Matching pursuit decomposition in Svarog

Mp5 software for **m**atching **p**ursuit (MP) decomposition of (biomedical multivariate) time series was developed at the University of Warsaw, Faculty of Physics. The algorithm is based upon the seminal paper by Mallat and Zhang (Mallat1993) with modifications described partly by Durka et al. (Durka2001) and Kuś et al. (Kuś2013). Mp5 is designed for batch processing input signals and writing results to disk files called—after (Mallat1993)—*decomposition books*. These books (*.b) contain parameters of the functions selected for representation of the analyzed signal.

Svarog offers an interactive interface for MP decomposition, allowing for:

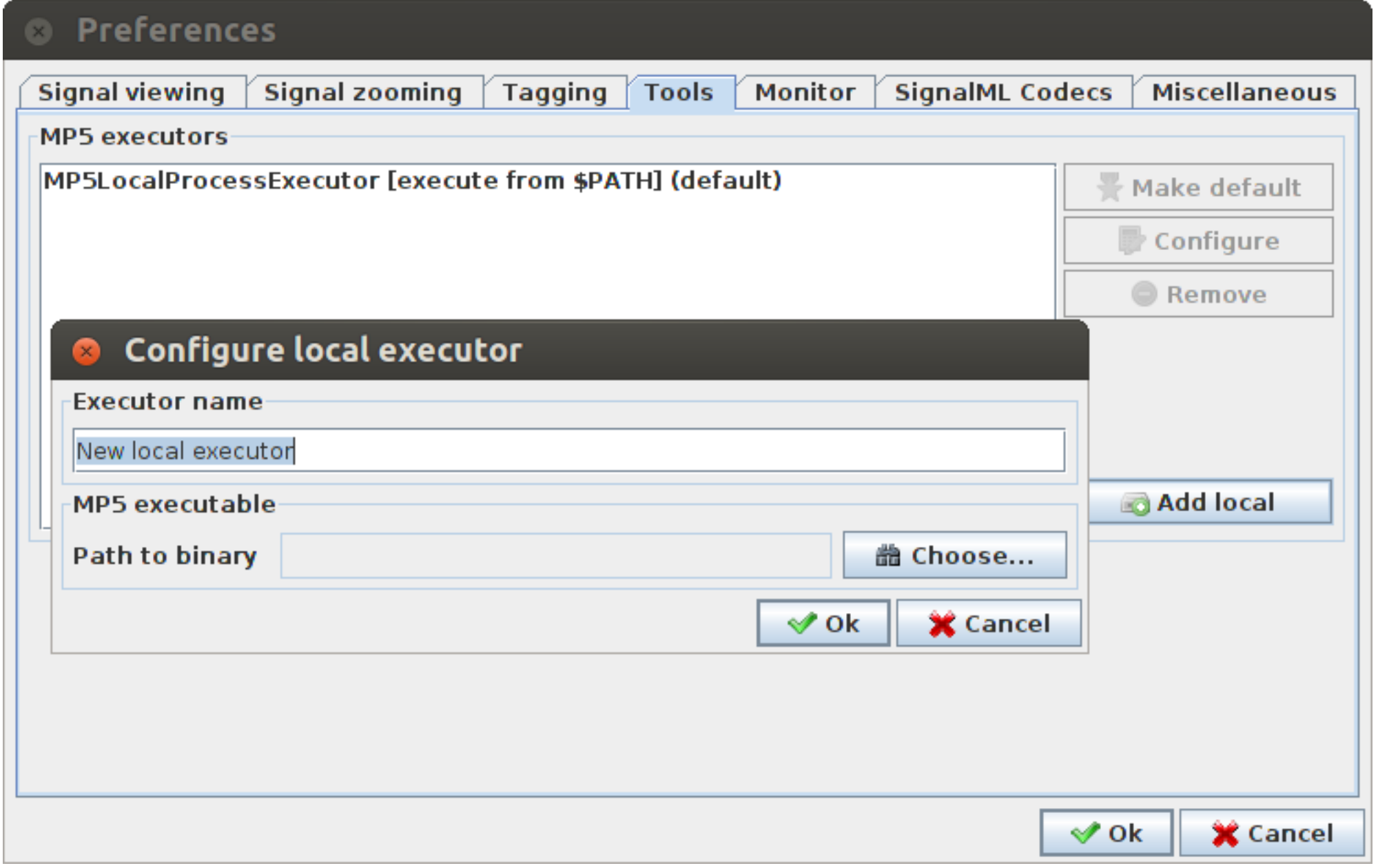
1. simple selection of the part of the signal for MP decomposition,
2. running mp5 decomposition according to selected parameters
3. visualization of the results in terms of interactive time-frequency maps of signal's energy density.

