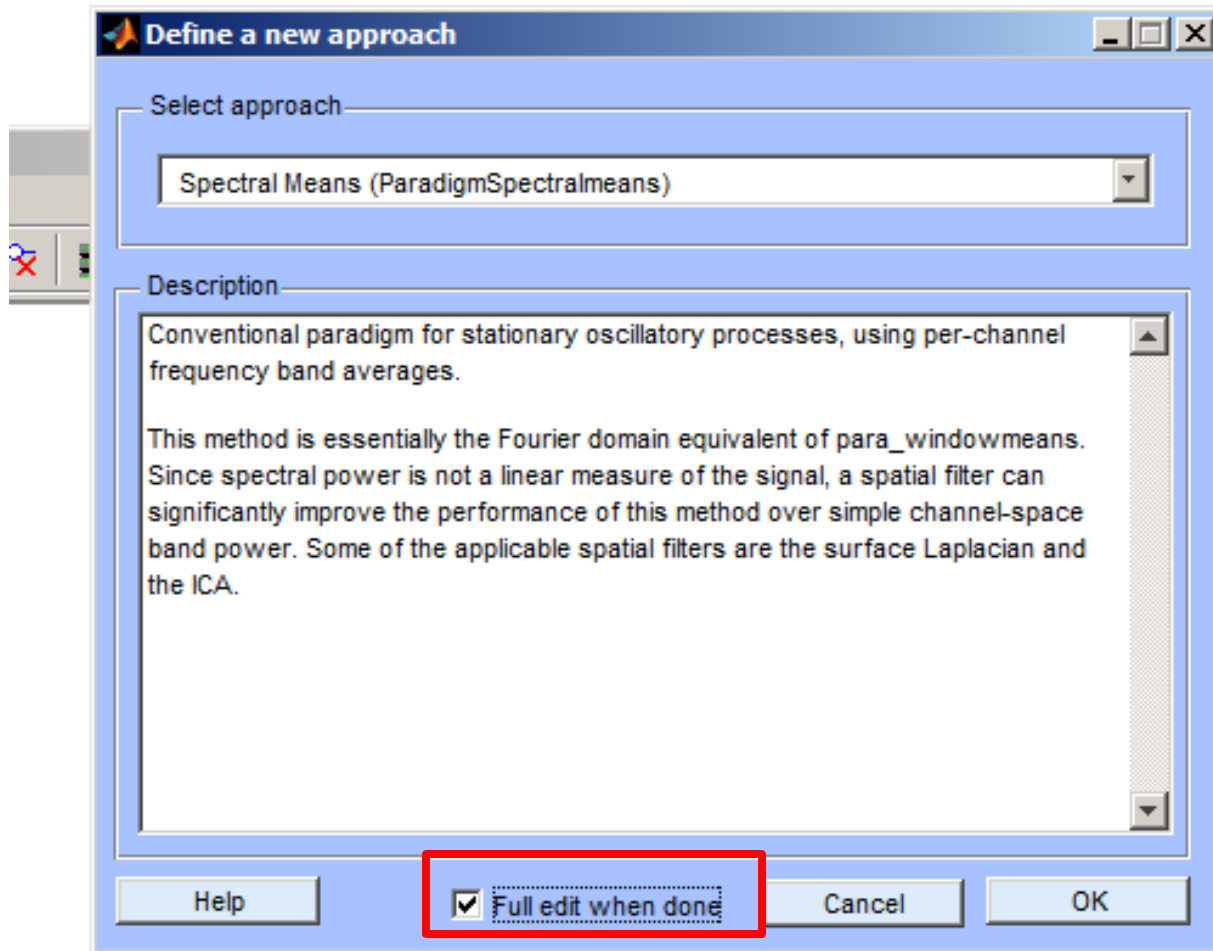
Create a New Approach



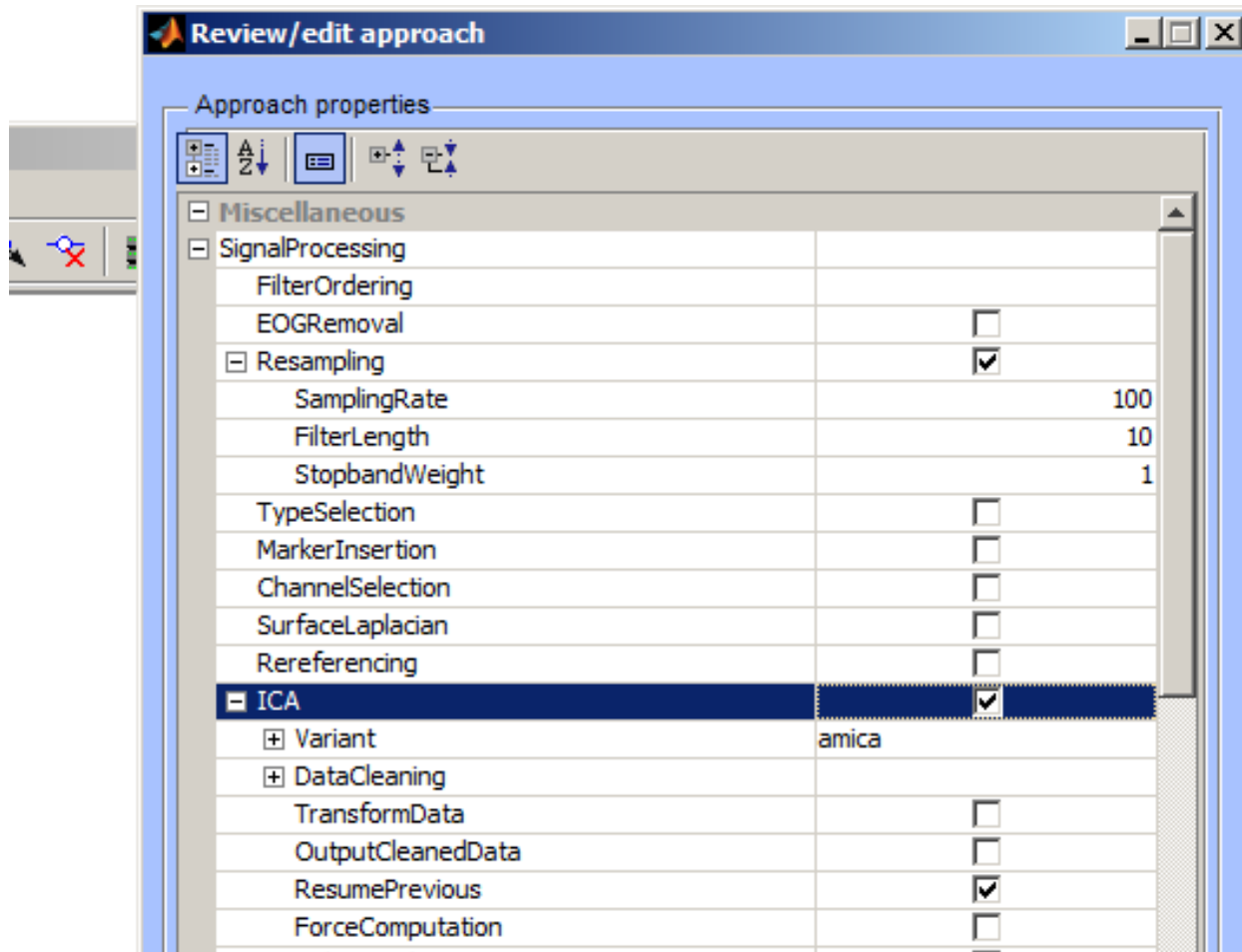
Custom ICA-based Approach



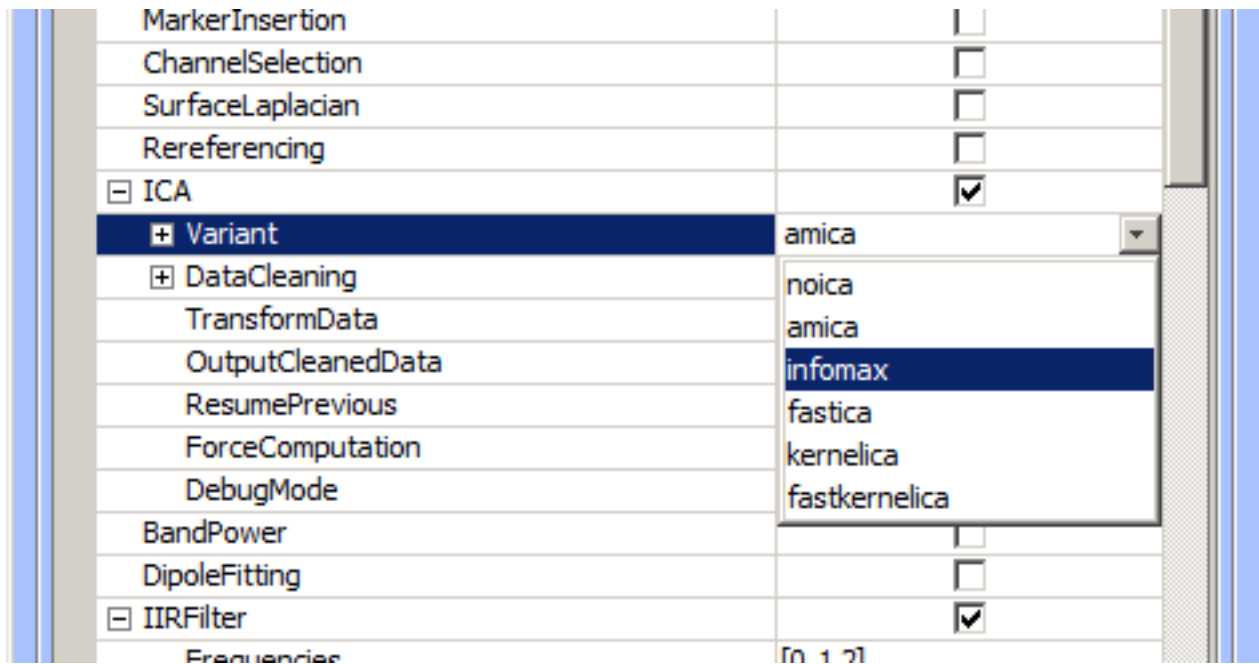
Custom ICA-based Approach



Enable ICA Filter Stage



Select the Infomax Variant



Enable Dipole Fitting

ResumePrevious		<input checked="" type="checkbox"/>	
ForceComputation		<input type="checkbox"/>	
DebugMode		<input type="checkbox"/>	
