

Package ‘BayesfMRI’

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Type Package

Title Spatial Bayesian Methods for Task Functional MRI Studies

Version 0.11.0

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Description Performs a spatial Bayesian general linear model (GLM) for task functional magnetic resonance imaging (fMRI) data on the cortical surface. Additional models include group analysis and inference to detect thresholded areas of activation. Includes direct support for the 'CIFTI' neuroimaging file format. For more information see A. F. Mejia, Y. R. Yue, D. Bolin, F. Lindgren, M. A. Lindquist (2020) <[doi:10.1080/01621459.2019.1611582](https://doi.org/10.1080/01621459.2019.1611582)> and D. Spencer, Y. R. Yue, D. Bolin, S. Ryan, A. F. Mejia (2022) <[doi:10.1016/j.neuroimage.2022.118908](https://doi.org/10.1016/j.neuroimage.2022.118908)>.

License GPL-3

URL <https://github.com/mandymejia/BayesfMRI>

BugReports <https://github.com/mandymejia/BayesfMRI/issues>

Additional_repositories <https://inla.r-inla-download.org/R/testing>

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BayesfMRI-package	<i>BayesfMRI: Spatial Bayesian Methods for Task Functional MRI Studies</i>
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Description

Performs a spatial Bayesian general linear model (GLM) for task functional magnetic resonance imaging (fMRI) data on the cortical surface. Additional models include group analysis and inference to detect thresholded areas of activation. Includes direct support for the 'CIFTI' neuroimaging file format. For more information see A. F. Mejia, Y. R. Yue, D. Bolin, F. Lindgren, M. A. Lindquist (2020) [doi:10.1080/01621459.2019.1611582](https://doi.org/10.1080/01621459.2019.1611582) and D. Spencer, Y. R. Yue, D. Bolin, S. Ryan, A. F. Mejia (2022) [doi:10.1016/j.neuroimage.2022.118908](https://doi.org/10.1016/j.neuroimage.2022.118908).

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See Also

Useful links:

- <https://github.com/mandymejia/BayesfMRI>
- Report bugs at <https://github.com/mandymejia/BayesfMRI/issues>

.findTheta

Perform the EM algorithm of the Bayesian GLM fitting

Description

Perform the EM algorithm of the Bayesian GLM fitting

Usage

```
.findTheta(theta, spde, y, X, QK, Psi, A, Ns, tol, verbose = FALSE)
```

Arguments

<i>theta</i>	the vector of initial values for theta
<i>spde</i>	a list containing the sparse matrix elements Cmat, Gmat, and GtCinvG
<i>y</i>	the vector of response values
<i>X</i>	the sparse matrix of the data values
<i>QK</i>	a sparse matrix of the prior precision found using the initial values of the hyper-parameters
<i>Psi</i>	a sparse matrix representation of the basis function mapping the data locations to the mesh vertices
<i>A</i>	a precomputed matrix $\text{crossprod}(X\%*\%Psi)$
<i>Ns</i>	the number of columns for the random matrix used in the Hutchinson estimator
<i>tol</i>	a value for the tolerance used for a stopping rule (compared to the squared norm of the differences between $\theta(s)$ and $\theta(s-1)$)
<i>verbose</i>	(logical) Should intermediate output be displayed?

<code>.getSqrtInvCpp</code>	<i>Get the prewhitening matrix for a single data location</i>
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Description

Get the prewhitening matrix for a single data location

Usage

```
.getSqrtInvCpp(AR_coefs, nTime, avg_var)
```

Arguments

<code>AR_coefs</code>	a length-p vector where p is the AR order
<code>nTime</code>	(integer) the length of the time series that is being prewhitened
<code>avg_var</code>	a scalar value of the residual variances of the AR model

<code>.initialKP</code>	<i>Find the initial values of kappa2 and phi</i>
-------------------------	--------------------------------------------------

Description

Find the initial values of kappa2 and phi

Usage

```
.initialKP(theta, spde, w, n_sess, tol, verbose)
```

Arguments

<code>theta</code>	a vector of length two containing the range and scale parameters kappa2 and phi, in that order
<code>spde</code>	a list containing the sparse matrix elements Cmat, Gmat, and GtCinvG
<code>w</code>	the beta_hat estimates for a single task
<code>n_sess</code>	the number of sessions
<code>tol</code>	the stopping rule tolerance
<code>verbose</code>	(logical) Should intermediate output be displayed?

<code>.logDetQt</code>	<i>Find the log of the determinant of $Q_{\tilde{}}$</i>
------------------------	---------------------------------------------------------------------

Description

Find the log of the determinant of $Q_{\tilde{}}$

Usage

```
.logDetQt(kappa2, in_list, n_sess)
```

Arguments

<code>kappa2</code>	a scalar
<code>in_list</code>	a list with elements <code>Cmat</code> , <code>Gmat</code> , and <code>GtCinvG</code>
<code>n_sess</code>	the integer number of sessions

<code>activations</code>	<i>Identify field activations</i>
--------------------------	-----------------------------------

Description

Identify areas of activation for each field from the result of `BayesGLM` or `fit_bayesglm`.

Usage

```
activations(
  x,
  Bayes = TRUE,
  gamma = NULL,
  alpha = 0.05,
  correction = c("FWER", "FDR", "none"),
  fields = NULL,
  sessions = NULL,
  verbose = 1
)

id_activations(
  x,
  Bayes = TRUE,
  gamma = NULL,
  alpha = 0.05,
  correction = c("FWER", "FDR", "none"),
  fields = NULL,
  sessions = NULL,
  verbose = 1
)
```

Arguments

x	Result of BayesGLM or fit_bayesglm model call, of class "BGLM" or "fit_bglm".
Bayes	Use spatial Bayesian modeling to identify activations based on the joint posterior distribution? Default: TRUE. If FALSE, activations will be based on classical (massive univariate) GLM model, with multiple comparisons correction (see correction). Note that TRUE is only applicable if x includes Bayesian results (i.e. x <- BayesGLM(..., Bayes = TRUE) was run.)
gamma	Activation threshold, for example 1 for 1 percent signal change if scale_BOLD=="mean" during model estimation. Setting a gamma is required for the Bayesian method; NULL (default) will use a gamma of zero for the classical method.
alpha	Significance level for inference. Default: 0.05.
correction	For the classical method only: Type of multiple comparisons correction: "FWER" (Bonferroni correction, the default), "FDR" (Benjamini Hochberg), or "none".
fields	The field(s) to identify activations for. Give either the name(s) as a character vector, or the numerical indices. If NULL (default), analyze all fields.
sessions	The session(s) to identify activations for. Give either the name(s) as a character vector, or the numerical indices. If NULL (default), analyze the first session.
verbose	1 (default) to print occasional updates during model computation; 2 for occasional updates as well as running INLA in verbose mode (if Bayes), or 0 for no printed updates.