Some of the topics presented below are covered in a screencast avaialble at http://braintech.pl/svarog/screencast.html. *Caveat*: default settings are optimized for speed rather than quality of the decomposition. This may be sufficient for the first try, but serious use requires some understanding of the procedure.

Contents:

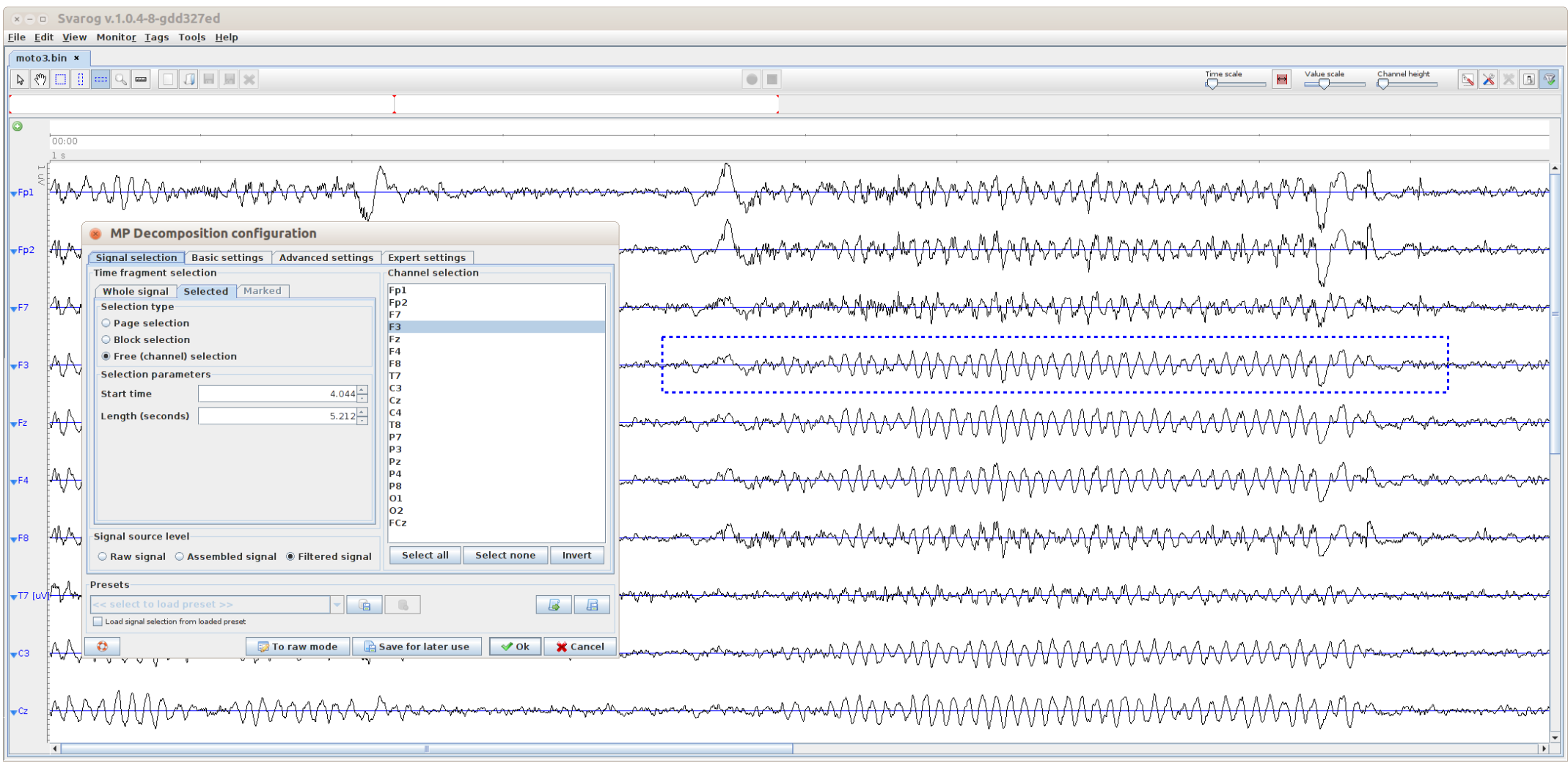
Configuration

By default, Svarog looks for the file containing the mp5 binary in PATH. If you installed the system from .deb packages (see http://deb.braintech.pl) it should be already preconfigured. If that does not work, you should provide the correct path in the "Preferences" dialog (`Edit/Preferences`), tab `Tools`:

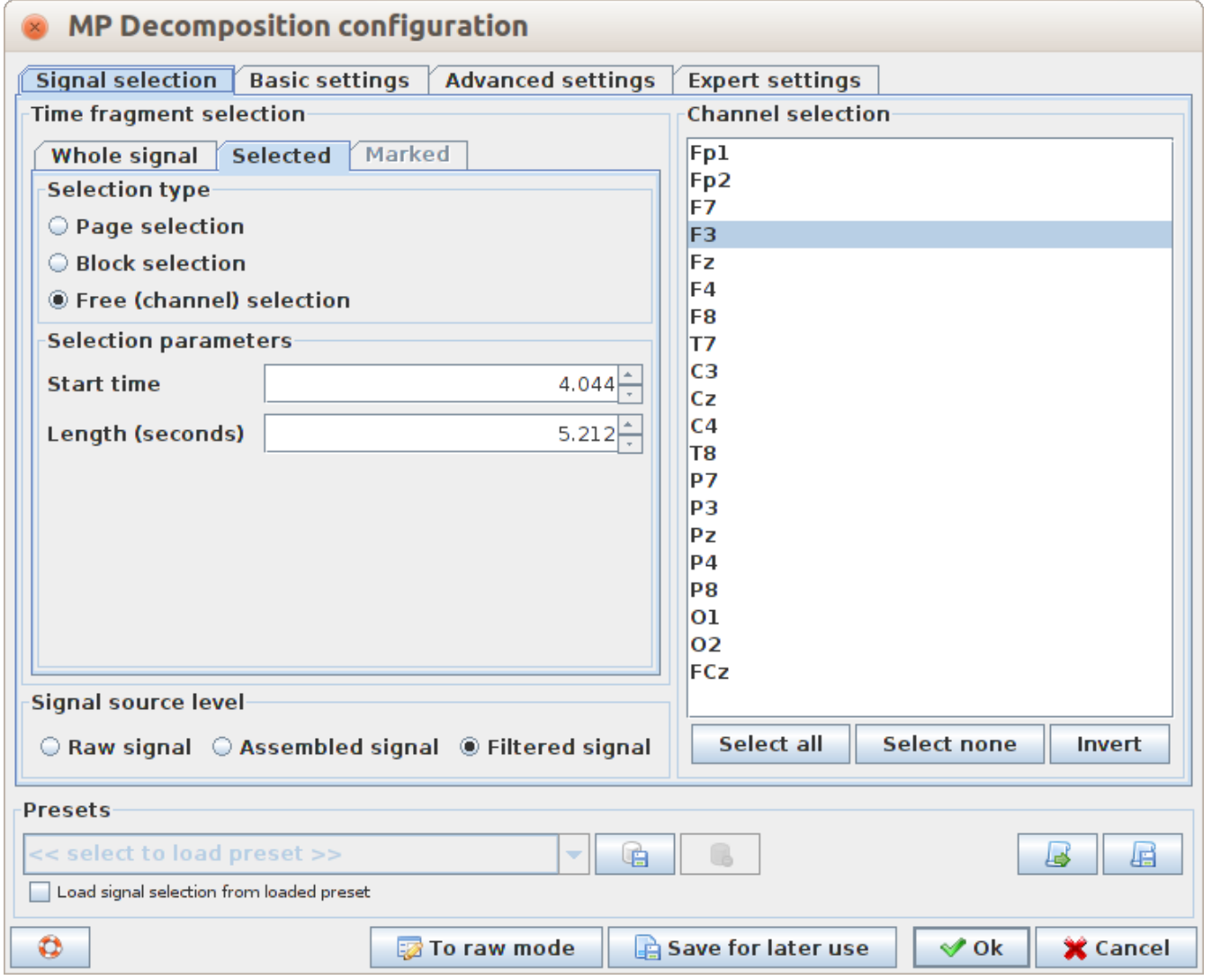


If you downloaded mp5 together with Svarog in one archive, executables for different operating systems can be located under `mp5` in subfolders `linux`, `windows`, and `mac`.

Selecting the signal epoch(s) for decomposition

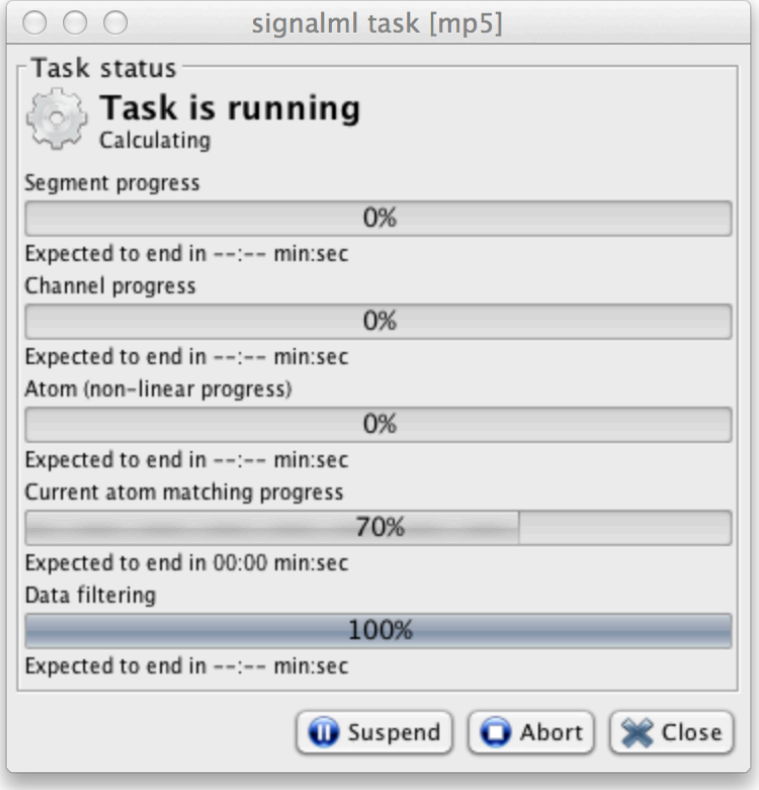


Using icons in the toolbar, mark in Svarog the part of the signal that you want to decompose and select `Tools/MP decomposition` from the menu



`Signal selection` tab allows you to change selection or e.g. set up decomposition of the whole signal page by page. Settings in other tabs correspond to the parameters of decomposition that will be written to the configuration file. Their meaning is explained in the next chapter.

