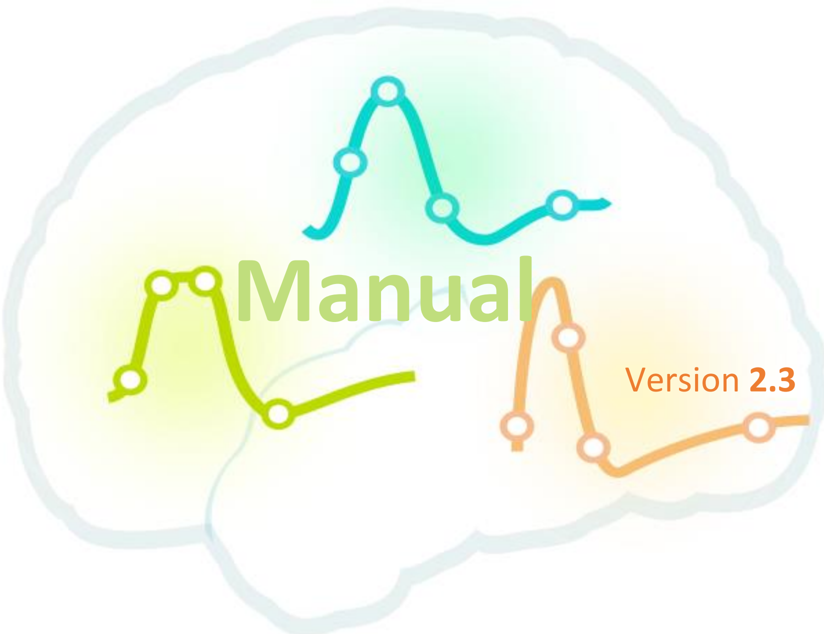
rsHRF: A Toolbox for Resting State HRF Deconvolution and Connectivity Analysis (MATLAB)



https://www.nitrc.org/projects/rshrf

Guo-Rong WU
e-mail: guorongwu@swu.edu.cn

Sofie Van Den Bossche
e-mail: Sofie.VanDenBossche@ugent.be

Daniele Marinazzo
e-mail: daniele.marinazzo@ugent.be

October 10, 2020

Contents

Overview

rsHRF is a Matlab/Python-based cross-platform software for the computation, display, and analysis of resting-state hemodynamic response function (HRF).

rsHRF is aimed to retrieve the onsets of pseudo-events triggering a hemodynamic response from resting-state hemodynamic signal (e.g. BOLD-fMRI). It is based on point process theory (Tagliazucchi et al., 2012) and fits a model to retrieve the optimal lag between the events and the HRF onset, as well as the HRF shape, using the basis function sets (Wu et al., 2013; Wu & Marinazzo, 2015; Wu & Marinazzo, 2016). There are a number of basis function sets available in rsHRF, including "informed" basis set (canonical HRF with its delay and dispersion derivatives), Gamma functions, Fourier set (Hanning), (smoothed) Finite Impulse Response (FIR), and the nonparametric impulse response function.

Once that the HRF has been retrieved, it can be deconvolved from the time series (for example to improve lag-based connectivity estimates), or one can map the shape parameters everywhere in the brain (including white matter), and use it as a pathophysiological indicator.

Input can be 2D GIfTI, or 3D/4D NIfTI images, but also on time series matrices/vectors.

The output are three HRF shape parameters (response height, time to peak, full width at half maximum) for each voxel/vertex/ROI, plus the deconvolved time series, and the number of retrieved pseudo-events.

In the rsHRF MATLAB version, brain connectivity analysis (seed to voxels/vertices, ROI to ROI analysis) can be further performed using the (partial) correlation (Pearson/Spearman) and Granger causality methods (Pairwise GC, partially conditioned GC, Conditional GC).

General

Input data

In order to perform HRF/connectivity analyses using this toolbox you will need:

Resting-state functional data. Either 2D Surface (GIfTI), 3D/4D Volume (NIfTI), or time series (text/mat) can be analysed.

ROI definitions. for regions of interest (ROIs) based HRF/connectivity analysis, ROIs can be defined from mask images, MNI coordinates (or **native space** coordinates), or multiple-label images.

The following basic information should be defined before HRF analysis:

- Denoising: remove possible confounds in the resting-state hemodynamic signal, including motion, physiological and other noise sources;
- **HRF basis function**: informed basis function, Gamma functions, Fourier set (Hanning), (smooth) Finite impulse response, nonparametric impulse response;
- Duration of HRF;
- Minimum/maximum time delay;
- Microtime resolution for onset estimation;
- Serial correlation model (AR model);
- Threshold for point process detection;
- Temporal mask to exclude spurious events;

The brain connectivity analysis (seed based or ROI to ROI connectivity) can be further performed based on the signal with/without HRF deconvolution.

Statistical analysis (second-level analyses)

- With the 3dMVM function embedded in AFNI, one can even run a multivariate analysis in which the three HRF parameters are modelled as multiple, simultaneous response variables (Chen, Adleman, Saad, Leibenluft, & Cox, 2014).
- The Matlab code of multivariate analysis of variance (*manova*.m) can be used for statistical analysis of HRF parameters (e.g. ROI-wise HRFs). There are four different methods provided in *manova*.m: Wilks' lambda, Pillai's trace, Hotelling-Lawley trace, Roy's maximum root statistic.
- …

Display (voxel-wise HRF visualization)

The HRF viewer (rsHRF_viewer.m) is designed to visualize the HRF shape at the voxel/ROI level with a statistical image (3D NIfTI) and HRF results (mat-file generated from rsHRF SPM plugin). For the moment, the rsHRF viewer only works with voxel-wise HRF results.

FAQ

1. *Should the input data be standardized (i.e. z-scored) a priori?*

No, the standardization of the resting-state fMRI BOLD signal has already been included in the code.

2. *Should the input data already be denoised?*

The input data consists of voxelwise/vertexwise resting-state fMRI BOLD signal, which you can already preprocess according to your favourite recipe; however, the rsHRF toolbox also provides the following denoising steps implemented in the SPM plugin:

- nuisance variable regression;
- polynomial detrending;
- band-pass filter (e.g. 0.01 - 0.1 Hz);
- despiking.

It is also possible to use a temporal mask to exclude some time points using the temporal mask for event detection included in the SPM plugin.

3. *Voxel-/vertex-wise or ROI analysis?*

The rsHRF toolbox consists of two main analysis options: 1) rsHRF retrieval and deconvolution and 2) connectivity analysis. Both analyses are supported on either the voxels/vertex or ROIs-volume levels.

The rsHRF retrieval and deconvolution is advised at the voxel level when possible, in order to avoid deviation from the mean in case of inhomogeneities within ROIs.

However, outlier removal is only legit when conducting a whole-brain analysis (3D volume).

Help resources

Forums for RS-HRF: https://www.nitrc.org/forum/?group_id=1304

Version information

The historical modification information was summarized in rsHRF_update_log.txt, with a more detailed description in Github: https://github.com/compneuro-da/rsHRF/blob/update/documentation/manual/01_History%26Development.md

Getting started

Download

rsHRF and demo data can be downloaded from:

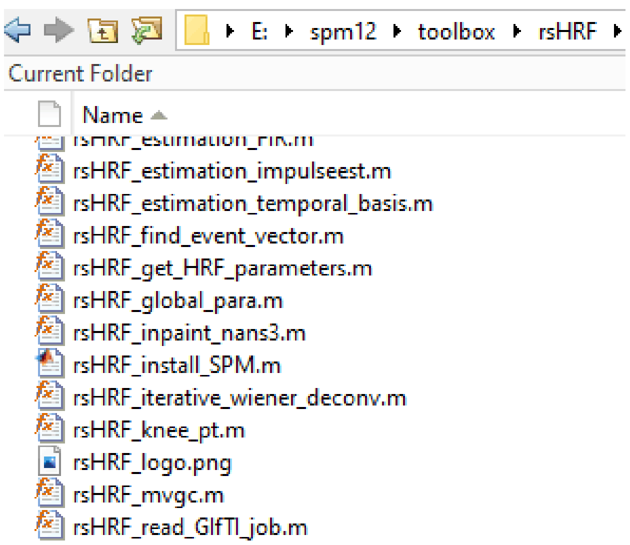
https://github.com/compneuro-da/rsHRF
&
www.nitrc.projects/rshrf

Installation

Copy or extract the whole folder “rsHRF” into the SPM toolbox directory. The folder “spm/toolbox/rsHRF” should now contain all m-files, matlabbatch job files (SPM plugin) as well as a subfolder named “demo-code”, containing the demo codes (MATLAB Standalone).

This will allow you to start the program directly from the SPM user interface via the toolbox button on the GUI.

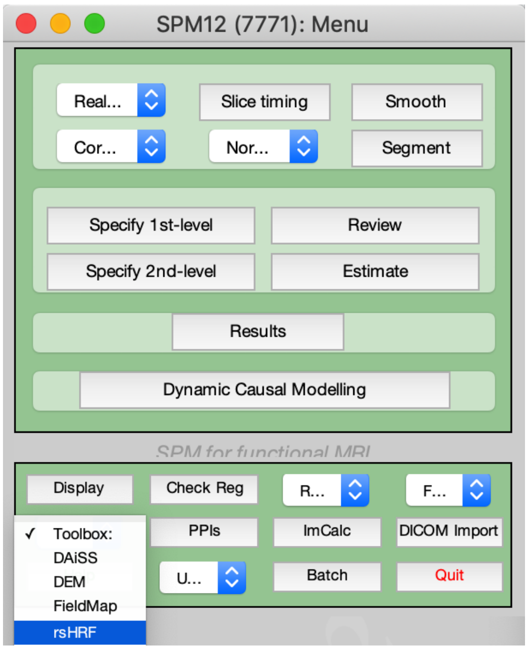
Note: run the rsHRF_install_SPM.m script in the MATLAB Command Window, all scripts within the downloaded rsHRF folder will be copied into a folder named ‘rsHRF’ located in the path/to/spm/toolbox/ folder.

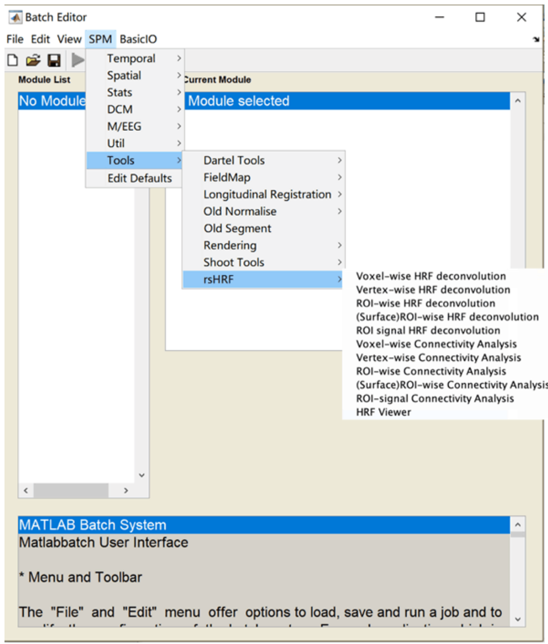


Start the toolbox (SPM Plugin)

Via GUI

- Click on toolbox and then select “rsHRF” from the drop-down menu.
- Or, Click Batch, SPM→ Tools → rsHRF



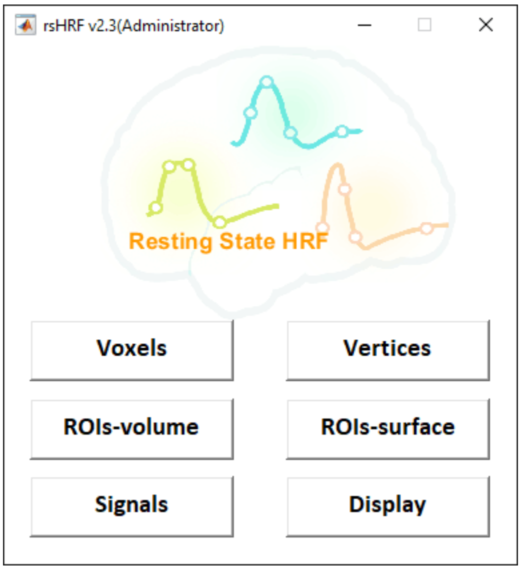


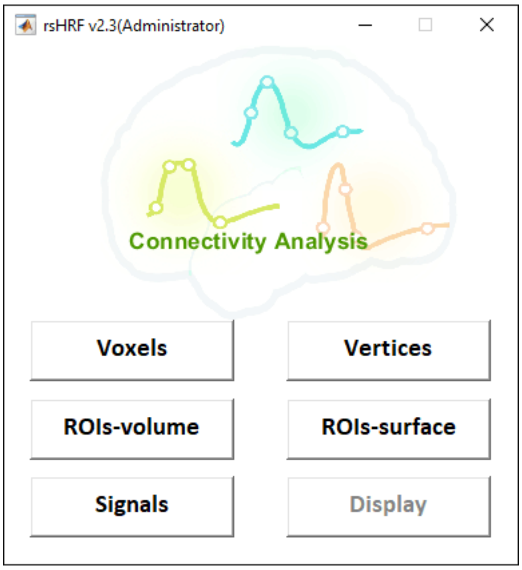
Via command line

Make sure that the directory of the m-files is included in the MATLAB search path. Then type ‘rsHRF’ or ‘rsHRF conn’ in the MATLAB prompt.

Command Window:	
>> rsHRF	>> rsHRF conn Or >> rsHRF(‘conn’)

The following Main-menu should appear in an additional window:



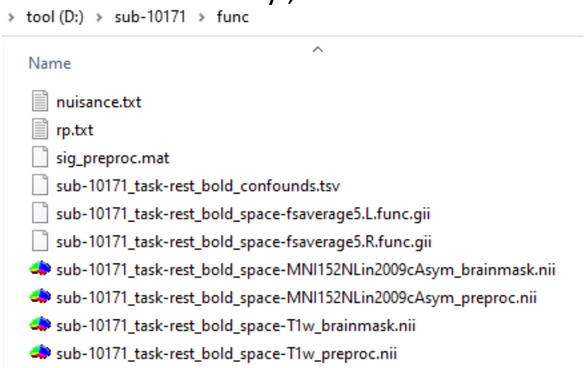


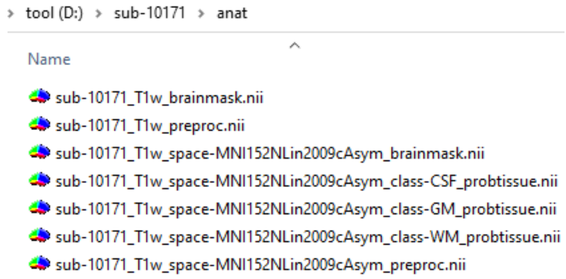
Resting State HRF	Connectivity Analysis
○ **Voxels** Voxel-wise HRF estimation, deconvolution and connectivity analysis (NIfTI files, 3D/4D volumes) ○ **Vertices** Vertex-wise HRF estimation, deconvolution and connectivity analysis (GIfTI files, 2D surfaces) ○ **ROIs-volume** ROI-wise HRF estimation, deconvolution and connectivity analysis (NIfTI files, 3D/4D volumes) ○ **ROIs-surface** ROI-wise HRF estimation, deconvolution and connectivity analysis (GIfTI files, 2D surfaces) ○ **Signals** Signals based HRF estimation, deconvolution and connectivity analysis (text/mat files) ○ Display HRF Visualization	○ Voxels Voxel-wise connectivity analysis (NIfTI files, 3D/4D volumes) ○ Vertices Vertex-wise connectivity analysis (GIfTI files, 2D surfaces) ○ ROIs-volume ROI-wise connectivity analysis (NIfTI files, 3D/4D volumes) ○ ROIs-surface ROI-wise connectivity analysis (GIfTI files, 2D surfaces) ○ Signals Signals based connectivity analysis (text/mat files)

Data processing examples

Demo data

The demo data (one subject, sub-10171) was from ‘UCLA Consortium for Neuropsychiatric Phenomics LA5c Study’, can be download from www.nitrc.projects/rshrf .





This data has been preprocessed by fMRIPrep and described in

- Gorgolewski KJ, Durnez J and Poldrack RA. Preprocessed Consortium for Neuropsychiatric Phenomics dataset. F1000Research 2017, 6:1262 https://doi.org/10.12688/f1000research.11964.2

Generate file for nuisance variable regression

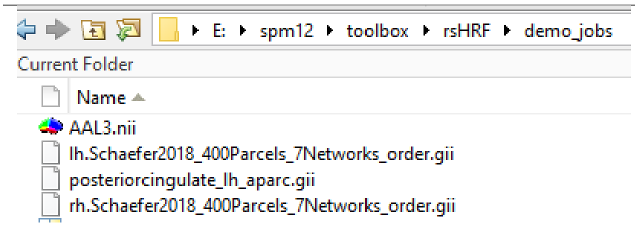
```
>> dat=spm_load('D:\sub-10171\func\sub-10171_task-rest_bold_confounds.tsv');
>> nuisance=[dat.aCompCor00, dat.aCompCor01, dat.aCompCor02, dat.aCompCor03,
dat.aCompCor04, dat.aCompCor05, dat.X, dat.Y, dat.Z, dat.RotX, dat.RotY, dat.RotZ];
>> save('D:\sub-10171\func\nuisance.txt','nuisance','-ascii')
>> rp = [dat.X, dat.Y, dat.Z, dat.RotX, dat.RotY, dat.RotZ];
>> save('D:\sub-10171\func\rp.txt','rp','-ascii')
```

Temporal mask

```
>> FD = dat.FramewiseDisplacement; FD(1)=0;
>> Temporal_Mask = double(FD<0.3);            % [1 1 1 0 1 1 …. ]; only for GUI input
```

The atlas files for ROIs analysis can be downloaded from

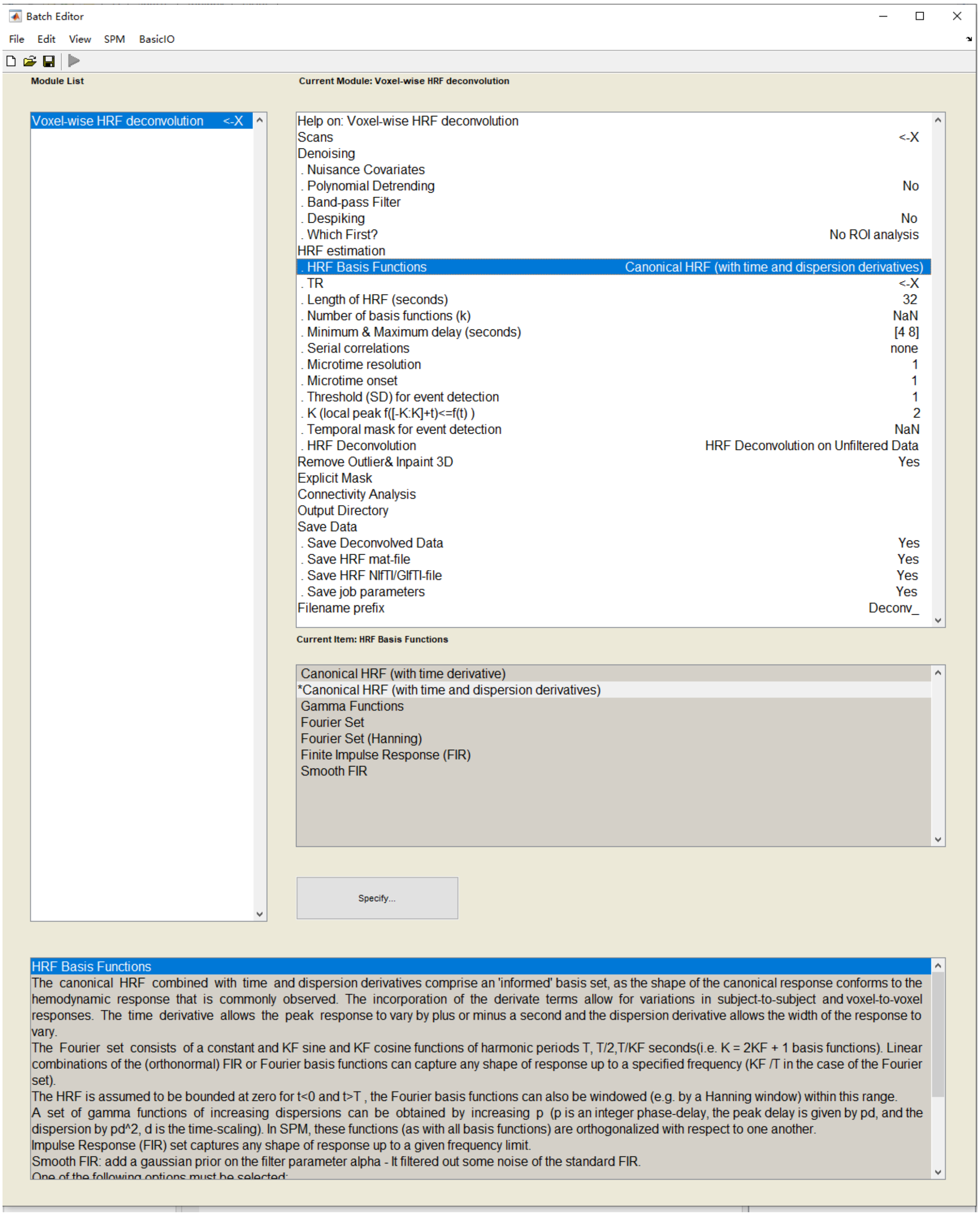
AAL3.nii	https://www.gin.cnrs.fr/en/tools/aal/
Yeo 7 networks	ftp://surfer.nmr.mgh.harvard.edu/pub/data/Yeo_JNeurophysiol11_MNI152.zip
Schaefer-2018:	https://github.com/ThomasYeoLab/CBIG/
Posterior cingulate (surface ROI)	converted from \freesurfer\subjects\fsaverage5\label\lh.aparc.annot



Batch interfaces and demo matlabbatch jobs

○ Voxel-wise HRF estimation, deconvolution and connectivity analysis

The voxels-wise based analysis module in the matlabbatch is called by clicking the ‘Voxels’ button in the main menu.



Demo jobs

Batch Editor → Load Batch

***Job 1**: \spm12\toolbox\rsHRF\demo_jobs\vox_hrf_canon2dd_deconv_job1_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- HRF basis function: informed basis function;
- Duration of HRF: 32s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 2, i.e. TR/2 = 2/2=1s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t\pm 1) < f(t)$ & $f(t\pm 2) < f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ....];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- HRF parameter outlier will be removed and replaced by surrounding values.
- HRF computation only inside the '*brainmask.nii'
- The HRF parameters, and deconvolved data will be saved in NIfTI files.