Value

An "act_BGLM" or "act_fit_bglm" object, a list which indicates the activated locations along with related information.

 aic_Param

aic

Description

aic

Arguments

aic	(For prewhitening) Use the Akaike information criterion (AIC) to select AR model orders between 0 and ar_order? Default: FALSE.
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ar_order_Param	<i>ar_order</i>
----------------	-----------------

Description

ar_order

Arguments

ar_order	(For prewhitening) The order of the autoregressive (AR) model to use for prewhitening. If 0, do not prewhiten. Default: 6. For multi-session modeling, note that a single AR model is used; its coefficients will be the average estimate from each session.
----------	-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

ar_smooth_Param	<i>ar_smooth</i>
-----------------	------------------

Description

ar_smooth

Arguments

ar_smooth	(For prewhitening) The FWHM parameter for spatially smoothing the coefficient estimates for the AR model to use for prewhitening. Recall that $\sigma = \frac{FWHM}{2 * \sqrt{2 * \log(2)}}$. Set to 0 to not smooth the estimates. Default: 5.
-----------	--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

BayesGLM	<i>BayesGLM for CIFTI</i>
----------	---------------------------

Description

Performs spatial Bayesian GLM for task fMRI activation with CIFTI-format data. The cortex is modeled as a surface mesh, and subcortical structures are modeled as distinct volumetric regions. Includes the pre-processing steps of nuisance regression, prewhitening, scaling, and variance normalization. Supports both single- and multi-session analysis. Can also compute just the classical (spatially-independent)

Usage

```

BayesGLM(
  BOLD,
  brainstructures = c("left", "right"),
  subROI = c("Amygdala-L", "Amygdala-R", "Caudate-L", "Caudate-R", "Hippocampus-L",
    "Hippocampus-R", "Thalamus-L", "Thalamus-R"),
  design,
  nuisance = NULL,
  scrub = NULL,
  hpf = NULL,
  TR = NULL,
  surfL = NULL,
  surfR = NULL,
  resamp_res = 10000,
  nbhd_order = 1,
  buffer = c(1, 1, 3, 4, 4),
  session_names = NULL,
  scale_BOLD = c("mean", "sd", "none"),
  Bayes = TRUE,
  hyperpriors = c("informative", "default"),
  ar_order = 6,
  ar_smooth = 5,
  aic = FALSE,
  n_threads = 4,
  return_INLA = c("trimmed", "full", "minimal"),
  verbose = 1,
  meanTol = 1e-06,
  varTol = 1e-06
)

```

Arguments

- | | |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BOLD | <p>fMRI timeseries data in CIFTI format ("*.dtseries.nii"). For single-session analysis this can be a file path to a CIFTI file or a "xiffti" object from the <code>ciftiTools</code> package. For multi-session analysis this can be a vector of file paths or a list of "xiffti" objects.</p> <p>If BOLD is a "xiffti" object(s), the surfaces, if any, will be used for the spatial model. However, if <code>surfL</code> and <code>surfR</code> are provided, they will override any surfaces in BOLD.</p> |
| brainstructures | <p>Character vector indicating which brain structure(s) of BOLD to analyze: "left" cortex; "right" cortex; and/or "subcortical" structures. Or "all" to model all three. Default: <code>c("left", "right")</code> (cortex only).</p> |
| subROI | <p>Which subcortical ROIs should be analyzed? Can be "all" to analyze all sub-cortex ROIs. See the <code>ciftiTools_Name</code> column of <code>ciftiTools::substructure_table()</code> for a list of possible subcortical ROIs.</p> |
| design | <p>A numeric matrix or <code>data.frame</code>, or a "BayesfMRI_design" object from <code>make_design</code>.</p> |

	Can also be an array where the third dimension is the same length as the number of data locations, to model each location with its own design.
nuisance	<p>(Optional) A $T \times N_{nuis}$ matrix of nuisance signals, where T is the number of timepoints and N is the number of nuisance signals, or a list of these for multi-session analysis. Nuisance signals are regressed from the fMRI data and design matrix prior to GLM computation. Nuisance signals can include motion regressors, HRF derivatives not being modeled as tasks, and other sources of noise.</p> <p>Detrending/high-pass filtering is accomplished by adding DCT bases to the nuisance matrix; see the parameters <code>hpf</code> and <code>DCT</code>.</p> <p>Do not add spike regressors for scrubbing to the nuisance matrix. Rather, provide these in <code>scrub</code> so that their corresponding timepoints are also removed from the BOLD data after nuisance regression.</p>
scrub	<p>(Optional) A $T \times N_{scrub}$ matrix of spike regressors (one 1 value at the timepoint to scrub, and 0 for all other values), or a logical vector indicating the timepoints to scrub (TRUE to scrub, and FALSE to keep). For multi-session data, a session-length list of such matrices or logical vectors.</p> <p>The spike regressors will be included in the nuisance regression, and afterwards the timepoints indicated in <code>scrub</code> will be removed from the BOLD data and design matrix.</p>
hpf	<p>Add DCT bases to nuisance to apply a temporal high-pass filter to the data, for detrending? <code>hpf</code> is the filter frequency. Use NULL to skip detrending. Detrending is strongly recommended for fMRI data, to help reduce the autocorrelation in the residuals, so NULL will induce a warning. Use "already" to disable the warning while skipping highpass filtering.</p> <p>Using at least two DCT bases is as sufficient for detrending as using linear and quadratic drift terms in the nuisance matrix. So if DCT detrending is being used here, there is no need to add linear and quadratic drift terms to nuisance.</p>
TR	Temporal resolution of the data, in seconds.
surfL, surfR	<p>For cortex spatial model. Left and right cortex surface geometry in GIFTI format ("*.surf.gii"). These can be a file path to a GIFTI file or a "surf" object from <code>ciftiTools</code>.</p> <p>Surfaces can alternatively be provided through the <code>\$surf</code> metadata in BOLD if it is "xifti" data. If neither are provided, by default the HCP group-average <code>fs_LR</code> inflated surfaces included in <code>ciftiTools</code> will be used for the cortex spatial model.</p>
resamp_res	<p>For cortex spatial model. The number of vertices to which each cortical surface should be resampled, or NULL to not resample.</p> <p>For computational feasibility, a value of 10000 (default) or lower is recommended for Bayesian spatial modeling. If <code>Bayes=FALSE</code>, <code>resamp_res</code> can be set to NULL for full-resolution classical modeling.</p>
nbhd_order	<p>For volumetric model. What order neighborhood around data locations to keep? 0 for no neighbors, 1 for 1st-order neighbors, 2 for 1st- and 2nd-order neighbors, etc. Smaller values will provide greater computational efficiency at the cost of higher variance around the edge of the data.</p>