BandPower		<input type="checkbox"/>	
<input checked="" type="checkbox"/> DipoleFitting		<input checked="" type="checkbox"/>	
HeadModel	<input type="text"/>		
MRImage	<input type="text"/>		
ReferenceLocations	<input type="text"/>		
LookupLabels		<input checked="" type="checkbox"/>	
ConfusionRange			4
BrainAtlas	Talairach		
VarianceThreshold			15
UseMRIConstraints		<input type="checkbox"/>	

Enable Volume-Based Selection (Region of Interest)

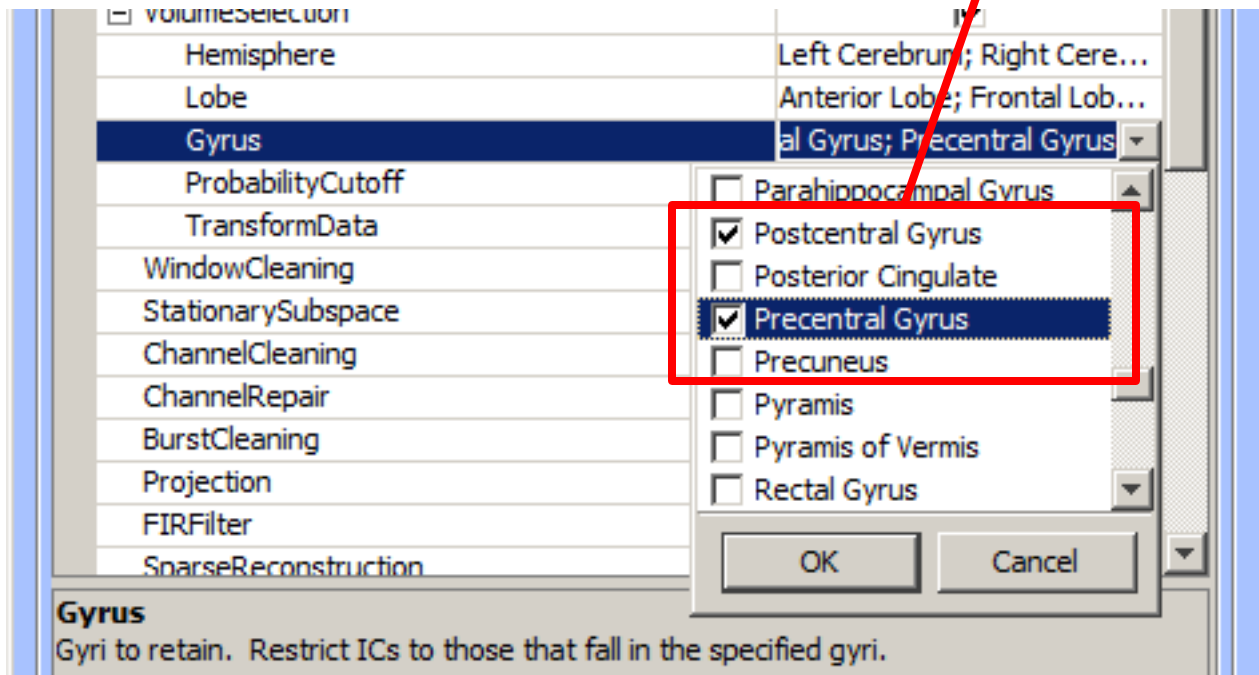
Mode	highpass
Type	butterworth
Attenuation	50
Ripple	0.5
<input checked="" type="checkbox"/> VolumeSelection	<input checked="" type="checkbox"/>
Hemisphere	Left Cerebrum; Right Cere...
Lobe	Anterior Lobe; Frontal Lob...
Gyrus	Angular Gyrus; Anterior Ci...
ProbabilityCutoff	0.7
TransformData	<input type="checkbox"/>
WindowCleaning	<input type="checkbox"/>

