## EEG classification and crossvalidation using the BCILAB toolbox: practicum

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Download the latest toolbox version from: ftp://sccn.ucsd.edu/pub/bcilab/

## System requirements

- MATLAB 2008a+ (scripts will run on 7.1+ (2005), but not this version)
- 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)

## Installation

- Extract the .zip file (it contains one folder)
- Open MATLAB, type

cd /your/directory/bcilab-0.9-stable startup

## Startup

| -1 | MATL   | AB 7.6.0 | (R2008a  | )       |        |                      | IX |
|----|--------|----------|----------|---------|--------|----------------------|----|
| Fi | e Edit | Debug    | Parallel | Desktop | Window | Help                 |    |
|    |        |          |          |         |        |                      |    |
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| L  |        |          |          |         |        |                      |    |
| 4  | Start  | Ready    |          |         |        | OV                   | R  |

#### **Toolbox GUI**

| MATLAB 7.6.0 (R2008a)                                      |        |
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| BCILAB 0.9   |        |
| Data Source Offline Analysis Online Analysis Settings Help |        |
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| cache is in C:\tmp\bcilab cache (location 1)               |        |
| temp is in C:\tmp\bcilab_temp                              |        |
|  |        |
| Welcome to the BCILAB toolbox!                             |        |
|  |        |
|  |        |
| 4 Start  | OVR // |

## Getting help (if needed)

| 📣 BCILAB 0  | .9               |                 |          |                  |  |
|-------------|------------------|-----------------|----------|------------------|--|
| Data Source | Offline Analysis | Online Analysis | Settings | Help             |  |
|             |                  |                 |          | BCI Paradigms    |  |
|             |                  |                 |          | Filters          |  |
|             |                  |                 |          | Machine Learning |  |
|             |                  |                 |          | Scripting        |  |
|             |                  |                 |          | Plugin authoring |  |
|             |                  |                 |          | About            |  |
|             |                  |                 |          | Save bug report  |  |

## Getting help (if needed)

| 🔞 Help   |                                     |  |
|--|-------------------------------------|--|
| File Edit View Go Favorites Desktop W                                    | /indow Help                         | ۲  |
| Help Navigator X   | 🖛 🔿 😂 🛤                             |  |
| Search for:  | Title: M-File Help: code/filters    | •  |
| Example: "plot tools" OR plot* tools Contents Index Search Results Demos | code/filters                        | Default Topics   |
| 🖅 🤣 Release Notes 📃  |                                     |  |
|  | Contents of filters:                |  |
| 🗄 🧼 Aerospace Toolbox  | flt clean channels                  | - Remove channels with abnormal data from a continuous data set. Currently offline o   |
| 🗄 🧼 🧼 Bioinformatics Toolbox   | flt clean peaks<br>flt clean spikes | - Project local peaks out of the data (blinks, muscle artifacts, brief jumps). Non-c<br>- Set outliers in data to zero.                              |
| 🗐 🗄 🧇 Communications Toolbox 🛛 🖳   | flt clean windows                   | - Remove periods of abnormal data from continuous data.  |
| 🕀 🤣 Control System Toolbox   | flt envelope                        | - Compute the signal envelope for a continuous data set. Non-causal.   |
| 🕀 🤣 Curve Fitting Toolbox  | <u>flt fur</u><br>flt fourier       | - Filter a continuous data set by a digital FIR filter.  |
| 🕀 🤣 Database Toolbox   | flt ica                             | - Annotate the Signal with a spatial decomposition into independent components (usin   |
| 🕀 🧼 Datafeed Toolbox   | flt iir                             | - Filter a continuous data set by a digital IIR lowpass/highpass/bandpass/bandstop f   |
| Embedded MATLAB  | flt laplace                         | - Applies a simple Hjorth-style surface laplacian filter.  |
| Filter Design Toolbox  | flt project                         | - The default extensible preprocessing pipeline for most BUI paradigms.<br>- Snatially project the given data set, e.g. to apply an IC decomposition |
| Eilter Design HDL Coder  | flt reconstruct                     | - Reconstruct the given data in a new (possibly overcomplete) basis.   |
| Einancial Toolhox  | <u>flt reref</u>                    | - Re-references the data to a new (set of) channel(s) or the average of all channels   |
| Einancial Derivativas Teelber  | flt resample                        | - Changes the sampling rate of a given data set.   |
|  | flt selchans                        | - Subcract a baseline from an data set, computed over the given baseline window.   |
| Eined Daiet Tealbar  | flt spectrum                        | - Select a frequency portion of the data in an epoched data set.   |
|  | flt standardize                     | - Standardize a continuous EEG set causally.   |
| 🗉 🥪 Fuzzy Logic Toolbox  | flt window                          | - Select a time portion of the data in an epoched data set.  |
|  | •                                   |  |