buffer	For volumetric model. The number of extra voxel layers around the bounding box. Set to NULL for no buffer. (We recommend not changing buffer unless you know what you're doing. Instead, to reduce the number of boundary voxels, adjust nbhd_order).
session_names	The names of the task-fMRI BOLD sessions, for multi-session analysis. If not provided here, will be inferred from names(BOLD), inferred from names(design), or generated automatically, in that order.
scale_BOLD	Controls scaling the BOLD response at each location. "mean" : Scale the data to percent local signal change. "sd" : Scale the data by local standard deviation. "none" : Center the data but do not scale it.
Bayes	Perform spatial Bayesian modeling? Default: TRUE. If FALSE, only perform classical (massive univariate) modeling. (The classical GLM result is always returned, whether Bayes is TRUE or FALSE.)
hyperpriors	Should informative or default non-informative hyperpriors be assumed on SPDE hyperparameters?
ar_order	(For prewhitening) The order of the autoregressive (AR) model to use for prewhitening. If 0, do not prewhiten. Default: 6. For multi-session modeling, note that a single AR model is used; its coefficients will be the average estimate from each session.
ar_smooth	(For prewhitening) The FWHM parameter for spatially smoothing the coefficient estimates for the AR model to use for prewhitening. Recall that $\sigma = \frac{FWHM}{2 * \sqrt{2 * \log(2)}}$. Set to 0 to not smooth the estimates. Default: 5.
aic	(For prewhitening) Use the Akaike information criterion (AIC) to select AR model orders between 0 and ar_order? Default: FALSE.
n_threads	The maximum number of threads to use for parallel computations: prewhitening parameter estimation, and the inla-program model estimation. Default: 4. Note that parallel prewhitening requires the parallel package.
return_INLA	Return the INLA model object? (It can be large.) Use "trimmed" (default) returns the results sufficient for activations and BayesGLM2 ; "minimal" returns enough for BayesGLM2 but not activations ; "full" returns the full inla output.
verbose	1 (default) to print occasional updates during model computation; 2 for occasional updates as well as running INLA in verbose mode (if Bayes), or 0 for no printed updates.
meanTol, varTol	Tolerance for mean and variance of each data location. Locations which do not meet these thresholds are masked out of the analysis. Default: 1e-6 for both. Note that locations with a median not meeting meanTol will also be masked out of the analysis (even if the mean is above it).

Details

To use BayesGLM, the design matrix must be provided. One option for constructing a design matrix from events is `hrf::make_design`.

Value

An object of class "BayesGLM": a list with elements

betas_Bayesian The field coefficients for the Bayesian model.

betas_classical The field coefficients for the classical model.

GLMs_Bayesian The entire list of GLM results, except for parameters estimated for the classical model.

GLMs_classical Parameters estimated for the classical model from the GLM.

brainstructures data.frame summarizing the spatial features of each brain structure modeled.

sessions data.frame with the name and nTime of each BOLD session.

fields data.frame with the name, related task, and HRF_order of each field.

Connectome Workbench Requirement

This function uses a system wrapper for the 'wb_command' executable. The user must first download and install the Connectome Workbench, available from <https://www.humanconnectome.org/software/get-connectome-workbench>.

INLA Requirement

This function requires the INLA package, which is not a CRAN package. See <https://www.r-inla.org/download-install> for easy installation instructions.

INLA Latent Fields Limit

INLA computation times increase greatly when the number of columns in the design matrix exceeds five: when there are more than five tasks, or more than three tasks each with a temporal derivative modeled as a field. In cases like the latter, we recommend modeling the temporal derivatives as nuisance signals using the option `dHRF_as="nuisance"`, rather than modeling the temporal derivatives as fields.

 BayesGLM2

Group-level Bayesian GLM

Description

Performs group-level Bayesian GLM estimation and inference using the joint approach described in Mejia et al. (2020).

Usage

```

BayesGLM2(
  results,
  contrasts = NULL,
  quantiles = NULL,
  excursion_type = NULL,
  contrast_names = NULL,
  gamma = 0,
  alpha = 0.05,
  nsamp_theta = 50,
  nsamp_beta = 100,
  num_cores = NULL,
  verbose = 1
)