Clear All Selected Gyri

Attenuation		50
Ripple		0.5
<input type="checkbox"/> VolumeSelection	<input checked="" type="checkbox"/>	
Hemisphere		Left Cerebrum; Right Cere...
Lobe		Anterior Lobe; Frontal Lob...
Gyrus		<input type="button" value="v"/>
ProbabilityCutoff		0.7
TransformData	<input type="checkbox"/>	
WindowCleaning	<input type="checkbox"/>	
StationarySubspace	<input type="checkbox"/>	

Select Only Motor Cortex

Just pick Precentral Gyrus and Postcentral Gyrus



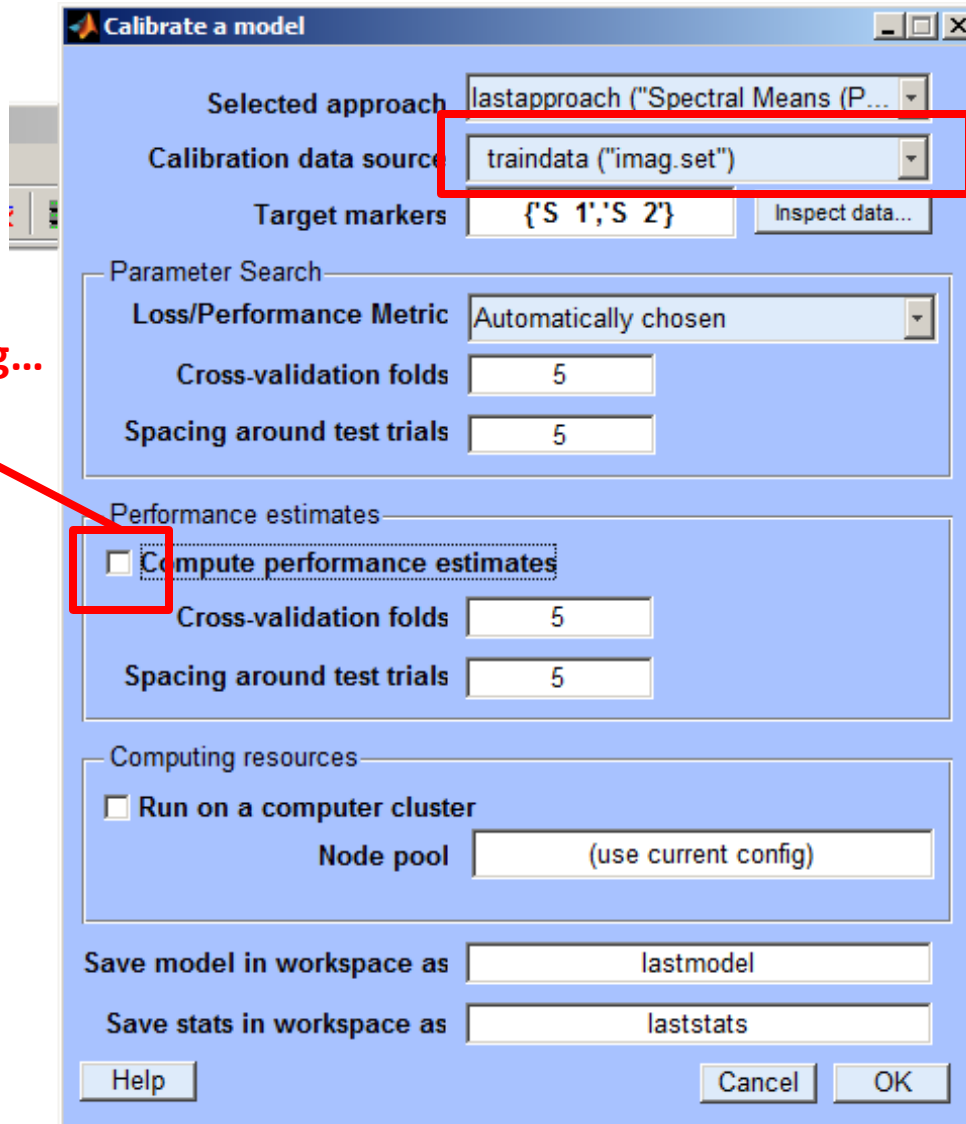
Transform the Data Into Components

Ripple	0.5
<input type="checkbox"/> VolumeSelection	<input checked="" type="checkbox"/>
Hemisphere	Left Cerebrum; Right Cere...
Lobe	Anterior Lobe; Frontal Lob...
Gyrus	Postcentral Gyrus; Precent...
ProbabilityCutoff	0.7
TransformData	<input checked="" type="checkbox"/>
WindowCleaning	<input type="checkbox"/>
StationarySubspace	<input type="checkbox"/>
ChannelCleaning	<input type="checkbox"/>

Calibrate a New Model



Calibrate a New Model



The screenshot shows a dialog box titled "Calibrate a model" with the following settings:

- Selected approach: lastapproach ("Spectral Means (P...")
- Calibration data source: **traindata ("imag.set")** (highlighted with a red box)
- Target markers: {'S 1'; 'S 2'} (with an "Inspect data..." button)
- Parameter Search:
 - Loss/Performance Metric: Automatically chosen
 - Cross-validation folds: 5
 - Spacing around test trials: 5
- Performance estimates:
 - Compute performance estimates** (highlighted with a red box)
 - Cross-validation folds: 5
 - Spacing around test trials: 5
- Computing resources:
 - Run on a computer cluster
 - Node pool: (use current config)
- Save model in workspace as: lastmodel
- Save stats in workspace as: laststats

Buttons at the bottom: Help, Cancel, OK.