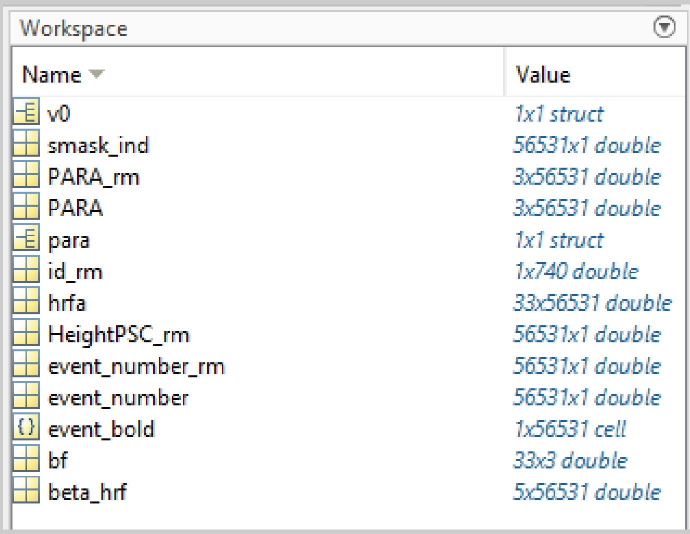
Help on: Voxel-wise HRF deconvolution	
Scans	...10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc.nii,1
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	No ROI analysis
HRF estimation	
. HRF Basis Functions	Canonical HRF (with time and dispersion derivatives)
. TR	2
. Length of HRF (seconds)	32
. Number of basis functions (k)	NaN
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	2
. Microtime onset	1
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Remove Outlier& Inpaint 3D	Yes
Explicit Mask	...171_task-rest_bold_space-MNI152NLin2009cAsym_brainmask.nii,1
Connectivity Analysis	
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save HRF NIfTI/GIfTI-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

Job1 results:

File Name	Description
Deconv_RAW_FILE_NAME.nii	HRF deconvolved data
Deconv_RAW_FILE_NAME_FWHM.nii	HRF parameter FWHM/width
Deconv_RAW_FILE_NAME_Height.nii	HRF parameter response height
Deconv_RAW_FILE_NAME_Height_PSC.nii	HRF parameter response height (percent signal change, PSC)
Deconv_RAW_FILE_NAME_Time2peak.nii	HRF parameter time to peak
Deconv_RAW_FILE_NAME_event_number.nii	estimated BOLD event number
Outlier removed and Inpainted (Olrm)	
Deconv_RAW_FILE_NAME_Olrm.nii	HRF deconvolved data
Deconv_RAW_FILE_NAME_Olrm_FWHM.nii	HRF parameter width
Deconv_RAW_FILE_NAME_Olrm_Height.nii	HRF parameter response height
Deconv_RAW_FILE_NAME_Olrm_Height_PSC.nii	HRF parameter response height (percent signal change, PSC)
Deconv_RAW_FILE_NAME_Olrm_Time2peak.nii	HRF parameter time to peak
Deconv_RAW_FILE_NAME_outlier_NAN.nii	detected outlier (value=1)
Mat-files	
Deconv_RAW_FILE_NAME_hrf.mat	HRF and HRF parameters
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters

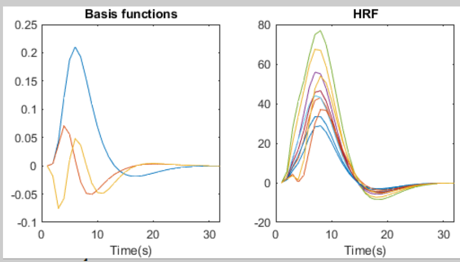
RAW_FILE_NAME = sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc

```
>> load('Deconv_ RAW_FILE_NAME_preproc_hrf.mat')
>> figure('color','w');subplot(1,2,1);
   plot(para.dt*[1:size(bf,1)],bf);title('Basis functions'); xlabel('Time(s)');xlim([0 para.len])
>> subplot(1,2,2);
   plot(para.dt*[1:size(bf,1)],hrfa(:,[1:10]));title('HRF'); xlabel('Time(s)');xlim([0 para.len])
```

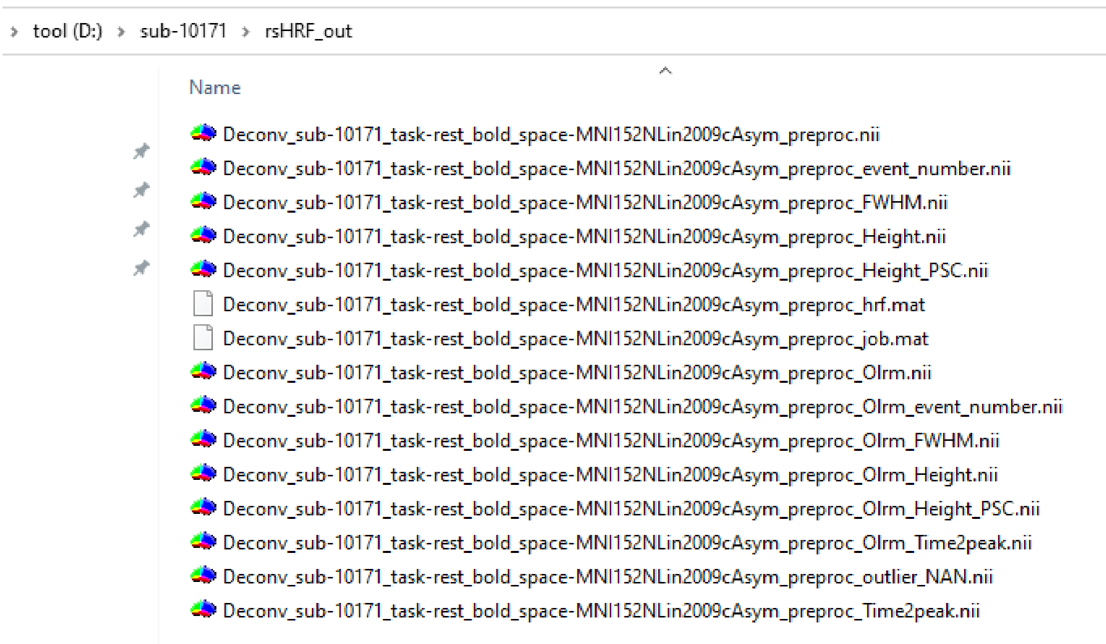


Workspace

Name	Value
v0	1x1 struct
smask_ind	56531x1 double
PARA_rm	3x56531 double
PARA	3x56531 double
para	1x1 struct
id_rm	1x740 double
hrfa	33x56531 double
HeightPSC_rm	56531x1 double
event_number_rm	56531x1 double
event_number	56531x1 double
event_bold	1x56531 cell
bf	33x3 double
beta_hrf	5x56531 double

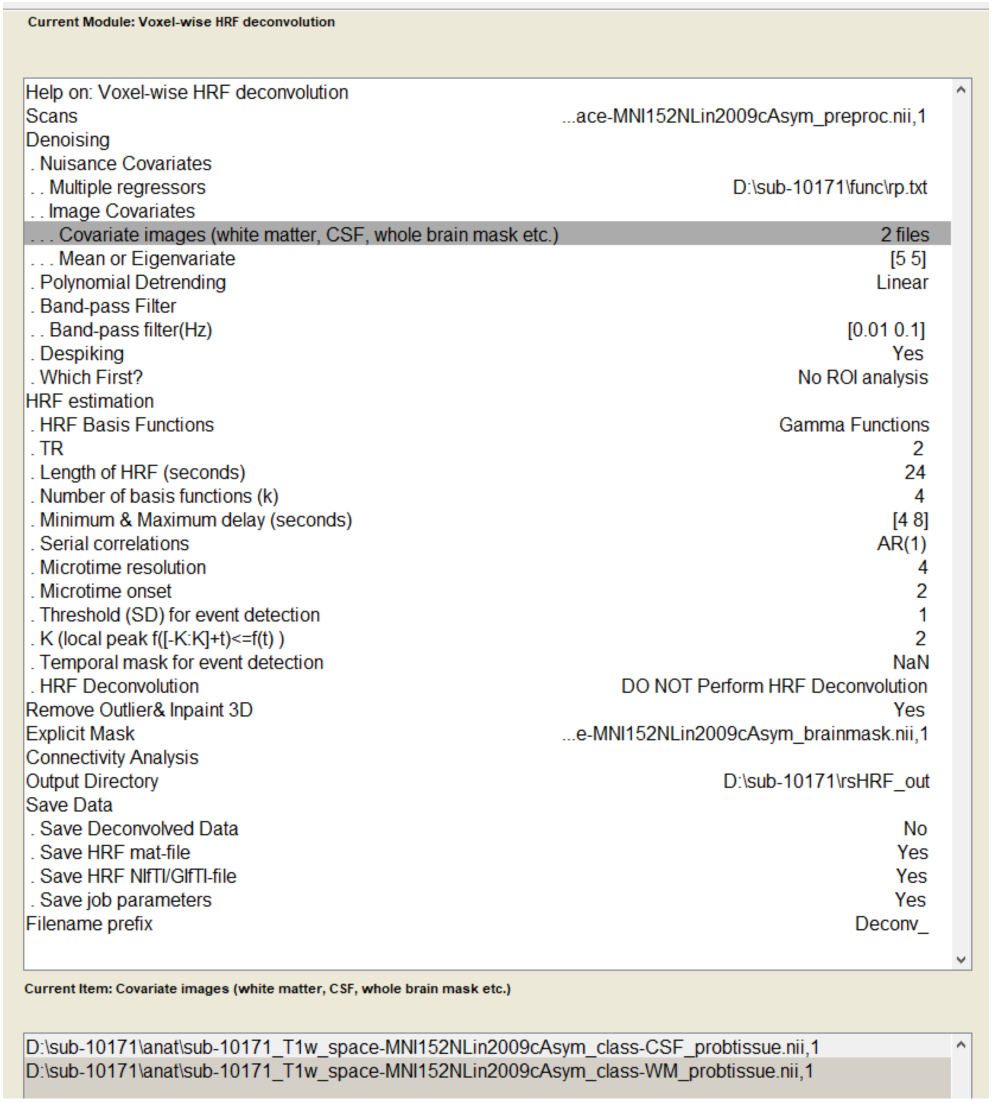


<table>
<tr><th colspan="2">hrf.mat</th></tr>
<tr><td>Variable</td><td>Description</td></tr>
<tr><td>V0</td><td>NIfTI header information</td></tr>
<tr><td>smask_ind</td><td>matrix index of analysis mask</td></tr>
<tr><td>event_number</td><td>number of detected spontaneous events</td></tr>
<tr><td>event_bold:</td><td>timing information of spontaneous events</td></tr>
<tr><td>PARA</td><td>HRF parameters: 1st row: Response Height;
2nd row: Time to peak; 3rd row: Width at half peak</td></tr>
<tr><td>para</td><td>input parameters for HRF estimation
para
1x1 struct with 11 fields
<table>
<tr><th>Field</th><th>Value</th></tr>
<tr><td>TR</td><td>2</td></tr>
<tr><td>T</td><td>2</td></tr>
<tr><td>T0</td><td>2</td></tr>
<tr><td>dt</td><td>1</td></tr>
<tr><td>order</td><td>NaN</td></tr>
<tr><td>AR_lag</td><td>1</td></tr>
<tr><td>thr</td><td>1</td></tr>
<tr><td>len</td><td>32</td></tr>
<tr><td>lag</td><td>[4,5,6,7,8]</td></tr>
<tr><td>localK</td><td>2</td></tr>
<tr><td>name</td><td>'Canonical HRF (with time and dispersion derivatives)'</td></tr>
</table></td></tr>
<tr><td>hrfa</td><td>All HRF</td></tr>
<tr><td>bf</td><td>HRF basis function</td></tr>
<tr><td>beta_hrf</td><td>beta_hrf = [beta coefficients; estimated lag]
i.e. hrfa = bf*beta_hrf(1:size(bf,2),:);
%HRF baseline value for PSC calculation.
hrf_baseline = beta_hrf(1+size(bf,2),:);</td></tr>
<tr><td>id_rm</td><td>index of removed outliers</td></tr>
<tr><td>HeightPSC_rm:</td><td>response height (percent signal change, PSC), outlier removed</td></tr>
<tr><td>PARA_rm</td><td>HRF parameters, outlier removed</td></tr>
<tr><td>event_number_rm:</td><td>number of detected spontaneous events, outlier removed</td></tr>
</table>



Job 2*:* *\spm12\toolbox\rsHRF\demo_jobs\vox_hrf_gamma_job2_v23.mat*

- Denoising: (1) remove motion (rp.txt), physiological confounds (top 5 principle components from CSF and white matter, *here we only select voxels with value > 0.9 in covariate images for nuisance regression*), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- HRF basis function: 4 Gamma functions;
- Duration of HRF: 24s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 4, i.e. TR/4 = 2/4=0.5s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t \pm 1) < f(t)$ & $f(t \pm 2) < f(t)$).
- Temporal mask to exclude spurious events: no;
- Do not perform HRF deconvolution.
- HRF parameter outlier will be removed and replaced by surrounding values.
- HRF computation only inside the '*brainmask.nii'
- The HRF parameters will be saved in NIfTI files.

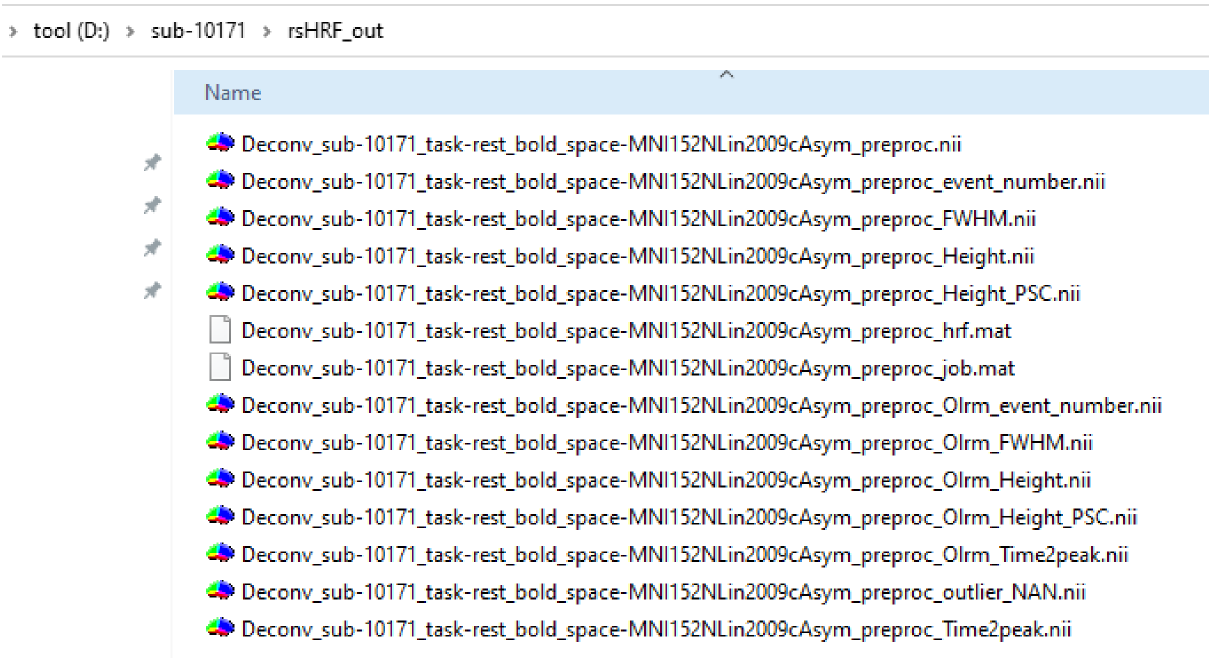

Current Module: Voxel-wise HRF deconvolution

Help on: Voxel-wise HRF deconvolution	
Scans	...ace-MNI152NLin2009cAsym_preproc.nii,1
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\rp.txt
. . Image Covariates	
. . . Covariate images (white matter, CSF, whole brain mask etc.)	2 files
. . . Mean or Eigenvariate	[5 5]
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	No ROI analysis
HRF estimation	
. HRF Basis Functions	Gamma Functions
. TR	2
. Length of HRF (seconds)	24
. Number of basis functions (k)	4
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	4
. Microtime onset	2
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	NaN
. HRF Deconvolution	DO NOT Perform HRF Deconvolution
Remove Outlier& Inpaint 3D	Yes
Explicit Mask	...e-MNI152NLin2009cAsym_brainmask.nii,1
Connectivity Analysis	
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	No
. Save HRF mat-file	Yes
. Save HRF NIfTI/GIfTI-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

Current Item: Covariate images (white matter, CSF, whole brain mask etc.)

D:\sub-10171\anat\sub-10171_T1w_space-MNI152NLin2009cAsym_class-CSF_probtissue.nii,1
D:\sub-10171\anat\sub-10171_T1w_space-MNI152NLin2009cAsym_class-WM_probtissue.nii,1

Job2 results:



Job 3*:* *\spm12\toolbox\rsHRF\demo_jobs\vox_deconv_job2_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- HRF basis function: 3 Gamma functions;
- Duration of HRF: 32s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 4, i.e. TR/4 = 2/4=0.5s ;
- Serial correlation model: none;
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t\pm 1)< f(t)$ & $f(t\pm 2)< f(t)$).
- Temporal mask to exclude spurious events: no;
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- HRF parameter outlier will be removed and replaced by surrounding values.
- HRF computation only inside the 'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii'
- Which first? (c)
  - (a) First denoise then generate ROI signal
  - (b) First generate ROI signal then denoise
  - (c) No ROI analysis (default)
    - if ROI analysis was included, it will automatedly change to (b) <-- (Job3).
- Connectivity analysis:
  - (1) Functional connectivity (FC) : seed to voxels analysis.
    - Data: denoised BOLD and deconvolved BOLD
    - seed of interest information defined as: [x, y, z, radius]

- two seeds: [10 -62 61 4;
  -52 -63 5 5].
- (2~4) Granger Causality (GC): ROI to ROI analysis.
  - Data: denoised BOLD and deconvolved BOLD
  - (2). pairwise GC, model order = 1;
  - (3). Conditional GC; model order = 1; only for deconvolved BOLD data.
  - (4). Partially Conditioned GC; model order=1; fixed number of conditional variables = 6, maximum number of conditional variables = 8 (which can be used for information gain plot).
- (5) Functional connectivity (FC) : ROI to ROI analysis.
  - Data: deconvolved BOLD
  - 14 sphere ROIs + 164 ROIs from atlas (AAL3, 164 ROIs are arranged in ascending order according to their label in AAL3 --- *see AAL3.nii.txt for label information*)

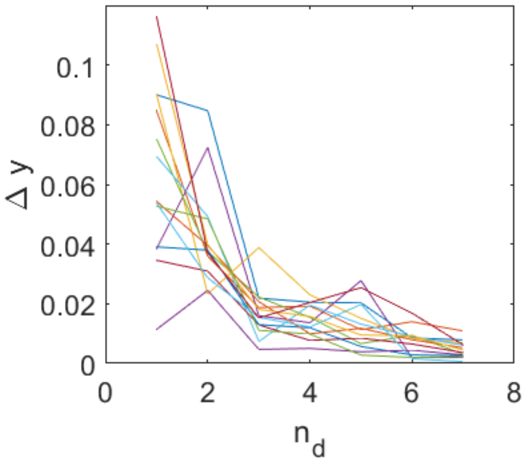
ROI index	Matrix index	ROI information	Label
1	[171701,1...	[10,-62,61,4]	[]
2	*1x14 dou...*	[-52,-63,5,5]	[]
3	*1x26 dou...*	[-47,-51,-21,6]	[]
4	[76943,76...	[46,-47,-17,4]	[]
5	*1x26 dou...*	[47,-30,49,6]	[]
6	[156625,1...	[22,-65,48,4]	[]
7	*1x16 dou...*	[46,-59,4,5]	[]
8	[171771,1...	[25,-58,60,4]	[]
9	*1x14 dou...*	[-33,-46,47,5]	[]
10	[141464,1...	[-27,-71,37,4]	[]
11	*1x41 dou...*	[-32,-1,54,7]	[]
12	[86599,86...	[-42,-60,-9,4]	[]
13	*1x26 dou...*	[-17,-59,64,6]	[]
14	[167937,1...	[29,-5,54,4]	[]
15	*790x1 do...*	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	1
16	*755x1 do...*	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	2
17	*1088x1 d...*	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	3
18	*1116x1 d...*	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	4
19	969x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	5
...			

Current Module: Voxel-wise HRF deconvolution

Help on: Voxel-wise HRF deconvolution	
Scans	...10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc.nii,1
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	No ROI analysis
HRF estimation	
. HRF Basis Functions	Gamma Functions
. TR	2
. Length of HRF (seconds)	32
. Number of basis functions (k)	3
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	none
. Microtime resolution	4
. Microtime onset	2
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Remove Outlier& Inpaint 3D	Yes
Explicit Mask	E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1
Connectivity Analysis	
. FC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Seed or ROI	Seed to voxels
. . ROI (Coordinate / NIfTI)	
. . . ROI (x,y,z,radius [in mm])	2x4 double
. . Method	Pearson Correlation
. . Filename prefix	Conn_
. GC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Seed or ROI	ROI to ROI
. . ROI (Coordinate / NIfTI)	
. . . ROI (x,y,z,radius [in mm])	14x4 double
. . Method	Pairwise GC(Granger causality)
. . Model order for GC	1
. . Parameters for PCGC	[NaN NaN]
. . Filename prefix	Conn_
. GC	
. . Data for Connectivity	Deconvolved BOLD
. . Seed or ROI	ROI to ROI
. . ROI (Coordinate / NIfTI)	
. . . ROI (x,y,z,radius [in mm])	14x4 double
. . Method	Conditional GC (only for ROIs)
. . Model order for GC	1
. . Parameters for PCGC	[NaN NaN]
. . Filename prefix	Conn_
. GC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Seed or ROI	ROI to ROI
. . ROI (Coordinate / NIfTI)	
. . . ROI (x,y,z,radius [in mm])	14x4 double
. . Method	Partially Conditioned GC (only for ROIs)
. . Model order for GC	1
. . Parameters for PCGC	[6 8]
. . Filename prefix	Conn_
. FC	
. . Data for Connectivity	Deconvolved BOLD
. . Seed or ROI	ROI to ROI
. . ROI (Coordinate / NIfTI)	
. . . ROI (x,y,z,radius [in mm])	14x4 double
. . . Atlas image	E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1
. . Method	Pearson Correlation
. . Filename prefix	Conn_
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	No
. Save HRF mat-file	No
. Save HRF NIfTI/GIfTI-file	No
. Save job parameters	Yes
Filename prefix	Deconv_

- ***Job3 results:***

File Name	Description
Seed to Voxels	
Conn_1_RAW_FILE_NAME_Z_Pearson.nii Conn_1_RAW_FILE_NAME_SeedInfo_Pearson.mat Conn_1_RAW_FILE_NAME_corr_Pearson.nii	Seed FC 'Z_Pearson' --Fisher's z transformed Pearson correlation coefficient, 'corr_Pearson' --Pearson correlation coefficient) , based on the denoised BOLD data 'SeedInfo' -- seed information ([10 -62 61 4]): seed_information 1x3 cell 1 2 3 1 [171701,1... [10,-62,61,4] []
Conn_1_RAW_FILE_NAME_deconv_Olrm_Z_Pearson.nii Conn_1_RAW_FILE_NAME_deconv_Olrm_corr_Pearson.nii Conn_1_RAW_FILE_NAME_deconv_Olrm_SeedInfo_Pearson.mat	Seed FC 'deconv_Olrm' -- based on the deconvolved (outlier removed) BOLD data
Conn_1_RAW_FILE_NAME_deconv_Z_Pearson.nii Conn_1_RAW_FILE_NAME_deconv_corr_Pearson.nii Conn_1_RAW_FILE_NAME_deconv_SeedInfo_Pearson.mat	Seed ([10 -62 61 4]) FC 'deconv' -- based on the deconvolved BOLD data
Conn_2_RAW_FILE_NAME_Z_Pearson.nii Conn_2_RAW_FILE_NAME_corr_Pearson.nii Conn_2_RAW_FILE_NAME_SeedInfo_Pearson.mat	Seed ([-52 -63 5 5]]) FC
Conn_2_RAW_FILE_NAME_deconv_Olrm_Z_Pearson.nii Conn_2_RAW_FILE_NAME_deconv_Olrm_corr_Pearson.nii Conn_2_RAW_FILE_NAME_deconv_Olrm_SeedInfo_Pearson.mat	
Conn_2_RAW_FILE_NAME_deconv_Z_Pearson.nii Conn_2_RAW_FILE_NAME_deconv_corr_Pearson.nii Conn_2_RAW_FILE_NAME_deconv_SeedInfo_Pearson.mat	
ROI to ROI	
Conn_RAW_FILE_NAME_PWGC.mat M 1x1 struct with 9 fields Field — Value seed_num — 0 nvar — 14 nobs — 152 order — 1 GC_type — 'Pairwise GC' ndinfo — [NaN,NaN] GC_Matrix — *14x14 double* pval_Matrix — *14x14 double* GC_Matrix_N — *14x14 double*	Pairwise GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test) GC_Matrix_N: transformed GC N: GC value *c* is transformed into *d*, which is considered to be approximately normal. (Geweke 1982)