```

Arguments

- results** Either (1) a length N list of "BGLM" objects, or (2) a length N character vector of files storing "BGLM" objects saved with `saveRDS`. "fit_bglm" objects also are accepted.
- contrasts** (Optional) A list of contrast vectors that specify the group-level summaries of interest. If NULL (DEFAULT), use contrasts that compute the average of each field (field HRF) across all subjects/sessions.
- Each contrast vector is length KSN specifying a group-level summary of interest, where K is the number of fields in the first-level design matrices, S is the number of sessions, and N is the number of subjects. The vector is grouped by fields, then sessions, then subjects.
- For a single session/subject, the contrast vector for the first field would be:
`c0 <- c(1, rep(0, K-1))` #indexes the first field for a single session
 so the full contrast vector for the group *average over all sessions/subjects for the first field* would be:
`contrasts = rep(c0, S*N) / (S*N)`.
- To obtain the group average for the first field, for *just the first session*, input zeros for the remaining sessions:
`c2 <- c(c0, rep(0, K*(S-1)))` `contrasts = rep(c2, N) / N`.
- To obtain the group mean *difference between two sessions* ($S = 2$) for the first field:
`c3 <- c(c0, -c0)` `contrasts = rep(c3, N) / N`.
- To obtain the *mean over sessions* of the first field, just for the first subject:
`c4 <- rep(c0, S) c(c4, rep(0, K*S*(N-1))) / S`.
- quantiles** (Optional) Vector of posterior quantiles to return in addition to the posterior mean.
- excursion_type** (For inference only) The type of excursion function for the contrast (" $>$ ", " $<$ ", " $!=$ "), or a vector thereof (each element corresponding to one contrast). If NULL, no inference performed.

contrast_names	(Optional) Names of contrasts.
gamma	(For inference only) Activation threshold for the excursion set, or a vector thereof (each element corresponding to one contrast). Default: 0.
alpha	(For inference only) Significance level for activation for the excursion set, or a vector thereof (each element corresponding to one contrast). Default: .05.
nsamp_theta	Number of theta values to sample from posterior. Default: 50.
nsamp_beta	Number of beta vectors to sample conditional on each theta value sampled. Default: 100.
num_cores	The number of cores to use for sampling betas in parallel. If NULL (default), do not run in parallel.
verbose	1 (default) to print occasional updates during model computation; 2 for occasional updates as well as running INLA in verbose mode (if Bayes), or 0 for no printed updates.

Value

A list containing the estimates, PPMs and areas of activation for each contrast.

INLA Requirement

This function requires the INLA package, which is not a CRAN package. See <https://www.r-inla.org/download-install> for easy installation instructions.

 Bayes_Param

Bayes

Description

Bayes

Arguments

Bayes Perform spatial Bayesian modeling? Default: TRUE. If FALSE, only perform classical (massive univariate) modeling. (The classical GLM result is always returned, whether Bayes is TRUE or FALSE.)

BOLD_Param_BayesGLM *BOLD*

Description

BOLD

Arguments

BOLD fMRI timeseries data in CIFTI format ("*.dtseries.nii"). For single-session analysis this can be a file path to a CIFTI file or a "xifti" object from the `ciftiTools` package. For multi-session analysis this can be a vector of file paths or a list of "xifti" objects.

If BOLD is a "xifti" object(s), the surfaces, if any, will be used for the spatial model. However, if `surfL` and `surfR` are provided, they will override any surfaces in BOLD.

brainstructures_Param_BayesGLM
 brainstructures

Description

brainstructures

Arguments

brainstructures Character vector indicating which brain structure(s) of BOLD to analyze: "left" cortex; "right" cortex; and/or "subcortical" structures. Or "all" to model all three. Default: `c("left", "right")` (cortex only).

buffer_Param *buffer*

Description

buffer

Arguments

buffer For volumetric model. The number of extra voxel layers around the bounding box. Set to NULL for no buffer. (We recommend not changing buffer unless you know what you're doing. Instead, to reduce the number of boundary voxels, adjust `nbhd_order`).

Connectome_Workbench_Description
Connectome Workbench

Description

Connectome Workbench

Connectome Workbench Requirement

This function uses a system wrapper for the 'wb_command' executable. The user must first download and install the Connectome Workbench, available from <https://www.humanconnectome.org/software/get-connectome-workbench>.

contrasts_Param *contrasts*

Description

contrasts

Arguments

contrasts List of contrast vectors to be passed to `inla::inla`.

design_Param_BayesGLM *design*

Description

design

Arguments

design A numeric matrix or `data.frame`, or a "BayesfMRI_design" object from `make_design`. Can also be an array where the third dimension is the same length as the number of data locations, to model each location with its own design.

do_QC	<i>Mask out invalid data</i>
-------	------------------------------

Description

Mask out data locations that are invalid (missing data, low mean, or low variance) for any session.

Usage

```
do_QC(BOLD, meanTol = 1e-06, varTol = 1e-06, medianToo = TRUE, verbose = TRUE)
```

Arguments

BOLD	A session-length list of $T \times V$ numeric BOLD data, where T is the number of timepoints and V is the number of locations.
meanTol, varTol	Tolerance for mean and variance of each data location. Locations which do not meet these thresholds are masked out of the analysis. Defaults: 1e-6.
medianToo	Also mask out locations with a median value below meanTol? Default: TRUE.
verbose	Print messages counting how many locations are removed? Default: TRUE.

Value

A logical vector indicating locations that are valid across all sessions.

Examples

```
nT <- 30
nV <- 400
BOLD1 <- matrix(rnorm(nT*nV), nrow=nT)
BOLD1[,seq(30,50)] <- NA
BOLD2 <- matrix(rnorm(nT*nV), nrow=nT)
BOLD2[,65] <- BOLD2[,65] / 1e10
BOLD <- list(sess1=BOLD1, sess2=BOLD2)
do_QC(BOLD)
```

emTol_Param	<i>emTol</i>
-------------	--------------

Description

emTol

Arguments

emTol	The stopping tolerance for the EM algorithm. Default: 1e-3.
-------	-------------------------------------------------------------

`EM_Param`*EM*

Description

EM

Arguments

EM

(logical) Should the EM implementation of the Bayesian GLM be used? Default: FALSE. This method is still in development.

`faces_Param`*faces*

Description

faces

Arguments

faces

An $F \times 3$ matrix, where each row contains the vertex indices for a given triangular face in the mesh. F is the number of faces in the mesh.