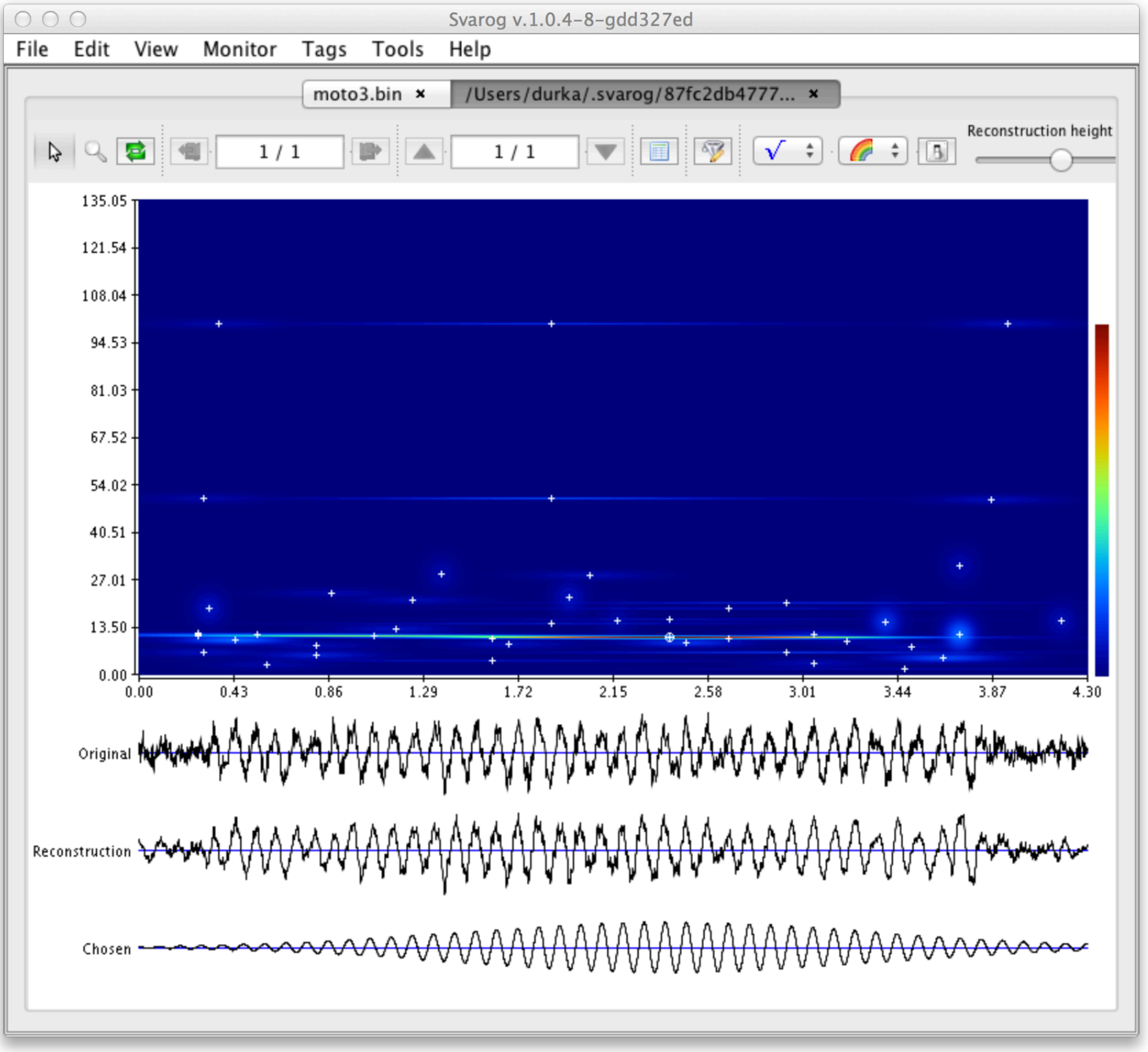
After pressing `Ok` we get the window showing the progress of the task



Execution time depends strongly on selected settings and length of the signal being decomposed. It can be quite long for multichannel decompositions. If a single channel was selected (as in the picture above) with default settings, and the sampling frequency was not extremely high (that is, there are no more than few thousand points in the selected epoch) decomposition should not take more than a minute on average PC.

You can move this window aside and continue working with Svarog in the meantime.

After the task completes, `Get result` button will appear at the bottom of the window. Pressing it opens a dialog where you can choose `Open in the viewer` and/or `Save to disk`. The former option opens a new tab in Svarog and diplays the timefrequency map of the signal's energy density, computed from the decomposition:



Below the map the program displays the original signal, its reconstruction from all the atoms from the (just computed) decomposition, and the reconstruction computed from the selected atoms. You can select atoms by clicking the crosses in their centers. After clicking the magnifying glass in the top left, you can zoom selected area of the map.