## Getting help (if needed)



## Use case 1

- You just recorded pilot data for some new study
- The idea is to try to estimate a certain aspecty of cognitive state
- The question is what method works best, and what accuracies can be achieved

#### Use case 1

- Scenario: Subject is instructed to imagine a hand movement, either left hand or right hand (standard BCI case)
- Task: Estimate, from raw data, which hand movement was imagined
- Experimental data: EEG, 32 channels, 2 sessions (each ~30 min.), 2 sub-blocks per session with intermittent pause

## Experimental task

- 160 trials
- Randomized Instruction: L or R
- Displayed for 3s, followed by blank screen for 3.5s
- Sample:



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|---|-------------|------------------|-----------|--------|----------|------|--|
|   | Data Source | Offline Analysis | Online An | alysis | Settings | Help |  |
| Ï | Load recor  | rding(s)         | Ctrl+L    |        |          |      |  |
|   | Load stud   | ý                |           | •      |          |      |  |
|   | Define ma   | rker transform   | Ctrl+D    |        |          |      |  |
|   | Workspace   | e                | •         |        |          |      |  |

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Data Source Offline Analysis Online Analysis Settings Help



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Data Source Offline Analysis Online Analysis Settings Help

| 📣 Select datase | et(s) to load      |                          | ×        |
|-----------------|--------------------|--------------------------|----------|
| Look in:        | 퉬 test             |                          |          |
| 0.55            | Name 🔺             | ▼ Date modified ▼ Type   | ▼ Size   |
| <b>1</b>        | errors.fdt         | 11/19/2010 3:59 FDT File | 8,437 K  |
| Recent Places   | errors.set         | 11/19/2010 3:59 SET File | 555 K    |
|                 | errors2.fdt        | 11/19/2010 3:59 FDT File | 6,594 K  |
|                 | errors2.set        | 11/19/2010 3:59 SET File | 351 K    |
| Desktop         | imag.fdt           | 11/21/2010 10:0 FDT File | 15,744 K |
|                 | imag.set           | 11/21/2010 10:0 SET File | 129 K    |
|                 | imag2.fdt          | 11/21/2010 10:0 FDT File | 15,835 K |
| Libraries       | imag2.set          | 11/21/2010 10:0 SET File | 127 K    |
|                 |                    |                          |          |
| Network         |                    | You need the .set file   |          |
|                 | •                  |                          |          |
|                 |                    |                          |          |
|                 | File name: ima     | g.set                    | Open     |
|                 | Files of type: any | v supported file         | Cancel   |



| • | 👃 Load source data 📃 🗖 🗙                           |
|---|--|
|   | Optionally load data in reduced form               |
|   | Channel index subset                               |
|   | Sample range subset                                |
|   | Time range subset                                  |
|   | Optionally add fields, if missing (raw files only) |
|   | Sampling rate                                      |
|   | Save data in workspace as lastdata                 |
|   |  |
|   | Add markers Cancel OK                              |

 An approach addresses both parts of the BCI problem: Mapping from observed signals to predictions, and learning the unknown parameters

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|-------------|--------------------------------|------------|--------|-----|
| Data Source | Offline Analysis Online Analys | is Setting | s Help |     |
|             | New approach                   | Ctrl+N     |        |     |
|             | Modify approach                | Ctrl+M     | J      |     |
|             | Review/edit approach           | Ctrl+R     |        |     |
|             | Save approach                  | Ctrl+S     |        |     |
|             | Train new model                | Ctrl+T     |        |     |
|             | Apply model to data            | Ctrl+A     |        |     |
|             | Visualize model                | Ctrl+V     |        |     |
|             | Investigate results            | Ctrl+I     |        |     |
|             | Transform data by model        | Ctrl+P     |        |     |
|             |                                |            |        |     |

 You never start completely from scratch, but on the basis of what is known to work



• Some of these work best for oscillatory processes, others for ERP-like features, etc.