<table>
<tr>
<td>
Conn_RAW_FILE_NAME_deconv_CGC.mat
M
1x1 struct with 8 fields
<table>
<tr><th>Field</th><th>Value</th></tr>
<tr><td>seed_num</td><td>0</td></tr>
<tr><td>nvar</td><td>14</td></tr>
<tr><td>nobs</td><td>152</td></tr>
<tr><td>order</td><td>1</td></tr>
<tr><td>GC_type</td><td>'Conditional GC'</td></tr>
<tr><td>ndinfo</td><td>[NaN,NaN]</td></tr>
<tr><td>GC_Matrix</td><td>14x14 double</td></tr>
<tr><td>pval_Matrix</td><td>14x14 double</td></tr>
</table>
roiid
14x3 cell
<table>
<tr><th></th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>1</td><td>[171701,1...</td><td>[10,-62,61,4]</td><td>[]</td></tr>
<tr><td>2</td><td>[101610,1...</td><td>[-52,-63,5,4]</td><td>[]</td></tr>
<tr><td>3</td><td>[71777,71...</td><td>[-47,-51,-21,4]</td><td>[]</td></tr>
<tr><td>4</td><td>[76943,76...</td><td>[46,-47,-17,4]</td><td>[]</td></tr>
<tr><td>5</td><td>[157413,1...</td><td>[47,-30,49,4]</td><td>[]</td></tr>
<tr><td>6</td><td>[156625,1...</td><td>[22,-65,48,4]</td><td>[]</td></tr>
<tr><td>7</td><td>[101708,1...</td><td>[46,-59,4,4]</td><td>[]</td></tr>
<tr><td>8</td><td>[171771,1...</td><td>[25,-58,60,4]</td><td>[]</td></tr>
<tr><td>9</td><td>[156996,1...</td><td>[-33,-46,47,4]</td><td>[]</td></tr>
<tr><td>10</td><td>[141464,1...</td><td>[-27,-71,37,4]</td><td>[]</td></tr>
<tr><td>11</td><td>[167982,1...</td><td>[-32,-1,54,4]</td><td>[]</td></tr>
<tr><td>12</td><td>[86599,86...</td><td>[-42,-60,-9,4]</td><td>[]</td></tr>
<tr><td>13</td><td>[176762,1...</td><td>[-17,-59,64,4]</td><td>[]</td></tr>
<tr><td>14</td><td>[167937,1...</td><td>[29,-5,54,4]</td><td>[]</td></tr>
</table>
</td>
<td>
Conditional GC
In variable M:
GC_Matrix: GC Value
pval_Matrix: p-value (F-test)
variable roiid : ROI information
ROI 1:
sphere radius 4mm, center at [10 -62 61]
…
ROI 1:
sphere radius 4mm, center at [29 -5 54]
</td>
</tr>
<tr>
<td>
Conn_RAW_FILE_NAME_PCGC.mat
M
1x1 struct with 10 fields
<table>
<tr><th>Field</th><th>Value</th></tr>
<tr><td>seed_num</td><td>0</td></tr>
<tr><td>nvar</td><td>14</td></tr>
<tr><td>nobs</td><td>152</td></tr>
<tr><td>order</td><td>1</td></tr>
<tr><td>GC_type</td><td>'Partially Conditioned GC'</td></tr>
<tr><td>ndinfo</td><td>[6,8]</td></tr>
<tr><td>information_gain</td><td>14x8 double</td></tr>
<tr><td>condition_id</td><td>14x8 double</td></tr>
<tr><td>GC_Matrix</td><td>14x14 double</td></tr>
<tr><td>pval_Matrix</td><td>14x14 double</td></tr>
</table>
</td>
<td>
Partially Conditioned GC
GC_Matrix: GC Value
pval_Matrix: p-value (F-test)
condition_id: (nvar x ndmax)
index of conditional variables,
information_gain:
mutual information gain[1]


(Marinazzo et al. 2012; Wu et al. 2013)
</td>
</tr>
<tr>
<td>
Conn_RAW_FILE_NAME_deconv_Corr_Pearson.mat
M
1x1 struct with 6 fields
<table>
<tr><th>Field</th><th>Value</th></tr>
<tr><td>seed_num</td><td>0</td></tr>
<tr><td>nvar</td><td>178</td></tr>
<tr><td>nobs</td><td>152</td></tr>
<tr><td>Matrix_r</td><td>178x178 double</td></tr>
<tr><td>Matrix_z</td><td>178x178 double</td></tr>
<tr><td>Matrix_pval</td><td>178x178 double</td></tr>
</table>
</td>
<td rowspan="2">
Matric_r: Pearson correlation coefficient) ,
Matrix_z: Fisher's z transformed Pearson correlation coefficient,
Matric_pval: p-value (t-test)
</td>
</tr>
<tr><td>Conn_RAW_FILE_NAME_deconv_Olrm_Corr_Pearson.mat</td></tr>
<tr><td>Conn_RAW_FILE_NAME_deconv_Olrm_CGC.mat</td><td rowspan="2">GC</td></tr>
<tr><td>Conn_RAW_FILE_NAME_deconv_Olrm_PCGC.mat</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Deconv_RAW_FILE_NAME_outlier_NAN.nii</td><td>detected outlier (value=1)</td></tr>
</table>

Mat-files	
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters

RAW_FILE_NAME = sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc

[1] plot(diff(M.information_gain')); xlabel('n_d'); ylabel('\Delta y')

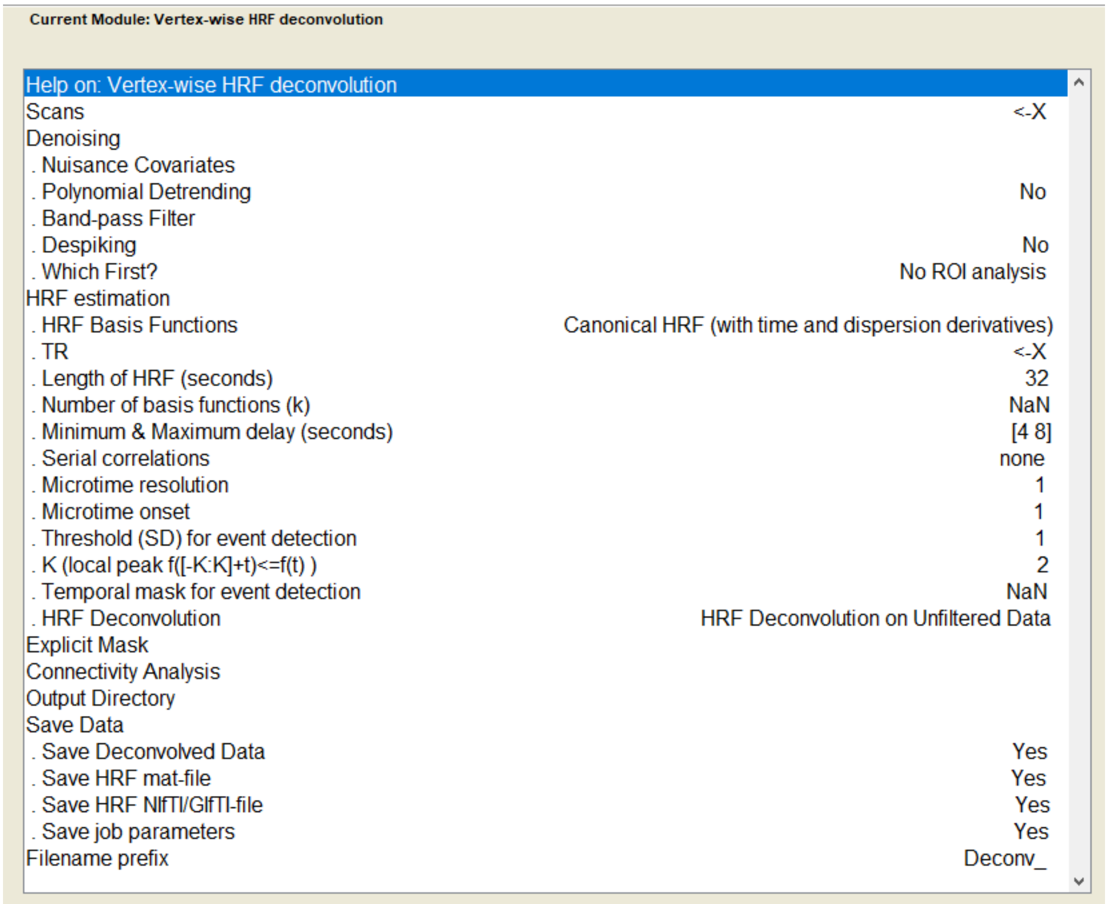
› tool (D:) › sub-10171 › rsHRF_out

Name

Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Deconv_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_outlier_NAN.nii
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_pwGC.mat
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_PCGC.mat
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_corr_Pearson.nii
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_SeedInfo_Pearson.mat
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Z_Pearson.nii
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_corr_Pearson.nii
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_SeedInfo_Pearson.mat
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Z_Pearson.nii
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_pwGC.mat
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_CGC.mat
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Corr_Pearson.mat
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_PCGC.mat
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_corr_Pearson.nii
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_SeedInfo_Pearson.mat
Conn_1_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_Z_Pearson.nii
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_corr_Pearson.nii
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_SeedInfo_Pearson.mat
Conn_2_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_Z_Pearson.nii
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_pwGC.mat
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_CGC.mat
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_Corr_Pearson.mat
Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_deconv_Olrm_PCGC.mat
Deconv_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_job.mat

o Vertex-wise HRF estimation, deconvolution and connectivity analysis

The vertex-wise based analysis module in the matlabbatch is called by clicking the 'Vertices' button in the main menu.

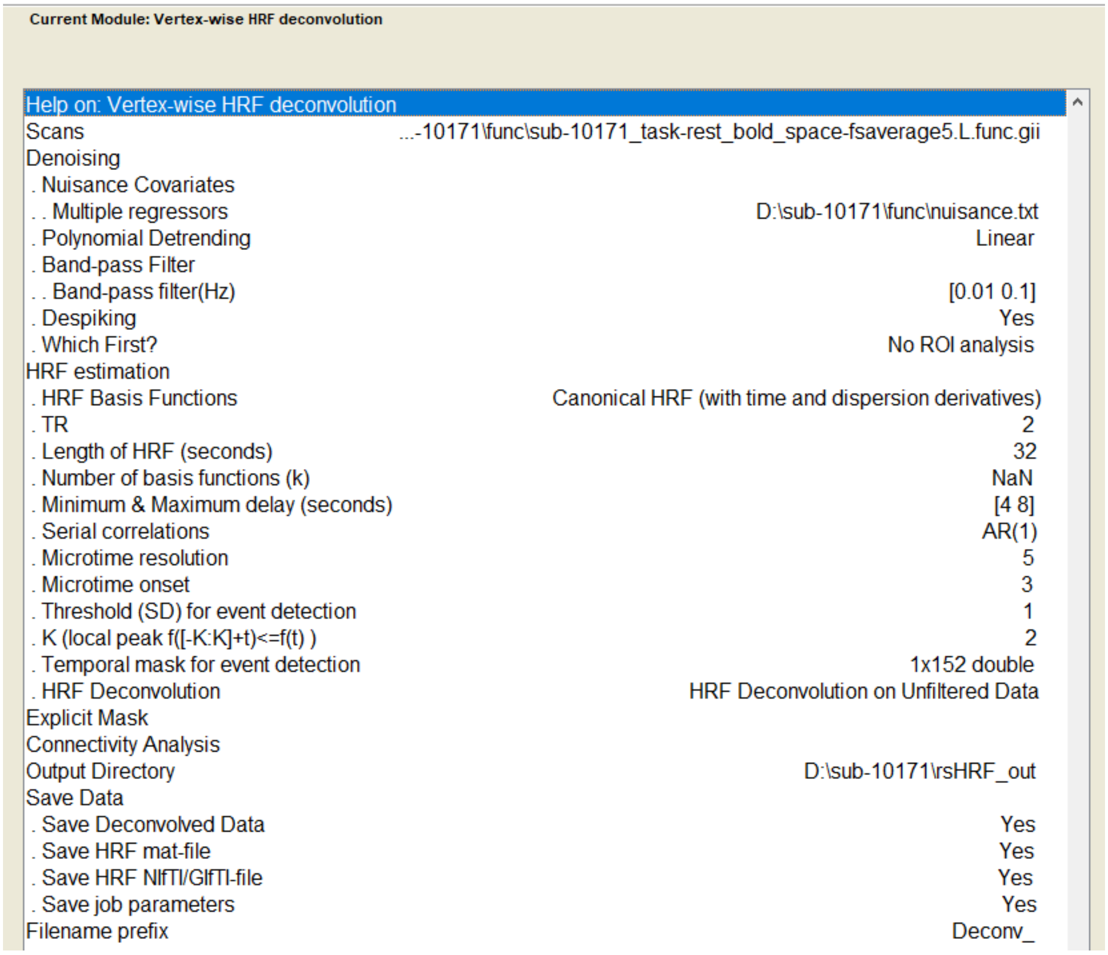


Demo jobs

Batch Editor → Load Batch

***Job 4**: \spm12\toolbox\rsHRF\demo_jobs\vertex_hrf_canon2dd_deconv_job4_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- HRF basis function: informed basis function;
- Duration of HRF: 32s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 2, i.e. TR/5 = 2/5=0.4s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t \pm 1) < f(t)$ & $f(t \pm 2) < f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ....];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- Explicit Mask: none.
- The HRF parameters, and deconvolved data will be saved in GIfTI files.



Current Module: Vertex-wise HRF deconvolution

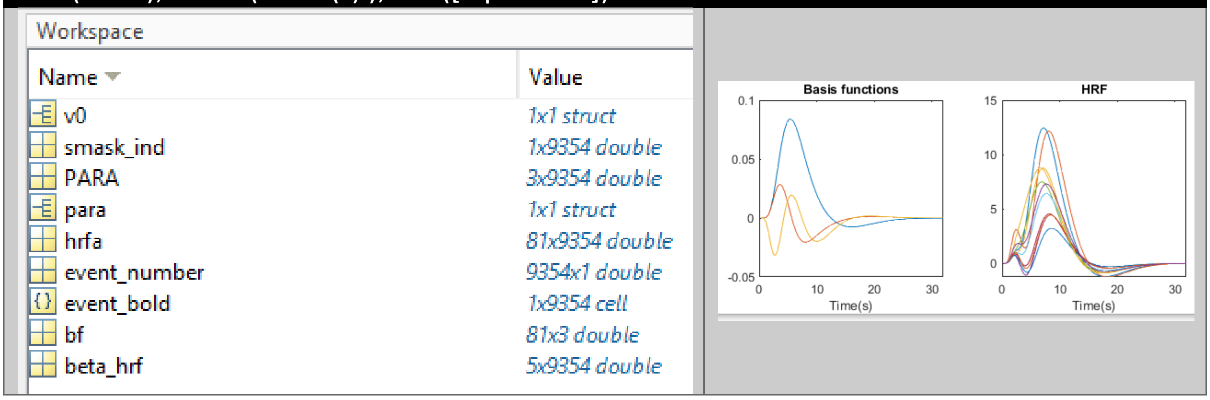
Help on: Vertex-wise HRF deconvolution	
Scans	...-10171\func\sub-10171_task-rest_bold_space-fsaverage5.L.func.gii
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	No ROI analysis
HRF estimation	
. HRF Basis Functions	Canonical HRF (with time and dispersion derivatives)
. TR	2
. Length of HRF (seconds)	32
. Number of basis functions (k)	NaN
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	5
. Microtime onset	3
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Explicit Mask	
Connectivity Analysis	
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save HRF NIfTI/GIfTI-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

- ***Job4 results:***

File Name	Description
Deconv_RAW_FILE_NAME.gii	HRF deconvolved data
Deconv_RAW_FILE_NAME_FWHM.gii	HRF parameter FWHM/width
Deconv_RAW_FILE_NAME_Height.gii	HRF parameter response height
Deconv_RAW_FILE_NAME_Height_PSC.gii	HRF parameter response height (percent signal change, PSC)
Deconv_RAW_FILE_NAME_Time2peak.gii	HRF parameter time to peak
Deconv_RAW_FILE_NAME_event_number.gii	estimated BOLD event number
Mat-files	
Deconv_RAW_FILE_NAME_hrf.mat	HRF and HRF parameters
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters

RAW_FILE_NAME = sub-10171_task-rest_bold_space-fsaverage5.L.func

```
>> load('Deconv_ RAW_FILE_NAME_hrf.mat')
>> figure('color','w');subplot(1,2,1);
plot(para.dt*[1:size(bf,1)],bf);
title('Basis functions'); xlabel('Time(s)');xlim([0 para.len])
>> subplot(1,2,2);
plot(para.dt*[1:size(bf,1)],hrfa(:,[1000:1010]));
title('HRF'); xlabel('Time(s)');xlim([0 para.len])
```



hrf.mat	
Variable	Description
V0	v0 1x1 struct with 1 field Field: dim — Value: [10242,1]
smask_ind	matrix index of analysis mask
event_number	number of detected spontaneous events
event_bold:	timing information of spontaneous events
PARA	HRF parameters: 1st row: Response Height; 2nd row: Time to peak; 3rd row: Width at half peak
para	input parameters for HRF estimation para 1x1 struct with 11 fields Field — Value TR — 2 T — 5 T0 — 5 dt — 0.4000 order — NaN AR_lag — 1 thr — 1 len — 32 lag — *1x11 double* localK — 2 name — 'Canonical HRF (with time and dispersion derivatives)'
hrfa	All HRF
bf	HRF basis function

beta_hrf	beta_hrf = [beta coefficients; estimated lag]
	i.e. hrfa = bf*beta_hrf(1:size(bf,2),:);
	%HRF baseline value for PSC calculation.
	hrf_baseline = beta_hrf(1+size(bf,2),:);

› tool (D:) › sub-10171 › rsHRF_out

Name

Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func_event_number.gii
Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func_FWHM.gii
Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func_Height.gii
Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func_Height_PSC.gii
Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func_hrf.mat
Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func_Time2peak.gii
Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func.gii
Deconv_sub-10171_task-rest_bold_space-fsaverage5.L.func_job.mat

Job 5*:* *\spm12\toolbox\rsHRF\demo_jobs\vertex_hrf_gamma_deconv_FC_job5_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- HRF basis function: 3 Gamma functions;
- Duration of HRF: 24s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 1, i.e. TR = 2 s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t\pm1)< f(t)$ & $f(t\pm2)< f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ….];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- Explicit Mask: none.
- The HRF parameters, and deconvolved data will be saved in GIfTI files.
- Which first? First denoise then generate ROI signal
- Connectivity analysis:
    - (1) Functional connectivity (FC) : seed to vertices analysis.
        - Data: denoised BOLD and deconvolved BOLD
        - seed of interest: posterior cingulate
    - (2) Functional connectivity (FC) : ROI to ROI analysis.
        - Data: denoised BOLD and deconvolved BOLD
        - 200 ROI from atlas (Schaefer-2018, 200 ROIs are arranged in ascending order according to their label in atlas file)
    - (3) Granger causality (GC) : ROI to ROI analysis.
        - Data: deconvolved BOLD
        - 7 ROIs from atlas (Yeo-2011, 7 ROIs are arranged in ascending order according to their label in atlas file)

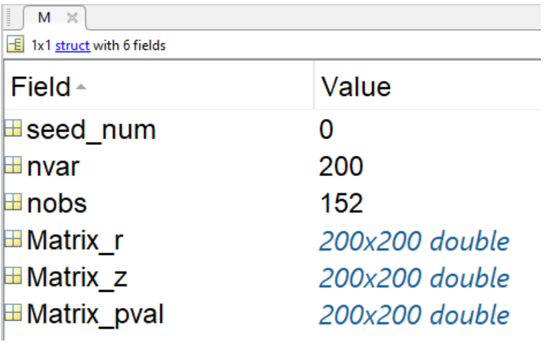
Help on: Vertex-wise HRF deconvolution	
Scans	...-10171\func\sub-10171_task-rest_bold_space-fsaverage5.L.func.gii
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	First denoise then generate ROI signal
HRF estimation	
. HRF Basis Functions	Gamma Functions
. TR	2
. Length of HRF (seconds)	24
. Number of basis functions (k)	3
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	1
. Microtime onset	1
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Explicit Mask	
Connectivity Analysis	
. FC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Seed or ROI	Seed to vertices
. . ROI (GIfTI)	
. . . Mesh Mask	E:\spm12\toolbox\rsHRF\demo_jobs\posteriorcingulate_lh_aparc.gii
. . Method	Spearman Correlation
. . Filename prefix	Conn_
. FC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Seed or ROI	ROI to ROI
. . ROI (GIfTI)	
. . . Mesh Atlas	...HRF\demo_jobs\lh.Schaefer2018_400Parcels_7Networks_order.gii
. . Method	Pearson Correlation
. . Filename prefix	Conn_
. GC	
. . Data for Connectivity	Deconvolved BOLD
. . Seed or ROI	ROI to ROI
. . ROI (GIfTI)	
. . . Mesh Atlas	...spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii
. . Method	Conditional GC (only for ROIs)
. . Model order for GC	1
. . Parameters for PCGC	[NaN NaN]
. . Filename prefix	Conn_
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save HRF NIfTI/GIfTI-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

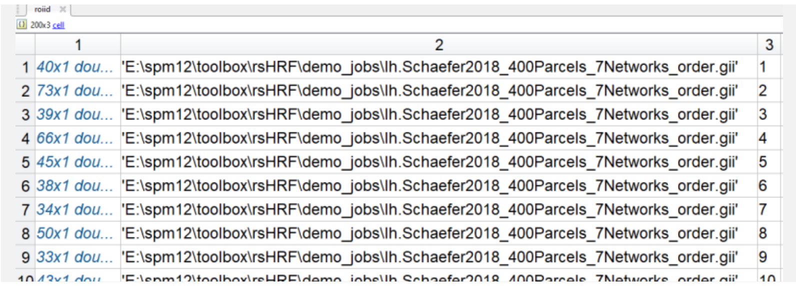
- ***Job5 results:***

<table>
<tr><th>File Name</th><th>Description</th></tr>
<tr><td colspan="2" align="center">Seed to Vertices</td></tr>
<tr><td>Conn_1_RAW_FILE_NAME_Z_Spearman.gii
Conn_1_RAW_FILE_NAME_SeedInfo_Spearman.mat

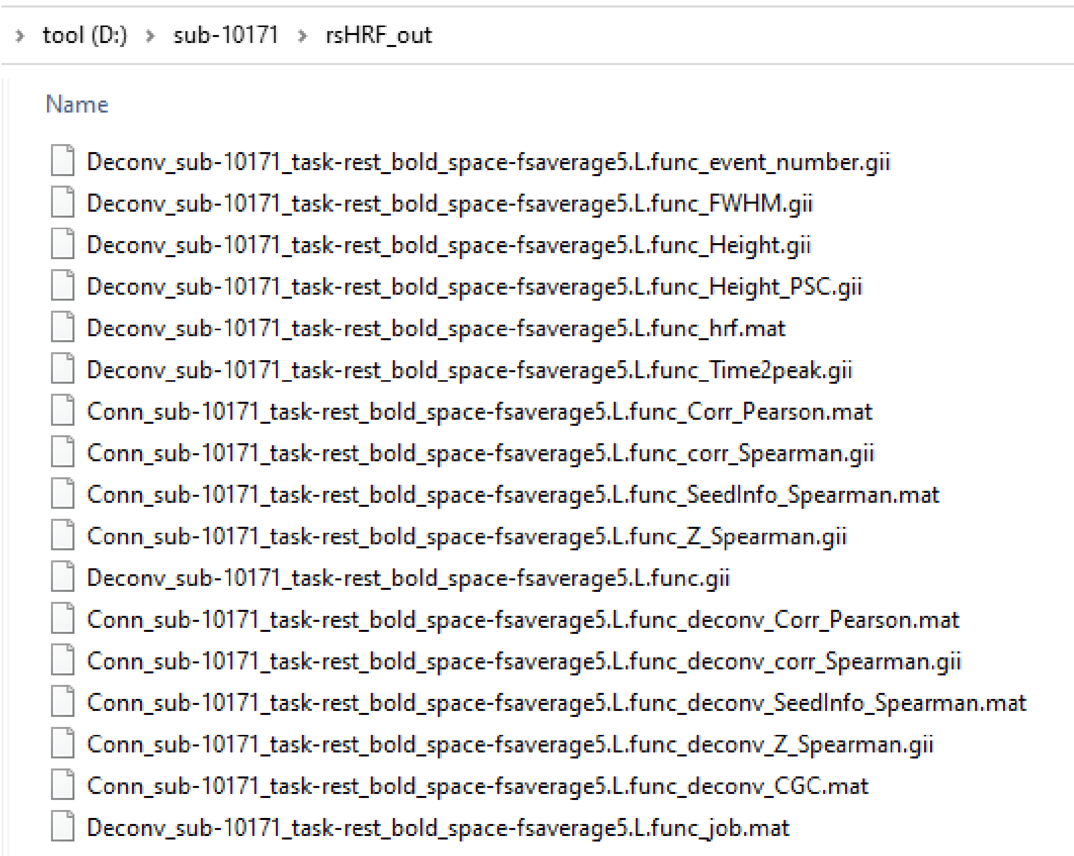
Conn_1_RAW_FILE_NAME_corr_Spearman.gii</td><td>Seed (posterior cingulate) FC
'_Z_ Spearman' --Fisher's z transformed Spearman correlation coefficient,
'_corr_ Spearman' -- Spearman correlation coefficient) ,
based on the denoised BOLD data
'SeedInfo' Seed information:
seed_information
1x3 cell<table><tr><th></th><th>1</th><th>2</th><th>3</th></tr><tr><td>1</td><td>180x1 do...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\posteriorcingulate_lh_aparc.gii'</td><td>[]</td></tr></table></td></tr>
<tr><td>Conn_1_RAW_FILE_NAME_deconv_Z_Spearman.gii
Conn_1_RAW_FILE_NAME_deconv_corr_Spearman.gii
Conn_1_RAW_FILE_NAME_deconv_SeedInfo_Spearman.mat</td><td>Seed (posterior cingulate) FC
'_deconv' -- based on the deconvolved BOLD data</td></tr>
<tr><td colspan="2" align="center">ROI to ROI</td></tr>
<tr><td>Conn_RAW_FILE_NAME_deconv_CGC.mat

