Package 'dfConn'

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Type Package

Title Dynamic Functional Connectivity Analysis

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Description
An implementation of multivariate linear process bootstrap (MLPB) method and sliding window technique to assess the dynamic functional connectivity (dFC) estimate by providing its confidence bands, based on Maria Kudela (2017) <doi: 10.1016/j.neuroimage.2017.01.056>.
It also integrates features to visualize non-zero coverage for selected a-priori regions of interest estimated by the dynamic functional connectivity model (dFCM) and dynamic functional connectivity (dFC) curves for reward-related a-priori regions of interest where the activation-based analysis reported.

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`coverage.tbl.list` *Sample dynamic functional connectivity estimates summary tables*

Description

Contains a list of data frames with comparisons and corresponding significant non-zero estimates coverage.

Usage

```
data(coverage.tbl.list)
```

Format

A list which contains 9 data frames:

coverage.zero.cond.diff Percentage of estimates for condition difference that are within 95% confidence interval with a center of zero.

coverage.zero.cond.1 Percentage of estimates for condition 1 that are within 95% confidence interval with a center of zero.

coverage.zero.cond.2 Percentage of estimates for condition 2 that are below 95% confidence interval with a center of zero.

coverage.below.zero.cond.2 Percentage of estimates for condition 2 that are below 95% confidence interval with a center of zero.

coverage.below.zero.cond.diff Percentage of estimates for condition difference that are below 95% confidence interval with a center of zero.

coverage.below.zero.cond.1 Percentage of estimates for condition 1 that are below 95% confidence interval with a center of zero.

coverage.above.zero.cond.diff Percentage of estimates for condition difference that are above 95% confidence interval with a center of zero.

coverage.above.zero.cond.1 Percentage of estimates for condition 1 that are above 95% confidence interval with a center of zero.

coverage.above.zero.cond.2 Percentage of estimates for condition 1 that are above 95% confidence interval with a center of zero.

`data_summary_coverage` *Obtain the non-zero coverage for both two conditions and the condition-based difference*

Description

Summarize the data from dynamic functional connectivity linear mixed modeling.

Usage

```
data_summary_coverage(dataList.CI, save_res = FALSE, output_dir = NULL)
```

Arguments

`dataList.CI`	list, a list of data matrices which include the confidence interval estimates obtained from linear mixed models.
`save_res`	logical, whether to save the result or not, if true, an output directory should be provided
`output_dir`	character, directory for output files

Value

A list which contains 9 data frames:

coverage.zero.cond.diff Percentage of estimates for condition difference that are within 95% confidence interval with a center of zero.

coverage.zero.cond.1 Percentage of estimates for condition 1 that are within 95% confidence interval with a center of zero.

coverage.zero.cond.2 Percentage of estimates for condition 2 that are below 95% confidence interval with a center of zero.

coverage.below.zero.cond.2 Percentage of estimates for condition 2 that are below 95% confidence interval with a center of zero.

coverage.below.zero.cond.diff Percentage of estimates for condition difference that are below 95% confidence interval with a center of zero.

coverage.below.zero.cond.1 Percentage of estimates for condition 1 that are below 95% confidence interval with a center of zero.

coverage.above.zero.cond.diff Percentage of estimates for condition difference that are above 95% confidence interval with a center of zero.

coverage.above.zero.cond.1 Percentage of estimates for condition 1 that are above 95% confidence interval with a center of zero.

coverage.above.zero.cond.2 Percentage of estimates for condition 1 that are above 95% confidence interval with a center of zero.

Examples

```
# Summarize the output of linear mixed effect model for dynamic functional connectivity
data(DynModel_results)
data_summary_coverage(DynModel_results$est_CI)
```

`DynModel_results` *Sample confidence interval output of dynamic functional connectivity (dFC) model*

Description

A sample confidence interval estimates (between pairwise regions of interest 1 and 2) coming from dynamic functional connectivity model