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|-------------|------------------|-----------------|----------|------|--|
| Data Source | Offline Analysis | Online Analysis | Settings | Help |  |

| 📣 Define a new approach   |  |  |  |  |  |  |  |  |  |
|---|--|--|--|--|--|--|--|--|--|
| Select approach   | Also see help t <mark>e</mark> x   |  |  |  |  |  |  |  |  |
| Common Spatial Pattern (para_csp)   |  |  |  |  |  |  |  |  |  |
| Description   |  |  |  |  |  |  |  |  |  |
| Standard paradigm for oscillatory processes via the Common<br>(CSP) algorithm. Result = para_csp(Input-Data, Operation-Mod  | Spatial Patterns   |  |  |  |  |  |  |  |  |
| The CSP paradigm is based on the design of the Berlin Brain-O<br>(BBCI) [1], more comprehensively described in [2],which is ma<br>(sensori-)motor imagery. The features exploited by this paradi<br>are Event-Related Synchronizationand Desynchronization [3]<br>(sensori-)motor cortex, but the paradigm is not restricted to th<br>CSP was originallyintroduced in [5] and first applied to EEG in | Computer Interface<br>ainly controlled by<br>igm in its original form<br>localized in the<br>ese applications.<br>[6]. |  |  |  |  |  |  |  |  |
| Due to its simplicity, speed and relative robustness, CSP is the bread-and-butter paradigm for oscillatory processes, and if nothing else, can be usedto get a quick estimate of whether the data contains information of interest or not. Like para_bandpower, CSP uses log-variance features over a singlenon-adapted   |  |  |  |  |  |  |  |  |  |
| Help Cancel Refi  | ine OK   |  |  |  |  |  |  |  |  |

| 📣 BCILAB (  | ).9              |                 |          |      |  |
|-------------|------------------|-----------------|----------|------|--|
| Data Source | Offline Analysis | Online Analysis | Settings | Help |  |

| 📣 Def  | e a new approach  | _ 🗆 >    | × |                    |
|--------|---|----------|---|--------------------|
| _ Sele | approach  |          |   |                    |
|        | nmon Spatial Pattern (para_csp)   | •        |   |                    |
| Des    | iption  |          |   |                    |
| Star   | ard paradium for oscillatory processes via the Common Spatial Patterns          |          |   |                    |
| (CSI   | algorithm. Result = para_csp(Input-Data, Operation-Mode, Options)               |          |   |                    |
| The    | SP paradigm is based on the design of the Berlin Brain-Computer Interface       |          |   |                    |
| (BB    | [1], more comprehensively described in [2], which is mainly controlled by       |          |   |                    |
| (ser   | ori-)motor imagery. The features exploited by this paradigm in its original for | m 📘      |   |                    |
| are    | ent-Related Synchronizationand Desynchronization [3] localized in the           |          |   |                    |
| (ser   | ori-)motor cortex, but the paradigm is not restricted to these applications.    |          |   | Adapt the templete |
| CSP    | vas originallyintroduced in [5] and first applied to EEG in [6].                |          |   | Adapt the template |
|        |   |          |   | to your experiment |
| Due    | its simplicity, speed and relative robustness, CSP is the bread-and-butter      |          |   | to your experiment |
| para   | gm for oscillatory processes, and if nothing else, can be usedto get a quick    |          |   |                    |
| esti   | te of whether the data contains information of interest or not. Like            | _        |   |                    |
| para   | bandpower, CSP uses log-variance features over a singlenon-adapted              | <b>_</b> |   |                    |
|        |   |          |   |                    |
|        | elp Cancel Refine Of  | <        |   |                    |
|        |   |          |   |                    |