**Cross-Validation
would take too long...**



Computation takes 5-10 Minutes...

```
In @(hObject,eventdata)gui_calibratemodel('pushbutt
In uiwait at 82
In gui_calibratemodel>gui_calibratemodel_OpeningFcn
In gui_mainfcn at 221
In gui_calibratemodel at 30
step 1 - lrate 0.001000, wchange 14.48427508, anglede
step 2 - lrate 0.001000, wchange 0.28528851, anglede1
step 3 - lrate 0.001000, wchange 0.16171884, anglede1
step 4 - lrate 0.000980, wchange 0.15829343, anglede1
step 5 - lrate 0.000960, wchange 0.15521940, anglede1
step 6 - lrate 0.000941, wchange 0.13290725, anglede1
step 7 - lrate 0.000922, wchange 0.12371815, anglede1
step 8 - lrate 0.000904, wchange 0.12281045, anglede1
step 9 - lrate 0.000886, wchange 0.12478248, anglede1
step 10 - lrate 0.000868, wchange 0.13012623, anglede
step 11 - lrate 0.000851, wchange 0.11619709, anglede
step 12 - lrate 0.000834, wchange 0.10145424, anglede
step 13 - lrate 0.000817, wchange 0.13254306, anglede
step 14 - lrate 0.000801, wchange 0.10610921, anglede
step 15 - lrate 0.000785, wchange 0.09375523, anglede
step 16 - lrate 0.000769, wchange 0.09268561, anglede
step 17 - lrate 0.000754, wchange 0.08530438, anglede
step 18 - lrate 0.000739, wchange 0.09399871, anglede
step 19 - lrate 0.000724, wchange 0.09112500, anglede
step 20 - lrate 0.000709, wchange 0.08083924, anglede
step 21 - lrate 0.000695, wchange 0.08624642, anglede
step 22 - lrate 0.000681, wchange 0.07391327, anglede
step 23 - lrate 0.000668, wchange 0.07154284, anglede
step 24 - lrate 0.000654, wchange 0.07210989, anglede
step 25 - lrate 0.000641, wchange 0.06489432, anglede
step 26 - lrate 0.000628, wchange 0.06580106, anglede
fx >>
```