Usage

```
data(DynModel_results)
```

Format

A list with 5 objects:

params Store the parameters for the linear mixed model

parallel Store the information about parallel computing environment and parameters

output_by_row Store the model results information for data between each pair of regions

modelDyn_results A combined dataframe with all the model results informations

est_CI A list of matrices, contains information of confidence band estimate, see description below. In each matrix of `est_CI`:

row 1 Base line estimate, difference between condition 1 and condition 2

row 2 Dynamic functional connecvity estimates for condition 1

row 3 Dynamic functional connecvity estimates for condition 2

row 4 Lower bound of 95% confidence interval of condition-difference estimates

row 5 Upper bound of 95% confidence interval of condition-difference estimates

row 6 Lower bound of 95% confidence interval of condition-1 estimates

row 7 Upper bound of 95% confidence interval of condition-1 estimates

row 8 Lower bound of 95% confidence interval of condition-2 estimates

row 9 Upper bound of 95% confidence interval of condition-2 estimates

fMRI_dataList *Sample fMRI time series data matrices*

Description

Sample functional magnetic resonance imaging (fMRI) data contains a list of data matrices with consisting time series data of two subjects, with 6 scans for each subject in total.

Usage

```
data(fMRI_dataList)
```

Format

A list consisting of two matrices, each with 278 rows and 750 columns:

subject1 sample time series data matrix for subject 1.

subject2 sample time series data matrix for subject 2.

For each data matrix in the list:

row index of regions of interest .

column fMRI time series data at each time point.

fMRI_dataList_shrinked *A shrinked sample subject functional magnetic resonance imaging (fMRI) time series data*

Description

Contains a list of data matrices with consisting time series data of only one subject, and only 1 scan is preserved. This shrinked dataset is useful for user to test the programs and functions.

Usage

```
data(fMRI_dataList_shrinked)
```

Format

A list which contains a matrix with 2 rows and 19 columns:

row index of regions of interest (ROIs).

column fMRI time series data at each time point.

lmmConn *Semiparametric modelling - Static*

Description

Linear mixed effect modeling for static functional connectivity

Usage

```
lmmConn(dataList, subjects, eff_time_points, num.scan, ntps.per.scan,
  save_res = FALSE, output_dir = NULL, ci_level = 0.975,
  ngrid = 201, cores = 1, seed = NULL)
```

Arguments

dataList	list, list of data matrices .
subjects	character vector, names of subjects.
eff_time_points	integer vector, effective sacn timepoints.
num.scan	integer, number of scans.
ntps.per.scan	integer, number of timepoints per scan.
save_res	logical, whether to save the result or not, if true, an output directory should be provided.
output_dir	character, directory for output files.
ci_level	numeric, level of confidence interval, default is 0.975.
ngrid	integer, number of grids.
cores	integer, number of cores to register for parallel jobs.
seed	numeric, random seed.

Details

lmmDyn and lmmConn, we need to summarize the bootstrapping by taking the mean or median of the dFC estimate at each time point.

Value

An object of list containing all the information of the static functional connectivity linear mixed model. It stores the information of model parameters, input data, and model results.

params Store the parameters for the linear mixed model

parallel Store the information about parallel computing environment and parameters

output_by_row Store the model results information for data between each pair of regions

modelDyn_results A combined dataframe with all the model results informations

est_CI A list of matrices, contains information of confidence band estimate, see description below. In each matrix of `est_CI`:

row 1 Base line estimate, difference between condition 1 and condition 2

row 2 Dynamic functional connecvity estimates for condition 1

row 3 Dynamic functional connecvity estimates for condition 2

row 4 Lower bound of 95% confidence interval of condition-difference estimates

row 5 Upper bound of 95% confidence interval of condition-difference estimates

row 6 Lower bound of 95% confidence interval of condition-1 estimates

row 7 Upper bound of 95% confidence interval of condition-1 estimates

row 8 Lower bound of 95% confidence interval of condition-2 estimates

row 9 Upper bound of 95% confidence interval of condition-2 estimates

Examples

```
# Assuming user has run MLPB_boot() and has summarized the bootstrapping results
# by calculating the median or mean.

## Example with 5 subjects bootstrap-based static functional connectivity estimates data included
## Each subject's data has 731 time points in total, which includes 6 scans and 105 effective
## time point for each scan.
## 3 regions of interest (ROIs) comparision pairs are selected

data(MLPB_output_median)
subjects <- c('subject1', 'subject2', 'subject3', 'subject4', 'subject5')

# In our demo data, each subject has a scan with a total of 750 time points
time.points <- c(1:105, 126:230, 251:355,
                 376:480, 501:605, 626:730)

num.scan <- 6 # Each subject has 6 scans
ntps.per.scan <- 105 # Each scan has 105 time points

resConn <- lmmConn(MLPB_output_median, subjects, time.points, num.scan, ntps.per.scan)
```

`lmmDyn` *Semiparametric modelling - dynamic functional connectivity model*

Description

Linear mixed effect model for dynamic functional connectivity.