• Key properties can be configured in this dialog

|                  | A BCILAB 0.9   |           |
|------------------|--|-----------|
|                  | Data Source Offline Analysis Online Analysis Settings Help |           |
|                  |  |           |
|                  | Configure approach   |           |
|                  |  |           |
|                  | New sampling rate of the data                              | 100       |
|                  |  |           |
|                  | Epoch time window relative to the events                   | [0.5 3.5] |
|                  | Event/marker types for which epochs shall be extracted     |           |
|                  | Frequency-domain selection                                 | [7 30]    |
|                  |  |           |
|                  | Number of CSP patterns (times two)                         | 3         |
|                  |  |           |
| Trial enoch prop | Artias usually need to be adapted                          | lda 🔽     |
|                  |  | Cancel Ok |
|                  |  |           |





Fill in the 2 event types for this dataset; Stimulus 1 & 2, called 'S 1' and 'S 2' (Brain Products names)



Note the two spaces between the S and the number!

#### 📣 BCILAB 0.9

Data Source Offline Analysis Online Analysis Settings Help

| 📣 Configure approach                                   | <u> </u>  |
|--|-----------|
|  |           |
| New sampling rate of the data                          | 100       |
| Epoch time window relative to the events               | [0.5 3.5] |
| Event/marker types for which epochs shall be extracted | (3132)    |
| Frequency-domain selection                             | [7 30]    |
| Number of CSP patterns (times two)                     | 3         |
| Machine learning function                              | lda 🗾     |
| Help   | Cancel Ok |

(Takes a while after clicking OK)

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## Review/edit approach

- The next panel allows to edit all properties of the approach
- Filter stages can be added and configured
- Feature extraction can be configured
- Machine learning components can be selected and configured
- For now, nothing to do

| ≝ 2↓ <b>□</b> ₽\$ ₽¥                  |                          |
|---------------------------------------|--------------------------|
| Signal Processing                     |                          |
| <ul> <li>SignalProcessing</li> </ul>  |                          |
| FilterOrdering                        |                          |
| Resampling                            |                          |
| SamplingRate                          | 100                      |
| ChannelSelection                      |                          |
| Rereferencing                         |                          |
| ICA                                   |                          |
| SurfaceLaplacian                      |                          |
| FIRFilter                             |                          |
| Projection                            |                          |
| IIRFilter                             |                          |
| Standardization                       |                          |
| SparseReconstruction                  |                          |
| <ul> <li>EpochExtraction</li> </ul>   |                          |
| TimeWindow                            | [0.5 3.5]                |
| EventTypes                            | S 1[]                    |
| BaselineRemoval                       |                          |
| WindowSelection                       |                          |
| SpectralTransform                     |                          |
| <ul> <li>SpectralSelection</li> </ul> |                          |
| FrequencySpecification                | [7 30]                   |
| Feature Extraction                    |                          |
| FeatureExtraction                     |                          |
| PatternPairs                          | 3                        |
| PluginFunctions                       |                          |
| FeatureAdaptor                        | para_csp::@csp_train     |
| FeatureExtractor                      | para_csp::@csp_predict   |
| FeatureAdaptorNeedsVoting             |                          |
| FeatureVisualizer                     | para_csp::@csp_visualize |
| Machine Learning                      |                          |
| - Machinel earning                    |                          |
| Name)                                 |                          |

#### Save approach

|                                 | AB 0.9  | _ <b>_</b> X        |   |
|---------------------------------|---|---------------------|---|
| Data Sou                        | rce Offline Analysis Online Analysis Settings H                           | Help                |   |
|                                 | Save approach   |                     |   |
|                                 | We just created this during the workshop, rela<br>well-understood setting | - (Your method of   | description)  |
|                                 |   | (Yo<br>stro<br>to r | our executive summary<br>ongly recommended<br>name this properly) |
|                                 | Name Imagined Moveme  | ents via CSP        |   |
|                                 | Save approach in Workspace as   | lastapproach        |   |
| (You can save or for later reus | n disk Save on dis<br>e)  | k ОК                |   |