`field_names_Param`*field_names*

Description

field_names

Arguments

field_names

(Optional) Names of fields represented in design matrix.

fit_bayesglm	<i>fit_bayesglm</i>
--------------	---------------------

Description

Performs spatial Bayesian GLM for task fMRI activation

Usage

```
fit_bayesglm(
  BOLD,
  design,
  nuisance = NULL,
  scrub = NULL,
  spatial,
  scale_BOLD = c("mean", "sd", "none"),
  Bayes = TRUE,
  hyperpriors = c("informative", "default"),
  ar_order = 6,
  ar_smooth = 5,
  aic = FALSE,
  n_threads = 4,
  return_INLA = c("trimmed", "full", "minimal"),
  verbose = 1,
  meanTol = 1e-06,
  varTol = 1e-06
)
```

Arguments

BOLD, design, nuisance	Session-length list of numeric matrices/arrays, each with volumes along the first dimension.
scrub	Session-length list of spike regressors: numeric matrices, with volumes along the first dimension, valued at 1 for scrubbed volumes and 0 otherwise. Scrubbing is performed by incorporating spike regressors in the nuisance matrix during nuisance regression (in a simultaneous framework), and then removing the scrubbed timepoints from the resulting BOLD and design.
spatial	Gives the spatial information: surf A list of two: vertices $V \times 3$ numeric matrix of vertex locations in XYZ coordinate space, and faces, $F \times 3$ matrix of positive integers defining the triangular faces. mask Mask of locations with valid data. For voxel data, a list of six: label 3D array of labeled locations to include in the model.

	trans_mat Projection matrix to convert voxel indices to XYZ position. Can be NULL.
	trans_units XYZ units. Can be NULL.
	nbhd_order See documentation for BayesGLM .
	buffer See documentation for BayesGLM .
scale_BOLD	Controls scaling the BOLD response at each location. "mean" : Scale the data to percent local signal change. "sd" : Scale the data by local standard deviation. "none" : Center the data but do not scale it.
Bayes	Perform spatial Bayesian modeling? Default: TRUE. If FALSE, only perform classical (massive univariate) modeling. (The classical GLM result is always returned, whether Bayes is TRUE or FALSE.)
hyperpriors	Should informative or default non-informative hyperpriors be assumed on SPDE hyperparameters?
ar_order	(For prewhitening) The order of the autoregressive (AR) model to use for prewhitening. If 0, do not prewhiten. Default: 6. For multi-session modeling, note that a single AR model is used; its coefficients will be the average estimate from each session.
ar_smooth	(For prewhitening) The FWHM parameter for spatially smoothing the coefficient estimates for the AR model to use for prewhitening. Recall that $\sigma = \frac{FWHM}{2 * \sqrt{2 * \log(2)}}$. Set to 0 to not smooth the estimates. Default: 5.
aic	(For prewhitening) Use the Akaike information criterion (AIC) to select AR model orders between 0 and ar_order? Default: FALSE.
n_threads	The maximum number of threads to use for parallel computations: prewhitening parameter estimation, and the inla-program model estimation. Default: 4. Note that parallel prewhitening requires the <code>parallel</code> package.
return_INLA	Return the INLA model object? (It can be large.) Use "trimmed" (default) returns the results sufficient for activations and BayesGLM2 ; "minimal" returns enough for BayesGLM2 but not activations ; "full" returns the full inla output.
verbose	1 (default) to print occasional updates during model computation; 2 for occasional updates as well as running INLA in verbose mode (if Bayes), or 0 for no printed updates.
meanTol, varTol	Tolerance for mean and variance of each data location. Locations which do not meet these thresholds are masked out of the analysis. Default: 1e-6 for both. Note that locations with a median not meeting meanTol will also be masked out of the analysis (even if the mean is above it).

Value

A "BayesGLM" object: a list with elements

INLA_model_obj The full result of the call to INLA: `: inla`.

field_estimates The estimated coefficients for the Bayesian model.

- result_classical** Results from the classical model: field estimates, field standard error estimates, residuals, degrees of freedom, and the mask.
- mesh** The model mesh.
- mask** A mask of mesh indicating the locations inside mesh.
- design** The design matrix, after centering and scaling, but before any nuisance regression or prewhitening.
- field_names** The names of the fields.
- session_names** The names of the sessions.
- hyperpar_posteriors** Hyperparameter posterior densities.
- theta_estimates** Theta estimates from the Bayesian model.
- posterior_Sig_inv** For joint group modeling.
- mu_theta** For joint group modeling.
- Q_theta** For joint group modeling.
- y** For joint group modeling: The BOLD data after any centering, scaling, nuisance regression, or prewhitening.
- X** For joint group modeling: The design matrix after any centering, scaling, nuisance regression, or prewhitening.
- prewhiten_info** Vectors of values across locations: phi (AR coefficients averaged across sessions), sigma_sq (residual variance averaged across sessions), and AIC (the maximum across sessions).
- call** match.call() for this function call.

INLA Requirement

This function requires the INLA package, which is not a CRAN package. See <https://www.r-inla.org/download-install> for easy installation instructions.

hpf_Param_BayesGLM *hpf*

Description

hpf

Arguments

hpf Add DCT bases to nuisance to apply a temporal high-pass filter to the data, for detrending? hpf is the filter frequency. Use NULL to skip detrending. Detrending is strongly recommended for fMRI data, to help reduce the autocorrelation in the residuals, so NULL will induce a warning. Use "already" to disable the warning while skipping highpass filtering.

Using at least two DCT bases is as sufficient for detrending as using linear and quadratic drift terms in the nuisance matrix. So if DCT detrending is being used here, there is no need to add linear and quadratic drift terms to nuisance.

INLA_Description	<i>INLA</i>
------------------	-------------

Description

INLA

INLA Requirement

This function requires the INLA package, which is not a CRAN package. See <https://www.r-inla.org/download-install> for easy installation instructions.

INLA_Latent_Fields_Limit_Description	<i>INLA Latent Fields</i>
--------------------------------------	---------------------------

Description

INLA Latent Fields

INLA Latent Fields Limit

INLA computation times increase greatly when the number of columns in the design matrix exceeds five: when there are more than five tasks, or more than three tasks each with a temporal derivative modeled as a field. In cases like the latter, we recommend modeling the temporal derivatives as nuisance signals using the option `dHRF_as="nuisance"`, rather than modeling the temporal derivatives as fields.

make_mesh	<i>Make Mesh</i>
-----------	------------------

Description

Make INLA triangular mesh from faces and vertices

Usage

```
make_mesh(vertices, faces)
```

Arguments

vertices	A $V \times 3$ matrix, where each row contains the Euclidean coordinates at which a given vertex in the mesh is located. V is the number of vertices in the mesh
faces	An $F \times 3$ matrix, where each row contains the vertex indices for a given triangular face in the mesh. F is the number of faces in the mesh.