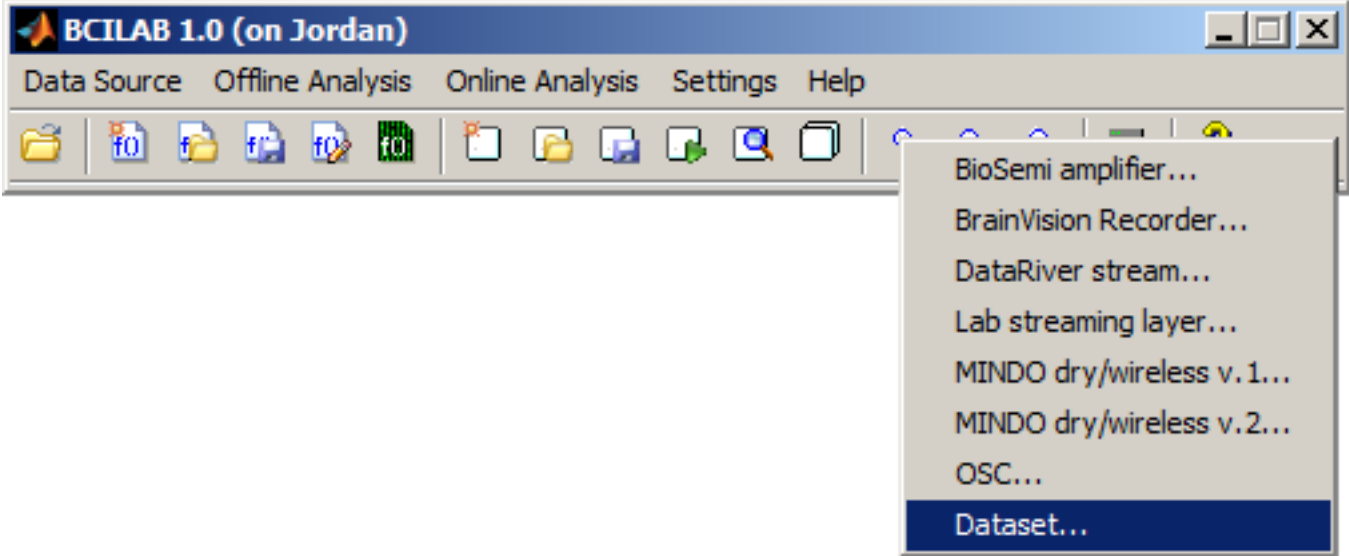
OVR

Computation takes 5-10 Minutes...

```
step 310 - lrate 0.000002, wchange 0.00000101, angledc
step 311 - lrate 0.000002, wchange 0.00000110, angledc
step 312 - lrate 0.000002, wchange 0.00000100, angledc
step 313 - lrate 0.000002, wchange 0.00000109, angledc
step 314 - lrate 0.000002, wchange 0.00000091, angledc
Sorting components in descending order of mean projec
Scaling components to RMS microvolt
Scaling components to RMS microvolt
Now fitting dipoles... (montage reference: C:\DEVEL\k
fx >>
```

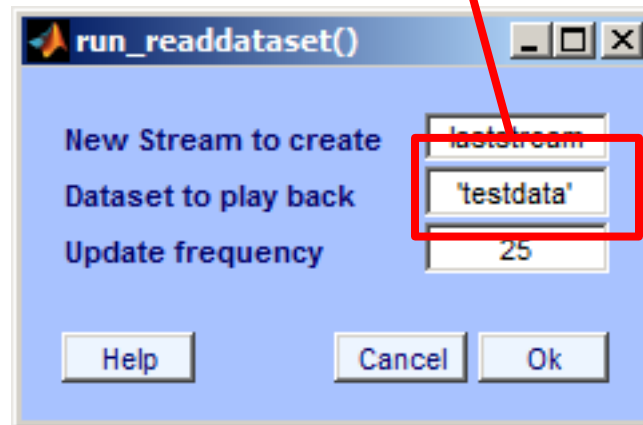
No results statistics dialog will pop up at the end (since statistics were turned off).
So just wait until the Calibration Dialog closes itself...

Running it Online...