#### Save approach



## Learn a predictive model

• Put the method to the test...

| 📣 BCILAB 0  | .9               |                |           |        |  |
|-------------|------------------|----------------|-----------|--------|--|
| Data Source | Offline Analysis | Online Analysi | s Setting | s Help |  |
|             | New approach     | <b></b>        | Ctrl+N    |        |  |
|             | Modify approa    | ich            | Ctrl+M    |        |  |
|             | Review/edit a    | pproach        | Ctrl+R    |        |  |
| Г           | Save approact    | h              | Ctrl+S    | 7      |  |
|             | Train new mod    | lel            | Ctrl+T    |        |  |
| L           | Apply model to   | o data         | Ctrl+A    | _      |  |
|             | Visualize mode   | ł              | Ctrl+V    |        |  |
|             | Investigate re   | sults          | Ctrl+I    |        |  |
|             | Transform dat    | a by model     | Ctrl+P    |        |  |

#### Learn a predictive model

|                          | 📣 Calibrate a model                         |                             |              |                     |
|--------------------------|---|-----------------------------|--------------|---------------------|
|                          | Selected approach                           | lastapproach ("Imagined Mov | vements vi 💌 |                     |
|                          | Calibration data source                     | lastdata ("imag.set")       | <b>*</b>     |                     |
| BCIL<br>Data So          | Parameter Search<br>Loss/Performance Metric | Automatically chosen        |              | L                   |
|                          | Cross-validation folds                      | 5                           |              |                     |
|                          | Spacing around test trials                  | 5                           |              |                     |
|                          | Performance estimates                       | (D                          | efines the   | performance metric) |
|                          | Compute performance est                     | imates                      |              |                     |
|                          | Cross-validation folds                      | 10 -                        | (smaller     | number: faster,     |
| (If this is checked, you | Spacing around test trials                  | 5                           | but lower    | quality estimates)  |
| get performance estimat  | ies)  |                             |              |                     |
|                          | Computing resources                         |                             |              |                     |
|                          | Run on a computer cluster                   | T                           |              |                     |
|                          | Node pool                                   | (use current cor            | nfig)        |                     |
|                          | Save model in workspace as                  | lastmodel                   |              |                     |
|                          | Save stats in workspace as                  | laststats                   |              |                     |
|                          | Help  | Cance                       | el OK        |                     |

#### Wait for results

| MATLAB 7.6.0 (R2008a)  |      |
|--|------|
| File Edit Debug Parallel Desktop Window Help   |      |
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|  |      |
|  |      |
|  |      |
|  |      |
|  |      |
| creating epochs  |      |
| pop_epoch():160 epochs selected  |      |
| Epoching   |      |
| <pre>pop_epoch():160 epochs generated</pre>  |      |
| <pre>pop_epoch(): checking epochs for data discontinuity</pre>                               |      |
| loading C:\DEVEL\Matlab\bcilab-0.9-stable\userdata\test\imag.set                             |      |
| <pre>pop_loadset(): loading file C:\DEVEL\Matlab\bcilab-0.9-stable\userdata\test\imag.</pre> | se:  |
| Reading float file 'C:\DEVEL\Matlab\bcilab-0.9-stable\userdata\test\imag.fdt'                |      |
| The loaded EEGLAB set is lacking an online expression; assuming it contains unfil            | te:  |
| If it contains filtered data, however, BCI models derived from it will likely not            | b    |
| creating epochs  |      |
| pop_epoch():160 epochs selected  |      |
| $Red  lext  Here  ? \to ISSUeS!$   |      |
| pop_epoch():160 epochs generated   |      |
| pop_epoch( <del>):</del> checking epochs for data discontinuity                              |      |
|  | الكر |
|  |      |
| <mark>∢ Start</mark>   | OVR  |

#### **Review results**



## **Review results**

- 11% error rate is quite good for imagined movements; mean across studies & methods is probably closer to 25%
- chance level is here 50% (keep that in mind when evaluating)
- You may get multiple outputs (e.g., false positives, true positives, which show up in the table), depending on loss measure