M
1x1 struct with 8 fields<table><tr><th>Field</th><th>Value</th></tr><tr><td>seed_num</td><td>0</td></tr><tr><td>nvar</td><td>7</td></tr><tr><td>nobs</td><td>152</td></tr><tr><td>order</td><td>1</td></tr><tr><td>GC_type</td><td>'Conditional GC'</td></tr><tr><td>ndinfo</td><td>[NaN,NaN]</td></tr><tr><td>GC_Matrix</td><td>7x7 double</td></tr><tr><td>pval_Matrix</td><td>7x7 double</td></tr></table>
roiid
7x3 cell<table><tr><th></th><th>1</th><th>2</th><th>3</th></tr><tr><td>1</td><td>1352x1 d...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'</td><td>1</td></tr><tr><td>2</td><td>1861x1 d...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'</td><td>2</td></tr><tr><td>3</td><td>1094x1 d...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'</td><td>3</td></tr><tr><td>4</td><td>1087x1 d...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'</td><td>4</td></tr><tr><td>5</td><td>712x1 do...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'</td><td>5</td></tr><tr><td>6</td><td>1041x1 d...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'</td><td>6</td></tr><tr><td>7</td><td>2207x1 d...</td><td>'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'</td><td>7</td></tr></table></td><td align="center">Conditional GC
GC_Matrix: GC Value
GC_Matrix(x,y) = GC from x to y
pval_Matrix: p-value (F-test)</td></tr>
</table>

<table>
<tr>
<td>Conn_RAW_FILE_NAME_Corr_Pearson.mat


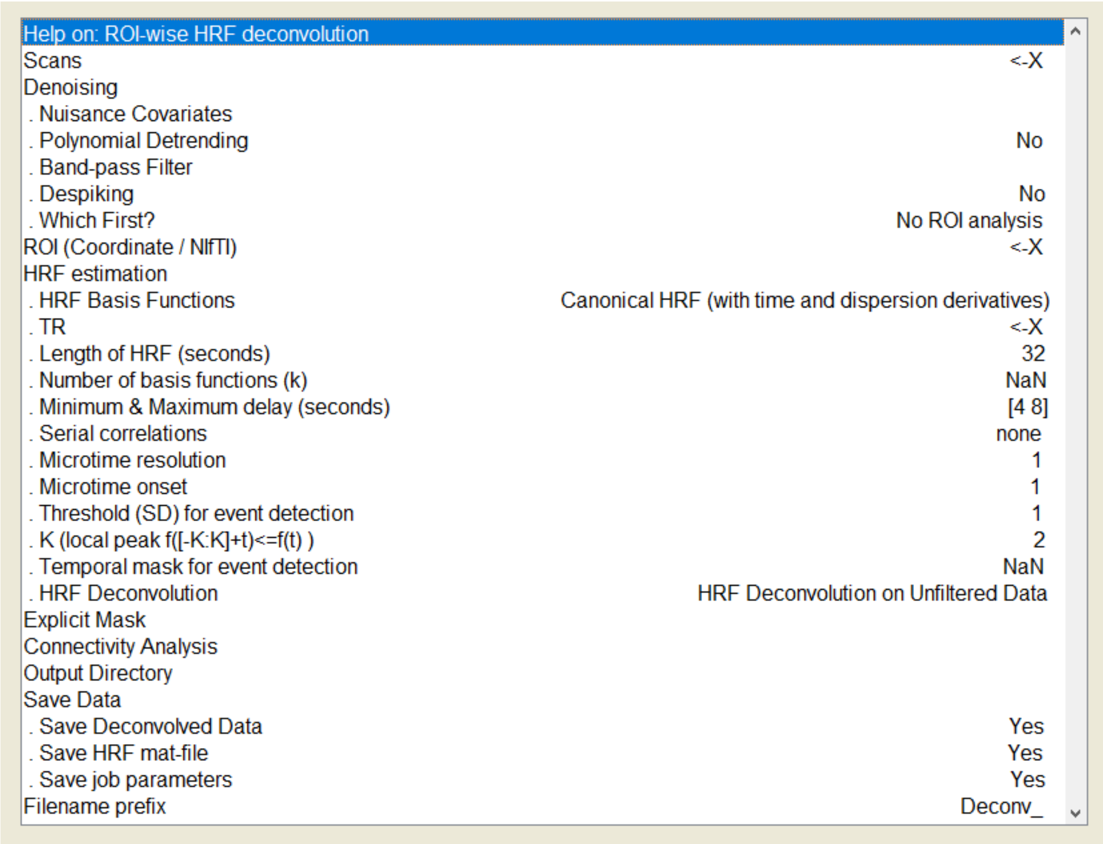


</td>
<td rowspan="2">Matric_r: Pearson correlation coefficient) ,
Matrix_z: Fisher's z transformed Pearson correlation coefficient,
Matric_pval: p-value (t-test)</td>
</tr>
<tr>
<td>Conn_RAW_FILE_NAME_deconv_Corr_Pearson.mat</td>
</tr>
<tr>
<td colspan="2">Mat-files</td>
</tr>
<tr>
<td>Deconv_RAW_FILE_NAME_job.mat</td>
<td>analysis/model parameters</td>
</tr>
</table>



o (Volume) ROI-wise HRF estimation, deconvolution and connectivity analysis

The volume based ROI analysis module in the matlabbatch is called by clicking the ‘ROIs-volume’ button in the main menu.



Help on: ROI-wise HRF deconvolution	
Scans	<-X
Denoising	
. Nuisance Covariates	
. Polynomial Detrending	No
. Band-pass Filter	
. Despiking	No
. Which First?	No ROI analysis
ROI (Coordinate / NIfTI)	<-X
HRF estimation	
. HRF Basis Functions	Canonical HRF (with time and dispersion derivatives)
. TR	<-X
. Length of HRF (seconds)	32
. Number of basis functions (k)	NaN
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	none
. Microtime resolution	1
. Microtime onset	1
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	NaN
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Explicit Mask	
Connectivity Analysis	
Output Directory	
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

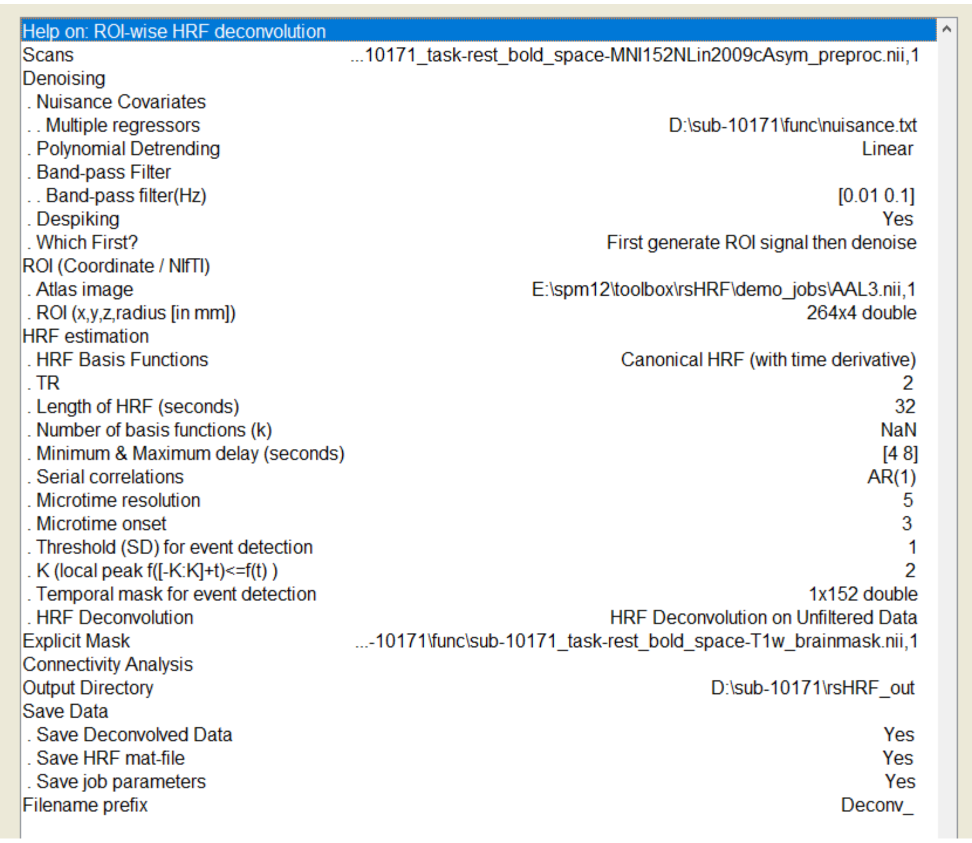
Figure : matlabbatch GUI for volume based ROI HRF deconvolution.

Demo jobs

Batch Editor → Load Batch

Job 6: *\spm12\toolbox\rsHRF\demo_jobs\ROI_hrf_canon2dd_deconv_job6_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? First denoise then generate ROI signal
- ROI definition:
  - atlas image: AAL3.nii
  - MNI coordinates+radius(sphere): 264 x 4
- HRF basis function: informed basis function (canonical HRF + time derivative);
- Duration of HRF: 32s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 2, i.e. TR/5 = 2/5=0.4s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t\pm1)< f(t)$ & $f(t\pm2)< f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ….];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- HRF computation only inside the '*brainmask.nii'
- The HRF parameters, and deconvolved data will be saved in Mat files.



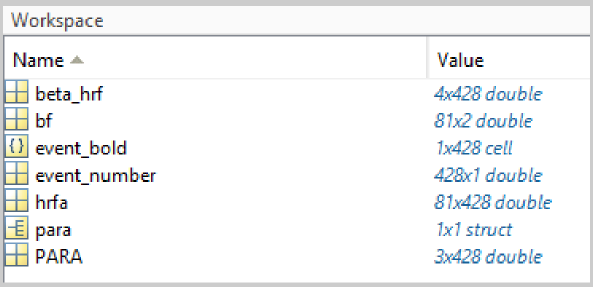
Help on: ROI-wise HRF deconvolution	
Scans	...10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc.nii,1
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	First generate ROI signal then denoise
ROI (Coordinate / NIfTI)	
. Atlas image	E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1
. ROI (x,y,z,radius [in mm])	264x4 double
HRF estimation	
. HRF Basis Functions	Canonical HRF (with time derivative)
. TR	2
. Length of HRF (seconds)	32
. Number of basis functions (k)	NaN
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	5
. Microtime onset	3
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Explicit Mask	...-10171\func\sub-10171_task-rest_bold_space-T1w_brainmask.nii,1
Connectivity Analysis	
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

- ***Job6 results:***

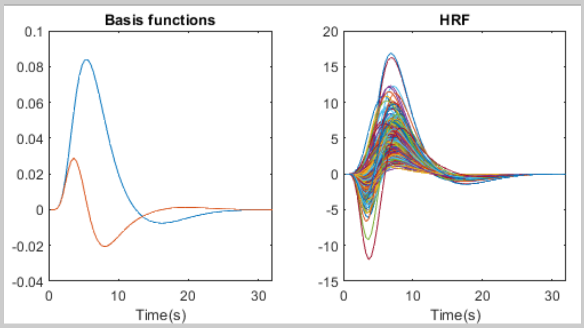
File Name	Description
Deconv_RAW_FILE_NAME_hrf.mat	HRF and HRF parameters
Deconv_RAW_FILE_NAME.mat	HRF deconvolved BOLD data
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters

RAW_FILE_NAME = sub-10171_task-rest_bold_space-fsaverage5.L.func

```
>> load('Deconv_ RAW_FILE_NAME_hrf.mat')
>> figure('color','w');subplot(1,2,1); plot(para.dt*[1:size(bf,1)],bf);
title('Basis functions');  xlabel('Time(s)');xlim([0 para.len])
>> subplot(1,2,2); plot(para.dt*[1:size(bf,1)],hrfa(:,[1:428]));
title('HRF'); xlabel('Time(s)');xlim([0 para.len])
```


Workspace

Name	Value
beta_hrf	4x428 double
bf	81x2 double
event_bold	1x428 cell
event_number	428x1 double
hrfa	81x428 double
para	1x1 struct
PARA	3x428 double



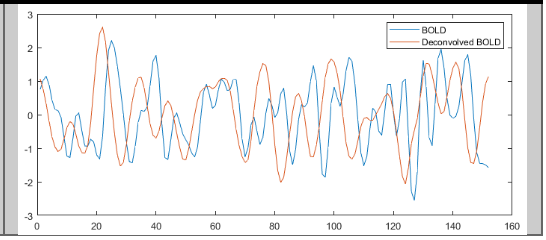
hrf.mat	
Variable	Description
event_number	number of detected spontaneous events
event_bold:	timing information of spontaneous events
PARA	HRF parameters: 1st row: Response Height; 2nd row: Time to peak; 3rd row: Width at half peak
para	input parameters for HRF estimation para 1x1 struct with 11 fields Field — Value TR — 2 T — 5 T0 — 5 dt — 0.4000 order — NaN AR_lag — 1 thr — 1 len — 32 lag — 1x11 double localK — 2 name — 'Canonical HRF (with time derivative)'
hrfa	All HRF
bf	HRF basis function

beta_hrf	beta_hrf = [beta coefficients; estimated lag]
	i.e. hrfa = bf*beta_hrf(1:size(bf,2),:);
	%HRF baseline value for PSC calculation.
	hrf_baseline = beta_hrf(1+size(bf,2),:);

```
>> load('Deconv_ RAW_FILE_NAME.mat')
>> figure('color','w');plot(zscore(data(:,5)));
>> hold on; plot(zscore(data_deconv(:,5)));legend({'BOLD','Deconvolved BOLD'})
```

Workspace

Name ▲	Value
data	152x428 double
data_deconv	152x428 double
roinfo	428x3 cell



Deconv_RAW_FILE_NAME.mat	
Variable	Description
data	(Denoised) BOLD data
data_deconv	HRF deconvolved BOLD Data
roiinfo	ROI information:

roinfo
428x3 cell

	1	2	3
1	[80819,80...	[-25,-98,-12,4]	[]
2	[80836,80...	[27,-97,-13,4]	[]
3	[78625,78...	[24,32,-18,4]	[]
4	[66899,66...	[-56,-45,-24,4]	[]
5	[68805,68...	[8,41,-24,4]	[]
6	[72436,72...	[-21,-22,-20,4]	[]
7	[77323,77...	[17,-28,-17,4]	[]
8	[67295,67...	[-37,-29,-26,4]	[]
9	[72464,72...	[65,-24,-19,4]	[]
10	[62190,62...	[52,-34,-27,4]	[]
264	[167937,1...	[29,-5,54,4]	[]
265	790x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	1
266	755x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	2
267	1088x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	3
268	1116x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	4
269	969x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	5
270	1065x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	6
271	220x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	7
272	327x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	8
273	597x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	9
274	476x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\AAL3.nii,1'	10

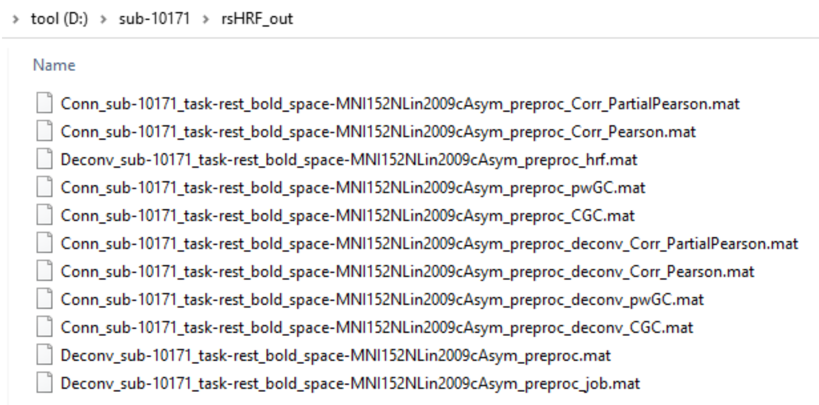
› tool (D:) › sub-10171 › rsHRF_out

Name

- Deconv_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_hrf.mat
- Deconv_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc.mat
- Deconv_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_job.mat

***Job7**: \spm12\toolbox\rsHRF\demo_jobs\ROI_hrf_gamma_deconv_FC_GC_job7_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? First generate ROI signal then denoise
- ROI definition:
  - atlas image: AAL3.nii
  - MNI coordinates+radius(sphere): 264 x 4
- HRF basis function: 3 Gamma functions;
- Duration of HRF: 32s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 1, i.e. TR = 2 s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t\pm1)< f(t)$ & $f(t\pm2)< f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ....];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- Explicit Mask: none.
- The HRF parameters, and deconvolved data will be saved in mat files.
- Connectivity analysis: **ROI to ROI; Data: denoised BOLD and deconvolved BOLD**
  - (1) Functional connectivity (FC) : Pearson correlation.
  - (2) Functional connectivity (FC) : Pearson Partial correlation.
  - (3) Granger causality (GC) : Pairwise Granger causality.
  - (4) Granger causality (GC) : Conditional Granger causality.



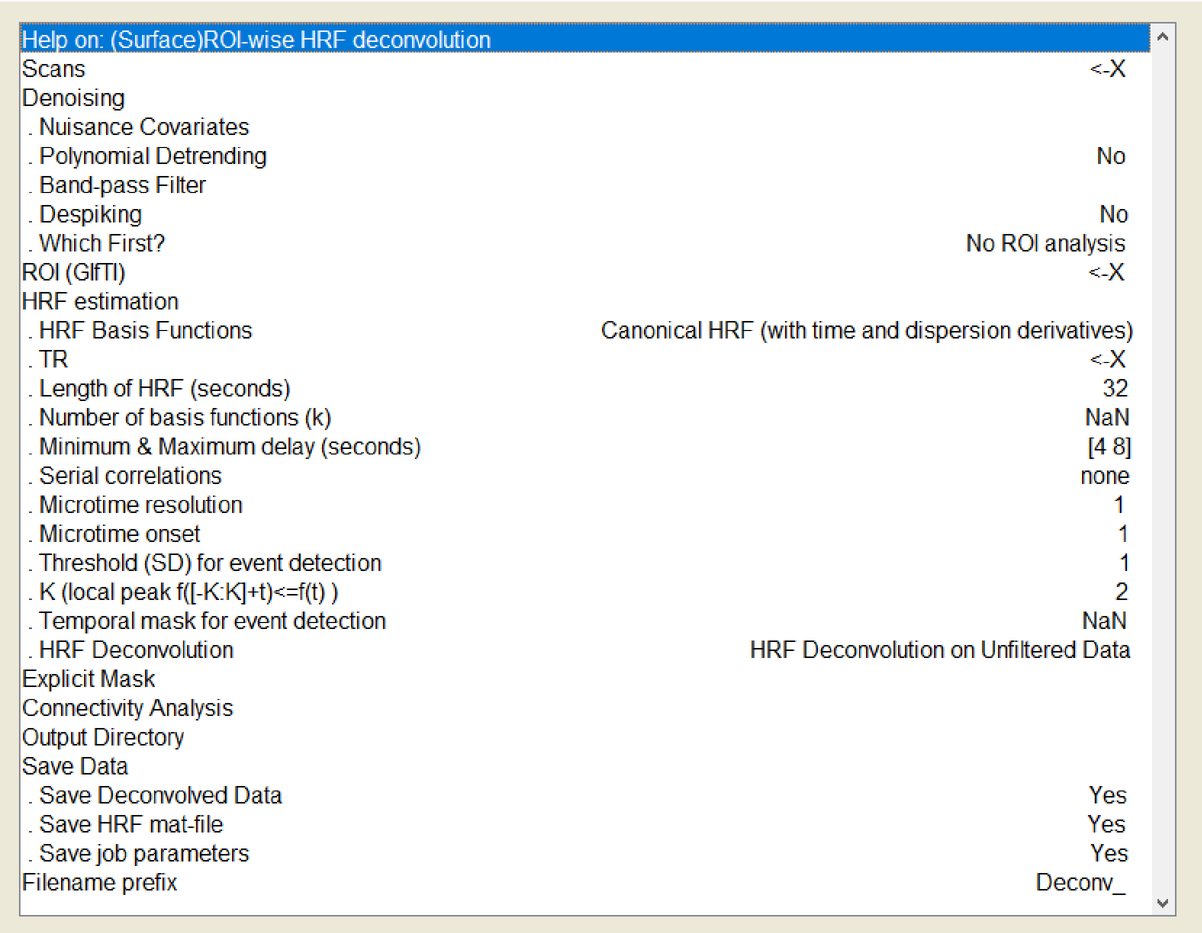
Help on: ROI-wise HRF deconvolution	
Scans	...10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc.nii,1
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	First generate ROI signal then denoise
ROI (Coordinate / NIfTI)	
. Atlas image	..._7Networks_MNI152_FreeSurferConformed2mm_LiberalMask.nii,1
. ROI (x,y,z,radius [in mm])	9x4 double
HRF estimation	
. HRF Basis Functions	Gamma Functions
. TR	2
. Length of HRF (seconds)	32
. Number of basis functions (k)	3
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	1
. Microtime onset	1
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Explicit Mask	...171_task-rest_bold_space-MNI152NLin2009cAsym_brainmask.nii,1
Connectivity Analysis	
. FC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Method	Pearson Correlation
. . Filename prefix	Conn_
. FC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Method	Pearson Partial Correlation (only for ROIs)
. . Filename prefix	Conn_
. GC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Method	Pairwise GC(Granger causality)
. . Model order for GC	1
. . Parameters for PCGC	[NaN NaN]
. . Filename prefix	Conn_
. GC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Method	Conditional GC (only for ROIs)
. . Model order for GC	1
. . Parameters for PCGC	[6 8]
. . Filename prefix	Conn_
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

- ***Job7 results:***

File Name	Description
roiid = []; % ROI information was saved in Deconv_RAW_FILE_NAME.mat	Workspace Name | Value M | 1x1 struct roiid | []
ROI to ROI	
Conn_RAW_FILE_NAME_CGC.mat Conn_RAW_FILE_NAME_deconv_CGC.mat 1x1 struct with 8 fields Field | Value seed_num | 0 nvar | 16 nobs | 152 order | 1 GC_type | 'Conditional GC' ndinfo | [6,8] GC_Matrix | 16x16 double pval_Matrix | 16x16 double	Conditional GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test)
Conn_RAW_FILE_NAME_pwGC.mat Conn_RAW_FILE_NAME_deconv_pwGC.mat 1x1 struct with 9 fields Field | Value seed_num | 0 nvar | 16 nobs | 152 order | 1 GC_type | 'Pairwise GC' ndinfo | [NaN,NaN] GC_Matrix | 16x16 double pval_Matrix | 16x16 double GC_Matrix_N | 16x16 double	Pairwise GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test) GC_Matrix_N: transformed GC N: GC value *c* is transformed into *d*, which is considered to be approximately normal. (Geweke 1982)
Conn_RAW_FILE_NAME_Corr_Pearson.mat Conn_RAW_FILE_NAME_Corr_PartialPearson.mat 1x1 struct with 6 fields Field | Value seed_num | 0 nvar | 16 nobs | 152 Matrix_r | 16x16 double Matrix_z | 16x16 double Matrix_pval | 16x16 double	Matric_r: Pearson correlation coefficient) , Matrix_z: Fisher's z transformed Pearson correlation coefficient, Matric_pval: p-value (t-test)
Conn_RAW_FILE_NAME_deconv_Corr_Pearson.mat Conn_RAW_FILE_NAME_deconv_Corr_PartialPearson.mat	
Mat-files	
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters
Deconv_RAW_FILE_NAME.mat	HRF deconvolved BOLD data

- ## (Surface) ROI-wise HRF estimation, deconvolution and connectivity analysis

The surface based ROI analysis module in the matlabbatch is called by clicking the ‘ROIs-surface’ button in the main menu.