Usage

```
lmmDyn(dataList, subjects, eff_time_points, num.scan, ntps.per.scan,
  save_res = FALSE, output_dir = NULL, ci_level = 0.975,
  ngrid = 201, cores = 1, seed = NULL)
```

Arguments

dataList	list, a list of data matrices.
subjects	character vector, names of subjects.
eff_time_points	integer, effective scan time points.
num.scan	integer, number of scan.
ntps.per.scan	integer, number of timepoints per scan.
save_res	logical, whether to save the result or not, if true, an output directory should be provided.
output_dir	string, directory for storing output files.
ci_level	numeric, level of confidence interval, with default 0.975.
ngrid	integer, number of grids.
cores	integer, number of cores to register while running parallel jobs.
seed	integer, random seed.

Details

The output of MLPB_boot is a complete bootstrapping result for the dynamic functional connectivity (dFC) estimates of each pair of region of interest, however, for further analysis, like lmmDyn and lmmConn, we need to summarize the bootstrapping by taking the mean or median of the dFC estimate at each time point.

Value

An object of list containing all the information of the static functional connectivity linear mixed model. It stores the information of model parameters, input data, and model results.

params Store the parameters for the linear mixed model

parallel Store the information about parallel computing environment and parameters

output_by_row Store the model results information for data between each pair of regions

modelDyn_results A combined dataframe with all the model results informations

est_CI A list of matrices, contains information of confidence band estimate, see description below. In each matrix of est_CI:

row 1 Base line estimate, difference between condition 1 and condition 2

row 2 Dynamic functional connecvity estimates for condition 1

row 3 Dynamic functional connecvity estimates for condition 2

row 4 Lower bound of 95% confidence interval of condition-difference estimates

row 5 Upper bound of 95% confidence interval of condition-difference estimates

row 6 Lower bound of 95% confidence interval of condition-1 estimates

row 7 Upper bound of 95% confidence interval of condition-1 estimates

row 8 Lower bound of 95% confidence interval of condition-2 estimates

row 9 Upper bound of 95% confidence interval of condition-2 estimates

Examples

```
# Assuming user has run MLPB_boot() and has summarize the bootstrapping result

data("MLPB_output_median")

subjects <- c('subject1', 'subject2', 'subject3', 'subject4', 'subject5')

# In our demo data, each subject has a scan with a total of 750 time points
time.points <- c(1:105, 126:230, 251:355,
                 376:480, 501:605, 626:730)

num.scan <- 6 # Each subject has 6 scans
ntps.per.scan <- 105 # Each scan has 105 time points

resDyn <- lmmDyn(MLPB_output_median, subjects, time.points, num.scan, ntps.per.scan, cores = 5)
```

MLPB3 *Multivariate Linear Bootstrapping - core function*

Description

Multivariate Linear Bootstrapping - core function

Usage

```
MLPB3(X, Boot, l = 1, eps = 1, beta = 1, l_automatic = 0,
  l_automatic_local = 0)
```

Arguments

X	data matrix
Boot	integer, number of bootstrap samples to be generated
l	numeric, the banding parameter, default is 1
eps	numeric the parameters for making Gamma_kappa_matrix positive definite if necessary, default is 1;
beta	numeric the parameters for making Gamma_kappa_matrix positive definite if necessary, default is 1;
l_automatic	numeric the banding parameter, default is 1, data-adaptively;
l_automatic_local	numeric, the banding parameter default is 0

Value

a numeric matrix with n*boot rows and m columns, where n, m refer to the number of rows and number of columns in input data matrix, and boot refer to number of bootstrap samples to be generated.

Examples

```
# Multivariate linear bootstrapping on a random matrix with 2 rows and 4 columns
MLPB3(matrix(rnorm(16),2,4), 3)
```

`MLPB_boot` *Multivariate Linear Process Bootstrap Method*

Description

Multivariate Linear Process Bootstrap (MLPB) method to assess the uncertainty in dynamic functional connectivity (dFC) by providing its confidence band.