## Visualize model properties

| A BCILAB 0  | .9                             |            |          |
|-------------|--------------------------------|------------|----------|
| Data Source | Offline Analysis Online Analys | is Setting | gs Help  |
| ļ.          | New approach                   | Ctrl+N     |          |
|             | Modify approach                | Ctrl+M     |          |
|             | Review/edit approach           | Ctrl+R     |          |
|             | Save approach                  | Ctrl+S     |          |
|             | Train new model                | Ctrl+T     |          |
| г           | Apply model to data            | Ctrl+A     | <b>F</b> |
|             | Visualize model                | Ctrl+V     |          |
| L           | Investigate results            | Ctrl+I     |          |
|             | Transform data by model        | Ctrl+P     |          |

## Visualize model properties





| 📣 BCILAB 0  | .9               |                 |          |      | _ 🗆 X |
|-------------|------------------|-----------------|----------|------|-------|
| Data Source | Offline Analysis | Online Analysis | Settings | Help |       |

| 📣 Select datas | et(s) to load  |                    |      |                 |          | ×        |
|----------------|----------------|--------------------|------|-----------------|----------|----------|
| Look in:       | 🔒 test         |                    | •    | - 🔁 📥           | ·        |          |
| <u>A</u> =     | Name 🔺         |                    | - Da | te modified 🛛 🚽 | Туре     | ✓ Size   |
| <b>S</b>       | errors.fdt     |                    | 11   | /19/2010 3:59   | FDT File | 8,437 K  |
| Recent Places  | errors.set     |                    | 11   | /19/2010 3:59   | SET File | 555 K    |
|                | errors2.fdt    |                    | 11   | /19/2010 3:59   | FDT File | 6,594 K  |
|                | errors2.set    |                    | 11   | /19/2010 3:59   | SET File | 351 K    |
| Desktop        | imag.fdt       |                    | 11   | /21/2010 10:0   | FDT File | 15,744 K |
| <u></u>        | imag.set       |                    | 11   | /21/2010 10:0   | SET File | 129 K    |
|                | imag2.fdt      |                    | 11   | /21/2010 10:0   | FDT File | 15,835 K |
| Libraries      | imag2.set      |                    | 11   | /21/2010 10:0   | SET File | 127 K    |
|                |                |                    |      |                 |          |          |
|                |                |                    |      |                 |          |          |
| Computer       |                |                    |      |                 |          |          |
|                |                |                    |      |                 |          |          |
|                |                |                    |      |                 |          |          |
| Network        |                |                    |      |                 |          |          |
|                |                |                    |      |                 |          |          |
|                |                |                    |      |                 |          |          |
|                | File name:     | imag2.set          |      |                 | -        | Open     |
|                | Files of type: | any supported file | :    |                 | •        | Cancel   |

| Data Source Offline Analysis Online Analysis Settings Help |  |
|--|--|
| New approach Ctrl+N  |  |
| Modify approach Ctrl+M                                     |  |
| Review/edit approach Ctrl+R                                |  |
| Save approach Ctrl+S                                       |  |
| Train new model Gtrl+T                                     |  |
| Apply model to data Ctrl+A                                 |  |
| Visualize model etrl+V                                     |  |
| Investigate results Ctrl+I                                 |  |
| Transform data by model Ctrl+P                             |  |

| 📣 BCILAB 0.9 | 9                |                 |          |      | <u> </u> |
|--------------|------------------|-----------------|----------|------|----------|
| Data Source  | Offline Analysis | Online Analysis | Settings | Help |          |

| Apply predictive model to dat  | <u> </u>               |          |
|--------------------------------|------------------------|----------|
| Source data set for prediction | lastdata ("imag2.set") | -        |
| Predictive model to use        | lastmodel              | <b>-</b> |
| Loss/performance metric        | Automatically chosen   | <b>*</b> |
| Save results in workspace as   | lastresults            |          |
| Help                           | Cancel O               | ĸ        |