Value

INLA triangular mesh

INLA Requirement

This function requires the INLA package, which is not a CRAN package. See <https://www.r-inla.org/download-install> for easy installation instructions.

mask_Param_vertices *mask: vertices*

Description

mask: vertices

Arguments

mask A length V logical vector indicating if each vertex is within the input mask.

max_threads_Param *max_threads*

Description

max_threads

Arguments

max_threads The maximum number of threads to use in the inla-program for model estimation. 0 (default) will use the maximum number of threads allowed by the system.

mean_var_Tol_Param *mean and variance tolerance*

Description

mean and variance tolerance

Arguments

meanTol, varTol Tolerance for mean and variance of each data location. Locations which do not meet these thresholds are masked out of the analysis. Default: 1e-6 for both. Note that locations with a median not meeting meanTol will also be masked out of the analysis (even if the mean is above it).

mesh_Param_either *mesh: either*

Description

mesh: either

Arguments

mesh An "inla.mesh" object (see [make_mesh](#) for surface data)

mesh_Param_inla *mesh: INLA only*

Description

mesh: INLA only

Arguments

mesh An "inla.mesh" object (see [make_mesh](#) for surface data).

nbhd_order_Param *nbhd_order*

Description

nbhd_order

Arguments

nbhd_order For volumetric model. What order neighborhood around data locations to keep? 0 for no neighbors, 1 for 1st-order neighbors, 2 for 1st- and 2nd-order neighbors, etc. Smaller values will provide greater computational efficiency at the cost of higher variance around the edge of the data.

nuisance_Param_BayesGLM
nuisance

Description

nuisance

Arguments

nuisance (Optional) A $T \times N_{nuis}$ matrix of nuisance signals, where T is the number of timepoints and N is the number of nuisance signals, or a list of these for multi-session analysis. Nuisance signals are regressed from the fMRI data and design matrix prior to GLM computation. Nuisance signals can include motion regressors, HRF derivatives not being modeled as tasks, and other sources of noise.

Detrending/high-pass filtering is accomplished by adding DCT bases to the nuisance matrix; see the parameters `hpf` and `DCT`.

Do not add spike regressors for scrubbing to the nuisance matrix. Rather, provide these in `scrub` so that their corresponding timepoints are also removed from the BOLD data after nuisance regression.

n_threads_Param *n_threads*

Description

n_threads

Arguments

n_threads The maximum number of threads to use for parallel computations: prewhitening parameter estimation, and the inla-program model estimation. Default: 4. Note that parallel prewhitening requires the `parallel` package.

plot.act_BGLM *S3 method: use [view_xiffti](#) to plot a "act_BGLM" object*

Description

S3 method: use [view_xiffti](#) to plot a "act_BGLM" object

Usage

```
## S3 method for class 'act_BGLM'
plot(x, idx = NULL, title = NULL, session = NULL, ...)
```

Arguments

x	An object of class "act_BGLM"
idx	Which field should be plotted? Give the numeric indices or the names. NULL (default) will show all fields. This argument overrides the idx argument to view_xiffti .
title	If NULL, the field names associated with idx will be used.
session	Which session should be plotted? NULL (default) will use the first.
...	Additional arguments to view_xiffti

Value

Result of the call to `ciftiTools::view_cifti_surface`.

plot.BGLM *S3 method: use [view_xiffti](#) to plot a "BGLM" object*

Description

S3 method: use [view_xiffti](#) to plot a "BGLM" object

Usage

```
## S3 method for class 'BGLM'
plot(
  x,
  Bayes = NULL,
  idx = NULL,
  title = NULL,
  session = NULL,
  zlim = c(-1, 1),
  ...
)
```

Arguments

x	An object of class "BGLM"
Bayes	TRUE for plotting Bayesian results, FALSE for plotting classical GLM results. Default: NULL, which will use the Bayesian results if available and the classical results if not.
idx	Which field should be plotted? Give the numeric indices or the names. NULL (default) will show all fields. This argument overrides the idx argument to view_xifti .
title	If NULL, the field names associated with idx will be used.
session	Which session should be plotted? NULL (default) will use the first.
zlim	Overrides the zlim argument for view_xifti . Default: c(-1, 1).
...	Additional arguments to view_xifti

Value

Result of the call to `ciftiTools::view_cifti`.

plot.BGLM2

S3 method: use [view_xifti](#) to plot a "BGLM2" object

Description

S3 method: use [view_xifti](#) to plot a "BGLM2" object

Usage

```
## S3 method for class 'BGLM2'
plot(x, idx = NULL, stat = c("contrasts", "activations"), zlim = c(-1, 1), ...)
```

Arguments

x	An object of class "BGLM2"
idx	Which contrast should be plotted? Give the numeric indices or the names. NULL (default) will show all contrasts. This argument overrides the idx argument to view_xifti .
stat	Estimates of the "contrasts" (default), or their thresholded "activations".
zlim	Overrides the zlim argument for view_xifti . Default: c(-1, 1).
...	Additional arguments to view_xifti

Value

Result of the call to `ciftiTools::view_cifti`.

plot.prev_BGLM *S3 method: use [view_xifti](#) to plot a "prev_BGLM" object*

Description

S3 method: use [view_xifti](#) to plot a "prev_BGLM" object

Usage

```
## S3 method for class 'prev_BGLM'
plot(
  x,
  idx = NULL,
  session = NULL,
  drop_zeros = NULL,
  colors = "plasma",
  zlim = c(0, 1),
  ...
)
```

Arguments

x	An object of class "prev_BGLM"
idx	Which task should be plotted? Give the numeric indices or the names. NULL (default) will show all tasks. This argument overrides the idx argument to view_xifti .
session	Which session should be plotted? NULL (default) will use the first.
drop_zeros	Color locations without any activation across all results (zero prevalence) the same color as the medial wall? Default: NULL to drop the zeros if only one idx is being plotted.
colors, zlim	See view_xifti .
...	Additional arguments to view_xifti

Value

Result of the call to `ciftiTools::view_cifti_surface`.

prevalence	<i>Activations prevalence.</i>
------------	--------------------------------

Description

Activations prevalence.