Demo jobs
Batch Editor → Load Batch

Job8: *\spm12\toolbox\rsHRF\demo_jobs\ROI_vertex_hrf_gamma_deconv_FC_GC_job8.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? First generate ROI signal then denoise
- ROI definition:
  - atlas mesh: Yeo 7 networks
- HRF basis function: Smooth FIR
- Duration of HRF: 24s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 1, i.e. TR2s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t \pm 1) < f(t)$ & $f(t \pm 2) < f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ….];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- The HRF parameters, and deconvolved data will be saved in Mat files

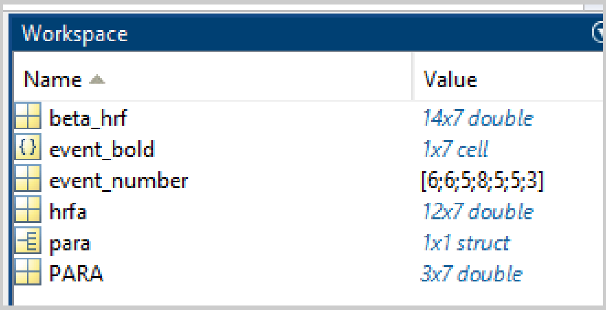
Help on: (Surface)ROI-wise HRF deconvolution	
Scans	...1\func\sub-10171_task-rest_bold_space-fsaverage5.R.func.gii
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	First generate ROI signal then denoise
ROI (GIfTI)	
. Mesh Atlas	...\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii
HRF estimation	
. HRF Basis Functions	Smooth FIR
. TR	2
. Length of HRF (seconds)	24
. Number of basis functions (k)	NaN
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	1
. Microtime onset	1
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Explicit Mask	
Connectivity Analysis	
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

- ***Job8 results:***

File Name	Description
Deconv_RAW_FILE_NAME_hrf.mat	HRF and HRF parameters
Deconv_RAW_FILE_NAME.mat	HRF deconvolved BOLD data
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters

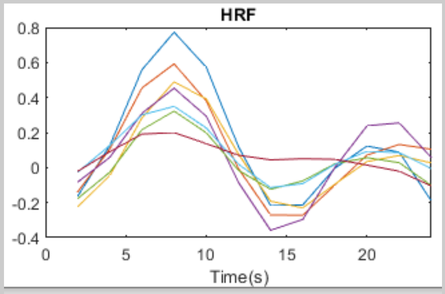
RAW_FILE_NAME = sub-10171_task-rest_bold_space-fsaverage5.R.func

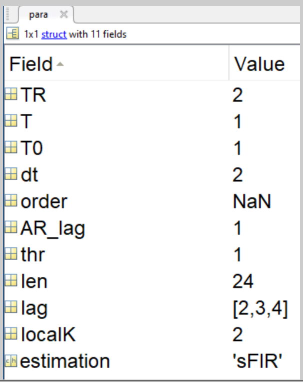
```
>> load('Deconv_ RAW_FILE_NAME_hrf.mat')
>>  figure('color','w');  plot(para.dt*[1:size(hrfa,1)],hrfa);
title('HRF'); xlabel('Time(s)');xlim([0 para.len])
```



Workspace

Name	Value
beta_hrf	14x7 double
event_bold	1x7 cell
event_number	[6;6;5;8;5;5;3]
hrfa	12x7 double
para	1x1 struct
PARA	3x7 double



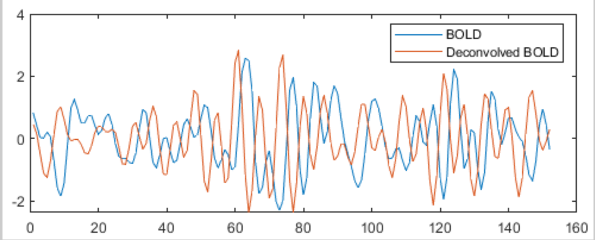
hrf.mat	
Variable	Description
event_number	number of detected spontaneous events
event_bold:	timing information of spontaneous events
PARA	HRF parameters: 1st row: Response Height; 2nd row: Time to peak; 3rd row: Width at half peak
para	input parameters for HRF estimation  para 1x1 struct with 11 fields Field / Value TR 2 T 1 T0 1 dt 2 order NaN AR_lag 1 thr 1 len 24 lag [2,3,4] localK 2 estimation 'sFIR'
hrfa	All HRF

beta_hrf	beta_hrf = [beta coefficients; estimated lag]
	i.e. hrfa = beta_hrf(1:end-2,:);
	%HRF baseline value for PSC calculation.
	hrf_baseline = beta_hrf(end-1,:);

```
>> load('Deconv_ RAW_FILE_NAME.mat')
>> figure('color','w');plot(zscore(data(:,5)));
>> hold on; plot(zscore(data_deconv(:,5)));legend({'BOLD','Deconvolved BOLD'})
```

Workspace

Name ▲	Value
data	152x7 double
data_deconv	152x7 double
roinfo	7x3 cell



Deconv_RAW_FILE_NAME.mat	
Variable	Description
data	(Denoised) BOLD data
data_deconv	HRF deconvolved BOLD Data
roiinfo	ROI information:

roinfo
7x3 cell

	1	2	3
1	1352x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'	1
2	1861x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'	2
3	1094x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'	3
4	1087x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'	4
5	712x1 do...	'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'	5
6	1041x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'	6
7	2207x1 d...	'E:\spm12\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii'	7

› tool (D:) › sub-10171 › rsHRF_out

Name

- Deconv_sub-10171_task-rest_bold_space-fsaverage5.R.func.mat
- Deconv_sub-10171_task-rest_bold_space-fsaverage5.R.func_hrf.mat
- Deconv_sub-10171_task-rest_bold_space-fsaverage5.R.func_job.mat

Job9: *\spm12\toolbox\rsHRF\demo_jobs\ROI_hrf_FIR_deconv_FC_GC_job9_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? First generate ROI signal then denoise
- ROI definition:
  - atlas mesh: Yeo 7 networks
- HRF basis function: FIR
- Duration of HRF: 24s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 1, i.e. TR = 2 s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t \pm 1) < f(t)$ & $f(t \pm 2) < f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ….];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- Explicit Mask: none.
- The HRF parameters, and deconvolved data will be saved in mat files.
- Connectivity analysis: **ROI to ROI; Data: denoised BOLD and deconvolved BOLD**
  - (1) Functional connectivity (FC) : Pearson correlation.
  - (2) Granger causality (GC) : Pairwise Granger causality.

Help on: (Surface)ROI-wise HRF deconvolution	
Scans	...1\func\sub-10171_task-rest_bold_space-fsaverage5.R.func.gii
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. Despiking	Yes
. Which First?	First generate ROI signal then denoise
ROI (GIfTI)	
. Mesh Atlas	...2\toolbox\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii
HRF estimation	
. HRF Basis Functions	Finite Impulse Response (FIR)
. TR	2
. Length of HRF (seconds)	24
. Number of basis functions (k)	NaN
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	AR(1)
. Microtime resolution	1
. Microtime onset	1
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	1x152 double
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Explicit Mask	
Connectivity Analysis	
. FC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Method	Pearson Correlation
. . Filename prefix	Conn_
. GC	
. . Data for Connectivity	BOLD and Deconvolved BOLD
. . Method	Pairwise GC(Granger causality)
. . Model order for GC	1
. . Parameters for PCGC	[NaN NaN]
. . Filename prefix	Conn_
Output Directory	D:\sub-10171\rsHRF_out
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

- ***Job9 results:***

File Name	Description
Deconv_RAW_FILE_NAME_hrf.mat	HRF and HRF parameters
Deconv_RAW_FILE_NAME.mat	HRF deconvolved BOLD data
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters

- RAW_FILE_NAME = sub-10171_task-rest_bold_space-fsaverage5.R.func

File Name	Description
roiid = []; % ROI information was saved in Deconv_RAW_FILE_NAME.mat	Workspace Name ▲ Value M 1x1 struct roiid []
ROI to ROI	
Conn_RAW_FILE_NAME_pwGC.mat Conn_RAW_FILE_NAME_deconv_pwGC.mat M 1x1 struct with 9 fields Field ▲ Value seed_num 0 nvar 7 nobs 152 order 1 GC_type 'Pairwise GC' ndinfo [NaN,NaN] GC_Matrix *7x7 double* pval_Matrix *7x7 double* GC_Matrix_N *7x7 double*	Pairwise GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test) GC_Matrix_N: transformed GC N: GC value *c* is transformed into *d*, which is considered to be approximately normal. (Geweke 1982)
Conn_RAW_FILE_NAME_Corr_Pearson.mat Conn_RAW_FILE_NAME_deconv_Corr_Pearson.mat M 1x1 struct with 6 fields Field ▲ Value seed_num 0 nvar 7 nobs 152 Matrix_r *7x7 double* Matrix_z *7x7 double* Matrix_pval *7x7 double*	Matric_r: Pearson correlation coefficient) , Matrix_z: Fisher's z transformed Pearson correlation coefficient, Matric_pval: p-value (t-test)
Mat-files	
Deconv_RAW_FILE_NAME_job.mat	analysis/model parameters
Deconv_RAW_FILE_NAME.mat	HRF deconvolved BOLD data

tool (D:) > sub-10171 > rsHRF_out

Name

- Conn_sub-10171_task-rest_bold_space-fsaverage5.R.func_Corr_Pearson.mat
- Conn_sub-10171_task-rest_bold_space-fsaverage5.R.func_deconv_Corr_Pearson.mat
- Conn_sub-10171_task-rest_bold_space-fsaverage5.R.func_pwGC.mat
- Deconv_sub-10171_task-rest_bold_space-fsaverage5.R.func_hrf.mat
- Conn_sub-10171_task-rest_bold_space-fsaverage5.R.func_deconv_pwGC.mat
- Deconv_sub-10171_task-rest_bold_space-fsaverage5.R.func.mat
- Deconv_sub-10171_task-rest_bold_space-fsaverage5.R.func_job.mat

○ Signals based HRF estimation, deconvolution and connectivity analysis

The time series analysis module in the matlabbatch is called by clicking the ‘Signals’ button in the main menu.

Help on: ROI signal HRF deconvolution	
Data	<-X
Denoising	
. Nuisance Covariates	
. Polynomial Detrending	No
. Band-pass Filter	
. Despiking	No
. Which First?	No ROI analysis
HRF estimation	
. HRF Basis Functions	Canonical HRF (with time and dispersion derivatives)
. TR	<-X
. Length of HRF (seconds)	32
. Number of basis functions (k)	NaN
. Minimum & Maximum delay (seconds)	[4 8]
. Serial correlations	none
. Microtime resolution	1
. Microtime onset	1
. Threshold (SD) for event detection	1
. K (local peak f([-K:K]+t)<=f(t))	2
. Temporal mask for event detection	NaN
. HRF Deconvolution	HRF Deconvolution on Unfiltered Data
Connectivity Analysis	
Output Directory	
Save Data	
. Save Deconvolved Data	Yes
. Save HRF mat-file	Yes
. Save job parameters	Yes
Filename prefix	Deconv_

Demo jobs

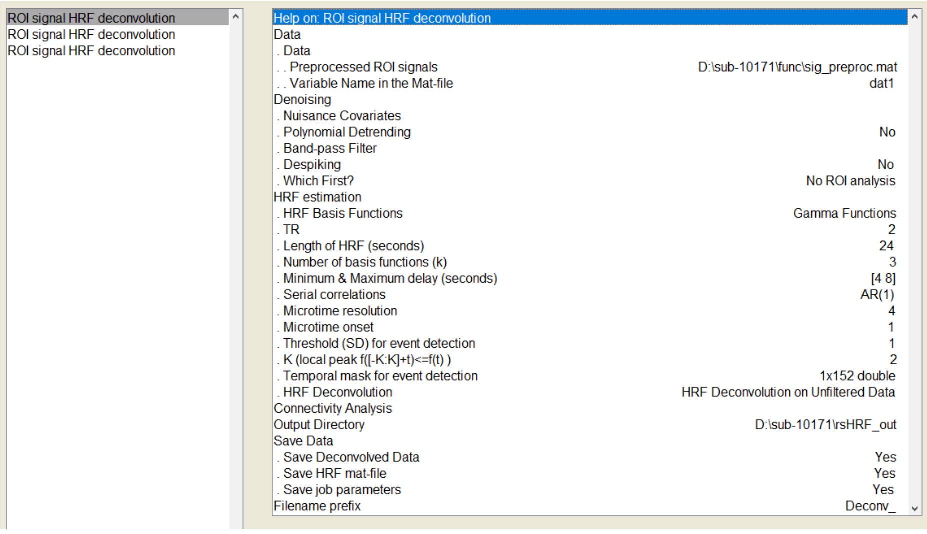
Batch Editor → Load Batch

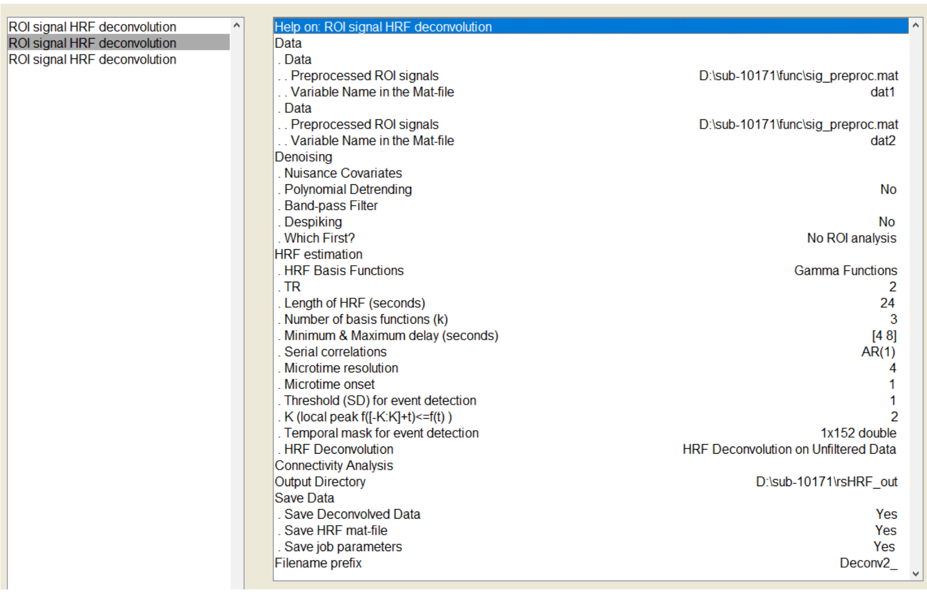
Job10: *\spm12\toolbox\rsHRF\demo_jobs\sig_hrf_gamma_deconv_FC_GC_job10_v23.mat*
This job file included three different jobs, the first two for HRF estimation and deconvolution, the third one further perform connectivity analysis.
(1,2):

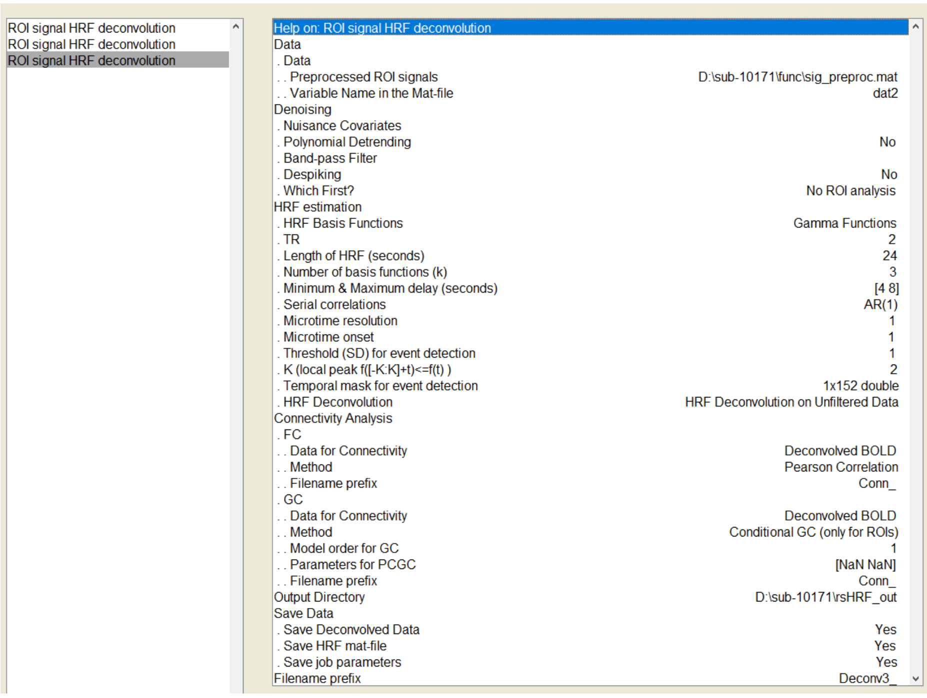
- Input Data:
  - (1) dat1
  - (2) dat1 & dat2
- Denoising: no.
- Which first? No ROI analysis.
- HRF basis function: 3 Gamma functions.
- Duration of HRF: 24s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 4, i.e. TR/4=0.5s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t\pm1)< f(t)$ & $f(t\pm2)< f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ….];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- The HRF parameters, and deconvolved data will be saved in Mat files

3.

- Denoising: no.
- Which first? No ROI analysis.
- HRF basis function: 3 Gamma functions.
- Duration of HRF: 24s;
- Minimum/maximum time delay: 4s, 8s;
- Microtime resolution for onset estimation: 1, i.e. TR2s ;
- Serial correlation model: AR(1);
- Threshold for point process detection: 1, i.e. mean + 1*SD;
- Local peak identification: as a 'spontaneous' event, the detected point process (t) should also be the local peak ($f(t\pm1)< f(t)$ & $f(t\pm2)< f(t)$).
- Temporal mask to exclude spurious events: [1 1 1 0 1 1 ….];
- HRF estimation from denoised data (1,2,3), but HRF deconvolution will be performed on the denoised data (1) without temporal filtering.
- The HRF parameters, and deconvolved data will be saved in Mat files (prefix: Deconv2).
- Connectivity analysis: **ROI to ROI; Data: deconvolved BOLD**
  - (1) Functional connectivity (FC) : Pearson correlation.
  - (2) Granger causality (GC) : Conditional Granger causality.


ROI signal HRF deconvolution
ROI signal HRF deconvolution
ROI signal HRF deconvolution
Help on: ROI signal HRF deconvolution
Data
. Data
. . Preprocessed ROI signals D:\sub-10171\func\sig_preproc.mat
. . Variable Name in the Mat-file dat1
Denoising
. Nuisance Covariates
. Polynomial Detrending No
. Band-pass Filter
. Despiking No
. Which First? No ROI analysis
HRF estimation
. HRF Basis Functions Gamma Functions
. TR 2
. Length of HRF (seconds) 24
. Number of basis functions (k) 3
. Minimum & Maximum delay (seconds) [4 8]
. Serial correlations AR(1)
. Microtime resolution 4
. Microtime onset 1
. Threshold (SD) for event detection 1
. K (local peak f([-K:K]+t)<=f(t)) 2
. Temporal mask for event detection 1x152 double
. HRF Deconvolution HRF Deconvolution on Unfiltered Data
Connectivity Analysis
Output Directory D:\sub-10171\rsHRF_out
Save Data
. Save Deconvolved Data Yes
. Save HRF mat-file Yes
. Save job parameters Yes
Filename prefix Deconv_


ROI signal HRF deconvolution
ROI signal HRF deconvolution
ROI signal HRF deconvolution
Help on: ROI signal HRF deconvolution
Data
. Data
. . Preprocessed ROI signals D:\sub-10171\func\sig_preproc.mat
. . Variable Name in the Mat-file dat1
. Data
. . Preprocessed ROI signals D:\sub-10171\func\sig_preproc.mat
. . Variable Name in the Mat-file dat2
Denoising
. Nuisance Covariates
. Polynomial Detrending No
. Band-pass Filter
. Despiking No
. Which First? No ROI analysis
HRF estimation
. HRF Basis Functions Gamma Functions
. TR 2
. Length of HRF (seconds) 24
. Number of basis functions (k) 3
. Minimum & Maximum delay (seconds) [4 8]
. Serial correlations AR(1)
. Microtime resolution 4
. Microtime onset 1
. Threshold (SD) for event detection 1
. K (local peak f([-K:K]+t)<=f(t)) 2
. Temporal mask for event detection 1x152 double
. HRF Deconvolution HRF Deconvolution on Unfiltered Data
Connectivity Analysis
Output Directory D:\sub-10171\rsHRF_out
Save Data
. Save Deconvolved Data Yes
. Save HRF mat-file Yes
. Save job parameters Yes
Filename prefix Deconv2_


ROI signal HRF deconvolution
ROI signal HRF deconvolution
ROI signal HRF deconvolution
Help on: ROI signal HRF deconvolution
Data
. Data
. . Preprocessed ROI signals D:\sub-10171\func\sig_preproc.mat
. . Variable Name in the Mat-file dat2
Denoising
. Nuisance Covariates
. Polynomial Detrending No
. Band-pass Filter
. Despiking No
. Which First? No ROI analysis
HRF estimation
. HRF Basis Functions Gamma Functions
. TR 2
. Length of HRF (seconds) 24
. Number of basis functions (k) 3
. Minimum & Maximum delay (seconds) [4 8]
. Serial correlations AR(1)
. Microtime resolution 1
. Microtime onset 1
. Threshold (SD) for event detection 1
. K (local peak f([-K:K]+t)<=f(t)) 2
. Temporal mask for event detection 1x152 double
. HRF Deconvolution HRF Deconvolution on Unfiltered Data
Connectivity Analysis
. FC
. . Data for Connectivity Deconvolved BOLD
. . Method Pearson Correlation
. . Filename prefix Conn_
. GC
. . Data for Connectivity Deconvolved BOLD
. . Method Conditional GC (only for ROIs)
. . Model order for GC 1
. . Parameters for PCGC [NaN NaN]
. . Filename prefix Conn_
Output Directory D:\sub-10171\rsHRF_out
Save Data
. Save Deconvolved Data Yes
. Save HRF mat-file Yes
. Save job parameters Yes
Filename prefix Deconv3_

- ***Job10 results:***

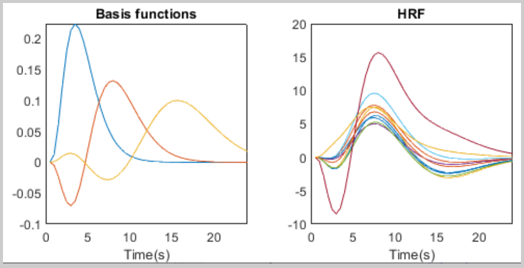
File Name	Description
Deconv_combROI_RAW_FILE_NAME_hrf.mat Deconv2_ combROI_RAW_FILE_NAME_hrf.mat Deconv3_ combROI_RAW_FILE_NAME_hrf.mat	HRF and HRF parameters
Deconv_ combROI_RAW_FILE_NAME.mat Deconv2_ combROI_RAW_FILE_NAME.mat Deconv3_ combROI_RAW_FILE_NAME.mat	HRF deconvolved BOLD data
Deconv_ combROI_RAW_FILE_NAME_job.mat Deconv2_ combROI_RAW_FILE_NAME_job.mat Deconv3_ combROI_RAW_FILE_NAME_job.mat	analysis/model parameters