Detailed settings and structure of the mp5 config file

Parameters of the decomposition, entered in subsequent tabs of the `MP Decomposition configuration` window, are written to a configuration file, which is in turn passed by Svarog to the mp5 binary. Mp5 config file consists of lines, which can be divided into three groups:

- Comments.
- Obligatory settings.
- Additional settings.

Each line, which is not a comment, is treated as a setting for the program. Each setting consists of its name and assigned value. If any of the obligatory settings is missing, mp5 will return error. If the user does not set the additional settings, mp5 sets the default values. Lines with commands and comments can occur within the config file in any order.

Comments in the config file

The user can add his own comments to the configuration file by placing a # sign in front of the line. There are two type of comments:

- lines starting with # are treated as comments and will exist only in the config file, but will be neglected by mp5, for example:
  `# Moly set the numberOfChannels to 5`
- lines starting with ## are also treated as comments but they will be copied into the output file (decomposition book), e.g.:
  `## channels selected above motor cortex decomposed with very small dictionary`

Although in general the results are written to the binary file, the comments are saved as text and can be viewed by standard text editor.

Input settings — obligatory settings

Signal (time series) for mp5 decomposition must be stored in a binary file as a 4-byte float numbers.

In case of multivariate (multichannel) recordings the values should be multiplexed, that is:
`s1ch1, s1ch2, …, s1chK, s2ch1, s2ch2, …, s2chK`
where `sXchY` is the X-th sample at channel Y, K is the number of channels

nameOfDataFile

Full path to the input file.

nameOfOutputDirectory

The path to the output directory, where the file with results should be saved. The default is the same as location of the input file.

writingMode

- `CREATE` — create a new file for writing (saving results of decomposition).
- `APPEND` — append the results to an already existing file or create a new file if there is no file to append to

Names of the output files are generated automatically; the name of the file with the data is appended with: `_smp.b` in case of a single channel mp algorithm (SMP), or `_mmp.b` in case of one of the multichannel mp algorithms (MMP1, MMP2, MMP3). The decomposition book includes also the original analyzed epoch.

numberOfChannels

Number of channels in the input file. Positive integer, range: 1 - 65535.

selectedChannels

In either of the algorithms—monochannel or multivariate—one does not have to use all the channels present in the data file. For example, using SMP we may decompose only few channels, and for MMP we may need to neglect non-EEG channels. This option lists the channels which we want to analyze. That is, to analyze all the channels from a 20-channel datafile config must contain:

```
numberOfChannels 20
selectedChannels 1-20
```

Channels are numbered starting from 1. Selection is written either as comma-separated list 1,2,3 or as ranges 1-3. Both can be combined in one line, e.g.:

```
selectedChannels 1, 3, 5, 7-11, 19
```

type: positive integer,
range: 1 - 65535

numberOfSamplesInEpoch

When decomposing susequent epochs of a long signal, this option determines the length of the epoch measured as number

of samples. Argument's value: positive integer. Range: 1 - 2147483647

selectedEpochs

Chooses which epochs (of the length defined by `numberOfSamplesInEpoch`) will be analysed. First epoch in the file is number 1. Written as comma-separated list with ranges as in `selectedChannels`.

typeOfDictionary

- `OCTAVE_FIXED` — functions distributed in a way to optimally cover the ranges of parameters reasonable for a given signal in a way that the distance between any two neighboring functions does not exceed the threshold given by a user (Kuś et al. 2013)
- `OCTAVE_STOCH` — distribution as in `OCTAVE_FIXED`, plus a stochastic element to remove the possible bias (Durka et al. 2001). The dictionary with Gabors is created according to the first parameter energyError command, but in the next step a fraction of randomly selected functions are removed from dictionary. The number of atoms left is controlled by the second value passed to the `EnergyError` parameter.

energyError

This parameter regulates the density of the dictionary. That is, for the same energyError, and different sizes of the analyzed epoch, effective sizes of the dictionary will be larger for longer epochs, but accuracy of the decomposition should be equivalent (except for the border effects). Changing this parameter in the "Basic settings" tab automatically computes the amount of RAM necessary to store the dictionary that will be prepared for decomposition.