#### **Review results**

| 📣 Review Results     |                                  |        |
|----------------------|----------------------------------|--------|
| – Data Summary – – – |                                  |        |
|                      | Error rate : 0.09 +/- 0.00 (N=1) |        |
| _ Data Details       |                                  |        |
|                      | Error rate                       |        |
| 1                    |                                  | 0.0938 |
|                      |                                  |        |
| Help                 | Explore Export Save              | ОК     |

# OR: Apply model online

- (if you have a subject sitting next to you)
- Today: use a simulated data source (playing back the 2<sup>nd</sup> session)

| A BCILAB 0.9 |                  |                 |             |      |                              |
|--------------|------------------|-----------------|-------------|------|------------------------------|
| Data Source  | Offline Analysis | Online Analysis | Settings    | Help |                              |
| ,            |                  | Process data    | within      | ►    |                              |
|              |                  | Receive input   | from        | →    | DataRiver                    |
|              |                  | Provide output  | ut to       | →    | BrainVision Recorder         |
|              |                  | Clear all onlin | e processir | ng 🗖 | ТСР                          |
|              |                  |                 |             |      | Simulated (dataset playback) |
|              |                  |                 |             | -    |                              |

## Apply model online

 This adds a data feed process in the background



| 📣 gui_receivedataset        |                  | <u> </u> |
|-----------------------------|------------------|----------|
| Dataset to replay           | lastdata ("imag2 | 2.s 🔻    |
| Update frequency            | 25               |          |
| Save stream in workspace as | laststream       |          |
| Cancel                      | Cancel           | ОК       |

## Apply model online

| A BCILAB 0.9 |                  |                 |             |      | _ 🗆 ×                |
|--------------|------------------|-----------------|-------------|------|----------------------|
| Data Source  | Offline Analysis | Online Analysis | Settings    | Help |                      |
|              |                  | Process data    | within      | •    |                      |
|              |                  | Receive input   | t from      |      |                      |
|              |                  | Provide output  | ut to       | Þ    | MATLAB visualization |
|              |                  | Clear all onlin | e processii | ng   | DataRiver            |
|              |                  |                 |             |      | TCP                  |

## Apply model online

 This adds a real-time inference process in the background



#### **Real-time output**



## Real-time output

- If you have more classes, you get more bars
- You can also remap to other parameters (e.g. expected value)
- Note: the simple graphics command always renders into the current window

#### **Real-time output**



## More ambitious approach?

| 🥠 BO                   | ILAB 0   | .9   |   |                    |      |        |          | 1    |
|------------------------|--|--|---|--------------------|------|--------|----------|------|
| Data                   | Source   | Offline Analysis   | Online Analysis   | Settings           | Help |        |          |      |
|                        | Define a<br>Select ap                            | a new approach<br>oproach<br>rally Weighted CSF  | (para_speccsp)  |                    |      |        |          |      |
| - C<br>4<br>8          | Comm<br>Dual-/<br>High-F<br>Low-f<br>Data-f      | andpower (para_b<br>ion Spatial Pattern<br>Augmented Lagrar<br>Frequency DAL (p<br>Frequency DAL (p<br>Flow Framework (<br>endent Modulators | andpower)<br>(para_csp)<br>ige (para_dal)<br>ara_dal_hifreq)<br>ara_dal_lofreq)<br>para_dataflow)<br>(para_modulators | 5)                 |      | (State | of the a | art) |
|                        | Multib<br>Multiple<br>Spect                      | and-CSP (para_mu<br>e Source Model GL<br>rally Weighted CSI  | (para_modulatore<br>iltiband_csp)<br>.M (para_multimod<br>2 (para_speccsp)  | lel)               |      |        |          |      |
| T<br>a<br>ti<br>Q<br>s | (From V<br>Imagin<br>(From D<br>XXX (<br>Error I | Workspace]<br>Norkspace]<br>Disk]<br>Jastapproach)<br>Responses (lastap  | _Windowmeans)<br>CSP (lastapproad   | ch)                |      |        |          |      |
|                        | Bandp<br>BCI50<br>Errors<br>Canor                | oower/nolap (para<br>100 (para_bandpov<br>s HKL - smallmem (<br>nical Motor Imag (la   | a_bandpower) 3 (<br>ver) 1 (lastapproa<br>lastapproach)<br>istapproach)   | lastapproa<br>ach) | ch)  |        |          |      |