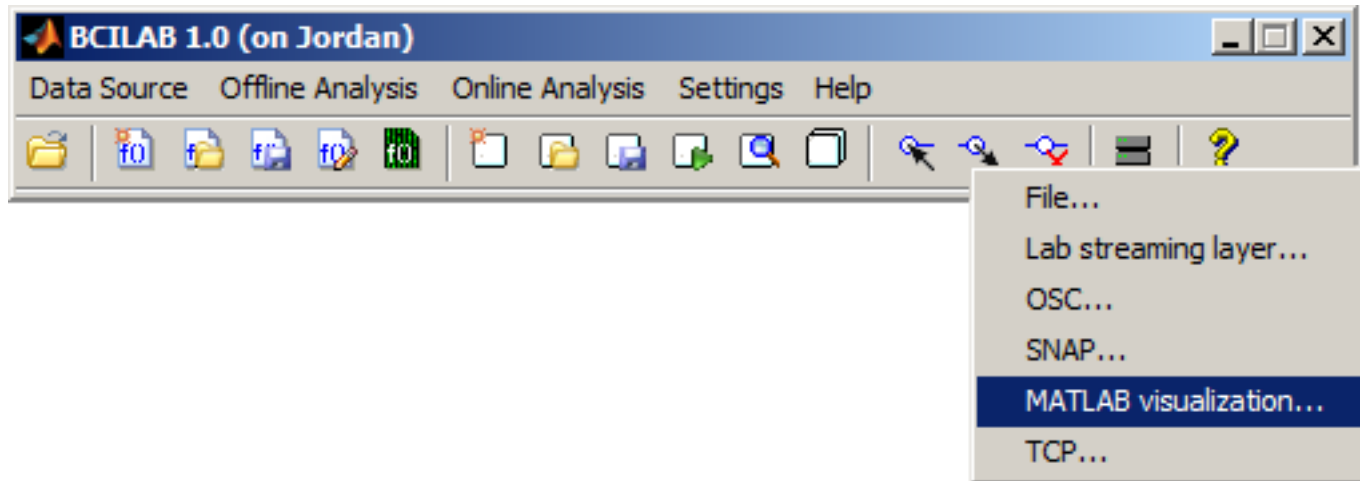


Starting Online Analysis

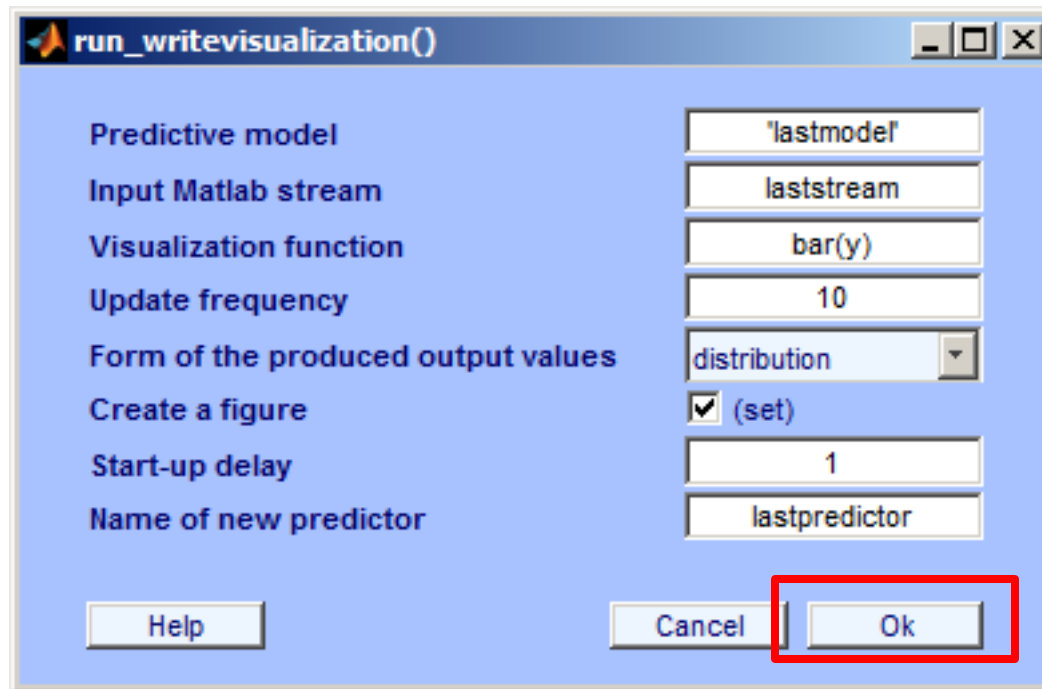
IMPORTANT: Put the name of your test data set here!



Select Output Destination



Configure/Confirm



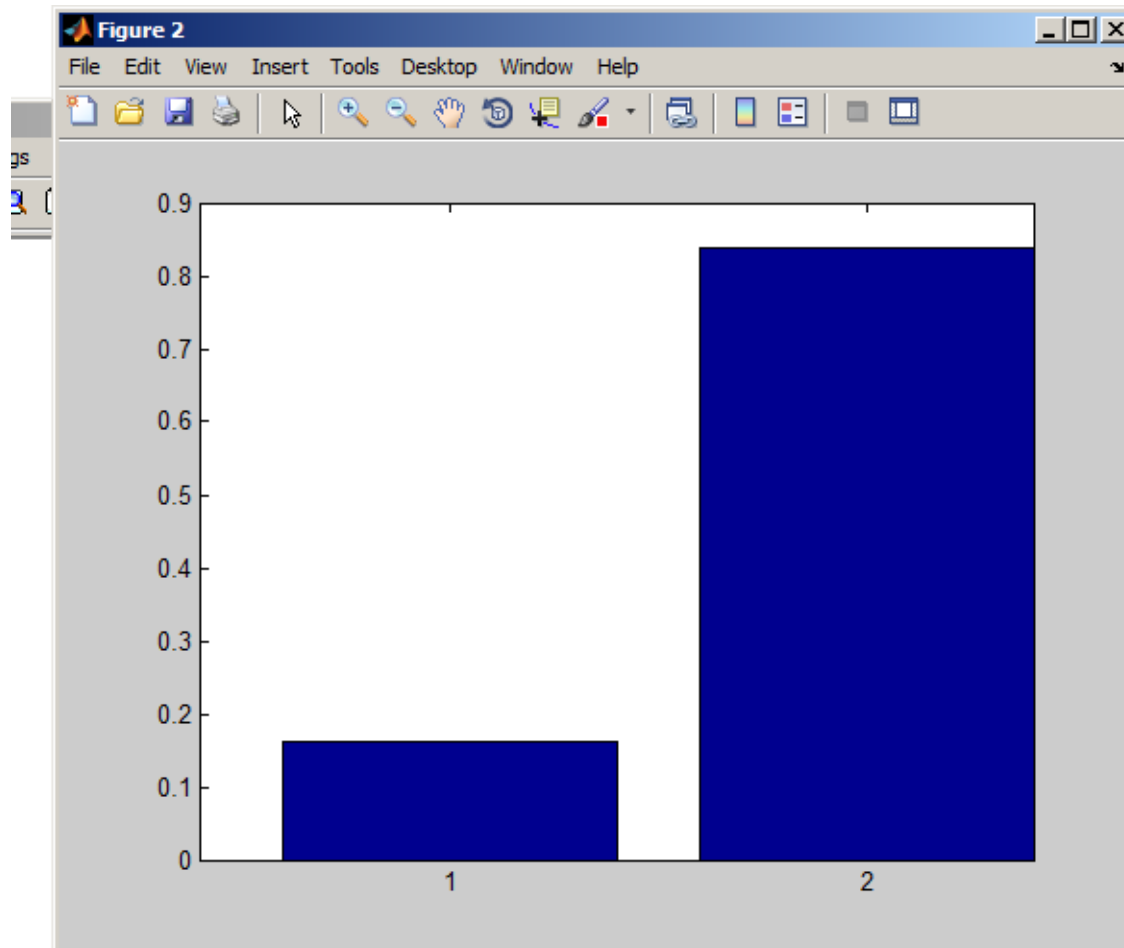
The image shows a MATLAB dialog box titled "run_writevisualization()". It contains several configuration options with corresponding input fields or checkboxes. The "Ok" button is highlighted with a red rectangle.