Usage

```
prevalence(
  act_list,
  gamma_idx = 1,
  p_test = NULL,
  alpha = 0.05,
  correction = c("FWER", "FDR", "none")
)
```

Arguments

<code>act_list</code>	List of activations from activations . All should have the same sessions, fields, and brainstructures.
<code>gamma_idx</code>	If activations at multiple thresholds were computed, which threshold should be used for prevalence? Default: the first (lowest).
<code>p_test</code>	For inference: the expected baseline rate of activation for all data locations, under the null hypothesis. Default: NULL (do not perform hypothesis testing).
<code>alpha</code>	Significance level for inference. Default: .05.
<code>correction</code>	For the classical method only: Type of multiple comparisons correction: "FWER" (Bonferroni correction, the default), "FDR" (Benjamini Hochberg), or "none".

Value

A list containing the prevalences of activation, as a proportion of the results from `act_list`.

resamp_res_Param_BayesGLM	<i>resamp_res</i>
---------------------------	-------------------

Description

resamp_res

Arguments

resamp_res For cortex spatial model. The number of vertices to which each cortical surface should be resampled, or NULL to not resample.
For computational feasibility, a value of 10000 (default) or lower is recommended for Bayesian spatial modeling. If Bayes=FALSE, resamp_res can be set to NULL for full-resolution classical modeling.

return_INLA_Param *return_INLA*

Description

return_INLA

Arguments

return_INLA Return the INLA model object? (It can be large.) Use "trimmed" (default) returns the results sufficient for [activations](#) and [BayesGLM2](#); "minimal" returns enough for [BayesGLM2](#) but not [activations](#); "full" returns the full inla output.

scale_BOLD *Scale the BOLD timeseries*

Description

Scale the BOLD timeseries

Usage

```
scale_BOLD(BOLD, scale = c("mean", "sd", "none"), v_means = NULL)
```

Arguments

BOLD fMRI data as a locations by time ($V \times T$) numeric matrix, where V is the number of locations and T is the number of timepoints.

scale Option for scaling the BOLD response.

v_means Original means of the BOLD data. ONLY provide if data has already been centered.

`"mean"` scaling will scale the data to percent local signal change.

`"sd"` scaling will scale the data by local standard deviation.

`"none"` will only center the data, not scale it.

Value

Scale to units of percent local signal change and centers

scale_BOLD_Param *scale_BOLD*

Description

scale_BOLD

Arguments

scale_BOLD Controls scaling the BOLD response at each location.
"mean": Scale the data to percent local signal change.
"sd": Scale the data by local standard deviation.
"none": Center the data but do not scale it.

scrub_Param_BayesGLM *scrub*

Description

scrub

Arguments

scrub (Optional) A $T \times N_{scrub}$ matrix of spike regressors (one 1 value at the timepoint to scrub, and 0 for all other values), or a logical vector indicating the timepoints to scrub (TRUE to scrub, and FALSE to keep). For multi-session data, a session-length list of such matrices or logical vectors.
The spike regressors will be included in the nuisance regression, and afterwards the timepoints indicated in scrub will be removed from the BOLD data and design matrix.

seed_Param *seed*

Description

seed

Arguments

seed Random seed (optional). Default: NULL.

session_names_Param	<i>session_names</i>
---------------------	----------------------

Description

session_names

Arguments

session_names The names of the task-fMRI BOLD sessions, for multi-session analysis. If not provided here, will be inferred from names(BOLD), inferred from names(design), or generated automatically, in that order.

summary.act_BGLM	<i>Summarize a "act_BGLM" object</i>
------------------	--------------------------------------

Description

Summary method for class "act_BGLM"

Usage

```
## S3 method for class 'act_BGLM'
summary(object, ...)

## S3 method for class 'summary.act_BGLM'
print(x, ...)

## S3 method for class 'act_BGLM'
print(x, ...)
```

Arguments

object	Object of class "act_BGLM".
...	further arguments passed to or from other methods.
x	Object of class "summary.act_BGLM".

Value

A "summary.act_BGLM" object, a list summarizing the properties of object.
 NULL, invisibly.
 NULL, invisibly.

summary.act_fit_bglm *Summarize a "act_fit_bglm" object*

Description

Summary method for class "act_fit_bglm"

Usage

```
## S3 method for class 'act_fit_bglm'
summary(object, ...)

## S3 method for class 'summary.act_fit_bglm'
print(x, ...)

## S3 method for class 'act_fit_bglm'
print(x, ...)
```

Arguments

object	Object of class "act_fit_bglm".
...	further arguments passed to or from other methods.
x	Object of class "summary.act_fit_bglm".

Value

A "summary.act_fit_bglm" object, a list summarizing the properties of object.
 NULL, invisibly.
 NULL, invisibly.

summary.BGLM *Summarize a "BGLM" object*

Description

Summary method for class "BGLM"

Usage

```
## S3 method for class 'BGLM'
summary(object, ...)

## S3 method for class 'summary.BGLM'
print(x, ...)

## S3 method for class 'BGLM'
print(x, ...)
```

Arguments

object	Object of class "BGLM".
...	further arguments passed to or from other methods.
x	Object of class "summary.BGLM".

Value

A "summary.BGLM" object, a list summarizing the properties of object.
 NULL, invisibly.
 NULL, invisibly.

summary.BGLM2	<i>Summarize a "BGLM2" object</i>
---------------	-----------------------------------

Description

Summary method for class "BGLM2"

Usage

```
## S3 method for class 'BGLM2'
summary(object, ...)

## S3 method for class 'summary.BGLM2'
print(x, ...)

## S3 method for class 'BGLM2'
print(x, ...)
```

Arguments

object	Object of class "BGLM2".
...	further arguments passed to or from other methods.
x	Object of class "summary.BGLM2".

Value

A "summary.BGLM2" object, a list summarizing the properties of object.
 NULL, invisibly.
 NULL, invisibly.

summary.fit_bglm	<i>Summarize a "fit_bglm" object</i>
------------------	--------------------------------------

Description

Summary method for class "fit_bglm"

Usage

```
## S3 method for class 'fit_bglm'
summary(object, ...)

## S3 method for class 'summary.fit_bglm'
print(x, ...)

## S3 method for class 'fit_bglm'
print(x, ...)
```

Arguments

object	Object of class "fit_bglm".
...	further arguments passed to or from other methods.
x	Object of class "summary.fit_bglm".