- RAW_FILE_NAME = sig_preproc

```
>> load('Deconv_ RAW_FILE_NAME_hrf.mat')
>> figure('color','w');subplot(1,2,1);plot(para.dt*[1:size(bf,1)],bf);title('Basis functions');
xlabel('Time(s)');xlim([0 para.len])
>> subplot(1,2,2);
plot(para.dt*[1:size(bf,1)],hrfa(:,[1:10]));title('HRF');xlabel('Time(s)');xlim([0 para.len])
```

Workspace

Name	Value
beta_hrf	5x264 double
bf	49x3 double
event_bold	1x264 cell
event_number	264x1 double
hrfa	49x264 double
para	1x1 struct
PARA	3x264 double



load('Deconv_ RAW_FILE_NAME_hrf.mat')	
Variable	Description
event_number	number of detected spontaneous events
event_bold:	timing information of spontaneous events
PARA	HRF parameters: 1st row: Response Height; 2nd row: Time to peak; 3rd row: Width at half peak
para	input parameters for HRF estimation para 1x1 struct with 11 fields Field / Value TR 2 T 4 T0 4 dt 0.5000 order 3 AR_lag 1 thr 1 len 24 lag [8,9,10,11,12,13,14,15,16] localK 2 name 'Gamma functions'
hrfa	All HRF
beta_hrf	beta_hrf = [beta coefficients; estimated lag] i.e. hrfa = beta_hrf(1:end-2,:);

	%HRF baseline value for PSC calculation. hrf_baseline = beta_hrf(end-1,:);

File Name	Description
ROI to ROI (load Deconv2_RAW_FILE_NAME.mat)	
Conn_RAW_FILE_NAME_deconv_CGC.mat M × 1x1 struct with 8 fields Field / Value seed_num 0 nvar 7 nobs 152 order 1 GC_type 'Conditional GC' ndinfo [NaN,NaN] GC_Matrix *7x7 double* pval_Matrix *7x7 double*	Pairwise GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test)
Conn_RAW_FILE_NAME_deconv_Corr_Pearson.mat M × 1x1 struct with 6 fields Field / Value seed_num 0 nvar 7 nobs 152 Matrix_r *7x7 double* Matrix_z *7x7 double* Matrix_pval *7x7 double*	Matric_r: Pearson correlation coefficient) , Matrix_z: Fisher's z transformed Pearson correlation coefficient, Matric_pval: p-value (t-test)

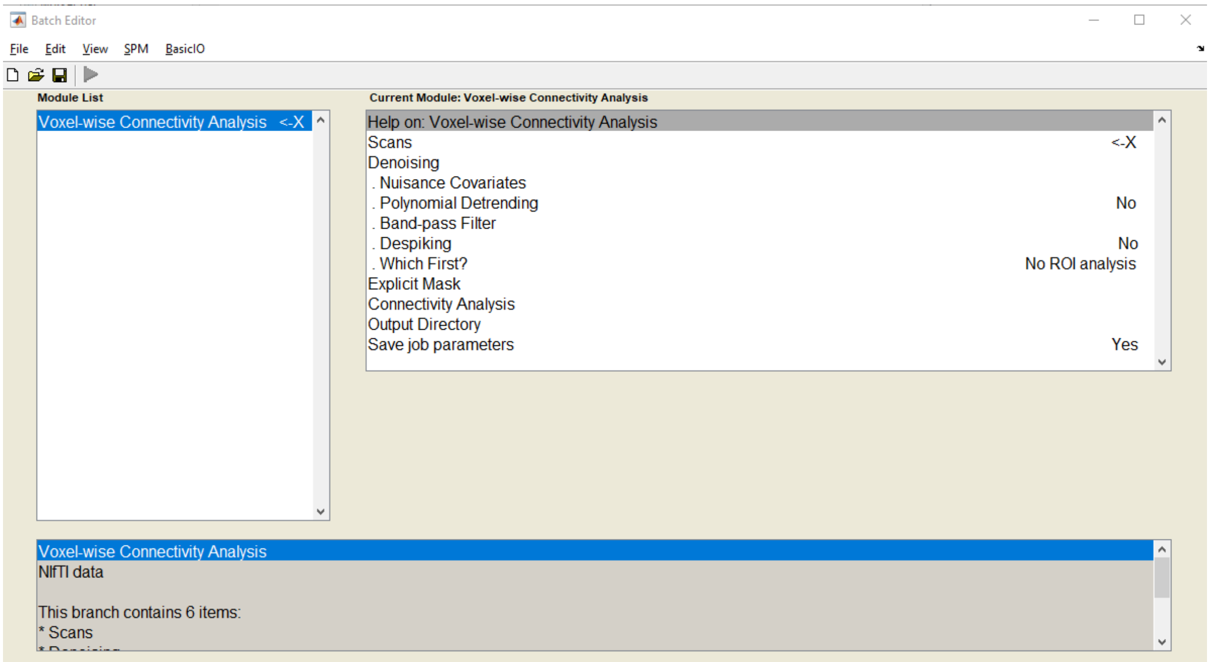
in rsHRF_global_para.m line 20:

%% Combine all input signals (here are dat1, dat2) for connectivity analysis

para.combine_ROI = 1; (default parameter) add '_combROI_' in result file names	para.combine_ROI = 0; add variable name as postfix in result file names, e.g. '_dat1', '_dat2'
› tool (D:) › sub-10171 › rsHRF_out Name Deconv_combROI_sig_preproc.mat Deconv_combROI_sig_preproc_hrf.mat Deconv_combROI_sig_preproc_job.mat Conn_combROI_sig_preproc_deconv_CGC.mat Conn_combROI_sig_preproc_deconv_Corr_Pearson.mat Deconv2_combROI_sig_preproc.mat Deconv2_combROI_sig_preproc_hrf.mat Deconv2_combROI_sig_preproc_job.mat Deconv3_combROI_sig_preproc.mat Deconv3_combROI_sig_preproc_hrf.mat Deconv3_combROI_sig_preproc_job.mat	› tool (D:) › sub-10171 › rsHRF_out Name Deconv_sig_preproc_dat1.mat Deconv_sig_preproc_dat1_hrf.mat Deconv_sig_preproc_dat1_job.mat Deconv2_sig_preproc_dat1_hrf.mat Conn_sig_preproc_dat2_deconv_CGC.mat Conn_sig_preproc_dat2_deconv_Corr_Pearson.mat Deconv2_sig_preproc_dat1.mat Deconv2_sig_preproc_dat1_job.mat Deconv2_sig_preproc_dat2.mat Deconv2_sig_preproc_dat2_hrf.mat Deconv2_sig_preproc_dat2_job.mat Deconv3_sig_preproc_dat2.mat Deconv3_sig_preproc_dat2_hrf.mat Deconv3_sig_preproc_dat2_job.mat

o Voxel-wise connectivity analysis

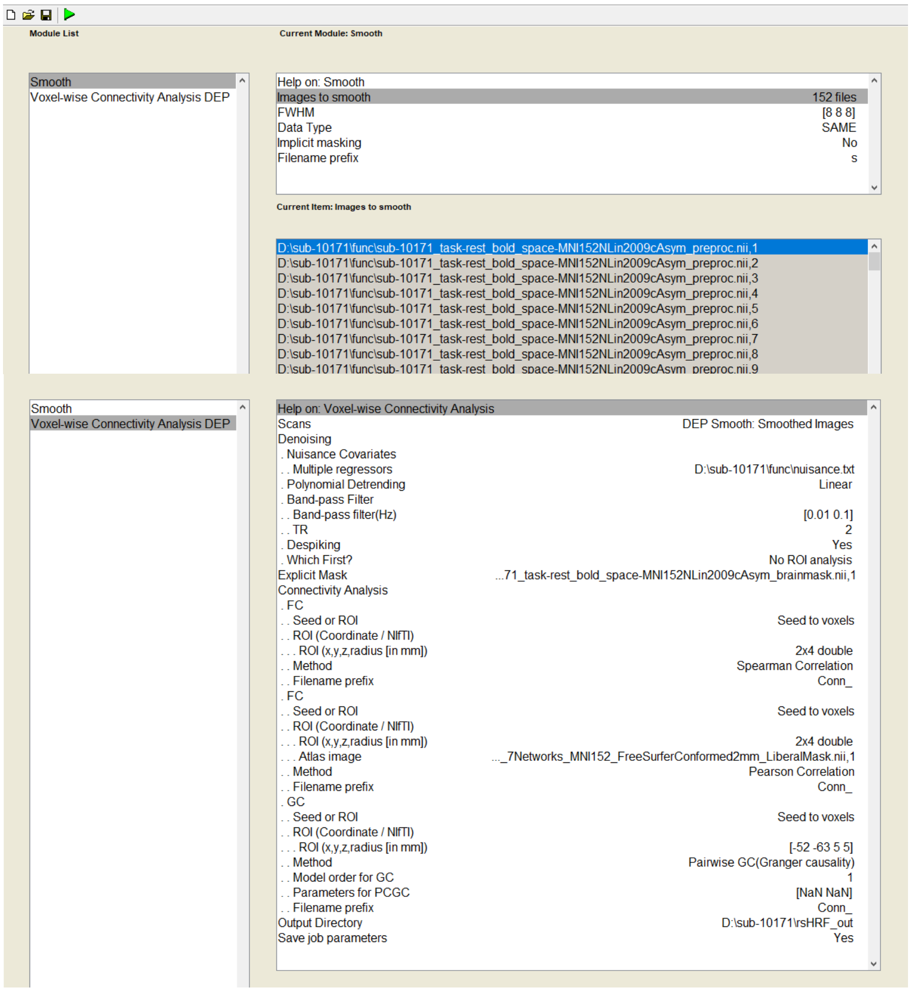
The voxel-wise connectivity analysis module in the matlabbatch is called by clicking the (rsHRF conn) 'Voxels' button in the main menu.



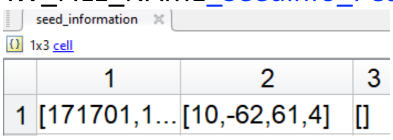
Demo jobs
Batch Editor → Load Batch

***Job 11**: \spm12\toolbox\rsHRF\demo_jobs\vox_seed_FC_GC_job11_v23.mat*

- Spatial Smooth: Gaussian kernel [8 8 8]
- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? (c)
  - (a) First denoise then generate ROI signal
  - (b) First generate ROI signal then denoise
  - (c) No ROI analysis (default)
    - as seed ROI analysis was included, it will change to (b) <-- (Job11).
- Connectivity analysis:
  - (1~2) Functional connectivity (FC) : seed to voxels analysis.
    - (1) Spearman Correlation (2) Pearson Correlation
    - seed of interest information defined as: [x, y, z, radius]
    - two seeds: [10 -62 61 4;
      -52 -63 5 5].
  - (3) Granger Causality (GC): seed to voxels analysis.
    - pairwise GC, model order = 1;



- ***Job11 results:***

File Name	Description
RAW_FILE_NAME_conn_job.mat	Analysis parameters
Conn2_RAW_FILE_NAME_Seedinfo_Pearson.mat  seed_information 1x3 cell 1: [171701,1... 2: [10,-62,61,4] 3: [] Conn2_RAW_FILE_NAME_corr_Pearson.gii Conn2_RAW_FILE_NAME_Z_Pearson.gii	Seed region: sphere radius 4mm, center at [10 -62 61] corr_Pearson: Pearson correlation coefficient , Z_Pearson: Fisher's z transformed Pearson correlation coefficient
Conn*_RAW_FILE_NAME_Seedinfo_Pearson.mat Conn*_RAW_FILE_NAME_corr_Pearson.nii Conn*_RAW_FILE_NAME_Z_Pearson.nii Conn*_RAW_FILE_NAME_Seedinfo_Spearman.mat Conn*_RAW_FILE_NAME_corr_Spearman.nii Conn*_RAW_FILE_NAME_Z_Spearman.nii	Seed based functional connectivity
Conn_ RAW_FILE_NAME_SeedInfo_pwGC_order1.mat Conn_ RAW_FILE_NAME_inflow_N_pwGC_order1.nii Conn_ RAW_FILE_NAME_inflow_pval_pwGC_order1.nii Conn_ RAW_FILE_NAME_inflow_pwGC_order1.nii Conn_ RAW_FILE_NAME_outflow_N_pwGC_order1.nii Conn_ RAW_FILE_NAME_outflow_pval_pwGC_order1.nii Conn_ RAW_FILE_NAME_outflow_pwGC_order1.nii	pwGC: Pairwise GC _order1: Model order = 1 inflow = others to seed region outflow = seed region to others pval: p-value (F-test) *_N_pwGC: transformed GC N: GC value *c* is transformed into *d*, which is considered to be approximately normal. (Geweke 1982)

RAW_FILE_NAME = ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc

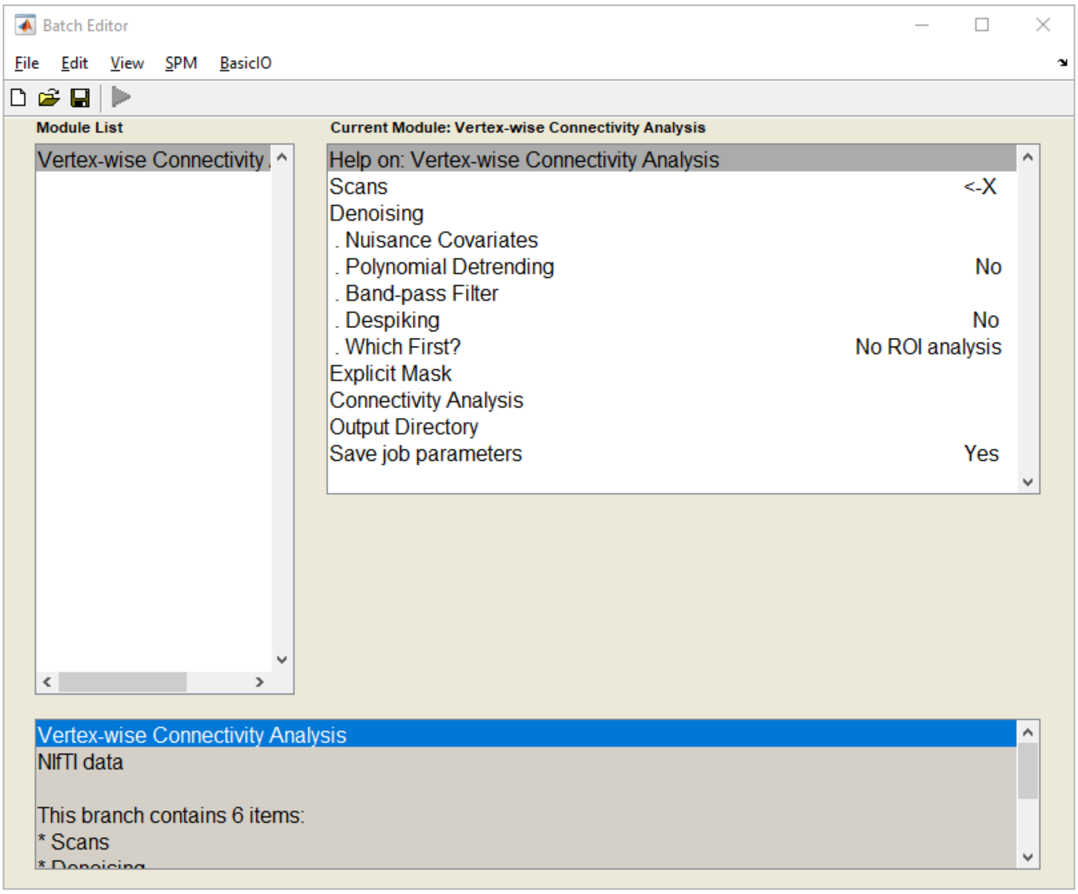
> tool (D:) > sub-10171 > rsHRF_out

Name

Conn_1_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_1_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Spearman.nii
Conn_1_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_1_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Spearman.mat
Conn_1_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_1_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Spearman.nii
Conn_2_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_2_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Spearman.nii
Conn_2_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_2_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Spearman.mat
Conn_2_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_2_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Spearman.nii
Conn_3_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_3_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_3_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_4_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_4_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_4_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_5_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_5_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_5_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_6_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_6_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_6_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_7_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_7_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_7_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_8_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_8_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_8_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_9_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_corr_Pearson.nii
Conn_9_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_Pearson.mat
Conn_9_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Z_Pearson.nii
Conn_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_inflow_N_pwGC_order1.nii
Conn_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_inflow_pval_pwGC_order1.nii
Conn_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_inflow_pwGC_order1.nii
Conn_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_outflow_N_pwGC_order1.nii
Conn_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_outflow_pval_pwGC_order1.nii
Conn_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_outflow_pwGC_order1.nii
Conn_ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_SeedInfo_pwGC_order1.mat
ssub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_conn_job.mat

○ Vertex-wise connectivity analysis

The vertex-wise based analysis module in the matlabbatch is called by clicking the (rsHRF conn) ‘Vertices’ button in the main menu.



Demo jobs

Batch Editor → Load Batch

Job 12: *\spm12\toolbox\rsHRF\demo_jobs\vertex_seed_FC_GC_job12_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? (b)
  - (a) First denoise then generate ROI signal
  - (b) First generate ROI signal then denoise
  - (c) No ROI analysis (default)
- Connectivity analysis:
  - Functional connectivity (FC) : seed to vertices analysis.
    - Pearson Correlation
    - seed of interest information defined as: mesh atlas
    - seven seeds: Yeo 7 networks .

Help on: Vertex-wise Connectivity Analysis	
Scans	...ub-10171_task-rest_bold_space-fsaverage5.L.func.gii
Denoising	
. Nuisance Covariates	
. . Multiple regressors	D:\sub-10171\func\nuisance.txt
. Polynomial Detrending	Linear
. Band-pass Filter	
. . Band-pass filter(Hz)	[0.01 0.1]
. . TR	2
. Despiking	Yes
. Which First?	First generate ROI signal then denoise
Explicit Mask	
Connectivity Analysis	
. FC	
. . Seed or ROI	Seed to vertices
. . ROI (GIfTI)	
. . . Mesh Atlas	...\rsHRF\demo_jobs\lh.Yeo2011_7Networks_N1000.gii
. . Method	Pearson Correlation
. . Filename prefix	Conn_
Output Directory	D:\sub-10171\rsHRF_out
Save job parameters	Yes

- ***Job12 results:***

File Name	Description
RAW_FILE_NAME_conn_job.mat	Analysis parameters
Conn2_RAW_FILE_NAME_Seedinfo_Pearson.mat seed_information 1x3 cell | | 1 | 2 | 3 | | 1 | 1861x1 d... | lh.Yeo2011_7Networks_N1000.gii | 2 | Conn2_RAW_FILE_NAME_corr_Pearson.gii Conn2_RAW_FILE_NAME_Z_Pearson.gii	Seed region: label=**2** in Yeo 7 network corr_Pearson: Pearson correlation coefficient , Z_Pearson: Fisher's z transformed Pearson correlation coefficient
Conn*_RAW_FILE_NAME_Seedinfo_Pearson.mat Conn*_RAW_FILE_NAME_corr_Pearson.gii Conn*_RAW_FILE_NAME_Z_Pearson.gii	Seed based functional connectivity

RAW_FILE_NAME = sub-10171_task-rest_bold_space-fsaverage5.L.func

› tool (D:) › sub-10171 › rsHRF_out

Name

Conn_1_sub-10171_task-rest_bold_space-fsaverage5.L.func_corr_Pearson.gii
Conn_1_sub-10171_task-rest_bold_space-fsaverage5.L.func_SeedInfo_Pearson.mat
Conn_1_sub-10171_task-rest_bold_space-fsaverage5.L.func_Z_Pearson.gii
Conn_2_sub-10171_task-rest_bold_space-fsaverage5.L.func_corr_Pearson.gii
Conn_2_sub-10171_task-rest_bold_space-fsaverage5.L.func_SeedInfo_Pearson.mat
Conn_2_sub-10171_task-rest_bold_space-fsaverage5.L.func_Z_Pearson.gii
Conn_3_sub-10171_task-rest_bold_space-fsaverage5.L.func_corr_Pearson.gii
Conn_3_sub-10171_task-rest_bold_space-fsaverage5.L.func_SeedInfo_Pearson.mat
Conn_3_sub-10171_task-rest_bold_space-fsaverage5.L.func_Z_Pearson.gii
Conn_4_sub-10171_task-rest_bold_space-fsaverage5.L.func_corr_Pearson.gii
Conn_4_sub-10171_task-rest_bold_space-fsaverage5.L.func_SeedInfo_Pearson.mat
Conn_4_sub-10171_task-rest_bold_space-fsaverage5.L.func_Z_Pearson.gii
Conn_5_sub-10171_task-rest_bold_space-fsaverage5.L.func_corr_Pearson.gii
Conn_5_sub-10171_task-rest_bold_space-fsaverage5.L.func_SeedInfo_Pearson.mat
Conn_5_sub-10171_task-rest_bold_space-fsaverage5.L.func_Z_Pearson.gii
Conn_6_sub-10171_task-rest_bold_space-fsaverage5.L.func_corr_Pearson.gii
Conn_6_sub-10171_task-rest_bold_space-fsaverage5.L.func_SeedInfo_Pearson.mat
Conn_6_sub-10171_task-rest_bold_space-fsaverage5.L.func_Z_Pearson.gii
Conn_7_sub-10171_task-rest_bold_space-fsaverage5.L.func_corr_Pearson.gii
Conn_7_sub-10171_task-rest_bold_space-fsaverage5.L.func_SeedInfo_Pearson.mat
Conn_7_sub-10171_task-rest_bold_space-fsaverage5.L.func_Z_Pearson.gii
sub-10171_task-rest_bold_space-fsaverage5.L.func_conn_job.mat

○ (Volume) ROI-wise connectivity analysis

The volume based ROI analysis module in the matlabbatch is called by clicking the (rsHRF conn) ‘ROIs-volume’ button in the main menu.