Option	Value
Predictive model	'lastmodel'
Input Matlab stream	laststream
Visualization function	bar(y)
Update frequency	10
Form of the produced output values	distribution
Create a figure	<input checked="" type="checkbox"/> (set)
Start-up delay	1
Name of new predictor	lastpredictor

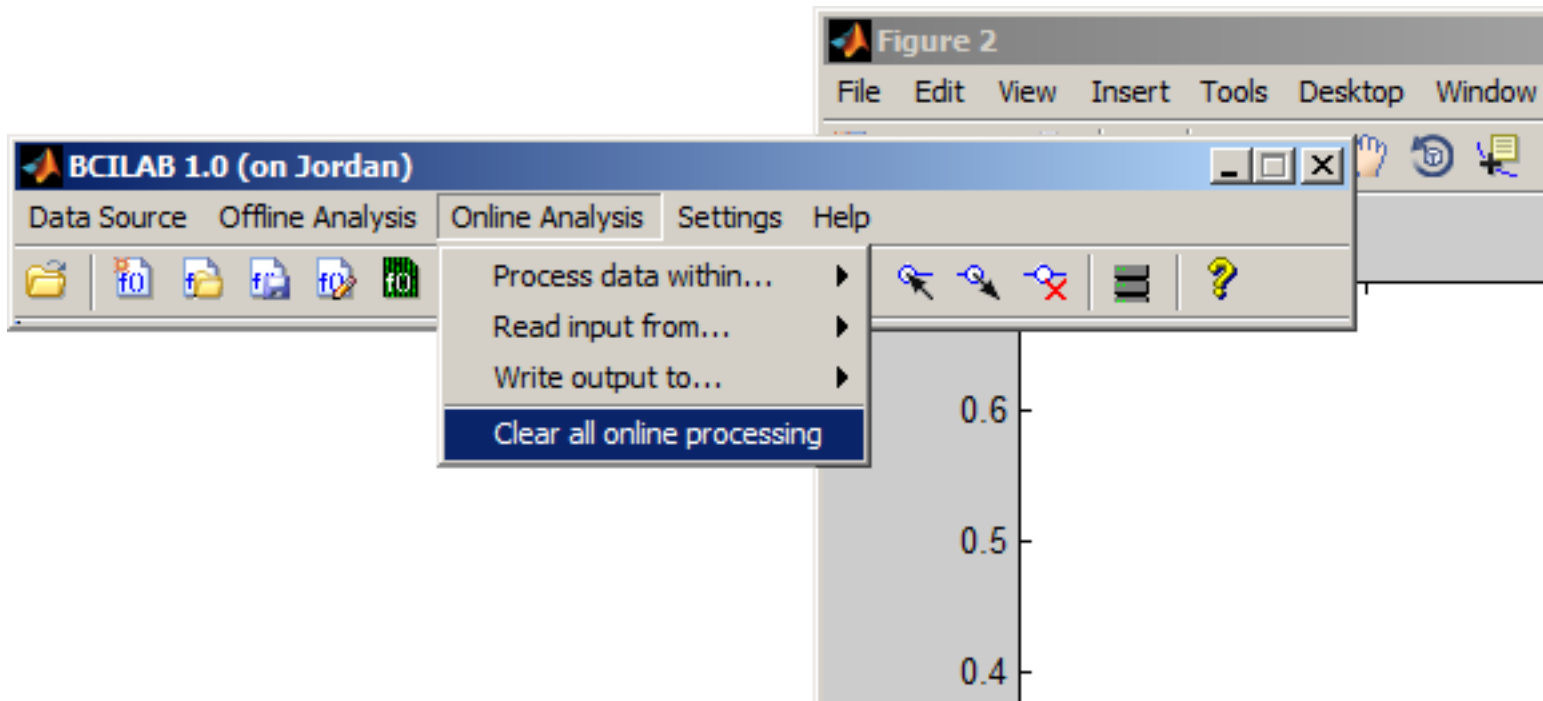
Buttons: Help, Cancel, Ok

Online Output

You can clearly see the timing of the person's imagination period on these data.



Clear Online Processing





For More Information

- Theory
- Scripting
- Creating Plugins

See Additional Materials



Even More Information

- See the `bcilab/userscripts` folder for commented sample scripts that perform some of the discussed analyses, and many more (although on other data sets)
- See the `bcilab/RELEASE_NOTES.txt` file for how to find extra documentation and help



Questions?