The energyError parameter has two values:

- the first one is a threshold for a distance between two nearest atom in dictionary, this value should be in range (0 1)
- the second is value percentage of atoms left after stochastic dictionary reduction; this value is omitted by mp5, when typeOfDictionary is set to OCTAVE_FIXED

For example, the configuration of commands:

```
typeOfDictionary OCTAVE_FIXED
energyError 0.3 30.0
```

results in generation of dictionary in which the maximal distance between nearest Gabors does not exceed value 0.3.

With another configuration:

```
typeOfDictionary OCTAVE_STOCH
energyError 0.3 40.0
```

the distribution of the atoms in dictionary is performed in such way that the maximal distance between nearest Gabors does not exceed value 0.3. After generation of the dictionary, the number of Gabors will be reduced to 40% of their initial amount (determined by the threshold 0.3) by random selection.

type of the first parameter (energyError): float number
range of the first parameter: (0.0 1.0)

type of the second parameter (stochastic reduction): float number
range of the second parameter: (0.0 100.0>

randomSeed

If provided, this value will be used for the seed of the random generator used in creations a stochastic dictionary. Otherwise, the seed will be generated from the computer's clock.

For example:

```
randomSeed 23432
```

The mp5 will used this number as a seed for random generator. The *seed* is the same for any stochastic reinitialization of

the dictionary (see the next command: reinitDictionary).

Second example:

```
randomSeed auto
```

The mp5 will used the time form the computer's clock as a seed for therandom generator. The seed is different for each reinitialization of the dictionary.

Type: string "auto" or positive integer number
range in case of integer: 0 - 2147483647

reinitDictionary

When using the default stochastic (randomized) dictionary, the randomization is called reinitialization of the dictionary. It can be performed:

- `REINIT_AT_ALL` — at each of the analyzed epochs, works only for `SMP`.
- `REINIT_IN_CHANNEL_DOMAIN` — exactly the same dictionary will be used to decompose all epochs within a channel. Before the analysis of another channel, parameters will be reinitialized, i.e. randomized again. This setting can be applied only in the case of separate decomposition of channels using `SMP` option.
- `REINIT_IN_OFFSET_DOMAIN` — dictionary will be reinitialized before decomposing each subsequent epoch.
- `NO_REINIT_AT_ALL` — the same dictionary for decompositions in all channels and all epochs.

maximalNumberOfIterations

Maximum number of iterations equals the largest allowed numbers of waveforms fitted to the analyzed epoch. This command together with the next `energyPercent` control the number of waveforms used for the approximation of the analyzed epoch, which equals the number of algorithms iteration performed before the stopping criterion is fulfilled. The iterations stop either after reaching this number, or after explaining the percentage of signal's energy set in the `energyPercent` parameter, whatever comes first. That is, if we want to force the decomposition to contain exactly `maximalNumberOfIterations` iterations, we should set `energyPercent` to 100. It does not influence the accuracy of the parameters of the waveforms fitted to the signal, in the sense that the 5 waveforms fitted to the signal in 5 iterations run will be just as good as the first 5 fitted in the 100 iterations run.

Time of computations is proportional to the number of algoritms iterations (except for the first, longer iteration), and obviously with more iterations we explain larger fraction of signal's energy; OTOH, too many iterations usually make no sense. Unfortunately, the meaning of "too many" depends on the properties of the signal and the aim of decomposition. For further considerations consult e.g. (Durka2007a) and (Durka2007b).

Type: positive integer
range: <1 65535>

energyPercent

Algorithm stops after explaining `energyPercent` % of the energy of the analyzed epoch, that is, when the sum of energies of functions fitted to the signals reaches `energyPercent`/100 of the signal's energy, unless `maximalNumberOfIterations` was reached first.