Value

A "summary.fit_bglm" object, a list summarizing the properties of object.
 NULL, invisibly.
 NULL, invisibly.

summary.fit_bglm2	<i>Summarize a "fit_bglm2" object</i>
-------------------	---------------------------------------

Description

Summary method for class "fit_bglm2"

Usage

```
## S3 method for class 'fit_bglm2'
summary(object, ...)

## S3 method for class 'summary.fit_bglm2'
print(x, ...)

## S3 method for class 'fit_bglm2'
print(x, ...)
```

Arguments

object Object of class "fit_bglm2".
 ... further arguments passed to or from other methods.
 x Object of class "summary.fit_bglm2".

Value

A "summary.fit_bglm2" object, a list summarizing the properties of object.
 NULL, invisibly.
 NULL, invisibly.

summary.prev_BGLM *Summarize a "prev_BGLM" object*

Description

Summary method for class "prev_BGLM"
 Summary method for class "prev_BGLM"

Usage

```
## S3 method for class 'prev_BGLM'
summary(object, ...)

## S3 method for class 'summary.prev_BGLM'
print(x, ...)

## S3 method for class 'prev_BGLM'
print(x, ...)

## S3 method for class 'prev_BGLM'
summary(object, ...)

## S3 method for class 'summary.prev_BGLM'
print(x, ...)

## S3 method for class 'prev_BGLM'
print(x, ...)
```

Arguments

object Object of class "prev_BGLM".
 ... further arguments passed to or from other methods.
 x Object of class "summary.prev_BGLM".

Value

A "summary.prev_BGLM" object, a list summarizing the properties of object.

NULL, invisibly.

NULL, invisibly.

A "summary.prev_BGLM" object, a list summarizing the properties of object.

NULL, invisibly.

NULL, invisibly.

summary.prev_fit_bglm *Summarize a "prev_fit_bglm" object*

Description

Summary method for class "prev_fit_bglm"

Summary method for class "prev_fit_bglm"

Usage

```
## S3 method for class 'prev_fit_bglm'
summary(object, ...)
```

```
## S3 method for class 'summary.prev_fit_bglm'
print(x, ...)
```

```
## S3 method for class 'prev_fit_bglm'
print(x, ...)
```

```
## S3 method for class 'prev_fit_bglm'
summary(object, ...)
```

```
## S3 method for class 'summary.prev_fit_bglm'
print(x, ...)
```

```
## S3 method for class 'prev_fit_bglm'
print(x, ...)
```

Arguments

object	Object of class "prev_fit_bglm".
...	further arguments passed to or from other methods.
x	Object of class "summary.prev_fit_bglm".

Value

A "summary.prev_fit_bglm" object, a list summarizing the properties of object.

NULL, invisibly.

NULL, invisibly.

A "summary.prev_fit_bglm" object, a list summarizing the properties of object.

NULL, invisibly.

NULL, invisibly.

surfaces_Param_BayesGLM

surfaces

Description

surfaces

Arguments

surfL, surfR For cortex spatial model. Left and right cortex surface geometry in GIFTI format ("*.surf.gii"). These can be a file path to a GIFTI file or a "surf" object from `ciftiTools`.

Surfaces can alternatively be provided through the `$surf` metadata in BOLD if it is "xifti" data. If neither are provided, by default the HCP group-average `fs_LR` inflated surfaces included in `ciftiTools` will be used for the cortex spatial model.

trim_INLA_Param

trim_INLA

Description

trim_INLA

Arguments

trim_INLA (logical) should the INLA_model_obj within the result be trimmed to only what is necessary to use activations? Default: TRUE.

TR_Param_BayesGLM	<i>TR</i>
-------------------	-----------

Description

TR

Arguments

TR	Temporal resolution of the data, in seconds.
----	----------------------------------------------

verbose_Param	<i>verbose</i>
---------------	----------------

Description

verbose

Arguments

verbose	1 (default) to print occasional updates during model computation; 2 for occasional updates as well as running INLA in verbose mode (if Bayes), or 0 for no printed updates.
---------	-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------

vertex_areas	<i>Surface area of each vertex</i>
--------------	------------------------------------

Description

Compute surface areas of each vertex in a triangular mesh.

Usage

```
vertex_areas(mesh)
```

Arguments

mesh	An "inla.mesh" object (see make_mesh for surface data).
------	-------------------------------------------------------------------------

Value

Vector of areas

INLA Requirement

This function requires the INLA package, which is not a CRAN package. See <https://www.r-inla.org/download-install> for easy installation instructions.

vertices_Param	<i>vertices</i>
----------------	-----------------

Description

vertices

Arguments

vertices	A $V \times 3$ matrix, where each row contains the Euclidean coordinates at which a given vertex in the mesh is located. V is the number of vertices in the mesh
----------	--------------------------------------------------------------------------------------------------------------------------------------------------------------------

vol2spde	<i>Construct a triangular mesh from a 3D volumetric mask</i>
----------	--------------------------------------------------------------

Description

Construct a triangular mesh from a 3D volumetric mask

Usage

```
vol2spde(mask, res, nbhd_order = 1, buffer = c(1, 1, 3, 4, 4))
```

Arguments

mask	An array of 0s and 1s representing a volumetric mask
res	The spatial resolution in each direction, in mm. For example, c(2,2,2) indicates 2mm isotropic voxels.
nbhd_order	For volumetric data, what order neighborhood around data locations to keep? (0 = no neighbors, 1 = 1st-order neighbors, 2 = 1st- and 2nd-order neighbors, etc.). Smaller values will provide greater computational efficiency at the cost of higher variance around the edge of the data.
buffer	For volumetric data, size of extra voxels layers around the bounding box, in terms of voxels. Set to NULL for no buffer.

Value

An inla.spde2 object.

INLA Requirement

This function requires the INLA package, which is not a CRAN package. See <https://www.r-inla.org/download-install> for easy installation instructions.

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