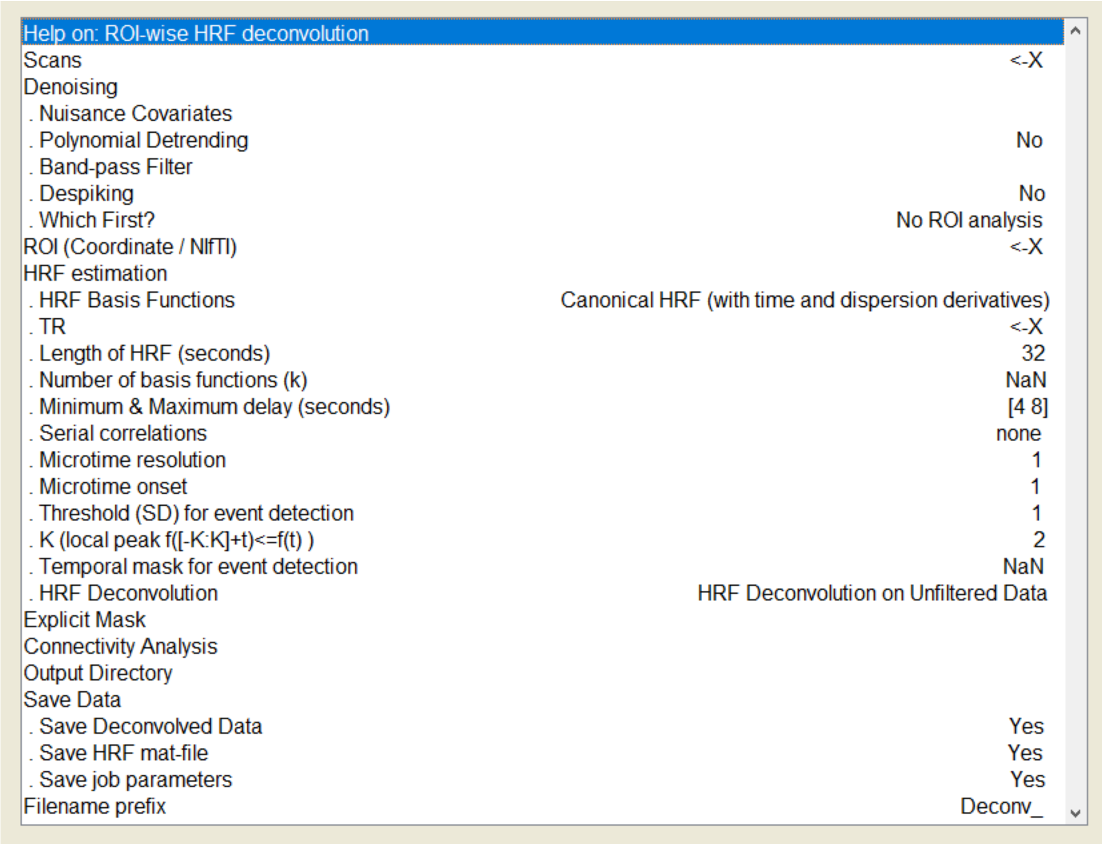


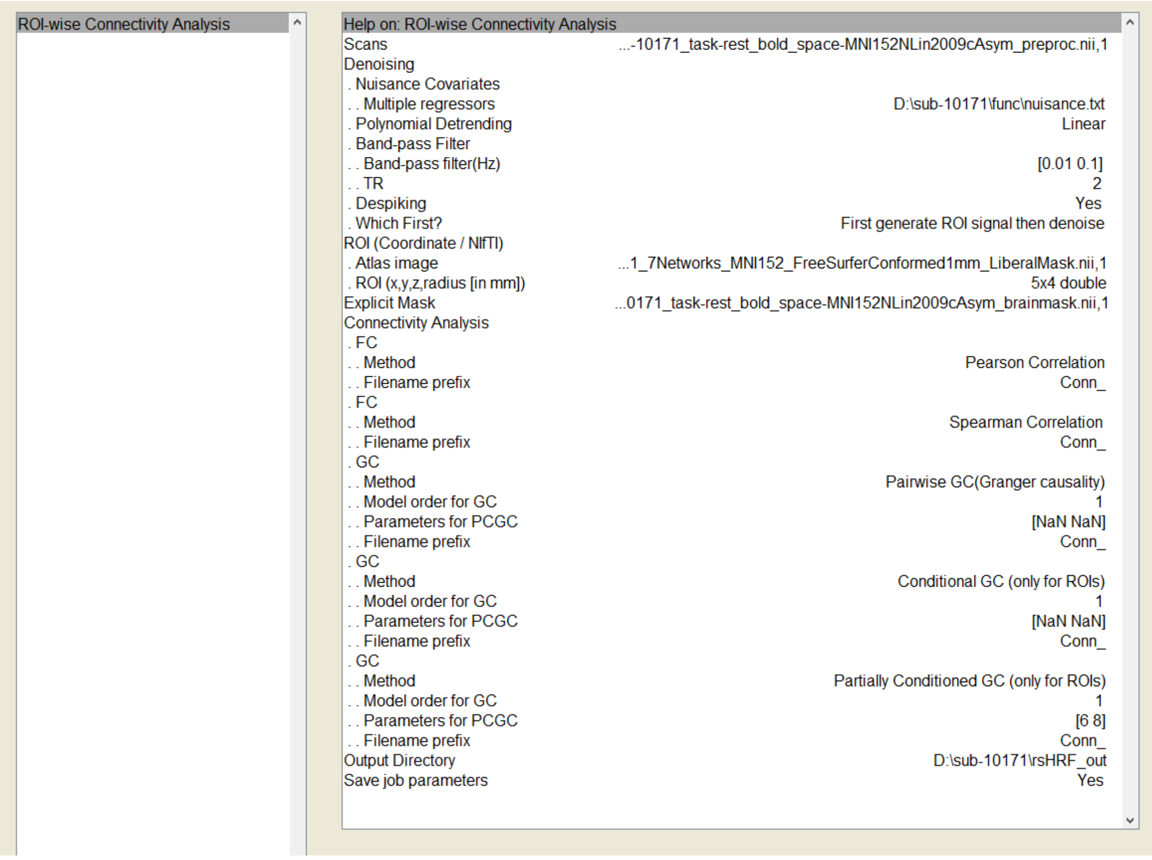
Figure : matlabbatch GUI for volume based ROI connectivity analysis.

Demo jobs

Batch Editor → Load Batch

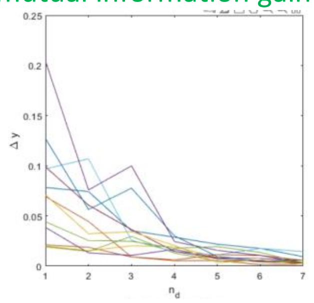
Job 13: *\spm12\toolbox\rsHRF\demo_jobs\ROI_FC_GC_job13_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? First generate ROI signal then denoise
- ROI definition:
  - atlas image: Yeo 7 networks
  - MNI coordinates+radius(sphere): 5 x 4
- Connectivity analysis:
  - (1) Pearson Correlation (2)Spearman Correlation
  - (3) Pairwise GC (4)Conditional GC (5) Partially conditioned GC



- ***Job13 results:***

File Name	Description
RAW_FILE_NAME_conn_job.mat RAW_FILE_NAME_roinfo.mat	analysis/model parameters
Conn_RAW_FILE_NAME_pwGC.mat	Pairwise GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test) GC_Matrix_N: transformed GC N: GC value *c* is transformed into *d*,

M 1x1 struct with 9 fields Field / Value seed_num 0 nvar 12 nobs 152 order 1 GC_type 'Pairwise GC' ndinfo [NaN,NaN] GC_Matrix *12x12 double* pval_Matrix *12x12 double* GC_Matrix_N *12x12 double*	which is considered to be approximately normal. (Geweke 1982)
Conn_RAW_FILE_NAME_CGC.mat M 1x1 struct with 8 fields Field / Value seed_num 0 nvar 12 nobs 152 order 1 GC_type 'Conditional GC' ndinfo [NaN,NaN] GC_Matrix *12x12 double* pval_Matrix *12x12 double*	Conditional GC In variable M: GC_Matrix: GC Value pval_Matrix: p-value (F-test) variable roiid : ROI information ROI 1: sphere radius 4mm, center at [10 -62 61] … ROI 12: sphere radius 4mm, center at [29 -5 54]
Conn_RAW_FILE_NAME_PCGC.mat M 1x1 struct with 10 fields Field / Value seed_num 0 nvar 12 nobs 152 order 1 GC_type 'Partially Conditioned GC' ndinfo [6,8] information_gain *12x8 double* condition_id *12x8 double* GC_Matrix *12x12 double* pval_Matrix *12x12 double*	Partially Conditioned GC GC_Matrix: GC Value pval_Matrix: p-value (F-test) condition_id: (nvar x ndmax) index of conditional variables, information_gain: mutual information gain[1]  (Marinazzo et al. 2012; Wu et al. 2013)
Conn_combROI_RAW_FILE_NAME_Corr_Pearson.mat Field / Value seed_num 0 nvar 12 nobs 152 Matrix_r *12x12 double* Matrix_z *12x12 double* Matrix_pval *12x12 double* Conn_combROI_RAW_FILE_NAME_Corr_Spearman.mat	Matric_r: Pearson/Spearman correlation coefficient) , Matrix_z: Fisher's z transformed Pearson correlation coefficient, Matric_pval: p-value (t-test)

RAW_FILE_NAME = sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc

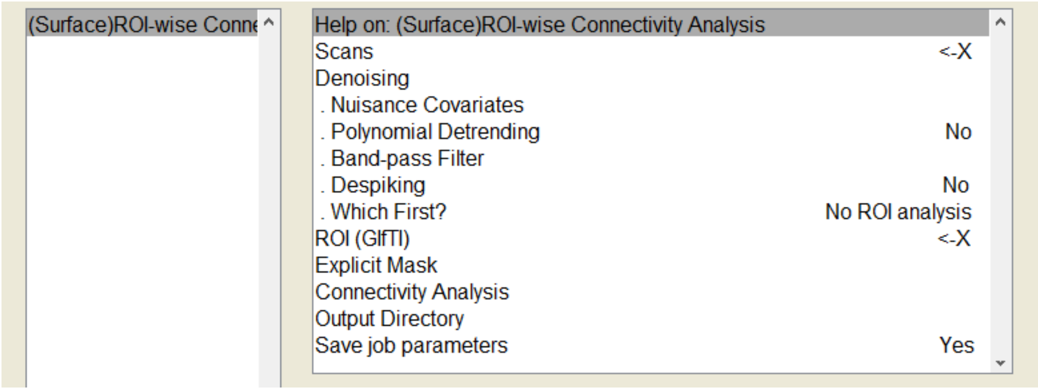
[1] plot(diff(M.information_gain')); xlabel('n_d'); ylabel('\Delta y')

tool (D:) › sub-10171 › rsHRF_out

Name
- Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_CGC.mat
- Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Corr_Pearson.mat
- Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_Corr_Spearman.mat
- Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_PCGC.mat
- Conn_sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_pwGC.mat
- sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_conn_job.mat
- sub-10171_task-rest_bold_space-MNI152NLin2009cAsym_preproc_roinfo.mat

○ (Surface) ROI-wise connectivity analysis

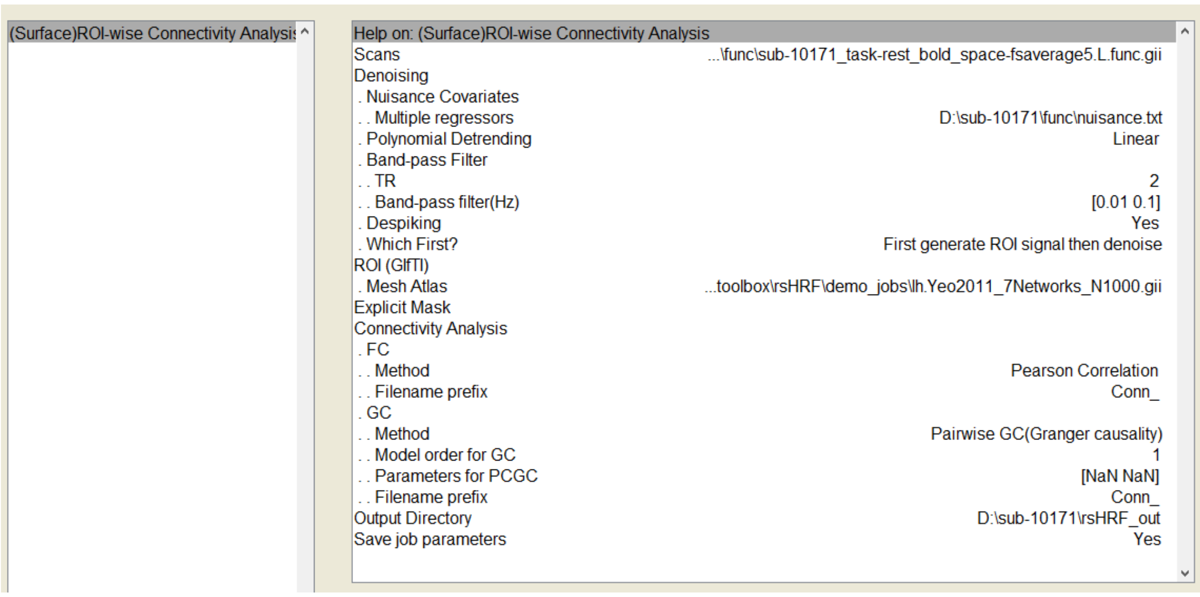
The surface based ROI analysis module in the matlabbatch is called by clicking the (rsHRF conn) 'ROIs-surface' button in the main menu.



Demo jobs
Batch Editor → Load Batch

Job 14: *\spm12\toolbox\rsHRF\demo_jobs\vertex_ROI_FC_GC_job14_v23.mat*

- Denoising: (1) remove motion, physiological confounds---aCompcor (saved in nuisance.txt), Linear Polynomial detrending; (2) Band-pass filter (0.01~0.1 Hz); (3) Despking.
- Which first? First generate ROI signal then denoise
- ROI definition:
    - atlas image: Yeo 7 networks
    - MNI coordinates+radius(sphere): 5 x 4
- Connectivity analysis:
    - (1) Pearson Correlation (2)Spearman Correlation
    - (3) Pairwise GC (4)Conditional GC (5) Partially conditioned GC



- ***Job14 results:***

File Name	Description
RAW_FILE_NAME_conn_job.mat RAW_FILE_NAME_roinfo.mat	analysis/model parameters
Conn_RAW_FILE_NAME_pwGC.mat 1x1 struct with 9 fields Field / Value seed_num 0 nvar 7 nobs 152 order 1 GC_type 'Pairwise GC' ndinfo [NaN,NaN] GC_Matrix *7x7 double* pval_Matrix *7x7 double* GC_Matrix_N *7x7 double*	Pairwise GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test) GC_Matrix_N: transformed GC N: GC value *c* is transformed into *d*, which is considered to be approximately normal. (Geweke 1982)
Conn_RAW_FILE_NAME_Corr_Pearson.mat 1x1 struct with 6 fields Field / Value seed_num 0 nvar 7 nobs 152 Matrix_r *7x7 double* Matrix_z *7x7 double* Matrix_pval *7x7 double*	Matric_r: Pearson/Spearman correlation coefficient) , Matrix_z: Fisher's z transformed Pearson correlation coefficient, Matric_pval: p-value (t-test)

RAW_FILE_NAME = sub-10171_task-rest_bold_space-fsaverage5.L.func

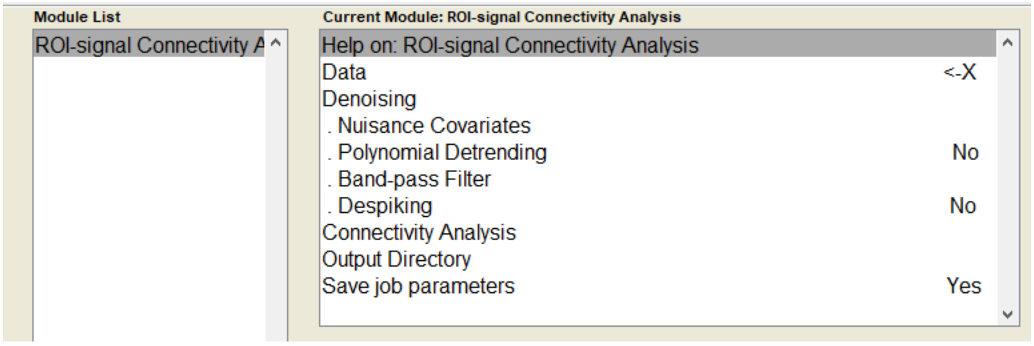
› tool (D:) › sub-10171 › rsHRF_out

Name

Conn_sub-10171_task-rest_bold_space-fsaverage5.L.func_Corr_Pearson.mat
Conn_sub-10171_task-rest_bold_space-fsaverage5.L.func_pwGC.mat
sub-10171_task-rest_bold_space-fsaverage5.L.func_conn_job.mat
sub-10171_task-rest_bold_space-fsaverage5.L.func_roinfo.mat

o Signals based connectivity analysis

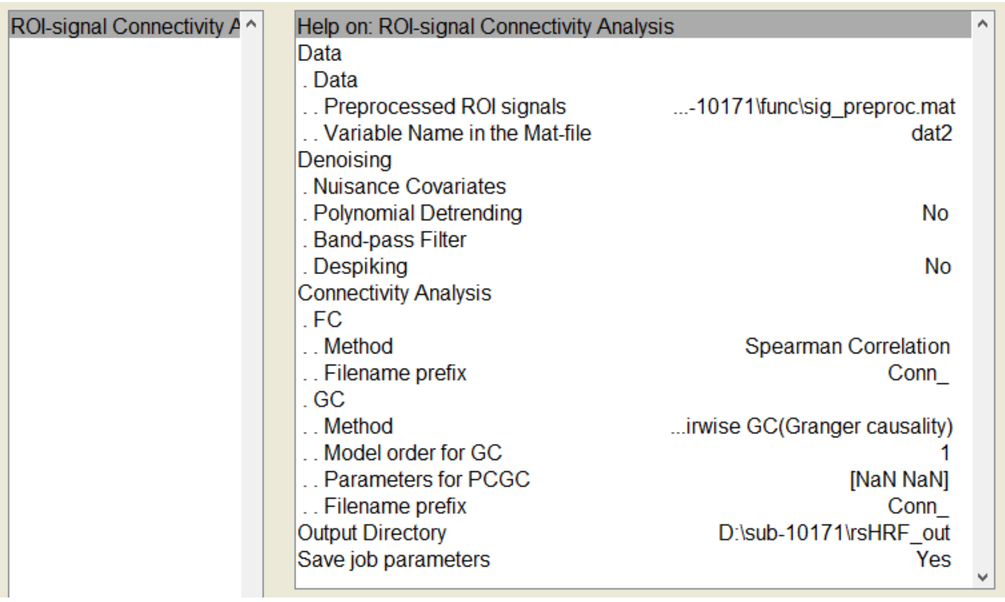
The time series analysis module in the matlabbatch is called by clicking the (rsHRF conn) 'Signals' button in the main menu.



Demo jobs
Batch Editor → Load Batch

Job15: *\spm12\toolbox\rsHRF\demo_jobs\sig _FC_GC_job15_v23.mat*
This job file included three different jobs, the first two for HRF estimation and deconvolution, the third one further perform connectivity analysis.
(1,2):

- Input Data:
  - dat2
- Denoising: no.
- Which first?   No ROI analysis.
- Connectivity analysis: **ROI to ROI**
  - (1) Functional connectivity (FC) : Spearman correlation.
  - (2) Granger causality (GC) : Pairwise Granger causality.



- ***Job15 results:***

File Name	Description
Conn_combROI_RAW_FILE_NAME_job.mat Deconv2_combROI_RAW_FILE_NAME_job.mat Deconv3_combROI_RAW_FILE_NAME_job.mat	analysis/model parameters
Conn_RAW_FILE_NAME_pwGC.mat M 1x1 struct with 9 fields Field / Value seed_num 0 nvar 7 nobs 152 order 1 GC_type 'Pairwise GC' ndinfo [NaN,NaN] GC_Matrix *7x7 double* pval_Matrix *7x7 double* GC_Matrix_N *7x7 double*	Pairwise GC GC_Matrix: GC Value GC_Matrix(x,y) = GC from x to y pval_Matrix: p-value (F-test) GC_Matrix_N: transformed GC N: GC value *c* is transformed into *d*, which is considered to be approximately normal. (Geweke 1982)
Conn_RAW_FILE_NAME_Corr_Pearson.mat M 1x1 struct with 6 fields Field / Value seed_num 0 nvar 7 nobs 152 Matrix_r *7x7 double* Matrix_z *7x7 double* Matrix_pval *7x7 double*	Matric_r: Pearson/Spearman correlation coefficient) , Matrix_z: Fisher's z transformed Pearson correlation coefficient, Matric_pval: p-value (t-test)

RAW_FILE_NAME = sig_preproc

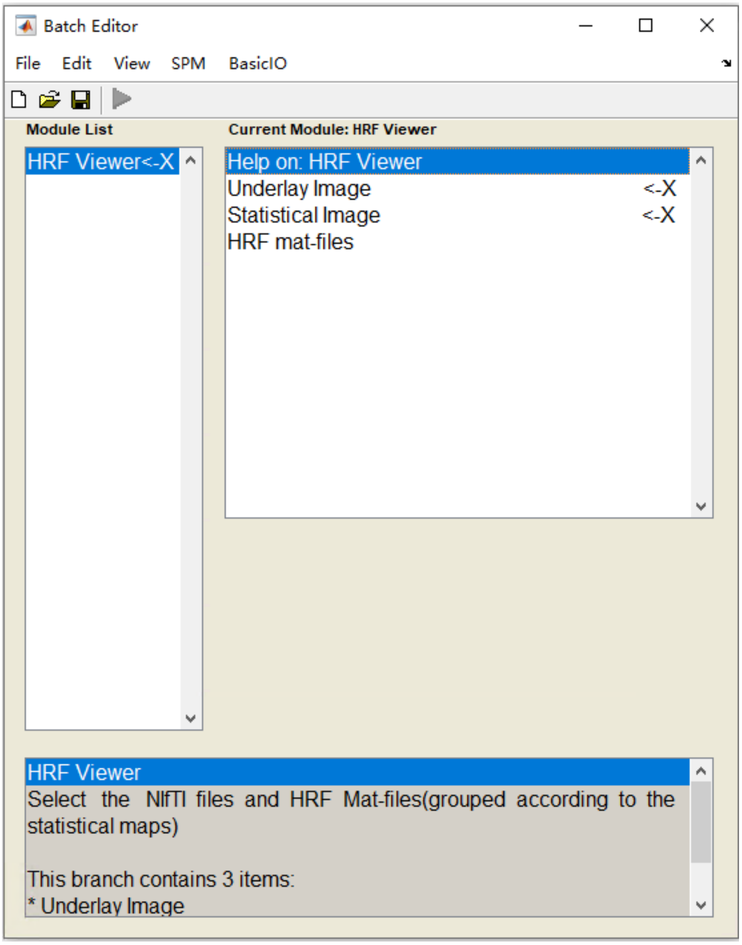
› tool (D:) › sub-10171 › rsHRF_out

Name

- Conn_sub-10171_task-rest_bold_space-fsaverage5.L.func_Corr_Pearson.mat
- Conn_sub-10171_task-rest_bold_space-fsaverage5.L.func_pwGC.mat
- sub-10171_task-rest_bold_space-fsaverage5.L.func_conn_job.mat
- sub-10171_task-rest_bold_space-fsaverage5.L.func_roinfo.mat
- combROI_sig_preproc_conn_job.mat
- Conn_combROI_sig_preproc_Corr_Spearman.mat
- Conn_combROI_sig_preproc_pwGC.mat

○ Display

The HRF visualization module in the matlabbatch is called by clicking the ‘Display’ button in the main menu.