Usage

```
MLPB_boot(dataList, output_dir, rois, timepoints, subset.subject = NULL,
  save_file_suffix = "", window_size = 20, number_of_intervals = 1,
  boot_rep = 250, n_boot = 1, cores = 1)
```

Arguments

`dataList`	list, subject-specific data.
`output_dir`	character, output directory for bootstrap samples.
`rois`	vector of integers, specify the list of regions of interests
`timepoints`	integer, number of timepoints in total
`subset.subject`	vector of character, which subject to run, specify the index in `dataList`, for example, c(1, 2, ...)
`save_file_suffix`	character, suffix of output files, treated as a labels.
`window_size`	integer, window size for sliding window technique
`number_of_intervals`	integer, number of intervals in sliding window technique
`boot_rep`	integer, bootstrapping repetition times
`n_boot`	integer, number of bootstrap sample to be generated in MLPB
`cores`	integer, number of cores to register for parallel execution, if set to 1 a sequential job will be run

Details

The `dataList` parameter is a list of matrices which contains time series data of each region of interest (ROI). Output directory is required here because the results to be generate is massive.

References

Kudela et al. (2017) NeuroImage 10.1016/j.neuroimage.2017.01.056 (PubMed)

Examples

```
# Load sample data

data(fMRI_dataList)

MLPB_boot(fMRI_dataList, output_dir = tempdir(),
          rois = c(54,191,235),
          timepoints = 750)
```

`MLPB_output_median` *Sample median output of Multivariate Linear Process Bootstrap (MLPB)*

Description

A dataset containing summarized by calculating the median for dynamic functional connectivity estimates of pairwise region of interest (ROI) comparisions.

Usage

```
data(MLPB_output_median)
```

Format

A list with 3 matrices, each matrix has 5 rows and 731 columns, where rows represent subjects-level multivariate linear process bootstrapping (MLPB) estimates and columns represent median of MLPB estimates at each window.

median_1_2 matrix with 5 rows and 731 columns, containing median of multivariate linear process bootstrapping results between region 1 and 2 in subject-level.

median_1_3 matrix with 5 rows and 731 columns, containing median of multivariate linear process bootstrapping results between region 1 and 3 in subject-level.

median_2_3 matrix with 5 rows and 731 columns, containing median of multivariate linear process bootstrapping results between region 2 and 3 in subject-level.

nzc_vis *Non-zero coverage correlation matrix visualization*

Description

Visualize non-zero coverage of dynamic functional connectivity modeling estimates.

Usage

```
nzc_vis(coverage.tbl.list, model_results, roi, ntps.per.scan,
  save_fig = FALSE, output_dir = NULL, alpha = 0.05,
  thres.cond1 = 0.5, thres.cond2 = 0.5, thres.diff = 0.1)
```

Arguments

coverage.tbl.list	A list with a list of zero-coverage table, can be obtained from data_summary_coverage.
model_results	data frame, output of either lmmConn or lmmDyn.
roi	integer vector, specify the list of regions of interests.
ntps.per.scan	integer, number of timepoints per scan.
save_fig	logical, whether to save the figures locally.
output_dir	character string, output directory of figures to save.
alpha	alpha level of proportion-testing, default is 0.05.
thres.cond1	numeric, threshold for cond1 flavor proportion-test, default is 0.5.
thres.cond2	numeric, threshold for cond2 flavor proportion-test, default is 0.5.
thres.diff	numeric, threshold for proportion-test of difference between condition 1 and condition 2 .

Examples

```
# load sample summary of the linear mixed model output
data(coverage.tbl.list)
data(DynModel_results)
nzc_vis(coverage.tbl.list, DynModel_results$modelDyn_results,
        roi=c(54,191,235), DynModel_results$params$ntp_per_scan, save_fig=FALSE)
```

plot_generate_timeDependence

95% Coverage time dependence plots for dFCM

Description

Visualize the dFC time dependence modeled in dynamic functional connectivity modelling along with its confidence band.

Usage

```
plot_generate_timeDependence(dataList.CI, scan.length, rois,
  save_fig = FALSE, output_dir = NULL, cores = 0)
```

Arguments

dataList.CI	The path of confidence interval data
scan.length	integer, usually set as number of total timepoints per scan
rois	Numerical array, regions of interests to generate plots
save_fig	logical, whether or not the plots should be saved as files
output_dir	character, output directory of PNG-format figures
cores	integer, indicate the number of cores to use in parallel execution

Examples

```
data(DynModel_results) # Load sample model result object
scan.length <- DynModel_results$params$ntp_per_scan
plot_generate_timeDependence(DynModel_results$est_CI[1], scan.length, rois=c(114,134))
```

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