Type: positive float
range: (0 100.0)

MP

There are significant differences between the 'classical' MP computed for the univariate time series, and the variety of possible versions of the multichannel MP. Choice of the appropriate flavor of multivariate algorithm is controlled by the MP variable, which can be assigned one of the following values. For equations and formulae see (Durka 2007a) and (Kuś et al. 2013)

- `SMP` — monochannel MP (separate decomposition of single channels)
- `MMP1` — multichannel algorithm maximizing in each iteration the sum of energies explained in all channels
- `MMP2` — suboptimal, faster version of `MMP1` maximizing in each iteration the sum of products of the waveform with

all the channels. In theory may degrade in the case when opposite polarities are present across channels
- `MMP3` — as `MMP1`, but allowing different phases in each channel.

scaleToPeriodFactor

All Gabor functions, for which the number of periods of the sine, given by this parameter, exceeds the half-width of the Gaussian, will be removed from the dictionary. It regulates removal of non-physical cases. For example, 1 Hz oscillation which lasts 100 milliseconds mathematically represents a well defined waveform. However, the very notion of frequency is dubious in such case. Also, the actul peak-to-peak amplitude of such function may significantly differ from the doubled amplitude of the Gaussian envelope. See (Durka2004)

Type: positive float
range: (0.0 3.402823466 E + 38>

samplingFrequency

Floating-point positive number. Decimal dot is obligatory, that is `"128.0"` and not `"128"`. This parameter has no influence on the decomposition -- value is copied into the decomposition book file and can be later used for scaling the display of results.

pointsPerMicrovolt

Conversion rate from the actual values stored in the datafile to physical units, for EEG microvolts [μV], for MEG femtotesla [fT]. This parameter has no influence on the decomposition -- value is copied into the decomposition book file and can be later used for scaling the display of results.

Decimal dot is obligatory. For example,

```
pointsPerMicrovolt 20.0
```

in EEG file says that the stored vaules must be multiplied by 20 to get microvolts.

Type: positive float
range: (0.0 3.402823466 E + 38>

Input parameters — additional settings

normType

The experimental feature of mp5 program, do not change it. The default value is set to `L2`.

diracInDictionary

Generate dictionary including Dirac Function. The possible argument of command is `YES` or `NO` string.

gaussInDictionary

Generate dictionary including Gauss Function. The possible argument of command is `YES` or `NO` string.

sinCosInDictionary

Generate dictionary including Harmonic function. The possible argument of command is `YES` or `NO` string.

gaborInDictionary

Generate dictionary including Gabor functions. The possible argument of command is `YES` or `NO` string.

progressBar

Plot text bar representing the progress of calculation. The possible argument of command is `YES` or `NO` string.

Example configuration file

```
# OBLIGATORY PARAMETERS
nameOfDataFile                  test.dat
nameOfOutputDirectory           ./
writingMode                     CREATE
samplingFrequency               128.0
numberOfChannels                24
selectedChannels                1-19
numberOfSamplesInEpoch          179
selectedEpochs                  1-31
typeOfDictionary                OCTAVE_FIXED
energyError                     0.3 50.0
randomSeed                      auto
reinitDictionary                NO_REINIT_AT_ALL
maximalNumberOfIterations       100
energyPercent                   95.0
MP                              SMP
scaleToPeriodFactor             1.0
pointsPerMicrovolt              1.0

# ADDITIONAL PARAMETERS
normType                        L2
diracInDictionary               YES
gaussInDictionary               YES
sinCosInDictionary              YES
gaborInDictionary               YES
progressBar                     ON
```

References

(Mallat1993) Stéphane Mallat and Zhifeng Zhang
Matching pursuit with time-frequency dictionaries. *IEEE Transactions on Signal Processing* 1993, 41:3397-3415

(Durka2007a) Piotr J. Durka
Matching Pursuit and Unification in EEG analysis, Artech House 2007, ISBN 978-1-58053-304-1

(Durka2007b) Piotr J. Durka
Matching Pursuit, Scholarpedia, p. 20910, 2007.

(Kuś et al.2013) Rafał Kuś, Piotr T. Różański and Piotr J. Durka
Multivariate matching pursuit in optimal Gabor dictionaries: mathematical foundations and software for EEG/MEG (submitted to *Biomedical Engineering Online*)

(Durka et al. 2001) Piotr J. Durka, D. Ircha and K. J. Blinowska
Stochastic time-frequency dictionaries for Matching Pursuit, *IEEE Transactions on Signal Processing*, vol. 49, No. 3, pp. 507-510, March 2001.

(Durka2004) Adaptive time-frequency parametrization of epileptic EEG spikes P.J. Durka, Physical Review E, vol. 69, 051914 (2004)