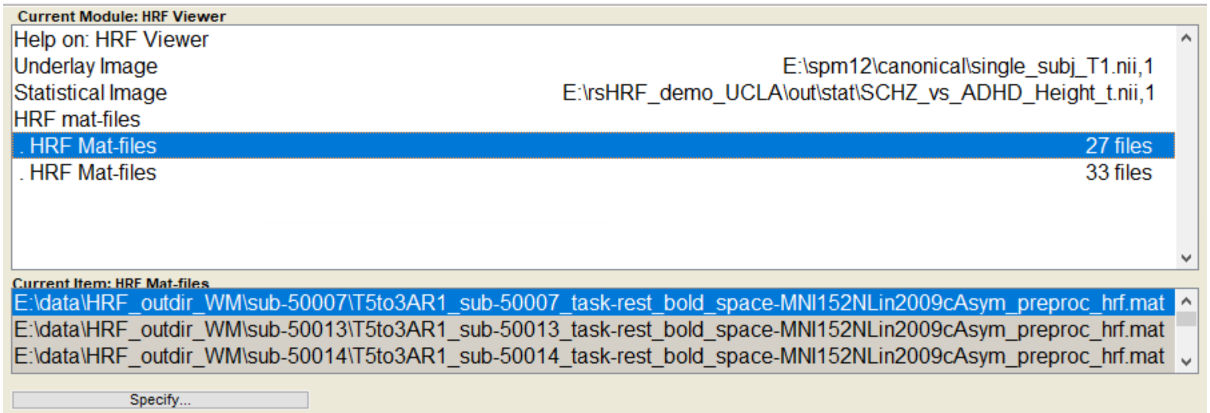


Demo jobs

Batch Editor → Load Batch

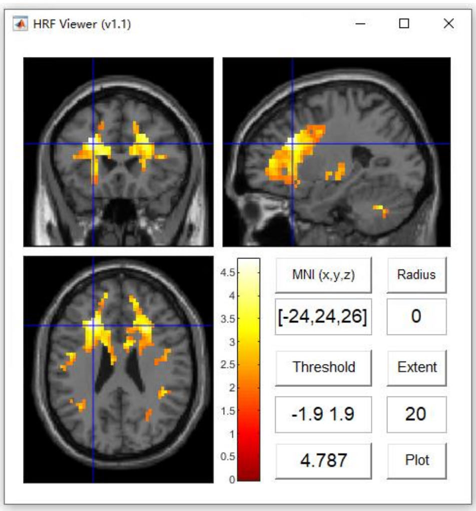
Job15: *\spm12\toolbox\rsHRF\demo_jobs\rsHRF_viewer_v23.mat*

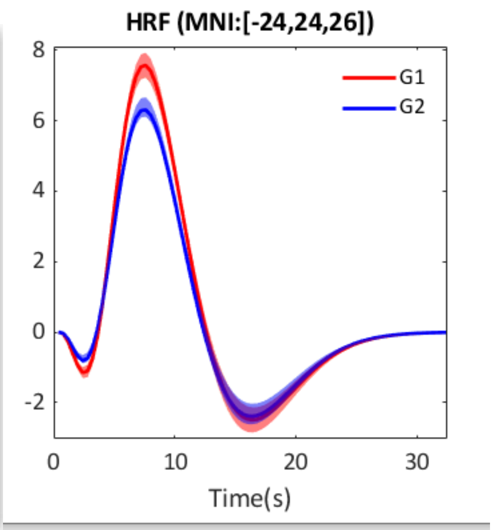
- Underlay Image: an anatomical image, e.g. E:\spm12\canonical\single_subj_T1.nii:
- Statistical Image: (F)T maps.
- HRF mat-files: HRF mat-files generated in voxel-wise HRF analysis
  - Group 1: 27 subjects
  - Group 2: 33 subjects



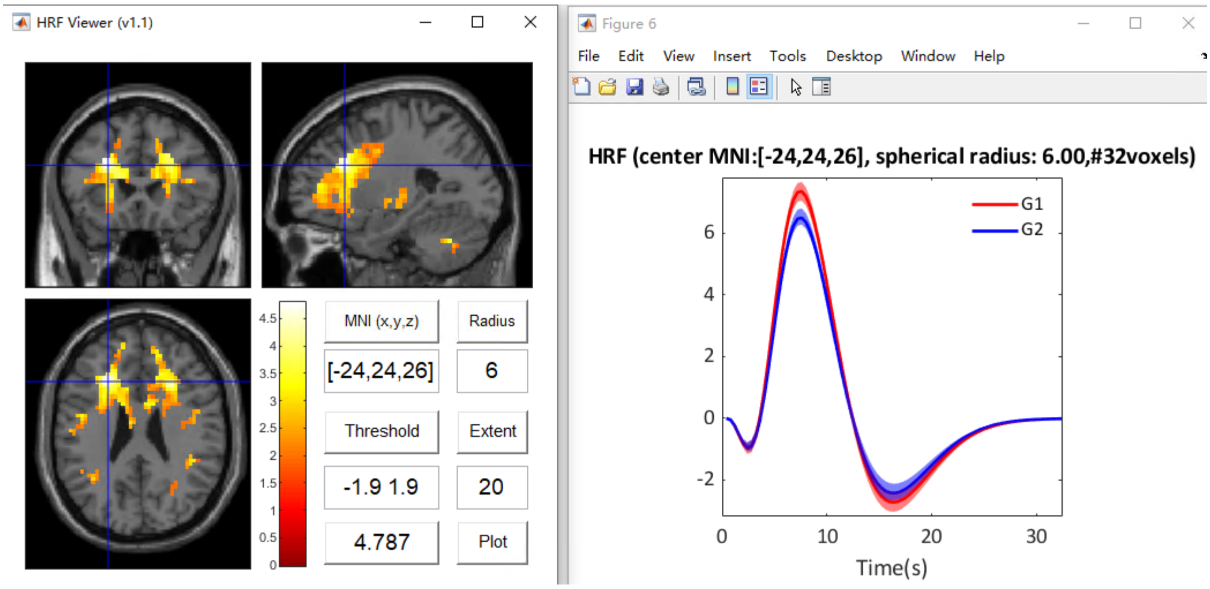
click ‘plot’ to generate one voxel HRF plot

(MNI coordinate: [024 24 26], T-value= 4.787)

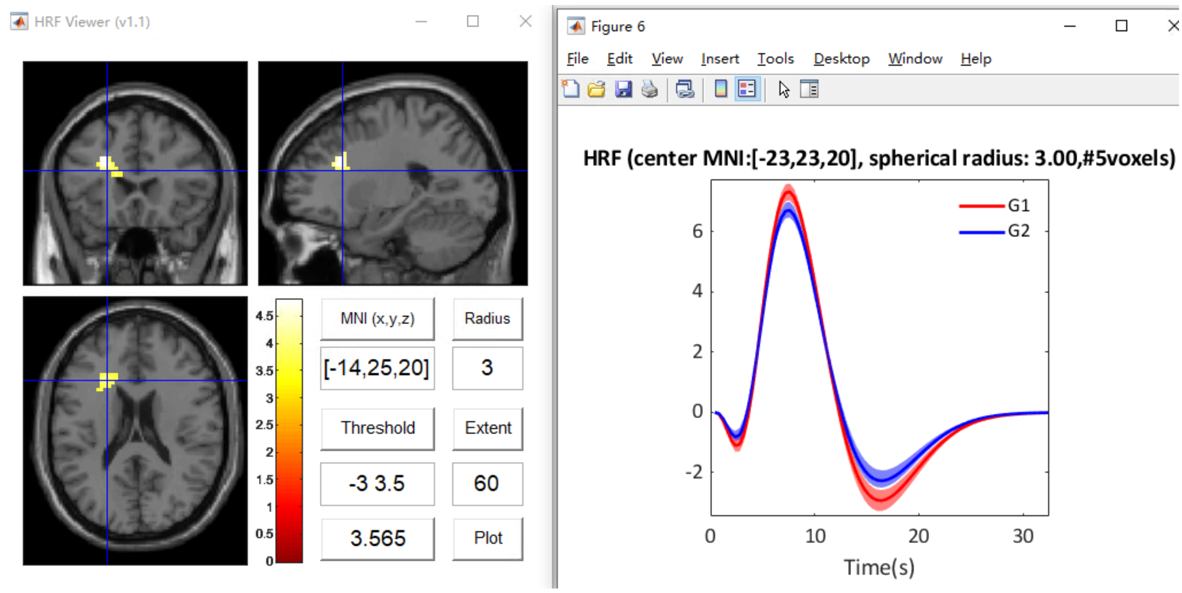




change ‘Radius’ to generate sphere ROI HRF plot



change MNI coordinate (click on the brain or manually edit the coordinates), (negative/positive) Threshold, cluster size(Extent), Sphere Radius.



Standalone demo codes

Some standalone demo codes were designed for the application on two specific examples, i.e., a sample voxel from the Human Connectome Project (HCP; HCP_100307_rfMRI_REST1_LR_Atlas_hp2000_clean_dtseries.mat) and Calcium-BOLD data (calcium_2Hz_15s_stimulation.mat).

- rsHRF_demo_temporal_basis.m

```
% Demo code for HRF deconvolution (Temporal Basis Functions)
clc,clear;close all;
%%===========BOLD-fMRI Data========================
load HCP_100307_rfMRI_REST1_LR_Atlas_hp2000_clean_dtseries.mat
nobs=size(bold_sig,1);
TR = .72;
bands=[0.01 0.1]; %bandpass filter lower and upper bound
data = rsHRF_band_filter(bold_sig,TR,bands);
sigma = std(data);

%%===========PARAMETERS========================
para.TR = TR;
BF = {'Canonical HRF (with time derivative)'
'Canonical HRF (with time and dispersion derivatives)'
'Gamma functions'
'Fourier set'
'Fourier set (Hanning)'};
% choose the set of basis functions THIS MUST BE AN INPUT
bf_id = 3; % Gamma functions
para.name = BF{bf_id};
para.order = 3; % for Gamma functions or Fourier set
temporal_mask = []; % without mask, it means temporal_mask = logical(ones(nobs,1)); i.e.
all time points included. nobs: number of observation = size(data,1). if want to exclude the
first 1~5 time points, let temporal_mask(1:5)=0;
% temporal_mask = logical(ones(nobs,1));  temporal_mask(5:15)=0;

para.T  = 3; % magnification factor of temporal grid with respect to TR. i.e. para.T=1 for no
upsampling, para.T=3 for 3x finer grid
para.T0 = 1; % position of the reference slice in bins, on the grid defined by para.T. For
example, if the reference slice is the middle one, then para.T0=fix(para.T/2)
if para.T==1
   para.T0 = 1;
end
para.dt  = para.TR/para.T; % fine scale time resolution.
para.AR_lag = 1; % AR(1) noise autocorrelation.
para.thr = 1; % (mean+) para.thr*standard deviation threshold to detect event.
para.len = 24; % length of HRF, in seconds
min_onset_search = 4; % minimum delay allowed between event and HRF onset
(seconds)
max_onset_search = 8; % maximum delay allowed between event and HRF onset
(seconds)
para.lag  = fix(min_onset_search/para.dt):fix(max_onset_search/para.dt);
%%=============HRF estimation======================
```

```
tic

[beta_hrf, bf, event_bold] = rsHRF_estimation_temporal_basis(data,para,temporal_mask);
hrfa = bf*beta_hrf(1:size(bf,2),:); %HRF
nvar = size(hrfa,2); PARA = zeros(3,nvar);
for voxel_id=1:nvar
    hrf1 = hrfa(:,voxel_id);
    PARA(:,voxel_id) = rsHRF_get_HRF_parameters(hrf1,para.dt); % estimate HRF
parameter
end

toc

%%============HRF deconvolution=====================
disp('Deconvolving HRF ...');
tic
T = round(para.len/TR);
if para.T>1
    hrfa_TR = resample(hrfa,1,para.T);
else
    hrfa_TR = hrfa;
end
hrf=hrfa_TR;

flag_deconv_raw = 0;
if flag_deconv_raw %HRF deconvolution with raw/filtered data
    zdata = zscore(bold_sig);
else
    zdata =  zscore(data);
end
data_deconv = rsHRF_iterative_wiener_deconv(zdata,hrf./sigma);

event_number=length(event_bold{1,1});
toc
disp('Done');


%% example plots
event_plot=nan(1,nobs);
event_plot(event_bold{1,1})=1;
figure(1);plot((1:length(hrfa(:,1)))*TR/para.T,hrfa(:,1),'b');xlabel('Time (s)')
title(['HRF (',BF{bf_id},')'])
figure(2);plot((1:nobs)*TR,zscore(data(:,1)));
hold on;plot((1:nobs)*TR,zscore(data_deconv(:,1)),'r');
stem((1:nobs)*TR,event_plot,'k');legend('BOLD','Deconvolved BOLD','BOLD
events');xlabel('Time (s)')
```

- rsHRF_demo_FIR_sFIR.m

```
% Demo code for HRF deconvolution ( (Smooth) Finite Impulse Response estimation)
clc,clear;close all;

%%===========BOLD-fMRI Data========================

load HCP_100307_rfMRI_REST1_LR_Atlas_hp2000_clean_dtseries.mat
nobs=size(bold_sig,1);
TR = .72;
bands=[0.01 0.1]; %bandpass filter lower and upper bound
data = rsHRF_band_filter(bold_sig,TR,bands);
sigma = std(data);
%%===========PARAMETERS========================
para.TR = TR;
BF = {'FIR'
'sFIR'};
bf_id = 1;
para.estimation = BF{bf_id}; % sFIR
temporal_mask = []; % without mask, it means temporal_mask = logical(ones(nobs,1)); i.e. all time points included. nobs: number of observation = size(data,1). if want to exclude the first 1~5 time points, let temporal_mask(1:5)=0;
% temporal_mask = logical(ones(nobs,1));  temporal_mask(5:15)=0;
para.T  = 1;
para.T0 = 1;
if para.T>1| para.T0>1
    para.T = 1; para.T0 = 1;
end
para.dt  = para.TR/para.T; % fine scale time resolution.
para.AR_lag = 1; % AR(1) noise autocorrelation.
para.thr = 1; % (mean+) para.thr*standard deviation threshold to detect event.
para.len = 20; % length of HRF, in seconds
min_onset_search = 4; % minimum delay allowed between event and HRF onset (seconds)
max_onset_search = 8; % maximum delay allowed between event and HRF onset (seconds)
para.lag  = fix(min_onset_search/para.dt):fix(max_onset_search/para.dt);

%%============HRF estimation======================

tic
[beta_hrf, event_bold] = rsHRF_estimation_FIR(data,para,temporal_mask);
hrfa = beta_hrf(1:end-2,:); %HRF
nvar = size(hrfa,2); PARA = zeros(3,nvar);
for voxel_id=1:nvar
    hrf1 = hrfa(:,voxel_id);
    PARA(:,voxel_id) = rsHRF_get_HRF_parameters(hrf1,para.dt); % estimate HRF parameter
end
toc

%%============HRF deconvolution======================
disp('Deconvolving HRF ...');
tic
```

```
hrf=hrfa(:,1);

flag_deconv_raw = 1;
if flag_deconv_raw %HRF deconvolution with raw/filtered data
   zdata = zscore(bold_sig);
else
   zdata =  zscore(data);
end
data_deconv = rsHRF_iterative_wiener_deconv(zdata,hrf./sigma);

event_number=length(event_bold{1,1});
toc
disp('Done');


%% example plots
event_plot=nan(1,nobs);
event_plot(event_bold{1,1})=1;
figure(1);plot((1:length(hrfa(:,1)))*TR,hrfa(:,1),'b');xlabel('Time (s)')
title(['HRF (',BF{bf_id},')'])
figure(2);plot((1:nobs)*TR,zscore(data(:,1)));
hold on;plot((1:nobs)*TR,zscore(data_deconv(:,1)),'r');
stem((1:nobs)*TR,event_plot,'k');legend('BOLD','Deconvolved BOLD','BOLD
events');xlabel('Time (s)')
```

- rsHRF_demo_impulseest.m

```
% Demo code for HRF deconvolution (Nonparametric impulse response estimations)
clc,clear;close all;

%%===========BOLD-fMRI Data========================

load HCP_100307_rfMRI_REST1_LR_Atlas_hp2000_clean_dtseries.mat
bold_sig = double(bold_sig); % double
nobs=size(bold_sig,1);
TR = .72;
bands=[0.01 0.1]; %bandpass filter lower and upper bound
data = rsHRF_band_filter(bold_sig,TR,bands);

%%===========PARAMETERS========================
para.TR = TR;
options = impulseestOptions; % see impulseestOptions.m for help
options.RegularizationKernel = 'none'; %Regularizing kernel, used for regularized estimates of impulse response for all input-output channels. Regularization reduces variance of estimated model coefficients and produces a smoother response by trading variance for bias
para.options = options;
temporal_mask = []; % without mask, it means temporal_mask = logical(ones(nobs,1)); i.e. all time points included. nobs: number of observation = size(data,1). if want to exclude the first 1~5 time points, let temporal_mask(1:5)=0;
% temporal_mask = logical(ones(nobs,1));  temporal_mask(5:15)=0;
para.T  = 1;
para.T0 = 1;
if para.T>1| para.T0>1
   para.T = 1; para.T0 = 1;
end
para.dt  = para.TR/para.T; % fine scale time resolution.
para.thr = 1; % (mean+) para.thr*standard deviation threshold to detect event.
para.len = 24; % length of HRF, in seconds
min_onset_search = 5; % minimum delay allowed between event and HRF onset (seconds)
max_onset_search = 8; % maximum delay allowed between event and HRF onset (seconds)
para.lag  = fix(min_onset_search/para.dt):fix(max_onset_search/para.dt);

%%============HRF estimation=====================
tic
[data,mu,sigma]=zscore(data);
[beta_hrf, event_bold] = rsHRF_estimation_impulseest(data,para);
hrfa = beta_hrf; %HRF
nvar = size(hrfa,2); PARA = zeros(3,nvar);
for voxel_id=1:nvar
   hrf1 = hrfa(:,voxel_id);
   PARA(:,voxel_id) = rsHRF_get_HRF_parameters(hrf1,para.dt); % estimate HRF parameter
end
toc
%%============HRF deconvolution=====================
disp('Deconvolving HRF ...');
```

```
tic
hrf=hrfa(:,1);

flag_deconv_raw = 1;
if flag_deconv_raw %HRF deconvolution with raw/filtered data
    zdata = zscore(bold_sig);
else
    zdata =  data;
end
data_deconv = rsHRF_iterative_wiener_deconv(zdata,hrf);

event_number=length(event_bold{1,1});
toc
disp('Done');


%% example plots
event_plot=nan(1,nobs);
event_plot(event_bold{1,1})=1;
figure(1);plot((1:length(hrfa(:,1)))*TR/para.T,hrfa(:,1),'b');xlabel('Time (s)')
title('HRF (nonparametric impulse response estimation)')
figure(2);plot((1:nobs)*TR,zscore(data(:,1)));
hold on;plot((1:nobs)*TR,zscore(data_deconv(:,1)),'r');
stem((1:nobs)*TR,event_plot,'k');legend('BOLD','Deconvolved BOLD','BOLD
events');xlabel('Time (s)')
```

- rsHRF_demo_voxel_calcium.m

```
% (Calcium BOLD Data) demo code for HRF deconvolution
clc,clear
%% load calcium data
load('calcium_2Hz_15s_stimulation.mat')

%%===========BOLD-fMRI Data========================
TR = BOLD_time(1);
bands = [0.01 0.1]; %bandpass filter lower and upper bound
data = rsHRF_band_filter(BOLD_calcium',TR,bands);
sigma = std(data);
%%===========PARAMETERS========================
para.TR = TR;

if 1
   BF = {'FIR'
   'sFIR'};
   % choose the set of basis functions THIS MUST BE AN INPUT
   bf_id = 1;
   para.estimation = BF{bf_id}; % sFIR

   para.T  = 1;
   para.T0 = 1;
   if para.T>1| para.T0>1
      para.T = 1; para.T0 = 1;
   end
   flag_FIR = 1;

else

   BF = {'Canonical HRF (with time derivative)'
   'Canonical HRF (with time and dispersion derivatives)'
   'Gamma functions'
   'Fourier set'
   'Fourier set (Hanning)'};
   % choose the set of basis functions THIS MUST BE AN INPUT
   bf_id = 2;
   para.name = BF{bf_id}; % Gamma functions
   para.order = 3; % for Gamma functions or Fourier set

   para.T  = 1; % magnification factor of temporal grid with respect to TR. i.e. para.T=1 for no upsampling, para.T=3 for 3x finer grid
   para.T0 = 1; % position of the reference slice in bins, on the grid defined by para.T. For example, if the reference slice is the middle one, then para.T0=fix(para.T/2)
   if para.T==1
      para.T0 = 1;
   end

   flag_FIR = 0;
end
```

```
temporal_mask = []; % without mask, it means temporal_mask = logical(ones(nobs,1)); i.e.
all time points included. nobs: number of observation = size(data,1). if want to exclude the
first 1~5 time points, let temporal_mask(1:5)=0;
% temporal_mask = logical(ones(nobs,1));  temporal_mask(5:15)=0;

para.dt  = para.TR/para.T; % fine scale time resolution.
para.AR_lag = 1; % AR(1) noise autocorrelation.
para.thr = 1; % (mean+) para.thr*standard deviation threshold to detect event.

para.len = 24; % length of HRF, in seconds

min_onset_search = 2; % minimum delay allowed between event and HRF onset
(seconds)
max_onset_search = 6; % maximum delay allowed between event and HRF onset
(seconds)
para.lag  = fix(min_onset_search/para.dt):fix(max_onset_search/para.dt);

%%=============HRF estimation======================

tic
if flag_FIR
    [beta_hrf, event_bold] = rsHRF_estimation_FIR(data,para,temporal_mask,0);
    hrfa = beta_hrf(1:end-2,:); %HRF
else
    [beta_hrf, bf, event_bold] =
rsHRF_estimation_temporal_basis(data,para,temporal_mask,0);
    hrfa = bf*beta_hrf(1:size(bf,2),:); %HRF
end
nvar = size(hrfa,2); PARA = zeros(3,nvar);
for voxel_id=1:nvar
    hrf1 = hrfa(:,voxel_id);
    PARA(:,voxel_id) = rsHRF_get_HRF_parameters(hrf1,para.dt); % estimate HRF
parameter
end

toc

%%=============HRF deconvolution======================
disp('Deconvolving HRF ...');
tic
T = round(para.len/TR);
if para.T>1
    hrfa_TR = resample(hrfa,1,para.T);
else
    hrfa_TR = hrfa;
end
hrf=hrfa_TR;

flag_deconv_raw = 1;
if flag_deconv_raw %HRF deconvolution with raw/filtered data
    zdata = zscore(BOLD_calcium');
else
    zdata =  zscore(data);
end
```

```
data_deconv = rsHRF_iterative_wiener_deconv(zdata,hrf./sigma,100);

event_number=length(event_bold{1,1});
toc
disp('Done');



%% example plots
nobs = size(BOLD_calcium,2);
event_plot=nan(1,nobs);
event_plot(event_bold{1,1})=1;
figure(1);plot((1:length(hrfa(:,1)))*TR/para.T,hrfa(:,1),'b');xlabel('Time (s)')
title(['HRF (',BF{bf_id},')'])
figure('WindowState','maximized');
% plot(BOLD_time,zscore(BOLD_calcium));
hold all;
plot(BOLD_time,zscore(data(:,1)));

plot(BOLD_time,zscore(data_deconv(:,1)),'r');

calcium_time = dt*(0:length(calcium_raw)-1);

plot(calcium_time,zscore(calcium_raw)-5,'g')

stem(trigger_time, trigger_times*0.1, 'y.');
stem((1:nobs)*TR/para.T,event_plot,'k');legend('BOLD(filtered)','Deconvolved
BOLD','calcium','2Hz 15s 2.5mA stimulation','BOLD events');xlabel('Time (s)')
% stem((1:nobs)*TR/para.T,event_plot,'k');legend('BOLD(raw)','Deconvolved
BOLD','calcium','2Hz 15s 2.5mA stimulation','BOLD events');xlabel('Time (s)')

set(gca,'FontSize',15,'FontWeight','Bold');
```

Third-party code

Some parts of the codes are from the third-party toolbox.

- Some HRF basis functions are from SPM toolbox (spm_get_bf.m, spm_hrf.m)
- rsHRF_get_HRF_parameters.m is modified from the HRF Estimation Toolbox (get_parameters2.m).
- Some subfunctions of rsHRF_mvgc.m are from MVGC Multivariate Granger Causality MATLAB® Toolbox, including: data_to_autocov.m, autocov_to_var.m, mvgc_pval.m, mvgc_cdf, dlyap_aitr.m).
- Outliers (detected from HRF parameter response height) are deleted (rsHRF_ deleteoutliers.m) and interpolated (rsHRF_deleteoutliers.m) using *deleteoutliers*.m and *inpaint_nans3*.m.
- The *knee_pt*.m function is used as an alternative to min() for the rsHRF lag estimation (rsHRF_knee_pt.m).
- conn_filter.m is a subfunction in rsHRF_band_filter.m for band-pass filtering.

Reference

Chen, G., Adleman, N. E., Saad, Z. S., Leibenluft, E., & Cox, R. W. (2014). Applications of multivariate modeling to neuroimaging group analysis: A comprehensive alternative to univariate general linear model. NeuroImage, 99, 571-588. https://doi.org/10.1016/j.neuroimage.2014.06.027

Marinazzo, D., Pellicoro, M., & Stramaglia, S. (2012). Causal information approach to partial conditioning in multivariate data sets. Computational and mathematical methods in medicine, 2012.
https://doi.org/10.1155/2012/303601

Wu, G. R., Liao, W., Stramaglia, S., Ding, J. R., Chen, H., & Marinazzo, D. (2013). A blind deconvolution approach to recover effective connectivity brain networks from resting state fMRI data. Medical Image Analysis, 17(3), 365-374. https://doi.org/10.1016/j.media.2013.01.003

Wu, G. R., Liao, W., Stramaglia, S., Chen, H., & Marinazzo, D. (2013). Recovering directed networks in neuroimaging datasets using partially conditioned Granger causality. Brain connectivity, 3(3), 294-301. https://doi.org/10.1089/brain.2013.0142

Wu, G. R., & Marinazzo, D. (2015). Retrieving the Hemodynamic Response Function in resting state fMRI: Methodology and applications. PeerJ PrePrints. https://peerj.com/preprints/1317

Wu, G. R., & Marinazzo, D. (2016). Sensitivity of the resting-state haemodynamic response function estimation to autonomic nervous system fluctuations. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374(2067), 20150190. https://doi.org/10.1098/rsta.2015.0190

Geweke, J. (1982). Measurement of linear dependence and feedback between multiple time series. Journal of the American statistical association, 77(378), 304-313. https://doi.org/10.1080/01621459.1982.10477803

Tagliazucchi, E., Balenzuela, P., Fraiman, D., & Chialvo, D. R. (2012). Criticality in large-scale brain fMRI dynamics unveiled by a novel point process analysis. Frontiers in Physiology, 3, 15. https://doi.org/10.3389/fphys.2012.00015