## More ambitious approach?

| BCILAB 0  | .9  |                 |          |        | <u> </u> |  |  |  |
|---|---|-----------------|----------|--------|----------|--|--|--|
| ata Source  | Offline Analysis  | Online Analysis | Settings | Help   |          |  |  |  |
| ▲ Define a<br>— Select ap   | new approach  |                 |          |        |          |  |  |  |
| Spectr  | ally Weighted CSP   | (para_speccsp)  |          |        |          |  |  |  |
| — Descriptio  | n   |                 |          |        |          |  |  |  |
| Advance<br>algorithm<br>The Spec<br>Berlin Bra<br>BCI,but th<br>range of  | Advanced paradigm for oscillatory processes via the Spectrally weighted CSP<br>algorithm. Result = para_speccsp(Input-Data, Operation-Mode, Options)<br>The Spec-CSP paradigm [1] is a more advanced variant of CSP, developed for the<br>Berlin Brain-Computer Interface (BBCI); the primary focus was motor imagery<br>BCI,but the algorithm was designed from the outset to be applicable for a wider<br>range of applications. The implementation closely follows the TR [2]. |                 |          |        |          |  |  |  |
| The paradigm is applicable to the majority of oscillatory processes, and is the most advanced spatio-spectrally adaptive method that is currentlyprovided in the toolbox. Whenever the exact frequency and location of some (conjectured) oscillatory process is not known exactly, Spec-CSP can be used, and typically gives better results than CSP with an appropriately unrestricted (e.g., broad-band) spectral filter. Several other methods exist to adaptthe spectrum to a process of |   |                 |          |        |          |  |  |  |
| Help  |   | Cance           |          | Refine | ОК       |  |  |  |

#### More ambitious approach \_ 🗆 🗵

📣 BCILAB 0.9

Data Source Offline Analysis Online Analysis Settings Help

| 🙏 Configure approach                                   | ×                   |
|--|---------------------|
| New sampling rate of the data                          | 100                 |
| Epoch time window relative to the events               | [0.5 3.5]           |
| Event/marker types for which epochs shall be extracted | {'S 1' 'S 2'}       |
| Frequency-domain selection                             | [5 45]              |
| Number of CSP patterns (times two) Enter the same      | as before 3         |
| Prior frequency weighting function                     | '@(f) f>=7 & f<=30' |
| Machine learning function                              | lda 🔽               |
| Help   | Cancel Ok           |

## Train model, review results

 Note that the model calibration takes longer for Spec-CSP.

|     | Review Results     |                            |          |                    |
|-----|--------------------|----------------------------|----------|--------------------|
| В   | — Data Summary———— |                            |          |                    |
| ata | Error rate : 0     | .05 +/- 0.05 (N=10)        |          |                    |
|     |                    |                            |          |                    |
|     |                    |                            |          | rally Weighted C 💌 |
|     | 5 percent!         |                            | <b>_</b> |                    |
|     | – Data Details     |                            |          | <b></b>            |
|     |                    | Error rate                 |          |                    |
|     | 1                  |                            | 0        |                    |
|     | 2                  |                            | 0.0625   |                    |
|     | 3                  |                            | 0        |                    |
|     | 5                  |                            | 0.0625   |                    |
|     | 6                  |                            | 0.0625   |                    |
|     | 7                  |                            | 0.1250   |                    |
|     | 8                  |                            | 0.1250   |                    |
|     | 9                  |                            | 0.0625   |                    |
|     | 10                 |                            | 0        |                    |
|     |                    |                            |          |                    |
|     |                    |                            |          |                    |
| J   | Help               | xplore Export Save         | ок       | ent config)        |
|     |                    | Save model in workspace as | lastr    | model              |
|     |                    | Save stats in workspace as | last     | stats              |
|     |                    | Help                       |          | Cancel OK          |

## Next steps

• Run online, apply to dataset, edit parameters, try to improve results, ...

#### Thanks!

Questions?